Radiation Tolerance of Straw-Tracker Read-Out System for COMET Experiment

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Outline

- Introduction
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  - Straw tracker
  - Readout system (ROESTI)
- Radiation tolerance
  - Neutron irradiation test
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- Summary

Introduction

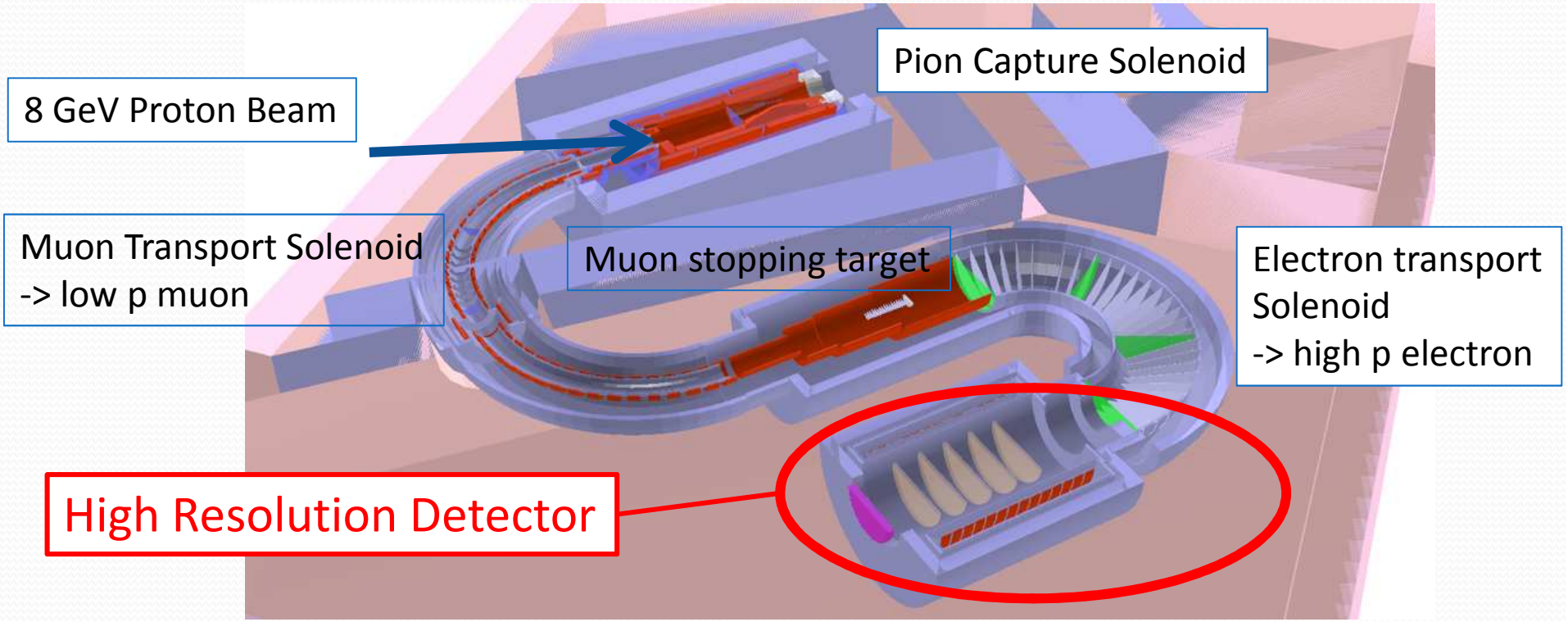
COMET = Search for muon to electron conversion @J-PARC

"$\mu^- + N \rightarrow e^- + N$"

Standard model+ ν mass : Branching Ratio (BR) **~O(-54)** unobservable…

➡ **CLFV = Beyond the SM**

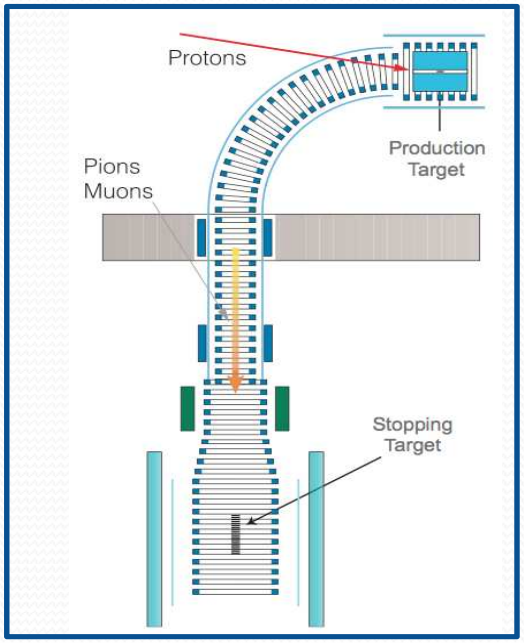
BSM(ex. SUSY-GUT, SUSY-SEASAW) : BR **~O(-15)** Observable!

