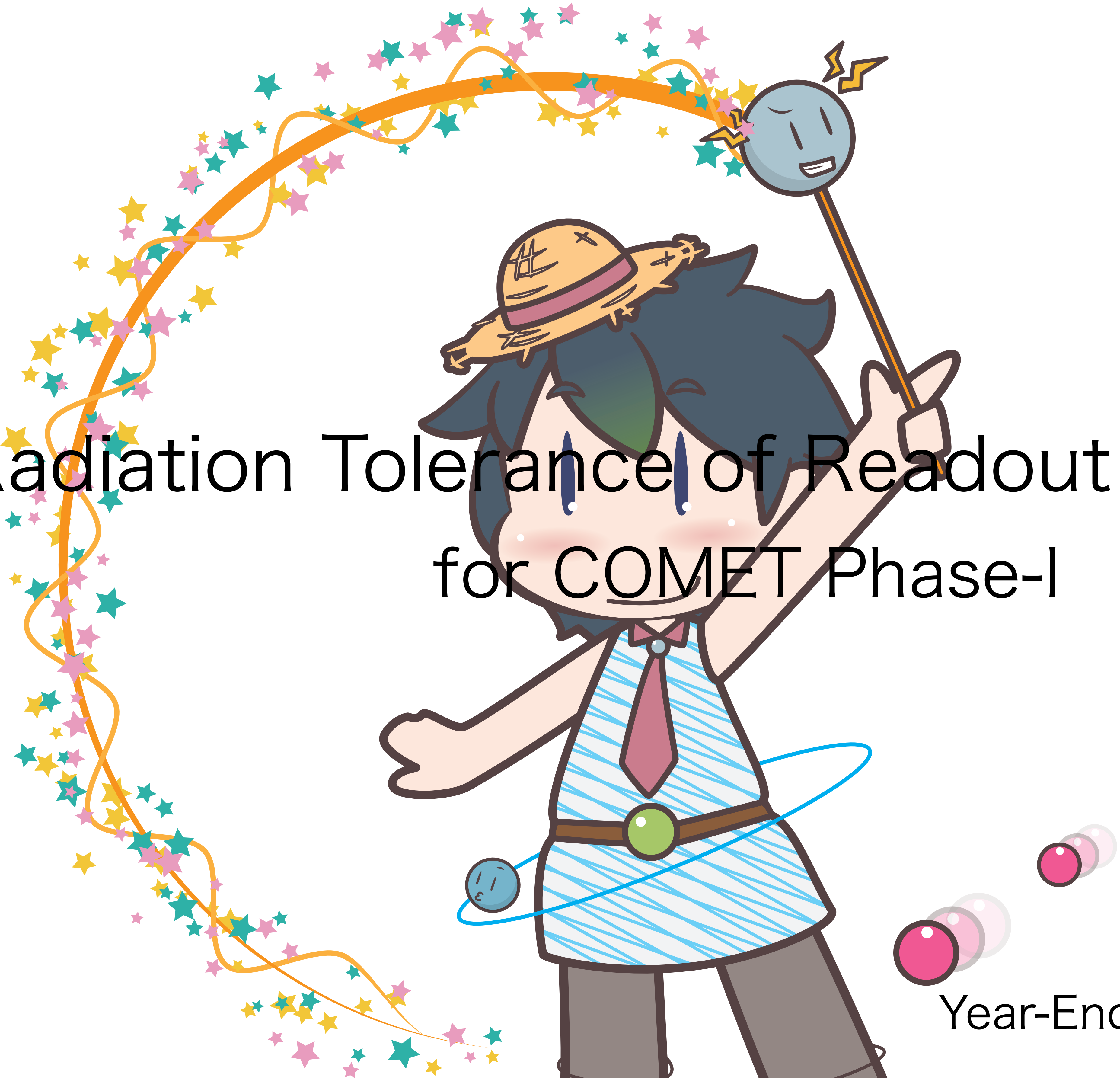
Radiation Tolerance of Readout Electronics for COMET Phase-I



COMETちゃん

Year-End Presentation 2017
2017.12.28
Yu Nakazawa

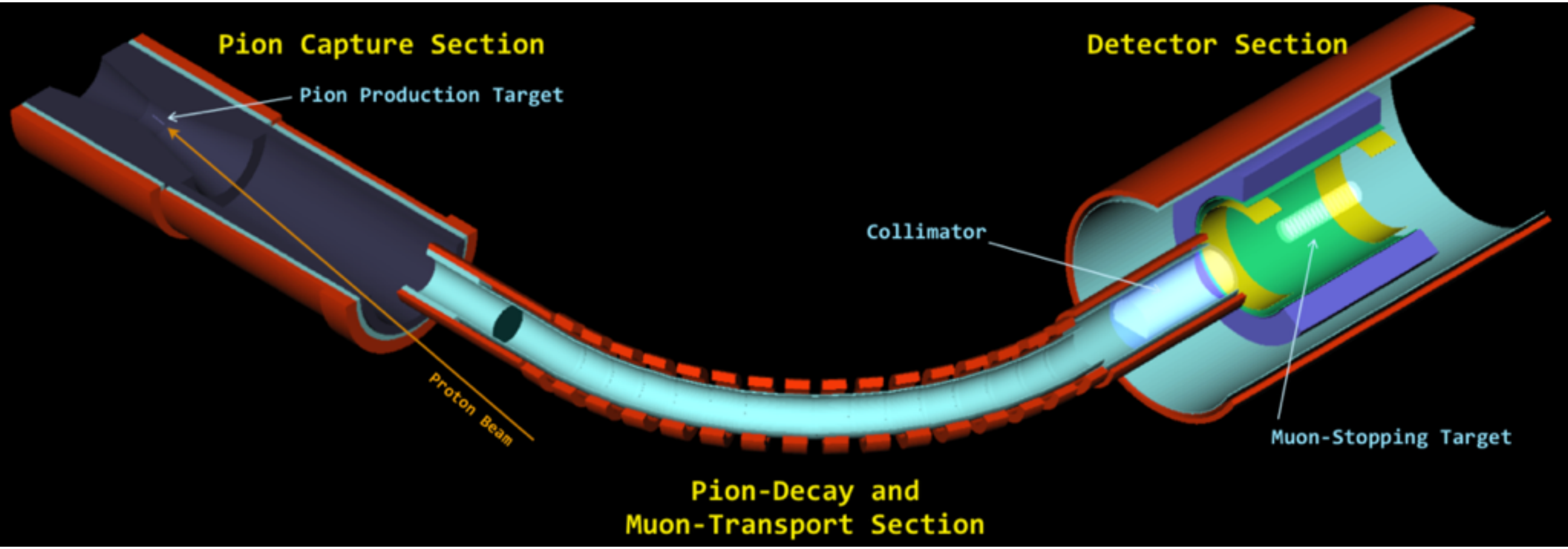
Main topic

- **The selection of rad-hard parts is more difficult and harder than I thought.**
  - The cost of rad-hard part is generally 10 ~ 100 times higher than normal one.
    - Regulator : ~10万円
    - FPGA : ~100万円

Outline

- Introduction
  - COMET Phase-I
  - Radiation Issue
- Gamma Ray Irradiation Test
  - Radiation effect
  - Setup
  - Result
- Summary

COMET Phase-I



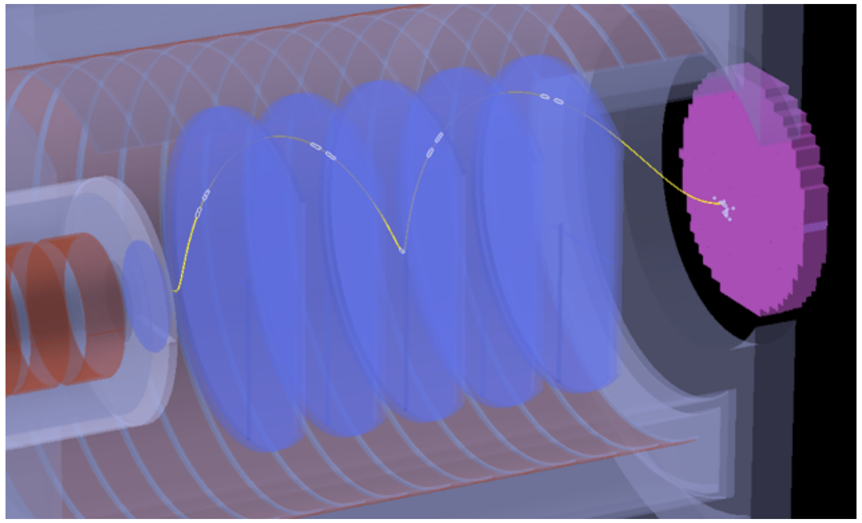
Purpose : Search for neutrino-less muon to electron conversion in a muonic aluminum

- @J-PARC in JFY2018/2019
- S.E.S. ~ 3×10^{-15} for 200 days

Detector system : Cylindrical Detector System & StrEcal

Signal : ~105 MeV/c electron for an aluminum target

Background : Decay-In-Orbit electron & Beam related BG
(muon three body decay)



