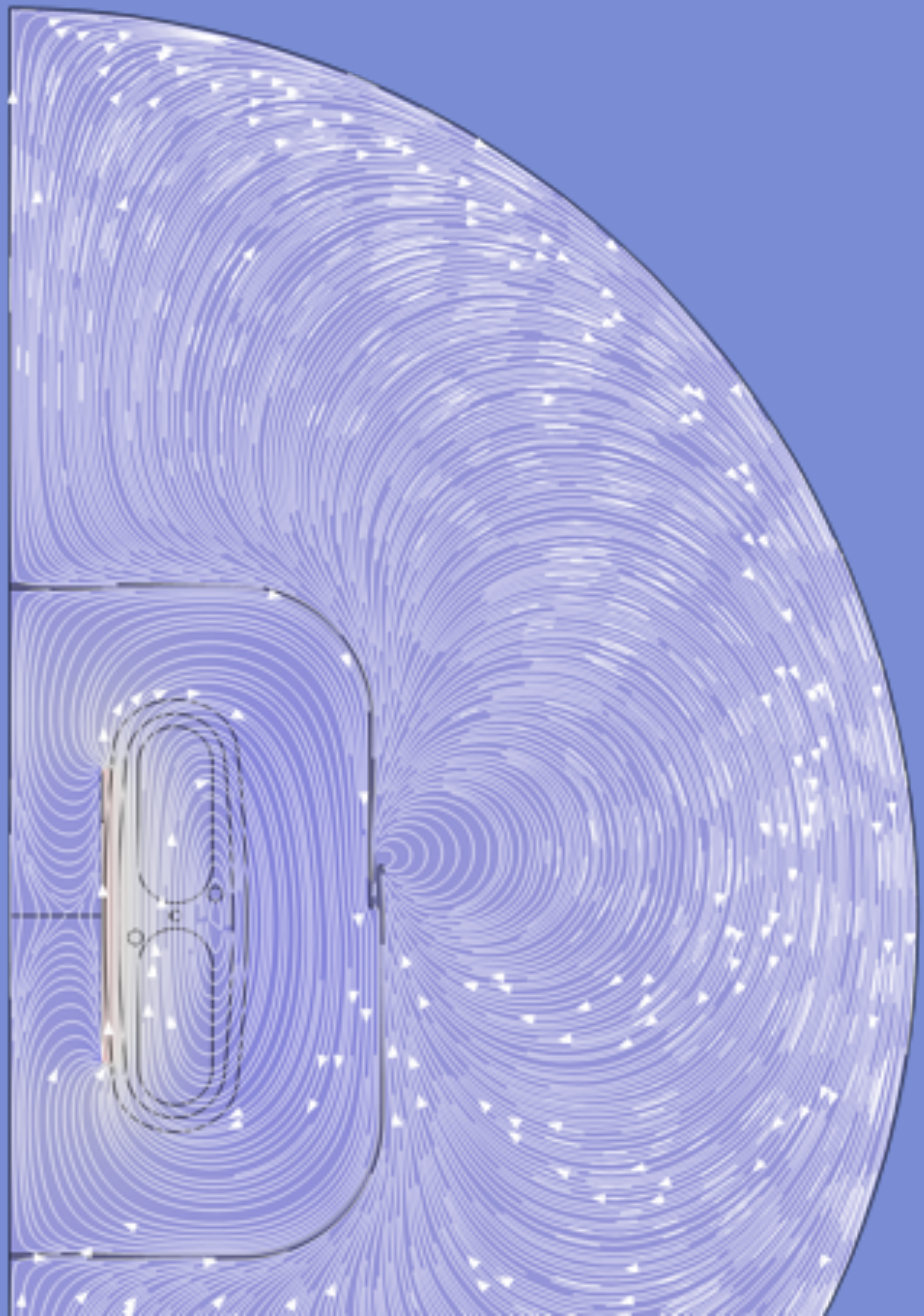
EM FIELD SIMULATIONS FOR

ABRACADABRA + DARK MATTER RADIO

Chiara Salemi, MIT

DM Radio + ABRACADABRA First Collaboration Meeting

24 Jan 2020



OUTLINE

WHY — the need for field simulations

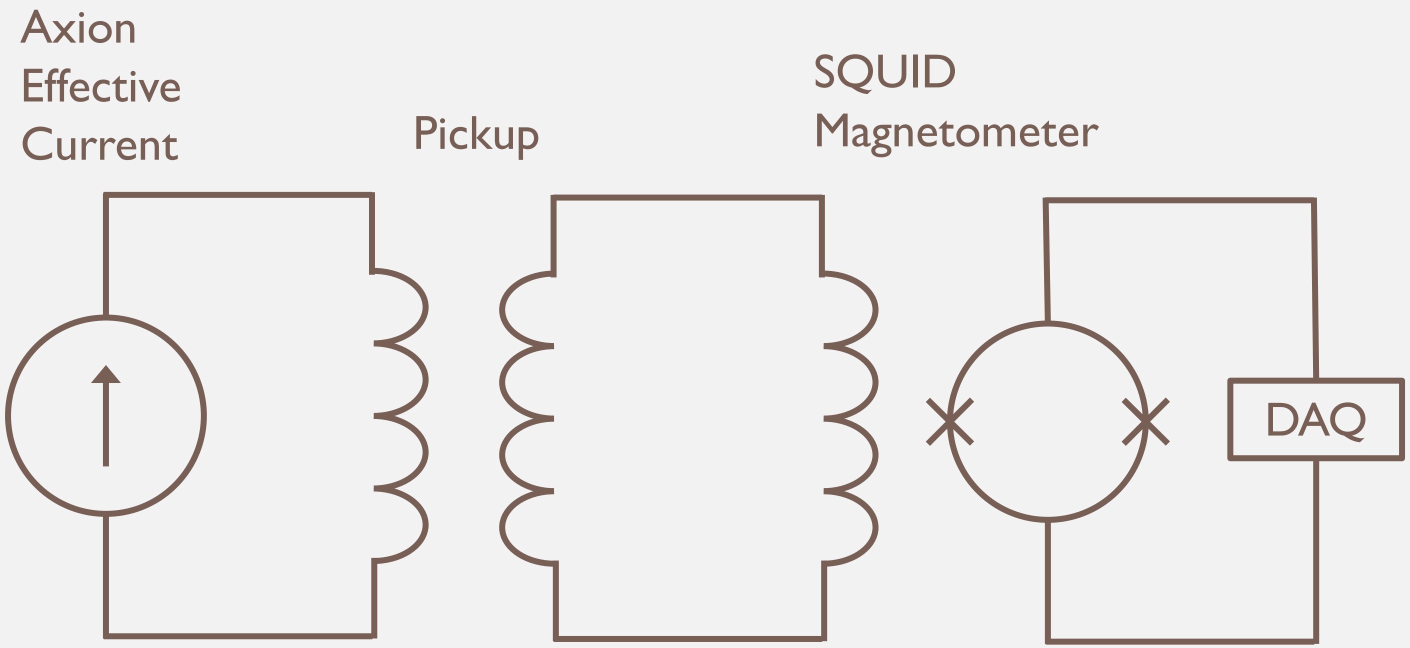
