ET Magnetic Noise WP

Andrea Chincarini, Irene Fiori

ET @ TO

Introduction - Main tasks of Magnetic noise WP

ANM-MN WP main tasks:

- Identify magnetic noise sources
- Identify ITF components where coupling occurs
- Define mitigation strategies to reduce ambient noise, especially close to ITF sensible spots
- Define mitigation strategies to reduce ITF magnetic susceptibility, to eventually comply with ET design
- Lay out the plan for the design, implementation, monitoring and management of the MN mitigation infrastructure

General overview on mitigation strategies

shielding factor **S(x,y,z)** is defined as: $\mathbf{S} = \dfrac{|\text{ Magnetic field in absence of shield }|}{|\text{ Magnetic field with shield }|}$

	passive shielding				active shielding
	magnetostatic	eddy currents	source canceling	exotic solutions	active cancelling
Freq	better @ low f	better @ high f	independent	solution specific	solution specific
	high permeability ferromagnetic materials	highly conductive materials	set of permanent magnets in suitable configuration	metamaterials superconductors composites	feedback circuit consisting of sensors, dsp, amplifiers and conductors in various configurations

MN noise mitigation questions

What shielding factor is necessary? on what volume?

Passive, active or both?

Where to put them? What configurations?

Materials? Environmental [vacuum] compatibility?

How much screened field homogeneity do we need? on what volume?

How do we monitor the solutions and potential anomalies / transients?

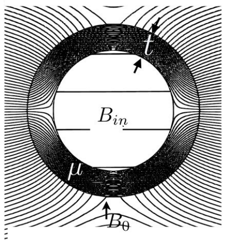
- Several configuration and solutions are possible, as well as the number and types of possible sensitive elements and sources.
  - Extensive simulations needed, possibly trying to set up a general framework divided by source type, solution, etc.
- Feld strength is an issue
  - B-H curve saturation
- Reproducibility and stability, additional noise
  - more challenging
- Long term “investment” in B-field mapping
  - Beware of hot spots in the screen configuration

magnetostatic shielding

several effects:

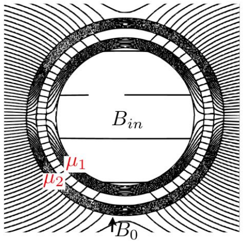
- nonlinearities in the B-H curve
- handling and material working
    - usually change towards a less performant B-H curve
- shield position, geometry and external field, uniformity
- junctions & screen topology

Single layer

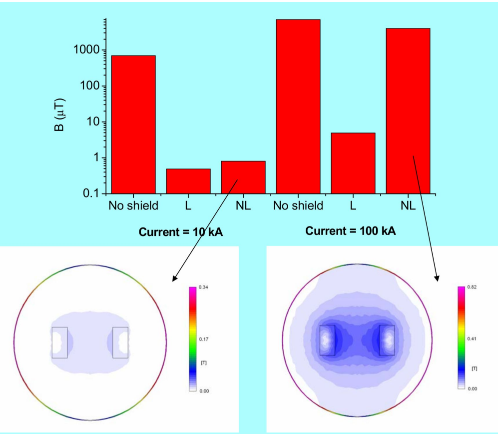


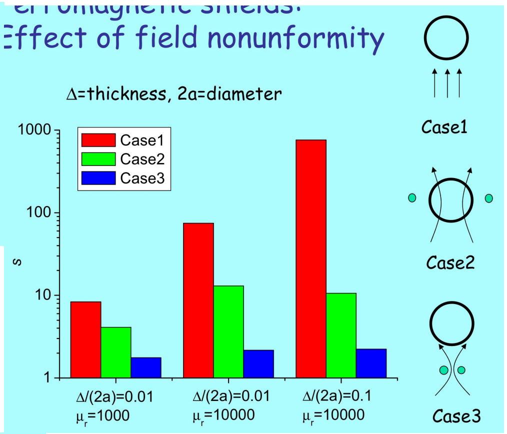
$$S = \frac{B_0}{B_{in}} \propto \mu t$$

