

**Vacuum-Compatible Ultra-Thin-Wall Straw Tracker;
Detector construction, Thinner straw R&D,
and the brand-new graphite-straw development**

by Hajime NISHIGUCHI, *KEK* , *J-PARC*  大強度陽子加速器施設, *COMET* 

VCI2022, 21-25.Feb.2022, Vienna→Online

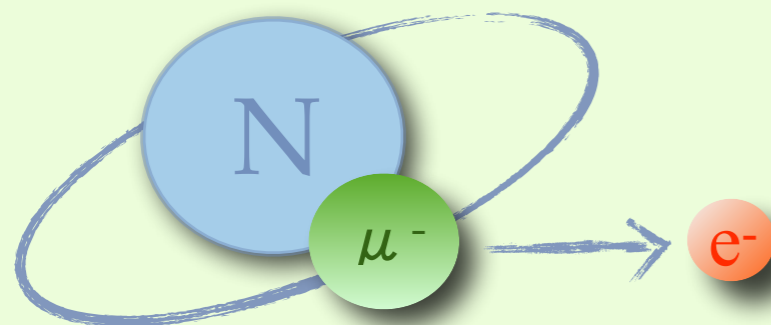
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- ❖ Motivation
 - ❖ The COMET Experiment — Search for “*Muon-to-Electron*” Conversion
 - ❖ Extremely Light Material Tracker → *Vacuum-Compatible Ultra-thin Straw*
- ❖ Straw-Tracker Development
 - ❖ Thin-wall / Vacuum-tight Straw Tube
 - ❖ Detector Development; *Past - Present - Future*
 - ❖ New Challenge; *Graphite straw*

Motivation

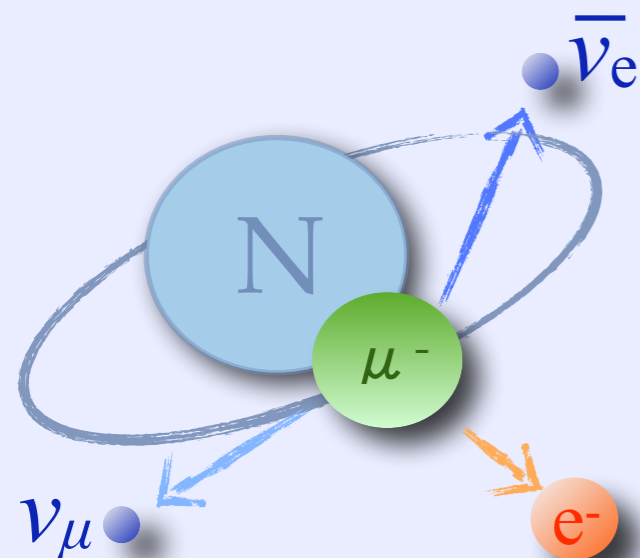
The COMET Experiment

- * An Experiment to Search for “ $\mu\text{-}N\rightarrow\text{e-}N$ ” 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

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

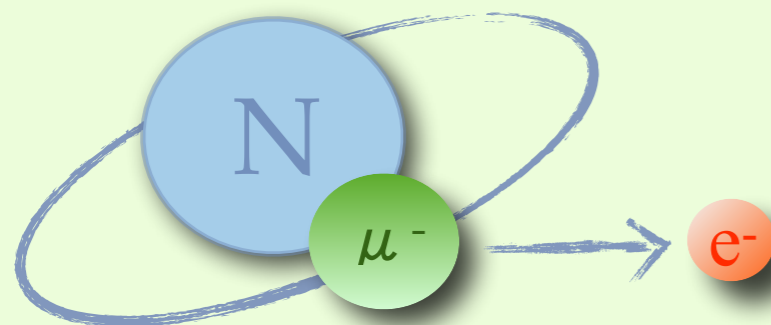


* BGs

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

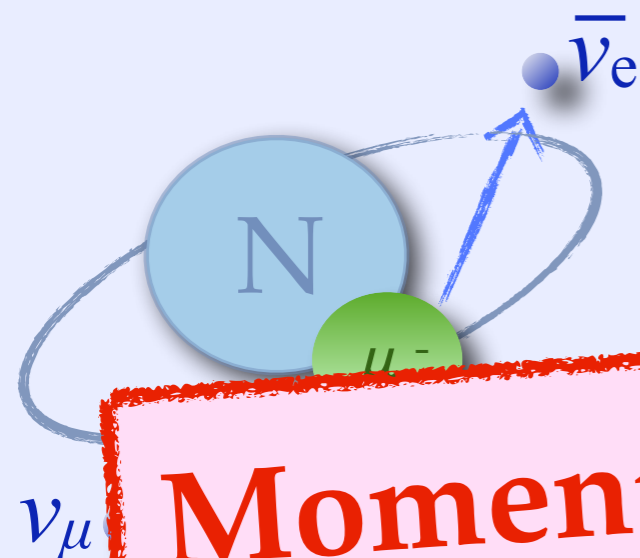
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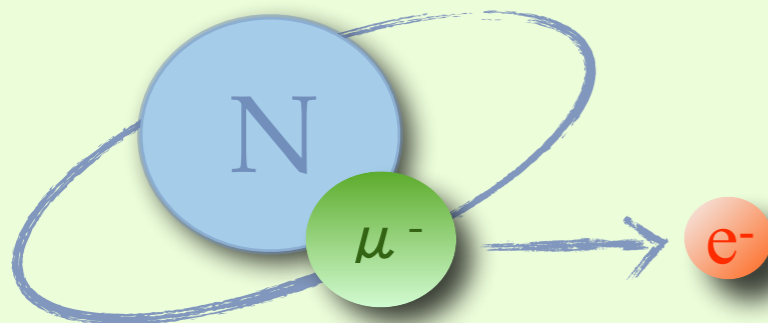
* BGs

- * **Prompt (Beam-related)**
- * **Decay in Orbit (DIO)**
- * **Radiation**

Momentum Resolution is Essential !!!

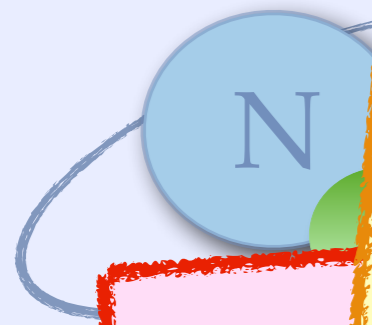
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Momentum

Need to achieve, at least,
 $< 200 \text{ keV}/c$ for $100\text{MeV}/c \text{ e}^-$

!!!