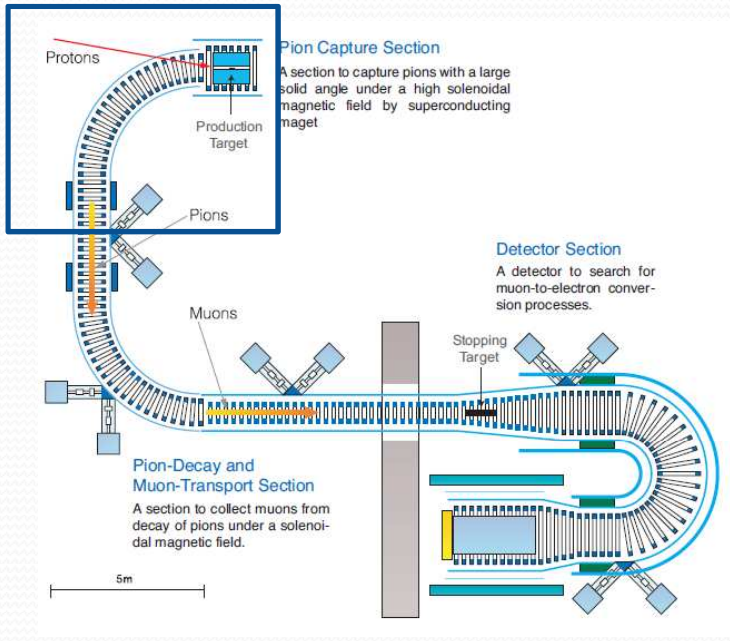


Goal sensitivity : 3×10^{-17} (x10000 better than current limit)

COMET Experiment

Staging aproarch





Phase-I（2019）

Phase-II（2020～）

Aim of Phase-I

1. R&D for Phase-II

   Beam (BG) measurement -> same detector as Phase-II

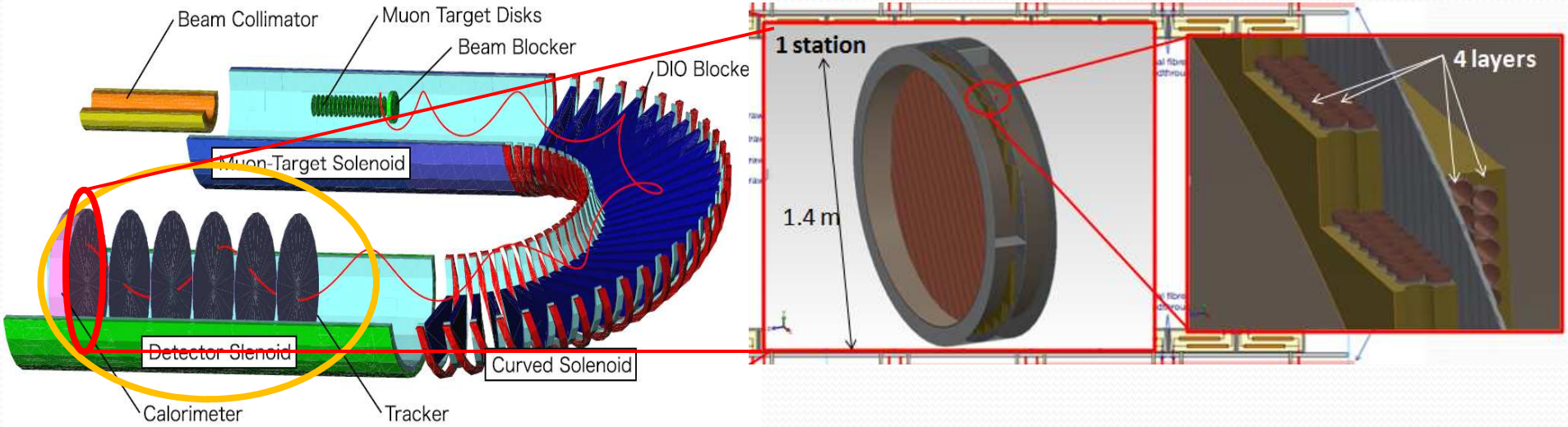
2. Search for Muon to Electron Conversion

   Search at the sensitivity of O(-15) -> CDC + CTH

Straw Tracker

Requirements

- high momentum resolution <200keV/c@105MeV/c
- Operational in vacuum, high-B (1T), and high radiation



StrECal system

Straw-tube tracker + Electron calorimeter

momentum

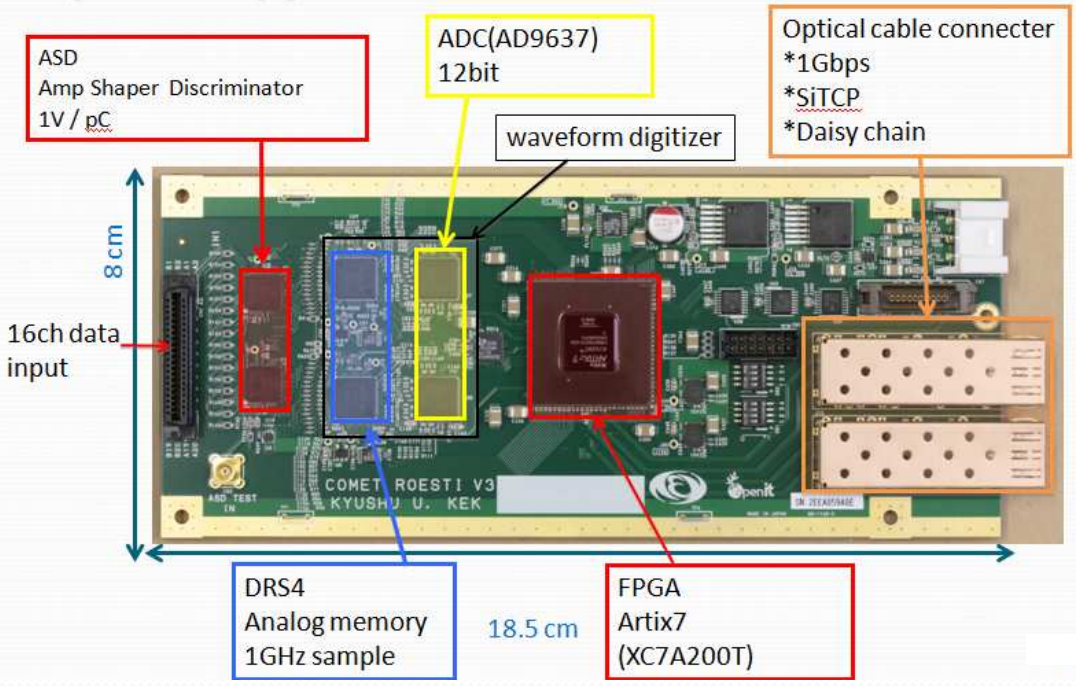
Energy, Timing, Hit Position
-> Trigger, PID

