Research and Development of Range Counter

2022/12/22 合同発表会

Aoki Lab. Shion Kuribayashi

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- COMET experiment
  - Phase-α
- Range Counter
  - Development
  - Design
  - Components
  - Prototype
- Range counter muon beam test at MLF
- Range counter update
- Conclusion

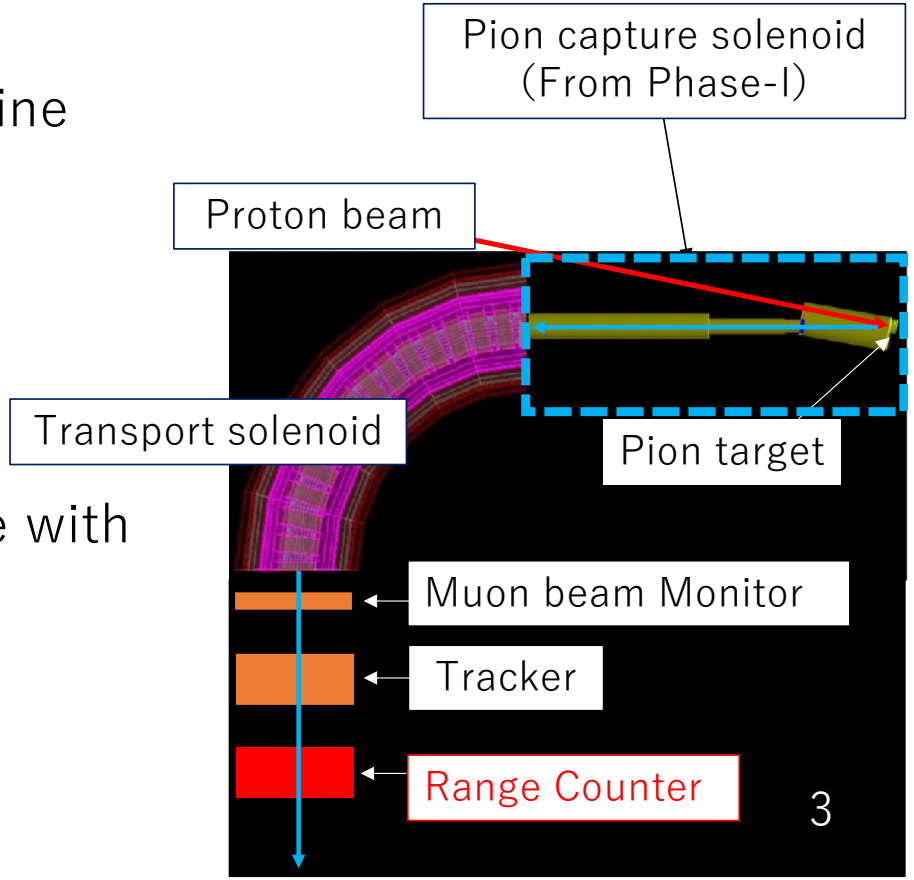
COMET

Experiment to explore the muon-to-electron conversion process in muonic atoms @J-PARC

- **COMET Phase-α** … Test of the COMET beamline
  - Purpose
    - Investigate the profile of proton beam
    - Validate Simulation
    - Investigate the property of muon beam
  - Beamtime
    - FY 2023

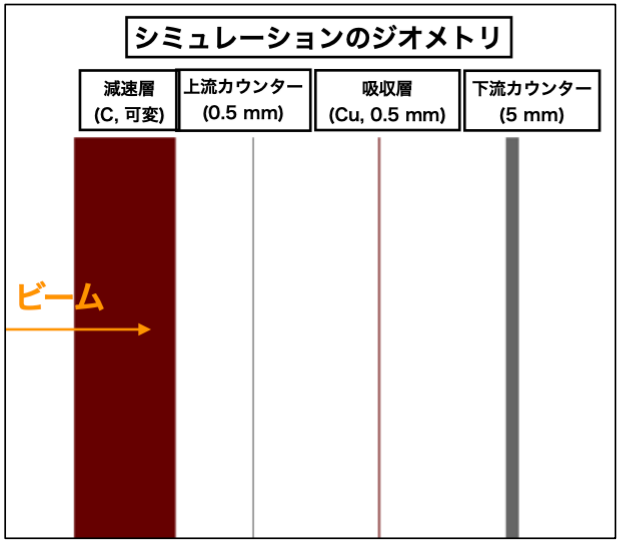
Measuring particles coming from the beamline with various detectors

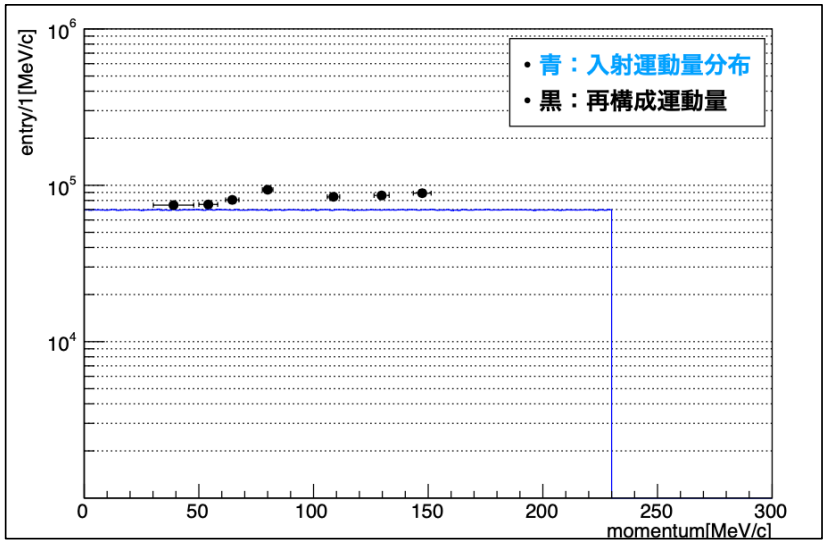
・Beam profile：Scintillating fiber hodoscope
・Beam direction：Straw tracker
・Particles and its momenta：Range Counter



Development of Range Counter system

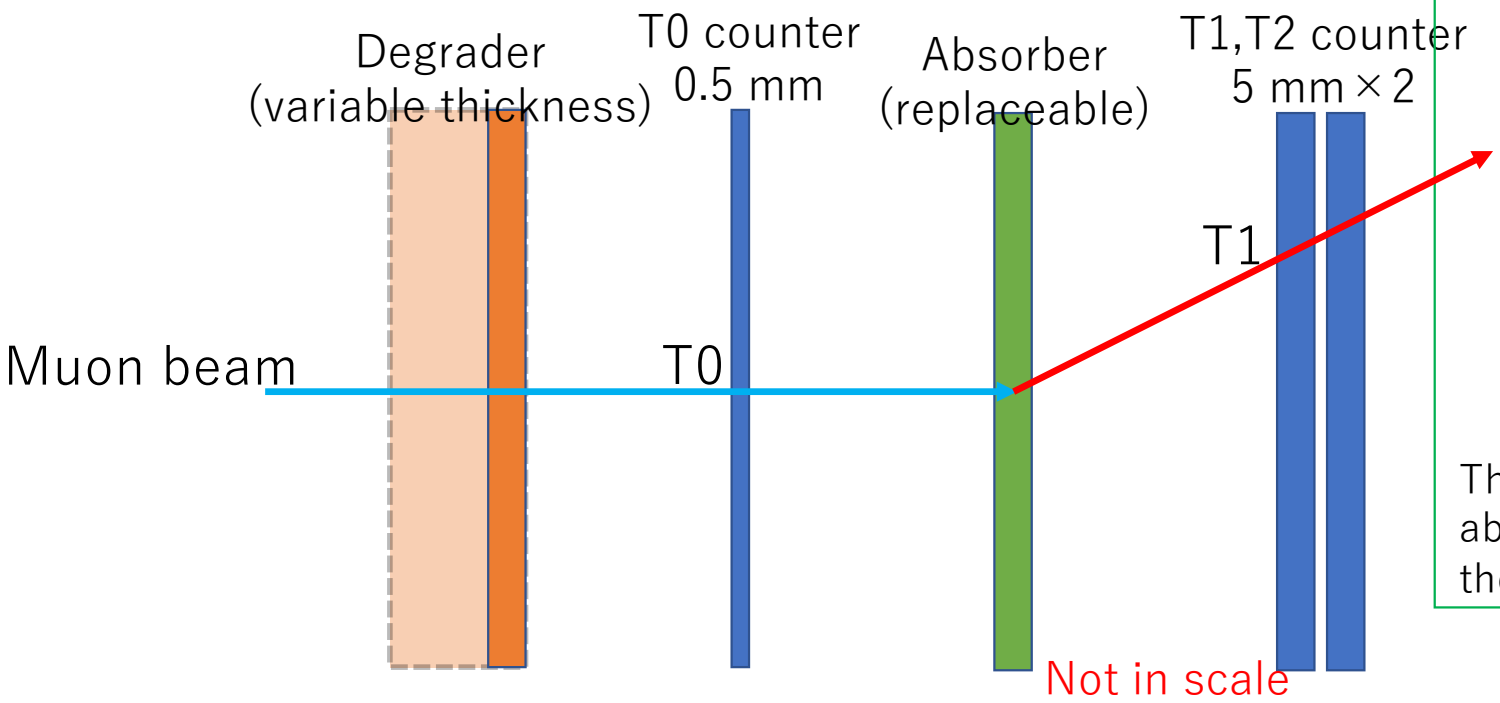
- **Purpose of the Range Counter**
  - Measurement of the momentum distribution of each particle and its yield
- **Previous study**（Osaka Univ. Y.Higuchi JPS 第77回年次大会）
  - A simple model of the range counter was created in a computer simulation and the muon momentum distribution was reconstructed in a computer simulation.

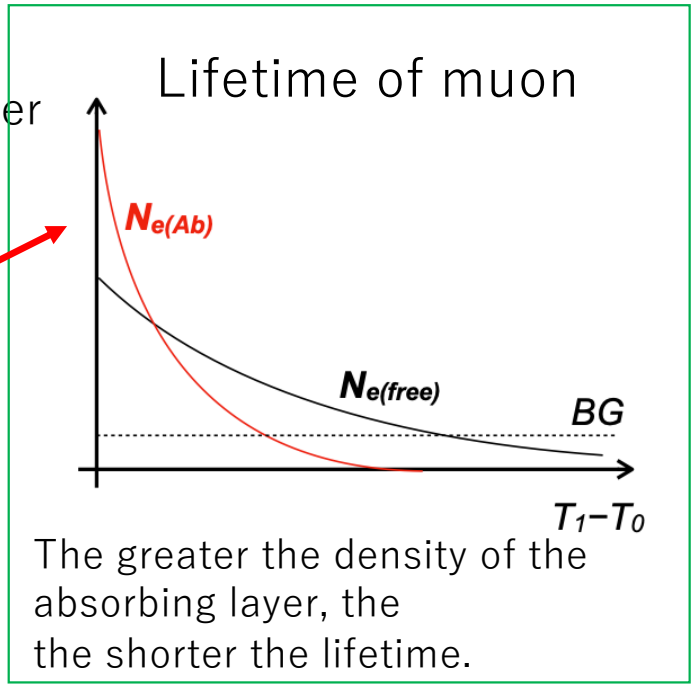




The muon momentum distribution was reconstructed by simulation.
Based on that, I have constructed the real Range Counter system.