StrEcal

Cylindrical Detector System

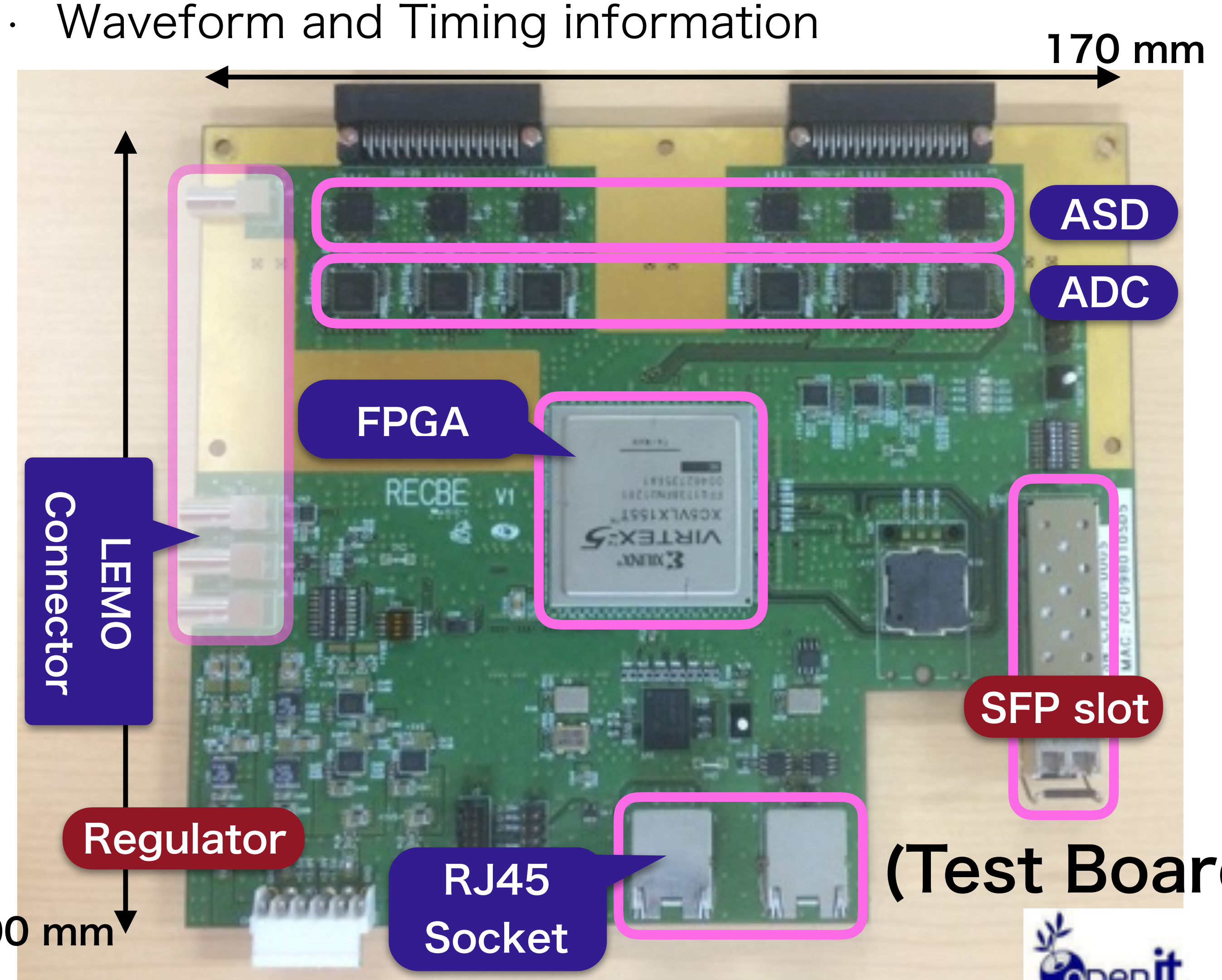
Cylindrical Drift Chamber

Momentum measurement

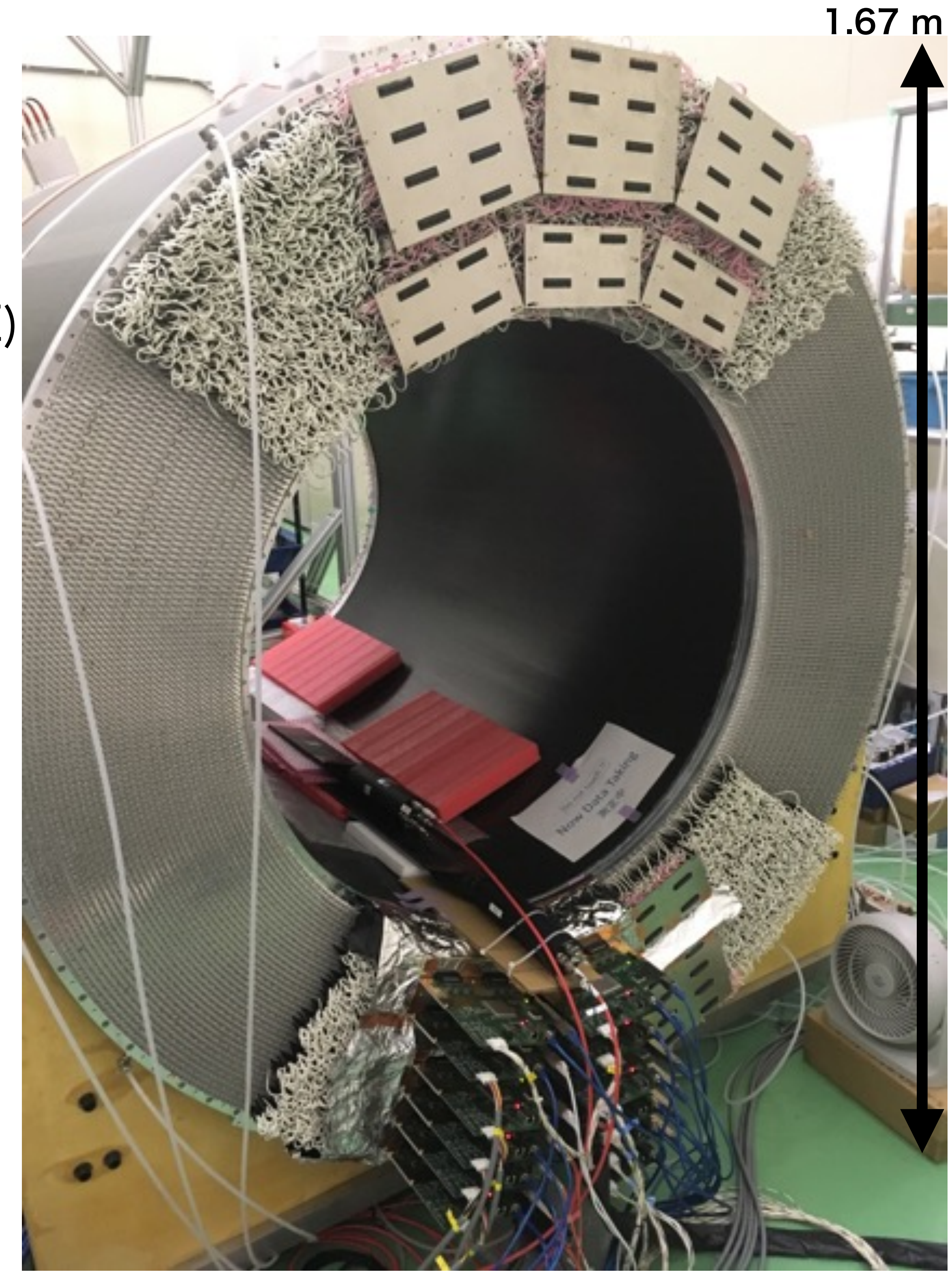
- Resolution : < 200 keV/c for 105 MeV electrons

Readout : Readout Electronics for the Central drift chamber of the BElle II detector (RECBE)

- Developed by the Belle-II CDC group
- Waveform and Timing information



(Test Board)



Cylindrical Detector System

Cylindrical Trigger Hodoscope

Counter

Scintillator : High momentum particle

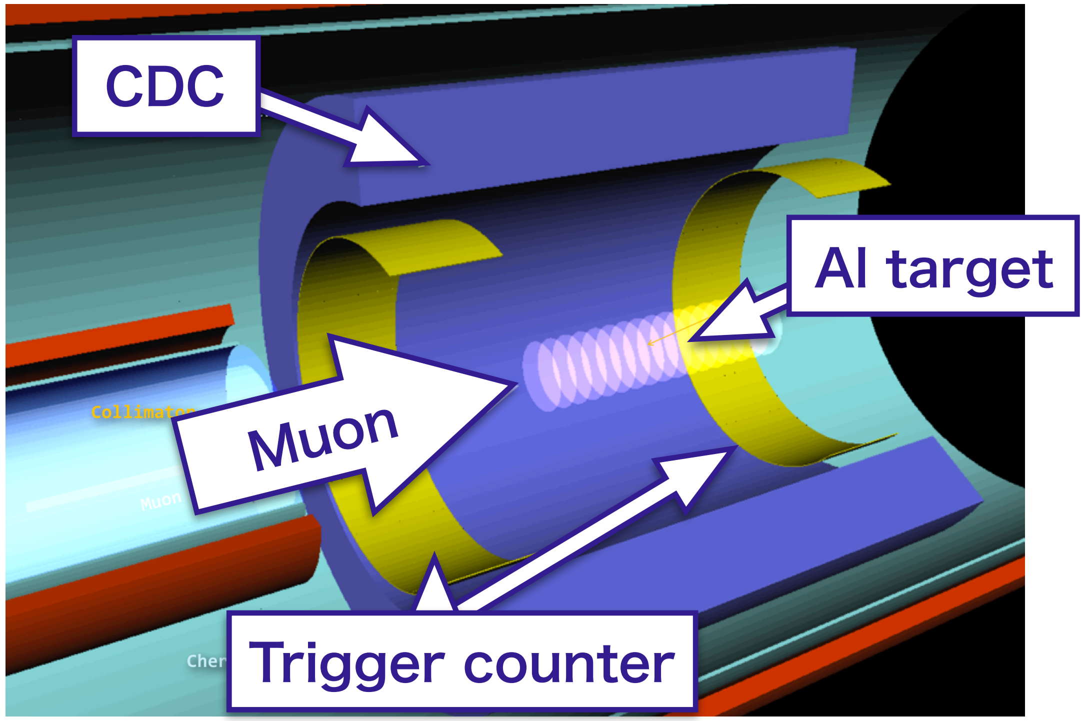
Cherenkov : Electron

Photo sensor : Fine-mesh PMT

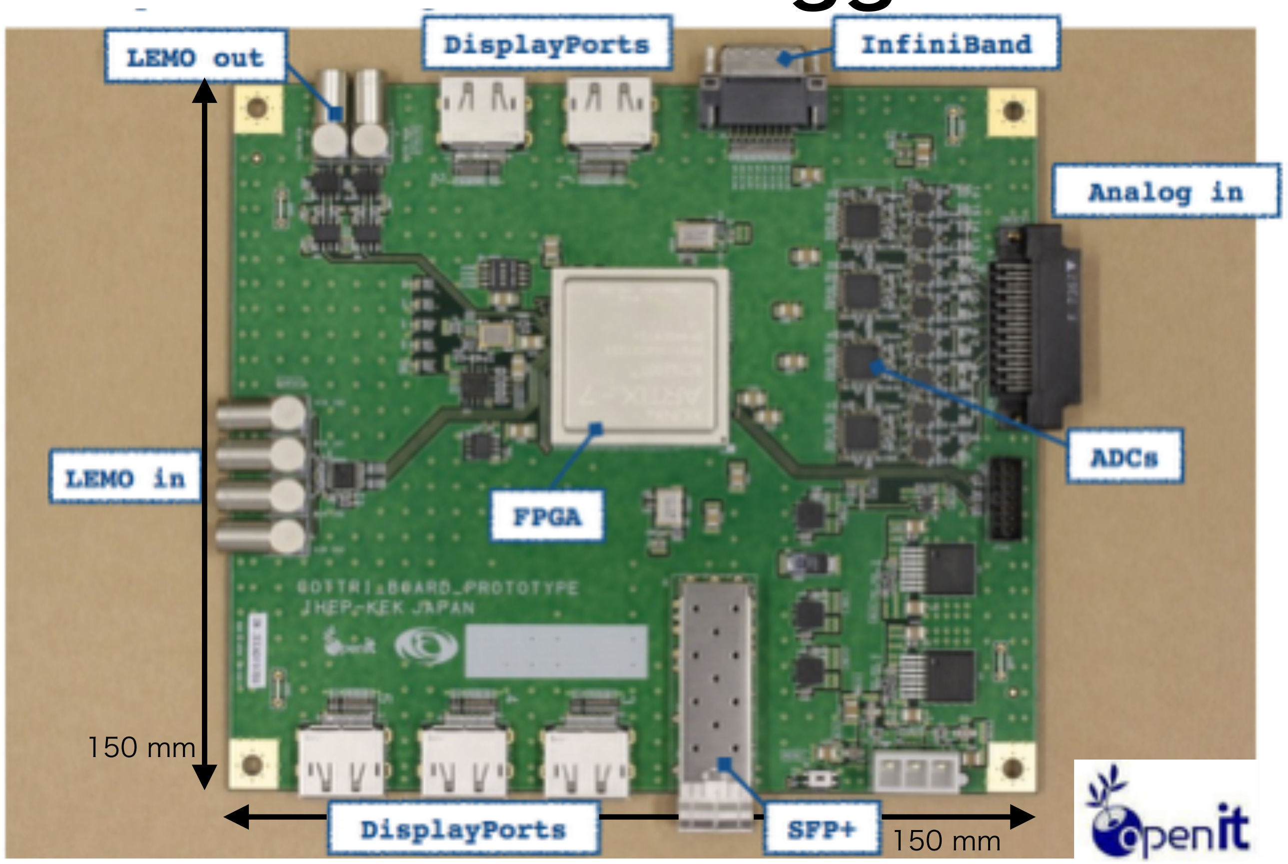
Readout

Front-end Board : Single-end to Differential

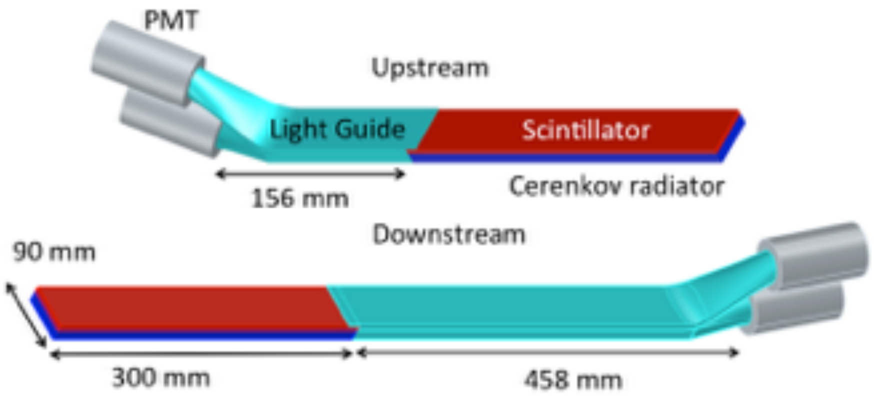
COTTRI : CTH signal processing、Trigger decision



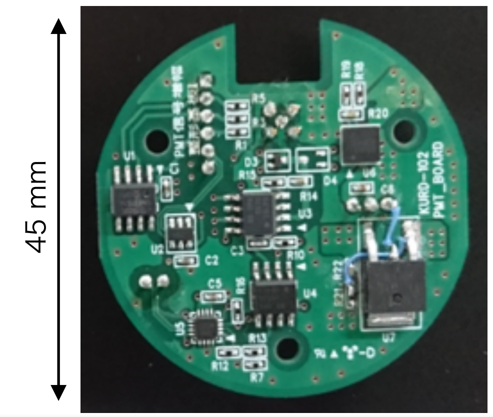
COmeT TRIgger



Cylindrical Trigger Hodoscope



Front-end Board



StrECAL

Straw Tube Tracker

Momentum measurement

- Resolution : < 200 keV/c for 105 MeV electrons

Readout : Read Out Electronics for Straw Tube Instrument (ROESTI)

