Baby MIND - NuFact2017

On behalf of the Baby MIND collaboration

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University of Glasgow | Experimental Particle Physics

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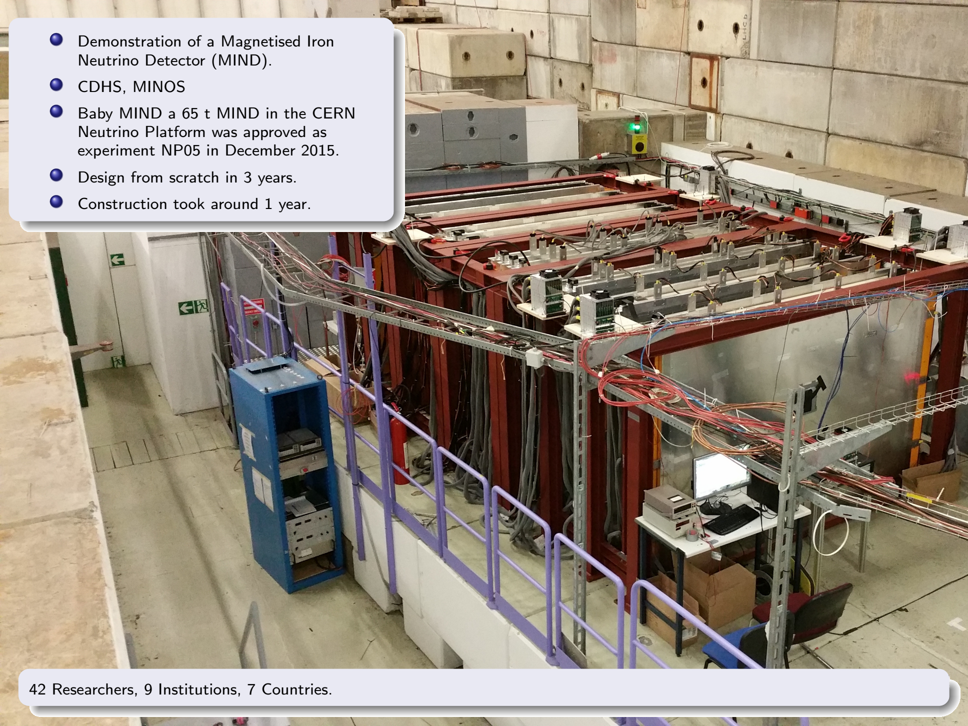
- Design
- Testbeam design
- Magnetisation
- Scintillator
- Electronics
- Motivation
- Software environment

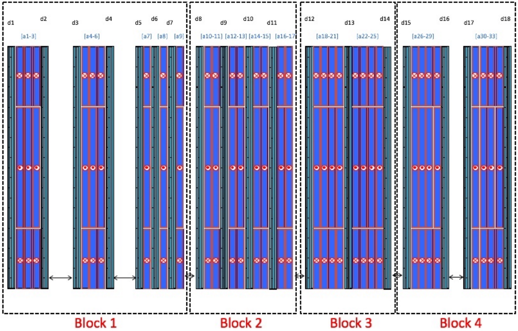
- Preliminary testbeam results
  - Charge identification
  - Momentum residuals
- CCQE studies

- Demonstration of a Magnetised Iron Neutrino Detector (MIND).
- CDHS, MINOS
- Baby MIND a 65 t MIND in the CERN Neutrino Platform was approved as experiment NP05 in December 2015.
- Design from scratch in 3 years.
- Construction took around 1 year.



42 Researchers, 9 Institutions, 7 Countries.

Design



- Fully modular, novel magnetisation scheme.
- Magnet module dimensions 3500 x 2000 x 30 mm^3 (Fe)
- Scintillator module dimensions 3000 x 1950 x 30 mm^3 (CH)

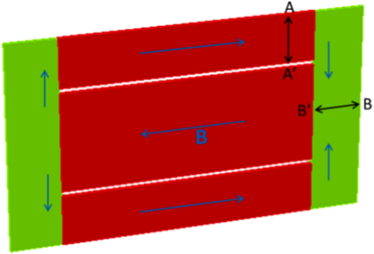
- Length $\approx 4m$
- 18 Scintillator modules.
- 33 Magnet modules.

