Simulation and commissioning of the full-setup of the WAGASCI experiment at J-PARC

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on behalf of the WAGASCI & BabyMIND collaboration

2018 7/16-19 International Symposium On Neutrino Frontiers
@ICISE center, Quy Nhon, Vietnam

OUTLINE

- Overview of T2K experiment
- Overview of WAGASCI project
- Result of commissioning run in 2018 Mar - May
- Simulation study for 2019 physics run

Overview

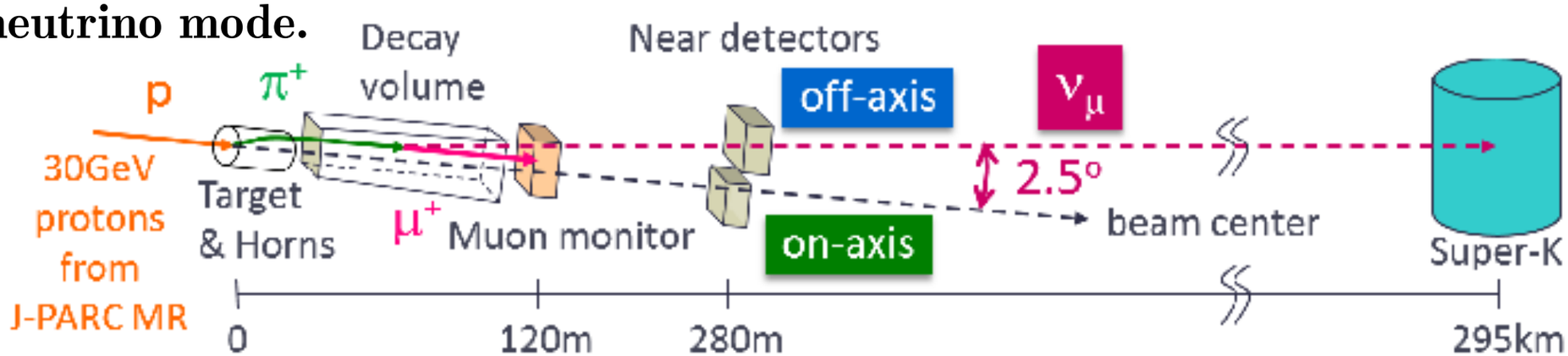
T2K experiment & WAGASCI project

OVERVIEW OF T2K EXPERIMENT

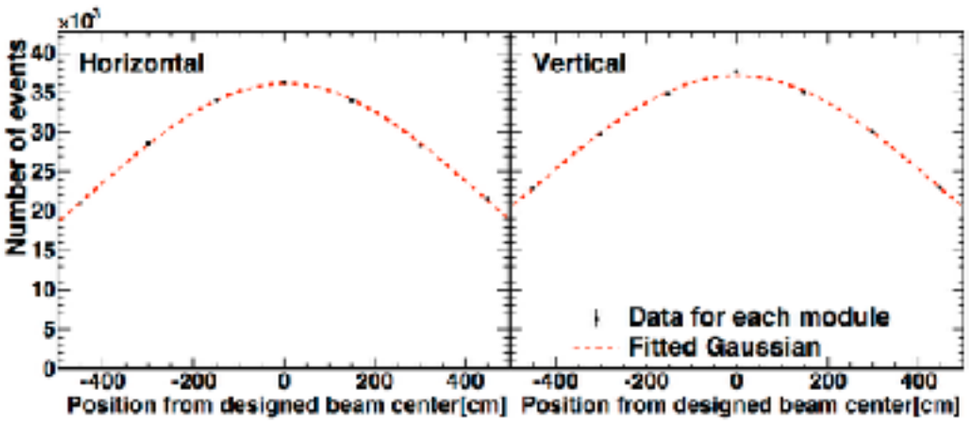
Physics goal : Measure oscillation parameters

Discover CP violation in the lepton sector

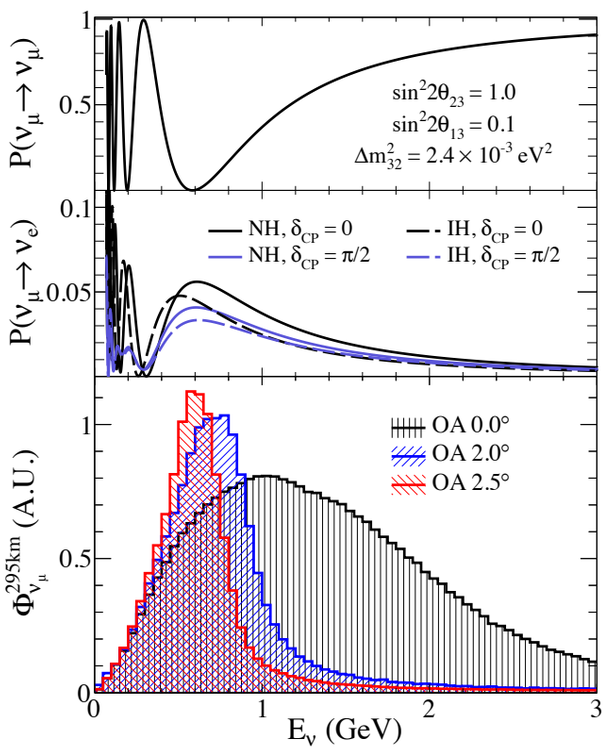
π+ (π-) is focused for (anti-)neutrino mode.



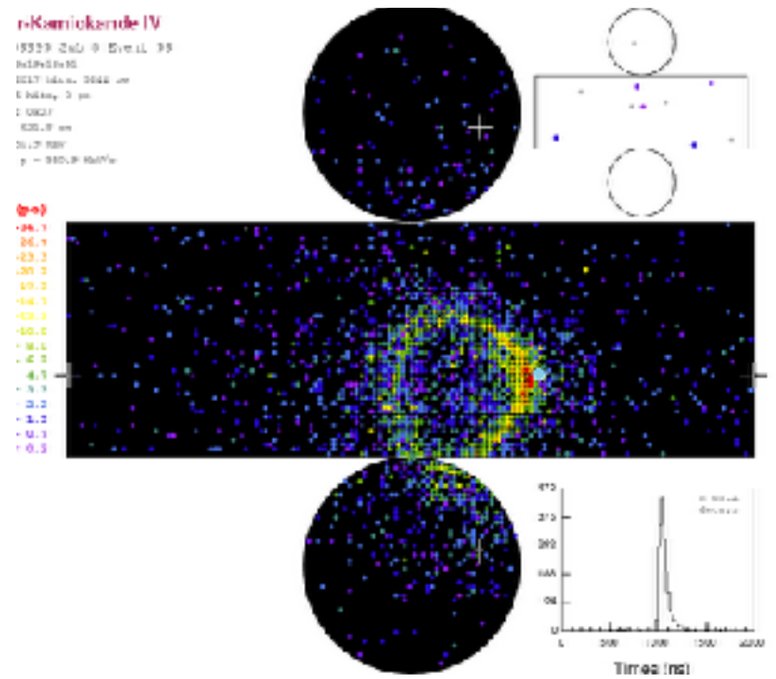
On-axis measurement



Off-axis method

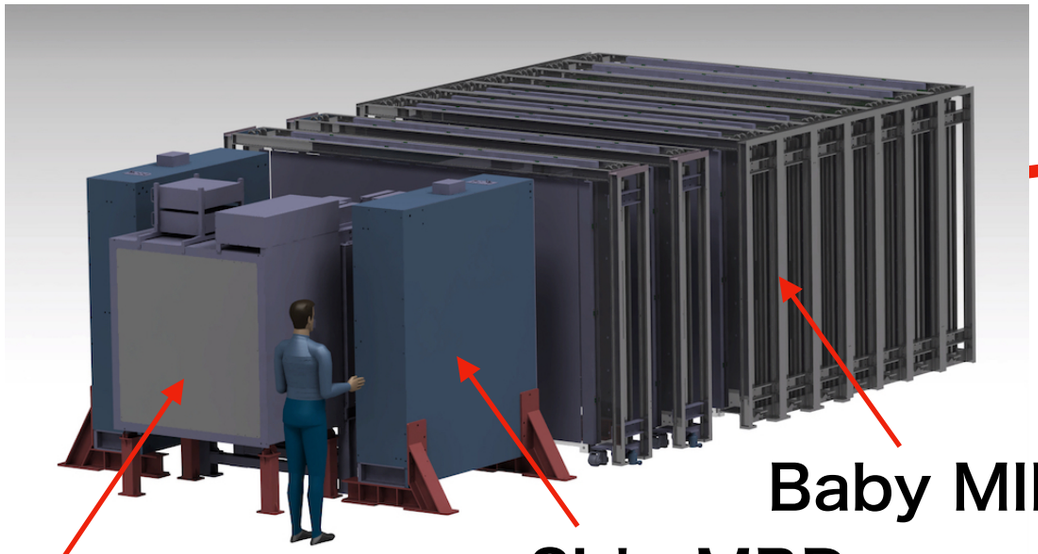


Detect neutrino



WAGASCI PROJECT OVERVIEW

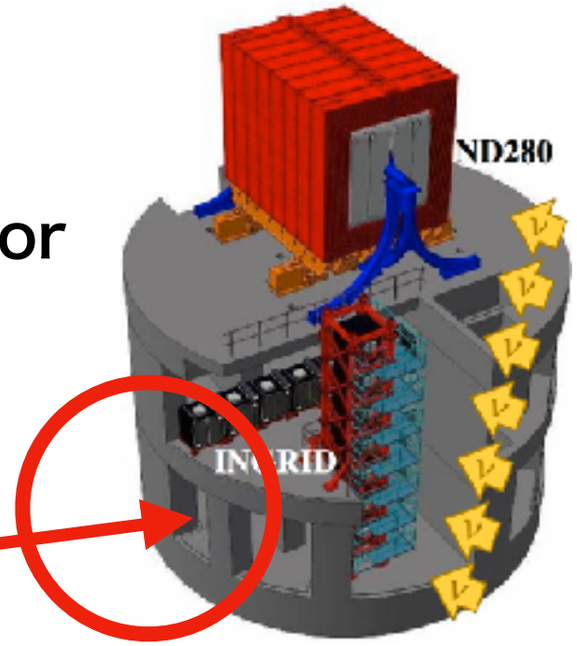
Configuration Plan

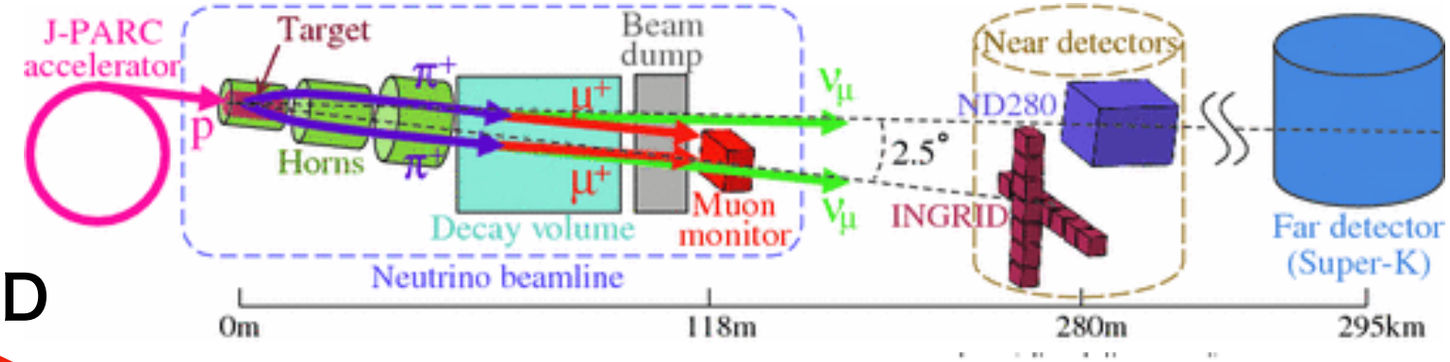


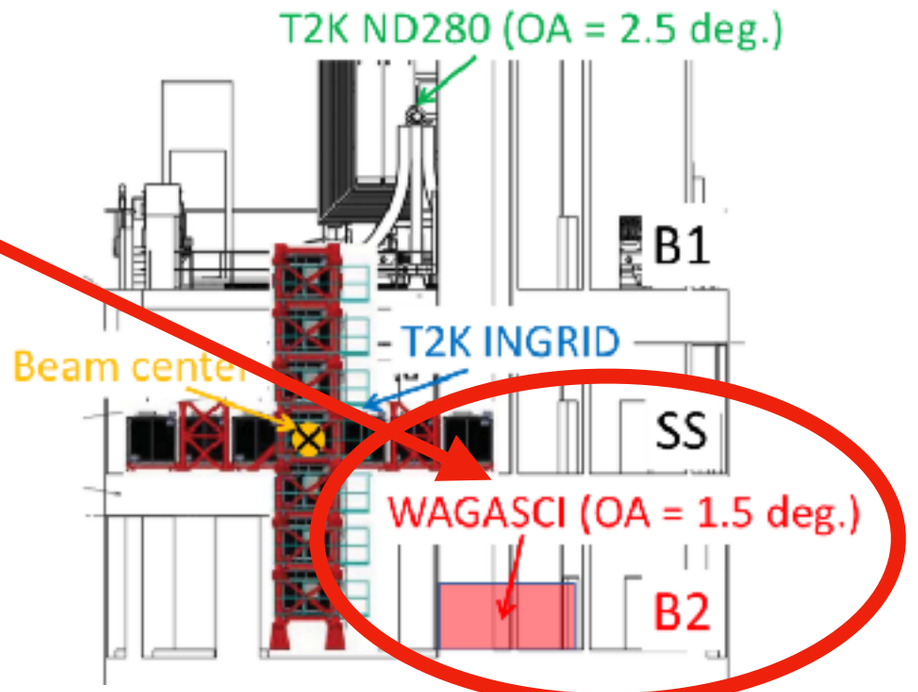
More later about detectors

WAGASCI detectors are located
at 1.5 degree off-axis
while ND280 located at 2.5 degree off-axis.

T2K Near Detector







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WAGASCI PROJECT OVERVIEW

Motivation

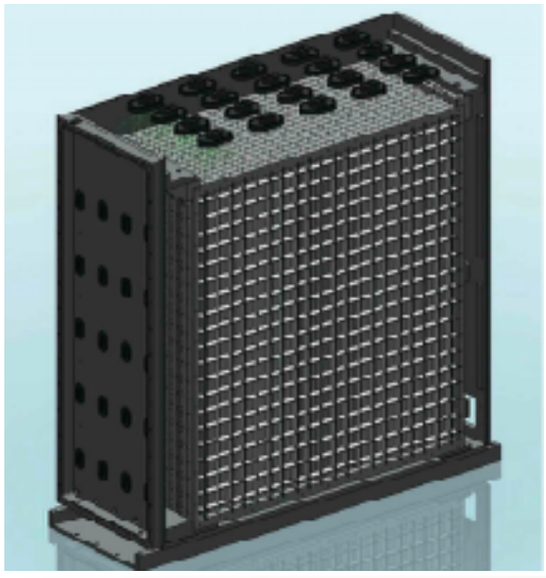
- Reduce the systematic error by measuring neutrino-nucleus interaction of neutrinos with less than 1 GeV energy.

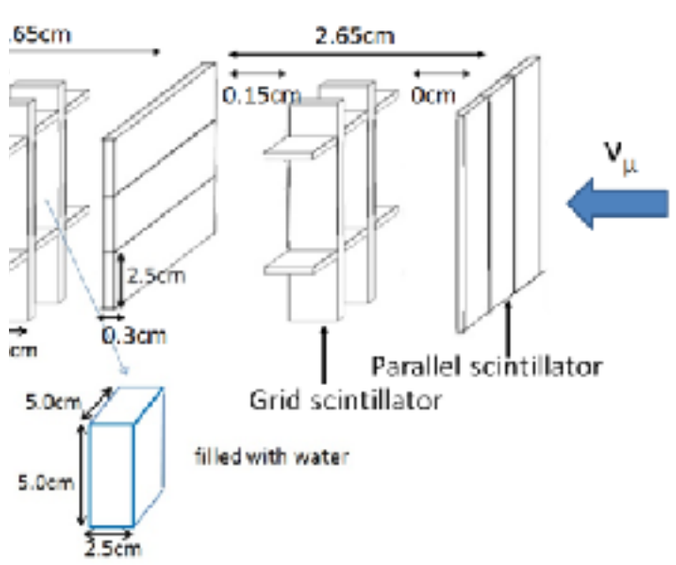
Current T2K Sys. error

- Total ~5%
- SK detector ~2%
- Flux & cross section ~ 3%
- Other 2%

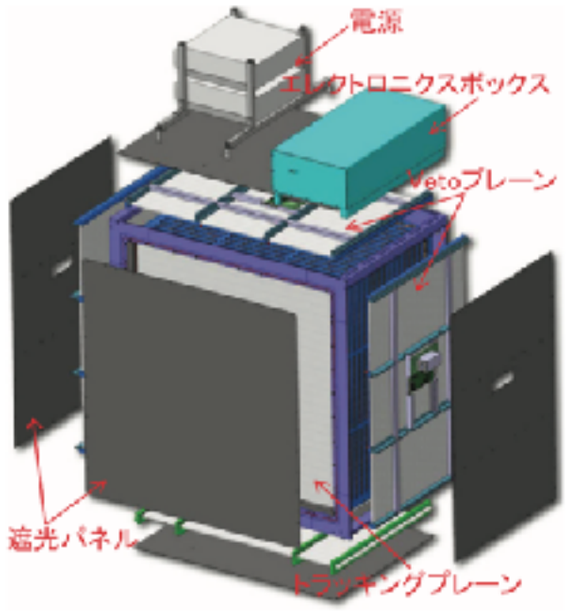
Detector (Neutrino detector)

