NINJA Prospects

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NINJA Internal Workshop, 2020/12/15

NINJA

- NINJA = **N**eutrino **I**nteraction research with **N**uclear emulsion and **J**-PARC **A**ccelerator
- Interaction on water with 200 MeV/c proton threshold.

NINJA so far…

1. Detector test runs -> published — Prog. Theor. Exp. Phys. 063C02 (2017); Prog. Theor. Exp. Phys. 063H02 (2017)
2. Run 6 (60 kg Fe) -> submitted to PTEP — arxiv:2012.05221
3. Run 8 (3 kg H2O) -> published — Phys. Rev. D 102, 072006 (2020)
4. Physics Run a (75 kg H2O) -> now in analysis

What we can see?

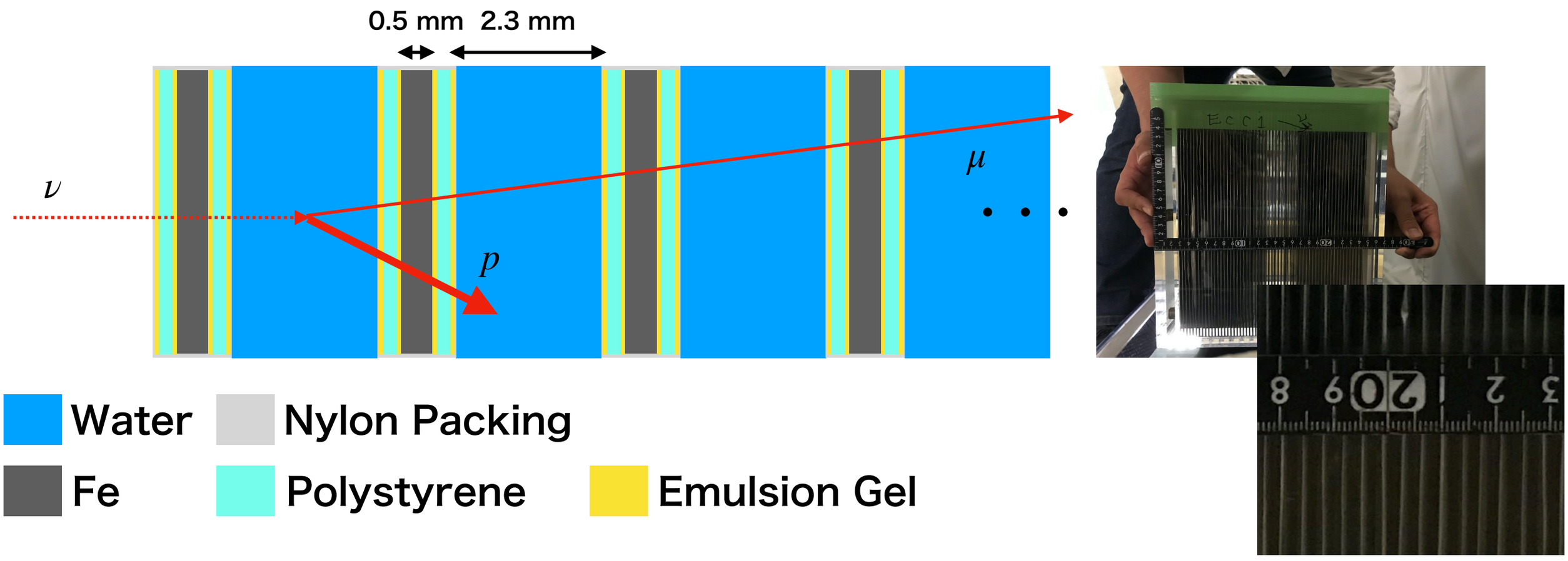
- ECC: charged particle's vector (position & angle) information in each film with high spatial resolution and PID (by dE/dx & momentum information)
  -> reconstruct secondary particle tracks as a connection of tracks in each film
- Baby MIND: dE/dx information as photoelectrons in each scintillator bar
  -> Muon identification, momentum measurement by sufficient range and curvature due to the magnet.

What we cannot see?

- Neutral particle: since emulsion film doesn't have timing information and is insensitive to charged particles, neutral particle tracks cannot be tagged to the interaction vertices.
  -> Neutrons, Neutral pions, Photons, and so on are hard to detect in NINJA.

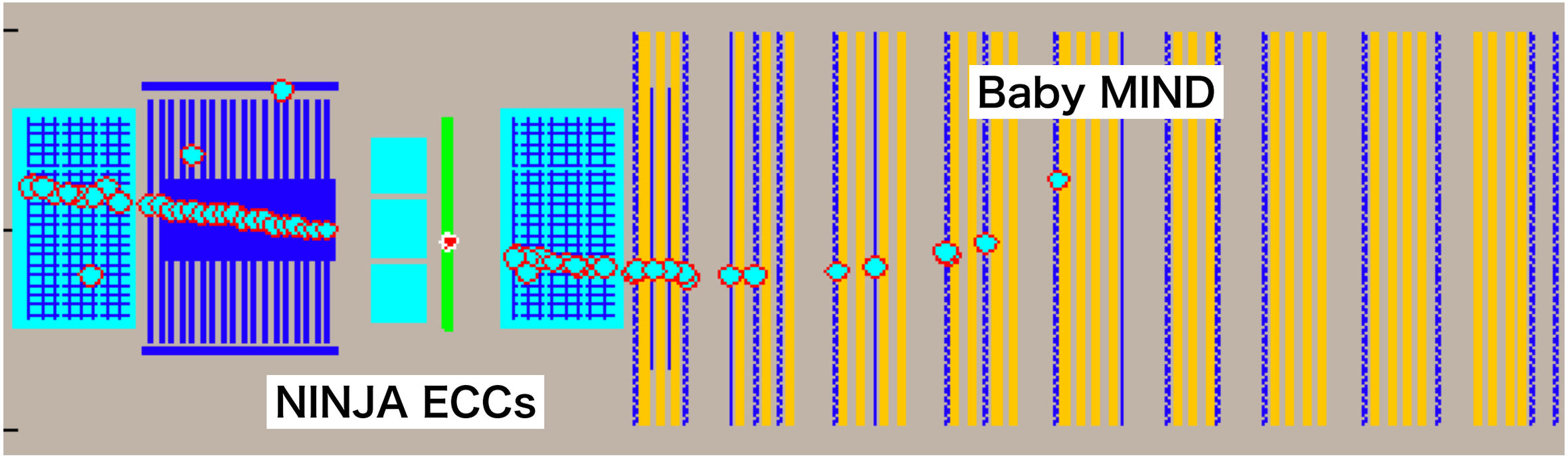
ECC

- Alternate structure of target material and tracking plane.
- Position, angle, and dE/dx at each plane is provided.
- We used 9 ECCs in PRa. -> H2O: 75kg, Fe: 130 kg



Baby MIND

- Plastic scintillators and magnetized iron
- Provide muon id, position, angle, range, and time.
- Muon momentum can be measured by range or curvature in Baby MIND.



