New extremely light straw tube detector with a non-woven graphite-textile

by Hajime NISHIGUCHI, *KEK*, *J-PARC*, *COMET*

DRD1 collaboration meeting, 06/Oct/2025

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Based on my talk @ VCI2025

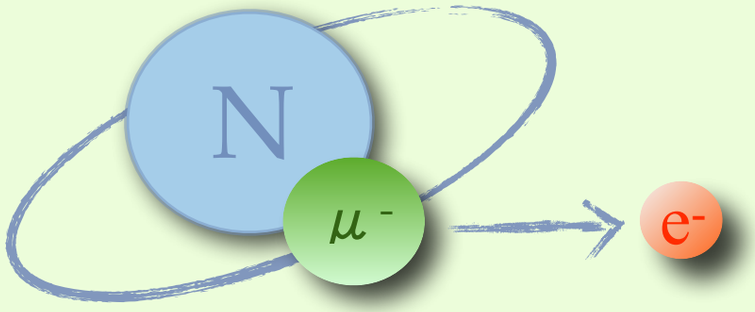
Contents

Motivation

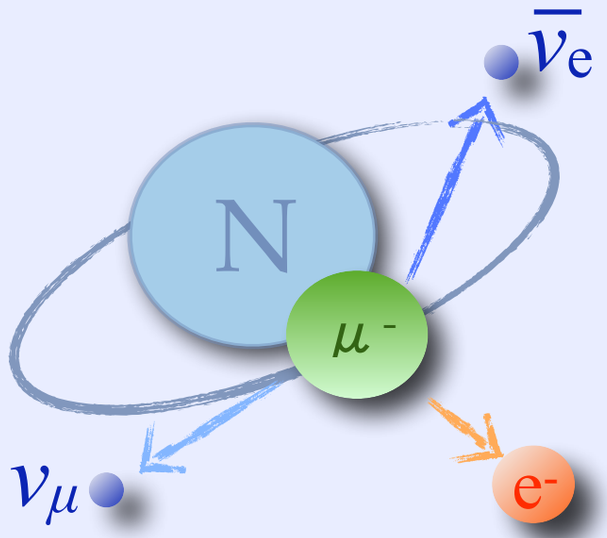
The COMET Experiment

- **An Experiment to Search for "$\mu^- N \rightarrow e^- N$" at J-PARC**
  - Muon-to-Electron Conversion = Lepton Flavour Violation
  - Very sensitive to the TeV-scale new physics, BSM

    → **Complementary** and **Competitive** to the **LHC**



- **Signal**
  - $E_e = m_\mu - B_\mu \sim 105$MeV
  - Coherent Process ($Z_{ini}=Z_{end}$)



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

The COMET Experiment

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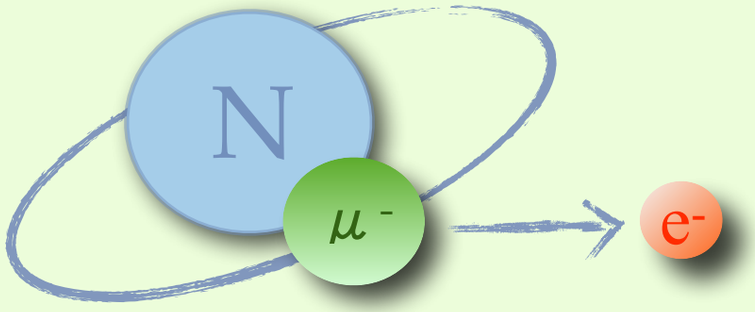

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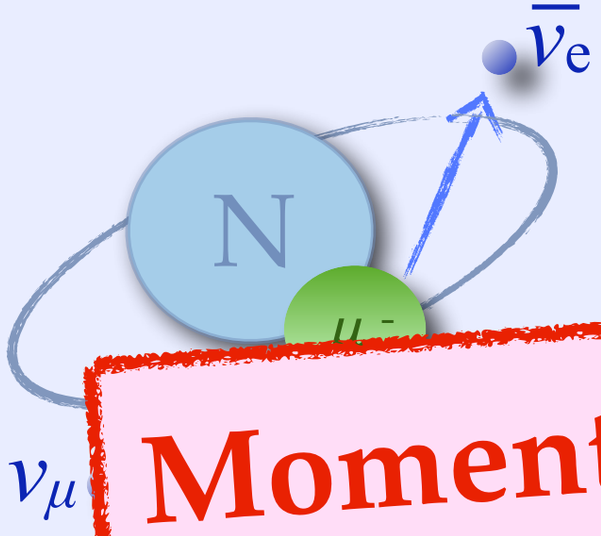

- **BGs**
  - **Prompt (Beam-related)**
  - **Decay in Orbit (DIO)**
  - **Radiative Muon Capture (RMC)**

Momentum Resolution is Essential !!!

The COMET Experiment

- **An Experiment to Search for "$\mu^- N \rightarrow e^- N$" at J-PARC**
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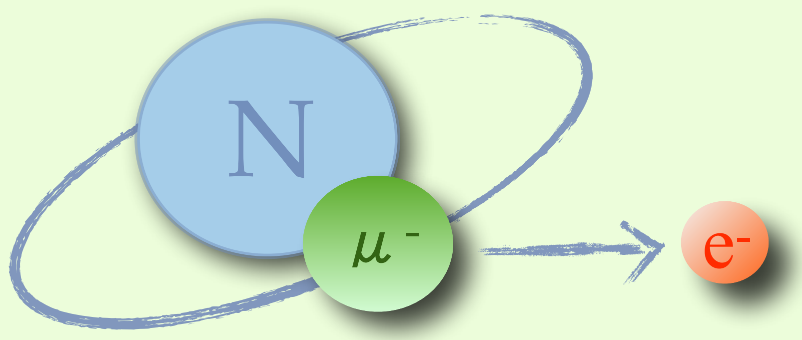
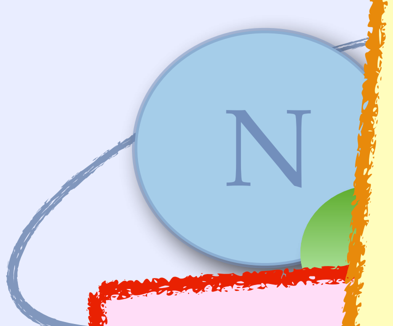
    → **Complementary** and **Competitive** to the **LHC**



- **Signal**
  - $E_e = m_\mu - B_\mu \sim$ **105MeV**
  - Coherent Process ($Z_{ini} = Z_{end}$)

(B…m-related)



ν_μ

Momentu… …al !!!

Need to achieve, at least, < 200 keV/c for 100MeV/c e^-

Tracker for COMET

Need to achieve, at least,
$\sigma_p/p < 200$ keV/c for 100MeV/c e^-

- **Material budget (Multiple Scattering) is Essential**
  - Need to be made by a very light material
    - Gaseous detector is suitable solution, *eg*. drift chamber
  - Need to be operational in vacuum
    - Required also by particle transportation

Not only COMET,
also Mu2e (μ-e conv.),
Muon g-2 Fermilab,
NA62 CERN ($K^+ \to \pi^+ \nu\nu$),
etc…

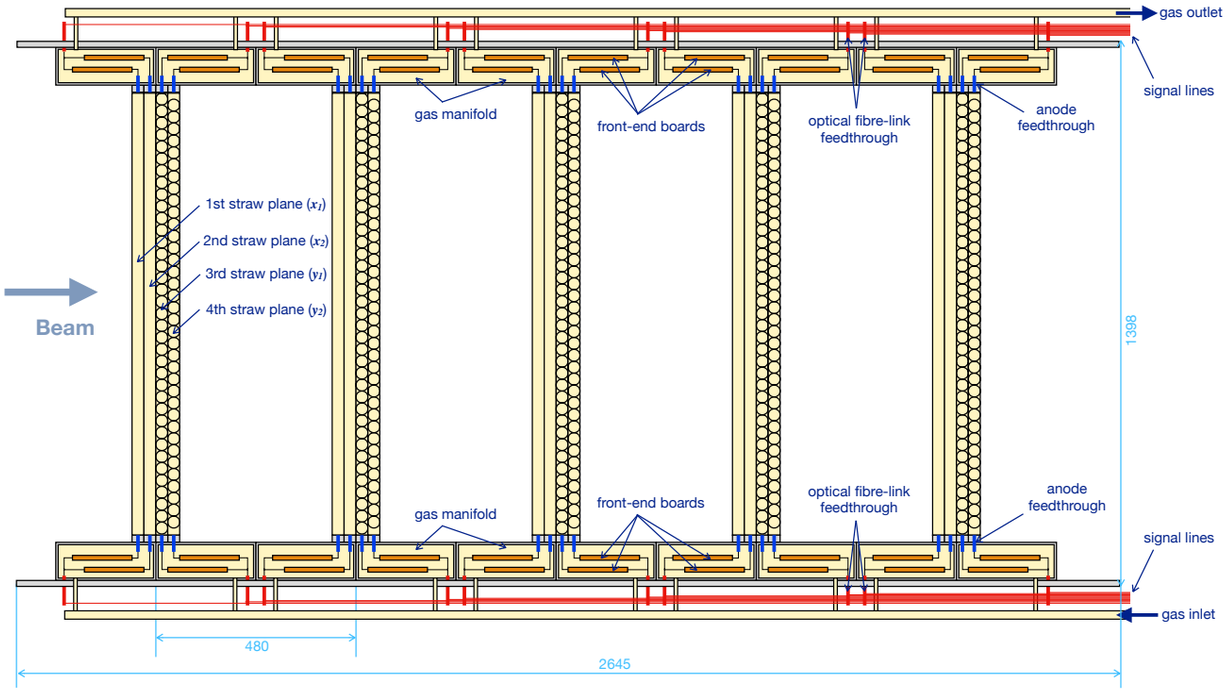
- **Solution : Vacuum-compatible Straw Tracker made by thin film**