Readout System for Straw Tracker

Requirements

Timing resolution : < 1ns Position resolution of tracker ~ 100um
Gain : ~1 V/pC S/N > 10 for Minimum Charge (~16 fC)
# of channels : > 16ch # of straw > 2000ch
High intensity, Compact, Operational in high radiation, B-field

ROESTI (ReadOut Electronics for Straw Tube Instrument)



- Develop step by step
- ver.3
- Function works
- Satisfy almost all the requirements
- Need investigation of radiation tolerance

→ This talk

Radiation effect

- Neutron
  - Soft error : Single Event Upset（SEU）and so on

    -> Investigation of SEU rate

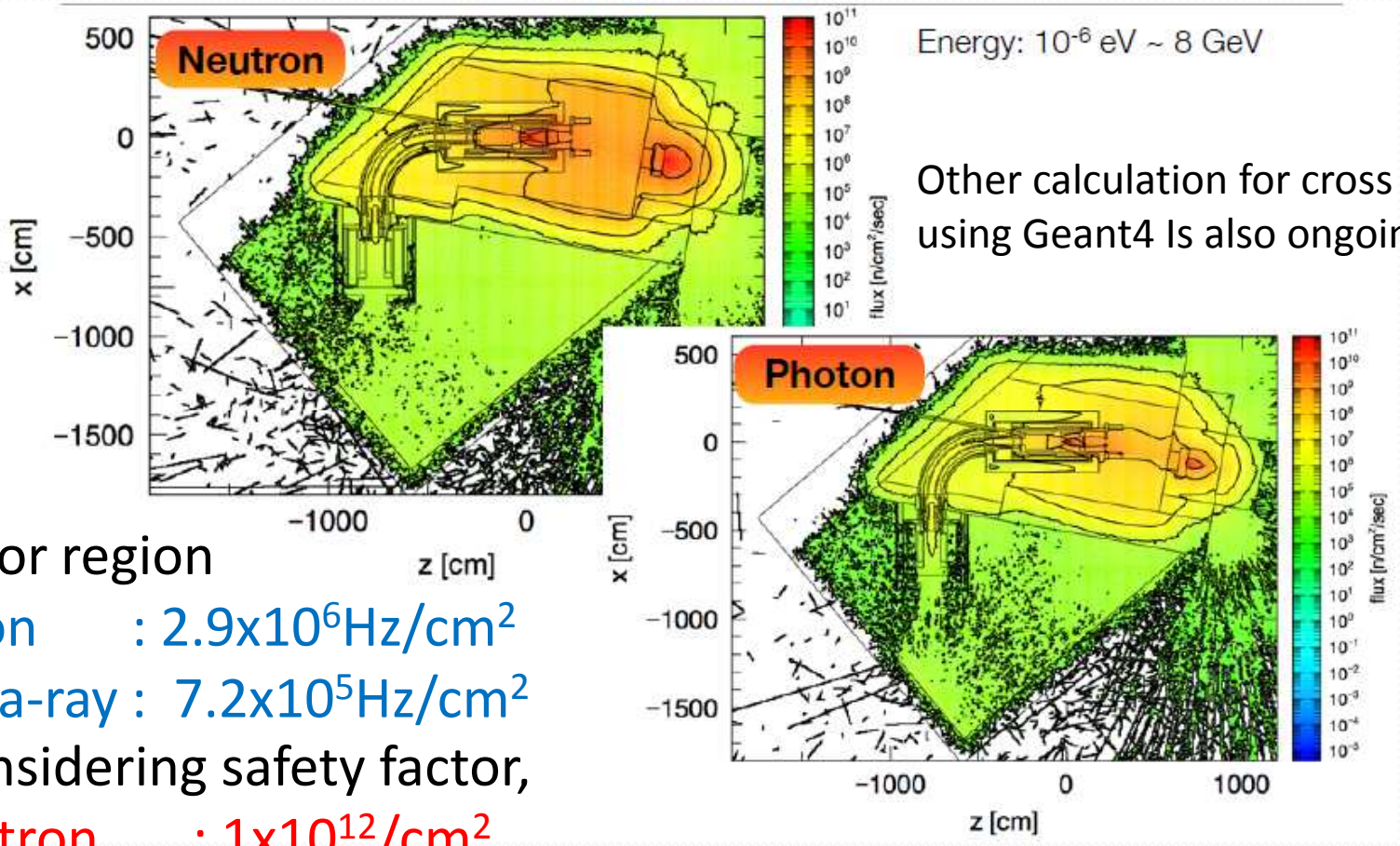
    Improvement of FPGA firmware (SEU detection/correction)
    - Error Correction Code (ECC), Triple Module Redundancy (TMR), etc…
    - Re-download scheme for FPGA
  - Hard error : Type inversion and so on

    -> Parts selection
- Gamma-ray
  - Hard error : Total Ionizing dose（TID）and so on

    -> Parts selection

Simulation study

- PHITS calculation for Phase-I



Other calculation for cross check using Geant4 Is also ongoing.

