Precise Neutron Lifetime Experiment Using Pulsed Neutron Beams at J-PARC

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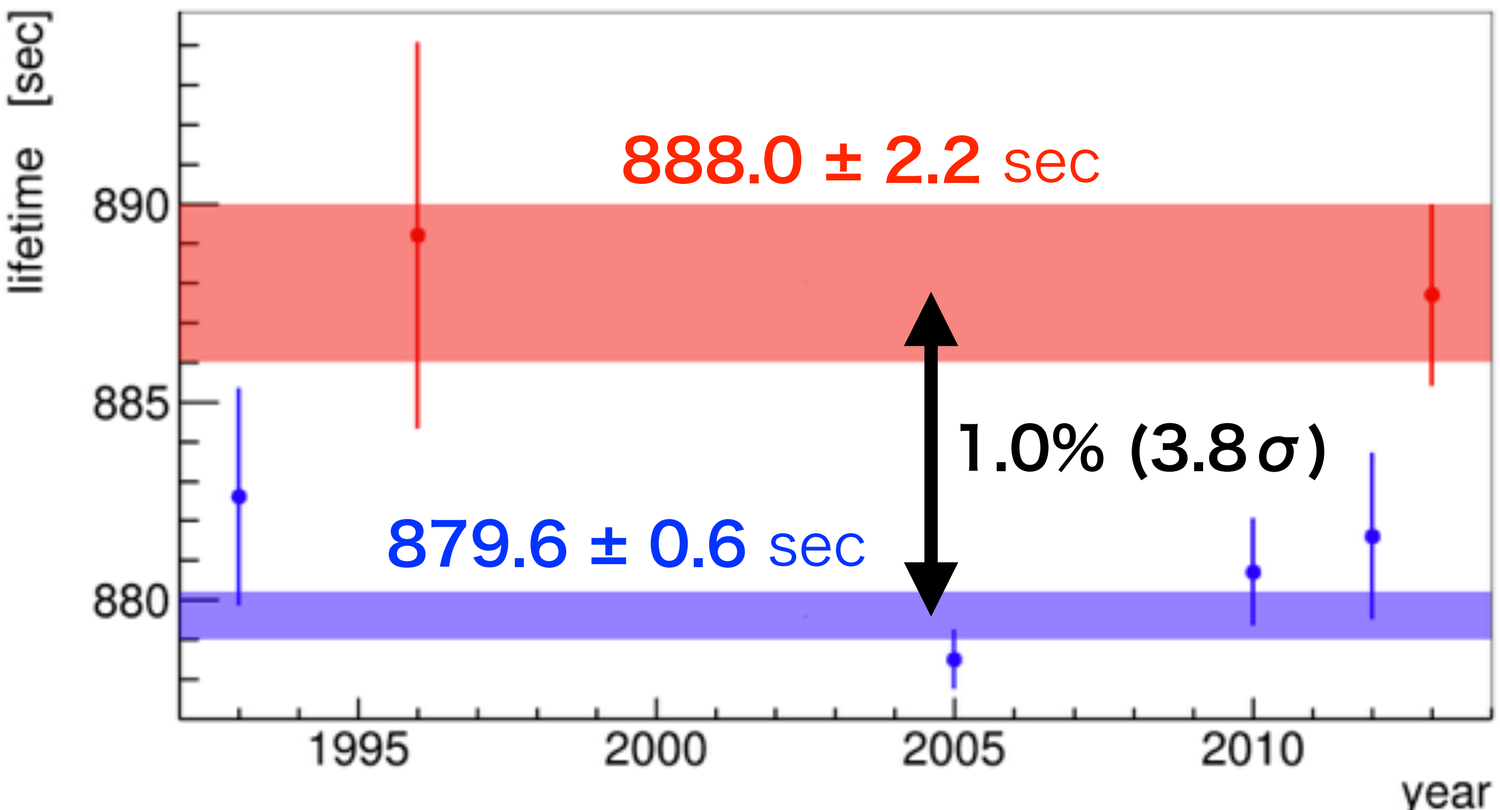
International Nuclear Physics Conference 2016

Motivation

neutron lifetime (τ_n) is a fundamental parameter in the weak interaction

1. used as an input parameter to Big Bang Nucleosynthesis theory, which **predicts light element synthesis** in the early universe
2. used to **evaluate V_{ud} element** in CKM matrix

1.0% (3.8σ) deviation between the result of two previous methods



Particle Data Group 2015

in-flight method

inject neutrons into detector and count protons from β decay

UCN storage method

store ultra-cold neutrons and count the remaining neutrons

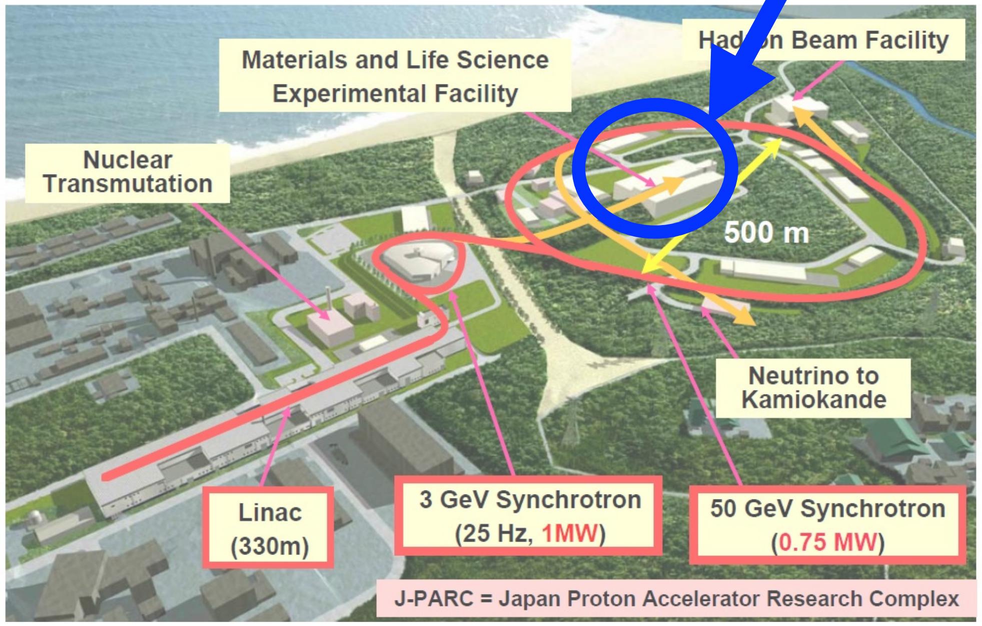
we plan to measure τ_n using another method with precision of 0.1%

J-PARC / BL05

MLF

facilities

spallation pulsed neutron beam
in **MLF** at **J-PARC**

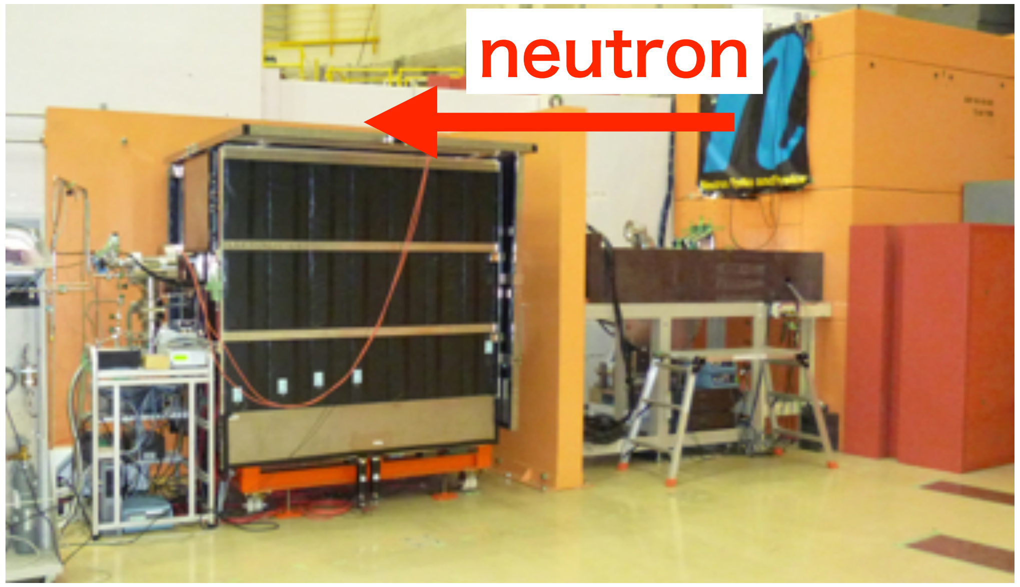


J-PARC bird's eye view

beamline

polarized beam branch of **BL05**

polarization : ~ 95%
neutron flux : 3.9×10^7 /sec·cm^2 (@1 MW)
energy : ~ 10 meV (cold neutron)

