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Magnet System for the Baby MIND Neutrino Detector at J-PARC

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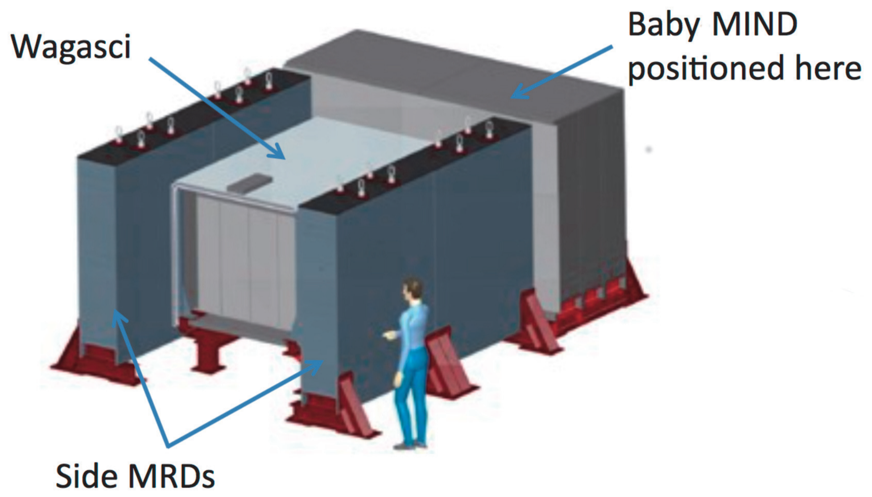
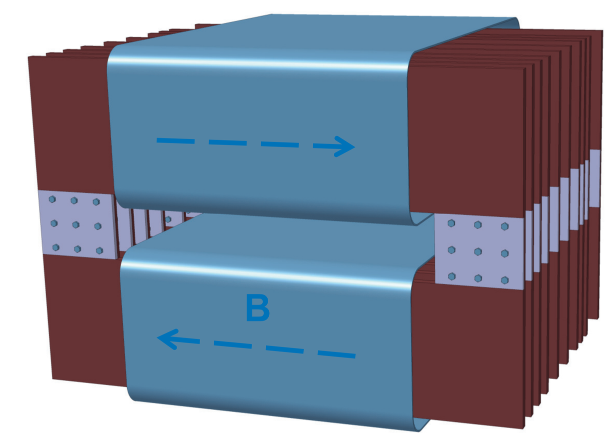
Motivation: Baby MIND, part of the CERN Neutrino Platform program, is a downstream muon spectrometer on the T2K beamline for the WAGASCI Experiment at J-PARC in Japan. The purpose of WAGASCI is to improve the measurements of the ratio of neutrino interaction cross-sections on water and carbon.

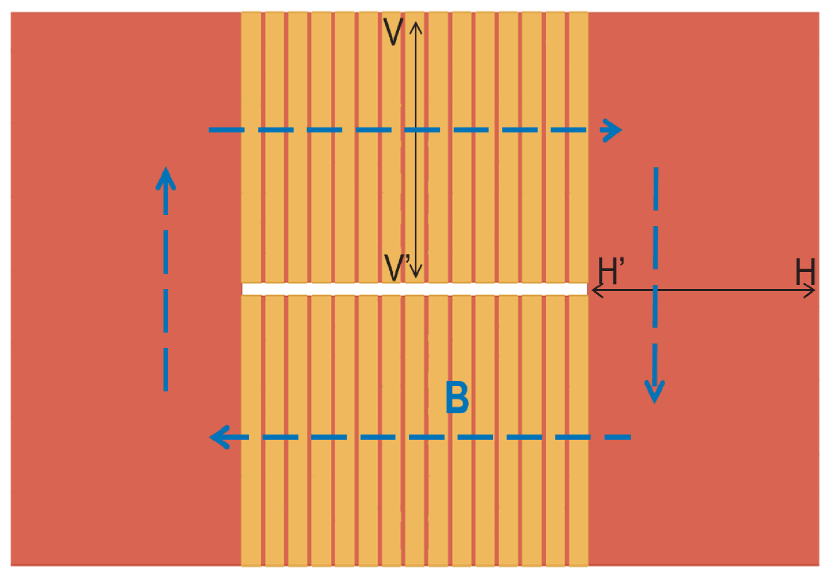
The Baby MIND Detector will contribute to this by measuring momentum and establishing the charge for muons over a range of momenta extending below 1 GeV/c, where multiple scattering degrades muon momentum measurements.

