NINJA

Status of the NINJA experiment

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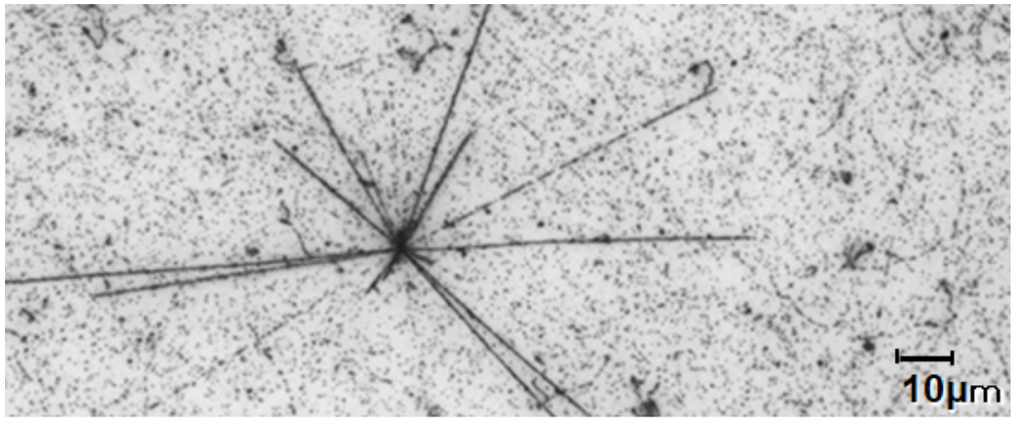
for the NINJA Collaboration

The 23rd International Workshop on Neutrinos from Accelerators
August 5th, 2022 @ the Cliff Lodge at Snowbird

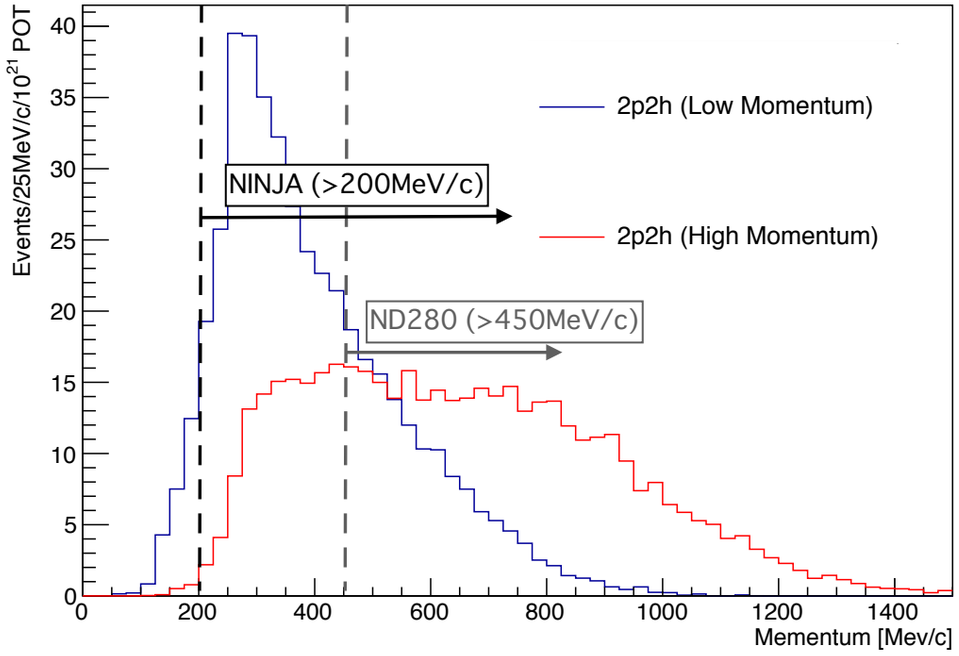
NINJA

- Neutrino Interaction research with Nuclear emulsion and J-PARC Accelerator
- Measurement of low-momentum charged hadrons from neutrino-nucleus interactions with high spatial resolution of emulsion detectors.

Neutrino interaction candidate in nuclear emulsion @ J-PARC



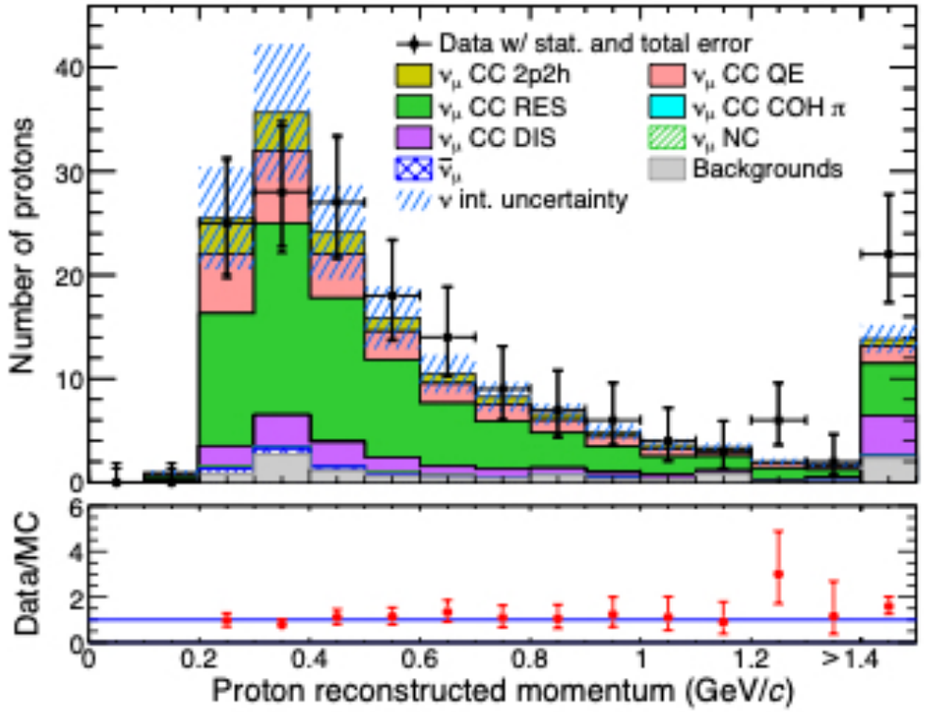
Proton momentum (NEUT5.4.0, water 2p2h interaction)



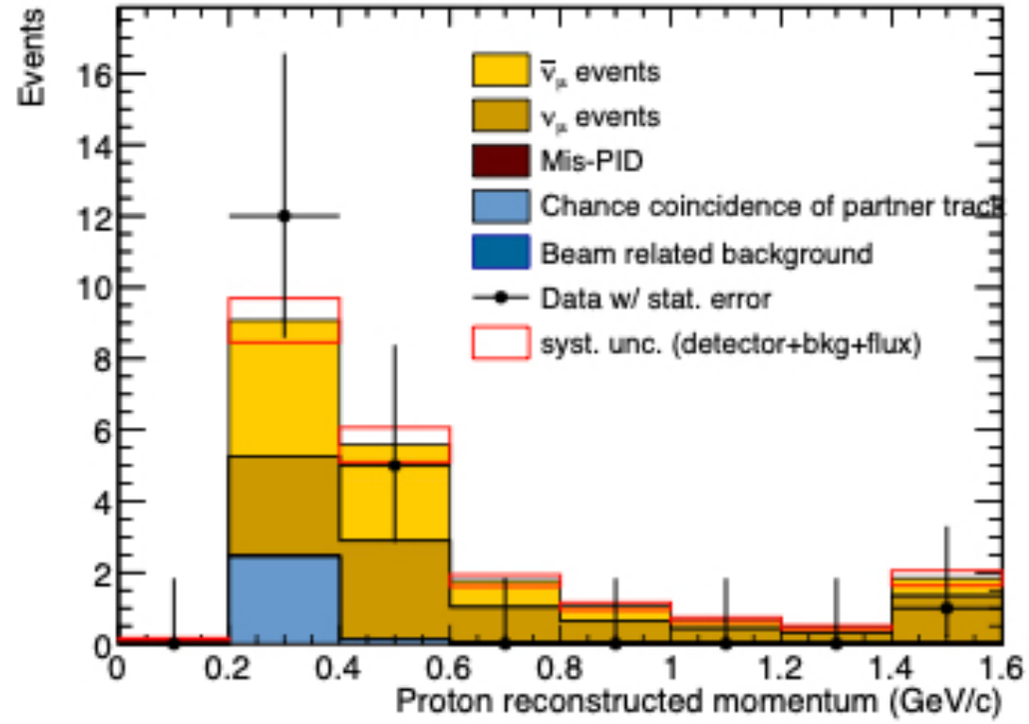
NINJA pilot runs

- J-PARC T60 : Feb. - May 2016 (65 kg Fe target)
- J-PARC T68 : Oct. 2017 - May 2018
  (3 kg water target)

65 kg iron target run



3 kg water target run



Detection of protons from interactions with 200 MeV/c threshold

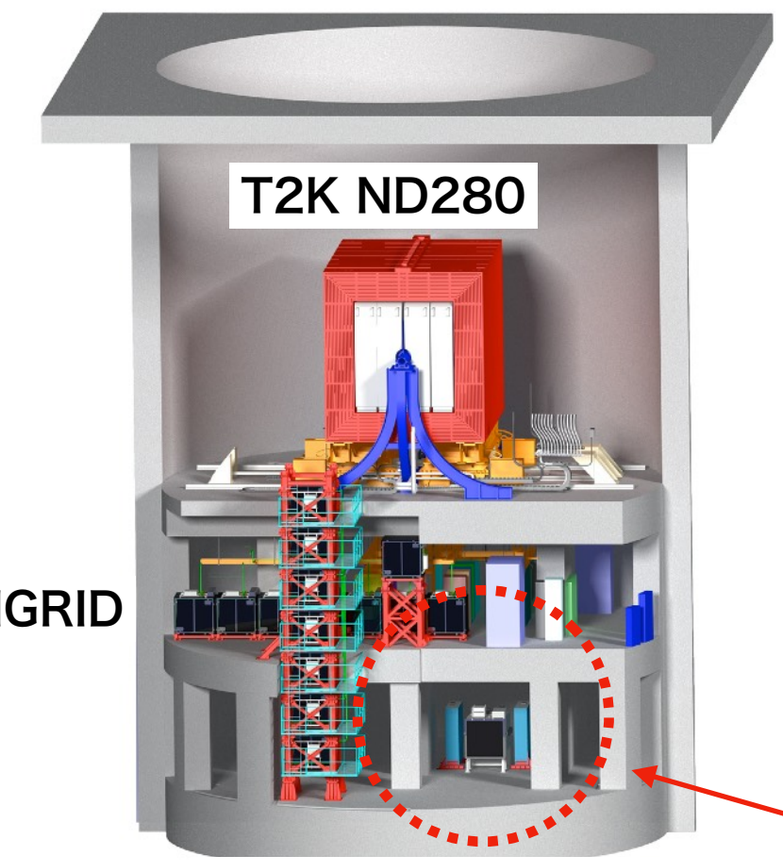
Prog. Theor. Exp. Phys. 2021(3), 033C01 (2021).

arXiv:2203.08367

Phys. Rev. D 102, 072006 (2020).

