超新星背景ニュートリノの発見に向けた酸素原子核破砕事象の研究

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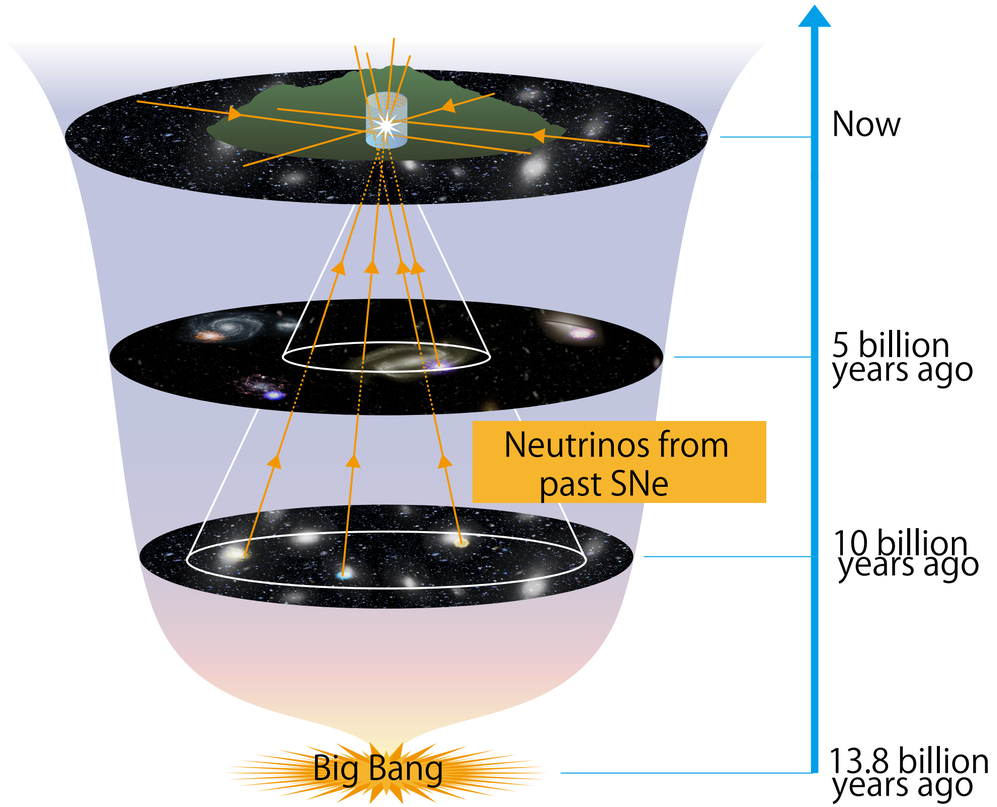
「超新星背景ニュートリノの発見に向けた酸素原子核破砕事象の研究」

Final goal

Discovery of the Diffuse Supernova Neutrino Background

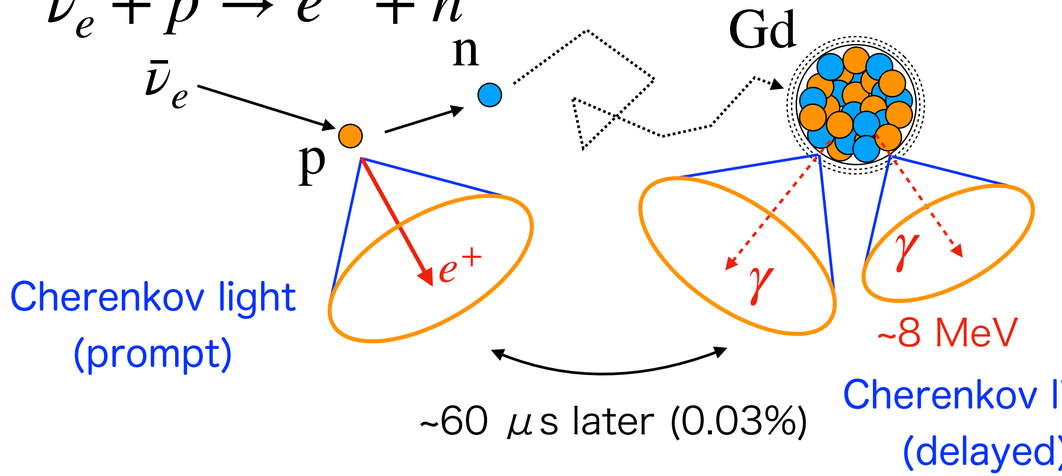
Neutrinos from past Supernovae since the beginning of the universe



How to detect in SK-Gd

Inverse Beta Decay (IBD)

$$\bar{\nu}_e + p \rightarrow e^+ + n$$



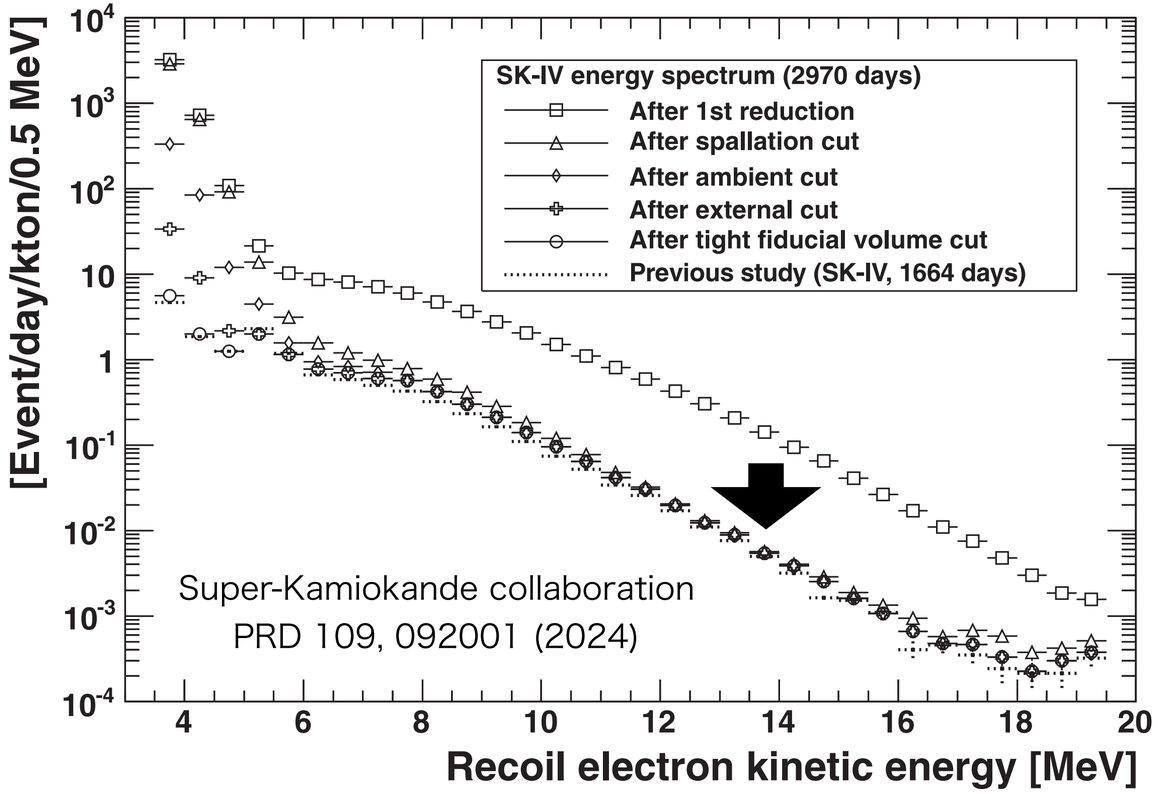
Merit of Gadolinium loading

- Large cross section of neutron capture
- Higher energy of gamma emission than pure water

