# Construction status and performance evaluation of the Straw-Tube Tracker for the COMET experiment

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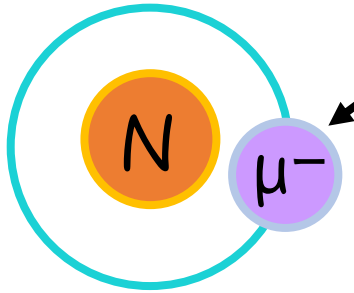
EPS-HEP 2025

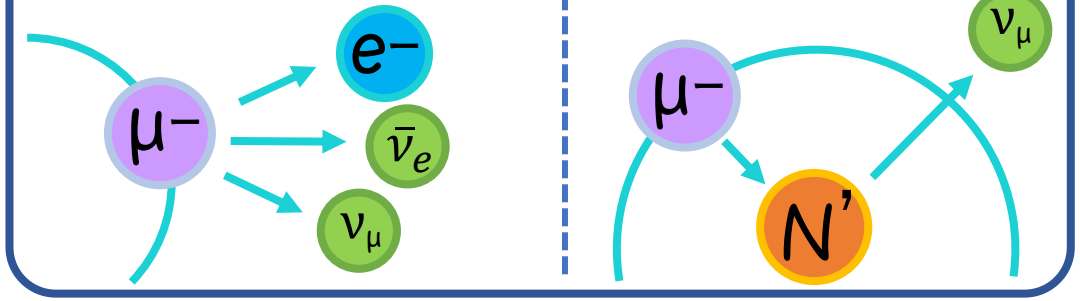
# Muon-to-Electron Conversion

**Muonic Atom**

A muon stopped in an atom will be captured by 1s orbit.

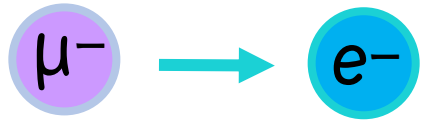



## The Standard Model (SM)




## Beyond the Standard Model (BSM)

**Muon-to-Electron (μ-e) Conversion**



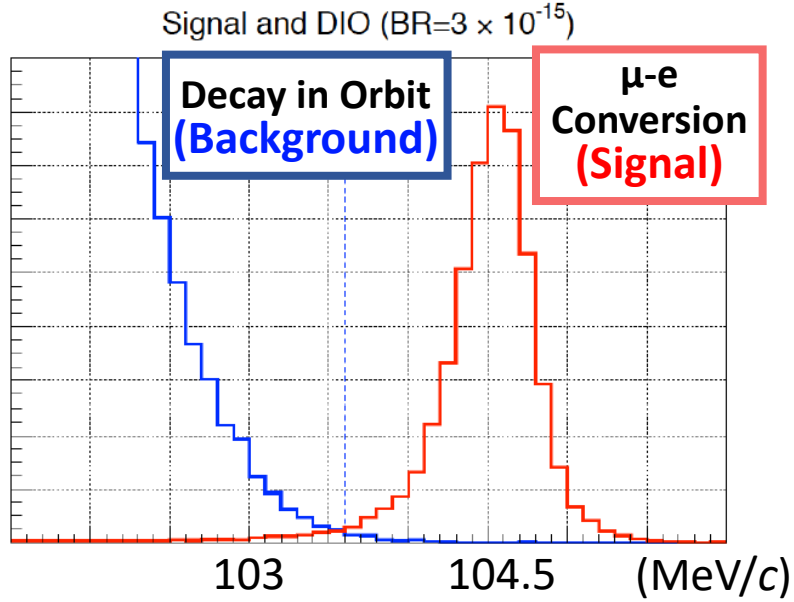

~ 105 MeV ( Al )

… A “charged lepton flavour-violating” process.

**SM : It is prohibited**. Even including the neutrino oscillation, it is strongly suppressed … ⇒ Branching ratio < $10^{-54}$

**BSM** : Reach up to ~ $\mathbf{10^{-15}}$ (SUSY-GUT, Z’,…)

**Its observation would be an evidence for new physics.**




**Electron momentum spectrum.**

# COMET Experiment

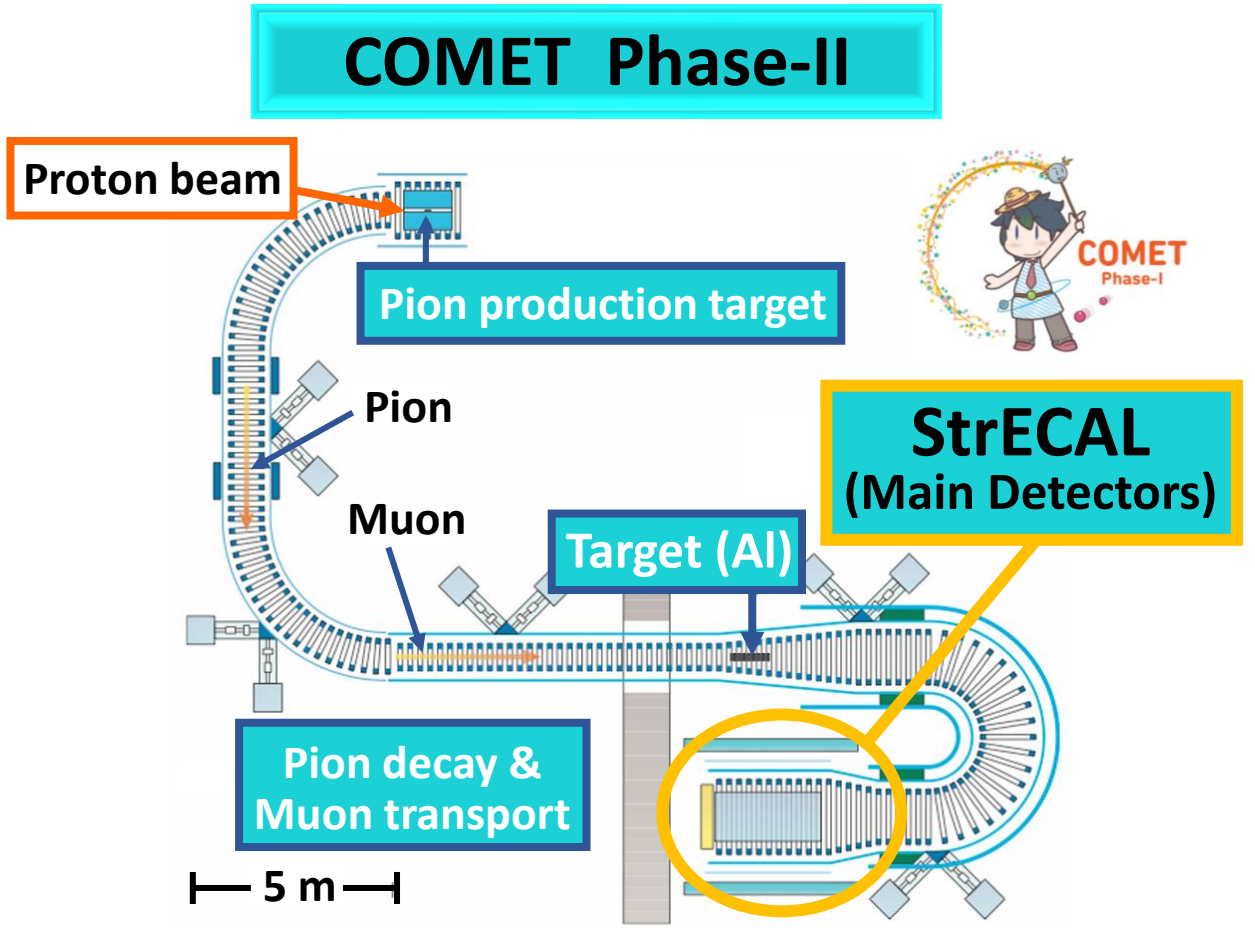
## COherent Muon to Electron Transition

- Searching for μ-e conversion at J-PARC (Japan Proton Accelerator Research Complex).
- Use a world-class intensity pulsed muon beam from the COMET beamline.
- Two staged plan : Phase-I and Phase-II

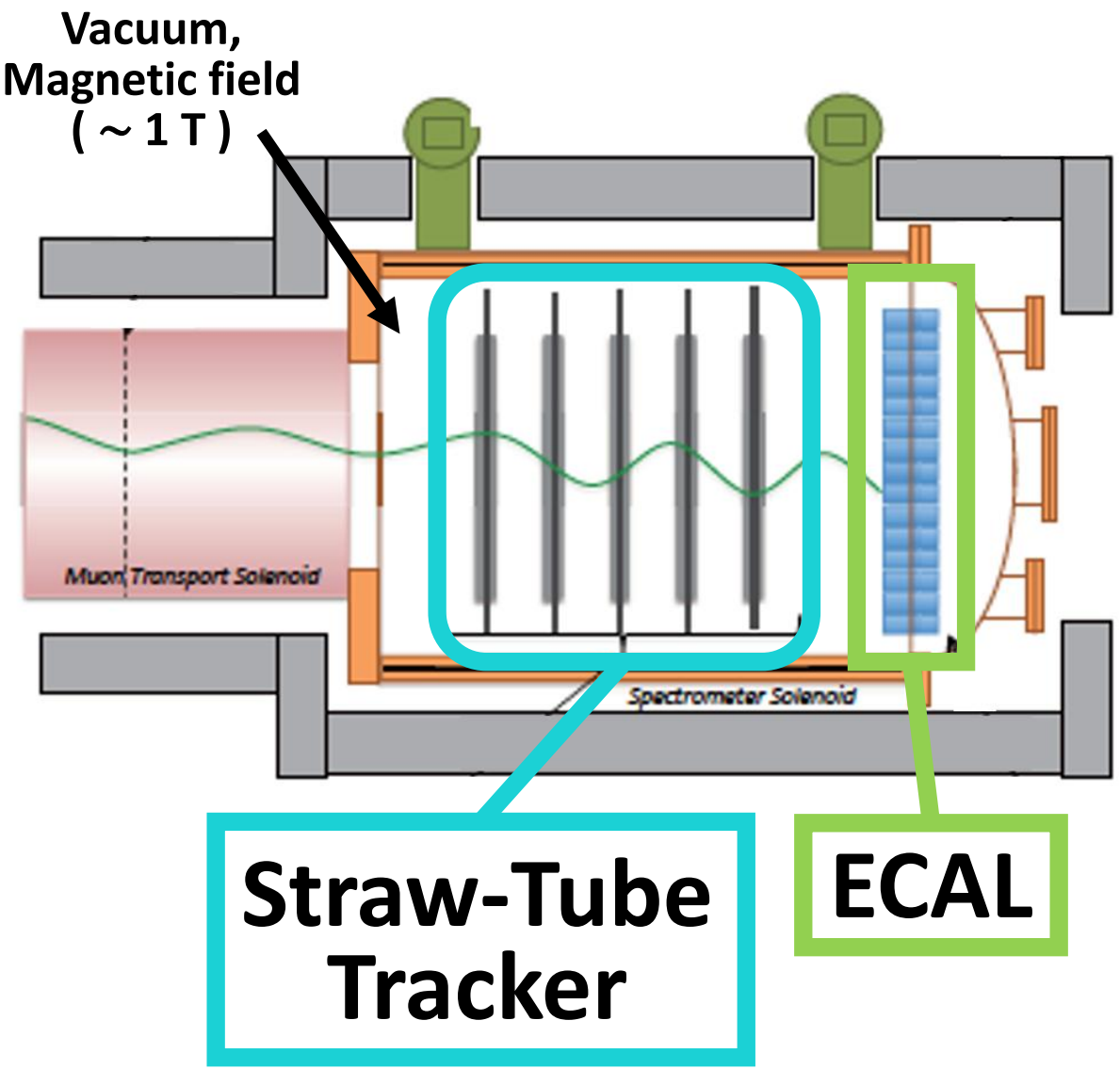
| | |
|---|---|
| **COMET** ( Al target)<br>Target sensitivity (S.E.S.) | Phase-I $O(10^{-15})$<br>Phase-II $O(10^{-17})$ |

| | |
|---|---|
| **SINDRUM II** (Au target)<br>Current limit | $7 \times 10^{-13}$<br>90% C.L. |