Sand muon event candidate

Muon Momentum

- NINJA requires Baby MIND tracks to identify muons
  -> momentum threshold ~300 MeV/c
- We have several choices to measure momentum

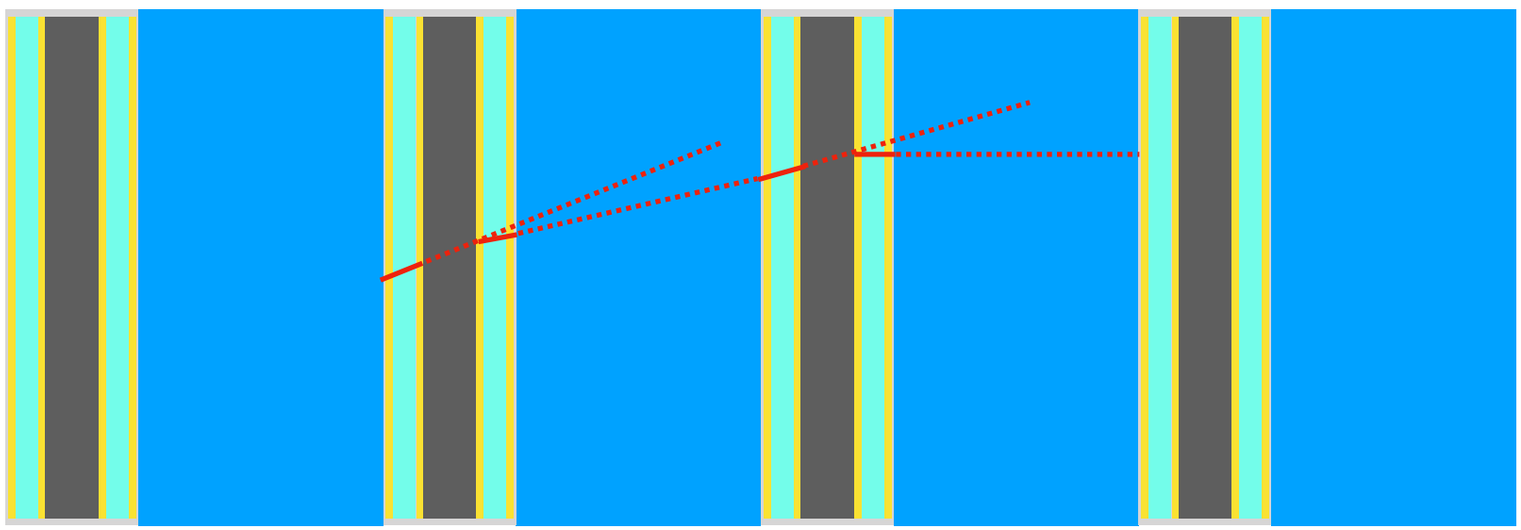
  1. Baby MIND Range (< 1.5 GeV/c)
     several % resolution but the track should be fully contained in Baby MIND fiducial volume
  2. Baby MIND Curvature (< a few GeV/c?)
     Resolution is worse but measurable for penetrate and side escaping tracks
  3. ECC Multiple Coulomb Scattering (next slide)

MCS

- We can estimate the momentum of charged particle from the deviation of angle difference by MCS

$$\theta_0 = \frac{13.6\ \mathrm{MeV}}{\beta cp} z \sqrt{\frac{x}{X_0}} \left[1 + 0.038 \ln \left(\frac{xz^2}{X_0 \beta^2} \right) \right]$$

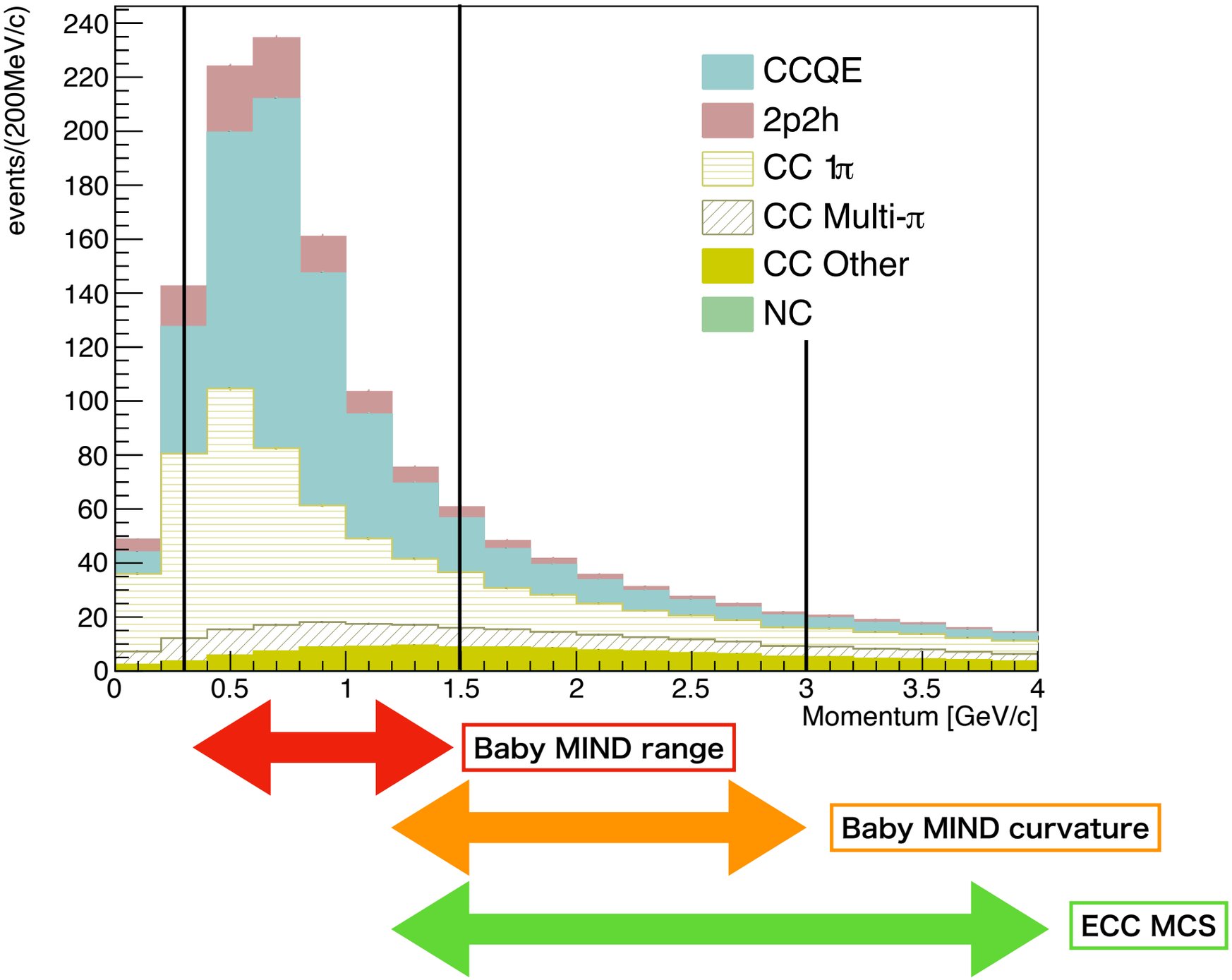
- Good angle resolution allows us this calculation!!
- 30% resolution up to 5 GeV/c