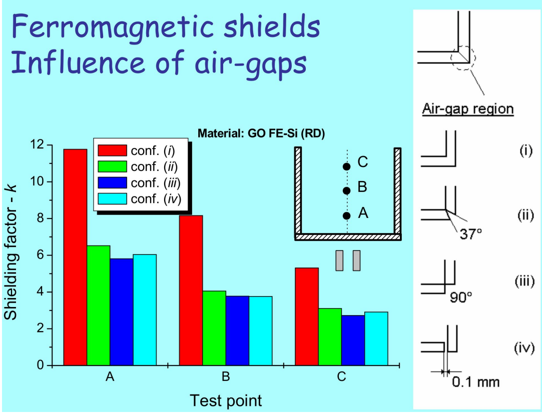
Multi-layer

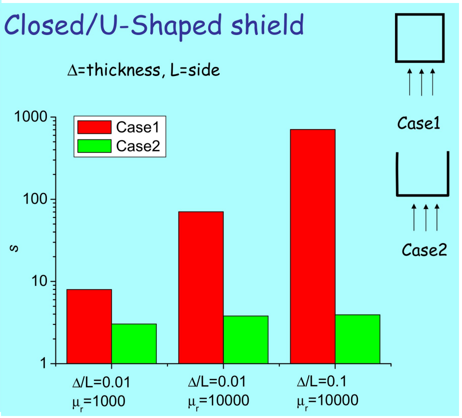


$$S = S_1 \times S_2 \propto \mu_1 t_1 \times \mu_2 t_2$$



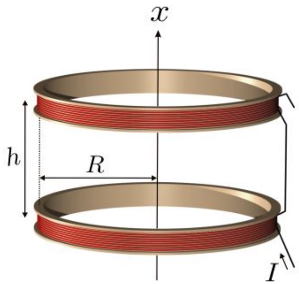


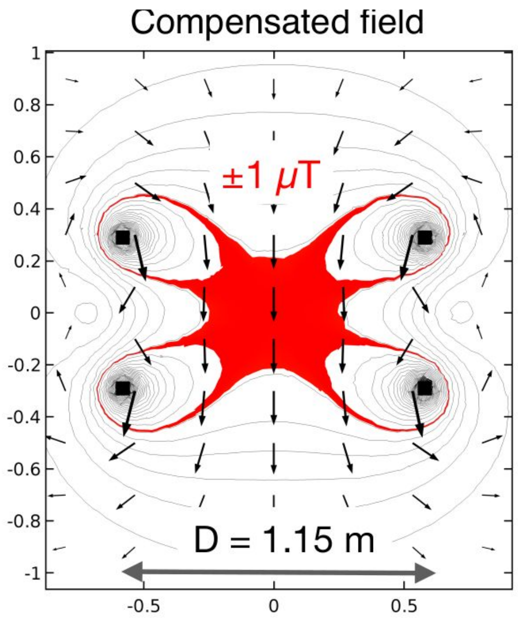




eddy current shielding

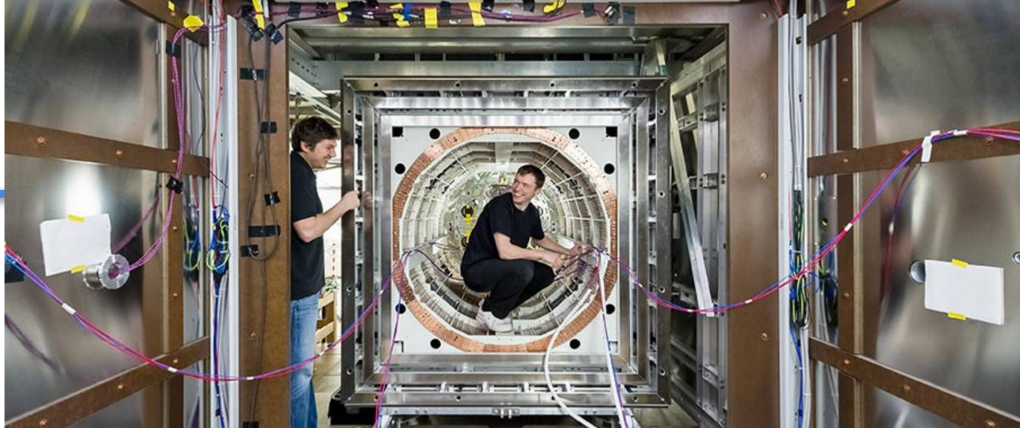
- Can be both passive and active
  - active HeCo are the standard in industry
- Mono-directional component
  - superimpose fields of different coils Helmholtz pair
- Most homogenous region → ~R/2
  - Large region → large coils (2R)
- In passive configuration can be coupled to a resonant circuit to screen particularly nasty frequencies (i.e. 50Hz)
  - Nested solutions, combined approaches can be devised, high design freedom





Takeaway for Helmholtz coil:
good homogeneity for its simplicity, versatile design, insufficient screening if used alone (passively)

more on passive solutions



Multi-layer → less material & better performance: keep the layers spaced (mech and thermal decoupling)