Tracker for COMET

Need to achieve, at least,
 $< 200 \text{ keV}/c$ for $100 \text{ MeV}/c \text{ e}^-$

- ❖ **Material effect (Multiple Scattering: MS) 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



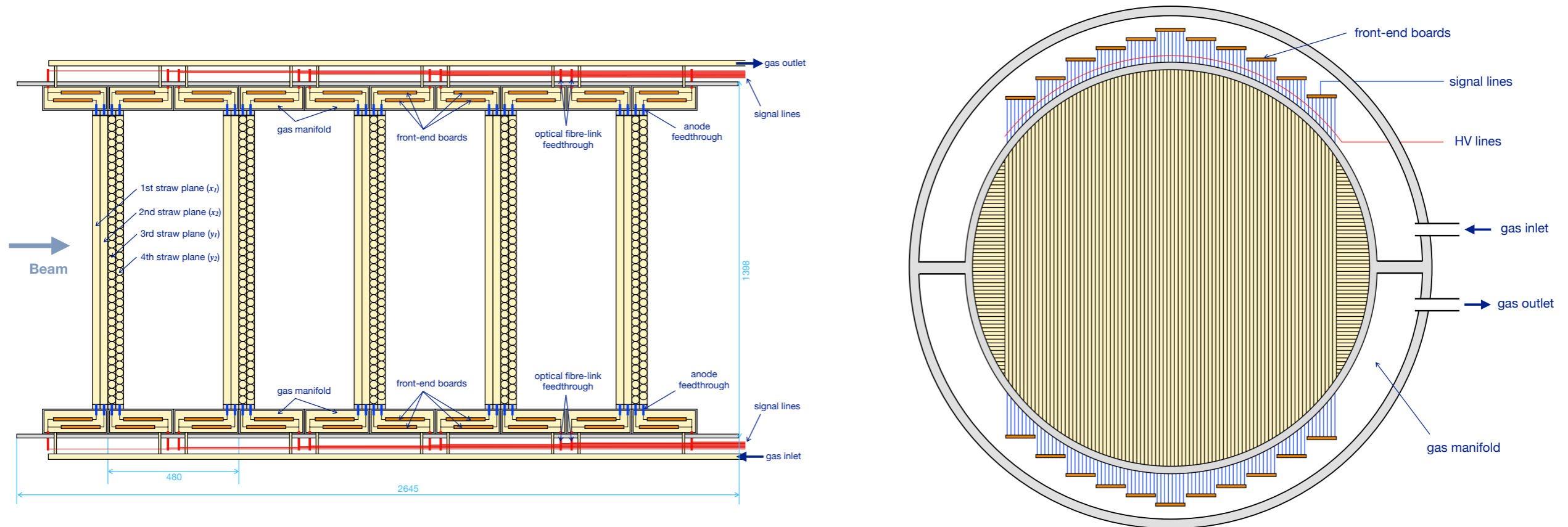
Not only COMET,
 also **Mu2e** (μ -e conv.),
Muon g-2 Fermilab,
NA62 CERN ($K^+ \rightarrow \pi^+ \nu \nu$),
etc...

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

Straw-Tracker Development

The COMET Straw Tracker

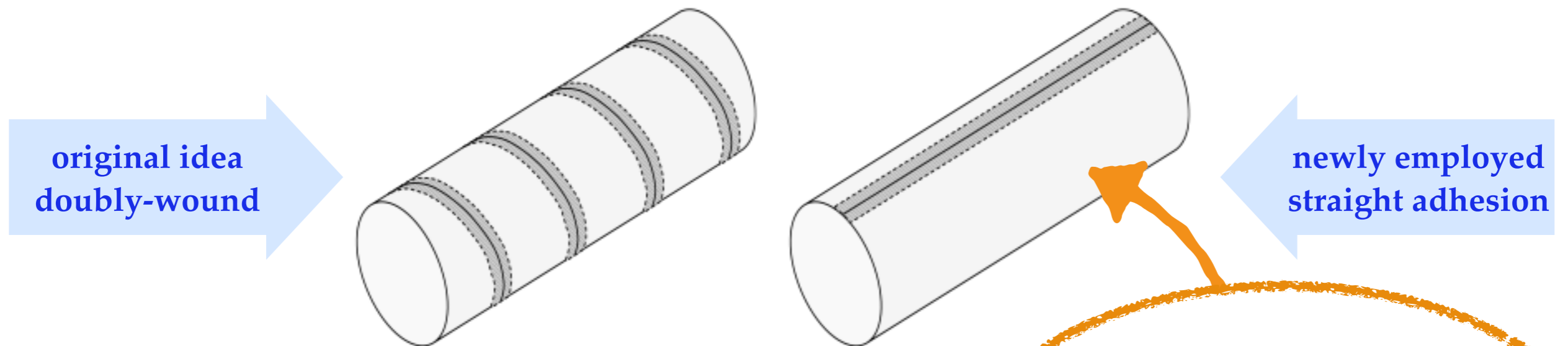
- ❖ **Planar** wire-chamber-base tracker in **Vacuum** → **Straw Tracker**



- ❖ Five super-layers (**module**) 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



- ❖ **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.**

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

Achievements to make a thin-wall straw

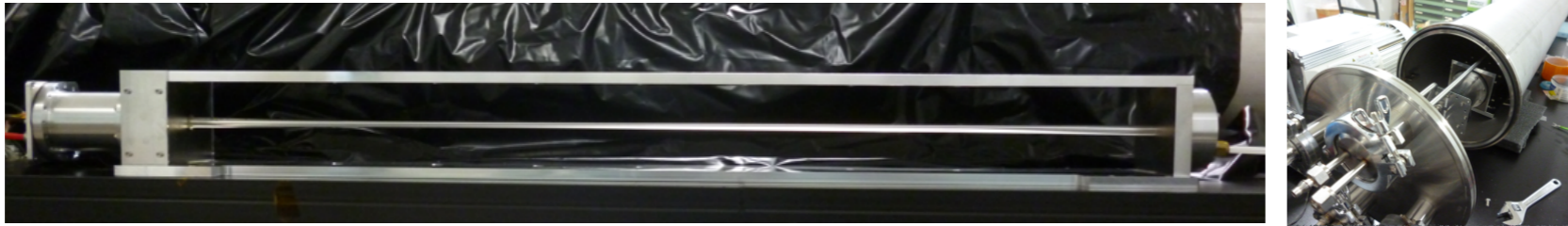
	NA62 straw	COMET straw 20 μ m	COMET straw 12 μ m
Mylar wall thickness	36 μ m	20 μ m	12 μ m
Tube diameter	9.8 mm	9.8 mm	5.0 mm
Cathode material	Cu(50nm) + Au(20nm)	Al (70 nm)	Al (70 nm)
Development status	In Operation	Detector Construction	R&D

- * Developed “COMET straw 20 μ m” is employed by “COMET phase-I”
 - * COMET employs two-staged approach
 - * Phase-I aims to achieve 10^{-15} sensitivity and investigate the beam background
 - * Phase-II aims to achieve the final sensitivity, 10^{-17}
- * COMET Phase-I straw tracker ($t20\mu\text{m}$, $\phi 10\text{mm}$) is under construction, and new “thinner and smaller” straw ($t12\mu\text{m}$, $\phi 5\text{mm}$) R&D is ongoing