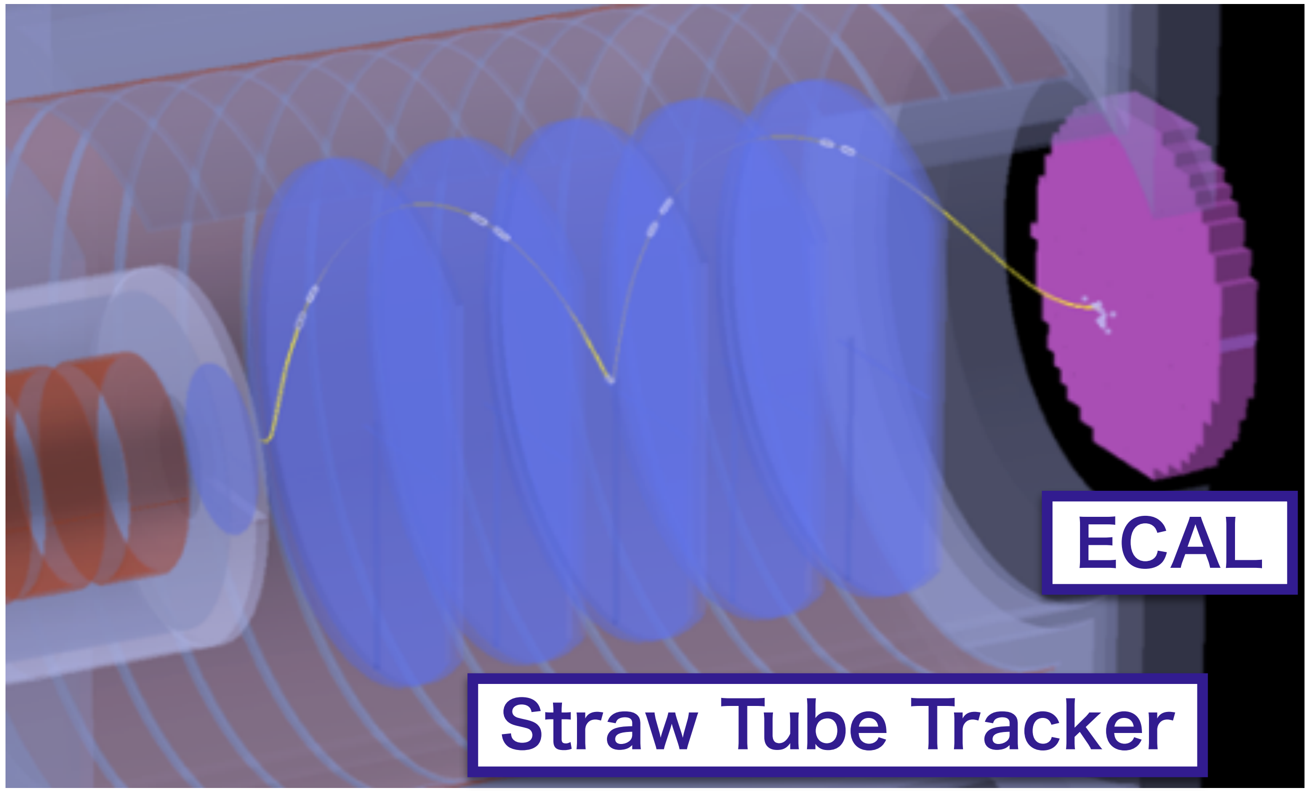
- Developed by the COMET StrECAL group

Electron Calorimeter

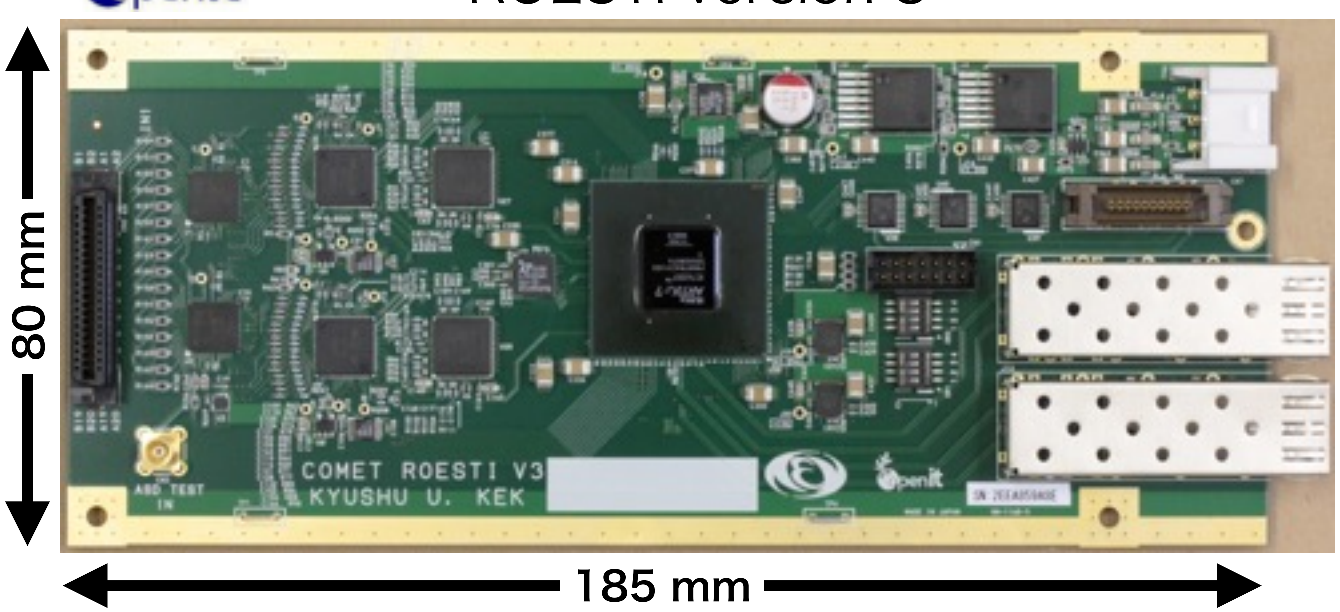
Crystal : LYSO

- Particle identification (e/μ/π)

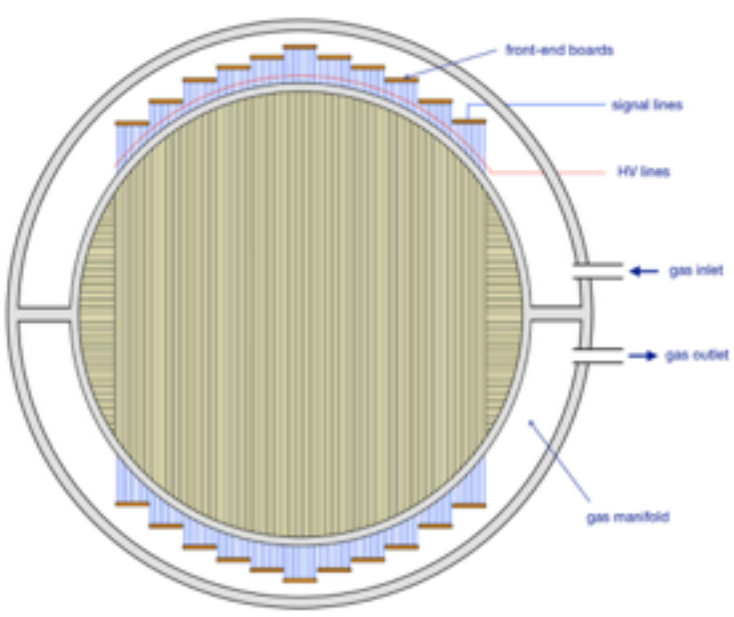
Readout : ROESTI



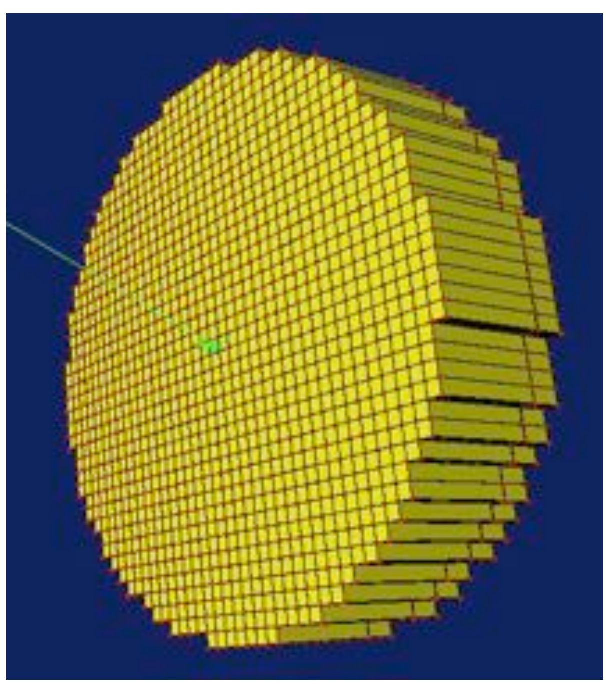
ROESTI version 3



Straw Tube Tracker

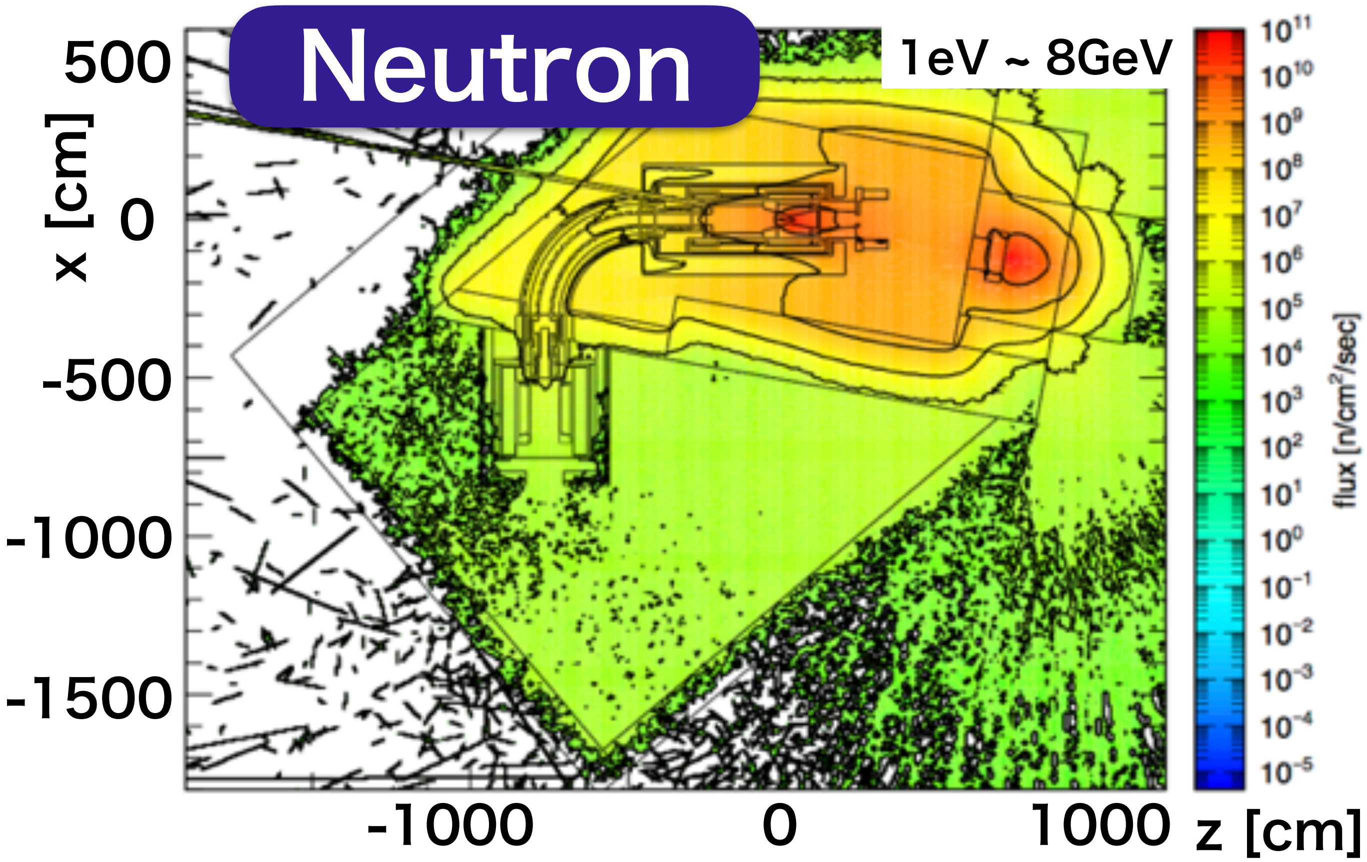


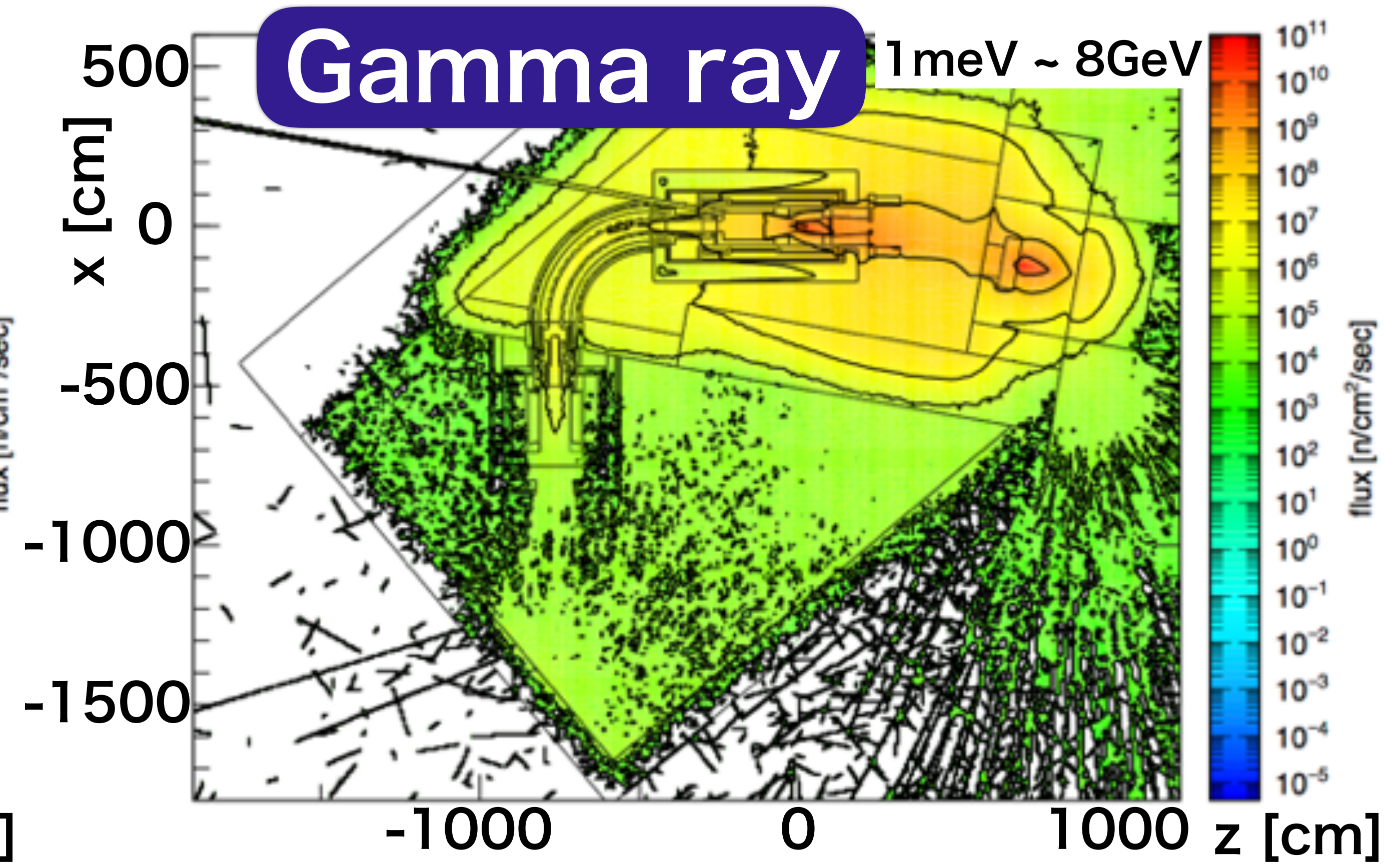
Electron Calorimeter



Radiation level

PHITS Simulation for COMET Phase-I





Requirement for 200 days （∗） Safety factor : 10

- **Gamma ray : ~2 kGy**
- Neutron : ~10^{12} neutrons/cm^2 (1 MeVeq.)
- (B-filed : 1 T)