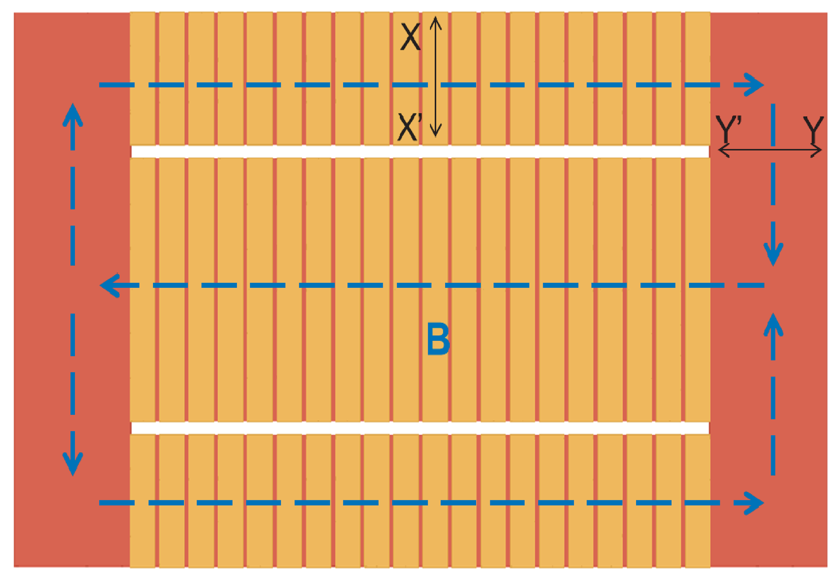


Original Magnetization Scheme: The traditional approach used in Magnetized Iron Neutrino Detectors relies on one or more large coils threading through the stack of iron plates.

- Such design results in a bulky magnet not meeting the transportation and installation constraints of Baby MIND.
- In addition, the traditional coil winding approach requires the development of dedicate tools, increasing production time and cost.







Baby MIND's Magnetization Scheme:

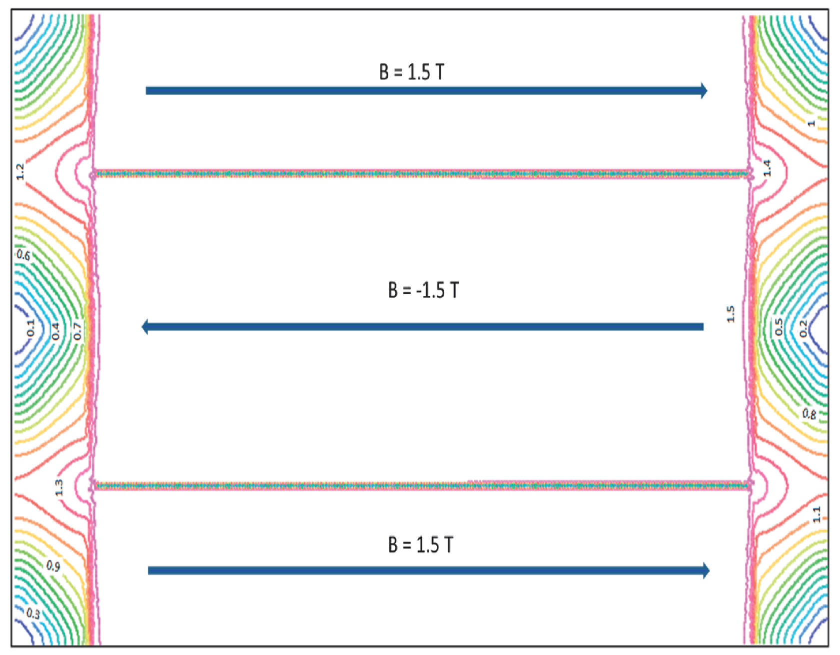
- Relies on the principle of flux return used in current transformers to minimize power dissipation and stray field.
- In its initial formulation, two (top and bottom) coils with currents in opposite directions magnetize each plate.

