Development of a thin-wall straw-tube tracker for COMET experiment

Kazuki Ueno (KEK)
on behalf of the COMET collaboration
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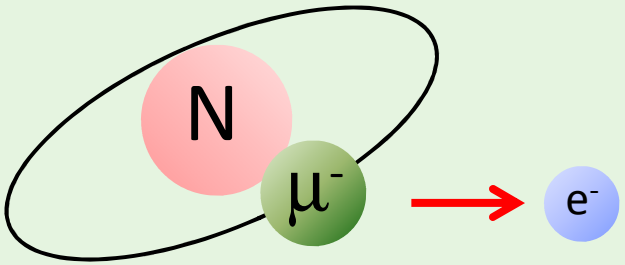
Outline

- The COMET experiment
- Detector system
- Straw tube tracker
- Performance evaluation
- Summary and prospects

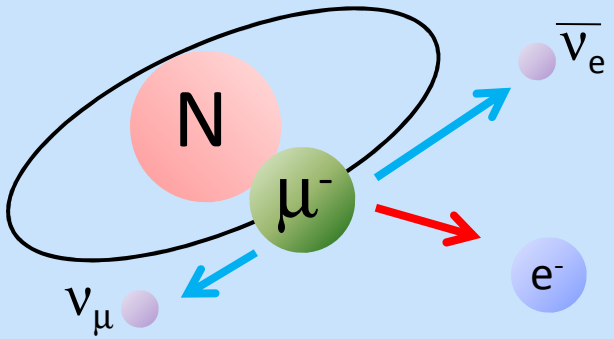
The COMET experiment

A search for "$\mu^- N \rightarrow e^- N$" at J-PARC.

- Muon-to-Electron Conversion = Lepton Flavor Violation
- Branching ratio (BR) at Standard Model (SM) + ν mass ~O(-54)
- BR at beyond SM ~O(-15)
- Our goal : O(-17) (4-order improvement from current limit)



- **Signal : Mono-energetic electron**
  $E_e = m_\mu - B_\mu$ ~ 105 MeV
- Coherent Process

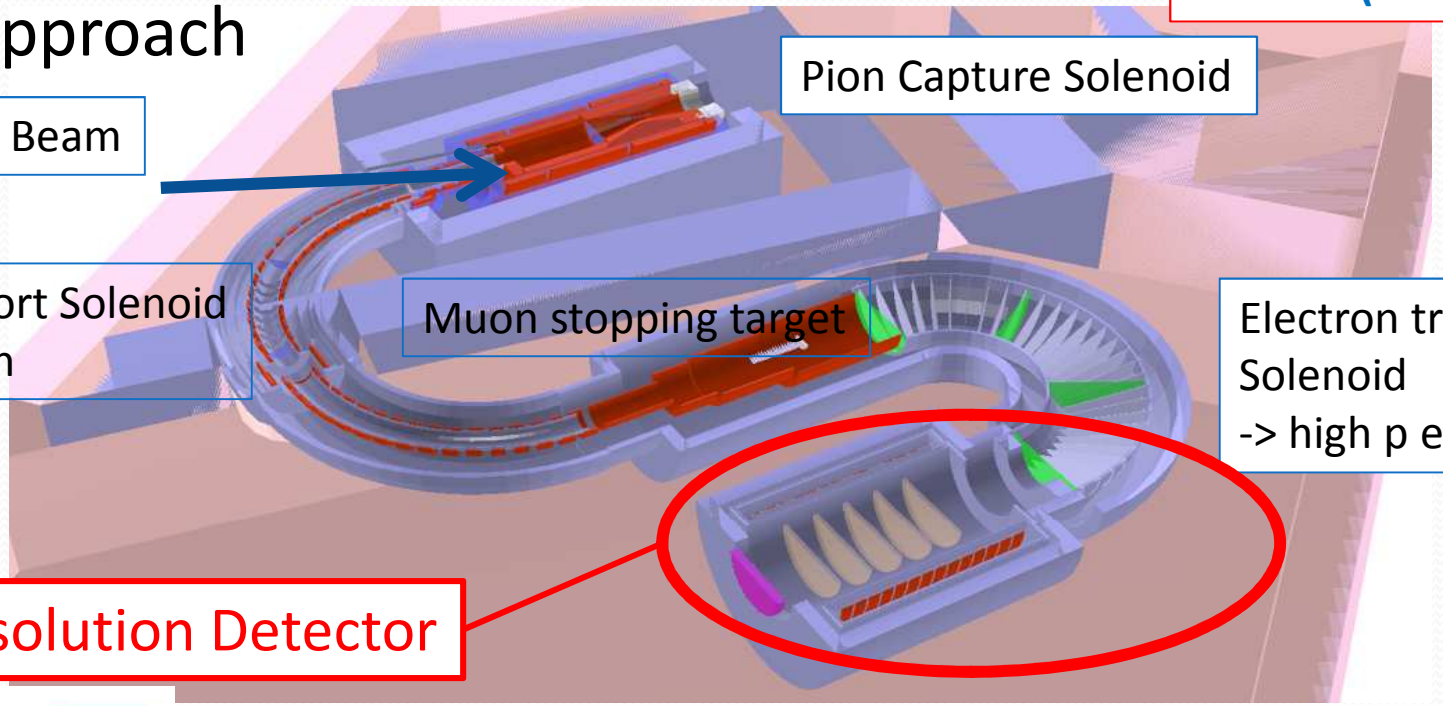


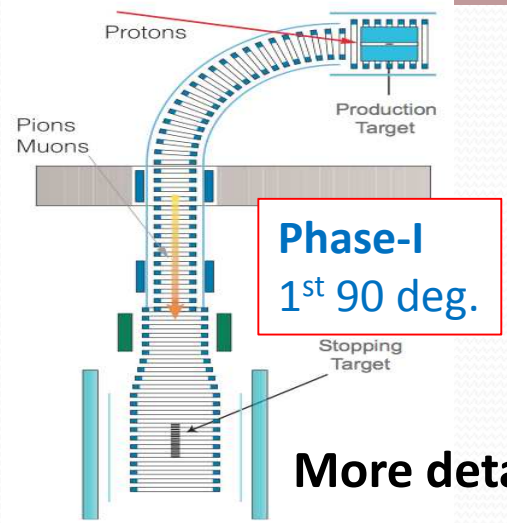
- BGs
  - Prompt (Beam-related)
  - Decay in Orbit (DIO)
  - Radiative π/μ-capture
  - Decay in Flight (DIF)
  - Cosmic-rays

The COMET experiment

Staging approach

Phase-II (final setup)





Phase-I

- 1st 90 degree setup to Phase-II is constructed.
- Search for μ-e conversion at the intermediate sensitivity of O(-15) with CDC-type tracker.
- Background study with Phase-II detector.