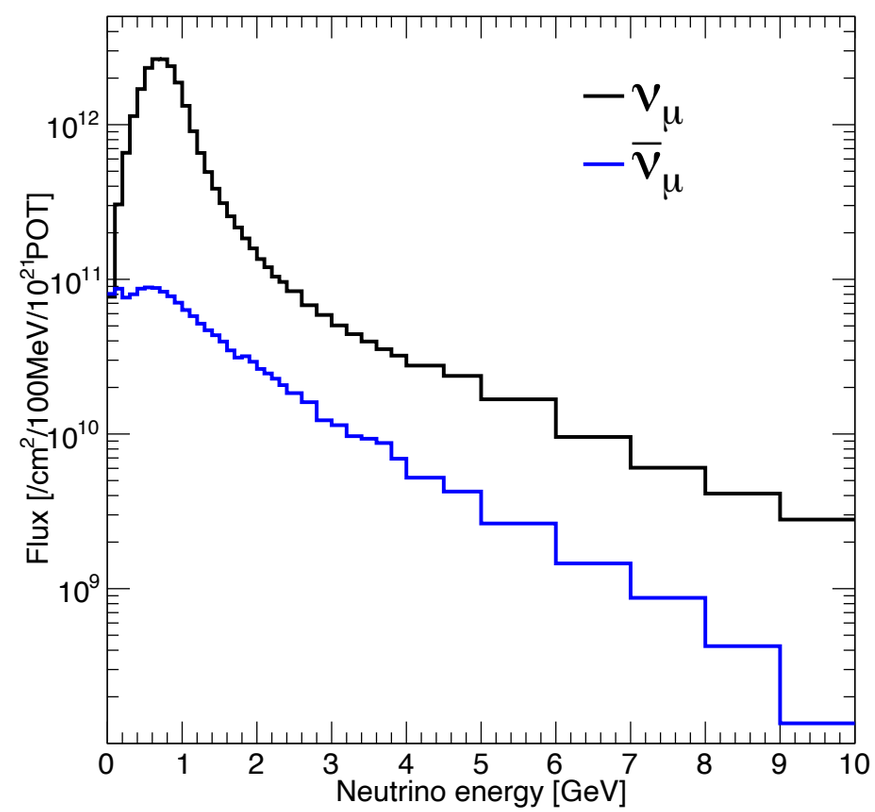
NINJA physics run

- J-PARC E71a : Nov. 2019 - Feb. 2020
  (75 kg water target)
- First physics run of the NINJA experiment



T2K WAGASCI + NINJA

Detectors located in
B2 floor of the T2K ND hall

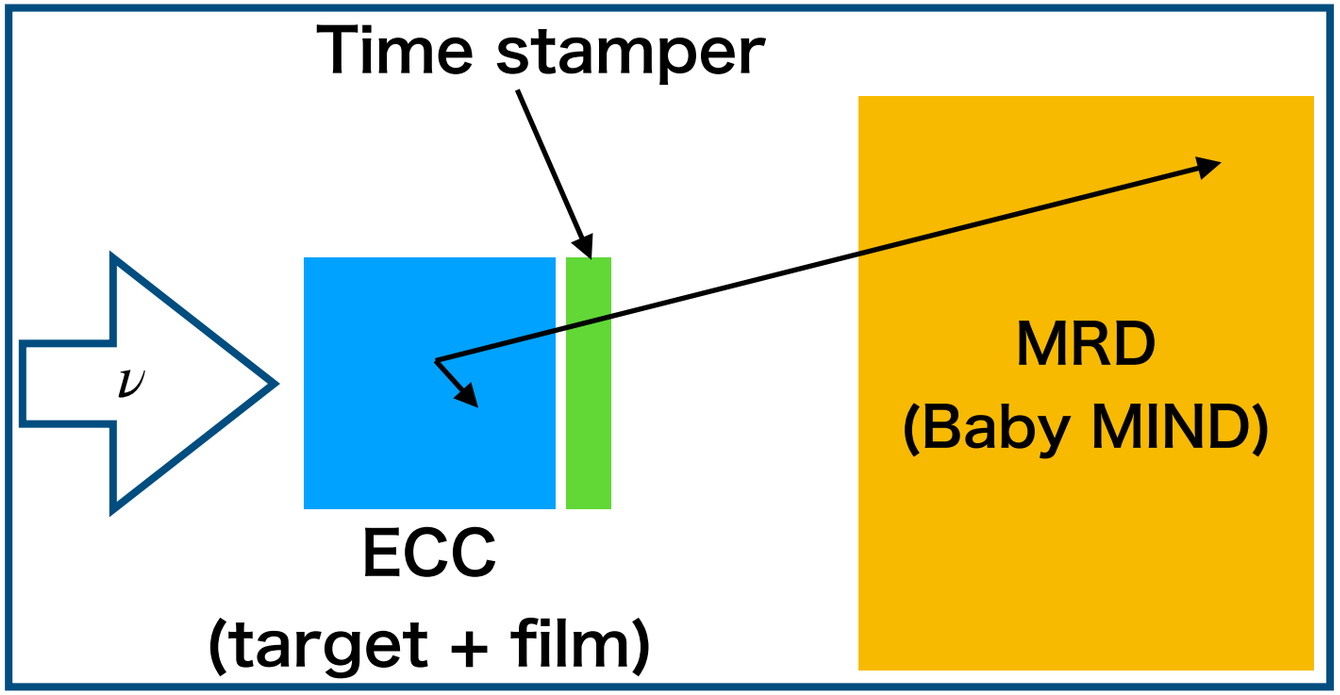


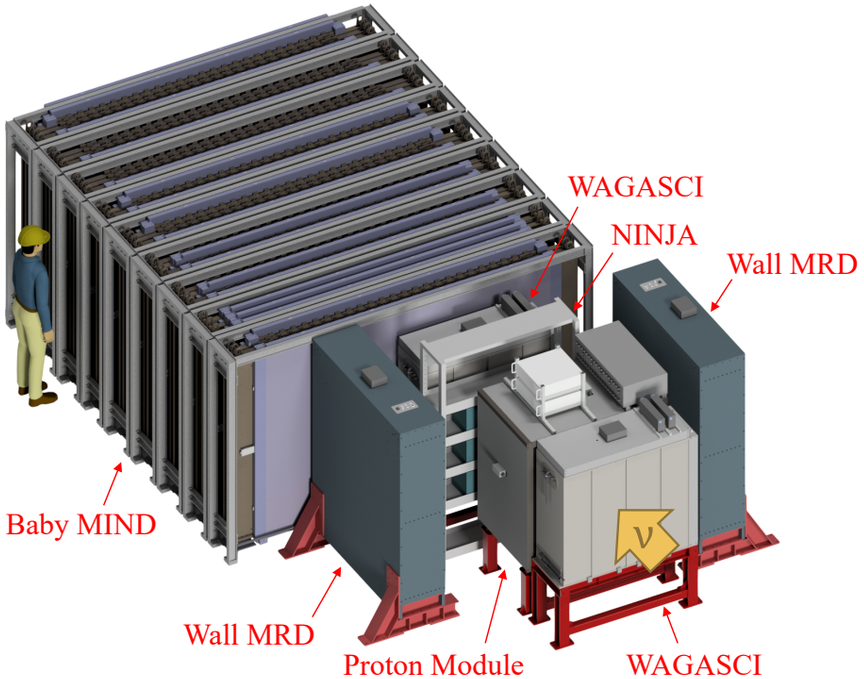
Flux at the detector location

Detectors

- Emulsion/scintillator hybrid apparatus

	ECC	Time stamper	MRD
Position/angle	◎	○	△
Time	×	◎	◎
Particle ID	Proton/pion	×	Muon ID