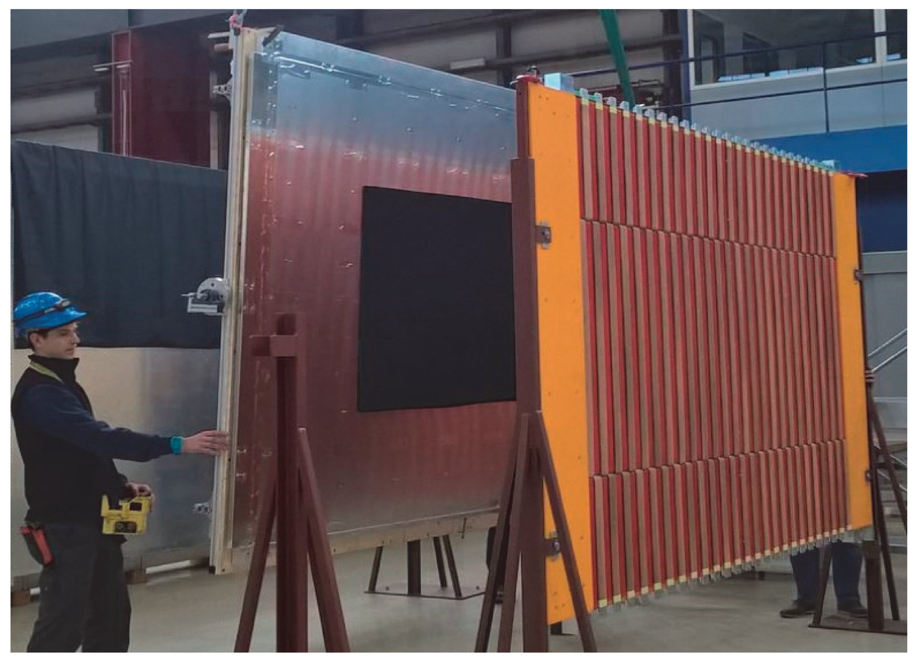
Two slit option:

- The cross-section area for flux return is reduced by moving from the one-slit-two-coils design to the two-slits-three coils design.
- This allows cutting the flux in cross-section X-X' by a factor 2 and extending the width of the tracking region to 2.5 m.

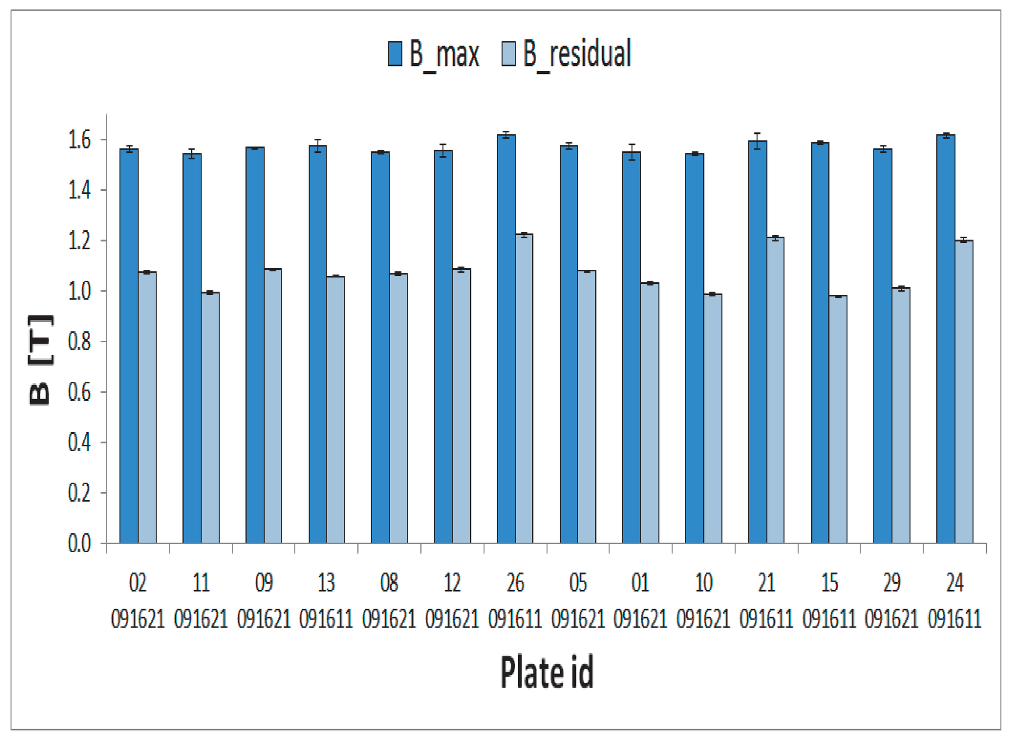
The construction phase for the 33 magnet modules began at CERN in August 2016. For the 18 scintillator modules it started in February 2017. Special attention was on qualifying all systems and parts before shipment from CERN to J-PARC.