WAGASCI

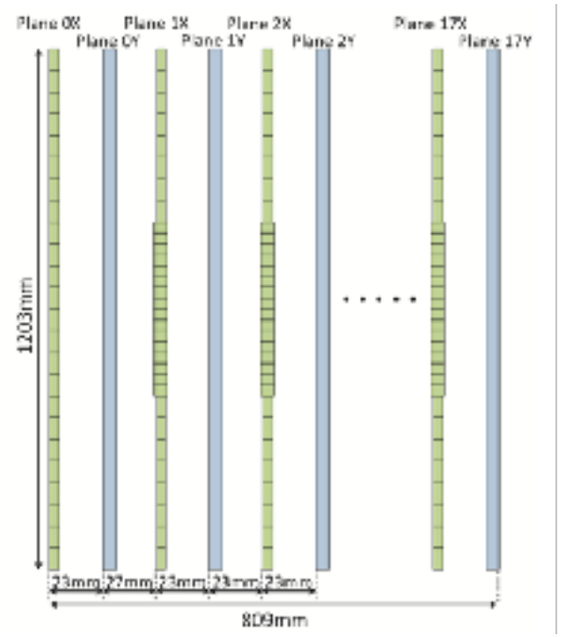




Proton Module



Tracking planes

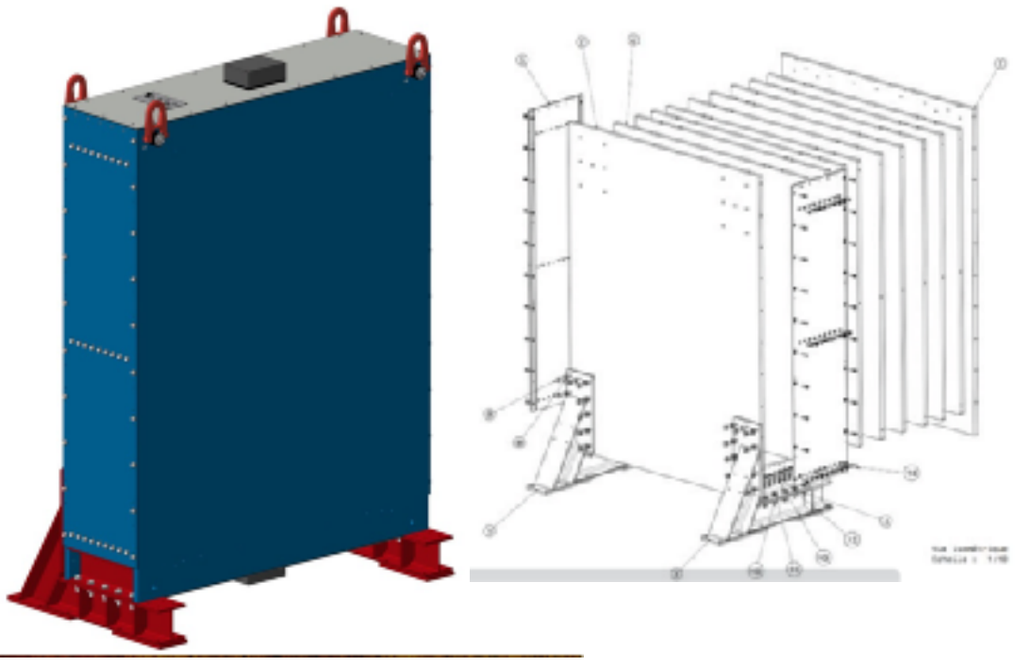


- **WAGASCI is a neutrino detector, which has 3-dimensional grid scintillators and water target.**
- **Proton module is also a neutrino detector, which has only plastic scintillators.**

WAGASCI PROJECT OVERVIEW

Detector (Muon Range Detector)

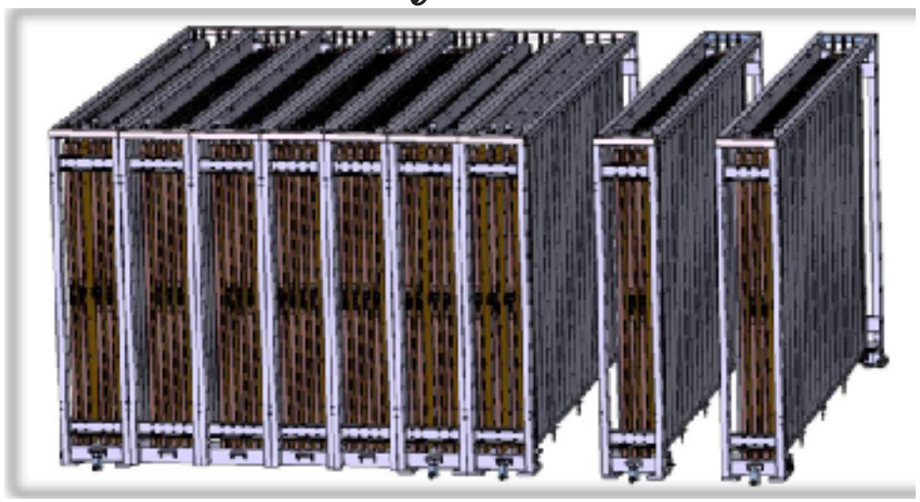
Side-MRDs



Sandwich of iron & scintillator

- Iron module : 11 layers
  Scintillator : 10 layers
- Measure momentum of muons flying aside neutrino detectors

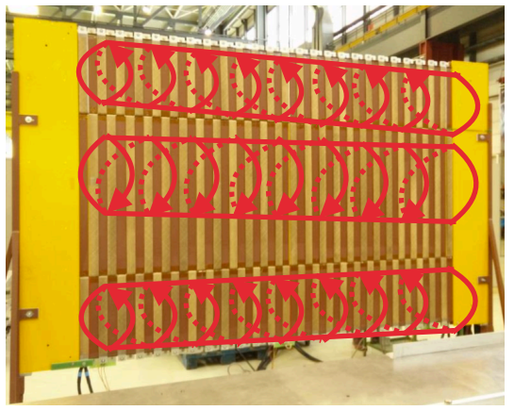
Baby-MIND

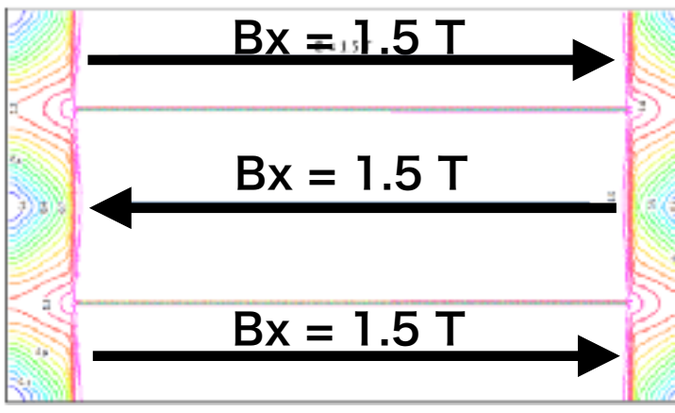


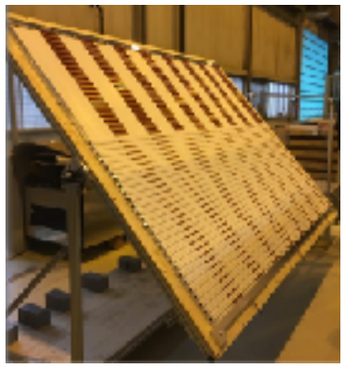
particle

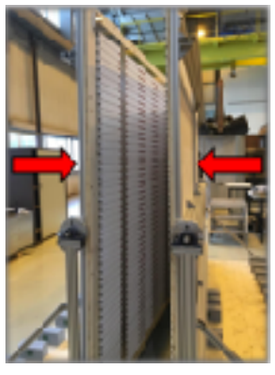
Sandwich of magnet modules & scintillator modules

Magnet module (33 modules)







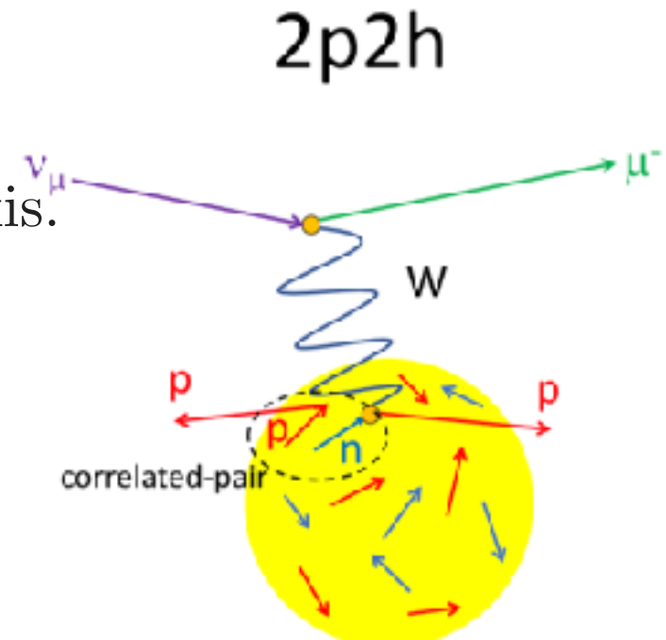


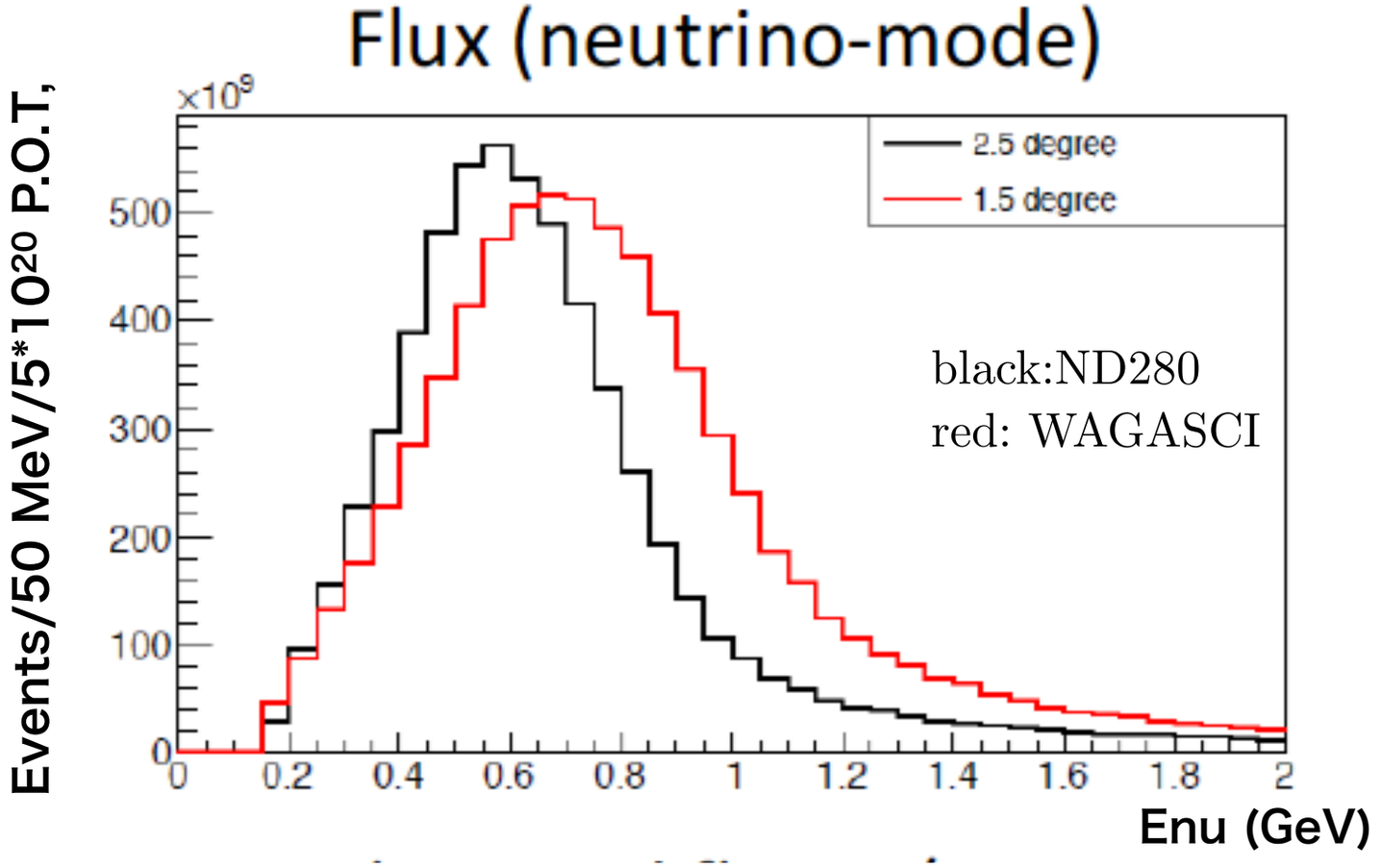
Scintillator module
(18 modules)

- Measure momentum of muons flying downstream and identify charge of muons

Physics Goal

- Precisely measure differential cross section at 1.5 degree off-axis.
- Evaluate the neutrino-nucleus interaction models with the narrower energy neutrino beam obtained by flux subtraction between WAGASCI data and ND280 data.
- Detect 2p2h interactions with water-out WAGASCI and Proton Module.

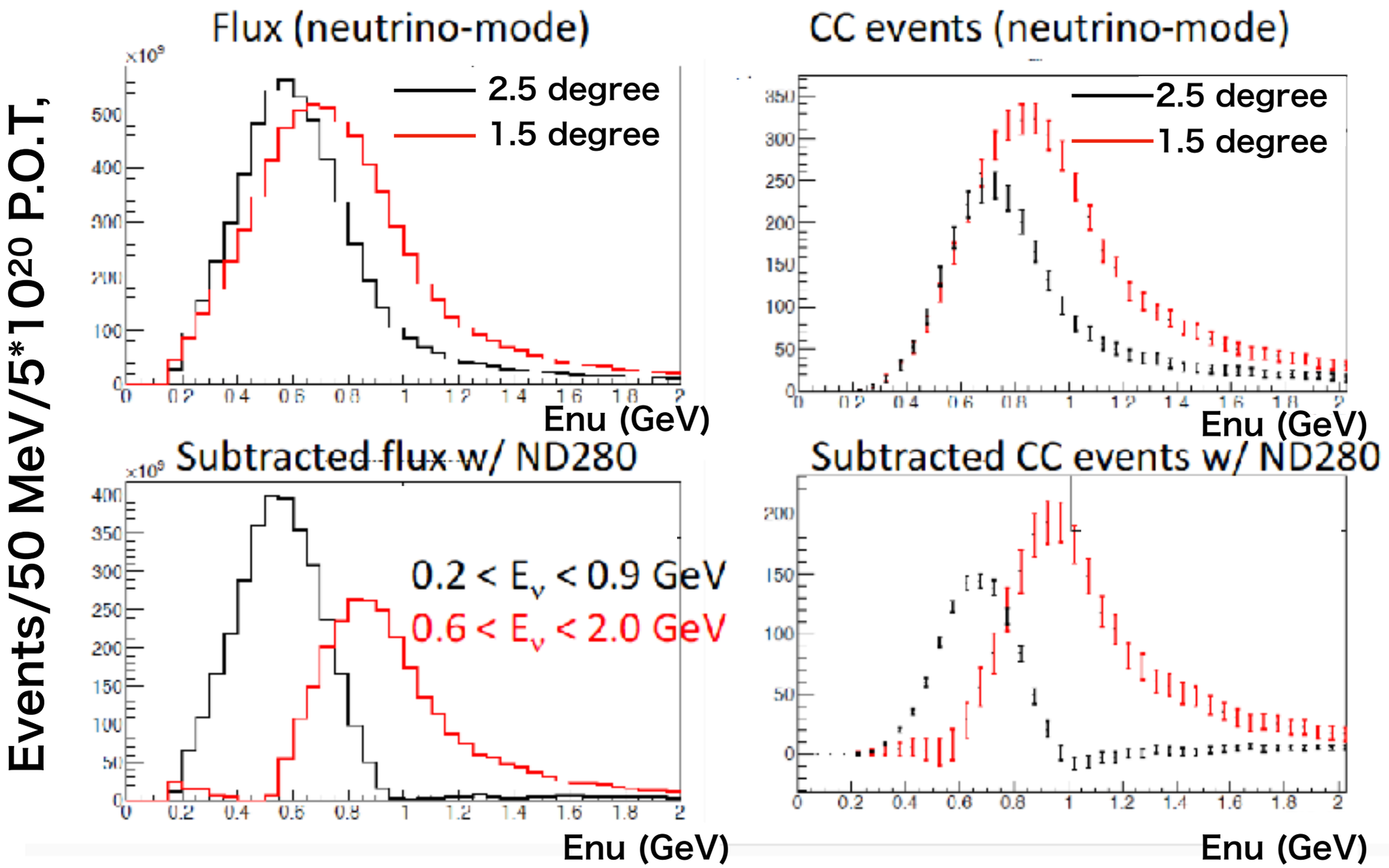




Enu (GeV)

