The Baby MIND detector

Etam NOAH (UniGe)

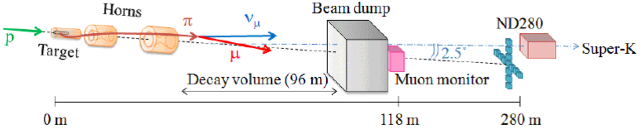
October 5, 2016

Long baseline neutrino experiments

- Some major unanswered questions in neutrino sector:
  - Mass hierarchy, δ_{CP}, LSND and short baseline anomalies, Majorana?
- Neutrino experiments:
  - Present (long baseline in 2016): MINOS/MINOS+ (USA - data collection stopped in 2016), NOvA (USA - started 2014), T2K (Japan - started 2010),
  - Future 2020-2030 (many more beyond!): T2K-II, JUNO, DUNE, INO-CAL, Hyper-K (T2HKK), ORCA/Pingu, nuSTORM, sterile ν exp. + lots of RD exp.!
- Accelerator neutrino facilities generate ν_μ, $\overline{\nu}_\mu$ beams, through charged-current interactions enable study of:
  - Δm^2_{32} (mass hierarchy) $\nu_\mu \rightarrow \nu_e$ appearance
  - δ_{CP} $\nu_\mu \rightarrow \nu_e$ appearance
  - $sin^2(2\theta_{23})$ (octant) $\nu_\mu \rightarrow \nu_e$ appearance
  - $sin^2(2\theta_{23})$ $\nu_\mu \rightarrow \nu_\mu$ disappearance , $\nu_\mu \rightarrow \nu_\tau$ appearance
  - $|\Delta m^2_{32}| \nu_\mu \rightarrow \nu_\mu$ disappearance , $\nu_\mu \rightarrow \nu_\tau$ appearance
  - ... and sterile neutrinos $sin^2(\theta_{24})$, $sin^2(2\theta_{14})$, $sin^2(\theta_{34})$

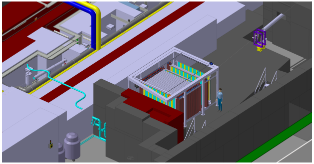
Muon spectrometers with conventional ν beams

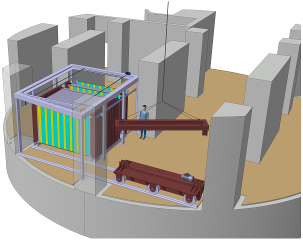
- Neutrino beam composition:
  - ... has inherent component of neutrino of wrong sign due to ν production mechanisms from decay of π then μ
- Magnetized iron neutrino detectors
  - ... as standalone detectors (e.g. CDHS, MINOS, and planned for Neutrino Factory and NuSTORM)
  - ... as detectors downstream of LAr, Water Cherenkov, totally active scintillator detector etc...



Baby MIND Introduction

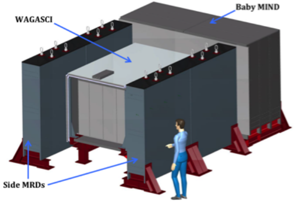
- Baby MIND was born from prototyping activities carried out within the AIDA project
  - Aim was to study muon charge ID with initial plans to use the SPS.
  - It was realized that it was well suited to measure charge ID at the WAGASCI experiment at J-PARC.
  - Proposal to design, build and test the detector at CERN, then ship it to Japan was submitted to the SPS committee for its October 2015 session.

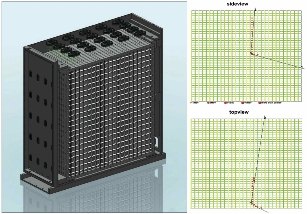




Baby MIND at WAGASCI

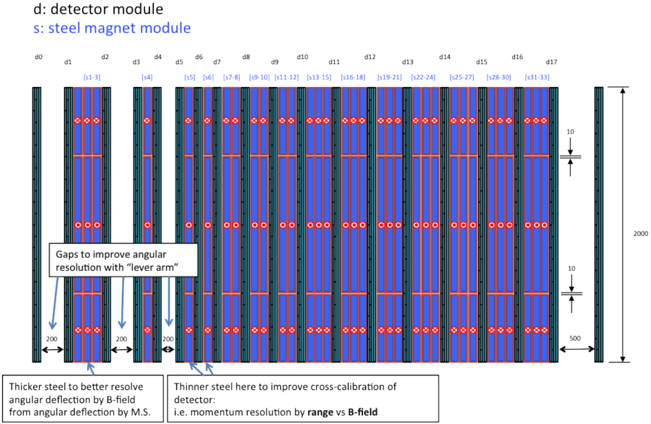
- Current T2K setup:
  - Far detector (SK) is H_2O with 4π acceptance.
  - Near detector (ND280) is plastic (CH), its acceptance is forward scattering.
  - Systematic error sources are dominated by ν flux and cross-section non-constrained by the ND280.
- Hence motivation for measurement of H_2O/CH ratio with large polar angle at WAGASCI (approved experiment T59 at J-PARC).
- Magnetized muon spectrometer required to tell the charge of muons, especially in anti-neutrino beam mode where wrong-sign contamination in the beam is up to 30%.