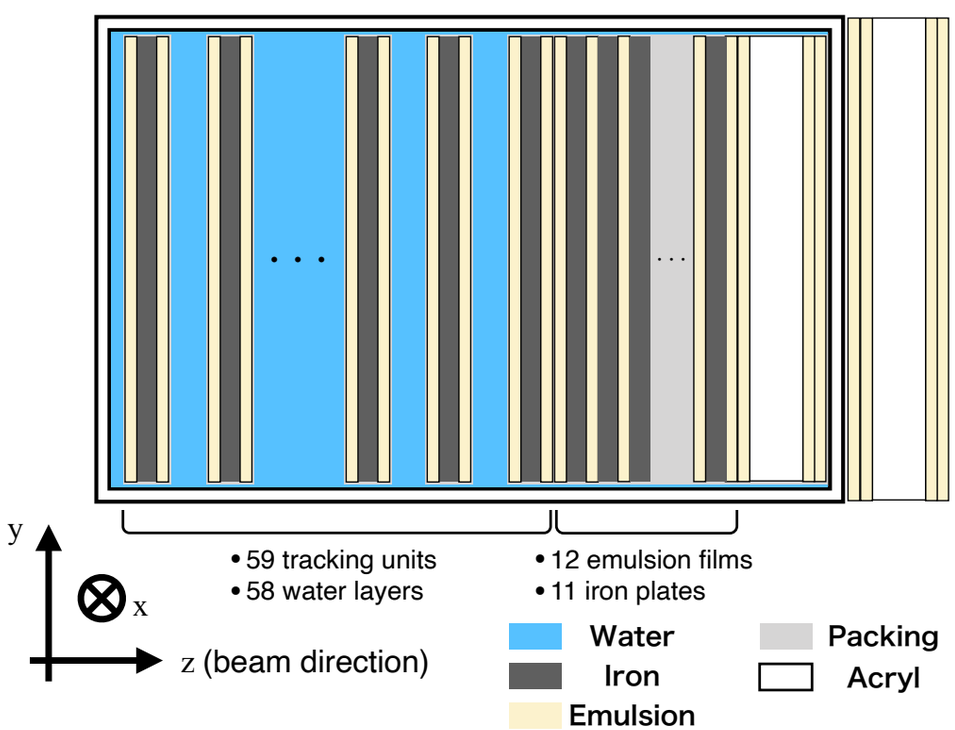


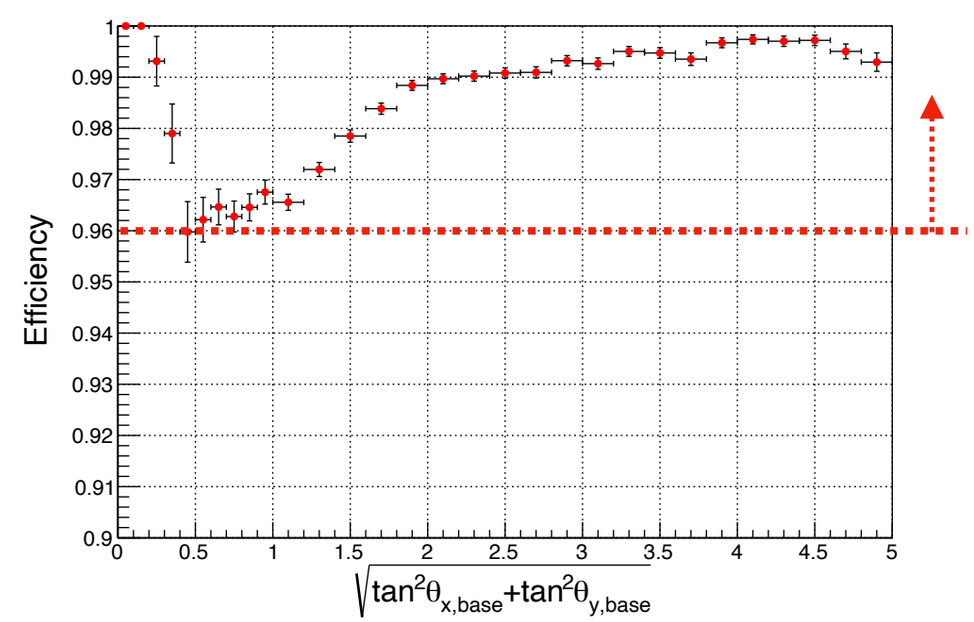


Nucl. Instrum. Methods Phys. Res. A 1034, 166775 (2022).

ECC

- Emulsion Cloud Chamber (ECC) is our main target detector. (8 kg water chamber x 9 -> 75 kg water)
- 2.3 mm thick water layers + emulsion films
- High spatial resolution, wide angular acceptance, and low momentum threshold





Prog. Theor. Exp. Phys. 2022(6), 063H01 (2022).

Momentum

NINJA

- We have a few choices for the momentum reconstruction.

	Muon	Proton	Pion
Baby MIND Range	When the particle stops in Baby MIND FV	N/A	N/A
ECC Range	N/A	When the particle stops in ECC FV	N/A
ECC MCS	When the particle does not stop in Baby MIND FV	When the particle escapes from ECC FV	All pions

Multiple Coulomb scattering

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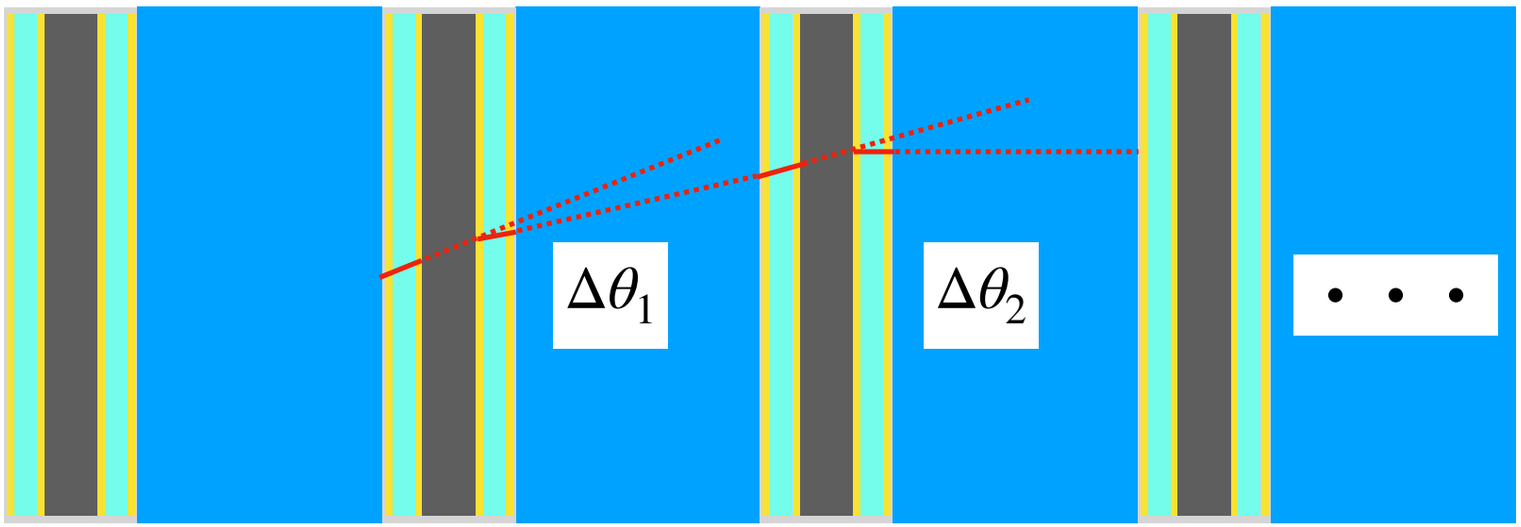
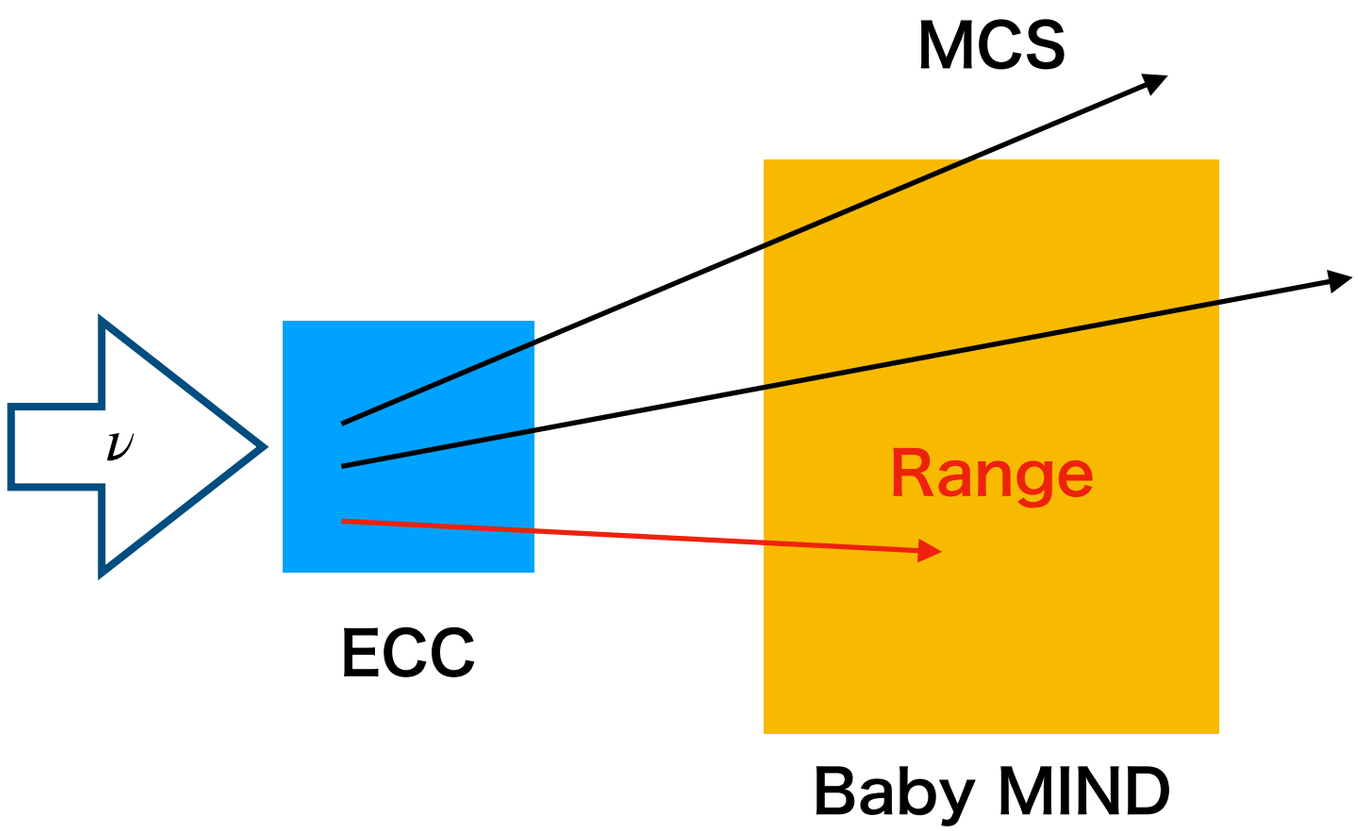
- Charged particles are scattered by each material layer (Multiple Coulomb scattering : MCS).
- Nuclear emulsion can measure small scattering angle, e.g. O(mrad) scattering of 1 GeV/c particle by a 0.5 mm Fe layer.
  -> Convert scattering angles into momentum

