Baby MIND/WAGASCI - NuFact2018

On behalf of the Baby MIND/WAGASCI collaboration

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University of Glasgow | Experimental Particle Physics

Content

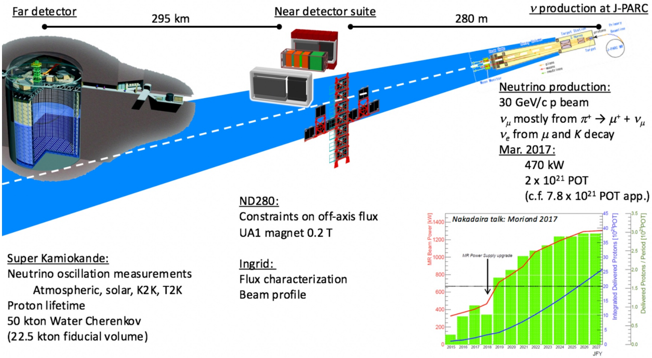
- Motivation
- **WAGASCI detector**
- Design
- **Baby MIND**
- Design
- Software environment
- Muon beam commissioning results
- **Neutrino data taking**
- WAGASCI Stand alone cross section analysis
- Preliminary neutrino CCQE results

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 654168

AIDA 2020

T2K experiment

T2K experiment overview



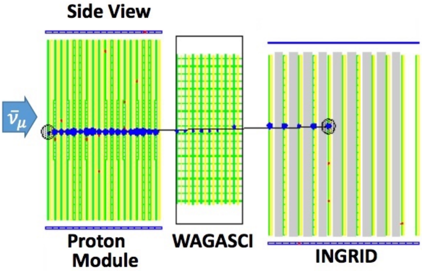
- One of the main systematic error comes from the measurement of flux and cross sections in CH and H2O.

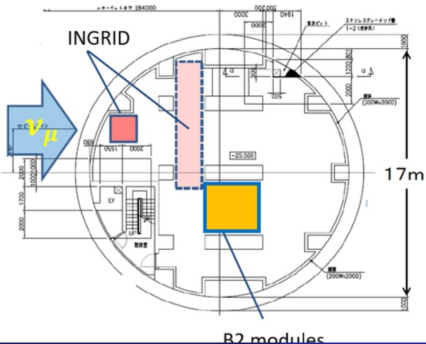
Motivation

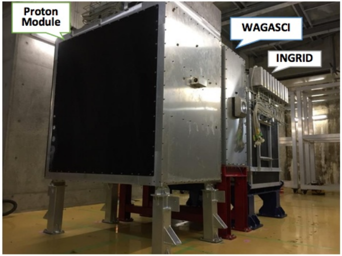
- Aiming to measure the differential cross section for charged-current (CC) interactions on H_2O and Hydrocarbon(CH).
- Hollow cuboid lattice scintillators are filled with water as the neutrino interaction target (WAGASCI module)
- Combining WAGASCI measurements with ND280 provide a model-independent extraction of the cross section.
- Similar to the TN322 on-axis experiment at J-Parc
- The Magnetised spectrometer as downstream range detector for charge selection, the so-called Baby MIND detector.
- These measurements would improve the understanding of the neutrino-nucleus interaction at around 1 GeV.
- Reducing one of the most significant sources of uncertainties of the T2K experiment.
- The collaboration will be ready to collect physics data by 2019.

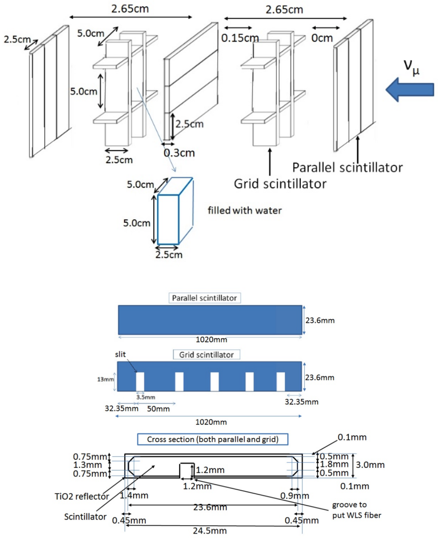
WAGASCI Detector setup

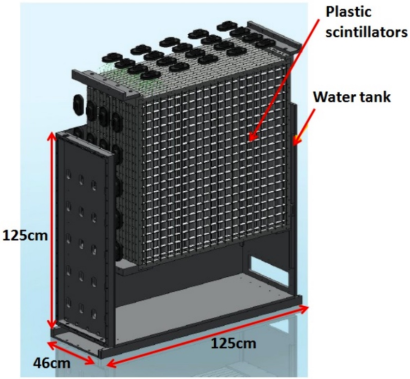
- WAter Grid And SCIntillator experiment (WAGASCI) consists of three modules in the near detector facility for T2K.
- The detector is 1.5° off-axis from the main T2K beam.
- Consists of a proton module, Hydrocarbon target.
- WAGASCI, water/scintillator target
- INGRID module, iron/scintillator target.