Development; **Past-Present-Future**

* ~2016, New straw ($t=20\mu\text{m}, \phi=10\text{mm}$) Development

- * Test in vacuum, 1-straw prototype detector

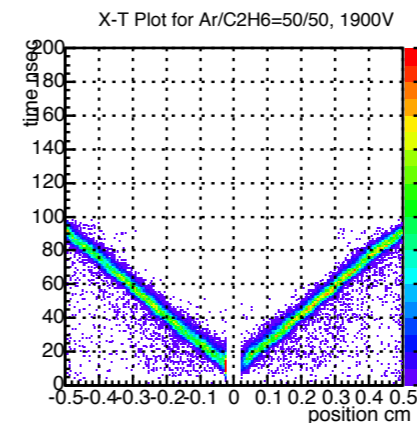


Reported at
VCI2016



* ~2019, Tracker development and Thinner straw development

- * Full-scale prototype detector, Test-beam for performance study



Reported at
VCI2019

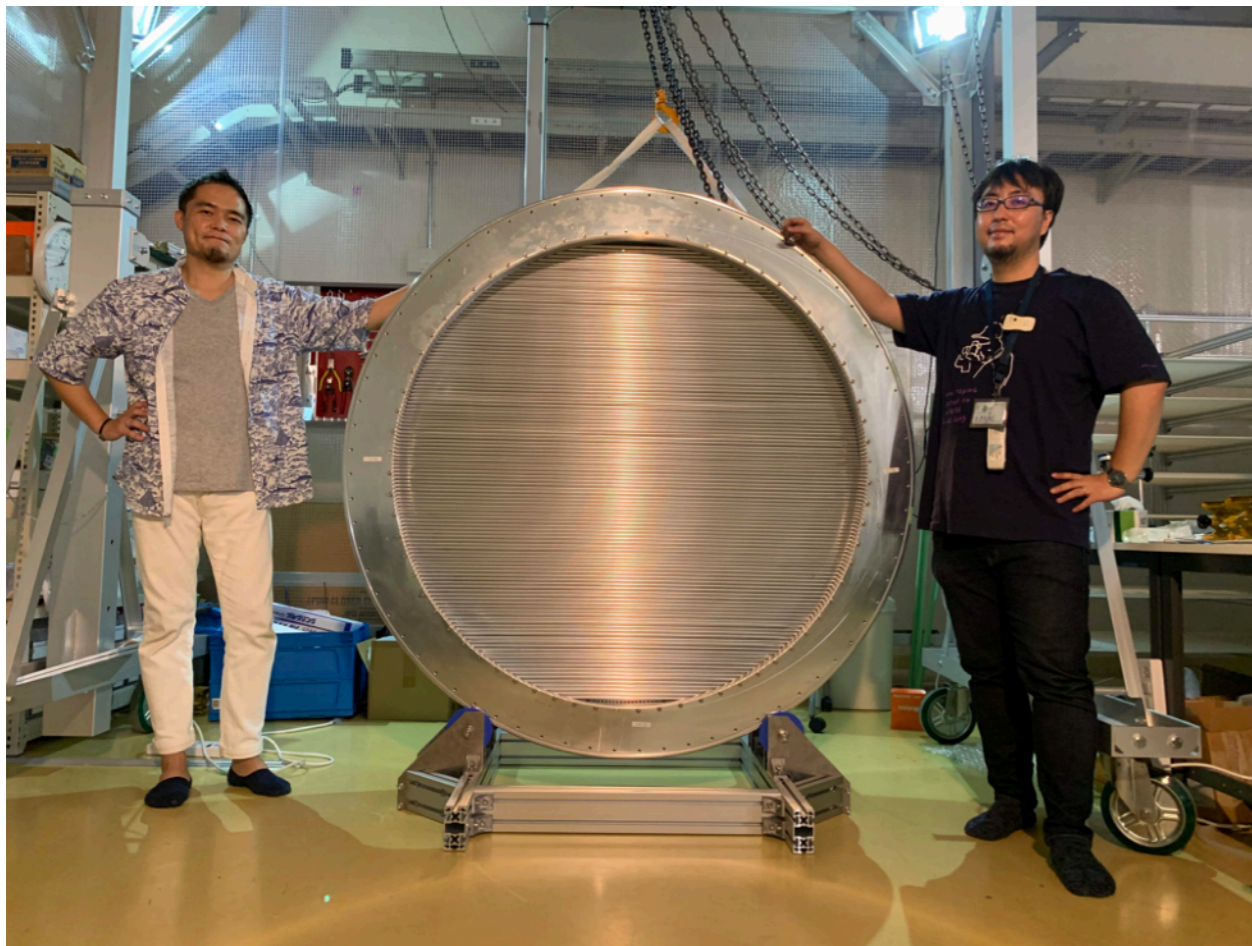


* Thinner straw R&D

- * Started to investigate “thinner and smaller” straw, and Decided to aim “ $12\mu\text{m}$ thickness and 5mm diameter”

Development; Past-**Present**-Future

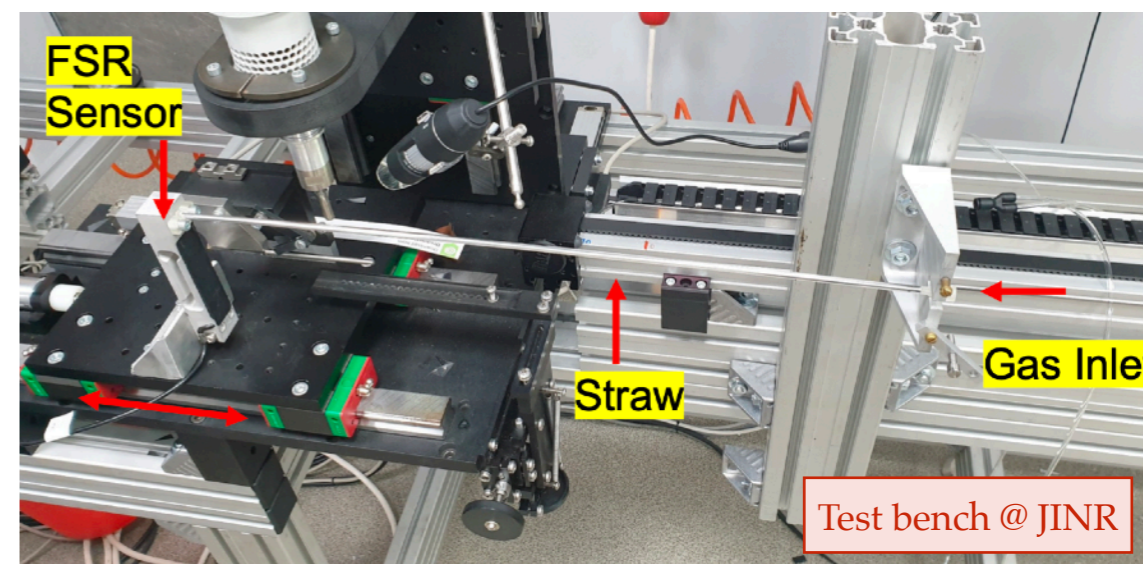
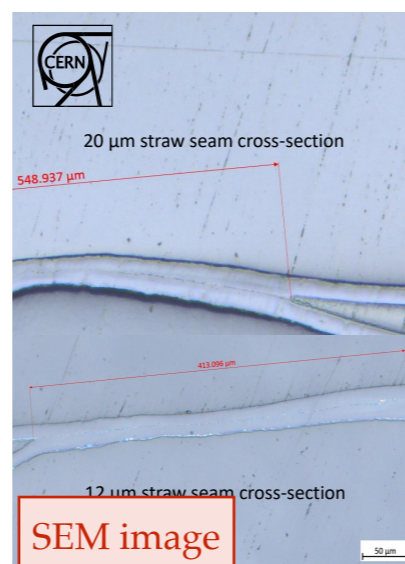
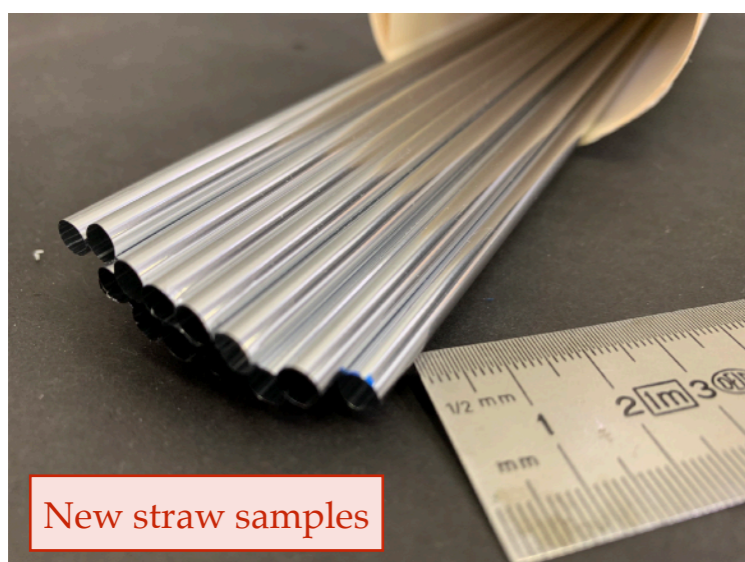
- ❖ Construction of the **Straw Tracker for COMET Phase-I** is ongoing.
- ❖ The 1st station, out of 5 stations, is completed.