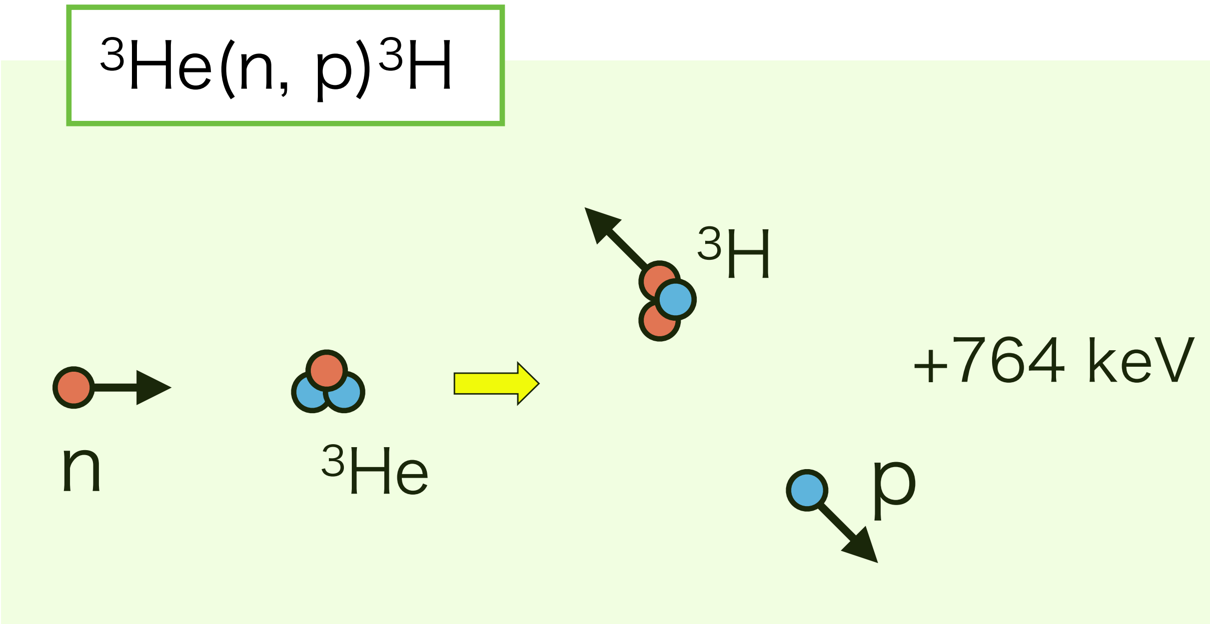


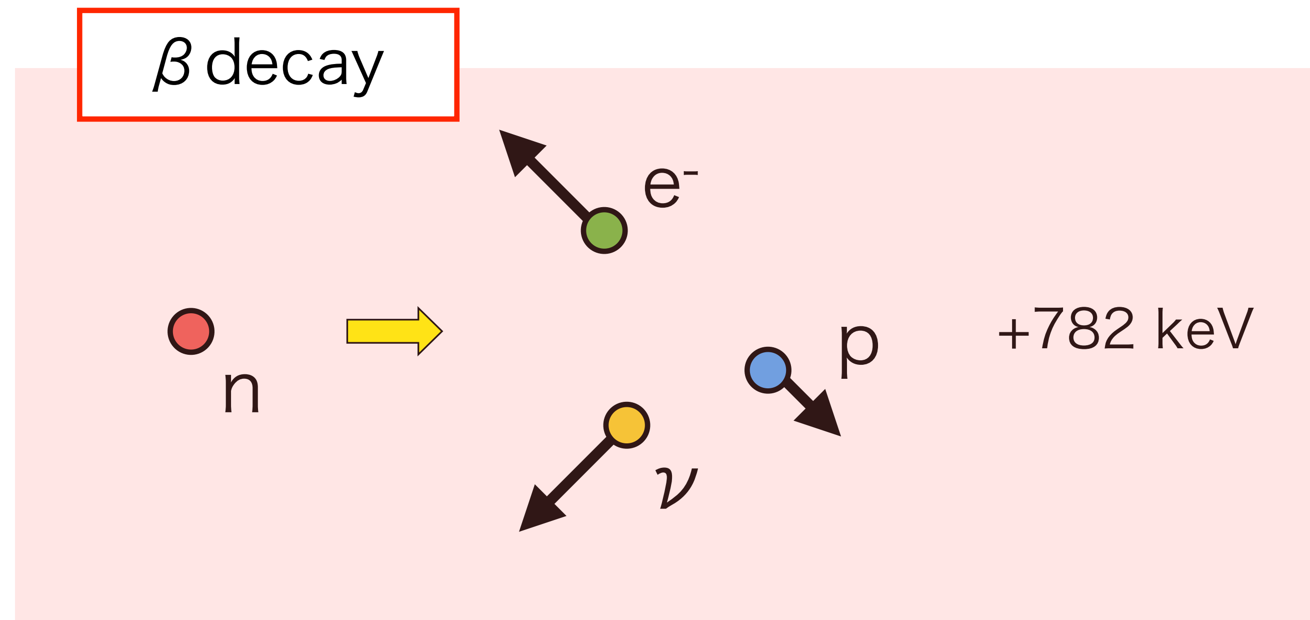
BL05 polarized beam branch

Measurement principle

detects both **^{3}He(n, p)^{3}H**と ***β* decay** at the same time

total neutron flux can be evaluated using **^{3}He(n, p)^{3}H**





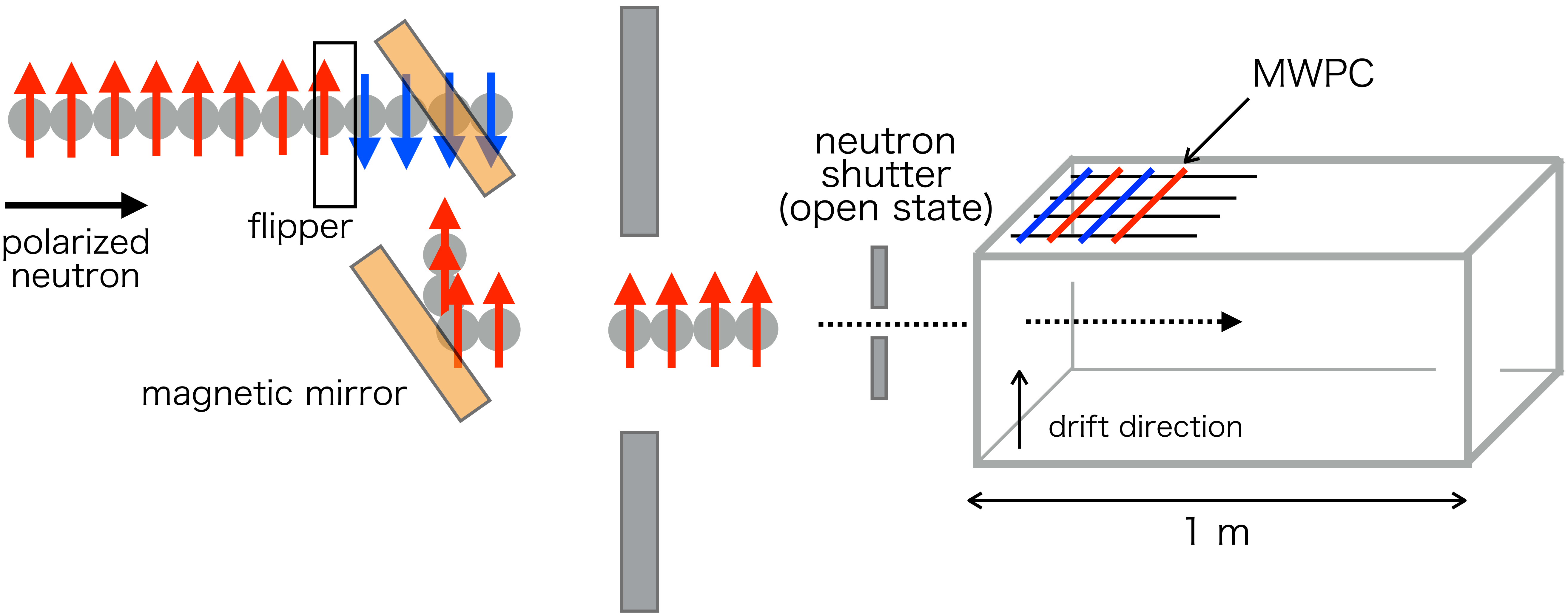
$$\tau_n = \frac{1}{\sigma(v_0)v_0\rho}\,\frac{\left(\dfrac{N_{^3\mathrm{He}}}{\varepsilon_{^3\mathrm{He}}}\right)}{\left(\dfrac{N_\beta}{\varepsilon_\beta}\right)}$$

- σ : ^{3}He(n, p)^{3}H cross section
- v : neutron velocity
- ε : selection efficiency
- N : number of events
- ρ : ^{3}He number density

$\sigma(v)\,v = \sigma(v_0)\,v_0 = 5333(7)$ barn × 2200 m/s

Setup

- use **pulsed neutron beam from accelerator** and **in-flight method**
- detect **electrons** from β decay



Spin Flip Chopper

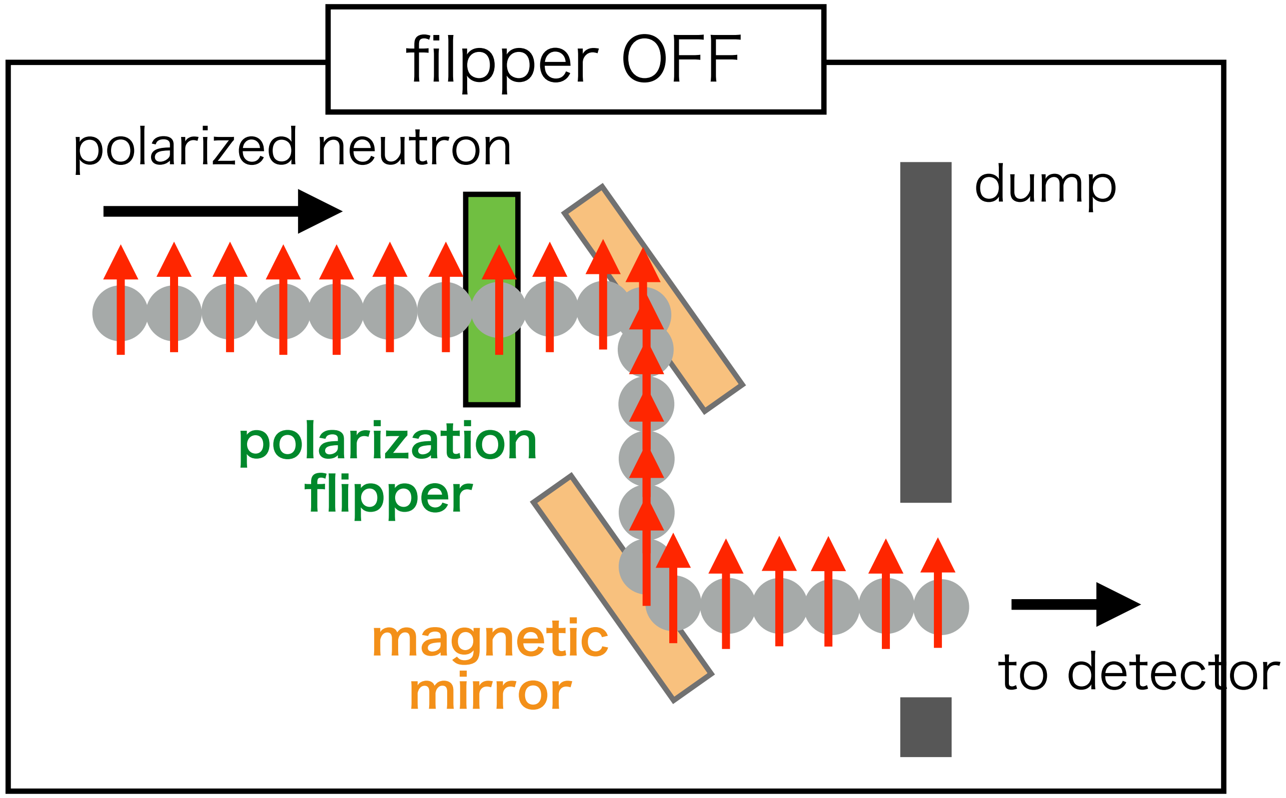
forms neutron bunches
for the 4π acceptance for a β decay

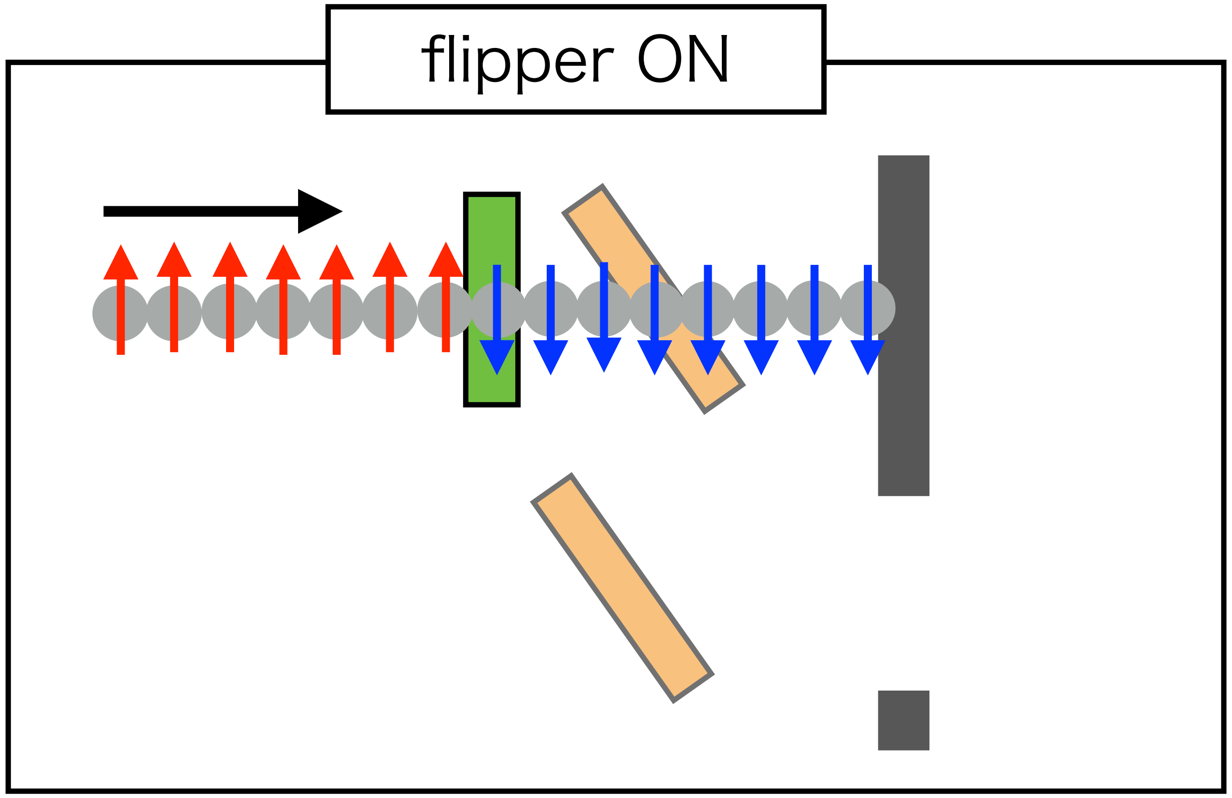
Time Projection Chamber

He + CO_2 gas

Spin Flip Chopper

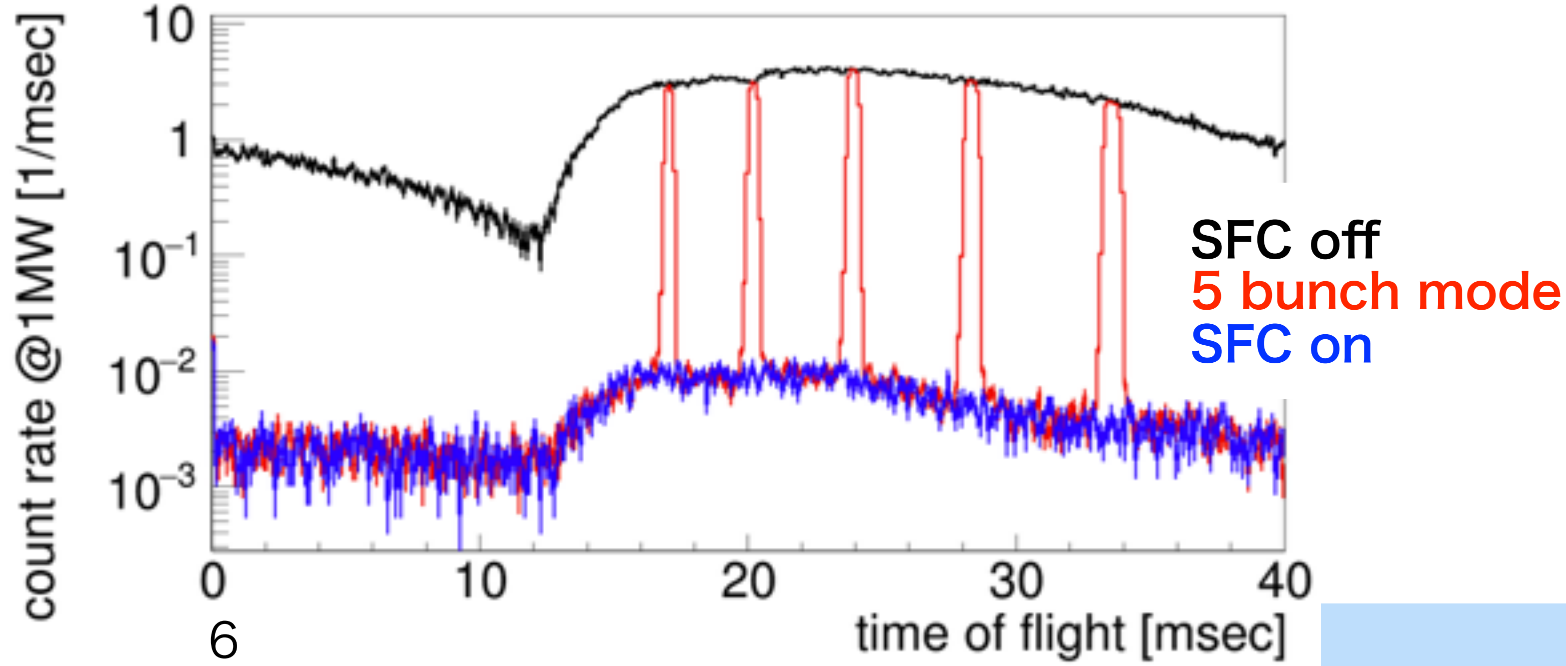
Spin Flip Chopper can form neutron bunches with arbitrary length by controlling neutron polarization