2.65cm
2.65cm
2.5cm
5.0cm
0.15cm
0cm
ν_μ
5.0cm
2.5cm
2.5cm
0.3cm
Parallel scintillator
Grid scintillator
5.0cm
5.0cm
2.5cm
filled with water
Parallel scintillator
23.6mm
1020mm
slit
Grid scintillator
13mm
23.6mm
3.5mm
32.35mm
32.35mm
50mm
1020mm
Cross section (both parallel and grid)
0.1mm
0.75mm
1.3mm
0.75mm
0.5mm
1.8mm
0.5mm
3.0mm
1.2mm
1.2mm
0.1mm
TiO2 reflector
1.4mm
0.9mm
23.6mm
groove to
put WLS fiber
Scintillator
0.45mm
0.45mm
24.5mm

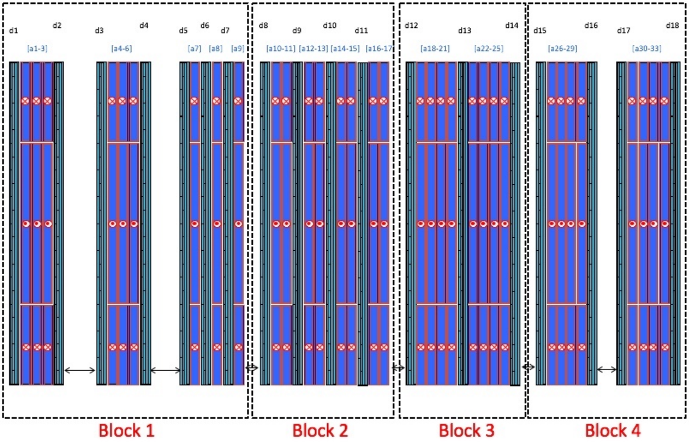

Plastic
scintillators
Water tank
125cm
125cm
46cm

Baby MIND

- Demonstration of a Magnetised Iron Neutrino Detector (MIND).
- Baby MIND a 65 t MIND at the CERN Neutrino Platform was approved as experiment NP05 in December 2015.
- Design from scratch in 3 years.
- Construction took around 1 year.
- First CERN neutrino platform experiment to see neutrinos!

- Charged particle beam test of electronics in 2016 and full system test of Baby MIND at CERN beam in June-July 2017

Baby MIND



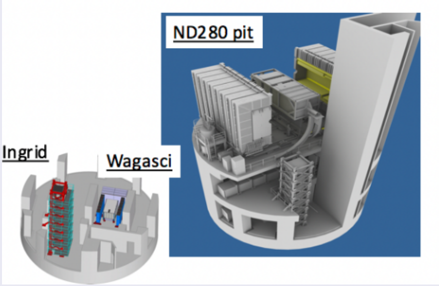
- Fully modular, novel magnetisation scheme.
- Magnet module dimensions 3500 x 2000 x 30 mm^3 (Fe)
- Scintillator module dimensions 3000 x 1950 x 30 mm^3 (CH)

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

Motivation

Baby MIND located downstream of WAGASCI

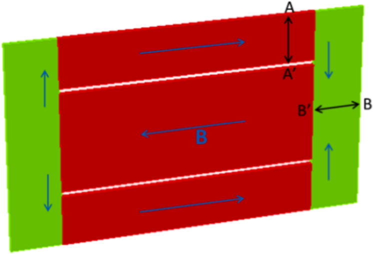
- Cross-section measurements have a large wrong sign contamination.
- Baby MIND was then found to be a good match for the downstream muon spectrometer at the WAGASCI experiment (T59) at J-PARC, using neutrinos from the T2K beamline.
- Baby MIND measures the charge and momentum of the outgoing muon from neutrino charged current interactions.
- Installation of Baby MIND detector in the ND280 pit February 2018.

