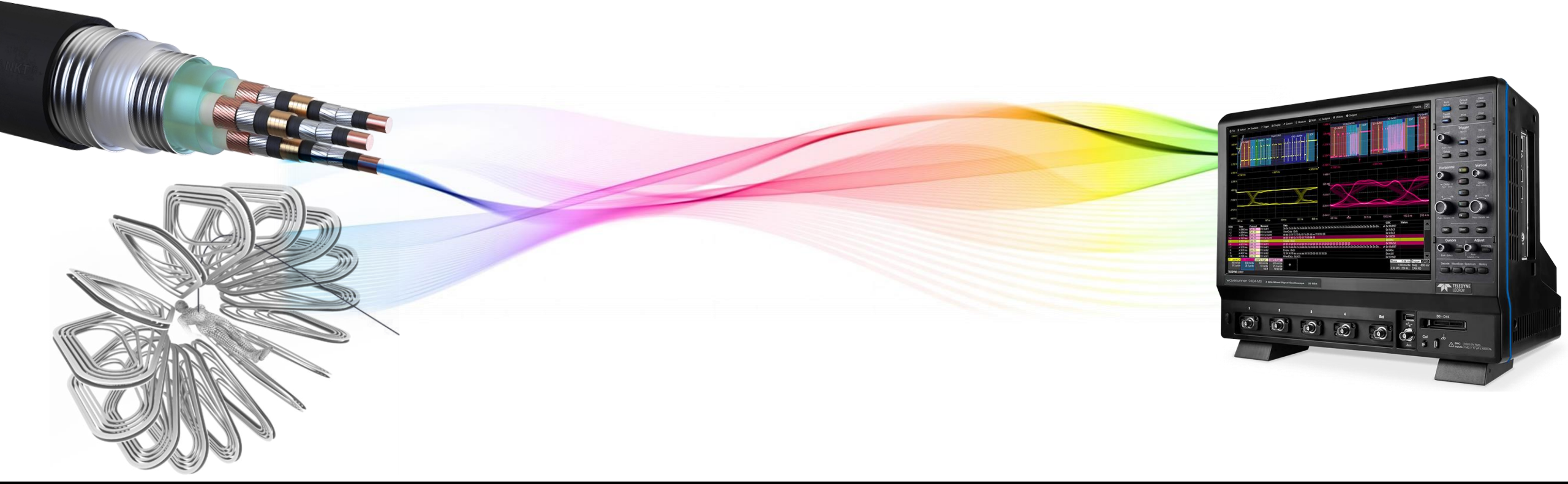
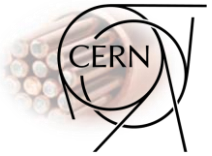


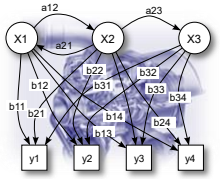
an advanced **instrumentation lab** for **superconducting cables** and **magnets**

Antonio Esposito
University of Naples Federico II

About the speaker

- Post-doc reasearcher
  - Ph.D. in **Metrology** at Politecnico di Torino (2018-2021)
    - thesis: «Instrumentation for daily-life brain-computer interfaces"
  - Master Degree in **Electronic Engineering** at University of Naples Federico II (2011-2017)
    - thesis: «Performance improvement of a current comparator quench detection system for superconducting cables»