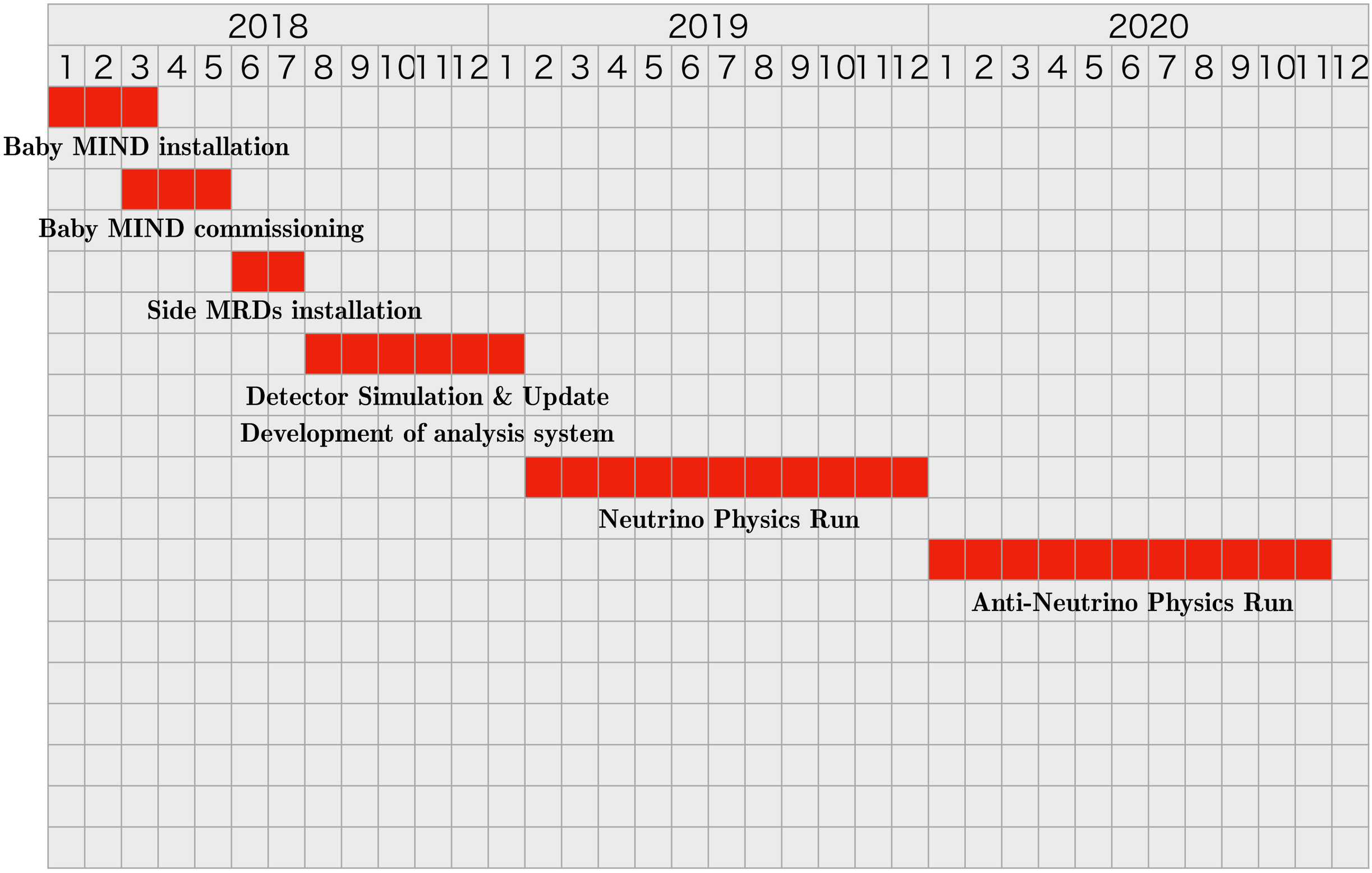
more later

FLUX SUBTRACTION

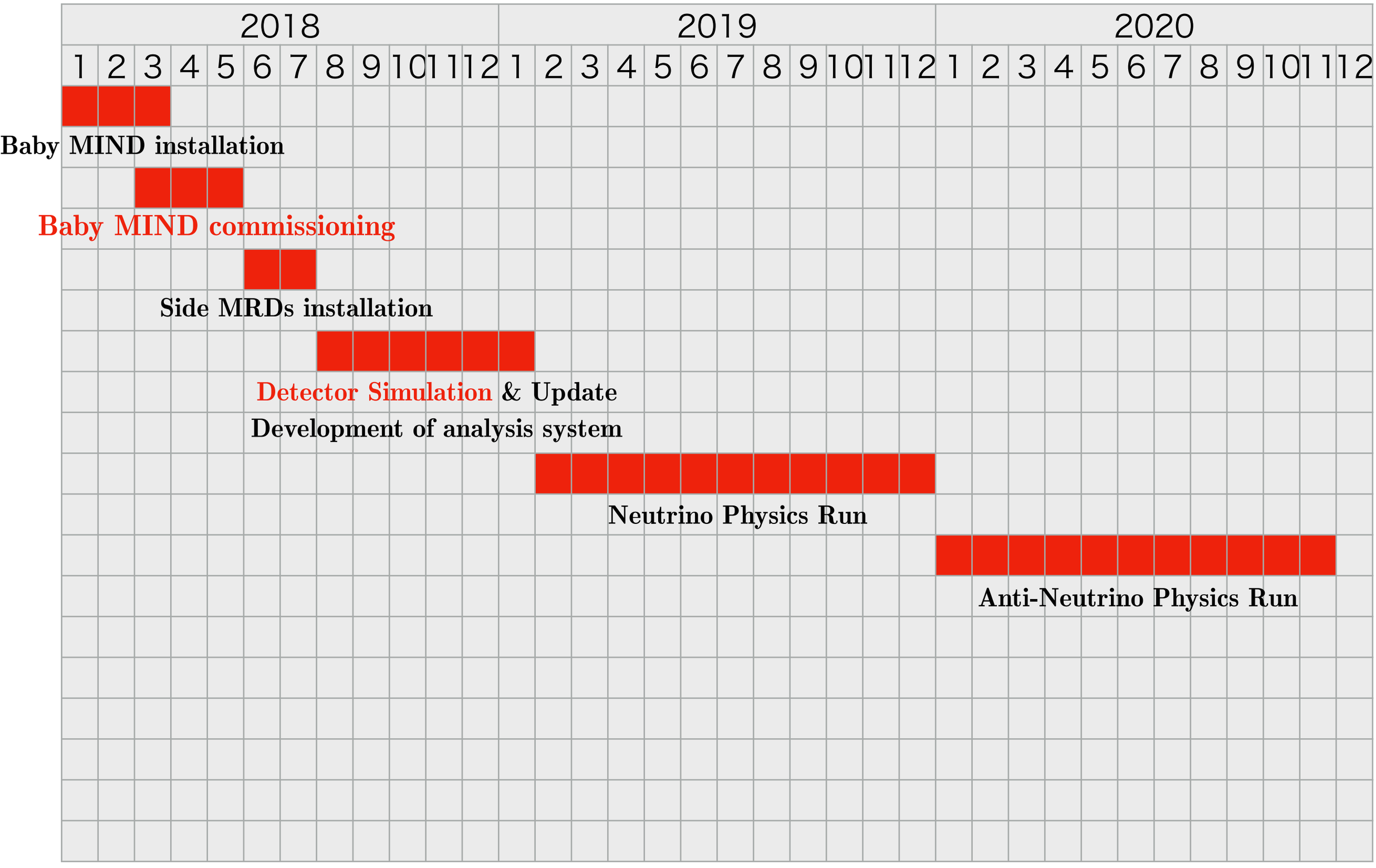


- Narrower energy spread fluxes are essential for investigation of neutrino-nucleus interaction and energy response function in detail.
- Flux subtraction with WAGASCI data (1.5 degree off-axis) and ND280 data (2.5 degree off-axis) is useful for this purpose.

Proposed timeline of WAGASCI project



Proposed timeline of WAGASCI project



BabyMIND

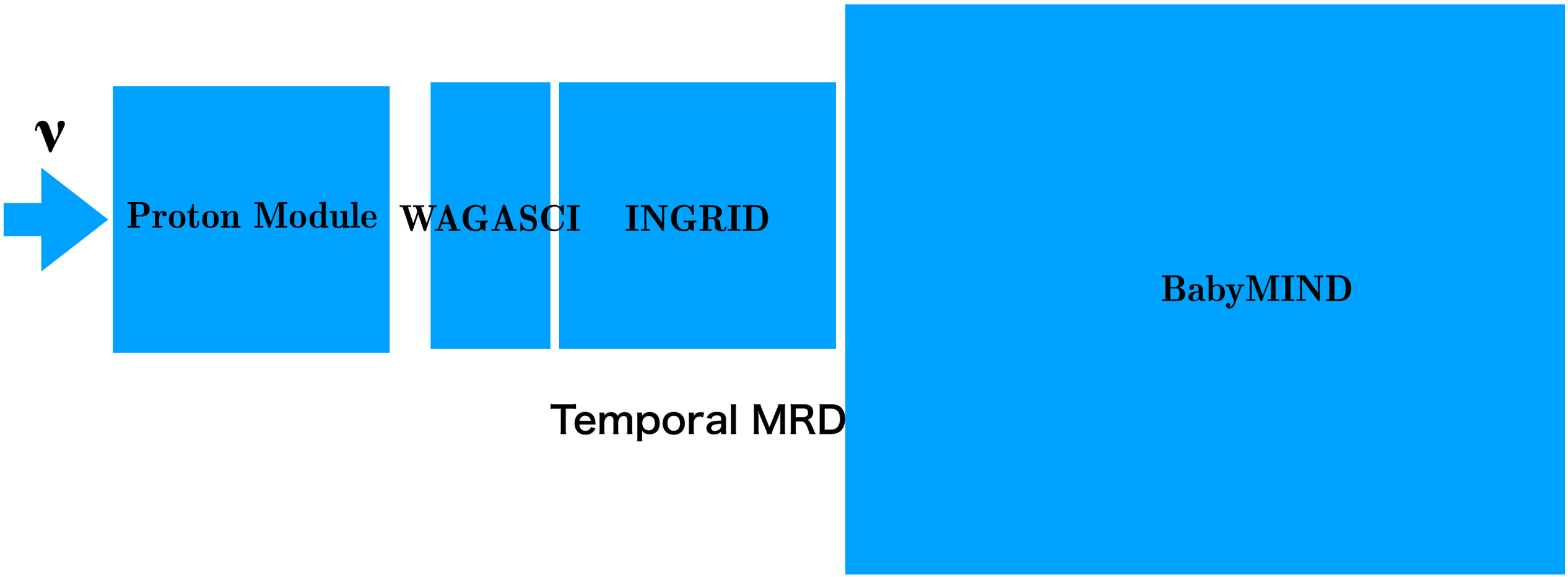
Commissioning Run

Snap shot after installation at J-PARC

BabyMIND was installed on Feb 17th 2018

Detector configuration

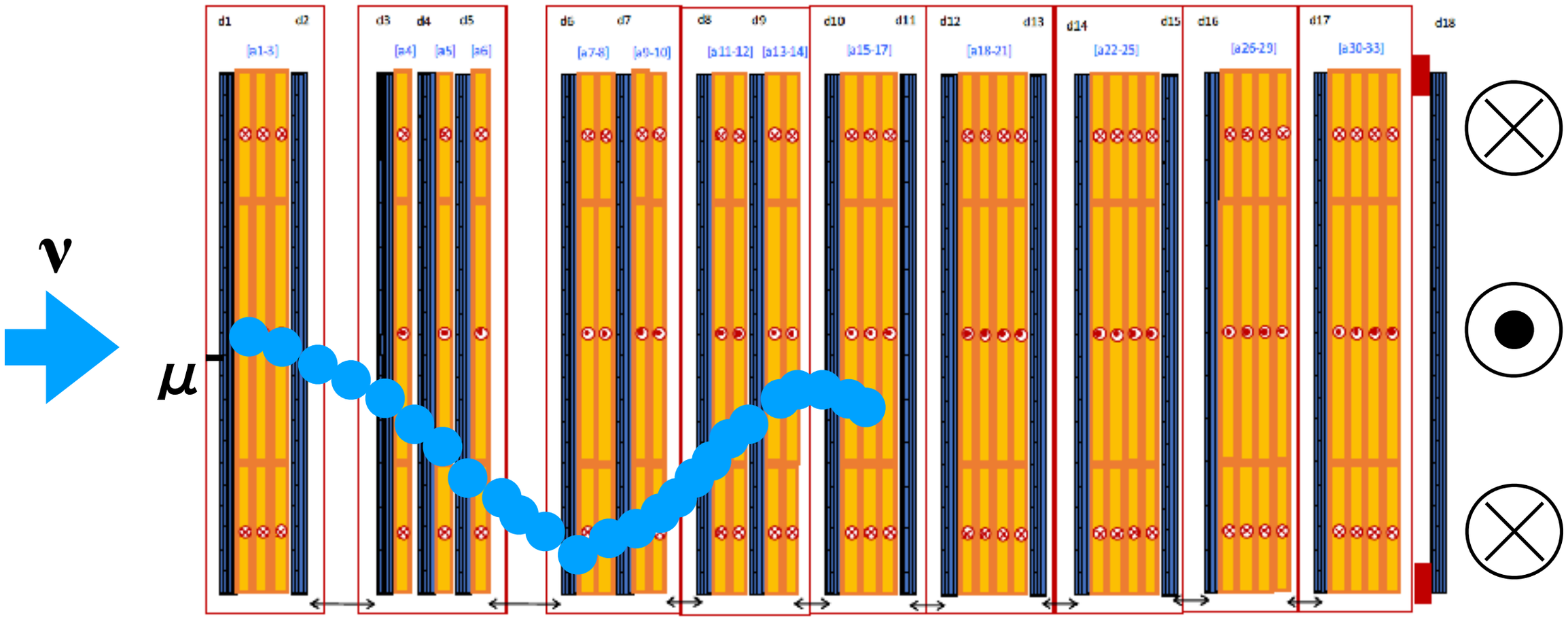
Top View



Scale ratio is not accurate

Configuration for only commissioning run

BabyMIND Detector



sandwich structure of iron and scintillator modules.

Importance of

charge identification

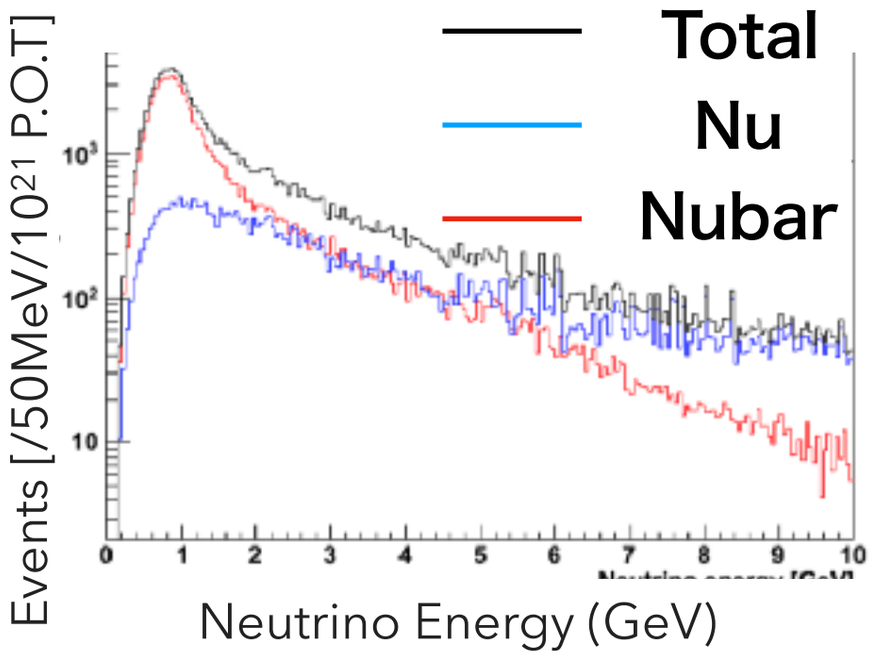


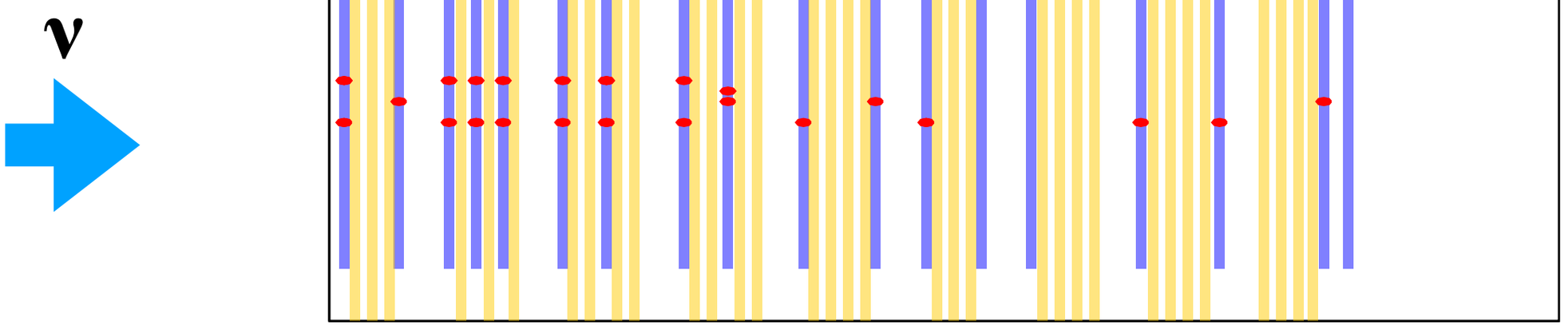
Fig.
contamination of neutrino events in anti-neutrino mode.

Charge ID is essencial due to ~30% contamination of neutrino events.

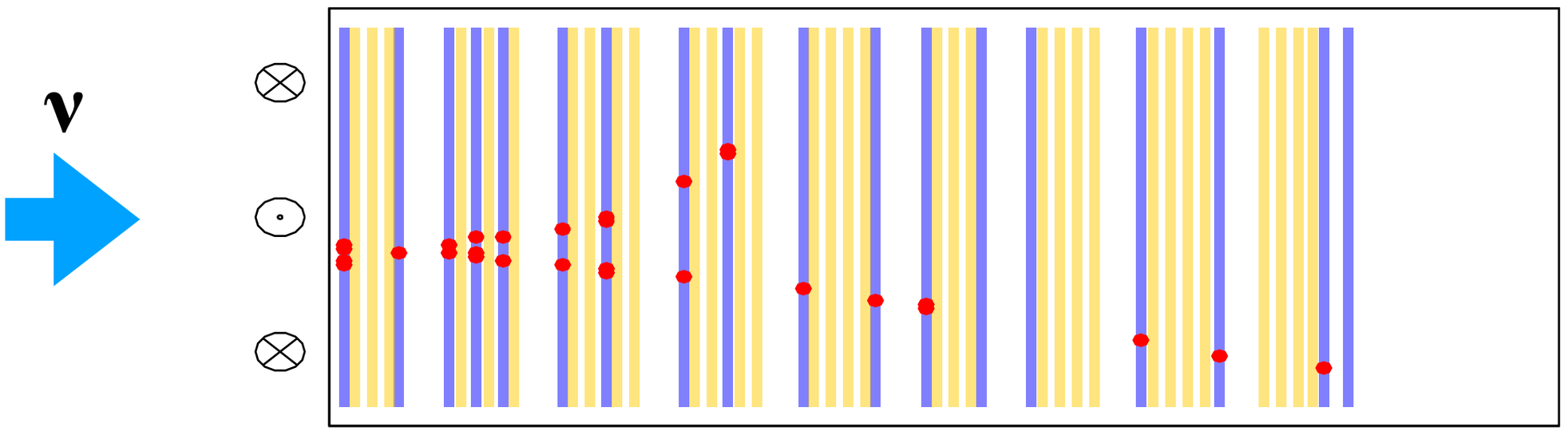
Detector Performance 1

Event Display

Top View



Side View

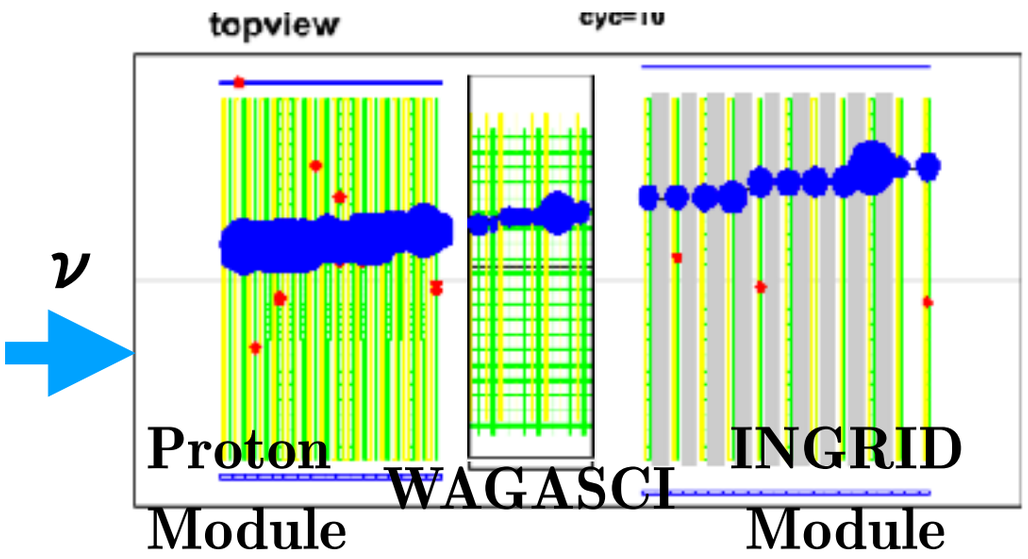


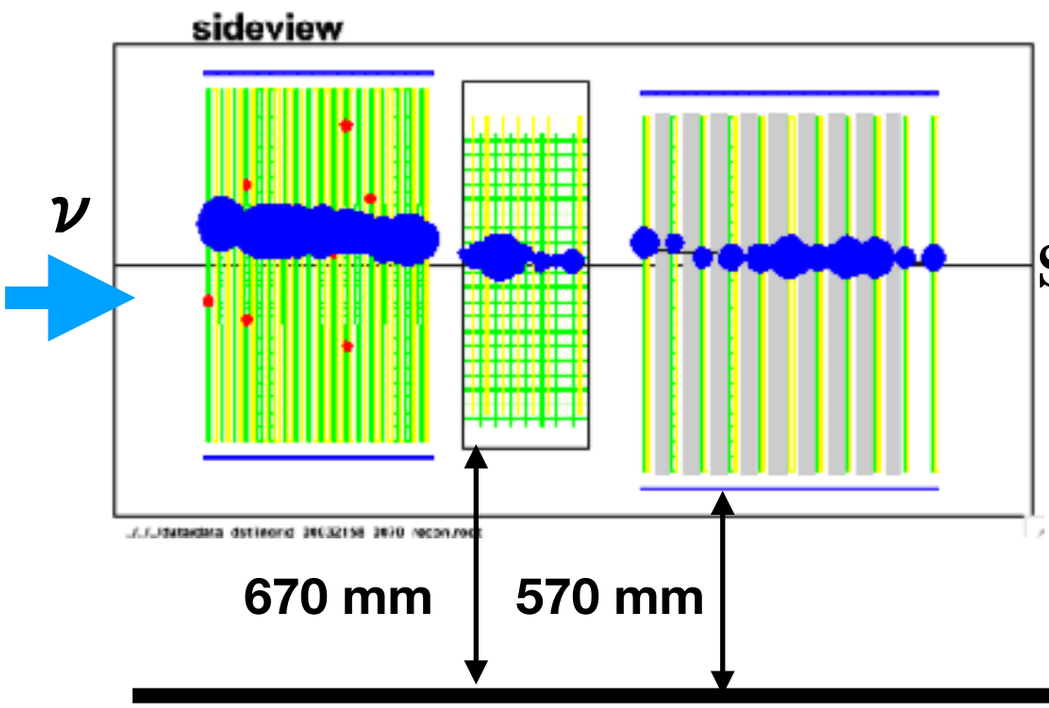
Baby MIND detects neutrino interaction !