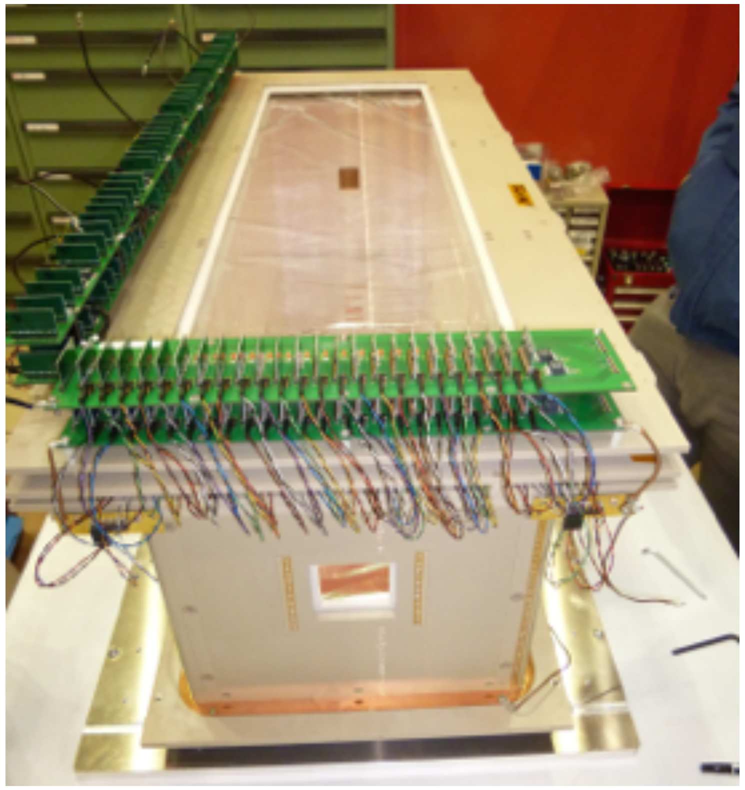


SFC is operated in **5 bunch** mode

bunch length is about half of TPC sensitive length

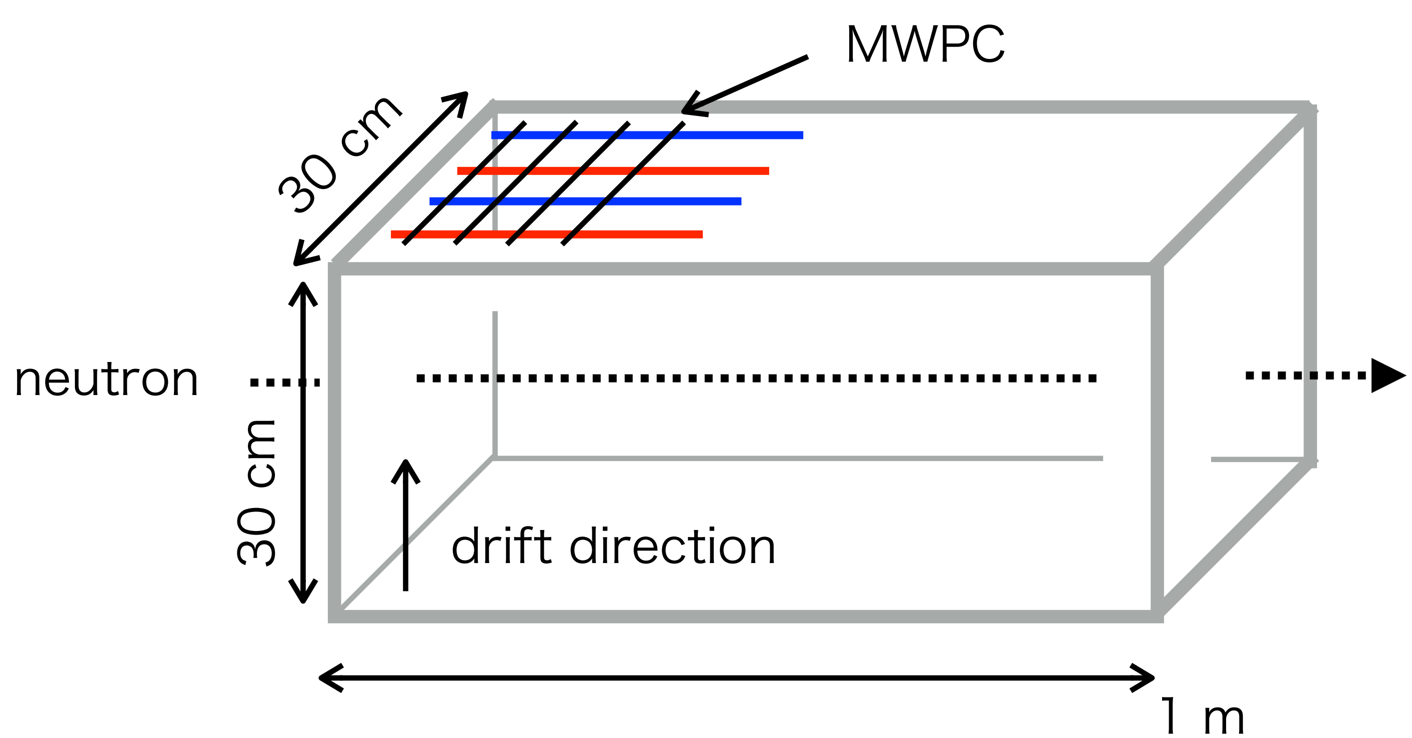


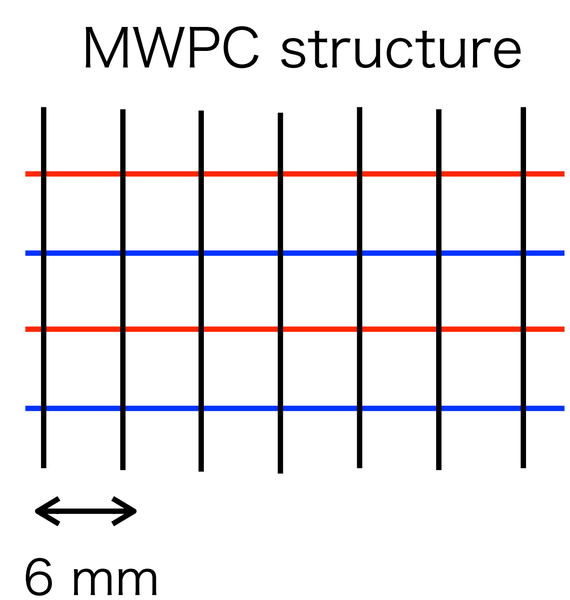
Time Projection Chamber (TPC)



- **^{4}He** (85 kPa) + **CO_2** (15 kPa) + **^{3}He** (100 mPa)
  measure ^{3}He pressure precisely in advance
- low background material （**PEEK**：PolyEthel Ethel ketone)
- inside walls covered by **^{6}LiF** to absorb scattered neutrons

take signal data only during the time in which neutrons are completely inside detector





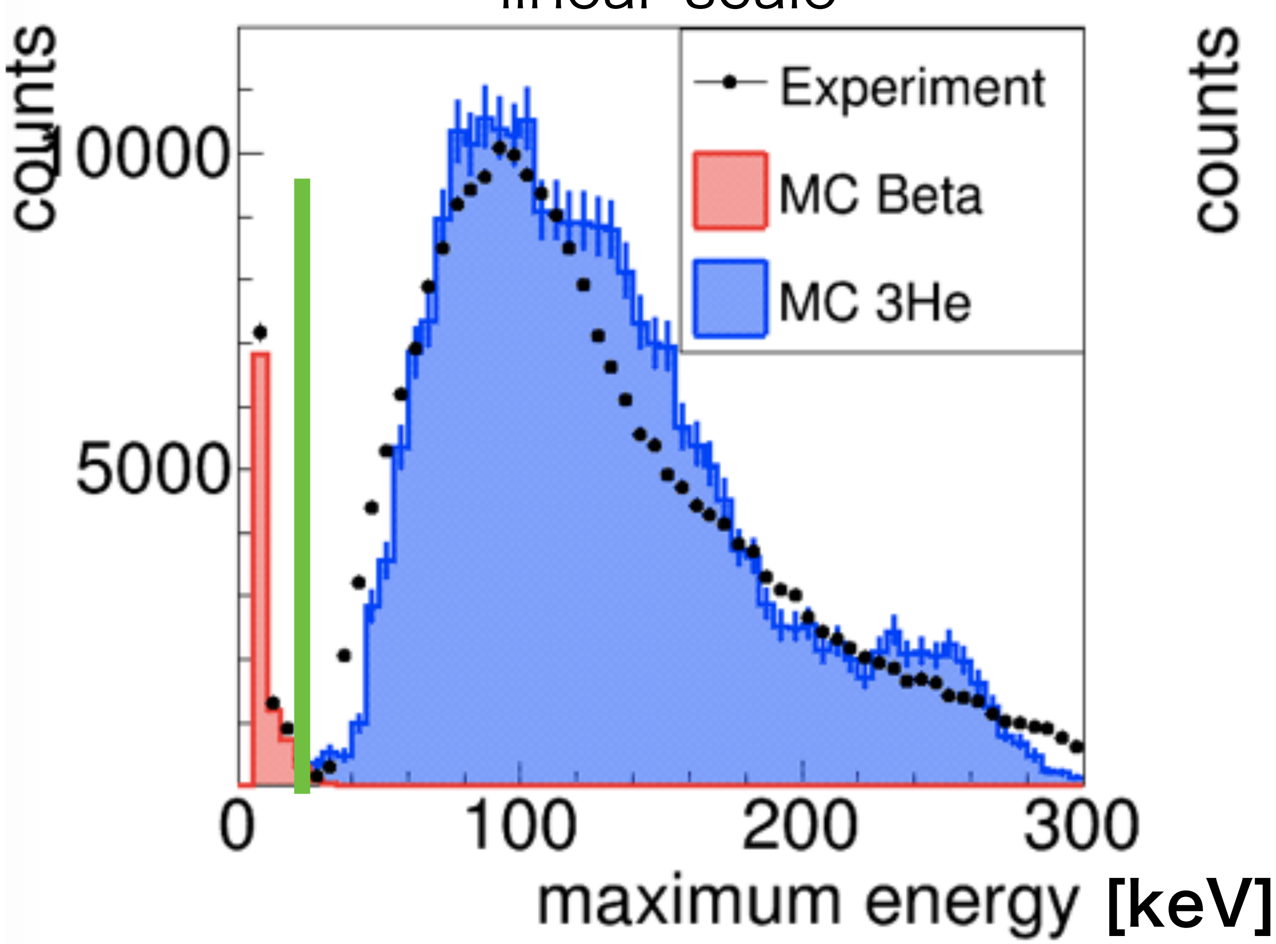
anode (1720 V) : 24 ch
field (0V) : 24 ch
cathode (0V) : 40 ch×2

Separation of β decay and $^3He(n, p)^3H$

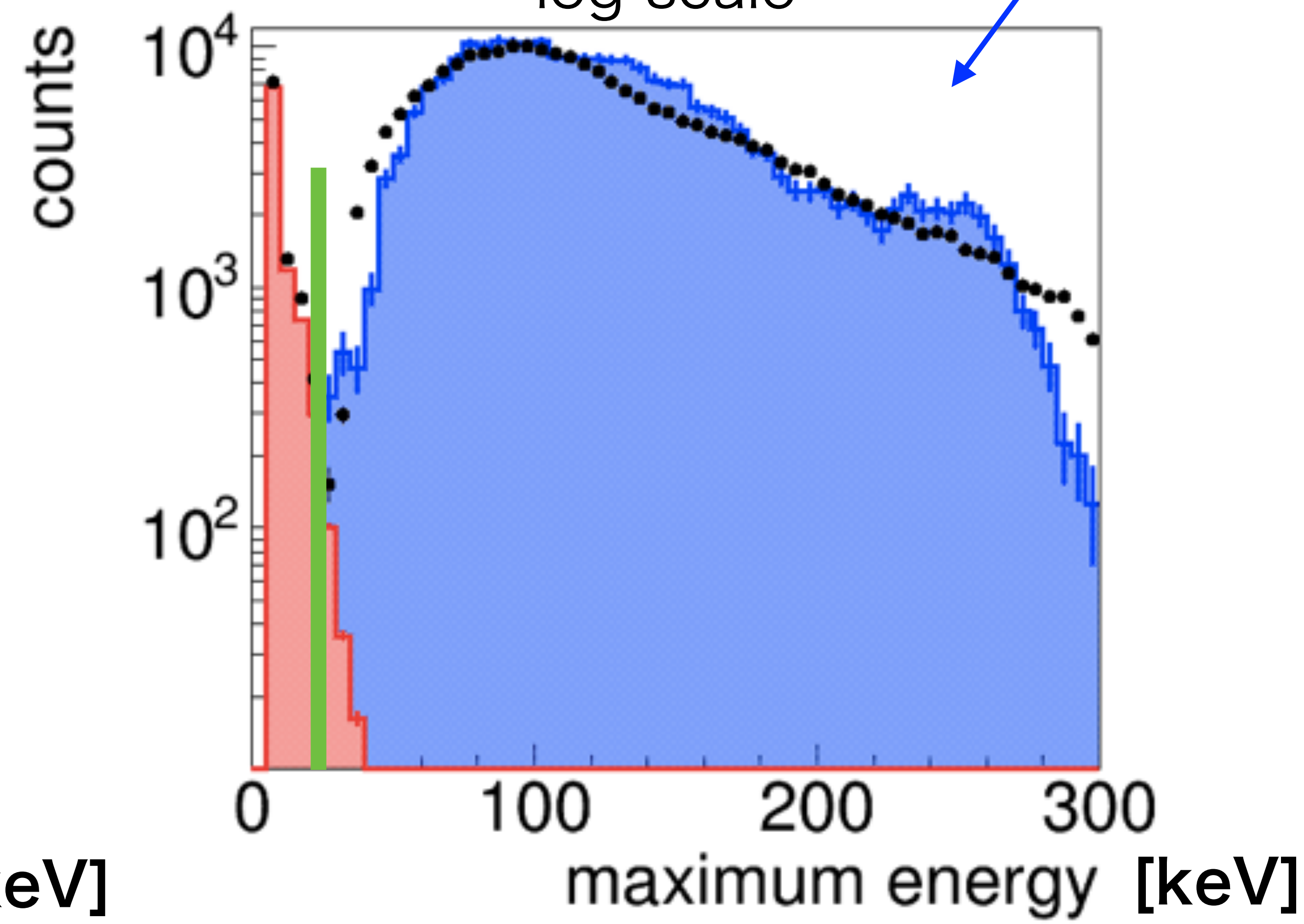
two kinds of signal events can be separated by maximum energy deposit among all wires