Spherical shells → best shielding and homogeneity

- best strategy is to shield the shield
  - Values of **S>100** are “easily” achievable
  - Relatively large volumes with passive tech. & record shielding values are in operation

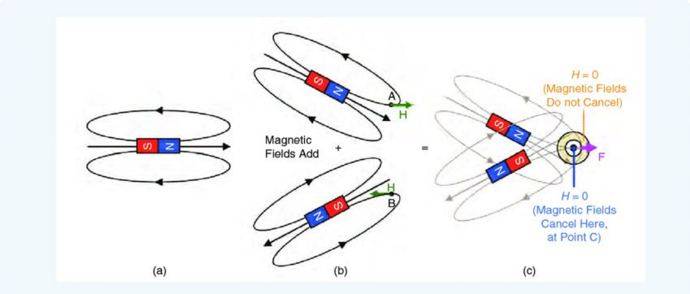
Best passively-shielded volumes to date:

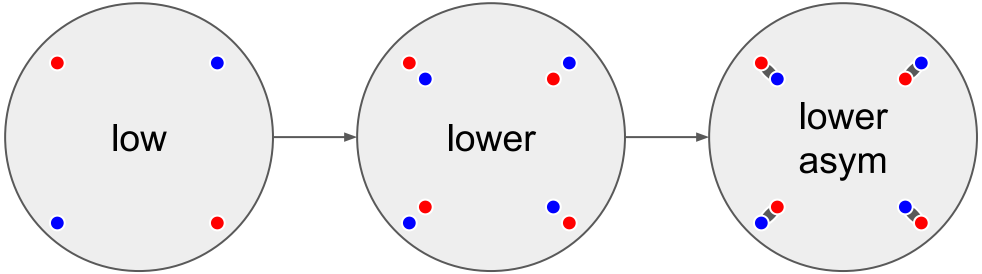
- Paul Scherrer Institute (PSI), Switzerland
  - TSV = 3 m3 (in a 25 m3 volume):
  - 1e5 < S < 1e6
  - residual field in chamber: B <1e-10 T
- Technische Universität München (TUM)
  - TSV = 4.1 m^3
  - S > 1e6
  - residual field in chamber: B <1e-10 T

Takeaway: currently, only the passive solution guarantees the highest shielding factor, absence of maintenance, simplicity & operational stability

However, both costs and ET configuration constraints render this approach not always feasible

alternatives: magnet configuration





Several papers on perm. magnet shape & topology optimization.

