Neutron Lifetime Measurement at J-PARC/MLF/BL05

Tatsuhiko Tomita[7],
Katsuya Hirota[2], Sei Ieki[1], Takashi Ino[3], Yoshihisa Iwashita[4], Masaaki Kitaguchi[5],
Ryunosuke Kitahara[6], Kenji Mishima[3], Aya Morishita[7], Hideyuki Oide[8], Hidetoshi Otono[9],
Yoshichika Seki[10], Tatsushi Shima[11], Hirohiko M. Shimizu[2],
Naoyuki Sumi[7], Hirochika Sumino[12], Kaoru Taketani[3], Naoki Nagakura[1],
Takahito Yamada[1], Satoru Yamashita[13], Mami Yokohashi[4], Tamaki Yoshioka[9]

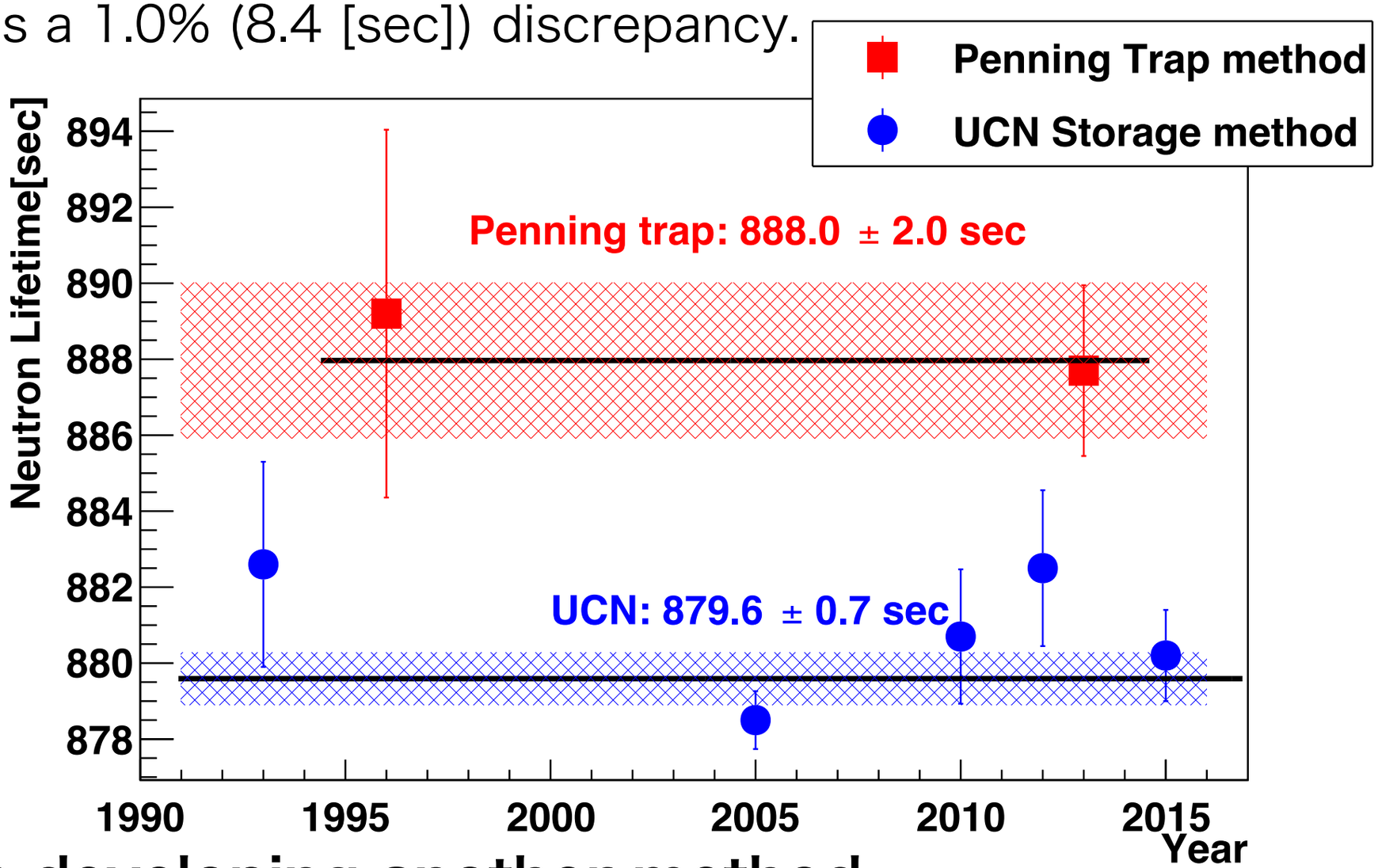
The Univ. of Tokyo[1], Nagoya Univ.[2], KEK[3], ICR, Kyoto Univ.[4], KMI, Nagoya Univ.[5], Kyoto Univ.[6],
Kyushu Univ.[7], CERN[8], RCAPP, Kyushu Univ.[9], J-PARC Center, Japan Atomic Energy Agency[10],
RCNP, Osaka Univ.[11], GCRC, The Univ. of Tokyo[12], ICEPP, The Univ. of Tokyo[13]

Neutron Optics and Physics

Motivation

- Neutron Lifetime (880.2 ± 1.0 [sec]) is a one of the most important parameters for Big Bang Nucleosynthesis.

- determined by Penning Trap and UCN Storage method.
  → There is a 1.0% (8.4 [sec]) discrepancy.



→ We are developing another method for 0.1% accuracy measurement.

Measurement Principle

- Neutron lifetime will be determined by following equation.

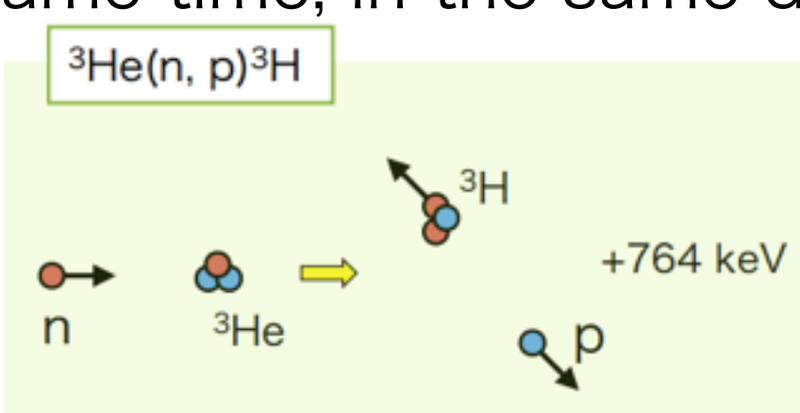
↓ **From Data Acquisition**

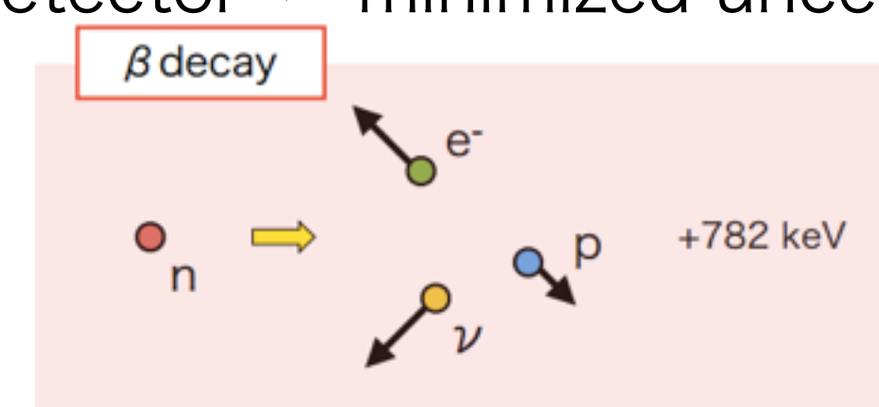
$$\tau_n = \frac{1}{\rho\sigma v}\left(\frac{S_{\mathrm{He}}/\varepsilon_{\mathrm{He}}}{S_\beta/\varepsilon_\beta}\right)$$

S_{He}: Number of Events (^{3}He)
S_β: Number of Events (beta decay)
ε_{He}: Detection Efficiency (^{3}He)
ε_β: Detection Efficiency (beta decay)
ρ: Number Density of ^{3}He
σ: Neutron capture cross section of ^{3}He
v: Velocity of neutron

↑ **number density of ^{3}He** ↑ **Constant** ↑ **From Monte Carlo Simulation**

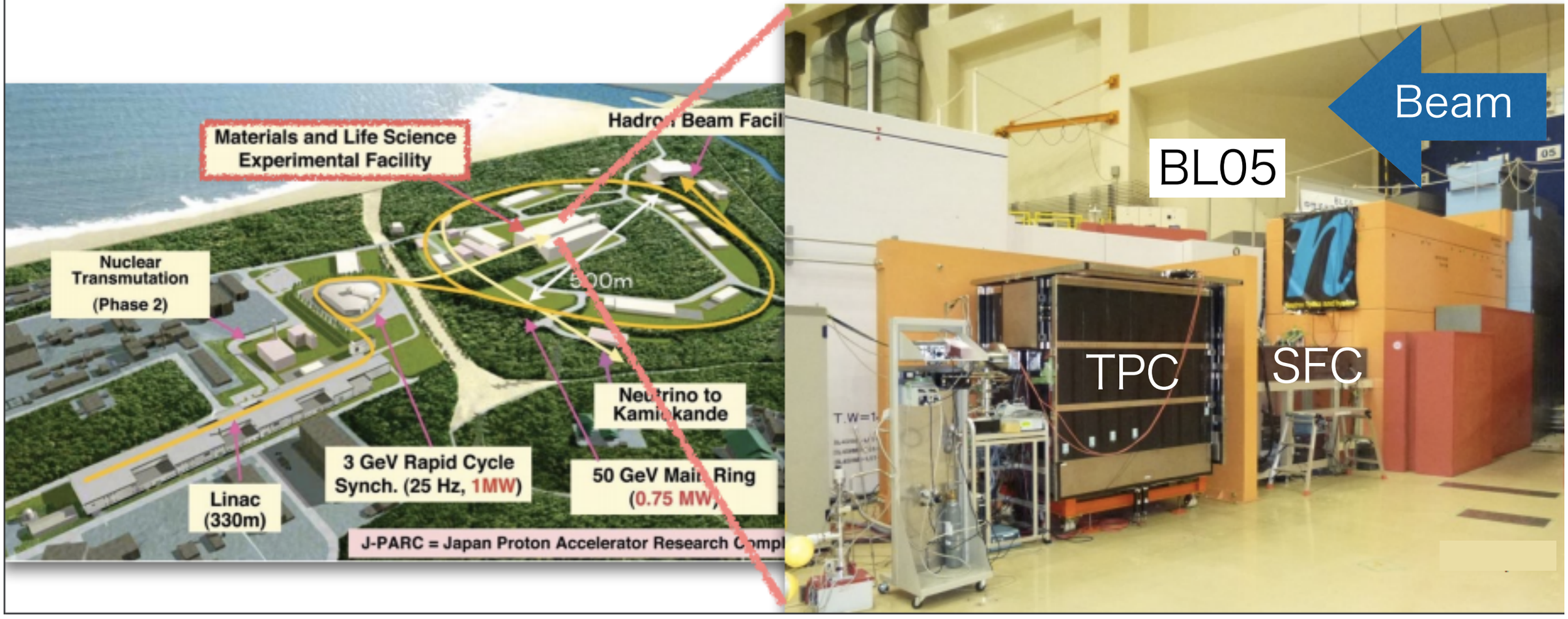
- We count the number of "electron" emitted from in-flight neutron beta decay.
- Neutron flux will be measured by neutron capture reaction in ^{3}He. (at the same time, in the same detector ← minimized uncertainty)