- ❖ Assembly for 2nd station is ongoing.
- ❖ Will be ready for COMET Phase-I commissioning in 2024.

Development; Past-Present-Future

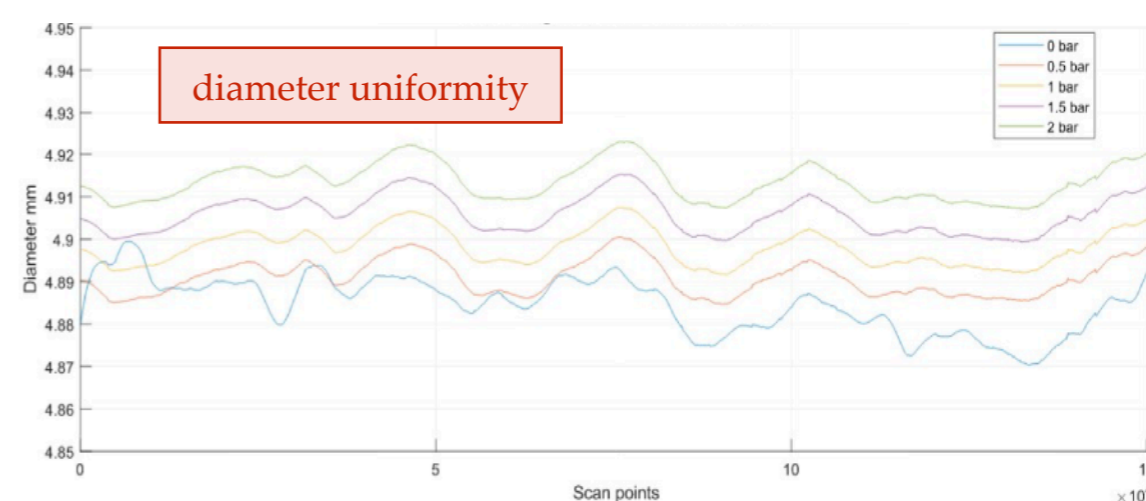
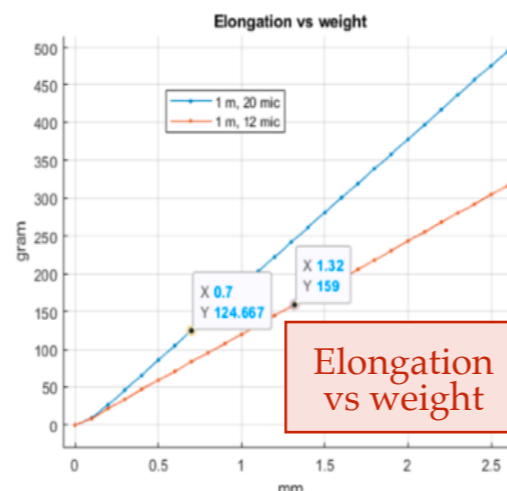
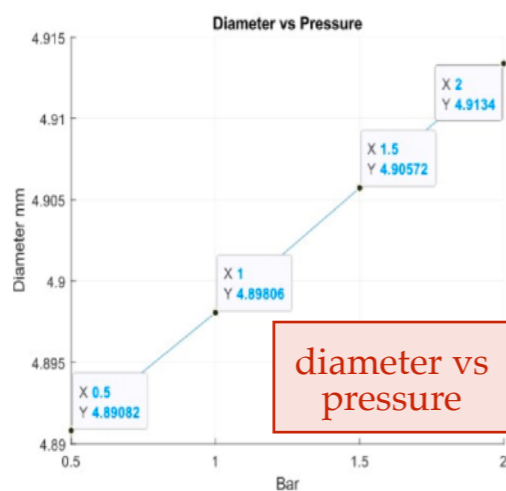
- ❖ New straw R&D is ongoing → “12 μ m thickness and 5mm diameter”
- ❖ Lead by **JINR COMET straw group** (N. Tsverava *et. al.*)
- ❖ Assembly technique R&D by joint effort with **NA62 collaboration at CERN** (H. Danielsson *et. al.*)



Mechanical study, ongoing



Looks OK,
Still need further studies

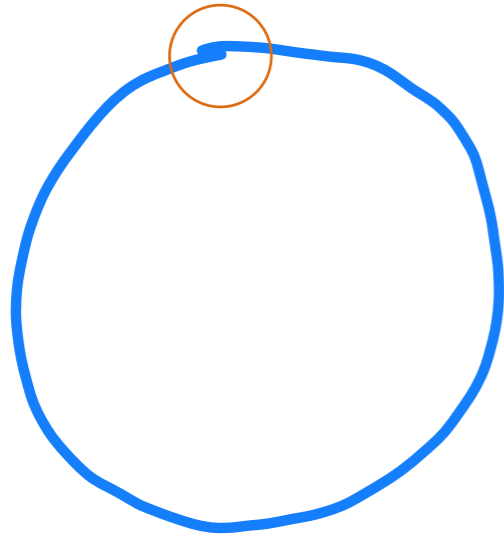


Even Thinner Straws ?