Phase-II

- Search for μ-e conversion at the intermediate sensitivity of O(-17).

More details will be reported by poster presentation. **H. Nishiguchi FL-15**

Detector system

Requirements

Momentum resolution is essential!

Detector should be operational in vacuum and B-field of 1 T.

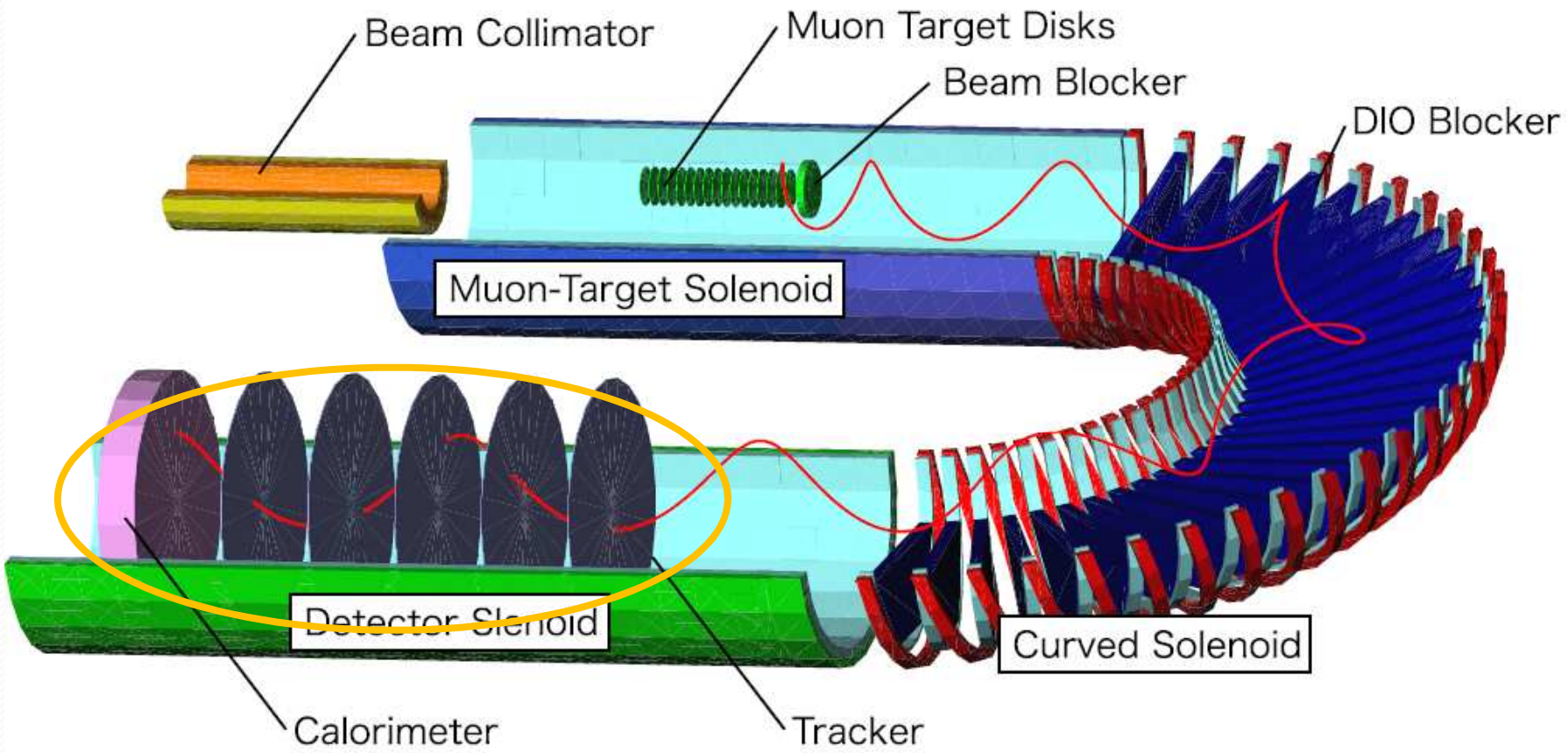
Electron tracker

- Detection of particle track in B-field -> momentum
- Momentum resolution : σ_p< 200 keV/c for 105 MeV/c e^-
- Spatial resolution : < 200μm
- Efficiency : >99%

Calorimeter

- Detection of timing, position, and energy of particles
  -> trigger, energy, and particle identification with tracker
- Energy resolution : σ_E < 5% for 105 MeV/c e^-
- Position resolution : < 1 cm
- Time response : < 100 ns