Muon Momentum

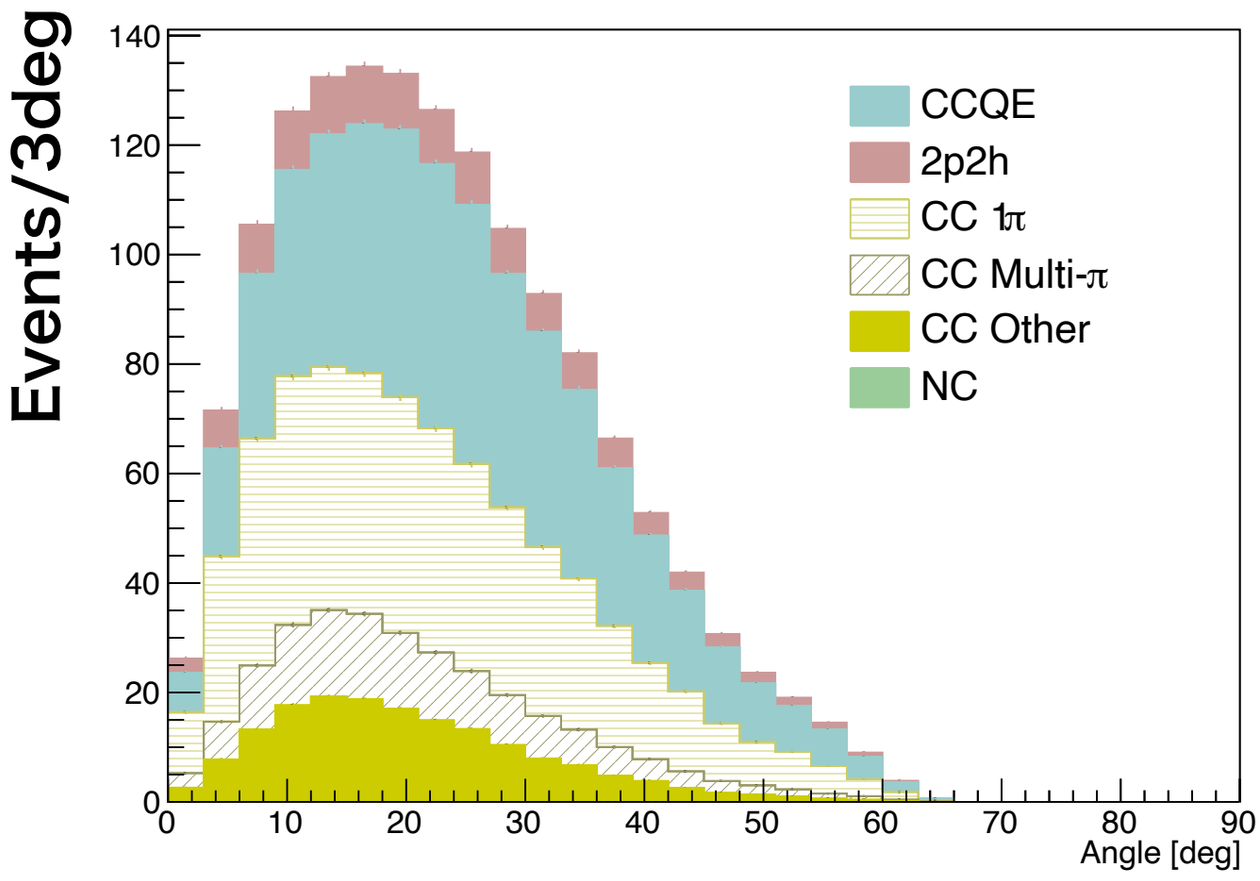
All plots later is NEUT generator level (detector simulation not considered)

Threshold



Muon Angle

- After matching between emulsion and Baby MIND, we can measure muon angle by film information
  -> precise angle information ~O(mrad)
- Angle acceptance is ruled by Baby MIND