Detector region

Neutron : 2.9×10^6 Hz/cm^2

Gamma-ray : 7.2×10^5 Hz/cm^2

After considering safety factor,

Neutron : 1×10^{12}/cm^2

Gamma-ray : ~ 1kGy (100days)

were estimated.

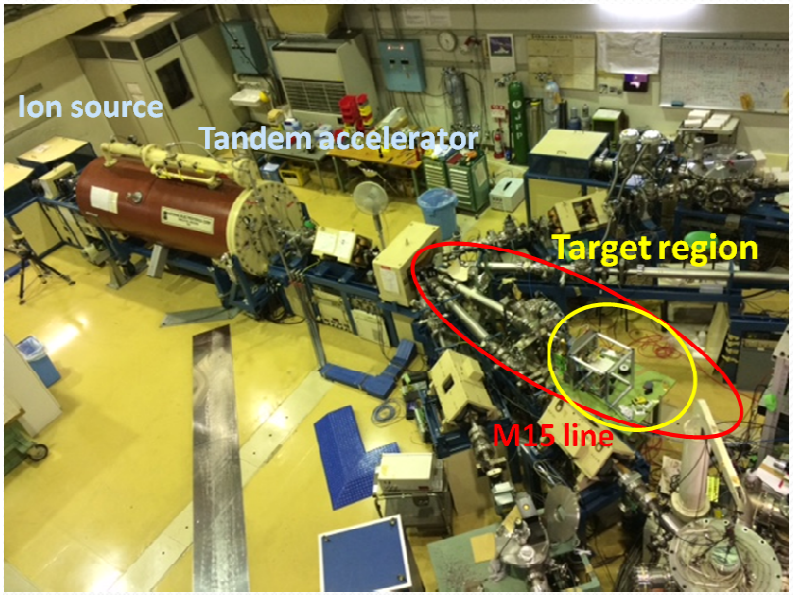
Based on those estimations, irradiation tests were performed.

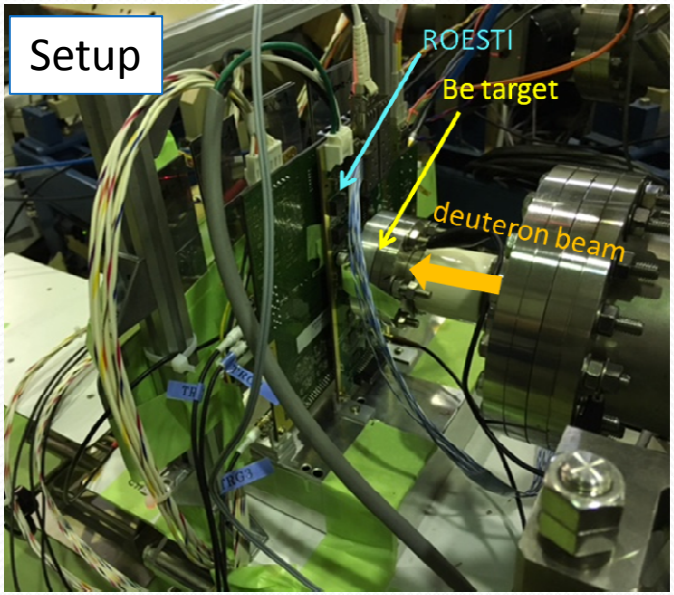
Neutron irradiation test

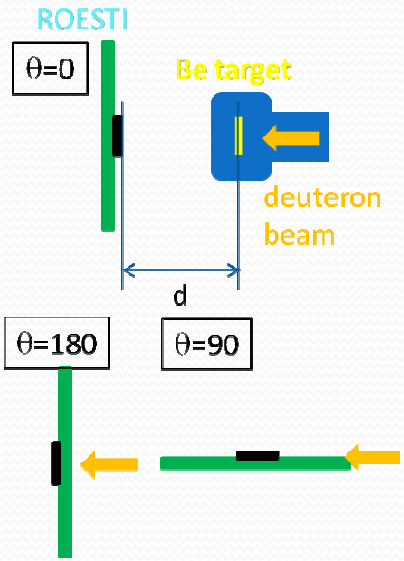
Aim of the test

- Measurement of SEU rate on FPGA (Artix7)
- Test of SEU detection/correction function for FPGA firmware
  - Configuration RAM (CRAM)
    - SEM（IP core from Xilinx） was implemented.
    - When UnRecoverable Error (URE) occurred, firmware re-download was automatically done via JTAG line.
    - #s of SEU and URE were recorded.
  - Block RAM (BRAM)
    - Error Correction Code (ECC) using Hamming code（IP core from Xilinx） was implemented.
    - Cyclic Redundancy Check (CRC) was implemented for check of ECC
    - Hamming code and CRC code were added in data. When Multi Bit Errors （MBE） occurred, data was checked in offline.
    - #s of SEU and MBE were recorded.
- Deterioration test

Neutron irradiation test

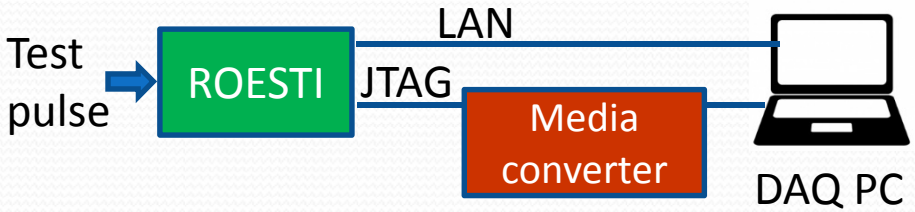






Tandem accelerator @Kobe Univ.