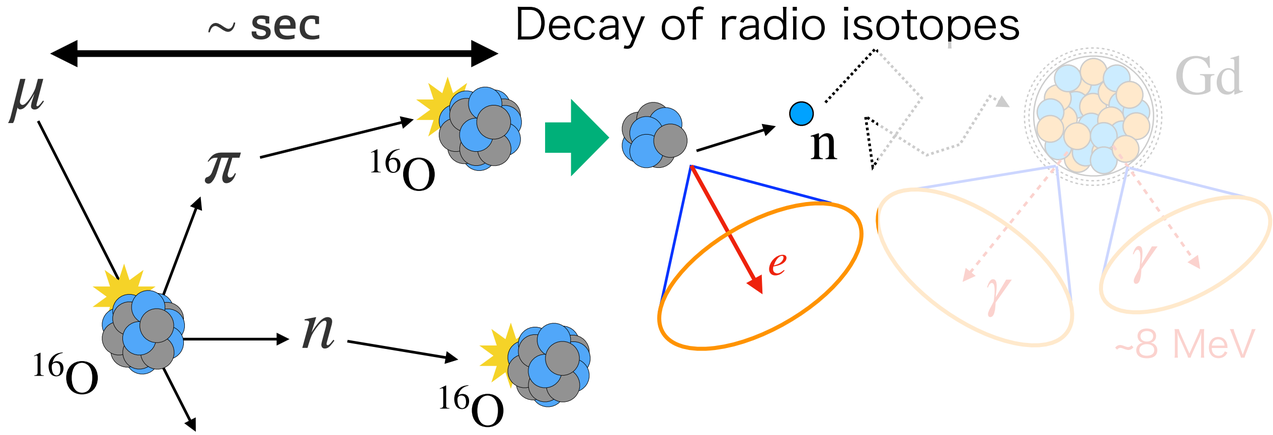
Spallation event

Serous background for MeV region neutrino in SK/HK

Remaining events after reduction in SK-IV



Spallation by cosmic muons

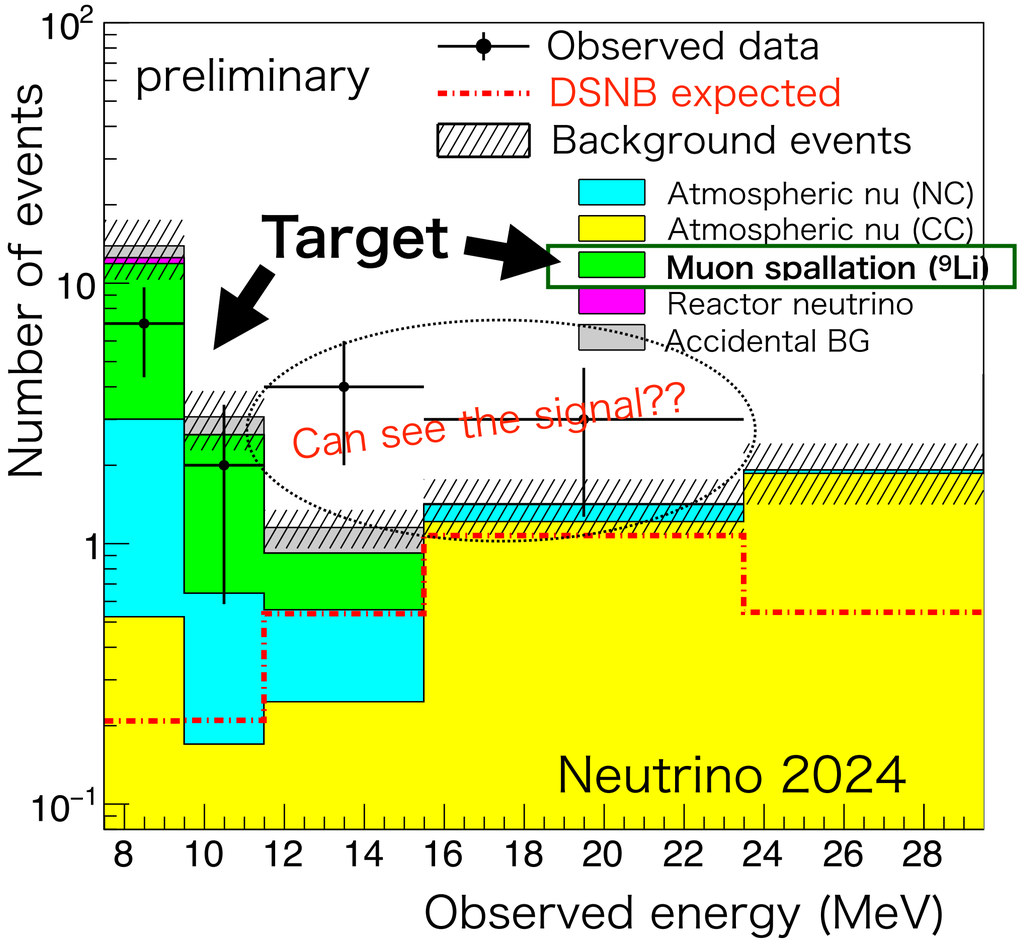


- Reduce ~10^{-2} by time-space correlation between muon track and candidate event
- Reduce ~10^{-4} by neutron tagging

Comparable to the DSNB expectation

Spallation event

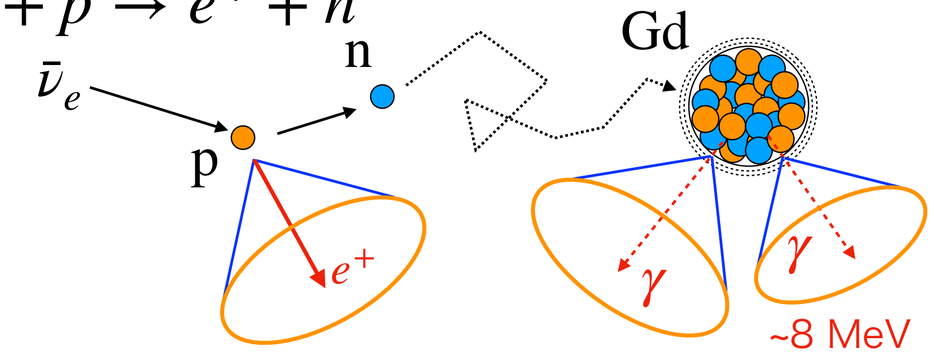
Key for DSNB search in lower energy region



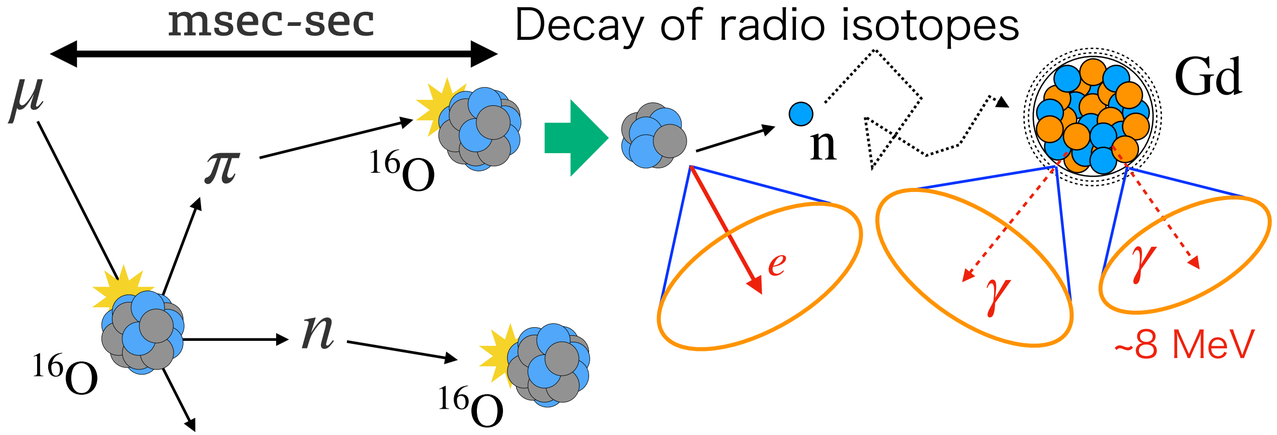
Cannot distinguish

Inverse Beta Decay (IBD)