— for the future experiments —

Technical limitation

- ❖ Straight adhesion by ultrasonic welding
 - ❖ (Maybe) **12 μ m-thickness is a limit**



Seam width is important;

Need to be **wide** enough to keep **tightness**

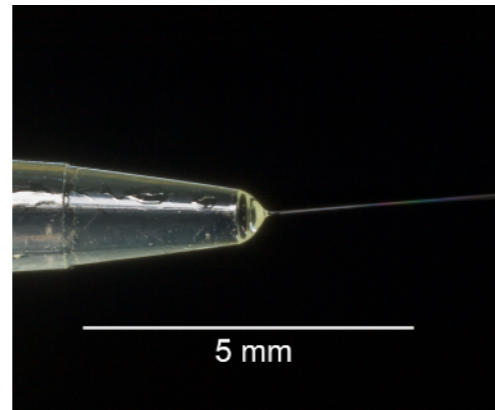
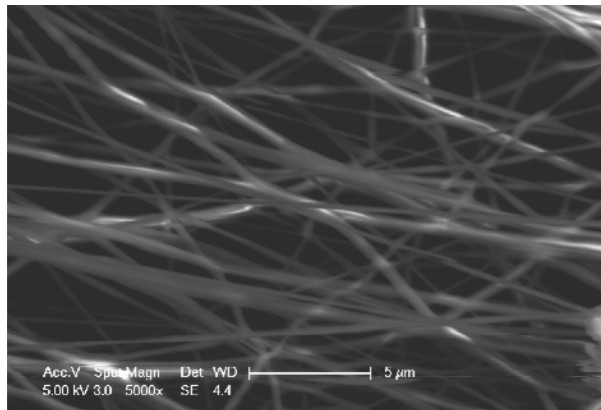
Need to be **narrow** enough to keep **roundness**

- ❖ 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.



- ❖ 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 !!**

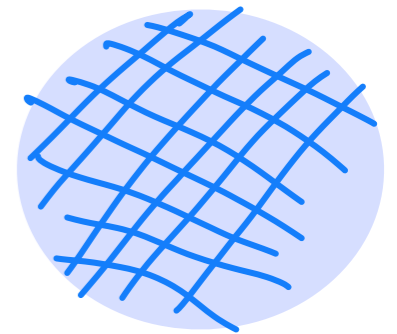
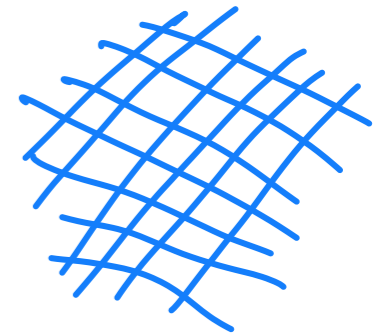
Problems to be solved:

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

Can we solve issues ? YES

* Gas-tightness

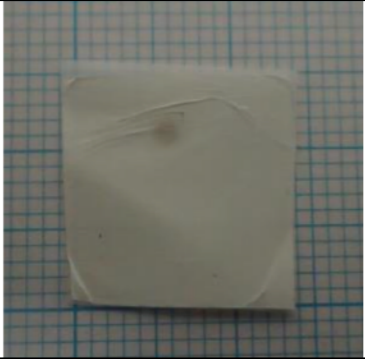



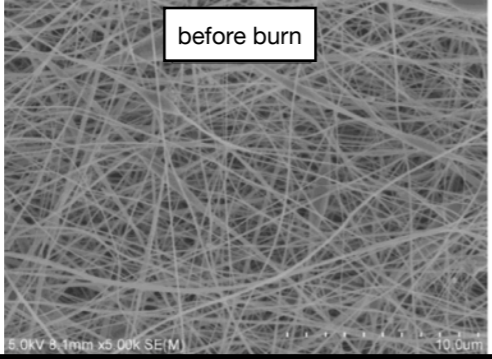
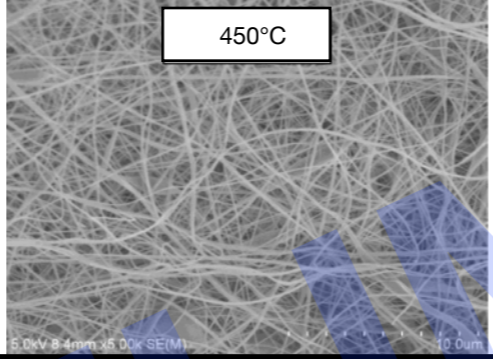
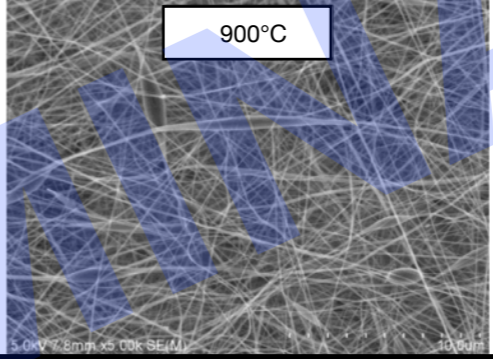
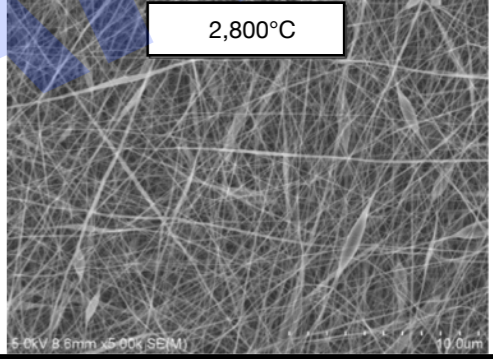
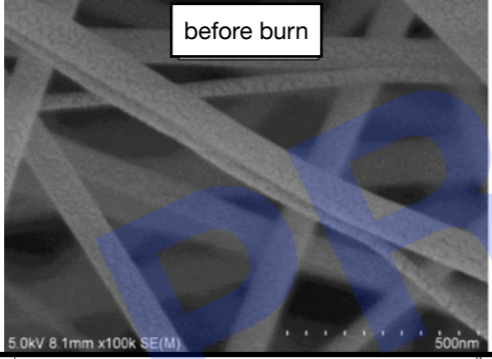
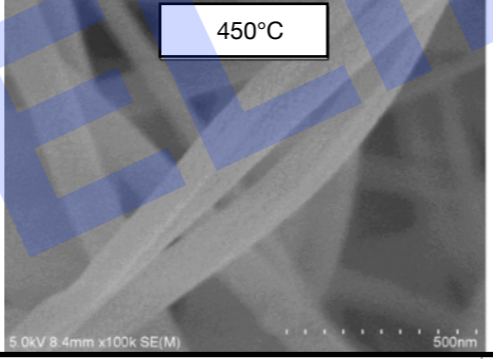
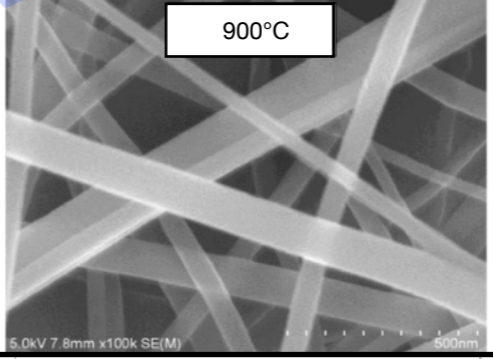
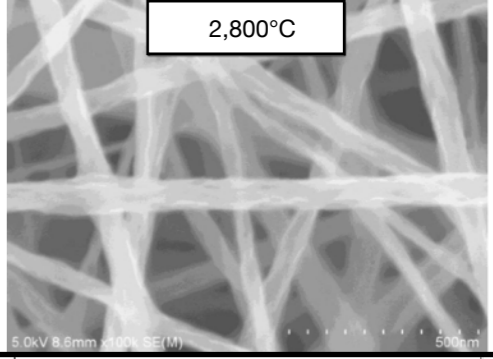
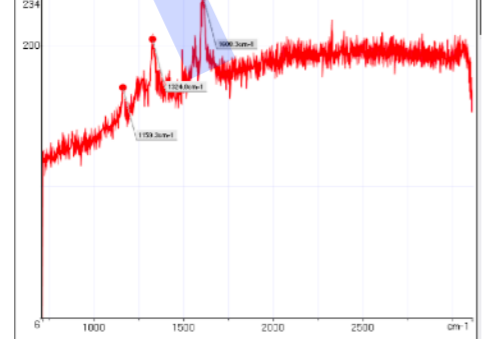