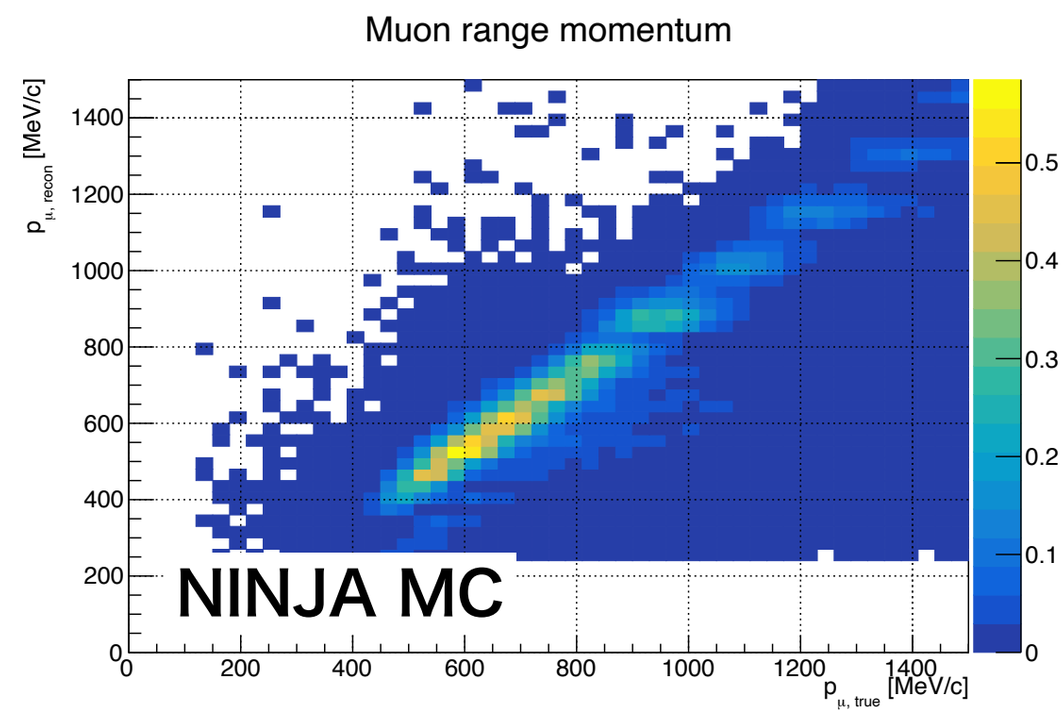


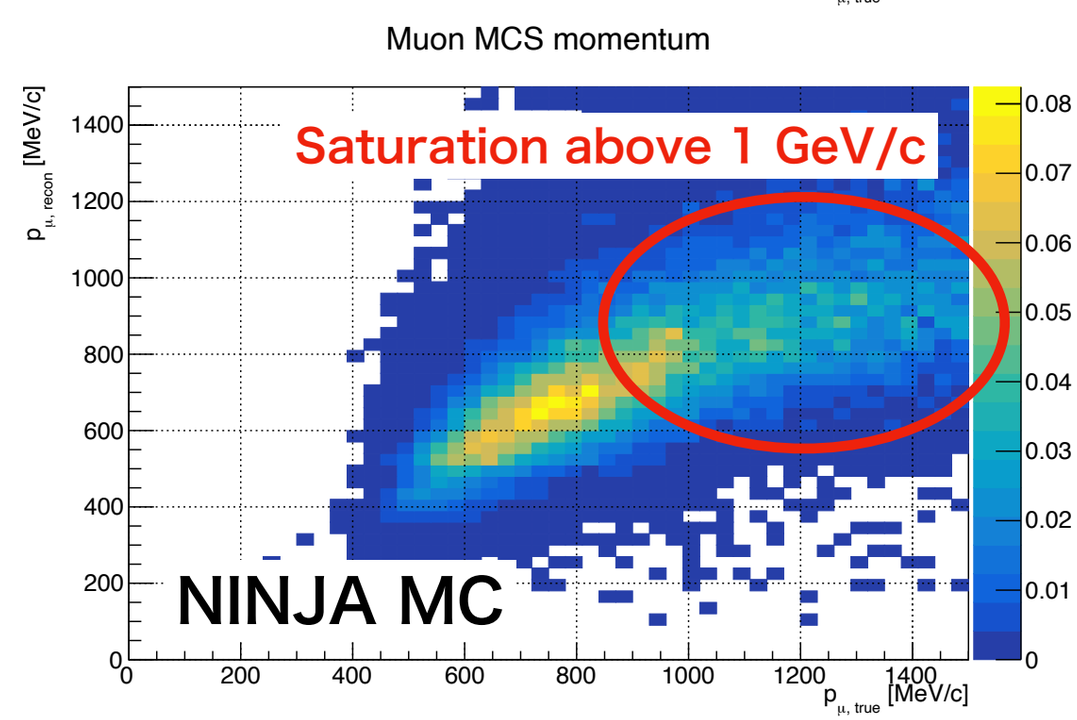
arXiv:2207.06640

Muon momentum

- Stopping in Baby MIND -> Range
  Otherwise -> MCS in ECC



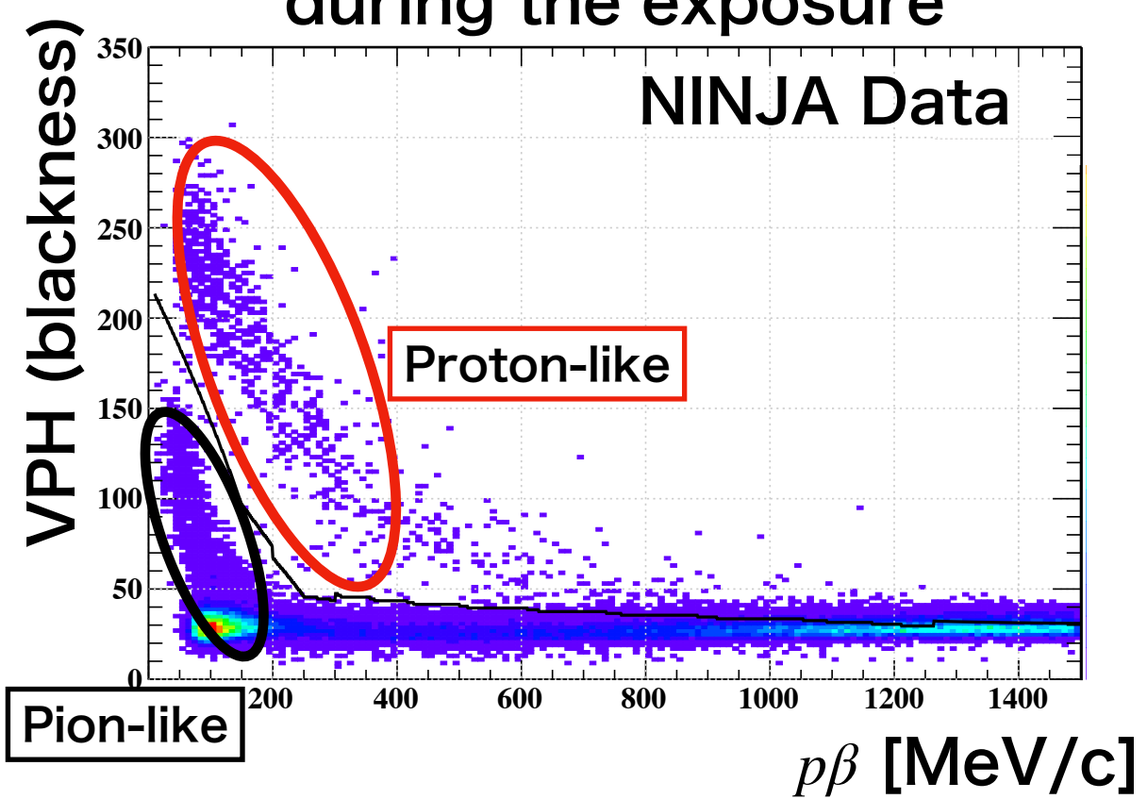


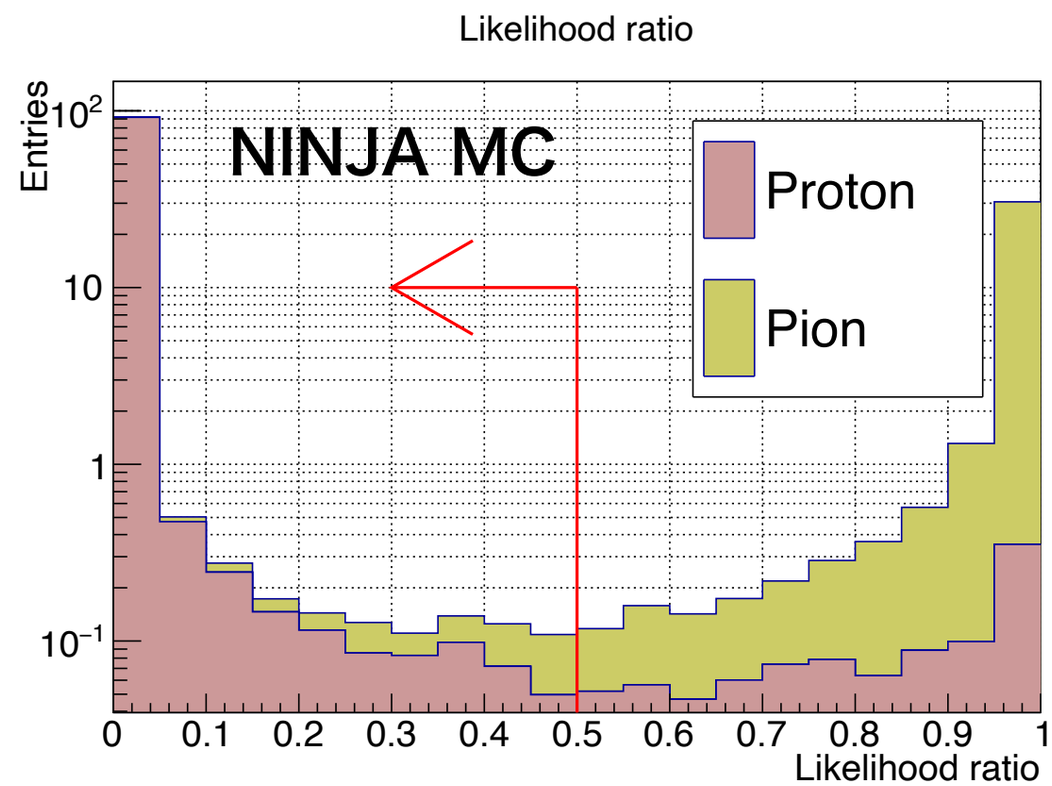


PID

- Using momentum reconstructed by ECC MCS and silver grain density of the track (VPH), PID is applied to each hadron track.