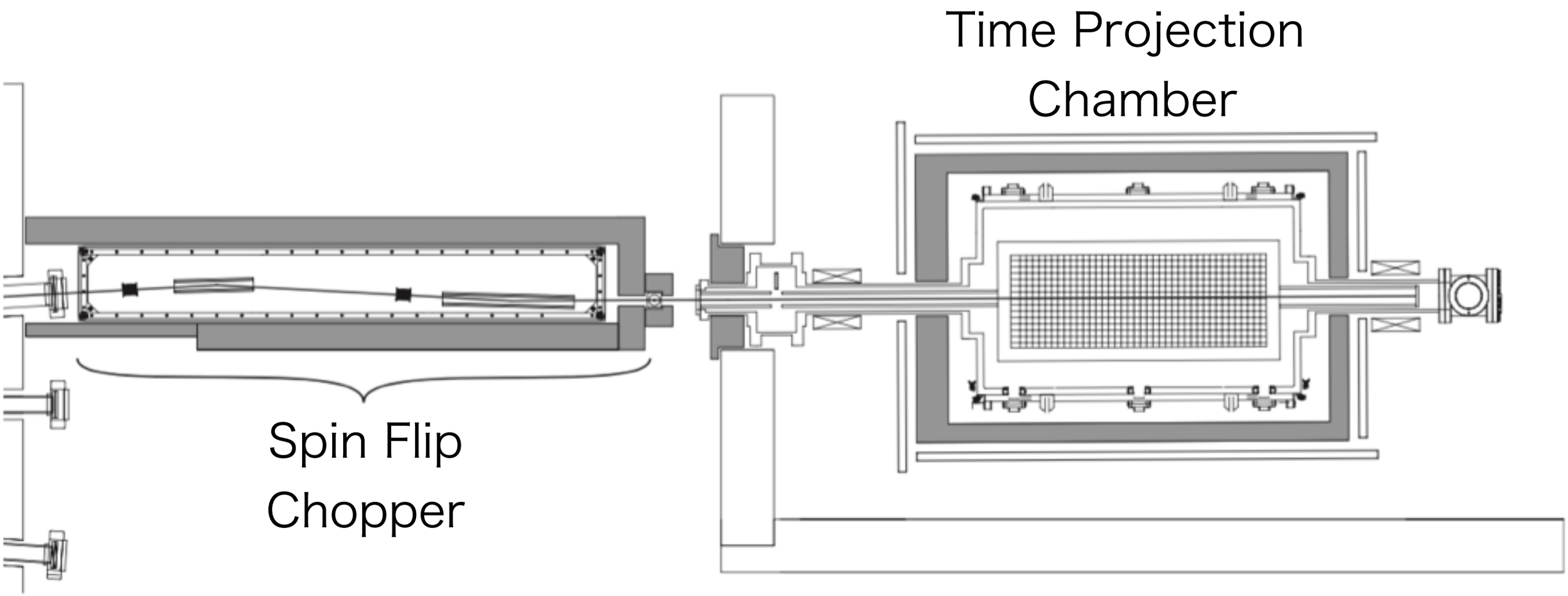


J-PARC MLF BL05

- J-PARC (Japan Proton Accelerator Research Complex)
  - 25 Hz pulsed proton beam
- MLF (Materials and Life science experimental Facility)
  - nuclear spallation neutron source (Hg Target)
- BL05 (Beam Line 05 [NOP])
  - Polarization : 95%
  - Flux : 4.0 x 10^7 [/sec·cm^2] (Cold Neutron ~10meV)



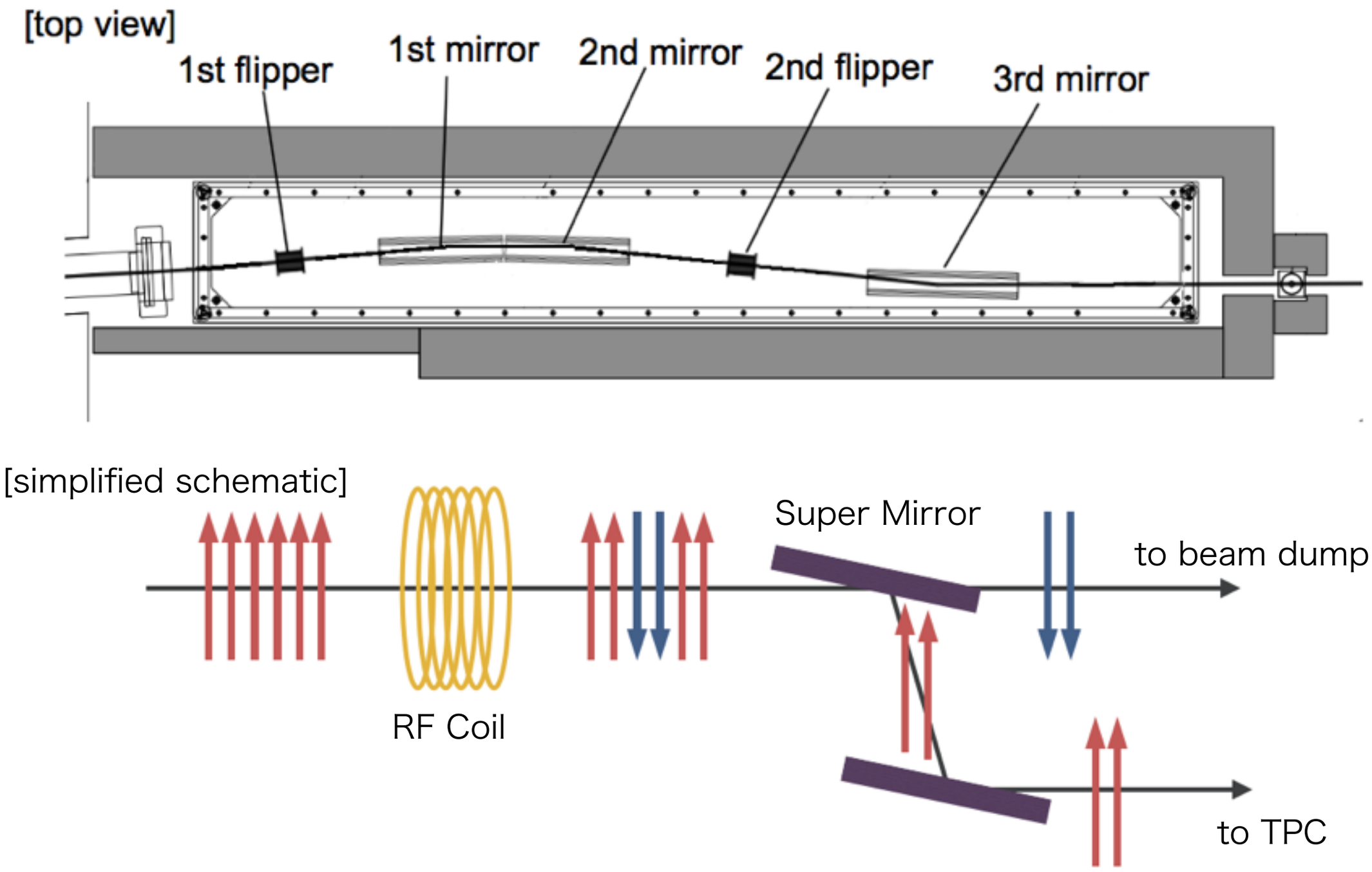
Setup



- SFC (Spin Flip Chopper) : forms neutron into bunches
- TPC (Time Projection Chamber) : detect beta decay and $^{3}He(n, \alpha)^{3}H$

SFC(Spin Flip Chopper)

- Pulsed neutron beam is formed into bunches using spin flipper and magnetic mirror.

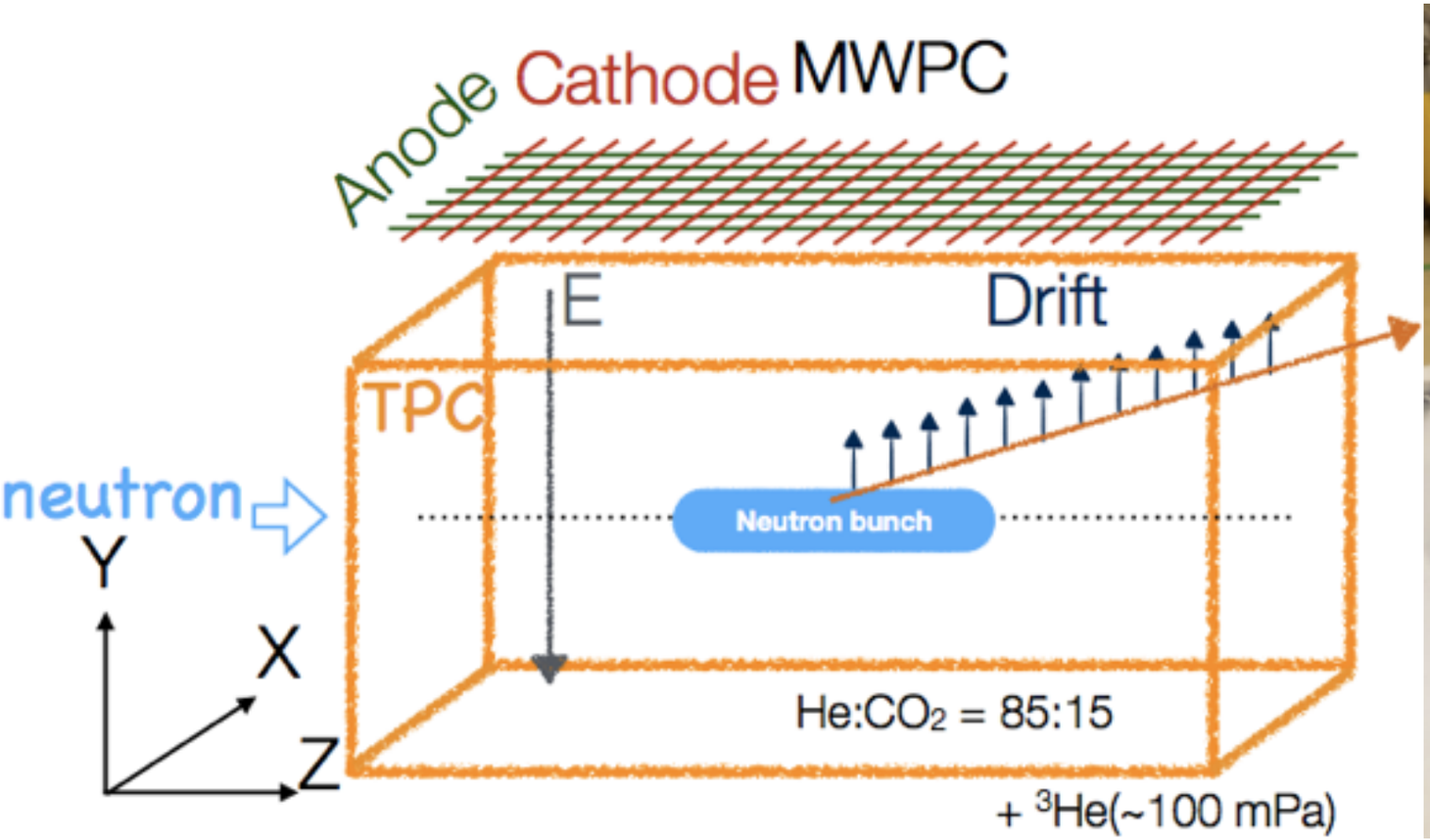


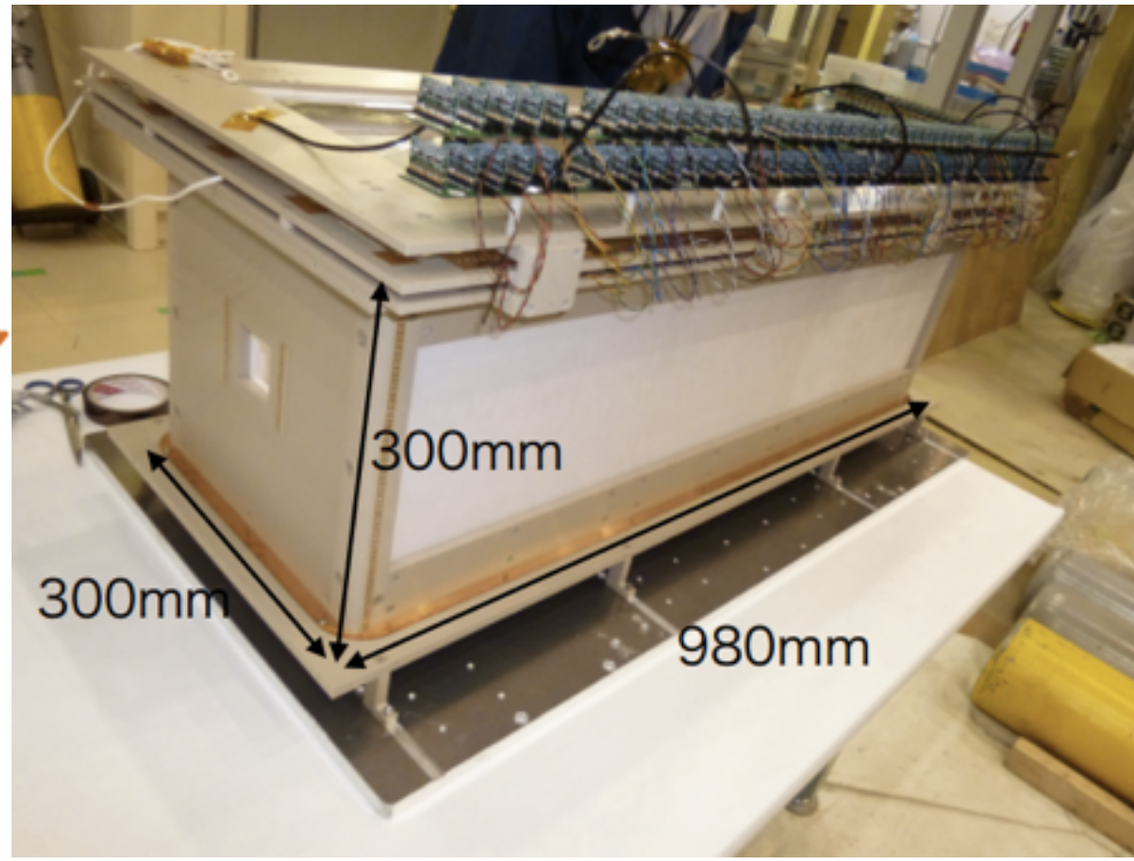
TPC(Time Projection Chamber)