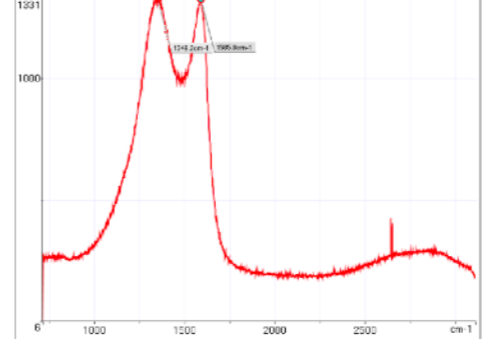
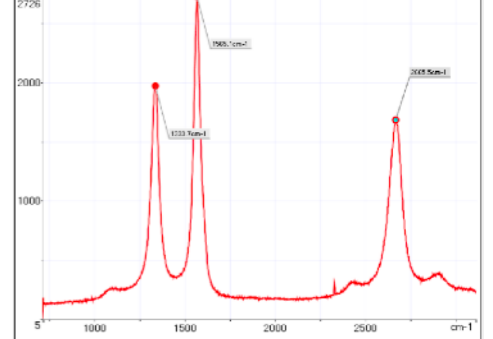
- * At the 1st step (polymer fabric), polymer straw is made with a polyamic-acid solution (=base of Polyimide).
- * At the 2nd step, by impregnation (soaking) with a polyamic-acid solution into polymer straw, gas-tight straw is realized.



