Forum on Tracking Detector Mechanics
19 May 2021

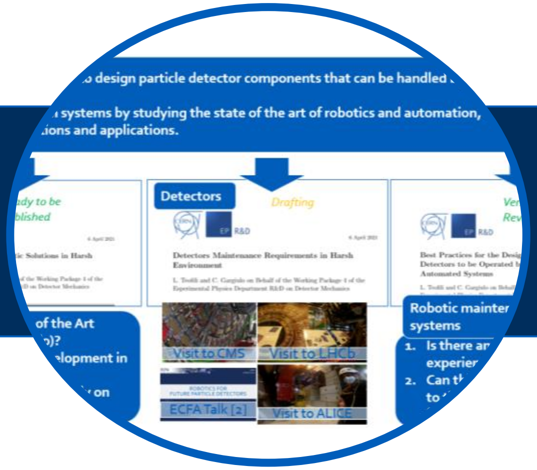
ROBOTICS AND ROBOT-DETECTOR INTERFACES FOR FUTURE PARTICLE DETECTORS

Lorenzo Teofili

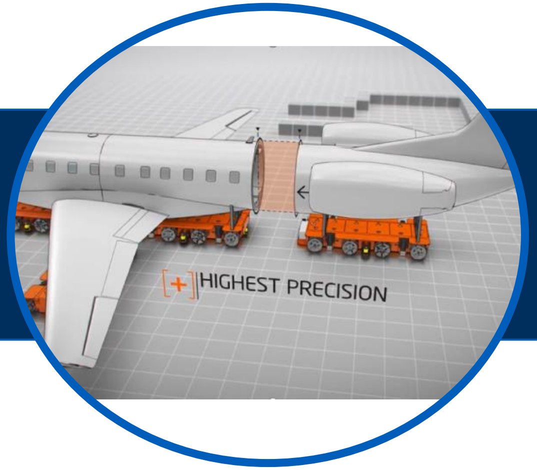
on behalf of

WP4 Mechanics and Cooling

INTRODUCTION

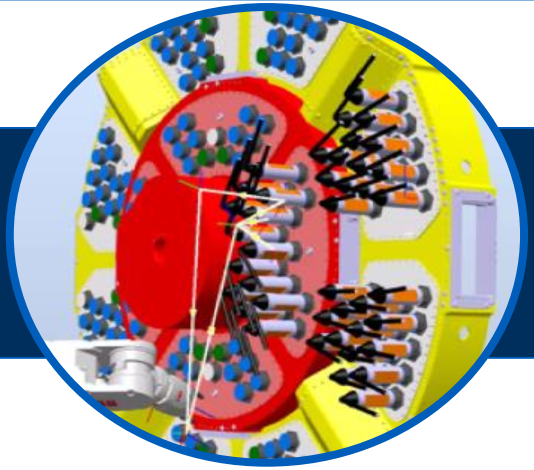


MOTION OF LARGE COMPONENTS (MOVES)

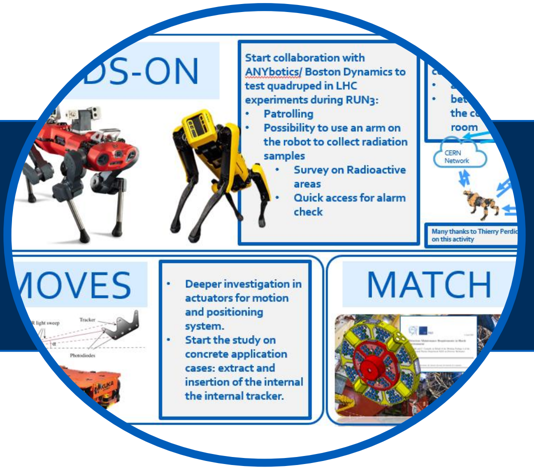


SURVEY AND OPERATIONS (HANDS-ON)

MAINTENANCE (MATCH)

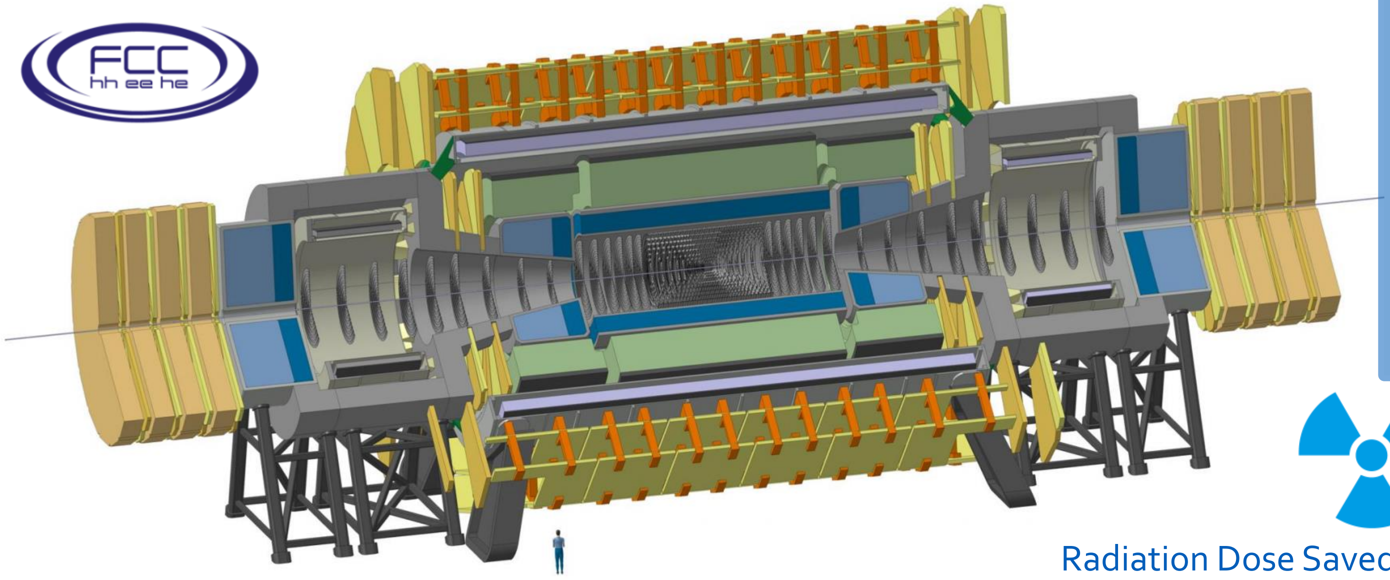


FUTURE WORK

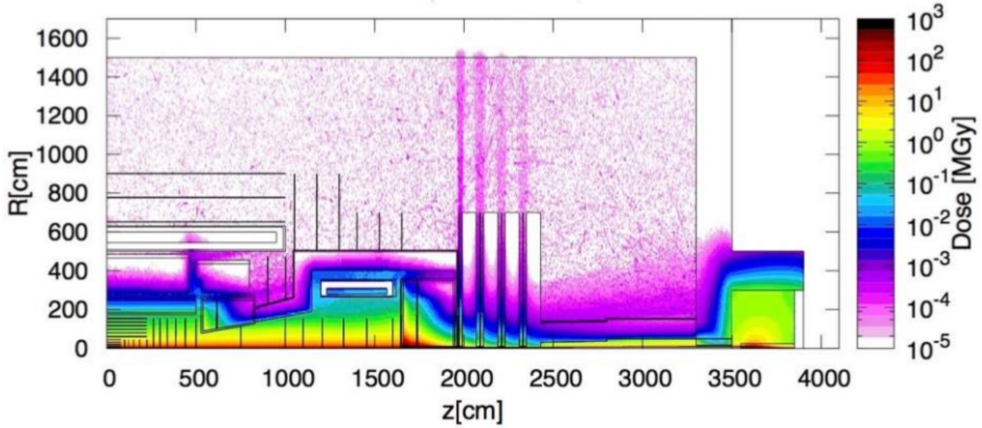


INTRODUCTION

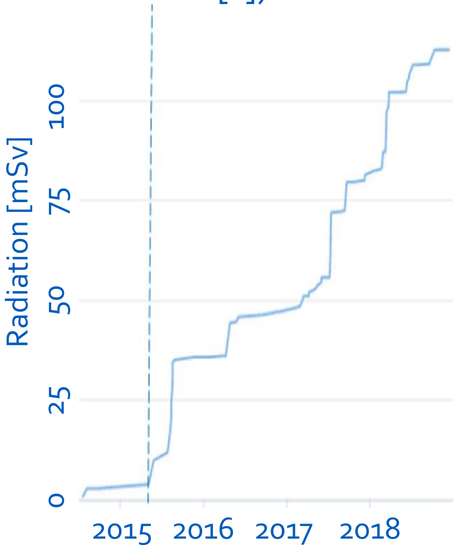
THE BENEFITS OF AUTOMATION AND SIMPLICITY IN FUTURE DETECTORS



1. Radiation is an increasing challenge in future detectors. For FCC-hh there is no significant decrease in delivered dose after one year.
2. Repetitive maintenance tasks are speeded-up.
3. Design a robotic friendly components facilitate also their human manipulation.

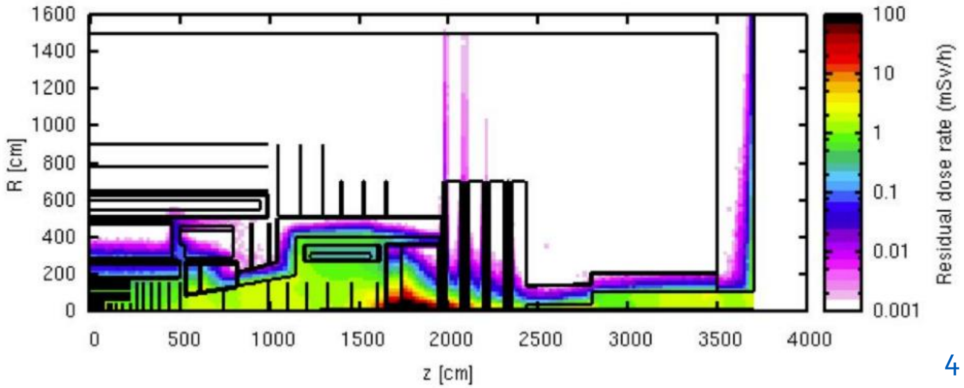


Radiation Dose Saved to Personnel (readapted from [1])



[STAUBLI Connectors]

Residual dose rate (LS5, 1 w cool down)



Developing guidelines to design particle detectors suitable to interface with automatic and robotic systems. Conceptualize such systems by studying the state of the art of robotics and automation, the current commercial solutions and applications.

Robotics

Ready to be Published

CERN EP R&D

6 April 2021

State of the Art Of Robotic Solutions in Harsh Environment

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

1. What is the state of the Art (what robots can do)?
2. What will be the development in the near future?
3. What is available currently on the market?