- Operated with ^4He (85 kPa) + CO_2 (15 kPa) + ^3He (100 mPa) gasses.
  (^3He : for measuring neutron flux)

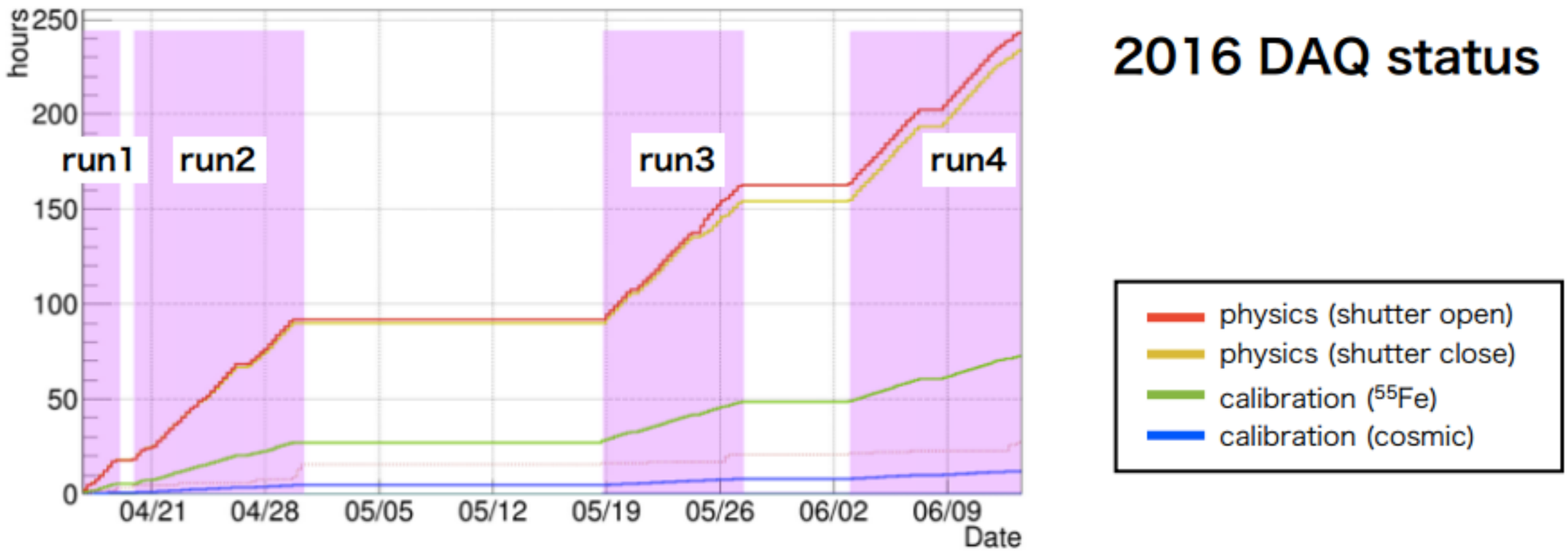
- For low background measurement,
  - TPC frame is made by PEEK (Poly Ethel Ethel Ketone)
  - inner walls are covered with ^6LiF board

Anode : 24ch, 12mm pitch, 1720V
Field : 24ch, 12mm pitch, 0V
Cathode : 40 x 2ch, 6mm pitch, 0V





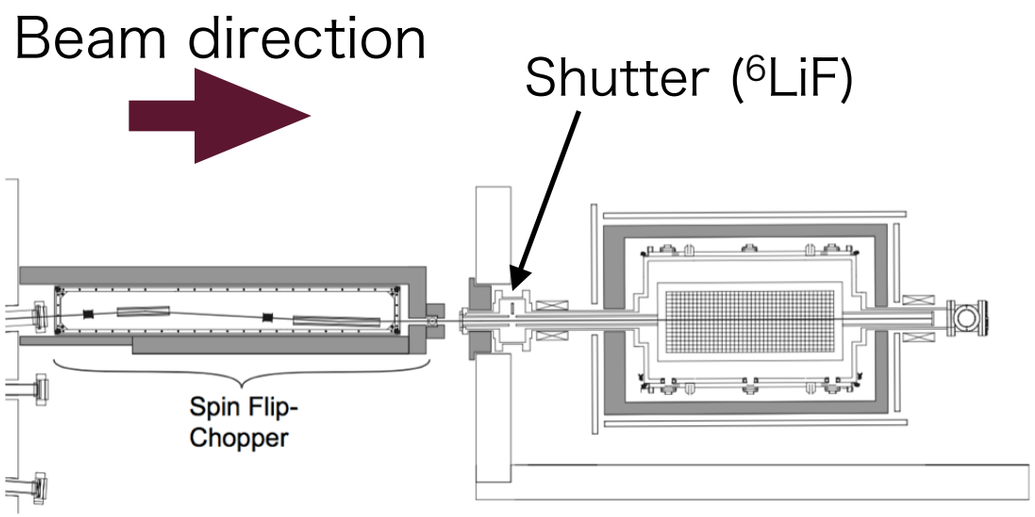
Operation Status

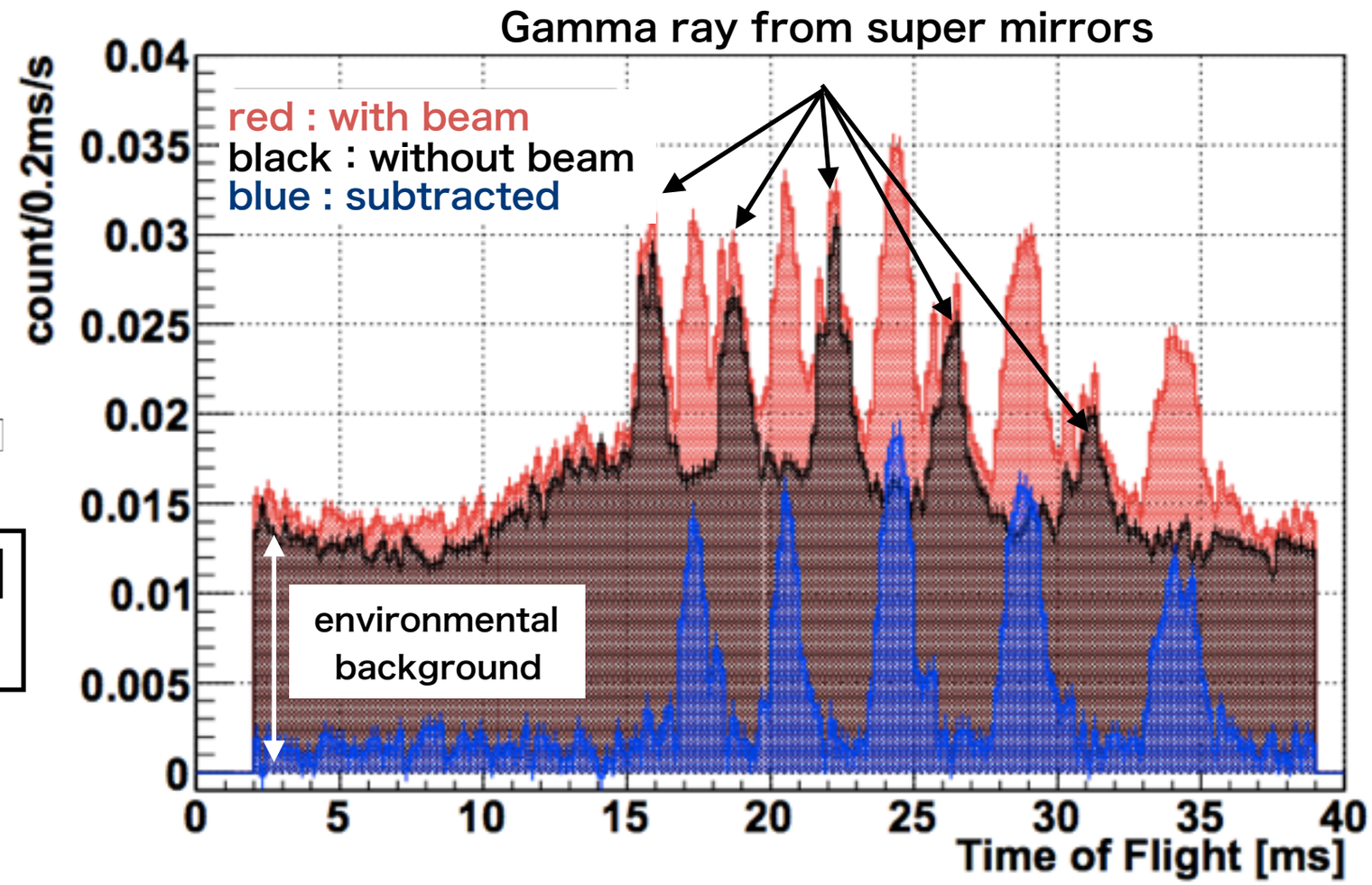


- Data acquisition was carried out from Apr. to Jun. in 2016.
  → total 37 days, ~80% runs : good for physics

- Statistical uncertainty is about 1-2% on neutron lifetime.

Backgrounds





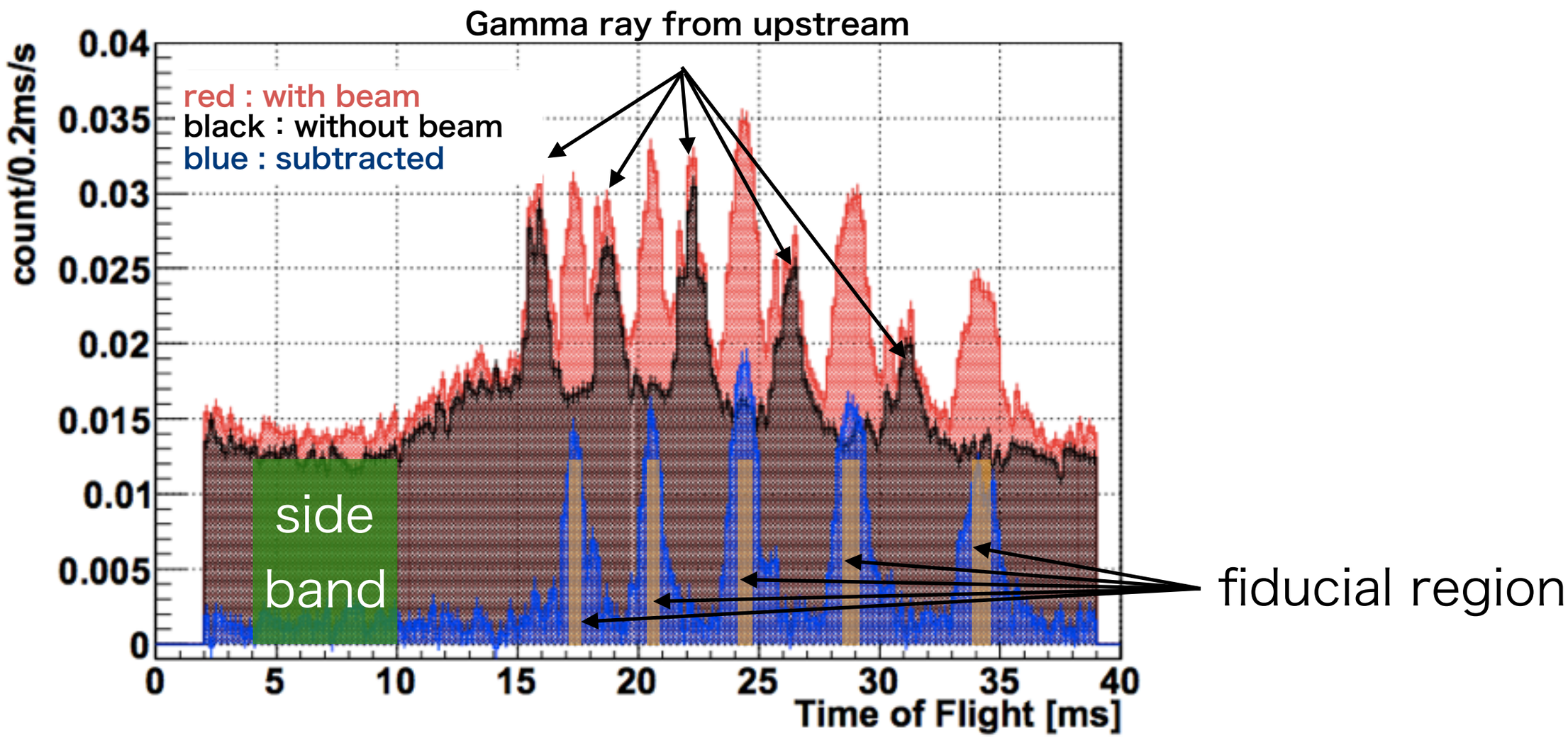
- Beam size : 3×3 (cm^2) [square]
- Polarization : > 95%