energy deposit decreases due to space charge effect

linear scale



log scale



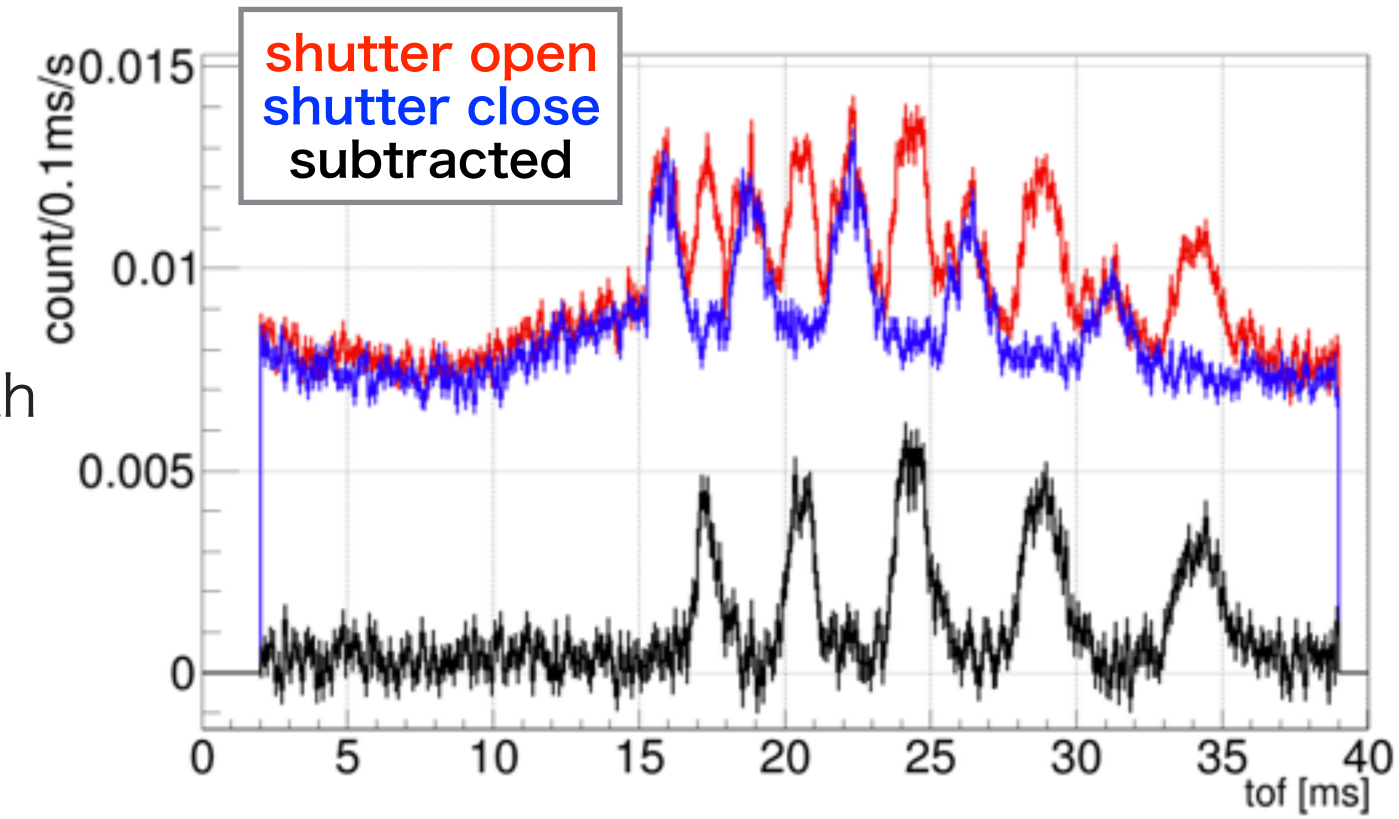
required to evaluate overlap between two processes precisely

Background

three types of background for β decay

1. environmental background ··· cosmic rays, radioisotopes
2. upstream γ-ray background ··· γ-ray from SFC
3. beam induced background ··· β decay from scattered neutron, γ-ray from TPC wall

type 1. and 2. can be subtracted using both
shutter open (beam on) data and
shutter close (beam off) data

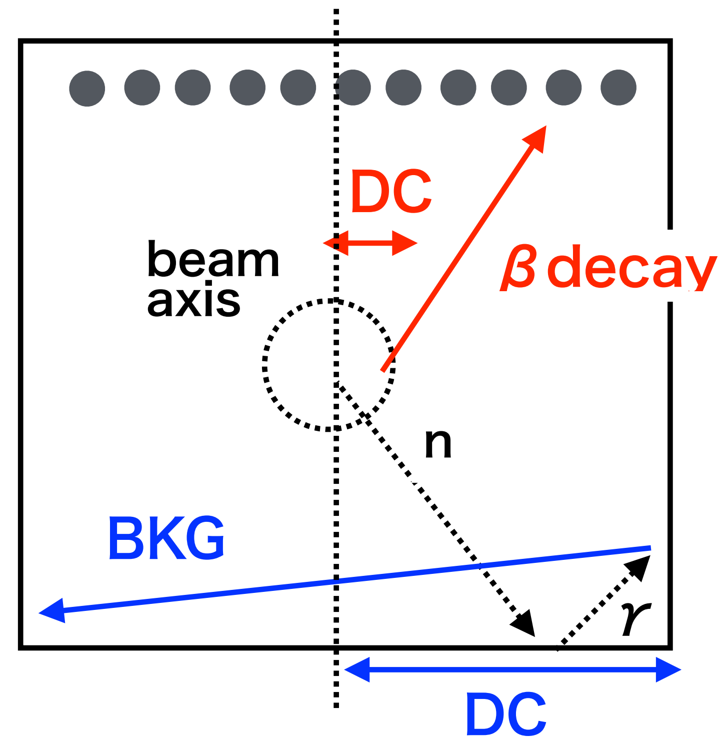


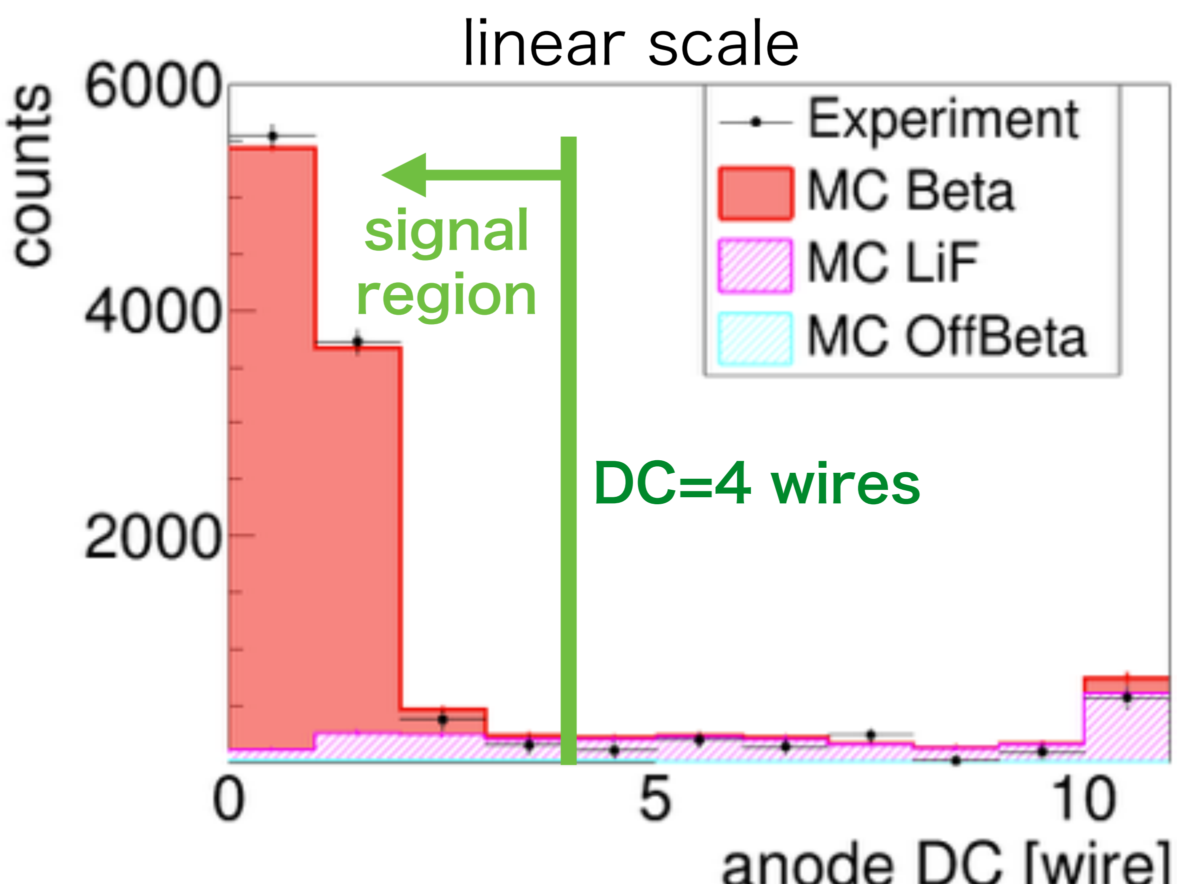
Beam-induced background

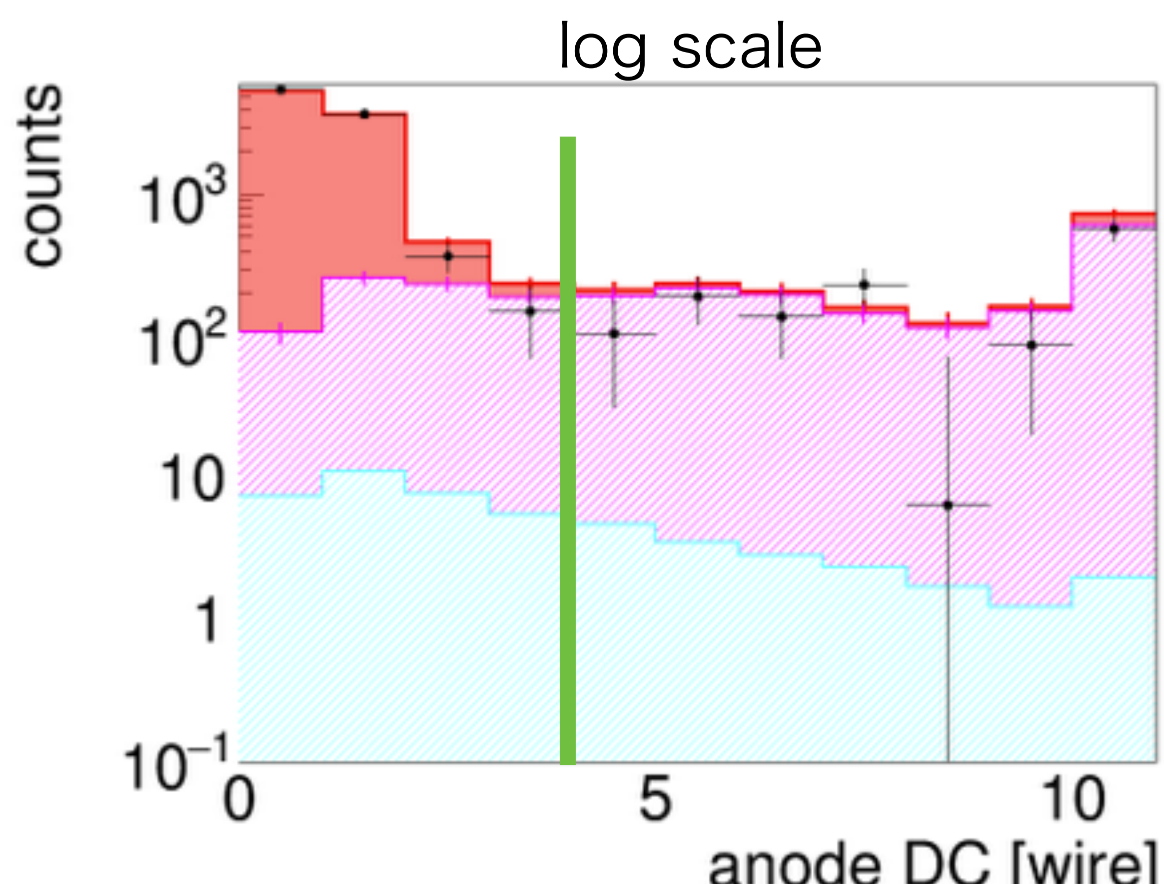
origin of the background is near TPC wall