WHAT — an assortment of calculations

HOW — EM simulation software

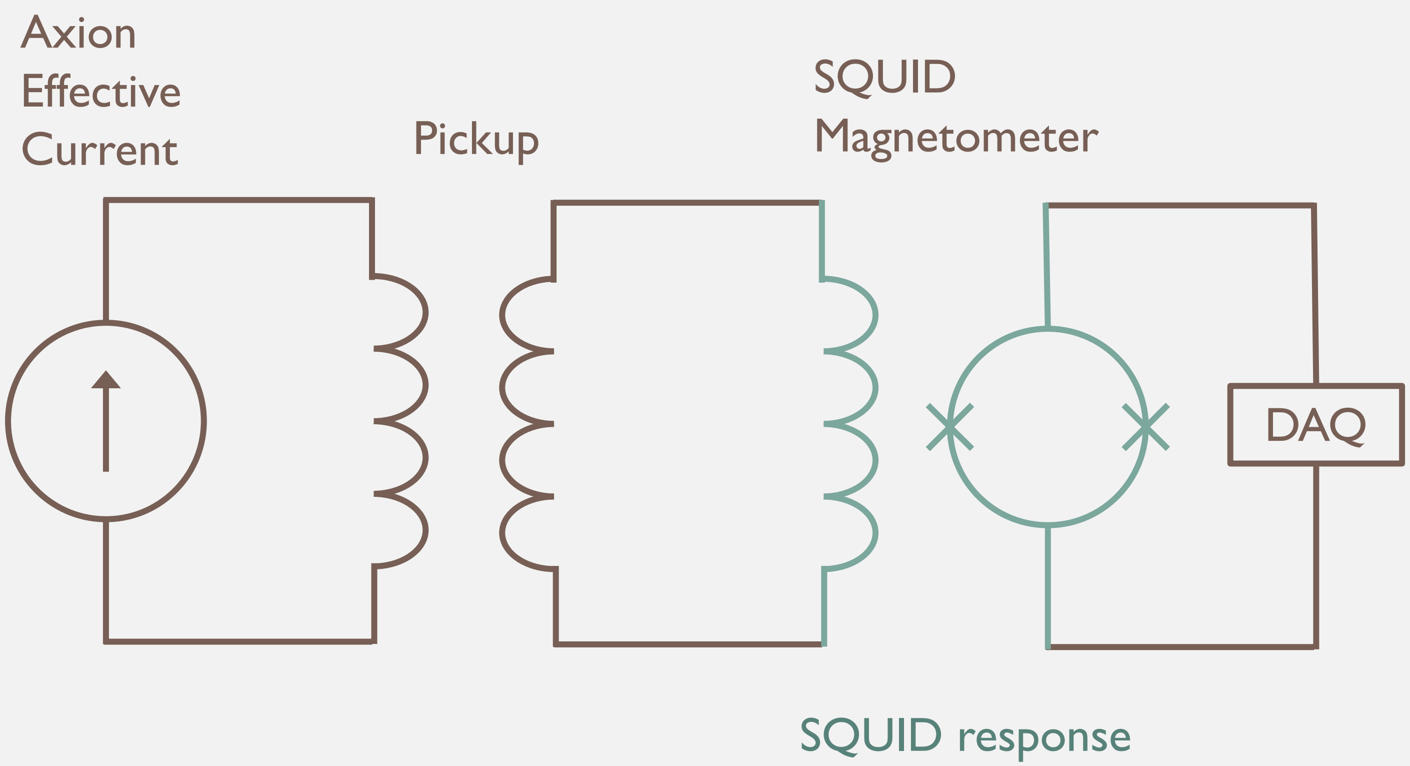
WHY

the need for field simulations

UNDERSTANDING OUR SENSITIVITY



UNDERSTANDING OUR SENSITIVITY



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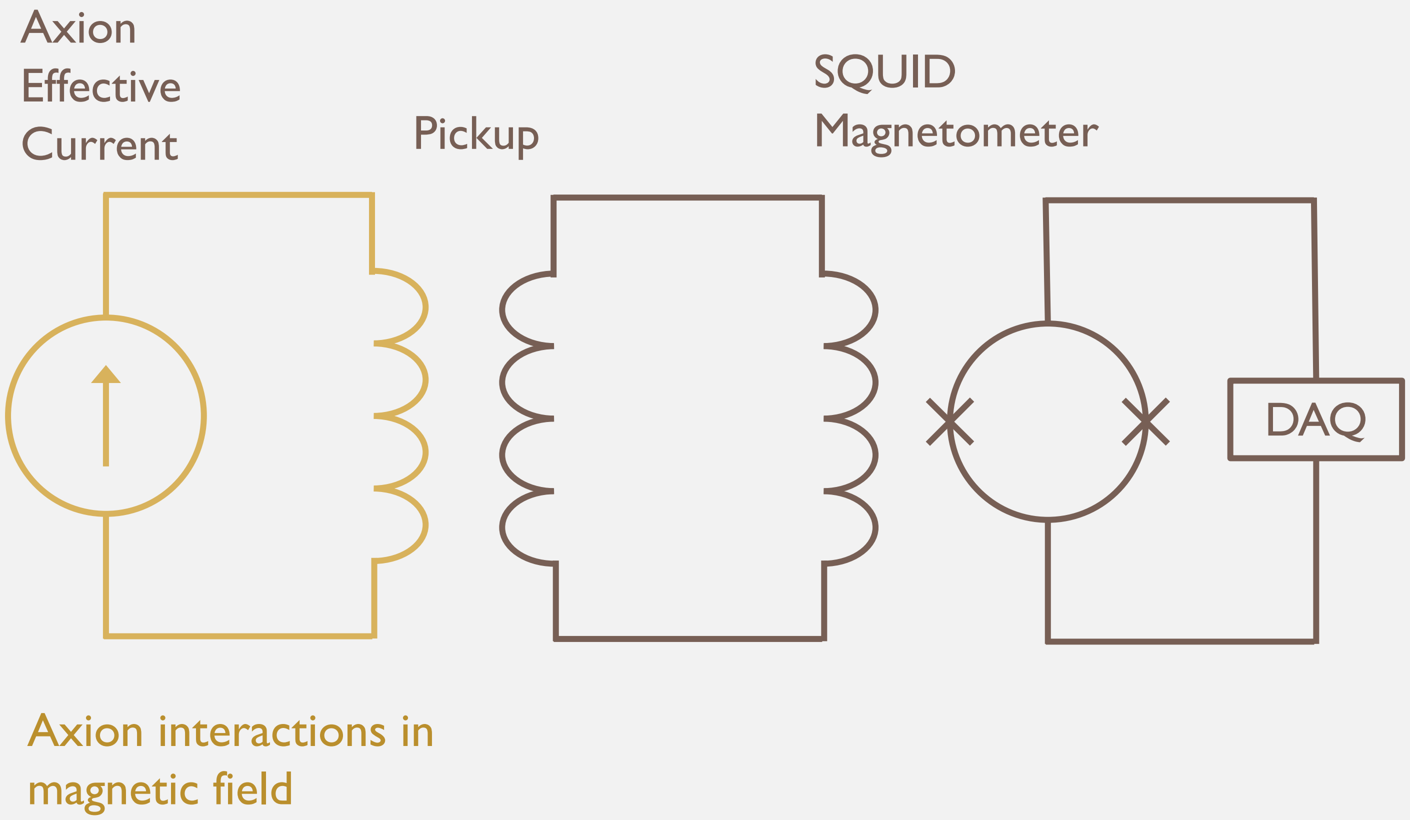