$$\bar{\nu}_e + p \rightarrow e^+ + n$$

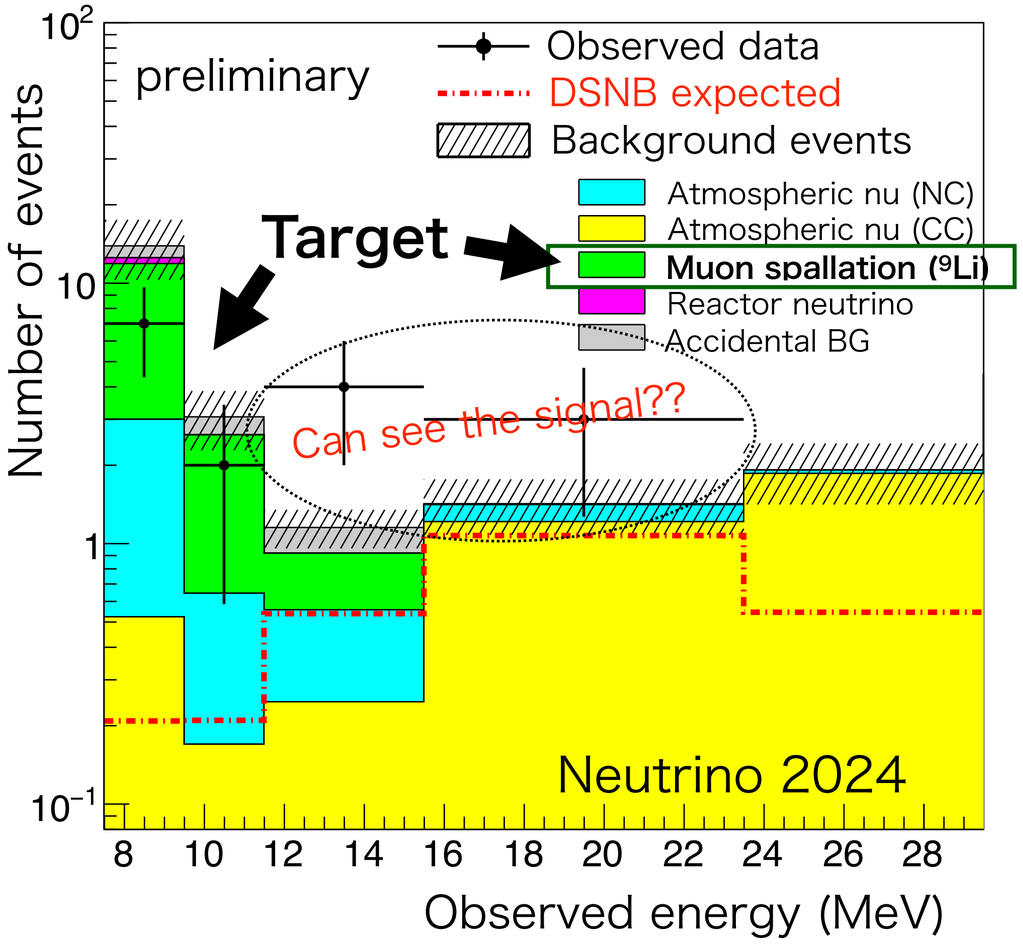


Spallation by cosmic muons

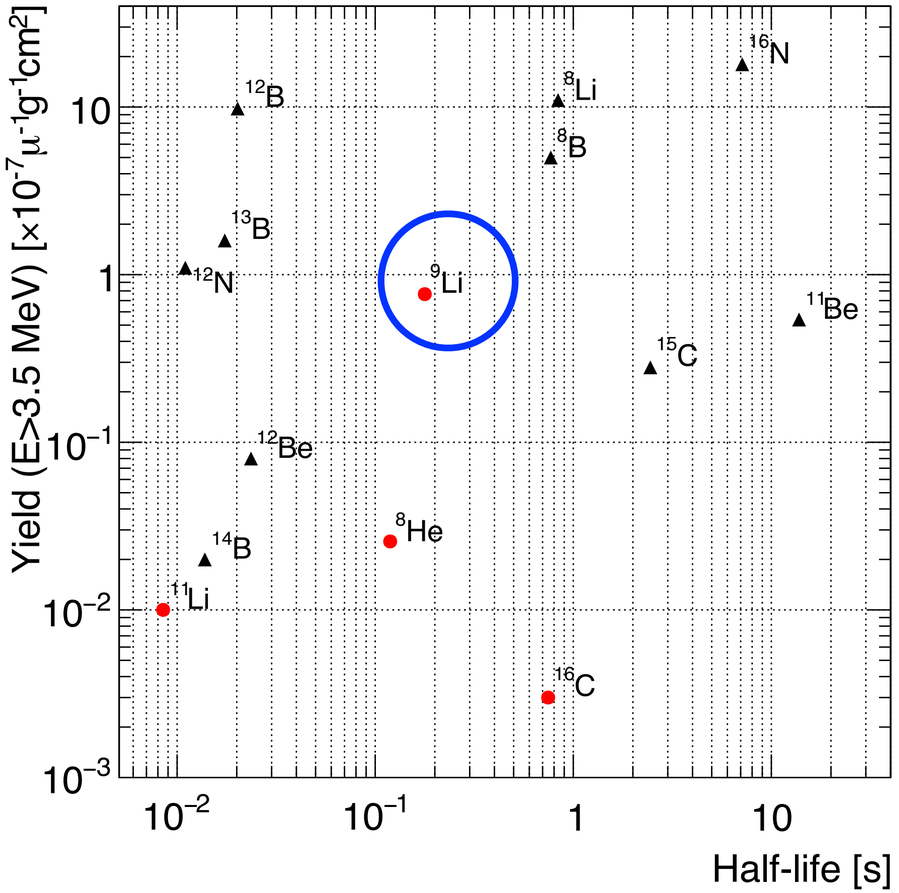


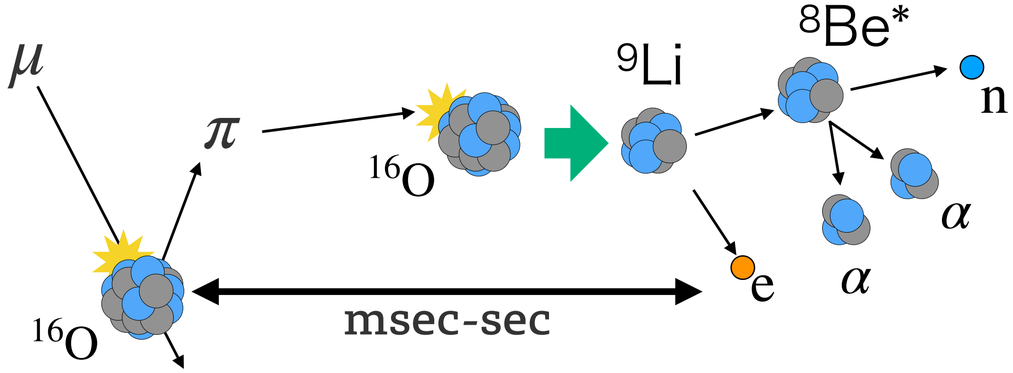
Spallation event

^{9}Li (long-lived with neutron)