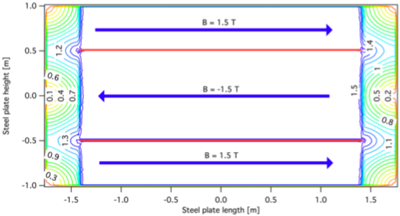
- Testbeam design, redesigned with construction and time constraints in mind.
- Construction of Baby MIND detector completed in June 2017 (Poster by S. Parsa)
- Charged particle beam test characterisation of Baby MIND at CERN performed June-July 2017

Magnetisation

CERN contribution

- Individually magnetised iron (ARMCO) plates
- Two slit design, simple dipoles.
- Well contained and defined field lines.
- Very uniform in area of interest.
- Modular and flexible.
- Field ≈ 1.5 T for coil current ≈ 140 A
- Stray fields insignificant < 15 mT.
- Power required for all 33 modules: 12 kW.
- ... and much more (logistics, handling, assembly space through the CERN Neutrino Platform)



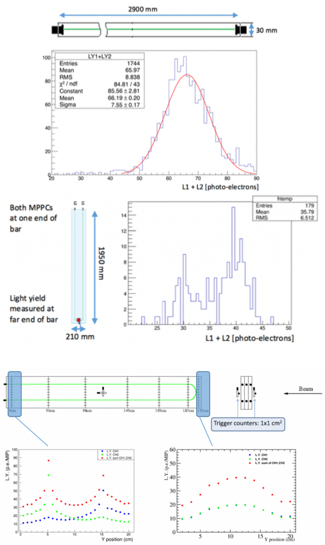


Scintillator module

- Composed of 4 layers, 2 horizontal and 2 vertical bars
- Bars are overlapped to ensure 100% hit efficiency for minimum ionising muons and improve resolution.
- In total 95 Horizontal bars: 3000 x 31 x 7.5 mm^3
- 8 vertical bars: 1950 x 210 x 7.5 mm^3
- Scintillators held together mechanically (no glue) within an aluminium support frame

Design and production by INR

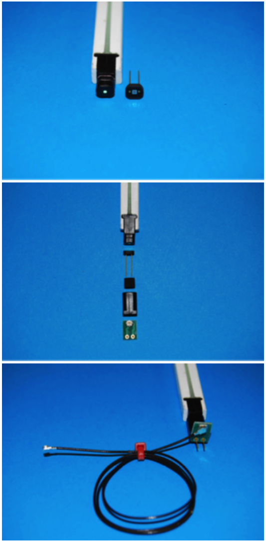
- Polysterene based, 1.5 %
- PTP, 0.01 % POPOP.
- Reflective coating 30 to 100 μm from chemical etching of surface.
- Kuraray WLS fiber (200ppm, S-type), dia 1.0 mm.
- Eljen EJ-500 optical cement.
- Custom optical connector.

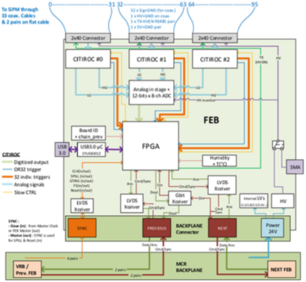


Connectivity

Hamamatsu MPPC

- S12571-025C (and derived S10943-5796).
- 1x1 mm^2 (65% fill factor).
- 25 μm cell size.
- Operating voltage $\approx$ 67.5 V.
- Photon detection efficiency (PDE) $\approx$ 35%
- Gain $5 x 10^5$
- Dark counts 100 kcps typ.