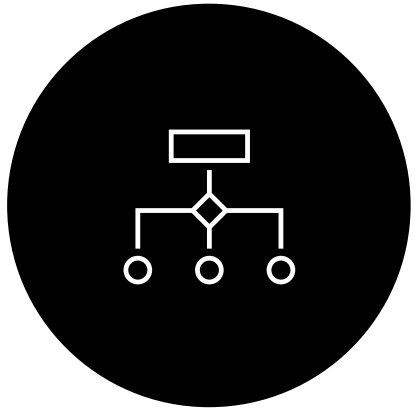




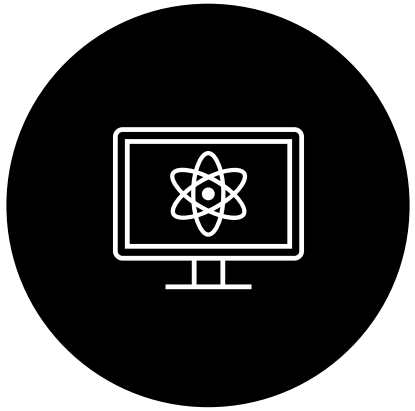
2016 2017 2018 2019 2020 2021 2022 2023

life is non-linear

Outline



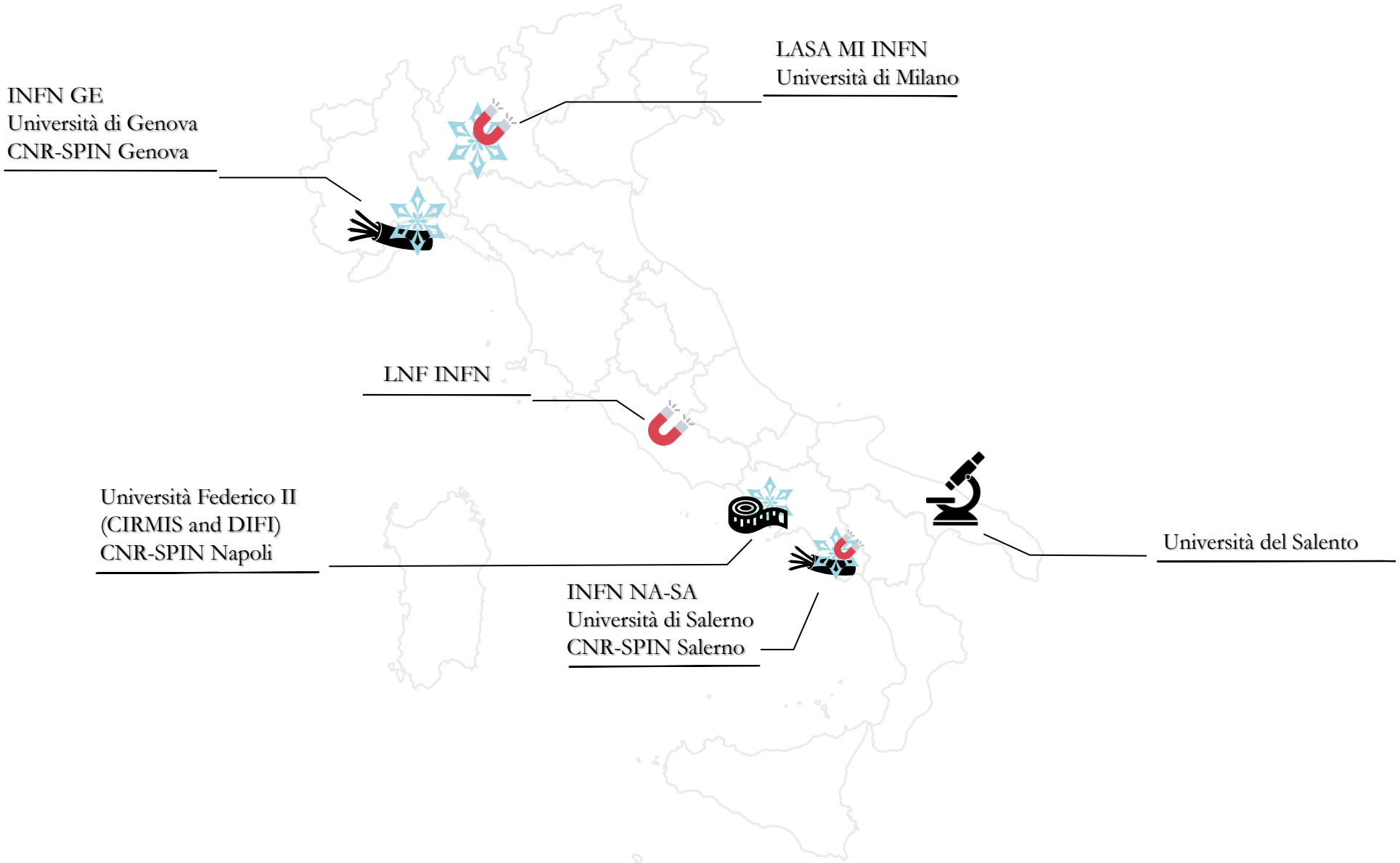
contextualization



lab overview

measurement methods

The IRIS project



Case studies

- **Green Superconducting Line**:
  - 1 GW target
  - 50 kV maximum voltage
  - 100 kA maximum current
  - MgB2 or REBCO
  - 20 K operating temperature
  - 1000 km long line
- Prototype:
  - 130-150 m demonstrator
  - flexible pipe of less than 300 mm