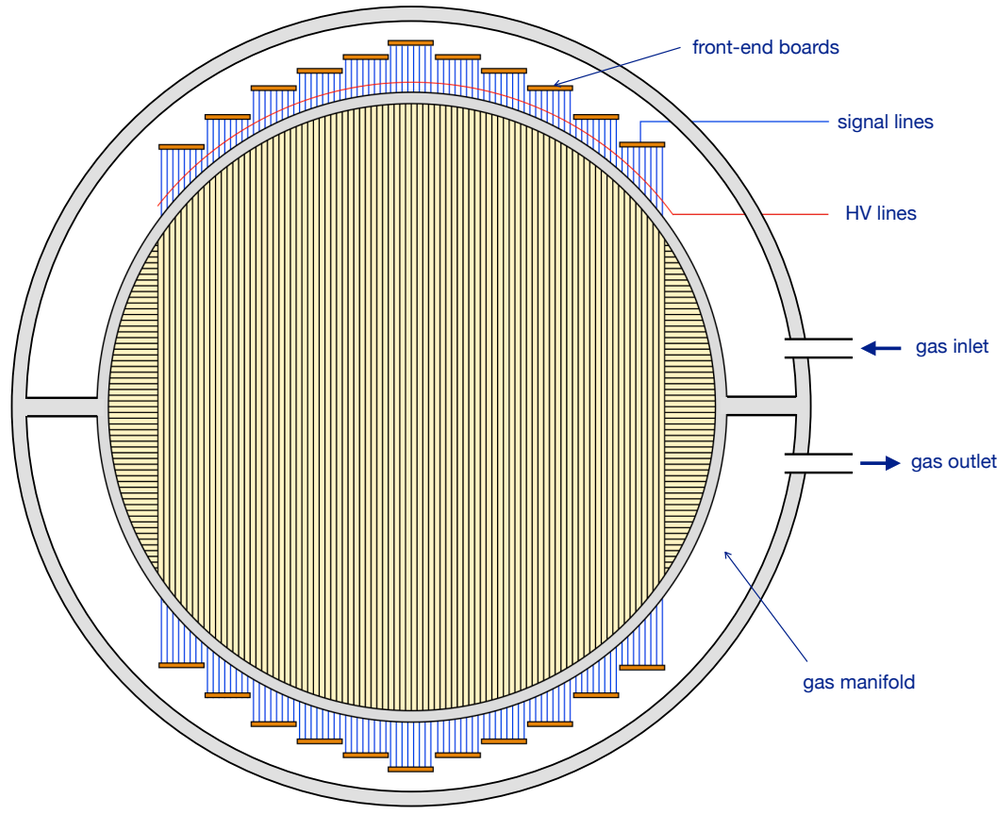
1) Present Straw

^{t}20μm ϕ10mm Mylar + 70nm Al
For **COMET Phase-I**

The COMET Straw Tracker

- **Planar** wire-chamber-base tracker in **Vacuum** → **Straw Tracker**

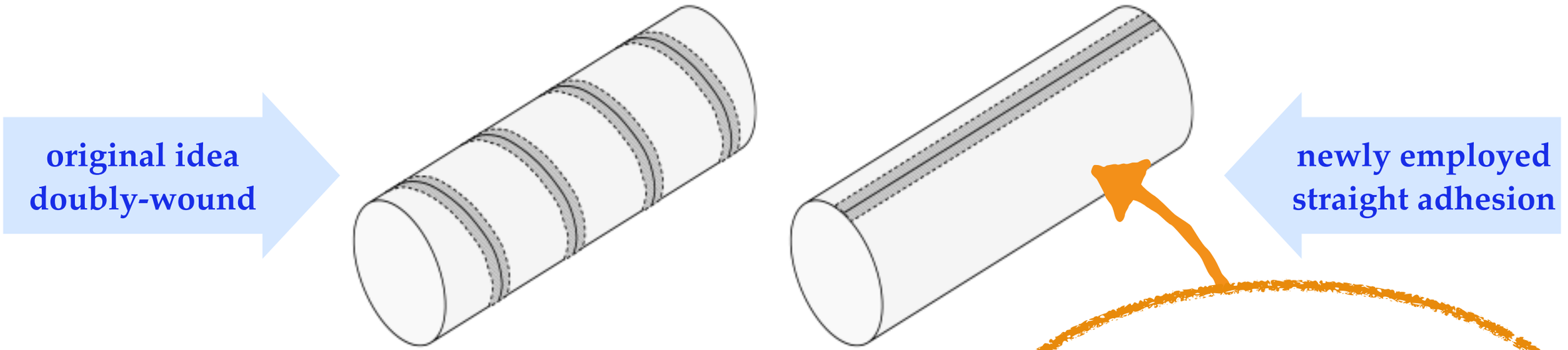




- Five super-layers (Station) consist of 4 planes of straw tubes
  - 2 planes for x-coordinate and 2 planes for y-coordinate, each layers are staggered by half a cell to solve the left-right ambiguity.
- All tracker modules are installed in **vacuum**.
- Timing(Trigger) is provided by the electromagnetic calorimeter.

Straw Tube as a Wire Chamber

- **Two methods to make a very-thin & gas-tight straw**
  - "Doubly-wound" style & "Straight adhesion" style



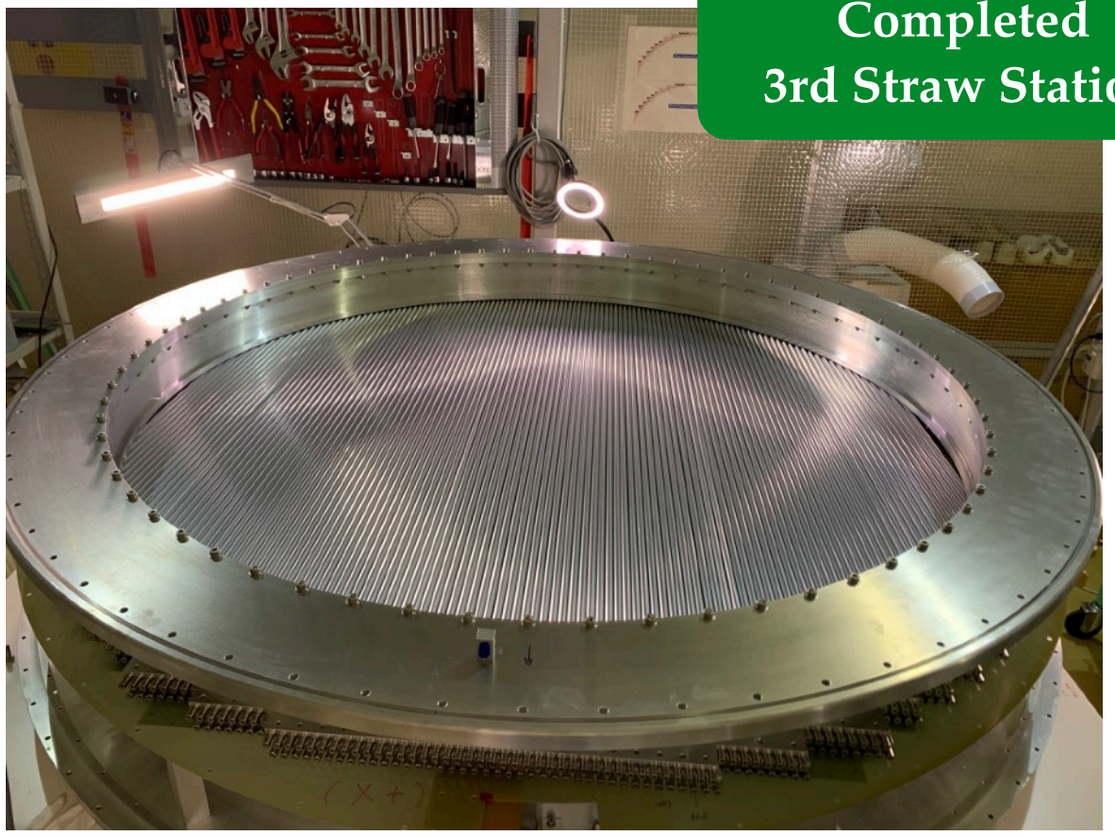
COMET employs straight adhesion, and aims to achieve an even thiner straw wall

- **Doubly-wound type;**
  - Easily obtained in the commercial market.
  - Limit to achieve an extremely thin wall
- **Straight-adhesion type;**
  - Big advantage from the view point of material budget
  - It was difficult to keep a true circle x-section ← **Enabled by NA62 collaboration by Ultra-Sonic Welding technique.**

Status of Present Straw

1st Straw Station w/ COMET beam line

Completed 3rd Straw Station



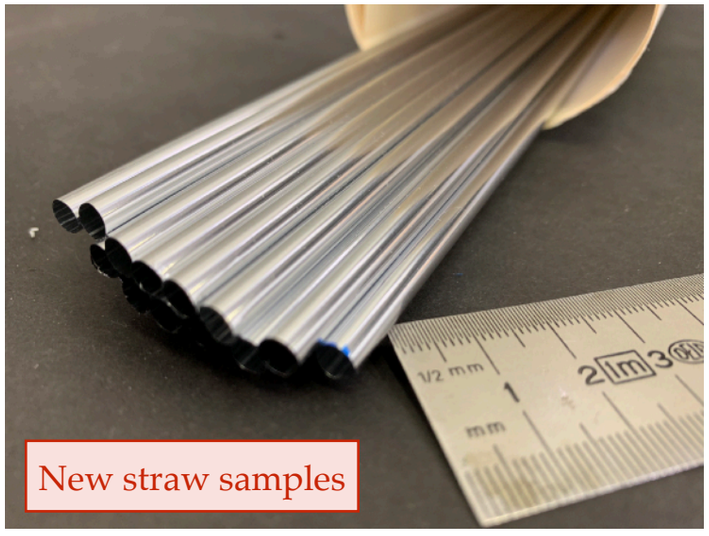
- Straw Tracker for COMET Phase-I is almost ready !!

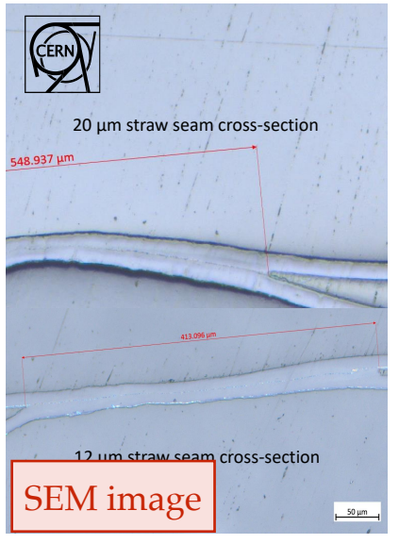
2) Future Straw

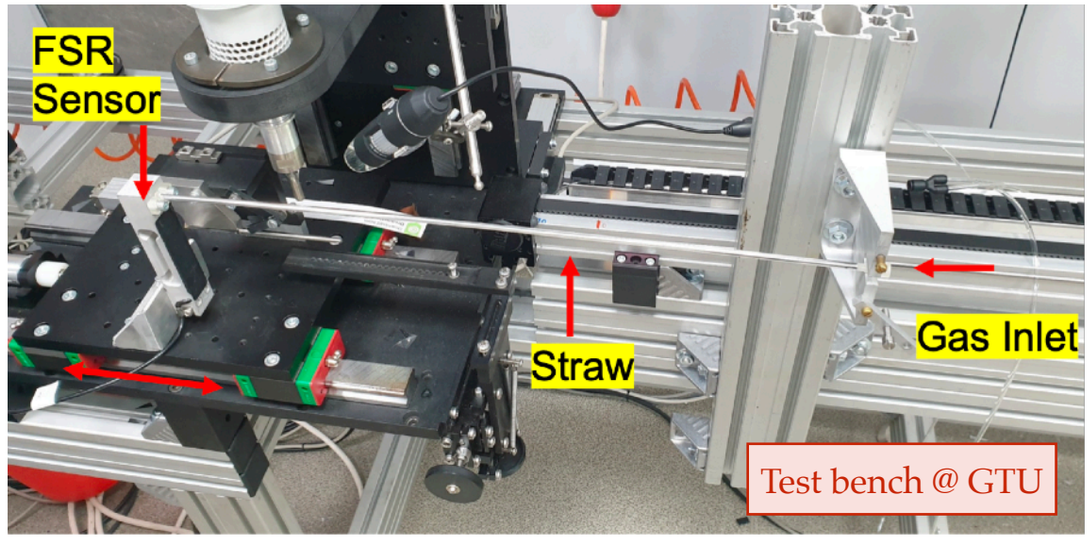
^{t}12μm ϕ5mm Mylar + 70nm Al
For **COMET Phase-II**

