Simulation studies of a detector for NuSTORM

Prototype Magnetised Iron Neutrino Detector

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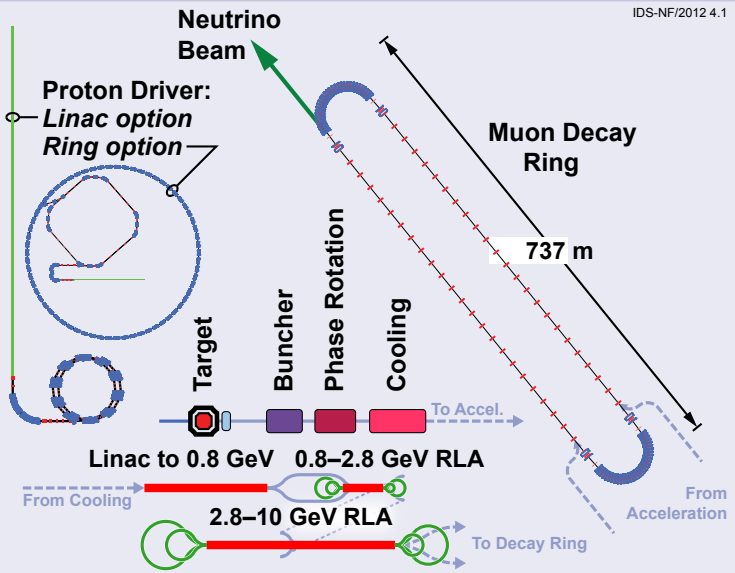
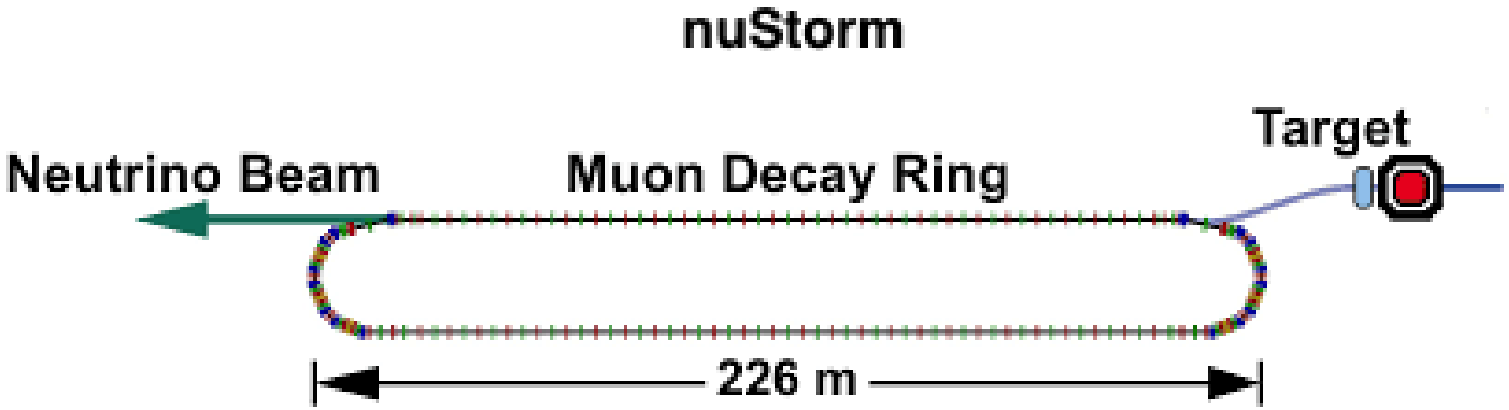
AIDA 2020

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.
- With nuSTORM a MIND detector could be used for sterile neutrino or oscillation measurements.



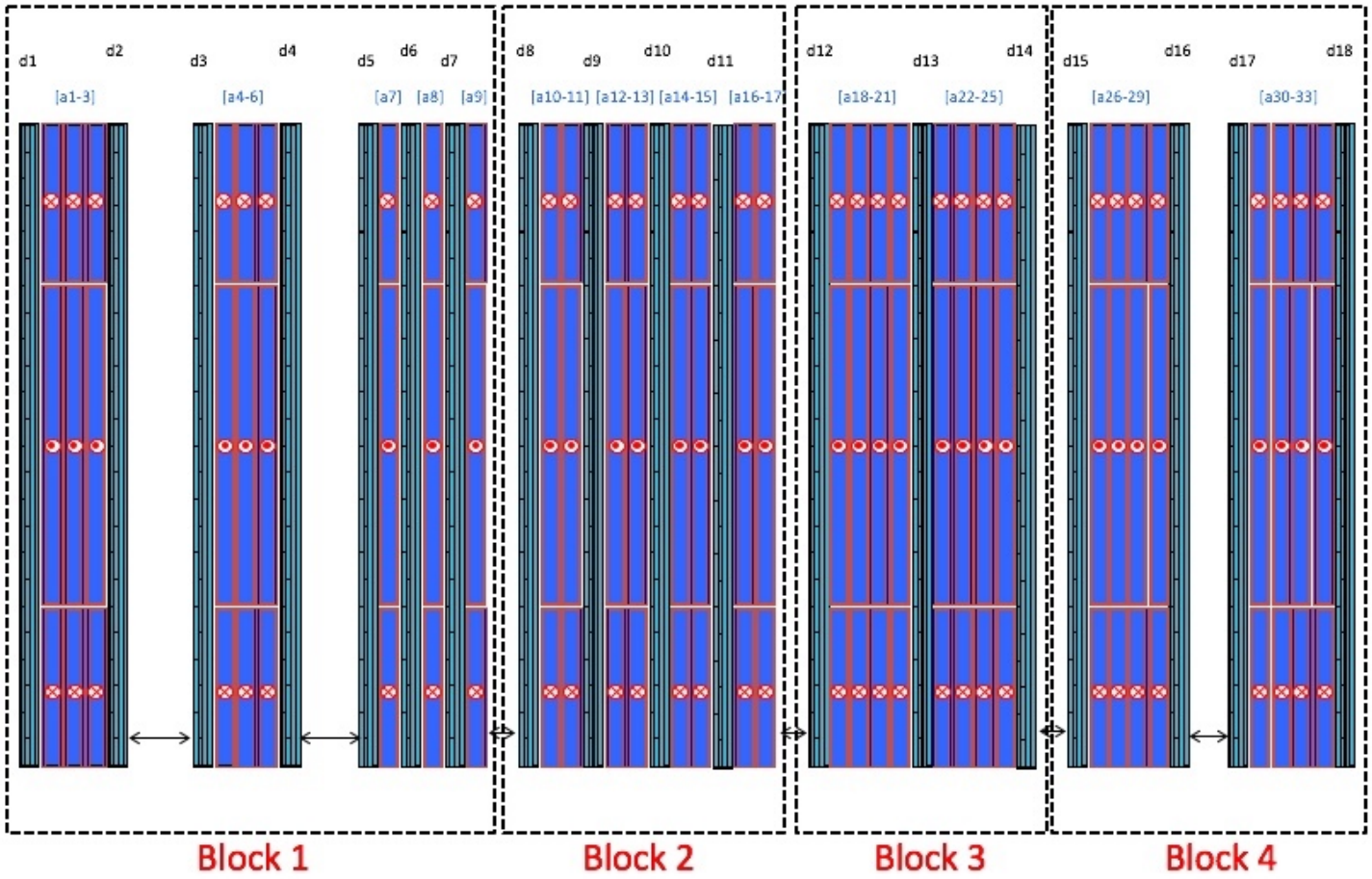


Baby MIND

- 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.