- **HTS Magnets for sustainable accelerators**:
  - 8 T or 10 T central field
  - dipole shape
  - 80 mm or 150 mm free aperture bore
  - REBCO or BSCCO
  - 10 – 20 K operating temperature
  - 1 m useful length
- Energy saving:
  - 70% to 90% with respect to LHC dipoles

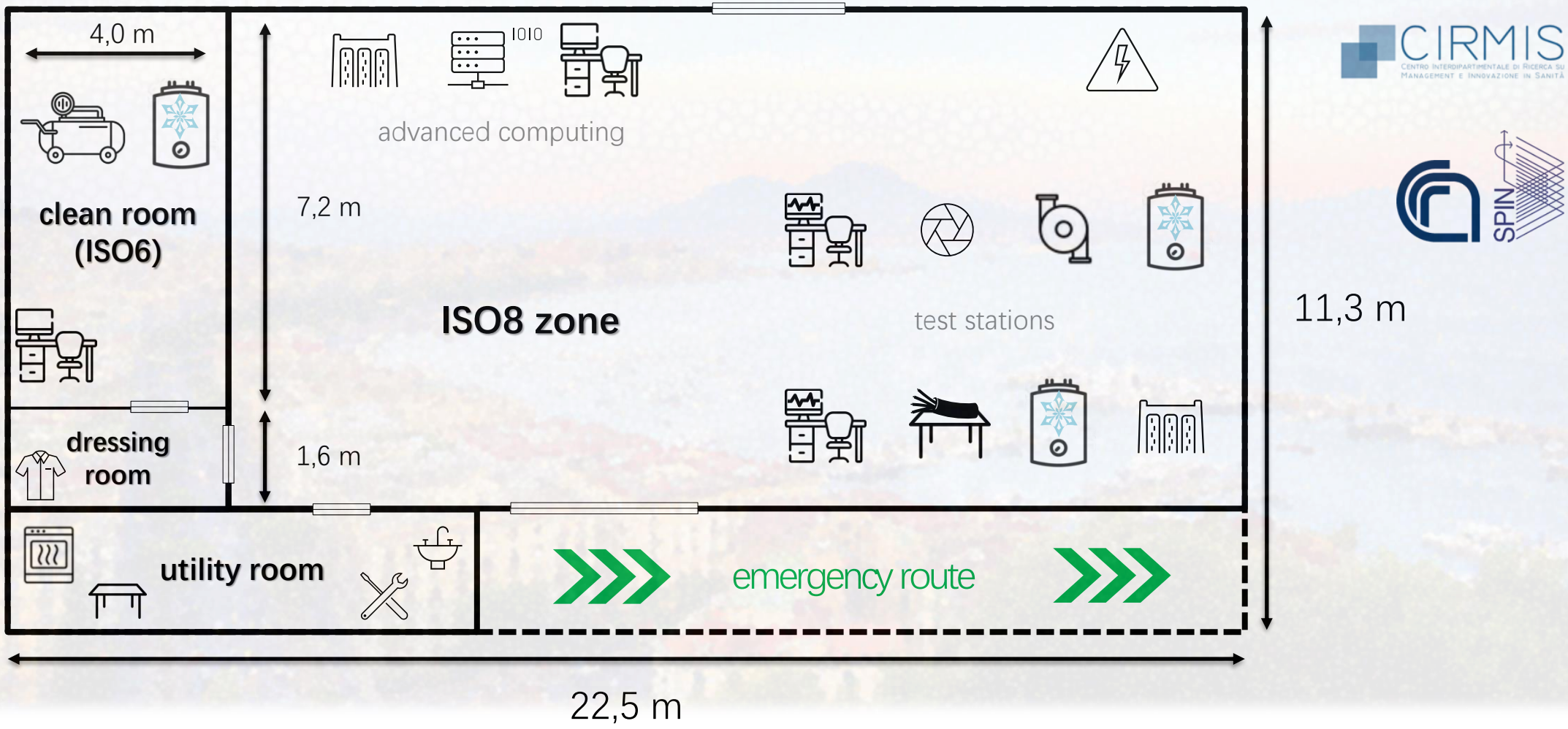
Existing facility: CRYOLAB

- Outside
  - liquid nitrogen storage (77 K)
  - liquid argon storage (86 K)
  - double wall vacuum insulated lines to clean room
  - air-handling unit with temperature and humidity control for clean room
- Inside
  - two-compartments clean room
    - light detector test facility
    - vacuum and cryogenic equipment
    - standalone cryo system
  - working area above clean room

coordinated by prof. G. Fiorillo