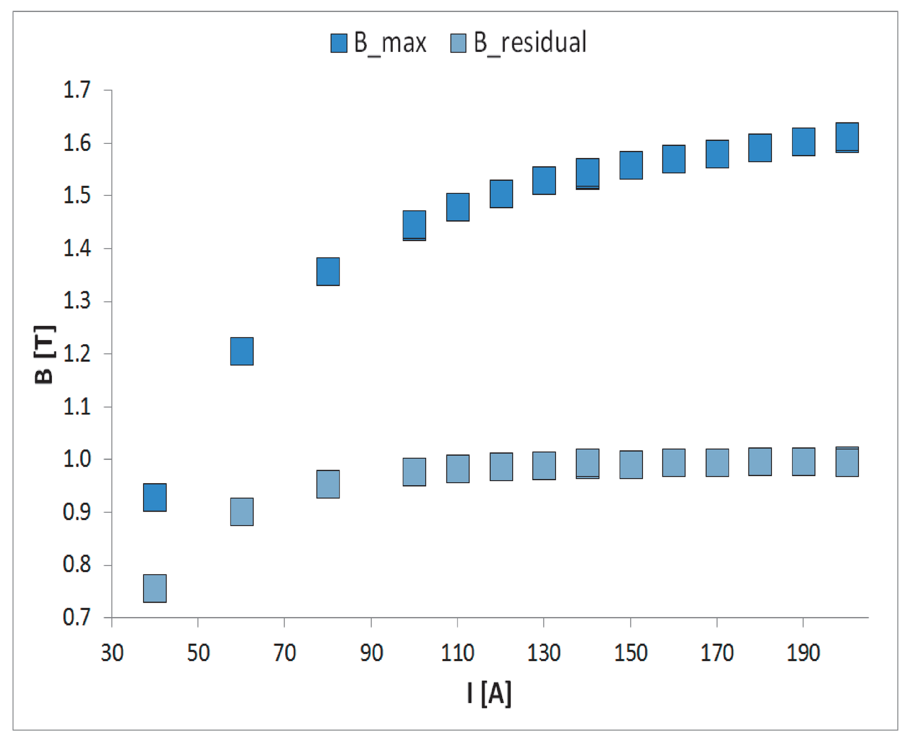
- **Winding of coils** on separate plates creates discontinuities in the flux return path, resulting in flux loss. The solution is to build each module out of a single plate with machined slits.
- **The coils are assembled** through the slits by dividing each turn into two halves. This requirement is met using the so-called "sewed coil" solution, where a conductor section is bent such as to pass through the two slits and it is then welded to the adjacent conductor sections at the top and bottom of the plate.