- Testbeam design, redesigned with construction and time constraints in mind.
- Charged particle beam test characterisation of Baby MIND at CERN performed June-July 2017

Baby MIND



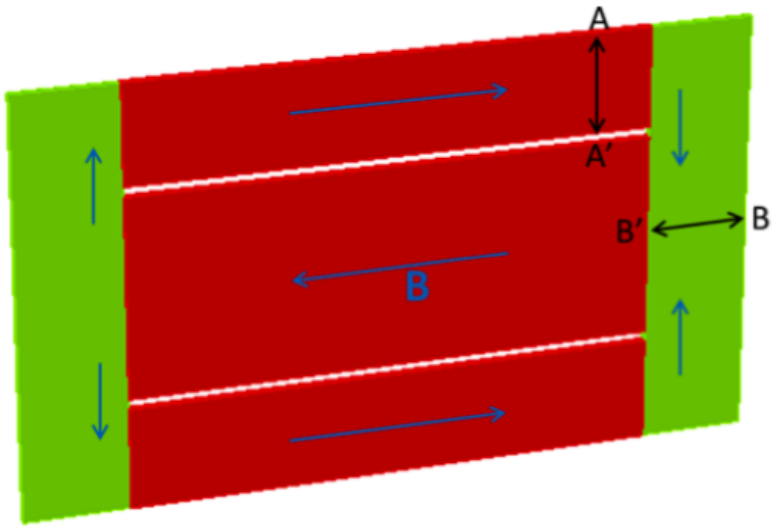
- Fully modular, novel magnetisation scheme.
- Magnet module dimensions 3500 x 2000 x 30 mm^3 (Fe)
- Scintillator module dimensions 3000 x 1950 x 30 mm^3 (CH)

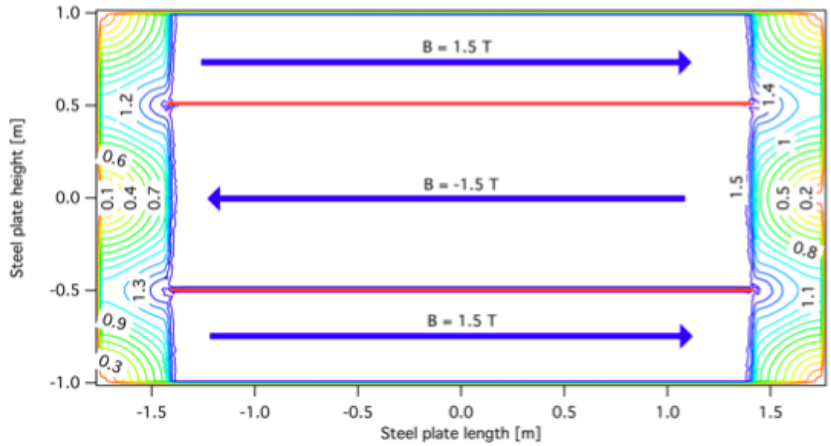
- Length $\approx 4m$
- 18 Scintillator modules.
- 33 Magnet modules.

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 $\approx$ 1.5 T for coil current $\approx$ 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)

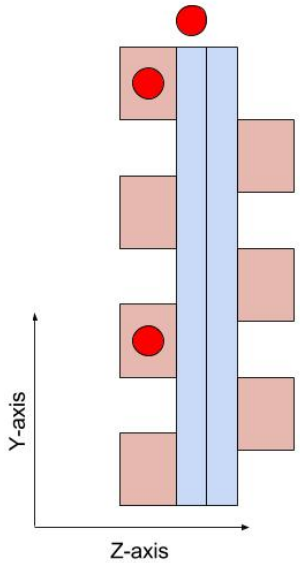


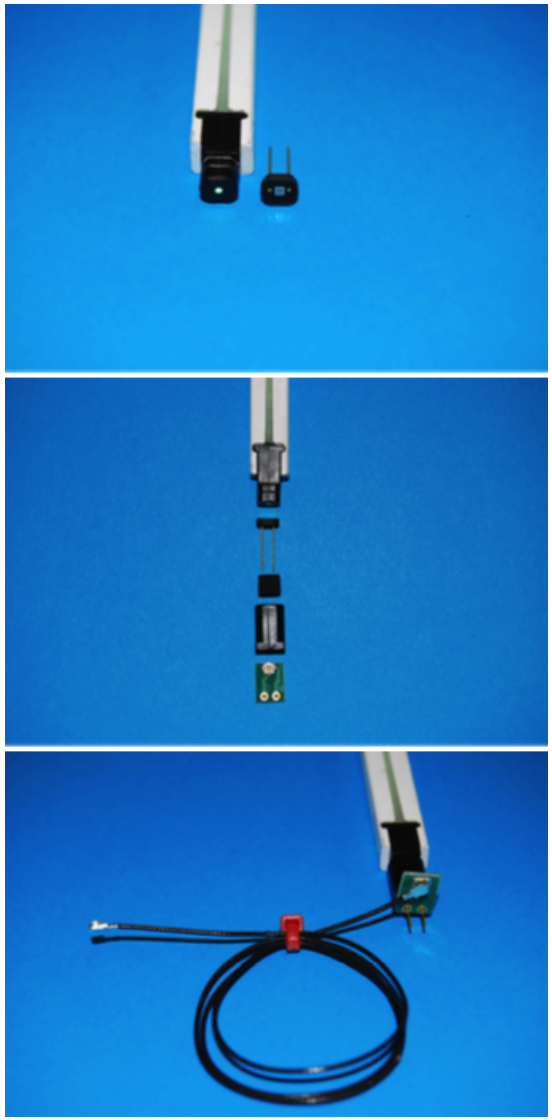


Connectivity

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 $5x10^5$
- Dark counts 100 kcps typ.