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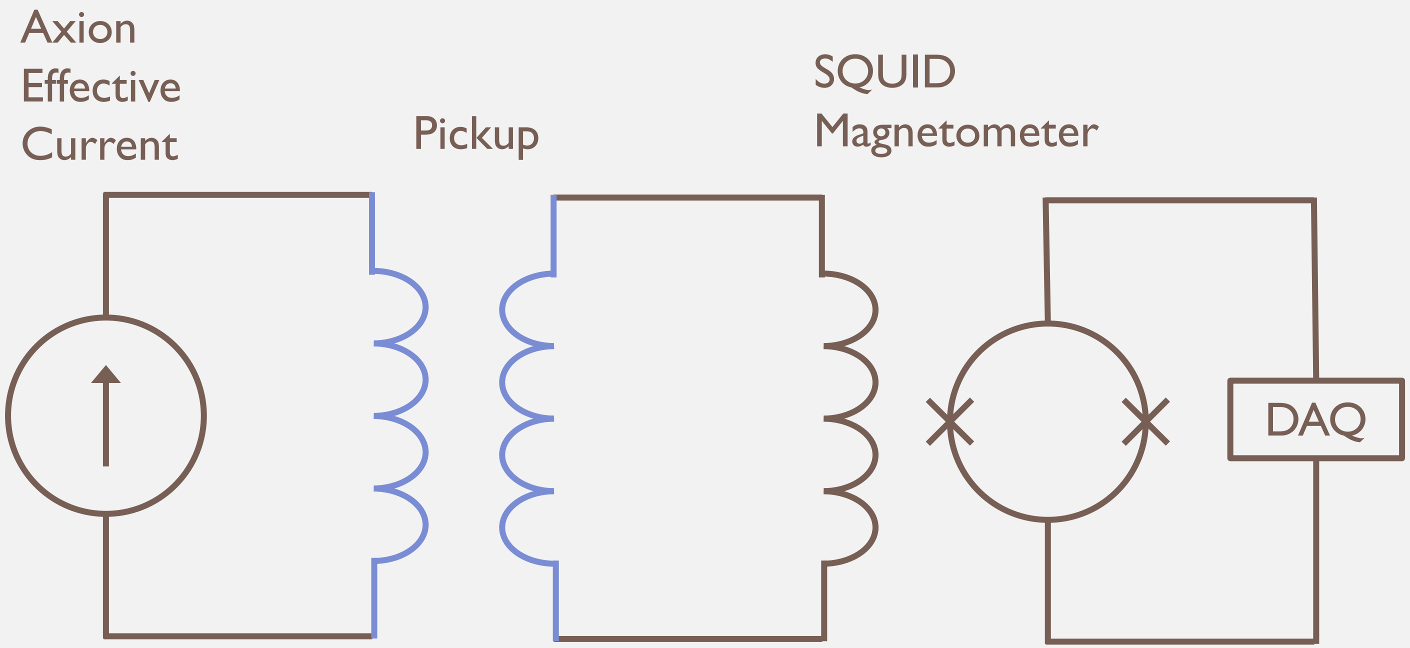
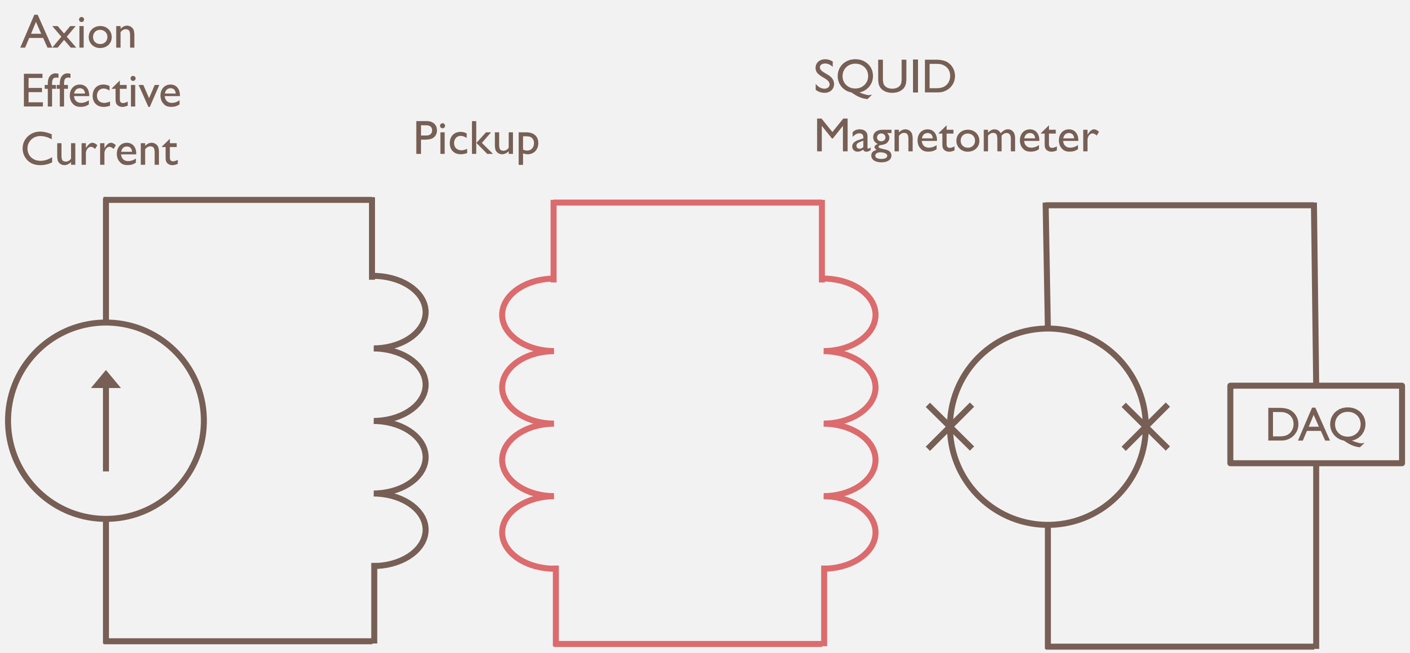