Design of Range Counter





・Select the event with which a muon has stopped in absorber and calculate T1-T0.

・T1-T0 spectrum means the lifetime of particle which stopped in absorber.

⇨ Particle identification

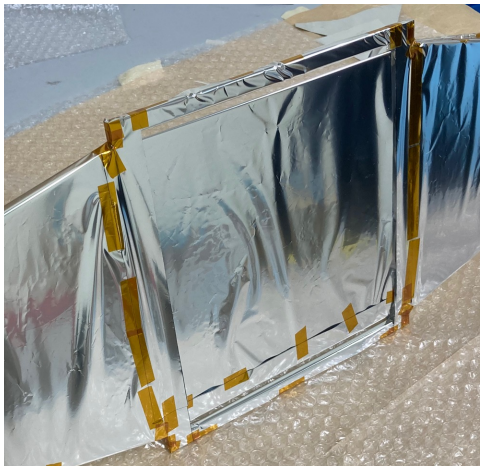
・We can change the thickness of the degrader so that the certain range of momentum is selected to be stopped in the absorber.

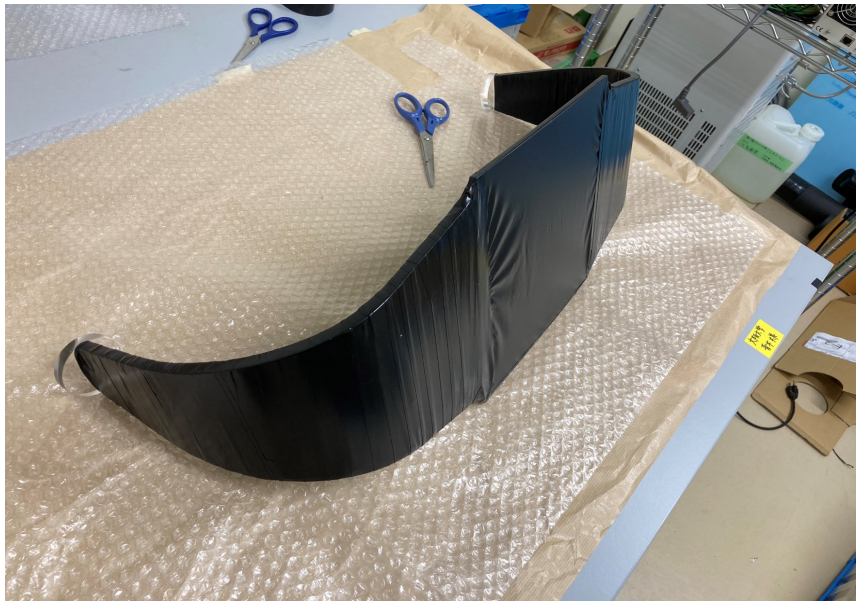
⇨ Reconstruction of beam momentum spectrum

T0 counter

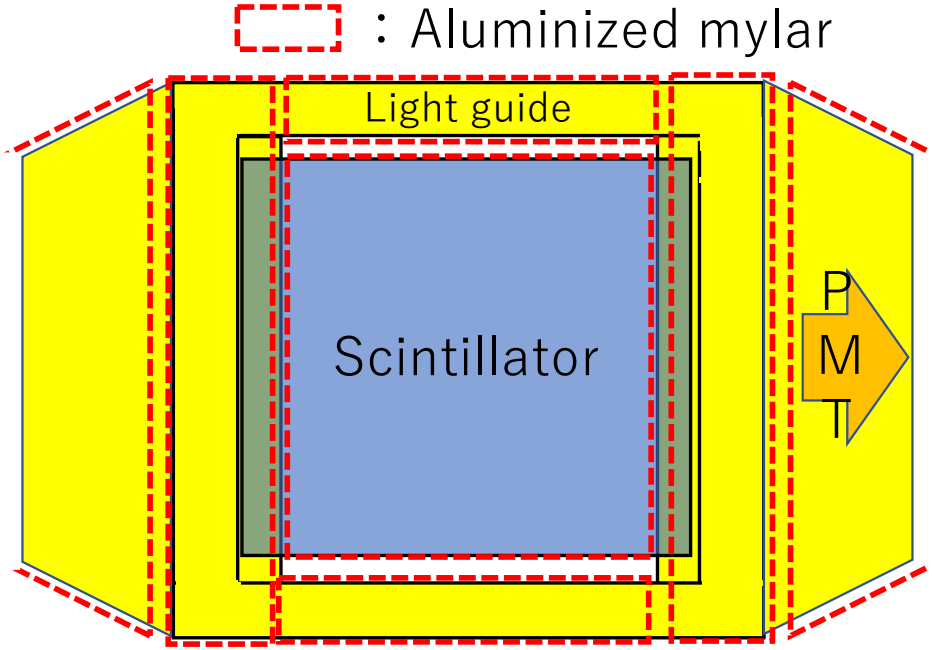
- Plastic Scintillator(EJ-212)

  20 cm × 20 cm × 0.5 mm
- Light guide：Acryl
- Reflector：Aluminized mylar
- Read out : Fine mesh PMT (Hamamatsu Photonics H6154)





inside

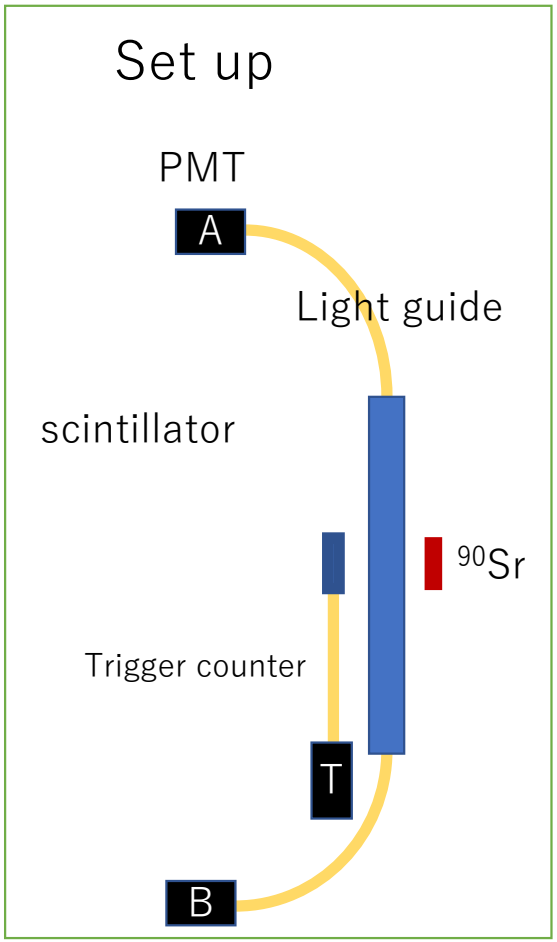


T0 counter operation check

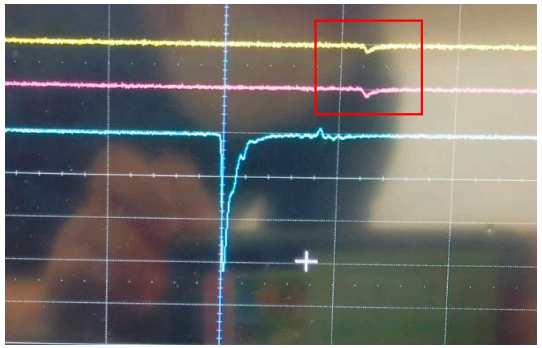
Purpose

- Confirmation that we can see the signal using 0.5 mm thick scintillator.
  → Find the number of photons reaching PMT A and B