- Mainly referred to specific applications but conceptually one could imagine a suitable set of magnets to shape a [local] field with given characteristics (within limits)
    - minimize dipole moment

- main target: test mass / big optics alignment

shaped field permanent magnets, arrangement and optimization examples:

Influence of the distribution of the properties of permanent magnets on the field homogeneity of magnet assemblies for mobile NMR

Y.P.Klein[1*], L.Abelmann[1,2], and J.G.E.Gardeniers [1*]

[1] University of Twente, Enschede, The Netherlands
[2] KIST Europe, Saarbrücken, Germany

ELSEVIER Journal of Magnetism and Magnetic Materials
Volume 421, 1 January 2017, Pages 269-282

On minimal energy dipole moment distributions in regular polygonal agglomerates

Adriano Possebon Rosa [a], Francisco Ricardo Cunha [a], Hector Daniel Ceniceros [b]

A Method on Decreasing Magnetic Moment of Halbach Cylinder Magnets

Publisher: IEEE Cite This PDF

Z. Wang; T. Song; Z. R. Dong; Q. L. Wang; H. S. Wang **All Authors**

alternatives: active shielding

Active magnetic shielding with magneto-impedance sensor

Issue title: Proceedings of the tenth International Symposium on Applied Electromagnetics and Mechanics ISEM-Tokyo

Article type: Research Article

Authors: Okazaki, Yasuo[a; *] | Yanase, Shunji[a] | Sugimoto, Noriko[a]

Prepared for submission to JINST

Study of active geomagnetic shielding coils system for JUNO

G. Zhang,[a,1] J. Songwadhana,[b,1] H. Lu,[a,1] Y. Yan,[b,1] N. Morozov,[c] F. Ning,[a] P. Zhang,[a] C. Yang,[a] K. Khosonthongkee,[b] A. Limphirat,[b] T. Yan,[b] T. Payupol,[e] N. Suwonjandee,[e] B. Asavapibhop,[e] U. Sawangwit,[f] A. Sangka,[g] Z. Zhu,[a] X. Wang,[a,d] X. Liu[a,d] and Z. Xie[a,d]

apparently not too many papers on the topic …

4554 IEEE TRANSACTIONS ON MAGNETICS, VOL. 48, NO. 11, NOVEMBER 2012

Active Magnetic Shielding Using Symmetric Magnetic Field Sensor Method

K. Kobayashi[1], A. Kon[1], M. Yoshizawa[1], and Y. Uchikawa[2]

[1]Faculty of Engineering, Iwate University, Morioka, Iwate 020-8551, Japan
[2]School of Science and Engineering, Tokyo Denki University, Saitama 350-0394, Japan

…ielding is a cheap and effective method for shielding magnetic noise that allows shielding the very low frequencies. In …ing, it is possible to shield magnetic field sensor positions. However, there is a problem in which the shielding factor …itions. Also, the problem of cross-axial interference occurs when the magnetic field sensor cannot be installed at the …ation coils, since the measurement object is installed at the center. In this study, an arrangement of the magnetic …lves these problems is proposed. This method installs pairs of magnetic field sensors symmetrically offset from …axis. An experimental demonstration was carried out in a small model in order to prove the effectiveness of the …r results show that a high shielding factor is obtained, even if the magnetic field sensor is not installed at the center.

…e magnetic shielding, cross-axial interference, magnetic field sensor position, symmetric sensor method.