Coupling between
axion current and
pickup circuit

UNDERSTANDING OUR SENSITIVITY

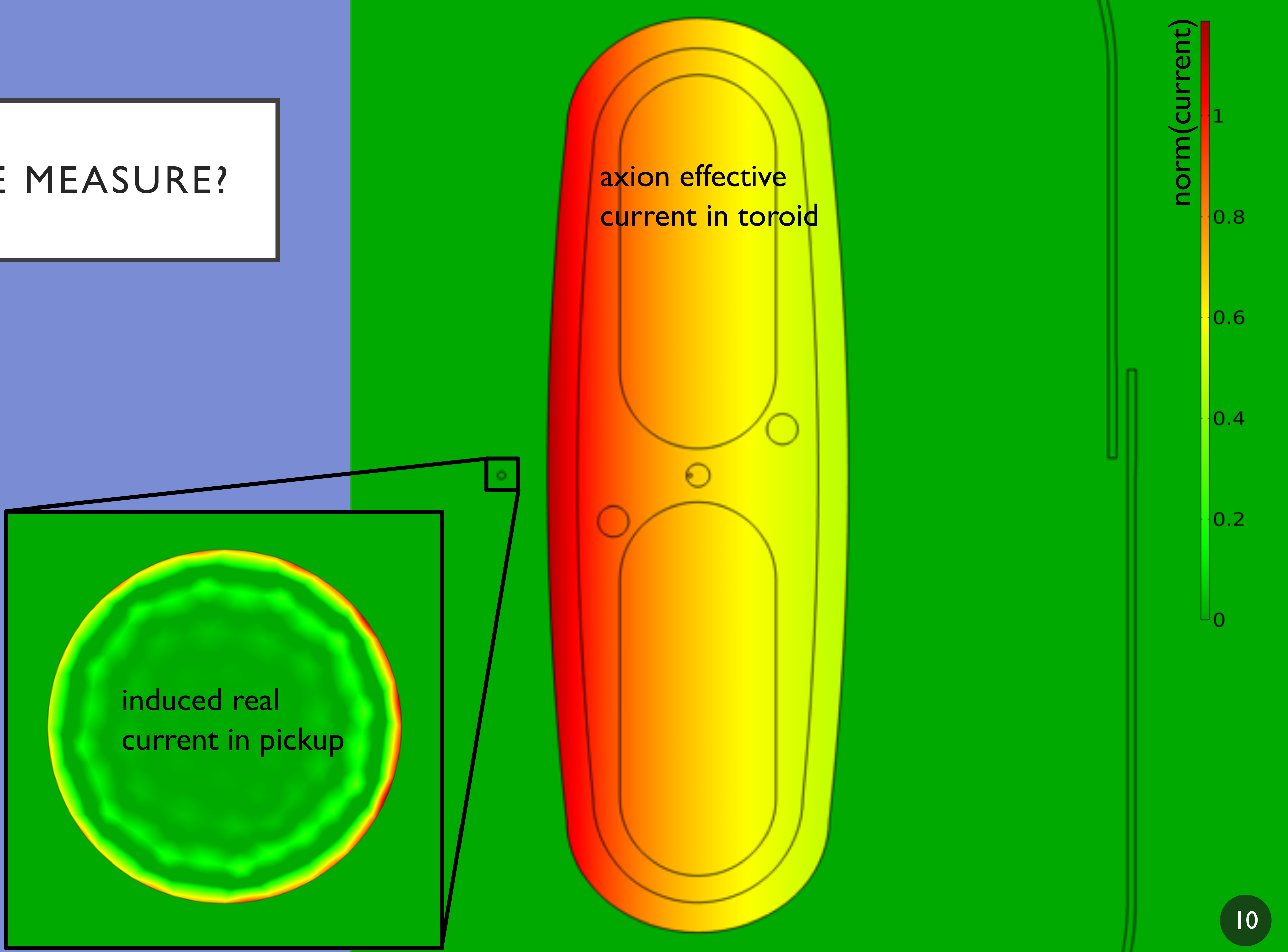


Impedance in pickup circuit

WHAT

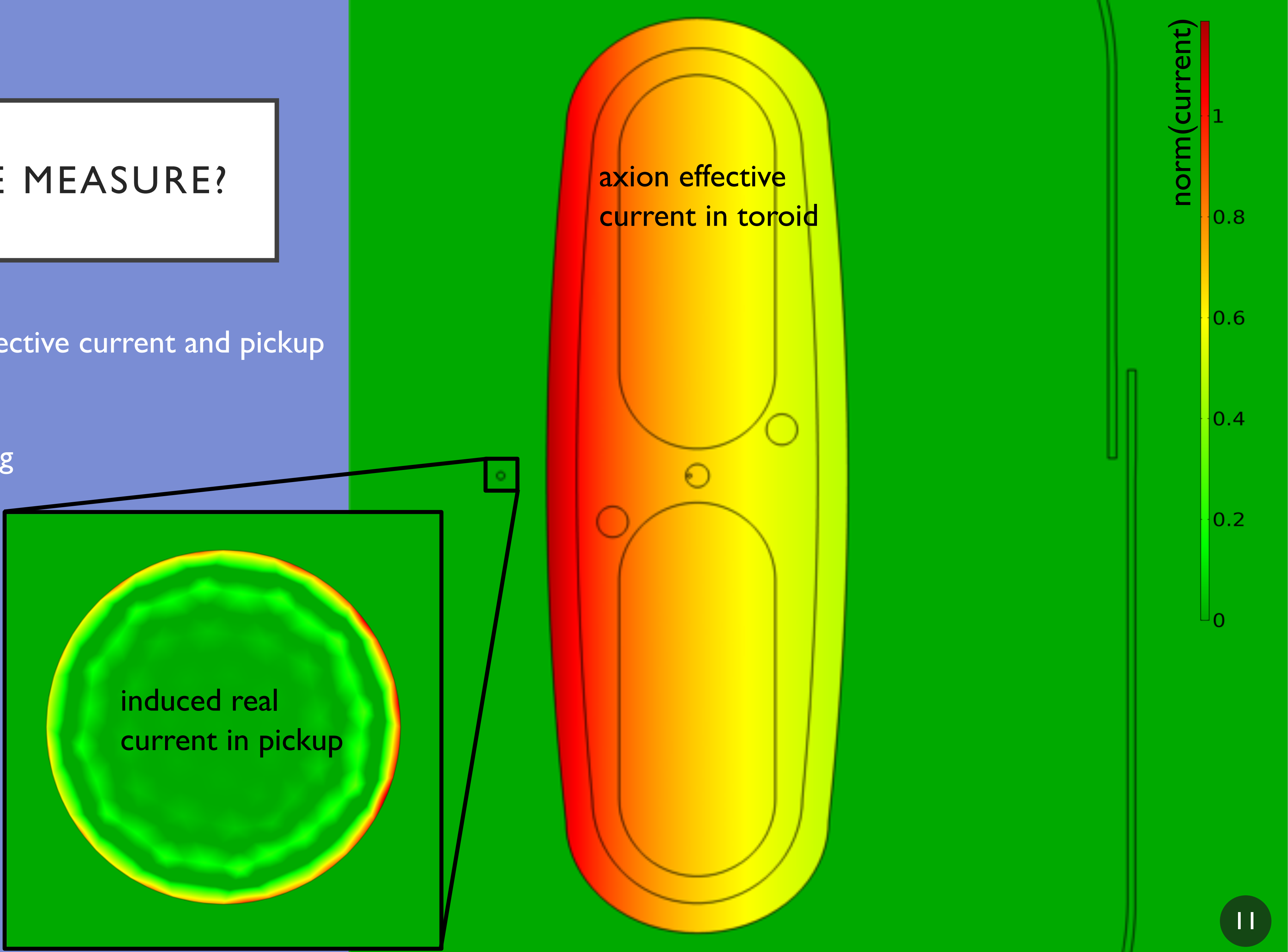
an assortment of calculations

WHAT CAN WE MEASURE?



WHAT CAN WE MEASURE?

- Coupling between axion effective current and pickup
- Self inductance of pickup
- Parasitic impedance in wiring
- …



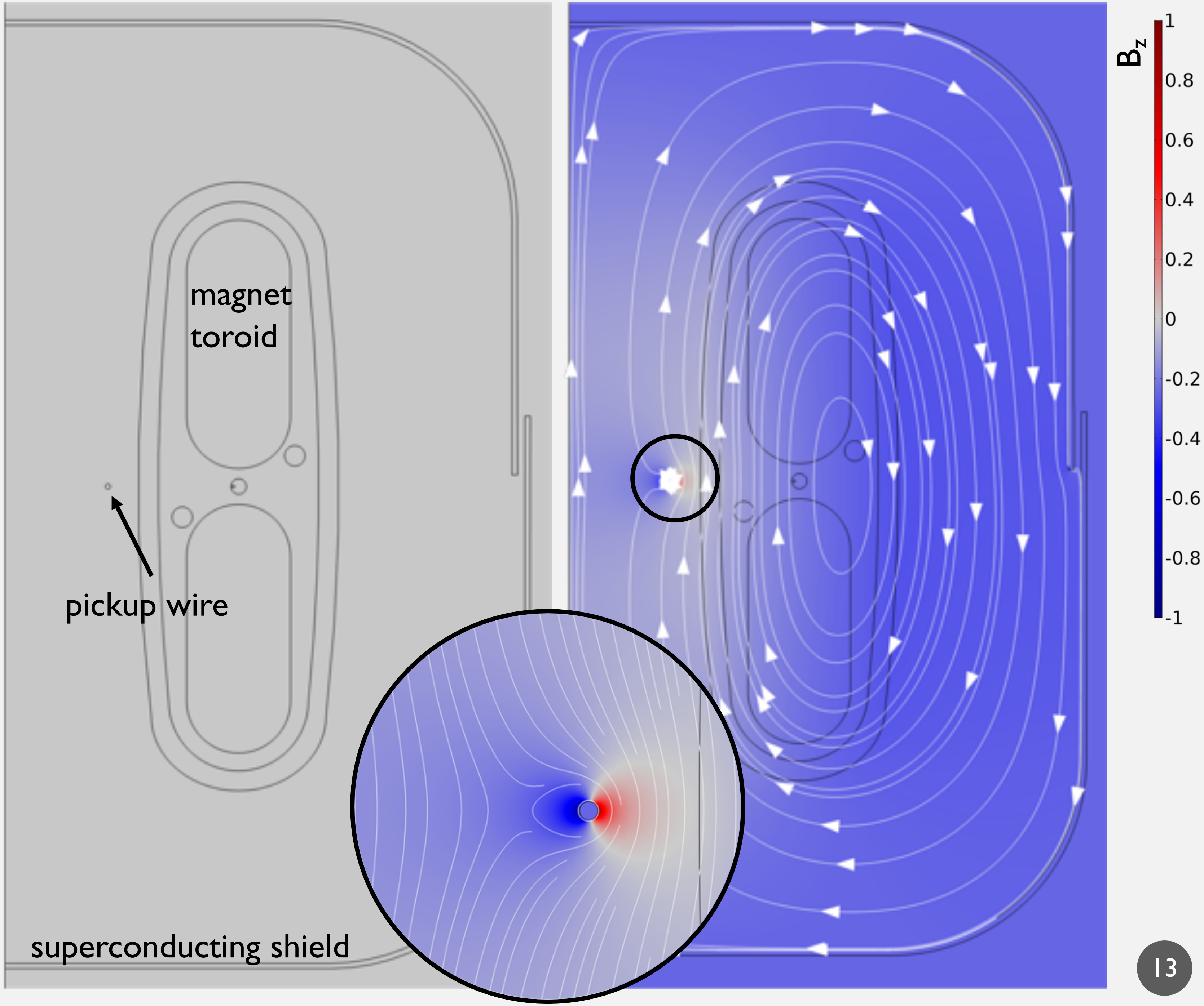
BASICS OF HOW TO CALCULATE

- **Mutual inductance (current ratio)**
  - Enforce current through magnet volume (proportional to B field)
  - Measure current in pickup