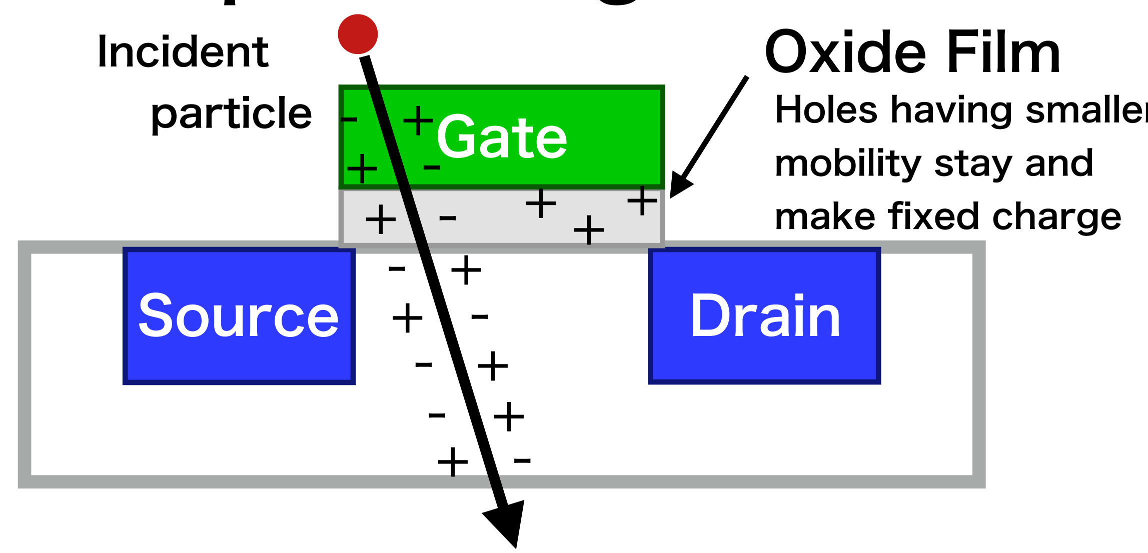
The parts selection for the readout electronics is ongoing!!

Gamma Ray Irradiation Test

Radiation effect of gamma ray

- Deterioration of semiconductor device
  - **Total Ionizing Dose (TID)**
    - Due to many radiations, ionizing effects occur and fixed charge is generated.
    - Degradation of specific and permanent damage
  - **Displacement Damage Dose (DDD)**
    - Due to a radiation, an atom of semiconductor is displaced.
- Gamma ray Irradiation Test (2017)
  - 4 irradiation tests were done.
    - SFP (AFBR57D9AMZ)
    - Regulators
  - The RECBE board was already studied by the Belle-II group. (~1 kGy)

Conceptual diagram of TID



Evaluation item (Regulator)

Positive		Negative
Linear	Switching	Linear
LT1963	LMZ10503	MC7905
LT1963-3.3	LTM4620	LM337
LT1963-2.5	LTM4644	L79
LT1963-1.8		TC59
LT3070		MIC5271
LT1764A		NJM2828
MAX8556		ADP7182
LTC3026		

(＊) Total : 18 types

Setup

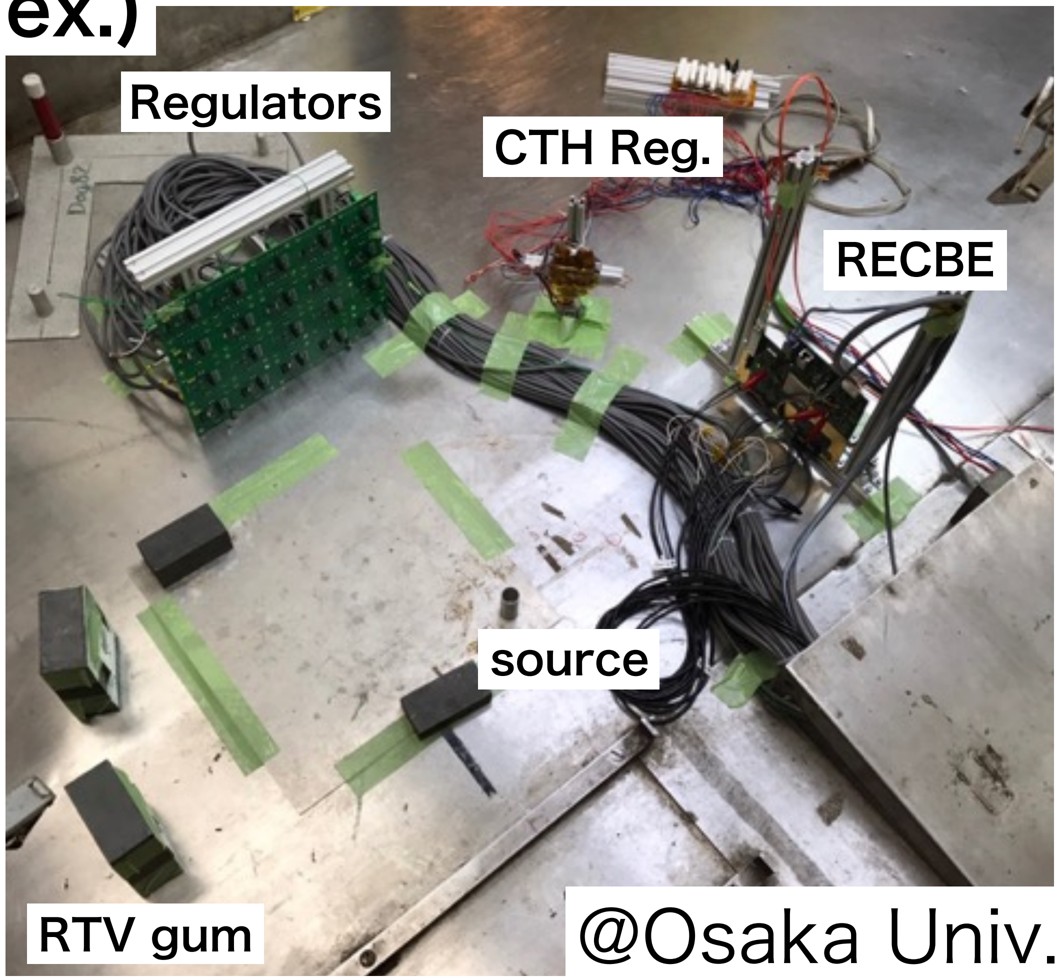
Institute

- The Institute of Scientific and Industrial Research @Osaka Univ. (1000 ¥/hour)
- Tokyo Institute of Technology Radioisotope Research Center (free)

Source : ^{60}Co

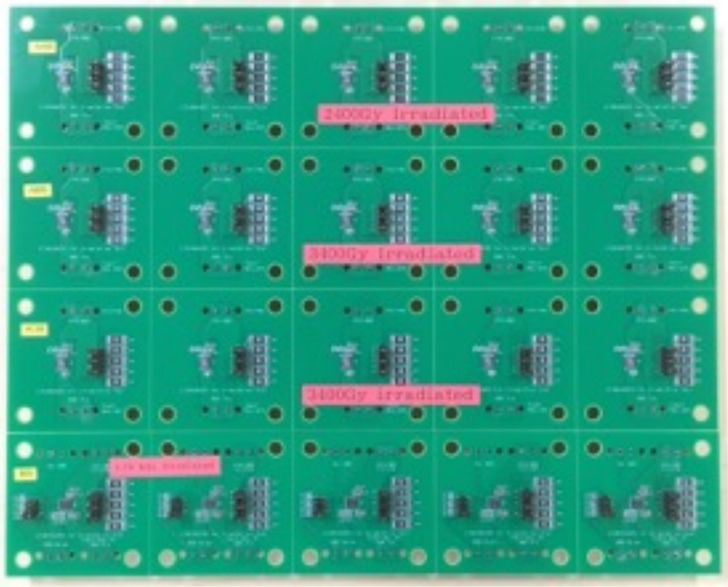
Energy : 1.17 MeV, 1.33 MeV

ex.)

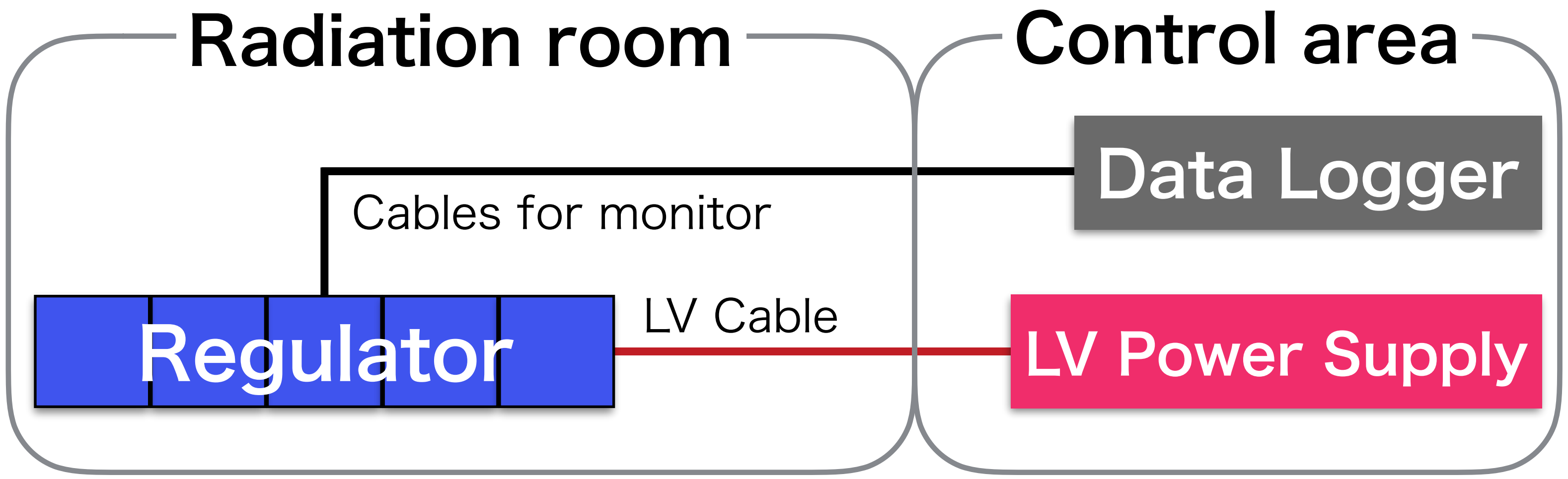


@Osaka Univ.

Regulator Test Board



SFP Test Board

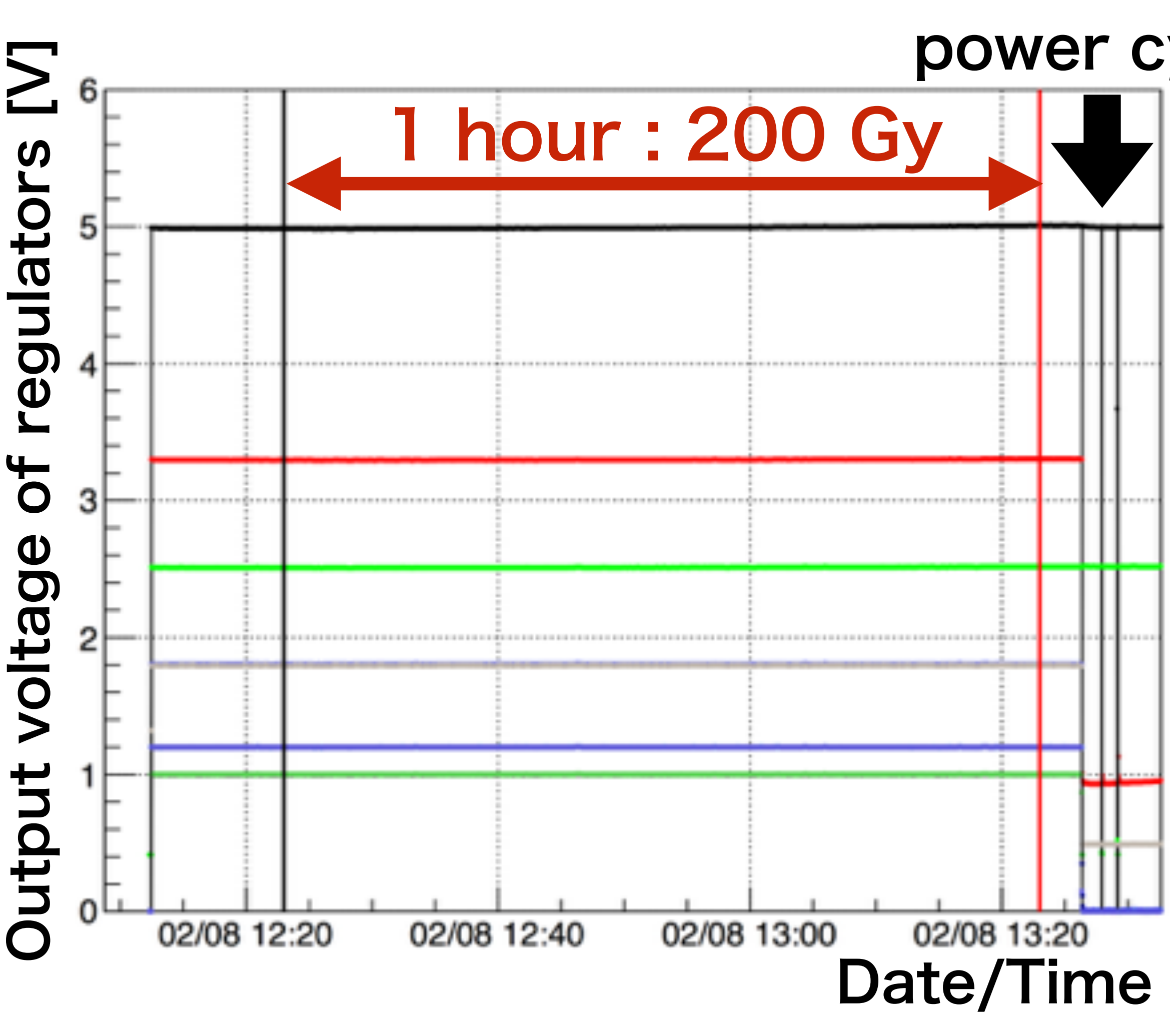


(with taking data from RECBE)