**COMET aims to achieve 10,000x better sensitivity than the current limit.**



# StrECAL




## Straw-Tube Tracker

- ⋆ Measuring the $e^-$ momentum
- ⋆ Ar : $C_2H_6$ = 50 : 50
- ⋆ 2,400 sense wires
- ⋆ Momentum resolution < 200 keV/*c*

## ECAL (Electromagnetic Calorimetor)

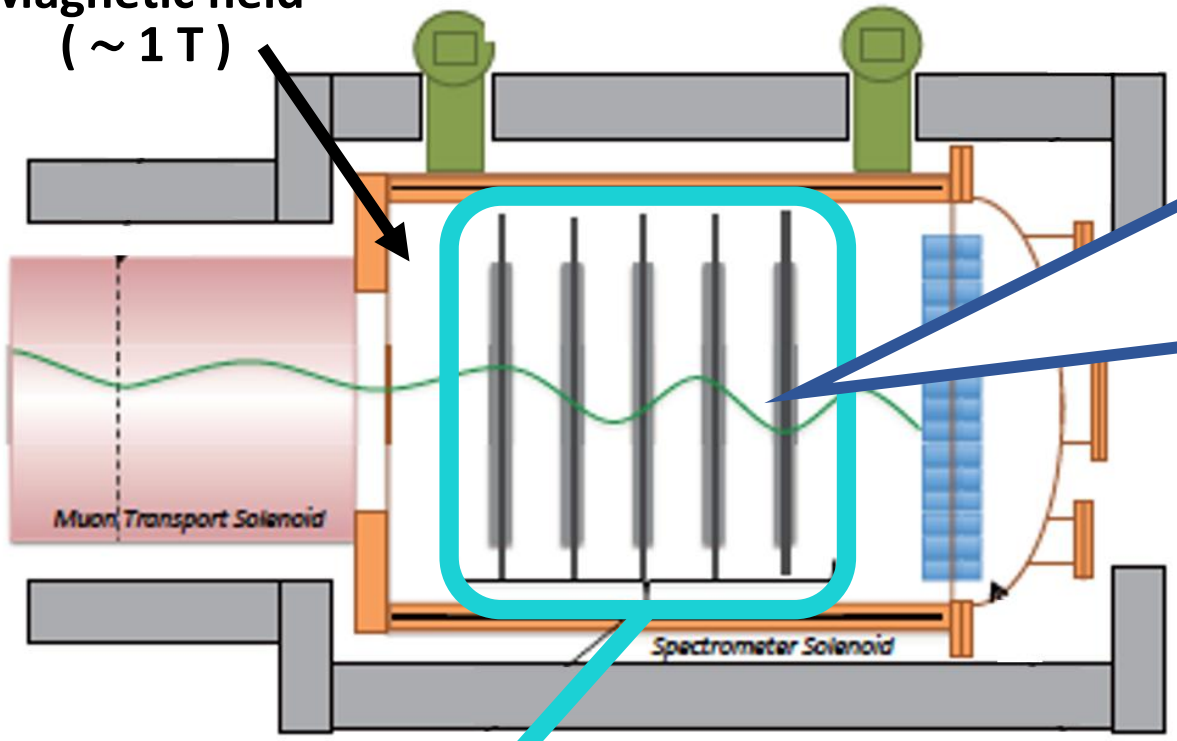
- ⋆ Measuring the $e^-$ energy
- ⋆ Particle identification
- ⋆ Generate trigger
- ⋆ ~ 2000 LYSO crystal scintillators

# Straw-Tube Tracker

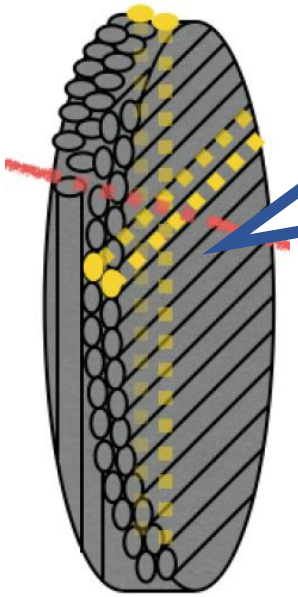


Vacuum,
Magnetic field
( ~ 1 T )

**Consists of five stations.**

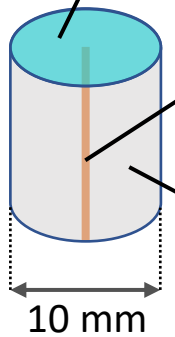



**Straw-Tube Tracker**



4 layers/station
2 layers : X-coordinate
2 layers : Y-coordinate
120 straw/layer

Chamber gas
Ar : $C_2H_6$ (50 : 50)




Sense wire
(Au-coated W)

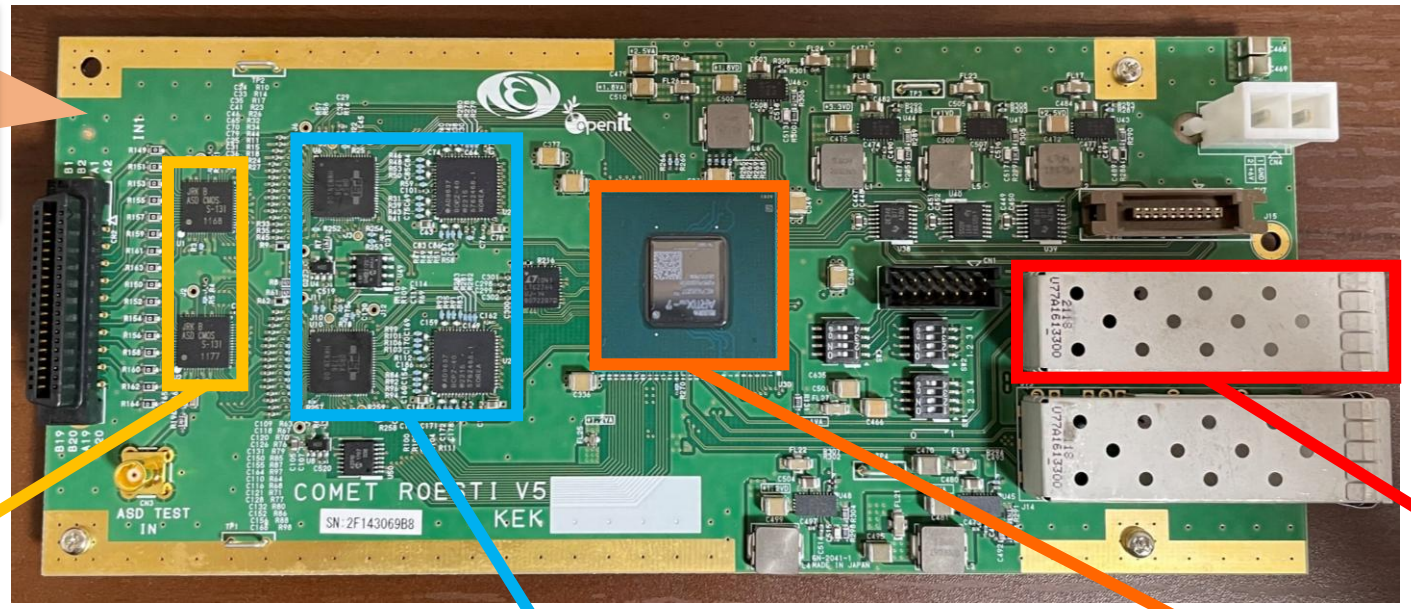
Aluminized
-Myler Tube.
(20 μm thick)

★ The use of this low-mass detector in vacuum further enables strong suppression of multiple scattering!

# Electronics

## Read Out Electronics of Straw Tube Instruments

**ROESTI was developed by us specifically for the straw-tube tracker!**




**16 ch**
**(16 Straws)**

**Signal**

**Data**

**Signal**

**ASD (Belle-II)**
(Amp-shaper Discriminator)

- Signal **amplification** : 1.1 V/pC
- Waveform **shaping**

**Waveform Digitizer**

**DRS4 (PSI)**

- 8 ch/chip
- 1024 **switched capacitor**/ch
- 1 GSPS sampling

+

**ADC**
AD9637BCPZ-40
(Analog/Digital Convertor)

- 8 ch/chip
- Resolution 12 bit
- 3.3 MSPS

**FPGA**
Artix-7

- **Store** the waveform data in a buffer and **transfer** the data upon trigger signal.
- **Control** ASD, DRS4 and ADC.

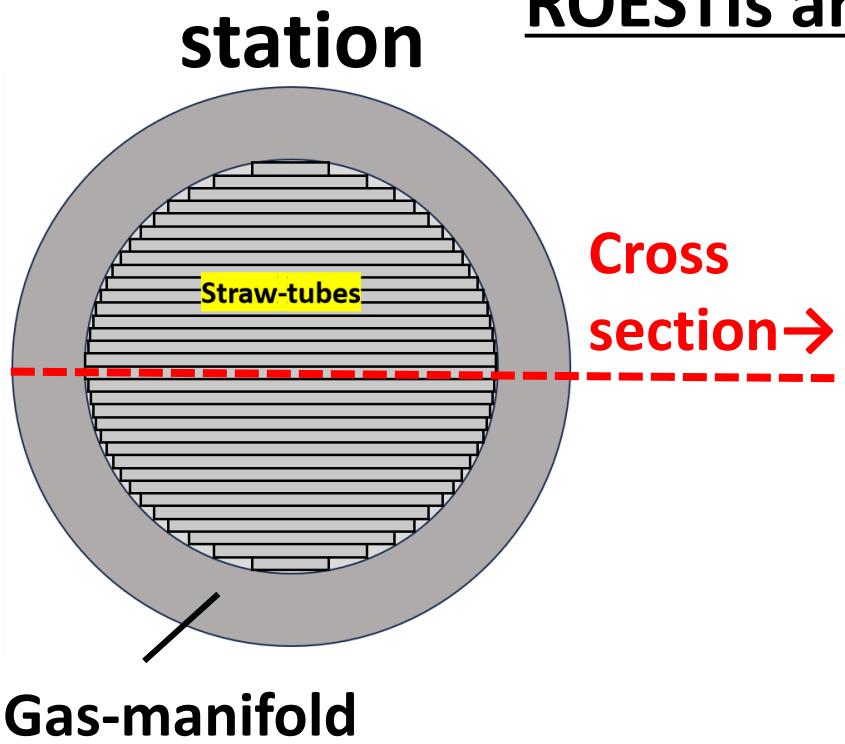
**Ethernet**

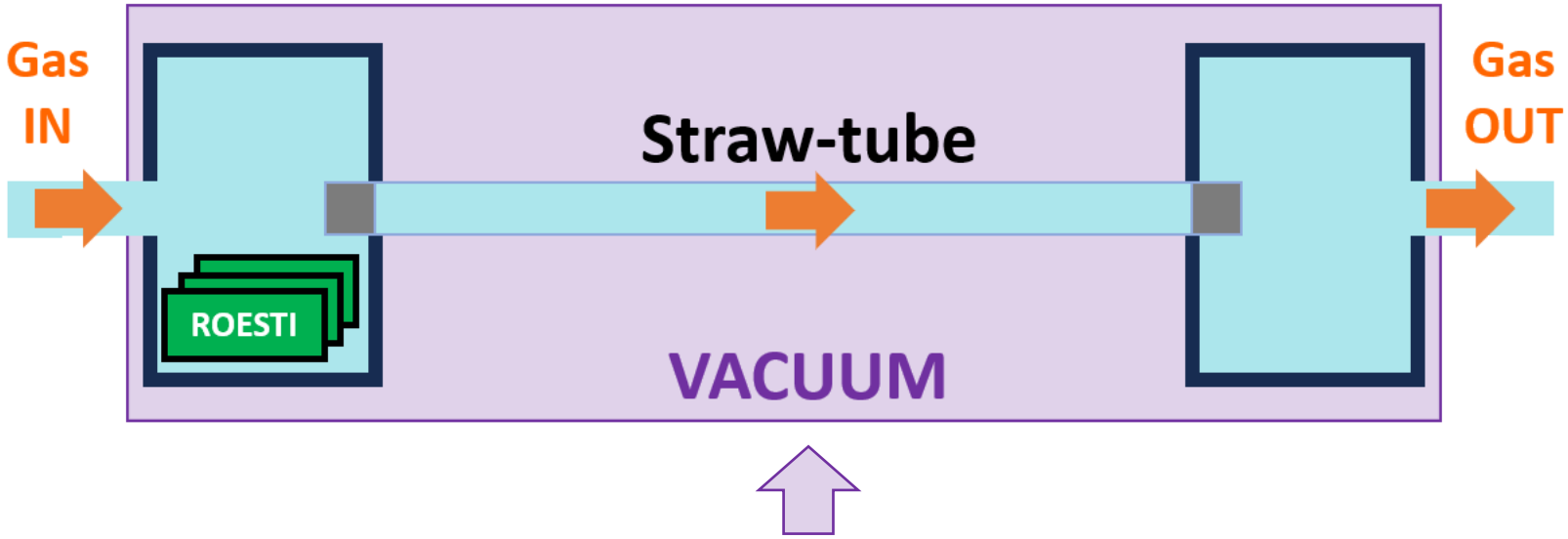
- **Transfer** the data to the DAQ PC.