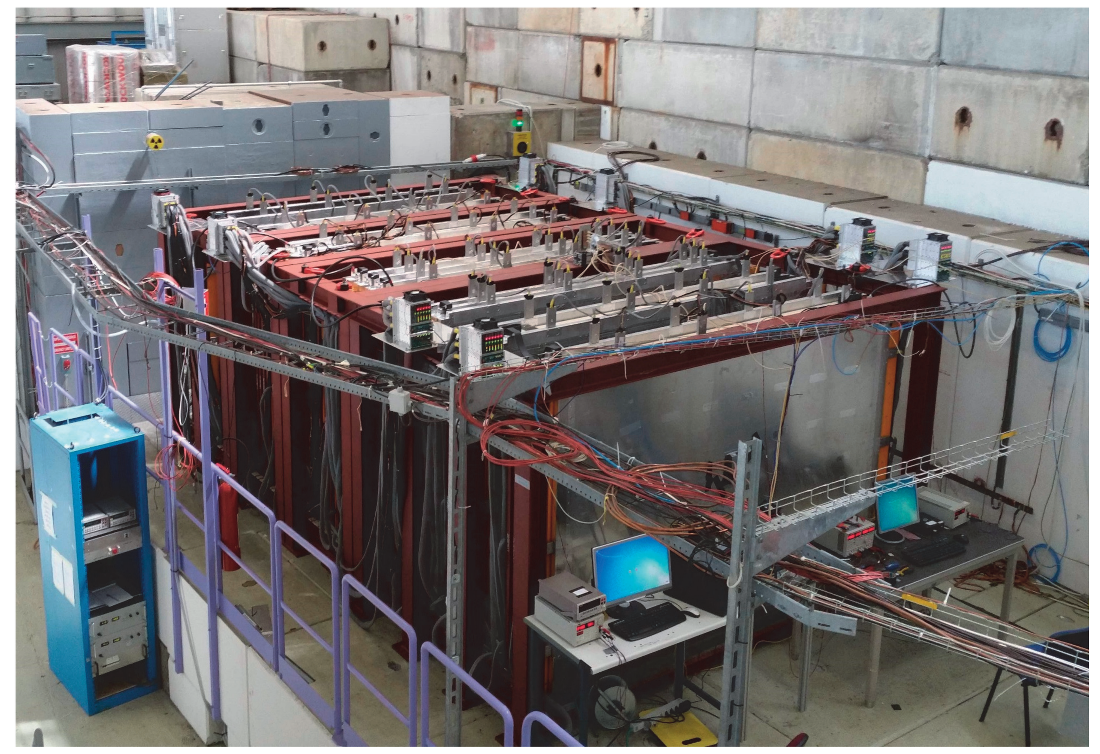


- **ARMCO magnetic steel** was selected for the Baby MIND plates, guaranteeing 1.5 T at about 1 kA/m. The field map shows the magnetic field distribution in a magnet module.
- **The conductor** material is aluminium alloy 1350. The width of the strip is 50 mm to minimize the number of turns while ensuring uniform magnetization. The thickness of the conductor of 4 mm, is determined by the combined needs of low power dissipation and ease of coil assembly.





- **The magnetic field** in the magnet modules is measured via pick-up coils wound around the plates. The magnetic field measured at a current of 140 A in the first 14 magnet modules appears to be very reproducible with an average value of B = 1.570 ± 0.025 mT.
- **The residual field** in the ARMCO is significant, amounting to almost 1 T for currents above 100 A.



The complete detector fully instrumented with electronics readout modules started taking data on a beam line at the CERN Proton Synchrotron East Hall experimental zone for characterization at the end of June 2017.

The detector magnet system comprises a horizontal stack of 30 mm thick, individually magnetized, iron plates of size 3.5 by 2.0 m. The overall mass of the block-shaped magnet system is 65 t including 2.3 t of insulated aluminium conductor. An innovative method of plate magnetization was developed. The magnetization scheme is optimized for flux return with minimum stray field and low operating current, while maximizing the useful tracking area with one-directional homogeneous magnetic field of 1.5 T. The magnet is operated at 140 A for generating the 1.5 T magnetic field in the iron plates requiring 12 kW power consumption only without requiring any active cooling system.