- **Self inductance**
  - Enforce current through pickup
  - Use $L = 2\int \frac{W_m}{I^2}$

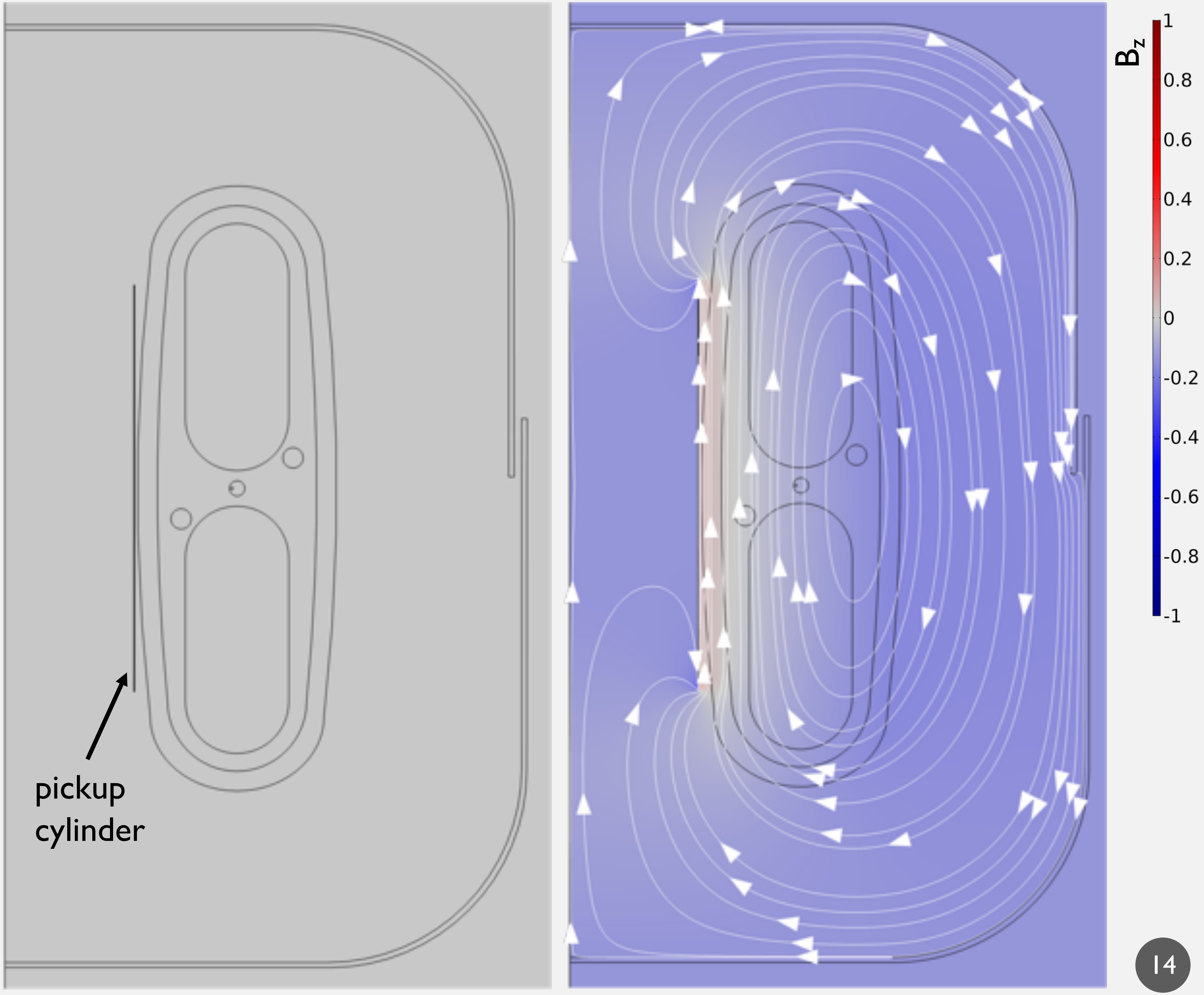
WIRE LOOP
(ABRA RUN 1)

- Current ratio ~ 0.11
- Self inductance ~ 100 nH
- Calculable analytically
  - Confirms COMSOL calculation



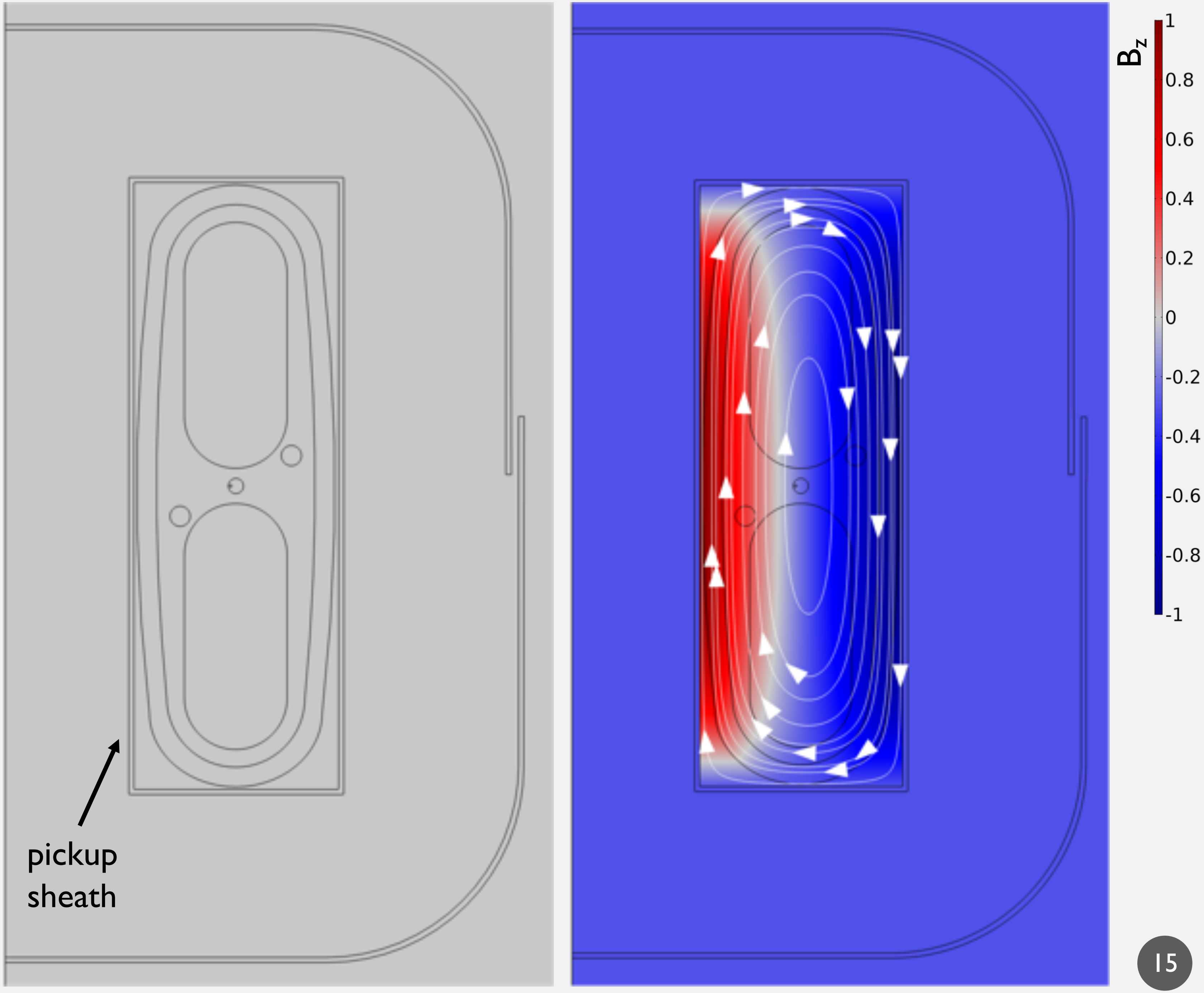
CYLINDER
(ABRA RUN 2)