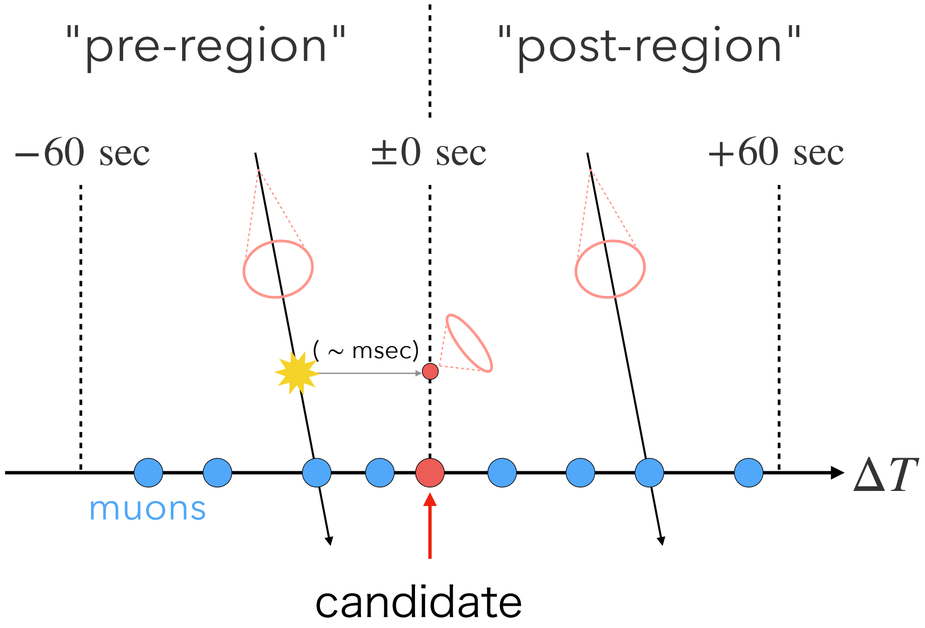
Spallation by cosmic muons

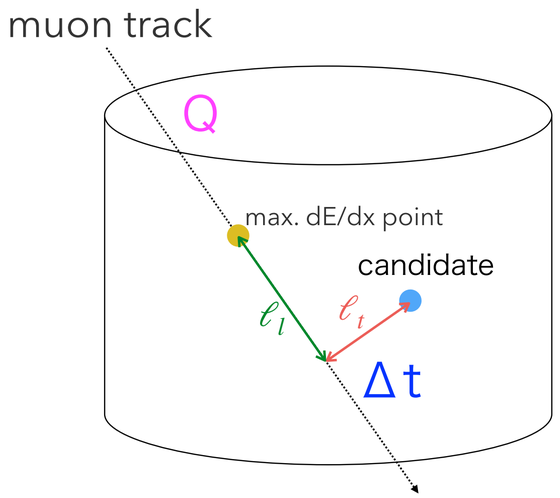




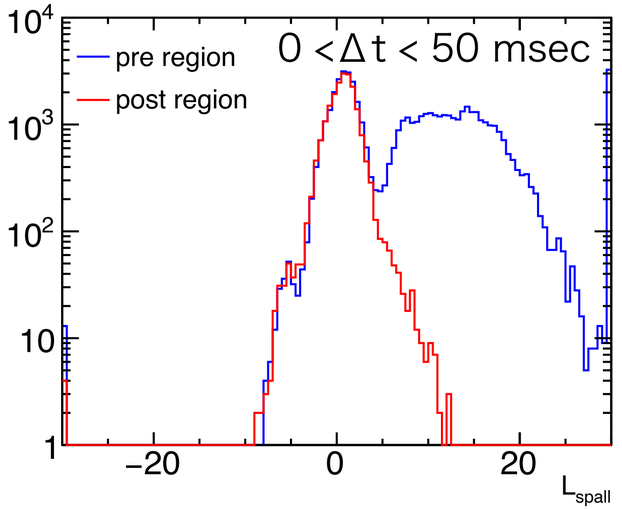
How to remove

Data driven method

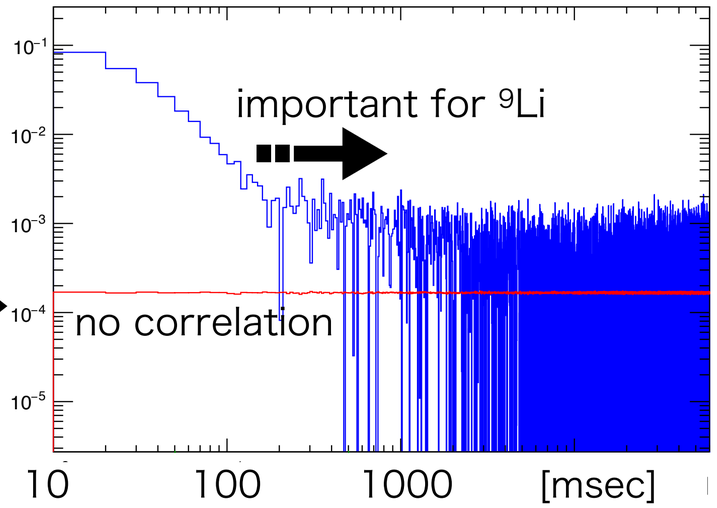




Likelihood distribution



Time difference between muon and candidate



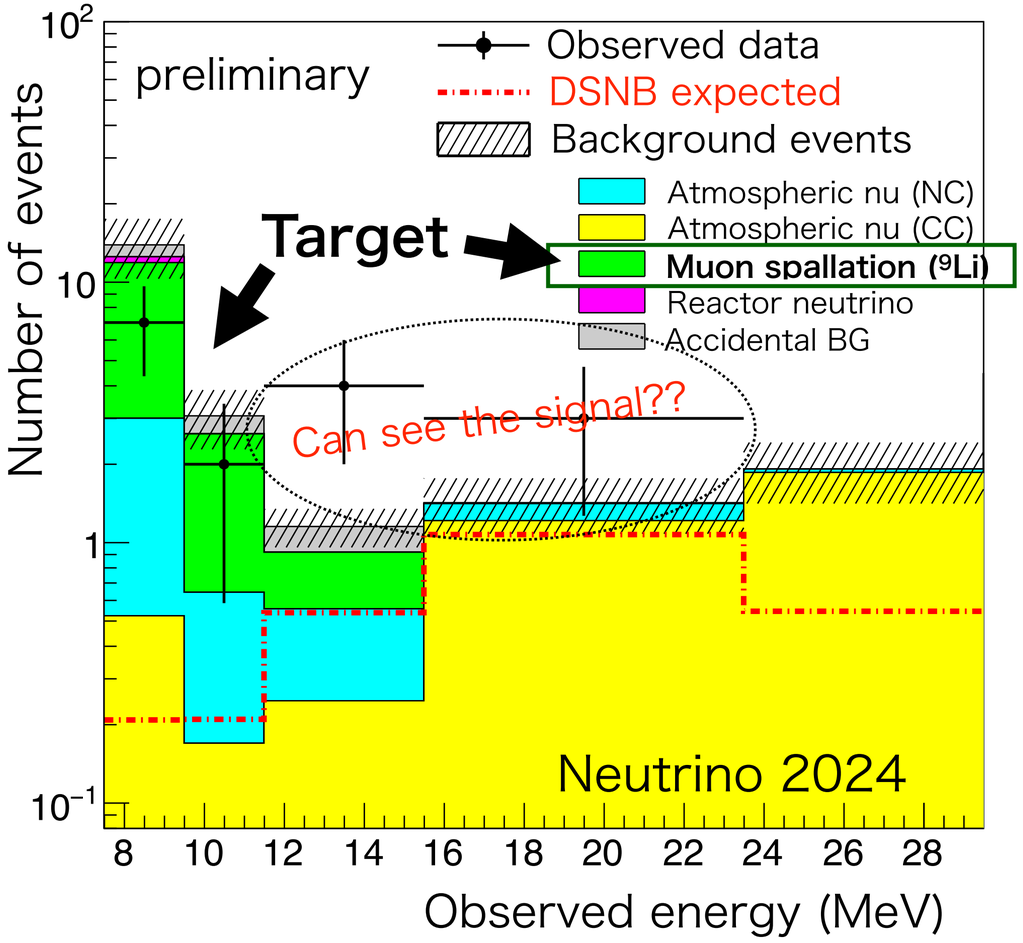
Sample with long time difference, which is important for 9Li, is insufficient..
It makes large uncertainty

Why not MC driven?

No reliable hadron simulations based on the experiment that produce long-lived (on the order of milliseconds) radioisotopes such as ^{9}Li (beta decay with neutron) by pion oxygen spallation. **-> WCTE**

Spallation event

^{9}Li (long-lived with neutron)



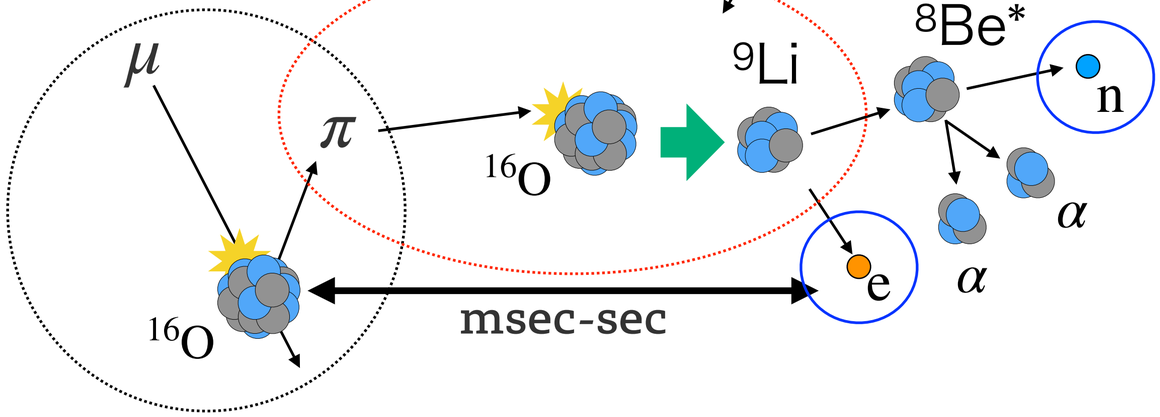
Super-K collaboration, PRD 93, 012004 (2016)

Isotope	Y_i in water	Expected [13]
^{12}B	$11.7 \pm 0.1 \pm 0.6$	12
^{12}N	$1.6 \pm 0.1 \pm 0.1$	1.3
^{16}N	$23.4 \pm 1.9 \pm 1.7$	18
^{11}Be	<10.0	0.81
^{9}Li w/o n-tag	$0.5 \pm 0.2 \pm 0.2$	1.9
^{9}Li w/ n-tag	$0.51 \pm 0.07 \pm 0.09$	1.9
^{8}He/^{9}C	<0.9	1.1
^{8}Li/^{8}B,	$4.9 \pm 0.2 \pm 0.2$	18.8
^{15}C	<3.9	0.82

$10^{-7}\ \mu^{-1}\ \mathrm{g}^{-1}\ \mathrm{cm}^{2}$.

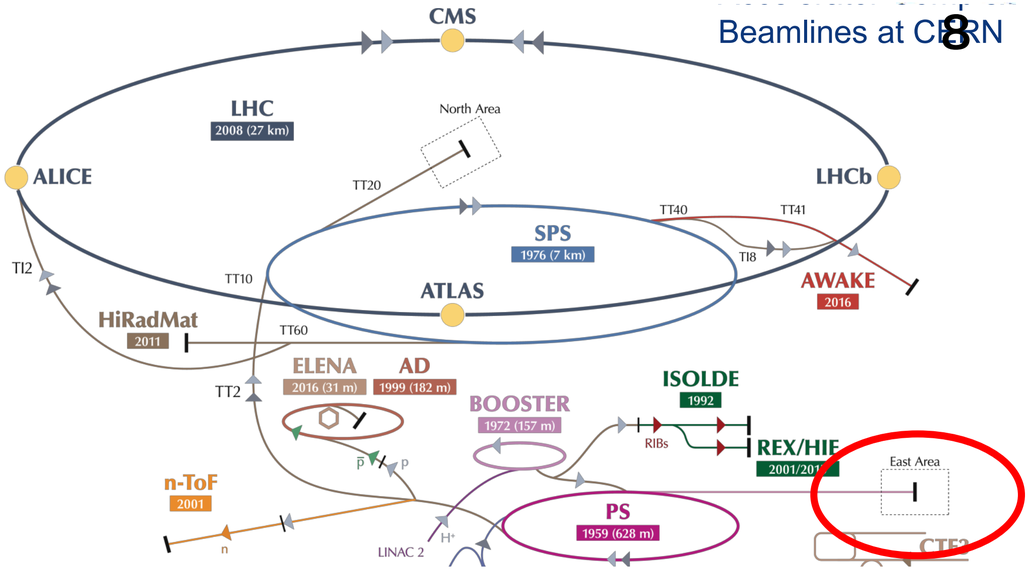
We'll measure this in WCTE

$$X[\mu \rightarrow \pi] * Y[\pi \rightarrow {}^{9}Li]$$

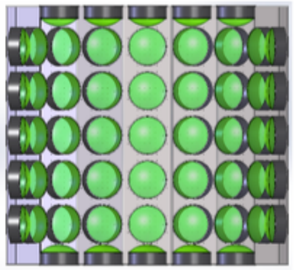


WCTE

Prototype IWCD in CERN test beam at East Area



Water Cherenkov Test Experiment

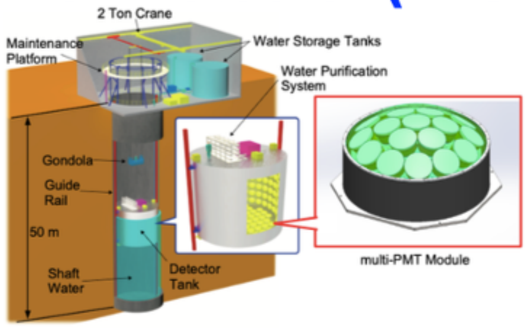


4 m tall x 4 m diameter

In charged particle test beam

~100 photosensor units

Intermediate Water Cherenkov Detector (IWCD)