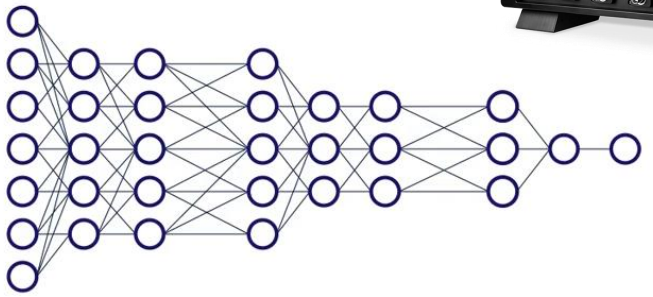
New plant

- IRIS lab under construction in Naples



New equipment

- **Goal**: instrumentation and measurement for HTS cables and magnets
- Inside the new plant
  - cryogenic facility
    - nitrogen storage tanks and cryostates
    - ultra-high vacuum systems
    - cryogenic probe station
  - instrumentation
    - general purpose electronic instruments
    - magnetic field measurements
    - current and resistance measurements
    - quench detection
  - advanced machine learning unit
  - magneto-optic imaging and low-T magneto-optical measurements [CNR-SPIN]



An example of R&D

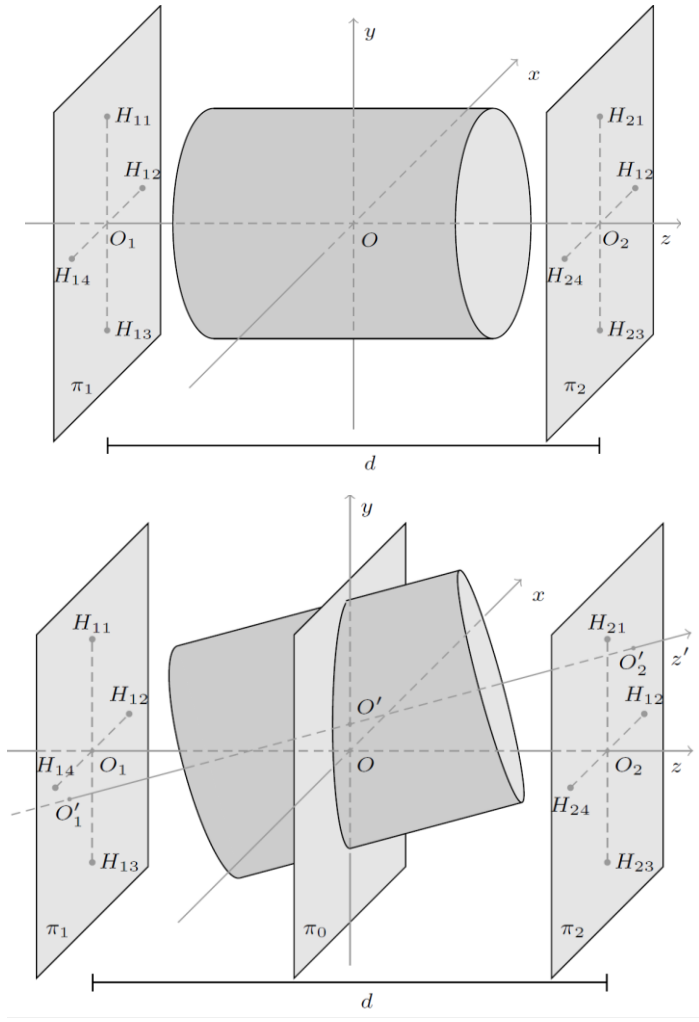
- Online monitoring of the magnetic axis
  - assumption of «small» misalignment
  - radially-placed uniaxial Hall probes