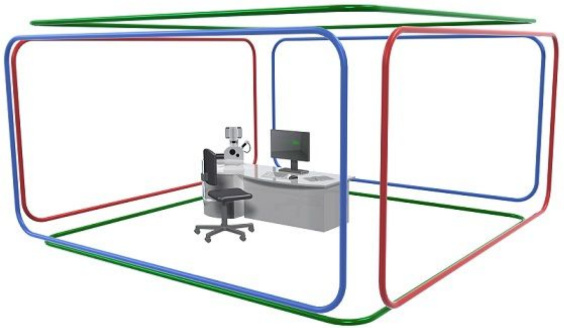
Open • Submitted: 07 July 2021 • Accepted: 08 November 2021 • Published Online: 03 December 2021

A high performance active noise control system for magnetic fields

Review of Scientific Instruments **92**, 124702 (2021); https://doi.org/10.1063/5.0062650

Tadas Pyragius[a)] *and* Kasper Jensen[a)]

commercial applications



Several commercial solutions are available: can be invaluable for some classes of items. According to specs:

- S > 50 field reduction at 50/60 Hz
- S > 400 field reduction at DC
- Bandwidth: DC to 5 kHz

CE Marked

exotic solutions

Superconductors, metamaterials & composites … but also: intelligent control for motors (magneto-mechanic noise) and other amenities

all fun stuff but not ready - as is - for reliable application.

Nice to know they exist but use as very last resort

Antimagnets: controlling magnetic fields with superconductor–metamaterial hybrids

Alvaro Sanchez[2,1], Carles Navau[1], Jordi Prat-Camps[1] and Du-Xing Chen[1]

Published 22 September 2011 • © IOP Publishing and Deutsche Physikalische Gesellschaft

New Journal of Physics, Volume 13, September 2011

Citation Alvaro Sanchez *et al* 2011 *New J. Phys.* **13** 093034

A quasistatic magnetic cloak

Ján Souc[1], Mykola Solovyov[1], Fedor Gömöry[1], Jordi Prat-Camps[2], Carles Navau[2] and Alvaro Sanchez[3,2]

Published 9 May 2013 • © IOP Publishing and Deutsche Physikalische Gesellschaft

New Journal of Physics, Volume 15, May 2013

Citation Ján Souc *et al* 2013 *New J. Phys.* **15** 053019

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Tailoring Magnetic Fields in Inaccessible Regions

Rosa Mach-Batlle, Mark G. Bason, Nuria Del-Valle, and Jordi Prat-Camps

Phys. Rev. Lett. **125**, 177204 – Published 23 October 2020

Active reduction of magnetic noise occurring in the stators of an induction motors

Check for updates

Artem Ermolaev[1], Vladimir Erofeev[2], Alexandr Plekhov[3], Dmitriy Titov[4]

[1, 2]Research Laboratory Controlled Vibration Protection of Electromechanical Systems, Mechanical
Russia

[3, 4]Institute of Electrical Power Engineering, Nizhny Novgorod State Technical University n.a. R.E. Al

[1]Corresponding author

Vibroengineering PROCEDIA, Vol. 38, 2021, p. 172-178. https://doi.org/10.21595/vp.2021.22078

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and reproduction in any medium, provided the original work is properly cited.

Open Access | Published: 20 August 2015

A Magnetic Wormhole

Jordi Prat-Camps, Carles Navau & Alvaro Sanchez

Scientific Reports **5**, Article number: 12488 (2015) | Cite this article

142k Accesses | **36** Citations | **630** Altmetric | Metrics

Electromagnetic cloaking by layered structure of homogeneous isotropic materials

Ying Huang, Yijun Feng, and Tian Jiang

Author Information ▾ Find other works by these authors ▾

Conferences > 2005 IEEE International Magne...