- Coupling ~7x higher than with wire loop
  - Current ratio ~ 0.74
- Reduces inductance in pickup circuit by ~5x
  - Self inductance ~ 20 nH



SHEATH
(FUTURE)

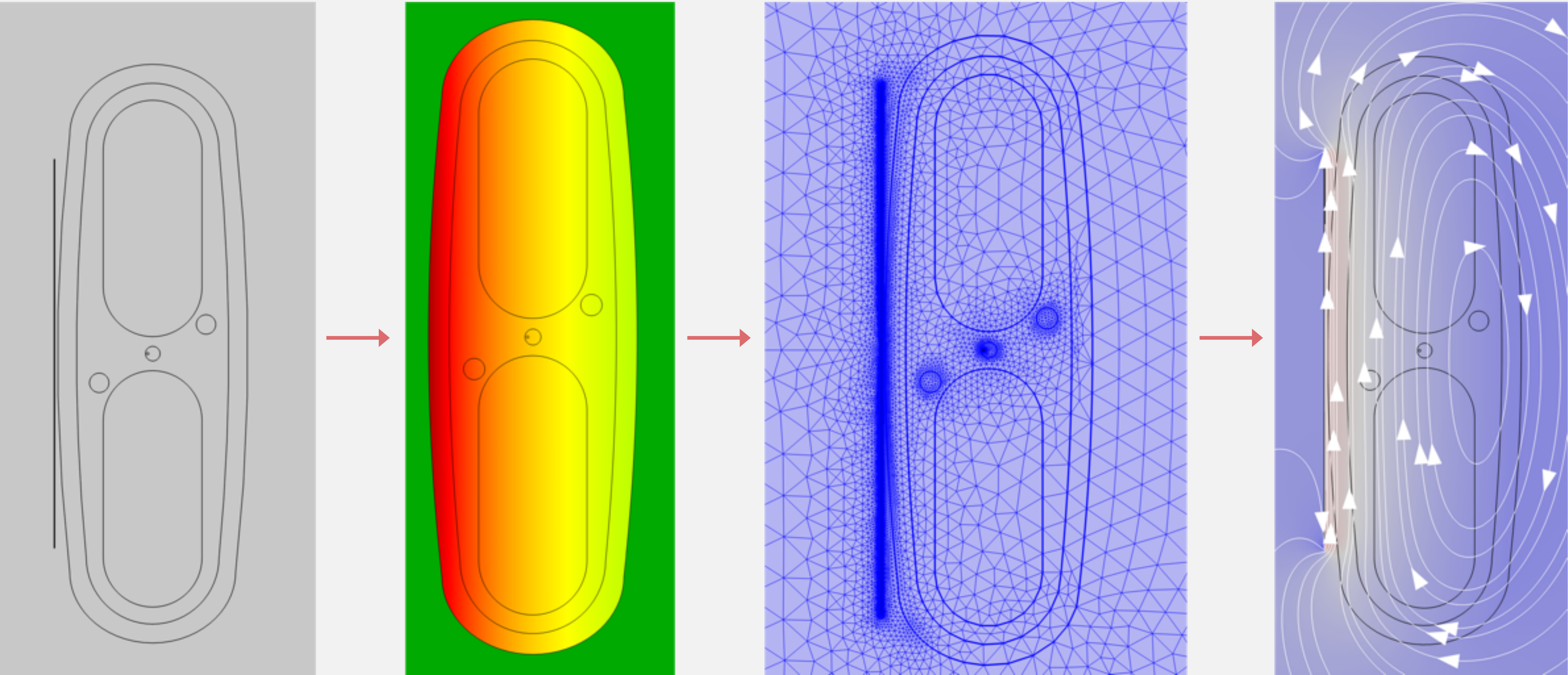
- Optimal coupling between axion effective current and pickup (current ratio = 1)
  - 10x better than wire loop!
- Difficult engineering
  - Construction
  - Access



HOW

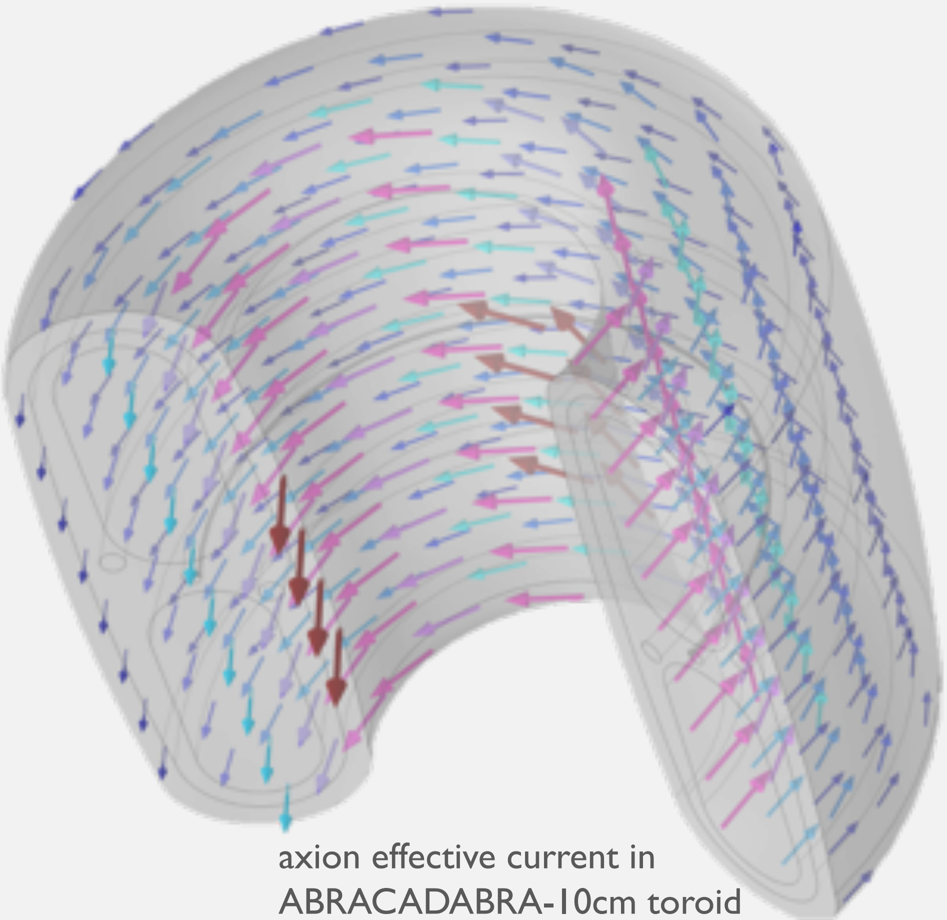
EM simulation software

HOW DO FINITE ELEMENT SOLVERS WORK?