$$x_{o'} = \frac{[B_m(H_{24}) - B_m(H_{22})] - [B_m(H_{14}) - B_m(H_{12})]}{4\frac{\partial B_r}{\partial r}\Big|_0}$$

$$y_{o'} = \frac{[B_m(H_{23}) - B_m(H_{21})] - [B_m(H_{13}) - B_m(H_{11})]}{4\frac{\partial B_r}{\partial r}\Big|_0}$$

$$\nu_1 = \frac{[B_m(H_{24}) - B_m(H_{22})] + [B_m(H_{14}) - B_m(H_{12})]}{2\left(\frac{\partial B_r}{\partial r}\Big|_0 - 2\frac{R_0}{d}\frac{\partial B_r}{\partial z}\Big|_0 - 2\frac{B_{z0}}{d}\right)}$$

$$\nu_2 = \frac{[B_m(H_{23}) - B_m(H_{21})] + [B_m(H_{13}) - B_m(H_{11})]}{2\left(\frac{\partial B_r}{\partial r}\Big|_0 - 2\frac{R_0}{d}\frac{\partial B_r}{\partial z}\Big|_0 - 2\frac{B_{z0}}{d}\right)}$$



[1] P. Arpaia, B. Celano, L. De Vito, A. Esposito, A. Parrella, and A. Vannozzi, "Measuring the magnetic axis alignment during solenoids working", Nature Scientific Reports, Volume 8, p. 11426; doi: 10.1038/s41598-018-29667-1 (2018)

Uncertainty assessment

- Analytical formuation for (x'_0, v_1)

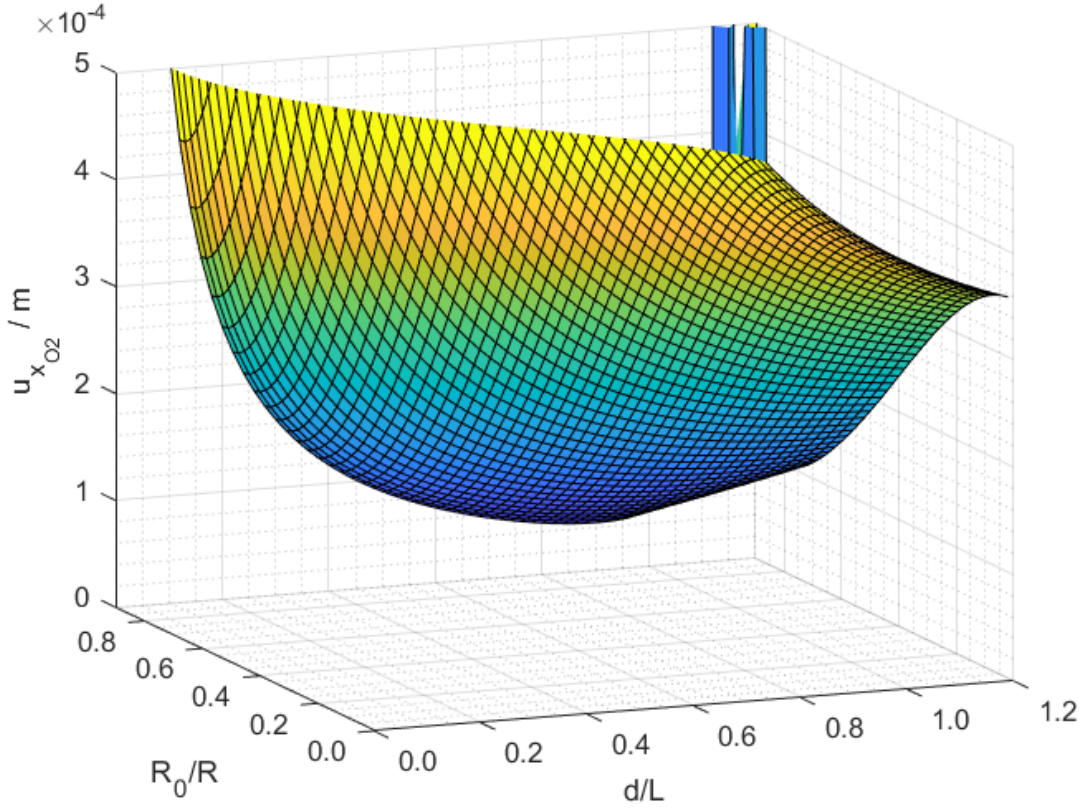
$$u^2_{xo'} \approx \frac{u_B^2}{4\left(\left.\frac{\partial B_r}{\partial r}\right|_0\right)^2}$$