Magnetic noise due to environmental vibration in magnetically-shielded room

Publisher: IEEE Cite This PDF

T. Abe; K. Yamazaki; N. Fujimaki; S. Miyauchi; K. Kobayashi; K. Fujiwara; K. Muramatsu **All Authors**

solutions in order of preference

1. passive solution
    a. pros: robustness, durability, well tested, very high S achievable, easily hybridizable, notch filters, cost
    b. cons: geometry constraints, size / weight, high S needs very detailed engineering, cost
2. source canceling [dipole minimization] where applicable
    a. pros: light, small solution for highly localized sources
    b. cons: works efficiently only for a limited number of applications, calibration issues, residual field, interactions and controls
3. active screening
    a. pros: may provide adequate screening on a wide range of disturbances, commercially available
    b. cons: source of extra noise, hereditary of the coil constraints, stability and control problems
4. hybrid solutions
    a. pros: extended frequency range, help whenever size/cost/geometry do not allow a single solution
    b. cons: hereditary of the cons of the component solutions + complexity
5. exotic solutions [as the very last resort]
    a. pros: cool for studying and paper publishing, potentially highly performant
    b. cons: validation and applicability is controversial, manufacturing and reliability unknown

MN solution management: monitoring fields, mapping inhomogeneities

Simulations, tests and implementations are not enough:

- Status and fluctuations must be monitored
  - wide array of sensor types needed depending on application, intensity, gradient, …
    - Gradient / Vibrating Reed / Vibrating Sample / Inductive / Flux gate / MEMS / Hall / …

- After the mitigation solution implementation:
  - Remove residual magnetization due to construction and handling with a decreasing alternating current through demagnetization coils (degaussing).
  - Verify homogeneity
    - Locate hot spots and install sensor there
  - integrate with DAQ

Calculation of an optimized design of magnetic shields with integrated demagnetization coils

AIP Advances **6**, 075220 (2016); https://doi.org/10.1063/1.4960329

Z. Sun[1, a)], A. Schnabel[2], M. Burghoff[2], *and* L. Li[1]

MN is linked with several other subsystems

for instance:

Investigation of magnetic noise in Advanced Virgo

A Cirone[1,2], I Fiori[3], F Paoletti[4], M M Perez[5], A R Rodríguez[5], B L Swinkels[6], A M Vazquez[5], G Gemme[1], A Chincarini[1]

- PAY
  - test-mass actuators / marionetta design
  - material, design, eddy currents, … see Cirone et al.
- high freq coupling behaviour → electronics / acquisition ?
- ENV
  - sensors, injection coils, …
- VAC
  - material compatibility for in-vacuum mitigation solutions
- …

SHORT TERM R&D

Short-term tasks [0-12 m]: simulations and coupling function

1. Simulation framework
    a. short term activity: input characterization of most commonly used material
        i. realistic B-H curves, conductivity, mech properties, etc [exper. check whenever possible]
    b. short-term activity: set up the simulation framework for passive solutions
        i. study standard set of geometries, material and optimizations. Model effect of AdV large injection coils
        ii. study perm. magnets/driving coil configurations for test mass / optics actuators

2. Coupling models
    a. short-term activity: phenomenological modeling of the coupling function [on AdV]
        i. → finer estimation of ET MN budget
        ii. experimental validation pending a functioning VIRGO IFO
    b. short-term activity: create/update the parametric MN budget curve into the ET sensitivity software tool (PyGWINC)

Short-term tasks [0-12 m]: experimental set-up

3. Environmental source catalogue
    a. short-term activity: start implementation of a database of known environmental sources (in AdV)
        i. i.e. chiller, pumps, heaters, … start with most obvious and known items
        ii. characterize source field shape (coarse est.) and intensity vs distance
4. Experimental setup
    a. short-term activity: cost / feasibility & design of an experimental room @ EGO for testing and validation of small-volume mitigation strategies
        i. room space, instrumentation, sensing, driving, acquisition, …