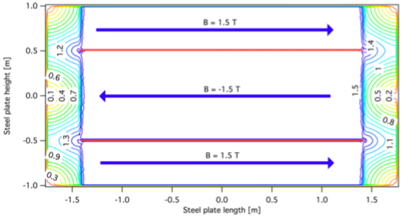


Magnetisation

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)





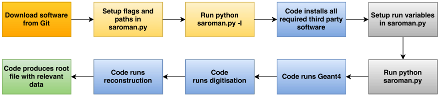
Software environment

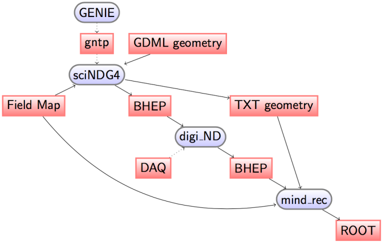
SaRoMaN

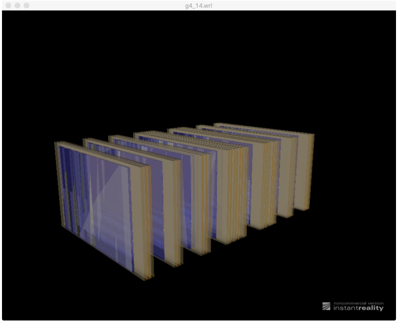
- Simulation and Reconstruction of Muons and Neutrinos
- Comprehensive software for MIND/nuSTORM simulations.
- Developed at The University of Glasgow.
- C++ with a python wrapper.

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.







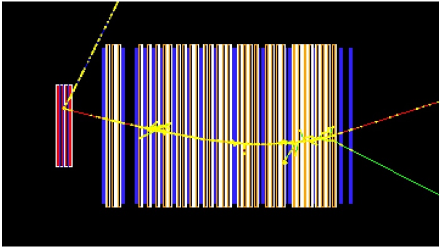
Future proofing the software environment

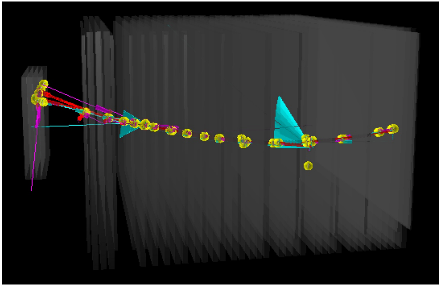
Moving up

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

Partitioned software

- C++ with a python wrapper.
- Using latest versions of Genie, Geant4 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)





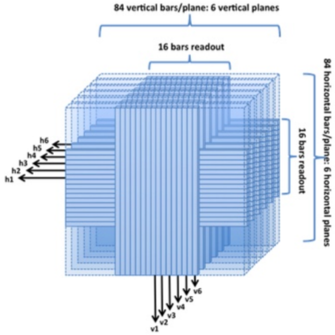
Testbeam

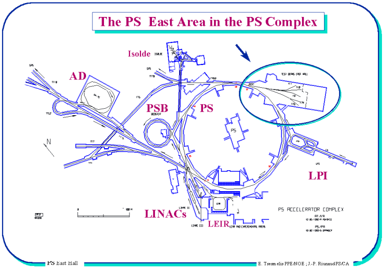
Two testbeams

- 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

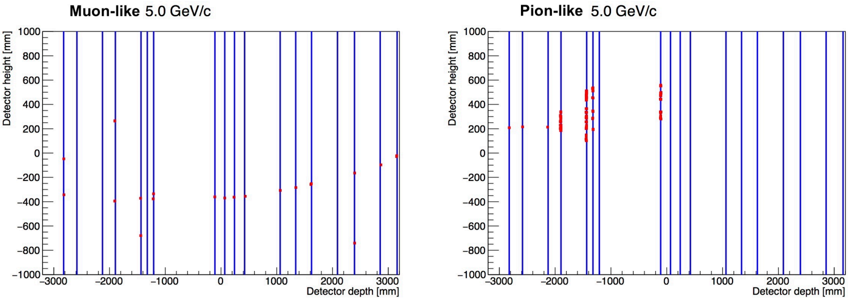
- Proton Synchrotron at CERN.
- PS accelerator produces particles for the T9 beam line.
- The beam line produces a mix of hadrons, electrons and muons and can transport either positively or negatively charged particles with momenta between 0.5 GeV and 10 GeV.





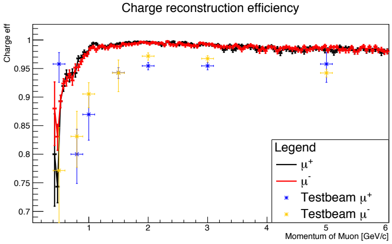
CERN T9 test beam (2017)

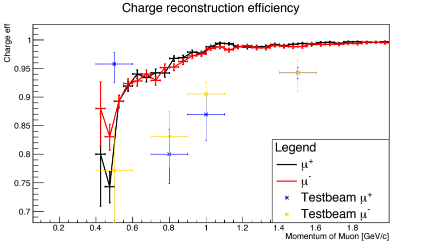
- Testbeam full of pion contamination, need to try to select muons.
- Define a track as enough hits in first 4 planes, to create space points (2 per plane minimum).
- Muon-like, hits in expected planes and plane occupancy ≤ 3
- Using machine learning techniques to clean up muon vs pion background.



