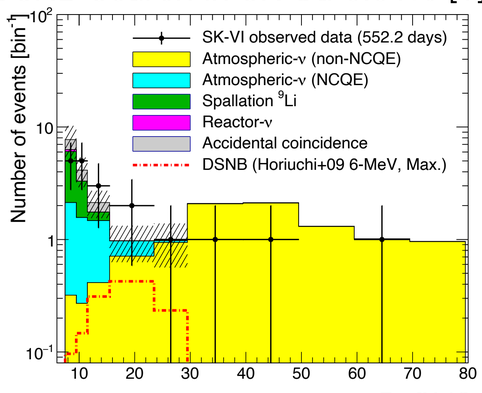
A comparison of n-^{16}O inelastic scattering between the experiment and simulations towards understanding neutrino reaction

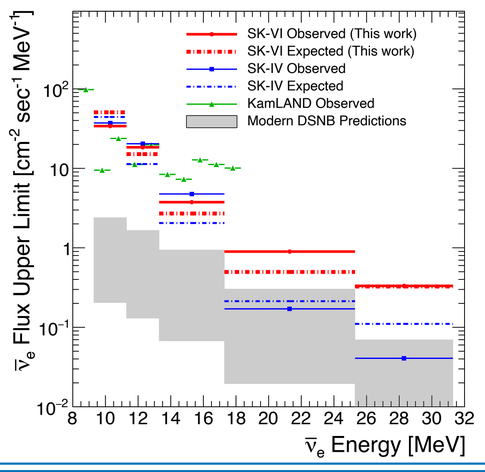
Y. Hino, T. Tano, Y. Koshio, Okayama University

10th Supernova Neutrino Workshop, @Okayama, Feb. 29th - Mar. 1st, 2024.

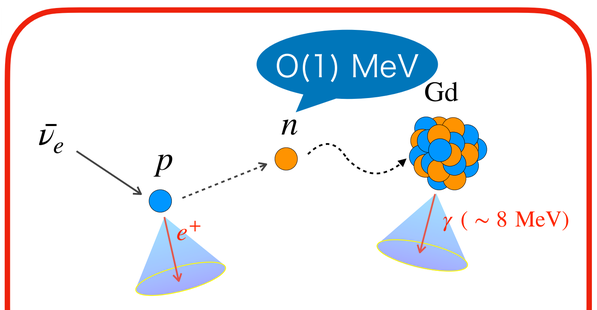
n-O scattering in DSNB Search

DSNB Search in SK-Gd 0.01% [1]