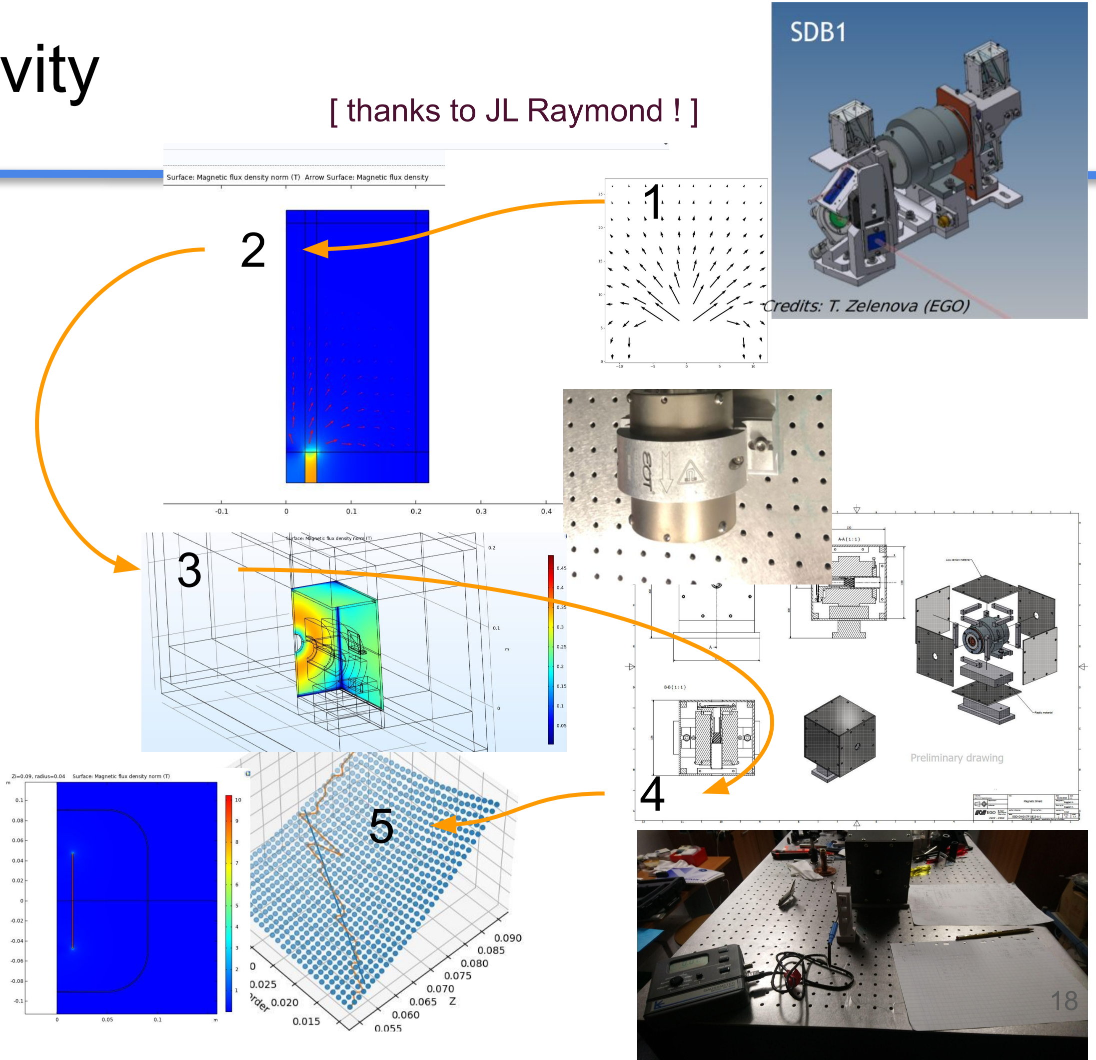
Test items 2022: AdV+ detection bench mitigation study [faraday isolator]

Test items 2022/23: test-mass actuators configuration studies, optical benches magnetic characterization

current MN ongoing activity

[thanks to JL Raymond !]