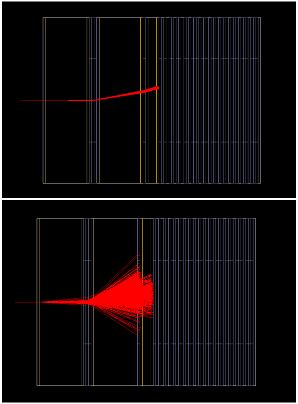


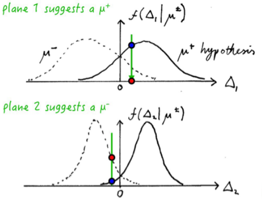
Baby MIND layout

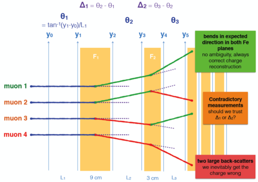
- 33 magnet modules: each 50 mm thick (30 mm Fe) (envelope: 60 mm).
- 18 detector modules: each 40 mm thick (31 mm CH).
- Finalization of the layout will be done with T9 and simulation info.

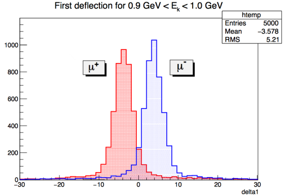


Low momenta: Lever Arm vs Multiple Scattering







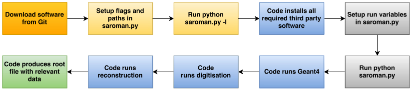


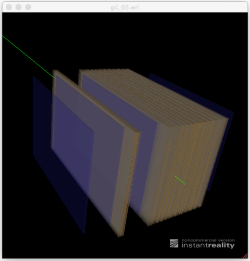
$$\text{Rec as } \mu^- \text{ if } \frac{f_{\mu^-}(\Delta_1)}{f_{\mu^+}(\Delta_1)} > \frac{f_{\mu^+}(\Delta_2)}{f_{\mu^-}(\Delta_2)}$$

$$\text{Rec as } \mu^+ \text{ if } \frac{f_{\mu^+}(\Delta_1)}{f_{\mu^-}(\Delta_1)} > \frac{f_{\mu^-}(\Delta_2)}{f_{\mu^+}(\Delta_2)}$$

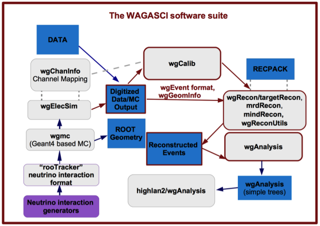
Two software environments to be merged into one

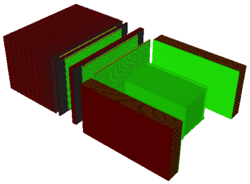
- The SaRoMan (Simulation And Reconstruction Of Muons And Neutrinos) package, derived from Neutrino Factory and nuSTORM studies.





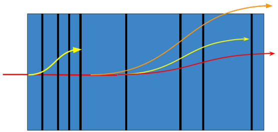
- The WAGASCI-Baby MIND package, derived from the T2K ND280 software suite.





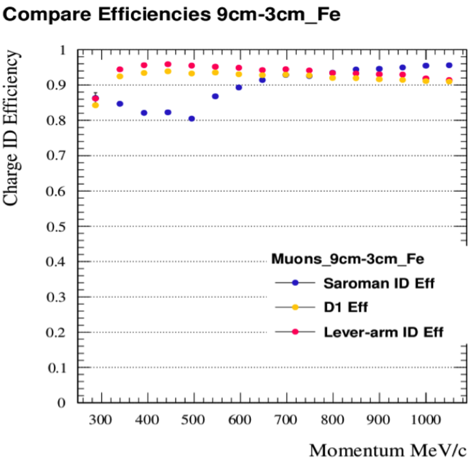
Reconstruction in SaRoMan

- 4-10 hits, use the lever arm, momentum from range and charge from a quadratic fit.
- $>$ 10 hits calculate a seed with momentum and charge and then feed this seed into a kalman fitter.
- If the track stops in the detector use a range momentum calculation and charge from a quadratic fit, if not estimate the momentum from the curvature.