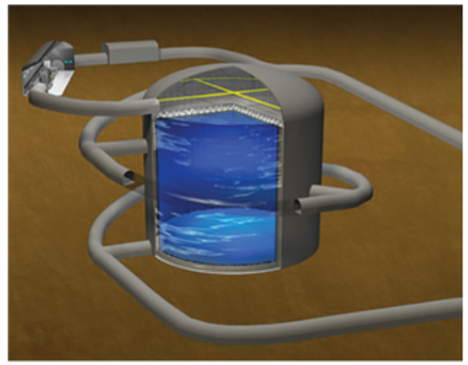


8 m tall x 10 m diameter

In J-PARC neutrino beam

~480 photosensor units

Hyper-K



71 m tall x 68 m diameter

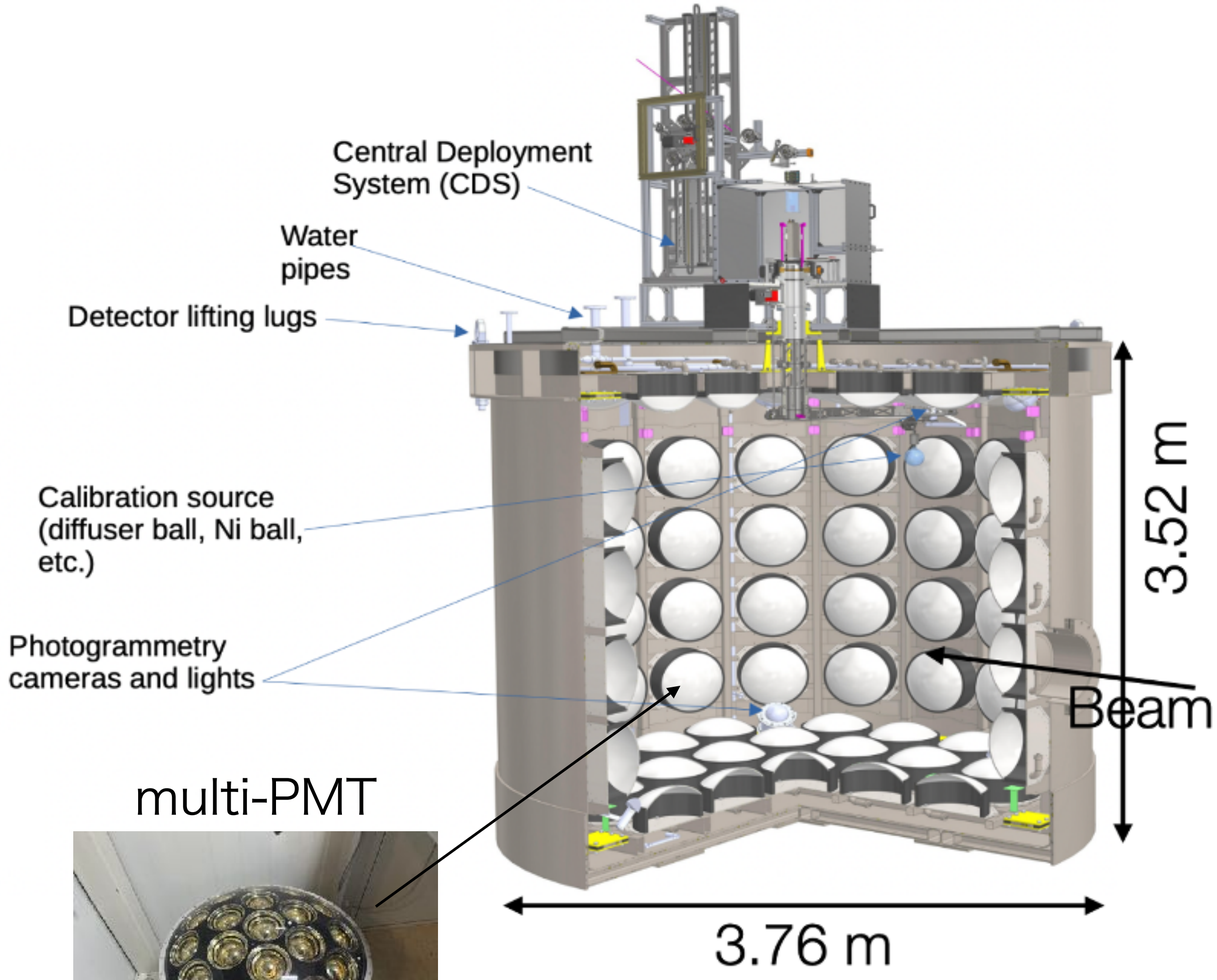
295 km from J-PARC neutrino source

>20,000 photosensor units

WCTE

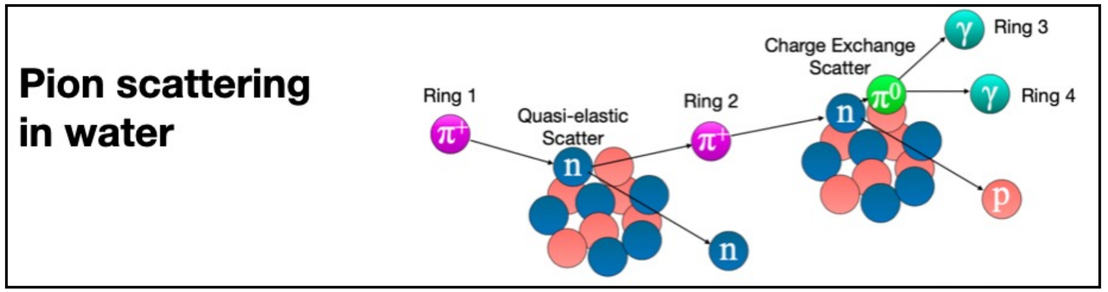
Water Cherenkov Test Experiment at CERN

- 30 ton water Cherenkov detector
- Instrumented with 97 multi-PMTs
- Instrumented with calibration systems
- Receive from T9 beam line in East Area
  - Interested in e, π, μ, p, γ in the 0.2-1.2 GeV/c range
- Operation modes with pure water and loading of $Gd_2(SO_4)_3$
- Operated in 2024 and 2025.



multi-PMT

WCTE
Physics motivation

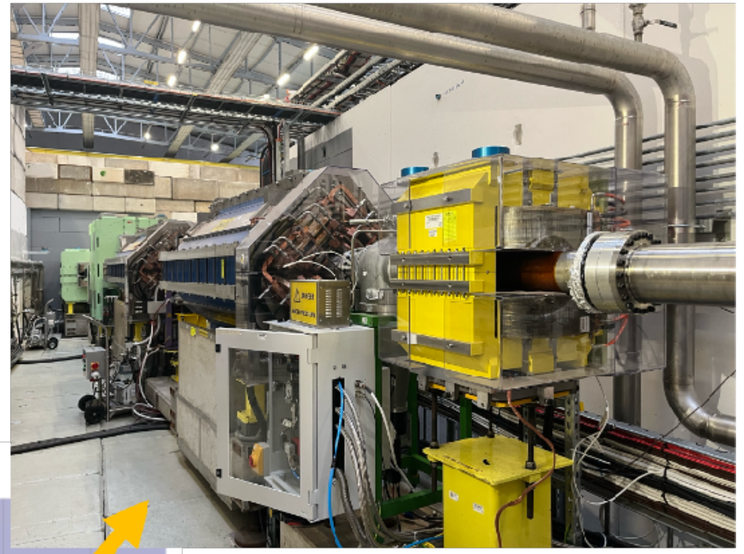


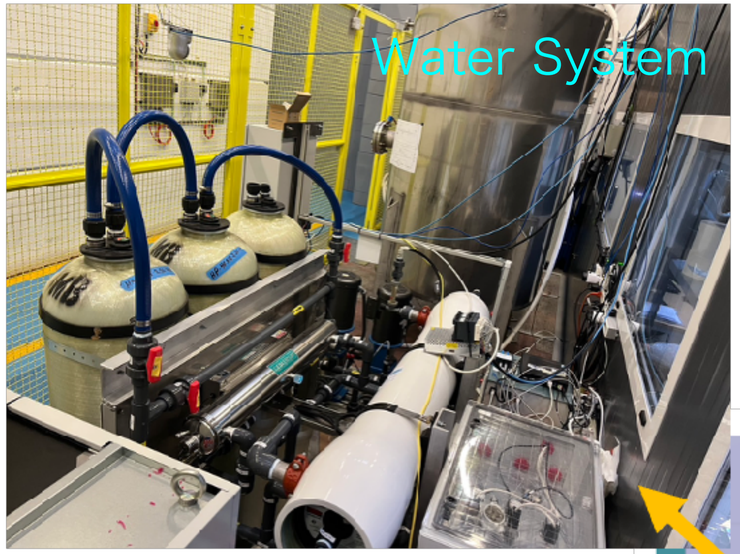
- Pions of ~500MeV/c or less are produced in neutrino interactions - we aim to study their hadronic scattering in water and apply data in T2K, SK and HK
- Particle identification is critical for selection muon or electron neutrino candidates - will be studied in WCTE with same photosensors to be used IWCD
- Neutron detection is avenue for neutrino/antineutrino separation in SK-Gd - will measure important effect of secondary neutron production
- Neutrino interactions producing gammas are dominant background for electron neutrinos - will study capability to separate gamma and electron/positron events
- Large samples of leptons and gammas in WCTE can be used to study scattering processes on nuclei that are related to neutrino-nucleus scattering
- 9Li is background for DSNB searches and may be produced by pions produced in muon-induced hadronic showers - measure 9Li production