Charge selection efficiency

After creating a pure muon sample with TMVA

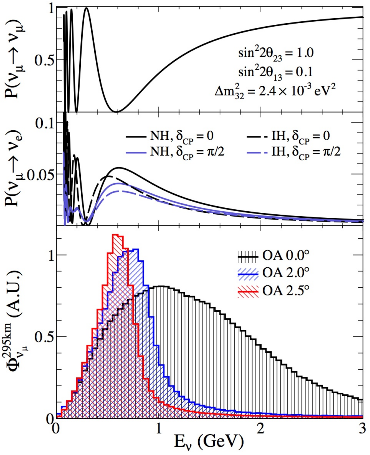


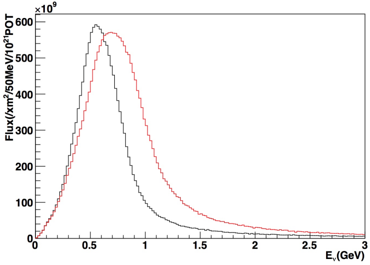


- Selection of charged particles from T9 test beam.
- Perform pion/muon separation using TMVA using 5 variables
- Number of total hits, Number of used planes,
- Number of hits used hits / number of used planes,
- Average number of hits per plane, Maximum distance between hits in an event.
- Providing data in bins of nominal momentum selected by T9 test beam.

Expected neutrino beam flux at J-PARC FHC

Forward horn current, neutrino dominant mode



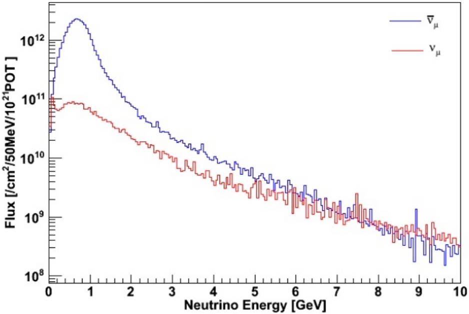


Neutrino energy spectrum for WAGASCI (red, off-axis 1.5 degree), ND280 (black, off-axis 2.5 degree). Peak energy at 1.5 degrees, 800 MeV, vs 600 MeV at 2.5 degrees

Expected neutrino beam flux RHC

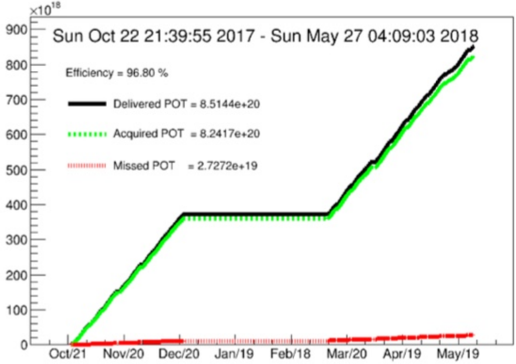
- Expected neutrino beam at WAGASCI, 1.5° off-axis.
- Reverse horn current mode anti-neutrino dominant mode.
- 280 meters from beam production.

	Mean Energy	Fraction
$\bar{\nu}_\mu$	0.86 GeV/c	92.0%
ν_μ	1.43 GeV/c	8.0%



Data taking

- Data taking with WAGASCI
- October 22, 2017 → May 27, 2018.
- Recorded 8.51×10^{20} POT
- Data taking efficiency 96.8%



Cross section analysis

Proposed measurements

- Ongoing analysis
- $\bar{\nu_\mu}$ CC inclusive interaction
- Will measure cross sections on H2O, CH, and Fe per nucleon
- σ_{H2O}, σ_{CH}, σ_{Fe}
- Will also produce cross section ratios.

Kinematic cuts

- Forward enhanced : Angle $<$ about 30° .
- Requiring momentum of produced muon 0.4 GeV/c $<$ 1 GeV/c

Analysis

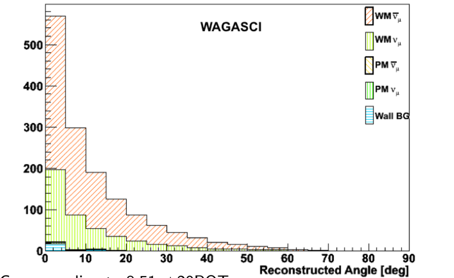
- Target: H_2O, CH, Fe
- 1.5° off-axis.
- Beam mean energy : 0.86 GeV.

