The study of the radiation damage to CIGS

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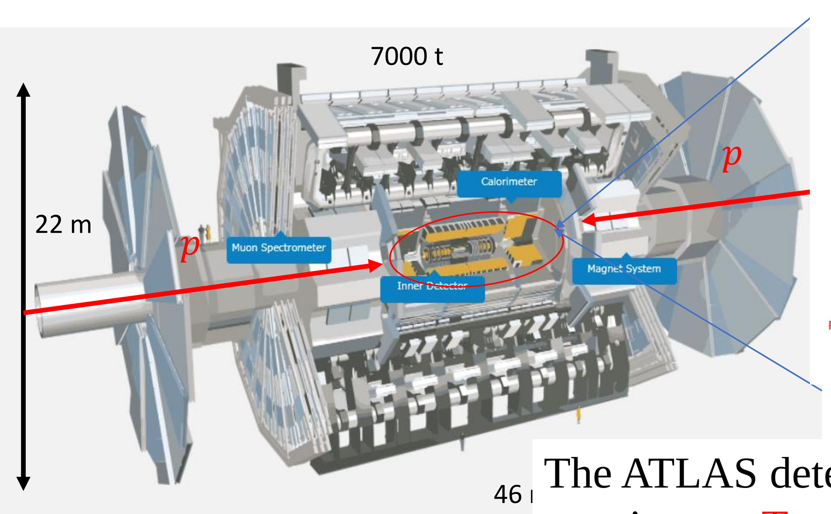
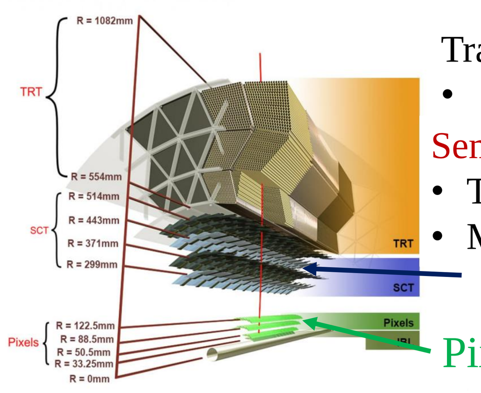
1. International Center for Quantum-field Measurement Systems for Studies of the Universe and Particles

1. ATLAS detectors

ATLAS detector is one of the huge detectors installed at CERN.
→ Equipped three types of inner detectors.





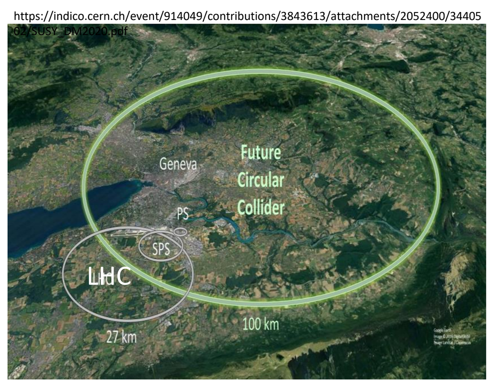
Transition Radiation Tracker (TRT)
- Particle identification

Semiconductor Tracker (SCT, Pixel)
- Tracking
- Momentum measurement

The ATLAS detector detects the charged particles produced by collision reactions.→ To give critical damage to Si semiconductor detectors

2. LHC major upgrades and radiation damage in the ATLAS detector

LHC at CERN plans major upgrades for the high energy and luminosity.

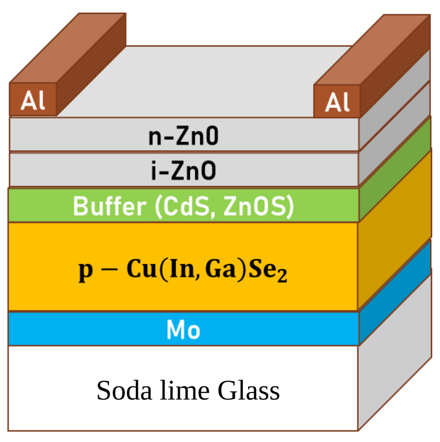


Characters	LHC	HL-LHC	HE-LHC/FCC
Start year	On going	~2029	Future
Collision energy $\sqrt{s}$ [TeV]	14	14	27/100
Luminosity / LHC (0.7 MGy)	× 1	× 10	× 100

ATLAS inner detectors are exposed to a high radiation environment.
→The detectors degrade due to the radiation damage.

→ The development of detectors with high radiation tolerance is necessary.