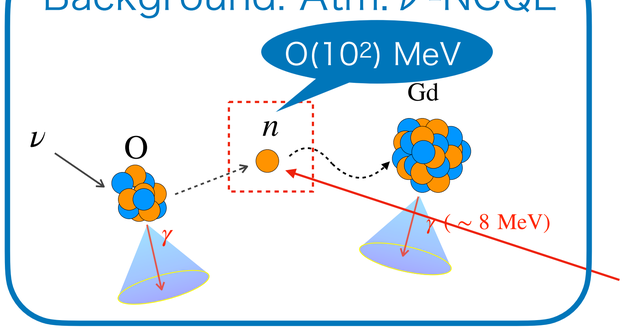




Signal: inverse beta decay



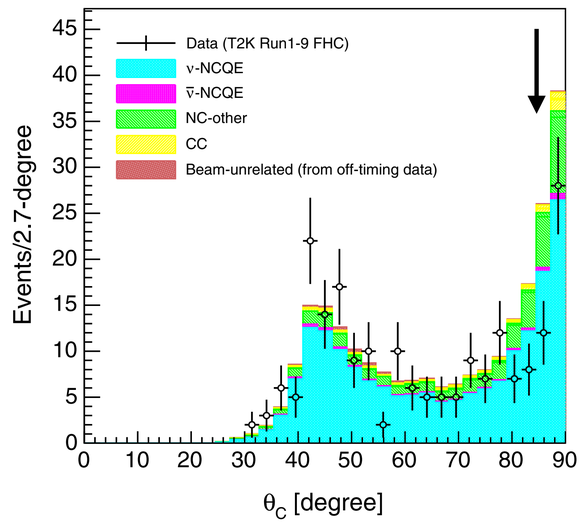
Background: Atm. ν -NCQE



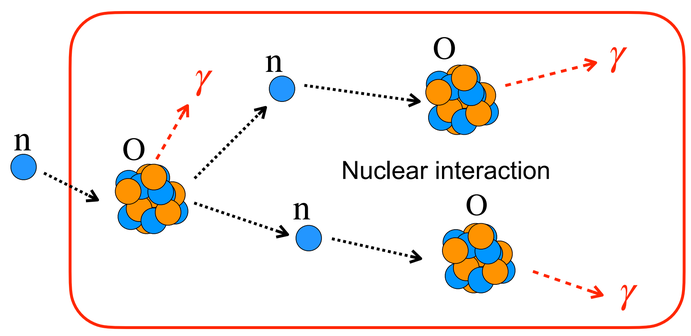
- Atm. ν -NCQE: 30 - 60% uncertainty due to secondary interaction in water.

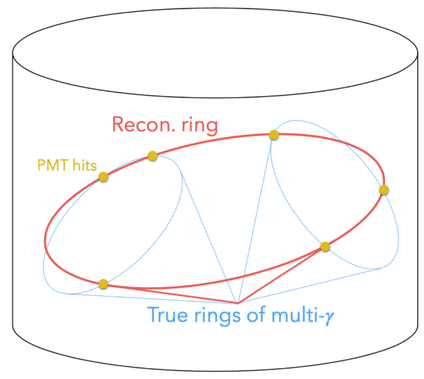
- Atmospheric neutrino induced neutral current quasi-elastic (NCQE) reaction mimics DSNB signal topology in SK-Gd.
  - limits the sensitivity in the major search region due to the reaction uncertainty.
- NCQE XS measurement using the T2K beam.
  - Observed discrepancy b/w data and MC in the large Cherenkov angle region.

-> indicated bad prediction using **inappropriate neutron-nucleus interaction model** [2].



Secondary interaction in water





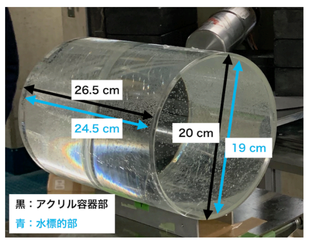
Experimental Dataset

- E525 experiment: gamma-ray measurement via n+O scattering
  - mono-energy neutron beam (30, 250 MeV)
  - Observed gamma-ray using Ge detector. -> Spectroscopy

n beam (30, 250 MeV)