Detectors

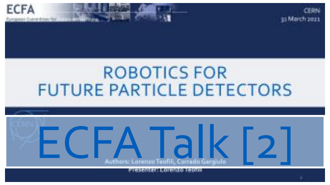
Drafting

CERN EP R&D

6 April 2021

Detectors Maintenance Requirements in Harsh Environment

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



Version 1.0 Being Reviewed

CERN EP R&D

6 April 2021

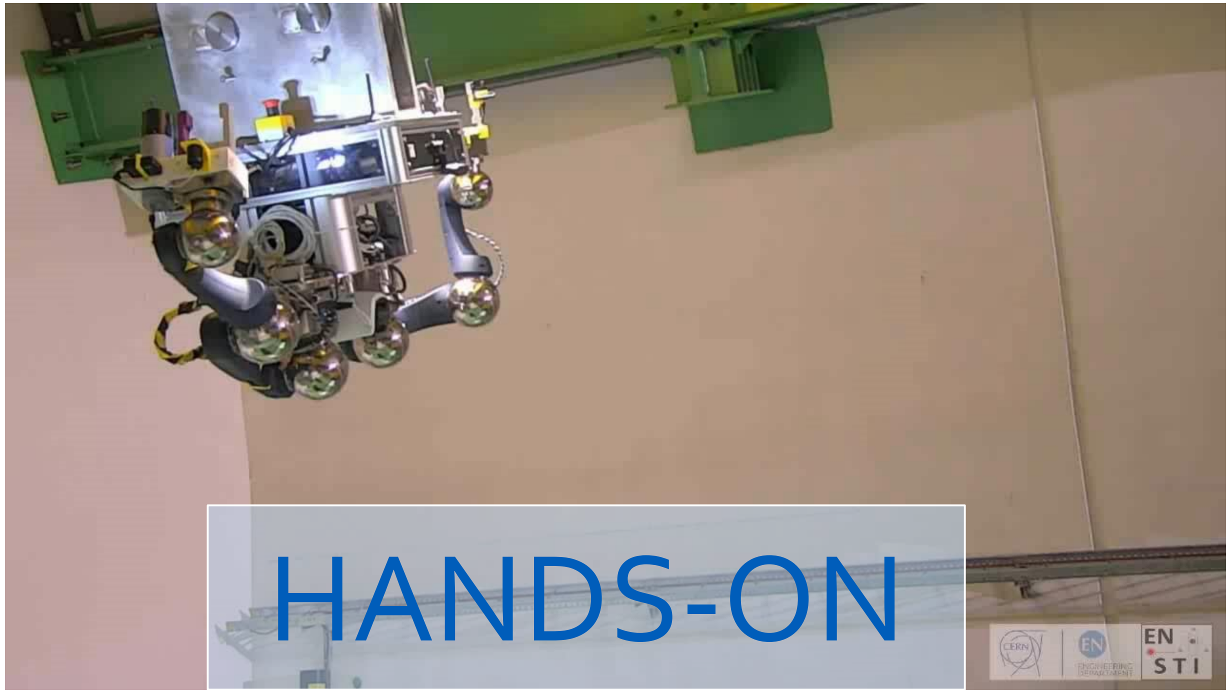
Best Practices for the Design of High Energy Physics Detectors to be Operated by Robotic and Automated Systems

L. Teofili and C. Gargiulo on Behalf of the Working Package 4 of the

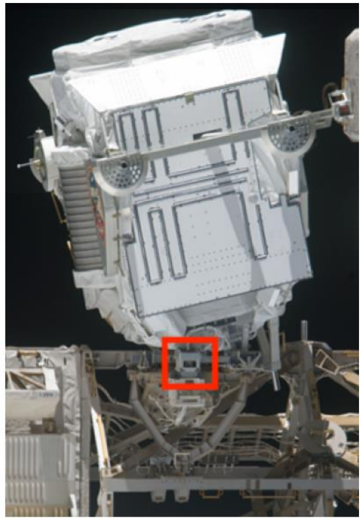
Robotic maintenance of complex systems

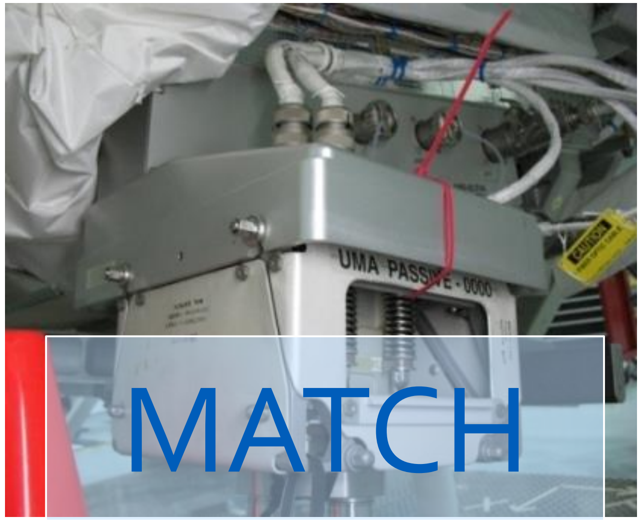
1. Is there any previous experience?
2. Can this experience be applied to the design of a robotic friendly particle detector?

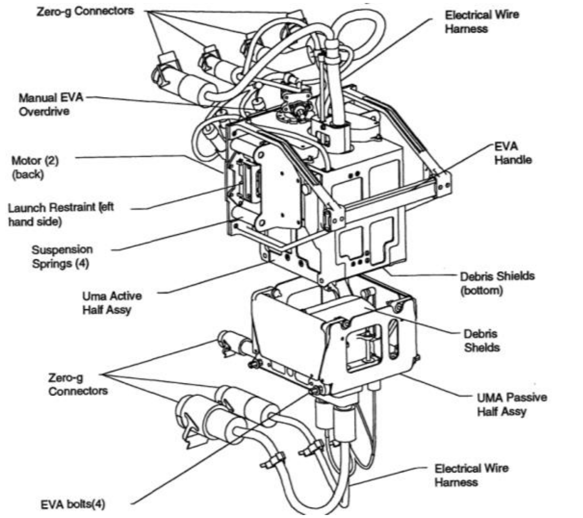
A ROBOTIC SYSTEM CONCEPT FOR PARTICLE DETECTORS



- **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)**

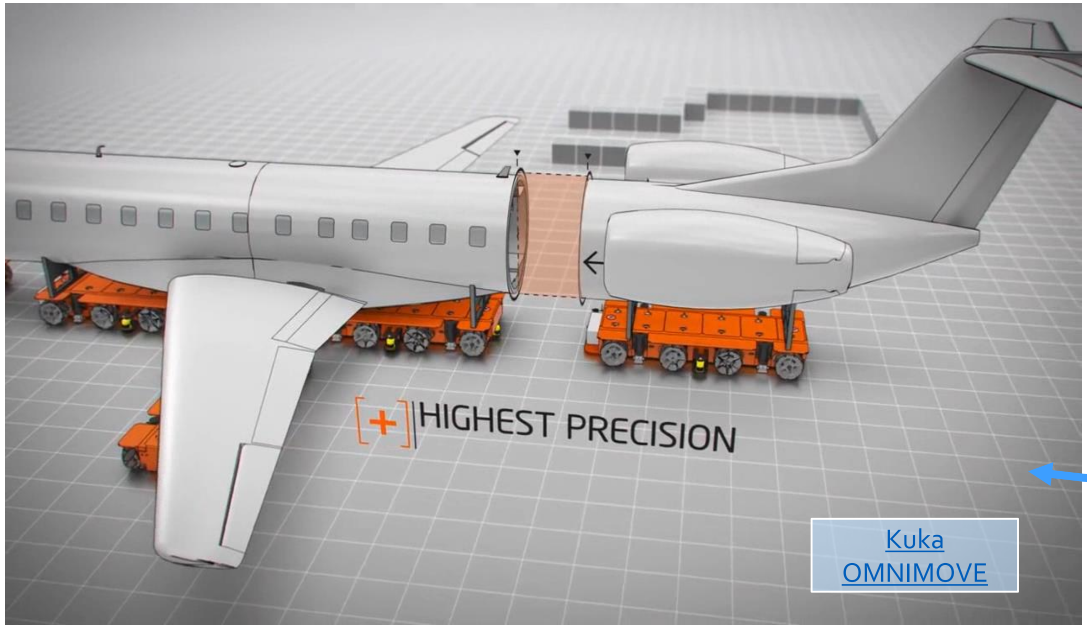






MOVES

Motion **O**f **V**olumetric and **M**assive **E**quipment **S**ystem

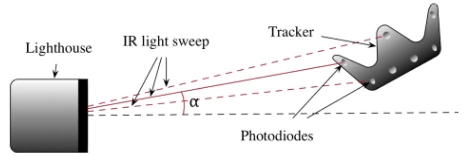


Kuka OMNIMOVE

CMS PARTS SLICING

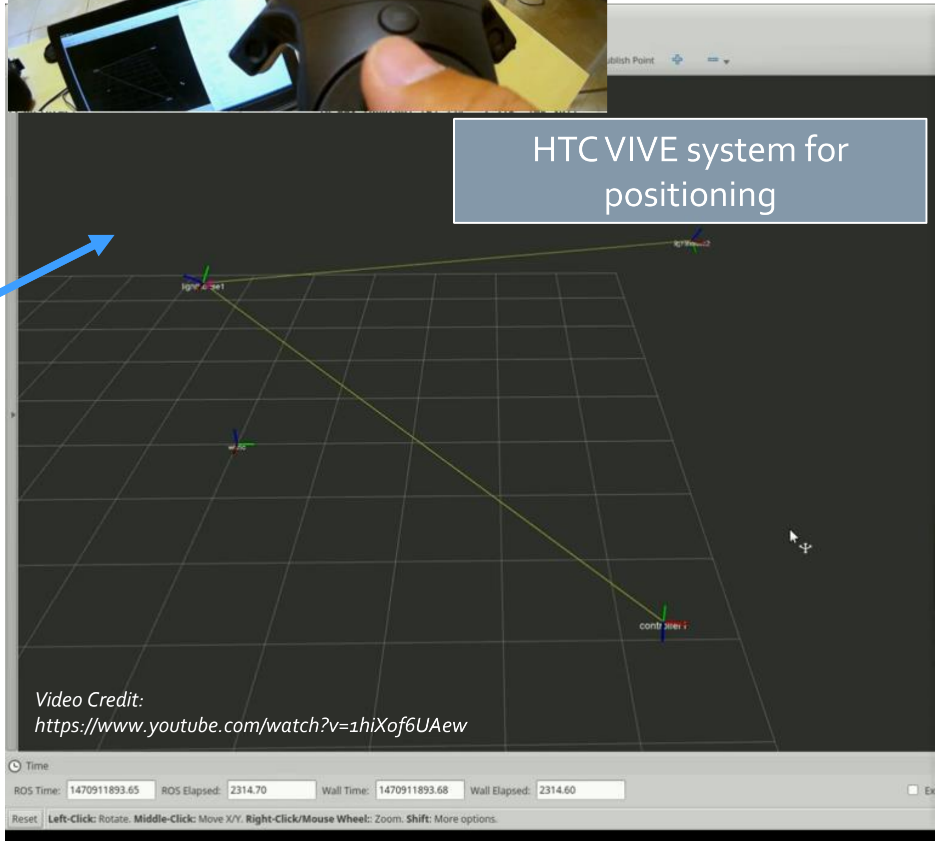
Main elements of a motion system:

- Actuators
- State estimators (Indoor Positioning System for Absolute Location)
- Control Algorithm for motion