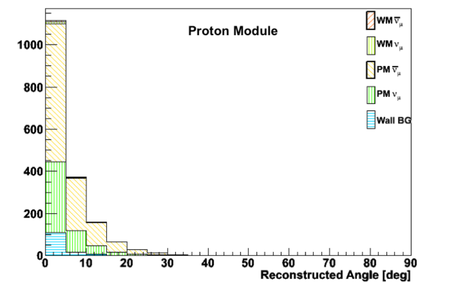
Previous analysis

- TN322: INGRID Water Module
- Target: H_2O, CH, Fe
- On-axis Beam mean energy : 1.5 GeV.

Expected Number of Events

1st Track angle (after cuts)



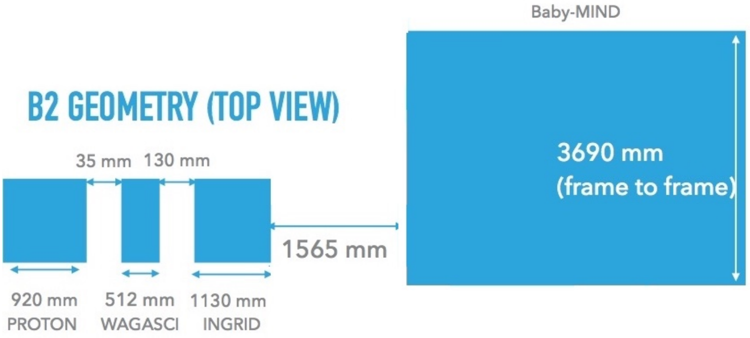


Corresponding to 8.51e+20POT

	WAGASCI	Proton Module
$\bar{\nu_\mu}$ CC	2206 (68.3%)	2387 (61.6%)
$\bar{\nu_\mu}$ NC	26 (0.8%)	20.4 (0.5%)
ν_μ	920 (28.5%)	1115 (28.8%)
Ext. BG	77 (2.4%)	350 (9.0%)
Total	3229 (100%)	3874 (100%)

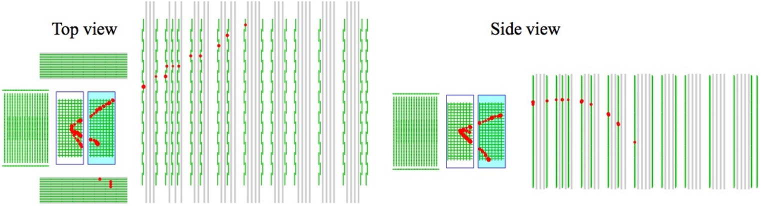
- Large wrong sign contamination still remains.
- Main motivation for using Baby MIND.
- Possible to further reduce background on proton module with harsher cuts.

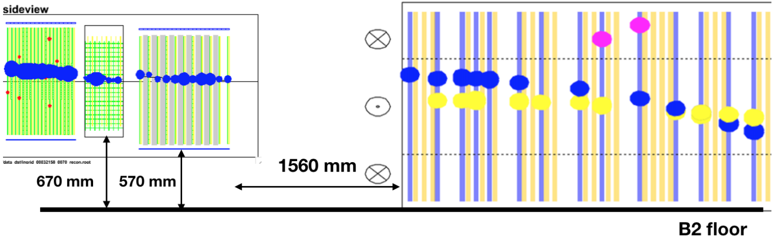
Baby MIND and WAGASCI neutrino data taking



- Future layout being studied and under discussion.
- Data taken during the 2018 run was with the full WAGASCI detector in front of the Baby MIND.
- Working on a combined neutrino analysis, currently will only show interactions in MIND.