- Mar. and Jul., 2016
- M15 line
- Beam : ~3MeV deuteron
- Target : Be
- Flux : 1.6x10^6 Hz/cm^2
  @10cm from target (1 μA)
  (including factor 2 of uncertainty)

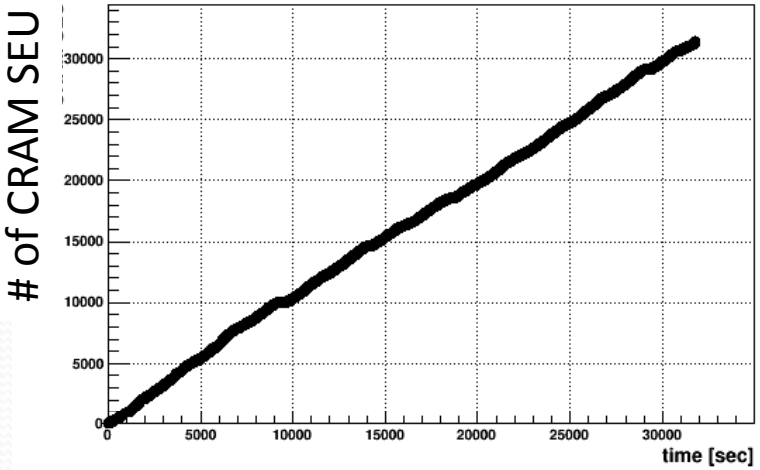


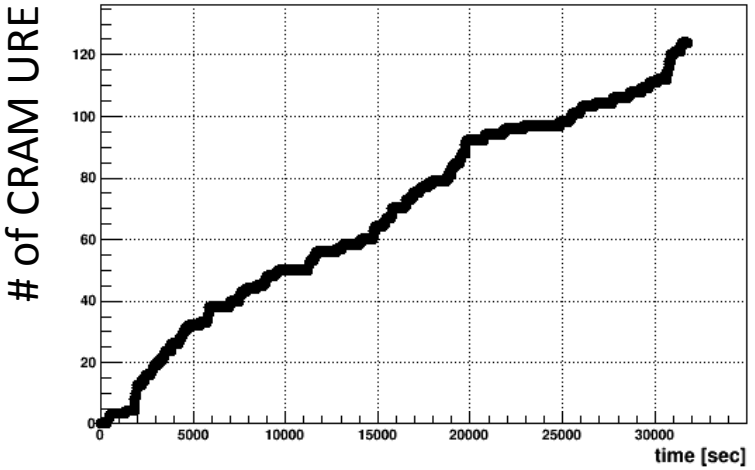
- Data taking of test pulse with 150 Hz trg.
- Counting #s of SEU, URE, and MBE
- Auto firmware re-downloading in case of URE

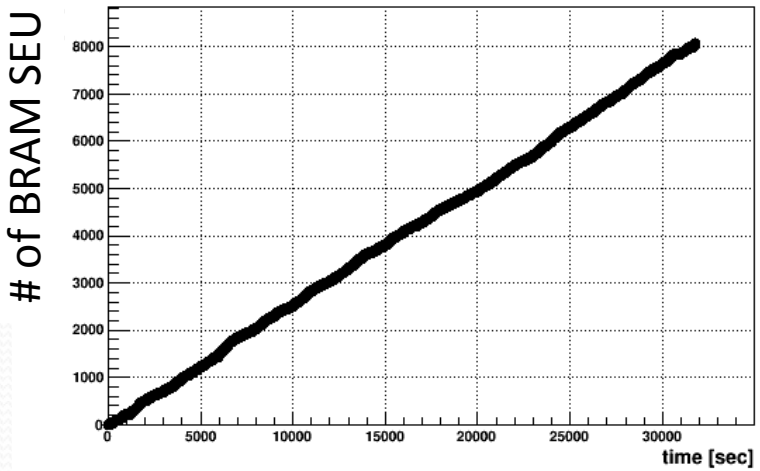
Dependence of n incident angle was also investigated.

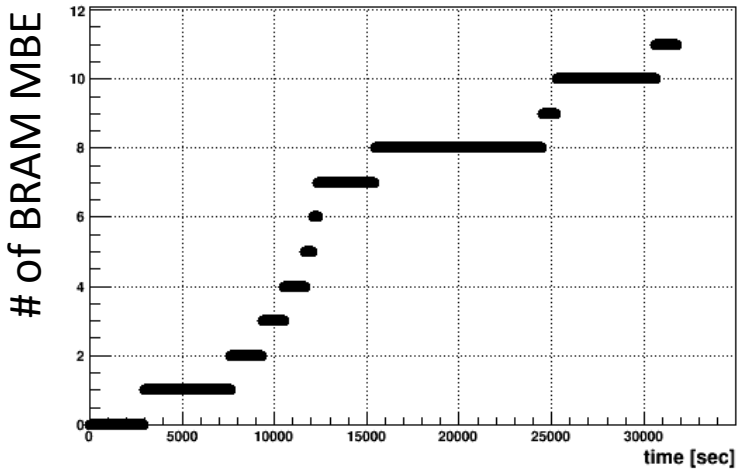
Neutron irradiation test

One example of results (θ=0, d=26 mm)









Firmware functions (SEM and ECC) and auto re-downloading scheme worked.

