Baby MIND for WAGASCI - EPS-HEP 2017

Etam NOAH (UniGe) - Baby MIND Collaboration

July 7, 2017
T59 (WAGASCI) Introduction
   Introduction to Baby MIND
   T2K and WAGASCI

Muon spectrometry at WAGASCI
   Baby MIND project
   Lever Arm
   Baby MIND layout
   Software environments

Hardware update
   Hardware systems status
   Magnet modules
   Scintillator modules
   Cable bundles
   Electronics
   Mechanics support frames

Beam tests at CERN
   Beam tests schedule
   Beam tests summer 2016
   Beam tests summer 2017

Summary
   Project timeline
   Baby MIND status summary
T2K experiment overview

Far detector 295 km Near detector suite 280 m

ν production at J-PARC

Neutrino production:
30 GeV/c p beam
ν_μ mostly from π⁺ → μ⁺ + ν_μ
ν_e from μ and K decay
Mar. 2017:
470 kW
2 × 10^{21} POT
(c.f. 7.8 × 10^{21} POT app.)

Super Kamiokande:
Neutrino oscillation measurements
Atmospheric, solar, K2K, T2K
Proton lifetime
50 kton Water Cherenkov
(22.5 kton fiducial volume)

ND280:
Constraints on off-axis flux
UA1 magnet 0.2 T

Ingrid:
Flux characterization
Beam profile

Etam NOAH (UniGe) - Baby MIND Collaboration
T2K off-axis beam
WAGASCI (T59 experiment) at J-PARC

**Neutrino flux at WAGASCI (1.6° off-axis)**

- **Ingrid**
- **Wagasci**
- **ND280 pit**
- **WAGASCI modules**
- **Downstream MRD Baby MIND**
- **Side MRDs**

**Figure Details:**
- Neutrino flux plots showing the variation with energy.
- Diagram of the experimental setup at J-PARC.
Baby MIND project

- Magnetized Iron Neutrino Detectors
  - ... as main detectors (CDHS, MINOS, Neutrino Factory, NuSTORM)
  - ... downstream/surrounding LAr, Water Cherenkov, totally active scintillator detector etc...

- Backgrounds with conventional $\nu$ beams
  - ... experiments must handle wrong sign neutrinos.

- Baby MIND at WAGASCI
  - Initial motivation for Baby MIND was study of charge identification of muons on a charged particle beamline at CERN.
  - Baby MIND was then found to be a good match for the downstream muon spectrometer at the WAGASCI experiment (T59) at J-PARC, using neutrinos from the T2K beamline.

- Baby MIND at the CERN Neutrino Platform
  - was approved as experiment NP05 in December 2015.
  - support from AIDA-2020.
Low momenta: Lever Arm vs Multiple Scattering
**Lever Arm charge identification**

- 300 MeV/c to 450 MeV/c: use the deflection angle after the first magnet stack only.
- 450 MeV/c to 1 GeV/c: use the Lever-Arm algorithm.
- Above 1 GeV/c: use RecPack.
Baby MIND layout: side view

- Magnet module thickness: 50 mm (30 mm Fe) (envelope: 60 mm).
- Detector module thickness: 38 mm (31 mm CH).

\[\mu^+, \mu^-\]
From neutrino interactions in WAGASCI

Thicker steel to better resolve angular deflection by B-field from angular deflection by M.S.

Gaps to improve angular resolution with “lever arm”

Thinner steel here to improve cross-calibration of detector:
I.e. momentum resolution by range vs B-field

Etam NOAH (UniGe) - Baby MIND Collaboration
Two software environments

- The SaRoMan (Simulation And Reconstruction Of Muons And Neutrinos) package, derived from Neutrino Factory and nuSTORM studies.

- The WAGASCI-Baby MIND package, derived from the T2K ND280 software suite.
Baby MIND main systems

- Novel magnet design: x 33 modules
- Custom scintillator modules: x 18 modules
- Support mechanics for transport to Japan: x 4 blocks
- Cable bundles (scintillator-to-electronics)
- Custom readout electronics (USB3)
## Baby MIND hardware status