Set up

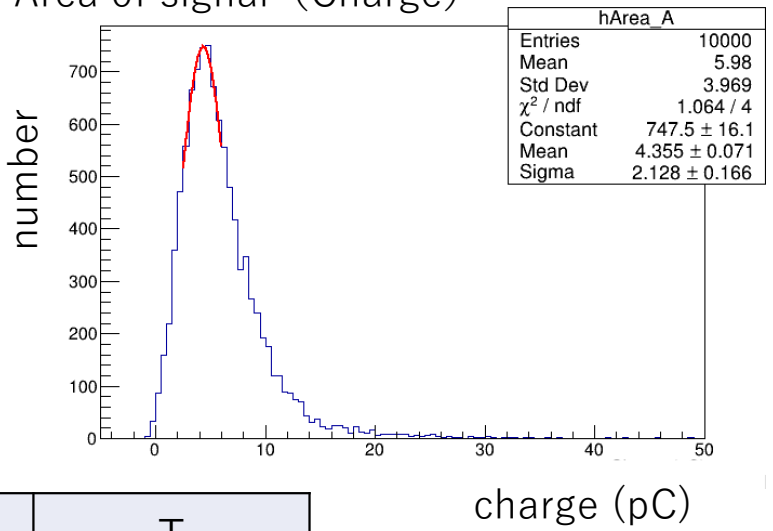


Signals



Unit(/1div)
Ver：100 mV
Hori：100 ns

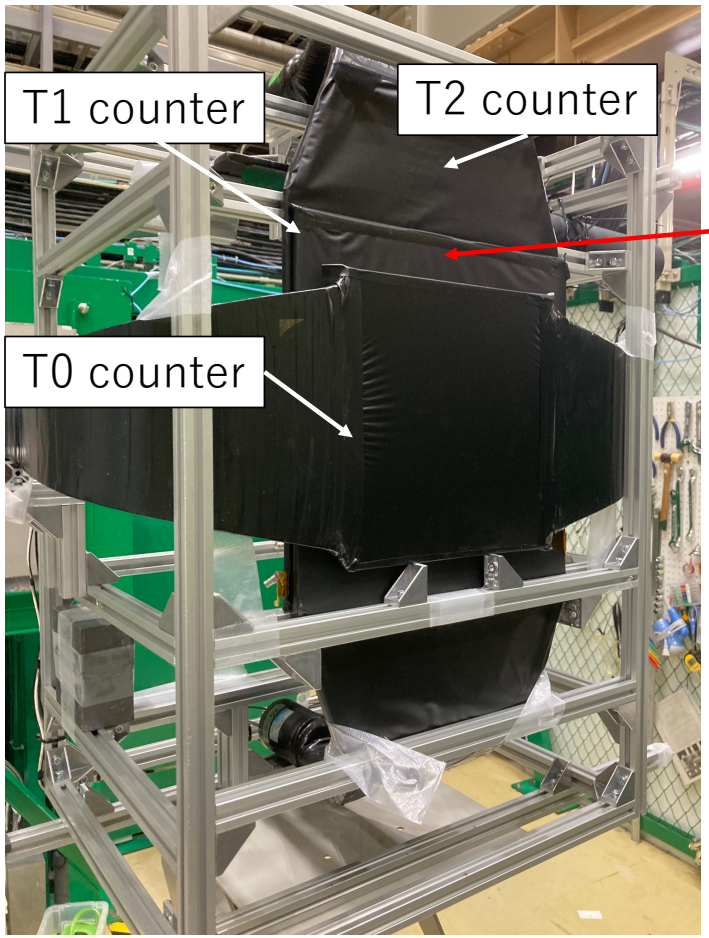
Area of signal（Charge）



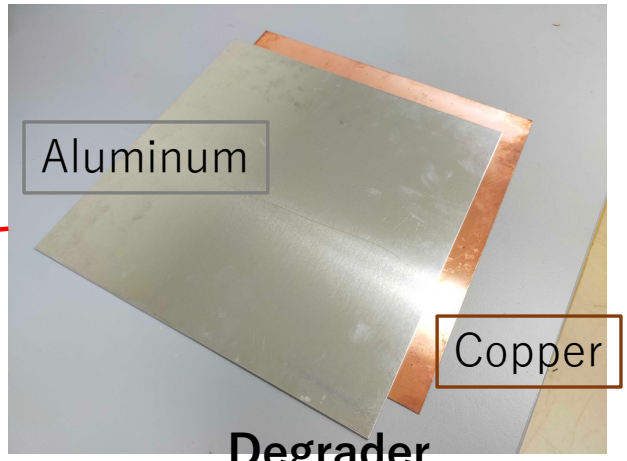
PMT	A	B	T
Ave. photons	4.6	5.6	92.3

→ I could see photons were produced and reaching the PMT.

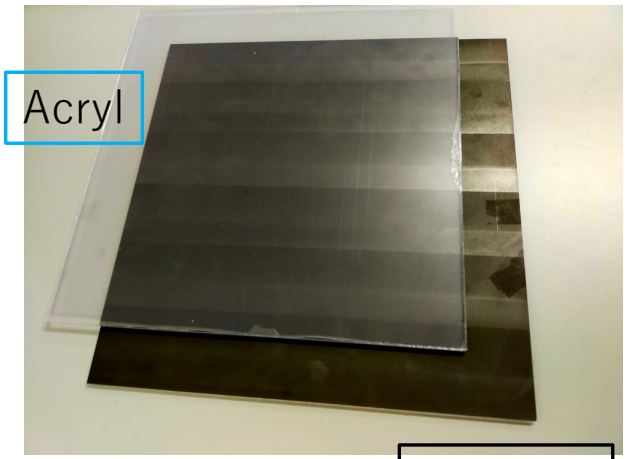
Range Counter Prototype

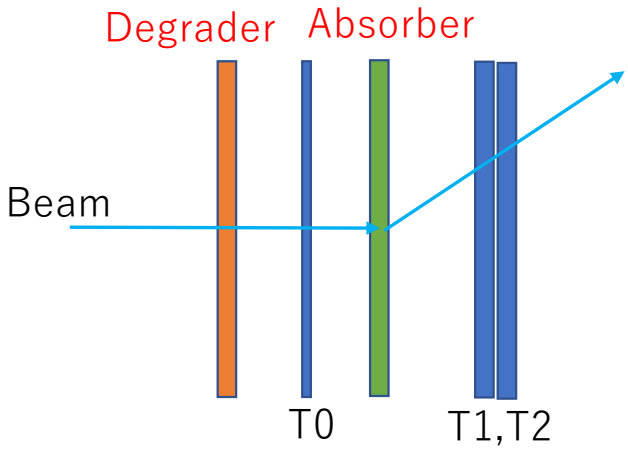


Absorber

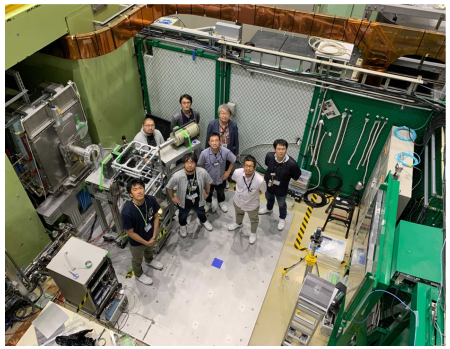


Degrader

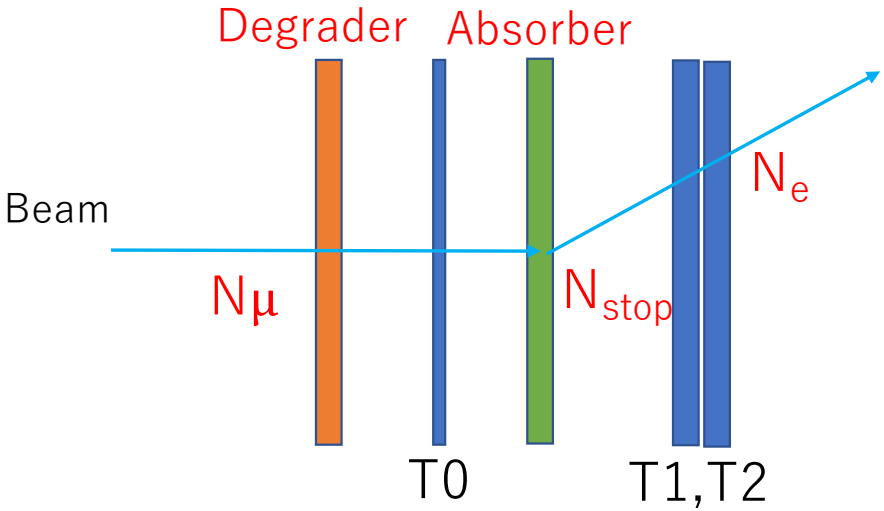


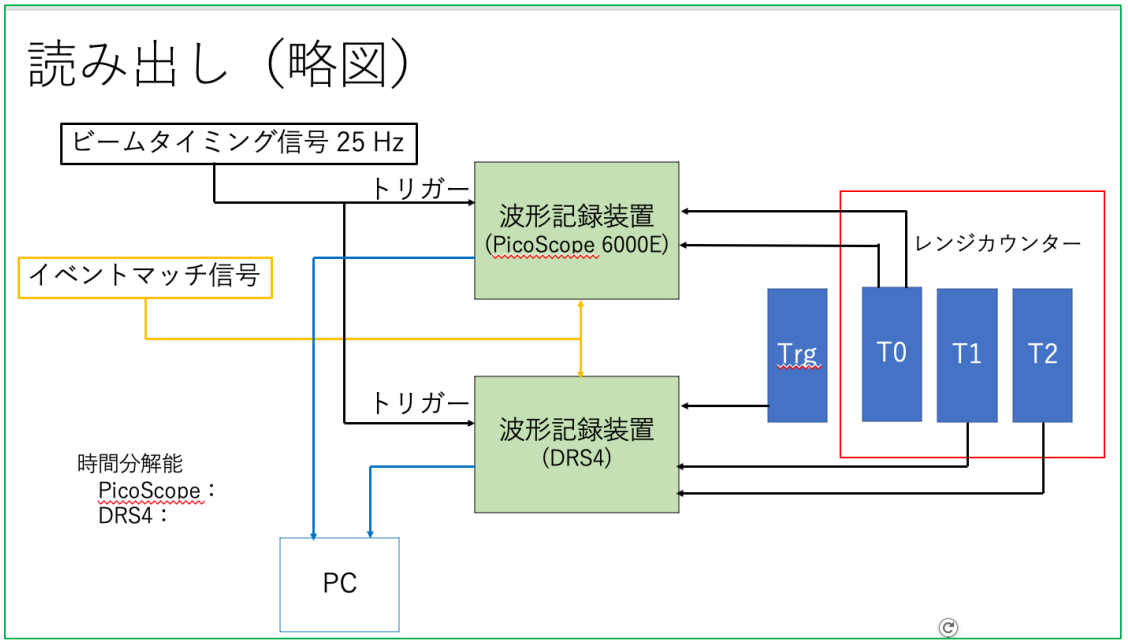


Range Counter test @ MLF muon beam



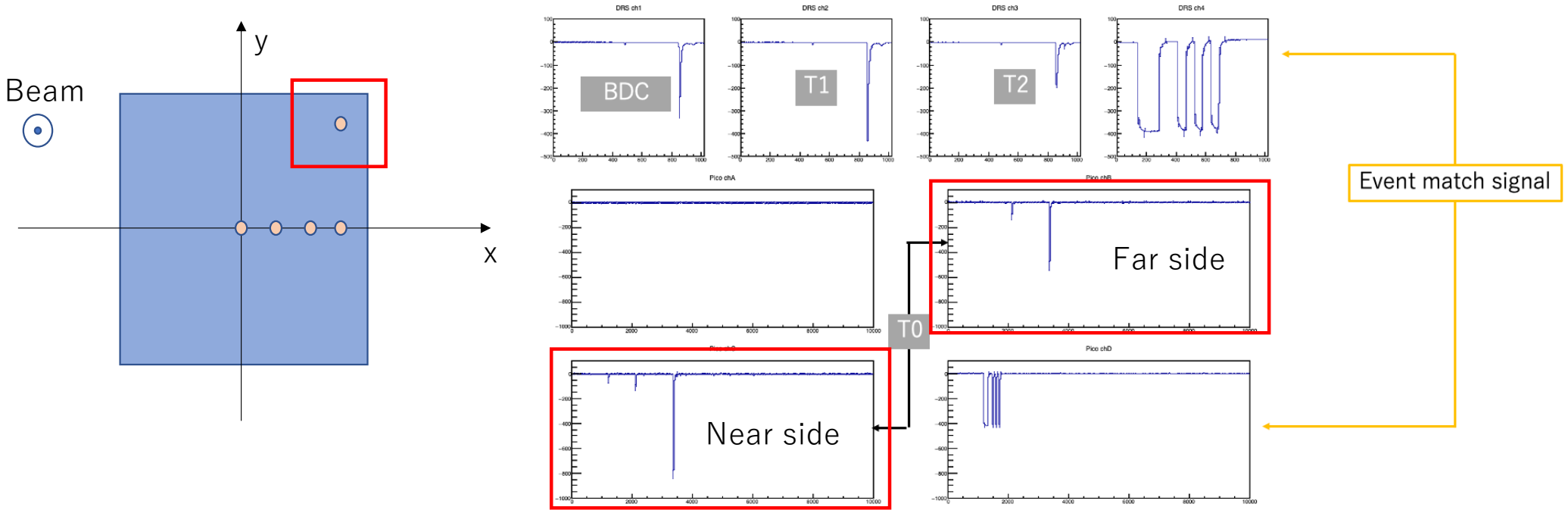
- Overview
  - J-PARC MLF
  - 2022/6/4,5,6
  - D2 beamline
  - 45 MeV/c muon beam





The range counter system with DAQ functioned very well.