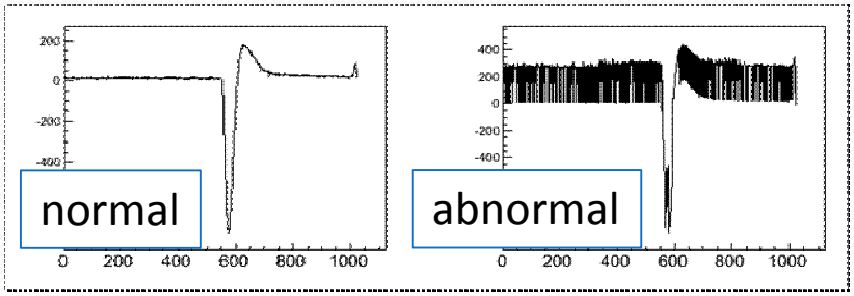
Neutron irradiation test

preliminary

θ	Distance [mm]	# of SEU (CRAM)	# of URE (CRAM)	# of SEU (BRAM)	# of MBE (BRAM)	SEU rate (CRAM)	URE rate (CRAM)	SEU rate (BRAM)	MBE rate (BRAM)
0	26	31361	124	8059	11	3.14e7	7.95e9	1.22e8	8.96e10
180	28	50499	254	12031	25	2.50e7	4.96e9	1.05e8	5.04e10
180	53	17483	55	4392	3	1.89e7	6.00e9	7.51e7	1.10e11
90	58	17211	114	3448	6	1.95e7	2.94e9	9.72e7	5.58e10

* Rate : # of nutron / # of SEU（URE、MBE）

- There was no large dependence of incident angle.
- Assuming Phase-I operation in the worst case, URE will occur every 1 hour. -> Firmware re-downloading scheme is indispensable.
- No fatal hard error was observed after irradiation of 5×10^{12} n/cm^2.
- Abnormal data was rarely seen.
  - Both SEM & ECC didn't detect that.
  - It was repaired by firmware re-downloading.
  - It was found that **this was due to SEU** after investigation with read-back method.



Gamma-ray irradiation test

Aim of the test

- Deterioration test
  - Dead parts in irradiation test using ROESTI ver.2
    - Memory -> Removed in ver.3
    - DAC -> Need parts selection
    - Regulator -> Need parts selection
    - SFP -> Need parts selection
  - New parts in ver.3
    - ADC -> Need deterioration test