Detector Performance 2

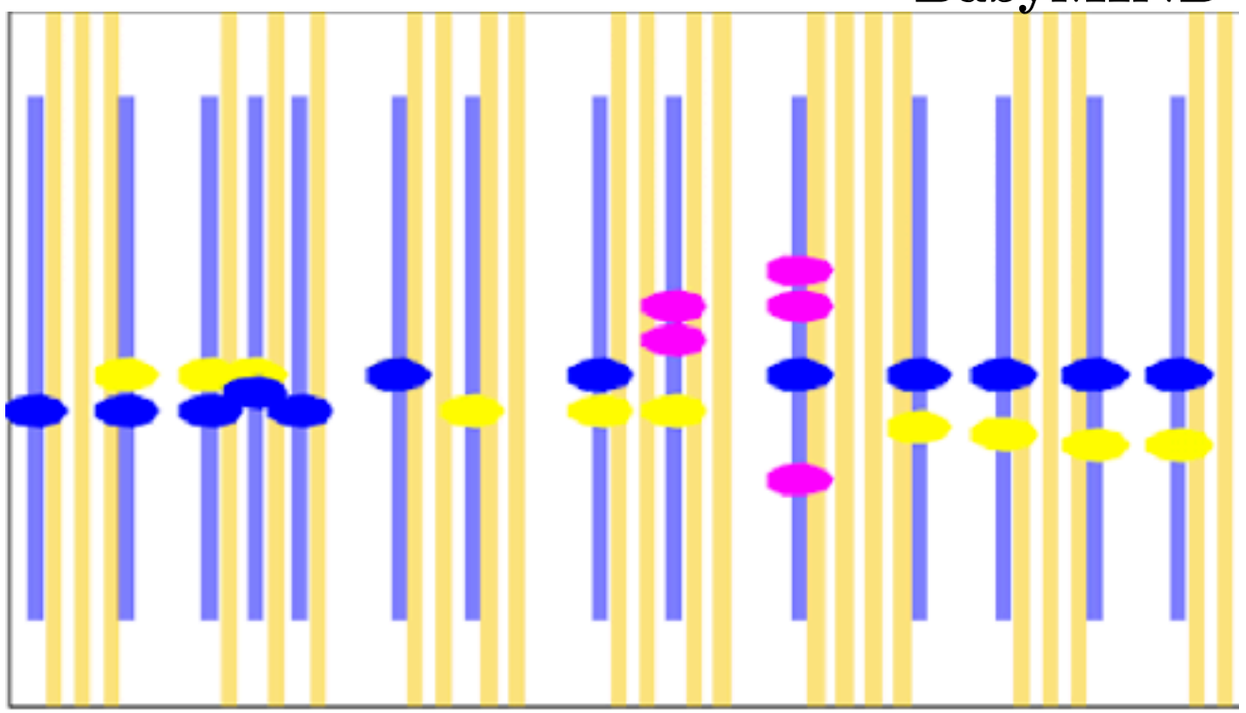
2018 5/4 Friday 19:27:29 JST

Confirmed successful track matching event
From Proton module to BabyMIND.



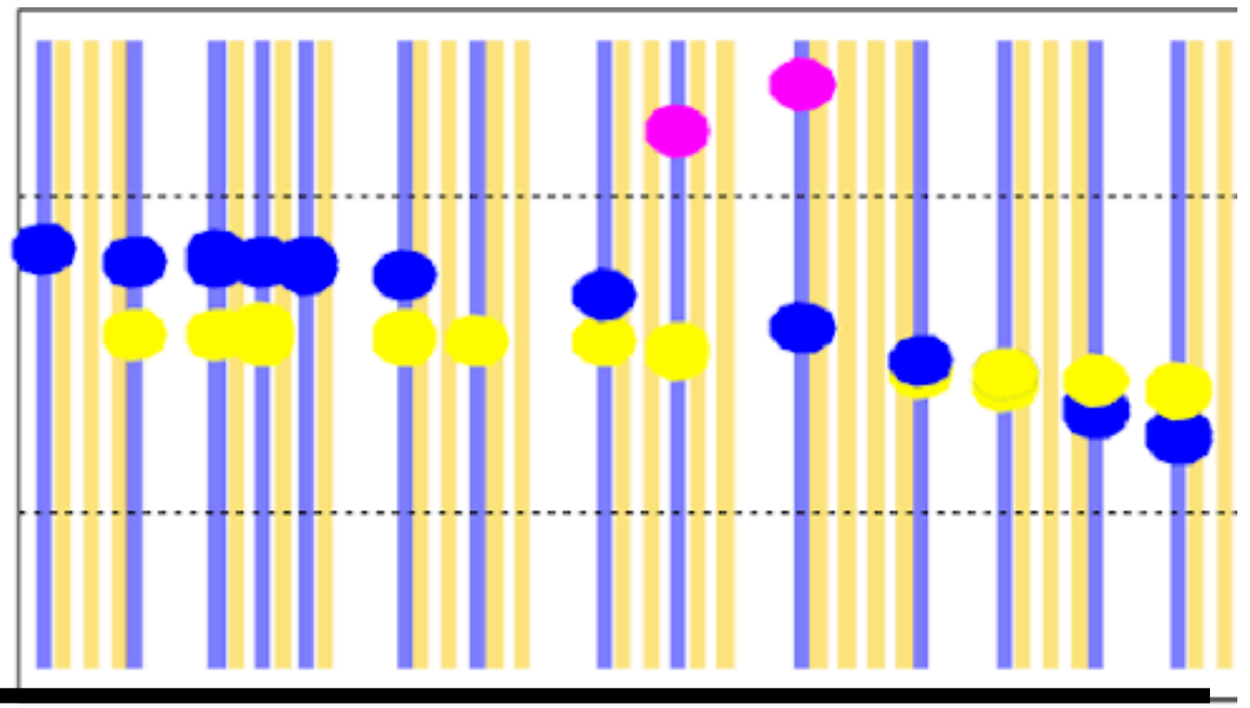


BabyMIND



Top View

Color means hit timing difference



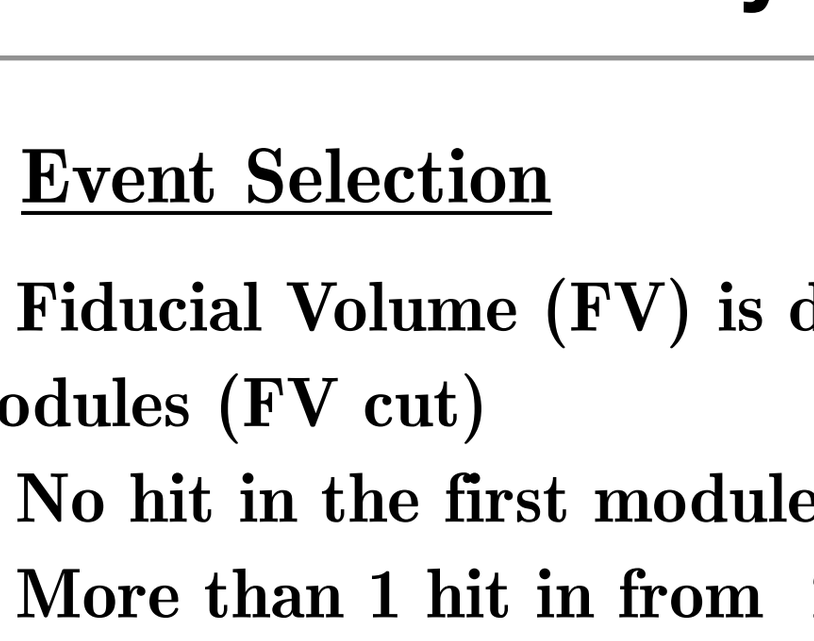
Side View

B2 floor

Analysis : Event Rate Check

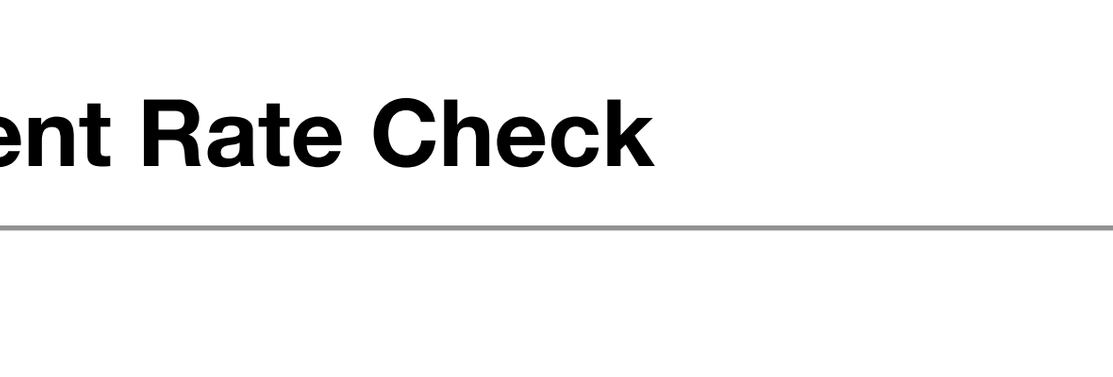
Event Selection

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

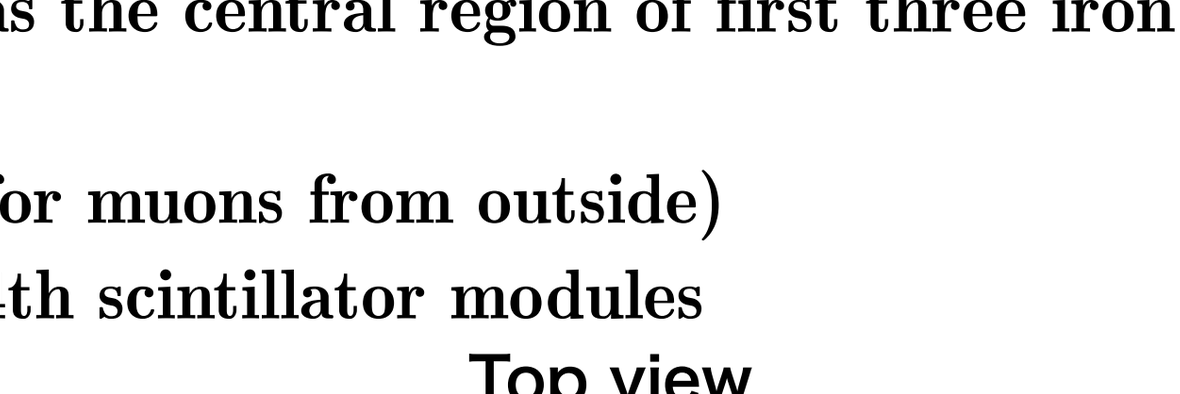


FV

Top view



Side view



Analysis : Event Rate Check

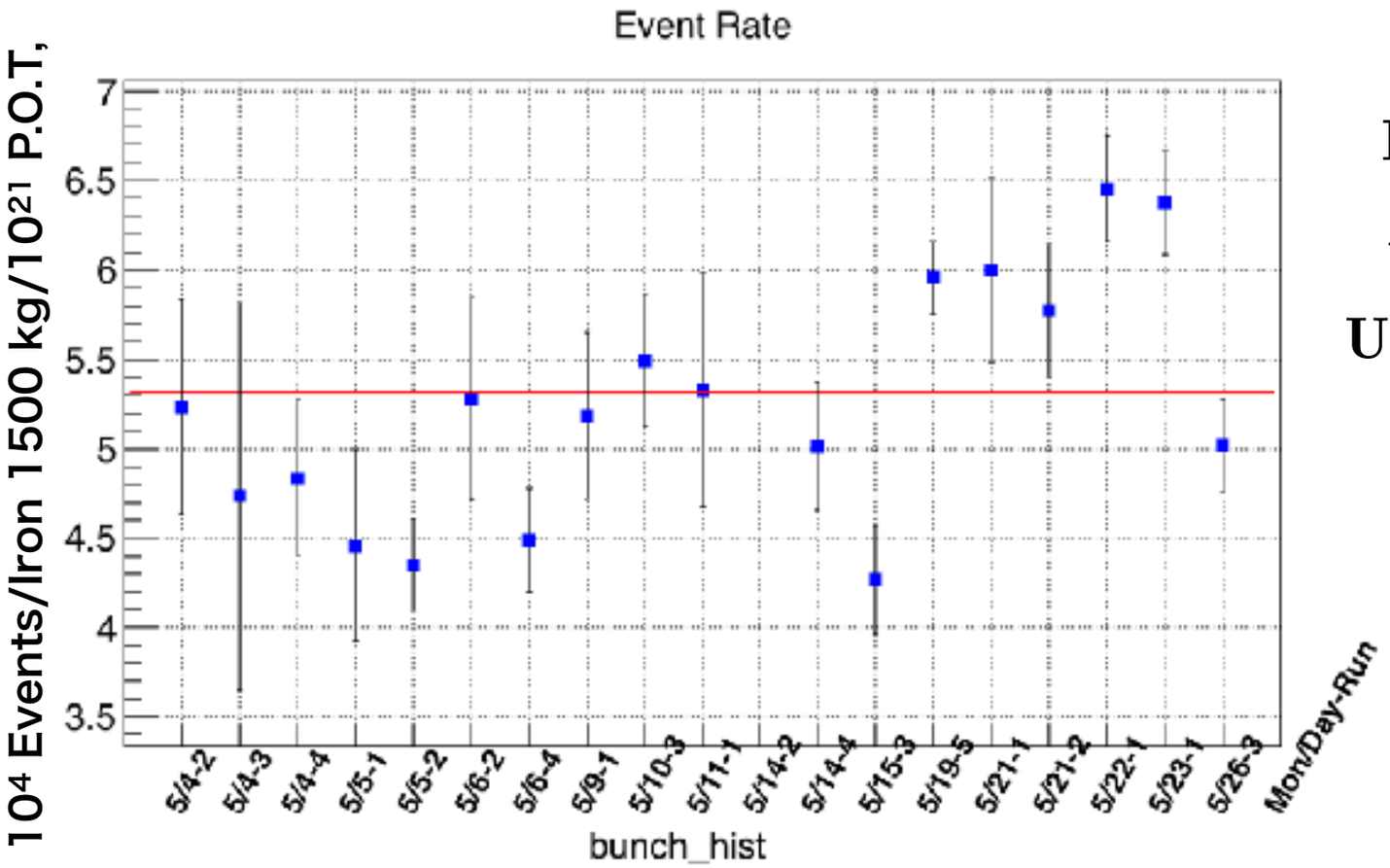


Fig. Event Rate

~ 5.246 ± 0.656 (stat)

Unit : 10^4 events/Iron 1500 kg/10^{21} P.O.T.

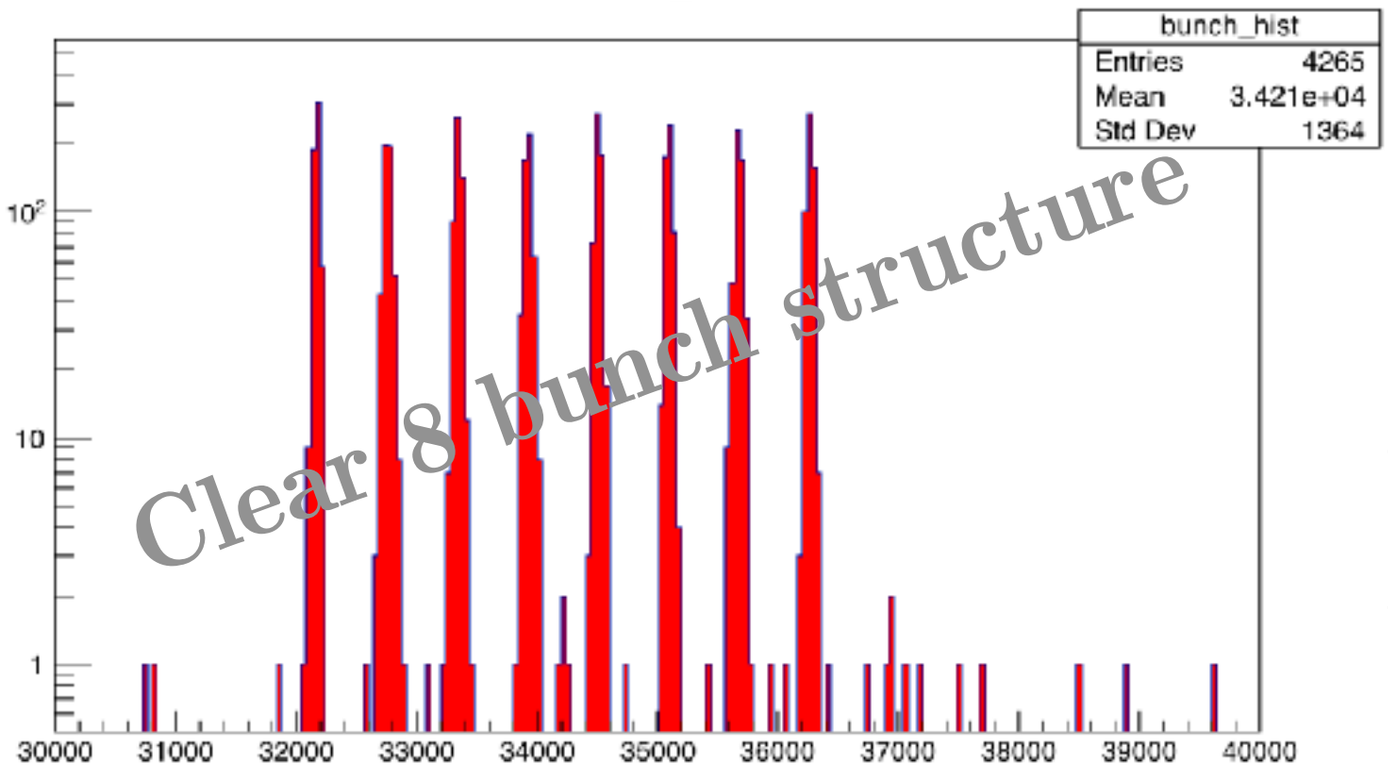


Fig. Bunch structure

J-PARC neutrino beam has

8 bunch structures for 1 neutrino

spill.