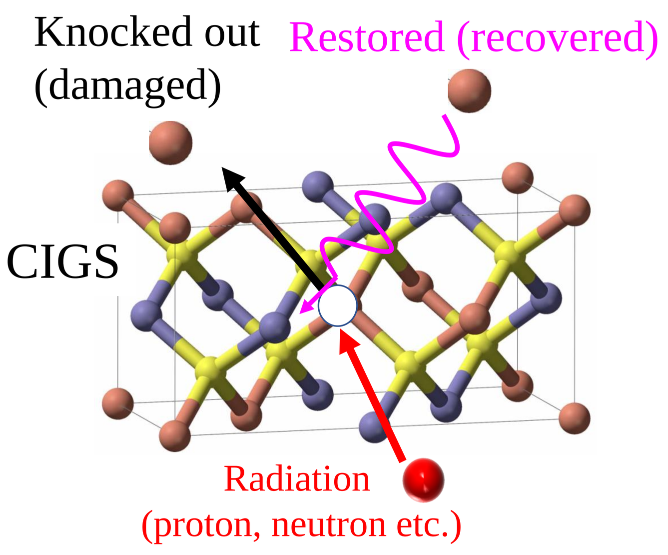
3. CIGS (Cu(In,Ga)Se_2)



CIGS is a mixed crystal semiconductors of $CuInSe_2$ and $CuGaSe_2$.

Main abilities of CIGS solar cells

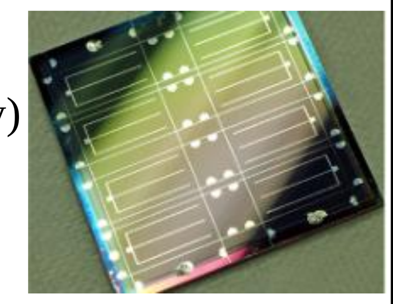
1. High light conversion efficiency : $\eta > 20$ %
2. Energy gap :1.01 – 1.64 eV (depends on fraction of In and Ga)
3. Absorption wavelength : 300 – 1200 nm
4. High radiation resistance
5. Light weight and flexible



Non Ionization Energy Loss (NIEL)
Radiation particles (proton, neutron, etc.) are knocked out atoms in the lattice.
Recovered mechanism by heat annealing
Heated ionic atoms restored defective lattices.

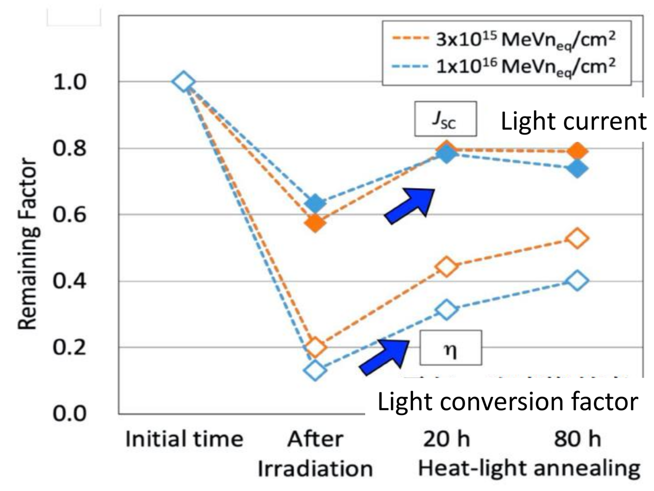
3.1 High radiation test with CIGS solar panels

Proton irradiation on the CIGS solar cell at CYRIC (Tohoku University)
Proton beam (70 MeV)
- NIEL (Non Ionization Energy Loss) : 10^{16} MeV/n_{eq}/cm^2
- TID (Total Ionization Doze) : 7 MGy



National Institute of Advanced Industrial Science and Technology (AIST)[2].

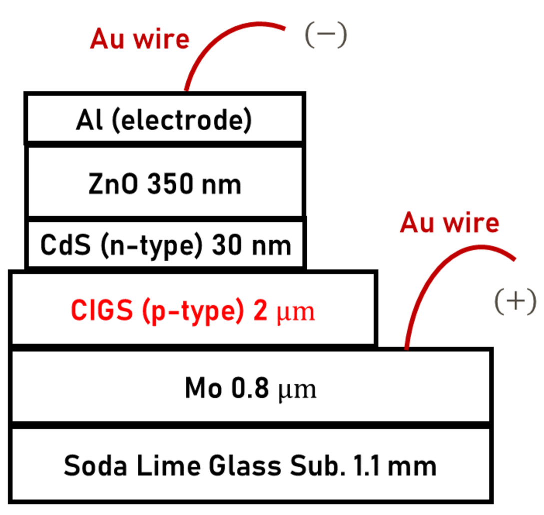
Proton beam with 70 MeV [1]