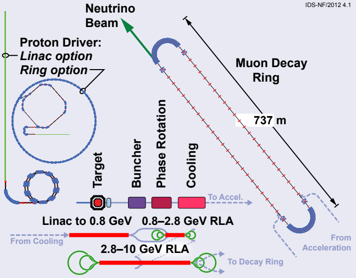
Custom-made FEB

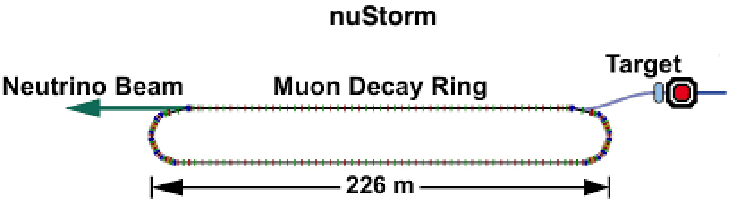
- Designed by Geneva University
- Rack mounted.
- x3 32-ch connectors, 3 CITIROC ASICs 32-ch.
- 12-bits 8-ch 40 MS/s/ch ADC.
- Altera ARIA5 FPGA.
- Timing: 400 MHz sampling.
- Analog readout: 8μs for 96-ch L-Gain and H-Gain.
- Readout/Slow control on USB3 and/or Gigabit on Backplane.
- Power supplies (HV/LV).
- Platform independent readout, Windows/Linux.
- CITIROC made by Weeroc, a spin-off company from Omega laboratory (IN2P3/CNRS)

Motivation

Near detector nuSTORM/Neutrino Factory

- Background with conventional ν beams experiments must handle wrong sign neutrinos.
- Initial motivation for Baby MIND was study of charge identification of muons on a charged particle beamline at CERN.
- nuSTORM: See Wednesdays talk by Dr. Jaroslaw Pasternak (WG3)
- With nuSTORM a MIND detector could be used for sterile neutrino or oscillation measurements.

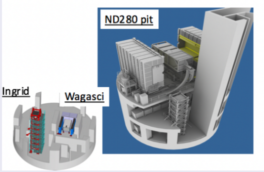


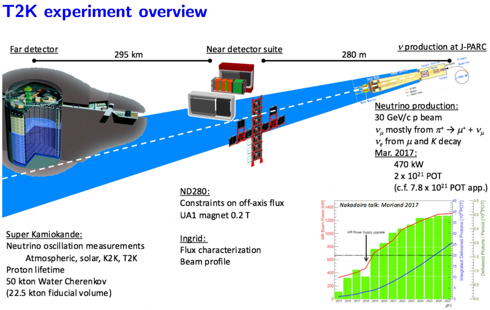


Motivation

Downstream of WAGASCI

- 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 will measure the charge and momentum of the outgoing muon from neutrino charged current interactions.
- Installation of Baby MIND detector in the ND280 pit early 2018.





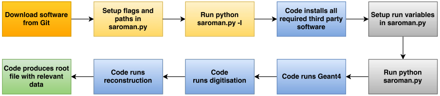
Software environment

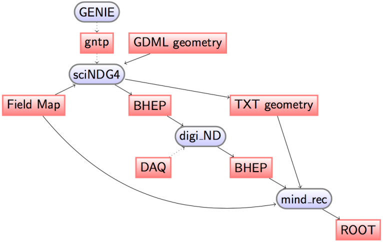
SaRoMaN

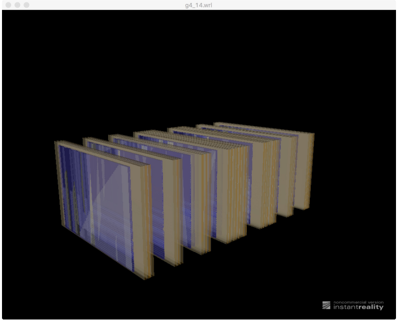
- Simulation and Reconstruction of Muons and Neutrinos
- Comprehensive software for MIND/nuSTORM simulations.
- Developed at The University of Glasgow.
- C++ with a python wrapper.

Partitioned software

- Geant 4.10/Genie 2.8.6 for simulations
- Recpack, Kalman filter and momentum reconstruction from IFIC
- Fully separable parts, can easily integrate new simulation, digitisation and reconstruction suites.
- Easily changed GDML geometry description.