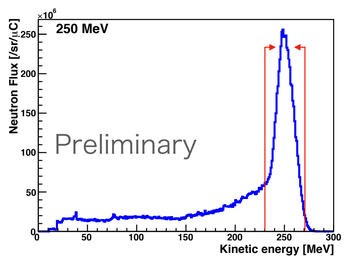
water target

γ -ray



Liq. Scint. Detector

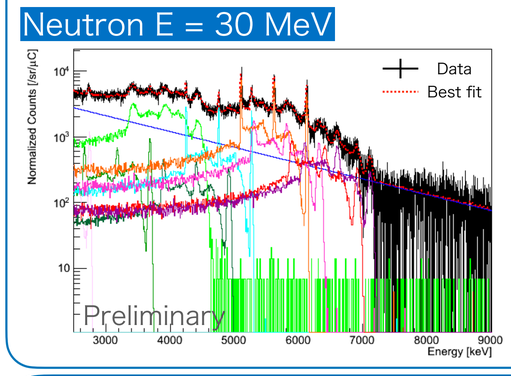
-> n flux estimation



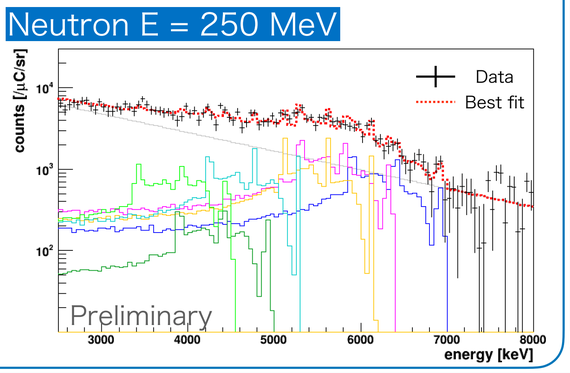
Ge Detector

-> gamma-ray detection

Neutron E = 30 MeV

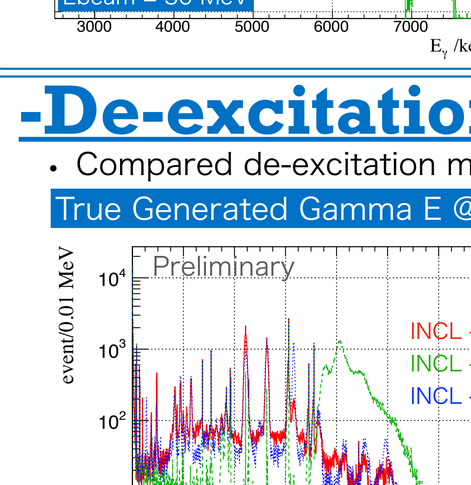


Neutron E = 250 MeV



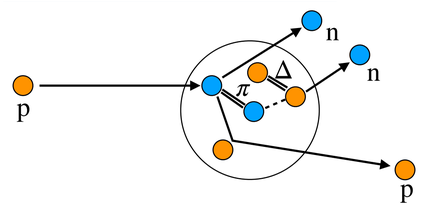
Simulation

Setup in Geant4 for 30 MeV

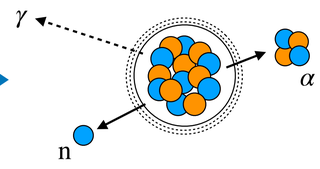


- MC simulation to compare with the result from E525.
- Made Geant4-based E525 MC simulation using 4.10.5.1 (same as G4-based SK detector simulation)
- We used the following models available in Geant4:
  - Liege Intranuclear Cascade (INCL++)
  - Binary Cascade (BIC)
  - Bertini Cascade (BERT)