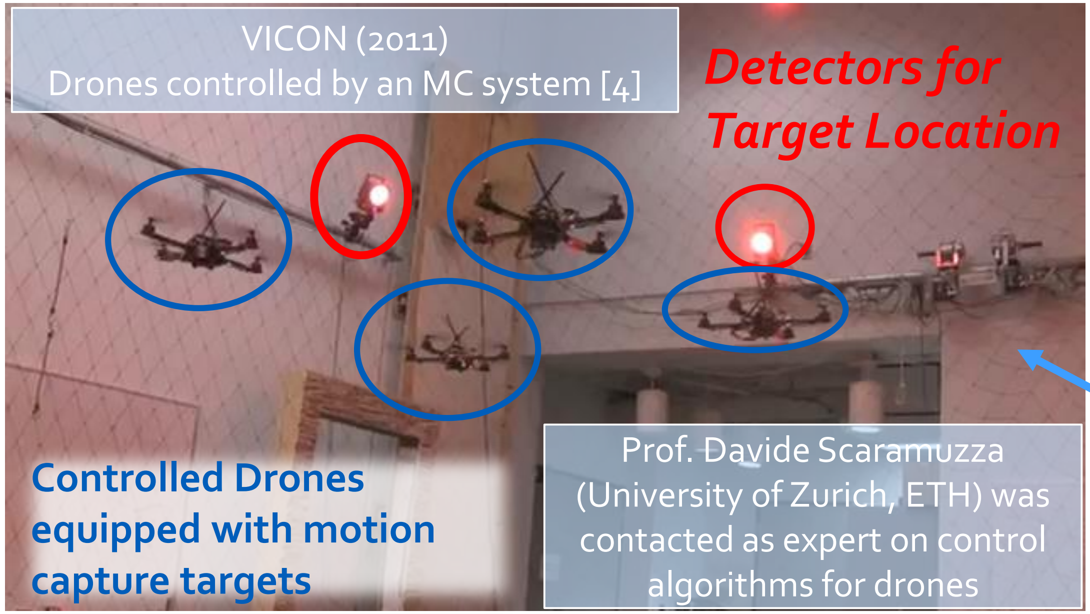
Motion Capture (MC) Indoor Positioning Systems

Sub-millimetric accuracy if the target is stationary [3]



HTC VIVE system for positioning

Video Credit: https://www.youtube.com/watch?v=1hiXof6UAew



VICON (2011)
Drones controlled by an MC system [4]

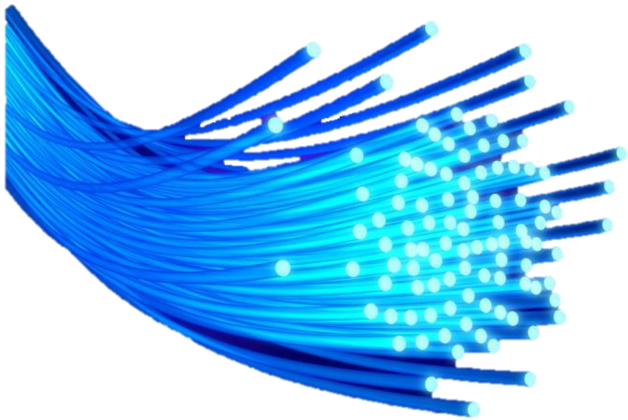
Detectors for Target Location

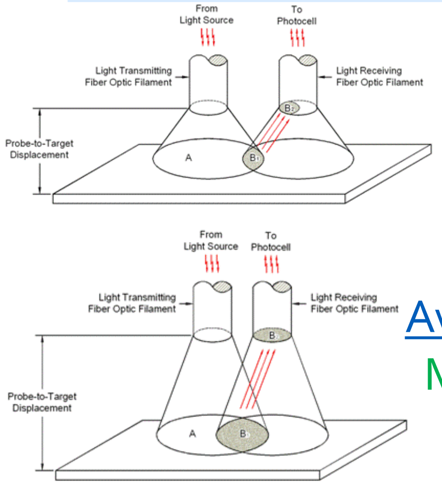
Controlled Drones equipped with motion capture targets

Prof. Davide Scaramuzza (University of Zurich, ETH) was contacted as expert on control algorithms for drones

Micrometer accuracy

Fiber Optic Sensors For Distances

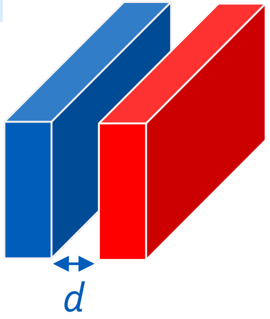




Suitable to Measure Small Distances, cm range

<u>Example of Product Available on the Market</u> [5]

Mature Technology to Be Customized for CERN Purposes



Capacitive sensors

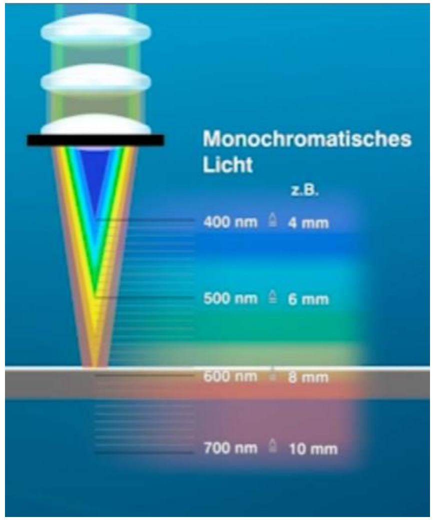
<u>Example of Product Available on the Market</u> [6]

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

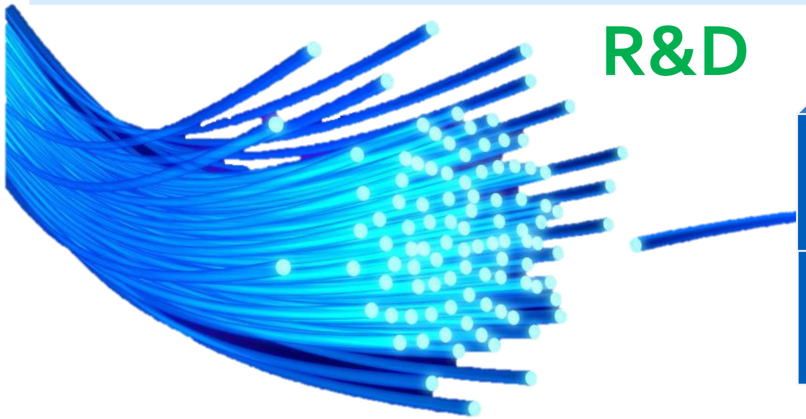
<u>Example of Product Available on the Market</u> [7]

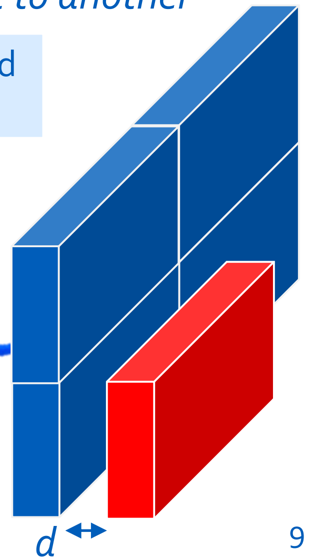
Mature Technology to Be Customized for CERN Purposes

Distance Sensors

Fiber Optic or Capacitors Grids For Distances and Positions

R&D

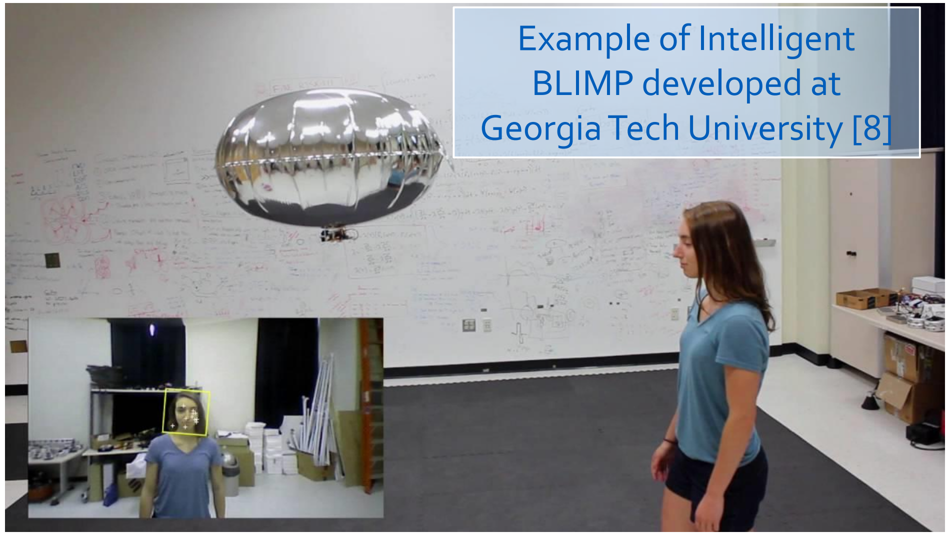




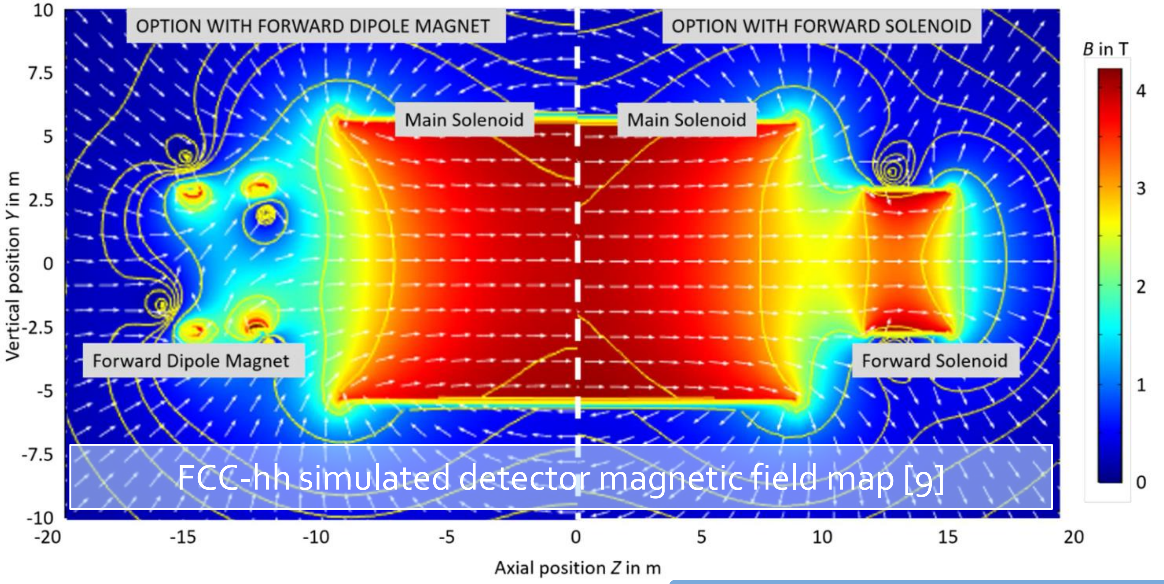
HANDS-ON

HANDling and **S**urvey **ON** Detector

THE HANDS-ON SYSTEM: BLIMPS FOR SURVEY



Example of Intelligent BLIMP developed at Georgia Tech University [8]



FCC-hh simulated detector magnetic field map [9]

THE MAIN NEED: 3D MAGNETIC FIELD MAPPING

MOVES sensors can be used to estimate precise BLIMPs positions

Concepts of BLIMPS inspecting a detector

A company specialized in pneumatic flying vehicles (San Jorge Tecnologica) has been contacted for the possible realization of a nonmagnetic pneumatically actuated blimp (wired solution)

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?