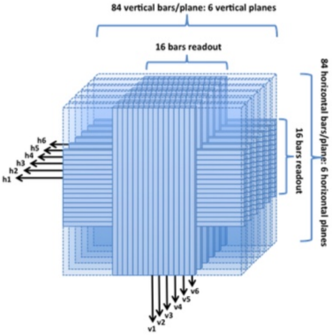
Testbeam

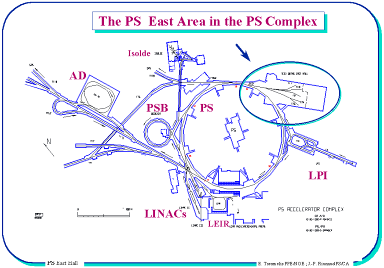
Two testbeams

- Beam tests at CERN: T9 beamline in the East Area
- 2016, characterization of the readout system, data acquisition (DAQ) and electronics with a TASD. (Totally Active Scintillator Detector)
- 2017, commissioning and characterization of the detector, magnets and analysis.

PS at CERN

- Proton Synchrotron at CERN.
- PS accelerator produces particles for the T9 beam line.
- The beam line produces a mix of hadrons and electrons and can transport either positively or negatively charged particles with momenta between 0.5 GeV and 10 GeV.





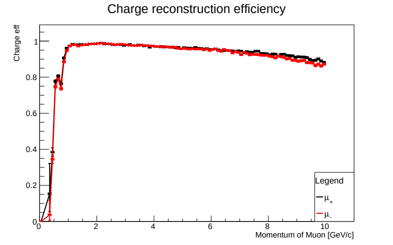
Testbeam

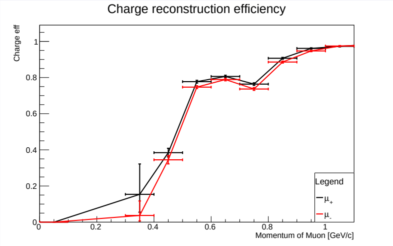
Please note

- All data shown is still preliminary. Analysis is ongoing.
- Testbeam full of pion contamination, need to try to select muons.
- Define a track as enough hits in first 4 planes, to create space points (2 per plane minimum).
- Muon-like, hits in expected planes and plane occupancy ≤ 3
- Data only taken from high momentum, also assume track hits last plane.

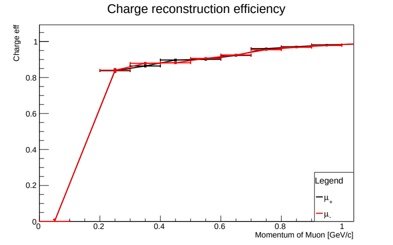
Testbeam simulations

Only Baby MIND



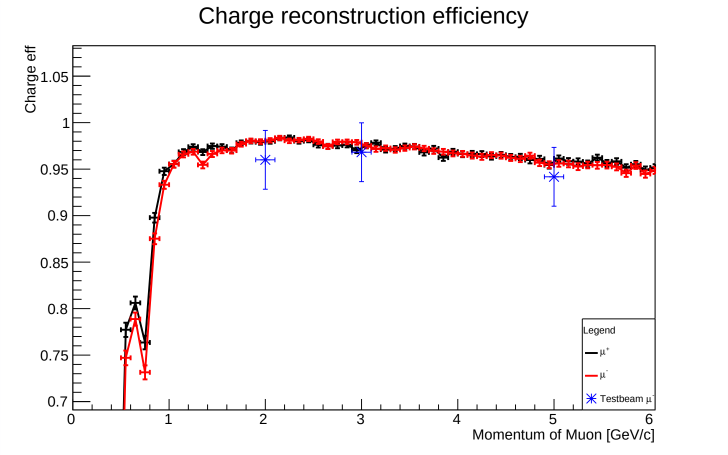


Additional position information



- Adding one position measurement before the Baby MIND.
- Showing MIND detector useful for low momentum, $\approx$ 200 MeV/c $\rightarrow$ 10 GeV/c