COMSOL MULTIPHYSICS

- Commercial finite element modeling software
  - $$$, but UNC has licenses
  - Helpful support team
- Can link together various physics modules (EM, mechanical, CAD imports, …)
  - Include vibration?
- Automatic meshing
- Allows precise field modeling for complex geometries, but…
  - Not good at large aspect ratios/large scale differences: wire windings are hard
  - Complex 3D systems are hard/slow



axion effective current in ABRACADABRA-10cm toroid

THERE ARE MANY OTHER OPTIONS
(that I don't know as much about)

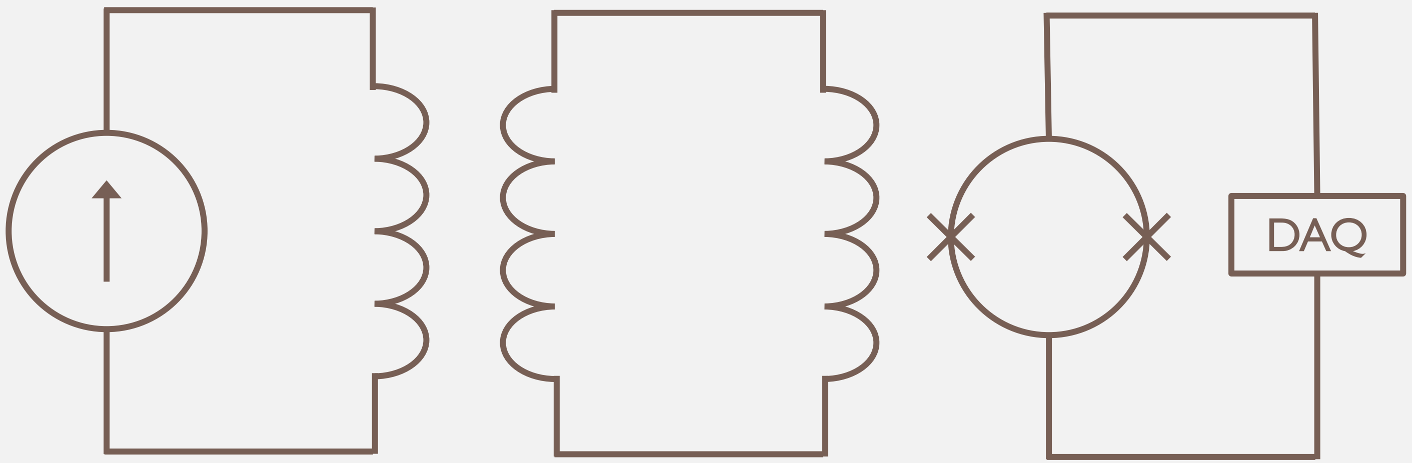
- **ANSYS HFSS**
  - Designed for high frequency antenna design
  - Only EM
- **Kassiopeia**
  - Designed for particle tracking in EM fields for Project 8 experiment
  - Doesn't really do AC
  - Boundary element method (BEM)
- **Opera**
  - Primary applications are magnets, motors, etc.
  - EM and electromechanical in 2D and 3D
- **ANSYS Maxwell, FastHenry, …**

probably not (ANSYS HFSS)

maybe! (Kassiopeia, Opera, ANSYS Maxwell, FastHenry, …)

SUMMARY

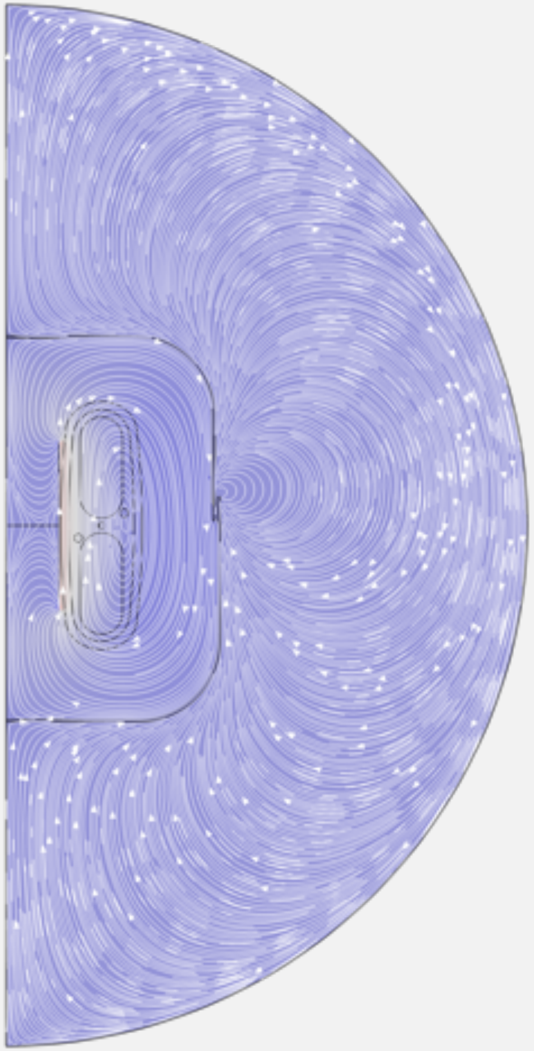
To determine our sensitivity we must fully understand the effective circuit from axions to DAQ



SUMMARY

To determine our sensitivity we must fully understand the effective circuit from axions to DAQ

This can be achieved with finite element modeling of the system's EM fields



SUMMARY

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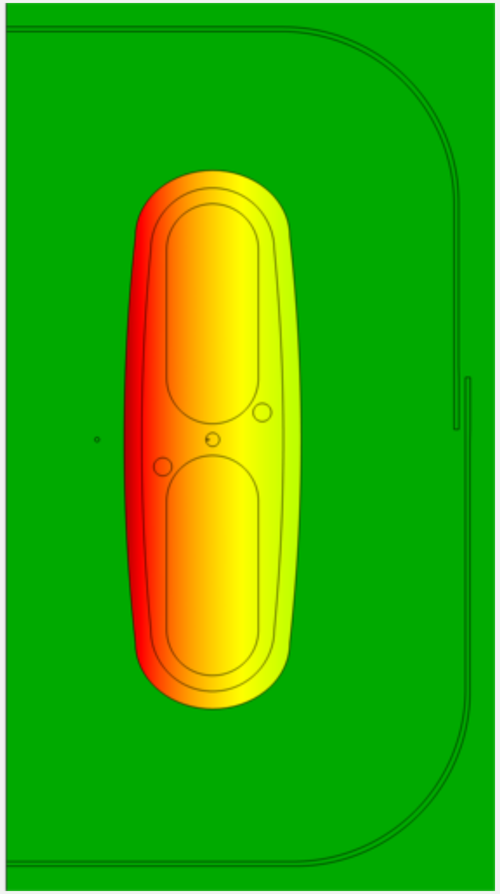
We have modeled and tested the ABRA-10cm setups and demonstrated the usefulness of this method



SUMMARY

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Simulations will continue to be necessary to optimize the sensitivity of future generations