<table>
<thead>
<tr>
<th></th>
<th>Design 07/2016</th>
<th>Design 07/2017</th>
<th>Prototyping 07/2016</th>
<th>Prototyping 07/2017</th>
<th>Production 07/2016</th>
<th>Production 07/2017</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Magnet modules</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standard steel plates</td>
<td>✓</td>
<td>N/A</td>
<td>✓</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>ARMCO plate machining</td>
<td>×</td>
<td>✓</td>
<td>×</td>
<td>✓</td>
<td>×</td>
<td>✓</td>
</tr>
<tr>
<td>Coil engineering</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>×</td>
<td>✓</td>
</tr>
<tr>
<td>Magnet module assembly</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>×</td>
<td>✓</td>
</tr>
<tr>
<td><strong>Scintillator modules</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scintillator bars</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Scintillator module mechanics</td>
<td>×</td>
<td>✓</td>
<td>×</td>
<td>✓</td>
<td>×</td>
<td>✓</td>
</tr>
<tr>
<td>Scintillator module assembly</td>
<td>×</td>
<td>✓</td>
<td>×</td>
<td>✓</td>
<td>×</td>
<td>✓</td>
</tr>
<tr>
<td><strong>Cable bundles</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cable selection</td>
<td>×</td>
<td>✓</td>
<td>×</td>
<td>✓</td>
<td>×</td>
<td>✓</td>
</tr>
<tr>
<td>HV Coax PCB</td>
<td>×</td>
<td>✓</td>
<td>×</td>
<td>✓</td>
<td>×</td>
<td>✓</td>
</tr>
<tr>
<td>FEB Coax PCB</td>
<td>×</td>
<td>✓</td>
<td>×</td>
<td>✓</td>
<td>×</td>
<td>✓</td>
</tr>
<tr>
<td>Cable bundle assembly</td>
<td>×</td>
<td>✓</td>
<td>×</td>
<td>✓</td>
<td>×</td>
<td>✓</td>
</tr>
<tr>
<td><strong>Electronics modules</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FEBv1</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>×</td>
<td>✓</td>
</tr>
<tr>
<td>FEBv2</td>
<td>×</td>
<td>✓</td>
<td>×</td>
<td>✓</td>
<td>×</td>
<td>✓</td>
</tr>
<tr>
<td>Backplane</td>
<td>×</td>
<td>✓</td>
<td>×</td>
<td>✓</td>
<td>×</td>
<td>✓</td>
</tr>
<tr>
<td>Master Clock Board</td>
<td>×</td>
<td>✓</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>×</td>
</tr>
<tr>
<td>Minicrate mechanics</td>
<td>×</td>
<td>✓</td>
<td>×</td>
<td>✓</td>
<td>×</td>
<td>✓</td>
</tr>
<tr>
<td><strong>Mechanics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Support frame #1</td>
<td>×</td>
<td>✓</td>
<td>×</td>
<td>✓</td>
<td>×</td>
<td>✓</td>
</tr>
<tr>
<td>Support frame #2</td>
<td>×</td>
<td>✓</td>
<td>×</td>
<td>✓</td>
<td>×</td>
<td>✓</td>
</tr>
<tr>
<td>Support frame #3</td>
<td>×</td>
<td>✓</td>
<td>×</td>
<td>✓</td>
<td>×</td>
<td>✓</td>
</tr>
<tr>
<td>Support frame #4</td>
<td>×</td>
<td>✓</td>
<td>×</td>
<td>✓</td>
<td>×</td>
<td>✓</td>
</tr>
</tbody>
</table>
Magnet module concept

- **Design principles:**
  - Individually magnetized iron (ARMCO) plates.
  - Two-slit design.
  - Well defined B-field lines in central zone: $B = B_x$.
  - Contained stray fields.
  - Modularity and flexibility.

- **Dimensions:**
  - $3500 \times 2000 \times 30\text{mm}^3$.
  - 10 mm wide slits (water jet).
  - 10 mm-thick flux return plates $\times 4$.
  - Aluminium coil: 50 mm wide $\times 4$ mm thick: half-turns.

- **Test measurements.**
  - Field $> 1.5$ T for coil current $\sim 140$ A
  - Power for all 33 modules: 12 kW
Magnet module assembly: all 33 modules complete

- B-field tests of complete modules
- Welding of aluminium coil interconnects
- Machined bare ARMCO main plates (red)
- Machined bare ARMCO side plates (yellow)
- Coil assembly 2 assembly stands
Magnet module B-field measurements

- First measurements were performed with 9 pick-up coils on one module.
- All 33 plates each have one pick-up coil for B-field measurements.

\[ \int_{t_{\text{start}}}^{t_{\text{end}}} V(t) \, dt = \int_{t_{\text{start}}}^{t_{\text{end}}} N_{pc} \cdot \frac{dB}{dt} \cdot dt = N_{pc} \cdot S \cdot \Delta B \]

![Image of magnet module with numbers 1 to 9 and measurement data charts]
Scintillator bar production

▶ Design and production by INR:
  ▶ Polystyrene based, 1.5 % PTP, 0.01% POPOP.
  ▶ Reflective coating 30 to 100 µm from chemical etching of surface.
  ▶ Kuraray WLS fiber (200 ppm, S-type), dia 1.0 mm.
  ▶ Eljen EJ-500 optical cement.
  ▶ Custom optical connector.