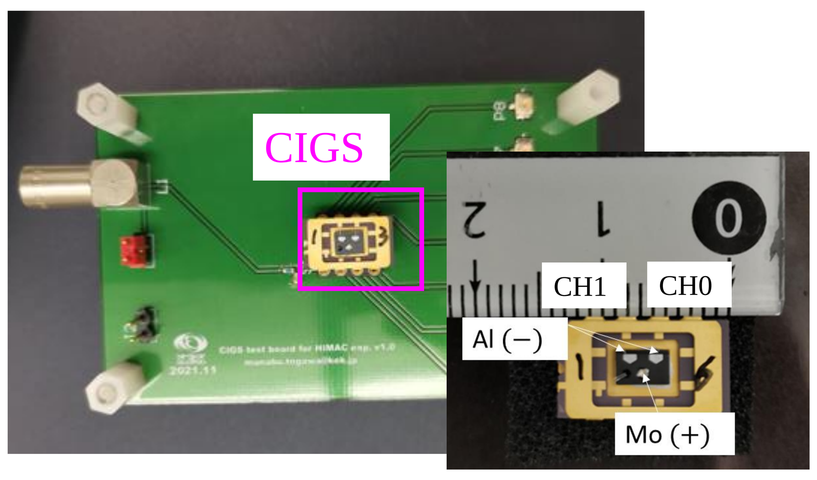


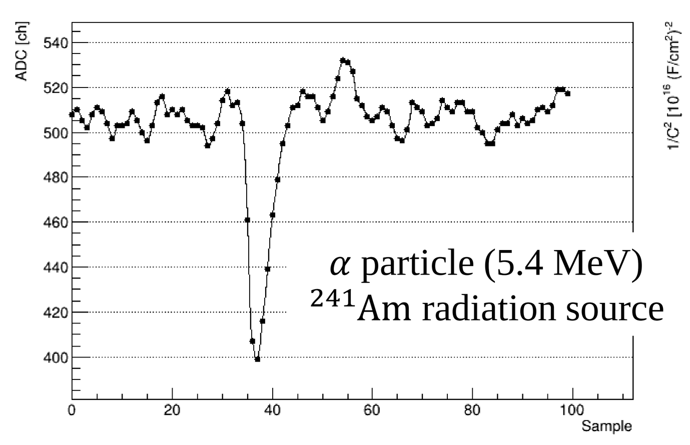
Light current (J_{SC}) and Light conversion factor (η) were recovered about 20% after 20h heat annealing (1 Sun, 95°C).

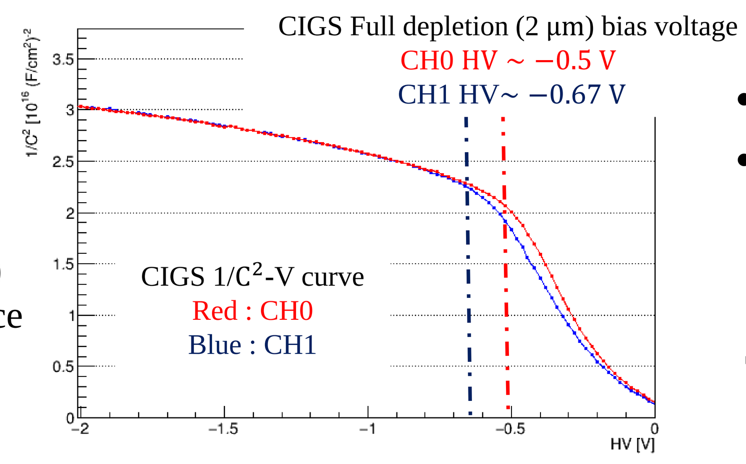
Confirmation of recovery from high radiation damage by the heat annealing (CIGS solar cell)
→ Development of particle detector with CIGS

3.2 Plot type of the CIGS detector







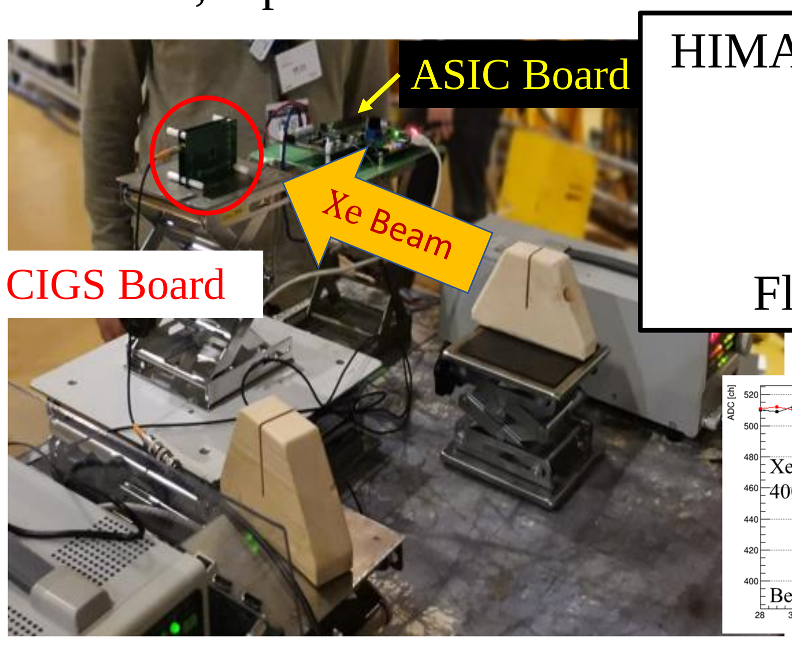


New CIGS sample
- Successful to detect $\alpha -$ particles
- Full depletion voltage ≤ -1 V