Testbeam data



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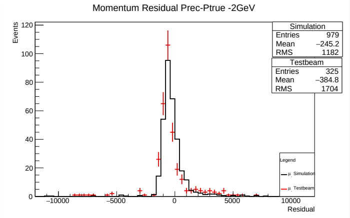
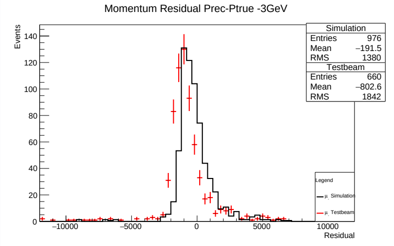
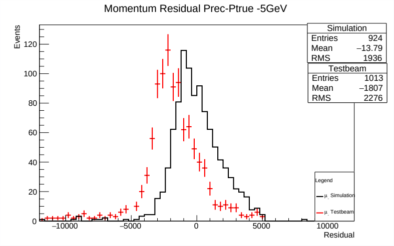
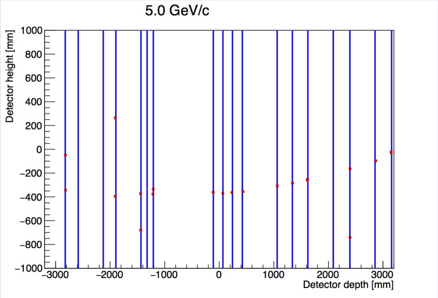
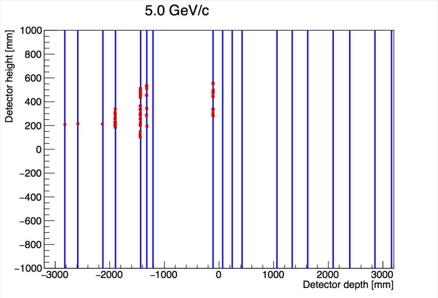






Testbeam events



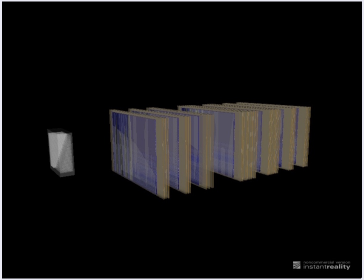


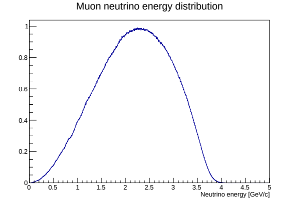
Testbeam analysis

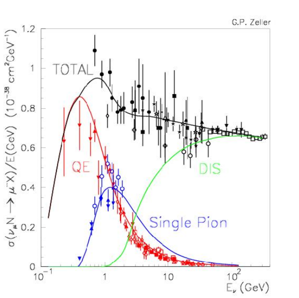
- So far data has been analysed for -2, -3 and -5 GeV/c muons.
- Data exists for range of 0.5 $\rightarrow$ 5 GeV/c for both μ^+ and μ^-
- Simulations show MIND detector useful for low momentum.
- Charge reconstruction efficiency very similar to simulations.
- Simulations have a simplified digitisation scheme, may explain difference.
- Wide distribution of momentum residual. Studies show that another Kalman filter needs to be implemented to handle the modular geometry properly.
- More analysis to follow in a/some paper/s to come.

CCQE Studies in Neutrino Detector with Baby MIND

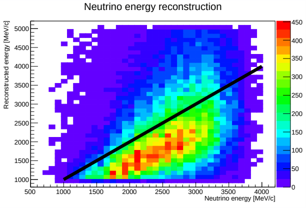
- Given the design of Baby MIND a vertex detector and/or target is needed for neutrino interaction studies.
- Simulations have been performed with our fully instrumented 1x1x1 m TASD with 84 x 84 planes.
- Currently only 6 x 6 planes have been instrumented.
- The software allows this to be changed to any target and/or vertex detector.
- $\nu_\mu + n \rightarrow \mu^- + p$
- Using a nuSTORM-like energy spectrum.
- Very preliminary.