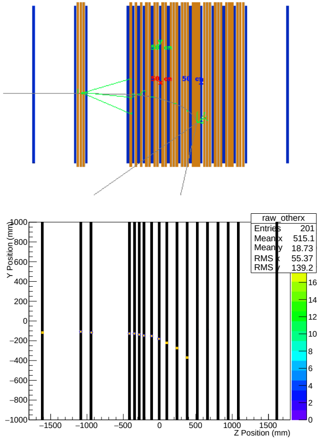
Charge ID with WAGASCI-Baby MIND

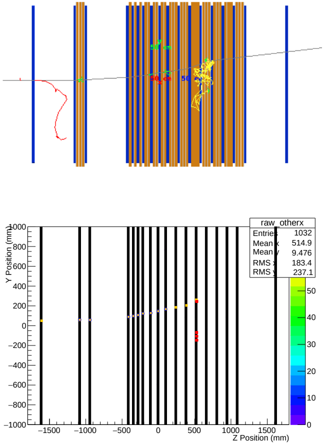
- $>$ 90% at 300 MeV/c.
- 97% at 500 MeV/c.



SaRoMan event topologies: 1 GeV μ^+ & 1 GeV μ^-

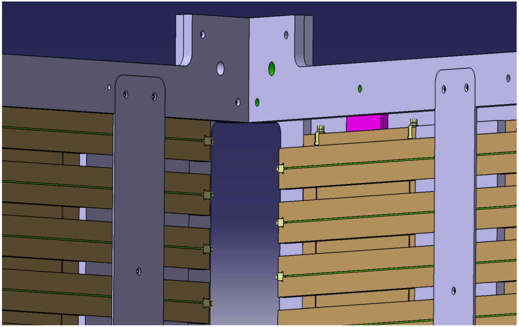
Green: γ; Red: e^-; Yellow: neutron; Grey: Other (incl. muon)

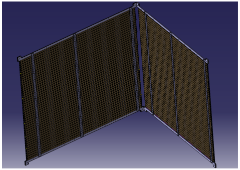


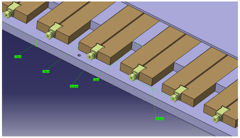


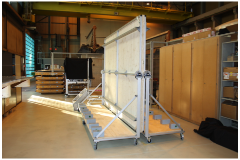
Scintillator module mechanics

- Two half-modules assembled separately and brought together to form a complete module.
- Each half-module: 1 horizontal + 1 vertical plane:
  - 95 horizontal bars: 3000 mm x 31 mm x 7.5 mm
  - 8 vertical bars: 1950 mm x 210 mm x 7.5 mm
- Scintillators held together mechanically (no glue) within aluminium support frame.





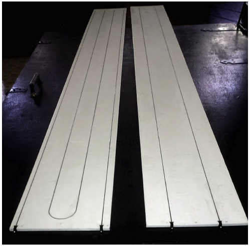


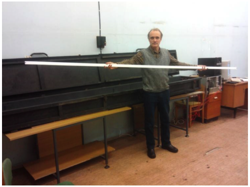


Scintillator bar production

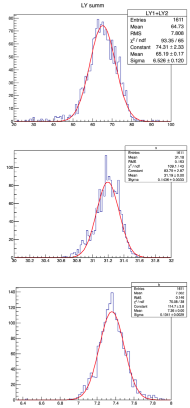
- Responsibility of INR.
- Polysterene based, 1.5 % PTP, 0.01% POPOP.
- Reflective coating 30 to 100 μm from chemical etching of surface.
- Kuraray WLS fiber (200 ppm, S-type), dia 1.0 mm.
- Eljen EJ-500 optical cement.
- Custom optical connector.
- **First batch** delivered **March 2016** - Good for 2 modules.
- **Second batch** expected **October 2016**.

Vertical bars (U vs W groove)
Horizontal bars



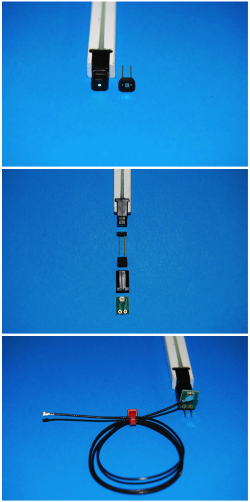


Horizontal bars light yield [p.e.], width [mm] & thickness [mm]