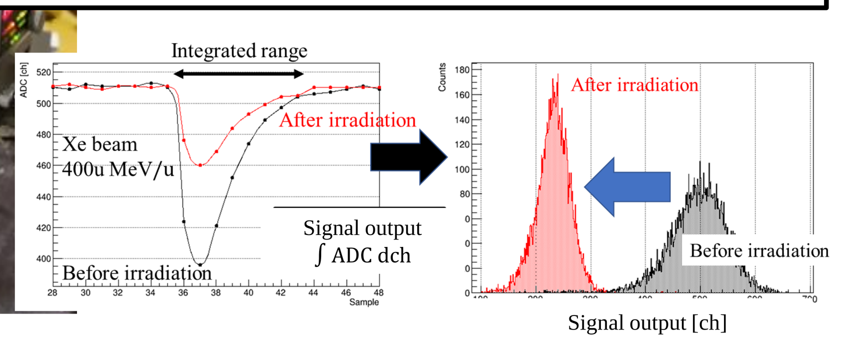
To study the radiation tolerance with heavy-ion (^{132}Xe) beam at HIMAC

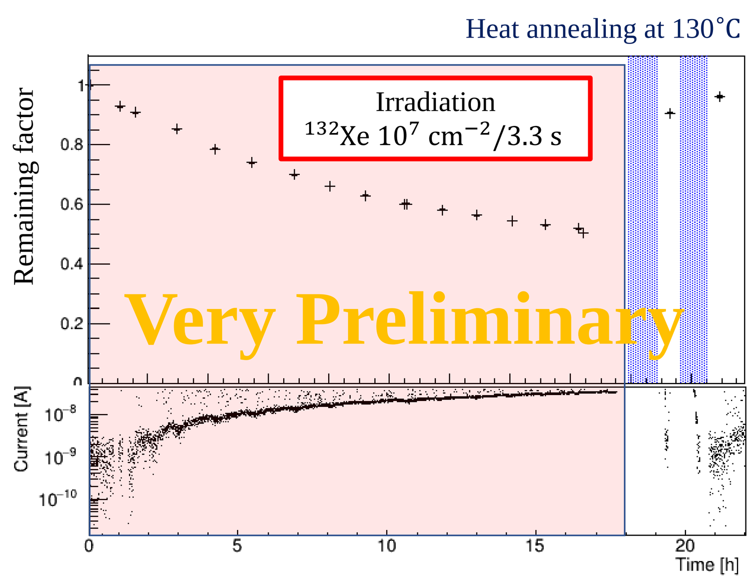
4. Radiation damage test at HIMAC

HIMAC is a heavy-ion cancer therapy device in National Institute of Quantum Science and Technology (QST) in Chiba, Japan.



HIMAC test beam condition (Nov. 2022)
Beam : ^{132}Xe ion
Energy : 400 (MeV/u)
Beam size (ϕ) : 3-5 mm
Fluence : 10^7 cm^{-2}/3.3 s (ppp)





Time dependence of Integrated ADC

After ^{132}Xe beam irradiation
- Decreasing signal output ~ 50%
- Leakage current : 10^{-9}A → 10^{-8} A (increased)

After heat annealing
- Remaining factor → 90% (1h at 130°C)
  → > 98% (2h at 130°C)
- Leakage current → 10^{-9} A (recovered)

The leakage current and integrated ADC were almost recovered fully by heat annealing (2h at 130°C)!

5. Summary

- LHC at CERN plans major upgrades for the high energy and luminosity. → The development of detectors with high radiation tolerance (70 MGy) is necessary.
- CIGS has the ability to recover from the radiation damage by annealing. → high radiation tolerance semiconductor
- We developed CIGS detector (plot-type) and tested the radiation tolerance at HIMAC.
- CIGS recovered the radiation damage in terms of leakage current and signal output by the heat annealing at 130 °C.

6. Future research plan for CIGS

Toward the practical application of CIGS detectors
- Study the temperature dependence of the annealing effect.
- Development of thick depletion layers for single-charged particles detection
- Development of the CIGS detector as a pixel and strip type.

Reference

[1] https://unit.aist.go.jp/rpd-envene/PV/ja/results/2019/poster/P34.pdf
[2] https://unit.aist.go.jp/rcpv/ci/r_teams/CSTFT/index.html