StrECal system

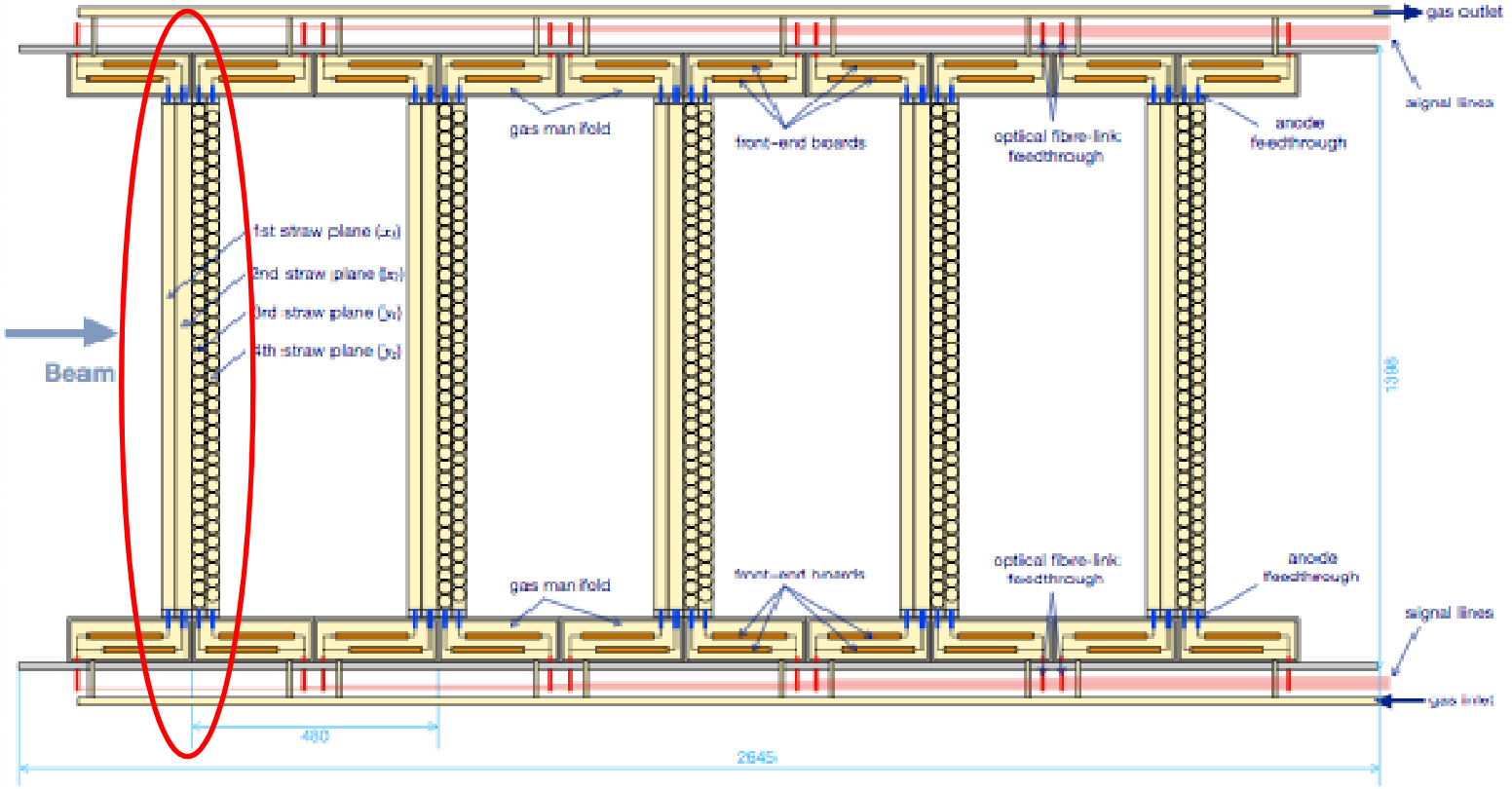


On the basis of the requirements, we employed “StrECal” system for detection and identification of 105 MeV/c electron.

StrECal= Straw tube tracker + Electro-magnetic Calorimeter

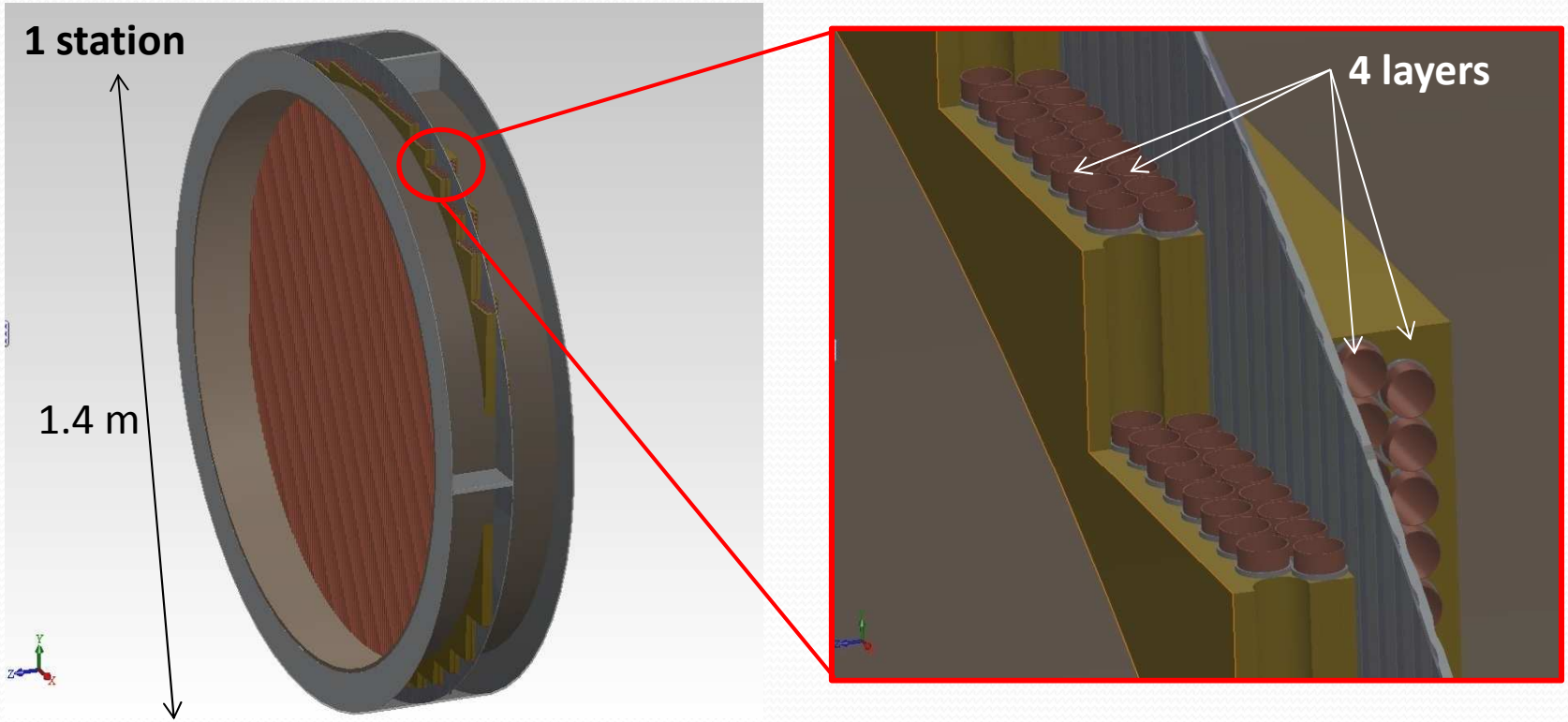
ECal : See poster presentation **K. Oishi DD-38**