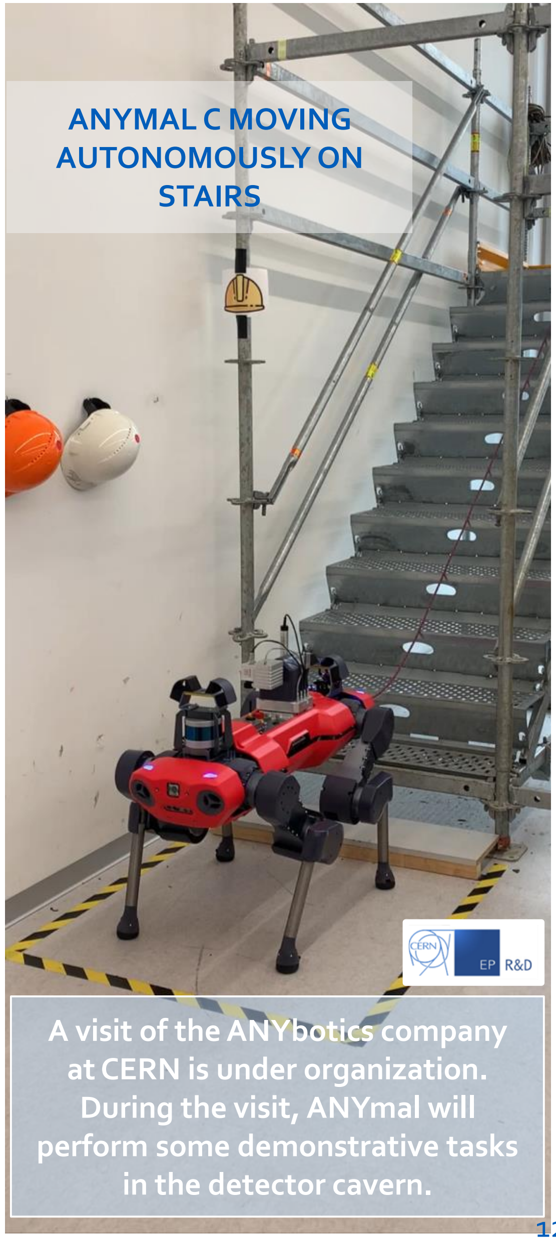
THE HANDS-ON SYSTEM: ROBOTS FOR SURVEYS AND OPERATIONS

Boston Dynamics SPOT

The company has been contacted to investigate the possible use of their robots at CERN

ANYMAL C CAPABILITIES

ANYMAL C MOVING AUTONOMOUSLY ON STAIRS



A visit of the ANYbotics company at CERN is under organization. During the visit, ANYmal will perform some demonstrative tasks in the detector cavern.

CERN Visit at the ANYbotics Zurich Headquarters

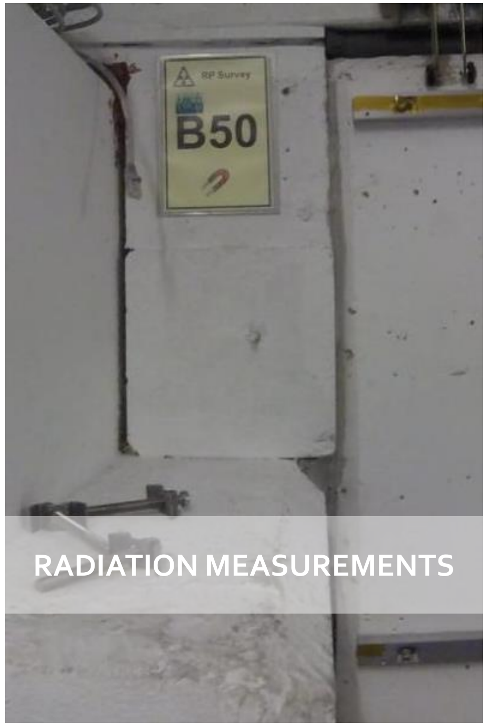
CERN (BE-CEM-MRO section) has large experience with wheeled robots!
However, they are limited by stairs, while quadruped robots should not have this problem.

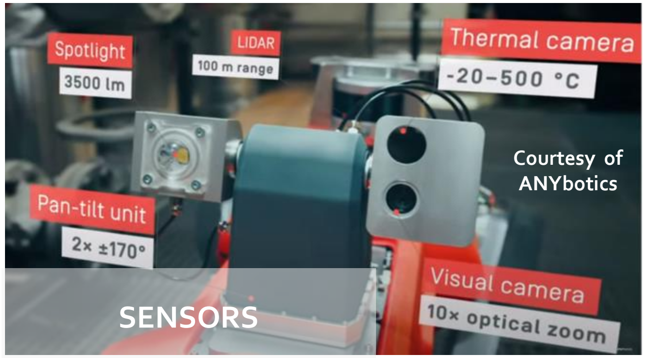
Example of CERN custom wheeled Robot

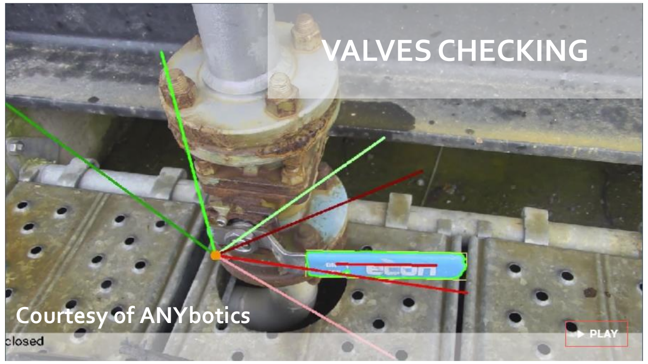
ANYBOTICS ANYMAL C

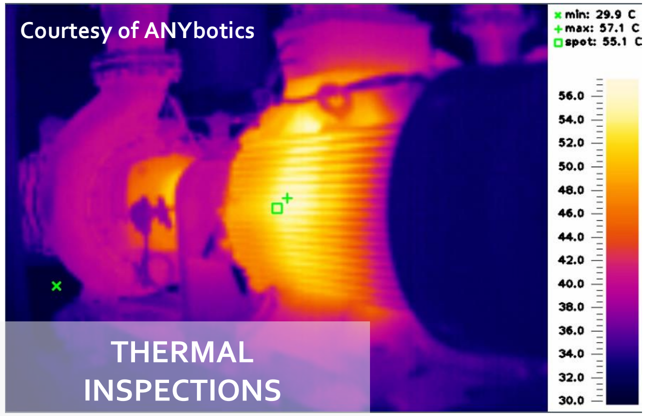
THE HANDS-ON SYSTEM: WHAT ROBOTS CAN DO

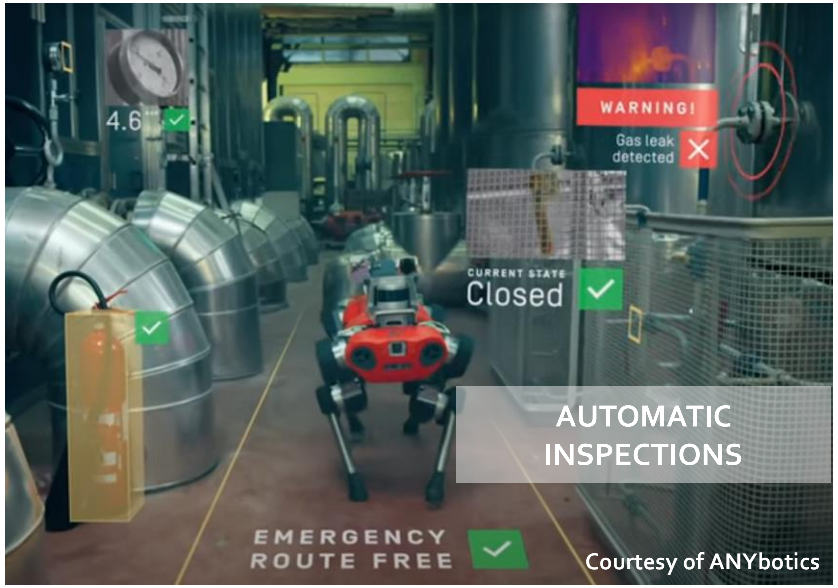
THE MAIN NEEDS: SURVEY OF RADIAOACTIVE AREAS, PATROLLING, FAST ACCESS TO DETECTORS FOR ALLARM VERIFICATION











Automated Robot: This robot can perform only pre-programmed tasks. It does not feel the environment, it repeats the same task continuously. Old Industrial robots are examples.

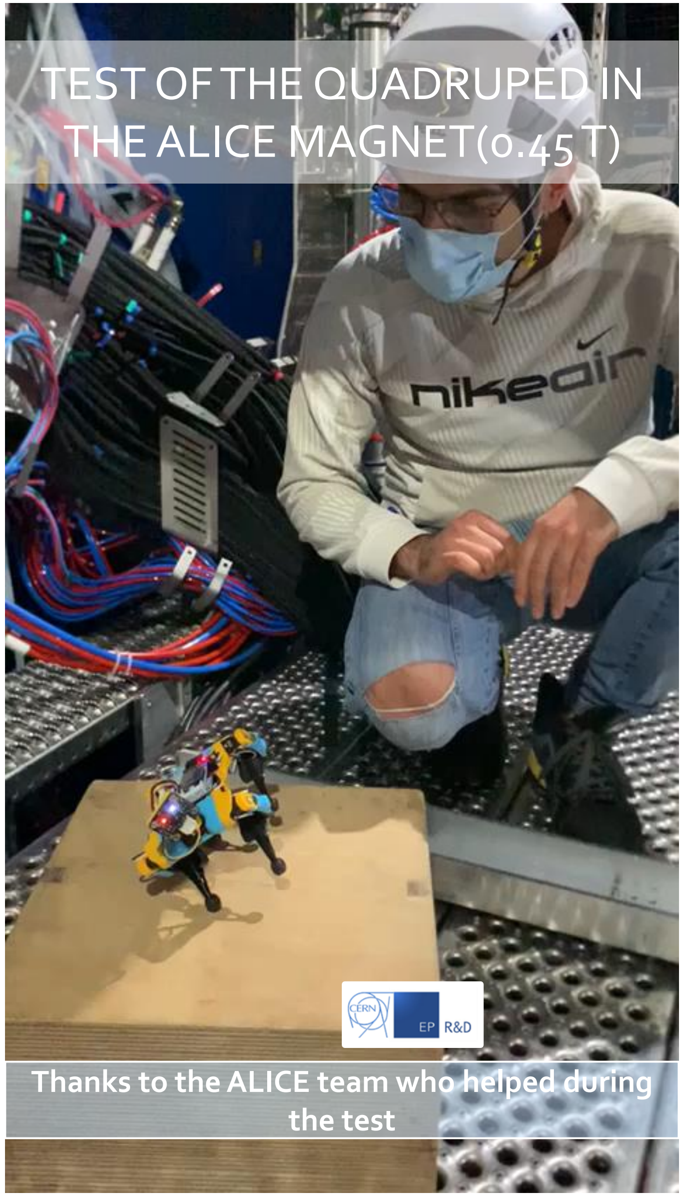
Teleoperated Robots:
This robot is controlled by a human operator, it can perform tasks only if instructed by the operator.
It may or may not feel the environment.