DC : <u>D</u>istance from beam <u>C</u>enter

background has **large DC value**



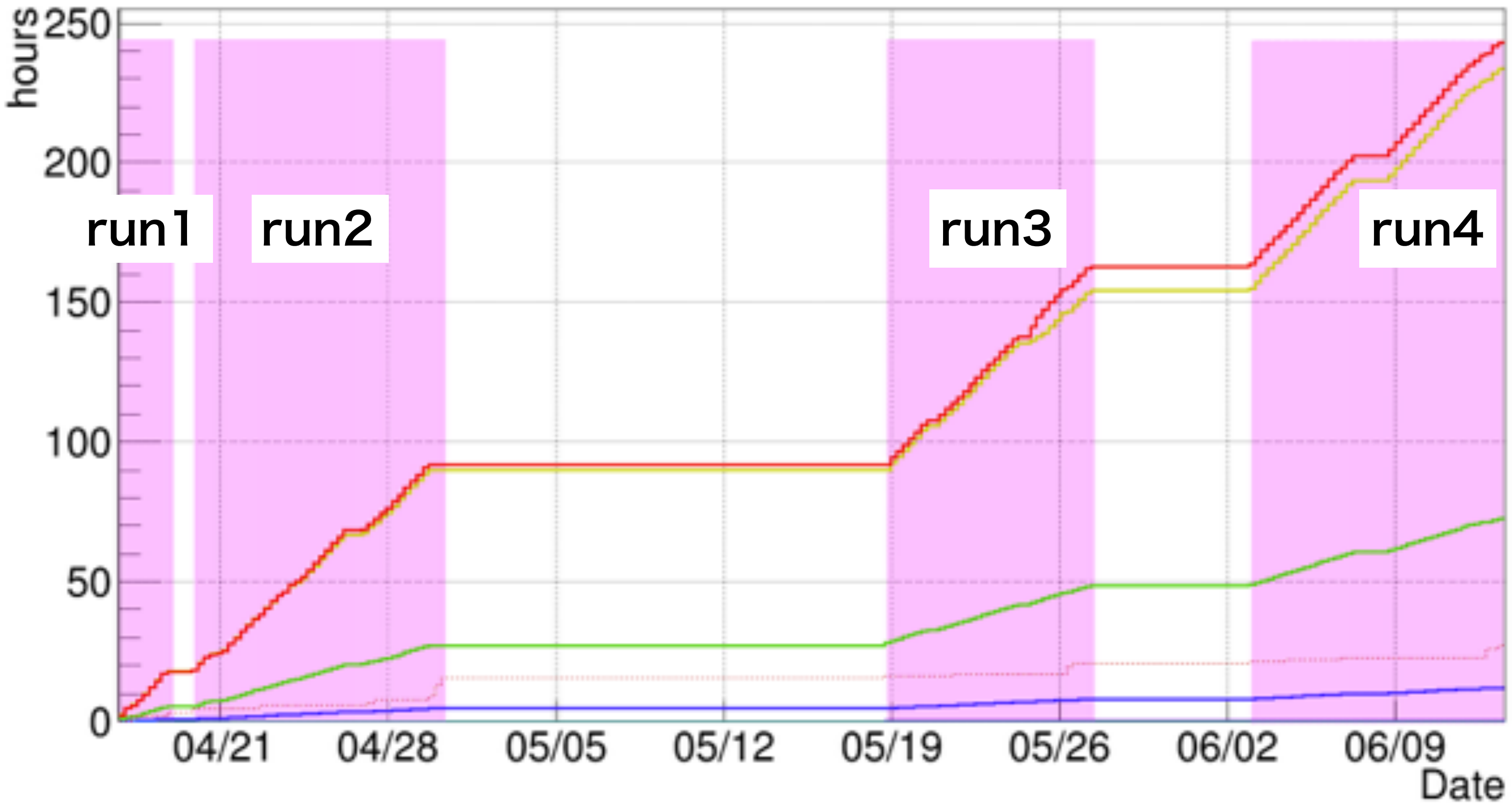




Status and future plan

status

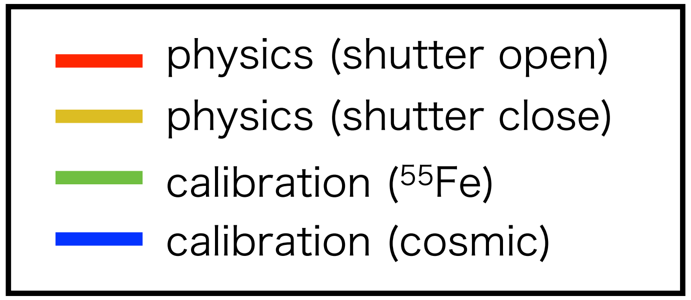
acquired data this year (statisical uncertainty ~1% of τ_n)



2016 DAQ status

Apr. - Jun in 2016

acquired 4 kinds of data



future plan

- MLF operation power will increase ： 200 kW → 1 MW
- upgrade **beam transportation system** and **detector**

we can achieve statistical precision of **0.1%** from **40 days data taking**

List of uncertainties

$$\tau_n = \frac{1}{\sigma_0 v_0 \rho} \frac{\left(\frac{N_{^3\mathrm{He}}}{\varepsilon_{^3\mathrm{He}}}\right)}{\left(\frac{N_\beta}{\varepsilon_\beta}\right)}$$

σ_0	^{3}He(n,p)^{3}H cross section for a 2200 m/s neutron
v_0	2200 m/s (neutron velocity)
ρ	^{3}He number density
N_β	number of β decay events
$N_{^3\mathrm{He}}$	number of ^{3}He(n,p)^{3}H events
ε	selection efficiency

		uncertainty (%)	correction (%)
N_β	statistics	~ 1	———
	^{3}He(n, p)^{3}H 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,α)^{14}C contamination	0.03	-0.5
N_β, N_{3He}	Spin Flip Chopper S/N	< 0.5	< 0.5
ρ	^{3}He number density	0.65	———
	chamber deformation (pressure)	<0.33	-0.33
	temperature non-uniformity	0.23	0.23
σ_0	^{3}He(n, p)^{3}H cross section	0.13	———

preliminary

Conclusion

- neutron lifetime is an important parameter in the weak interaction
  input parameter to the **BBN theory** and **V_{ud} determination**
- **significant deviation** between two previous types of measurement
- we use different method to measure the neutron lifetime,
  and we already **acquired data this year**
- **upgrade is undergoing** and we can achieve 0.1% precision
  within a few years