Gamma-ray irradiation test

RI Center

@Tokyo Institute of Technology

- Jun. and Oct., 2016
- Src : Co-60
- Dose : 191Gy/h@40cm

Targets

DAC
- AD5324, AD5624, AD5624R, DAC7564, DAC7565

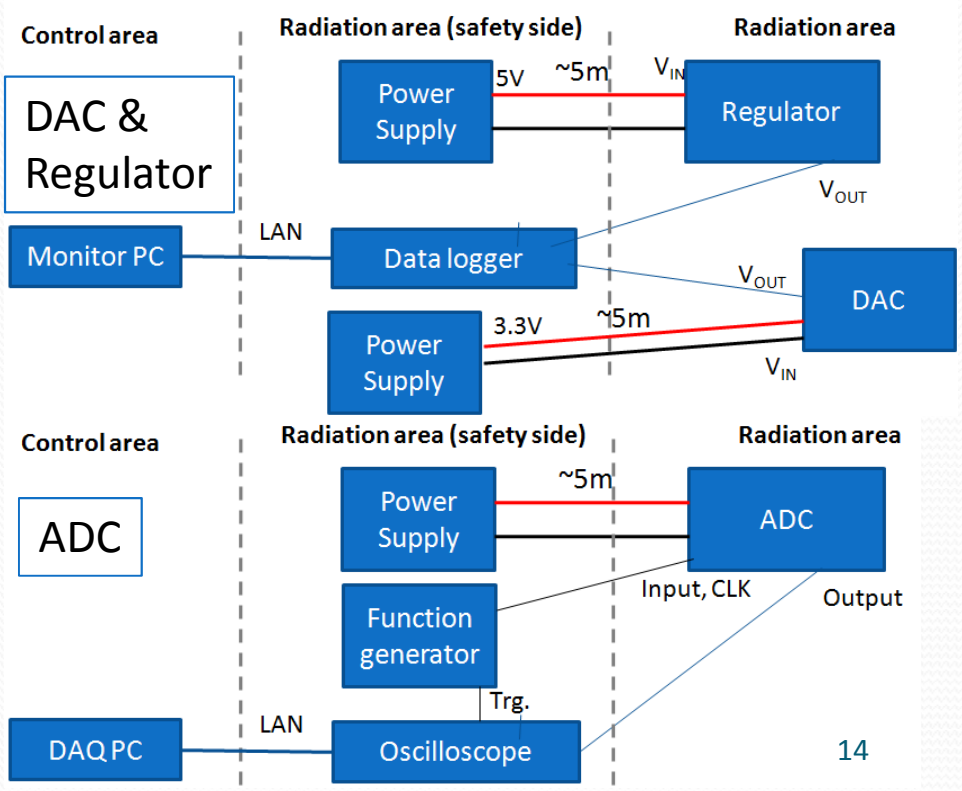
Regulator
- LT3086, LMZ10503

ADC
- LTC2264

Setup

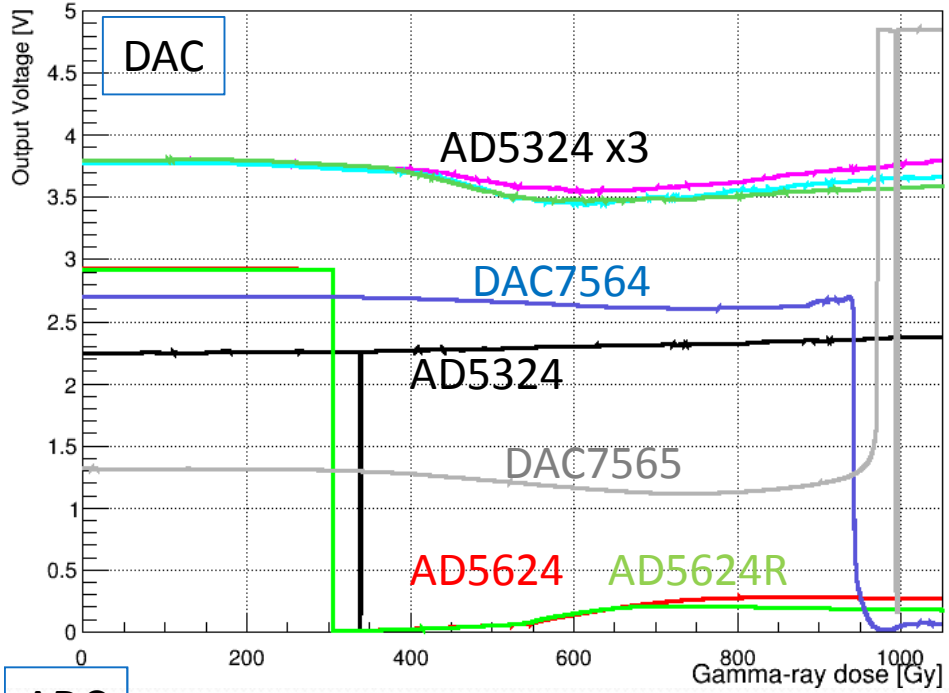
DAC & Regulator
- Output Voltage was recorded by logger.

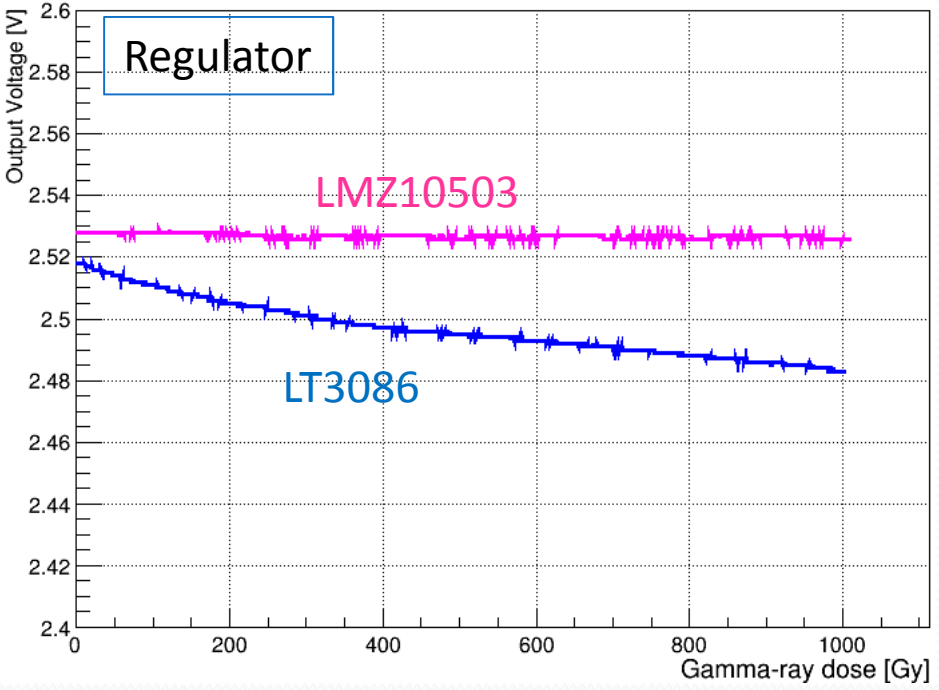
ADC
- Output signal was taken by Oscillo. DAQ.