Autonomous Robots (the current generation):
These are the robots that are being developed nowadays. They can perceive the environment and act consequently to perform the tasks that are assigned to them. They do not require to be operated by humans.

SOME EXPERIMENTS WITH QUADRUPED PROTOTYPES

To investigate the capabilities of quadruped robots and get experience in programming their motion, some prototypes were bought (PETOI BITTLE).
They arrived in February 2021.
They were assembled at CERN and partially programmed on site.
Programming work is still needed but the device was capable of withstanding 0.45 T inside the ALICE magnet.


PETOI BITTLE TESTS


TEST OF THE QUADRUPED IN THE ALICE MAGNET(0.45 T)

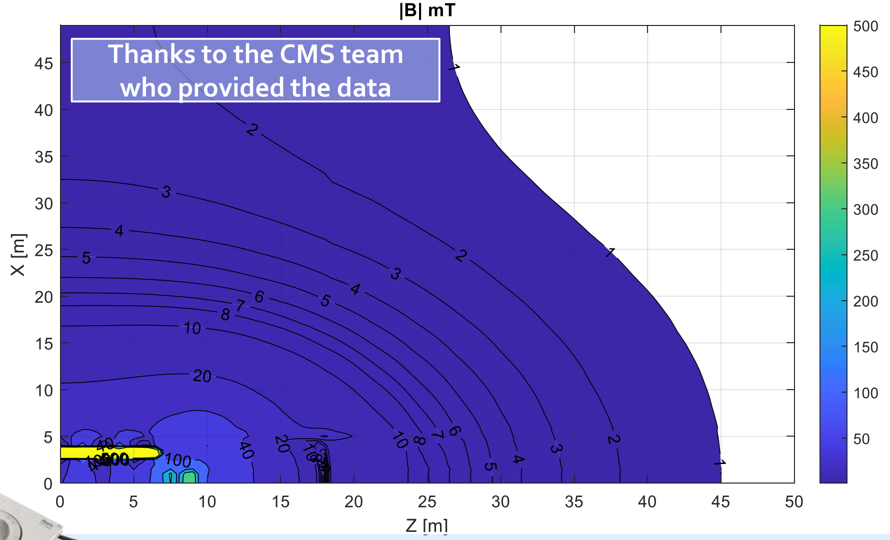
Thanks to the ALICE team who helped during the test


ASSEMBLY PROCESS

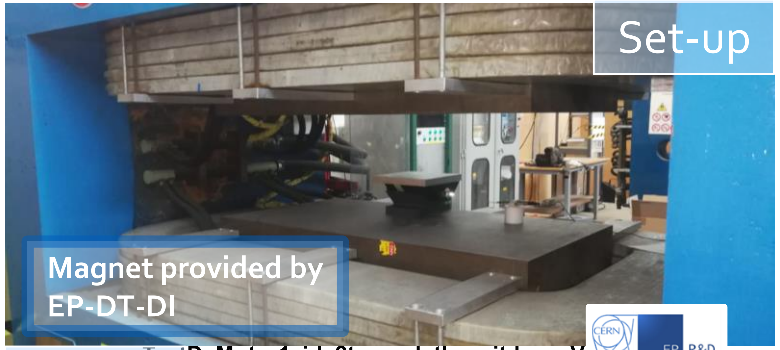

TEST OF THE QUADRUPED IN THE ALICE CAVERN WALKING AND RECOVERING FROM FALLING

A POSSIBLE CHALLENGE: THE MAGNETIC FIELD ENVIRONMENT

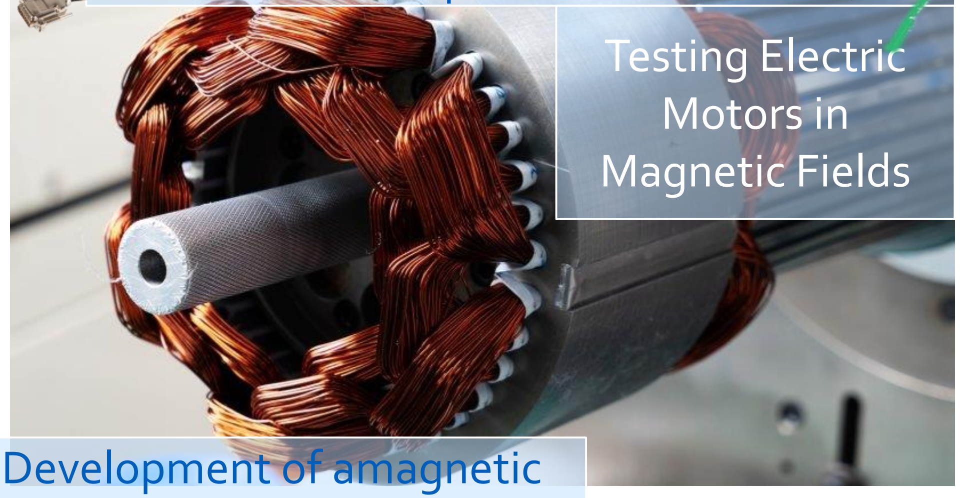
MAGNETIC FIELD AT THE CMS CAVERN GROUND (mT) From 0 to 100 mT



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



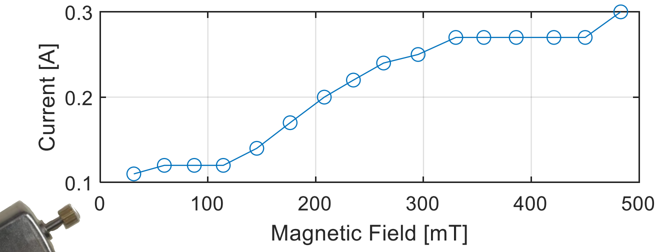
Checking possible substitutes for actuation (as piezoelectric motors)

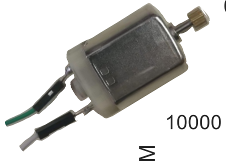


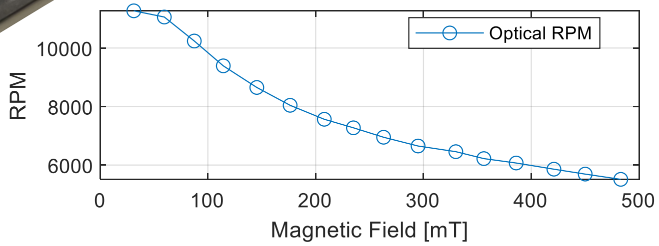
Testing Electric Motors in Magnetic Fields

Development of amagnetic robots and drones

Arduino Motor (Brushed) Measurements







- **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**

MATCH

Mechanism for f**A**st service in**T**erface **C**onnection **H**andling

CASE STUDY: DESIGN GUIDELINES FOR ROBOTIC FRIENDLY DETECTORS' COMPONENTS

Case Study: Interface Optimization for Robotic Manipulation of the new ATLAS INNER TRACKER Patch Panel 1

Lorenzo Teofili

01/04/2020

Version 1

Many thanks to Dario Orecchini
And Sandro Tomassini for providing the model of the PP1

Introduction

This document reports a case study where a design of a component to be installed in a detector is considered and analised under a robotic manipulation point of view.

The document lists the criticalities that can be encountered during the robotic manipulation of the component and proposes solutions.

The analysed component is the the new ATLAS patch panel 1 (PP1) presented at the ITK Pixel Services Preliminary Design Review [1].

The PP1 has been chosen for this case study among other components for two main reasons: It has to be dismounted and remounted to access the internal parts of the detectors, this makes it a component that will have high chanses to be handled during maintenance. It hosts connectors of different services (cooling, data, power), their disconnection and reconnection makes the manipulation of the PP1 not trivial.

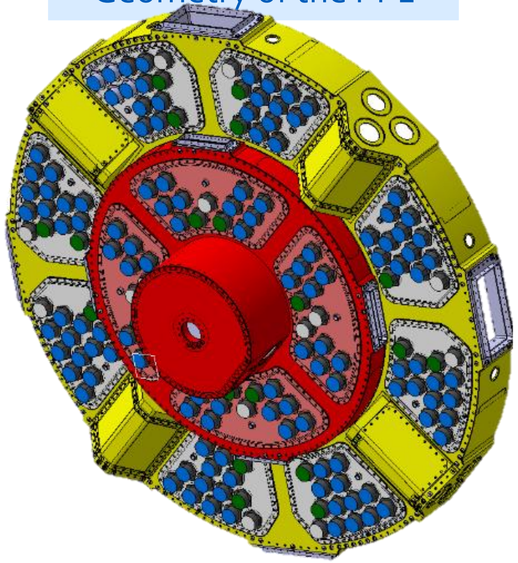
It is important to recall that robotic manipulation is not among the PP1 design requirements.

Robotic manipulation can reduce the exposure of human personnel to radiation (in case the device become activated) during the PP1 maintenance and disposal.

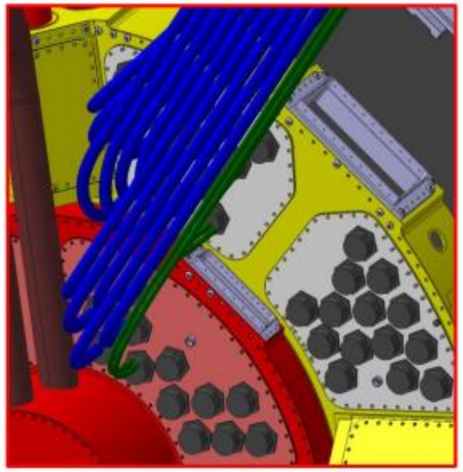
Usually, a device must have specific features to be efficiently manipulated by an automated system. Thus, this document reviews the PP1 design and propose mechanical modification aimed at making the design more human and robotic friendly, so to decrease maintenance and disposal time.

Case Study:
This case study was performed on a real component to be installed in the CERN detectors.
<u>Possible robotic manipulation was not among the design requirements of this component, this is just a case study</u>.