**Data**

# ROESTIs Integration and Cooling

**ROESTIs are integrated inside the gas-manifold**



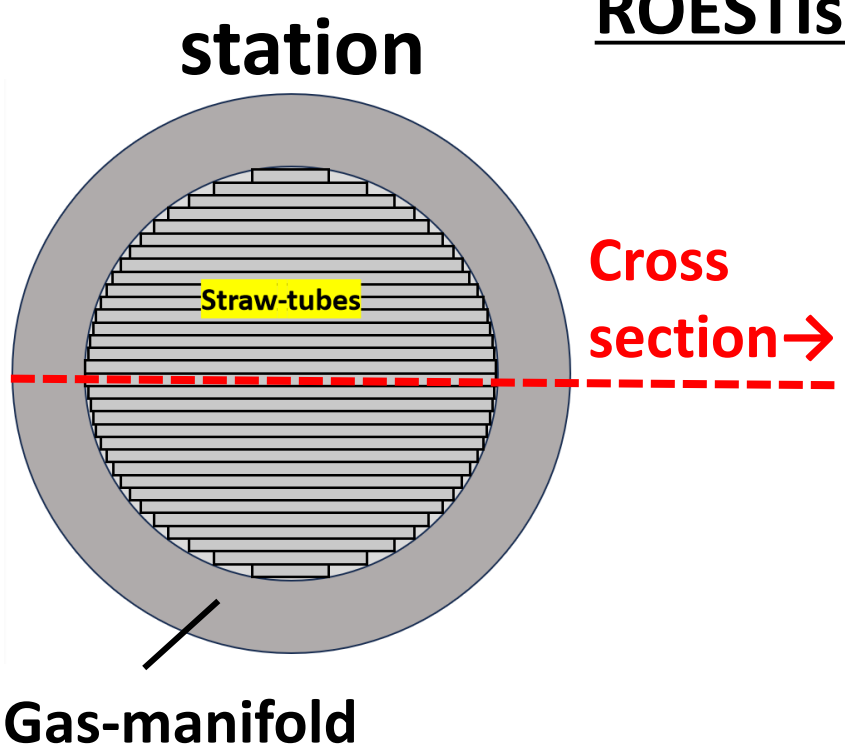

**Operation in vacuum**

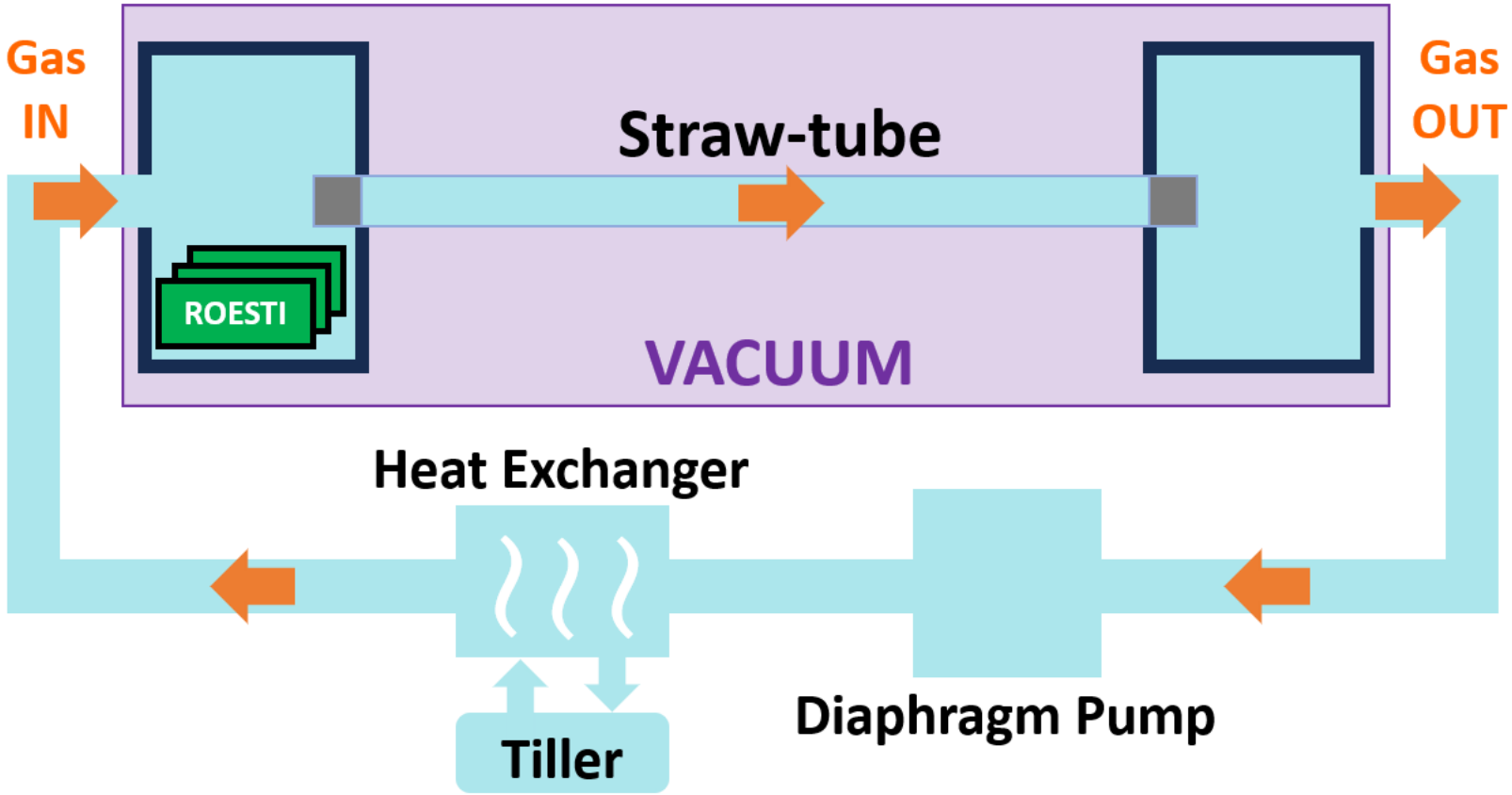
⇒ **Heat dissipation** of the electronics is necessary.

However, due to the limited space, there is no room to implement a cooling system …

# ROESTIs Integration and Cooling

**ROESTIs are cooled by chamber gas itself !**



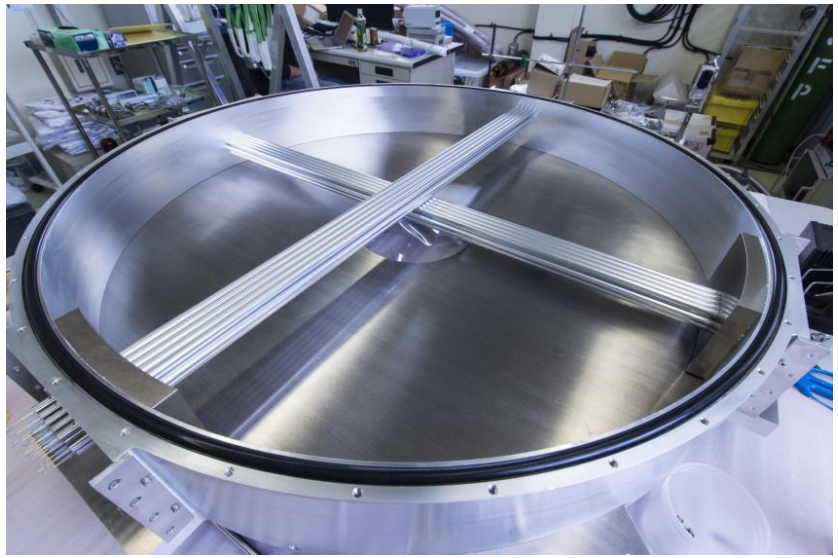

★ Enhance cooling efficiency by increasing the gas flow rate

# Full-Scale Prototype

◆ Same straw, same dimensions prototype

⋆ ROESTI was implemented

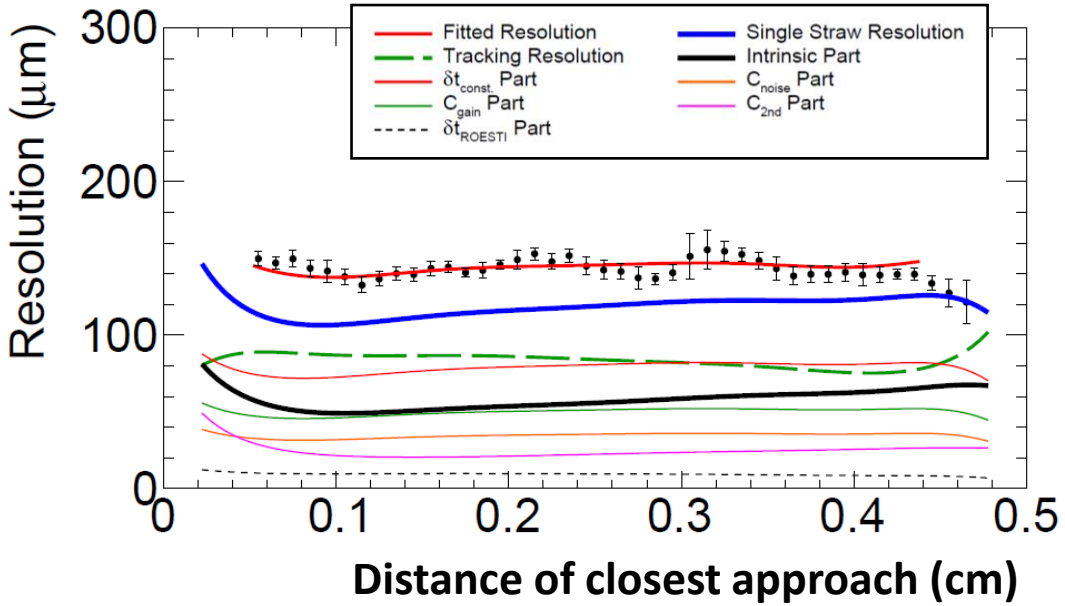
▶ It had been operated in a **50-300 MeV/*c* electron test beam** at Tohoku University (Japan).



**Requirement**

Spatial Resolution < 200 μm

⇒ **~110 μm was achieved !**




**We started to construct the final model stations going to be used in the COMET.**

# Construction

## ◆ Production of the straws

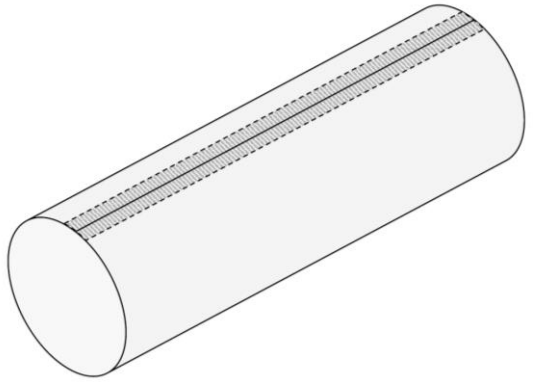
- Straight-adhesion type can achieve extremely thin wall.

  ⇔ Difficult to keep true circle…

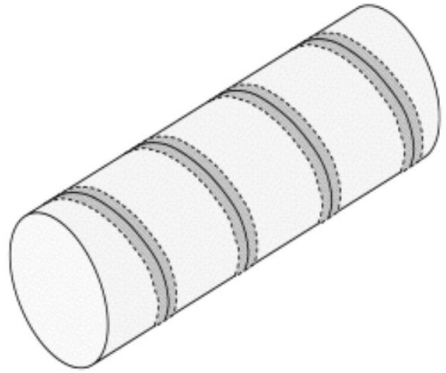
⇒ Enabled by **ultra-sonic welding** technique (by JINR-NA62) !