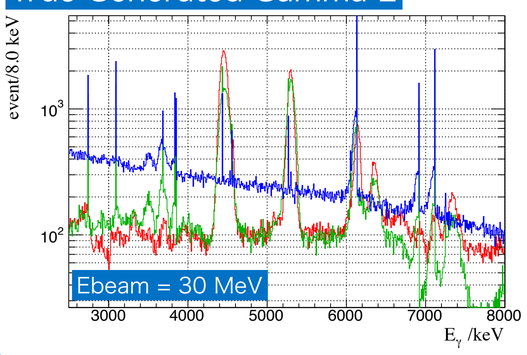
Intranuclear cascade



De-excitation



True Generated Gamma E



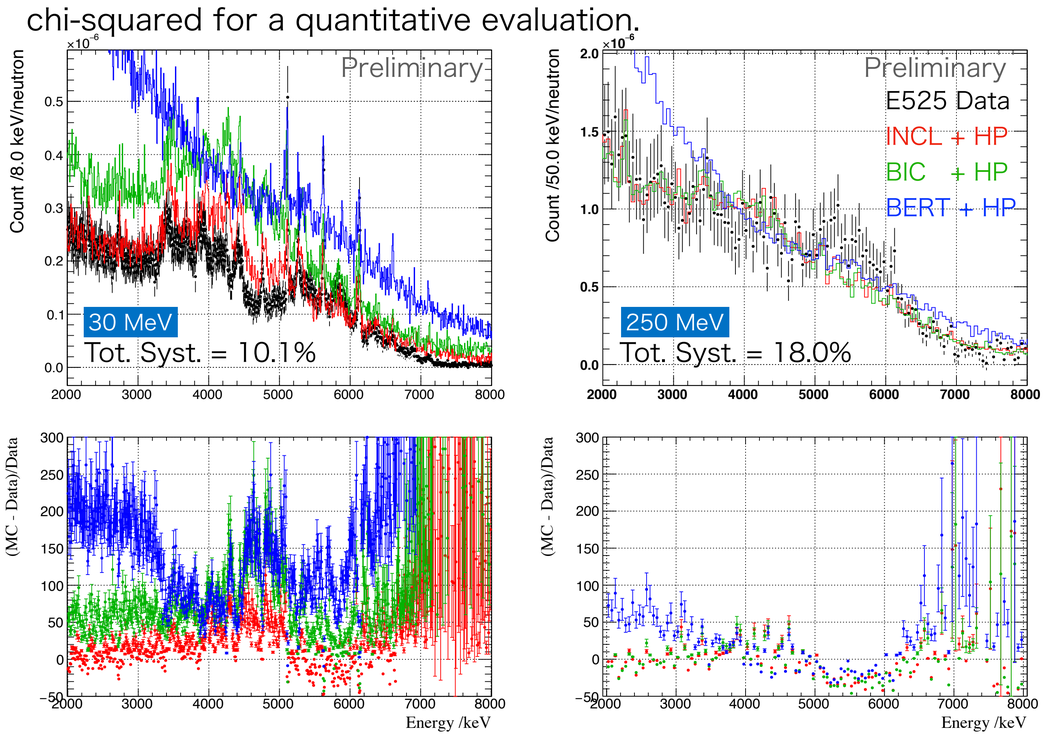
- INCL++
- BIC
- Bertini

- G4PreCompound
- ABLA
- NucDeEx v1.3 [3]
- G4cascade unique

- INCL++ compatible w/ some de-excitation models -> find out the best cascade-deexcitation pair.

Results -Cascade Models-

- Compared each cascade model w/ the E525 data, and computed chi-squared for a quantitative evaluation.



Model	χ^2/ndf @30 MeV	χ^2/ndf @250 MeV
INCL++	1933.4 / 750	122.4 / 120
BIC	2405.5 / 750	133.0 / 120
BERT	4632.9 / 750	238.6 / 120

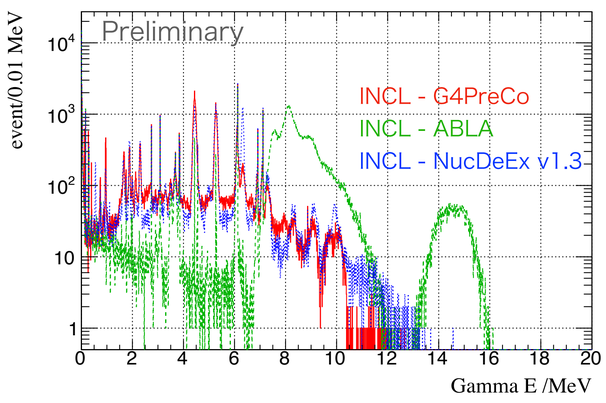
$$\chi^2 = \sum \left(\frac{N^{\mathrm{data}} - f \times N^{\mathrm{mc}}}{\sigma^{\mathrm{stat.}}} \right)^2 + \left(\frac{1-f}{\sigma^{\mathrm{syst.}}} \right)^2$$

- Added a nuisance par. for syst.
- Both dataset prefer INCL++ model.
- 30 MeV data show more significance.

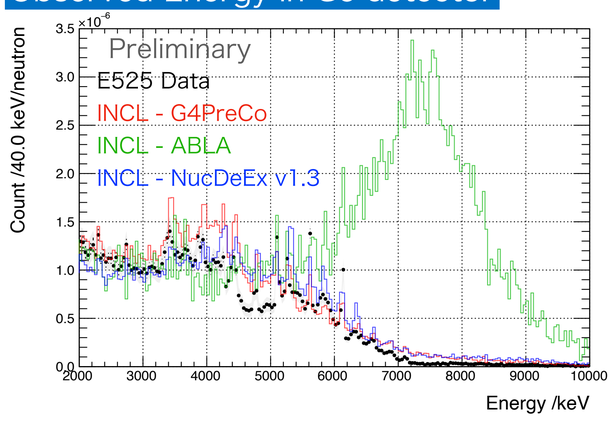
-De-excitation Models-

- Compared de-excitation models w/ the E525 data (cascade model: INCL++).

True Generated Gamma E @30 MeV



Observed Energy in Ge detector



- Compared de-excitation models w/ the E525 data (cascade model: INCL++).
- ABLA predicts a larger contribution in E > 8 MeV than INCL default, which shows inconsistency with an agreement in data and G4PreCo, NucDeEx.
- NucDeEx gives a better agreement in E < 4.5 MeV, while a larger contribution at some states, e.g., 6.32 MeV (p_3/2 hole state).

Summary

- We performed a comparison between the E525 data and Geant4-based simulation with the different hadron inelastic interaction models.
  - χ^2 test shows INCL++ has the “better” agreement in both 30 and 250 MeV.