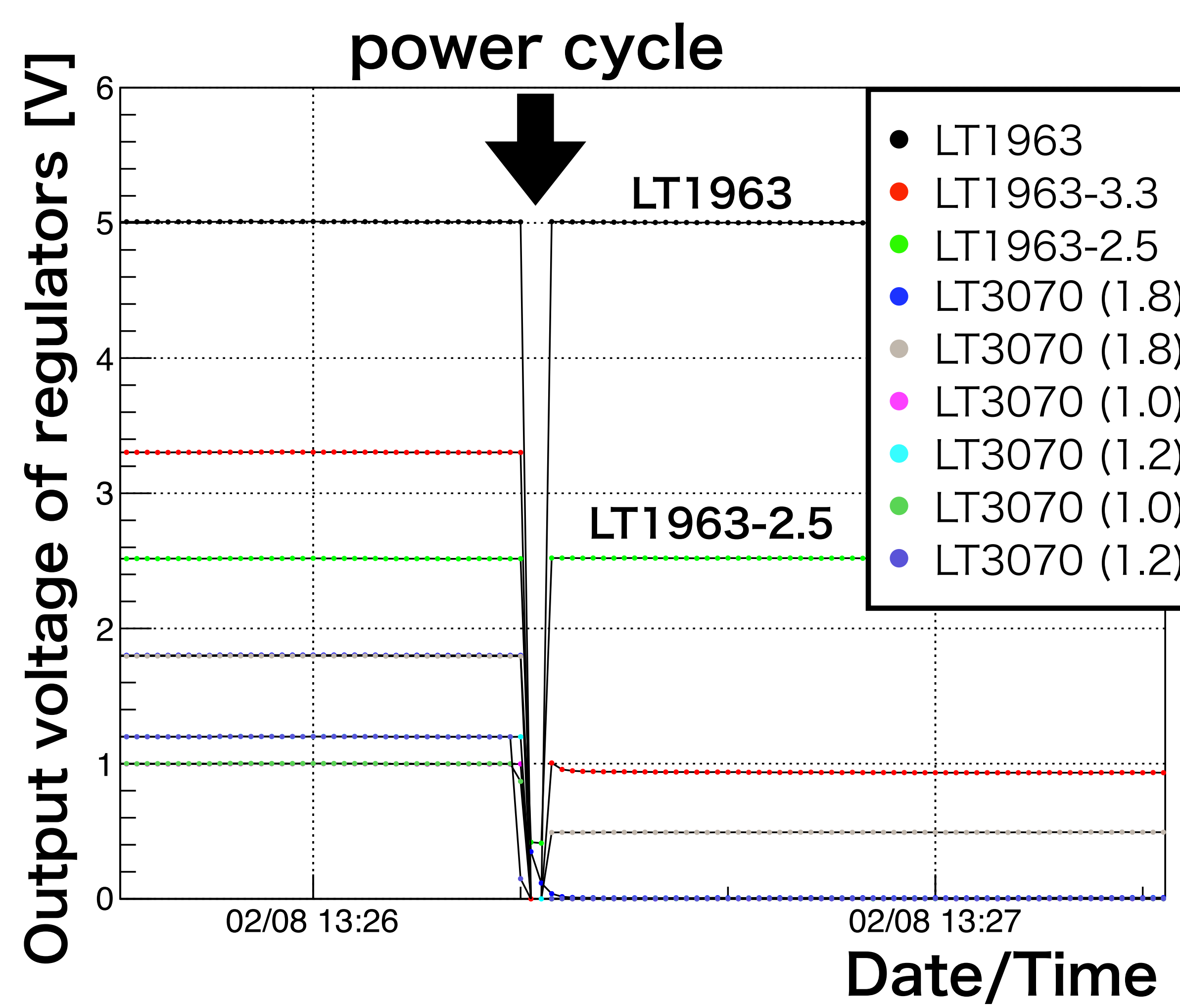
1st Irradiation Test

Dose rate : 200 Gy/h
2/7 @Osaka Univ.

- **Motivation** : SFP test for RECBE
- **Target** : SFP with RECBE (test board)×2
- **Result** : All LT3070s & LT1963-3.3 seemed to be dead after power cycle.
- **Study** : When the BIAS pins of LT3070s were applied 3.3 V, the RECBE boards worked.
  - The LT1963-3.3 chip applies 3.3 V to all LT3070s. → **LT1963-3.3s were dead.**
  - The SFP was survive. → **We could not achieve our goal.**



Zoom



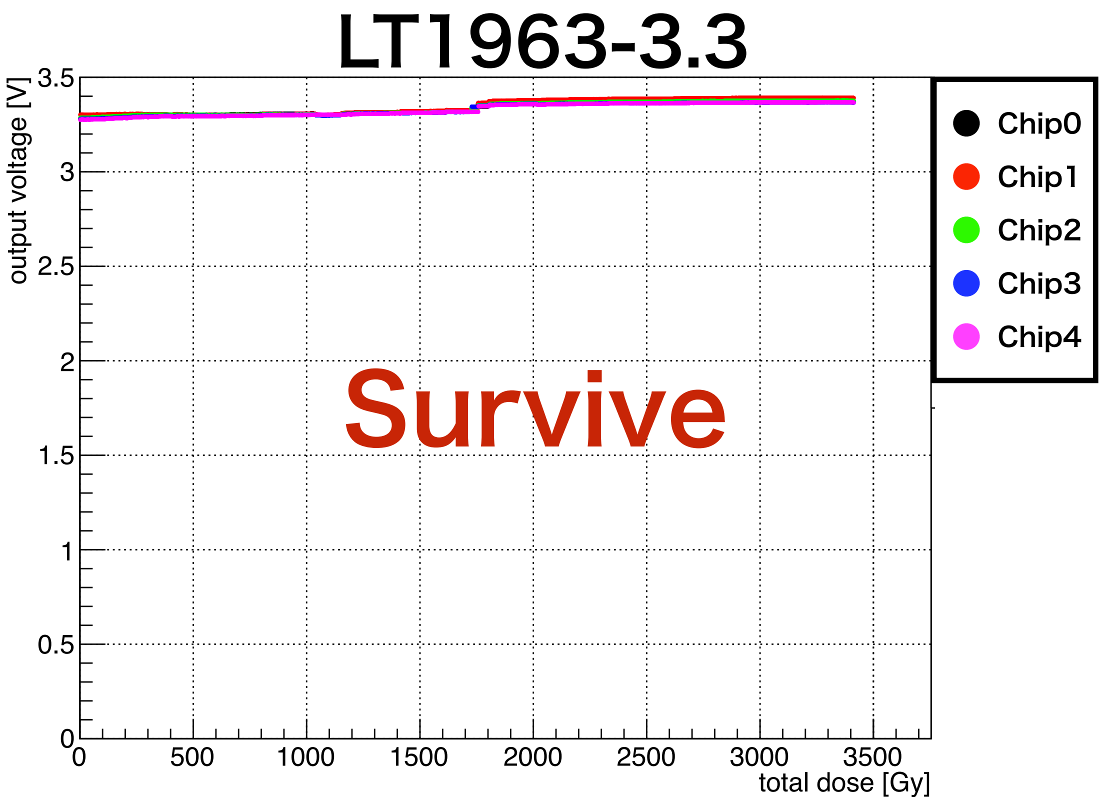
2nd Irradiation Test

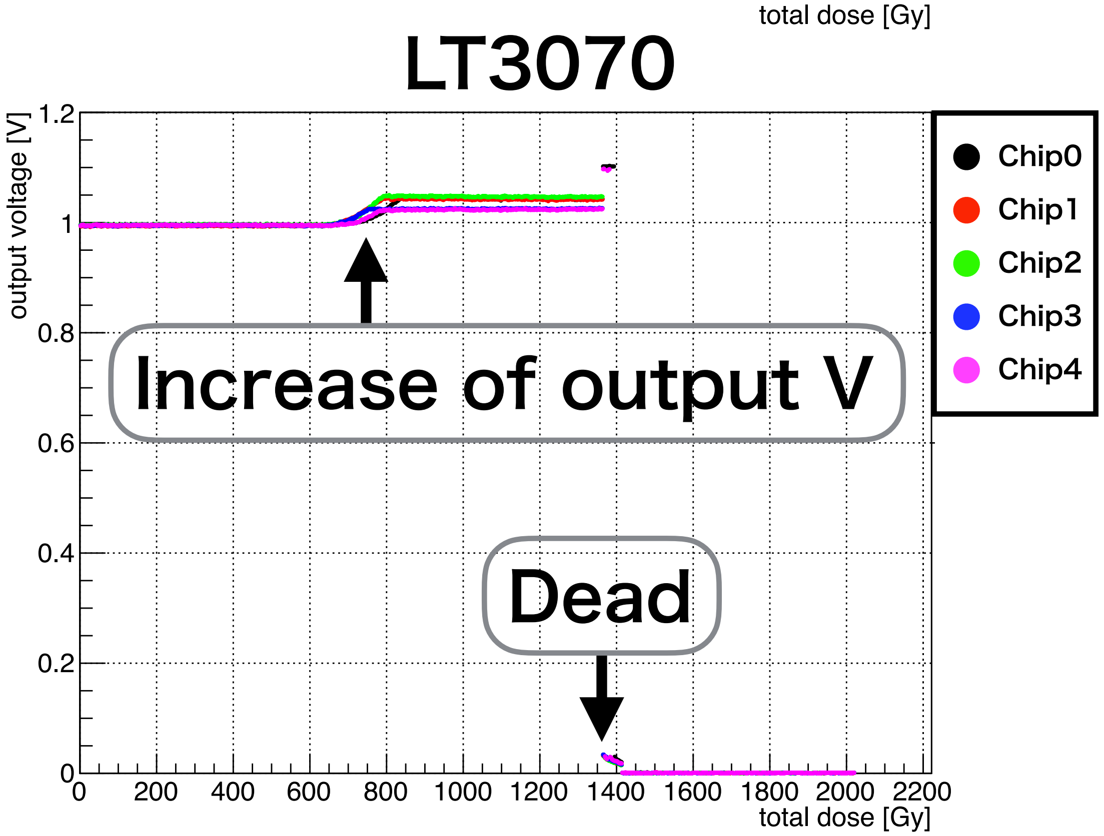
Dose rate : 200 Gy/h
8/1 - 8/4 @Osaka Univ.