- JINR-COMET group succeeded to produce **20 μm-thick** straw which is thinner than NA62.

**COMET employed**



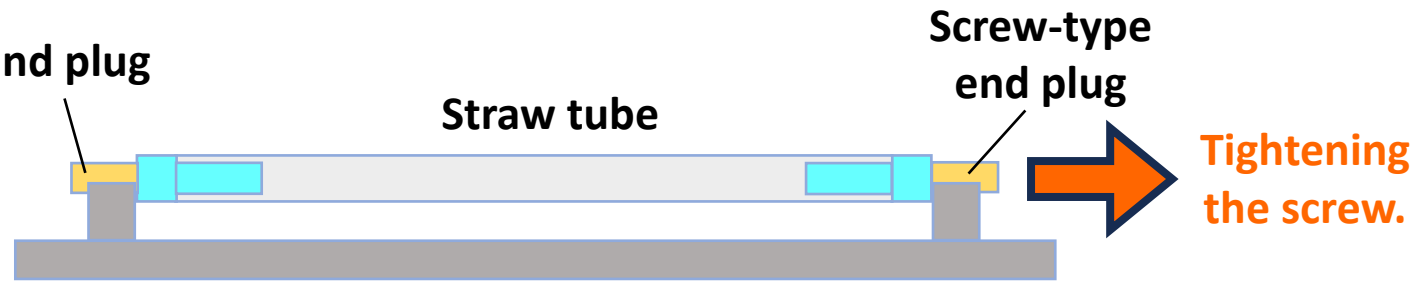
Straight-adhesion type



Double-wound type

## ◆ Pre-tensioning of the straw tubes

Applying a tension of **1 kg** to the straw tube **prevents deformation** during operation.

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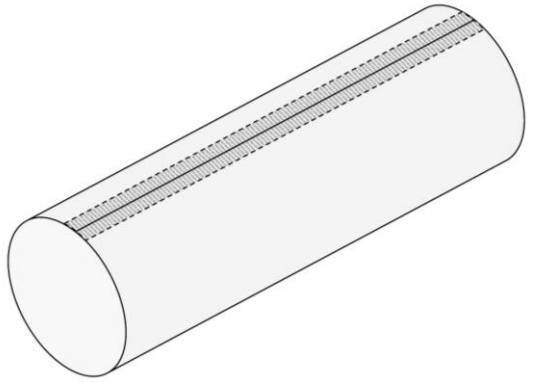
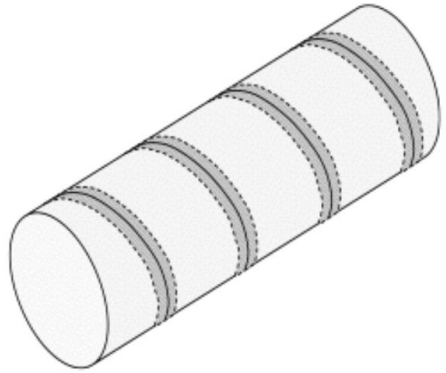


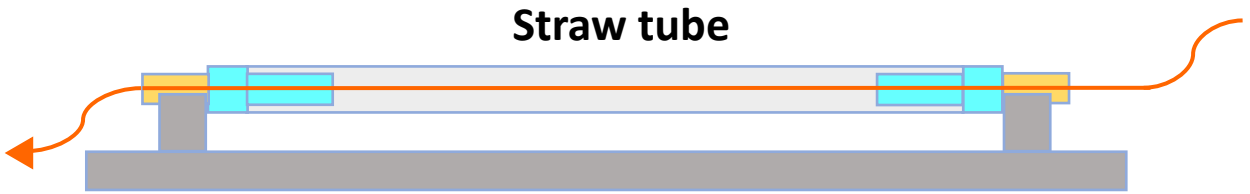
**Straight-adhesion type**



**Double-wound type**

## ◆ Installation of the sense wires

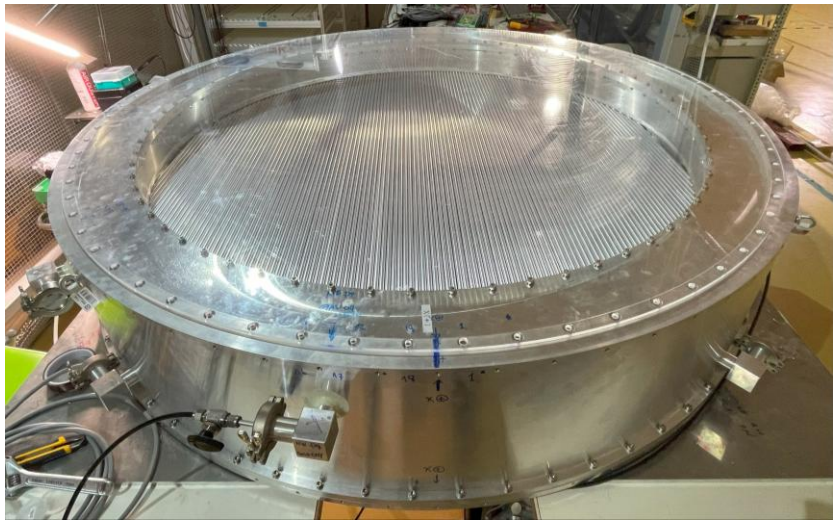
All of the sense wires are installed by our hand.



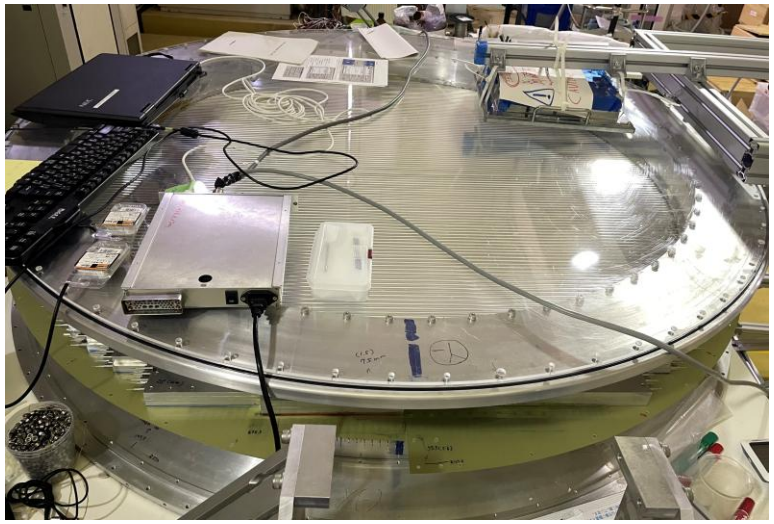
# Construction

**Construction of the 1st , 2nd and 3rd stations are completed !**

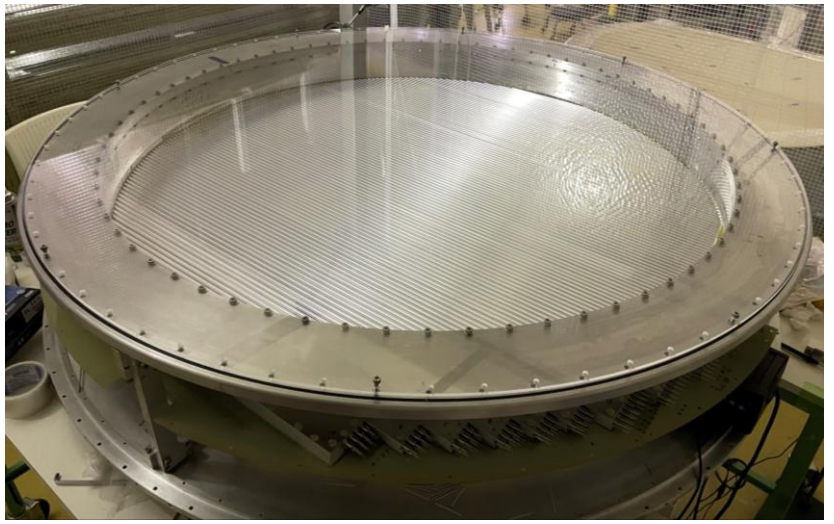
**1st station**



**2nd station**



**3rd station**



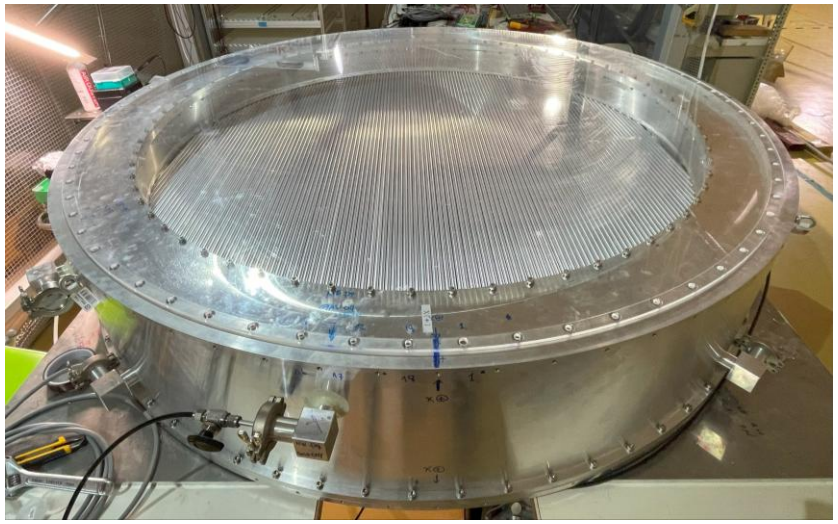
4th and 5th stations are going to be constructed in JFY2025-2026.

# Construction

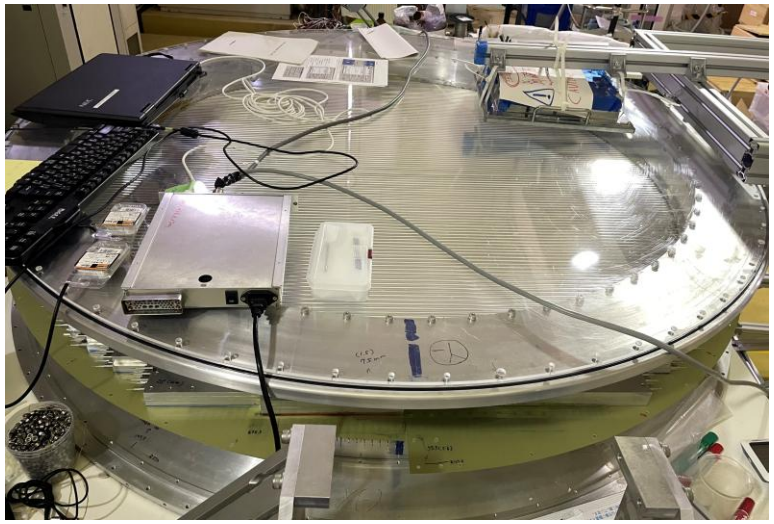
**Construction of the 1st , 2nd and 3rd stations are completed !**

**Read-out system is implemented.**

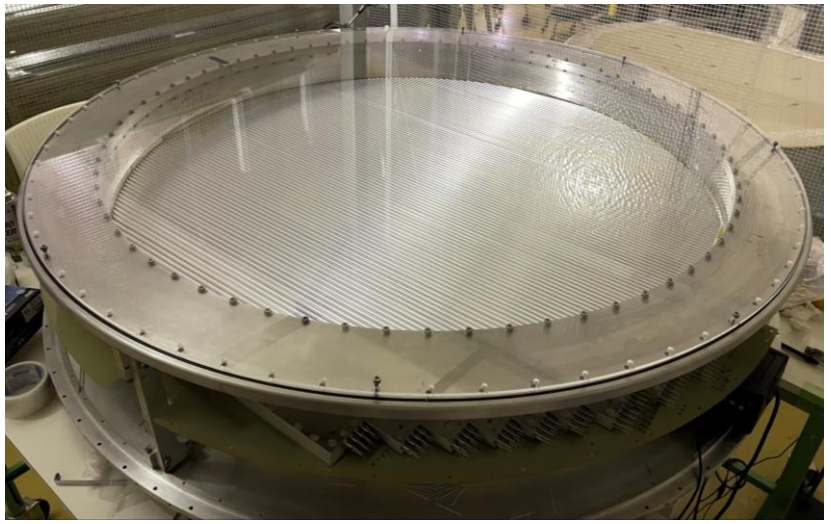
## 1st station



## 2nd station



## 3rd station



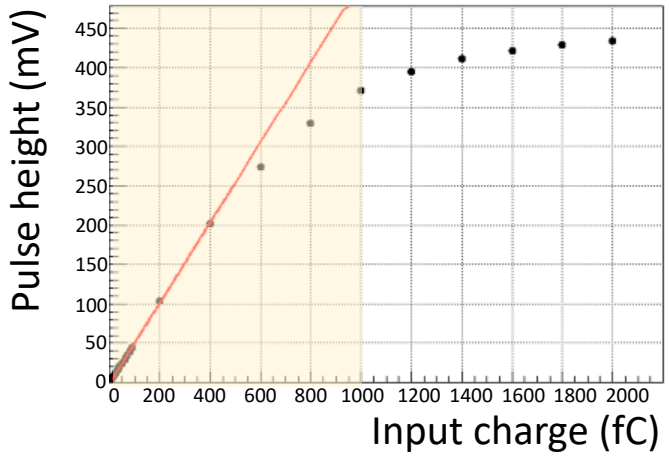
4th and 5th stations are going to be constructed in JFY2025-2026.