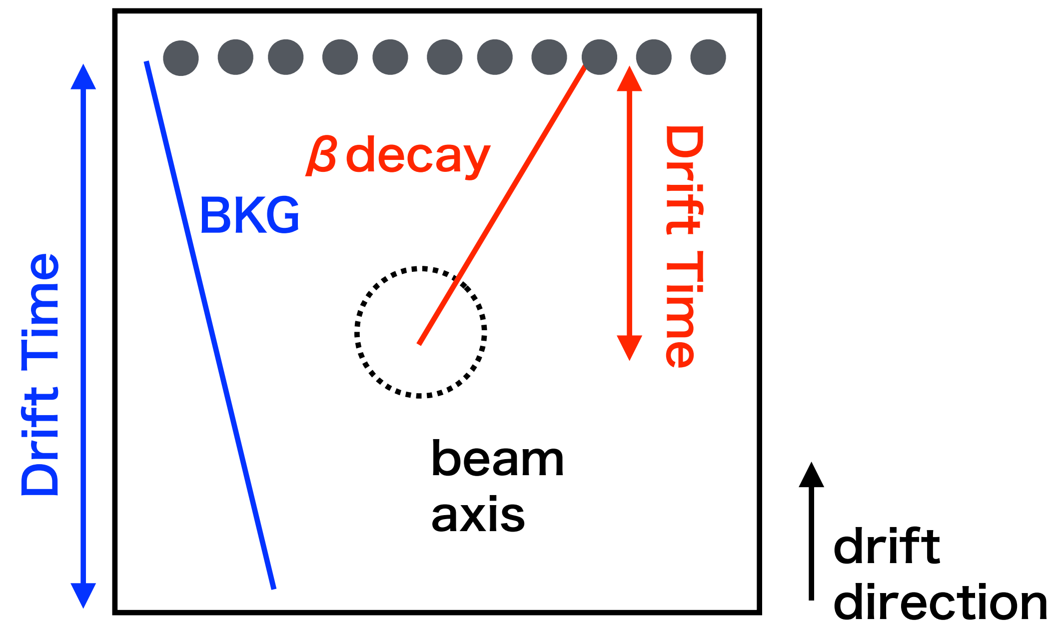
backup

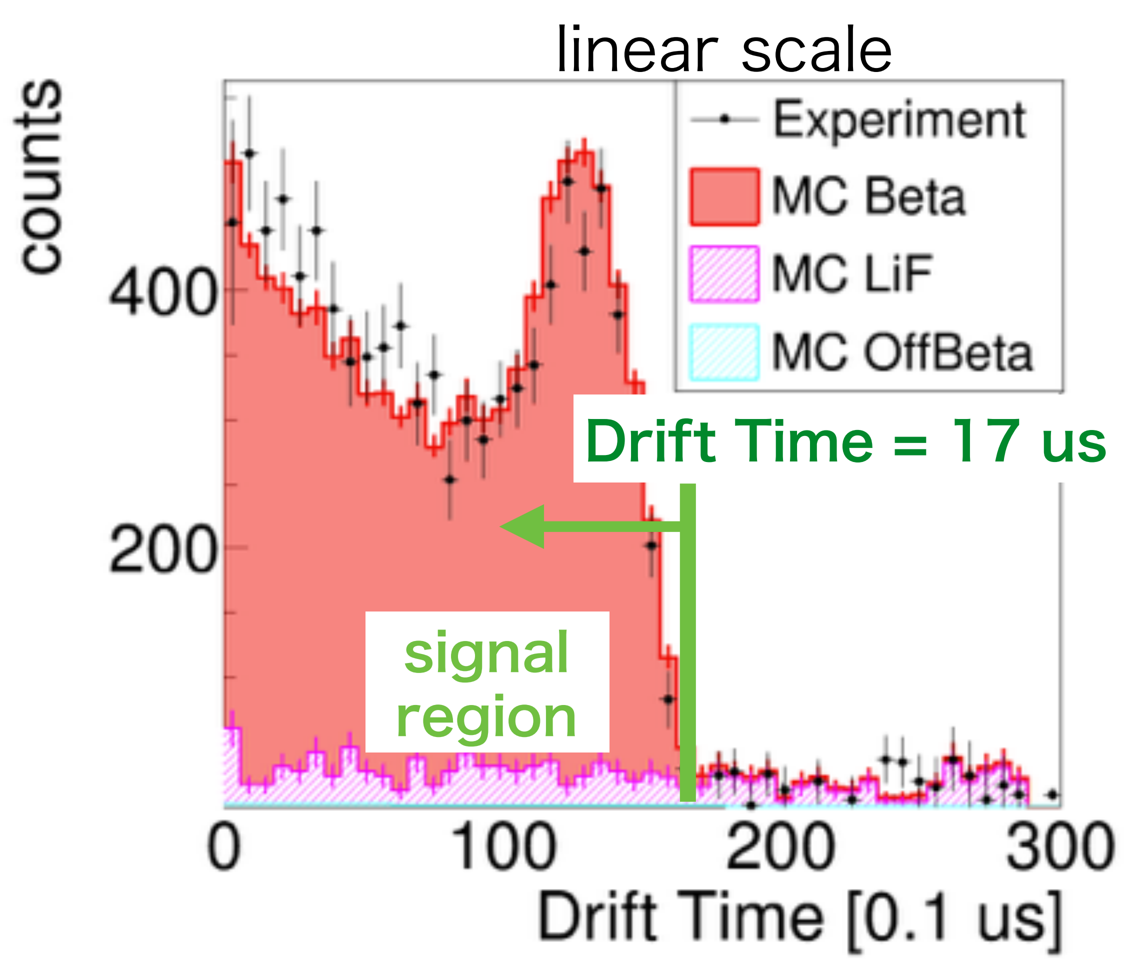
Beam-induced background 2

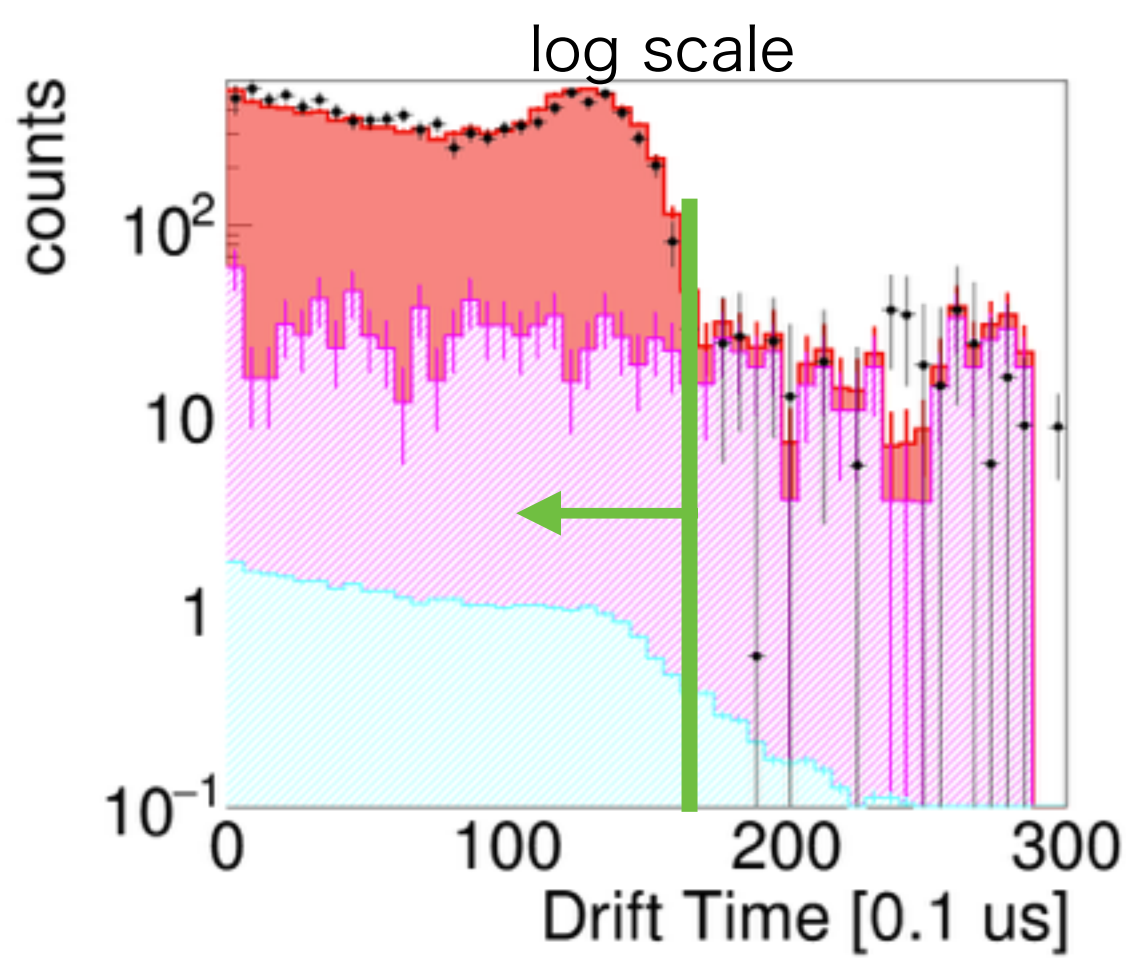
origin of track is near TPC wall

“Drift Time”
arrival time difference of drifting electrons

background has long DriftTime

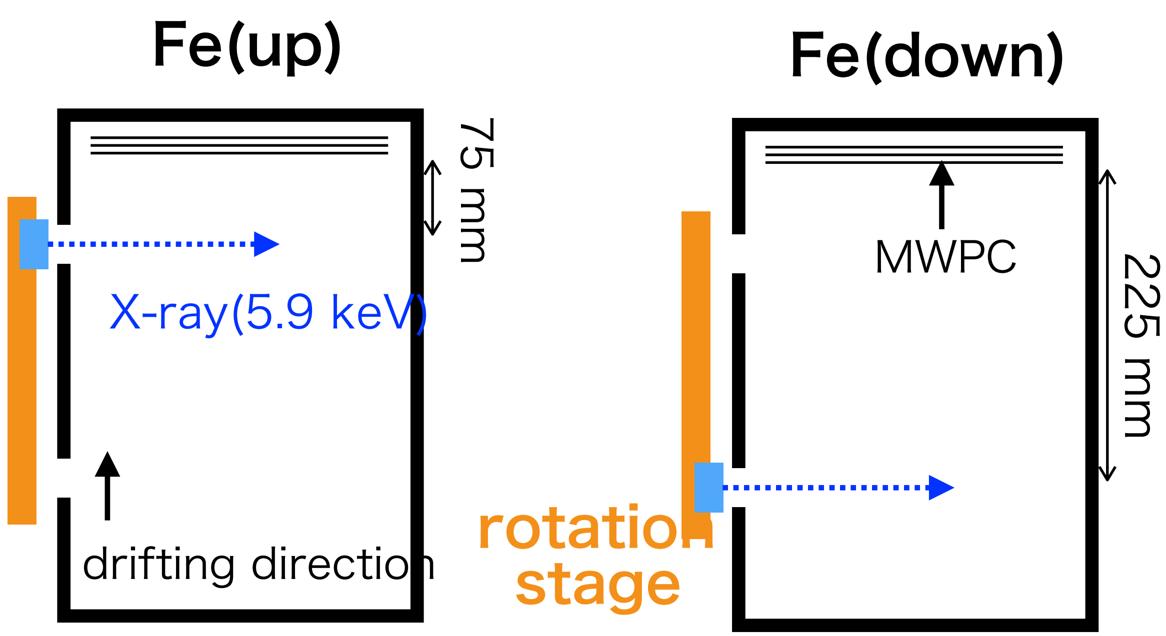


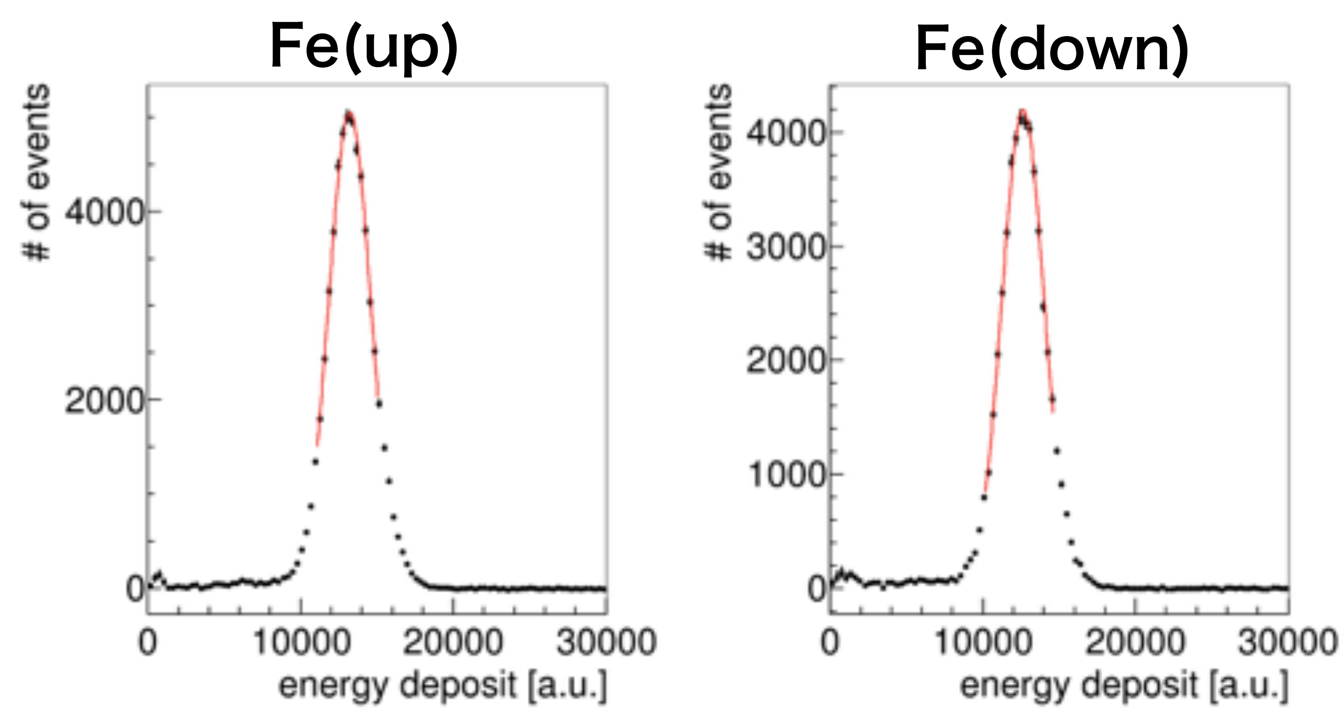




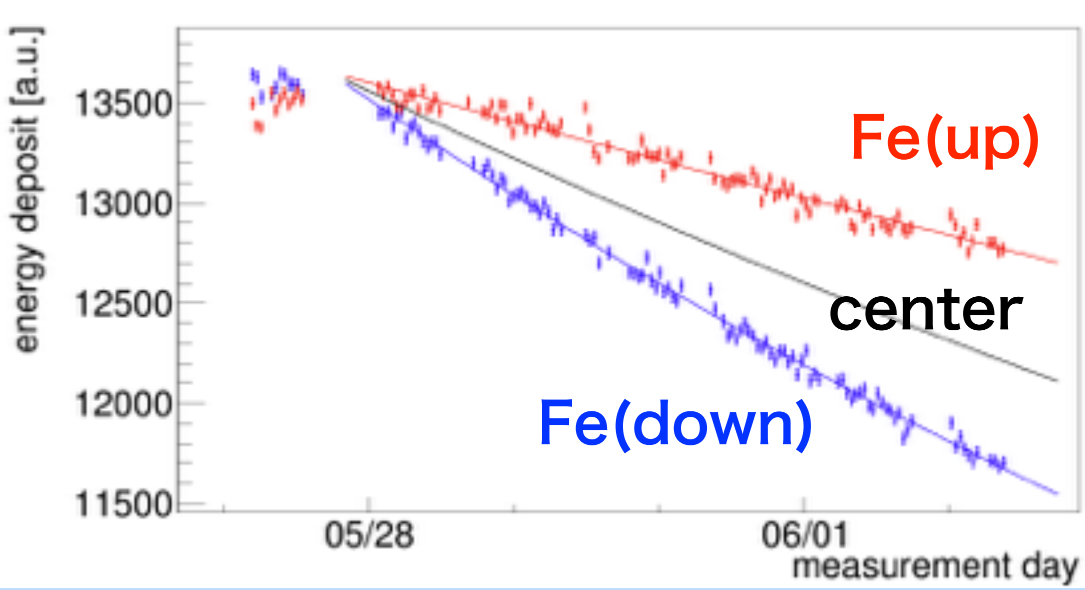
Energy calibration

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

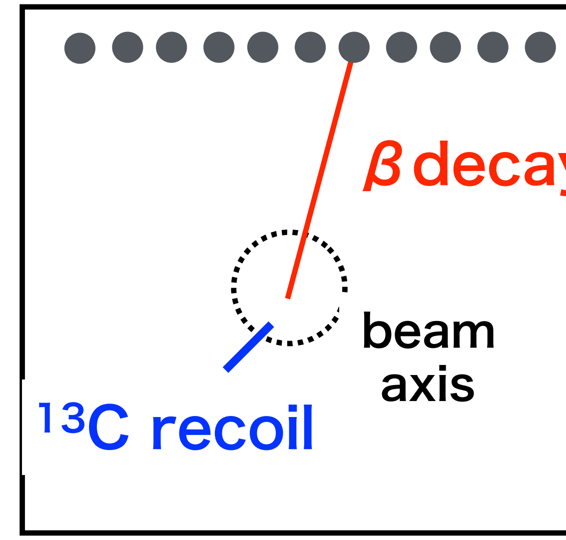


We can correct for the effect of attenuation of electrons during the drift using both **Fe(up) and Fe(down) data.**