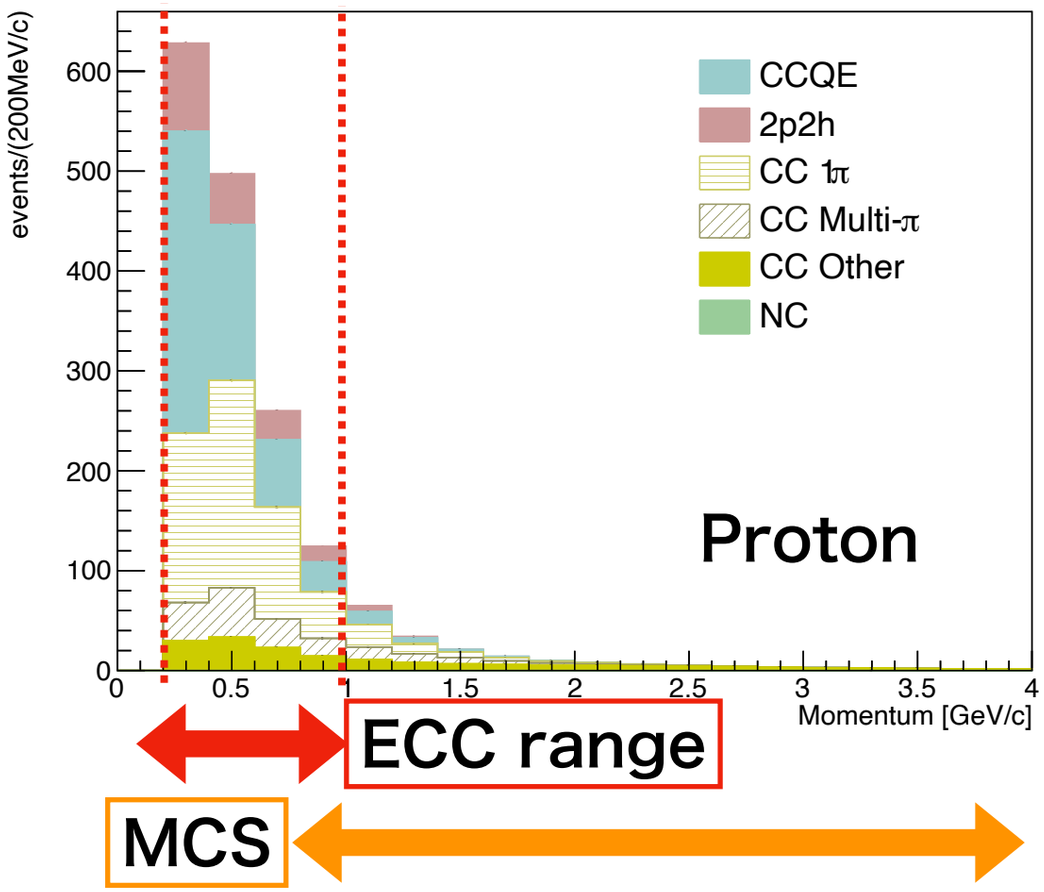
Summary of Muon Phase Space

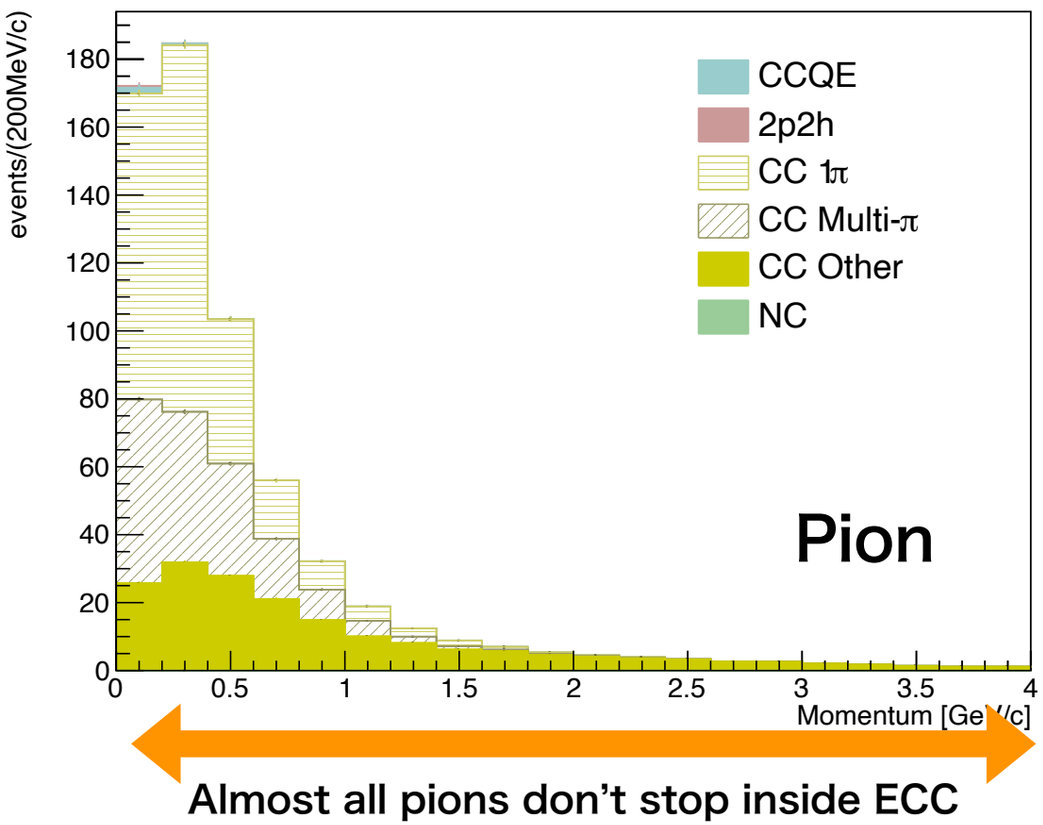
		Baby MIND Range	Baby MIND curvature	ECC MCS
Momentum	Minimum	300 MeV/c (3 layers of Baby MIND)		
	Maximum	1.5 GeV/c	A few GeV/c	~5 GeV/c
	Resolution	5%	30%	30%
Angle	Maximum	$\lvert\tan\theta_{x(y)}\rvert < 1.5 - 2.5$		
	Resolution	O(mrad)		

- Charge ID efficiency: > 90%, purity: 99.5%

Charged Pion/Proton Momentum

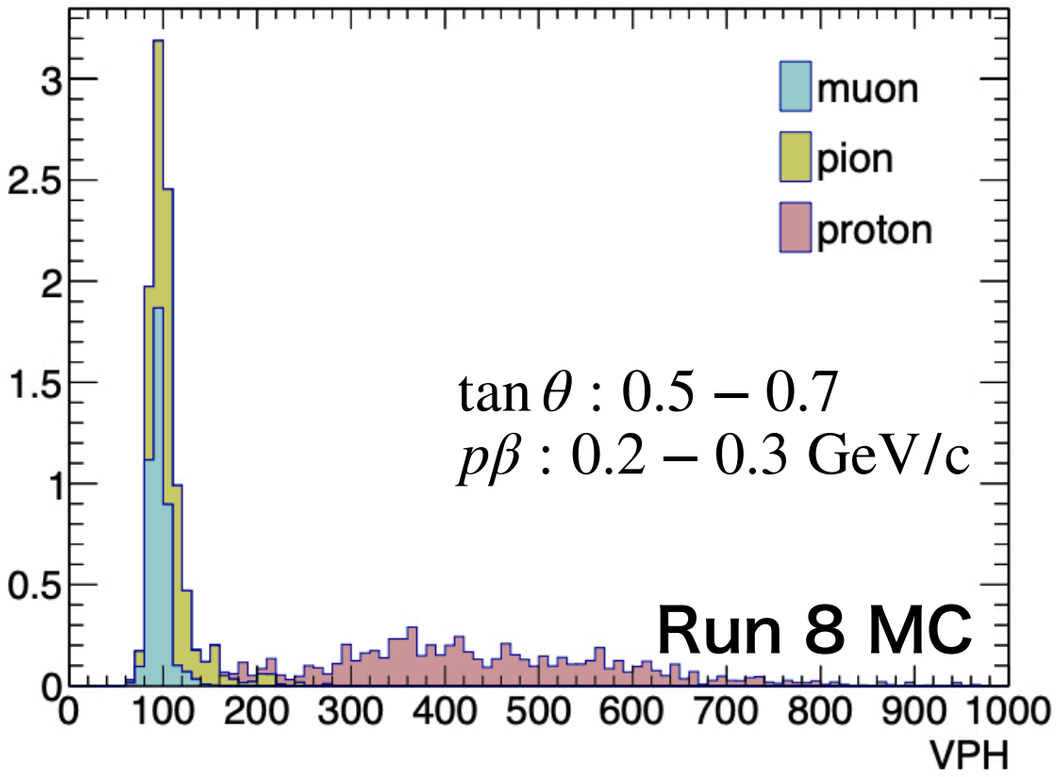
1. ECC range: fine segmentation for fully contained tracks (~5% resolution)
2. ECC MCS: same as the muon momentum measurement and applicable even for escaping tracks (30-40% resolution)