- Major background sources
  - Gamma ray from upstream of TPC
  - Environmental background : cosmic ray, radio isotopes
  - beam induced background : scattered neutron beta decay, gamma ray from TPC wall

Event selection - 1

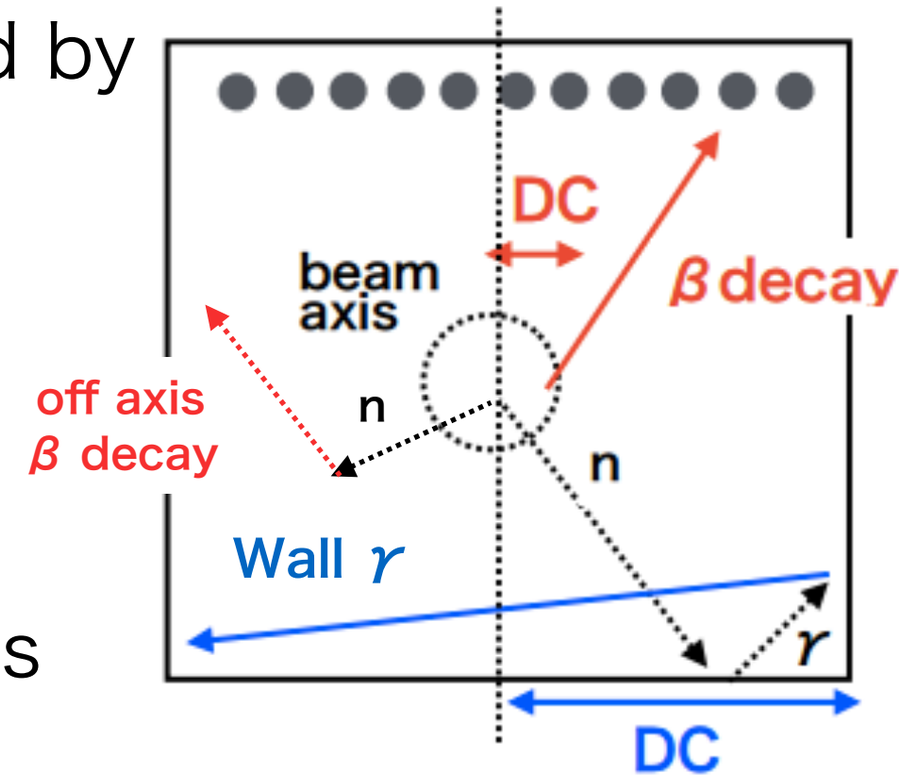
- Gamma ray from upstream and environmental background
  → well subtracted by using w/ beam and w/o beam runs.

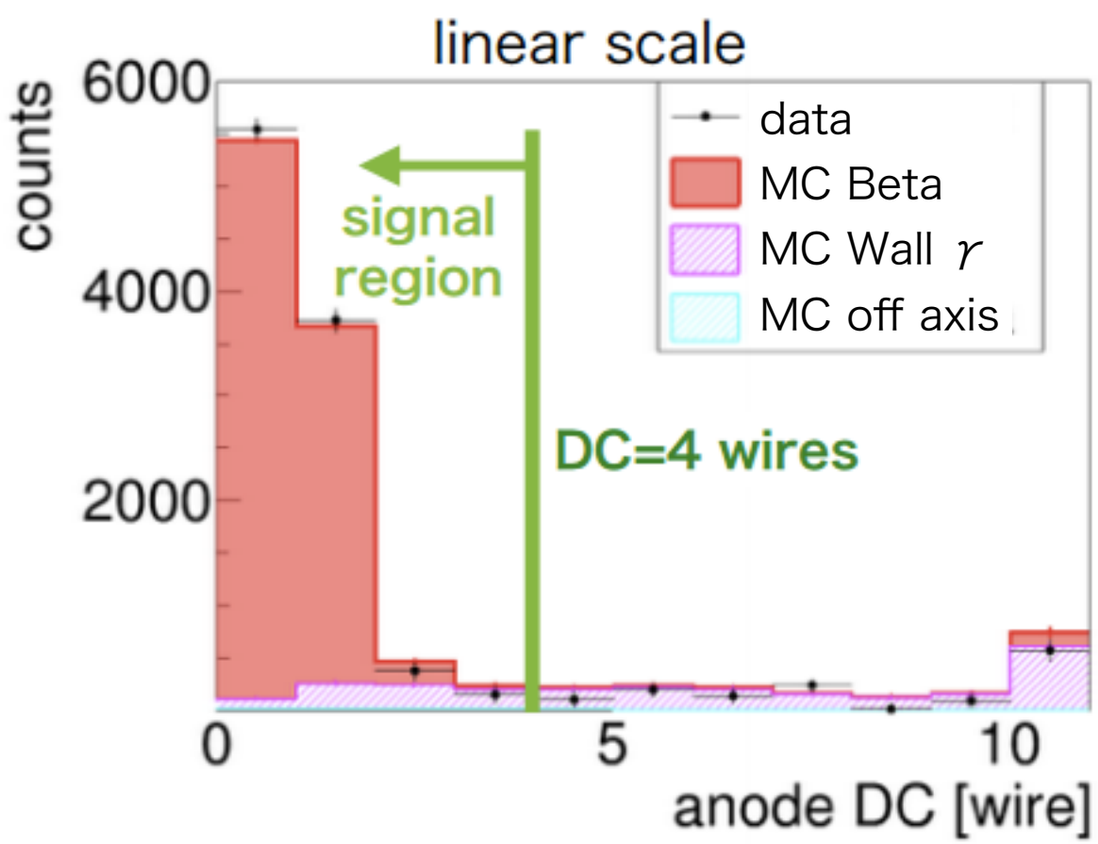
- Each bunch length is determined by taking account of TPC size.

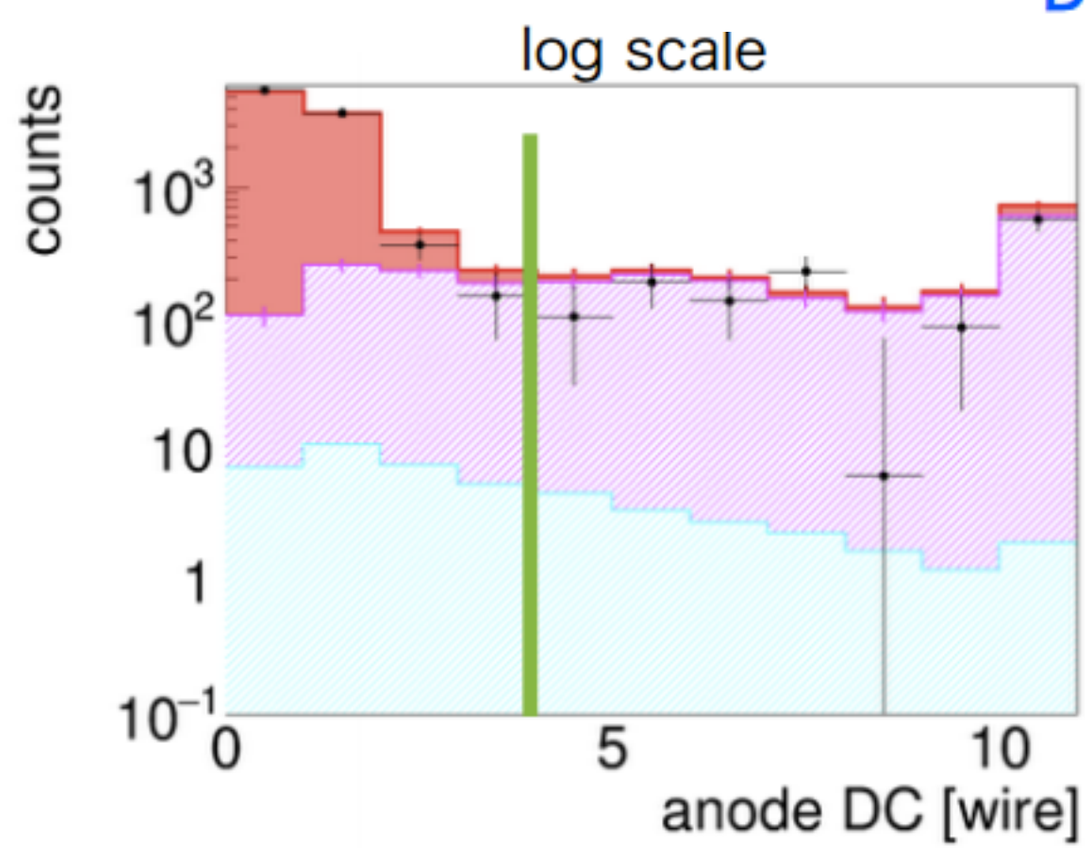


Event selection - 2

- Beam induced backgrounds is estimated by Monte Carlo Simulation (GEANT4).
- DC : Distance from beam Center.
- beta decay : from beam axis
  wall γ, off axis : far point from beam axis







Summary of uncertainty

- Statistical uncertainty is about 1-2%.

- We are now evaluating systematic uncertainties.
  → The number of beam induced background is a dominant source of uncertainty.

		uncertainty (%)	correction (%)
N_β	statistics	~ 1	———
	$^3He(n, p)^3H$ leakage	< 0.34	0
	beam-induced background	**being evaluated**	8.6
	efficiency	$^{+1.0}_{-0.3}$	6.1
	pileup	0.39	-0.39
	background subtraction	0.28	-0.43
N_{3He}	$^{14}N(n,p)^{14}C$ contamination	0.23	-1.45
	$^{17}O(n,\alpha)^{14}C$ contamination	0.03	-0.5
N_β, N_{3He}	Spin Flip Chopper S/N	< 0.5	< 0.5
ρ	^3He number density	0.65	———
	chamber deformation (pressure)	<0.33	-0.33
	temperature non-uniformity	0.23	0.23
σ_0	$^3He(n, p)^3H$ cross section	0.13	———

preliminary

Conclusion

- Neutron lifetime is one of the most important parameters for BBN.
  → There is a 1% discrepancy between previous two methods.

- We are developing another method : “electron counting”.

- Data acquisition was successfully done.
  (from Apr. to Jun. in this year)
  → We have already achieved ~1-2% accuracy of statistical uncertainty.

- Uncertainty evaluation is ongoing.
  → The first result is shown soon.

- to achieve 0.1% accuracy. . .
  → upgrade SFC : enlarge beam size, flux ~7 times stronger
  TPC : enable data driven BG estimation
  J-PARC will provide us 5 times strong beam in future. . .