- **Motivation** : Regulator test
- **Target** : 10 types of regulators
- **Power cycle** : every 200 Gy

Result

Target	Tolerance [kGy]
LT1963	> 2.4
LT1963-3.3	> 3.4
LT1963-2.5	> 3.4
LT1963-1.8	> 3.4
LT3070	1.4
LT1764A	0.6 ?
MAX8556	0.4
LMZ10503	0.4
LTM4620	0.3
LTM4644	1.7





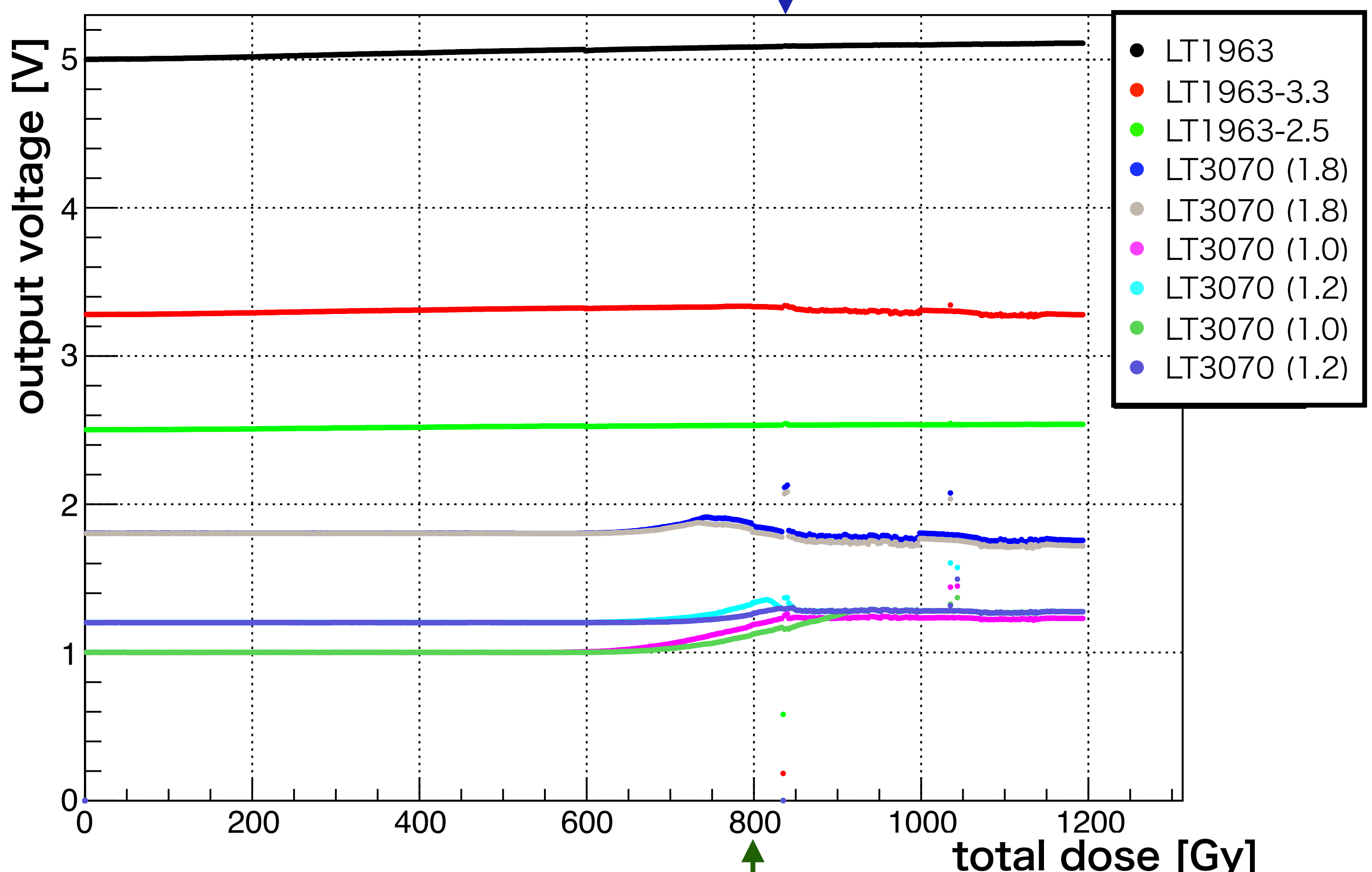
Many regulators couldn't satisfy the requirement.

2nd Irradiation Test

Dose rate : 200 Gy/h
8/1 - 8/4 @Osaka Univ.

- **Target** : RECBE×1, SFP (AFBR-57D9AMZ)×1
- **Power cycle** : every 200 Gy
- **Result**
  - **SFP** : Dead (0.8 kGy)
  - **RECBE (Consistent with Belle II)**
    - **Regulators** : the same result as chip tests
    - **ADC** : Strange waveform data (~0.85 kGy)
- **Study**
  - VCCINT of FPGA is applied 1 V (LT3070)
    - VCCINT : Internal power supply of FPGA
    - Absolute Maximum Rating : -0.5 ~ 1.1 V
  - **After 800 Gy, the FPGA might be unstable due to high applied voltage.**
  - The ADC data became correct after replacing LT3070.

ADC is "0000"



After power cycle, connection error was happened.
By replacing SFP, this problem was solved. (0.8 kGy)

This result was different with the previous one.
Lot dependence??

Dose rate dependence ?

Gamma irradiation results for the Linear Technologies **LTM4619**. The results are arranged in descending order by dose rate, and enhanced tolerance to ionizing radiation is evident at lower rates

annealing?

Sample	Rate (Gray/Hr)	Dose at Failure (Gray)
1	50	300[1]
2	22	1800[2]
3	22	2300[2]
4	16	2000[1]
5	5	$\geq$ 4000[2]

[2] ENEA Calliope

[1] Brookhaven SSIF

ref. “Radiation-hard power electronics for the ATLAS New Small Wheel”, TOPICAL WORKSHOP ON ELECTRONICS FOR PARTICLE PHYSICS 2014

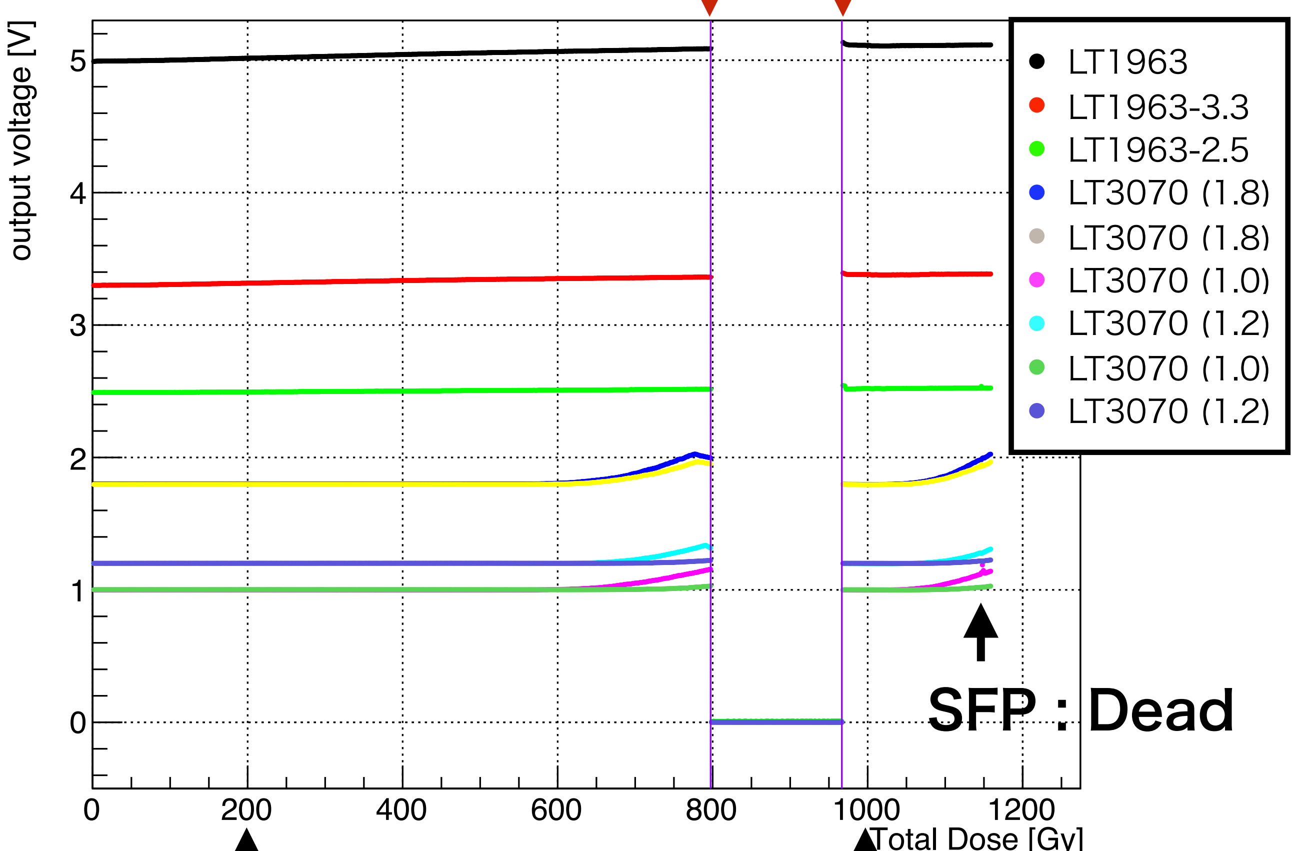
Dose rate in COMET Phase-I : ~0.04 Gy/h

3rd Irradiation Test

Dose rate : 40 Gy/h
8/22 - 8/23 @Osaka Univ.

- **Motivation** : Dose rate dependence
- **Target** : RECBE×3, SFP (AFBR5D9AMZ)×3, LT3070×5, LMZ10503×5
- **Result** : After 700 Gy irradiation, the outputs of LT3070s were sightly increased.
  LMZ10503s were dead after 0.8 kGy irradiation.
  - Doe to the instantaneous power failure with good timing, this result could not be really compared with other results.

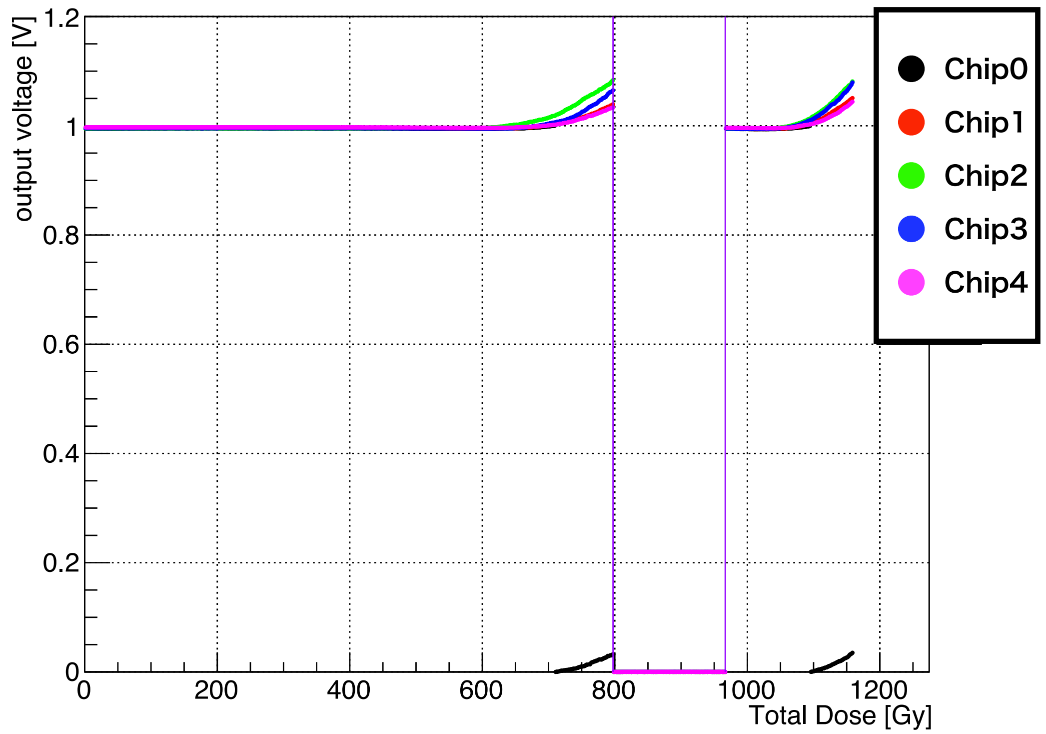
Instantaneous power failure
Power on



SFP : Dead

power cycle
power cycle

LT3070



Chip0 was only dead at 0.7 kGy.
The cause is unknown.

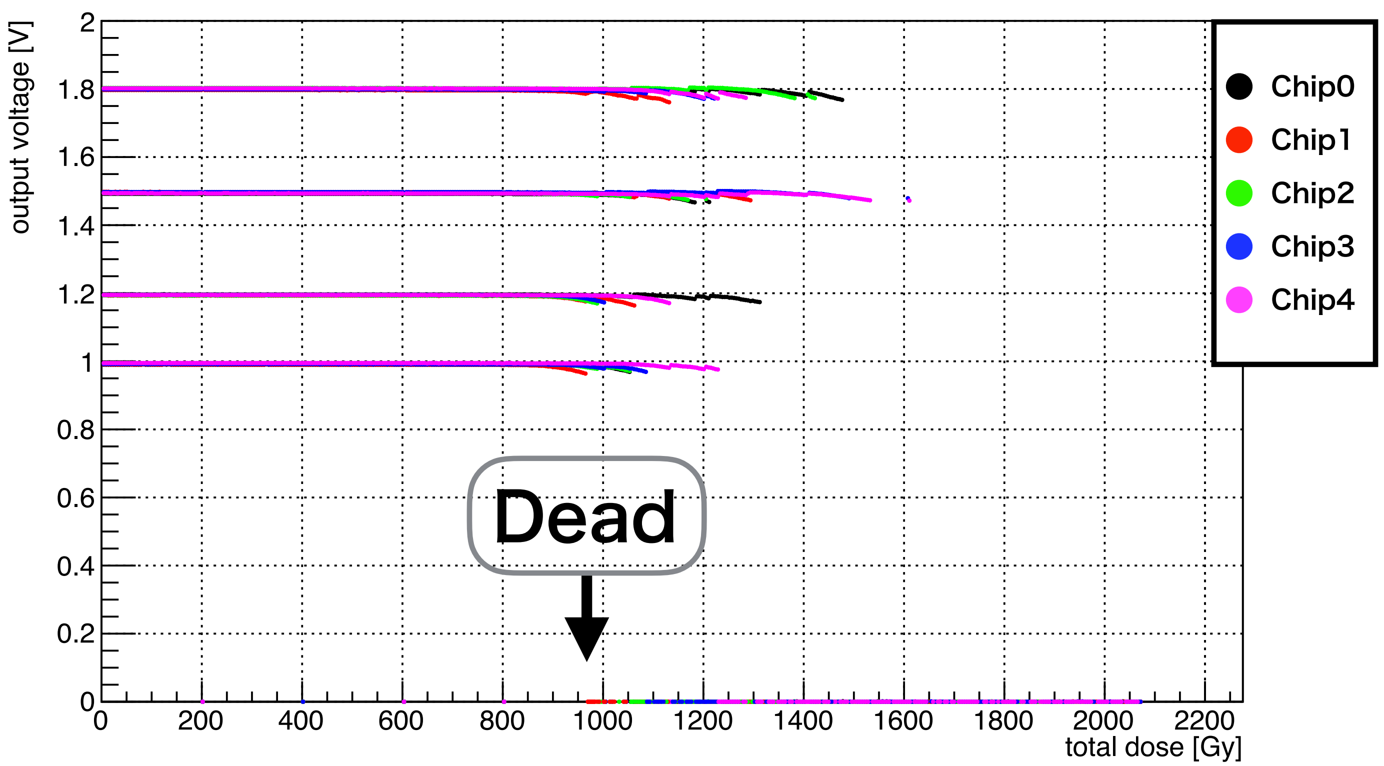
4th Irradiation Test

Dose rate : 4.5 Gy/h
11/21 - 12/12 @TIT

Preliminary

- **Motivation** : We hoped to conclude the Rad-hard study.
  - Dose rate dependence
- **Target** : RECBE×1,
  SFP (AFBR5D9AMZ)×5,
  12 types of regulators (×5)
- **Power cycle** : every 200 Gy
- **Result :** SFPs were dead at ~1.1 kGy