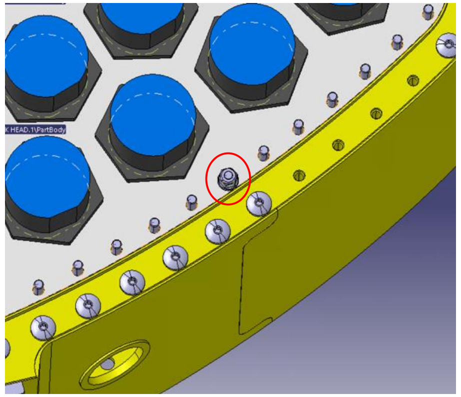
Geometry of the PP1



Detail of cables on the PP1



Detail of screws on the PP1



Study to improve the manipulability (of robots or humans) of the PP1:

1. Change connectors type, push-pull connectors are easier to mount/dismount than wiring connectors
2. Connectors spacing and distribution, ensure that the connectors are accessible by a robotic or human arm
3. Power Cable and Connector Labelling and Easy recognition
4. Power Cable Disconnection Sequence
5. Storing Power Cables During Operations
6. Use only captive screws
7. Minimize Screw Number
8. Use only Screws bigger than M3
9. Pick-up Points to hold the different components

Robotic maintenance of complex systems

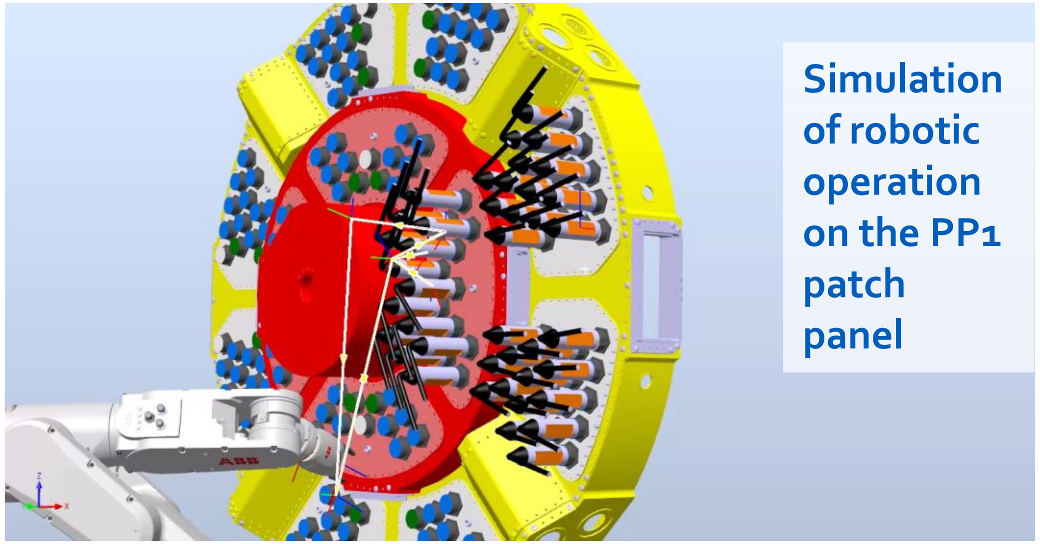
CERN EP R&D

6 April 2021

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

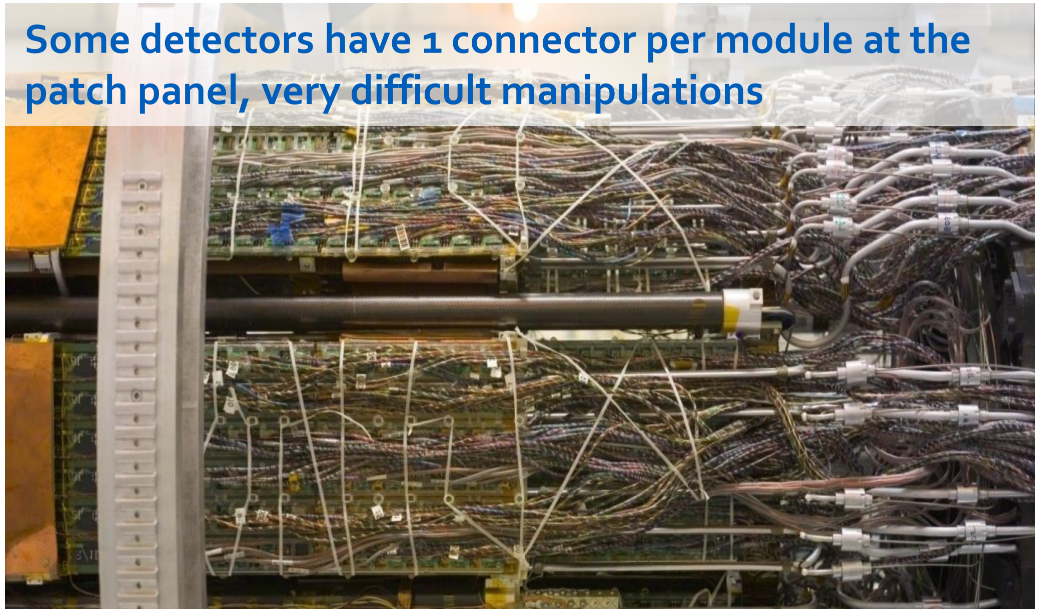
L. Teofili and C. Gargiulo on Behalf of the Working Package 4 of the Experimental Physics Department R&D on Detector Mechanics

MECHANISM FOR FAST SERVICE INTERFACE CONNECTION HANDLING (MATCH)

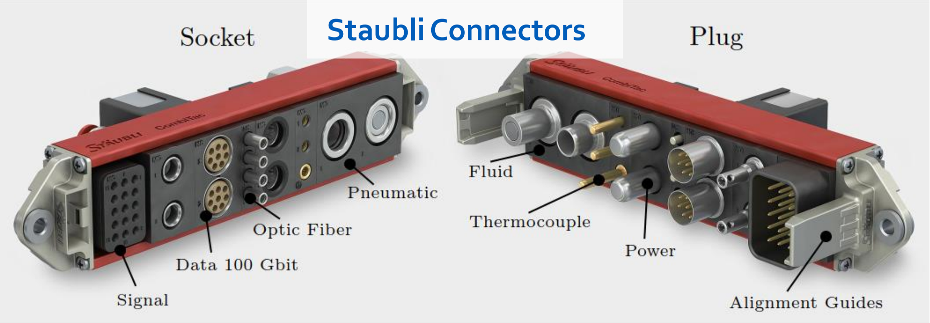


Simulation of robotic operation on the PP1 patch panel

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



THE MAIN NEED: Fast handling connectors would incredibly simplify the work of robots or humans for the maintenance of the plants



FUTURE WORK

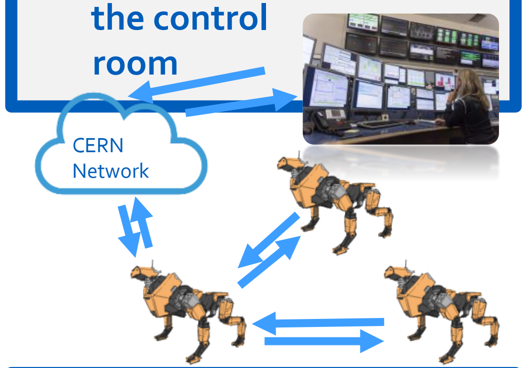
HANDS-ON

Start collaboration with ANYbotics/ Boston Dynamics to test quadrupeds in LHC experiments during RUN3:

- Patrolling
- Possibility to use an arm on the robot to collect radiation samples
  - Survey on Radioactive areas
  - Quick access for alarm check

Development of robust communication:

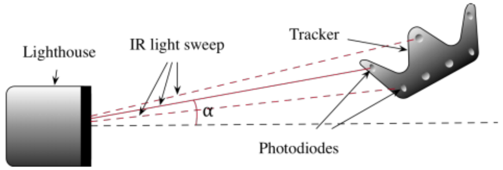
- among the robots
- between the robots and the control room



Many thanks to Thierry Perdichizzi for the support on this activity

- Understand the effects of magnetic forces on BLIMPS
- Operative design of a non magnetic blimp (in house study and collaboration with companies)
- Equip blimps with Hall probes for magnetic field measurement (Collaboration with EP-DT, Nicola Pacifico).

MOVES



- Deeper investigation in actuators for motion and on positioning system
- Deeper investigation on commercial solutions for indoor positioning systems
- Study on an automated system for extraction and insertion of the internal tracker of current experiments

MATCH

- Integrate commercial solutions for easy mating-demating of connectors in the particle detector components
- Establish guidelines for the robotic friendly design of new patch panels
- Optimize other detector components for robotic manipulation

THANK YOU FOR YOUR ATTENTION

REFERENCES

[1] A Novel Robotic Framework for Safe Inspection and Telemanipulation in Hazardous and Unstructured Environments

[2] Robotics for Future Particle Detectors, Presentation for the ECFA Detector R&D Roadmap Symposium of Task Force 8 Integration

[3] HTC Vive: Analysis and Accuracy Improvement, 2018 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), 2018

[4] Quadrotor Formation Flying Gets Aggressive, IEEE spectrum webpage

[5] Examples of Fiber Optic Sensors

[6] Examples of capacitive sensors

[7] Examples of cofocal sensors

[8] Autonomous flying blimp interaction with human in an indoor space

[9] FCC-hh: The Hadron Collider

[5] An Advanced Radiation Dose Estimation Tool for Decommissioning of HEP Experiments

[8] ITER remote handling code of practice

[9] Remote maintenance code of practice for inspection and telemanipulation

[10] The Curios Cryogenic Fish

[11] DUNE far detector module layout

[12] Oil-Filled Power Transformers: Time for Robotic Inspection?

BACKUP

INSPECTIONS IN CRYOGENIC ENVIRONMENT: THE CURIOUS CRYOGENIC FISH

Public deliverable for the ATTRACT Final Conference

The Curious Cryogenic Fish - CCF

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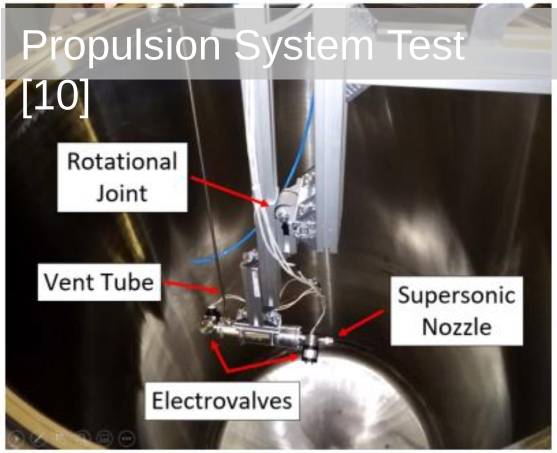
Thanks to Giovanna Lehmann Miotto for involving EP-R&D WP4 on this project



Propulsion System Test [10]

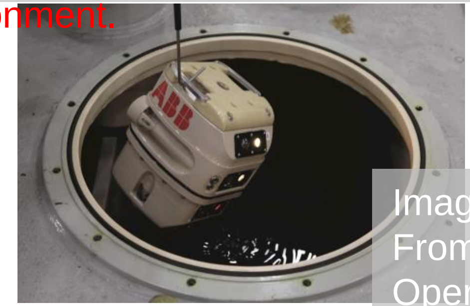

Battery System Test

The Curios Cryogenic Fish (CCF) Project [10]

	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 [10]

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.