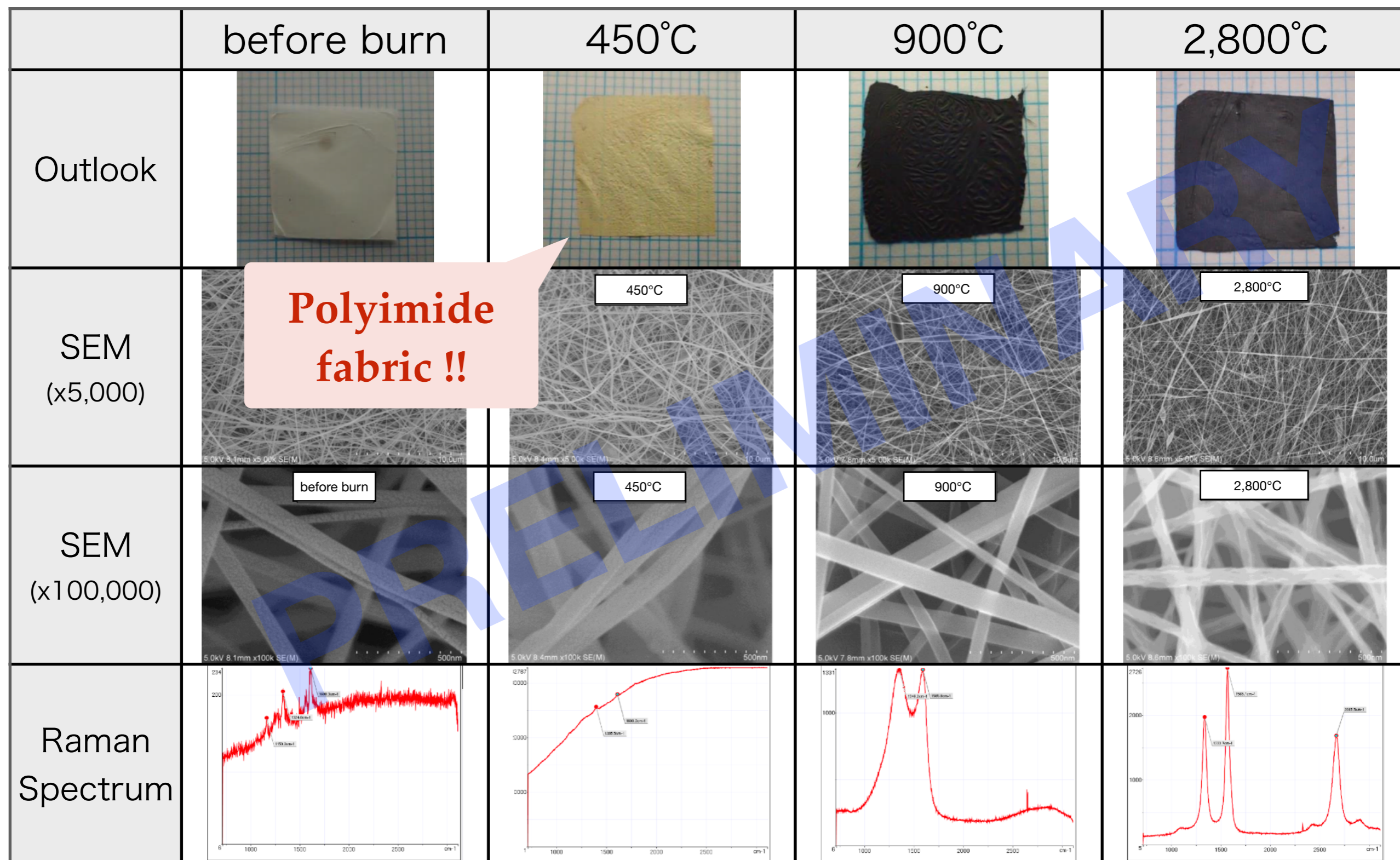
* Conductivity

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

Some pilot tests






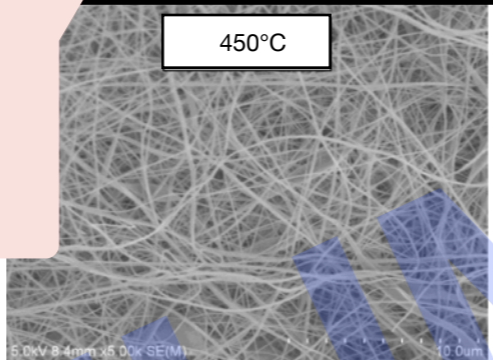
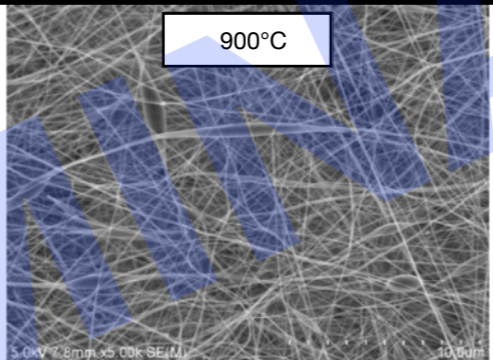
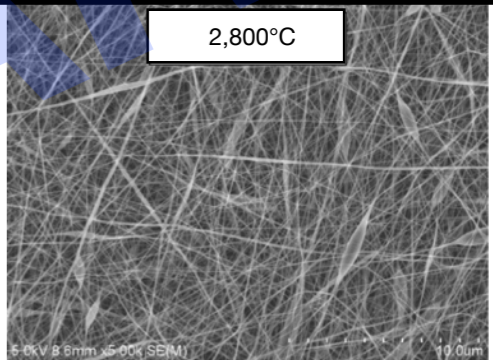
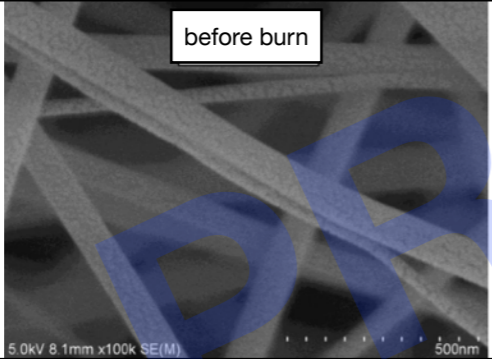
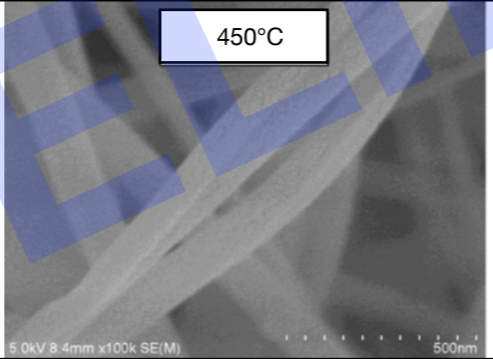
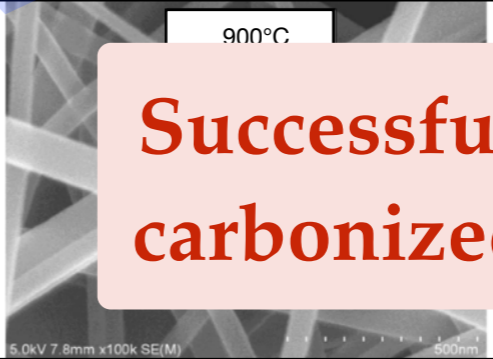
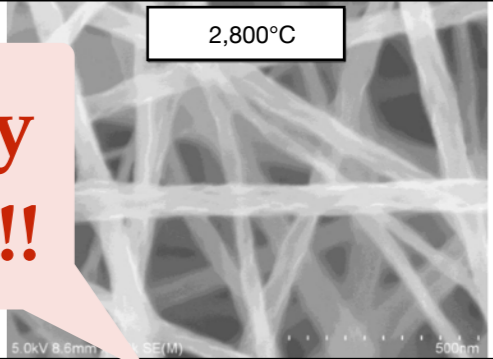
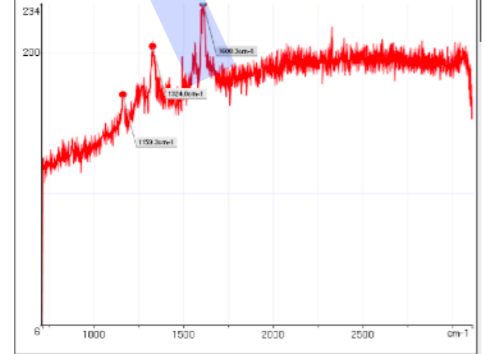
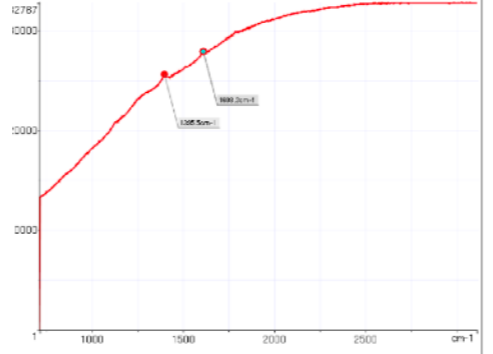
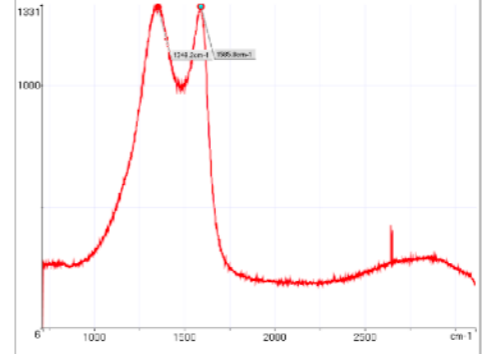
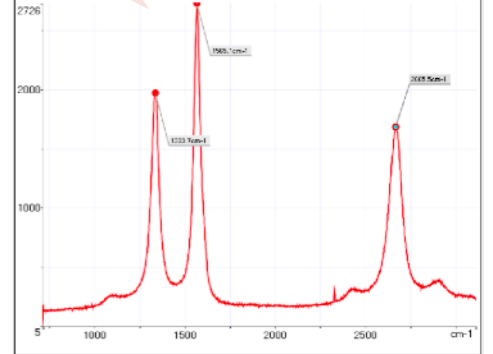
	before burn	450°C	900°C	2,800°C
Outlook				
SEM (x5,000)				
SEM (x100,000)				
Raman Spectrum				

Some pilot tests



Polyimide fabric !!

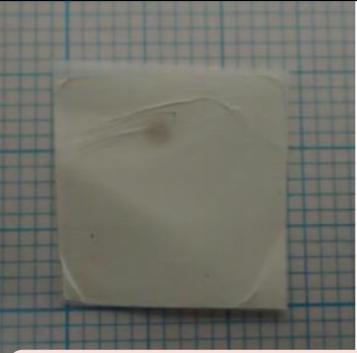
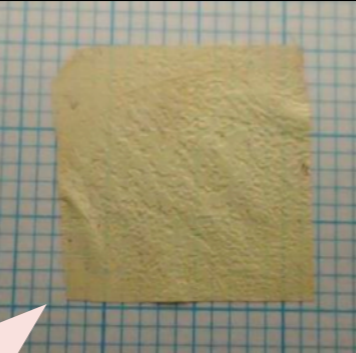
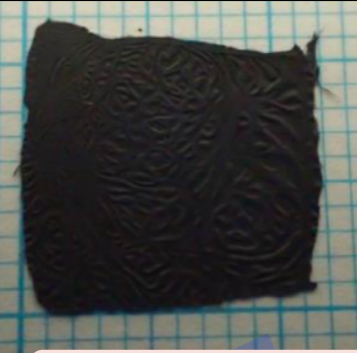