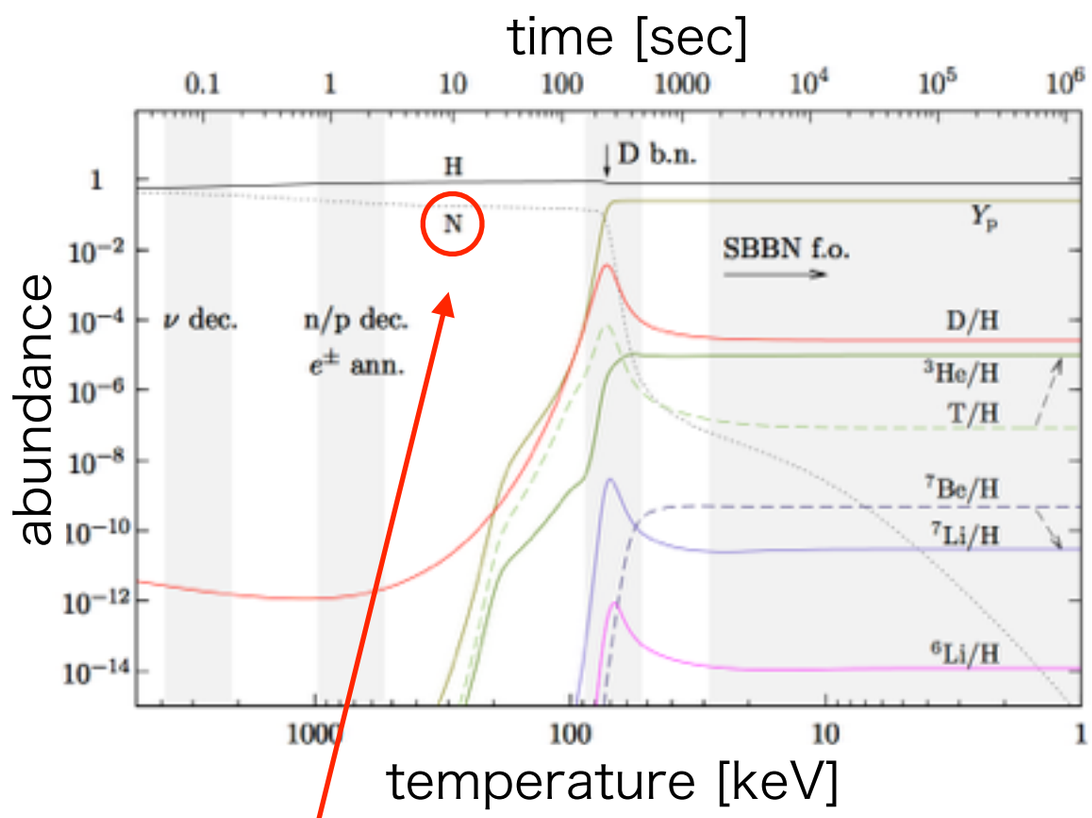
- backup

Motivation

input to BBN theory

BBN thory : predict light element synthesis in the early universe

τ_n affects the number of protons and neutrons at the beginning of nucleosynthesis



number of neutrons
decay into proton(H)

V_{ud} determination in CKM matrix

$$V_{\mathrm{CKM}} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

V_{ud} can be evaluated using τ_n

$$|V_{ud}|^2 = \frac{(4908.7 \pm 1.9)}{(3\lambda^2 + 1)\tau_n[\mathrm{sec}]}$$

τ_n : neutron lifetime

λ : coupling ratio to axial-vector to vector

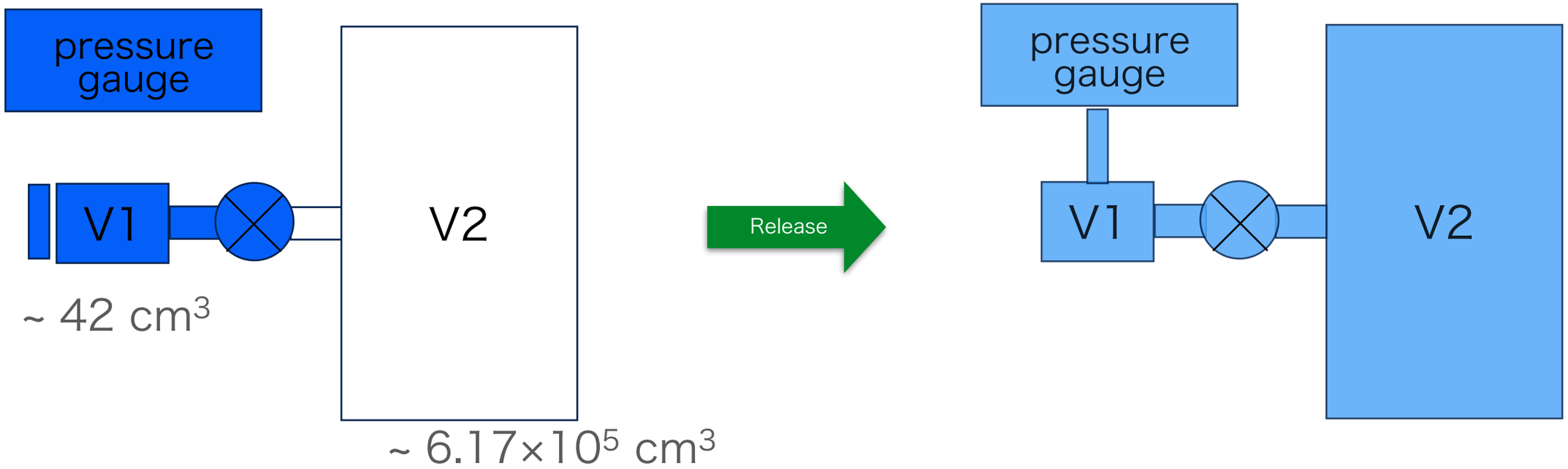
V_{ud} is considerable larger than other elements

→ important parameter for CKM unitarity test

^{3}He pressure measurement

we use **volume expansion method** to determine ^{3}He pressure in TPC

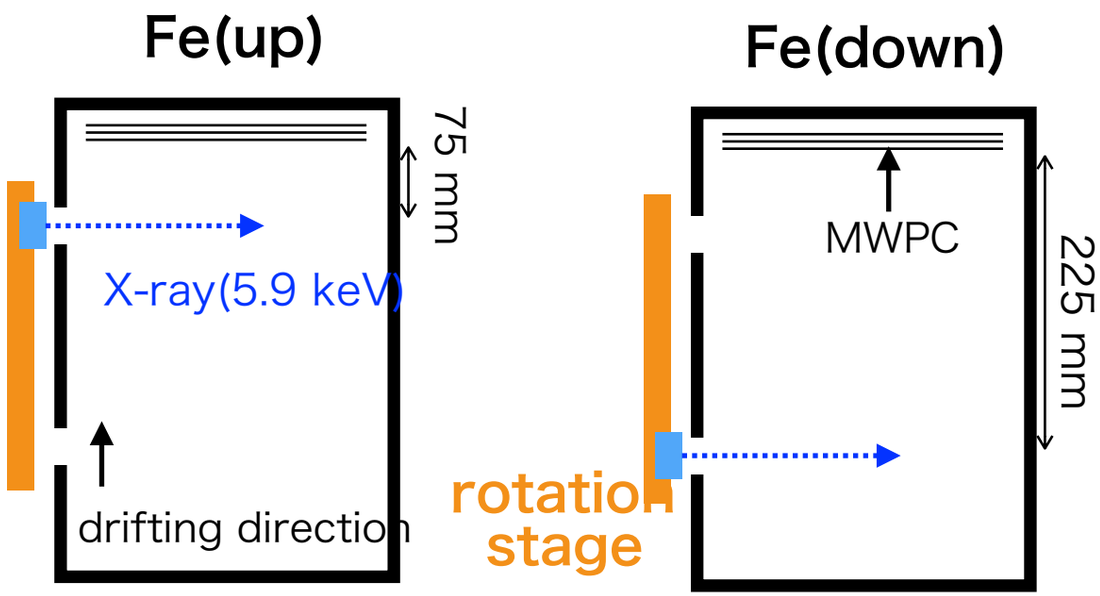
1. measure volume ration (V1/V2) in advance
2. store ^{3}He gas in V1 and measure pressure
3. expand ^{3}He gas into V2

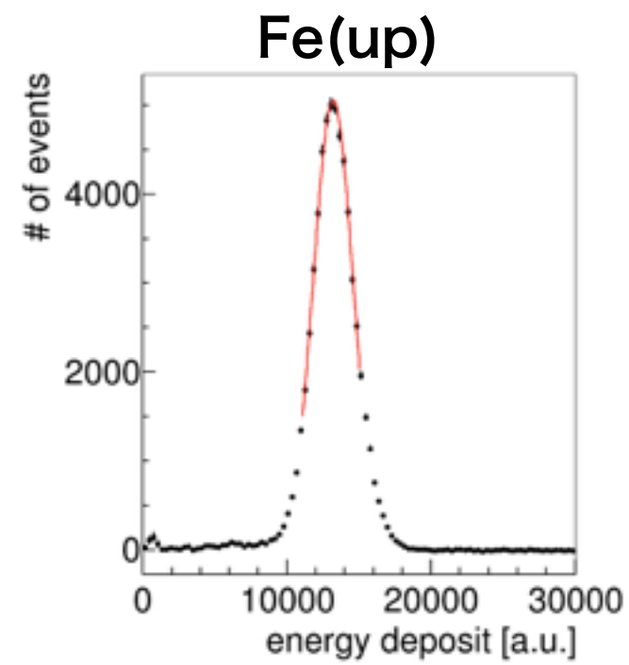


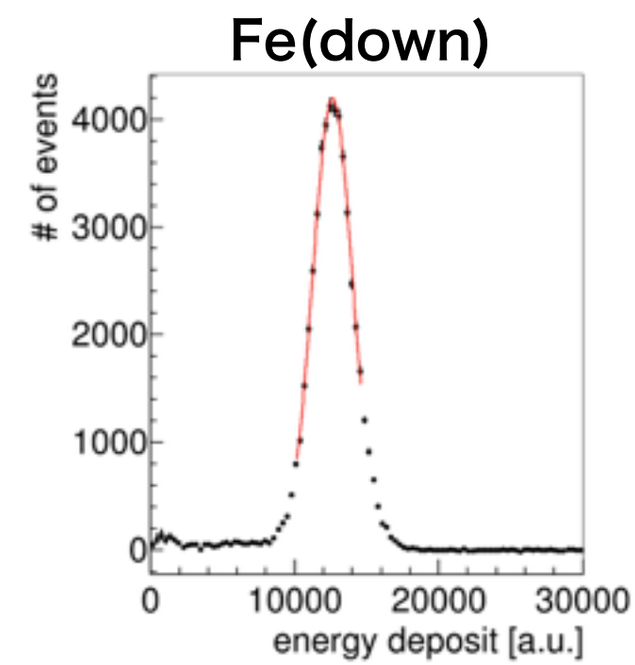
$$V1/V2 = 6.888(19)\times10^{-5}$$

Energy calibration

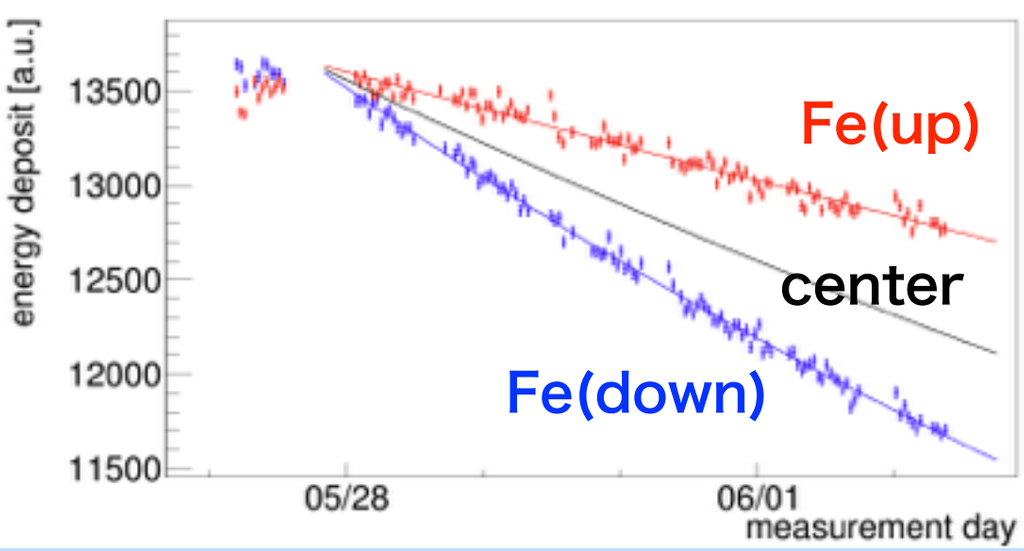
We use X-ray of the energy of **5.9 keV from ^{55}Fe** as a gain calibrator
We can change the drift length of electrons in two way**.**







calibration factor transition

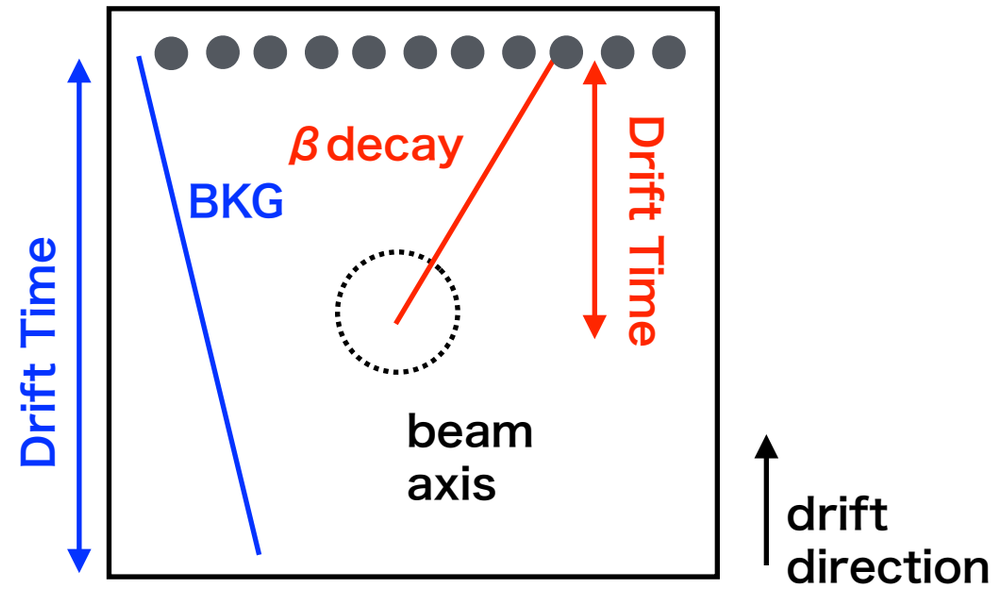


We can correct for the effect of attenutation of electrons during the drift using both **Fe(up) and Fe(down) data.**