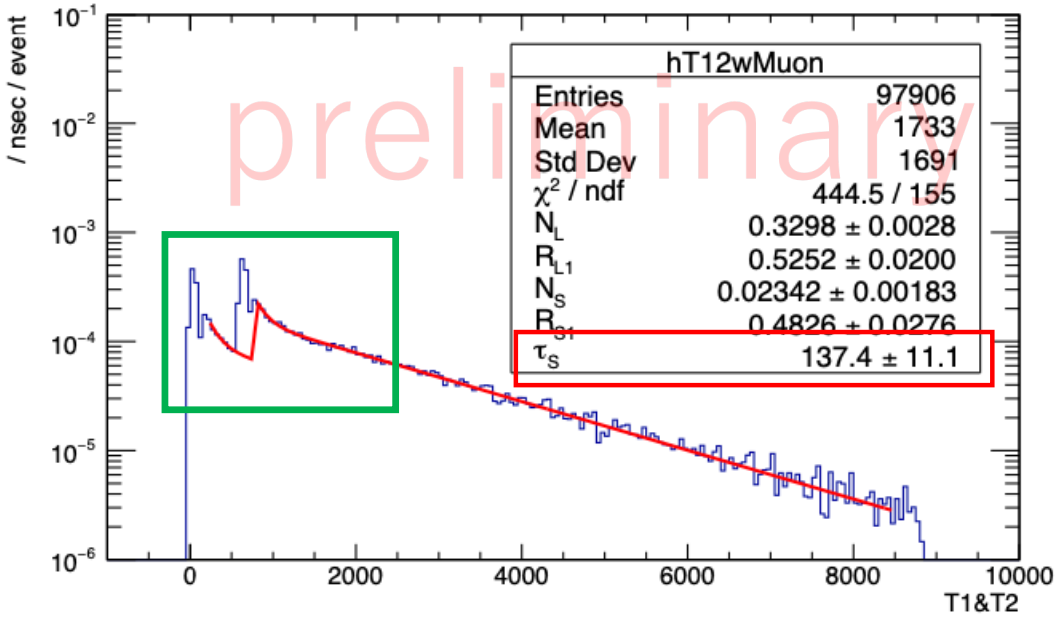
Signal check of T0 counter for different positions



- **Signals on the far side from the PMT are also visible.**
- **Wave height is about 200 mV~ 400 mV**

Preliminary analysis results

Absorber : Copper



Fitting function

$$u(t-t_1)\left\{\frac{N_{L1}}{\tau_L}e^{-\frac{t-t_1}{\tau_L}}+\frac{N_{S1}}{\tau_S}e^{-\frac{t-t_1}{\tau_S}}\right\}$$
$$+u(t-t_2)\left\{\frac{N_{L2}}{\tau_L}e^{-\frac{t-t_2}{\tau_L}}+\frac{N_{S2}}{\tau_S}e^{-\frac{t-t_2}{\tau_S}}\right\}$$

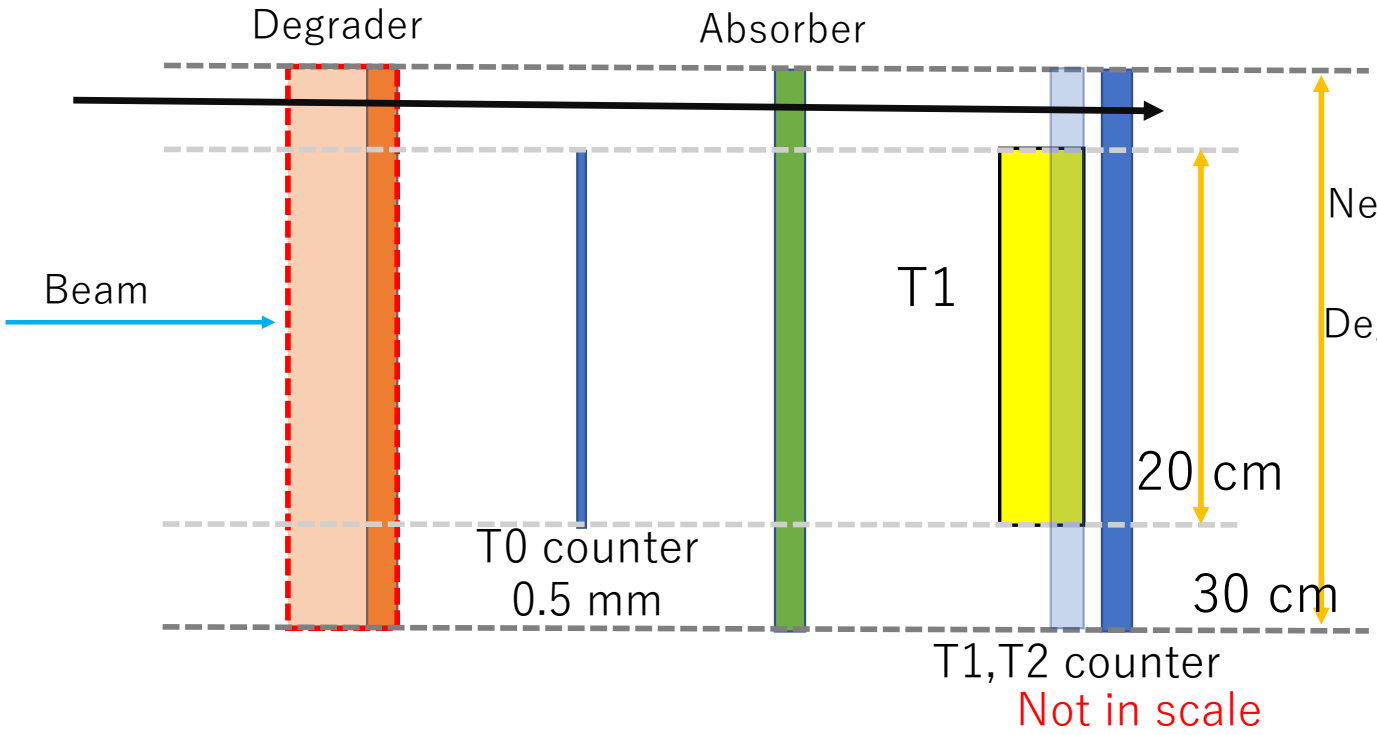
$$N_{L1}=N_L R_{L1},\quad N_{L2}=N_L-N_{L1}$$
$$N_{S1}=N_S R_{S1},\quad N_{S2}=N_S-N_{S1}$$

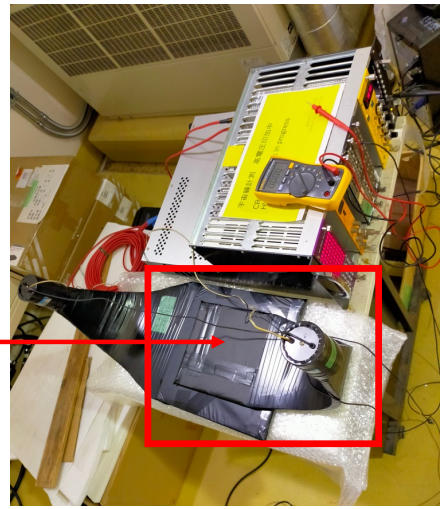
Lifetime of muons in matter

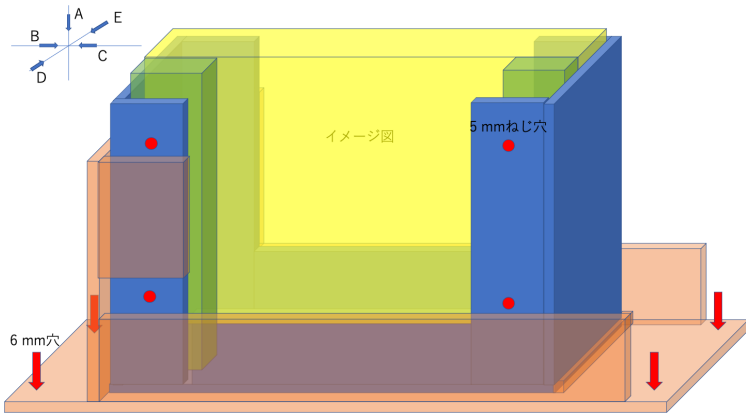
matter	aluminum	copper
Literature(ns)	864	160
Reconstruction(ns)	856	137

Fitted life time for Al target is consistent with the known value.
Fitted life time for Cu target is 2 sigma smaller than the known value and is not inconsistent with it.

Range Counter Update







- New T1 counter
  - Area : To avoid taking the signal as shown by the black arrow
  - Thickness :To be easier to distinguish between protons and electron

30 cm ×30 cm × 0.5 cm ⇨ 20 cm ×20 cm × 1 cm

Conclusion

- COMET experiment
  - Experiment to explore the muon-electron conversion process in muon atoms at J-PARC.
- COMET Phase-α
  - Test of the beamline of COMET Phase-I
- Range Counter is required for particle identification and momentum distribution reconstruction in COMET Phase-α
  - Particle identification ： Difference in lifetime of particles stopped in absorber
  - Momentum distribution ：The number of particles stopped in absorber with difference degrader
- Range Counter prototype
  - performance evaluation test
  - Range counter test using 45 MeV/c muon beam at J-PARC MLF
  - Under detailed analysis
- Ongoing
  - Detailed analysis of the beam test
  - Detailed test of each counter in laboratory
  - Range Counter update