▶ Delivery schedule INR-CERN:
  ▶ First batch delivered March 2016.
  ▶ Second batch delivered November 2016.
Test system with LED driver from Sofia

- Every sci. bar is tested at INR before shipping with cosmic ray setup.
- Every sci. bar is tested at CERN after shipping with LED setup.
Beam tests at T9 summer 2016: vertical bars
**Scintillator module assembly**

- Two half-modules assembled separately.
- Each half-module: 1 horizontal + 1 vertical plane:
  - 95 horizontal bars: $3000 \times 31 \times 7.5 \text{ mm}^3$
  - 8 vertical bars: $1950 \times 210 \times 7.5 \text{ mm}^3$
- Scintillators held together mechanically (no glue) within aluminium support frame.
Photosensors and connectivity

- Photosensor characteristics:
  - Hamamatsu MPPC S12571-025C (and derived S10943-5796).
  - $1 \times 1 \text{ mm}^2$ (65% fill factor).
  - 25 $\mu$m cell size.
  - Operating voltage $\sim 67.5$ V.
  - PDE $\sim 35\%$.
  - Gain $5 \times 10^5$.
  - Dark counts 100 kcps typ.
- Custom connectors:
  - Designed by INR.
  - Alignment of MPPC and coupling to WLS fiber.
  - Small pcb with UFL connector.
  - Coax cable: I-PEX 0.5 m length to cable bundle.
Cable bundles

- **Design principle:**
  - Decouple electronics Front End Boards from scint. modules.
  - Better accessibility and maintainability.
  - 5 m extension between photosensors and FEB.
  - No amplification before FEB.
  - Control of MPPC HV ch-by-ch on bundle PCB close to scint. module.

- **Production Timeline:**
  - Option chosen October 2016.
  - Validation December 2016.
  - Production April 2017.
Electronics readout scheme

**Hardware systems status**
- Magnet modules
- Scintillator modules
- Cable bundles
- Electronics
- Mechanics support frames

**Summary**
- Hardware update
- Beam tests at CERN

**Introduction**
- Muon spectrometry at WAGASCI

**Electronics readout scheme**

**Beam Line & ext synchro**
- Spill
- Reset *
- Clock *

* optional signals

**Control room**
- PC

**10G Ethernet Switch**

**Master Clock (7 RA45)**

**DAQ**
- PC #0
  - #3 USB3 ports

**Detector**
- #6 FEB per mini-crates

**Backplane**
- Mini crate #0
  - FEB 96-ch
- ...
- Mini crate #5

**Backplane**
- Mini crate #2
  - FEB 96-ch
- ...
- Mini crate #5

**Backplane**
- Mini crate #2
  - 3 mini crates

**Backplane**
- Mini crate #0
  - FEB 96-ch

**USB**
- READOUT (EP1/N, 2Gb/s)
- CMD (EP2OUT, 1Mb/s)
- ANS (EP2IN, 1Mb/s)

**SYNCHRO**
- 1 RA45/ 4 pairs
  - CLOCK (50/100MHz)
  - GTRIG (100KHz)
  - SPILL (ST/END, NBR)
  - RESET
  - FS (10KHz-100KHz frame sync)

**CHAIN +SYNCHRO**
- on backplane
  - READOUT (1Gb/s on FS)
  - CMD (1Mb/s) + ANS (1Mb/s)
  - CLOCK (50/100MHz)
  - GTRIG (100KHz)
  - SPILL (ST/END, NBR)
  - RESET
  - FS (10KHz-100KHz frame sync)

**Etam NOAH (UniGe) - Baby MIND Collaboration**

**Baby MIND for WAGASCI - EPS-HEP 2017**
Custom electronics Front End Board

Features of the Front End Board:

- Rack mounted.
- ×3 32-ch connectors.
- 3 CITIROC ASICs 32-ch.
- 12-bits 8-ch 40 MS/s/ch ADC.
- Altera ARIA5 FPGA.
  - Timing: 400 MHz sampling.
  - Analog readout: 8µs for 96-ch L-Gain and H-Gain.
  - HV, ASIC T + board T + RH%.
- Readout/Slow control on USB3 and/or Gigabit RJ45 chain.
- External propagated Trig/sync. signal.
- Power supplies (HV/LV).