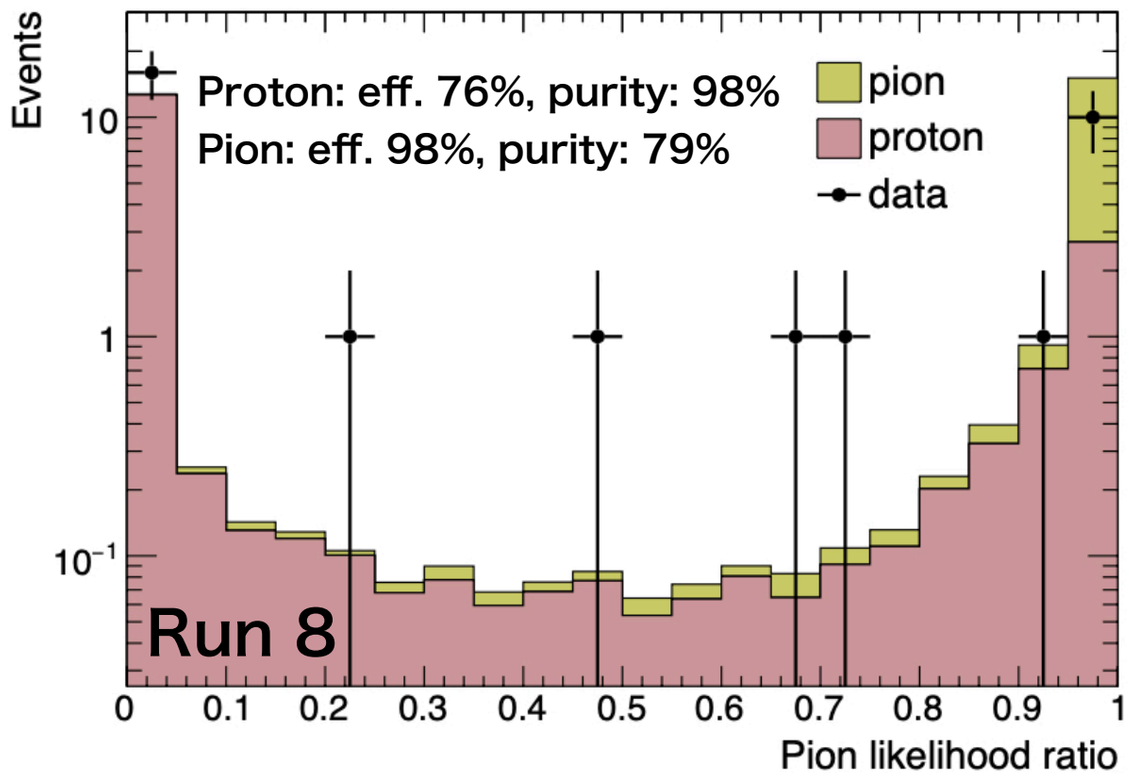




Charged Pion/Proton PID

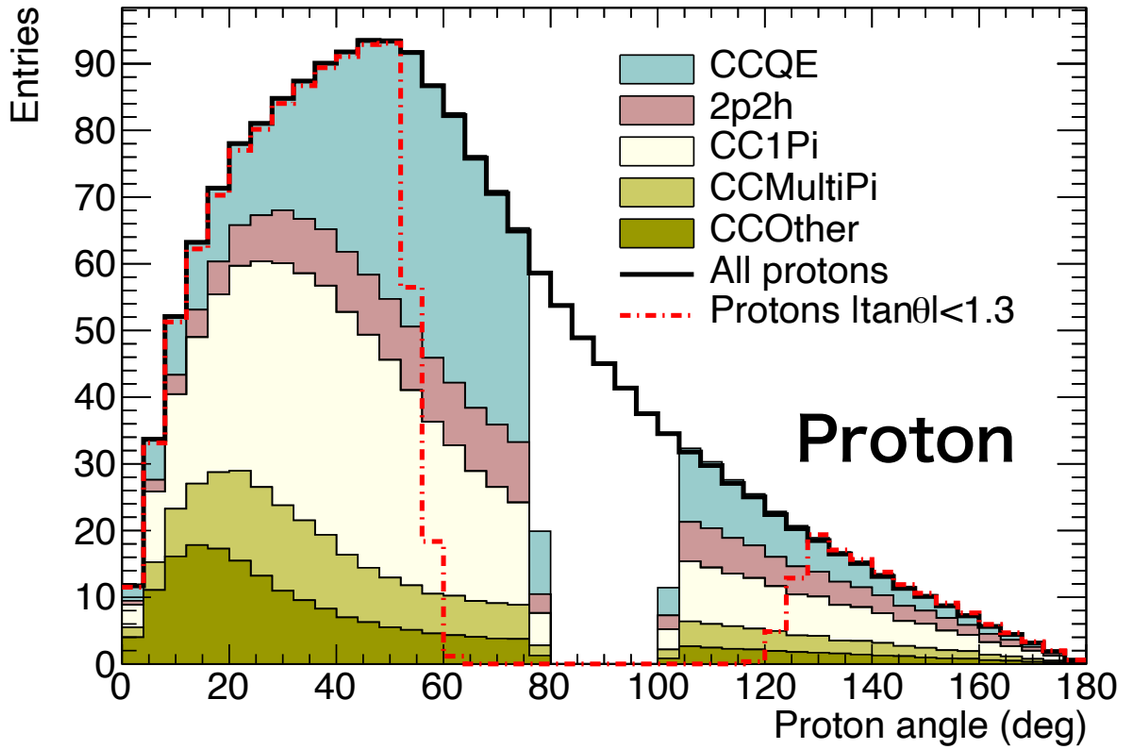
- Particle identification for hadrons is possible using momentum ($p\beta$) and track blackness (dE/dx).
- # of pixels in a track is measured during film scanning -> MIP (π) and black (p) peaks