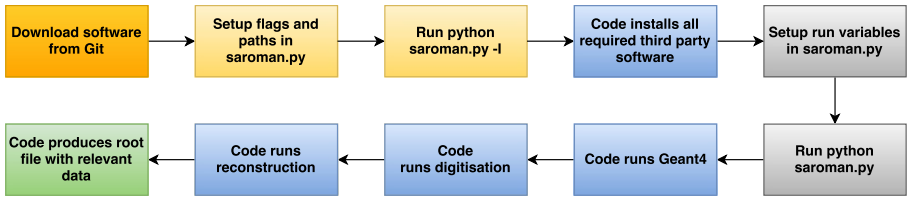
Software environment

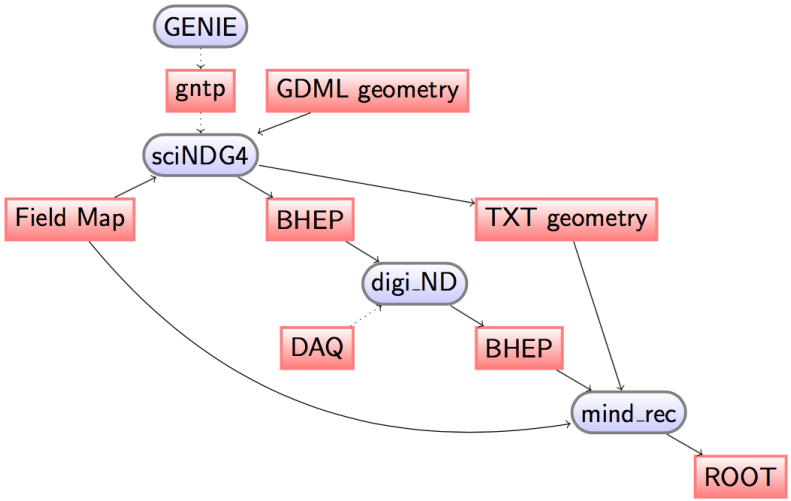
SaRoMaN

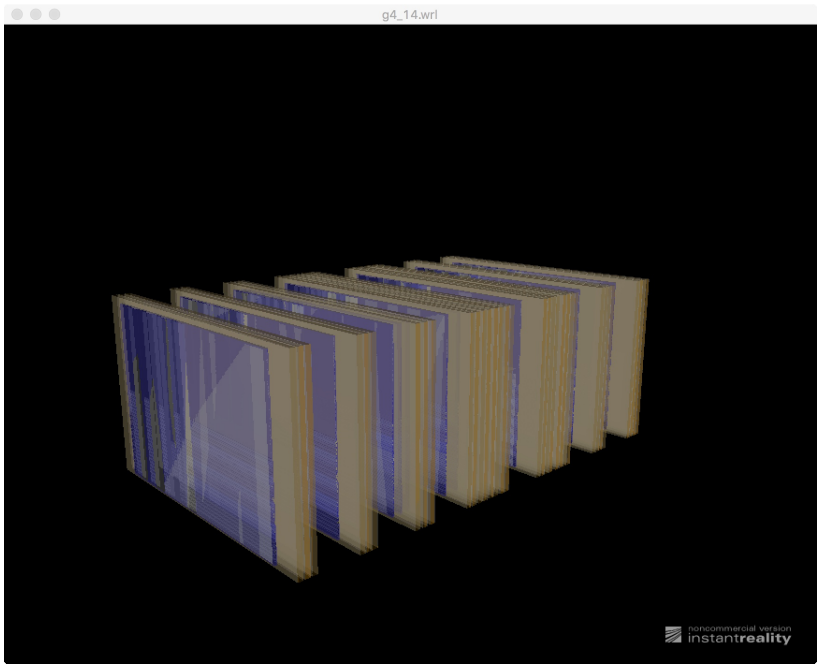
- Simulation and Reconstruction of Muons and Neutrinos
- Comprehensive software for MIND/nuSTORM simulations.
- Developed at The University of Glasgow.
- C++ with a python wrapper.

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.