# Standalone evaluation of the ROESTIs

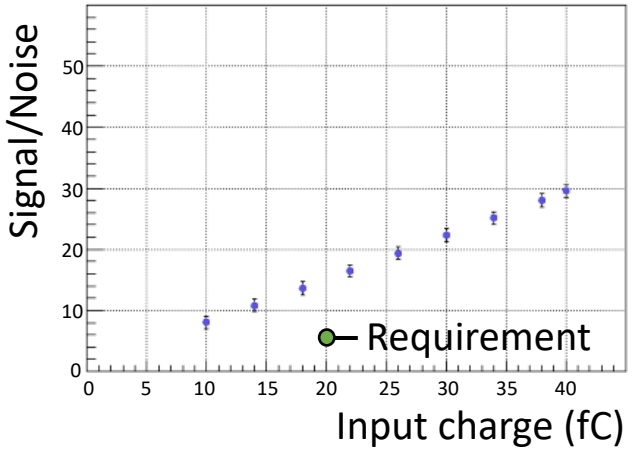
We evaluated the performance of the 30 ROESTI boards for the 1st station.

## Dynamic Range

**Requirement : 20-1000 fC**

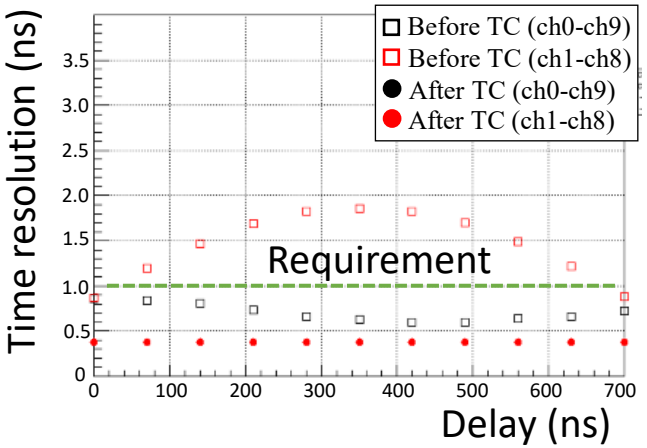



## Signal/Noise ratio




## Time Resolution

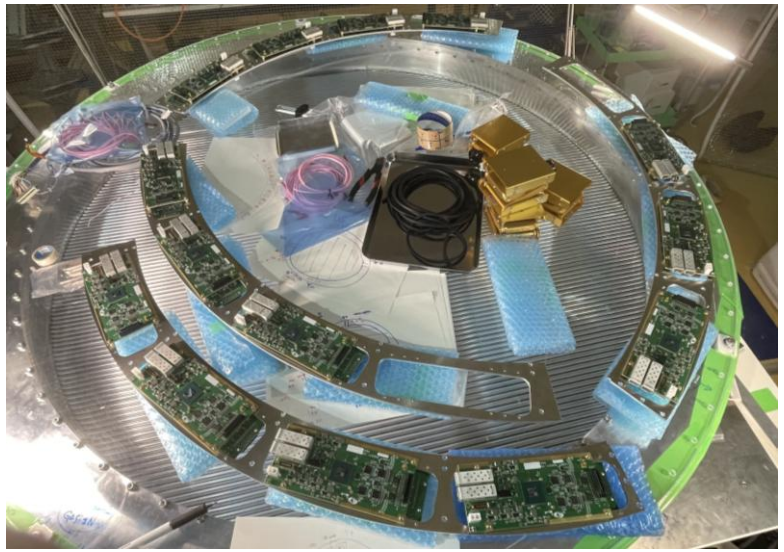
**w/o & w/ timing calibration(TC)**

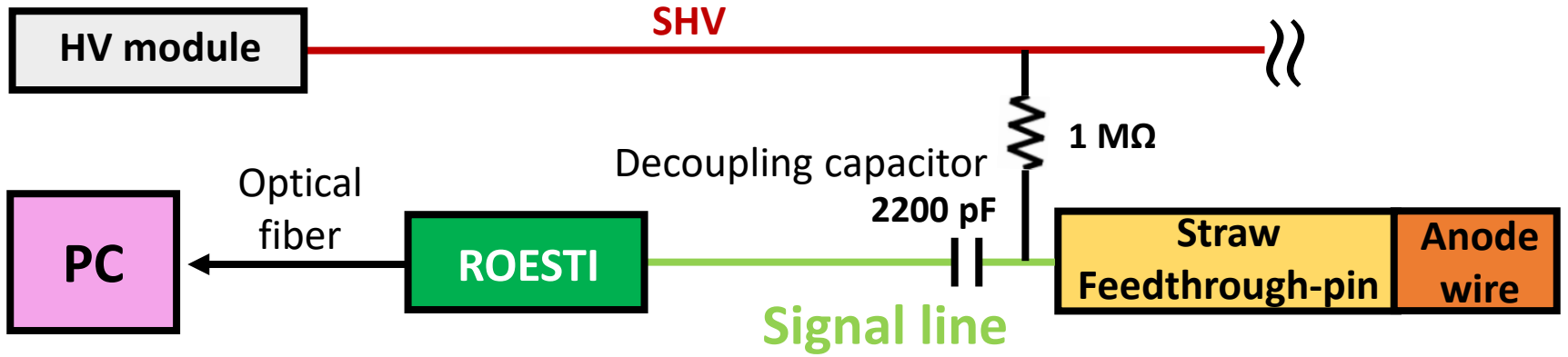



**All of the ROESTI for the 1st station met required performance.**

# Implementation of the readout system

The readout system has been implemented in the 1st station.





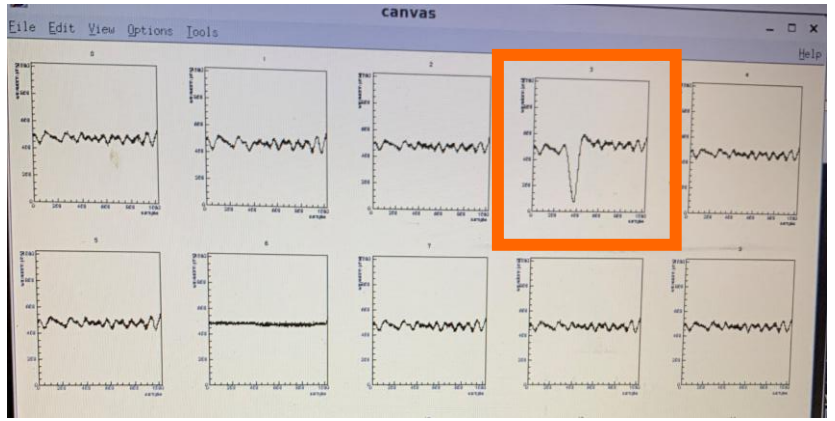
# Operation check of the 1st station

## ◆ Signal read-out

- We check the signal read-out with checking source

⇒ We confirmed that the signal read-out system is operating correctly.

**The first signal by the 1st station**

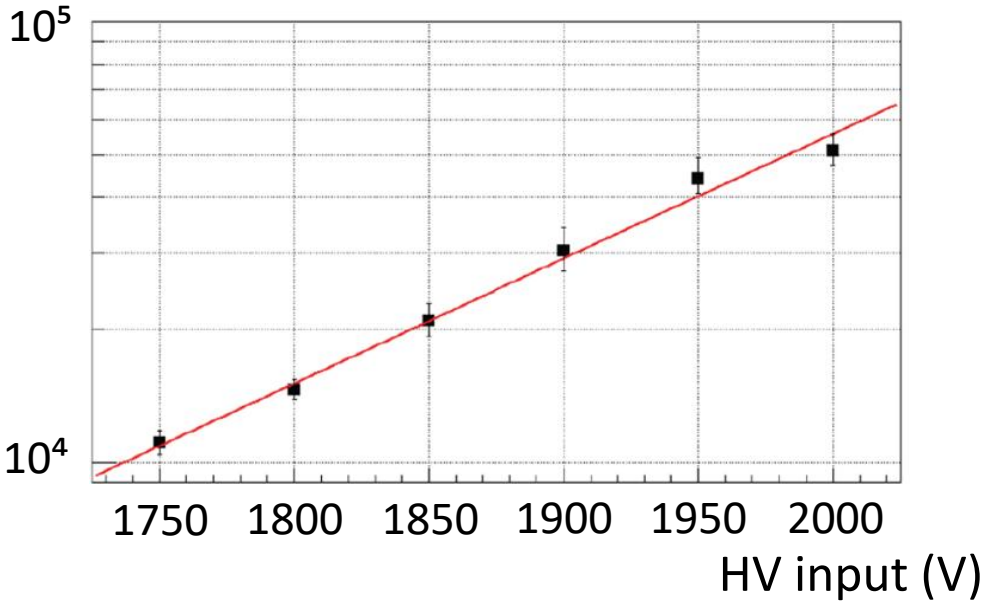



## ◆ Gain

- We Evaluated the gas amplification factor at each applied HV (1750-2000 V).
- $^{55}$Fe (X-ray) source was used.

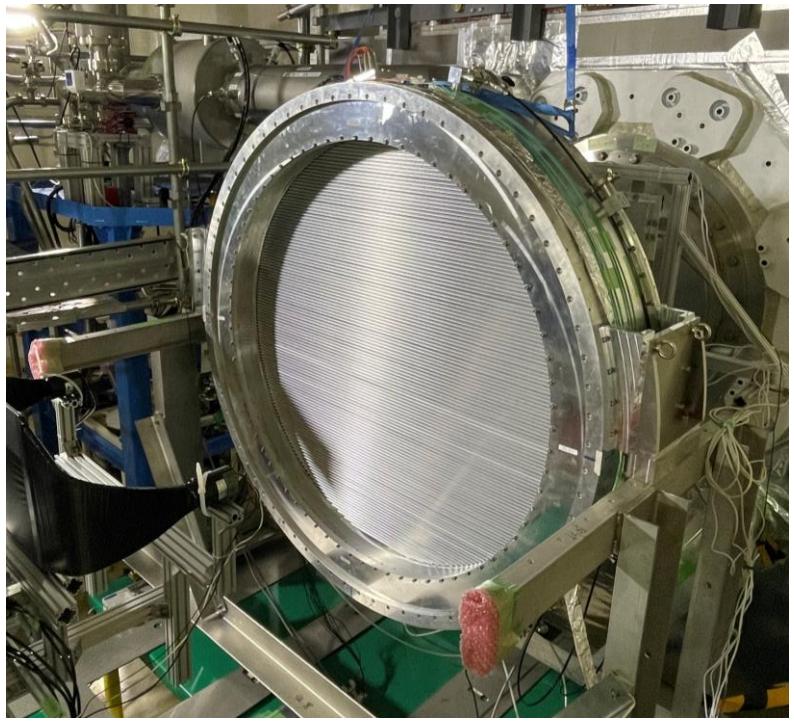
⇒ We confirmed over $10^4$ gain @ >1750 V.