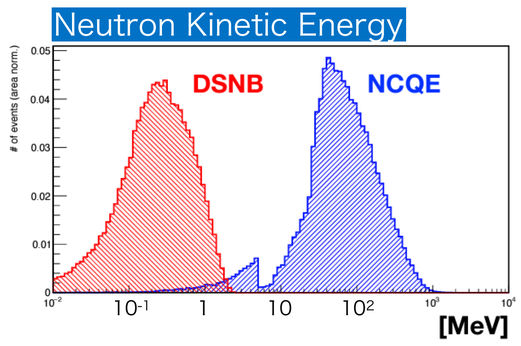
Reference

[1] Harada et al., ApJ Let. 951:L27
[2] Phys. Rev. D 100, 112009 (2019)
[3] Phys. Rev. D 109, 036009 (2024)

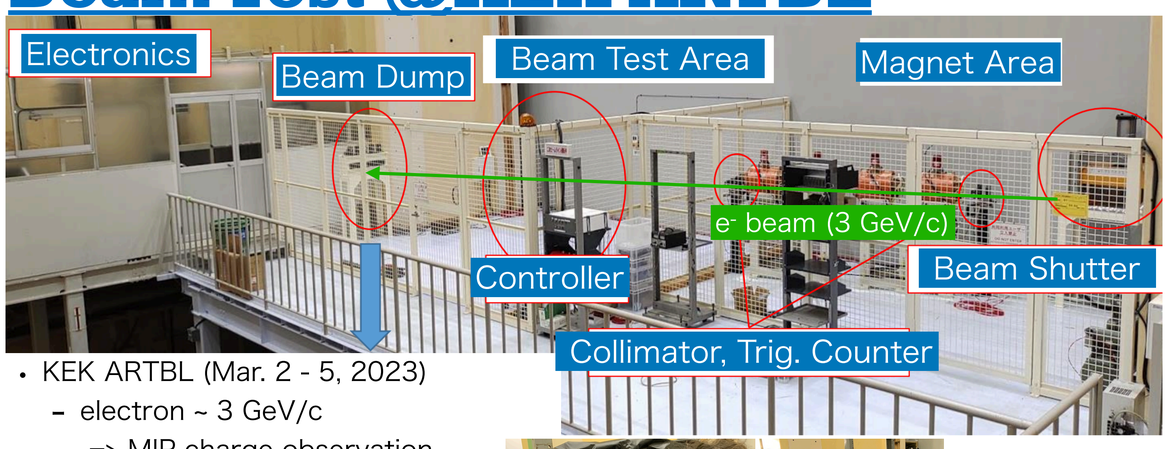
A comparison of n-^{16}O inelastic scattering between the experiment and simulations towards understanding neutrino reaction

Y. Hino, T. Tano, Y. Koshio, Okayama University

10th Supernova Neutrino Workshop,
@Okayama, Feb. 29th - Mar. 1st, 2024.

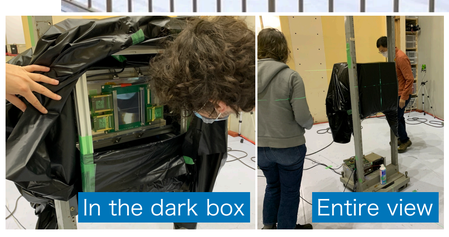


Beam Test @KEK ARTBL

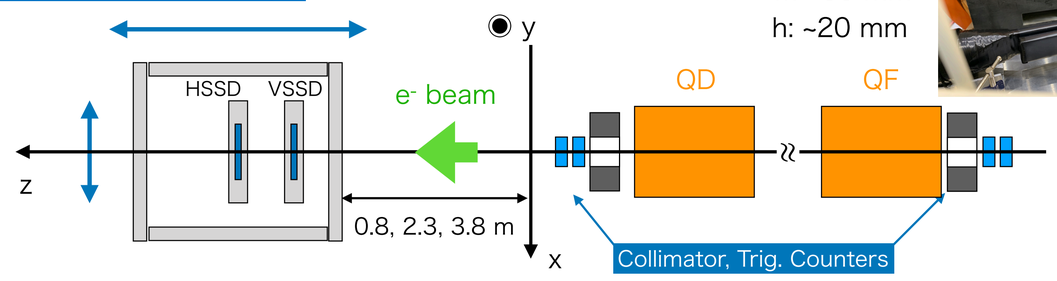


- KEK ARTBL (Mar. 2 - 5, 2023)
  - electron ~ 3 GeV/c
    => MIP charge observation, beam profile measurement
- The beam profile was investigated by several groups
  - V: ~20 mm, H: ~60 mm