1. source study - simplified model based on measures
2. FEA implementation & optimization [simulated equivalent source]
3. FEA simple Fe screen design
4. Model validation (experiment)
5. FEA realistic screen optimization
6. Screen prototype, model validation, adaptation as needed
7. FEA final analysis
8. final prototype
9. test & acceptance



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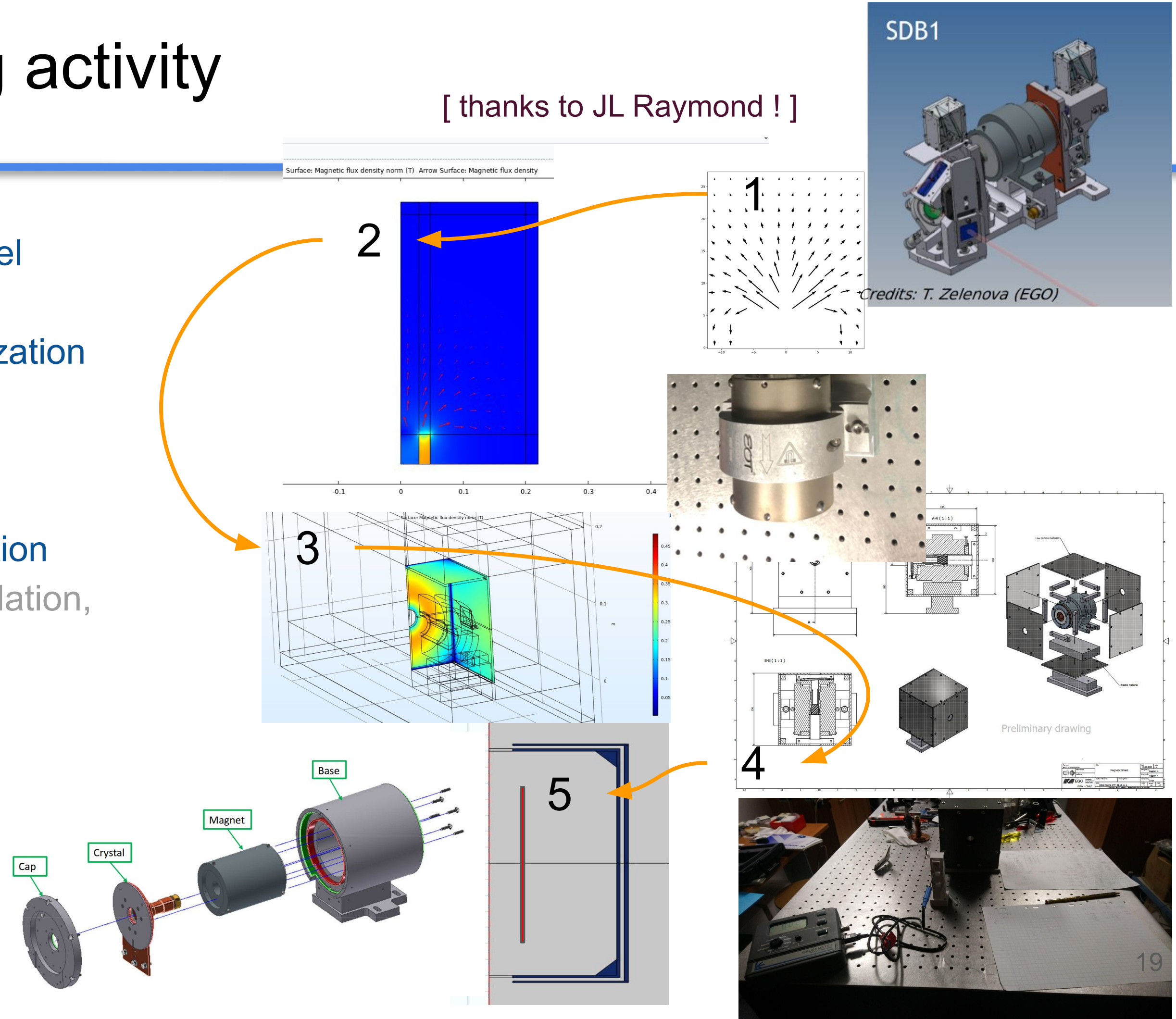

The end …