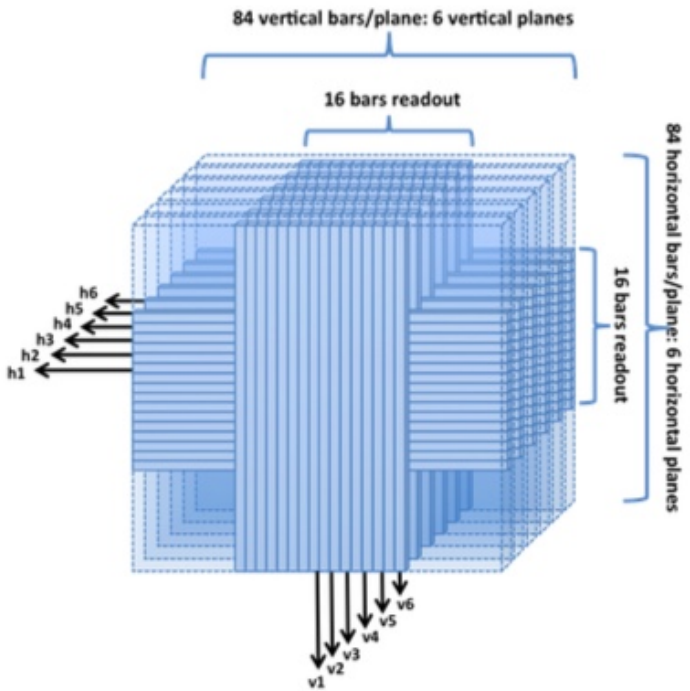
Testbeam

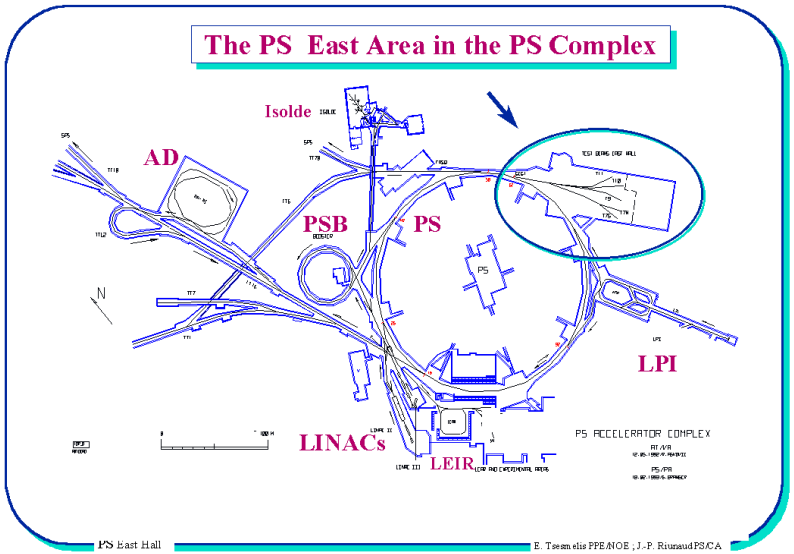
Two testbeams

- 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

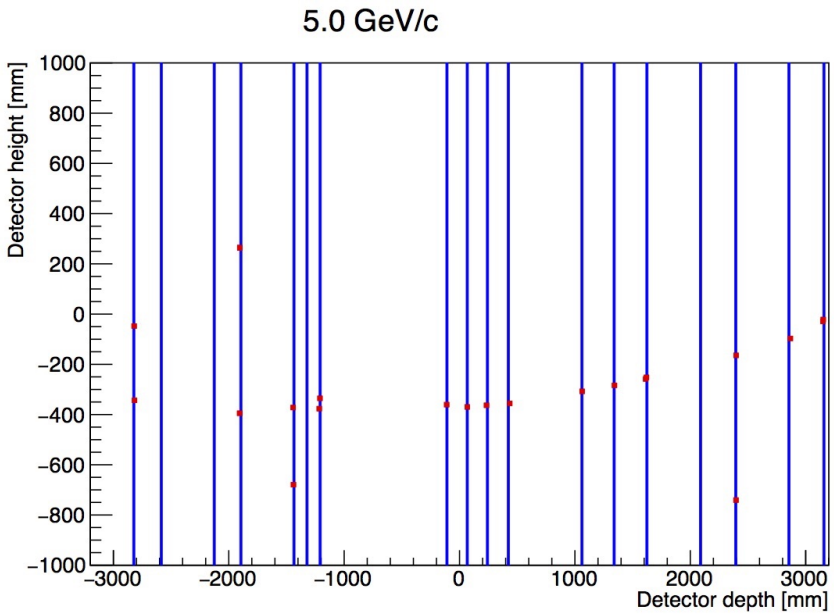
- Proton Synchrotron at CERN.
- PS accelerator produces particles for the T9 beam line.
- The beam line produces a mix of hadrons and electrons and can transport either positively or negatively charged particles with momenta between 0.5 GeV and 10 GeV.

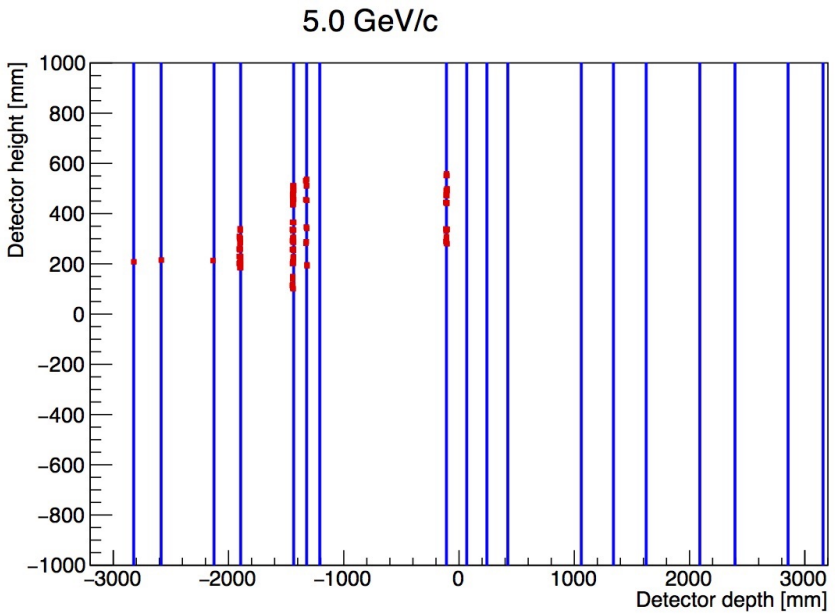




Testbeam

- More details will be provided in my thesis.
- 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
- Using TMVA to clean up muon vs background.