Baby MIND and WAGASCI neutrino data taking

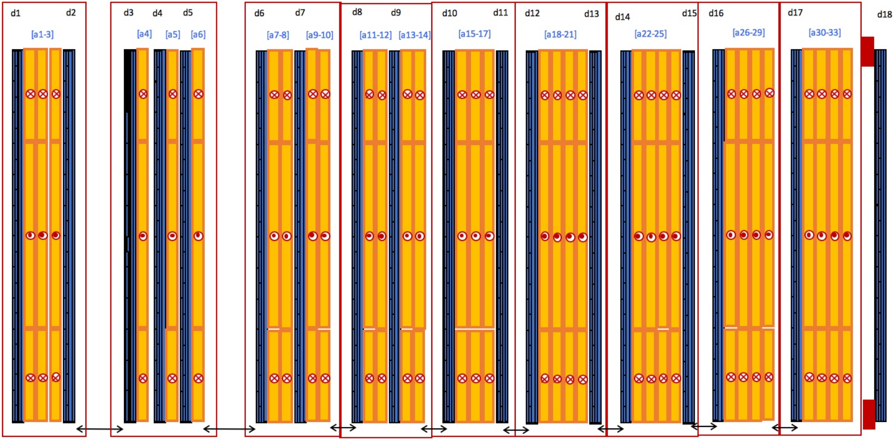




ν_μ CCQE Studies in IRON in MIND

- Will show simulated interactions in the first three iron plates (1, 2 and 3) in MIND.
- Simulated using the T2K near detector neutrino beam spectrum.
- Will also show data collected during the 2018 T2K neutrino run.

Baby MIND neutrino data

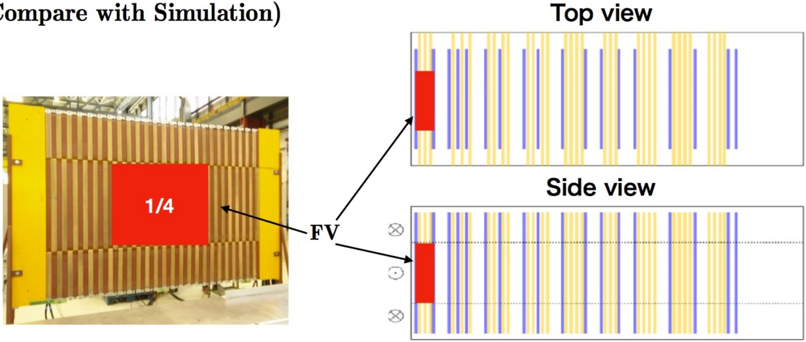


Slightly changed layout.

Event Selection

1. Fiducial Volume (FV) is defined as the central region of first three iron modules (FV cut)
2. No hit in the first module (Veto for muons from outside)
3. More than 1 hit in from 2nd to 4th scintillator modules

(Compare with Simulation)



Presented by Kenji Yasutome at International Symposium on Neutrino Frontiers

Event rate analysis

Comparison with Simulation

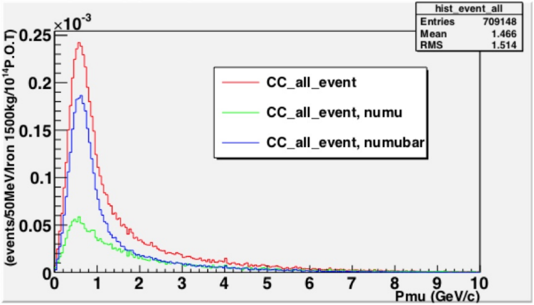
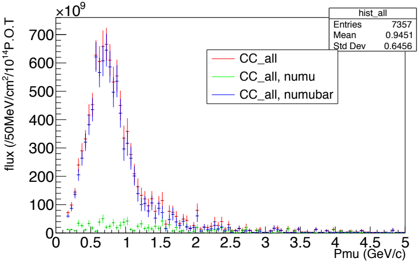


Fig. Neutrino energy distribution from simulation
Flux at 1.5 degree off-axis and NEUT for the water target were used

All events	Neutrino	Anti-Neutrino
4.366	1.458	2.908

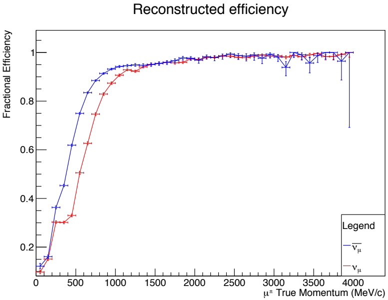
Data : 5.246 $\pm$ 0.656 (stat) **Unit : 10^4 events/Iron 1500 kg/10^{21} P.O.T.**

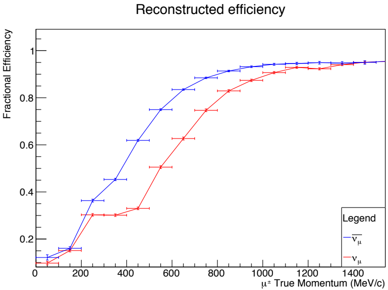
ν_μ CCQE Study



- Simulations with T2K beam near detector neutrino beam spectrum.
- Reverse horn current.
- 1.5° off-axis.
- CCQE
- $\nu_\mu + n \rightarrow \mu^- + p$
- $\bar{\nu_\mu} + p \rightarrow \mu^+ + n$
- Interactions in iron.