LTM4644 (4 outputs regulator)



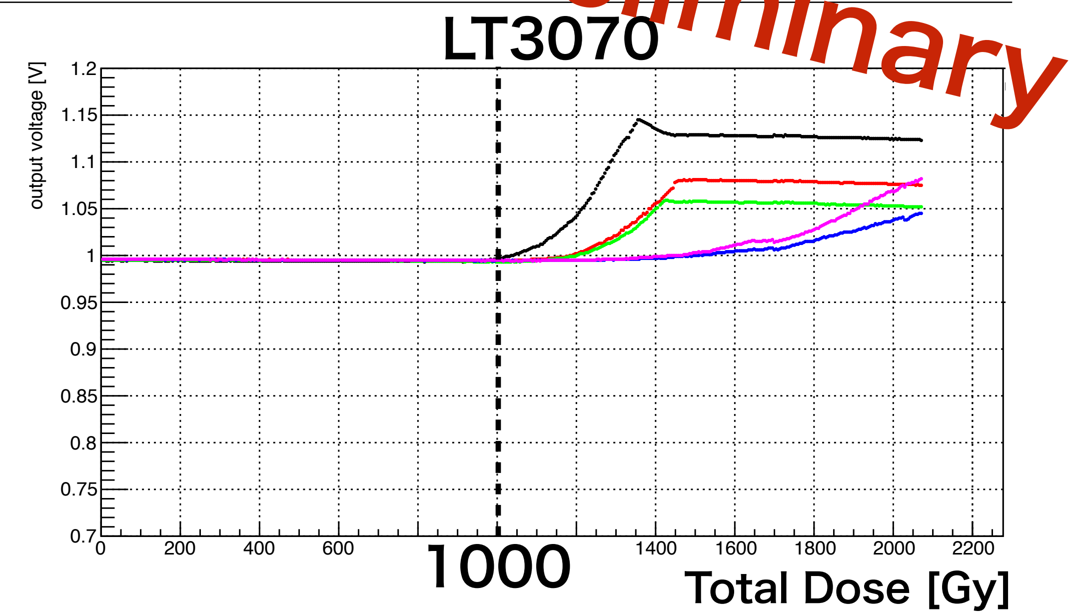
Result

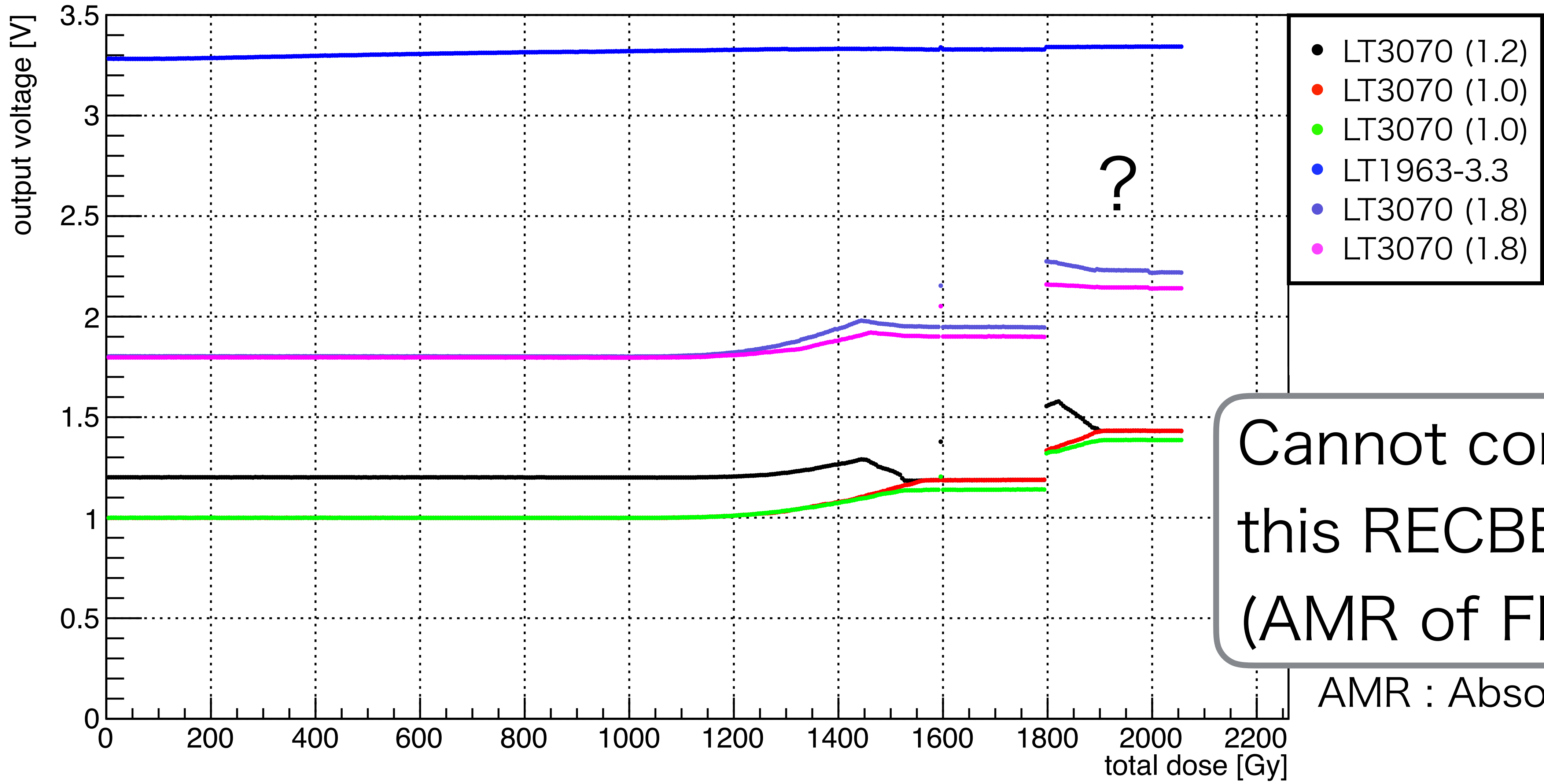
Target	Tolerance [kGy]
LT1963-1.8	> 2.0
LT3070	> 2.0
LTC3026	> 2.0 ??
LMZ10503	0.8
LTM4644	< 1.1
MC7905	> 2.0
LM337	0.4
L79	> 2.0
TC59	< 0.1
MIC5271	< 0.1
NJM2828	> 2.0 ??
ADP7182	2.0

4th Irradiation Test

Dose rate : 4.5 Gy/h
11/21 - 12/12 @TIT

- **Target** : RECBE (LT3070)
- **Power cycle** : every 200 Gy
- **Result** : Dead at 1.8 kGy power cycle
  - The data from RECBE was correct until 1.8 kGy.
  - This result is better than the previous one.





Cannot connect with this RECBE board (AMR of FPGA < 1.1V)

AMR : Absolute Maximum Rating

4th Irradiation Test

Dose rate : 4.5 Gy/h
11/21 - 12/12 @TIT

- We found 2 candidates for negative regulators.

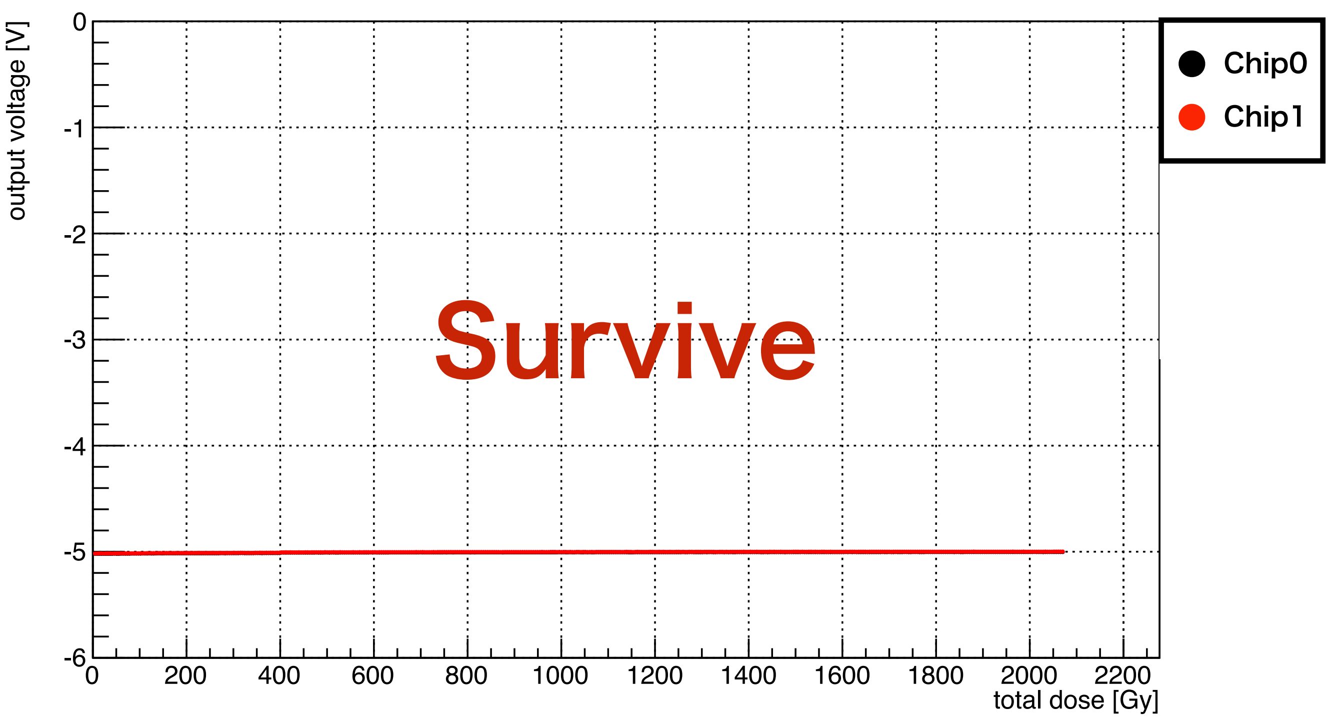
 2 kGy : pass

 10^{12} n/cm^2 : pass

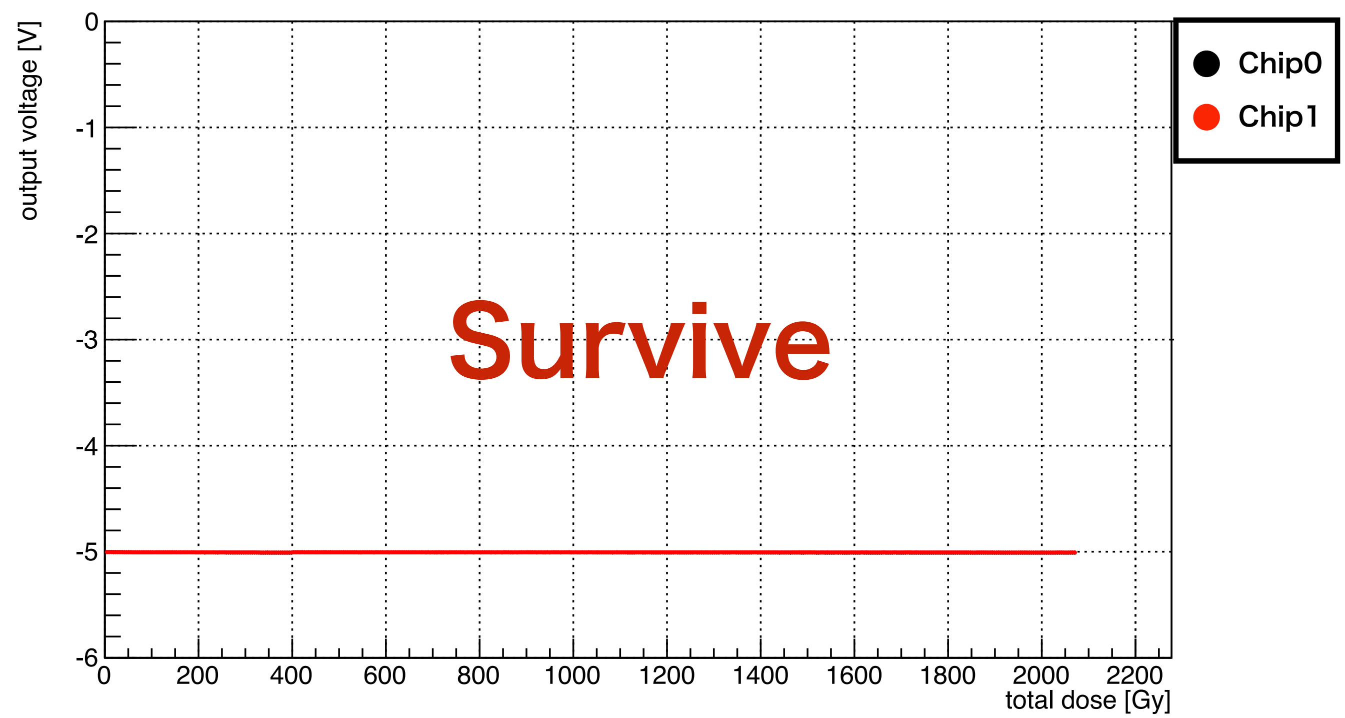
 1 T B-field : pass

Goooooood news!!!! for COMET :-)