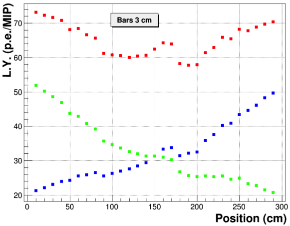
Photosensors and connectivity

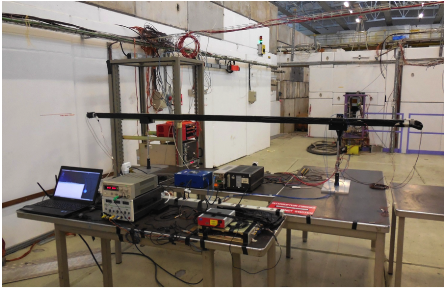
- Photosensor characteristics:
  - Hamamatsu MPPC S12571-025C.
  - 1×1 mm^2 (65% fill factor).
  - 25 μm cell size.
  - Operating voltage $\sim$ 67.5 V.
  - PDE $\sim$ 35%.
  - Gain 5×10^5.
  - Dark counts 100 kcps typ.
- Custom connectors.
  - Designed by INR.
  - Alignment of MPPC and coupling to WLS fiber.
  - Small pcb with UFL connector.
  - Coax cable: HIROSE 1 m length to FEB.



Horizontal bar tests: CERN PS-T9 beamline: October 2015

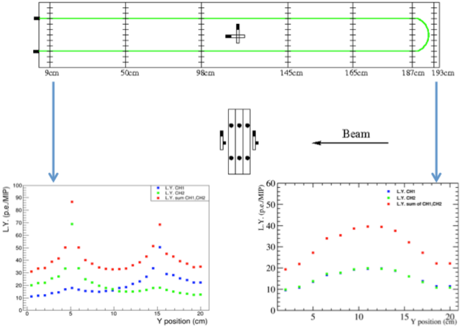
- Beam test for SHiP experiment with bar similar to Baby MIND horizontal bars: 3000 x 30 x 7.5 mm^3.
- CAEN DT5742 digitizer.
- 10 GeV/c muons.
- Light yield: 60 p.e..
- Light propagation: 1.7×10^8 $m.s^{-1}$.



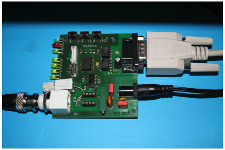


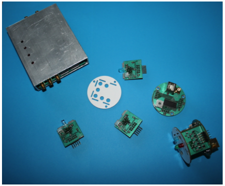
Vertical bar tests: CERN PS-T9 beamline: July 2016

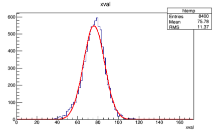
- Beam test with Baby MIND vertical bars: 1950 x 210 x 7.5 mm^3.
- 1 x 1 cm^2 trigger scan.
- Avg. light yield at 9 cm: 41.5 p.e.
- Avg. light yield at 193 cm: 30.5 p.e.
- ... but min. from one end: 10 p.e.