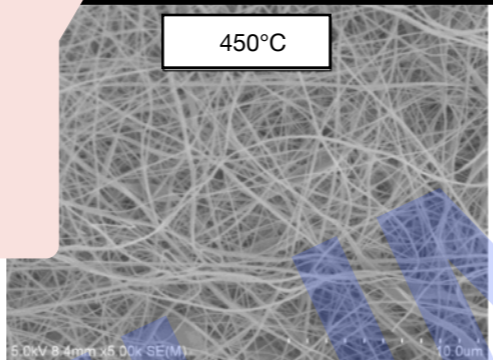

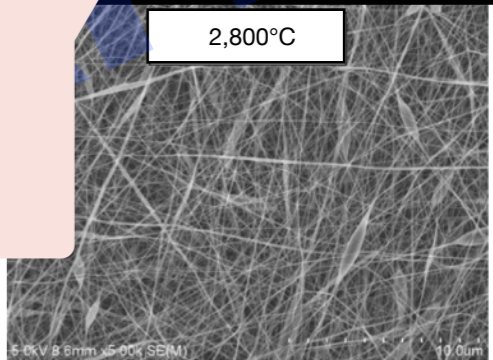
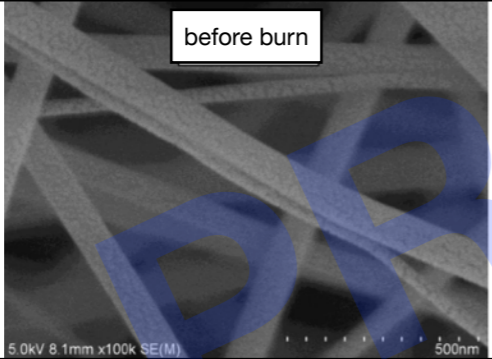
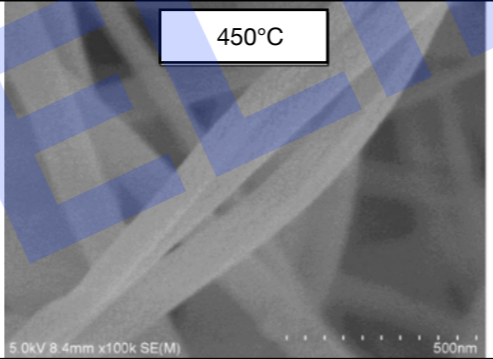
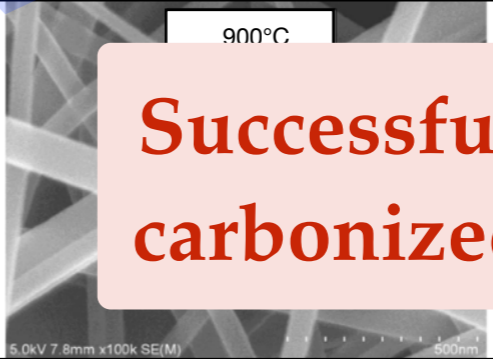
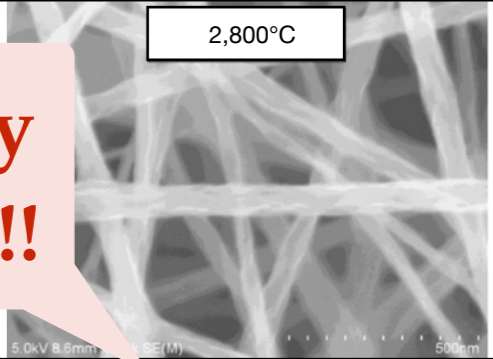
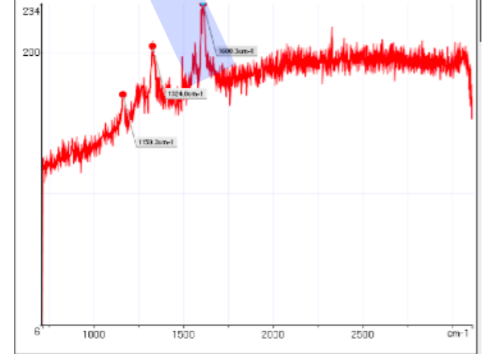
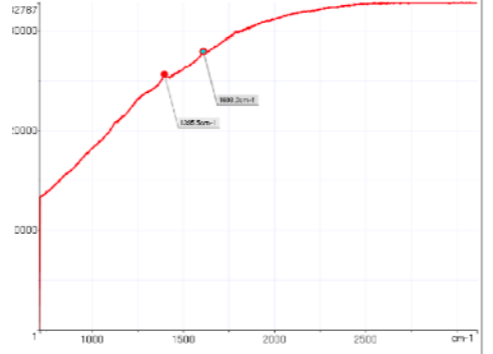
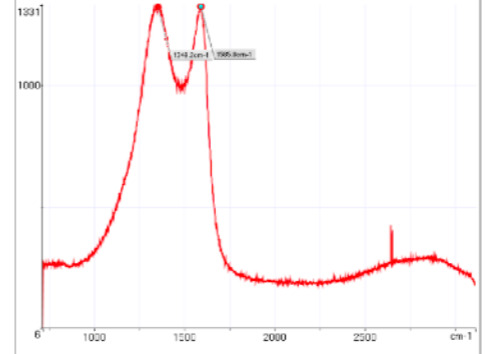
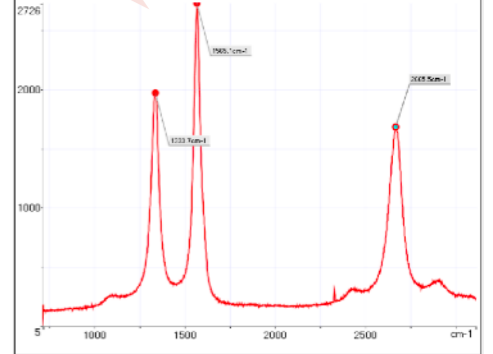
Some pilot tests

	before burn	450°C	900°C	2,800°C
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SEM (x5,000)				
SEM (x100,000)				
Raman Spectrum				

Polyimide fabric !!

Successfully carbonized !!

Some pilot tests

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

Polyimide fabric !!

Graphite textile !!

Successfully carbonized !!

Issues still to be solved

❖ Roundness

- ❖ How we can make it roundly ?



- ❖ First trial looks very wavy...
- ❖ More sophisticated method is necessary...

❖ Conductivity

- ❖ Electrical conductivity was measured with the first burned samples; **19.8 S/cm** for 900°C sample and **439 S/cm** for 2,800°C sample, respectively. → Worse than expected
- ❖ Might be caused by a base textile → Possible to make a dense textile at the 1st step.

Conclusions

- Vacuum-compatible Ultra-thin straw is a good tracker for low-energy charged particle tracking, *eg.* μ -e conversion search, μ g-2, K rare decay, *etc.*
- COMET experiment developed $t20\mu\text{m} / \phi10\text{mm}$ straw for COMET Phase-I
 - After VCI2019, final assembly for COMET Phase-I tracker started.
 - The 1st station, completed. Aim to complete 5 stations in 2024.
- New thinner / smaller straw ($t12\mu\text{m} / \phi5\text{mm}$) developed at JINR
 - Aim to develop new tracker for COMET Phase-II and NA62-upgrade with a joint effort among KEK/JINR/CERN.
- Even thinner straw ?
 - Polyimide fabric by a nano-fibre technology can make a paradigm shift !
 - Gas-tightness / Conductivity can be realized by carbonization
 - **Graphite Straw !!**
 - Some pilot tests showed promising results, but still many issues we have.
- In the next VCI, Hope to report i) completion of Phase-I tracker, ii) development of thinner/smaller straw tracker, and iii) prototype detector of the graphite straw !