Testbeam initial with contamination

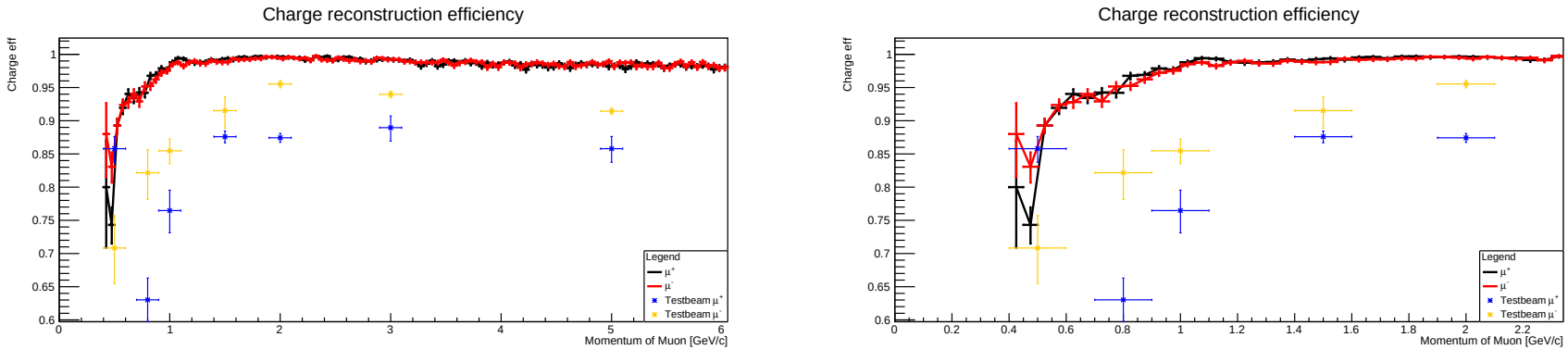


Figure: Initial charge id results

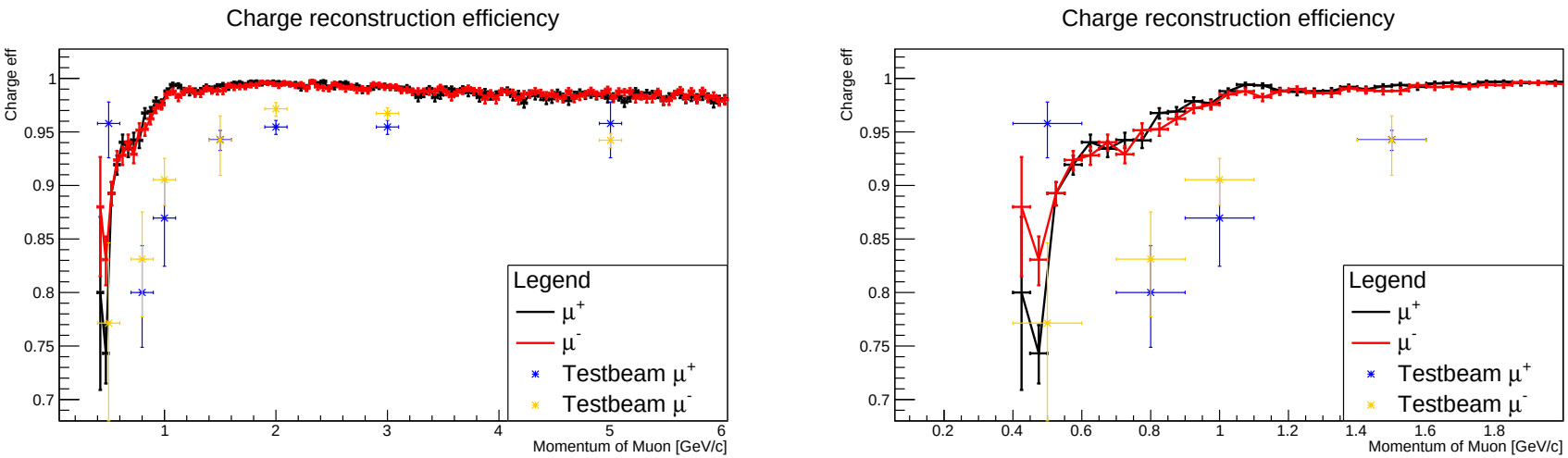


Figure: After creating a pure muon sample with TMVA

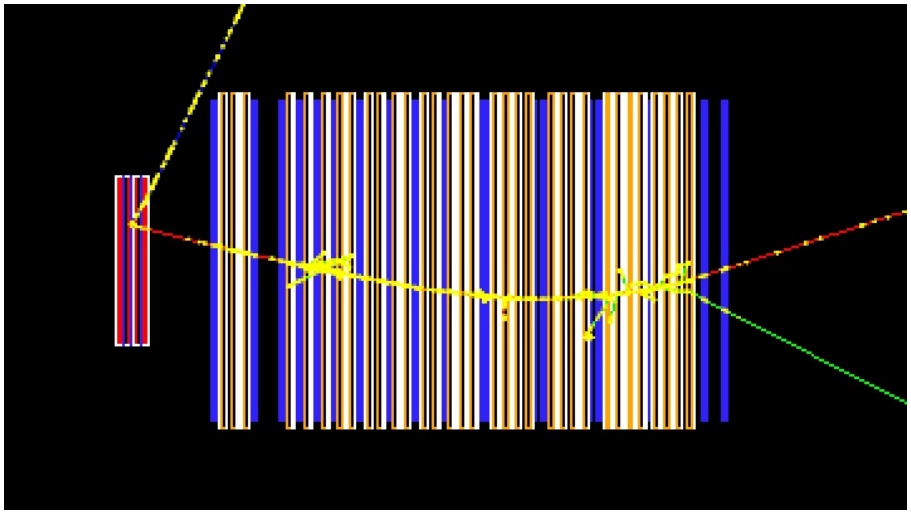
Future proofing the software environment

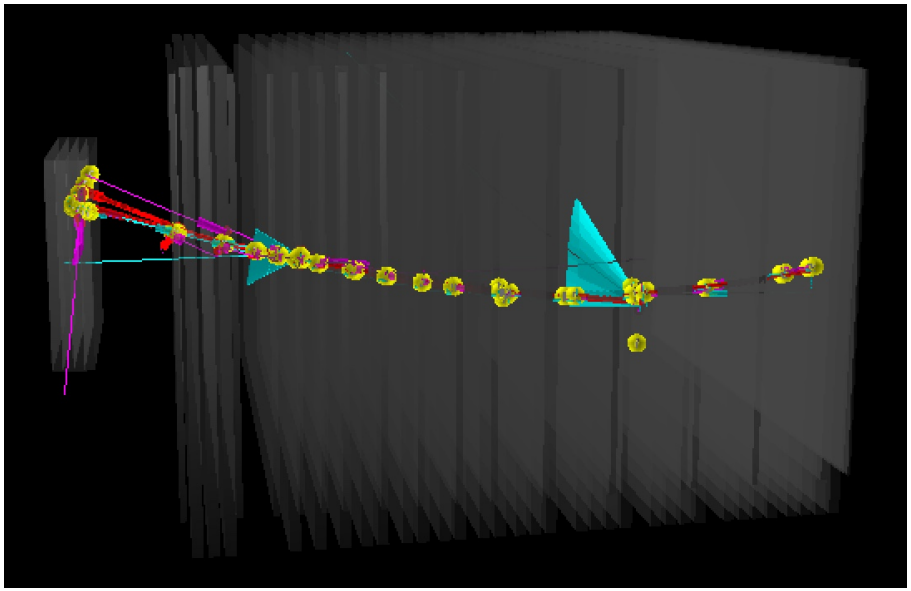
Moving up

- From Baby MIND specific to generic, can handle WAGASCI + Baby MIND.
- Required a new fitter to handle momentum reconstruction in the complex geometry.
- SaRoMaN $\rightarrow$ SAURON
- Simulation and Universal Reconstruction of Neutrinolike events.
- Developed at The University of Glasgow.

Partitioned software

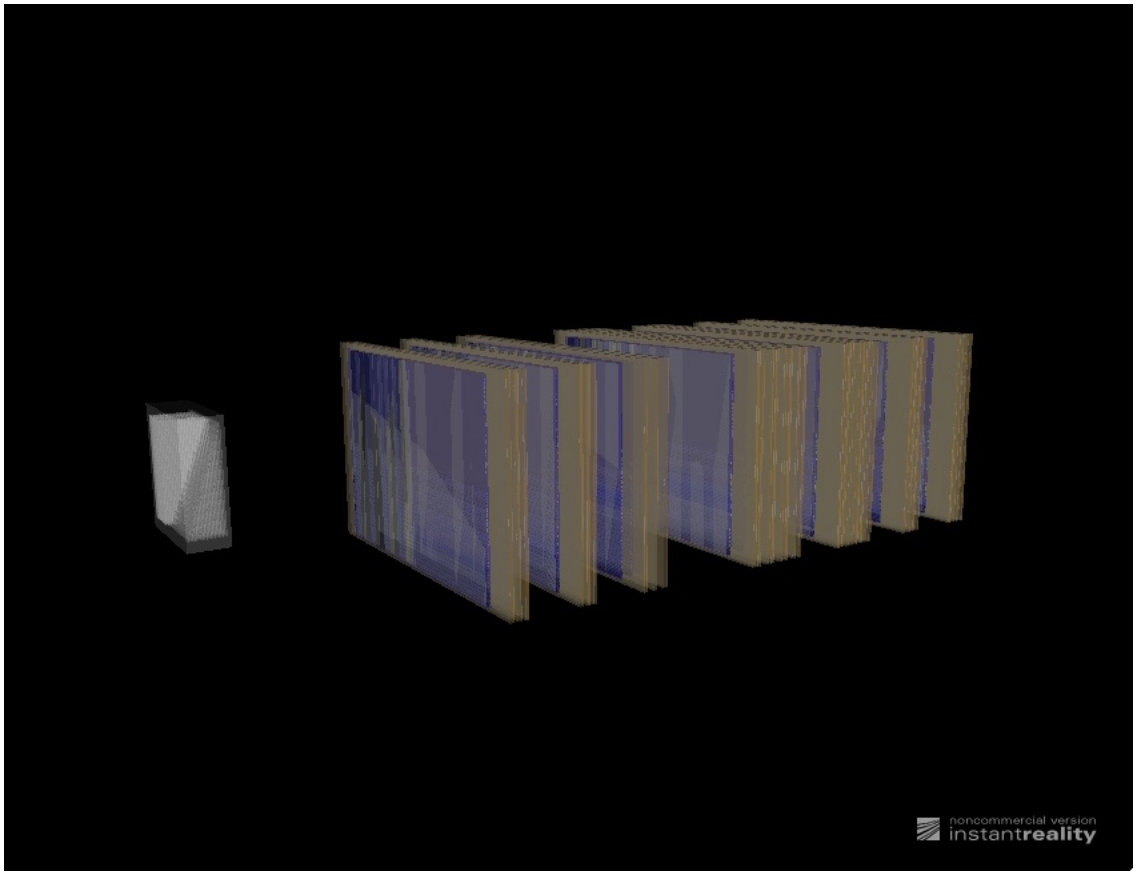
- C++ with a python wrapper.
- Using latest versions of Genie, Geant and ROOT.
- Using a new reconstruction framework based on Runge-Kutta and Kalman.
- Using GenFit package.
- Shareable using modern software techniques, git and containers (docker)