horizontal axis

hit time from beam interaction timing (ns)

vertical axis

The number of event

Analysis : Event Rate Check

Comparison with Simulation

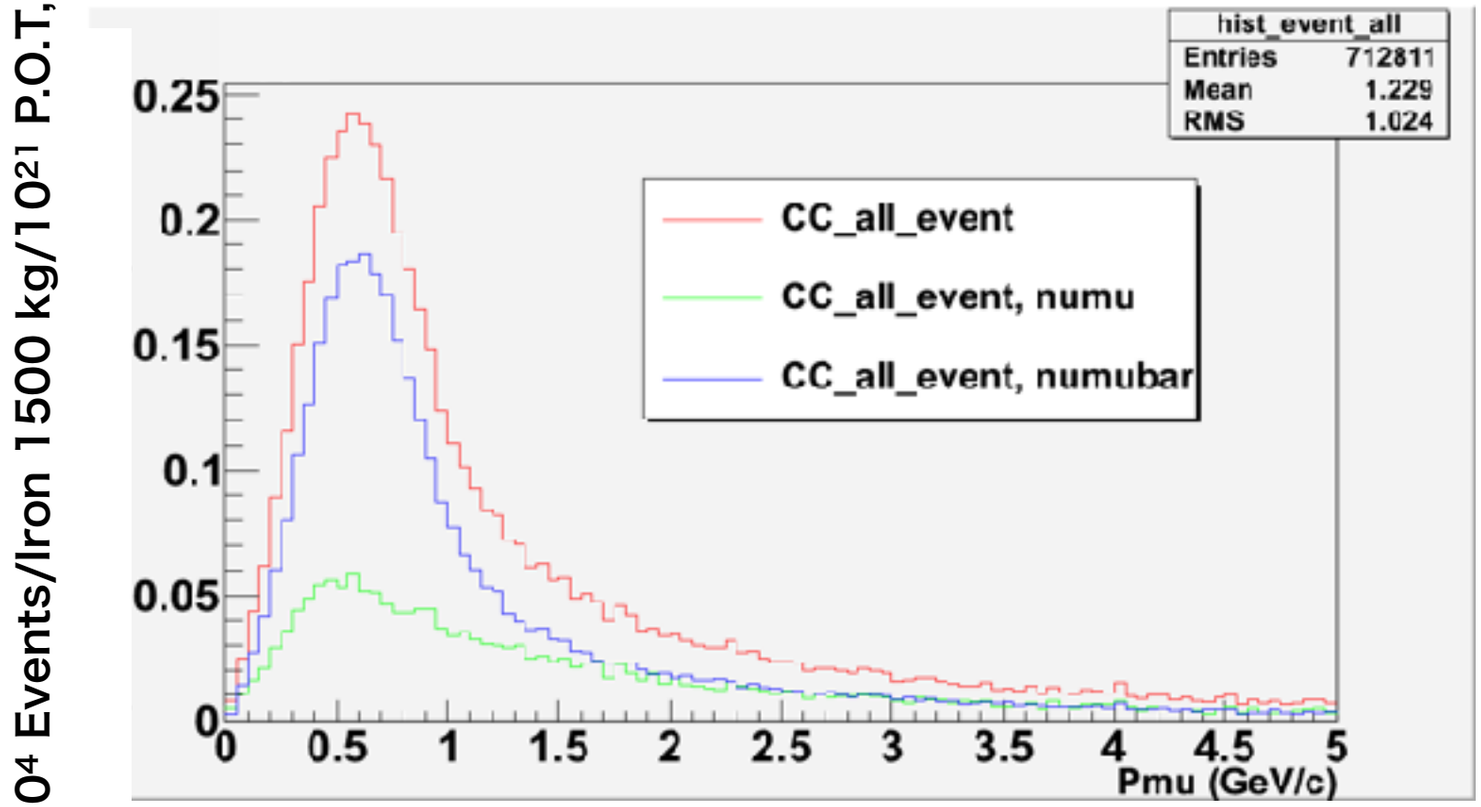


Fig. Neutrino energy distribution from simulation

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.

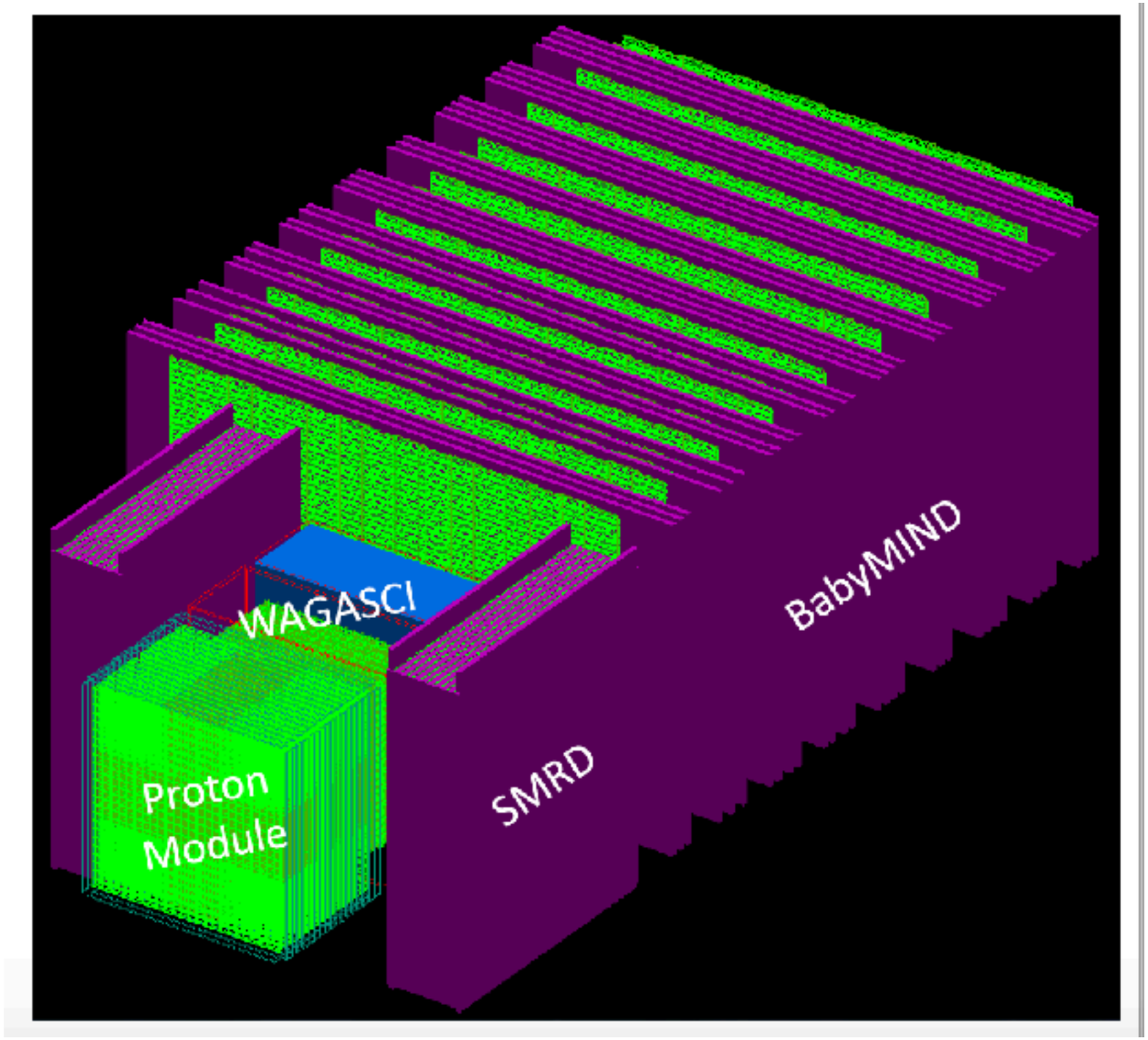
Simulation for next year's Physics Run

Simulation Framework

- Neutrino Flux
  JNUBEAM

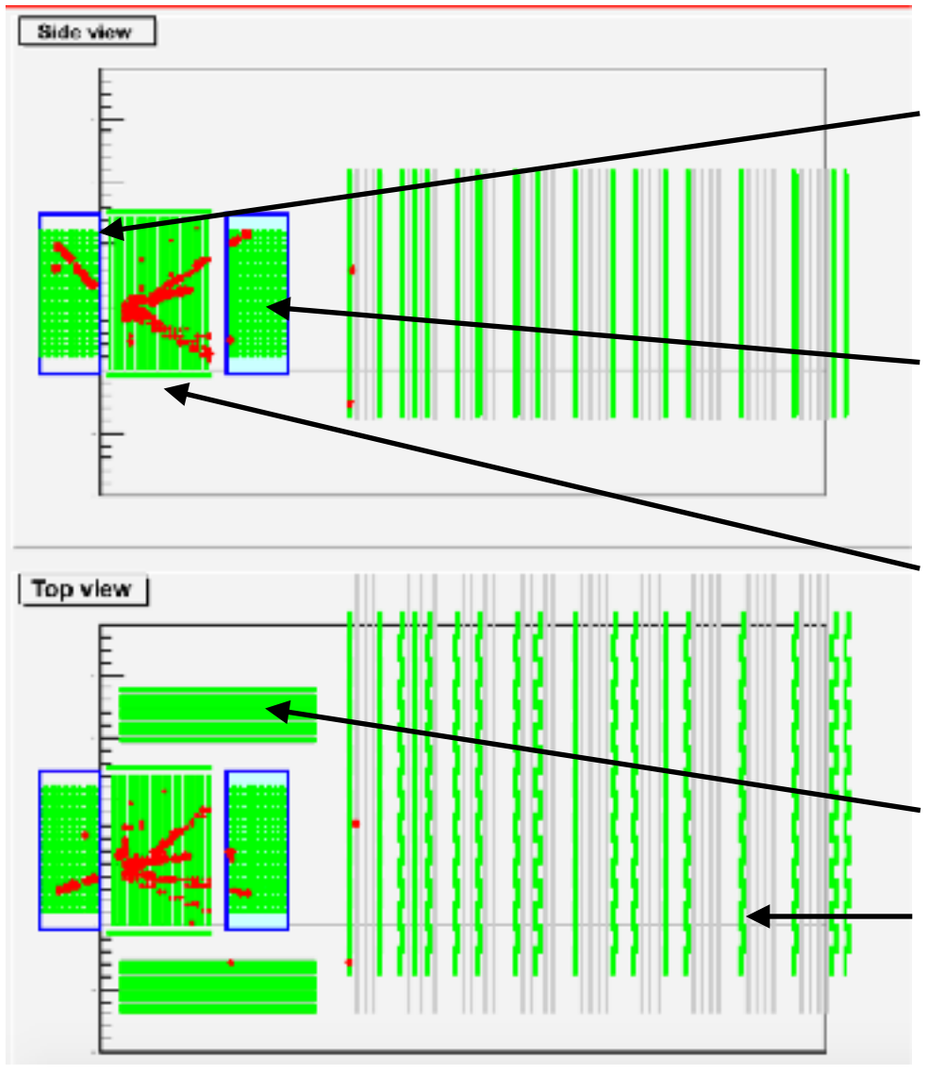
- Neutrino Interaction
  NEUT

- Detector simulation
  Geant4 based



Main purpose of simulation

Configuration A



suitable for measurement of cross section on pure water

Water-out WAGASCI

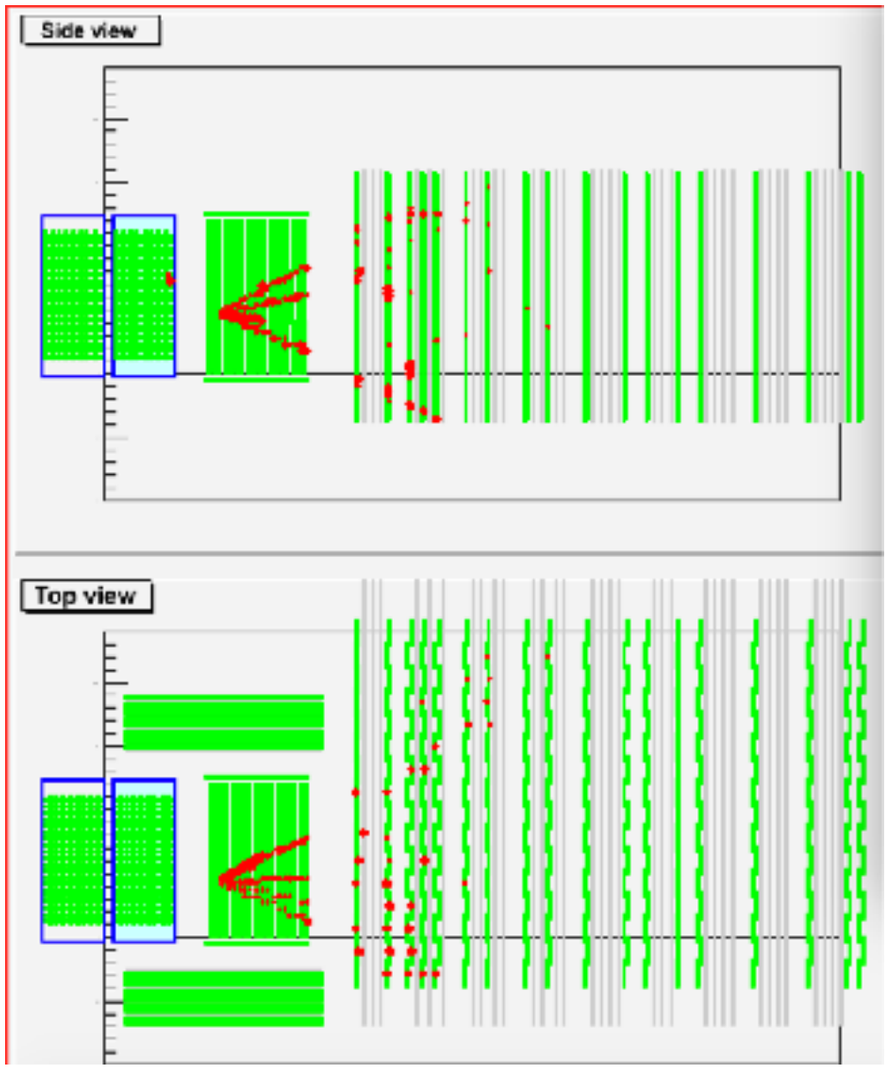
Water-in WAGASCI

Proton Module

Side MRDs

BabyMIND

Configuration B



suitable for subtraction from cross section measurement of T2K near detector.

Need to decide which configuration is good for our physics goal

Event Selection

1. Selected muon tracks from CC interactions
   — require tracks of particles produced from neutrino interactions should be muon's.

2. Track matching with MRDs
   — require tracks should be matched with Baby MIND or Side-MRDs

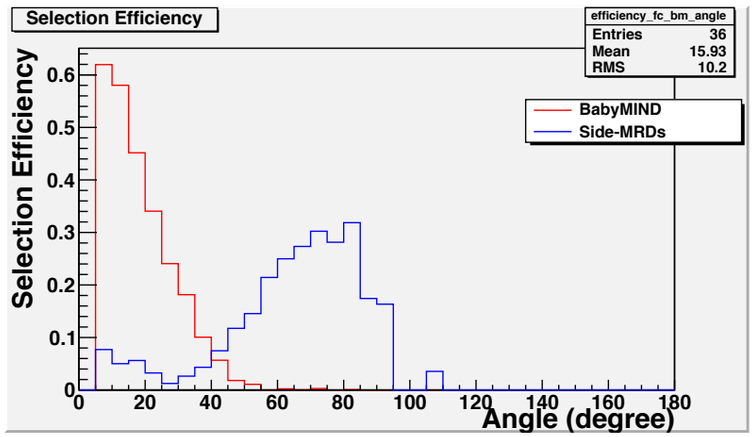
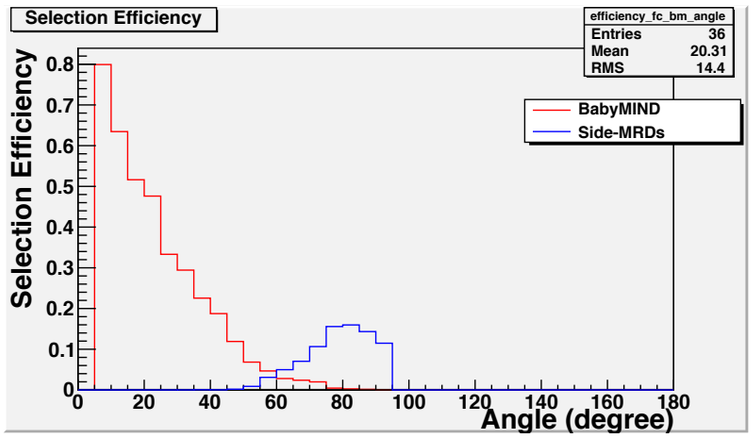
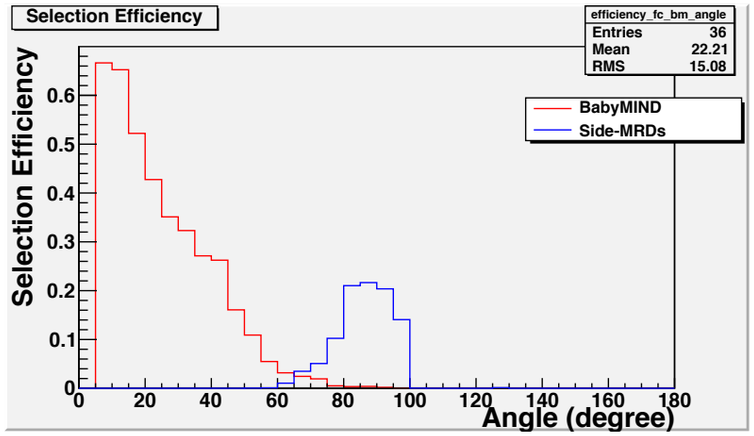
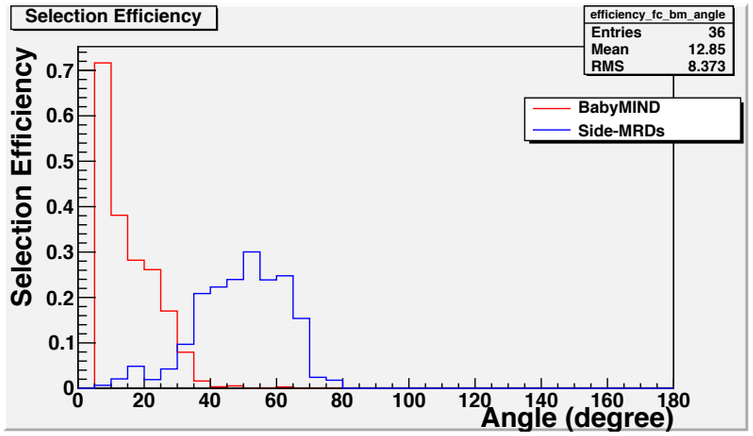
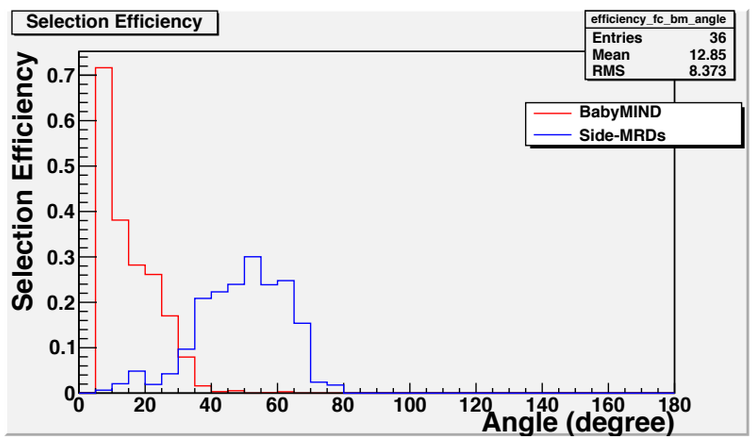
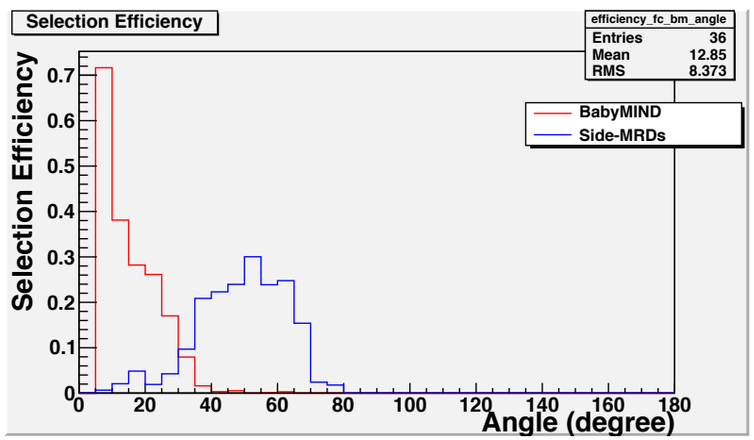
3. Fiducial Volume Cut
   — WAGASCI : Water + Plastic (133 kg + 32 kg)
   — Proton Module : Plastic 304 kg