Test system with LED driver from Sofia

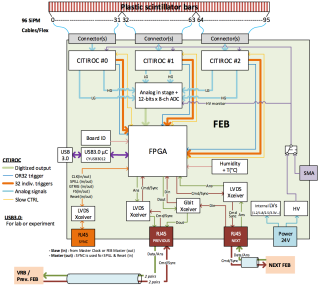


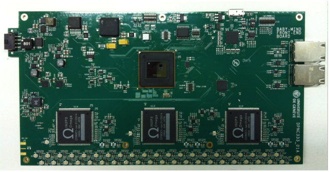




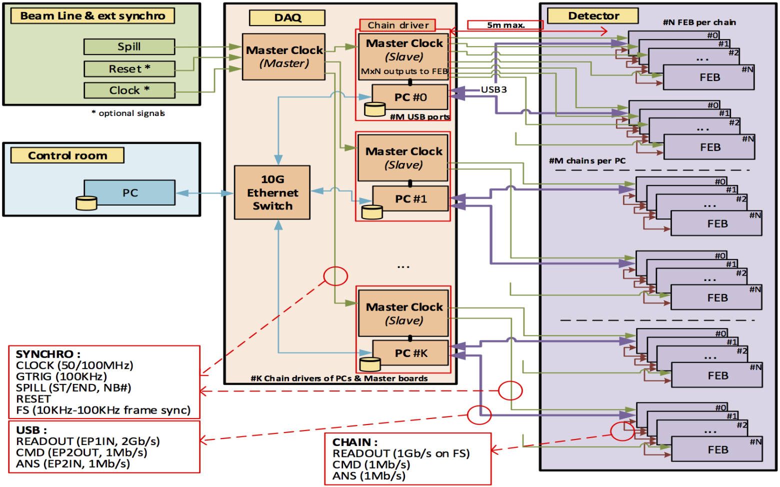
Custom electronics Front End Board

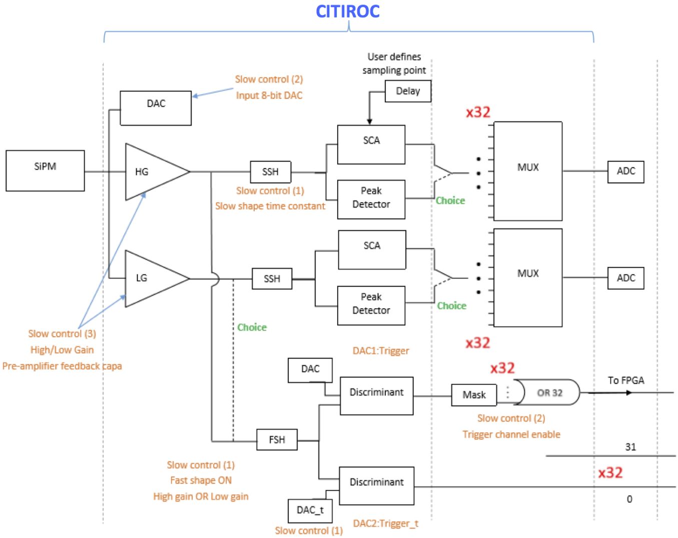
- Features of the Front End Board:
  - 96 coax. connectors.
  - 3 CITIROC ASICs 32-ch.
  - 12-bits 8-ch 40MS/s/ch ADC.
  - Altera ARIA5 FPGA.
    - Timing: 2.5 ns resolution.
    - Analog readout: 8μs for 96c-ch LGain and HGain.
    - HV, ASIC T + board T + RH%.
  - Readout/Slow control on USB3 and /or Gigabit RJ45 chain.
  - External propagated Trig/sync. signal.
  - Power supplies (HV/LV).
- Firmware and software:
  - FPGA firmware: Analog readout + slow control on USB done.
  - Software engineer hired for low level software.



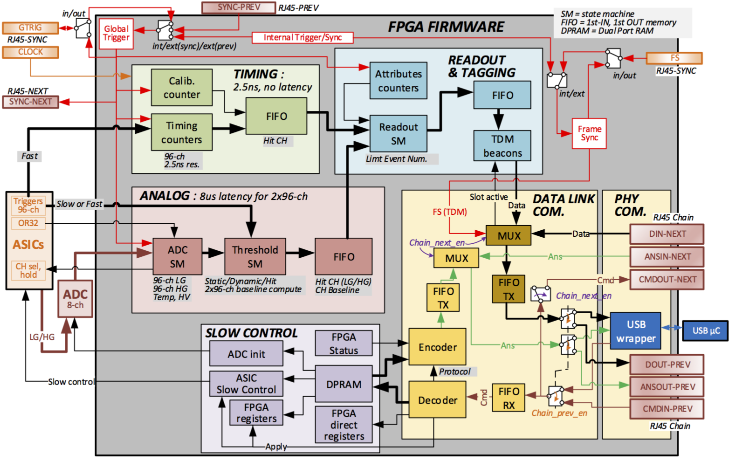


Baby MIND electronics scheme

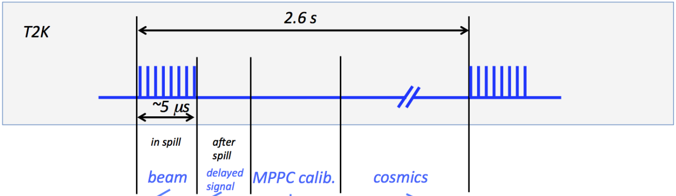



CITIROC
User defines
sampling point
Delay
Slow control (2)
Input 8-bit DAC
DAC
SiPM
HG
LG
SSH
SCA
Peak
Detector
Slow control (1)
Slow shape time constant
Choice
x32
MUX
ADC
Slow control (3)
High/Low Gain
Pre-amplifier feedback capa
DAC1:Trigger
DAC
Discriminant
Mask
OR 32
To FPGA
Slow control (2)
Trigger channel enable
FSH
Slow control (1)
Fast shape ON
High gain OR Low gain
DAC_t
Slow control (1)
DAC2:Trigger_t
31
0

FEB FPGA firmware



Baby MIND data taking at WAGASCI T59



ν interactions in:
- Baby MIND

... & beam induced muons from ν interactions in:
- WAGASCI
- sMRD
- INGRID, cavern walls etc...

in WAGASCI:
CH (1 t): 3.3 × $10^{-3}/10^{14}$ POT
H_2O (1 t): 3.3 × $10^{-3}/10^{14}$ POT

evaluate MPPC & electronics periodically:
- all 4000 channels
- every few hours

< 100 kHz dark cnts

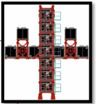
cosmics:
- mean light yield
- timing resolution
- hit efficiency as a function of track angle