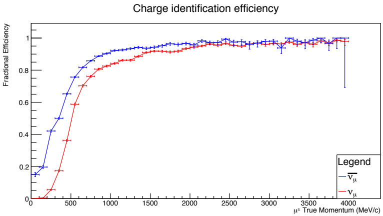
CCQE Study Fitted efficiency

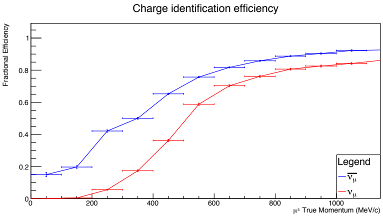




Out of all simulated neutrino interactions, what ratio of them can be reconstructed by the software?

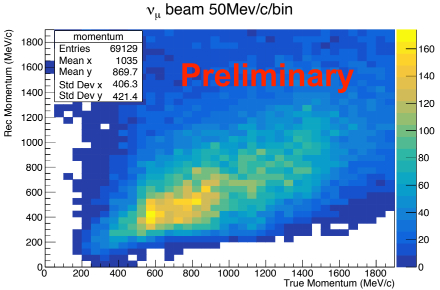
CCQE Study Charge reconstruction

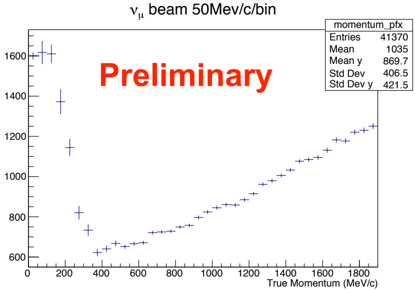




Out of all tracks, what ratio of them can be reconstructed and have the correct charge?

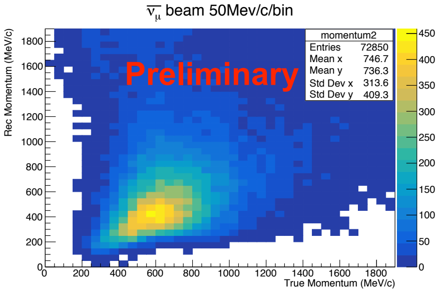
CCQE Study Momentum reconstruction

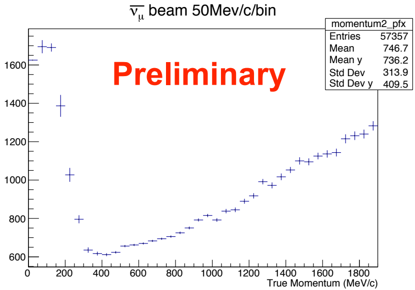




Expect few events over 1.2 GeV, affecting the momentum reconstruction mean. Reconstruction not reproducing momentum < 400 MeV

CCQE Study Momentum reconstruction





Expect few events over 0.9 GeV, affecting the momentum reconstruction mean. Reconstruction not reproducing momentum < 400 MeV

Conclusion

- Installation of the Baby MIND detector at the J-PARC ND280 pit done in 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.
- Combination of Baby MIND / WAGASCI DAQ ongoing.
- 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

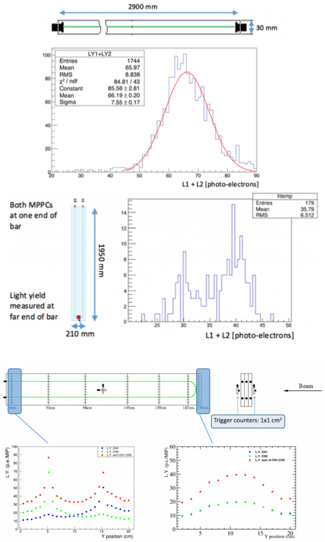
Backup

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 Moscow

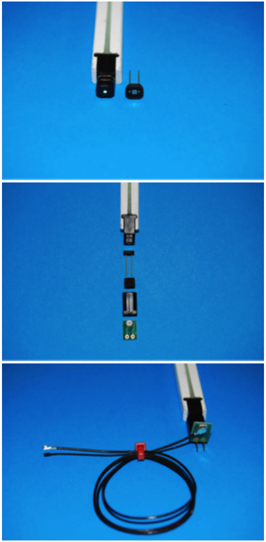
- Polysterene based, 1.5 %
- PTP, 0.01 % POPOP.
- Reflective coating 30 to 100 μm from chemical etching of surface.
- Kuraray WLS fiber (200ppm, S-type), dia 1.0 mm.
- Eljen EJ-500 optical cement.
- Custom optical connector.