$$u^2_{v1} \approx \frac{u_B^2 + v_1^2\left(1 + 4\frac{R_0^2}{d^2}\right)u_\partial^2}{\left(\left.\frac{\partial B_r}{\partial r}\right|_0 - 2\frac{R_0}{d}\left.\frac{\partial B_r}{\partial z}\right|_0 - 2\frac{B_{z0}}{d}\right)^2}$$

* assuming $u_B \approx 10^{-4}$ T and probes placement by laser with uncertainty less than 10 μm

- Uncertainty of x'_{0_2} and optimal placement

$$u_{x_{O'_2}} = \sqrt{u^2_{x_{O'}} + \frac{u^2_{v1}}{4}}$$

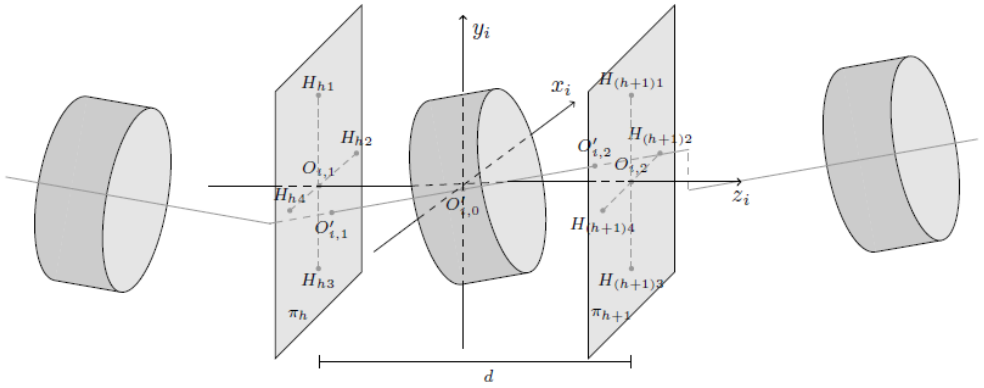


minimum relative uncertainty point

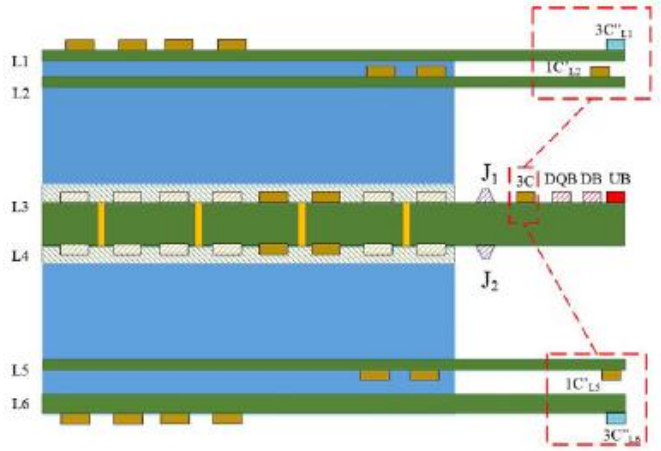
- R_0 is about the 90% of the aperture
- d is about the 90% of the solenoid length