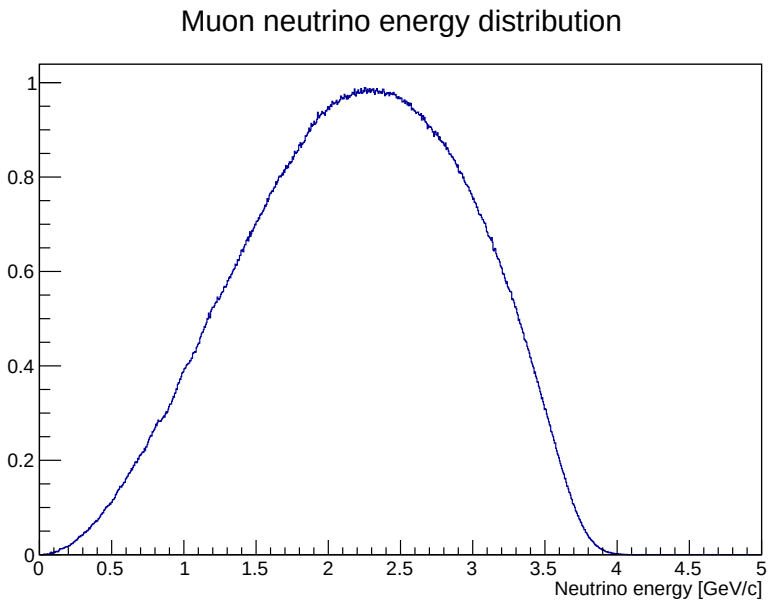


ν_μ CCQE Studies in IRON in MIND

- Interactions in TASD with MIND.
- Simulated using a NuSTORM spectrum.

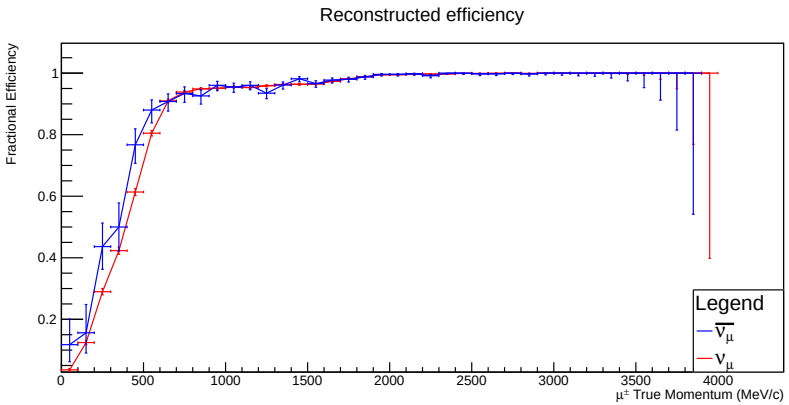


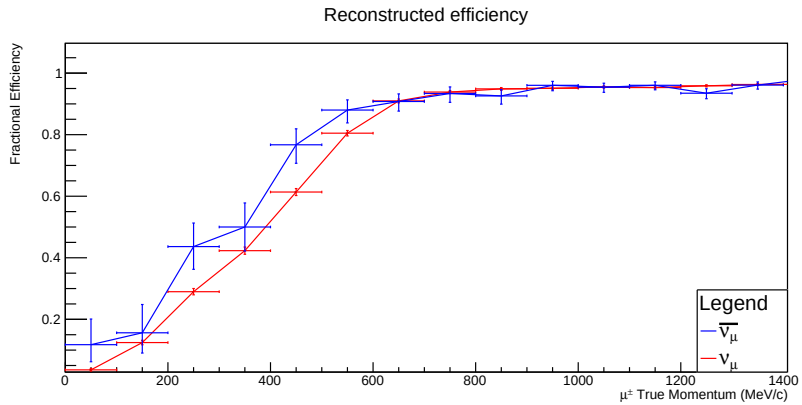
ν_μ CCQE Studies NuSTORM



- Simulations with NuSTORM beam neutrino beam spectrum.

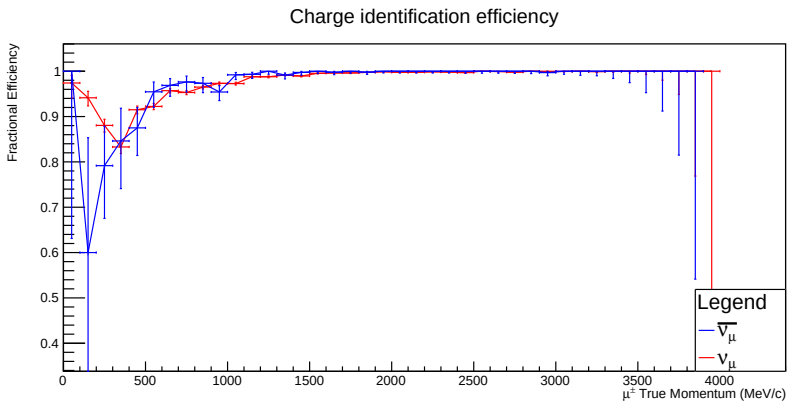
CCQE Studies NuSTORM Fitted efficiency

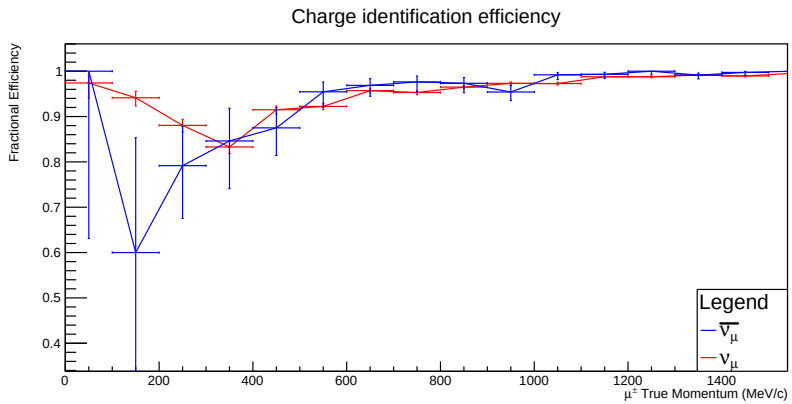




Out of all simulated neutrino interactions, what percentage of them can be reconstructed by the software?