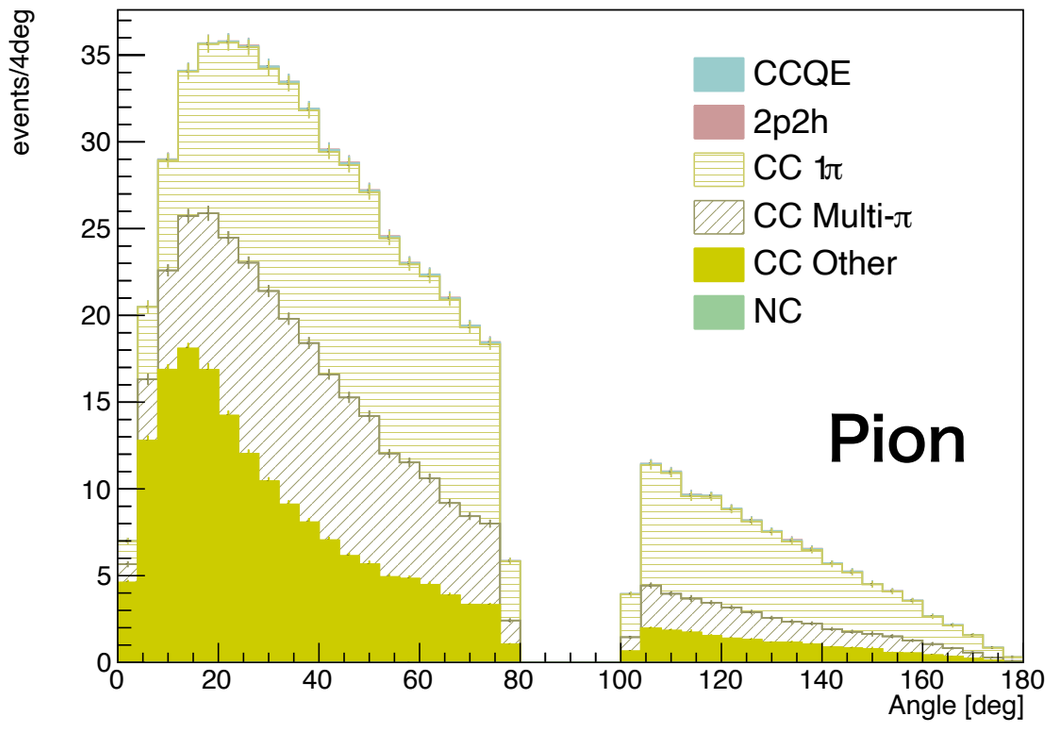




Charged Pion/Proton Angle

- Secondary hadron acceptance is ruled by scanning acceptance. (Currently $|\tan\theta_{x(y)}| < 4.0$)
- O(mrad) resolution of emulsion films





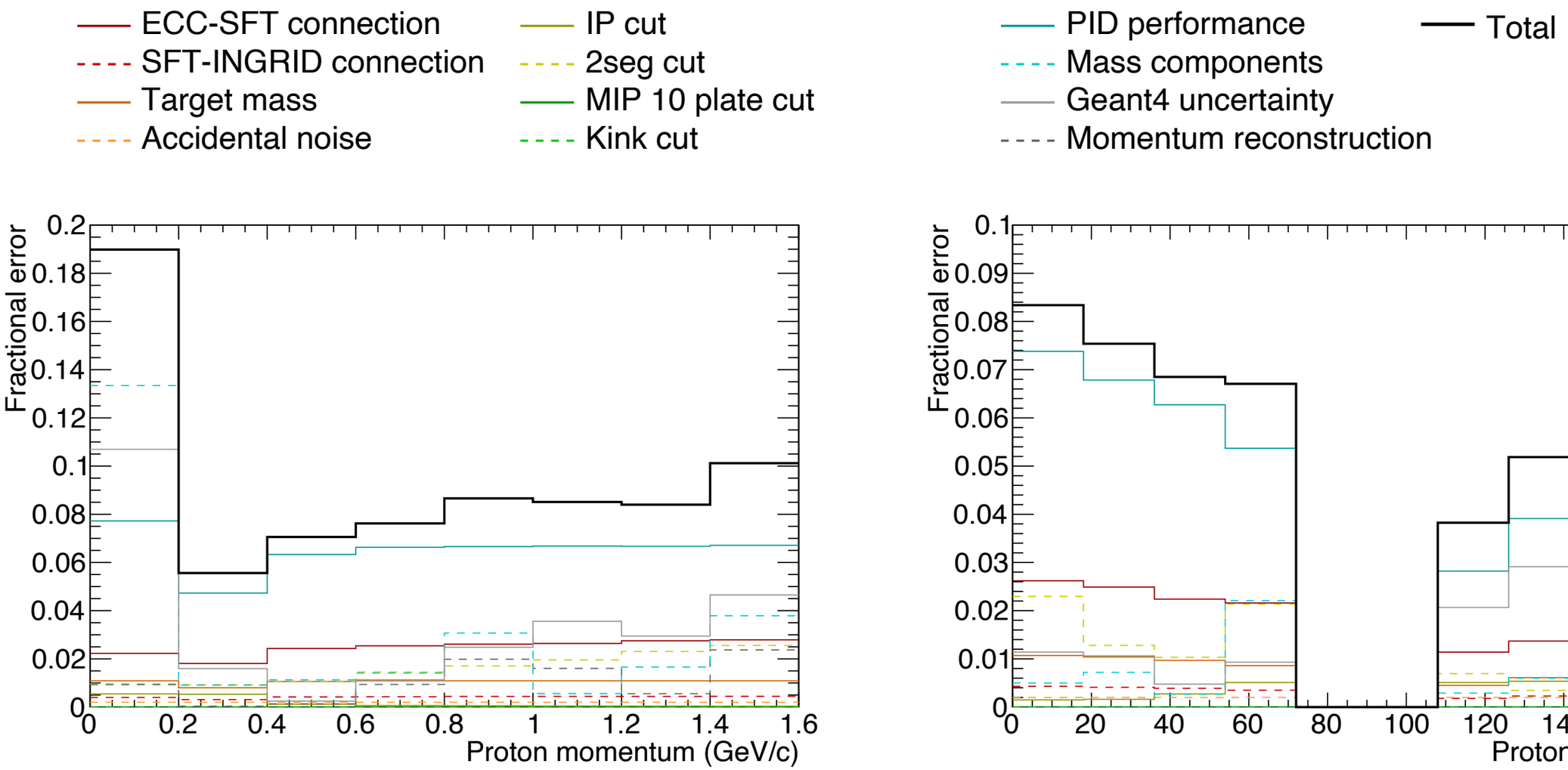
Summary of Charged Pion/Proton Phase Space