**Gain curve**

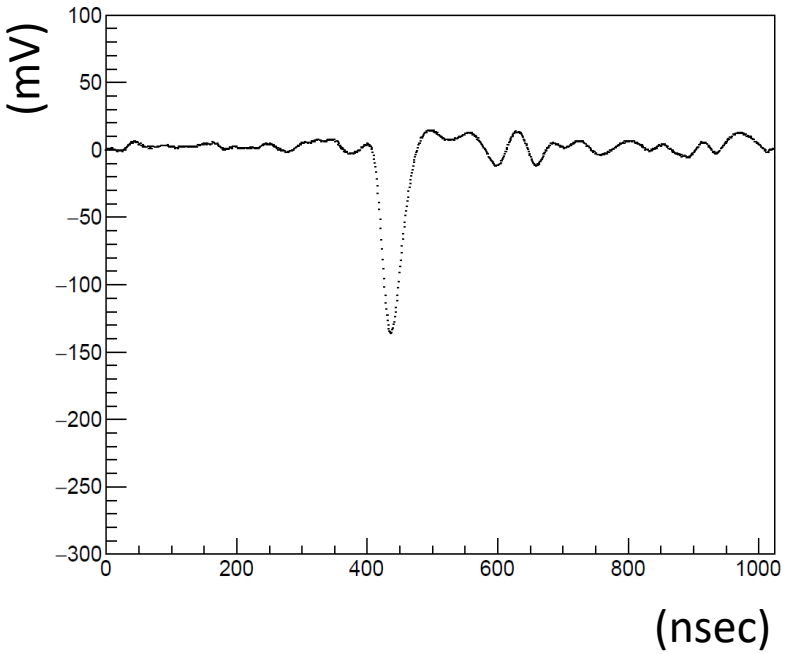


# Commissioning

We operated the 1st station in the COMET beam commissioning ( Phase-α )



**Signal obtained in Phase-α**




We succeeded in obtaining
**the first signal !!**

In addition to achieving successful signal readout,
we identified issues to **improve**.

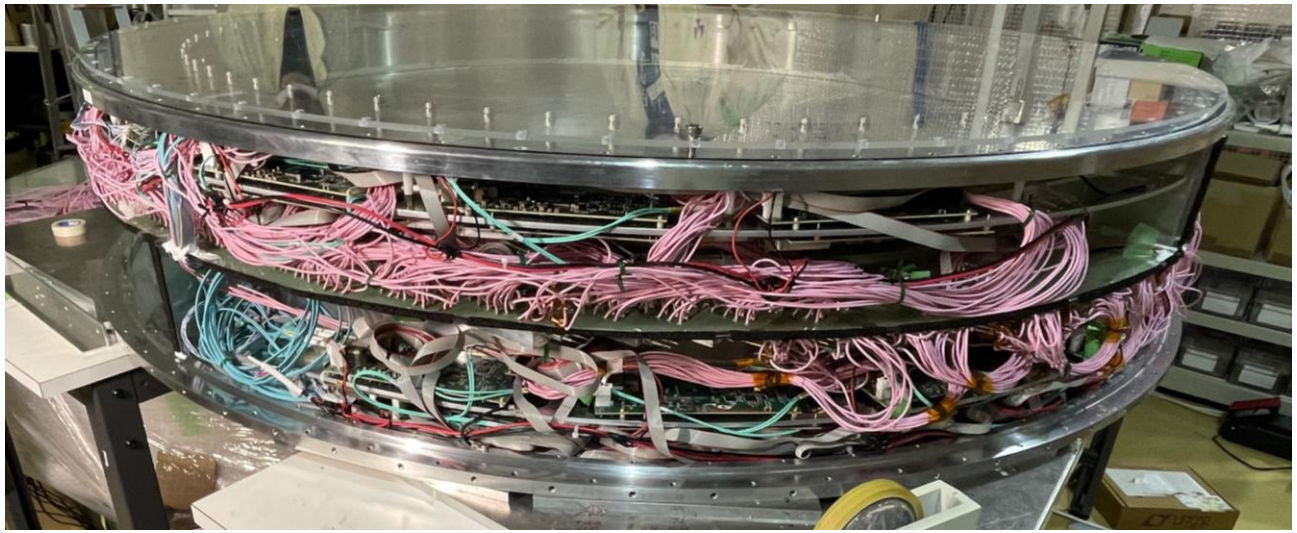
# Improvements

In particular, the noise issue needed to be resolved.

**Manifold space is limited.**

We reviewed and modified,

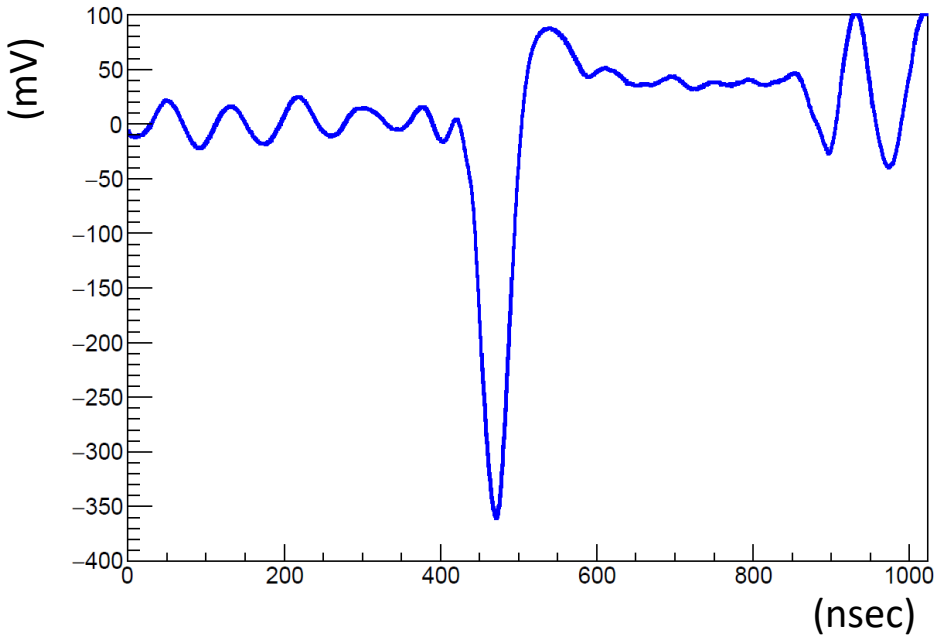
- Cabling layout.
- Cable designs.
- Grounding condition.



# Improvements

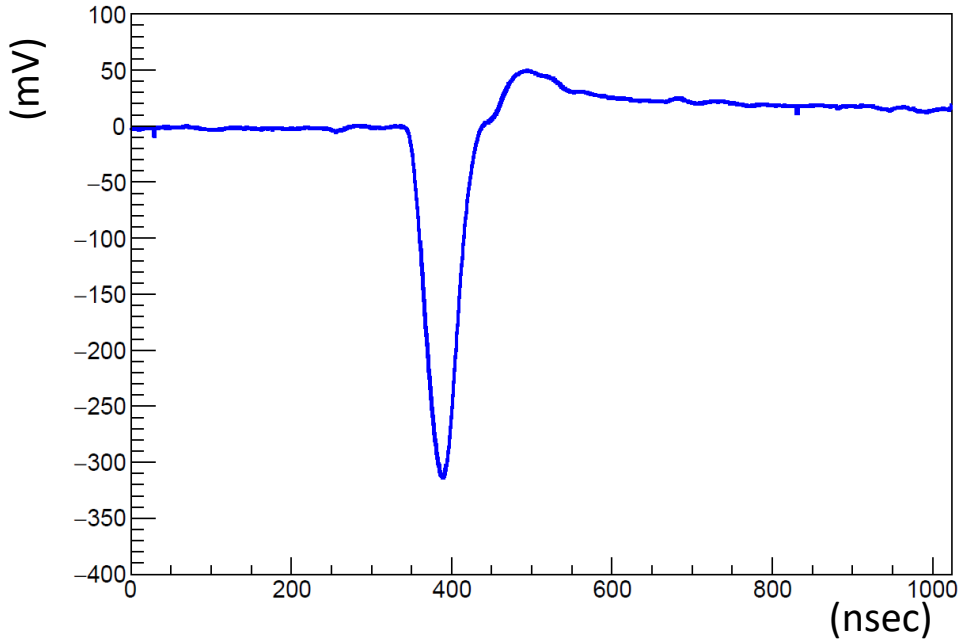
⇒ As a result of modifications, we successfully eliminated the baseline noise that had been observed in the 1st station.

## Before




Noiselevel : **13.6 mV**

## After




Noiselevel : **1.2 mV**

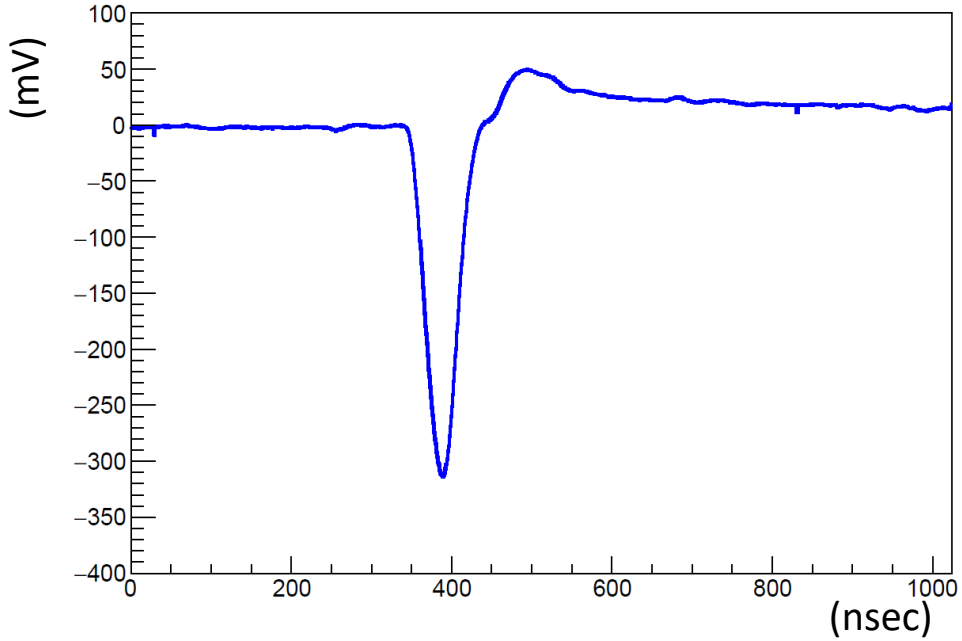
# Improvements

⇒ As a result of modifications, we successfully eliminated the baseline noise that had been observed in the 1st station.

**NEAR FUTURE WORK**

**The spatial resolution of the 1st station is going to be evaluated using this optimized data taking system.**

**After**




Noiselevel : **1.2 mV**

# Summary

## COMET experiment

⋆ We are going to search μ-e conversion which is one of the cLFV process.
⋆ We are aiming for 10,000x better sensitivity over the current limit.

## Straw-Tube Tracker

⋆ The detector for the momentum measurement in the COMET.
⋆ Very low-mass designed and going to be used in vacuum to suppress the scatterings.

## - Full-scale prototype

⋆ We made a same scale prototype, but fewer straw.
⋆ With a beam test, we confirmed that the straw-tube tracker can perform as it designed.