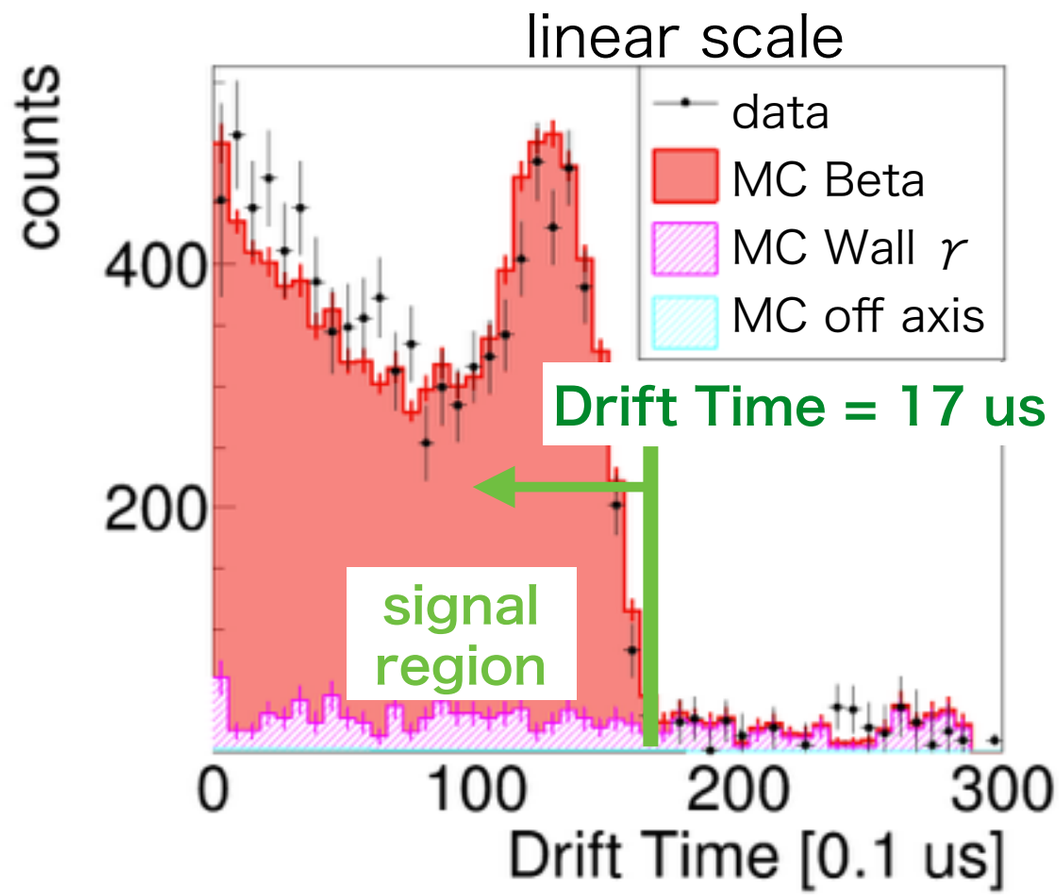
Beam-induced background 2

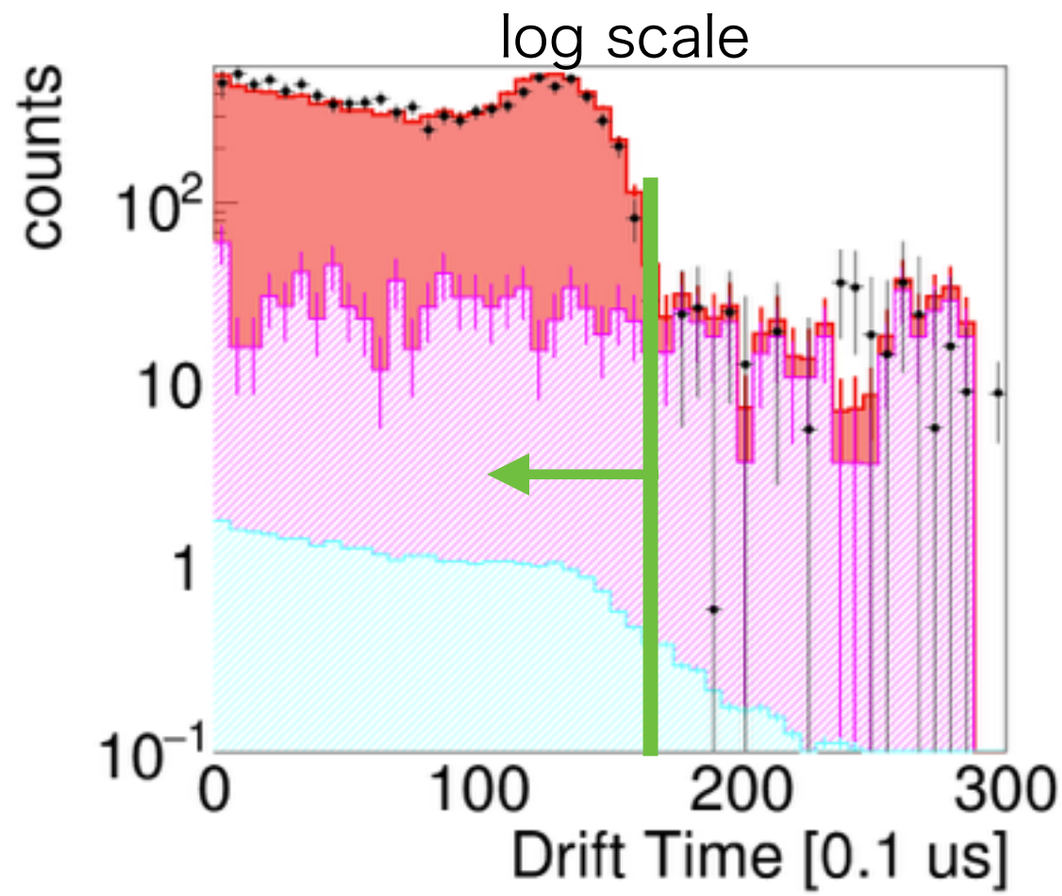
origin of track is near TPC wall

"Drift Time"
arrival time difference of drifting electrons



background has long DriftTime

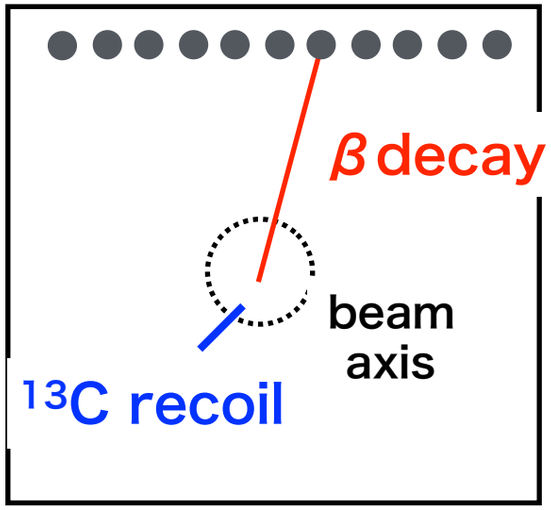




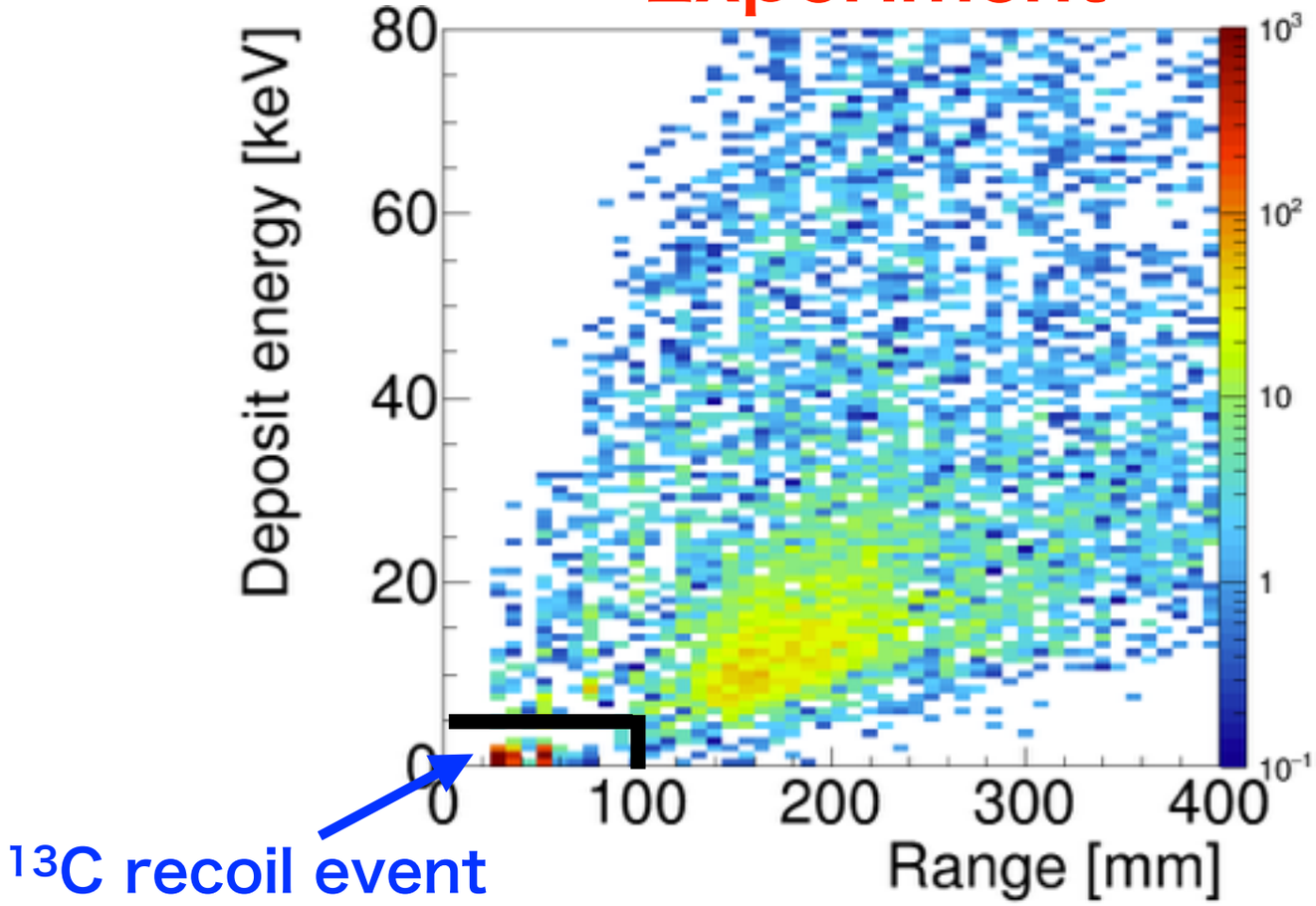
12C(n, γ)13C background

13C recoil from $^{12}C(n,\gamma)^{13}C$

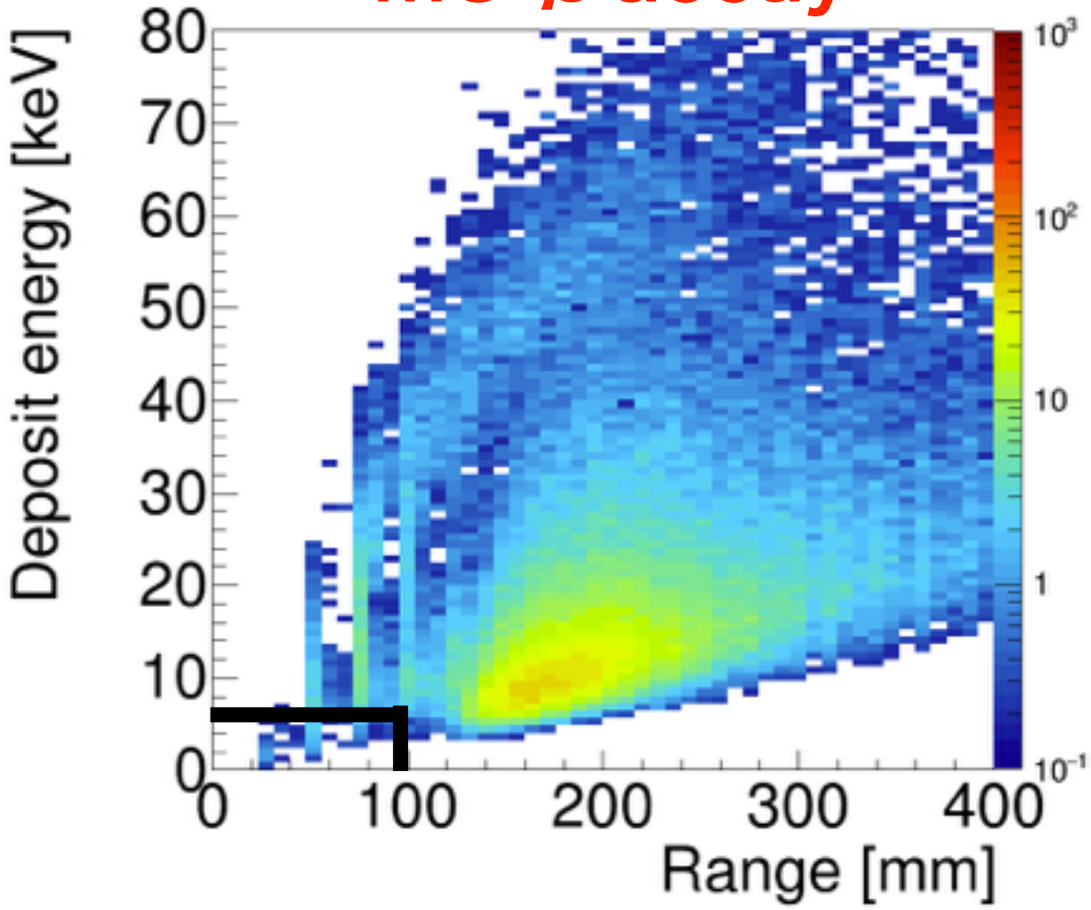
- short track
- low energy deposit



Experiment