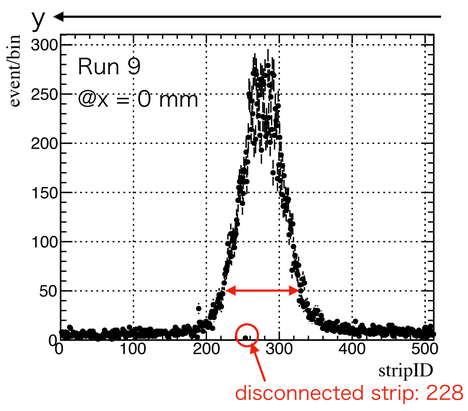
=> **reproducing this w/ our setup**

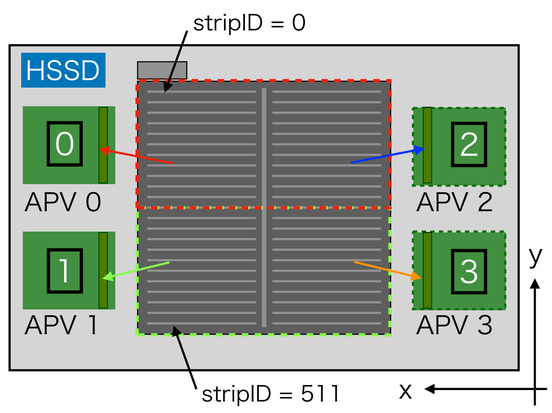


Experimental Setup

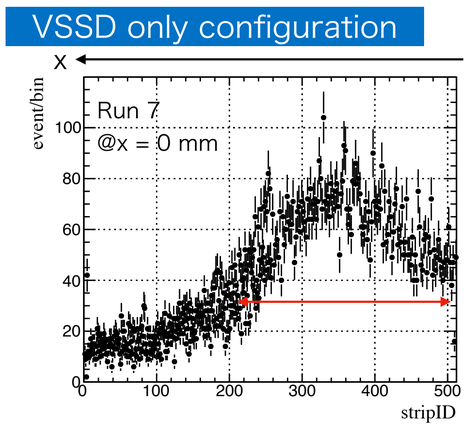


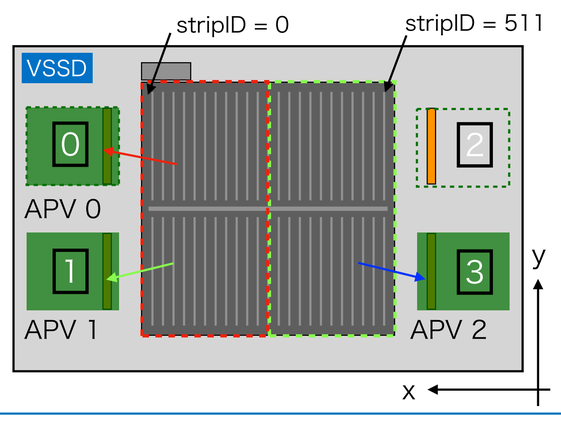
HSSD only configuration





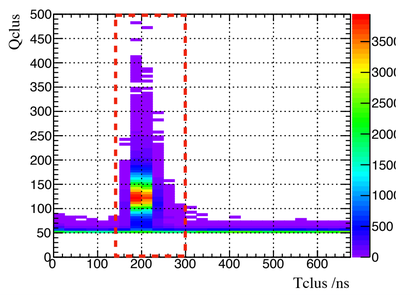
VSSD only configuration

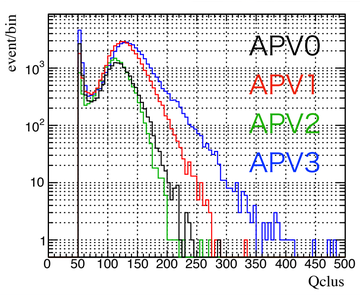




Si Strip Detector

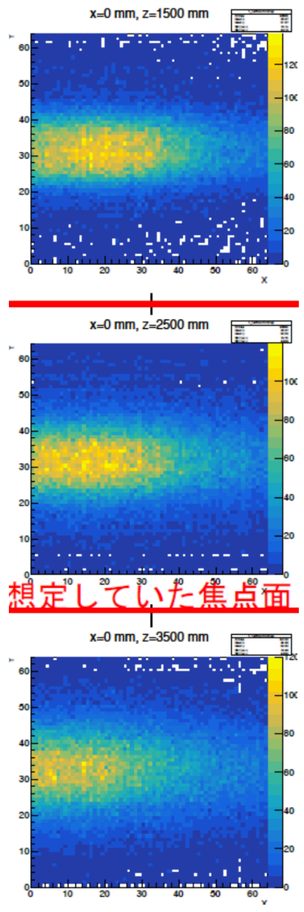
- Prototype detector based on Hamamatsu S13804 (silicon strip sensor) + SRS system (readout).
  - 10 × 10 cm, 320 μm thick
  - 512 strips w/ 0.19 mm pitch
  - 4 APVs (65 fC/mV, 128 ch)
- ~140 ADC@MIP (3.8 fC) expected [2]



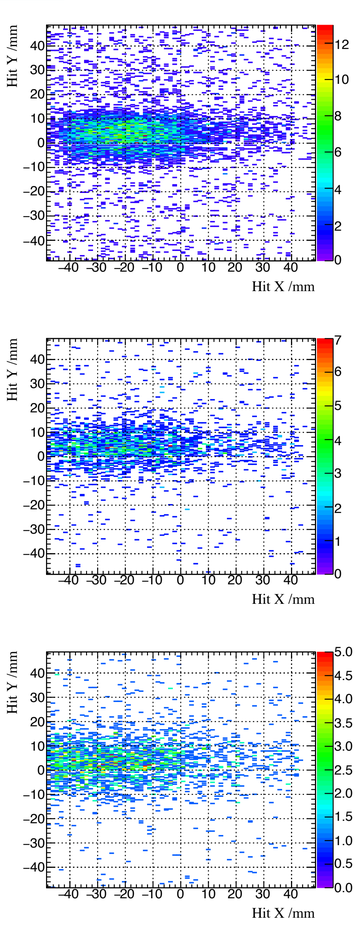