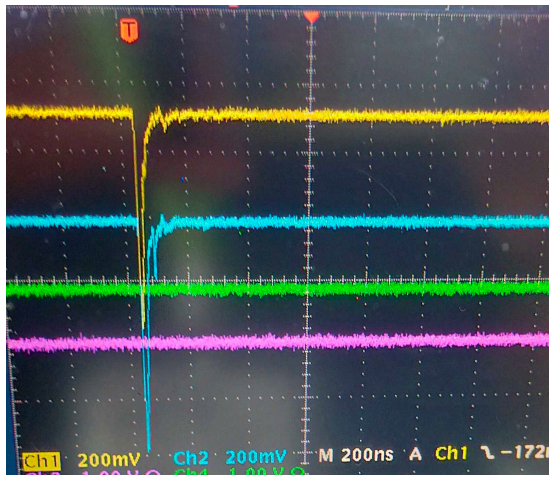
kokomade

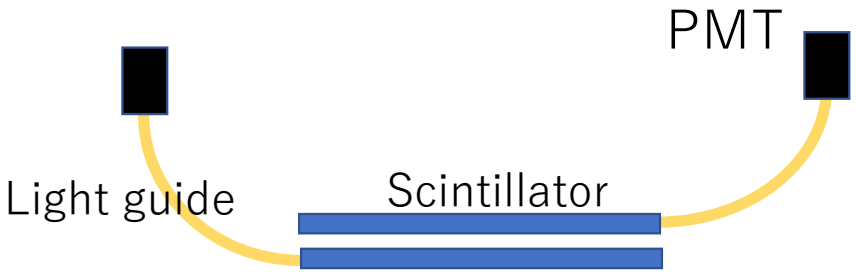
T1,T2 counter

言ってしまえば普通のシンチレーターなので１ページ使うまでもない

- Plastic scintillator(EJ-200)
  30 cm × 30 cm × 5 mm
- Light guide : acryl
- Reflector：Aluminized mylar
- Read out : Fine mesh PMT (Hamamatsu Photonics H6154)

Signal check by using cosmic muon

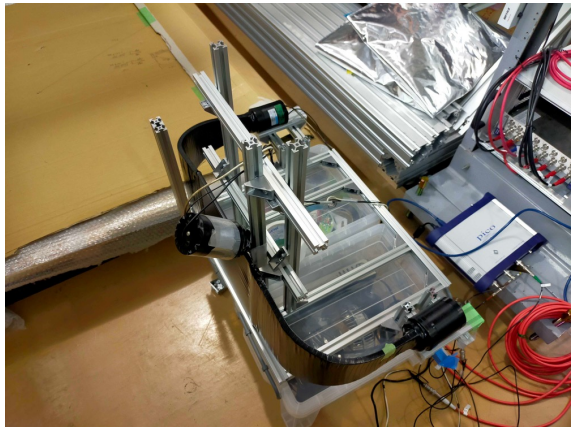


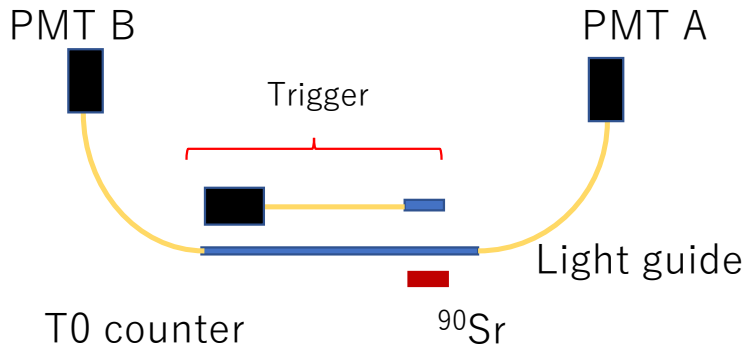


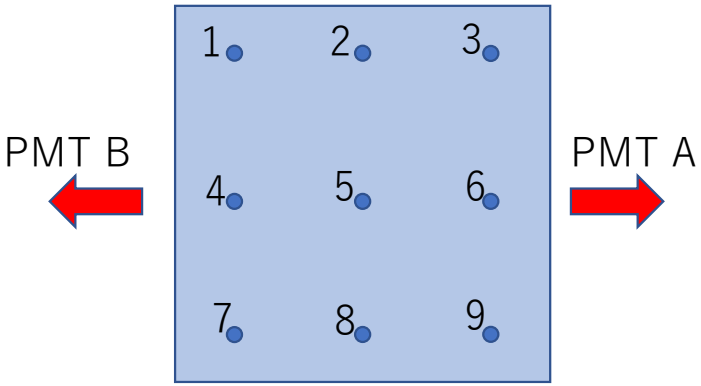
Unit(/1div)
Ver：200 mV
Hori：200 ns

→ I could see the signal.

T0 positioning check

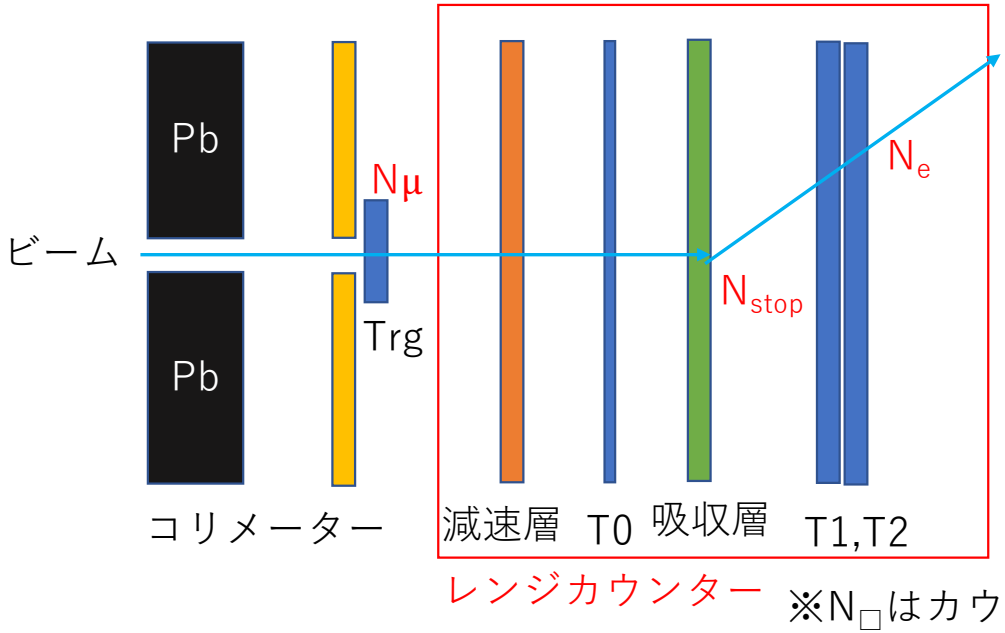




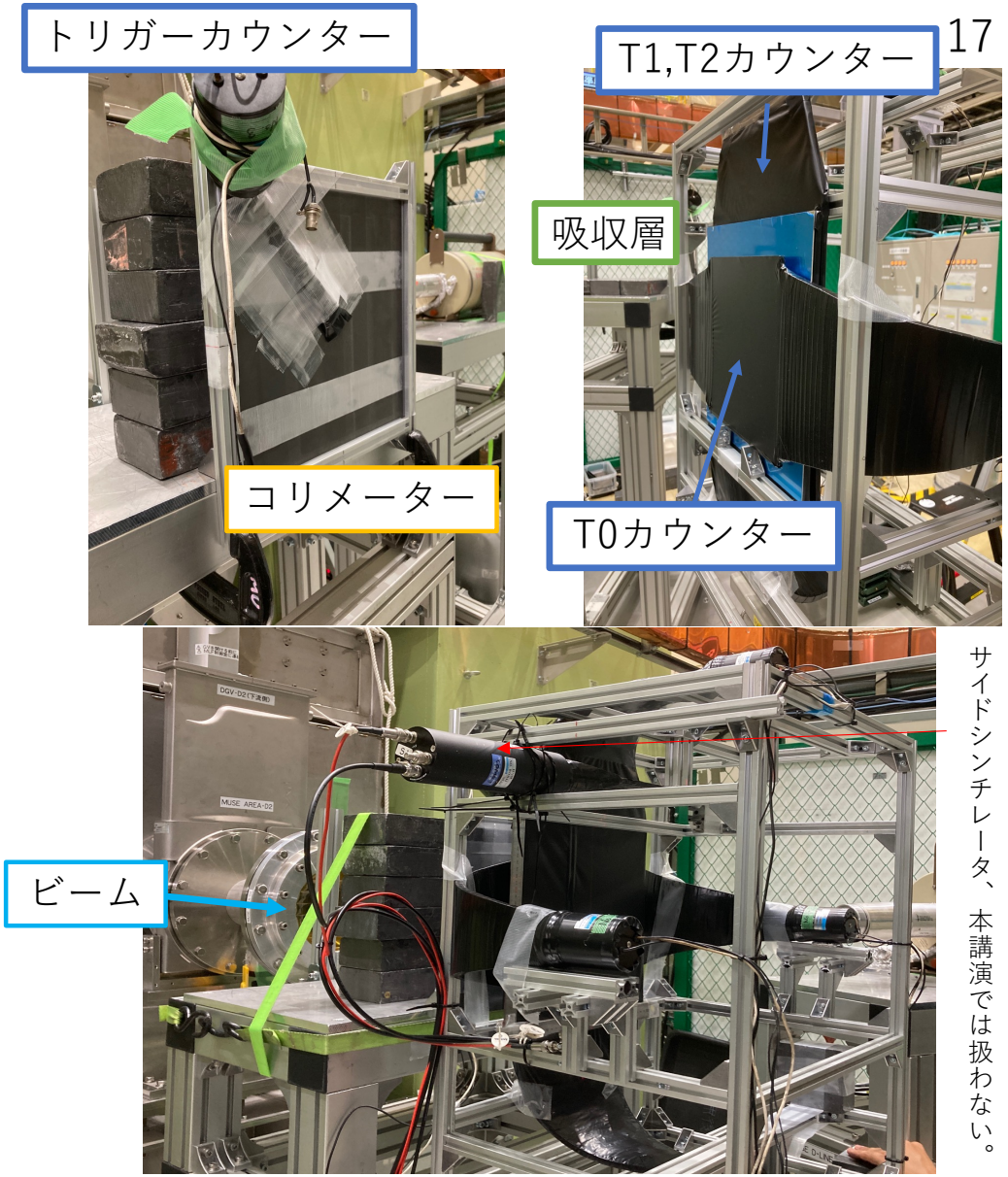


- I named each points from 1 to 9 and took 10,000 waveforms at each point.
- I converted the integral value of each waveform to a charge, drew a histogram of it, and compared its mean value.