Firmware and DAQ:

- Analog readout + slow control on USB.
- Platform independent readout. Windows/Linux.
CITIROC peak detector gate

- T2K beam
- Proton beam bunches
- μ through sci.
- FSB shaper
- Digi hits
- SSH shaper
- Peak detector "gate"
- Charge readout

- typ. < 100 digital hits per charge hit
- typ. < 100 hits

- FEB i, Ch #: i_n
- FEB i, Ch #: i_m

- 2.6 s
- ~5 µs
- 80 ns
- 580 ns
- 5-10 µs
Block 1 (of 4) load tests: March 2017: 20 t
Beam tests at CERN

- **Beam tests 2016**: 3 weeks in summer 2016 on T9 beamline at the PS in the East Area. Electronics, vertical sci. bars.

- **Beam tests 2017**: 1 week: 1st to 8th May. Block 1 (of 4 blocks), with 9 magnet modules, 7 scintillator modules. 5 weeks: 7th June to 12th July. Tests of full detector: 33 magnet modules, 18 scintillator modules.

- **Removal from T9**: Removeable in 4 blocks, 21t/18t/18t/18t, 2hrs.
Beam tests at T9 summer 2016

- Electronics FEBv1 characterization online:
  - 4 FEBs.
  - 384 MPPCs.
  - Scintillator modules developed under AIDA project.

- Tests of FEB functionality:
  - Calibration.
  - Analogue readout.
  - Time-over-threshold.
FEBv1 at T9 summer 2016: calibration

- MPPC signal calibration:
  - Pre-selection of MPPCs with $V_{op} = \text{nominal} \pm 100$ mV.
  - Gain $\sim 20$ ADC/p.e.
  - FEBv1 dynamic range HG $\sim 120$ p.e.

- Zero suppression:
  - 3 ASICs on each FEB require different thresholds.
  - Localization of true baseline.
Complete Baby MIND at T9

- 8 readout electronics minicrates
- 44 Front End Boards
- 18 scintillator modules
- 33 magnet modules
- 75 tonnes
- Magnet power supply rack
- Timing Sync PC
- DAQ PCs

Etam NOAH (UniGe) - Baby MIND Collaboration

Baby MIND for WAGASCI - EPS-HEP 2017
First event displays: 6 July 2017

Magnet in forward current mode

-3 GeV/c muon Event_253

Magnet in reverse current mode

-3 GeV/c muon Event_341

+3 GeV/c muon Event_383
Project milestones

- Electronics Front End Board beam test at T9 in June 2016.
- First complete Baby-MIND scintillator module in October 2016.
- Delivery of all scintillators from Russia INR by November 2016.
  - Was end Q1 2017 in October 2015 schedule
- Detector modules ready end of May 2017.
- Beam tests characterization at T9 in May 2017 - Block 1.
- Beam tests full detector at T9 in June 2017.
- Shipment to Japan in ...
- Installation at J-PARC ND280 pit in the planning.
Summary

- **NP05 Baby MIND project status**: Project approved by the CERN Research Board in December 2015 as a Neutrino Platform project. Muon charge ID efficiencies of 95% for momenta above 400 MeV/c.

- **Magnet modules**: the novel design, with each of the 33 modules having its own coil, enables far greater flexibility in detector layout compared with previous designs for this type of detector.

- **Scintillator modules**: Scintillator bars by INR. All 18 modules extensively tested and qualified with cosmics and LED test system before integration to magnet modules and beam tests.

- **Electronics**: Front End Board redesigned, integrating feedback from 2016 T9 beam tests, and new cabling scheme. Production and commissioning of ~ 50 FEBs was completed early July 2017.

- **Cable bundles**: Photosensors connected to FEBs via 5 m, 32-ch extension cable bundles, with no pre-amplification of the SiPM signals. Production of ~ 150 bundles complete.

- **Installation at J-Parc**: Support mechanics concept takes into account access constraints due to the pit shaft. Logistics planning ongoing with WAGASCI colleagues.