4. Fully Contained Cut
   — require muons should stop in Baby MIND or Side-MRDs

Efficiency

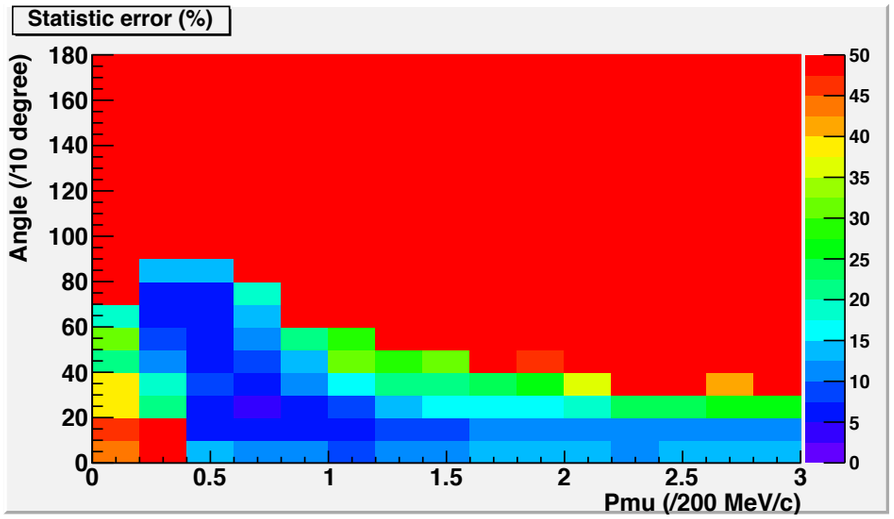
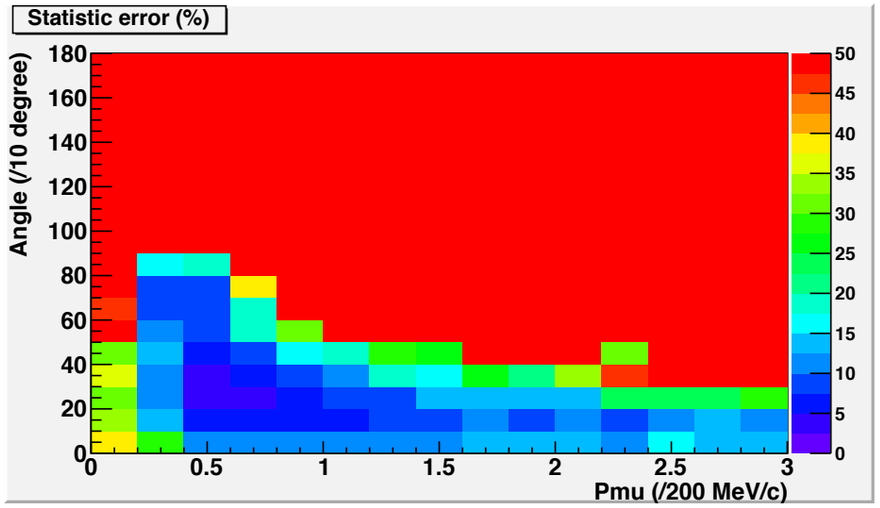
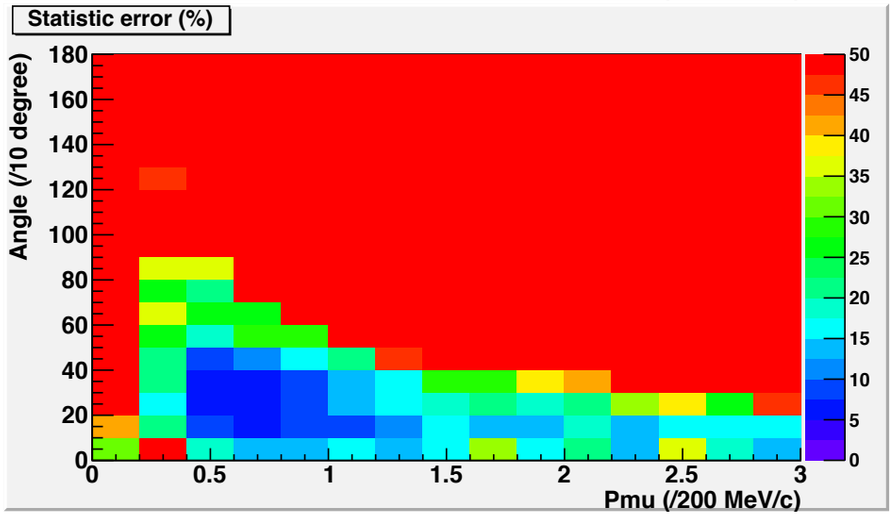
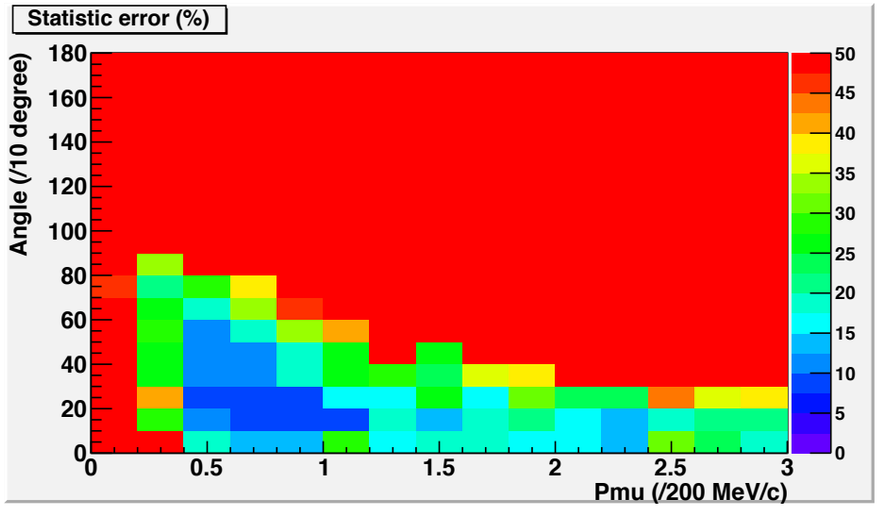
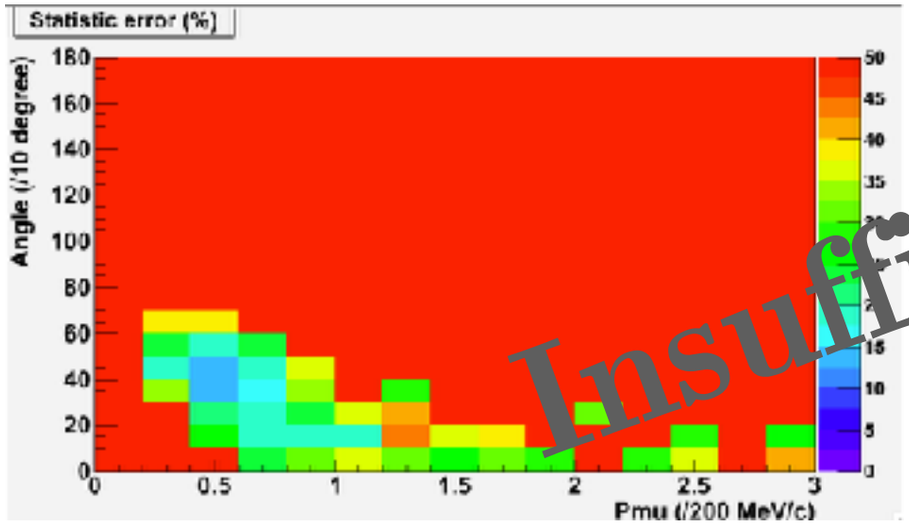
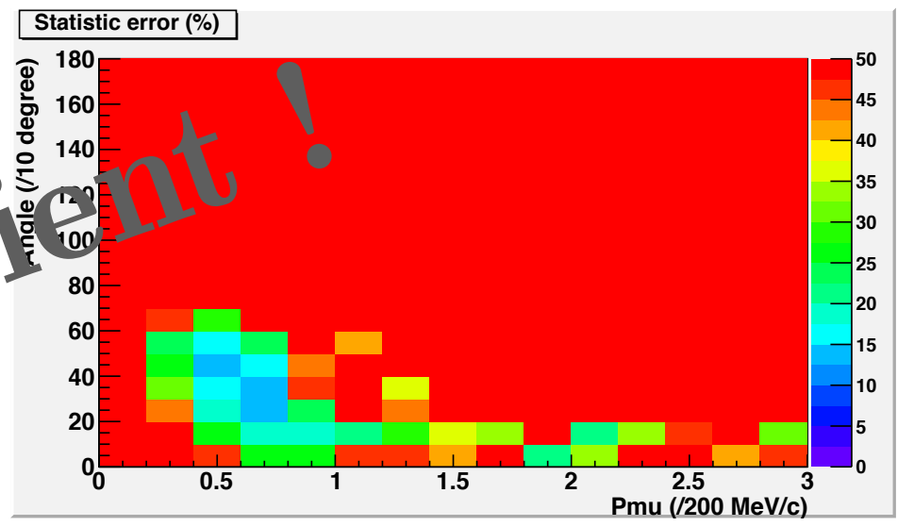
Blue : Track is matched with SMRD

Red : Track is matched with BabyMIND

	Configuration A	Configuration B
Proton Module		
Water-in WAGASCI		
Water-out WAGASCI		

Statistical error for 1 year neutrino-mode operation

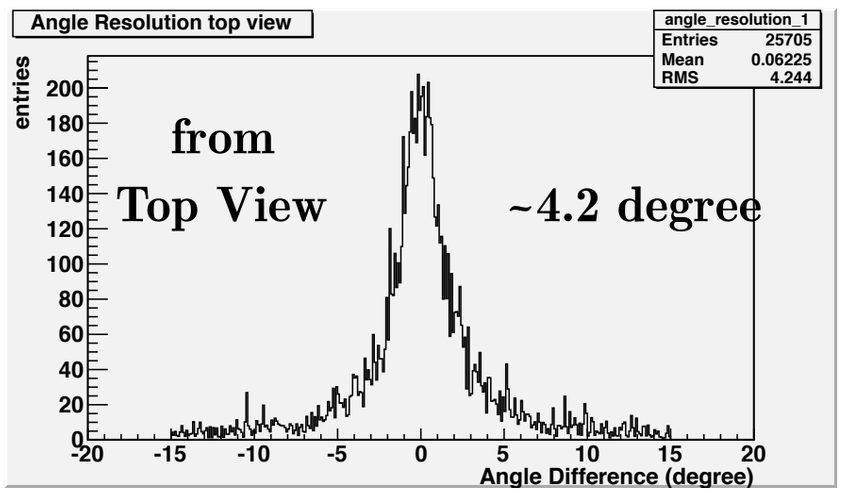
Fig. Statistical error

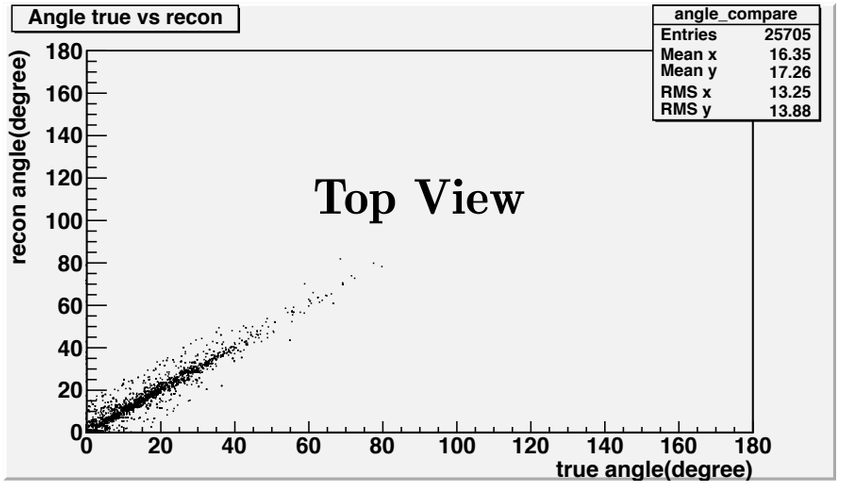
	Configuration A	Configuration B
Proton Module		
Water-in WAGASCI		
Water-out WAGASCI		

Insufficient !

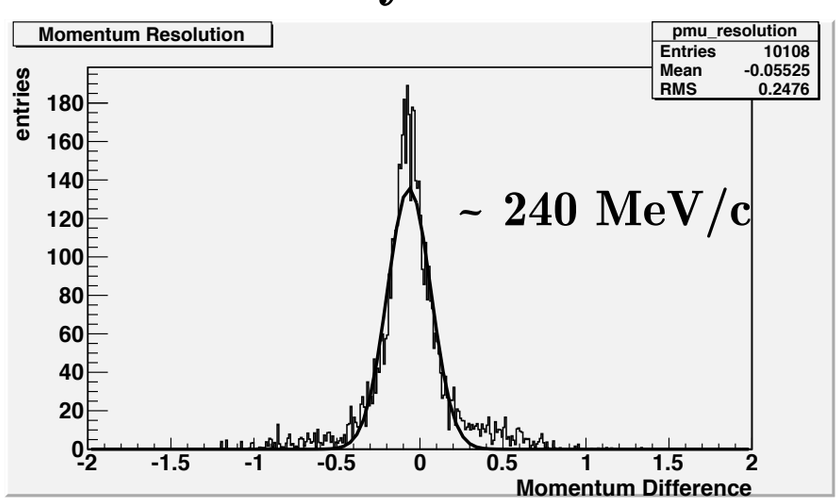
Expected resolution (very preliminary)

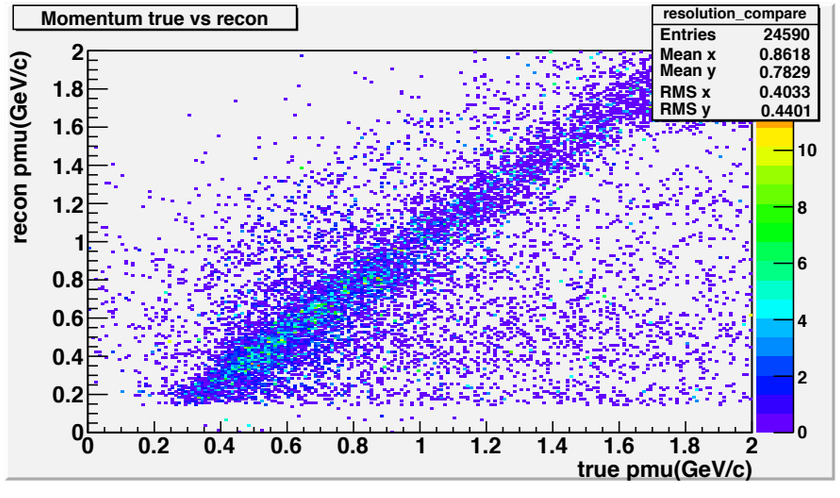
Angle (calculated from track) With Only Proton module



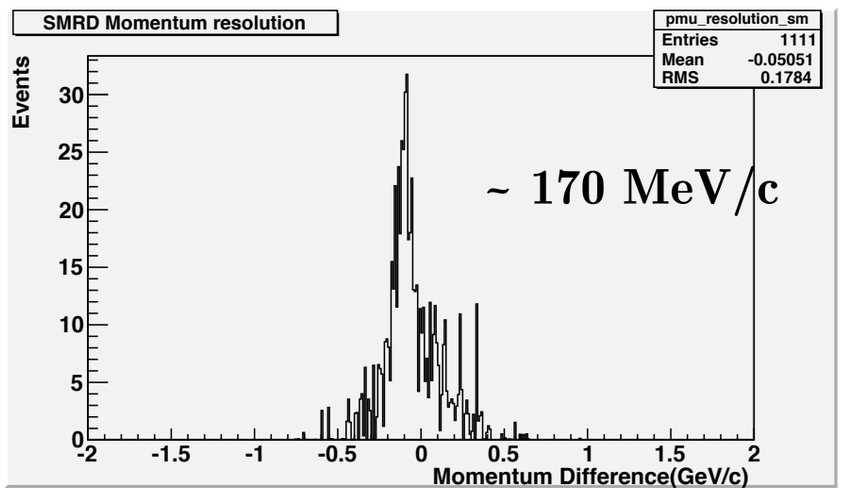


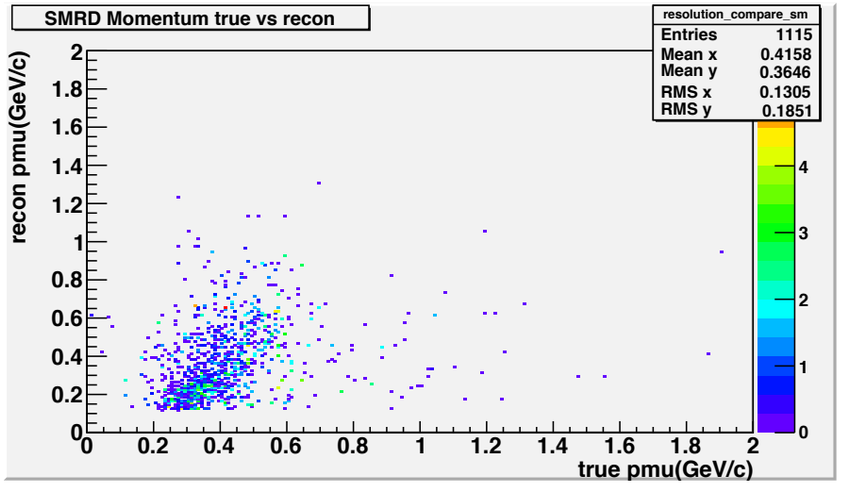
momentum (calculated from path length) With BabyMIND



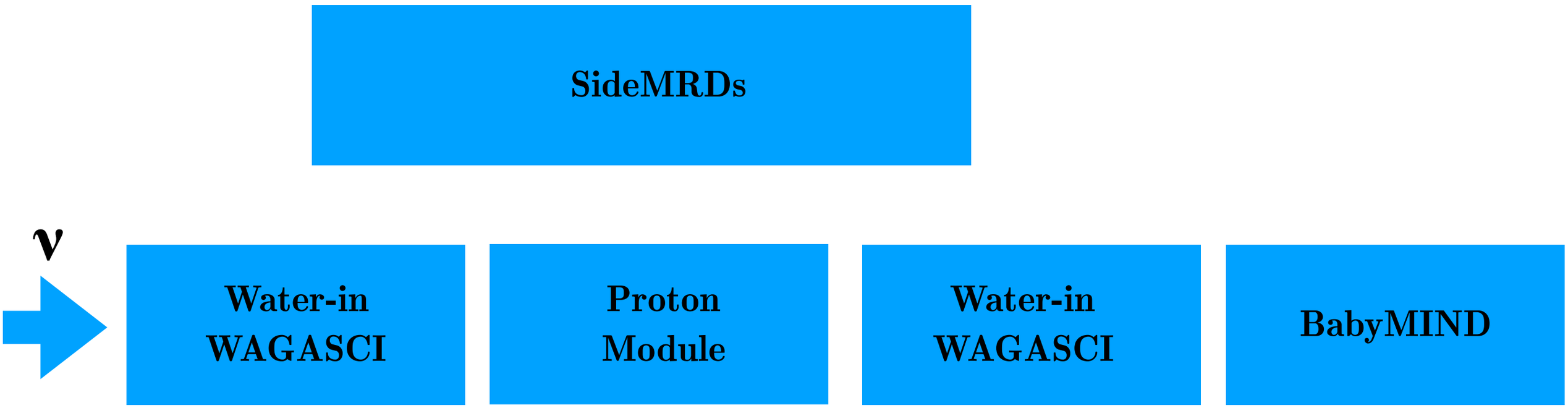


With SideMRDs





Baseline Plan



Scale ratio is not accurate

Aim to

- get statistics of Water-in WAGASCI as much as possible for measurement of differential cross section.