## - Construction

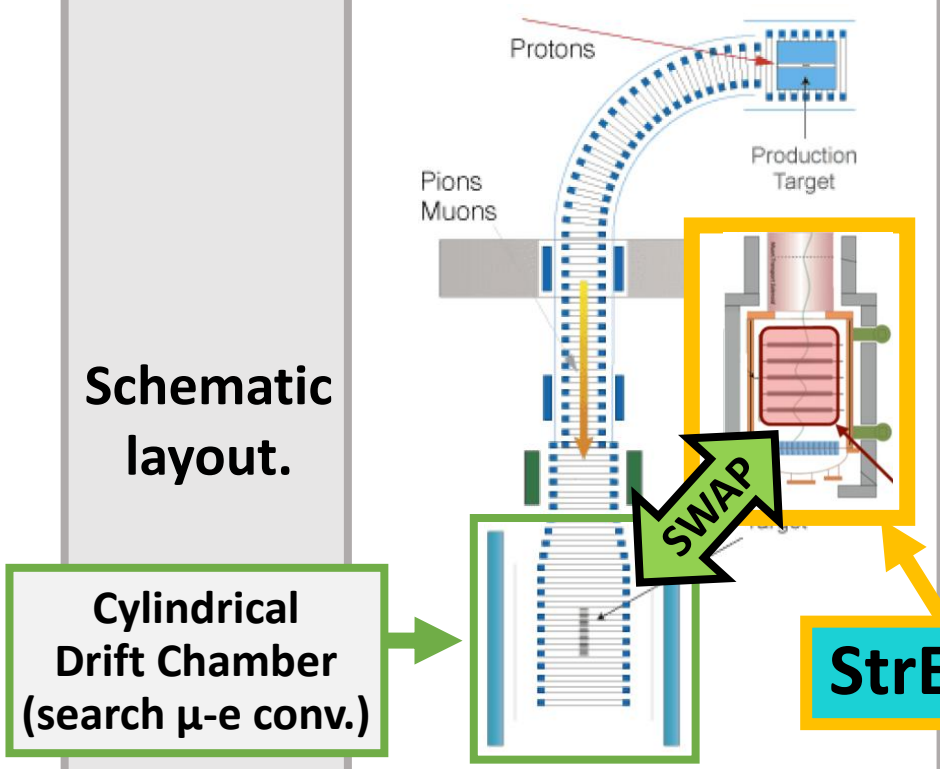
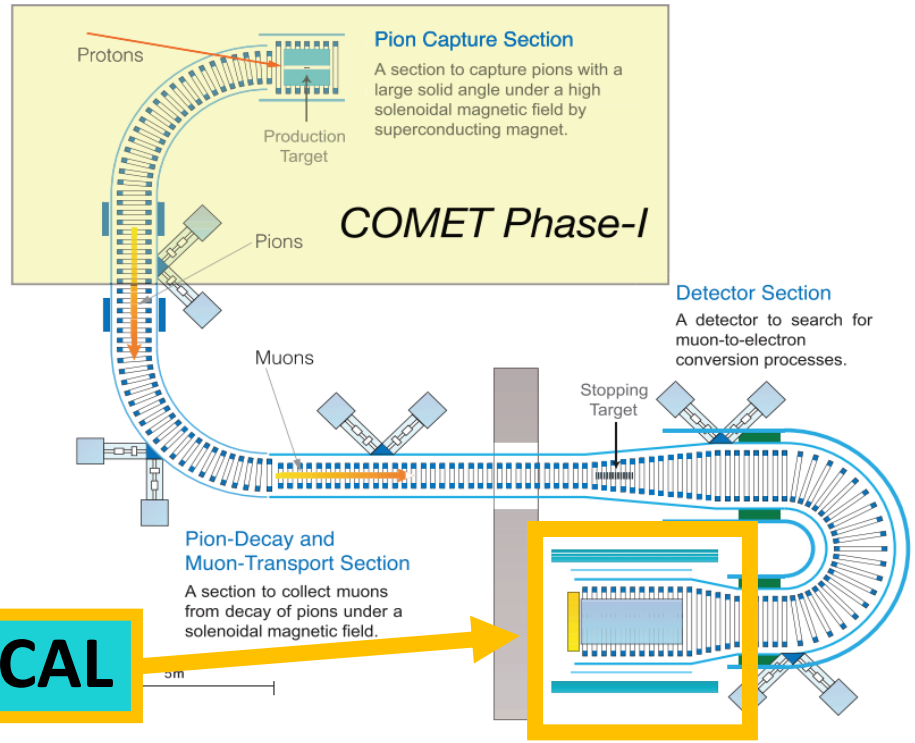
⋆ Construction of the 3/5 stations are completed, and all station is going to be constructed within JFY2025-26
⋆ The read-out electronics (ROESTI) was developed by us. 30 ROESTI boards for the 1st station was evaluated its basic performance and met the requirement.

## - Commissioning & Improvements

⋆ We successfully obtained the first signal from COMET beamline using the 1st station, and we got feedbacks
⋆ The noises were eliminated by improvement. The spatial resolution of the 1st station is going to be evaluated.

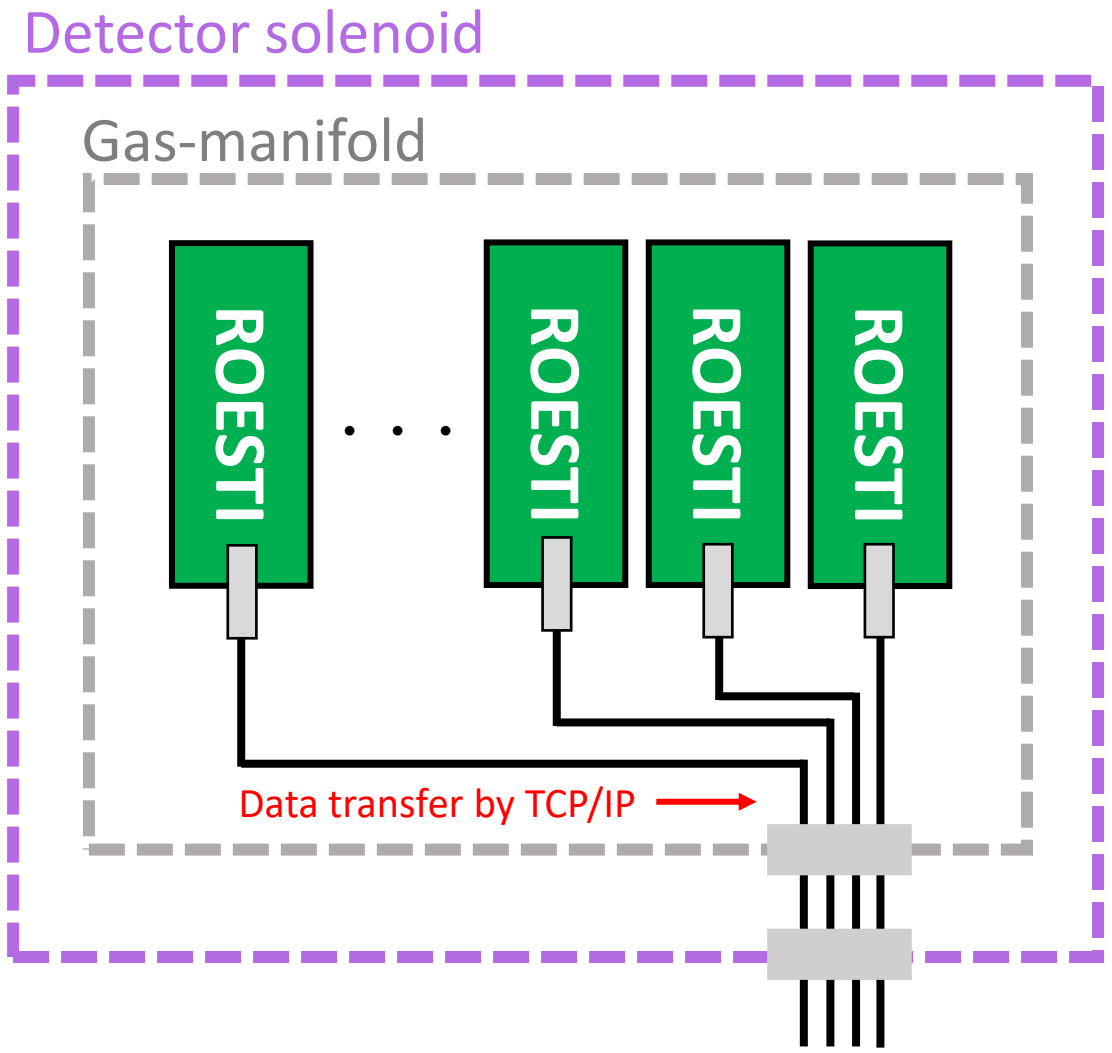
# Appendices

# StrECAL in the COMET Phase-I&II

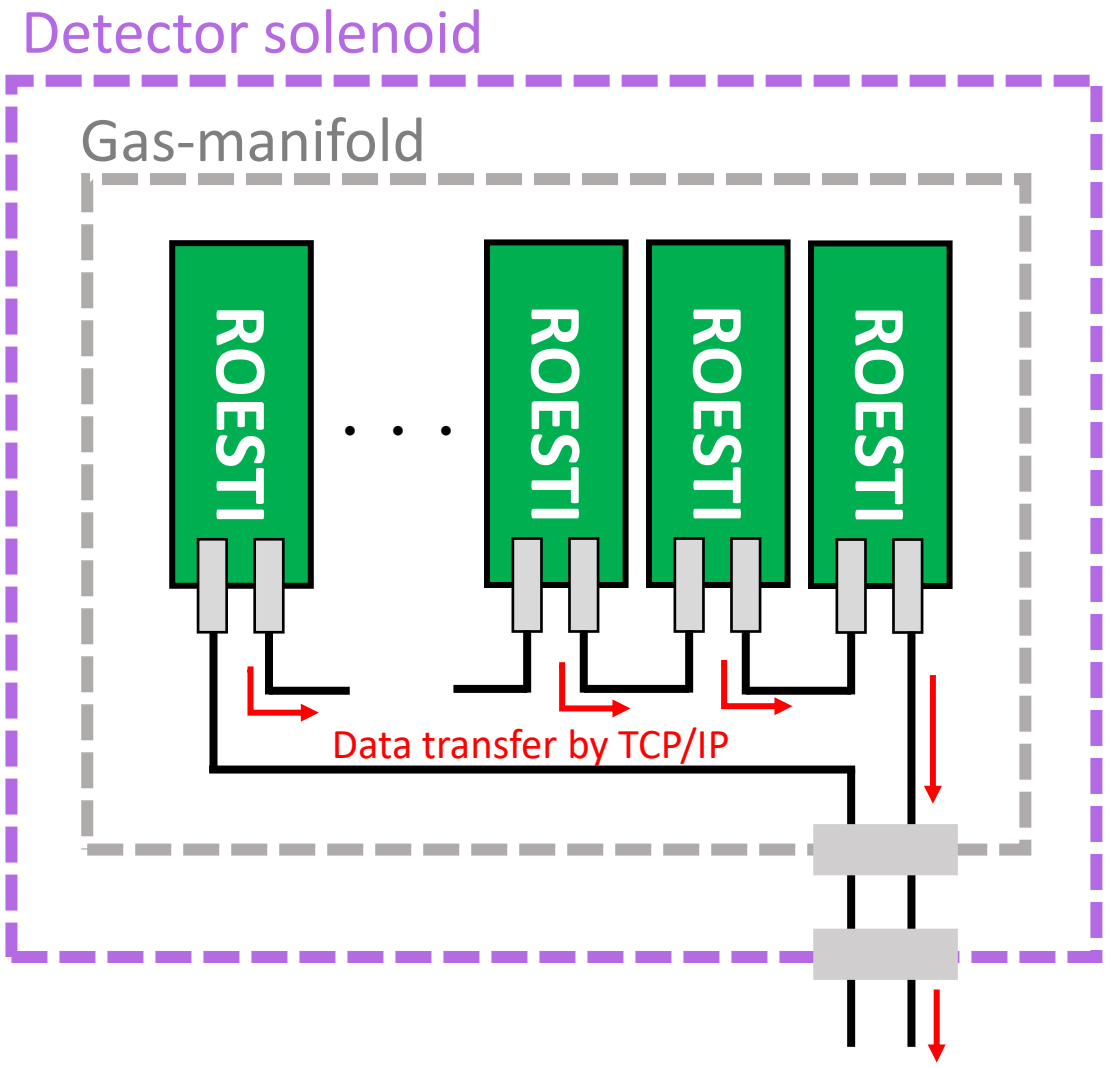
| | Phase-I | Phase-II |
|---|---|---|
| Schematic layout. |   |   |
| StrECAL | Beam measurement | Search for the μ-e conversion |