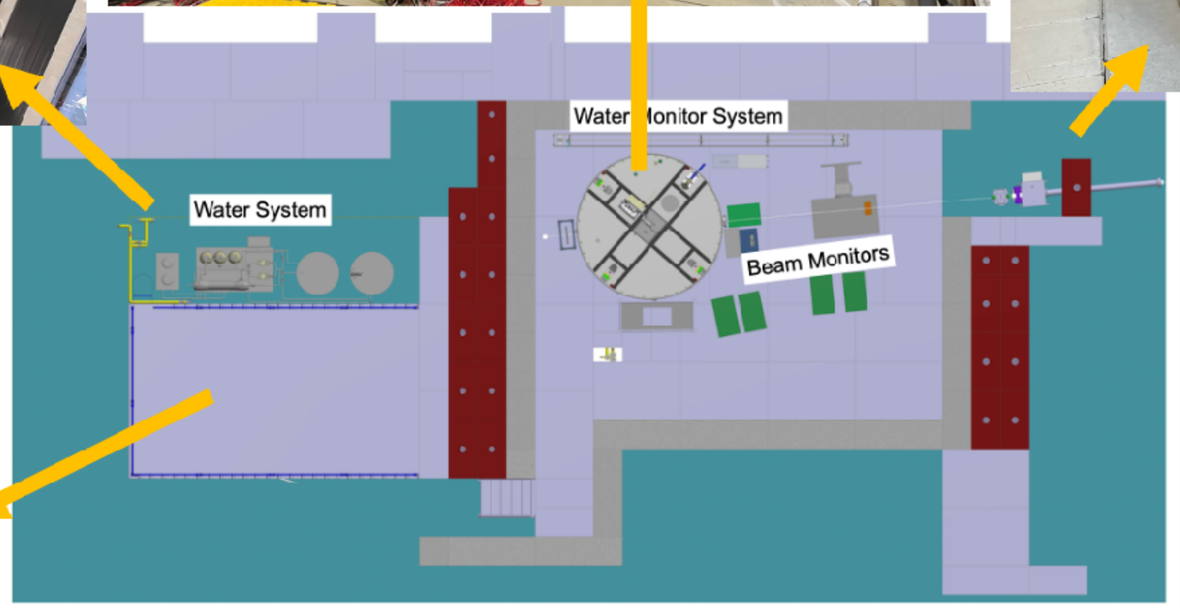
WCTE
Setup overview

Water Cherenkov Detector

Beam Line



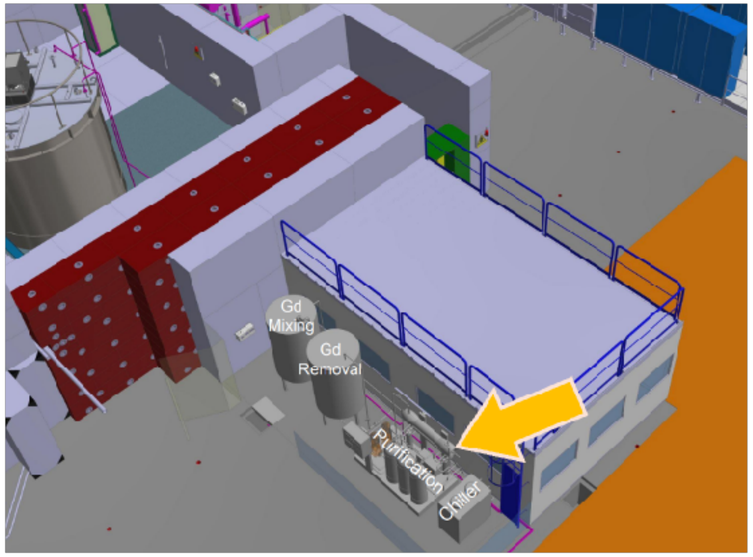


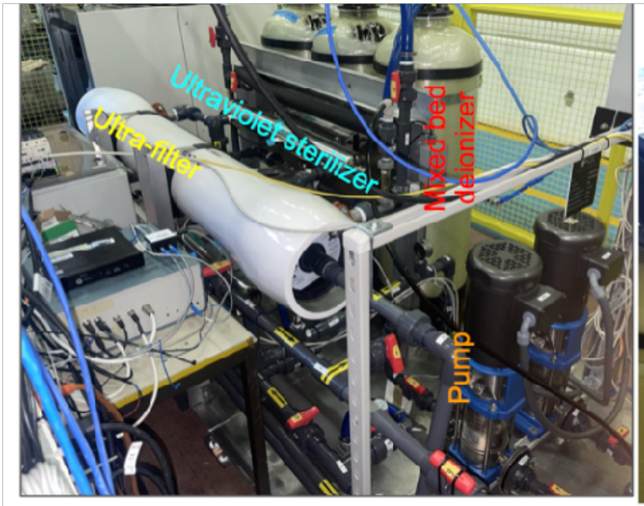


WCTE

Water system

K.Hamaguchi (Okayama) joined the final setting work Jan.20~Feb.11, 2025





水システム

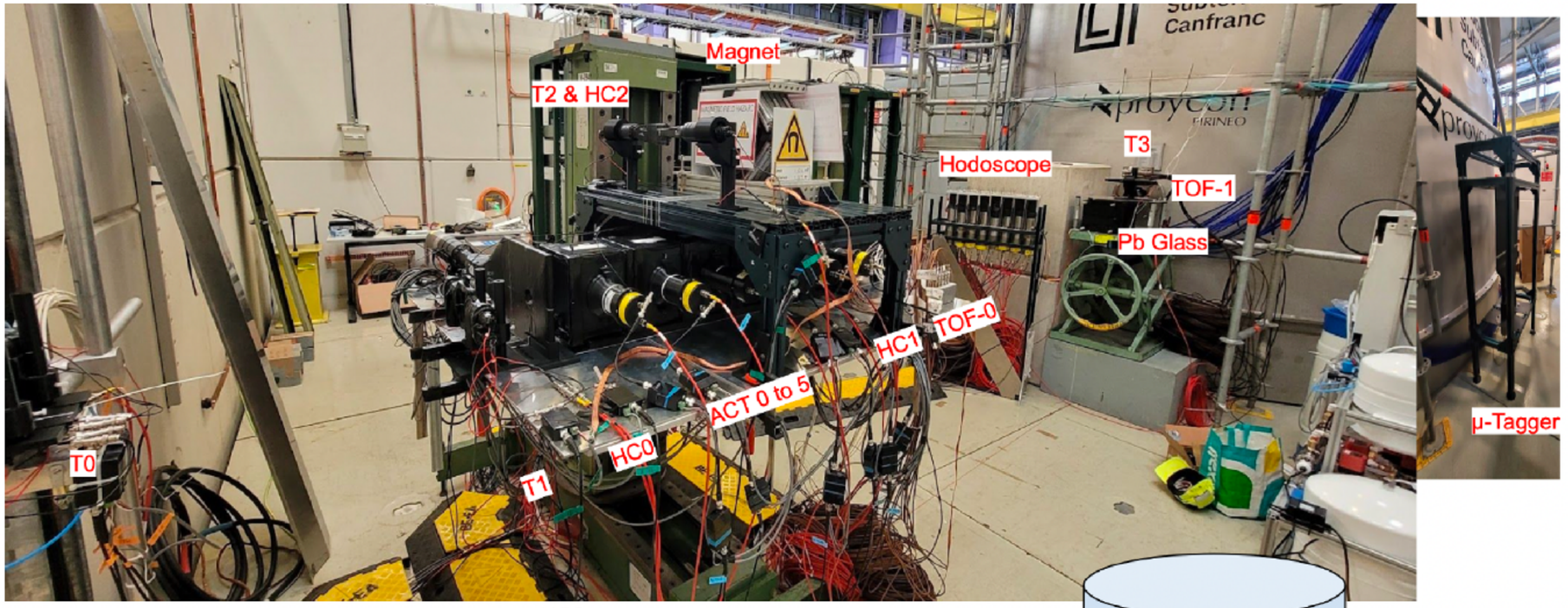
フィルター、
イオン交換樹脂、
UV 殺菌装置、
チラー　を搭載

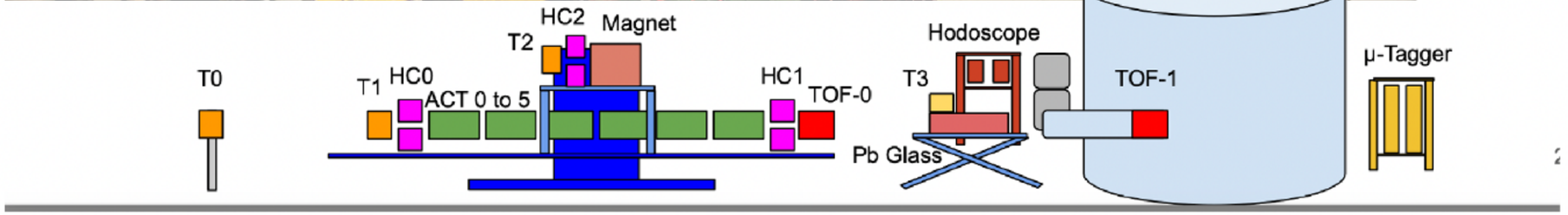
流量 2t/hr

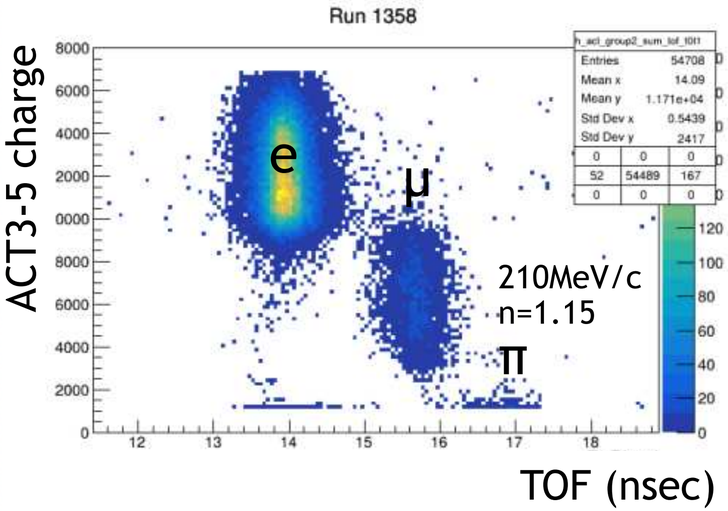
Gd濃度を下げずに
不純物を取り除く

WCTE
Beam monitors

very preliminary!