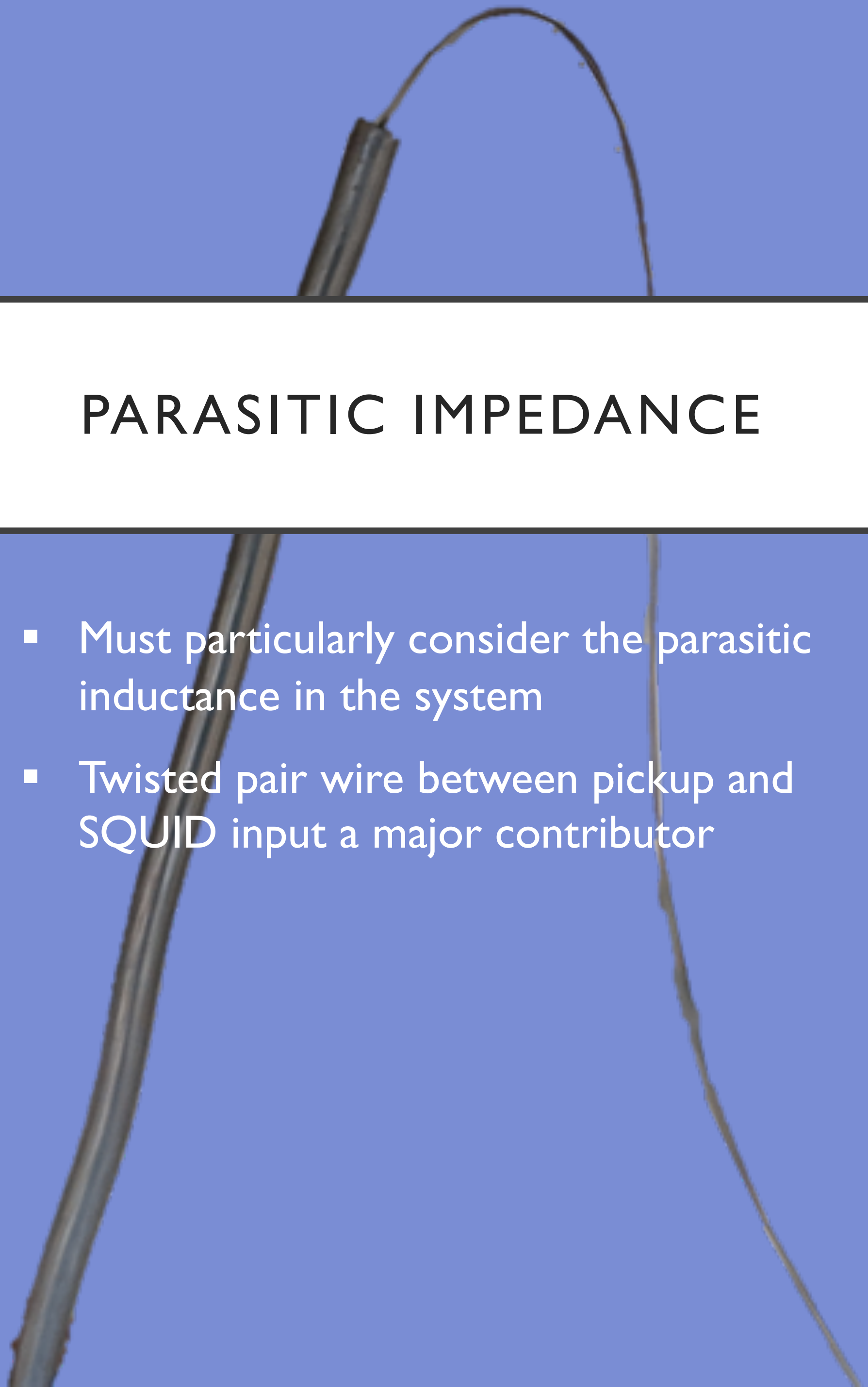
BACKUP

ERROR AND CHECKS

- **Is this even right?**
  - Compare to analytic calculations where possible (e.g. twisted pair, simple wire pickup loop, …)
- **How precise is COMSOL anyway?**
  - Vary parameters to see effects (e.g. conductivity, geometry, boundary conditions, …)

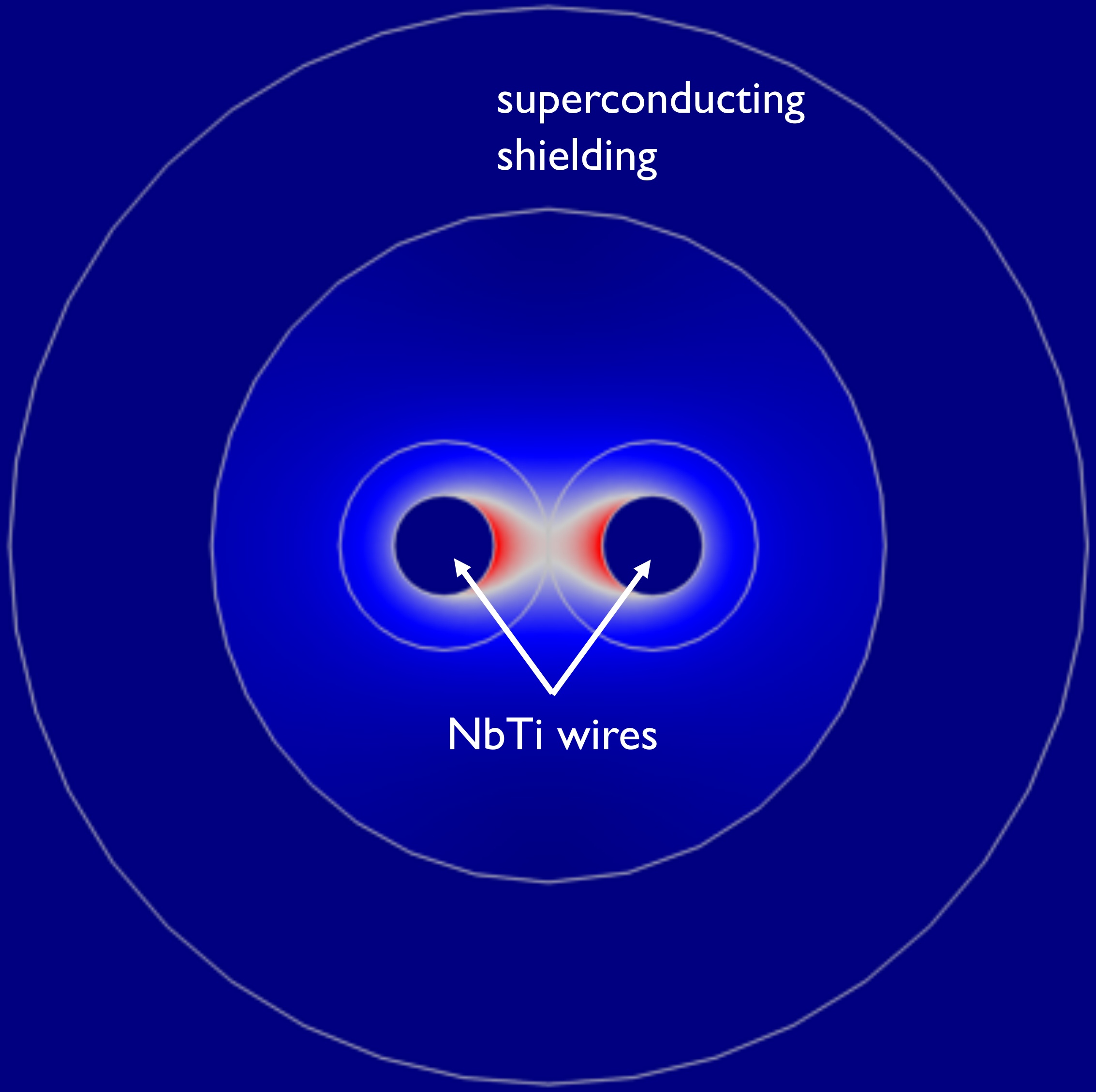
Example: Simple pickup loop geometry self inductance

Wire Diameter (mm)	COMSOL inductance, surface current (nH)	Analytical inductance, surface current (nH)	COMSOL inductance, volume current (nH)	Analytical inductance, volume current (nH)
0.5	112.5	112.8	118.8	119.1
1	95.0	95.3	101.3	101.6
2	77.5	77.8	83.8	84.1



PARASITIC IMPEDANCE

- Must particularly consider the parasitic inductance in the system
- Twisted pair wire between pickup and SQUID input a major contributor



PARASITIC IMPEDANCE

- For a realistic configuration, simulations give 0.48 μH/m and 29 pF/m
  - Wire diameter: 0.075 mm
  - Insulation thickness: 0.08 mm
  - Shield inner radius: 0.5 mm
  - Conductivity: varied $[10^7, 10^{25}]$