# ROESTI : Daisy Chain

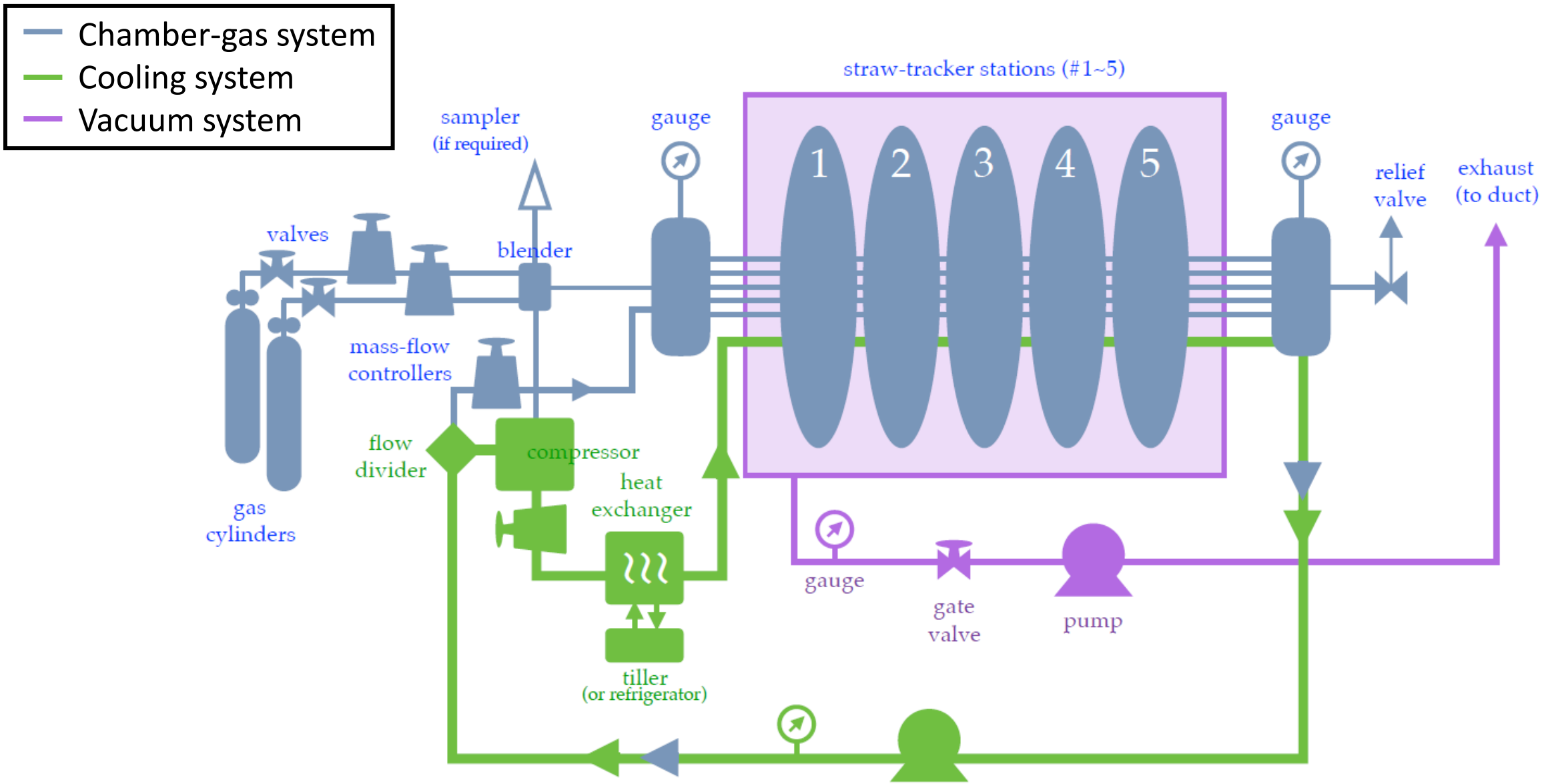
## Conventional Connection




## Daisy Chain Connection

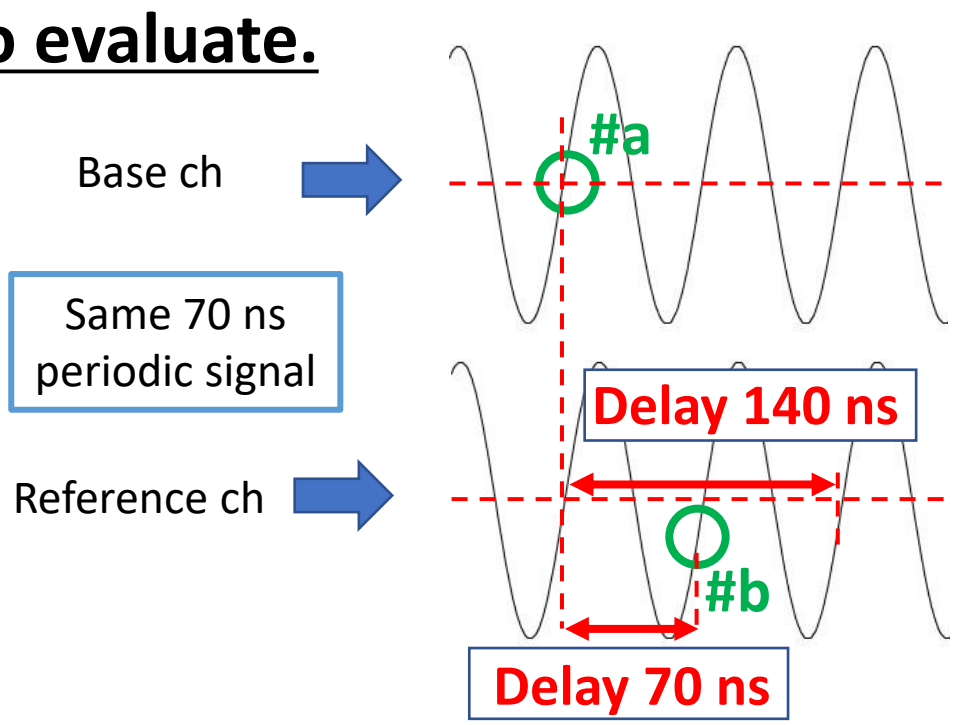


# Gas, Cooling and Vacuum Systems



# ROESTI : Time resolution evaluation

## How to evaluate.



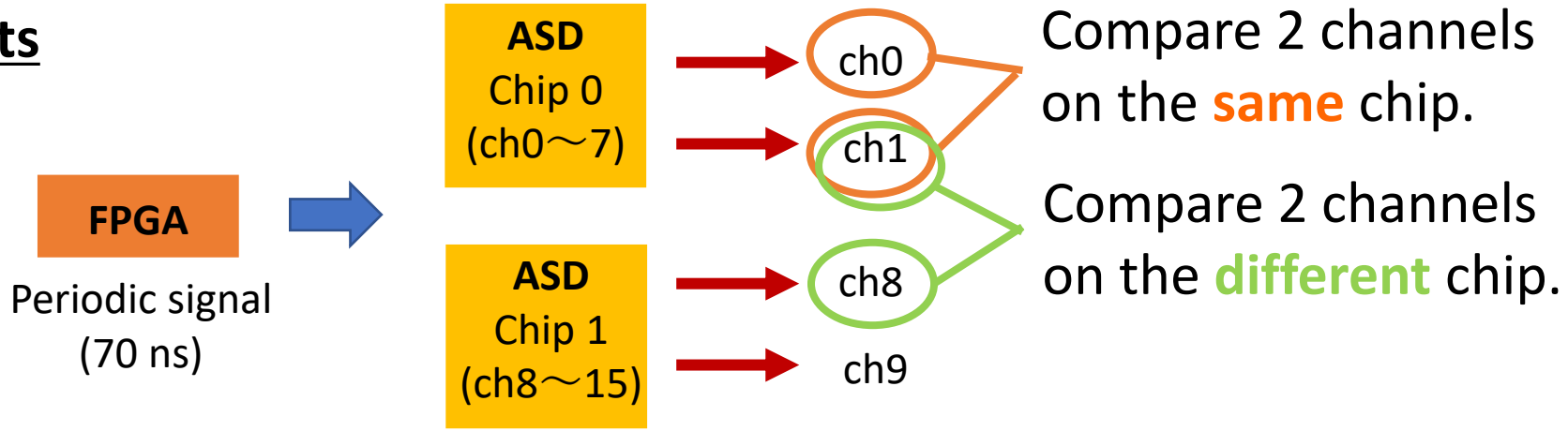

Ex ) Delay 70 ns

- Fill hist with (#b - #a) for 30000 events
- Define (RMS of hist) = (Time Resolution)

Calculate it for each delay (0 ns-700 ns)

## 2 types of measurements

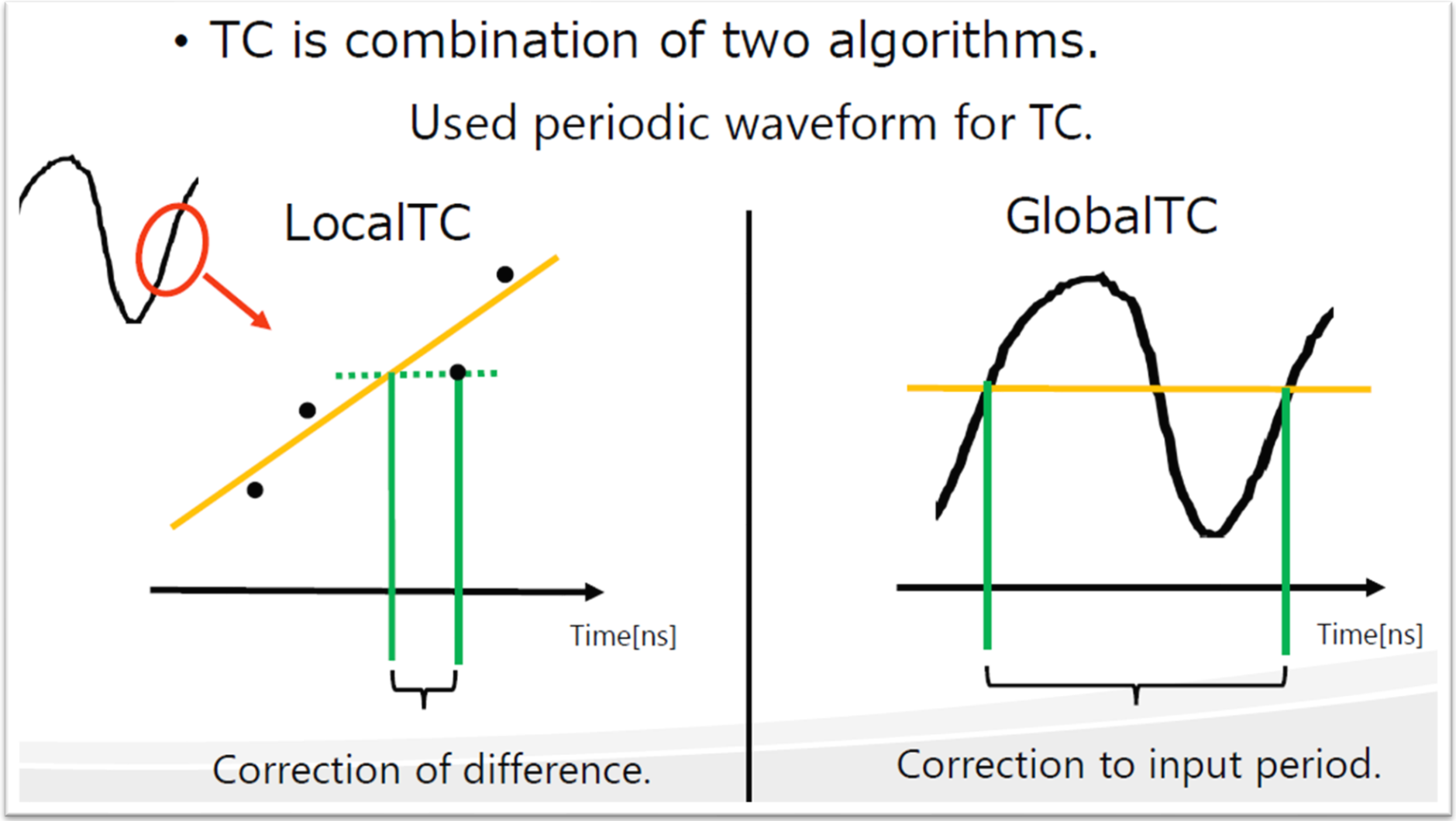
- Same chip channels
- Different chip channels



# ROESTI : Time resolution evaluation (con'd)

## Timing calibration

← DRS4's sampling interval is not exactly 1 nsec.



# Straw : Cross section