MC β decay



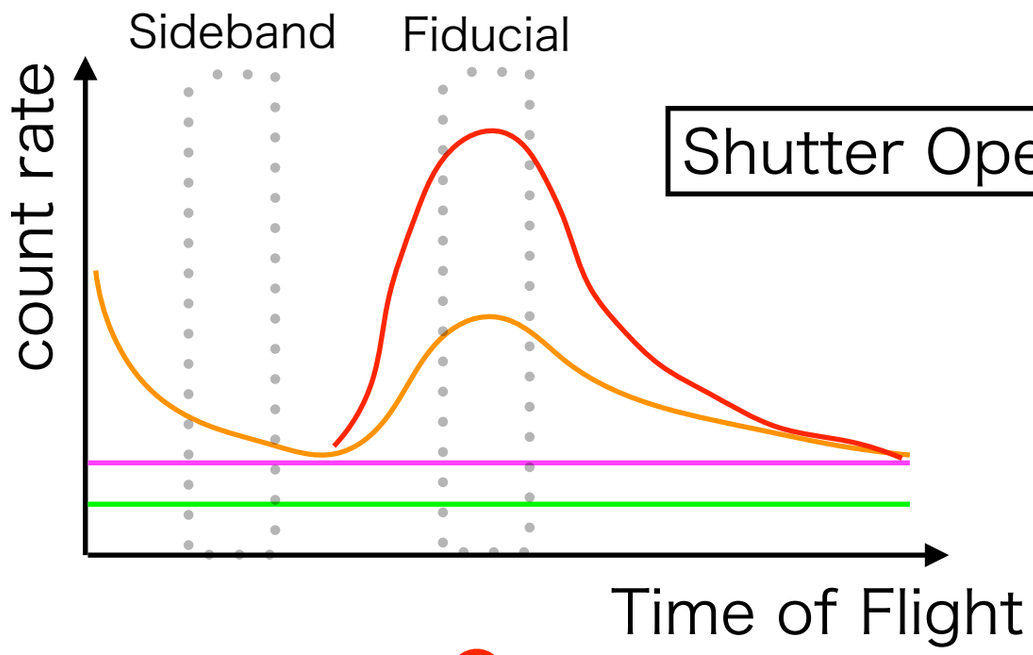
BG subtraction : TOF and shutter open/close data

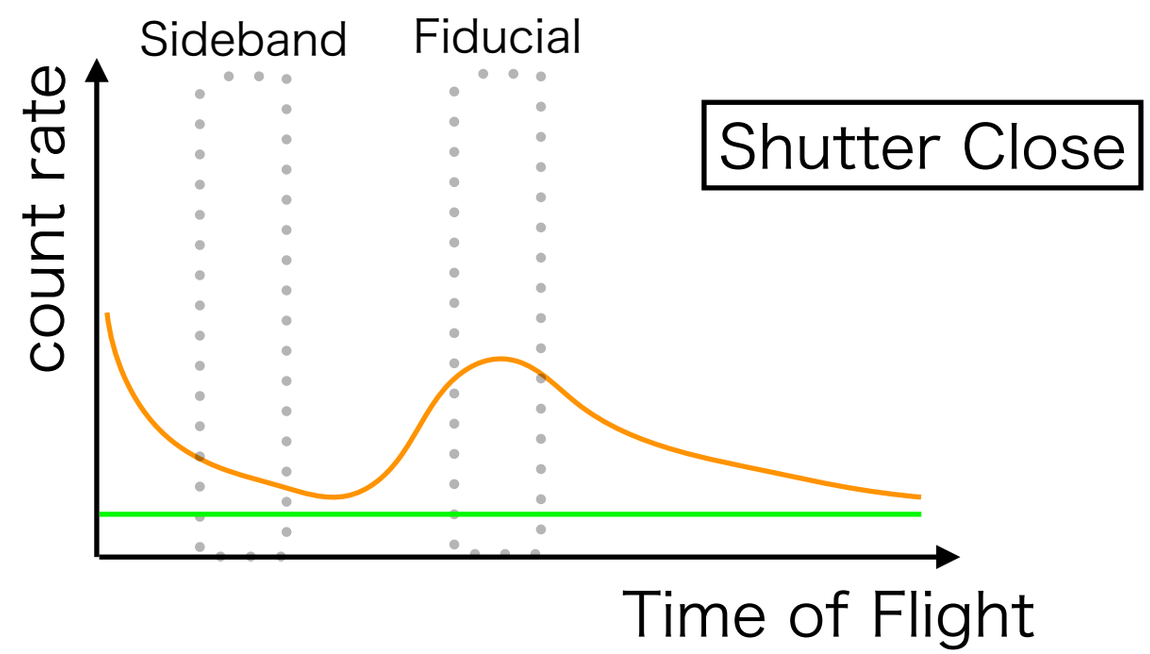
signal + beam-induced BKG

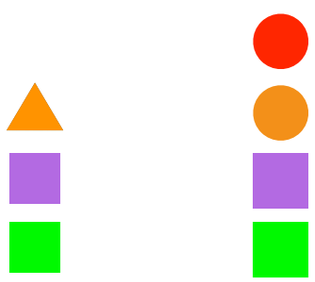
upstrema γ ray BkG

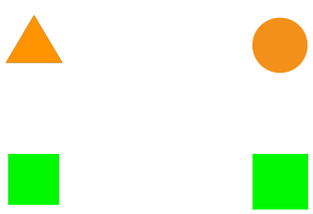
radiation in TPC

cosmic, environmental BG









[(Open Fiducial) − (Open Sideband)] − [(Close Fiducial) − (Close Sideband)]

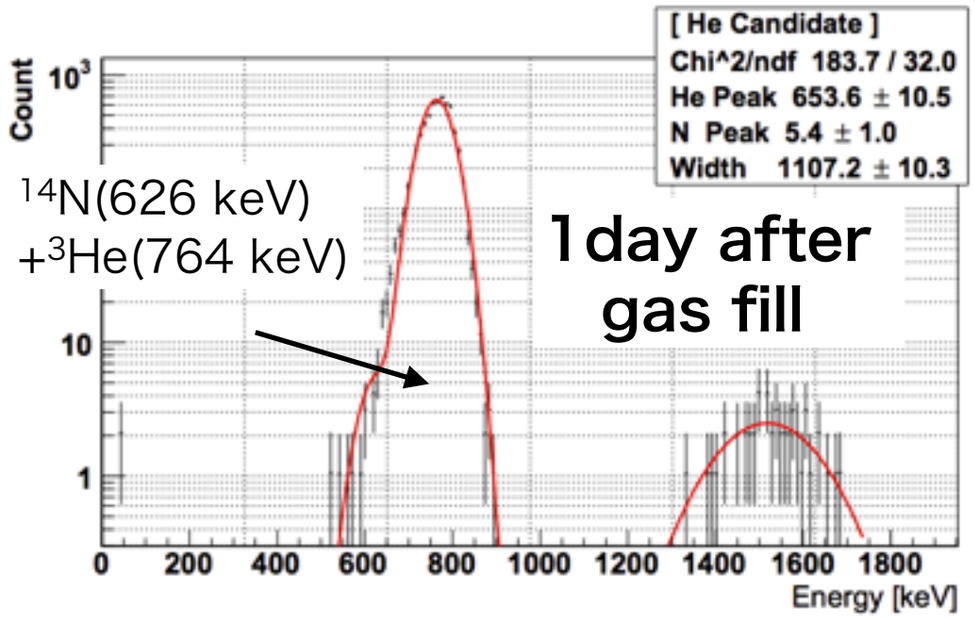
=(● ● ■ ■ − ▲ ■ ■) - (● ■ − ▲ ■)