All tracks accumulated during the exposure





Proton Efficiency: 99%
Proton Purity : 99%
(limited to $p\beta \lesssim 700\,\mathrm{MeV/c}$)

Proton momentum

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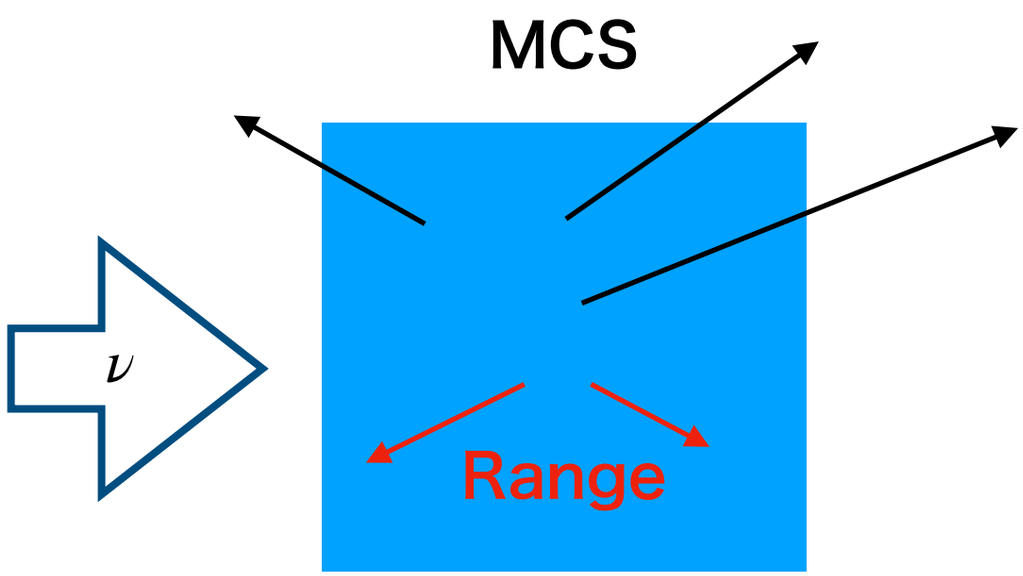
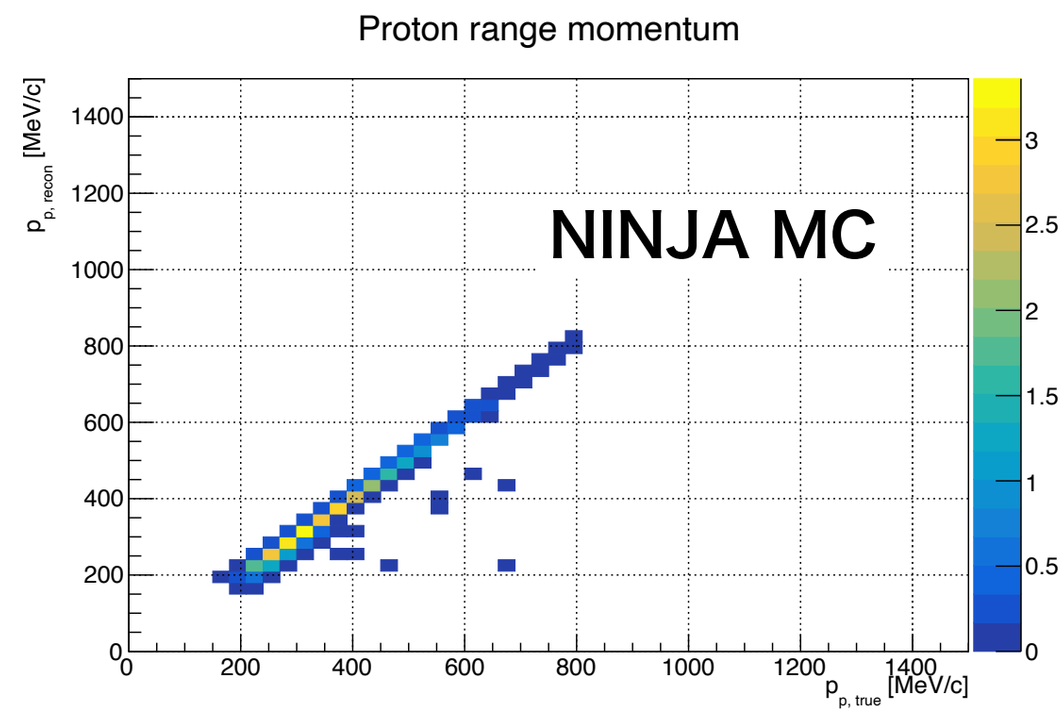
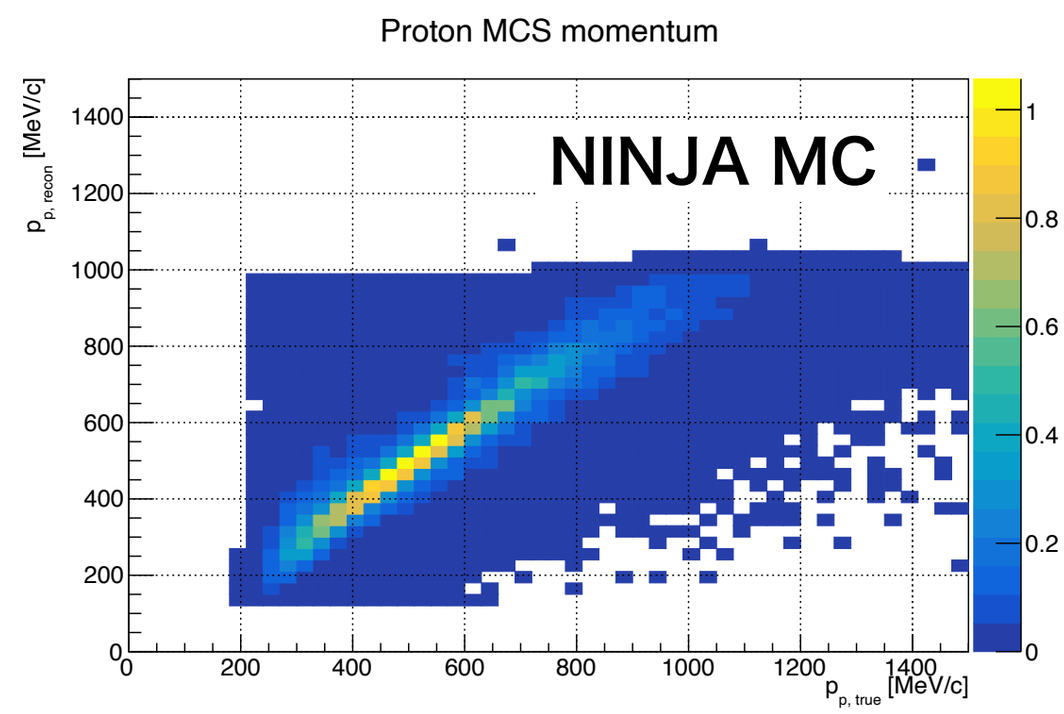
- Proton stopping in ECC -> ECC range
  Otherwise -> ECC MCS



ECC

ECC range method has
a good resolution (~ a few %)
while MCS method can measure
a wide phase space





Muon distribution

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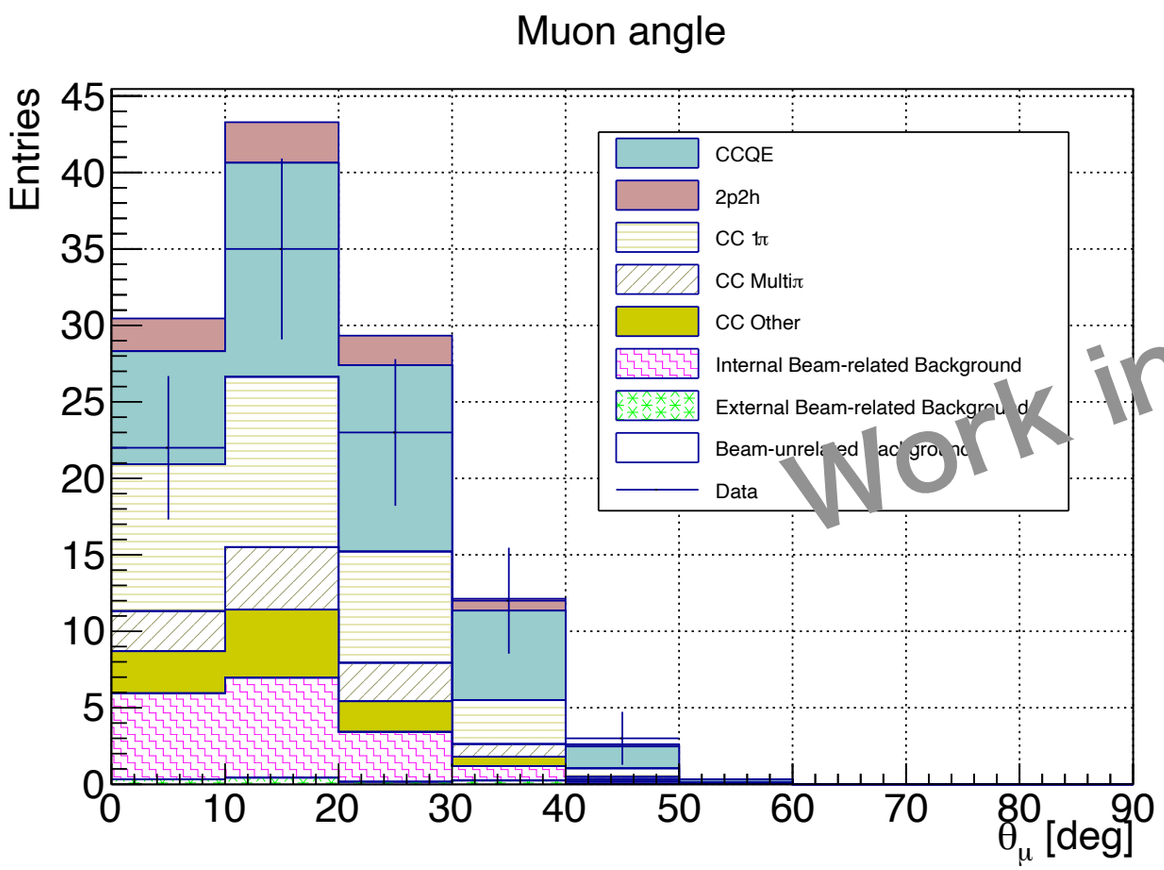
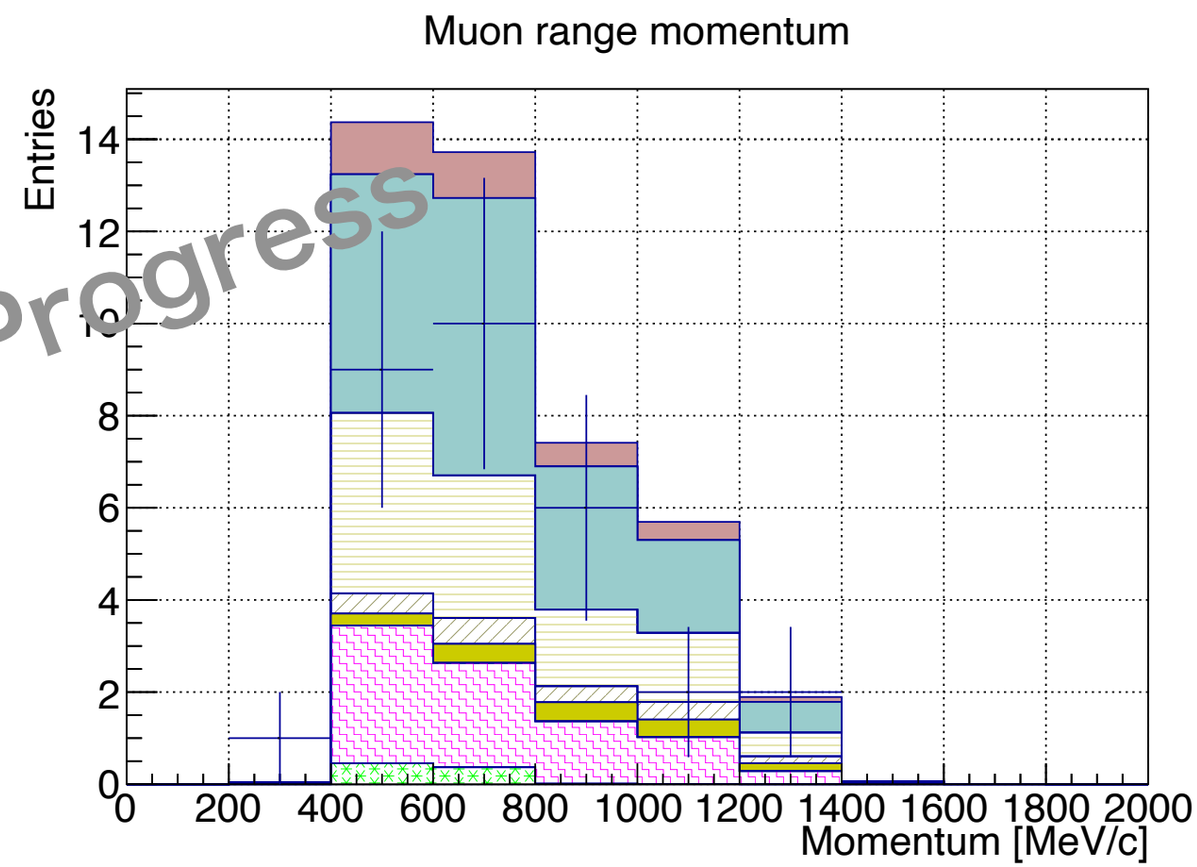
- CC inclusive events with one ECC (out of nine) -> ~ 8 kg water
- Momentum is range-method only