< 100 Hz cosmics

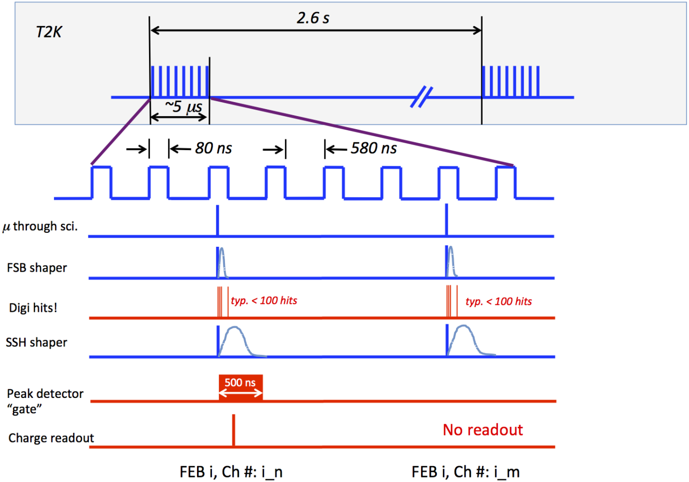
NIM A 694 (2012) 211-223:
PhysRev D90, 052010 (2014) (a little more... x1.36 TBC)

e.g. event rates @ INGRID (~ 22 m^2, 99.4 t Fe):
- ν events: 1.5 / 10^{14} POT
- beam induced events cavern walls: 4 / 10^{14} POT

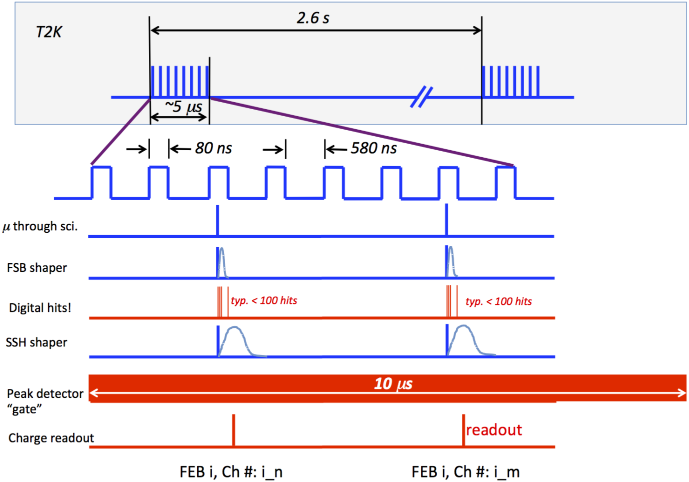
for runs I and II: max. 145 kW (3 × 10^{14} POT --> 750 kW)



Readout with peak detector window set to 500 ns

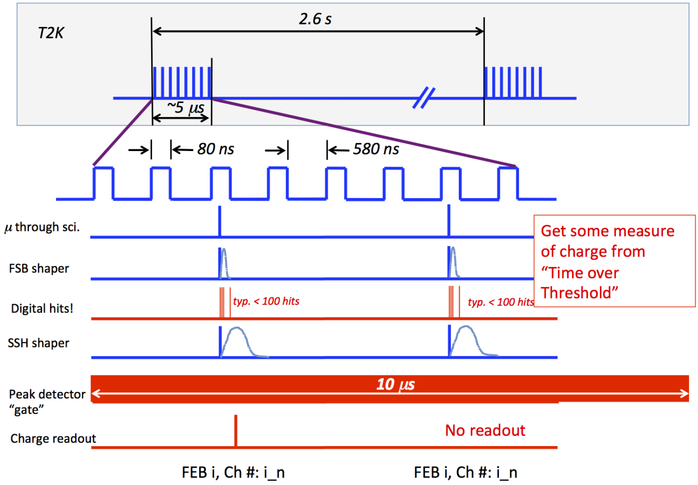


Readout with peak detector window set to 10 μs



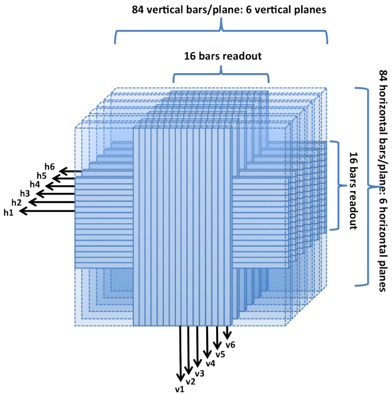
Single channel occupancy issue

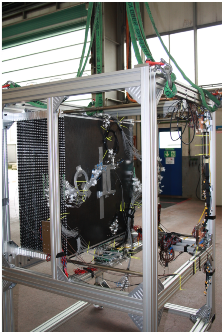
For a given channel "Peak detector" will only retain highest amplitude hit occuring in its 10 µs window