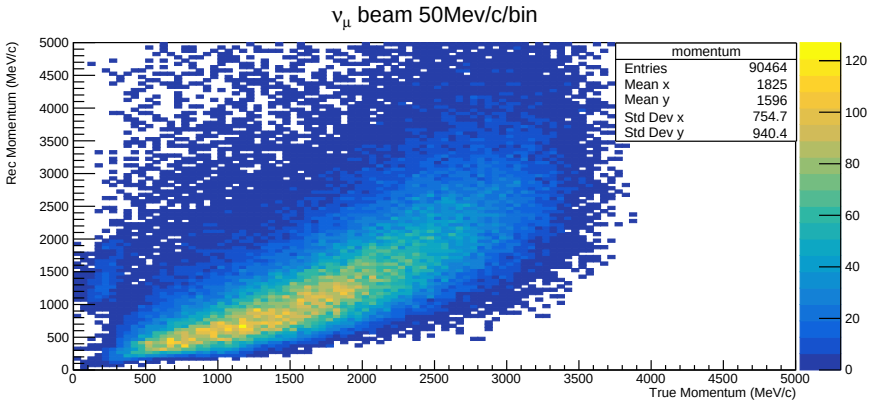
CCQE Studies NuSTORM Charge reconstruction

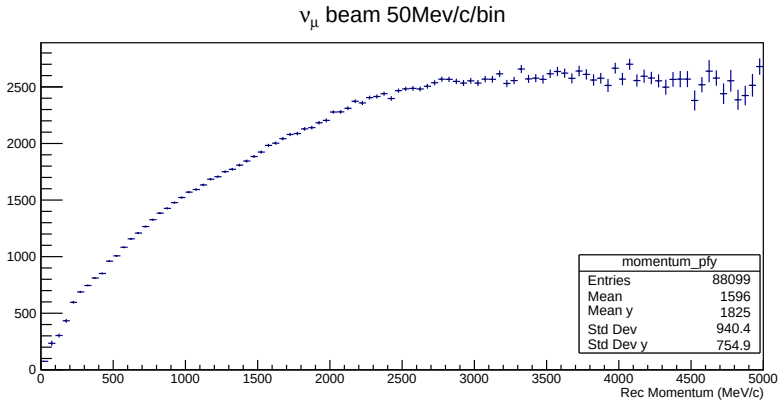




Out of all reconstructed tracks, what percentage of them can be reconstructed with the correct charge?

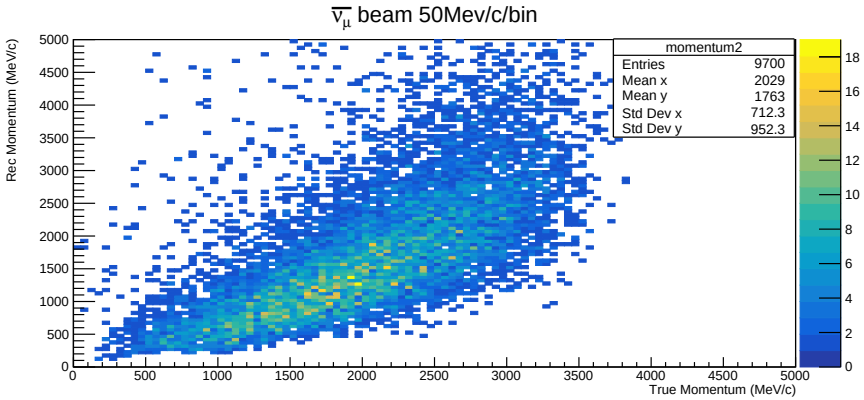
CCQE Studies NuSTORM Momentum reconstruction

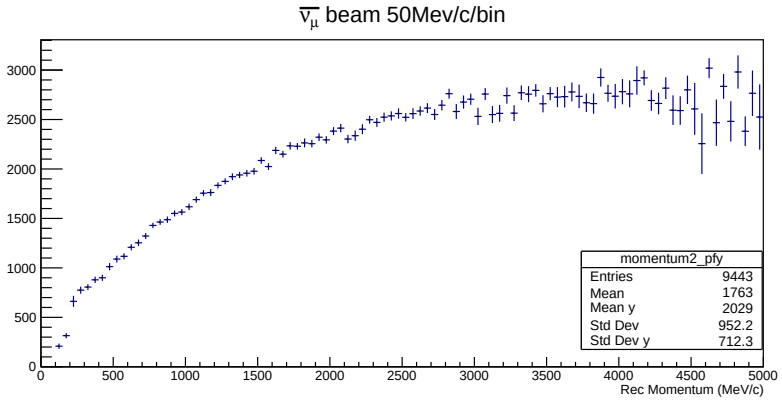




Expect very few event over 3.0 GeV, affecting the momentum reconstruction mean.

CCQE Studies NuSTORM Momentum reconstruction





Expect very few event over 3.0 GeV, affecting the momentum reconstruction mean.