Development of future straw

- New straw R&D launched → "12μm thickness and 5mm diameter"
  - Straw production @ Georgia Tech Univ, Well established !
  - Assembly technique R&D by joint effort with **NA62 collaboration at CERN** (H. Danielsson *et. al.*)

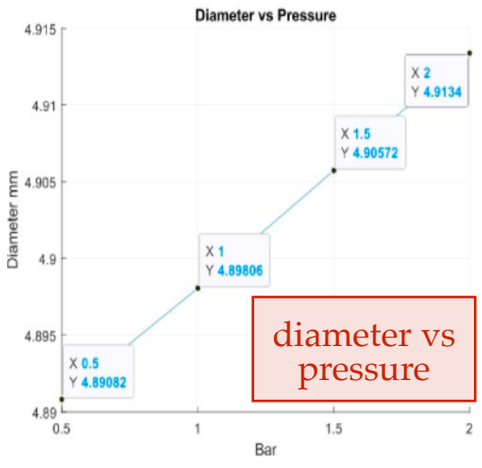


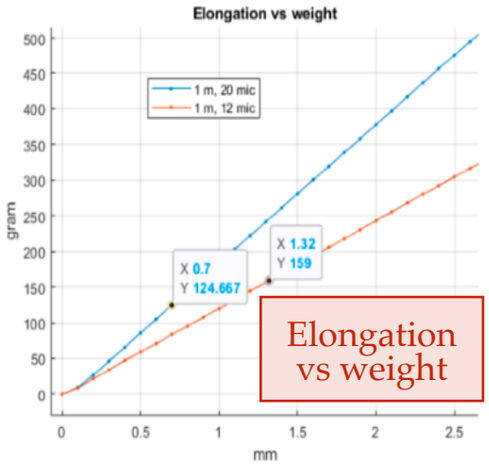


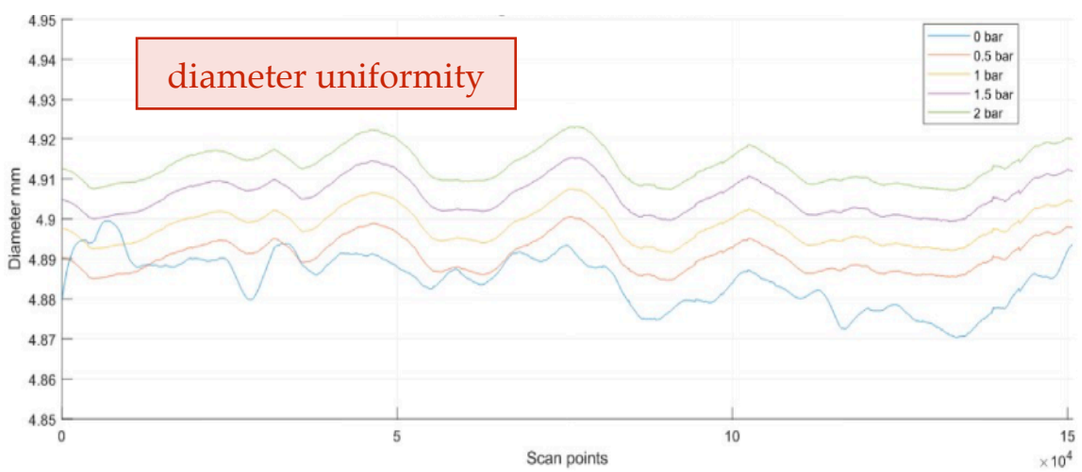


Mechanical study, done

Looks OK for radiation detectors

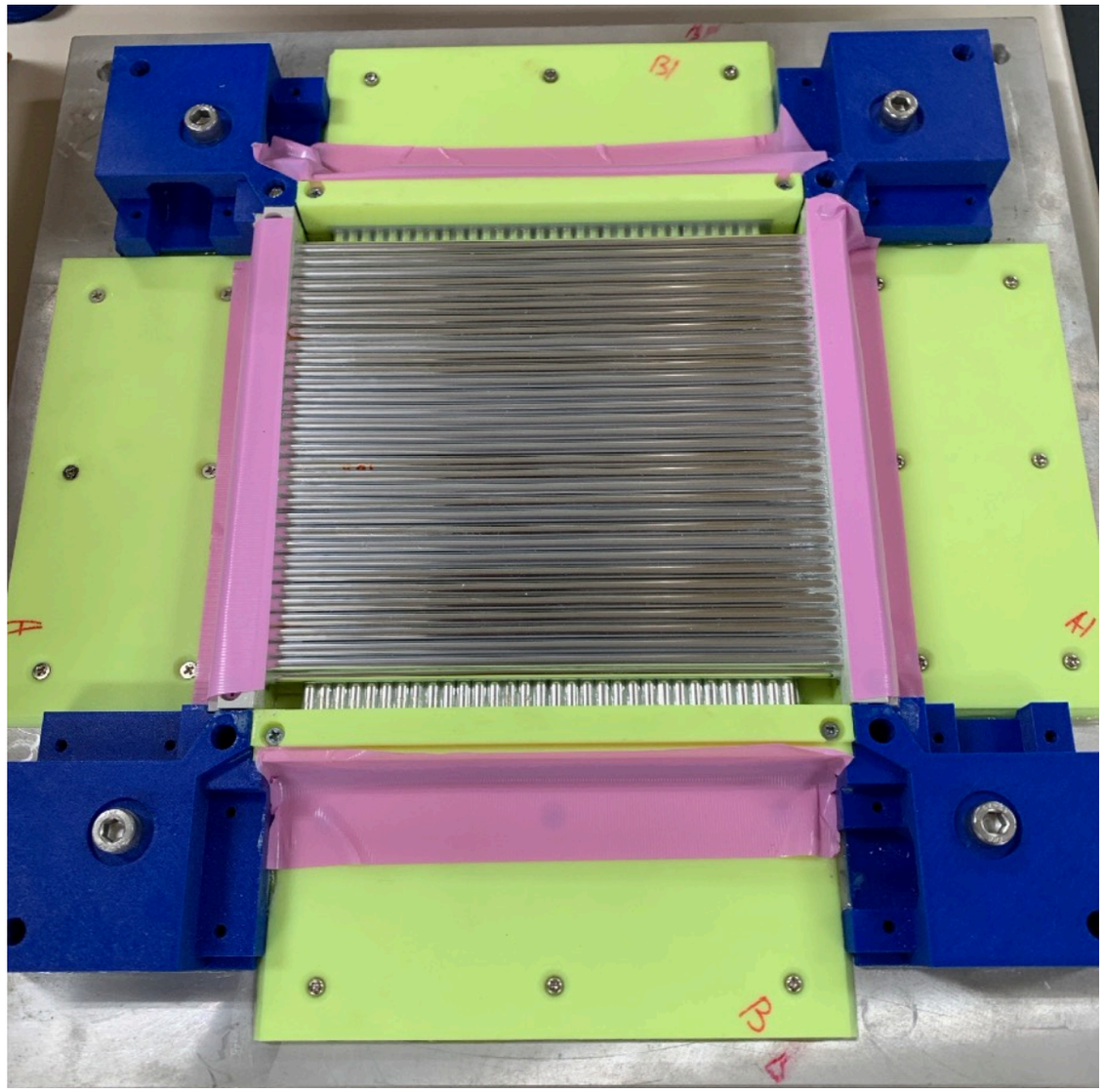






Prototype

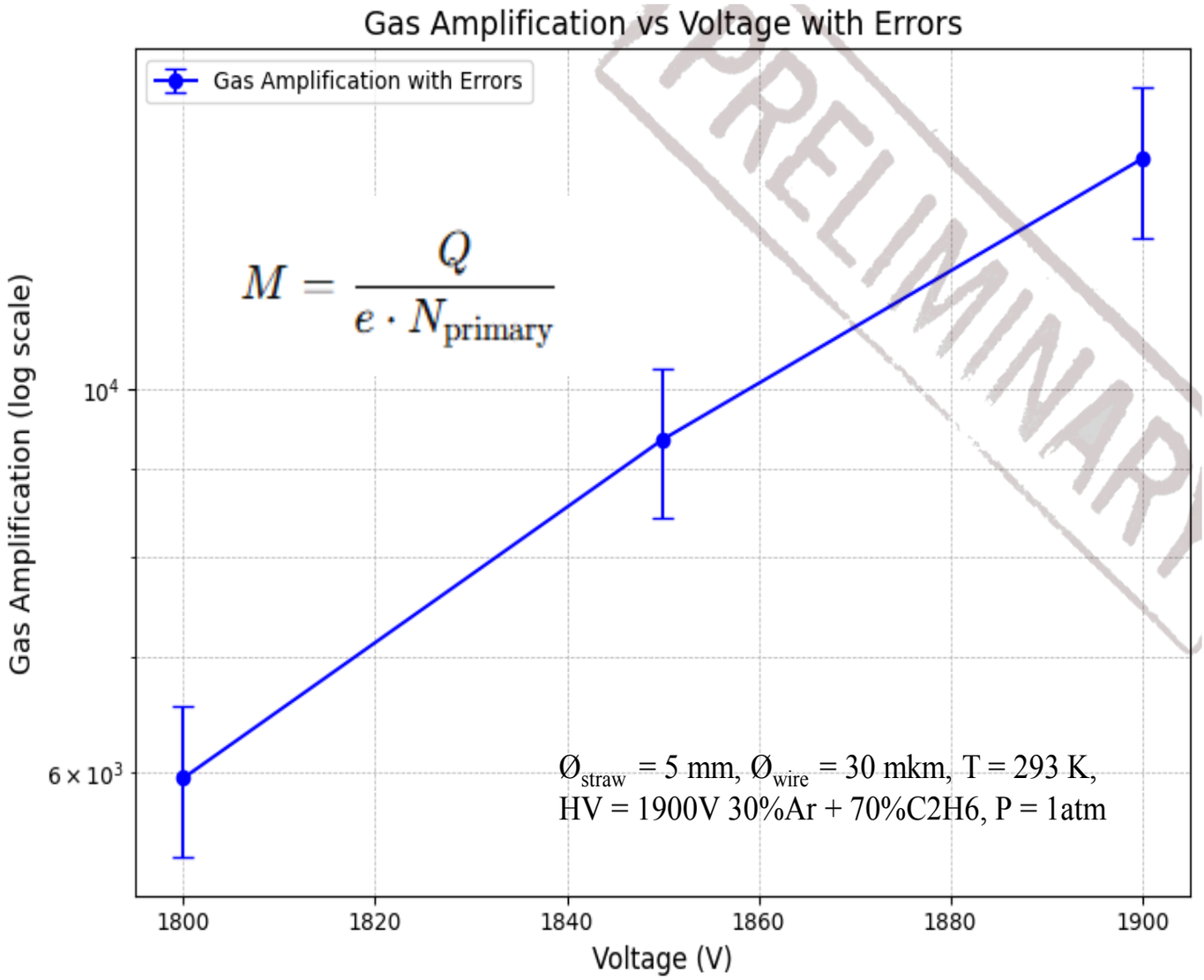
- w/ ^{t}12μm ϕ5mm straw, New prototype, constructed @ J-PARC