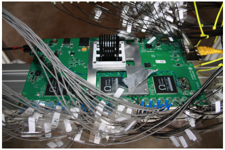


Prototype FEB testing at CERN T9 beamline

- 4 boards fully tested:
  - Hardware, firmware blocks, USB3 link.
  - 384 channels

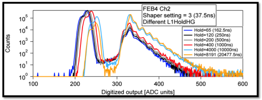


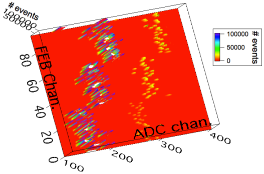


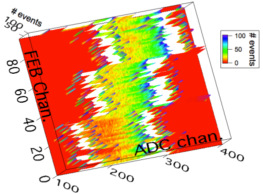


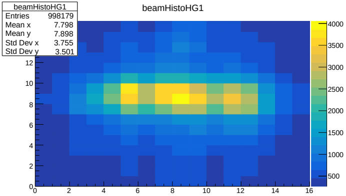
Prototype FEB testing at CERN T9 beamline

- Calibration
- CITIROC parameter scans
  - pre-amp gain HG/LG.
  - shaper time constants
  - discriminator DAC thresholds
  - L1HoldHG/L1HoldLG
  - pk detector mode vs SCA mode
- Timing studies



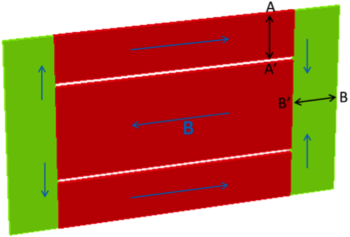


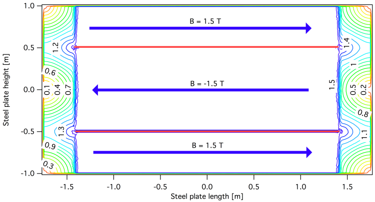




Magnet module concept

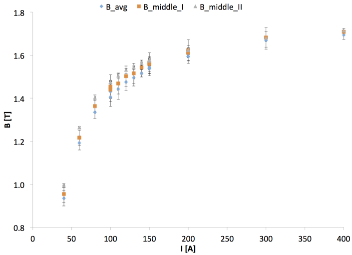
- Magnet system funded by CERN Neutrino Platform.
- Individually magnetized iron plates respond to installation constraints at J-Parc.
- Modularity and flexibility.
  - Allows for deployment in much wider range of detector topologies compared with conventional large coil designs such as CDHS or MINOS.
- Two-slit design.
- Well defined B-field lines in central zone: $B = B_x$.
- Contained stray fields.
- Low power (400 W/module).

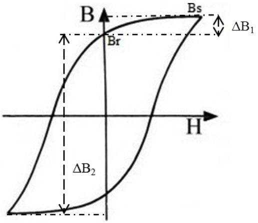


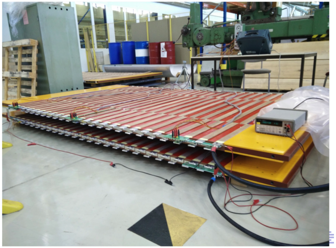


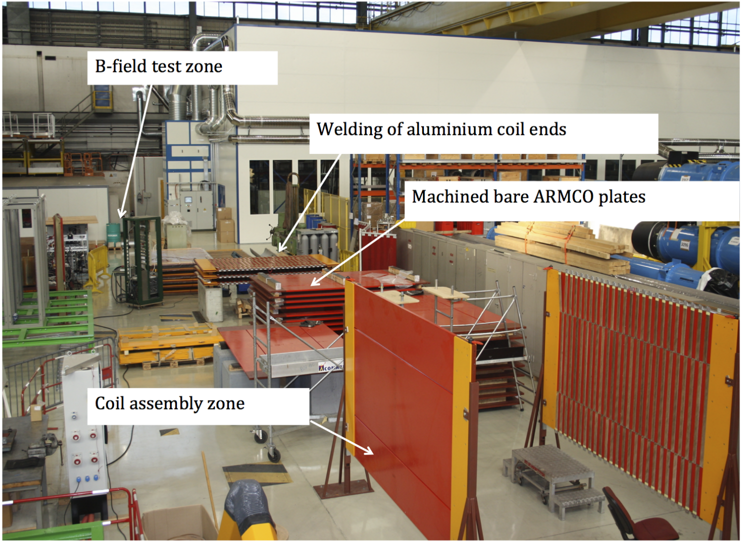
Magnet module tests

- Full size ARMCO modules $3500 \times 2000 \times 30\text{mm}^3$.
- Aluminium coil: 50 mm wide $\times$ 4 mm thick: half-turns.
- Fiber glass insulation sheath.
- I = 130 - 140 A: B = 1.5 T: P = 12.4 kW (33 modules - 150 A)
- I = 200 A: B = 1.6 T: P = 22.1 kW (33 modules)