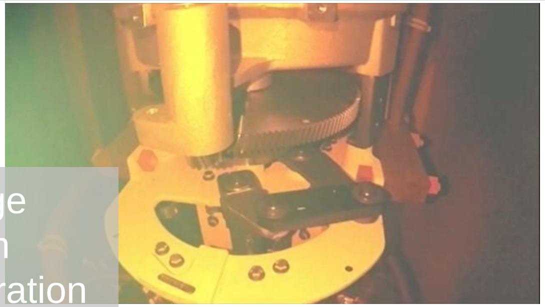
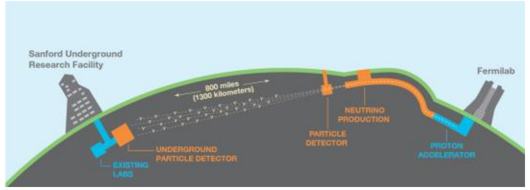
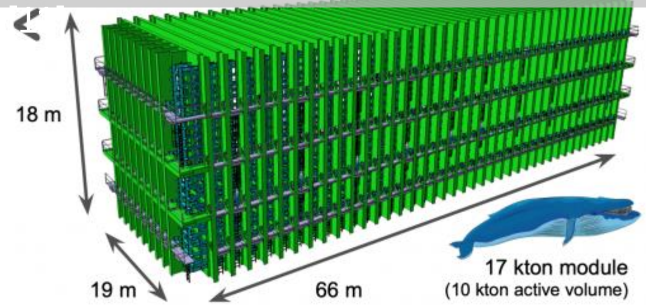


Image From Operation

DUNE DEEP UNDERGROUND NEUTRINO EXPERIMENT



DUNE Cryogenic Module Dimensions



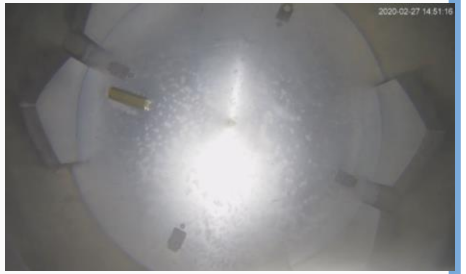
CAMERAS FOR HARSH ENVIRONMENT

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

Mature technology, different models are available on the market

The Cryo-Tolerant Cameras

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.

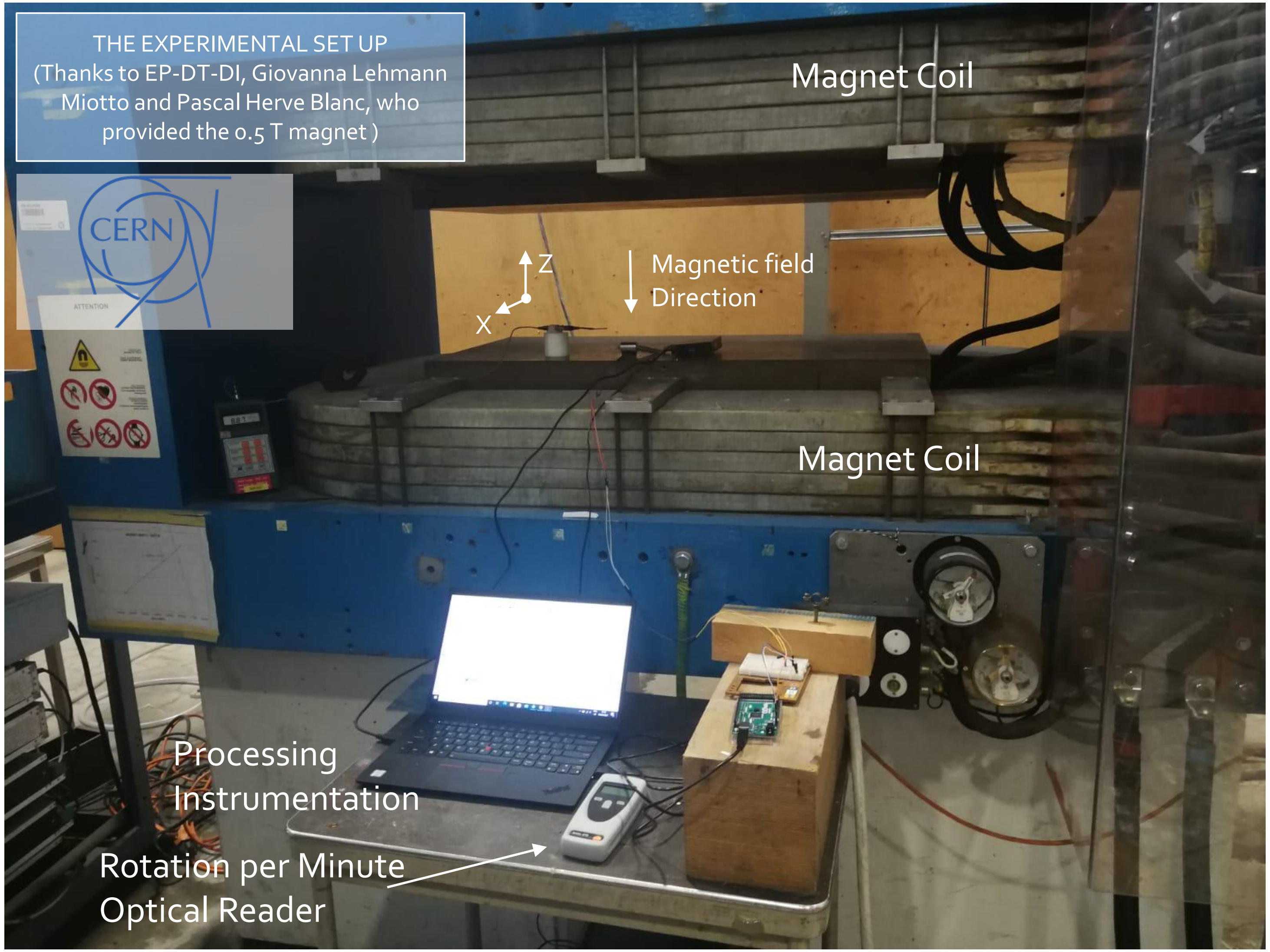
Development of a camera casing suited for cryogenic and vacuum applications

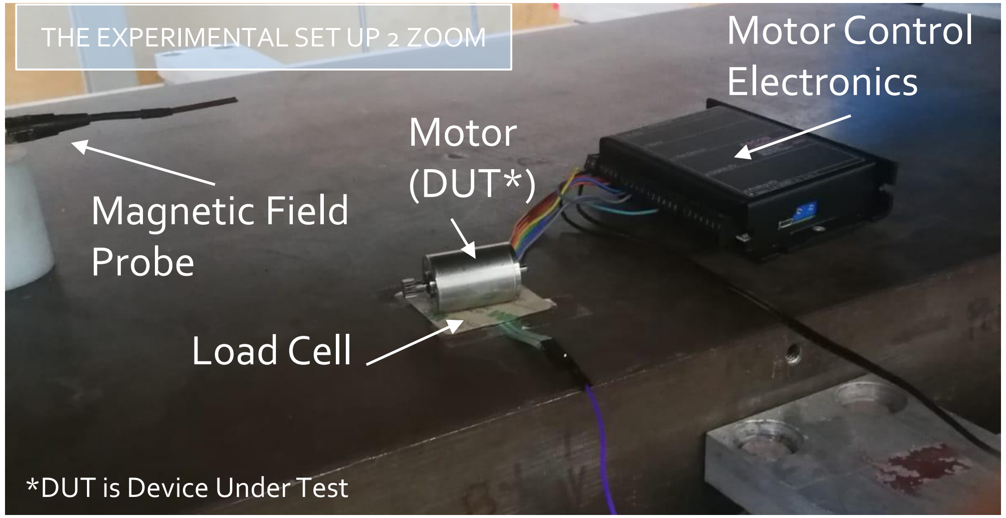
R&D

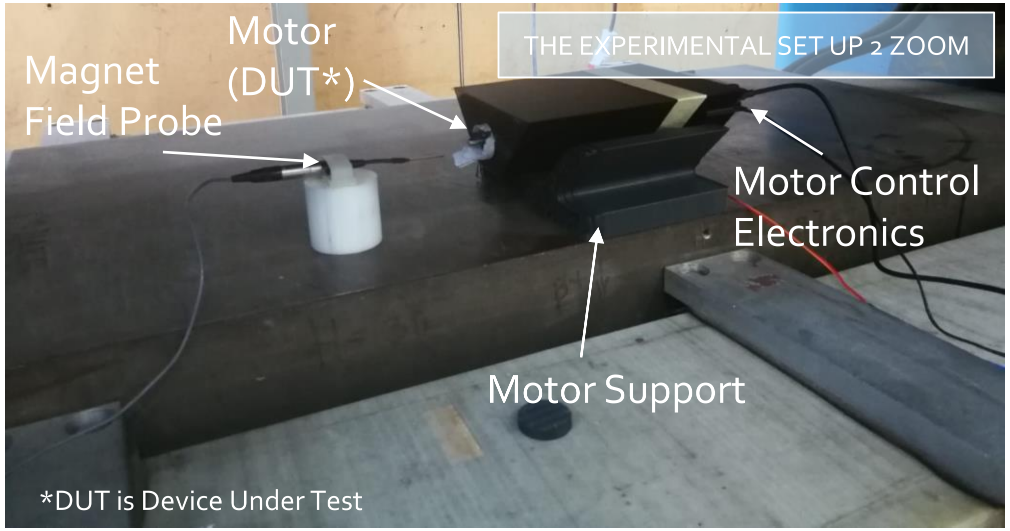
S. C. Delaquis, R. Gornea, S. Janos, M. Lüthi, Ch. Rudolf von Rohr, M. Schenk, and J.-L. Vuilleumier

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

A POSSIBLE CHALLENGE: THE MAGNETIC FIELD ENVIRONMENT





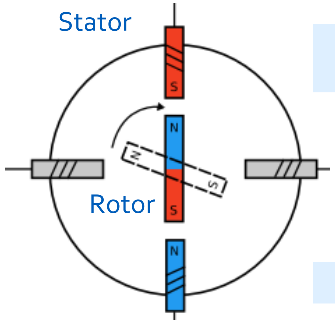


Experimental set-ups for calculating the response of an electric motor to a magnetic field