- Observed ~20 and 60 mm width profiles along each axis in the single SSD config.
- 2D profiles at some distance points were observed.
- Reproduced the profile measured by Kyushu & Kobe U. (e.g., beam center shift).
  => Succeeded to observe the MIP charge events and the beam profile!

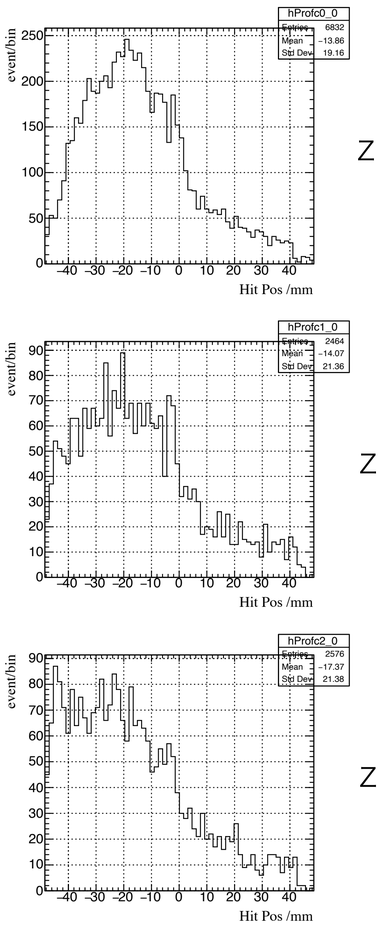
Double SSD configuration



Scint. Fiber Result
(Kyushu Univ. & Kobe Univ.)



2D Profile



X Profile

Summary & Prospect

- Developed the beam profiling detector based on Hamamatsu SSD + APVs.
- Performed MIP charge and beam profile measurement in the beam test at KEK ARTBL.
- Accelerating TOF detector development as well.

Reference
[1] Eur. Phys. J. C79, no.2 100 (2019)
[2] JINST 15 P04027 (2020)
[3] Phys. Rev. Accel. Beams 22, 061003