- 32 x 32 straws (2-layer) prototype was completed

Prototype, cont'd

- X-ray signal from ^{55}Fe was successfully obtained (Ar/C2H6 50:50, >1.8kV)



- Fundamental studies are ongoing.
- Test-beam, Will be performed soon

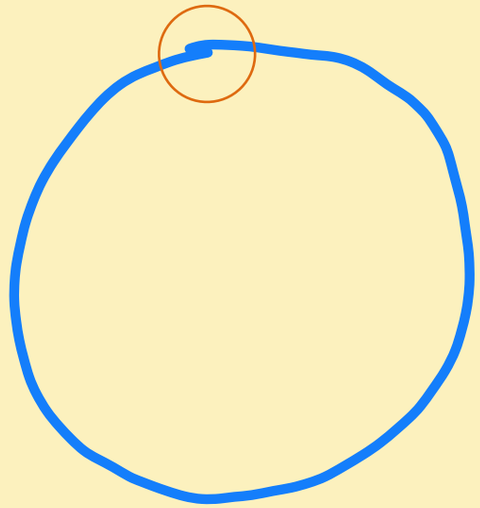
3) Further Future Straw

t6μm ϕ3mm Graphite

For **Further Future Experiments**

Technical limitation

- Straight adhesion by Ultrasonic Welding
  - (Maybe) **12μm-thickness is a limit**



"Seam width" is critical;

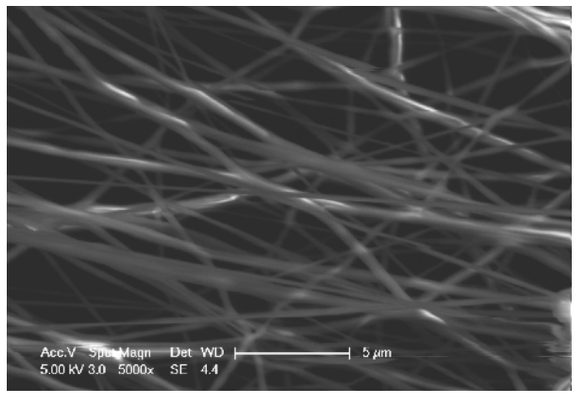
- Need to be **wide** enough to keep **tightness**
- Need to be **narrow** enough to keep **roundness**

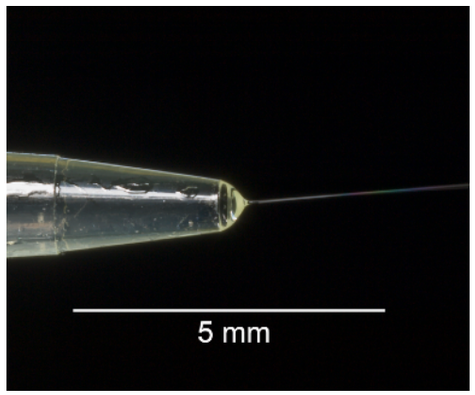
- Doubly-wound adhesion
  - (Maybe) **Also close to a limit**
  - Need a glue, cannot reduce a certain amount of glue

➡ **Need a *Paradigm Shift* !!**

Idea of a Seamless Straw

- Paid attention to the *"electrospinning"* technique by the newest nano-technology = **Popular for non-woven fabric products**





Electrospinning is a fiber production method that uses electric force to draw charged threads of polymer solutions or polymer melts up to fiber diameters in the order of some hundred nanometers.

WIKIPEDIA
The Free Encyclopedia

- By the electrospinning method, we can produce a kind of polymer fabric.

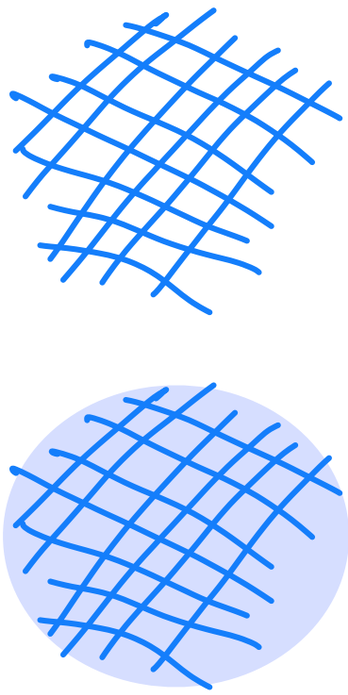
  ➡ by using "a bar (or a tube) target" for electrospinning,
  a seamless and extremely thin polymer tube can be realized !!

Issues to be solved:

1. **Gas-tightness**
2. **Conductivity**

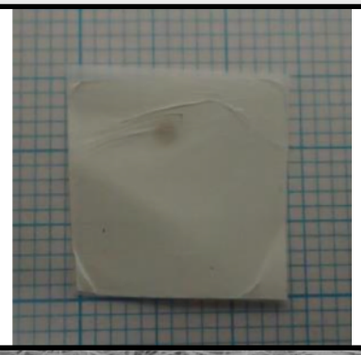
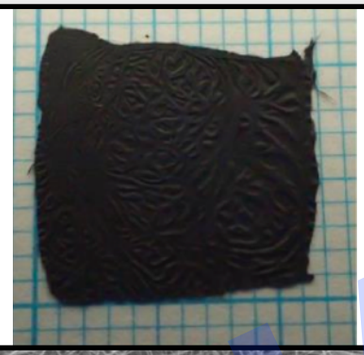
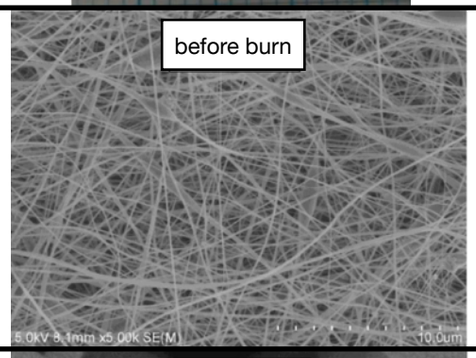
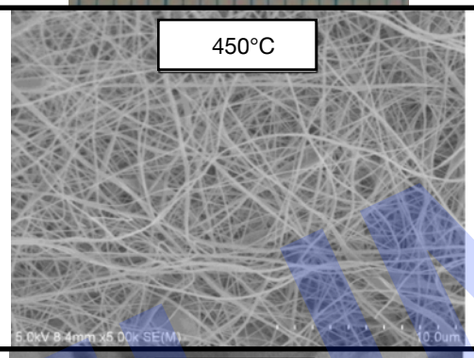
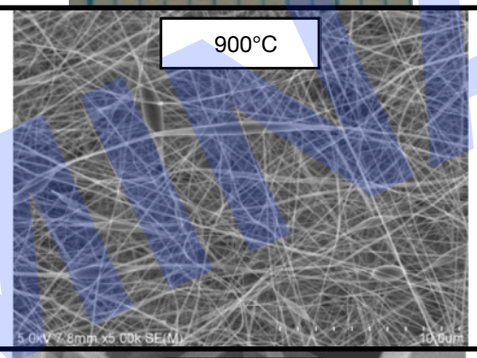
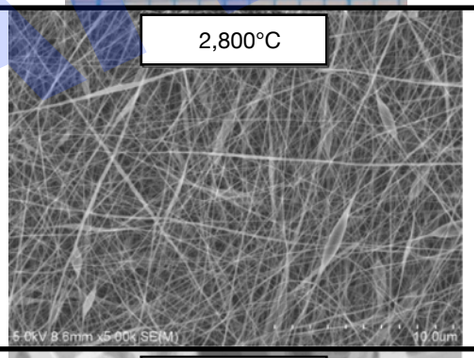
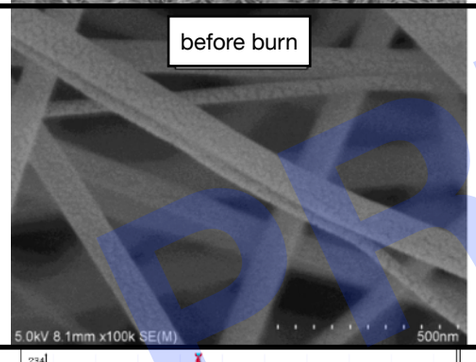
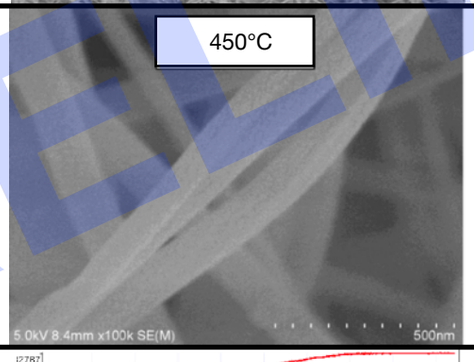
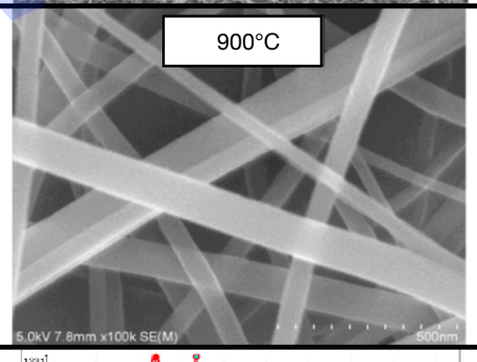
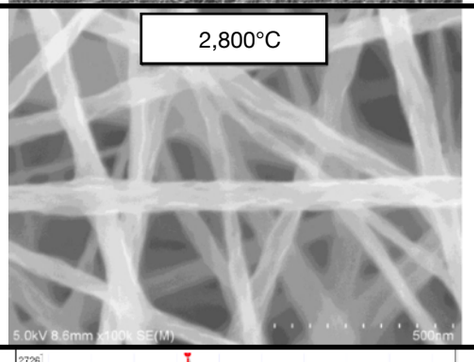
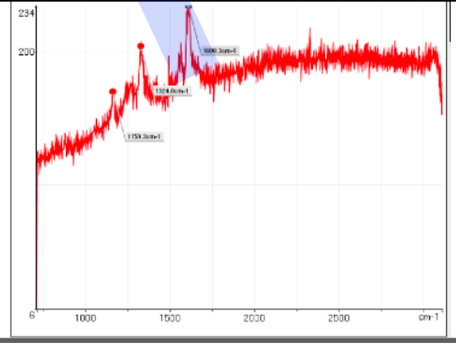
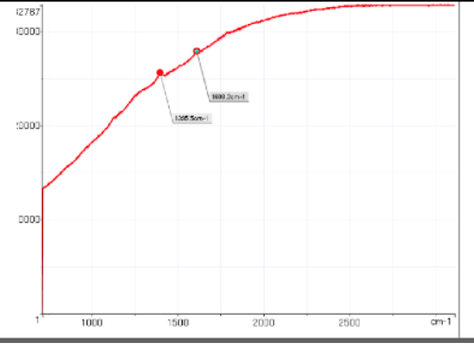
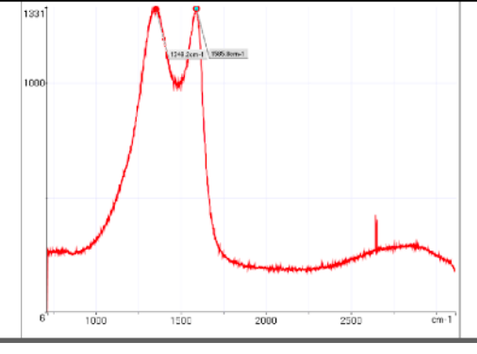
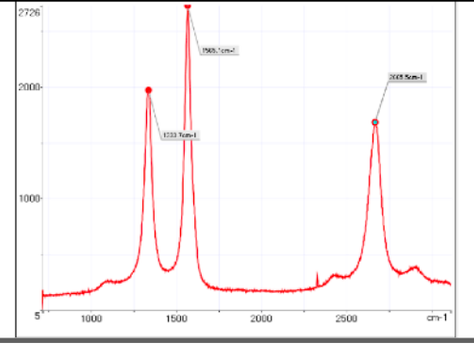
Can we solve issues ? YES !