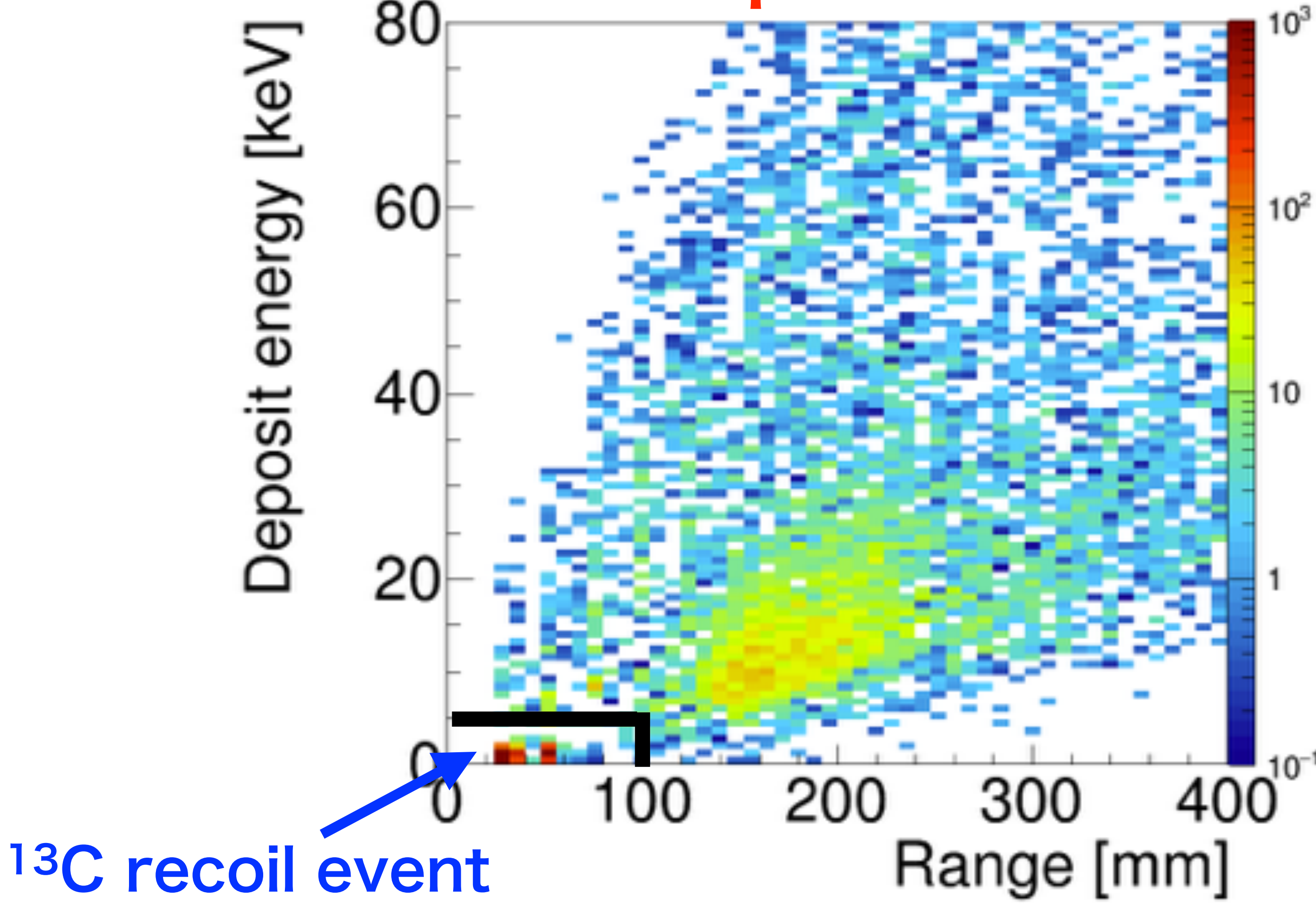
12C(n,γ)13C background

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

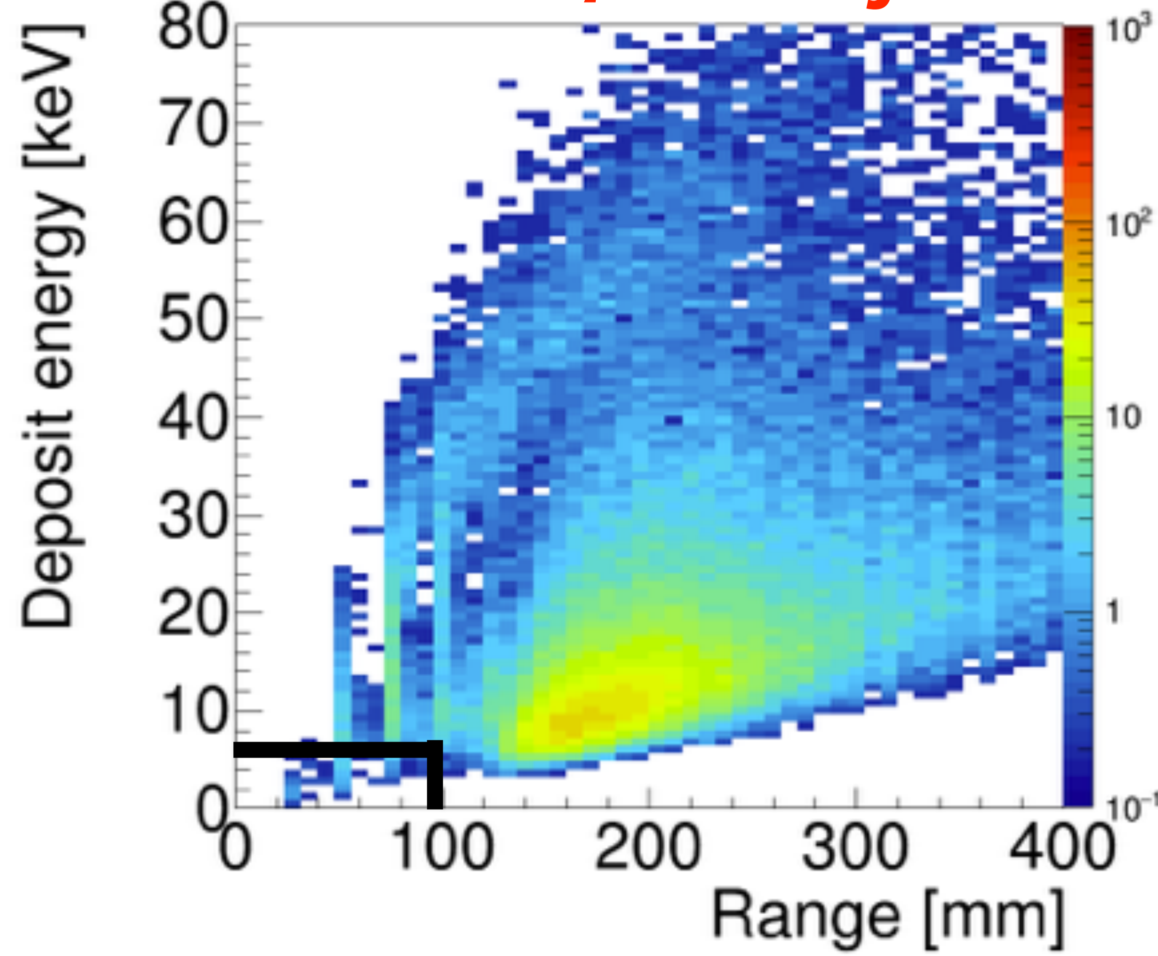
- short track
- low energy deposit



Experiment



MC β decay

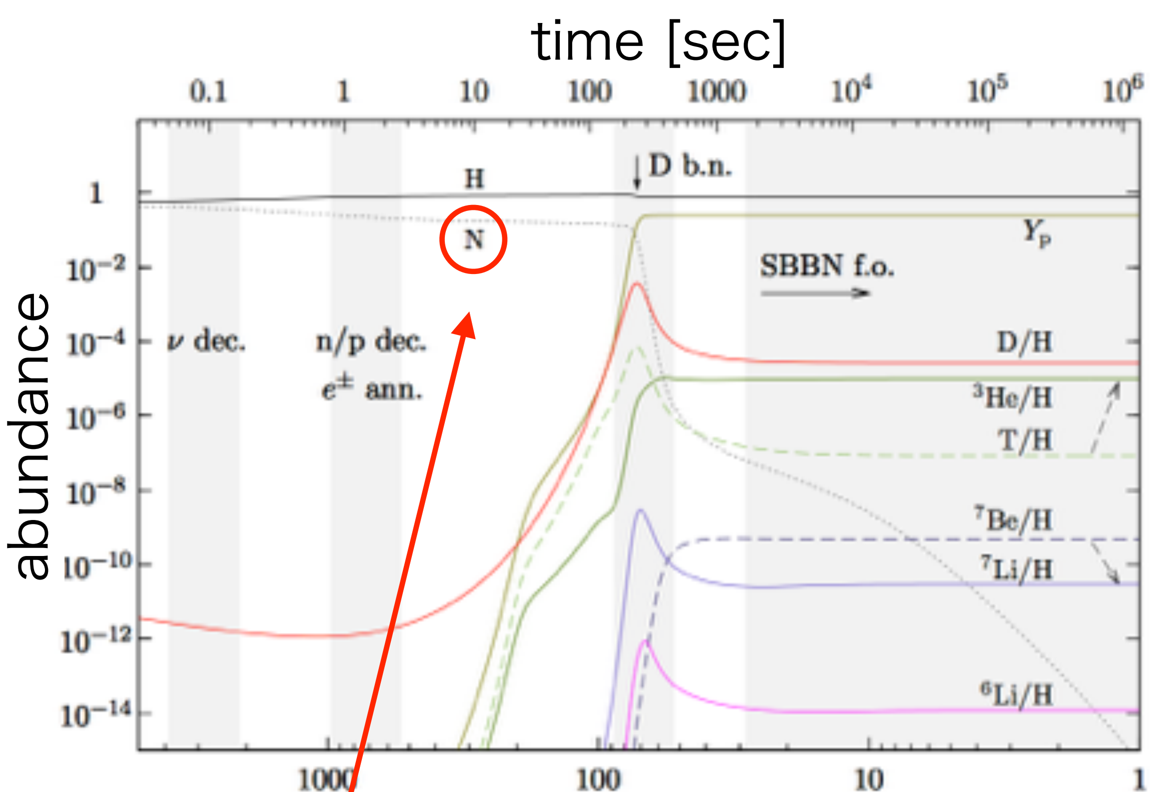


Motivation

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

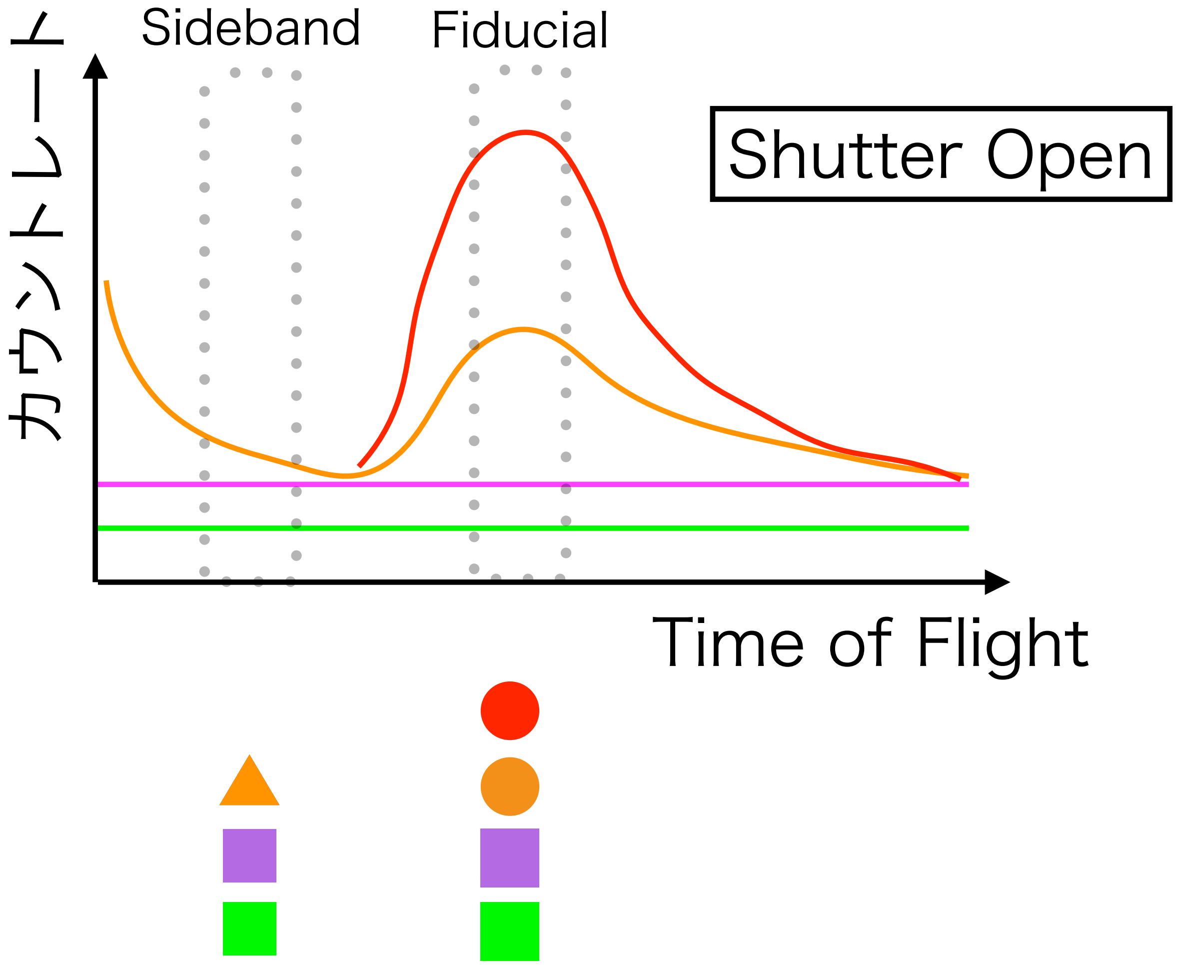
BG subtraction：TOF and shutter open/close data

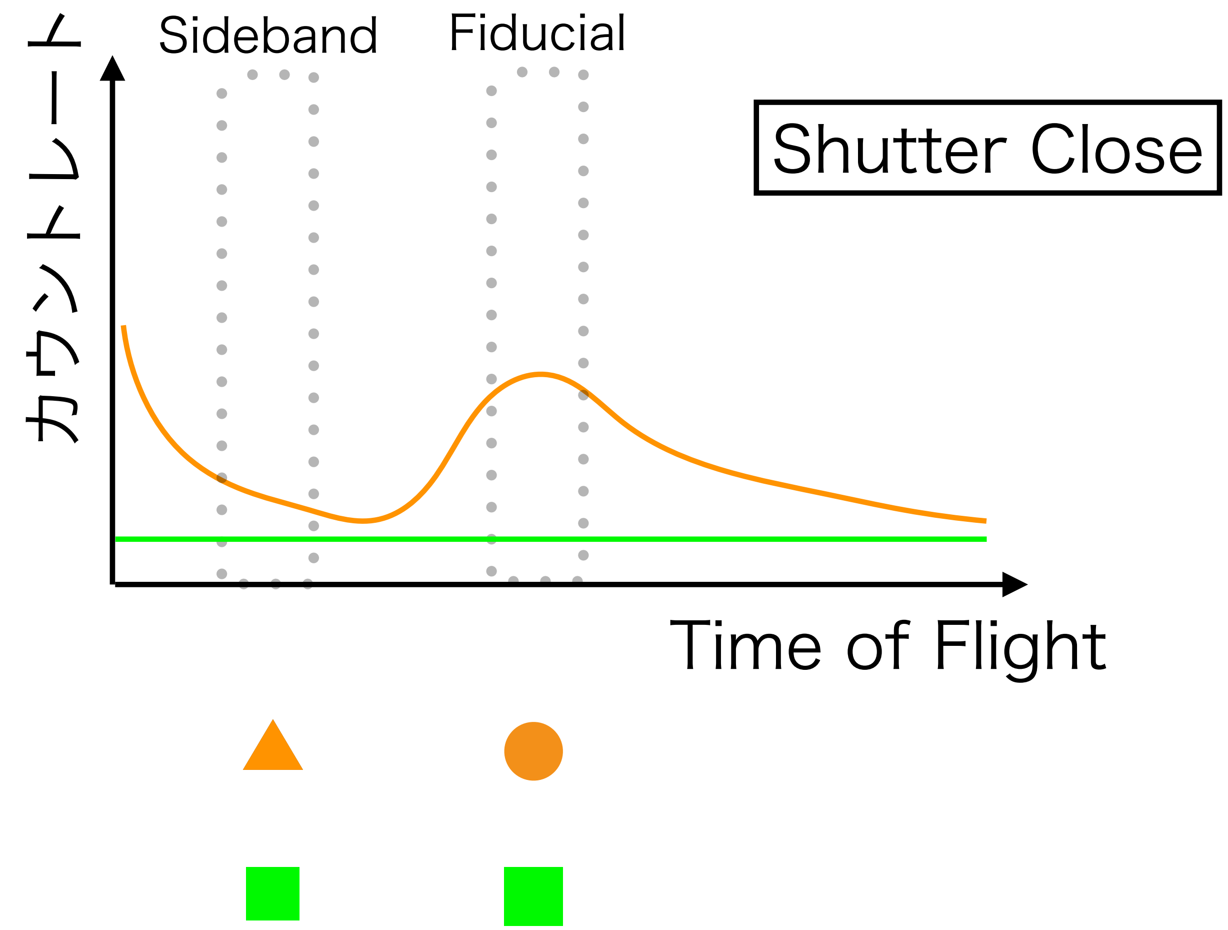
signal + beam-induced BKG

upstrema γray BkG

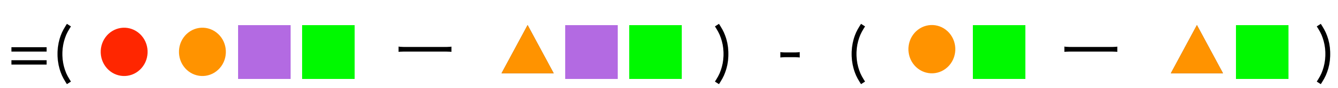
TPC内部の放射化

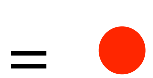
環境放射線、宇宙線vetoもれ





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



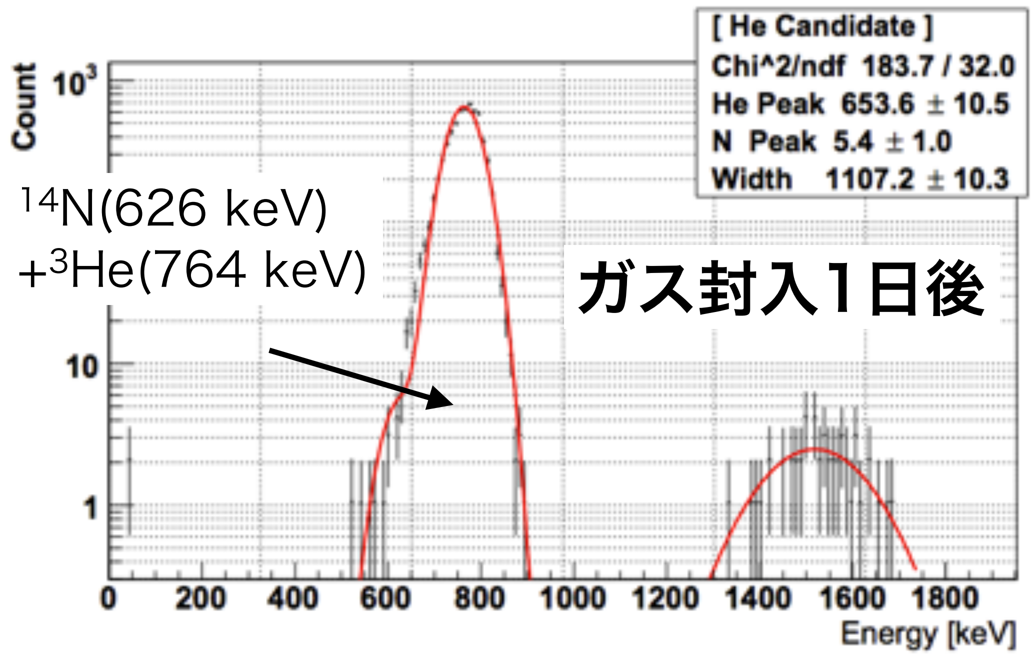


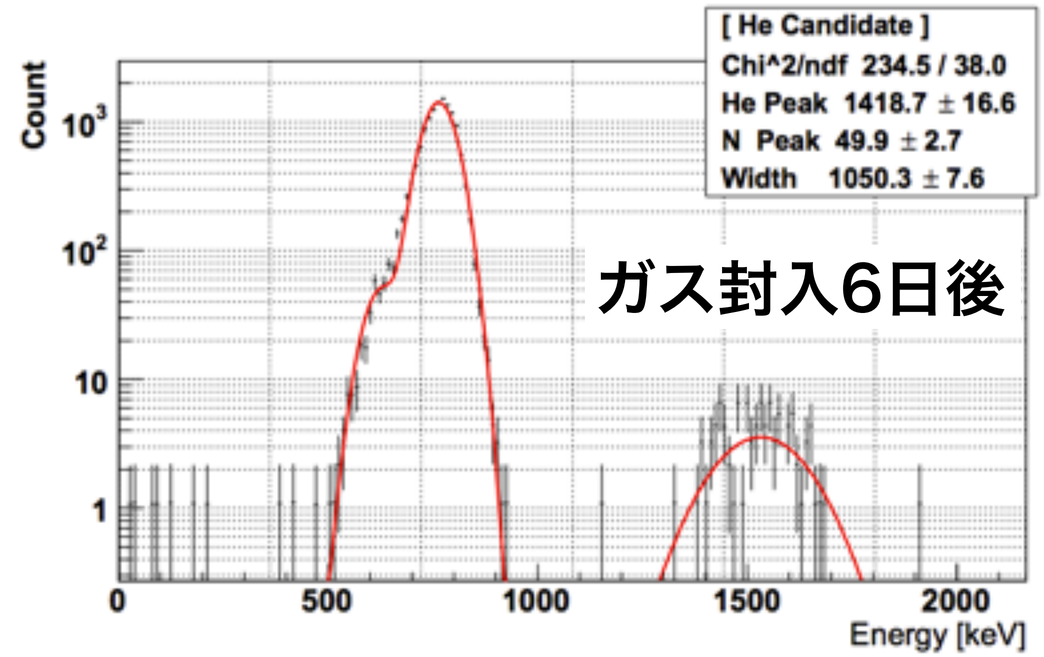
※ビーム変動を補正するため、openとcloseのビームモニターのカウント総数でスケールする