セットアップ



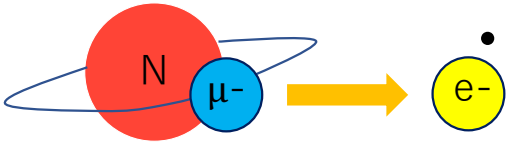
- コリメーター
  - 鉛ブロックの穴の大きさ
    5 cm × 3 cm (厚さ 10 cm)
  - グラファイトの穴の大きさ
    直径1 cm (厚さ 1 cm)



サイドシンチレータ、本講演では扱わない。

COMET

- Experiment to explore the muon-electron conversion process in muon atoms
- Muon-electron conversion process
  - Charged lepton flavor number is not preserved
  - Difficult to observe with current standard theory including neutrino oscillations

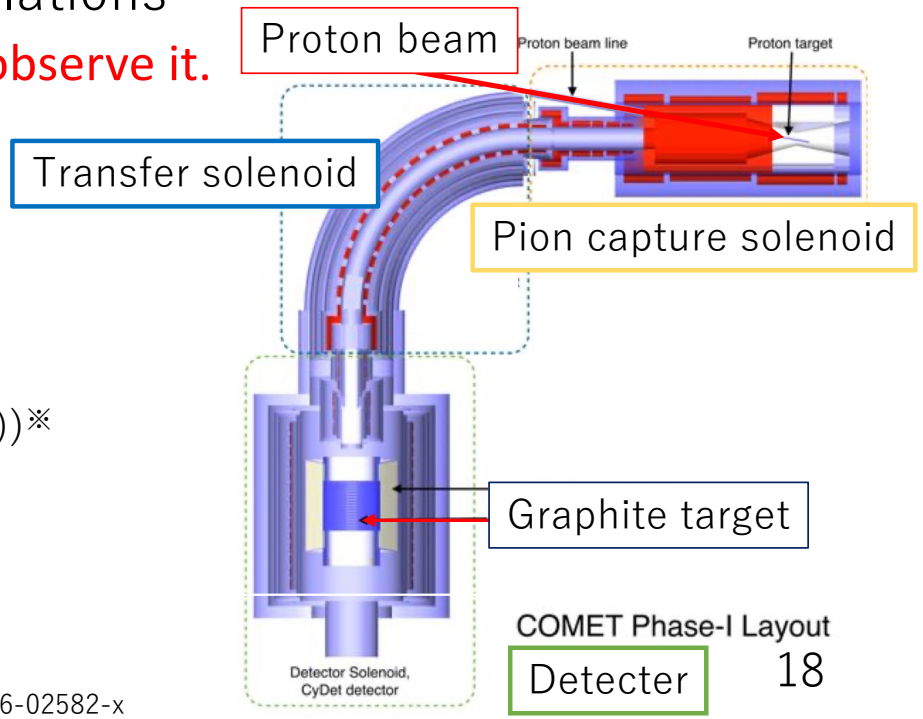


$\mu^- + N(A,Z) \rightarrow e^- + N(A,Z)$

⇨New physics if we can observe it.

- COMET experiment
  - Place：J-PARC
  - Single event sensitivity
    - Phase-I：~O(10^{-15})
    - Phase-II：~O(10^{-17})

  SINDRUM-II (O(10^{-13}))※ を10^2~10^4倍更新
  - Ready for Phase-I



※https://doi.org/10.1140/epjc/s2006-02582-x

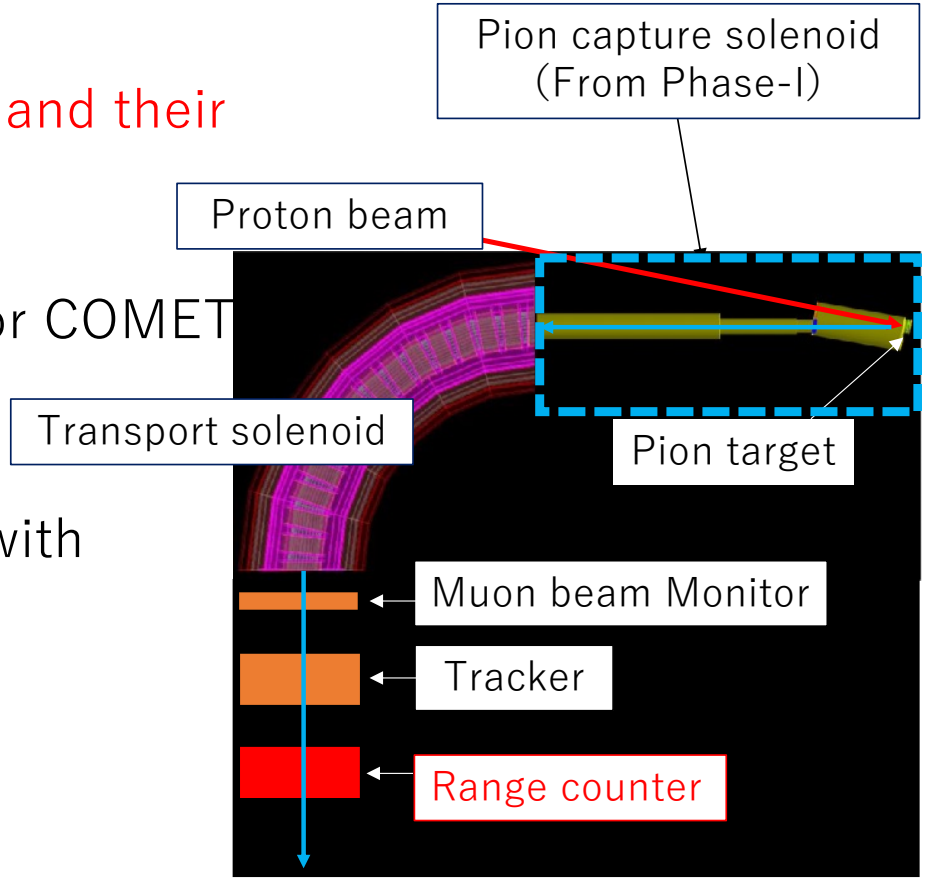
COMET Phase-α

Test of the beamline of COMET

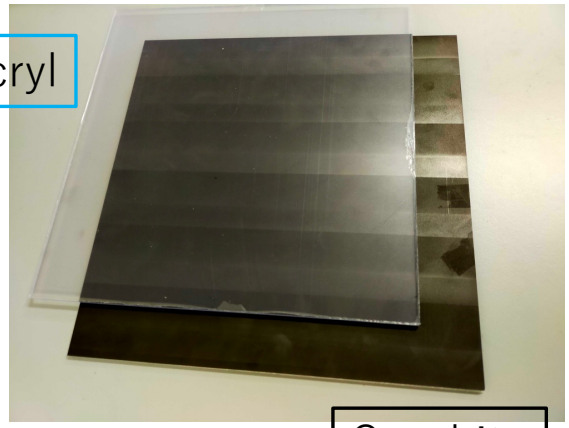
- Purpose
  - Investigate of the profile of proton beam
  - Investigate the number of muons produced and their momentum
- Feature
  - First experiment using transport solenoid for COMET
- Date
  - FY 2023

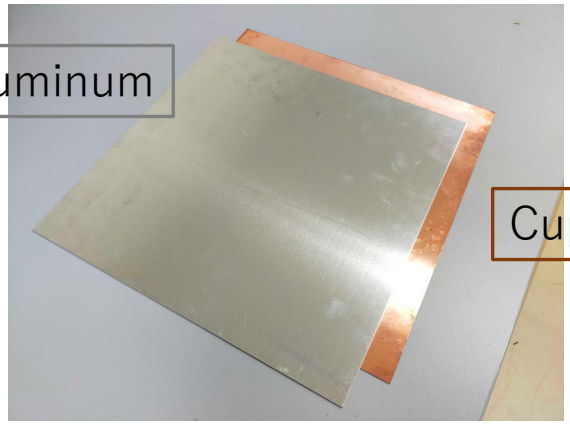
Measuring particles coming from the beamline with various detectors

・Beam profile：Muon beam monitor
・Beam direction：Tracker
・Particles and its momenta：Range counter



Degrader, Absorber



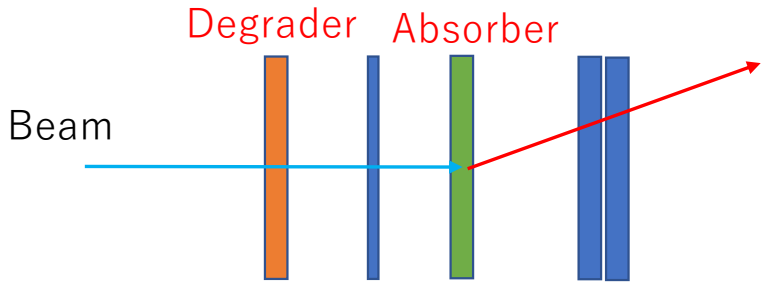


Degrader

- Momentum selection of the muon beam
- Graphite : 30 cm × 30 cm × 1, 2, 4, 8, 16, 32 mm
- (Acryl : 30 cm × 30 cm × 0.4, 0.8 mm)

Absorber

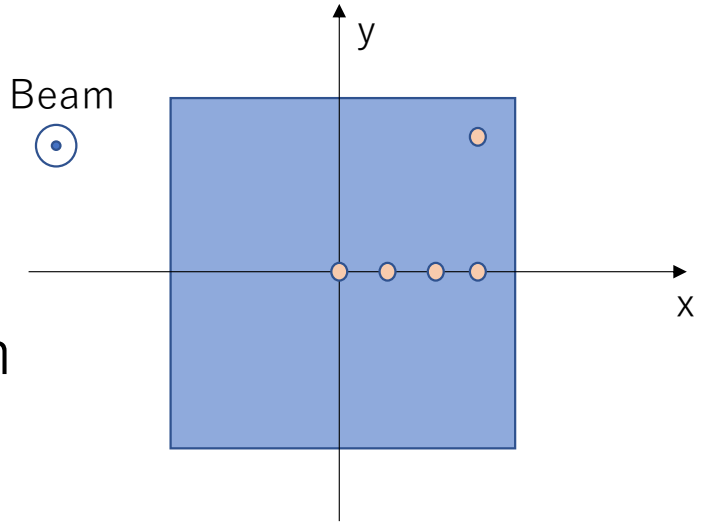
- The muon beam is stopped and decays within the electron orbit of each material.
- Two different absorbing layers were prepared to see the difference in lifetime.
- Cupper : 30 cm × 30 cm × 0.5 mm
- Aluminum : 30 cm × 30 cm × 1.6 mm