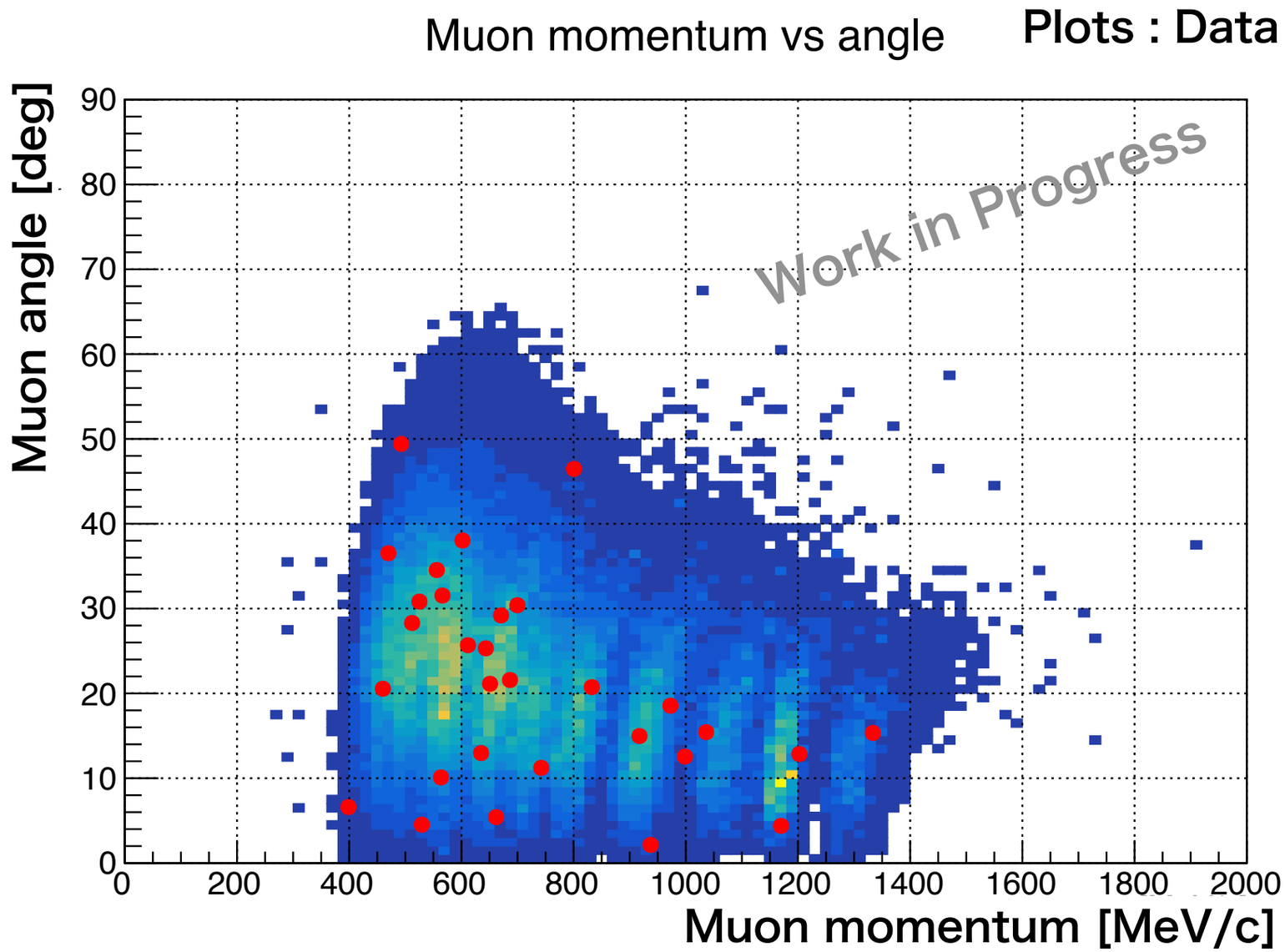
Detailed study of the detector efficiencies is still ongoing

Muon distribution

NINJA

- Muon 2-d kinematics (range only)

2d histogram : MC (signal only)
Plots : Data



Detailed study of the detector efficiencies is still ongoing

Proton distribution

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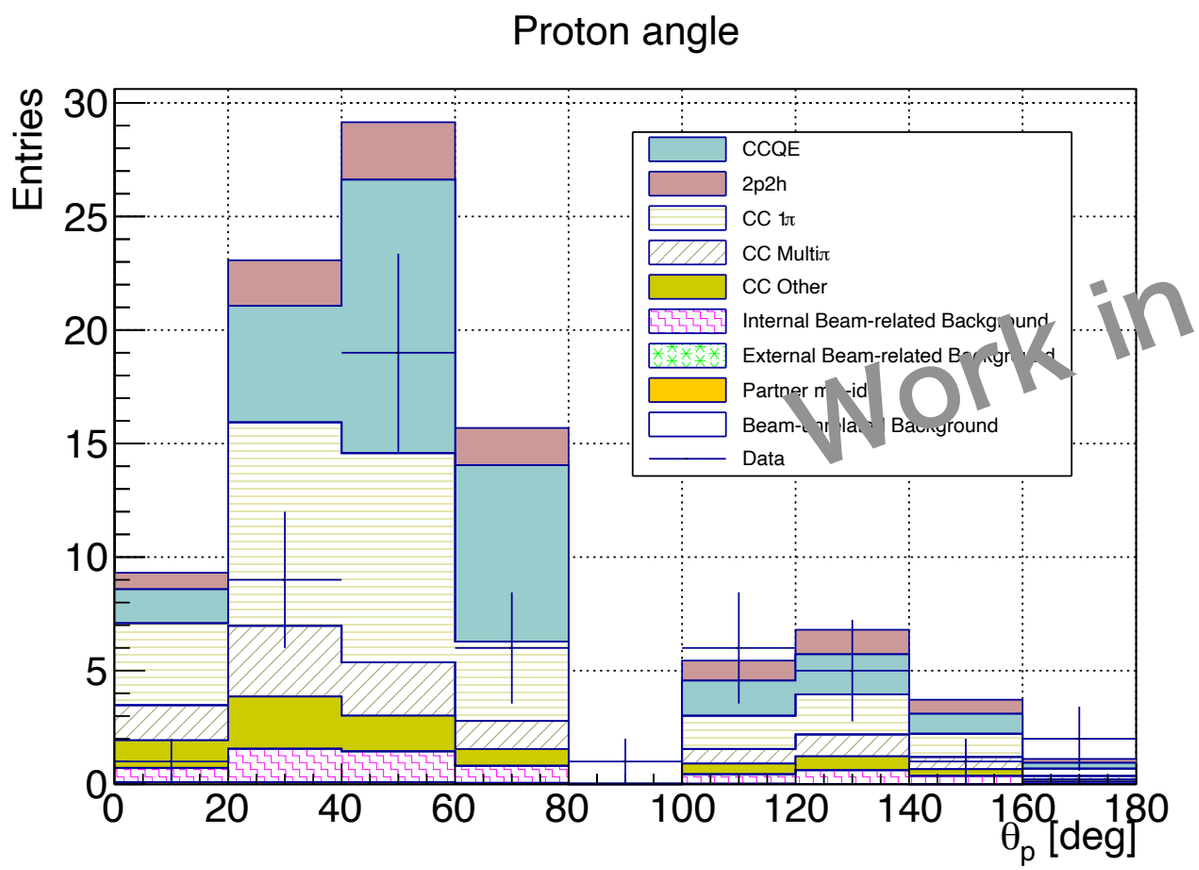
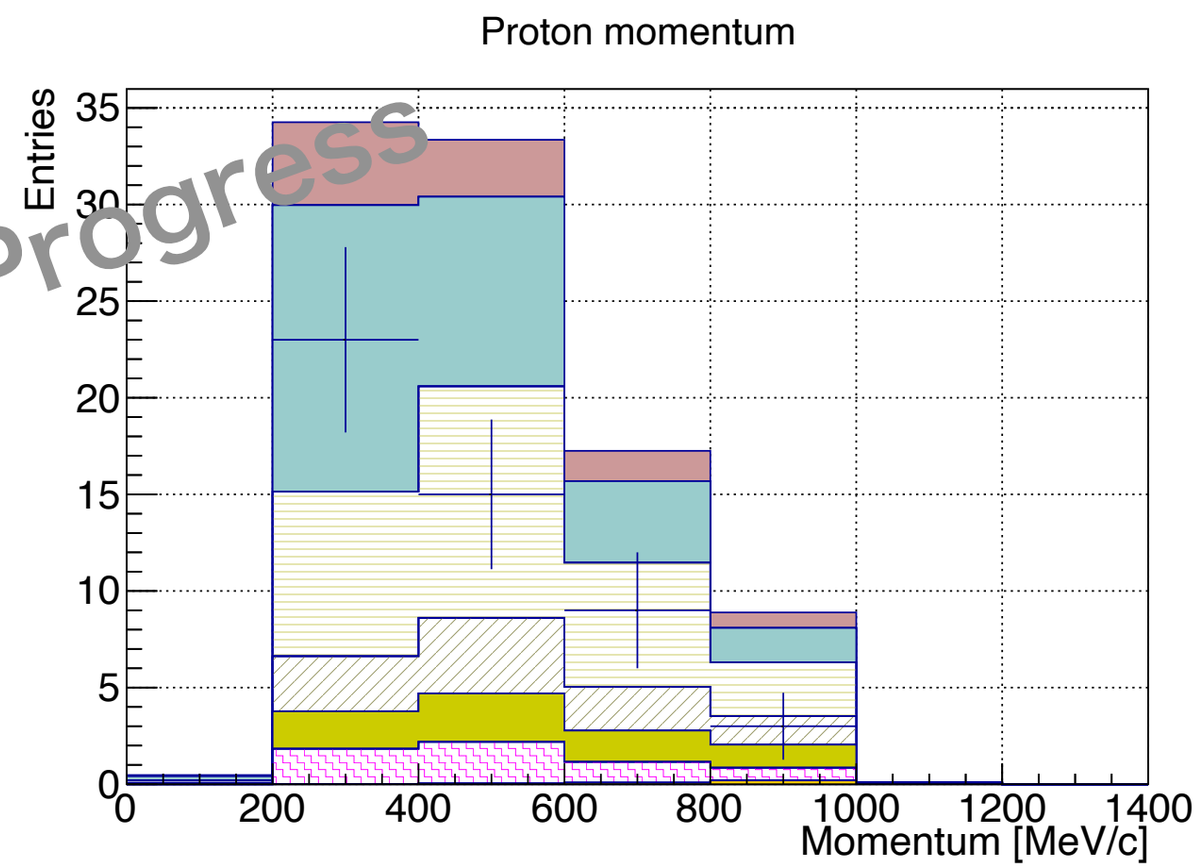
- Proton kinematics
- Protons down to 200 MeV/c are detected with wide angular acceptance.