Straw tube tracker



- Straw tube tracker consists of 5 stations (module).
- 5 stations consist of 4 layers of straw tubes.
- 2 layers for x-coordinate and 2 layers for y-coordinate, each layers are staggered by half a cell to solve the left-right ambiguity.
- Straw specification Gas Ar:C_2H_6 = 50:50 or Ar:CO_2 = 70:30, Al-cathode 9.75 mm diam., 0.6-1.2 m length, mylar 20μm (Phase-I) 12 μm (Phase-II),

Straw tube tracker



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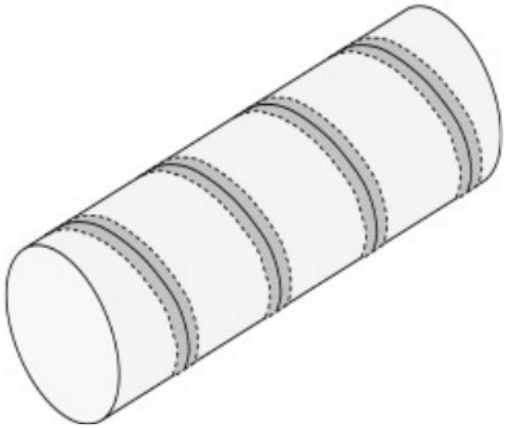
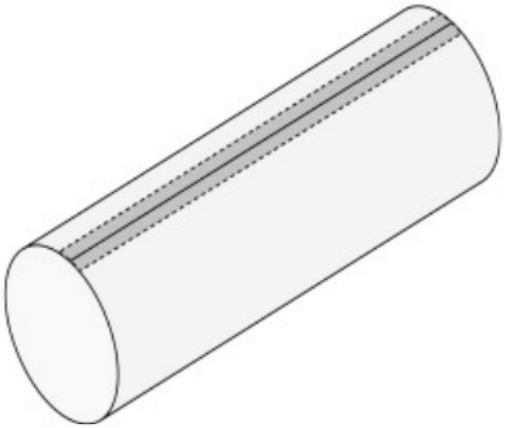
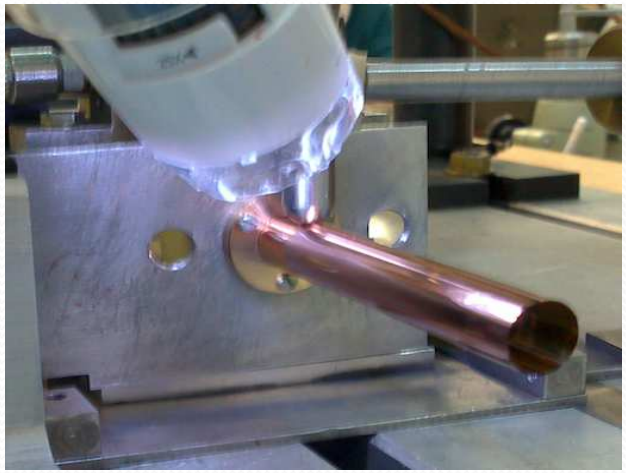


Traditional method
"doubly-wound"