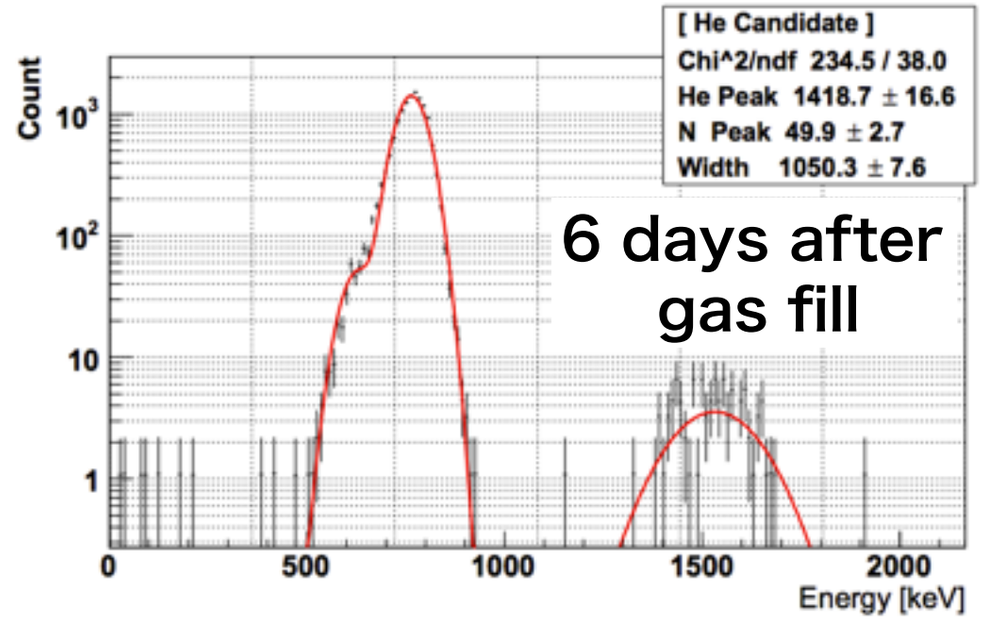
= ●

※normalization : using the number of counts beam monitor

BG subtraction : $^{14}N(n,p)^{14}C$、$^{17}O(n,\alpha)^{14}C$

$^{14}N(n,p)^{14}C$





correction factor　Fill42 : (1.20±0.07)%
Fill53 : (0.4±0.1)%

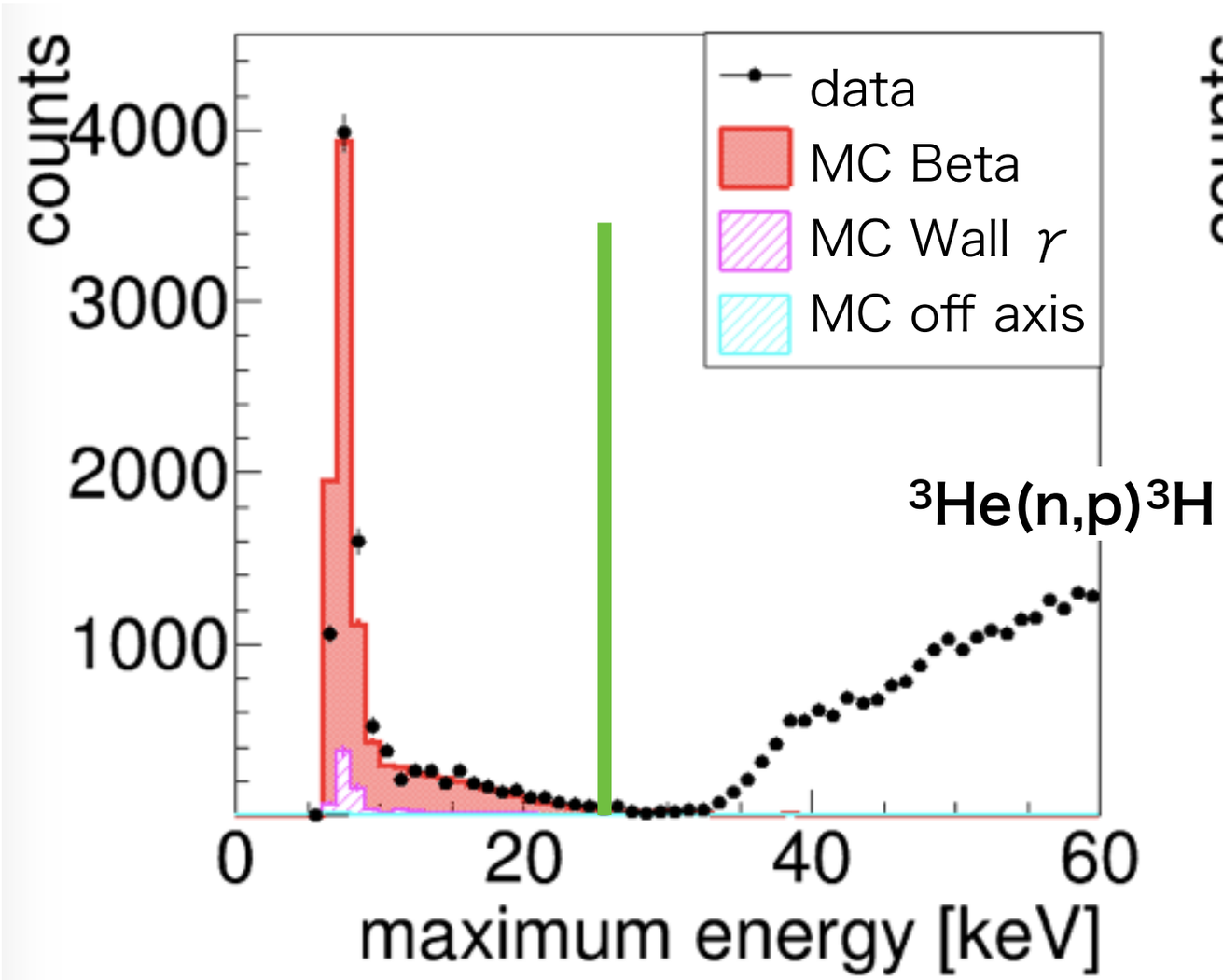
$^{17}O(n,\alpha)^{14}C$

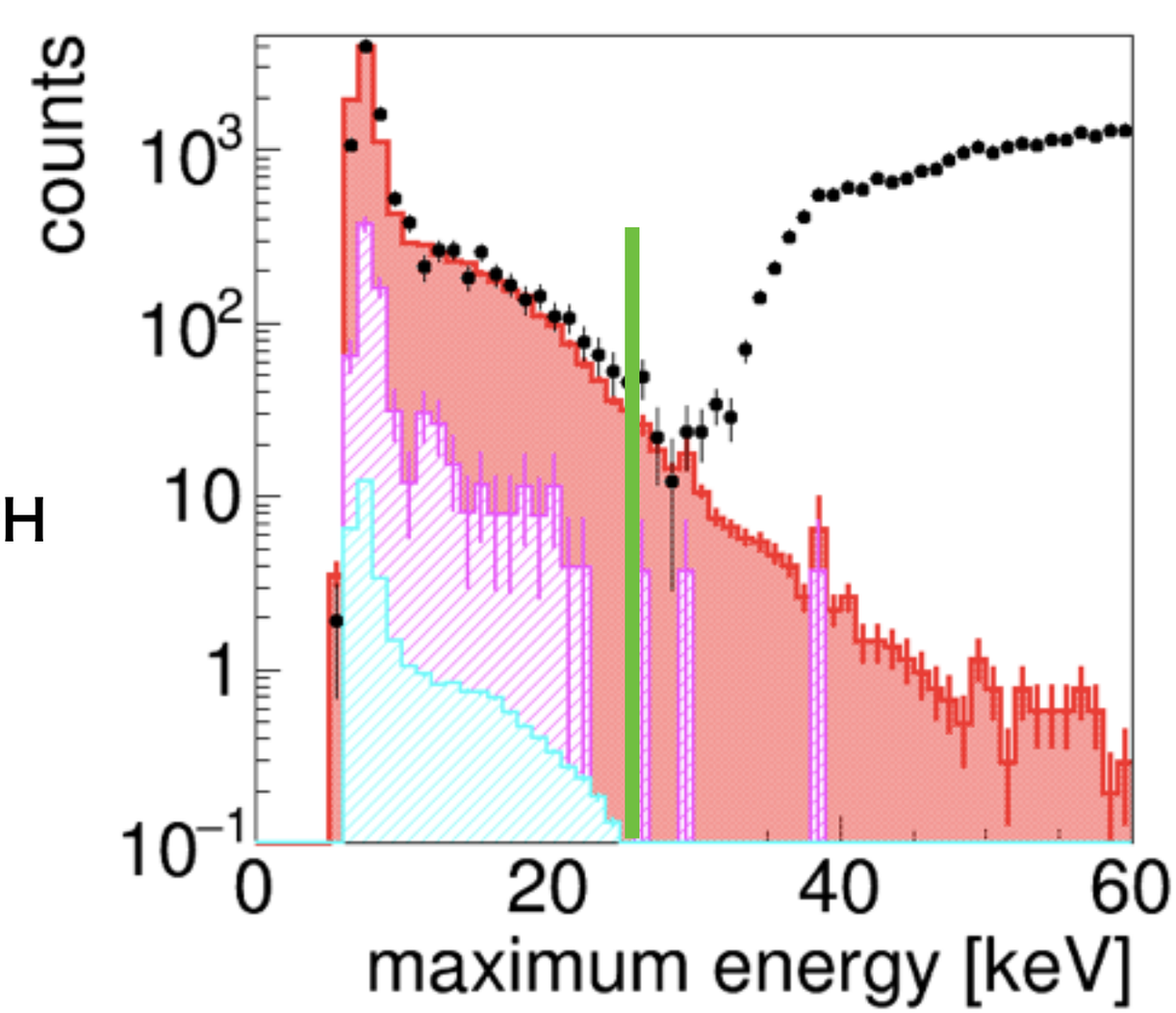
correction factor = $$-\frac{P_{^{17}\mathrm{O}} \times \sigma_{^{17}\mathrm{O}}}{P_{^{3}\mathrm{He}} \times \sigma_{^{3}\mathrm{He}}} = -0.50 \pm 0.03\ \%$$

Separation of signal events

two kinds of signal events can be separated by maximum energy deposit among all wires

β decay : **small** maximum energy deposit
^{3}He(n, p)^{3}H : **large** maximum energy deposit



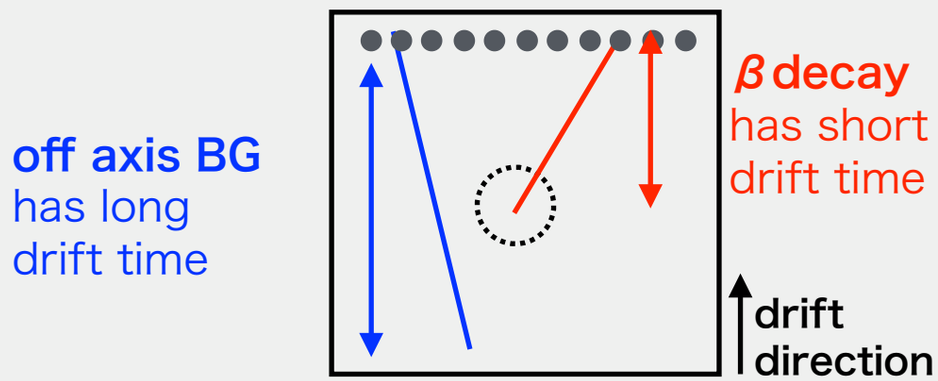


selection

Drift time cut

selection：short drift time

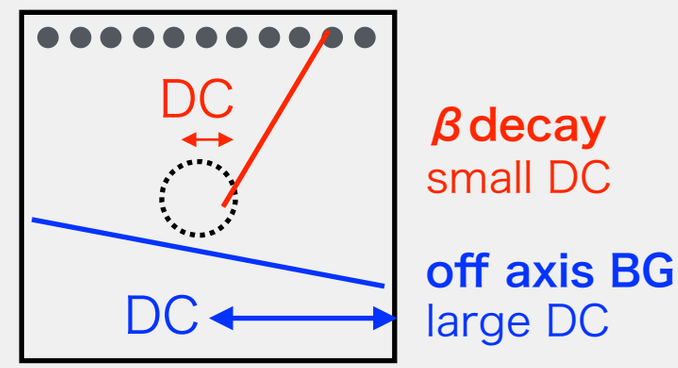
remove off axis BG



DC cut

selection： has small DC

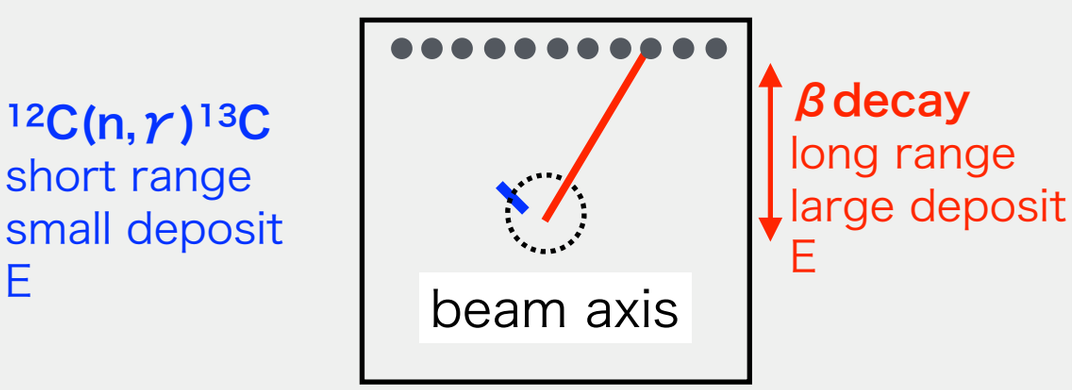
remove the event from out of beam axis



point like cut

selection：long range or large deposit E

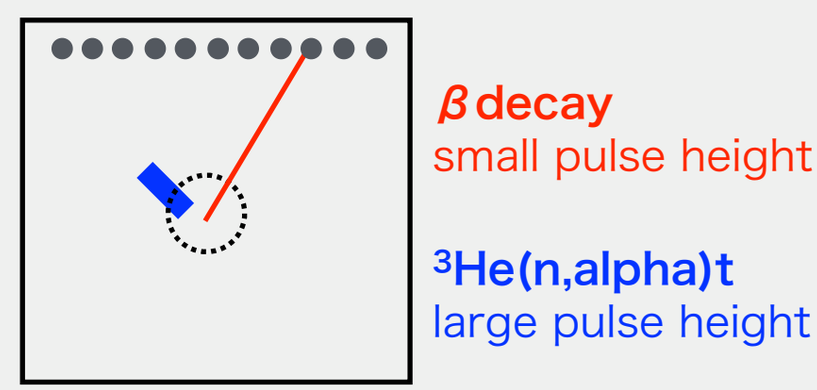
remove point like event



pulse height maximum

selection：has small pulse height maximum

remove $^{3}He(n,alpha)t$



Data acquisition

We acquired engineering data in last 2 years.

gas No.	^{3}He pressure	data acuisition period	MLF power	statictical uncertainty
1	101 mPa	2014/5/27 - 2014/6/2	300 kW	2.1%
2	87 mPa	2015/4/27 - 2015/4/29	500 kW	2.3%

We acquired the data to publish the result of our experiment.

gas No.	^{3}He pressure	data acuisition period	MLF power	statictical uncertainty
3	~ 100 mPa	2016/4/14 - 2016/4/20	200 kW	~ 1% (all combined)
4	~ 200 mPa	2016/4/20 - 2016/5/1	200 kW	
5	~ 50 mPa	2016/5/19 - 2016/5/28	200 kW	
6	~ 100 mPa	2016/6/3 - 2016/6/14	200 kW	