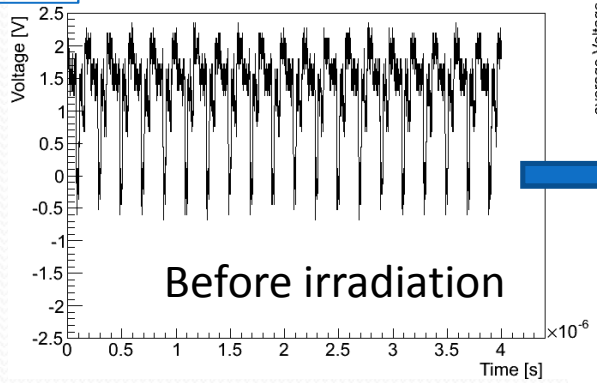
Gamma-ray irradiation test

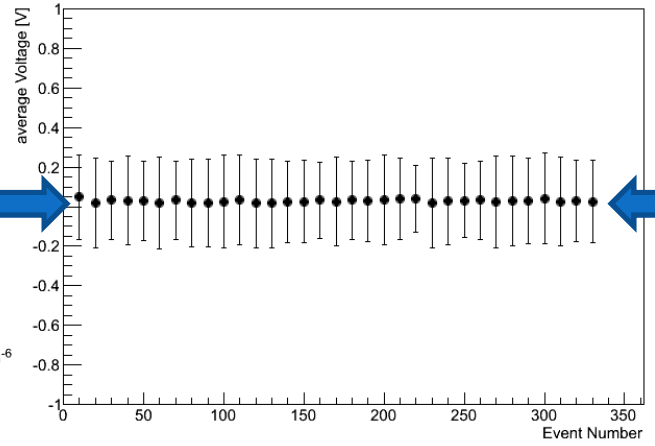
Results

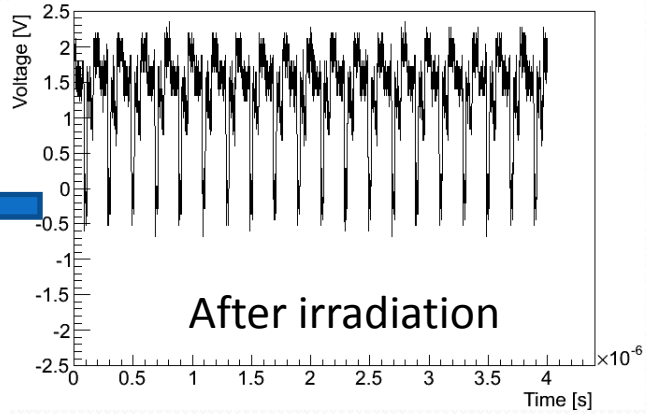




ADC







Gamma-ray irradiation test

Results

- DAC
  - AD5324 : Available although slightly change was seen
  - AD5624 : dead
  - AD5624R : dead
  - DAC7564 : dead
  - DAC7565 : dead

  -> - Evaluation of ROESTI performance with slight change of DAC output will be done.
  - Other candidate will be also searched.
- Regulator
  - LT3086 : Available although slightly change was seen
  - LMZ10503 : good

  -> - Individual specification will be investigated.
- ADC
  - LTC2264: good

  -> - Individual specification will be investigated.

Summary

- COMET experiment @J-PARC is aiming for mu-e conversion search.
- StrECal system is being developed.
- Development of Straw readout（ROESTI） is ongoing.
- Radiation tolerance of ROESTI is ongoing.
  - Firmware functions for SEU(SEM、ECC、CRC、Firmware re-download) worked.
  - URE rate was estimated to 1/1hour in worst case.
  - Hard error was not seen after neutron irradiation.
  - Parts selection with gamma-ray irradiation is ongoing.

Future

- Fix parts selection.
- Improve SEU detection/correction function (TMR, DPR) if needed.
- Construct final version of ROESTI after fixing parts selection.

ROESTI (ReadOut Electronics for Straw Tube Instrument)

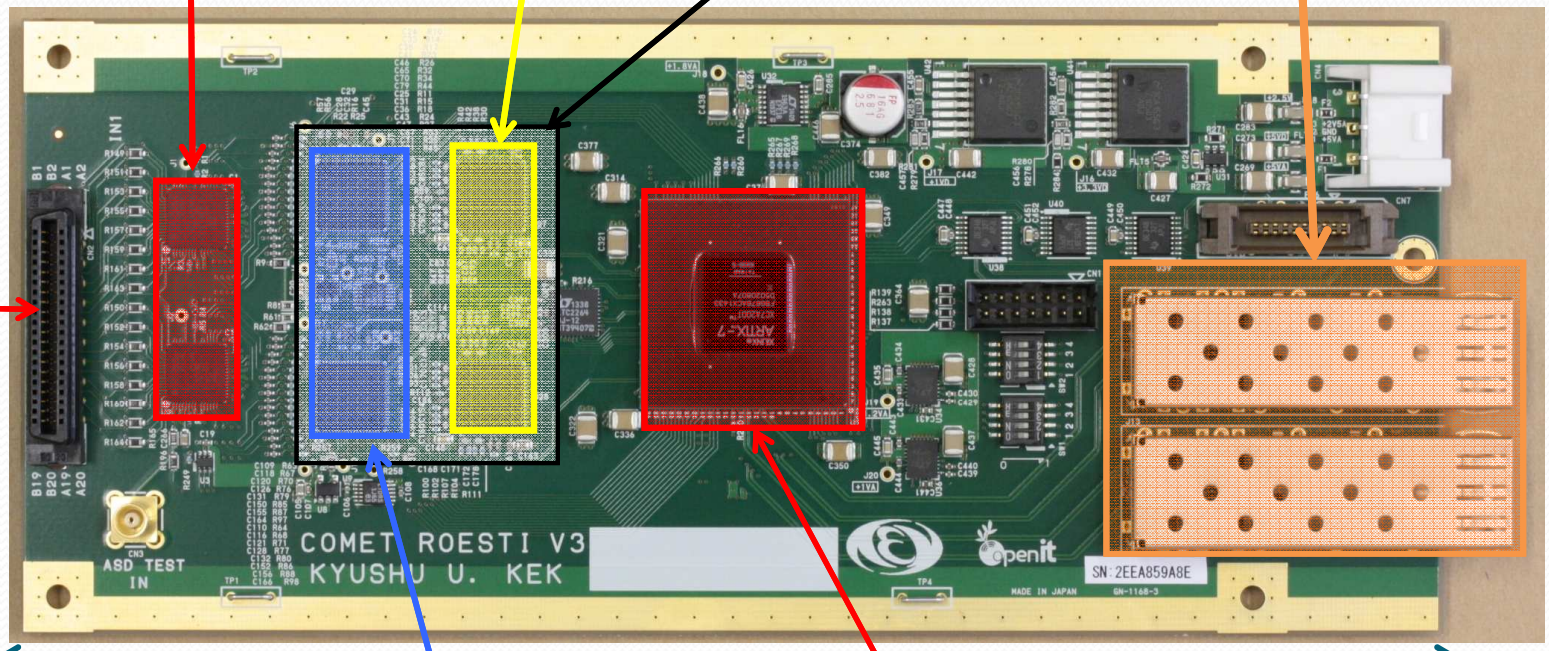
prototype ver.3

ASD
Amp Shaper Discriminator
1V / pC

ADC(AD9637)
12bit

waveform digitizer

Optical cable connecter
*1Gbps
*SiTCP
*Daisy chain



DRS4
Analog memory
1GHz sample

18.5 cm

FPGA
Artix7
(XC7A200T)