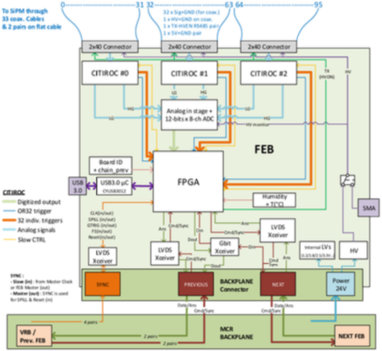
Connectivity

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 5x10^5
- Dark counts 100 kcps typical.



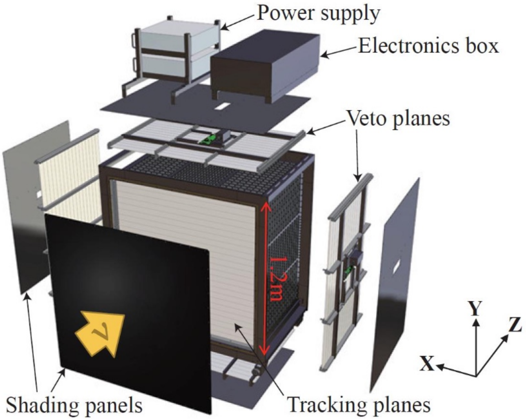
Electronics

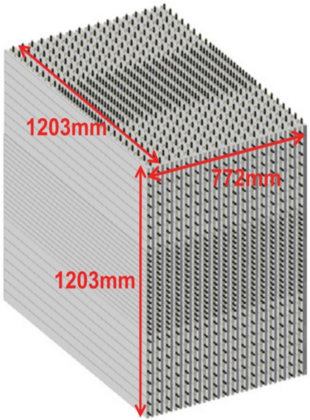


Custom-made FEB

- 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)

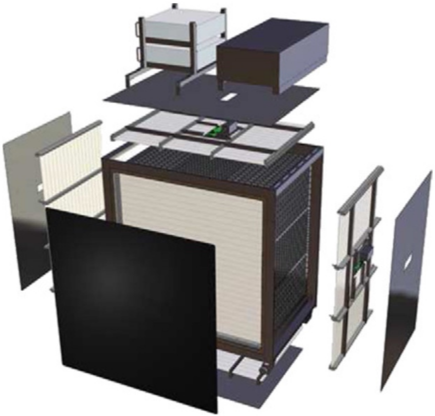
Proton module

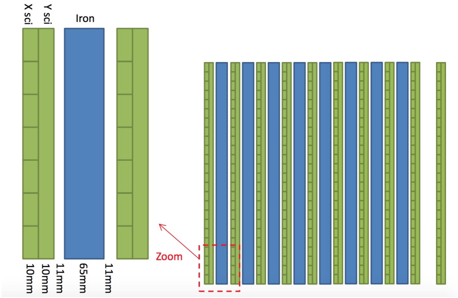




Tracking plane of Proton Module

INGRID module





Electronics

- FEB SPIROC is a 36-channel auto-triggered front-end ASIC by OMEGA/ IN2P3
- Containing analog and digital signal processing.
- Each FEB Process signals from 32 MPPC.
- Data acquisition is similar to the ILC.
- 32-channel arrayed MPPCs, as shown in the Figure 10, are used for the WAGASCI modules.
- The MPPC is a product of Hamamatsu Photonics, S13660(ES1)
- Suppressed noise rate of 6 kHz per channel at 0.5 p.e. threshold.
- We use 40 of the 32-channel arrayed MPPCs (1200 channels) in the WAGASCI module

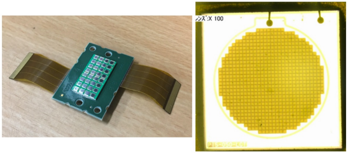


Figure 10: 32-channel arrayed MPPC (left) and an enlarged view of one MPPC channel (right).

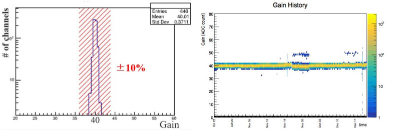


Figure 11: Typical gain distribution (left) and gain history from October 2017 to December 2017 (gains are set to 40 ADC counts) in the WAGASCI module.

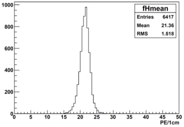


Figure 18: Typical light yield of scintillators in the Proton Module.

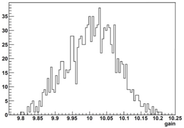


Figure 19: Calibrated gains of MPPCs in the Proton Module.