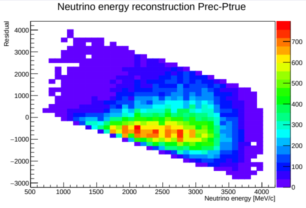


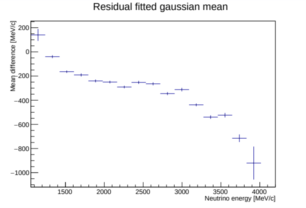


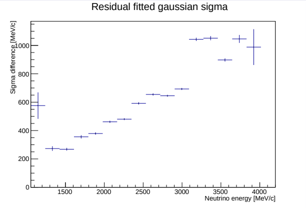


CCQE Studies in Neutrino Detector with Baby MIND









$$E_{rec} = \frac{m_n E_\mu - m_\mu^2/2}{m_n - E_\mu + |\vec{p_\mu}| \cos\theta_\mu}$$

- m_n, neutron mass.
- m_μ, E_μ, $\vec{p_\mu}$, muon mass, energy and three momentum.
- θ_μ is the scattering angle with respect to the neutrino beam direction.

Conclusion

Summary

- Installation of the Baby MIND detector at the J-PARC ND280 pit early 2018.
- Magnet modules: novel design, innovative magnetization scheme with optimal flux return, enables far greater flexibility in detector layout compared with previous designs for this type of detector.
- The CERN Neutrino Platform provided extensive support for the design, construction and testing of the Baby MIND.
- Scintillator modules: All 18 modules extensively tested and qualified with testbeam.
- Previously MINDs not considered for lower than 1 GeV/c.
- MINDs both as standalone muon spectrometer or neutrino detector.
- Baby MIND can go down to lower momentum, $\approx$ 200 MeV/c $\rightarrow$ 10 GeV/c
- Possible for near or far detector.
- Modular so it can be wrapped around any target, LAr, TPC etc...
- More data analysis in the works.
- Muon charge efficiency above 80% with additional position information full range, above 95% at 800 MeV/c for both layouts.

Acknowledgement

- We acknowledge the large contribution made by CERN through the Neutrino Platform to Baby MIND.
- We also acknowledge the funding received through the AIDA2020

Current publications

- 2017-02-03 New and Optimized Magnetization Scheme for the Baby Magnetized Iron Neutrino Detector at J-PARC
  http://ieeexplore.ieee.org/document/7842530
- 2017-04-26 Baby MIND: A magnetised spectrometer for the WAGASCI experiment
  https://arxiv.org/abs/1704.08079
- 2017-04-28 Baby MIND Experiment Construction Status
  https://arxiv.org/abs/1704.08917
- 2017-05-29 Baby MIND: A magnetized segmented neutrino detector for the WAGASCI experiment
  https://arxiv.org/abs/1705.10406

Thank you

Backup

Overall architecture and synchronization

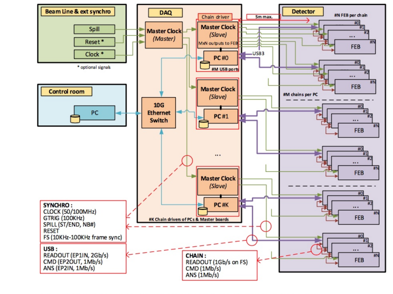
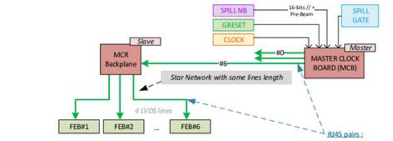


Figure 10: Overview of the Generic DAQ system for the Baby-MIND neutrino detector.



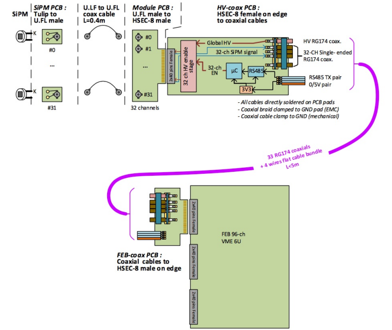


Figure 42 : SiPM to FEB Cabling details for the horizontal bars