- do flux subtraction with Proton Module.

Summary

- All detectors are in J-PARC now
  — Proton Module, WAGASCI module, BabyMIND, SideMRDs

- First evaluation of BabyMIND commissioning run was done.
  — Succeeded track matching
  — Confirmed 8 bunch structures of J-PARC neutrino beam
  — Estimated neutrino interaction rate in BabyMIND

- Configuration study is ongoing
  — Baseline configuration was obtained

Acknowledgement

We appreciate essential help for our project to the following institutions

Cern Neutrino Platform

— Construction of Baby MIND

— Beam test for Baby MIND

J-PARC Neutrino facility group

— Installation of Baby MIND, Side MRDs

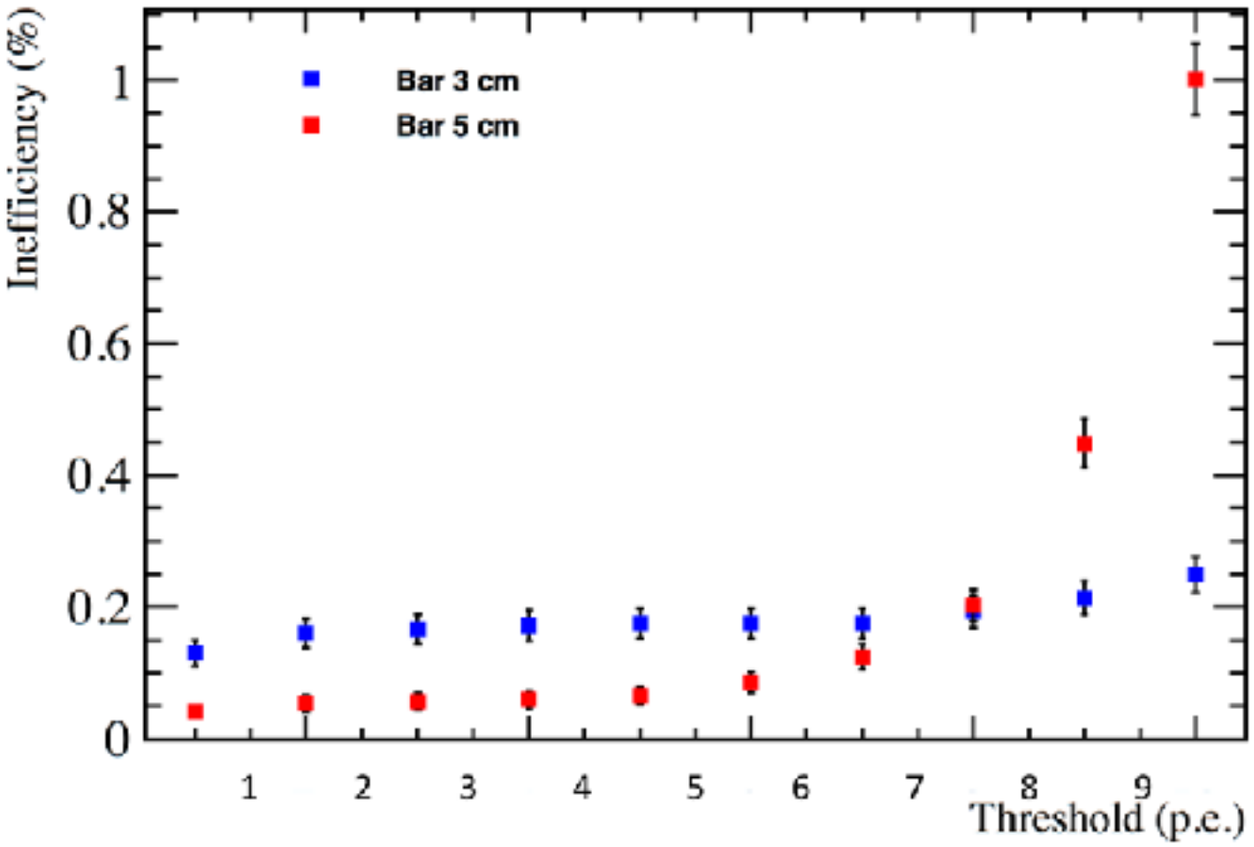
T2K Collaboration

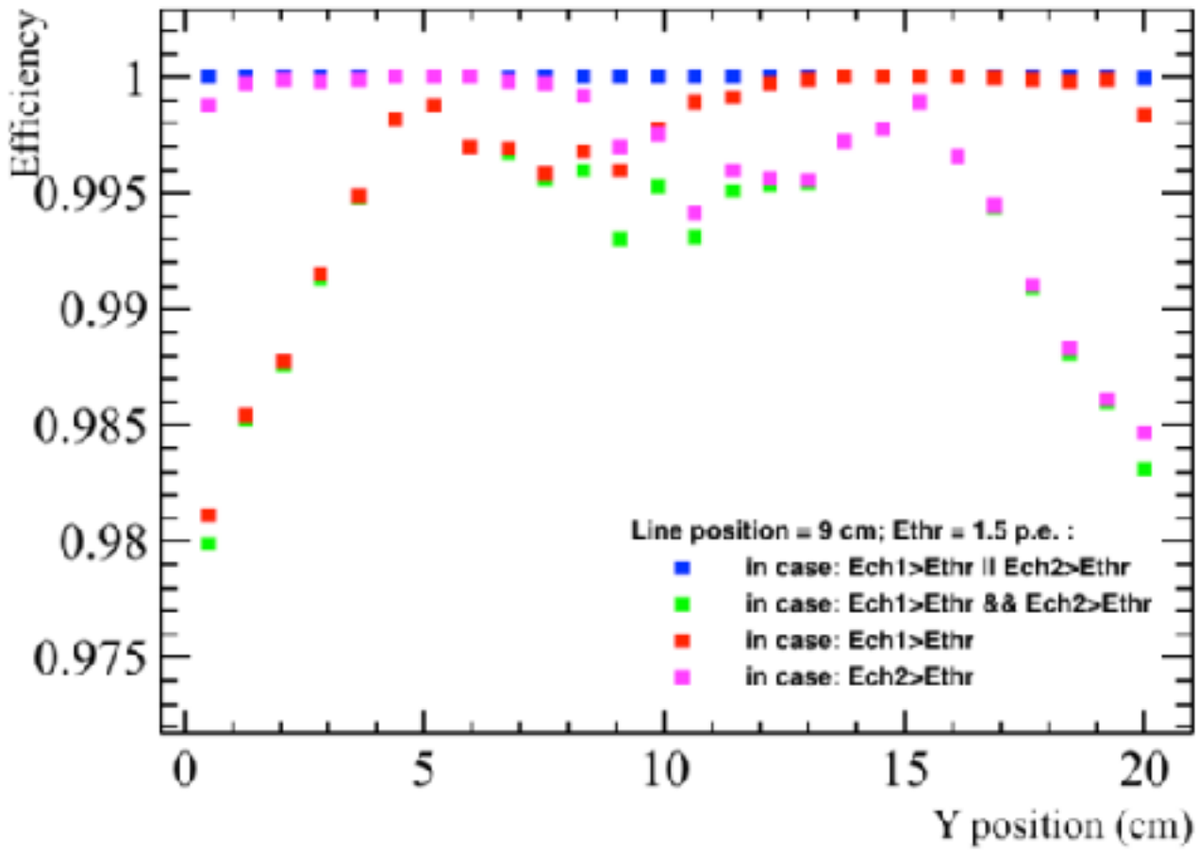
— Neutrino beam operation

Backup

Detector Performance

Hit efficiency was measured at Cern beam test 2017 summer



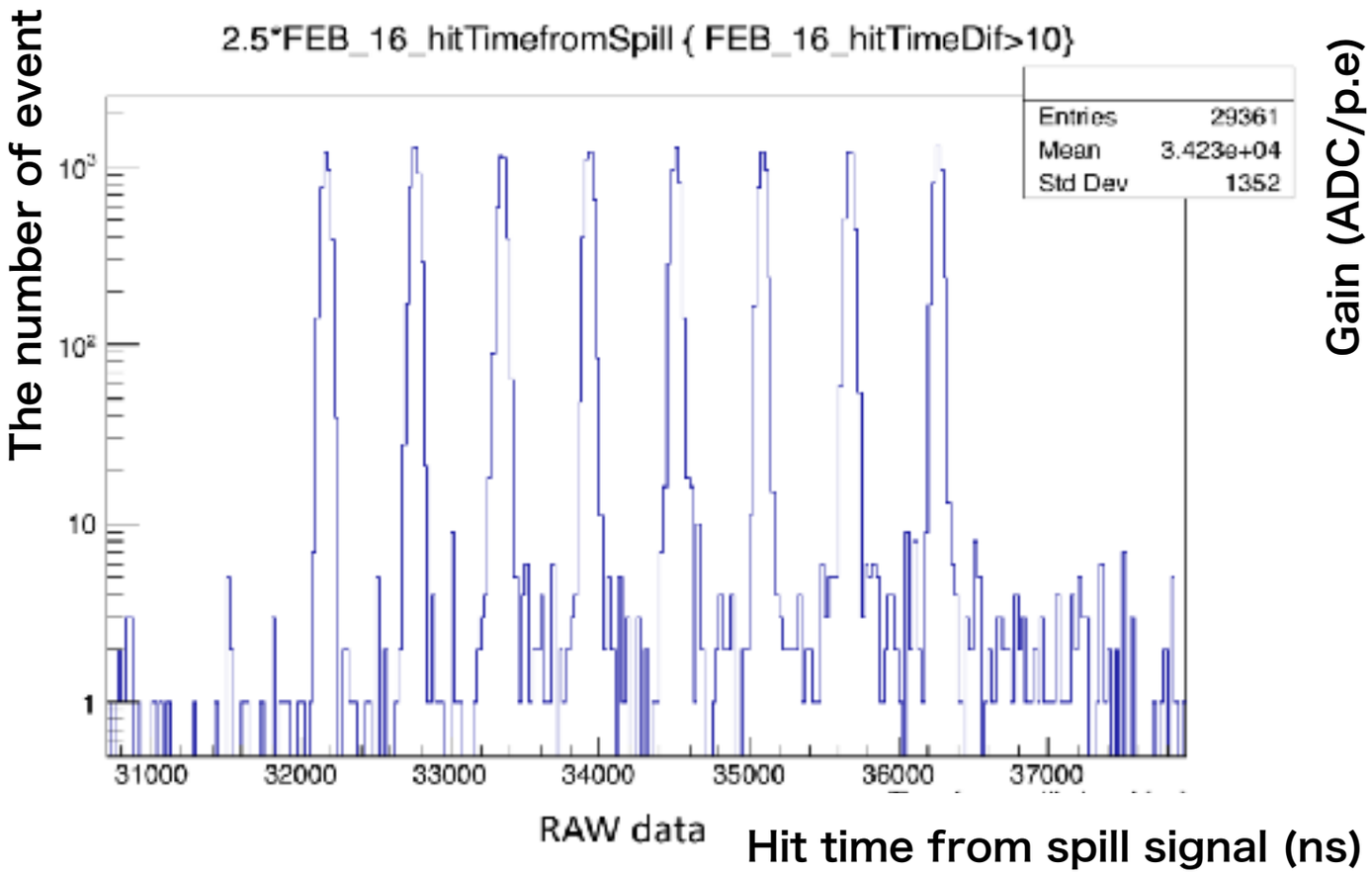


Properties

- Light yield for Hor. ~67 p.e., ~37 p.e. for Ver.
- Time resolution ~707 ps
- Efficiency ~99.9% for both bars

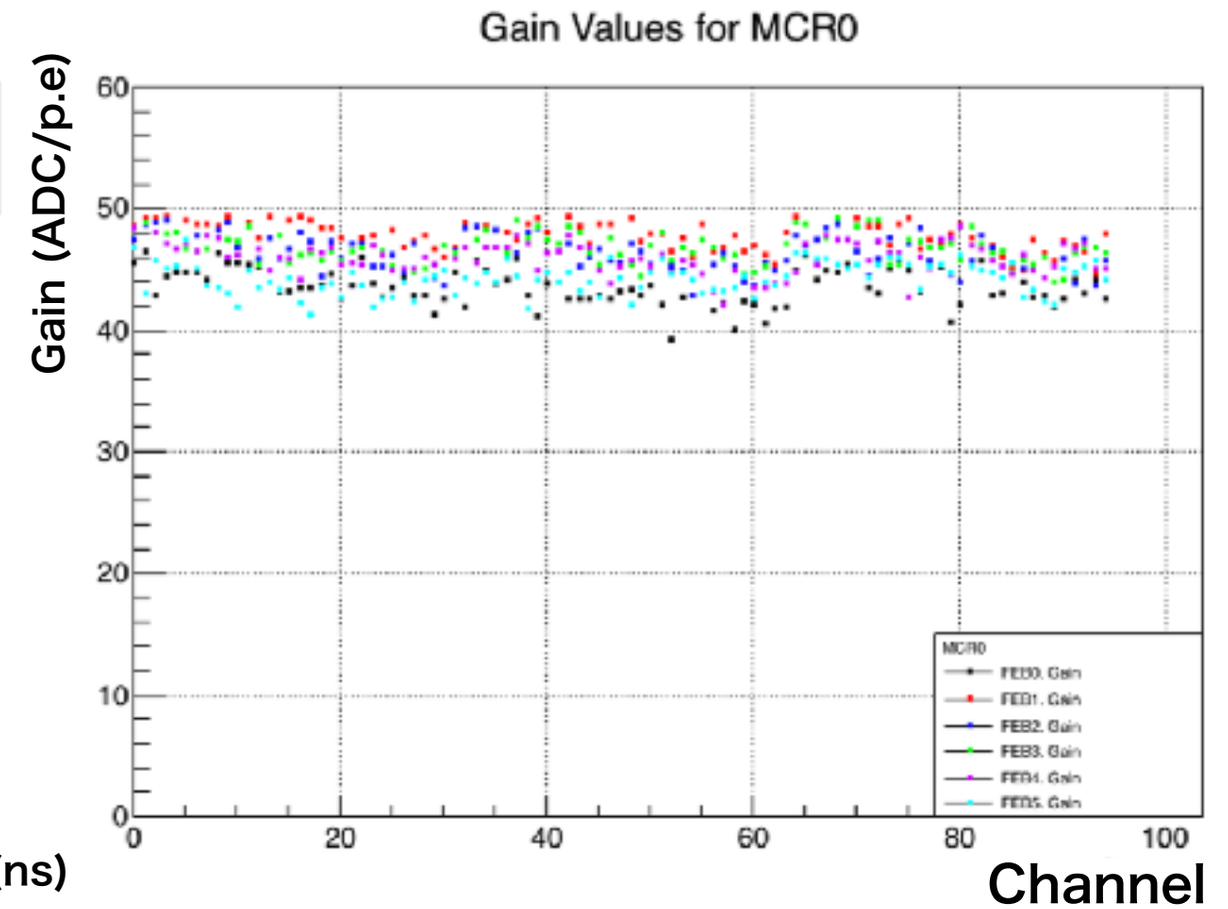
Detector Performance

Event Timing



- Bunch structure of J-PARC neutrino beam. before event selection.
- Most events were in good timing while some noise events were contaminated.

Gain Stability



- All 3996 channels are working.
- Average of gain is ~ 47 count/1 p.e .

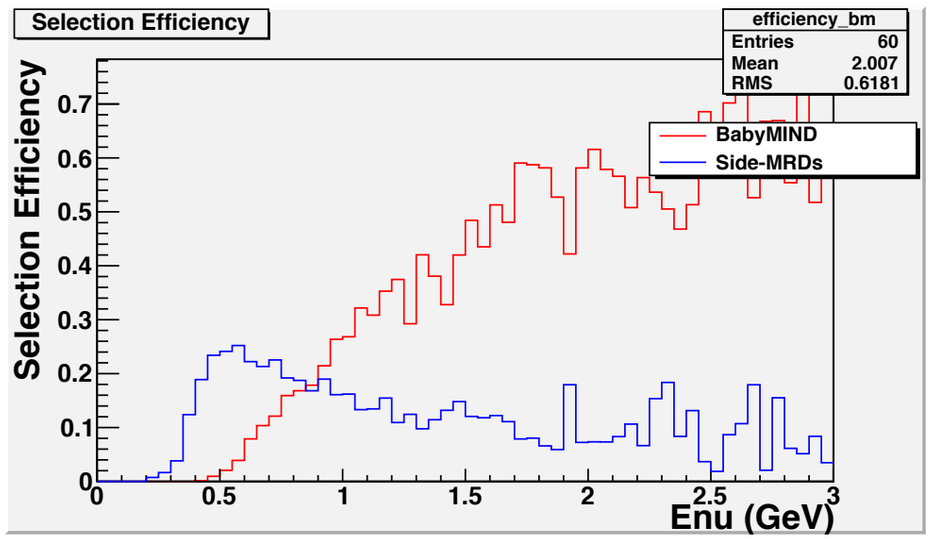
From J-PARC neutrino beam measurement

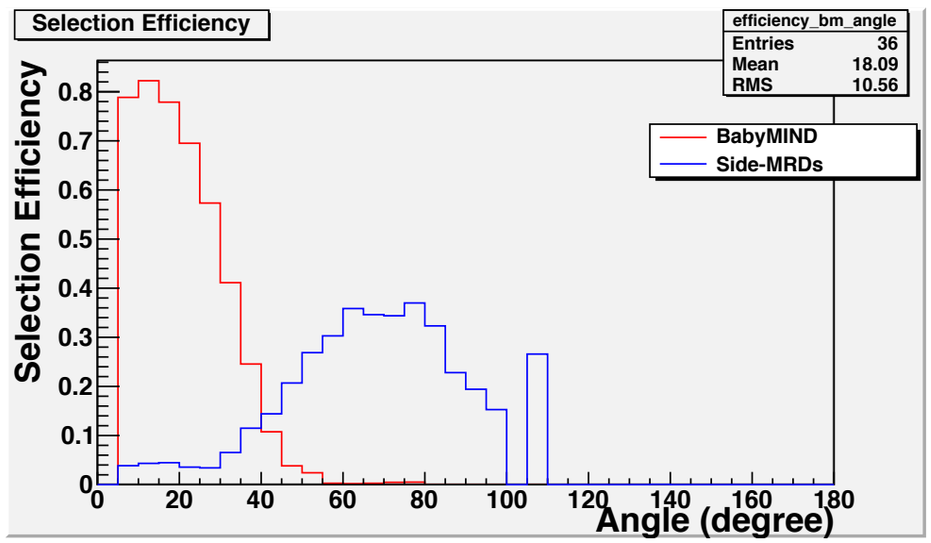
Simulation for Baseline Plan

Detection Efficiency (FV)