Work in Progress

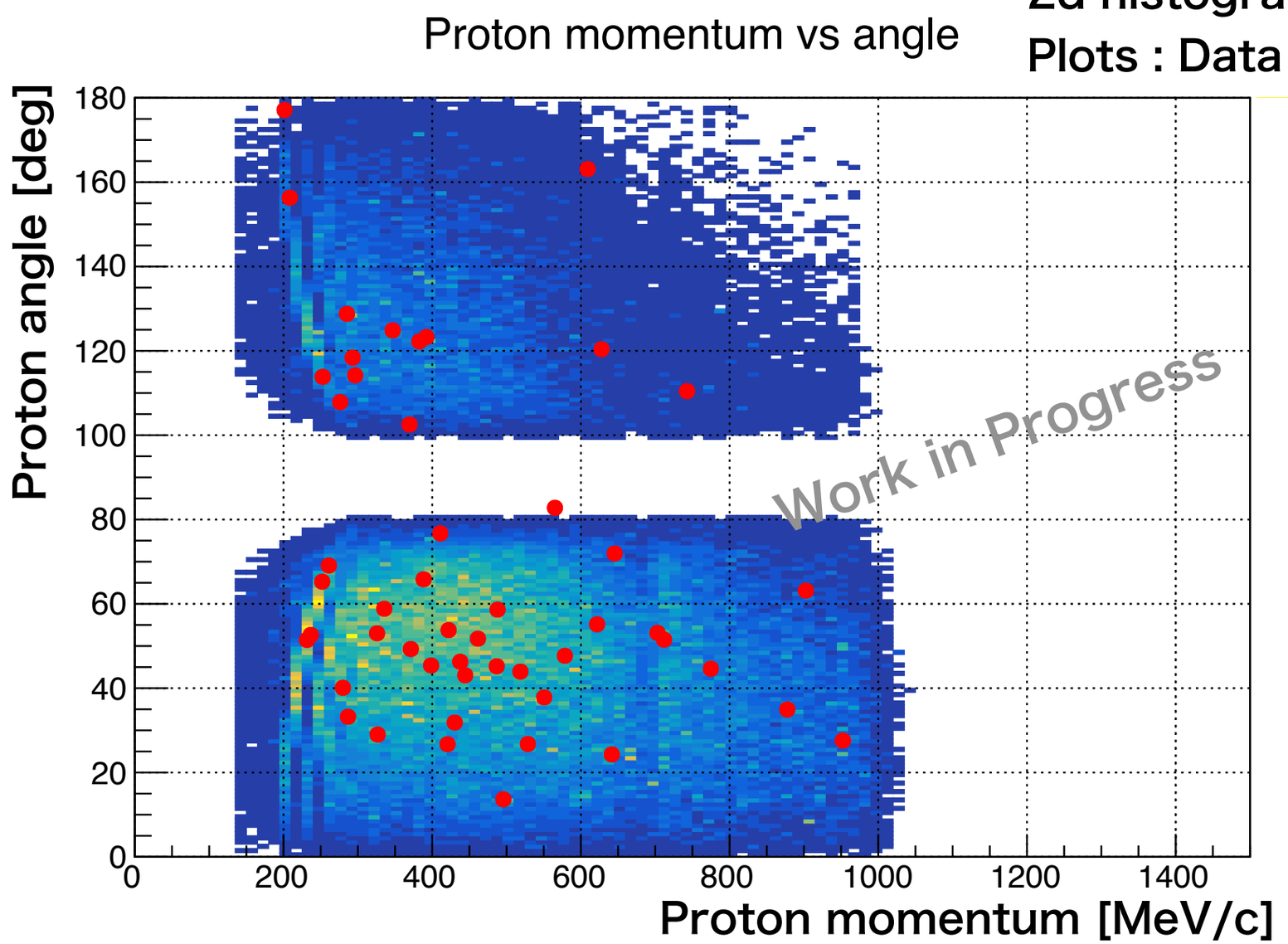
Detailed study of the detector efficiencies is still ongoing

Proton distribution

NINJA

- Proton 2-d kinematics

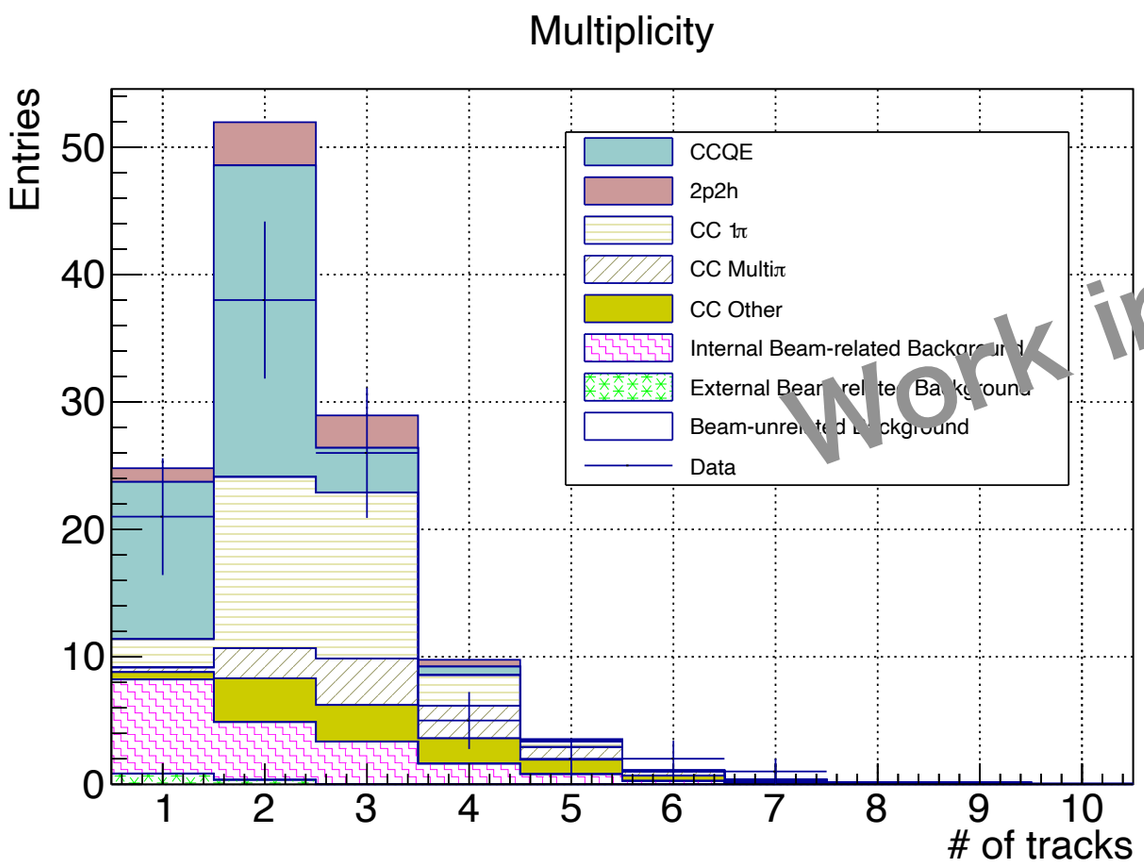
2d histogram : MC (signal only)
Plots : Data