- Proton PID efficiency: 76%, purity: 98%
- Pion PID efficiency: 98%, purity: 79%

		Range	MCS
Momentum	Minimum	200 MeV/c (p) 50 MeV/c (π)	-
	Maximum	< 1 GeV/c (p)	~5 GeV/c
	Resolution	5%	30-40%
Angle	Maximum	$\lvert\tan\theta_{x(y)}\rvert < 4.0$	
	Resolution	O(mrad)	

Detector Uncertainty

- Uncertainty from detector response for muon is ~ a few %, while for hadrons is ~ 10%
- To be reduced ~ a few % (PID performance)



Pion is in backup

Analysis overview

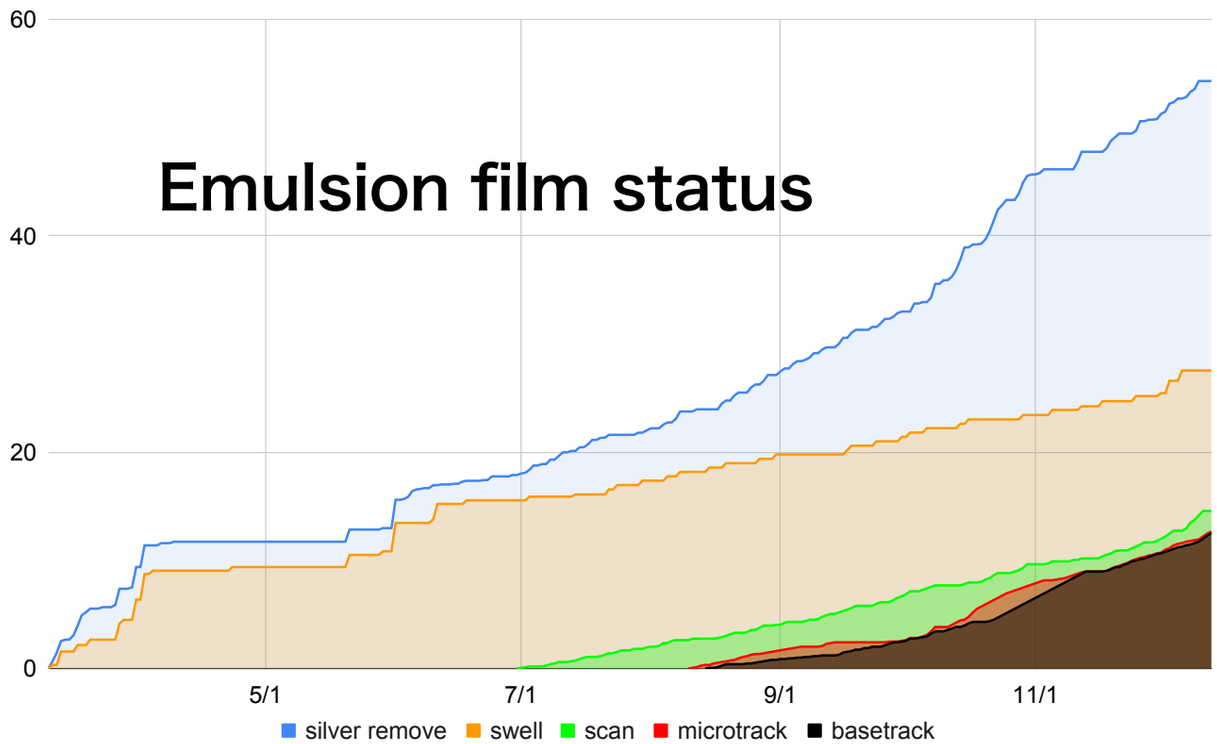
1. Position/angle reconstruction in each detector
   (ECC, Shifter, Tracker, Baby MIND)
2. Connect tracks of each detector
   using position/angle/timing information
   -> Muon identification
3. Analysis of emulsion film tracks

We can measure…

- (Charged) particle multiplicity
- Position/angle of each track
- dE/dx and pβ -> particle id

Analysis Prospects

- We finished 1 ECC scanning (analysis preparation)
  -> Our first target is to measure numu CC interaction with ~8 kg water within this JFY.
- BabyMIND-ECC muon matching and ECC analysis are now ongoing.



Current Analysis Plan

- We have a few students to analyze the data.
- Our first goal is to measure
  muon neutrino-water(/iron) charged-current
  p-θ differential cross section
  (phase space limited)
  w/ proton multiplicity
  (no charged pion and phase space limited)
- CCNpiN'p? Emulsion/plastic interaction? Electron neutrino interaction? (In the future)

How can we contribute to T2K?