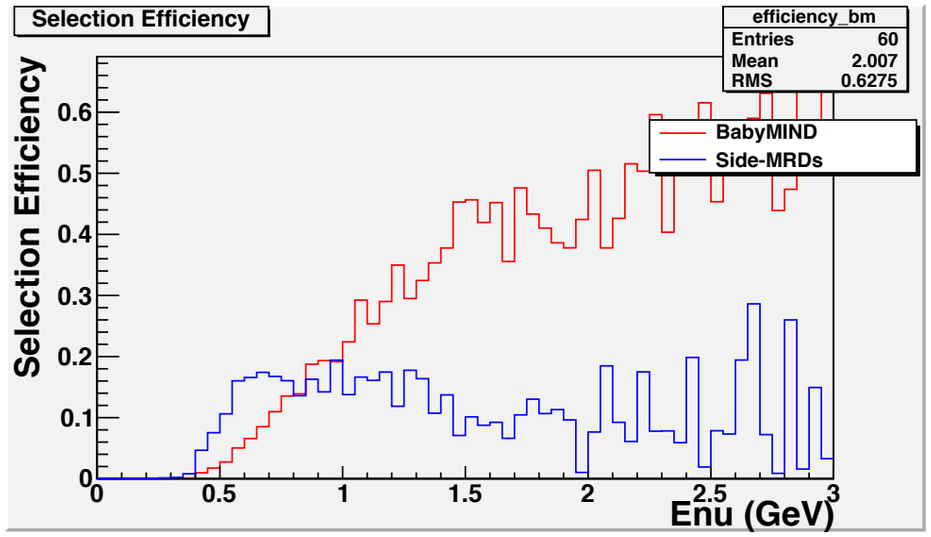
events matching with BM or SMRD/events after FV cut + track reconstruction

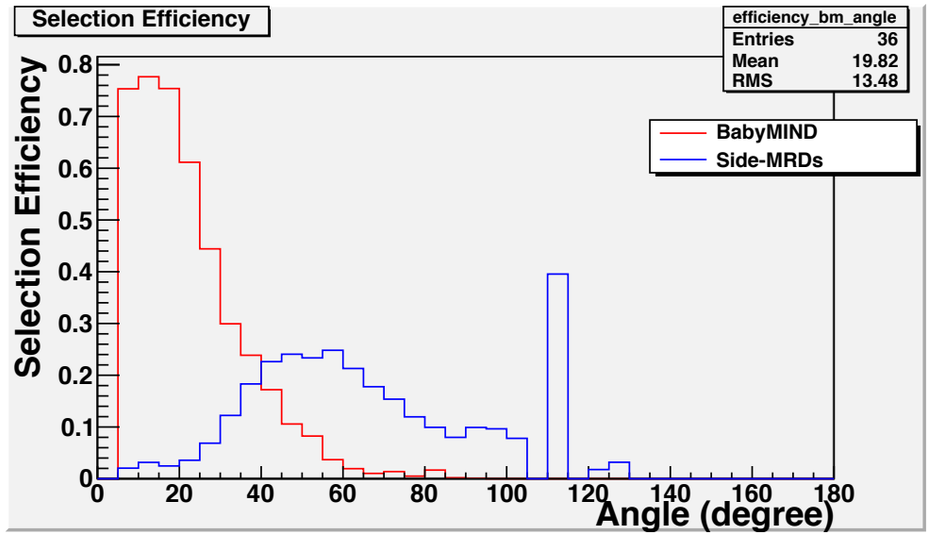
Proton module





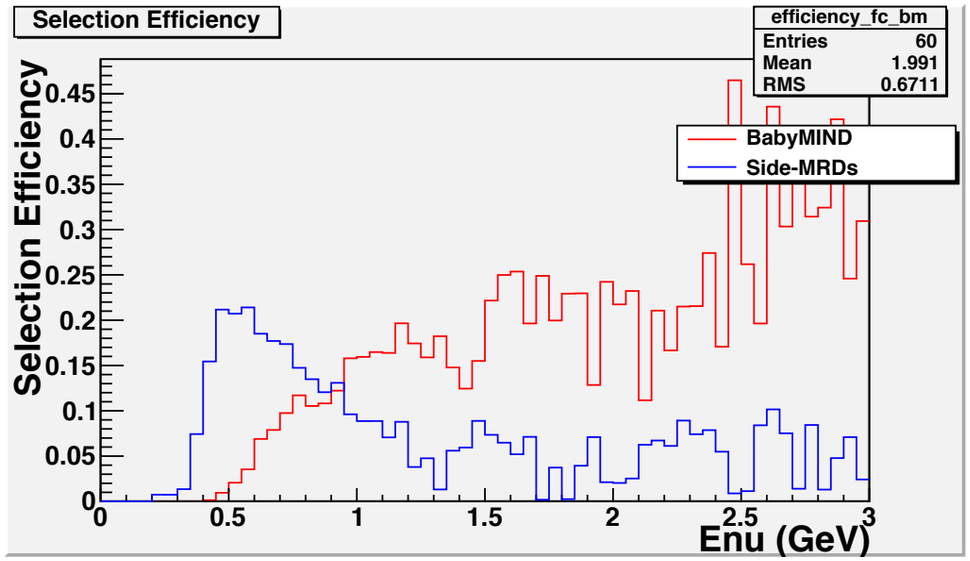
Water-in (upstream)
Water-in (downstream)

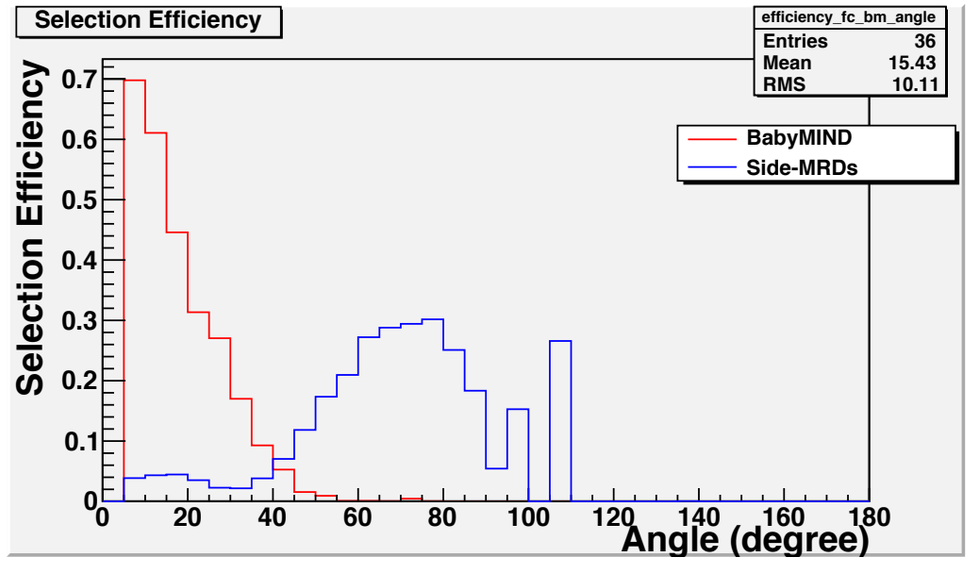




Detection Efficiency (FC)

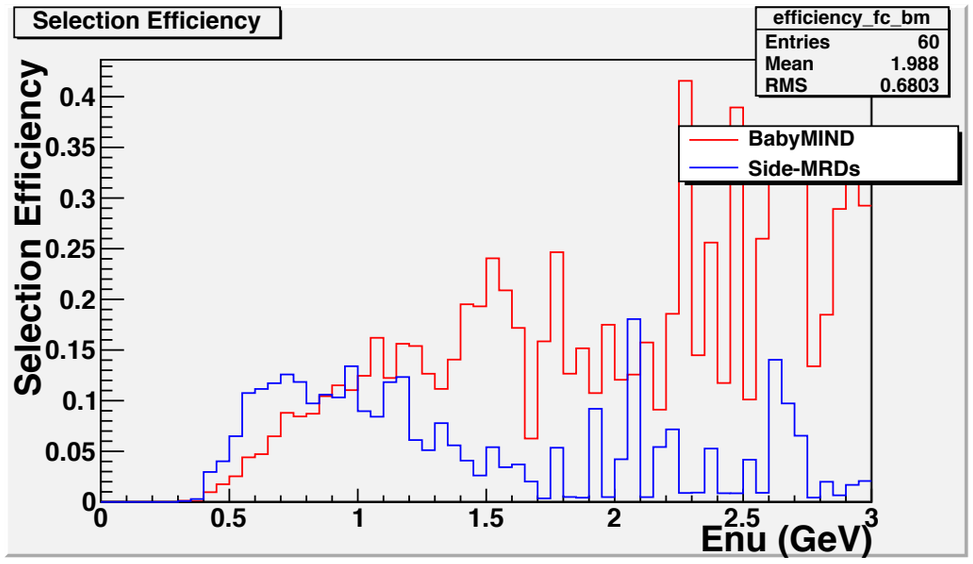
Proton module

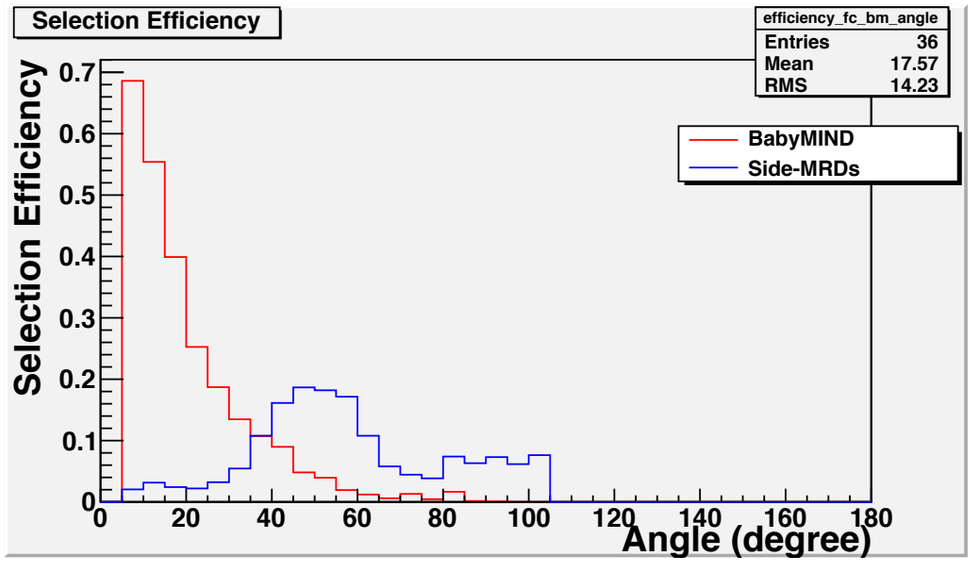




Water-in (upstream)

Water-in (downstream)

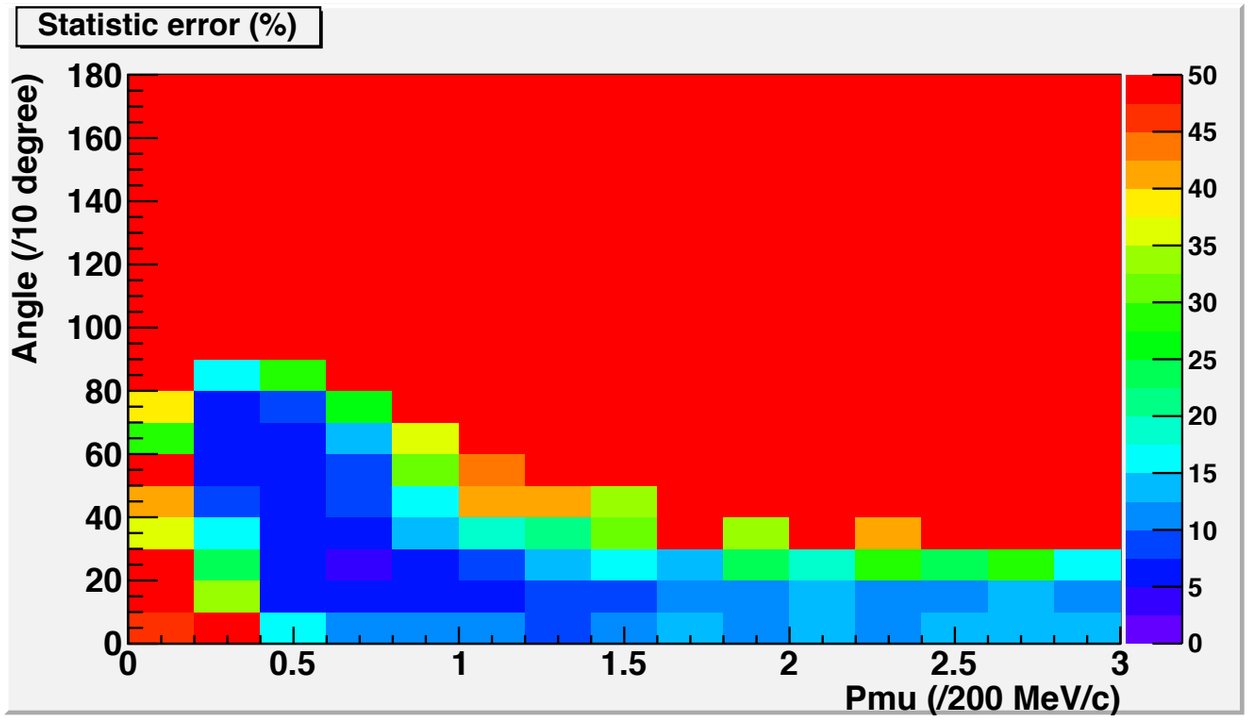


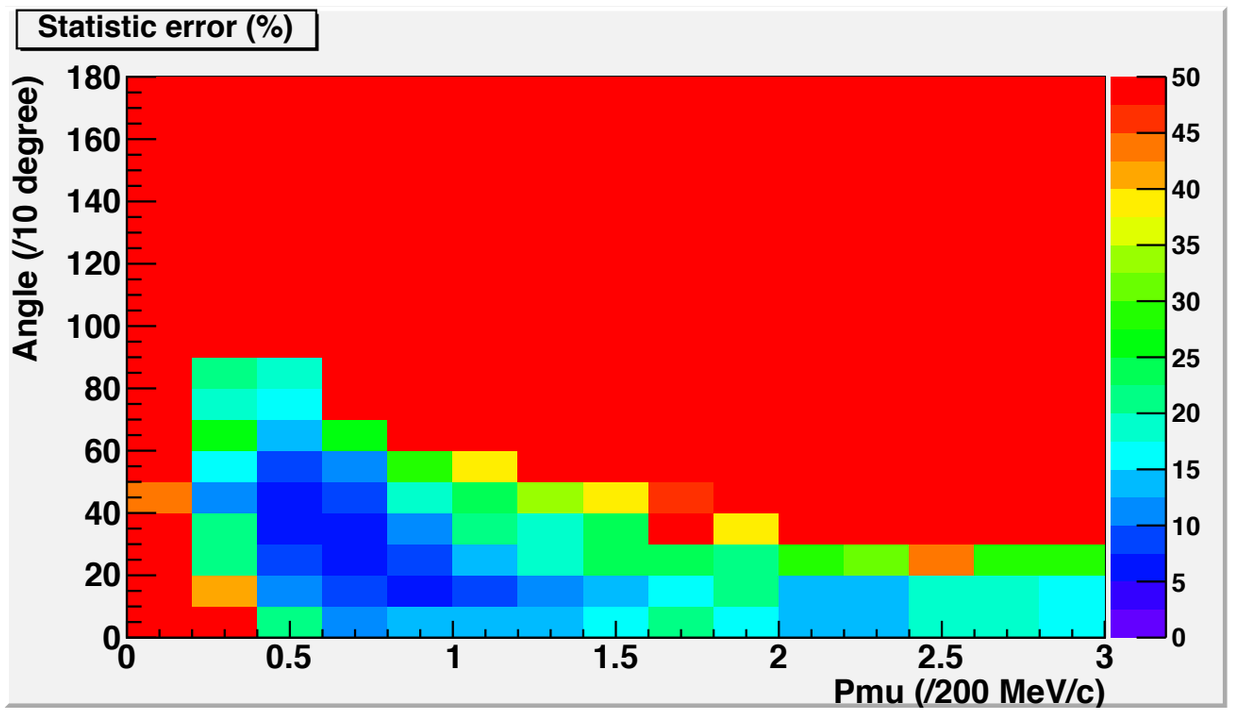


Statistic Error Ratio (of expected events (FC))

Proton module

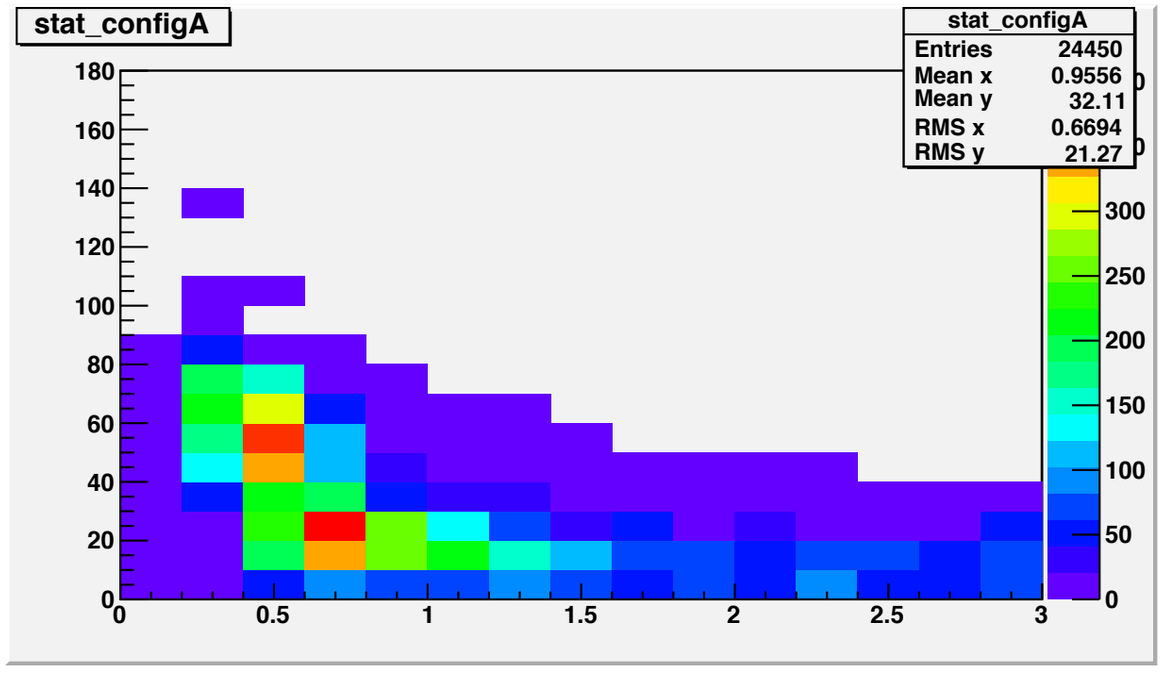
Water-in (u) Water-in (d)





The number (of expected events (FC))

Proton module



Water-in (u) Water-in (d)