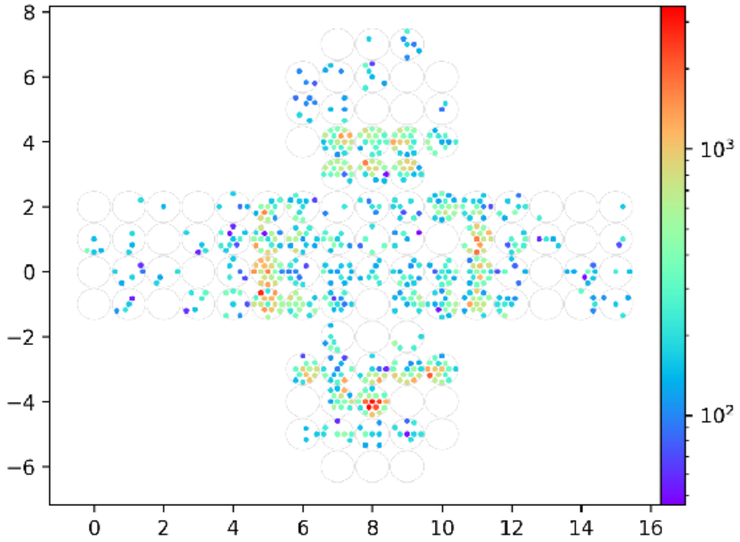


Good Particle Identification! using combination of time-of-flight (TOF) and aerogel Cherenkov threshold (ACT) monitors

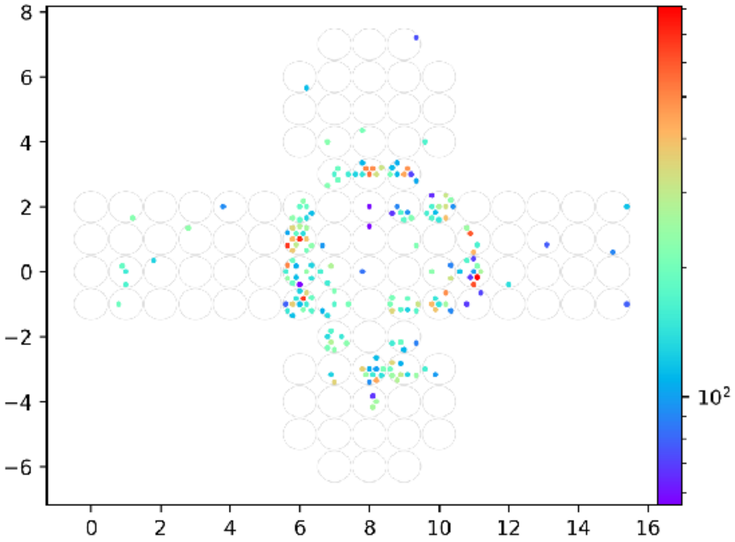
WCTE
Event display

very preliminary!

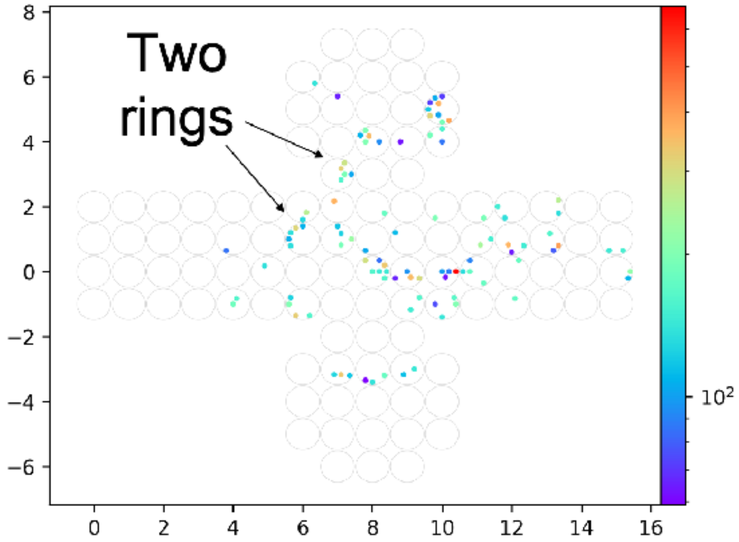
Electron 250 MeV/c



Muon 250 MeV/c



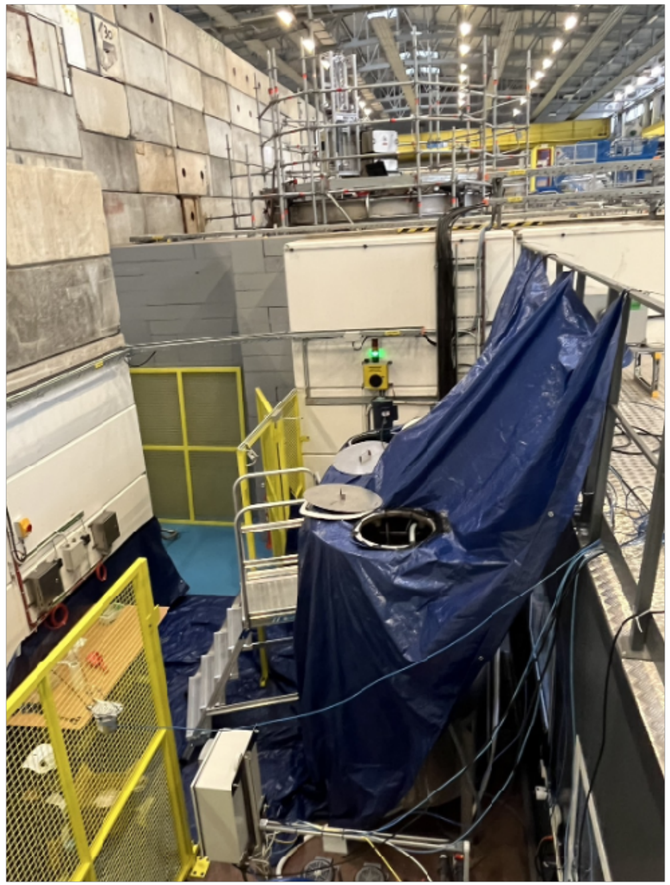
Pion 250 MeV/c

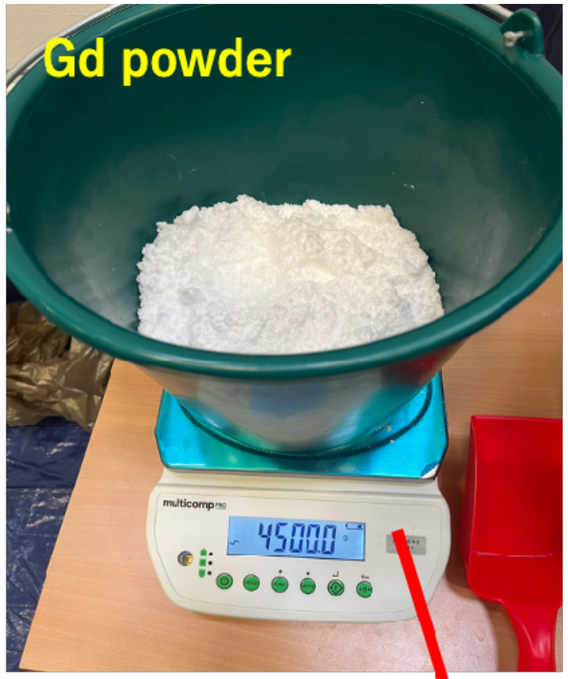


- Using beam monitor data, we can select electron, muon and pion-like event
- See expected patterns for Cherenkov rings, including events consistent with pion hadronic scattering

WCTE
Gadolinium loading

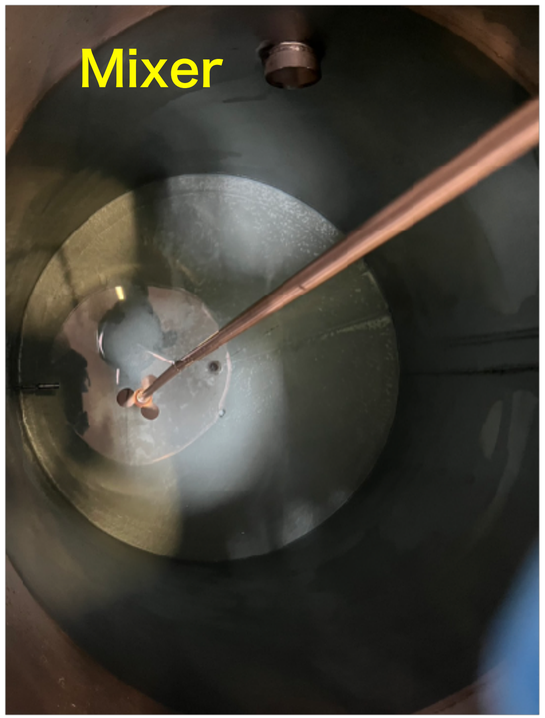
Completed on May 23.
(~ 2 days work)





- Move 1.4m^3 of water from the detector into the Gd mixing tank
- Measure between 0.5 and 10kg of $Gd_2(SO_4)_3$
- Add the $Gd_2(SO_4)_3$ to the mixing tank
- Turn on the mixer and mix for 1-2 hours
- When $Gd_2(SO_4)_3$ is dissolved, move Gd loaded water back into the WCTE detector