NINJA

1. Internal constraint

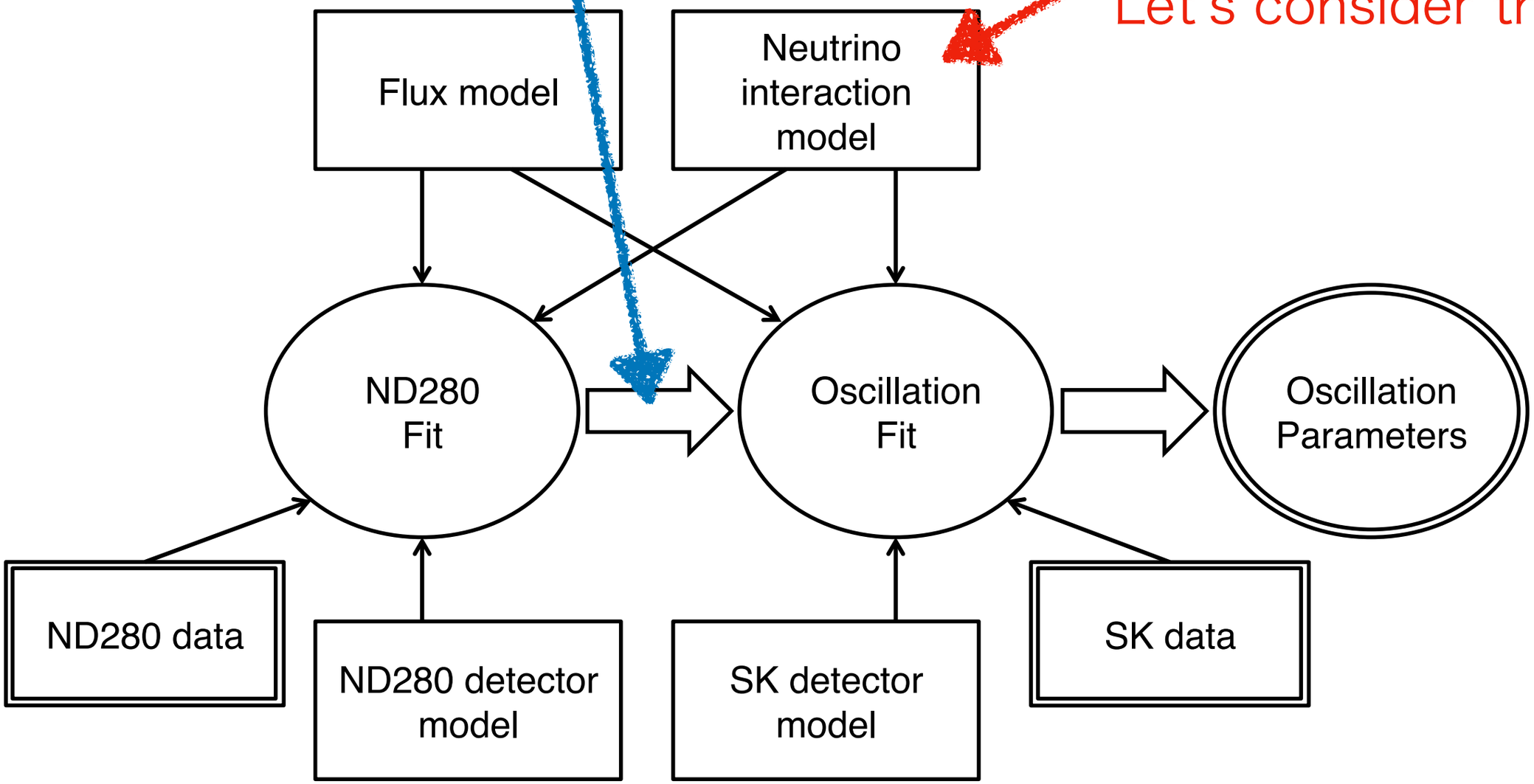
Fitting NINJA data after BANFF

=> not strong …

2. External constraint

Test/validate models by NINJA measurements

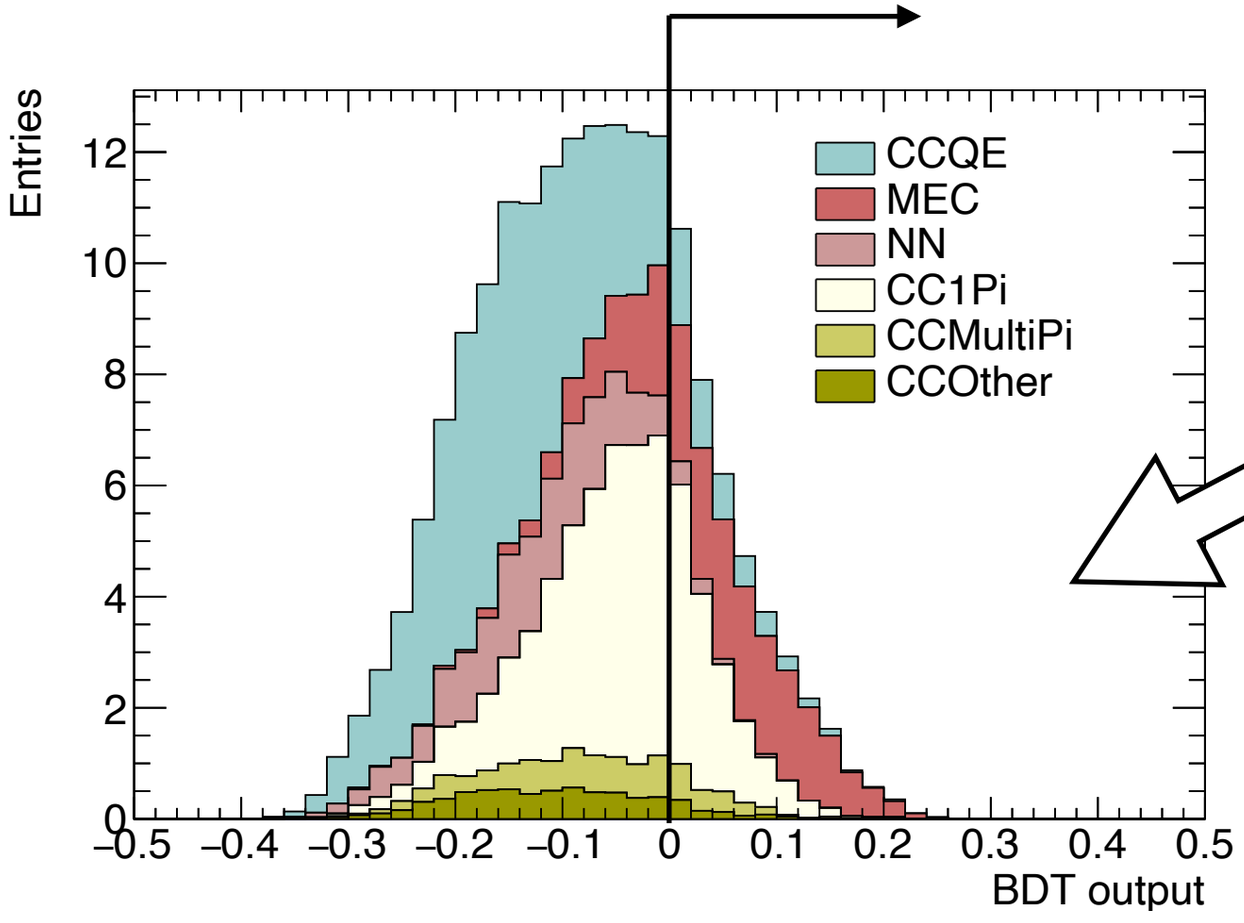
Let's consider this



Multivariate analysis

- NINJA can obtain precise proton information
  -> Multivariate analysis using muon & proton kinematics

e.g.) Extracting MEC-like interactions in CC0pi2p sample



(E71a stat.)

MEC: 18.5 events

Background: 23.3 events

Background uncertainty: ~15%

Schedule

PRa (T2K run10) | Run 9 (T2K run11) | PRb (T2K run12?)

JFY2021

1 ECC scan finish
Establish analysis procedure

Full target mass result

New detectors now prepared

Beam exposure

Development

Performance study for PRb

Feedback

Mass production of emulsion films

Beam exposure

JFY2022

Summary

- NINJA experiment measures neutrino-nucleus interactions with nuclear emulsion detectors.
- Muon momentum is basically measured by Baby MIND and detailed angle information around the vertices can be acquired in ECCs.
- Charged hadron measurement by ECCs
  PID, and momentum, angle phase space are described.
- Physics run analysis, OA sensitivity study, and future experiment preparations are now ongoing.

Backup