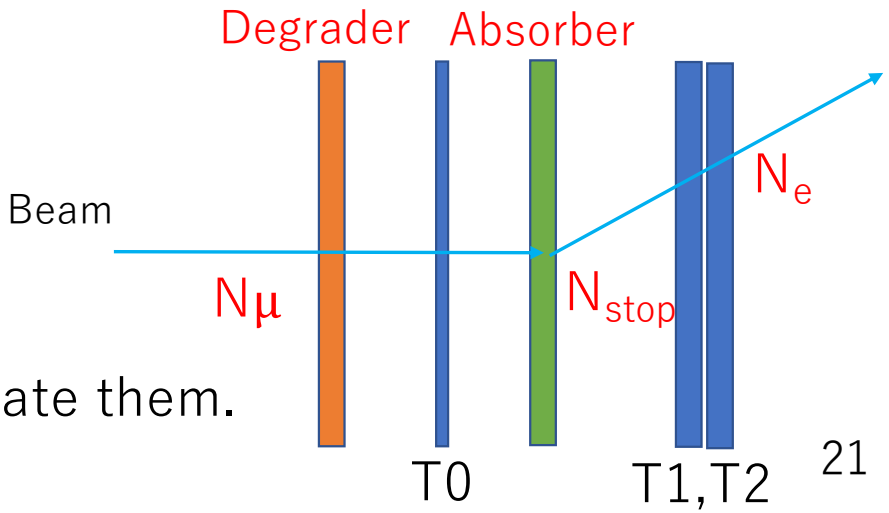


Performance evaluation

Contents

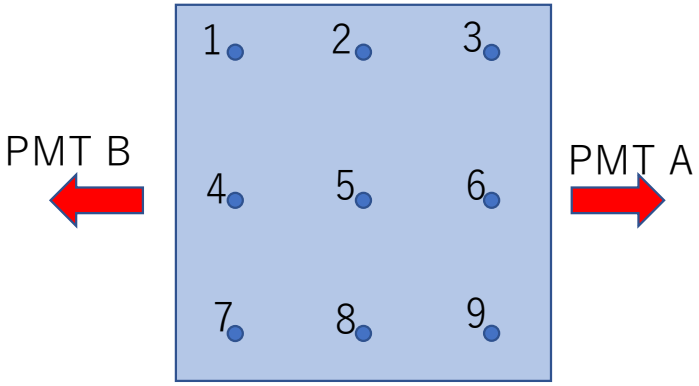
- Efficiency
- Resolution of momentum distribution
- position dependence
  - Yields at each point
  - Detection efficiency ：N_e / N_{stop}
- Stopping Ratio
  - Ratio of particles stopping at the absorber, varying with the thickness and combination of the degraders. ：N_{stop} / $N\mu$
- Lifetime of different absorber.





Beam tests were conducted to evaluate them.

T0 positioning check in lab.



PMT A

2.7	3.7	4.8
2.6	3.4	5.2
3.6	4.6	5.9

(pC)

Ratio to the center

0.79	1.1	1.4
0.76	1	1.5
1.1	1.4	1.7

PMT B

8.3	6.4	4.5
8.1	5.1	3.8
8.5	7.0	5.6

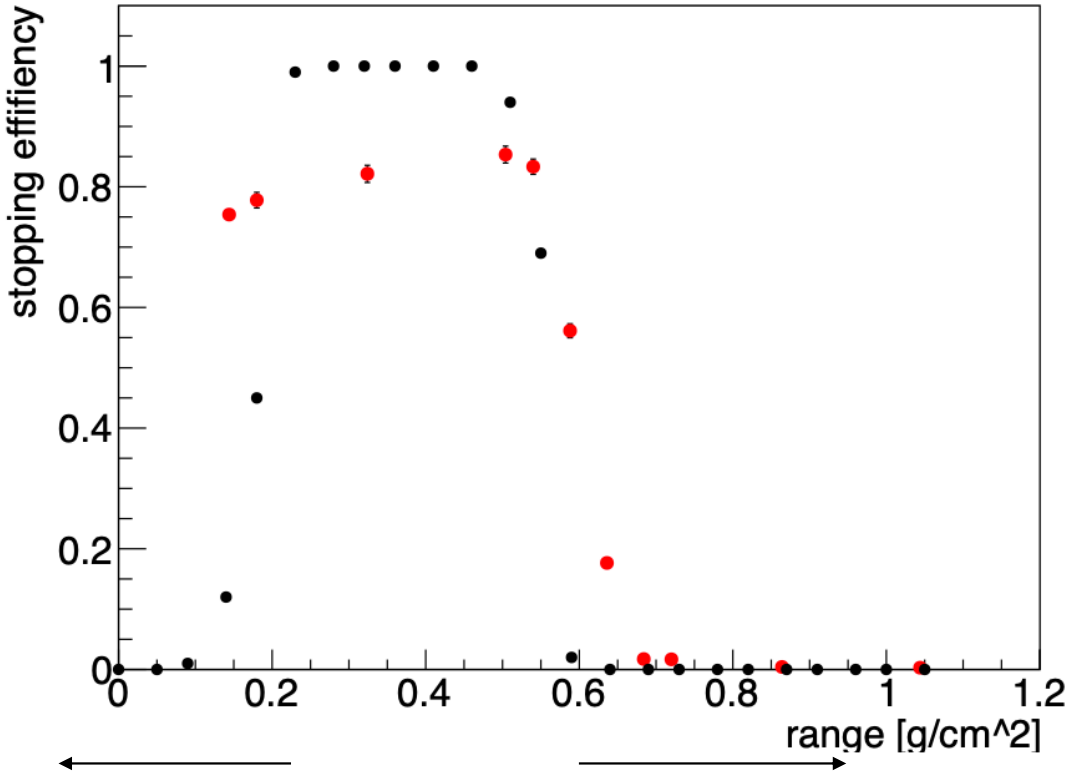
(pC)

Ratio to the center

1.6	1.3	0.88
1.6	1	0.75
1.7	1.4	1.1

- The values on the side closer to the PMT are larger.
- The values on the side closer to the ground are larger.
- The values of PMT B is 1.5 times larger than that of PMT A.

黒点：シミュレーション
赤点：データ



落とすエネルギーが小さい領域
（ミューオンは吸収層も通過）

落とすエネルギーが大きい領域
（ミューオンは吸収層まで届かない）

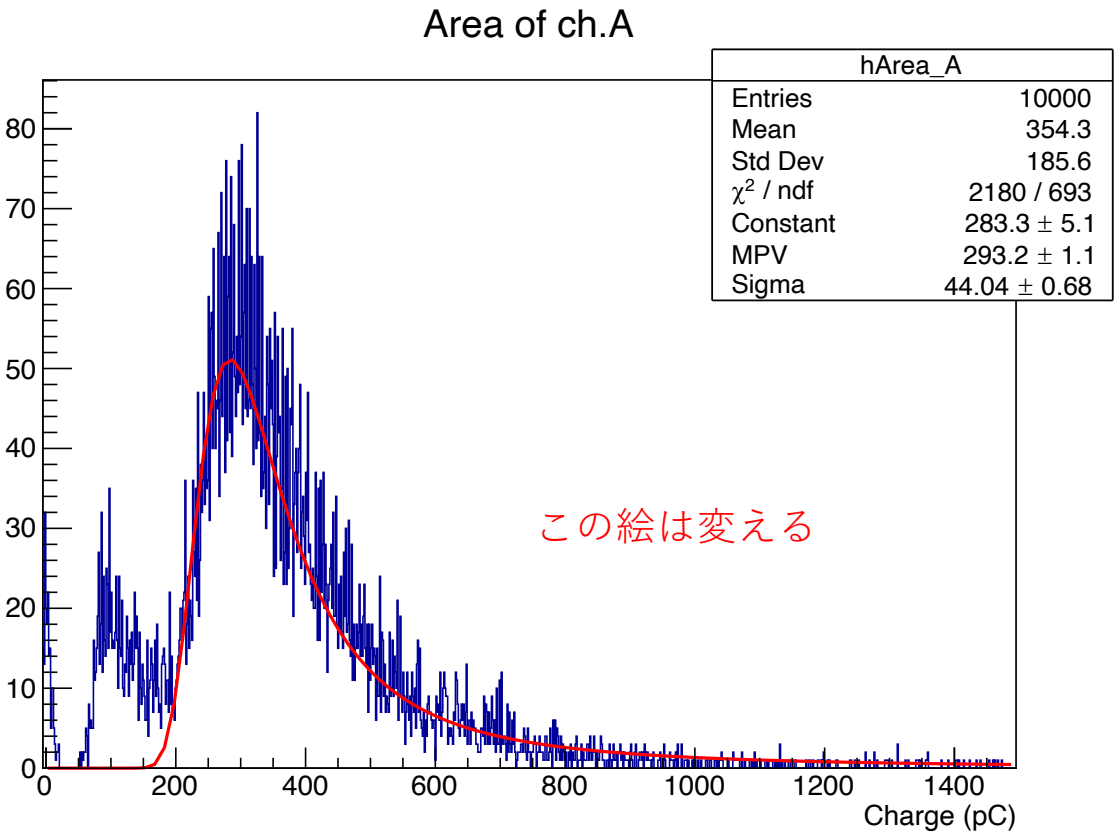
減速層　g/cm^{2}換算

Run #	Graphite Thickness [mm]	Acrylic Thickness [mm]	Total Range [g/cm^2]
31	0	1.2	0.144
32	1	0	0.18
34	1	1.2	0.324
35	3	1.2	0.684
36	2	1.2	0.504
37	3	0.8	0.636
38	3	0.4	0.588
39	3	0	0.54
40	4	0	0.72
41	4	1.2	0.864
42	5	1.2	1.044
45	1	1.2	0.324

0.5 g/cm^{2}の時85%で最大値をとる

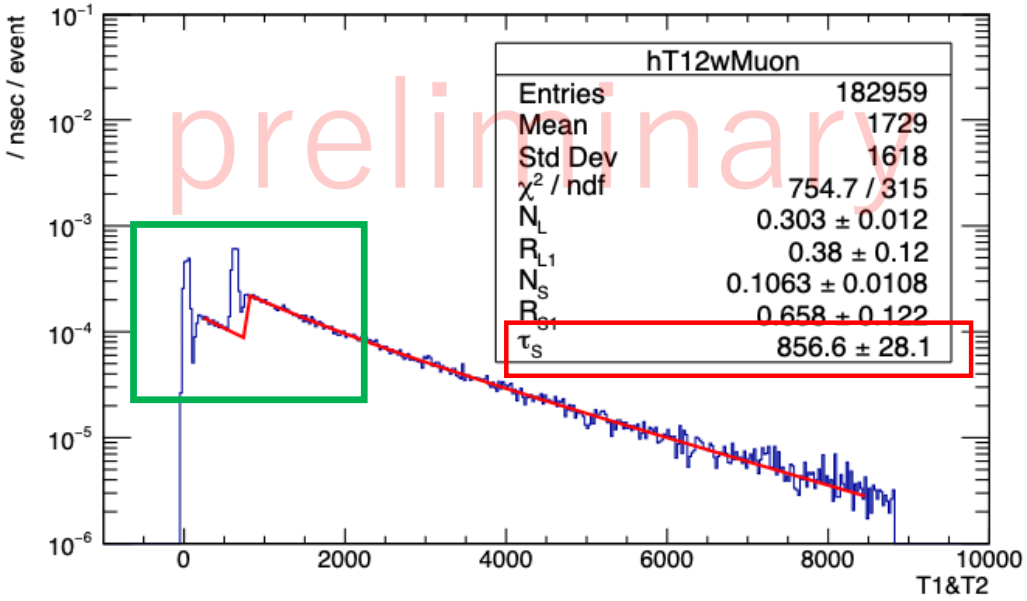
New T1 counter

Signals : cosmic ray
Trigger : coincidence of T1 and T2 counter.