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

$^{14}N(n,p)^{14}C$反応

アウトガス由来のN_2が中性子を吸収する反応が^{3}He反応のBGとなる





低電圧で^{14}N反応と^{3}He反応を切り分け、^{14}N反応が直線的に増加していると仮定して通常電圧でのもれ込み量を内挿する

補正量の結果　Fill42 : (1.20±0.07)%
　　　　　　　Fill53 : (0.4±0.1)%

Fill53は真空引き時間が長かったので
アウトガスが少なかったと考えられている。

$^{17}O(n,\alpha)^{14}C$反応

CO_2ガス中に含まれる^{17}Oが中性子を吸収する反応が^{3}He反応のBGとなる

CO_2ガス中に天然存在比(0.038%)で^{17}Oが存在していると仮定し、断面積から補正量を決定

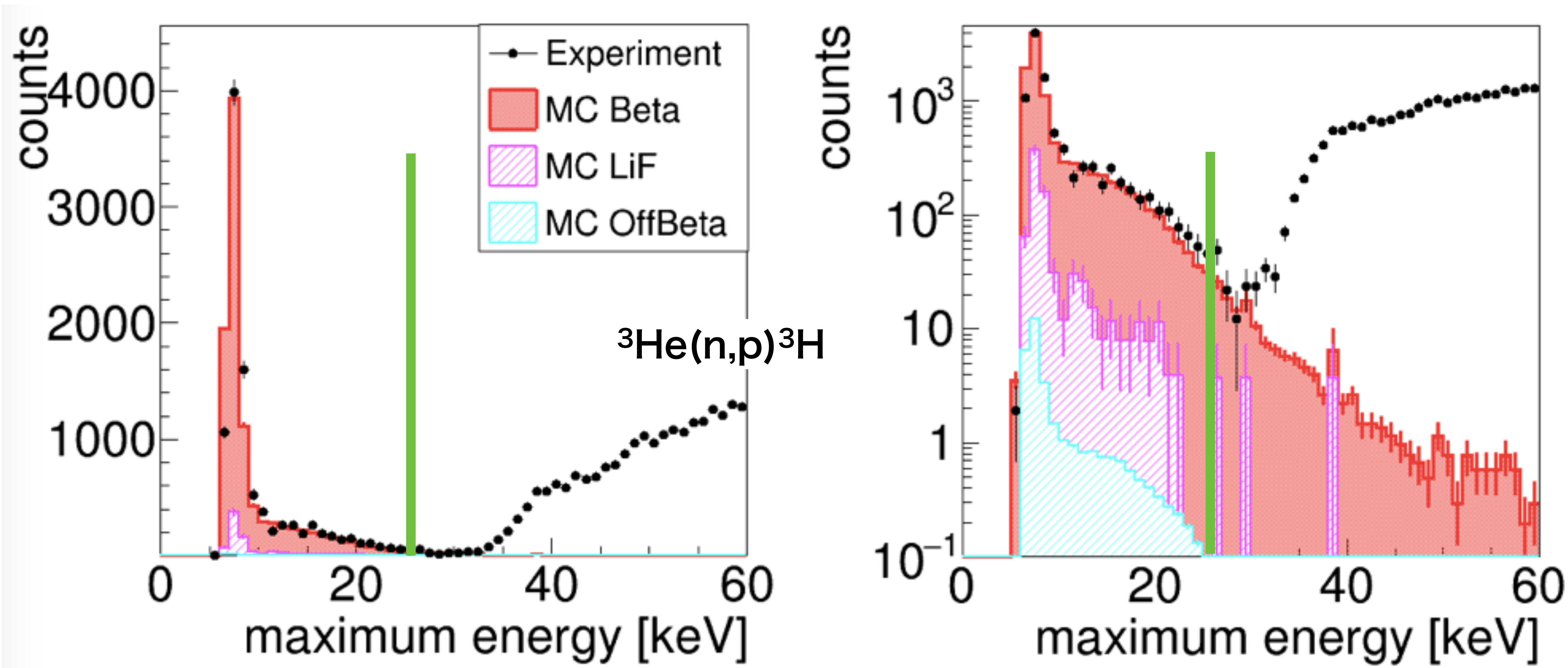
$$\text{中性子寿命に対する補正量} = -\frac{P_{^{17}\mathrm{O}} \times \sigma_{^{17}\mathrm{O}}}{P_{^{3}\mathrm{He}} \times \sigma_{^{3}\mathrm{He}}} = -0.50 \pm 0.03\ \%$$

Separation of signal events

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

β decay : **<u>small</u>** maximum energy deposit

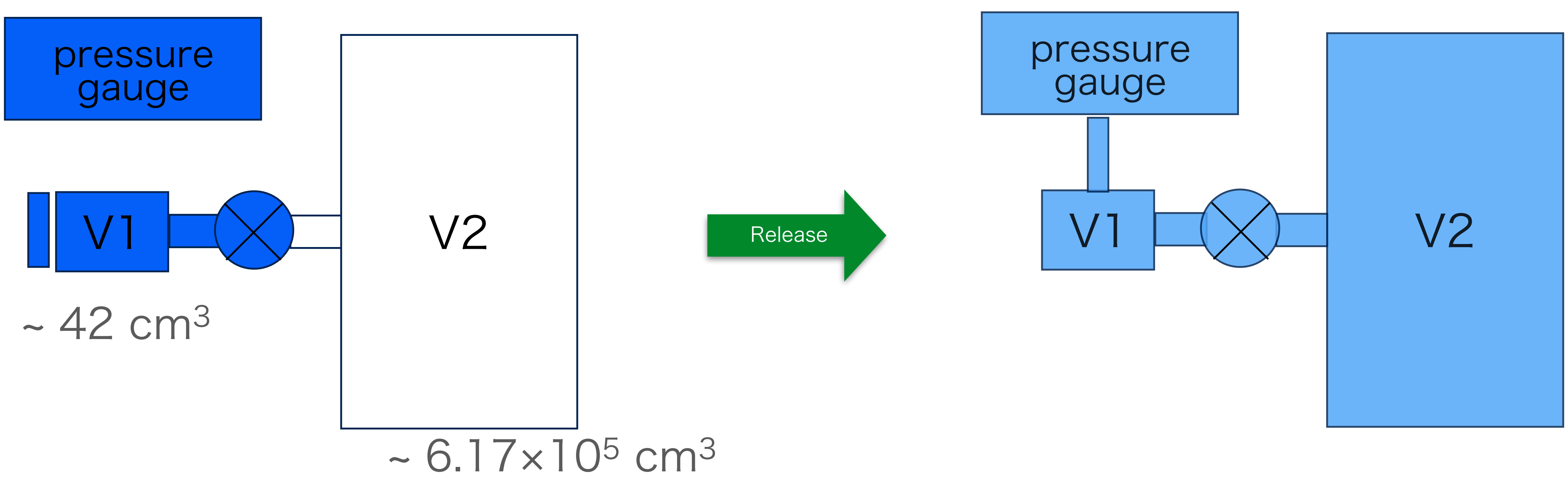
$^3He(n, p)^3H$: **<u>large</u>** maximum energy deposit



^{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



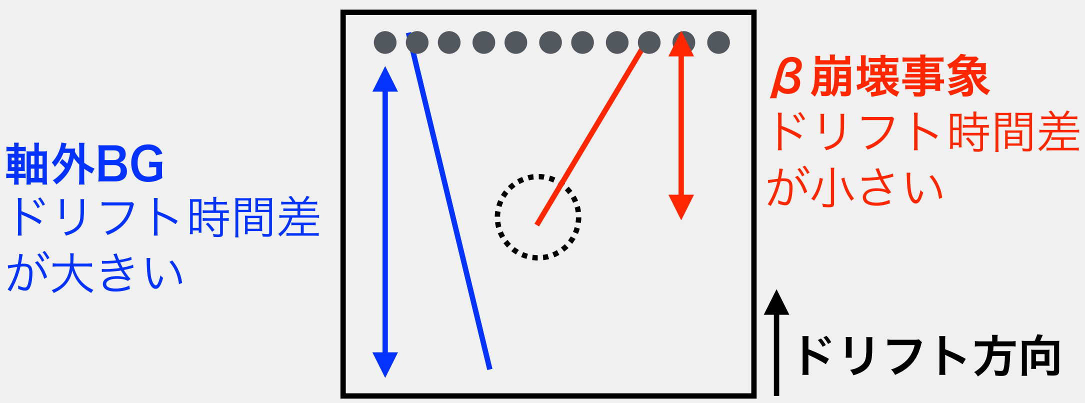
$$V1/V2 = 6.888(19)\times10^{-5}$$

β崩壊事象の抽出条件

ドリフト時間カット

抽出条件：ドリフト時間差が小さい

軸外BGイベントを除く

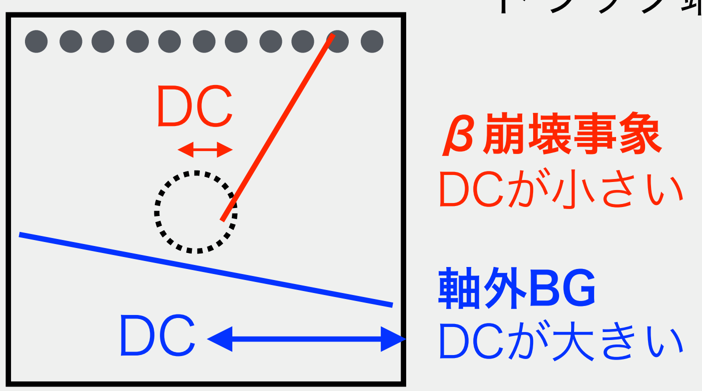


トラックの端点カット

抽出条件： DC が小さい

ビーム軸起因でないイベントを除く

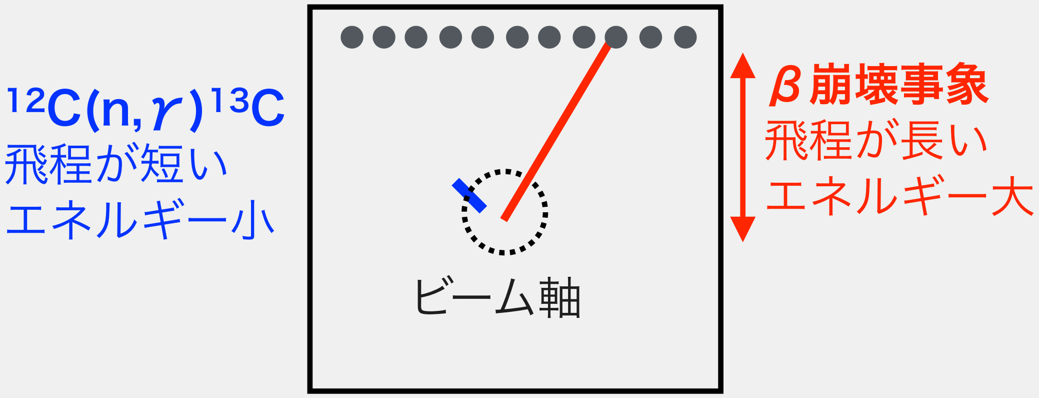
DC (Distance from Center)
…トラック端点とビーム軸との距離



ポイントライクカット

抽出条件：飛程が長いorエネルギー大

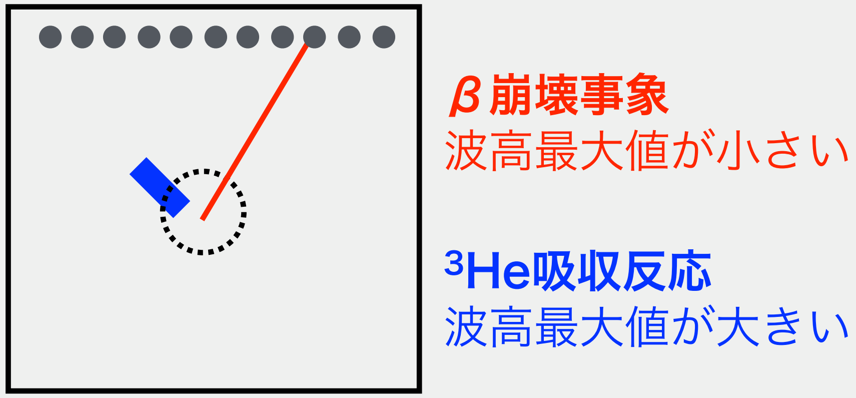
ポイントライクイベントを除く



波高最大値カット

抽出条件：波高最大値が小さい

^{3}He吸収反応を除く



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	