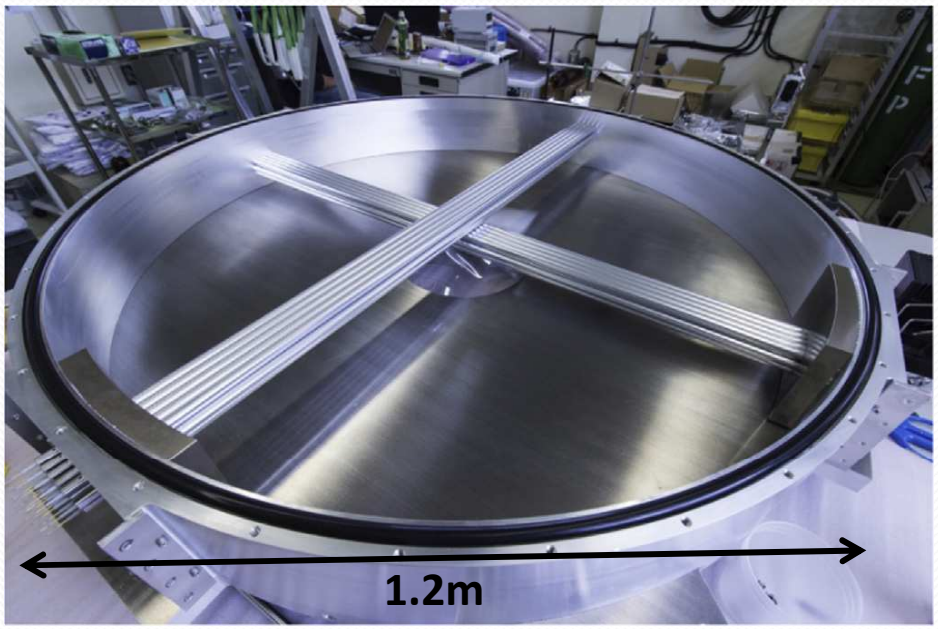


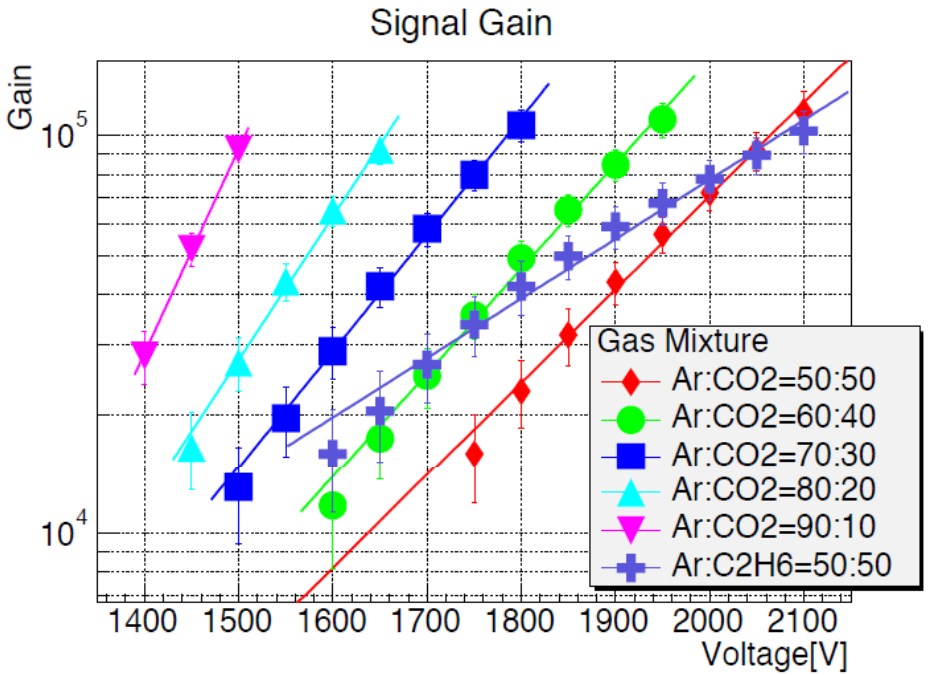
New method
"straight adhesion"



- New adhesion style developed by JINR group for NA62 exp. at CERN, which was enabled by ultrasonic welding method, was adopted for COMET.
- 1st trial (**20 μm thickness + 70 nm Al deposition**) was successfully done.
- Straw mechanical properties in vacuum has been already investigated in detail.
- 2nd trial (**12 μm thickness + 70 nm Al deposition**) is ongoing.

Prototype of straw tube tracker





- Prototype tracker was constructed using 20 μm COMET straw.
- It consists of 32 straw tubes (16 for X and 16 for Y).
- Fundamental performance evaluation has been done with general readout system.
- Gas gain were investigated as a function of applied HV and gas mixture.
- Good performance was confirmed.
- More details are described in *H. Nishiguchi et al. NIM A 845 (2017) 269*.

Readout electronics

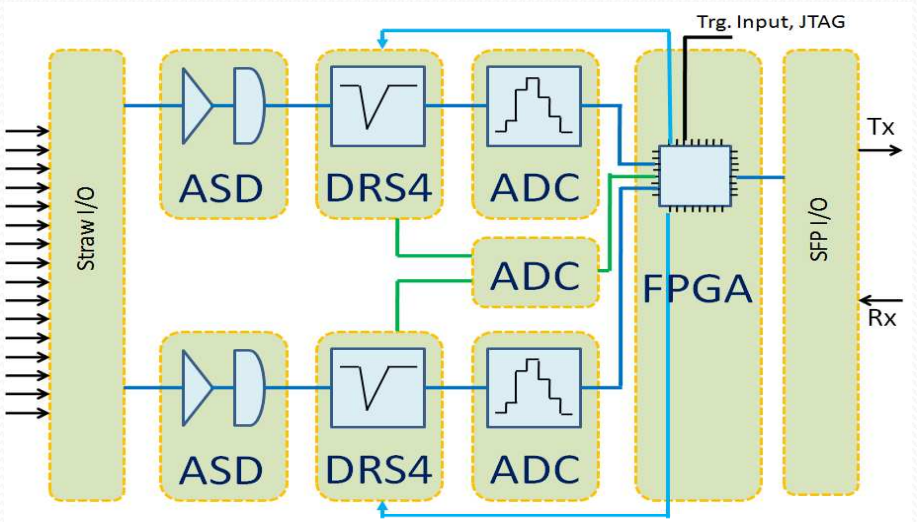
Own readout electronics has been newly developed.

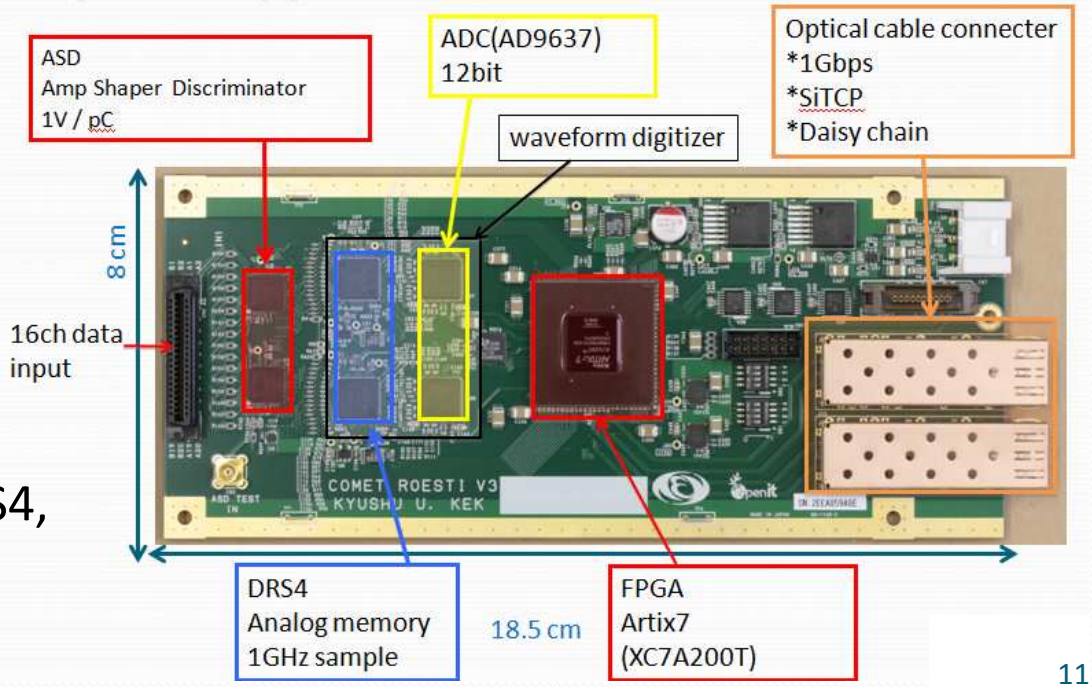
ROESTI : Read Out Electronics for Straw Tube Instrument