- **Gas-tightness**
  - At the 1st step (polymer fabric), polymer straw is made with a polyamic-acid solution (=base of Polyimide).
  - At the 2nd step, by impregnation (soaking) with a polyamic-acid solution into polymer straw, gas-tight straw is realized.



- **Conductivity**
  - To make it a cathode of wire chamber, inner surface of straw should be metalized.
  - By burning it, it can be carbonized !! → **Graphite Straw**
    - A **graphite straw** can make a paradigm shift !!

Some pilot tests

	before burn	450℃	900℃	2,800℃
Outlook				
SEM (x5,000)				
SEM (x100,000)				
Raman Spectrum				

Some pilot tests

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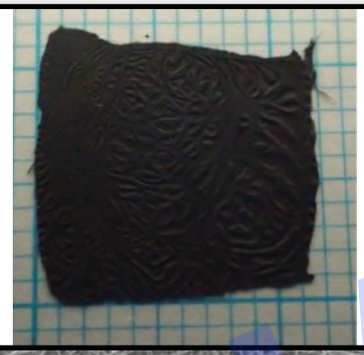
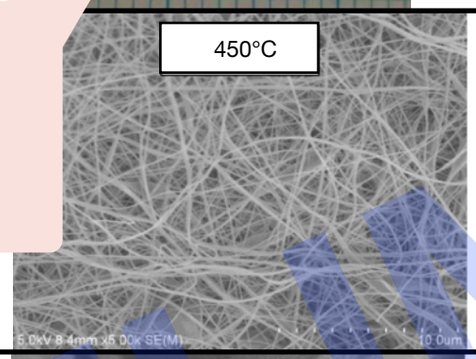
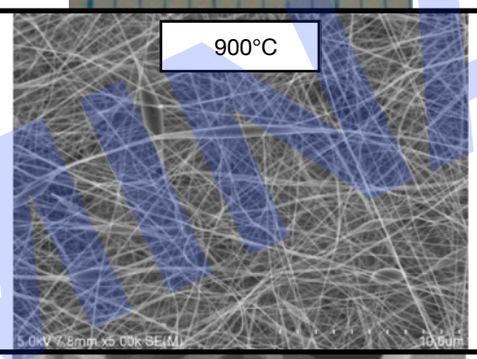
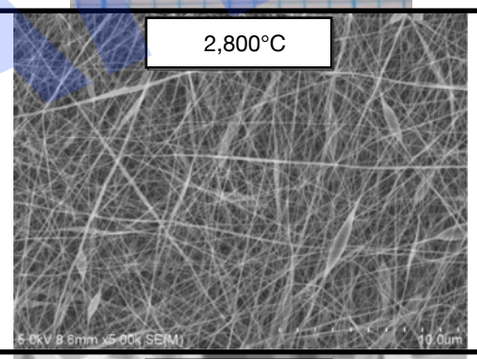
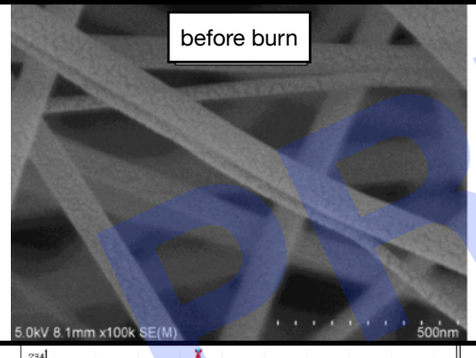
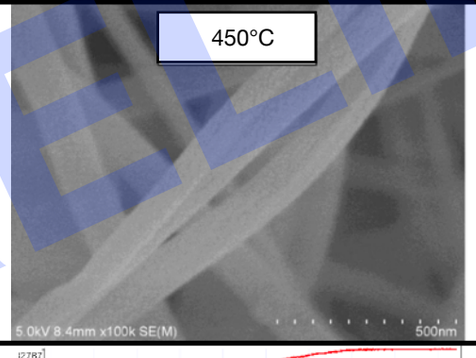
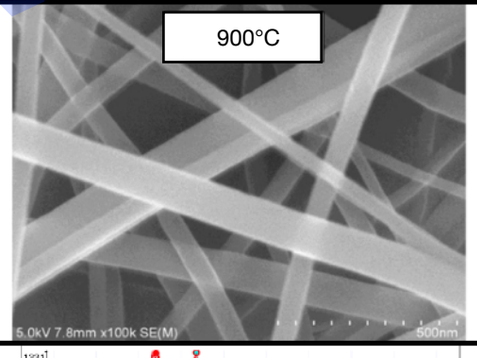
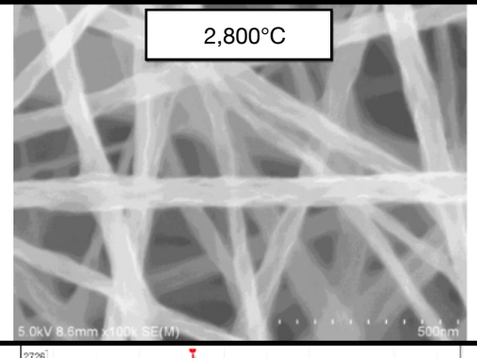
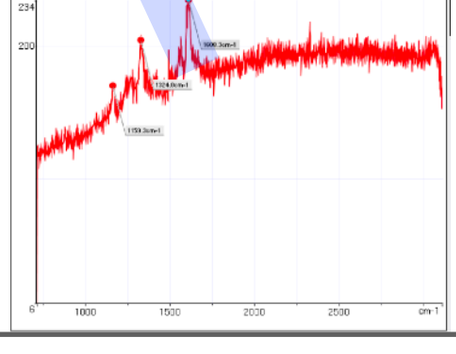
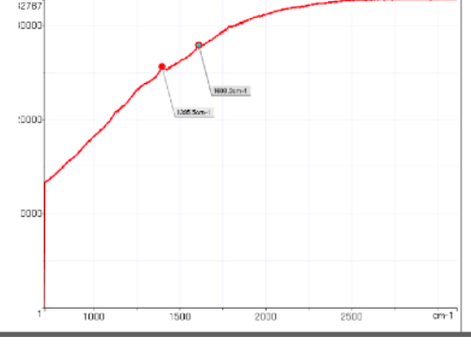
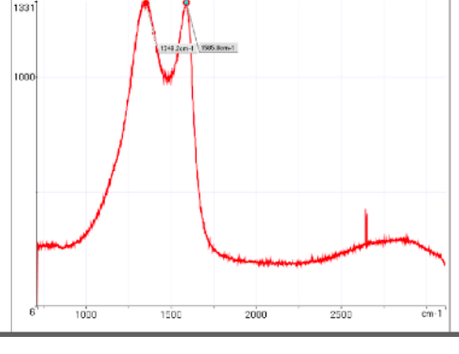
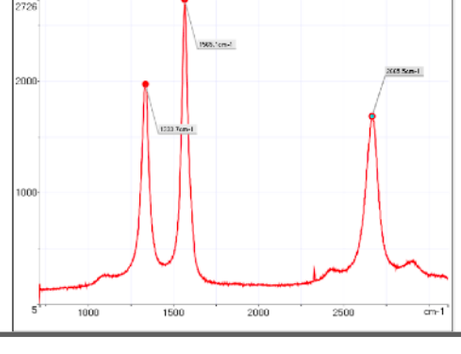
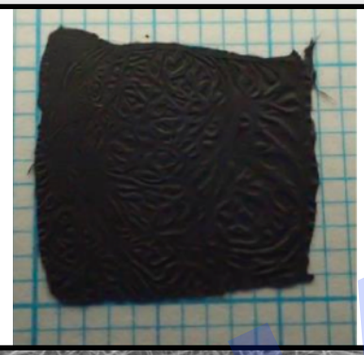
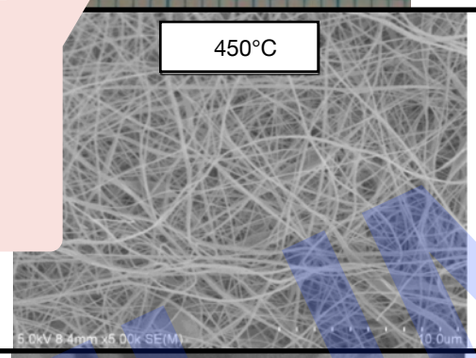
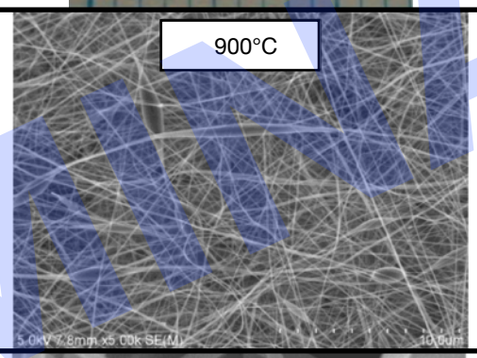
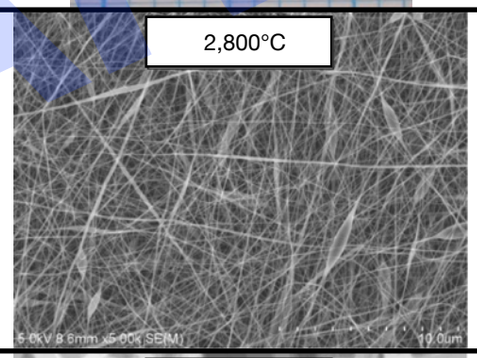
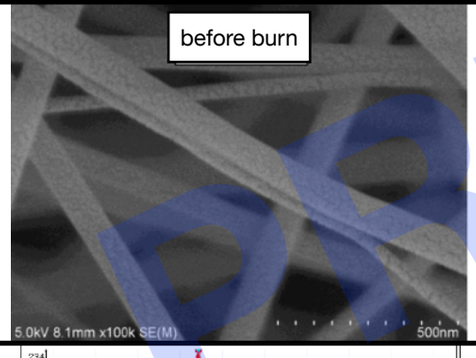
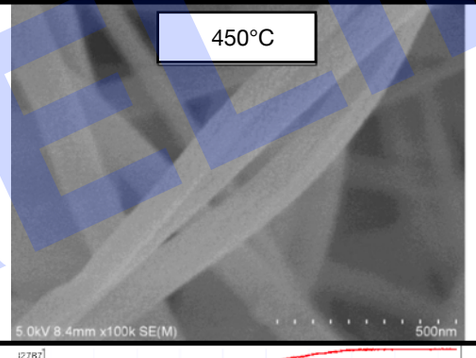
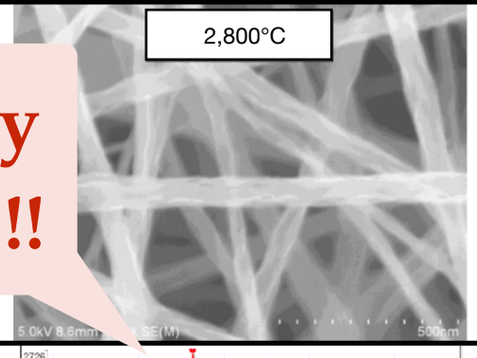
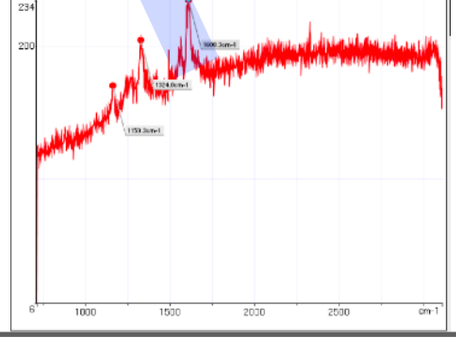
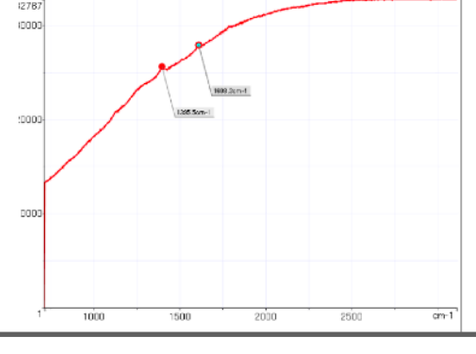
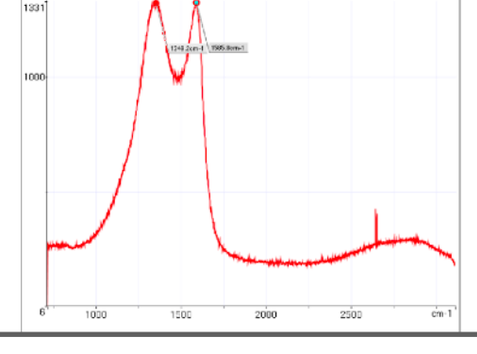
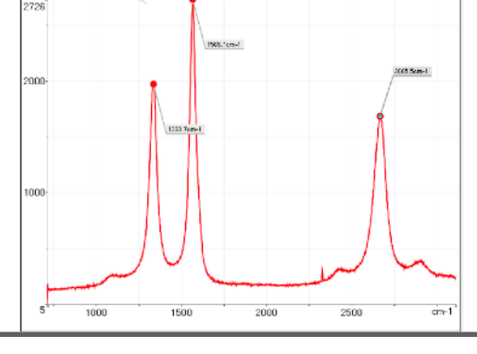
Outlook				
SEM (x5,000)				
SEM (x100,000)				
Raman Spectrum				