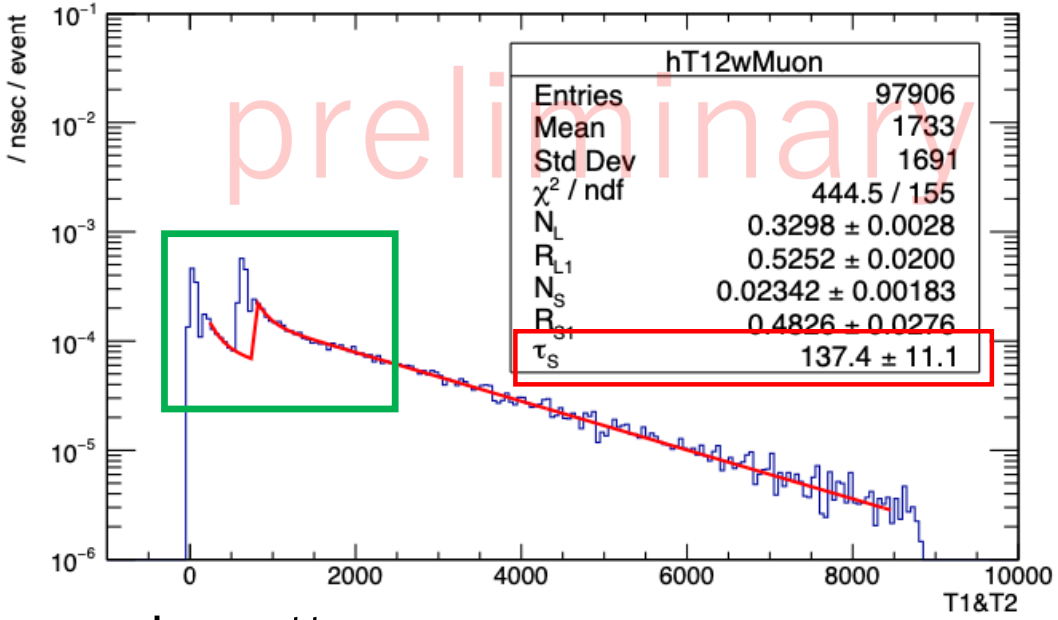


Preliminary analysis results

Absorber：Aluminum



Absorber：Copper

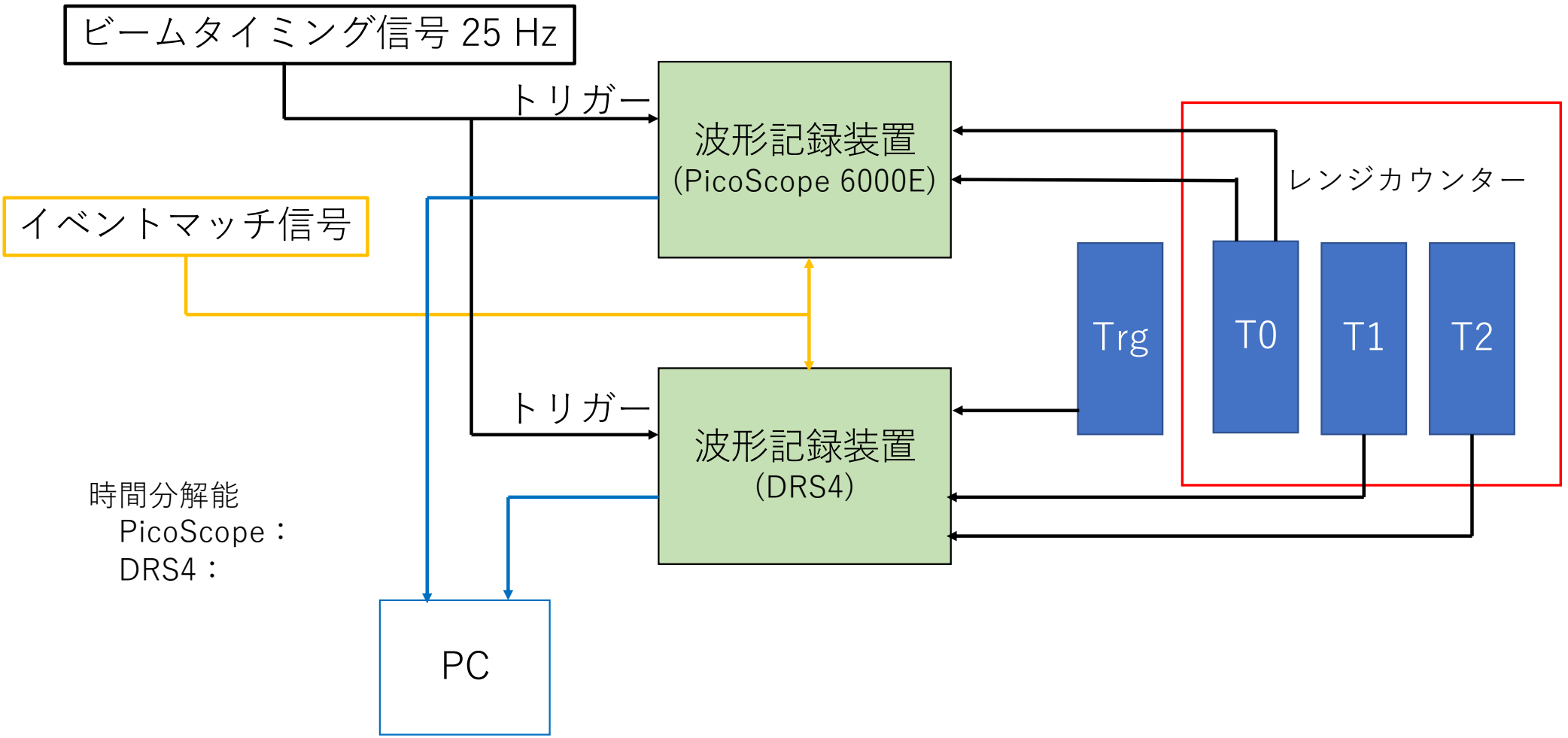


Lifetime of muons in matter

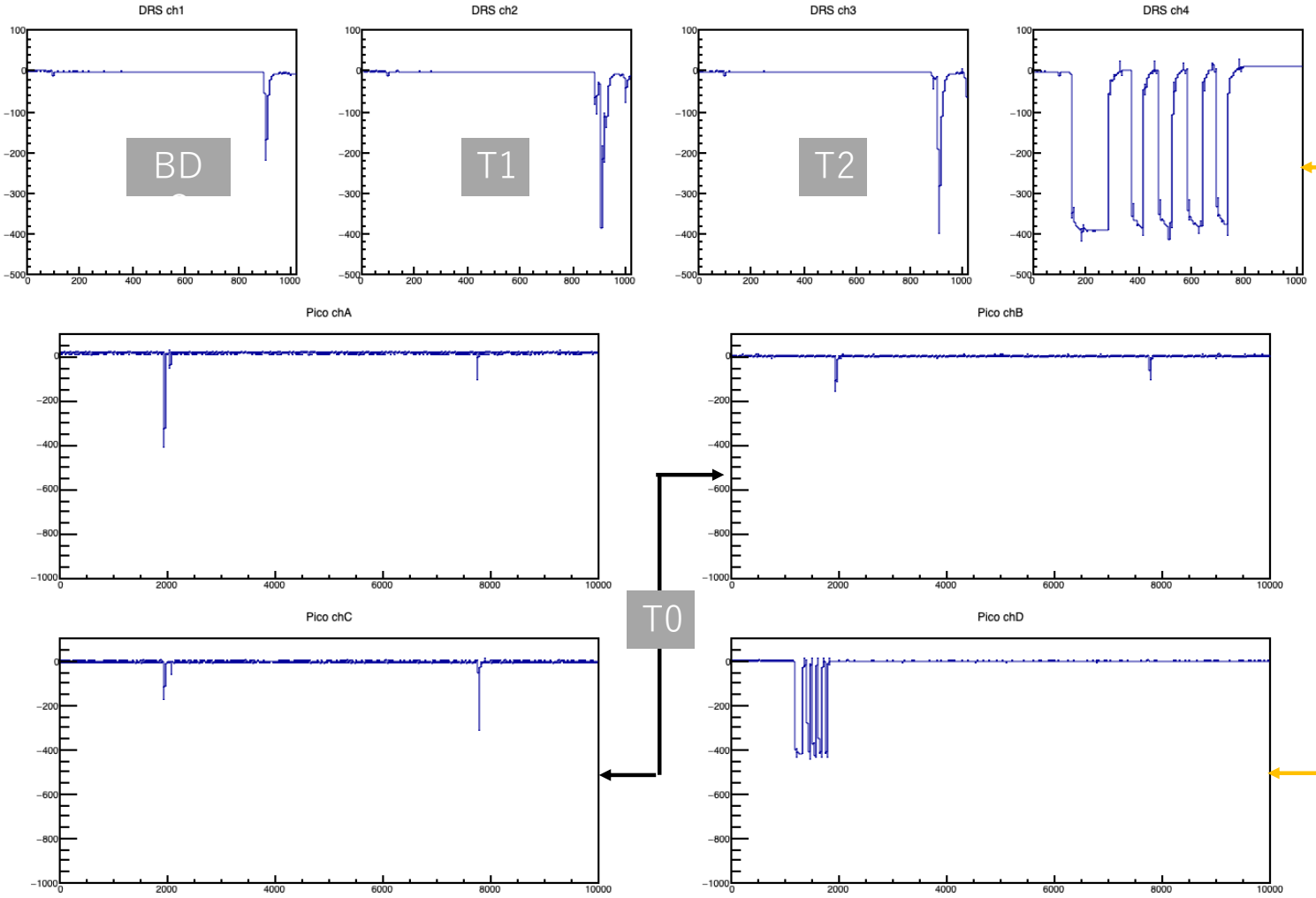
matter	aluminum	copper
Literature(ns)	864	160
Reconstruction(ns)	856	137

➡ Lifetimes of muons in the reconstructed atoms were close to literature values.

読み出し（略図）


ビームタイミング信号 25 Hz
トリガー
波形記録装置
(PicoScope 6000E)
イベントマッチ信号
レンジカウンター
Trg
T0
T1
T2
トリガー
波形記録装置
(DRS4)
時間分解能
PicoScope：
DRS4：
PC

読み出し信号


DRS ch1
DRS ch2
DRS ch3
DRS ch4
BD
T1
T2
Pico chA
Pico chB
Pico chC
Pico chD
T0
イベントマッチ信号