<Requirements>

- Pileup identification -> WD
- Timing resolution -> <1 ns
- Gain -> 1 V/pC
- # of feedthrough -> Daisy chain
- Radiation tolerance -> Reported at IEEE NSS 2016

•Pre-amplification, shaping, and discrimination are done by ASD and waveform digitization is done by DRS4, controlled by FPGA-based local bus control system on the board.

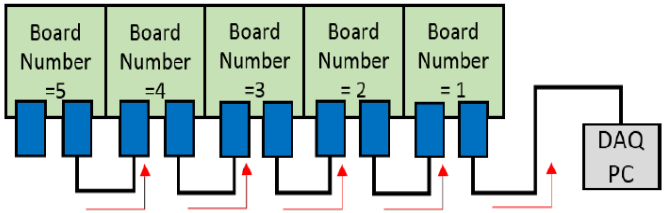


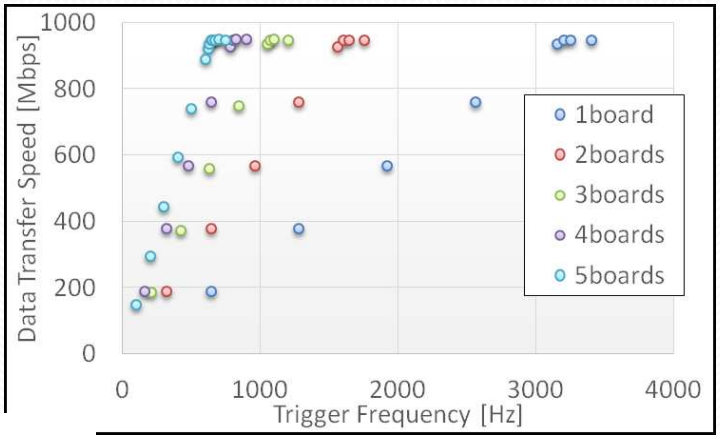


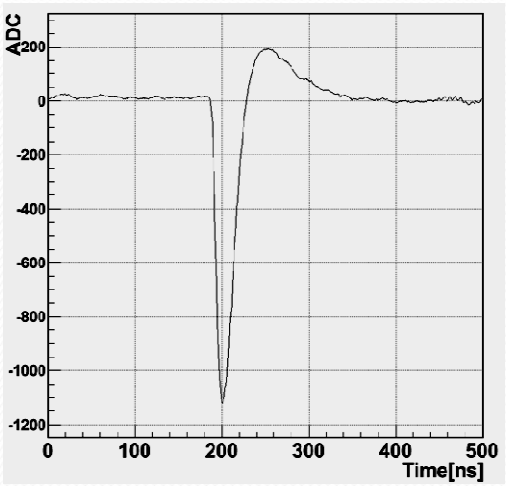
Readout electronics

Performance evaluation of the prototype was almost done.