L79



MC7905



Summary

- The radiation environment of COMET Phase-I is very severe.
- **The method of rad-hard study is very simple, but it is so hard.**
- Result
  - The dose rate dependence seems to be observed only for regulator.
  - (I hope) RECBE might be survive after 2.0 kGy irradiation with 0.04 Gy/h.
    - γ-ray tolerance with 4.5 Gy/h : 1.8 kGy
  - 2 candidates of negative regulators which passed all of tests were found.
- The rad-hard study is still continued :-(

Open source consortium of Instrumentation

つづく

We start up a new project for sharing information of rad-hard study.

http://openit.kek.jp/project/RADHARD


高放射線環境対応技術の共有化

作者: New Project Proposer — 最終変更 2017年10月03日 07時29分 — 履歴

概要

高放射線環境対応技術やそれに関連するスタディについて情報共有等を行う。

メンバー

- 上野一樹, Ueno Kazuki(代表:KEK IPNS)
- 吉田学立, Yoshida Hisataka (大阪大)
- 中沢遊, Nakazawa Yu (大阪大)
- 内田智久, Uchida Tomohisa（KEK IPNS）
- 池野正弘, Ikeno Masahiro（KEK IPNS）
- 庄子正剛, Shoji Masayoshi（KEK IPNS）

Summary Table

Unit : kGy

* Including chips mounted on RECBEs

Type		Regulator	Output Vout [V]	Output Iout [A]	1st test 200 Gy/h	2nd test 200 Gy/h	3rd test 40 Gy/h	4th test 4.5 Gy/h
Positive	Linear	LT1963	1.5	0.73	> 0.2 (2/2)*	> 2.4 (5/5)	> 1.1 (3/3)	no monitor
Positive	Linear	LT1963 - 3.3	3.3	0.76	0.2 (2/2)*	> 3.4 (5/5)	> 1.1 (3/3)	> 2.0 (1/1)*
Positive	Linear	LT1963 - 2.5	2.5	0.75	> 0.2 (2/2)*	> 3.4 (5/5)	> 1.1 (3/3)	no monitor
Positive	Linear	LT1963 - 1.8	1.8	0.72		> 3.4 (5/5)		
Positive	Linear	LT3070	1.2	1.88	> 0.2	1.4 (5/5)	0.7 (1/23)*	> 2.0 ?
Positive	Linear	LT1764A	1.5	1.50		0.6 ? (5/5)		
Positive	Linear	MAX8556	1.0	1.88		0.4 (1/5)		
Positive	Linear	LTC3026	1.2	?				> 2.0 (1/1)
Positive	Switch-ing	LMZ10503	1.2	1.33		0.4 (5/5)	0.8 (5/5)	0.8 (5/5)
Positive	Switch-ing	LTM4620	1.0, 2.5	1.25, 0.50		0.3 (3/5)		
Positive	Switch-ing	LTM4644	1.0, 1.2, 1.5, 1.8	1.25, 0.80, 1.00, 0.58		1.7 (1/5)		< 1.1 (5/5)
Negative	Linear	MC7905	-5.0	?				> 2.0 (2/2)
Negative	Linear	LM337	-5.0	?				0.4 (2/2)
Negative	Linear	L79	-5.0	?				> 2.0 (2/2)
Negative	Linear	TC59	-5.0	?				< 0.1 (2/2)
Negative	Linear	MIC5271	-5.0	?				< 0.1 (2/2)
Negative	Linear	NJM2828	-5.0	?				> 2.0 ? (2/2)
Negative	Linear	ADP7182	-5.0	?				2.0 (2/2)

Backup

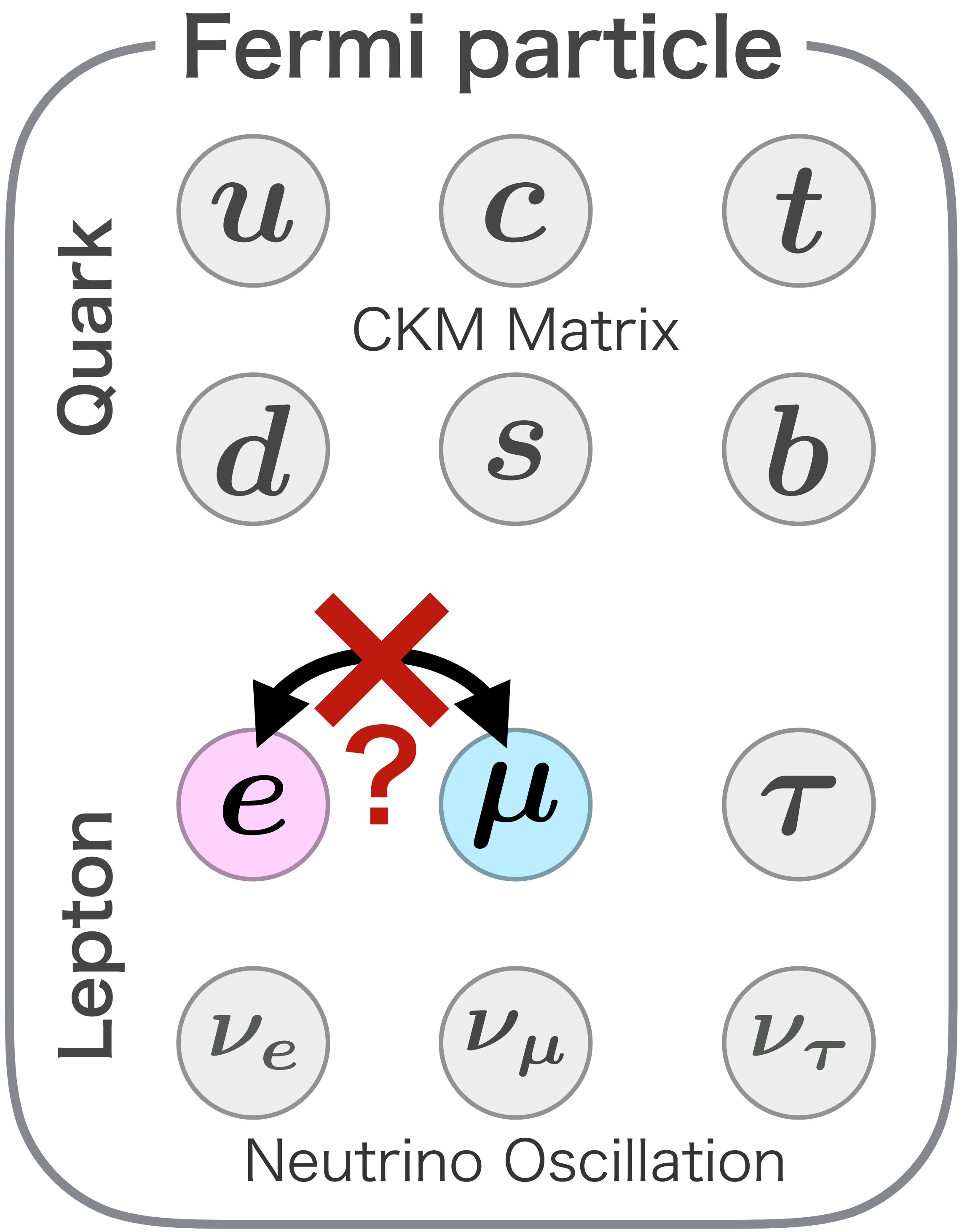
Radiation Tolerance of Readout Electronics for COMET Phase-I

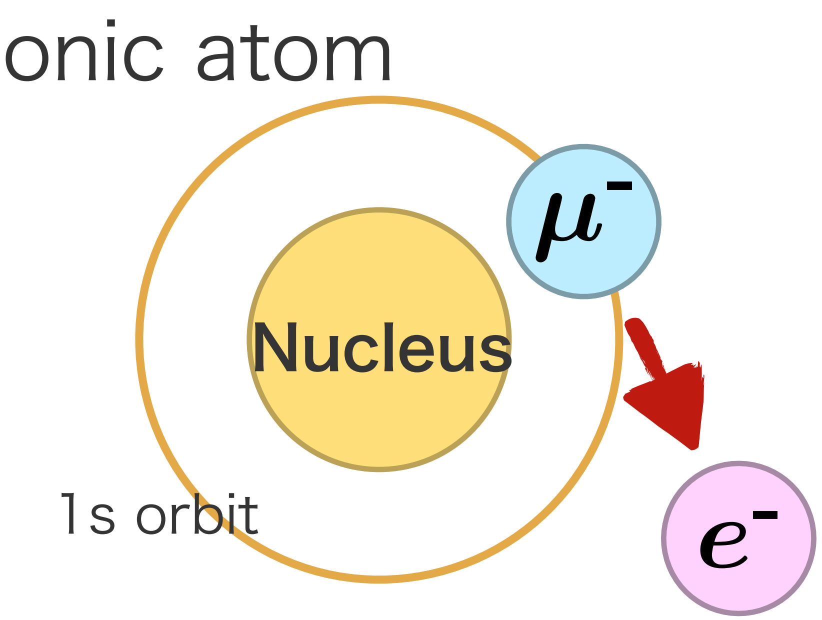
Year-End Presentation 2017

2017.12.28

Yu Nakazawa

Muon to electron conversion





μ-e conversion

(Charged Lepton Flavor Violation)

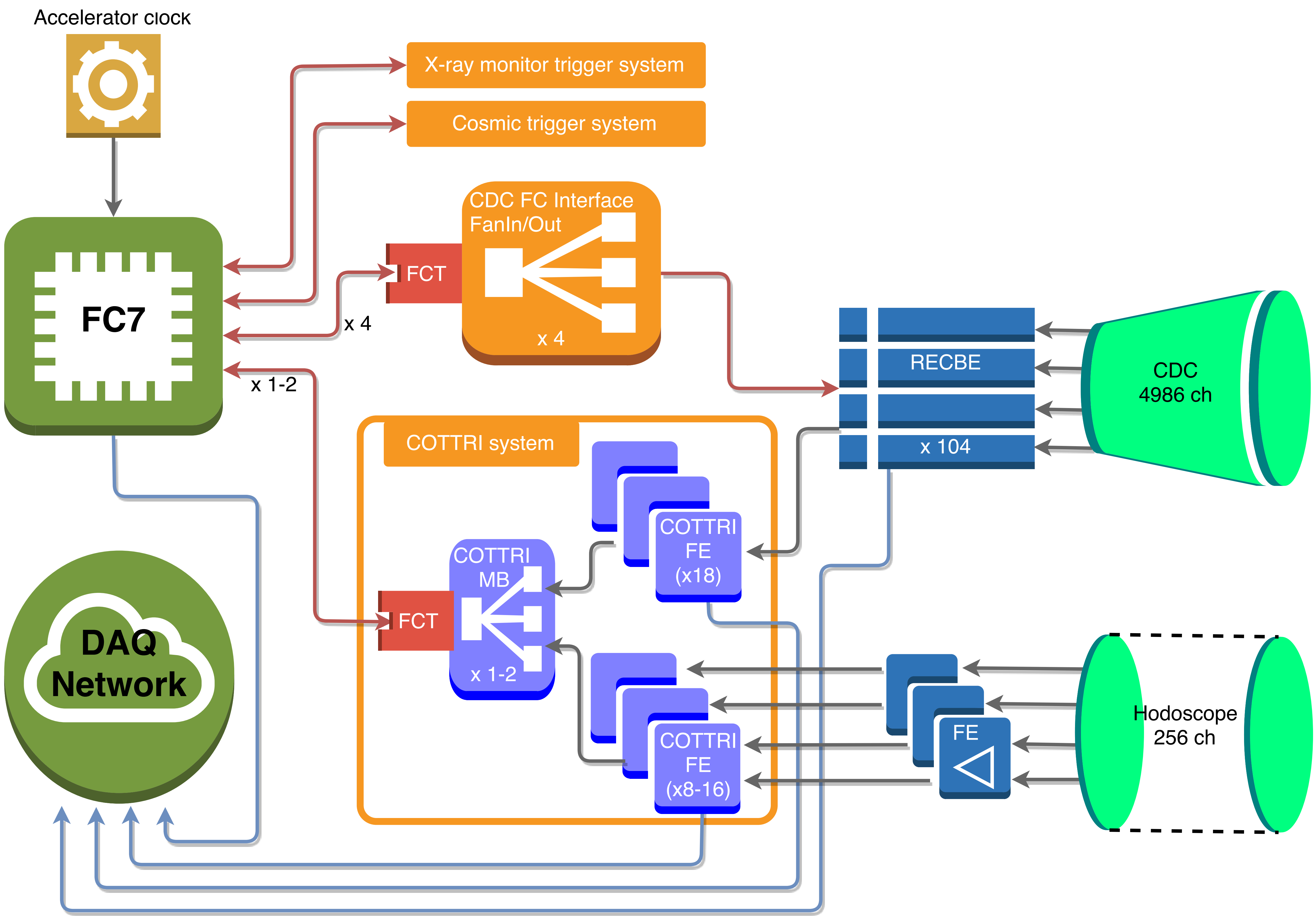
Branching ratio

Standard Model : $O\left(10^{-54}\right)$

Beyond the SM : $O\left(10^{-15 \sim -17}\right)$

Observation of μ-e conversion would indicate new physics

Trigger schematic : CyDet



Trigger schematic : StrEcal