B-field test zone
Welding of aluminium coil ends
Machined bare ARMCO plates
Coil assembly zone

Collaboration members

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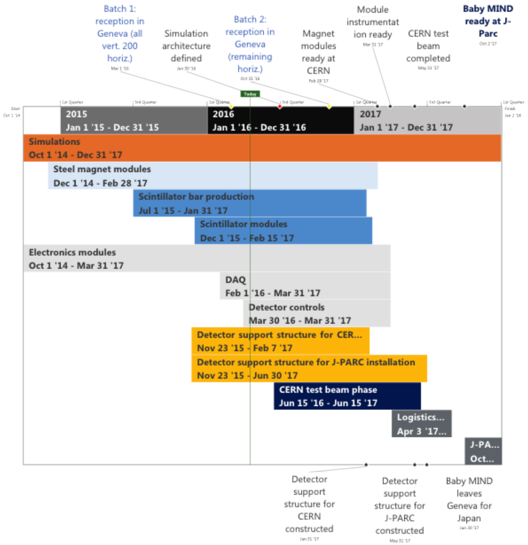
Spoke: A. Blondel, Co-spoke: Y. Kudenko, Contact: E. Noah


Batch 1: reception in Geneva (all vert. 200 horiz.)
Simulation architecture defined
Batch 2: reception in Geneva (remaining horiz.)
Magnet modules ready at CERN
Module instrumentation ready
CERN test beam completed
Baby MIND ready at J-Parc
Today
2015
Jan 1 '15 - Dec 31 '15
2016
Jan 1 '16 - Dec 31 '16
2017
Jan 1 '17 - Dec 31 '17
Simulations
Oct 1 '14 - Dec 31 '17
Steel magnet modules
Dec 1 '14 - Feb 28 '17
Scintillator bar production
Jul 1 '15 - Jan 31 '17
Scintillator modules
Dec 1 '15 - Feb 15 '17
Electronics modules
Oct 1 '14 - Mar 31 '17
DAQ
Feb 1 '16 - Mar 31 '17
Detector controls
Mar 30 '16 - Mar 31 '17
Detector support structure for CER...
Nov 23 '15 - Feb 7 '17
Detector support structure for J-PARC installation
Nov 23 '15 - Jun 30 '17
CERN test beam phase
Jun 15 '16 - Jun 15 '17
Logistics...
Apr 3 '17...
J-PA...
Oct...
Detector support structure for CERN constructed
Detector support structure for J-PARC constructed
Baby MIND leaves Geneva for Japan

Project milestones

- **Electronics Front End Board** beam test at T9 in **June 2016**.
- **First** complete **Baby-MIND module** in **August 2016**.
- **Delivery** of remaining **scintillators** in **October 2016**.
  - *Was end Q1 2017 in October 2015 schedule*
- **Magnet modules** ready on the **T9** platform end of **February 2017**.
- **Detector modules** ready on the **T9** platform end of **March 2017**.
- **Beam tests** characterization at T9 in **May 2017**.
- **Shipment** to **Japan** in **July 2017**.
- **Installation** in Japan **ND280 pit** in September for operation in **October 2017**.

Summary

- **Baby MIND status** The Baby MIND was approved by the CERN Research Board at its meeting of 9 December 2015 as a Neutrino Platform project and is now listed as NP05 in the CERN Grey Book database.
- **Physics simulations**: We are working on a custom simulation environment for the Baby MIND.
- **Charge ID efficiencies**: Using a Lever Arm algorithm combining two lever arms, charge ID efficiencies $> 90\%$ for momenta between 320 MeV/c and 450 MeV/c, $> 97\%$ for momenta > 450 GeV/c.
- **Scintillator modules**: Production of scintillator bars under the responsibility of INR completed end September 2016. Assembly tooling is complete, ready for first module.
- **Electronics**: The first prototype Front End Board has undergone extensive tests in lab and on T9 beamline. Now designing the second version of the board.
- **Magnet modules**: Designed for modularity, adaptable to range of detector topologies, production of magnet modules is well underway.
- **Support mechanics and logistics**: Design of support mechanics for installation at T9, transport to Japan and installation at J-Parc planned over coming months.

Acknowledgements

- **CERN Neutrino Platform**
- **UniGe**: Mechanical engineering (F. Cadoux, L. Nicola) and electronics engineering (Y. Favre)
- **Collaboration**: Several contributors to these slides
- **... thank you**