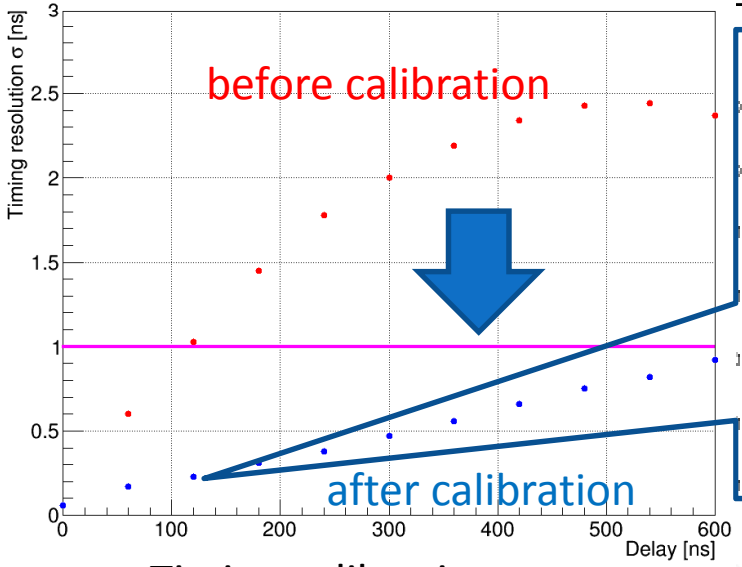
Daisy chain test



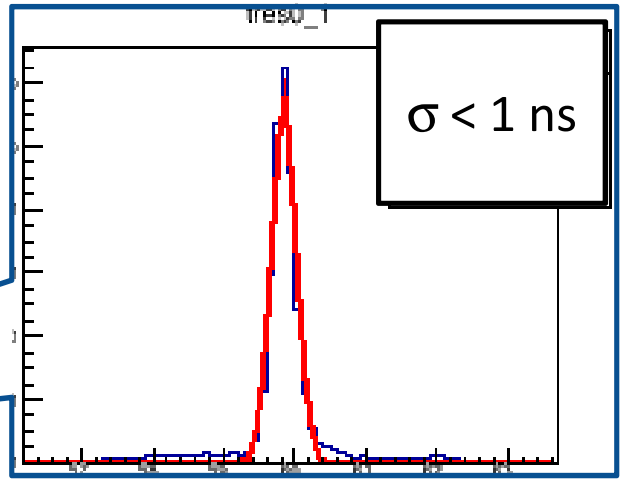




Waveform output



Timing calibration

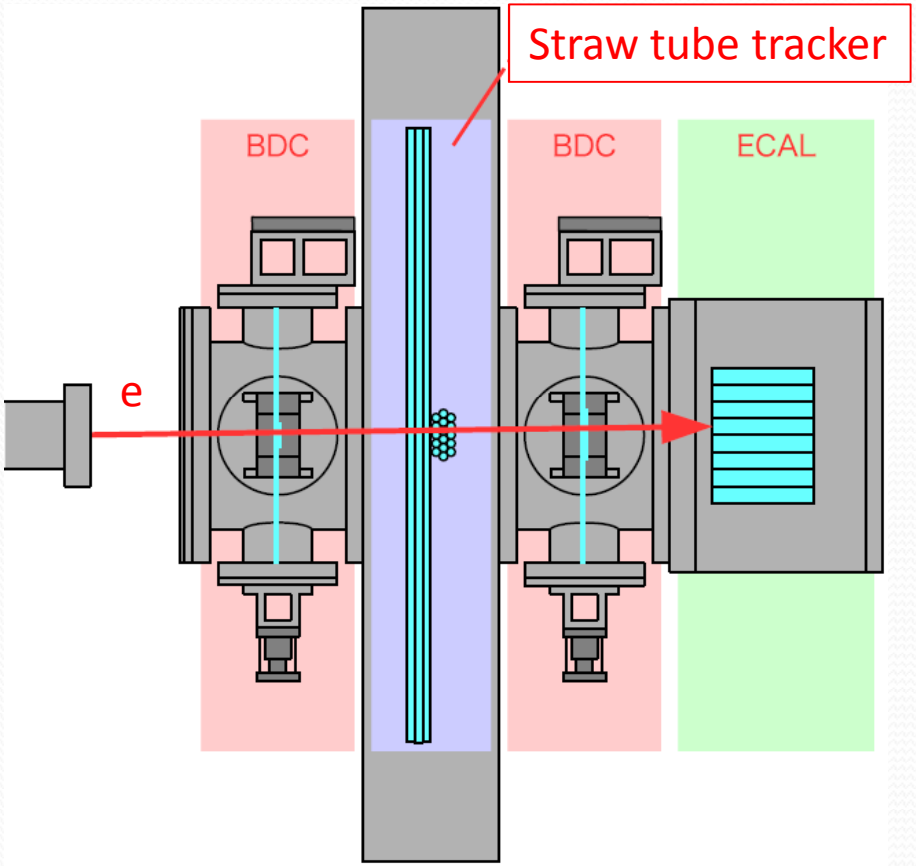


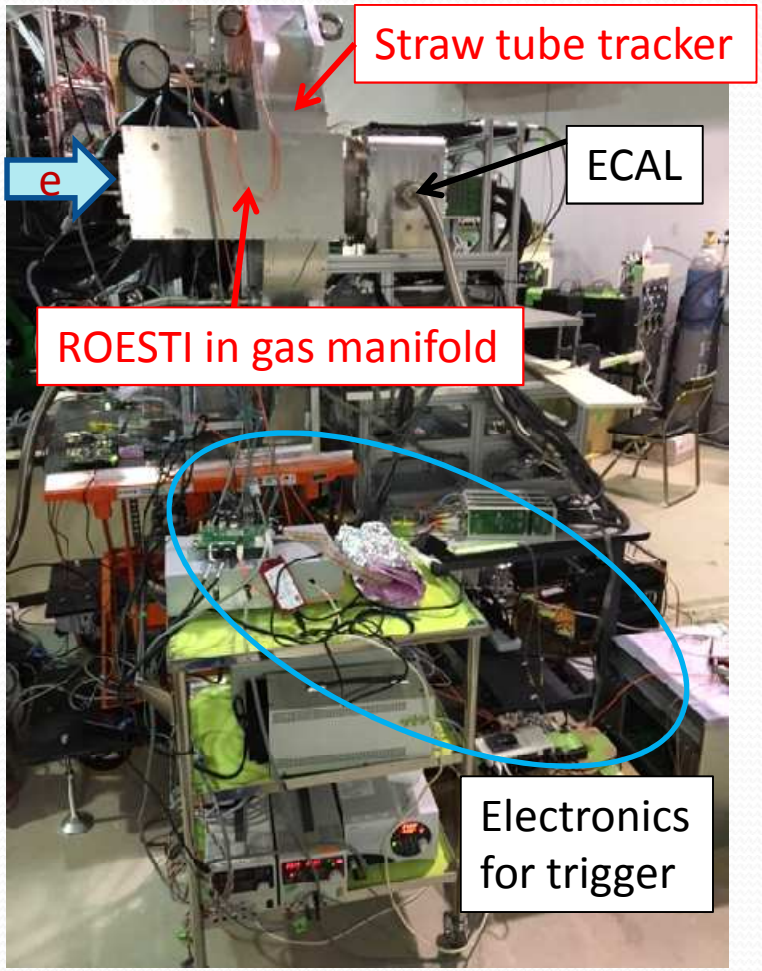
Timing resolution

Almost all the performances satisfy requirements. Final prototype is under development.

Performance evaluation

Test-beam experiment was carried out at ELPH, Tohoku Univ. in March 2017.