MAXON MOTOR
EC-MAX 283840 MEASUREMENTS

EC MAX 283840

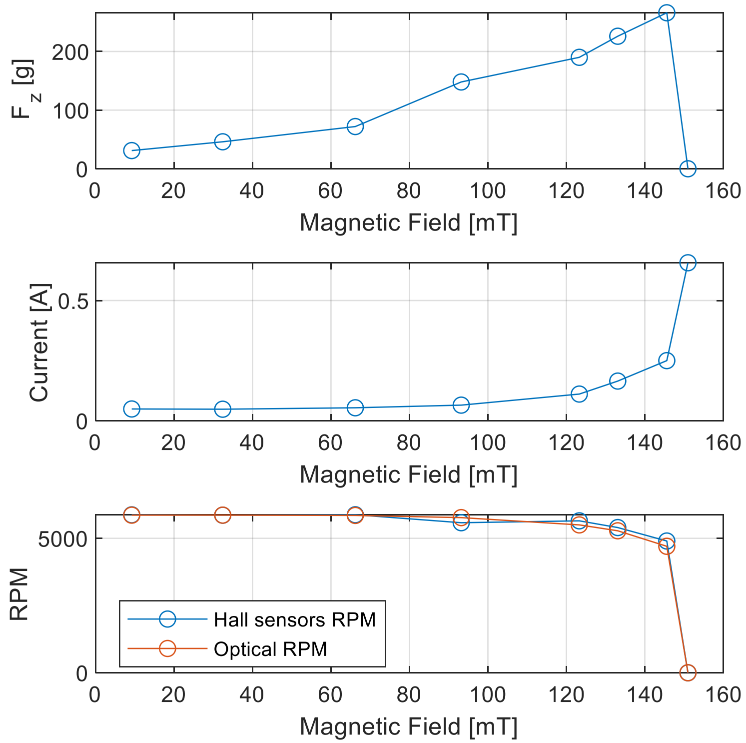
- One layer of Mu metal (0.5 mm thickness) increase the tolerance of the motor to external magnetic fields of 15%.
- The second layer of mu metal seems to have no effects.
- Increasing the external magnetic field force on the motor increases as well (expected result)
- The RPM is well read by the internal hall sensors until the motor stops.
- Current consumption increases exponentially before the motor stops



Working Principle of a Brushless Motors

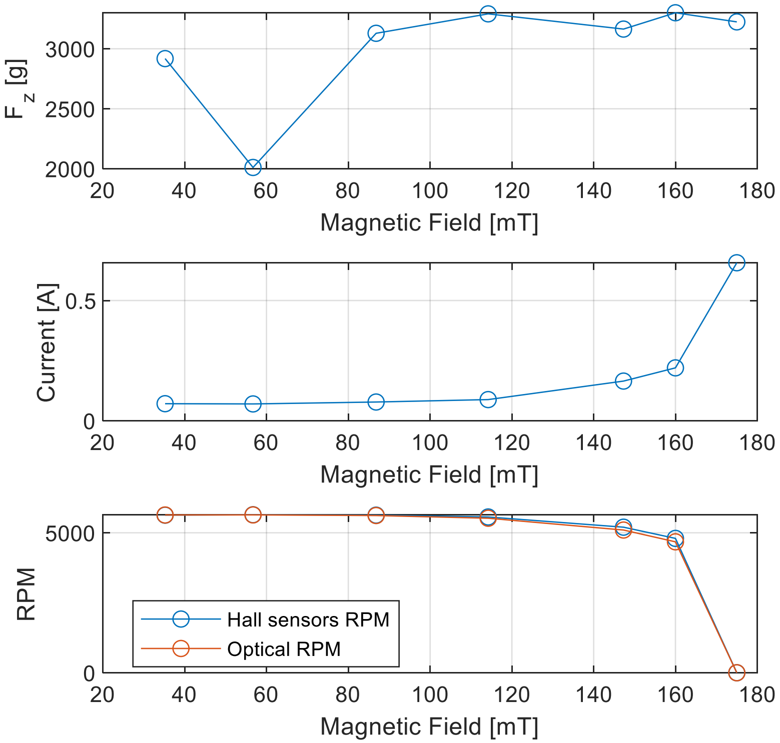
Image Source

No Shielding



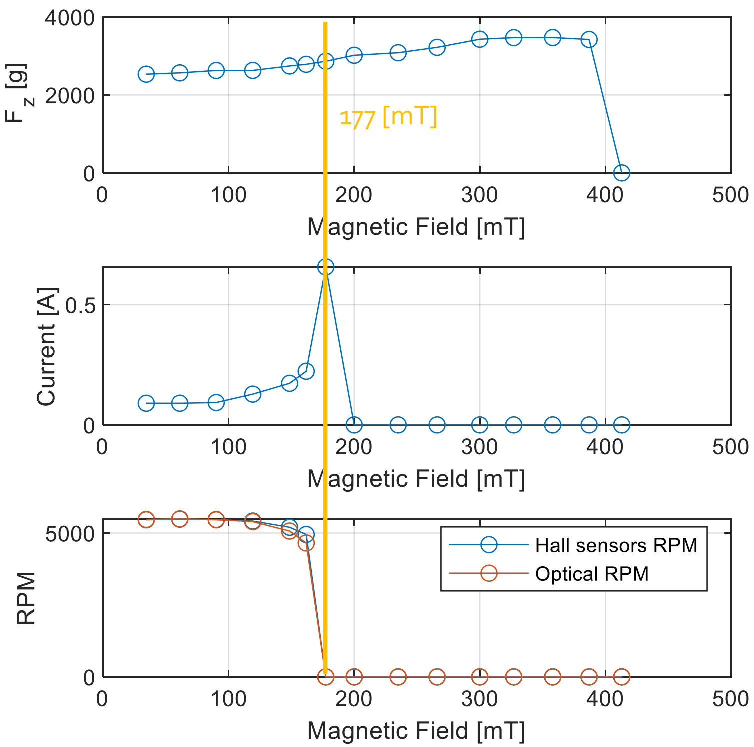
Set-up one

Shielding 1 Mu metal layer (0.2 mm thickness)



Set-up two

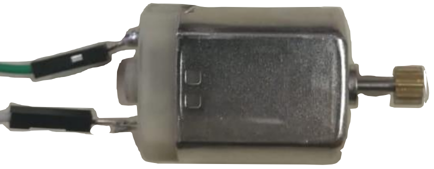
Shielding 2 Mu metal layer (0.2 mm thickness)



Set-up two

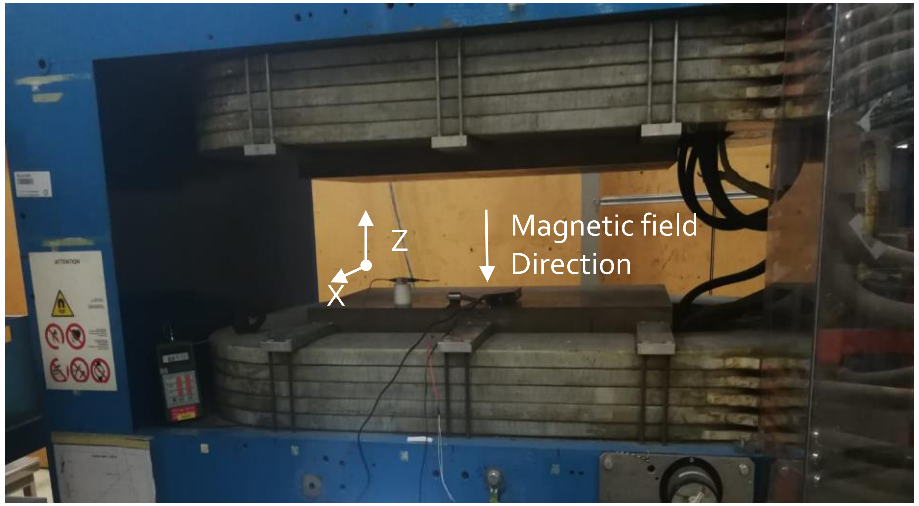
ARDUINO DC MOTOR MEASUREMENTS

Arduino Motor



Side one

Side two



Working Principle of a Brushled Motors

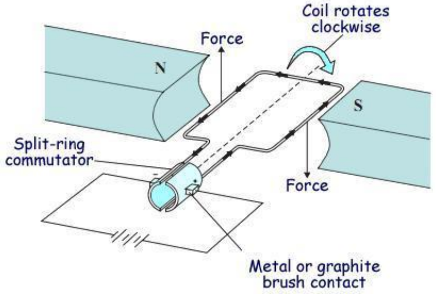


Image Source

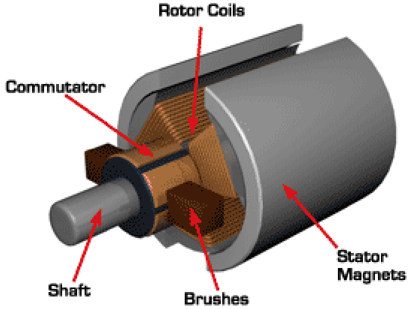
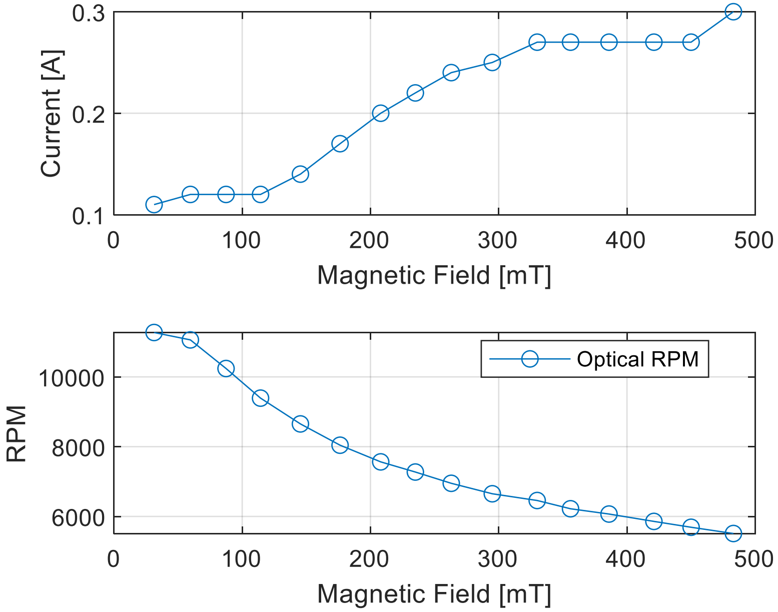


Image Source

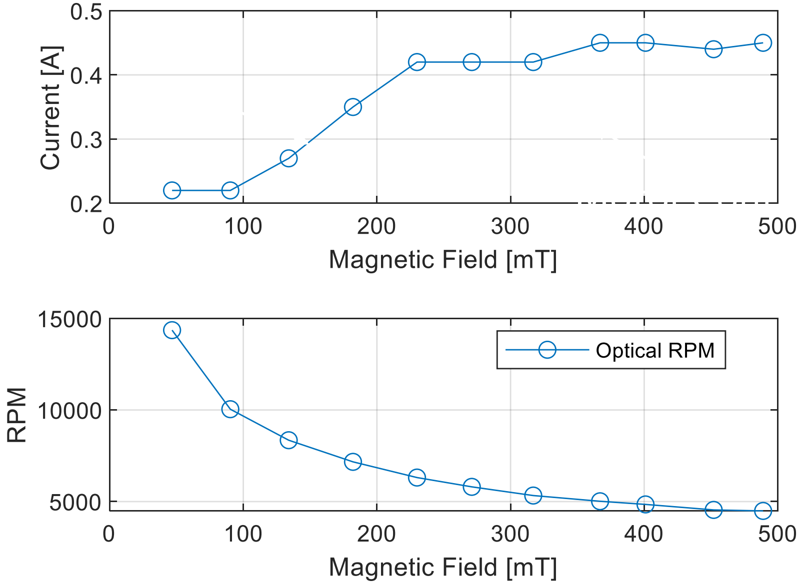
- **The RPM as a function of the magnetic field is dependent on the motor orientation.**
- **In general, RPM decreases increasing the external magnetic field.**
- **In general, the motor do not stop.**

Side two towards the Z axis



Set-up two

Side two towards the X axis



Set-up two