Polyimide fabric !!

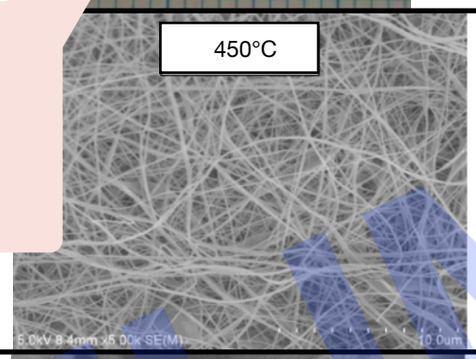
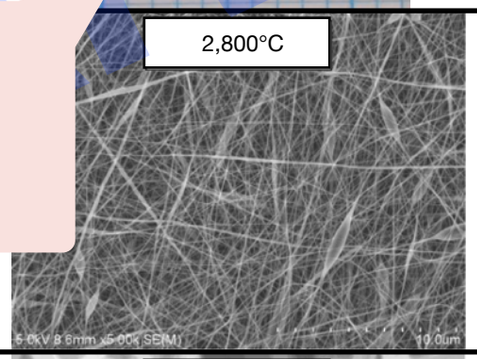
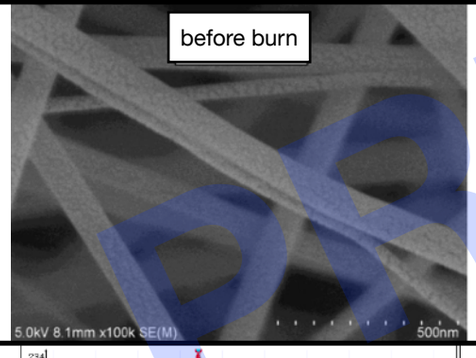
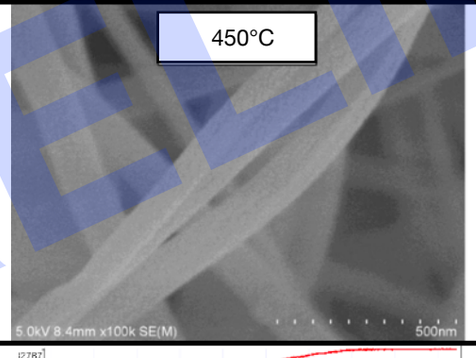
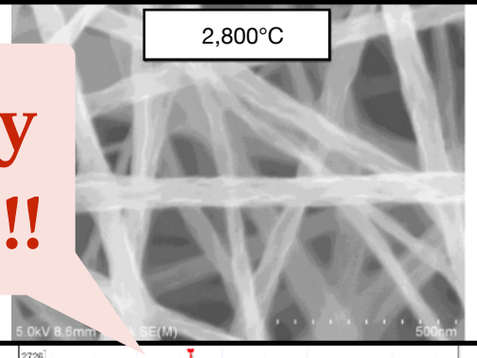
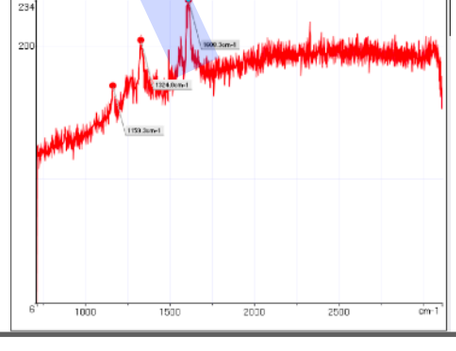
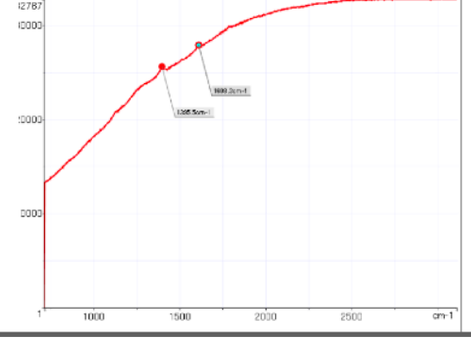
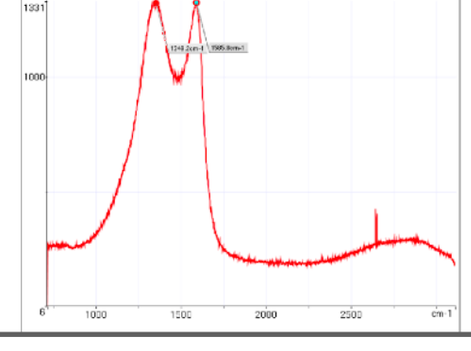
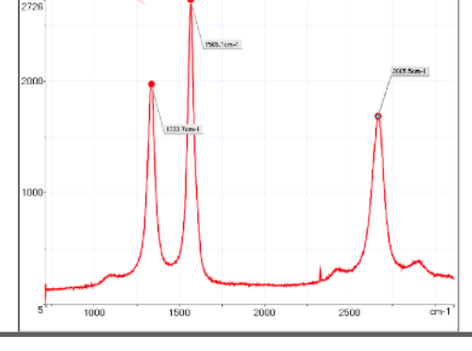
Some pilot tests

	before burn	450℃	900℃	2,800℃
Outlook				
SEM (x5,000)				
SEM (x100,000)				
Raman Spectrum				

Polyimide fabric !!

Successfully carbonized !!

Some pilot tests

	before burn	450℃	900℃	2,800℃
Outlook				
SEM (x5,000)				
SEM (x100,000)				
Raman Spectrum				

Polyimide fabric !!

Graphite textile !!

Successfully carbonized !!

Now, make it as Straw tube !

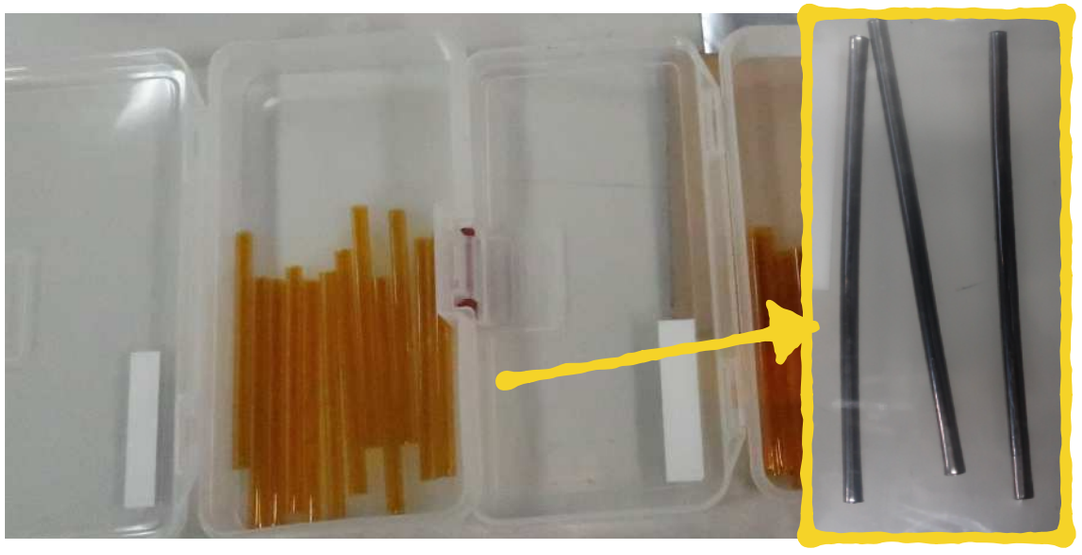
- By electrospining with a bar target, then burning it to 900°C
- PI-textile straw was produced ①
- Soaking PAA into PI-textile straw, then burning it again to 900°C
- PI straw tube was successfully produced !! (ϕ3.5mm) ②
- Burning it again up to 2,800°C
- **Graphite straw was successfully produced !!** ③