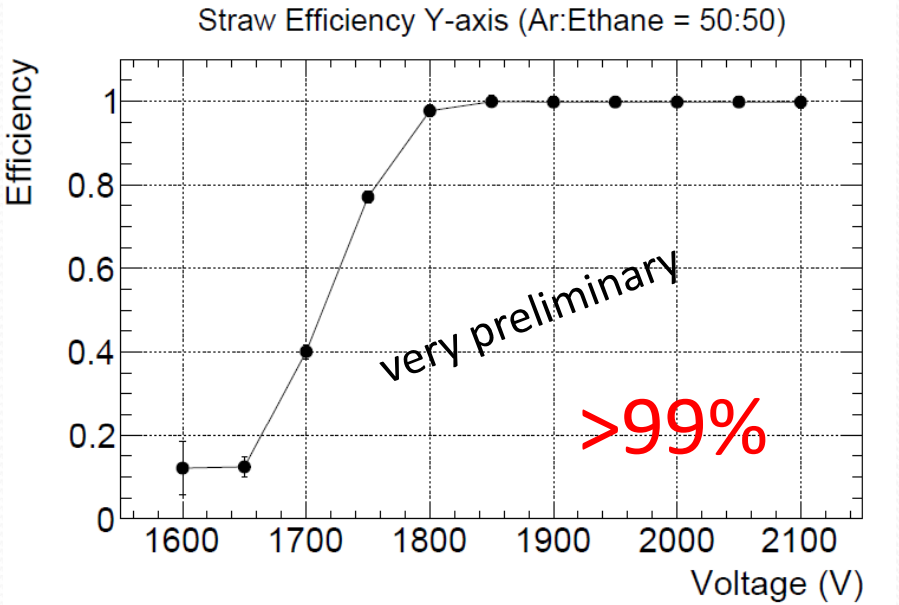


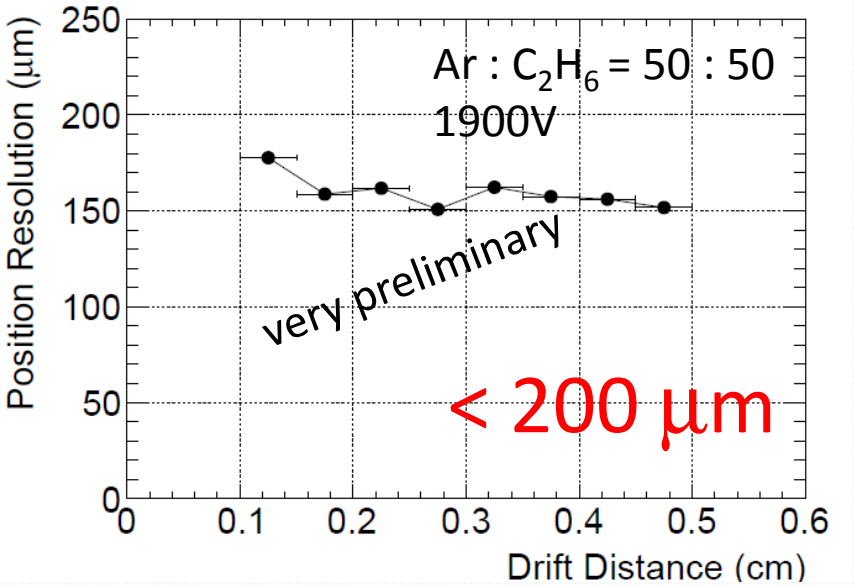


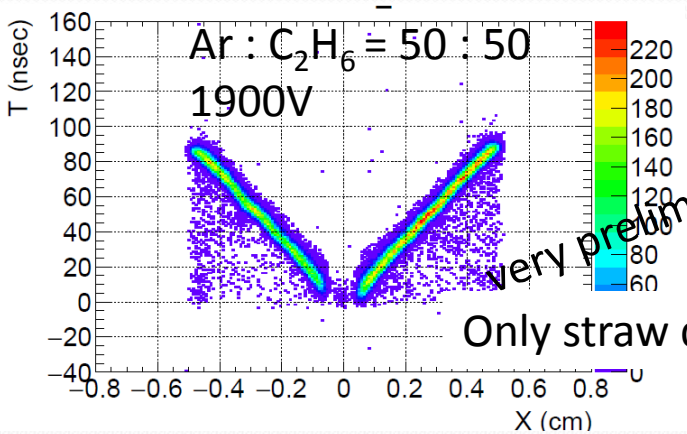
- Fundamental performances were investigated with a 100 MeV/c electron beam.
- Performance evaluation were done in vacuum.

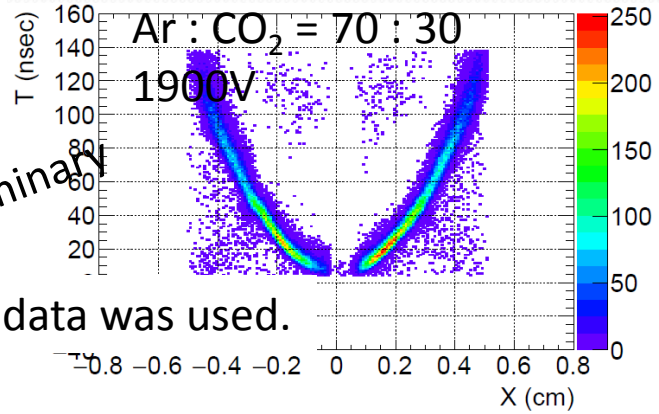
Performance evaluation

Efficiency and intrinsic spatial resolutions were measured.









Only straw data was used.

- Good enough performances were obtained.
- Investigation of behavior of position resolution is ongoing.

More improvements were expected. (timing calibration, BDC analysis, etc…)

Summary and prospect

- COMET experiment aims to search for μ-e conversion with an excellent sensitivity of O(-17) which is 4 orders of magnitude better than the current upper limit.
- For achieving that, very light and operational in vacuum tracker is needed. -> Thin-wall straw-tube tracker.
- 20 μm straw tube was successfully developed by a ultra-sonic welding technique with a help from NA62 collaboration.
- Mechanical properties and fundamental performance of straw tube were investigated.
- Prototype chamber with newly developed readout electronics was constructed.
- Test beam experiment using prototype chamber was performed with 100 MeV/c electron beam at ELPH.
- Performances were investigated in vacuum and confirmed to be OK.
- Tracker assembly for COMET Phase-I will start soon.
- R&D of the 12 μm straw for COMET Phase-II is ongoing.

Acknowledgement

- This research is supported by the grant-in-aids, JSPS KAKENHI 16H02192 and 17H04841.
- The development of readout electronics is supported by Open-It.