Further research

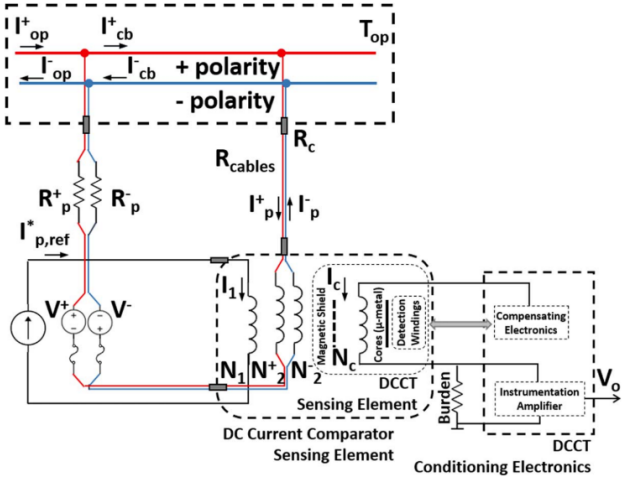
- Misalignment in multi-coils



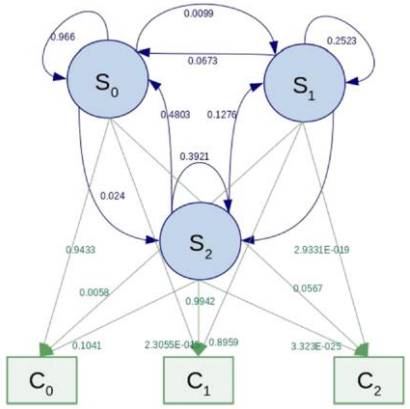
- Reconfigurable rotating coils



- Current-comparator quench detection



- Fault detection for fluid machinery



Conclusions

- Applied superconductivity is an exciting topic with the capability to enable technological breakthroughs

- Through the IRIS project, Europe and Italy are investing in a novel distributed infrastracture with many expertise contaminations
  - we must properly exploit this «fat cows period» to avoid a future «thin cows period»

- As metrologists, we would serve this technical/scientific community by our expertise in instrumentation and measurements

References

1. P. Arpaia, B. Celano, L. De Vito, A. Esposito, A. Parrella, and A. Vannozzi, “Measuring the magnetic axis alignment during solenoids working”, Nature Scientific Reports, Volume 8, p. 11426; doi: 10.1038/s41598-018-29667-1 (2018).

2. P. Arpaia, L. De Vito, A. Esposito, A. Parrella, and A. Vannozzi, “On-field monitoring of the magnetic axis misalignment in multi-coils solenoid”, IOP Journal of Instrumentation, JINST 08 P08017, Vol. 13, August 2018, doi: 10.1088/1748-0221/13/08/P08017

3. G. Severino, P. Arpaia, A. Esposito, “A reconfigurable miniaturized transducer based on rotating coils for testing particle accelerator magnets”, Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, Volume 910, 1 December 2018, Pages 106-114, doi: 10.1016/j.nima.2018.08.118

4. P. Arpaia, C. Baccigalupi, A. Esposito, “Low-complexity Voltage and Current Sources for Large-scale Quench Detection of High-Temperature Superconducting Cables”, Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, Volume 920, 11 March 2019, Pages 73-80, doi: 10.1016/j.nima.2018.12.042

5. P. Arpaia, U. Cesaro, M. Chadli, H. Coppier, L. De Vito, A. Esposito, F. Gargiulo, and M. Pezzetti, “Fault Detection on Fluid Machinery using Hidden Markov Models”, Measurement, Volume 151, February 2020, p.107126., doi: 10.1016/j.measurement.2019.107126

Thank you for your attention

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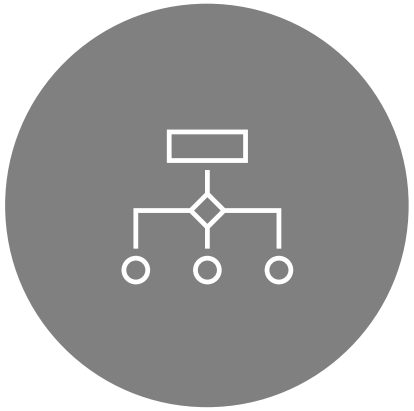
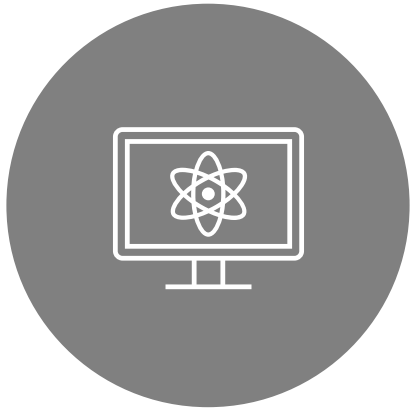


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