①

②

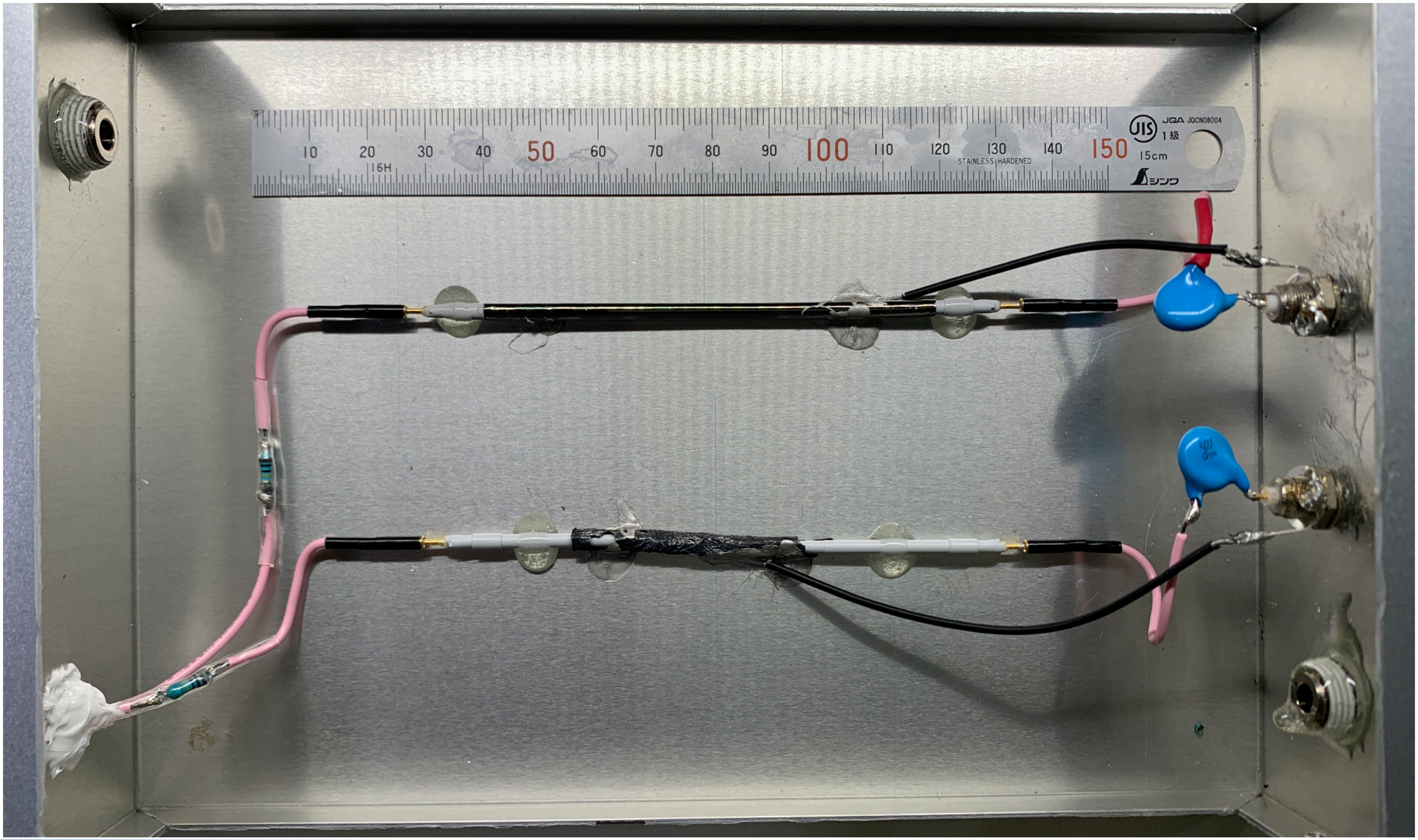
③

- As a reference sample, commercial PI tubes were also burned. (ϕ3.5mm)



Prototyping !!

- Employing 2 samples, graphite-straw prototype detector was assembled.



Prototyping !!

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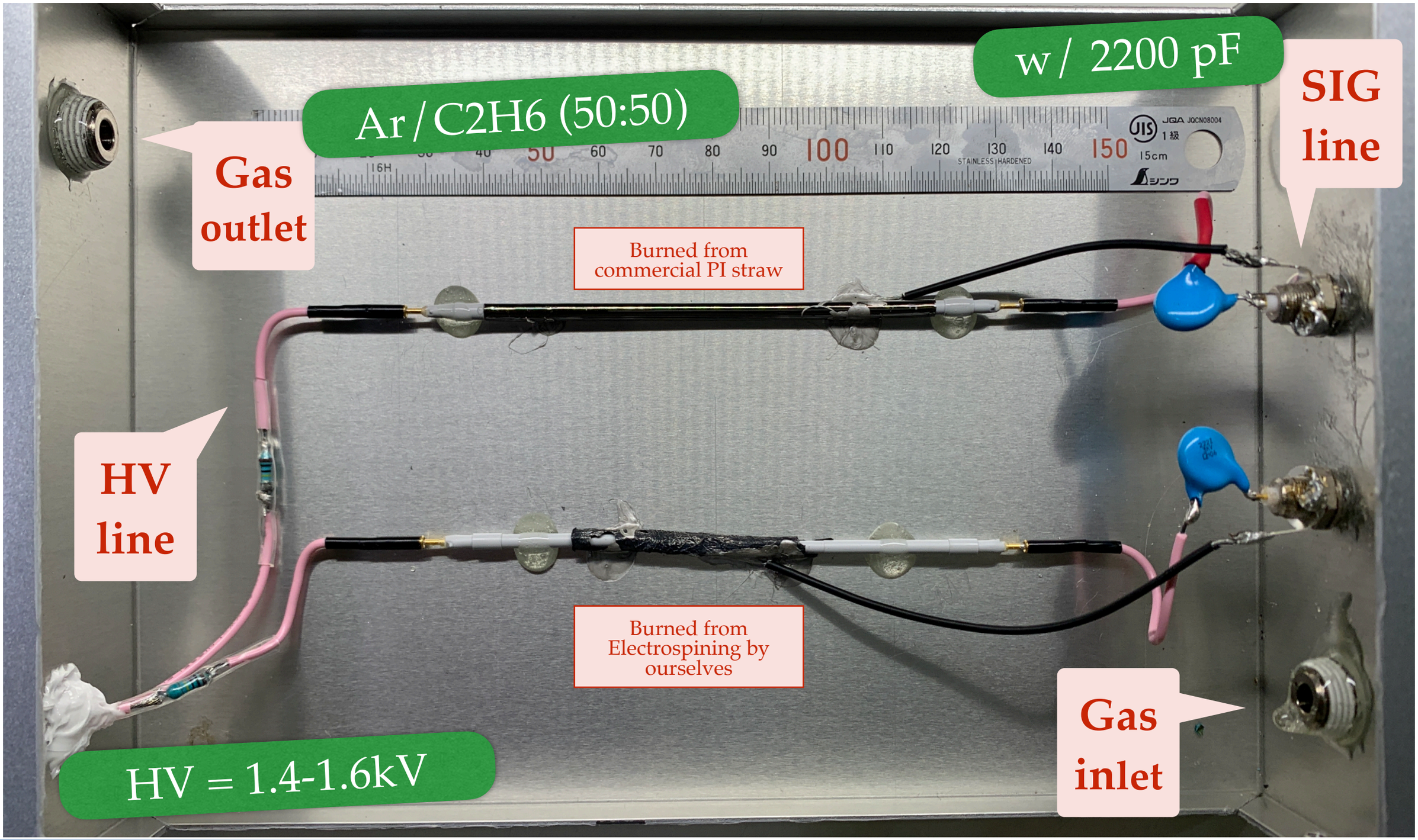
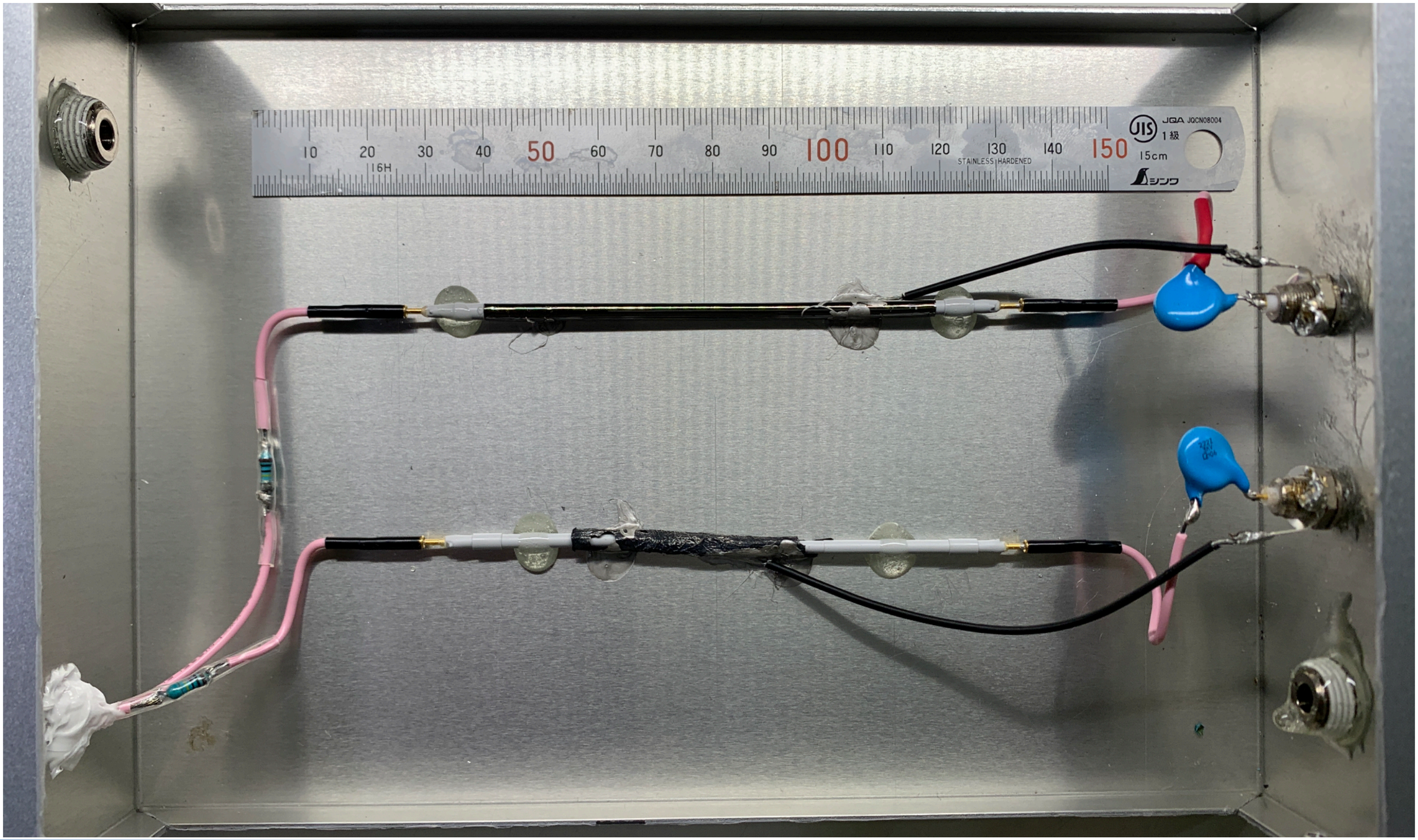


First Fire !!