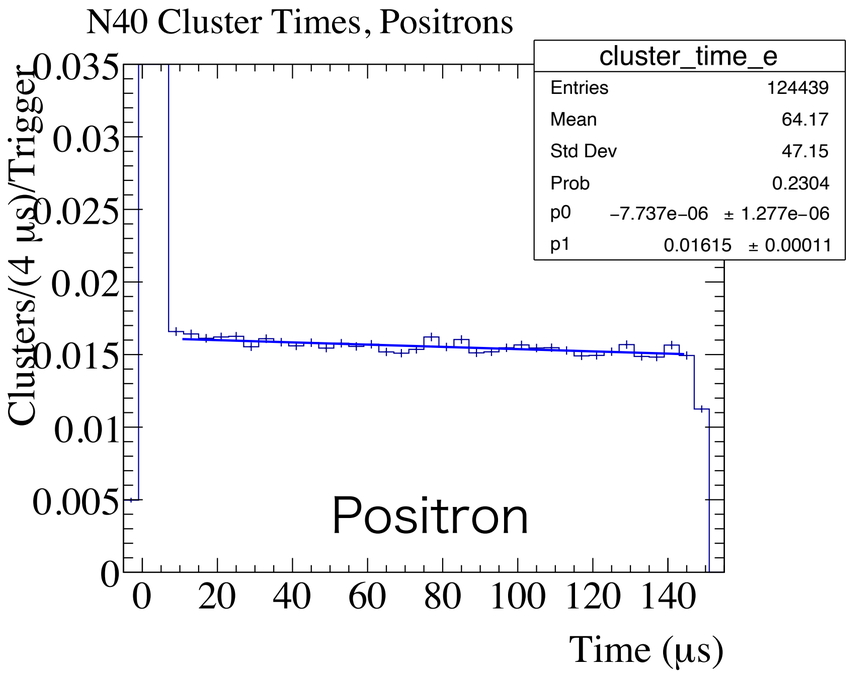
$Gd_2(SO_4)_3$: 20kg
Gd concentration : 0.03% (same as SK-Gd)

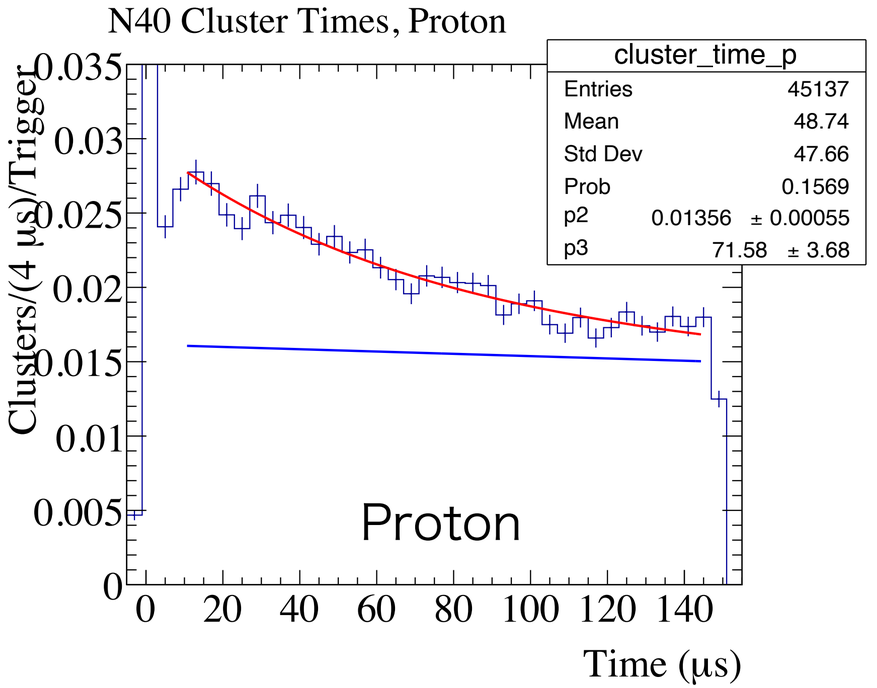


WCTE

Indication of neutron signal

very preliminary!



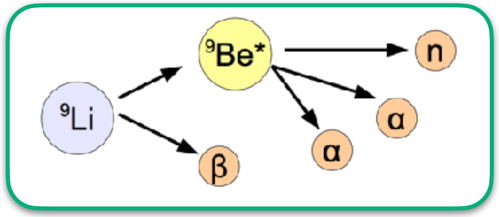


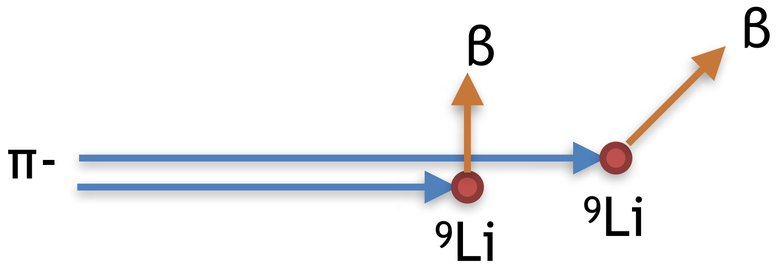
- Investigate 1000MeV data, looking at hit clusters with 10≦Nhits≦30
- Fit proton sample with background model from positrons and exponential function
- Clear excess in proton events, best fit with time constant (capture time) of 72±4 μs
- Integral of fitted exponential gives 0.24 neutrons per proton

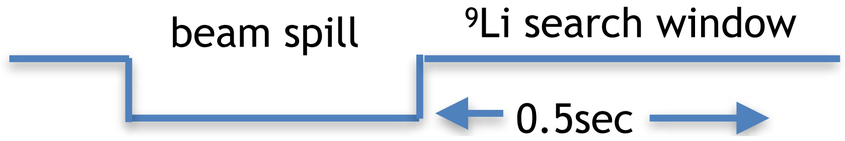
WCTE
Decommissioning

WCTE

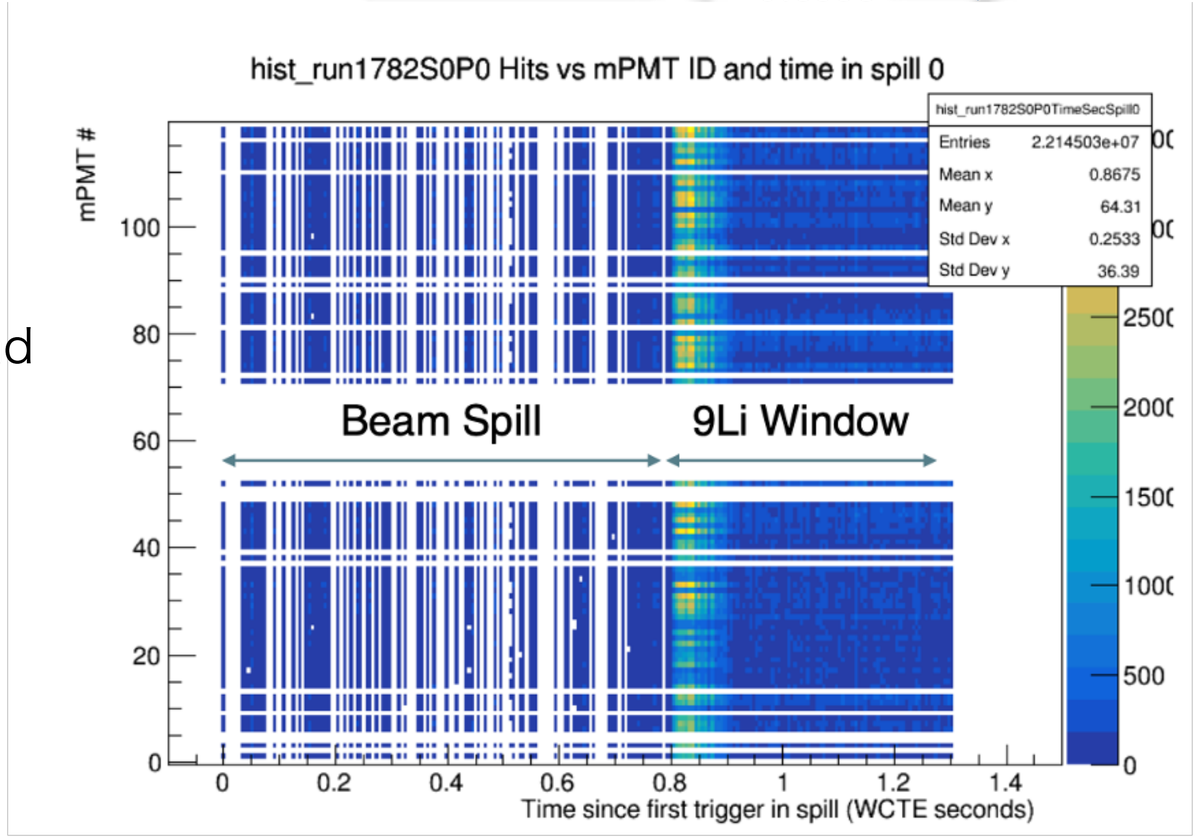
^{9}Li production study







- Beta decay (τ =0.26sec.) with neutron (49.5%)
- ^{9}Li decay vertex provides pion interaction point
- More data being taken with Gd loading for neutron tagging
- Prepared a continuous trigger that runs after end of spill to collect data 0.5 sec of data after each spill
- We've taken ~4days of 260, 280, 300, 320, 340, 360MeV/c π- data
- Start data analysis.



Status and the next
toward understanding spallation

- First look at the pure water data of pion beam in 9Li window. Please see the Hamaguchi-san's poster.
- Next, going to the Gd loading data. Neutron tagging is essential. This will be the same method as SK-Gd. Please see the Nishigami-san's poster.
- Tune the hadron interaction model based on this experiment, it will be installed to the SK-Gd analysis.
- In future, hope to understand overall spallation mechanism using high energy muon beam (>10 GeV).

Stay tuned!