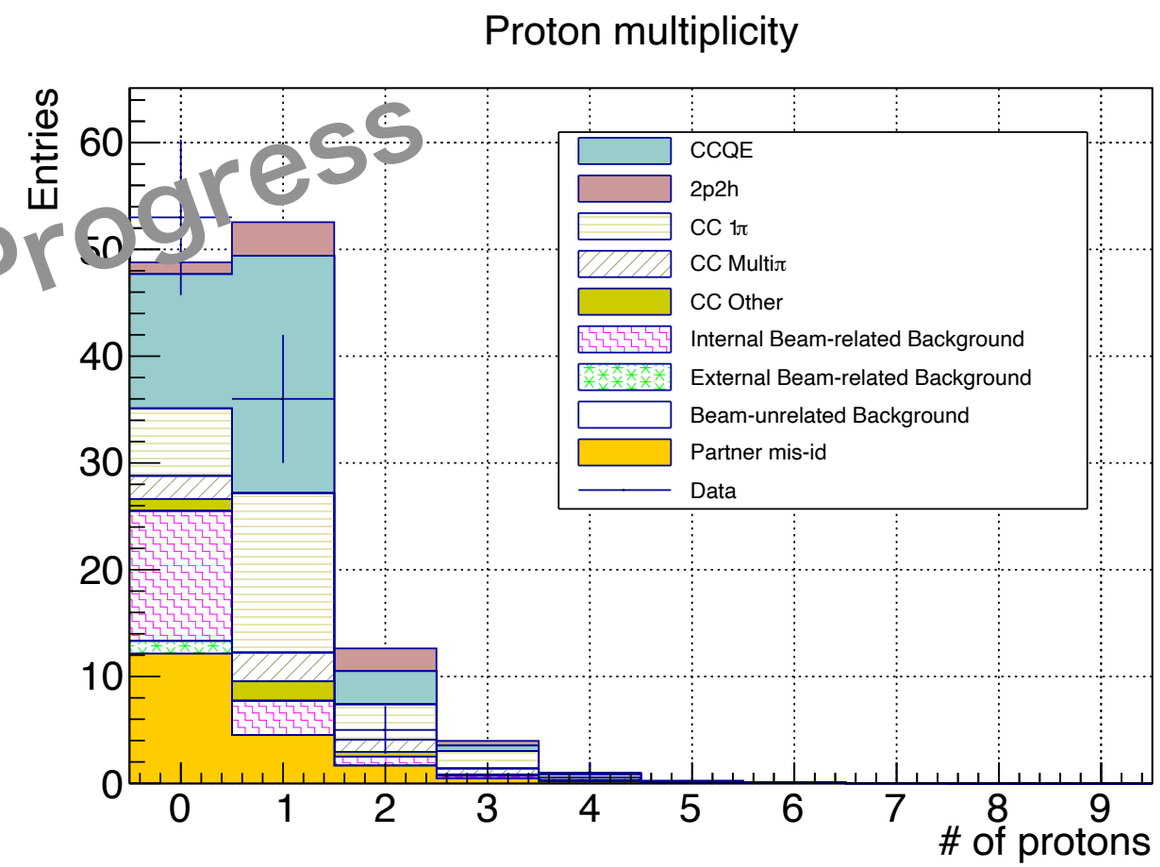


Detailed study of the detector efficiencies is still ongoing

Multiplicity

- Charged particle multiplicity
- Proton ($p\beta \lesssim 1\,\mathrm{GeV}/c$) multiplicity





Detailed study of the detector efficiencies is still ongoing

NINJA future

NINJA

- J-PARC T81 : Mar. - Apr. 2021
  (9 kg heavy water target)
  -> We try to analyze neutrino scattering on (quasi-)free neutron.
- J-PARC E71b : (planned in Fall 2023, 300 kg water target) -> Automated film production and higher-speed scanning system realize a larger detector.
- We can measure neutrino interactions on various targets (H_2O, D_2O, Fe, CH, Emulsion…)

Summary

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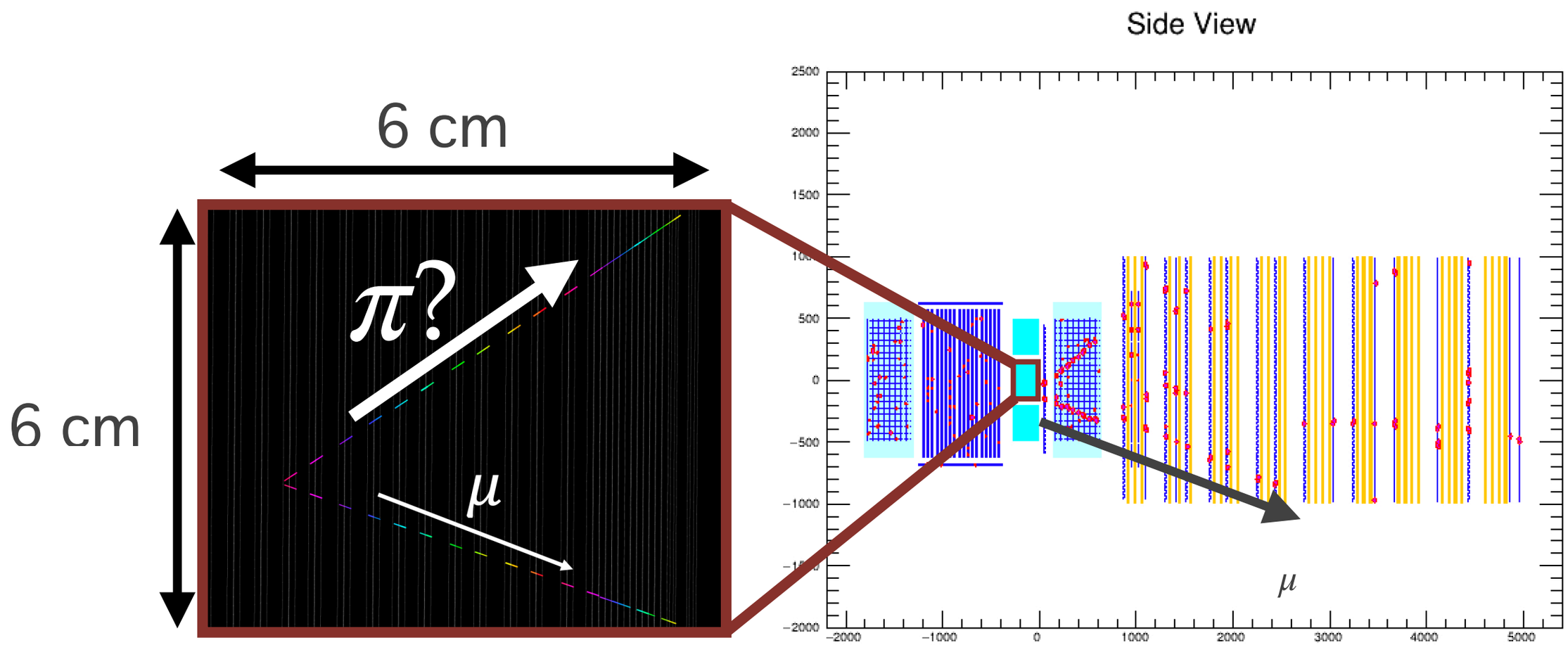
- NINJA experiment aims to measure neutrino-water interactions with 200 MeV/c proton threshold.
- Distributions of charged particles' kinematics from the interactions are shown.
- We will increase statistics (x 9) and improve our understandings to the detectors and other systematic uncertainties.
- Preparation for the future runs are also ongoing.

Backup

Event display

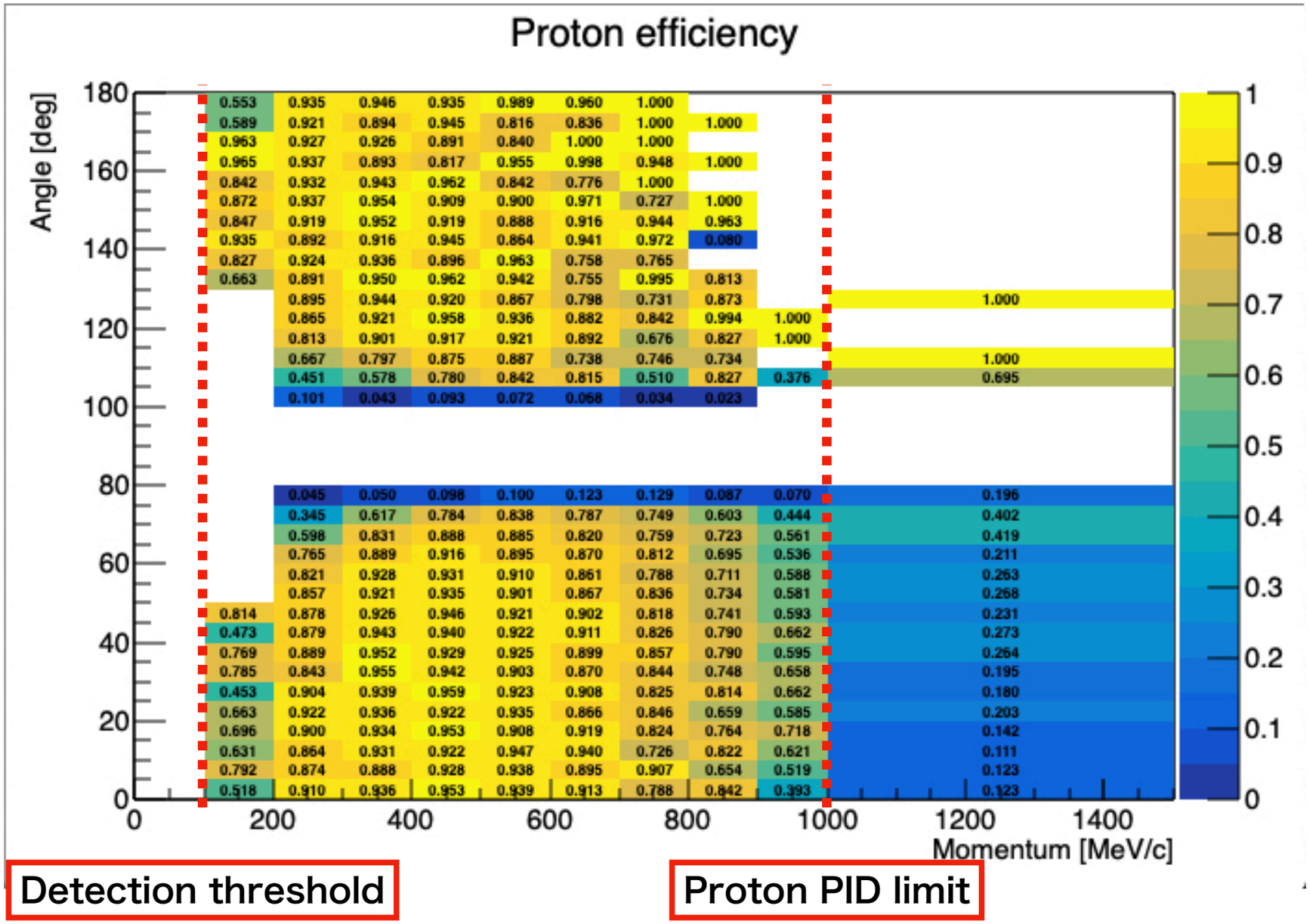
- We detect sub to a few cm length track with a high sampling rate



Proton Efficiency

NINJA

- We achieve a high proton detection efficiency in a few - several hundred MeV/c region.



Muon phase space

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		Baby MIND Range	ECC MCS
Momentum	Minimum	300 MeV/c (3 layers of Baby MIND)	
	Maximum	1.5 GeV/c	a few GeV/c
	Resolution	5-10%	10-30%
Angle	Maximum	$\lvert \tan\theta_{x(y)} \rvert < 1.5 - 2.5 \sim 56^{\circ}$	
	Resolution	O(mrad)	

Hadron phase space

NINJA

		Range	MCS
Momentum	Minimum	200 MeV/c (p) 50 MeV/c (π)	-
	Maximum	< 1 GeV/c (p)	a few GeV/c
	Resolution	a few %	10-30%
Angle	Maximum	$\lvert \tan\theta_{x(y)} \rvert < 4.0 \sim 76^{\circ}$	
	Resolution	O(mrad)	