- Employing 2 samples, graphite-straw prototype detector was assembled.



First Fire !!

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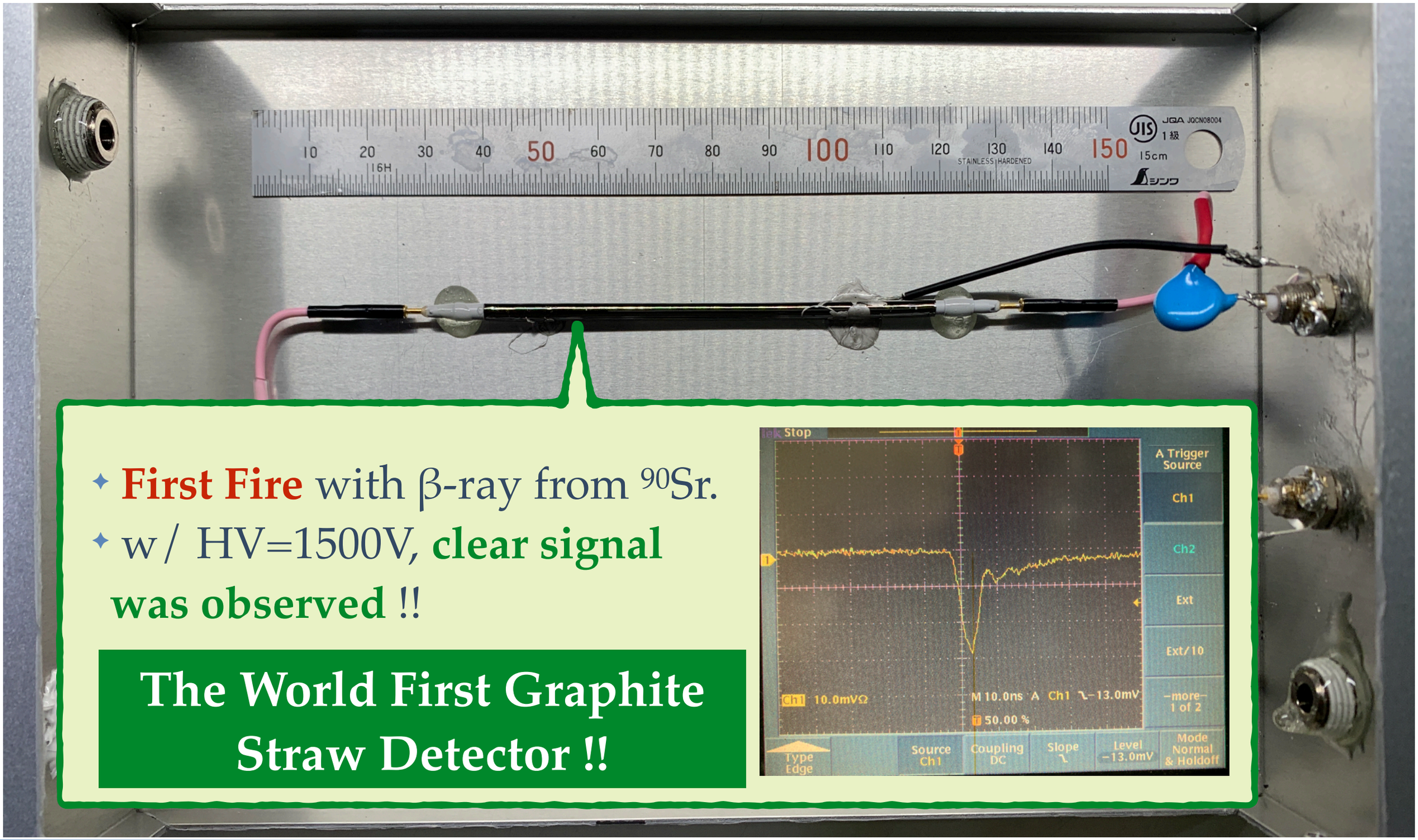
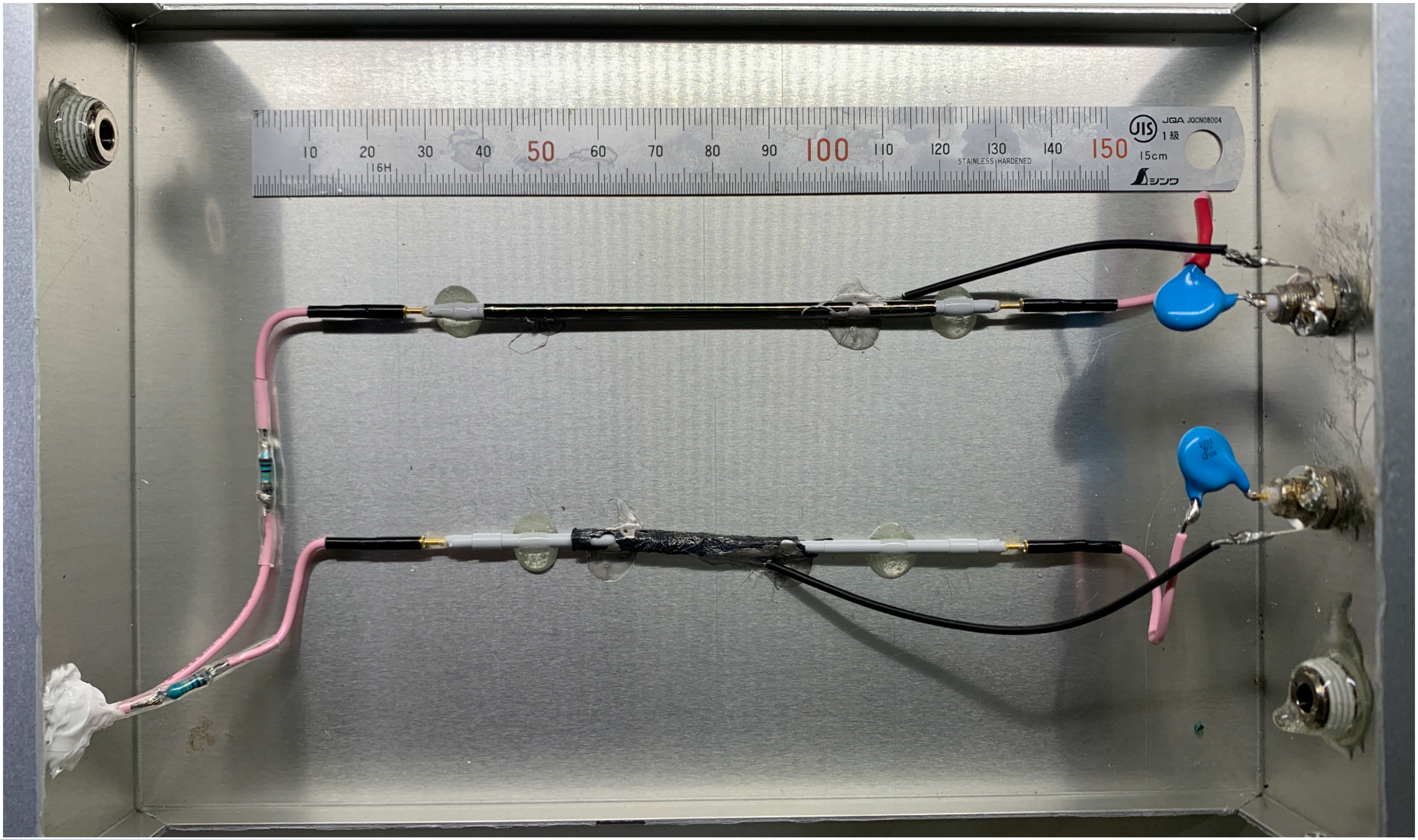


- **First Fire** with β-ray from ^{90}Sr.
- w/ HV=1500V, **clear signal was observed** !!

The World First Graphite Straw Detector !!

First Fire !!

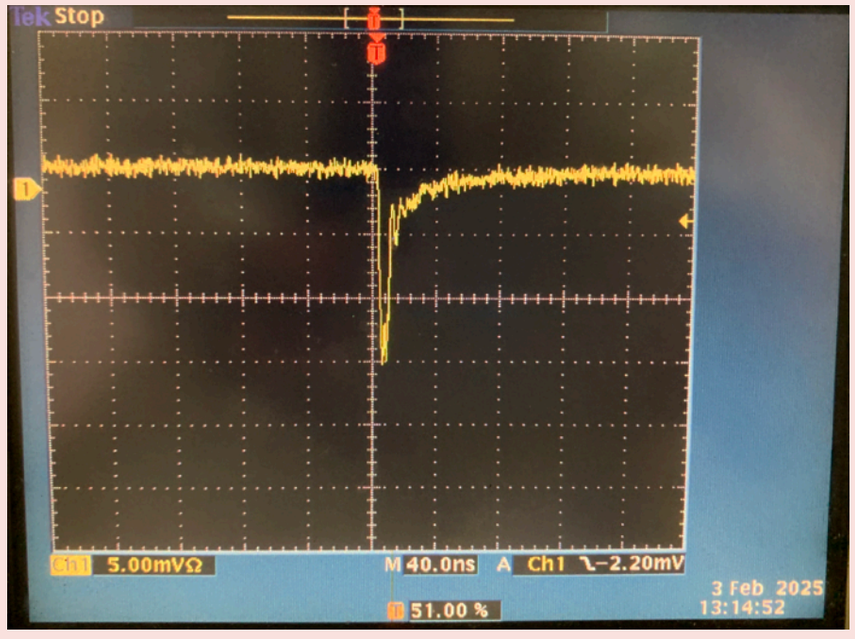
- Employing 2 samples, graphite-straw prototype detector was assembled.



First Fire !!

- Employing 2 samples, graphite-straw prototype detector was assembled.

- **First Fire** with β-ray from 90Sr.
- w/ HV=1400V, **clear signal was observed** !!
- But, a bit unstable… current rampages sometimes. Maybe some microdischarges ?



Some Prospects…

- **World First Graphite Straw-tube Detector**
  - **Advantages;** Extremely Thin, Metalization is not necessary, Robust against radiation and heat, Good Conductivity, *etc*.
  - **Disadvantages;** Need many R&Ds to make it stably

- **Ideas of Application, Under Discussion**
  - ***eg*. target, radiation-hard electrodes**
  - **Even for other than radiation detectors !**
    - **idea-1) Sheet-type electrode for capacitor, idea-2) Sheet-type heating element, idea-3) Harsh environment gas sensor, idea-4) Electromagnetic filter, and idea-5) Cell current element in Biology, were already proposed by some material scientists.**

thanks !