Conclusion

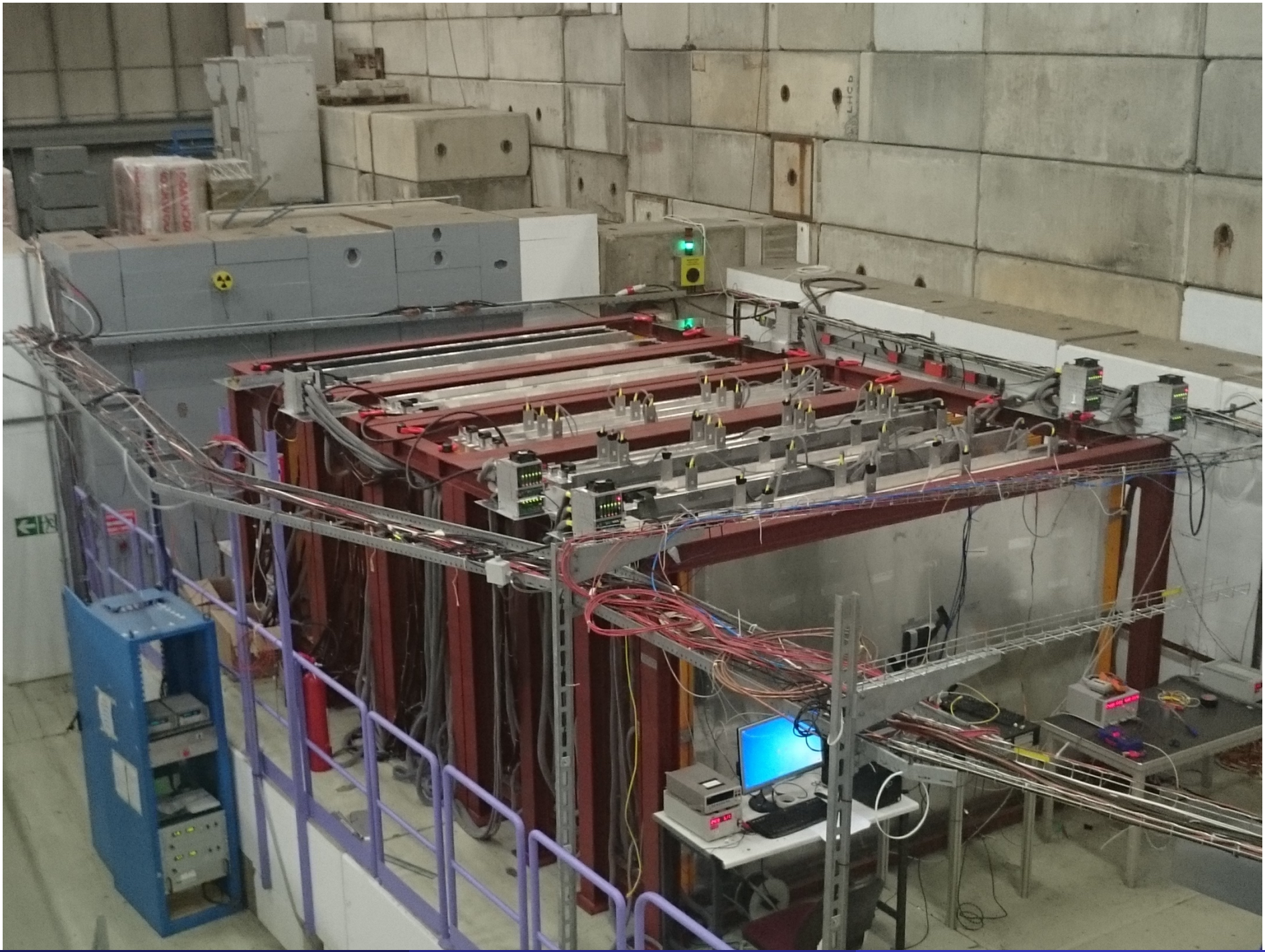
Summary

- 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.
- Baby MIND / WAGASCI aiming for combined data taking 2019

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

Backup

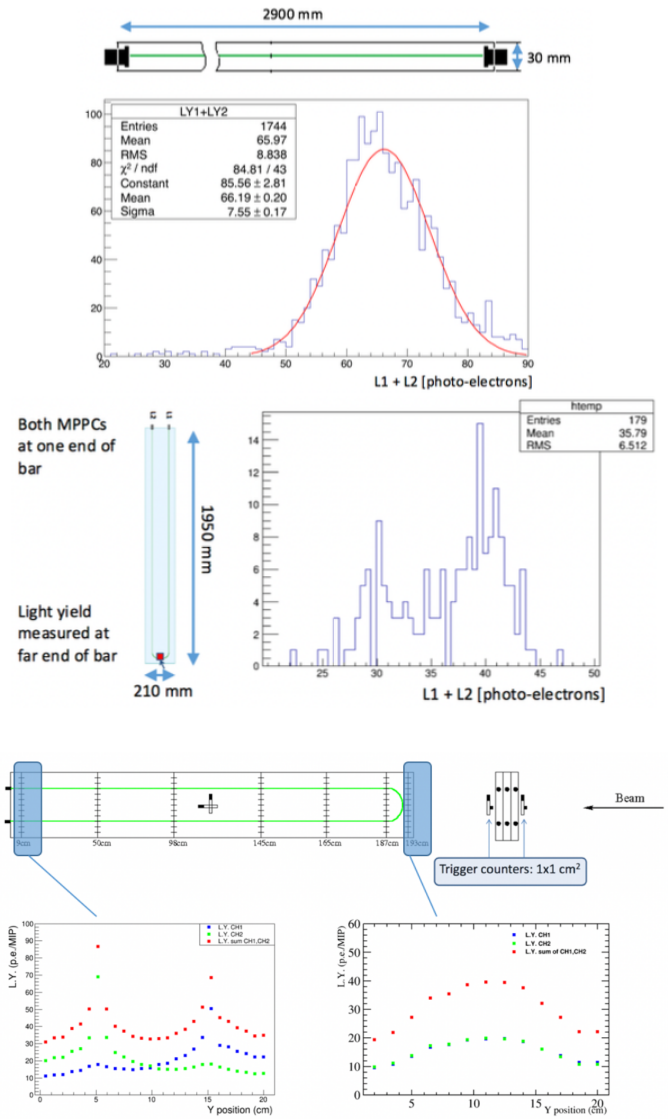


Scintillator module

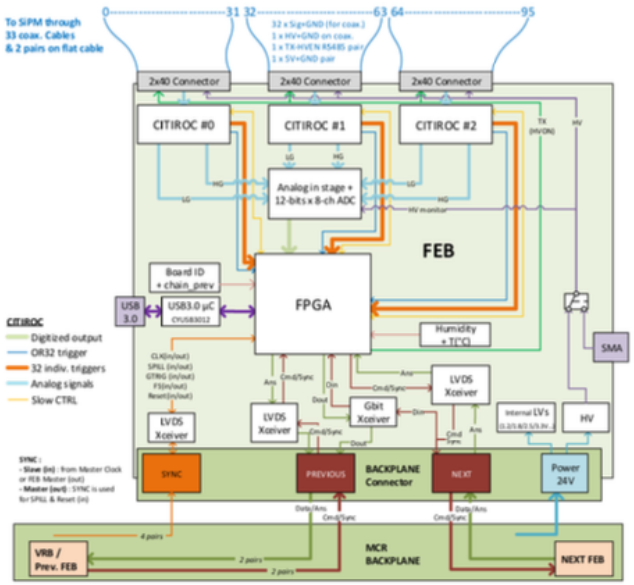
- Composed of 4 layers, 2 horizontal and 2 vertical bars
- Bars are overlapped to ensure 100% hit efficiency for minimum ionising muons and improve resolution.
- In total 95 Horizontal bars: 3000 x 31 x 7.5 mm^3
- 8 vertical bars: 1950 x 210 x 7.5 mm^3
- Scintillators held together mechanically (no glue)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



Electronics



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)