DarkLight Collaboration Meeting at TRIUMF, Vancouver, May 27, 2022

GEM Trackers for DarkLight*

Michael Kohl <kohlm@jlab.org>
Jesmin Nazeer **, Tanvi Patel, Ishara Fernando

Hampton University, Hampton, VA 23668
Jefferson Laboratory, Newport News, VA 23606

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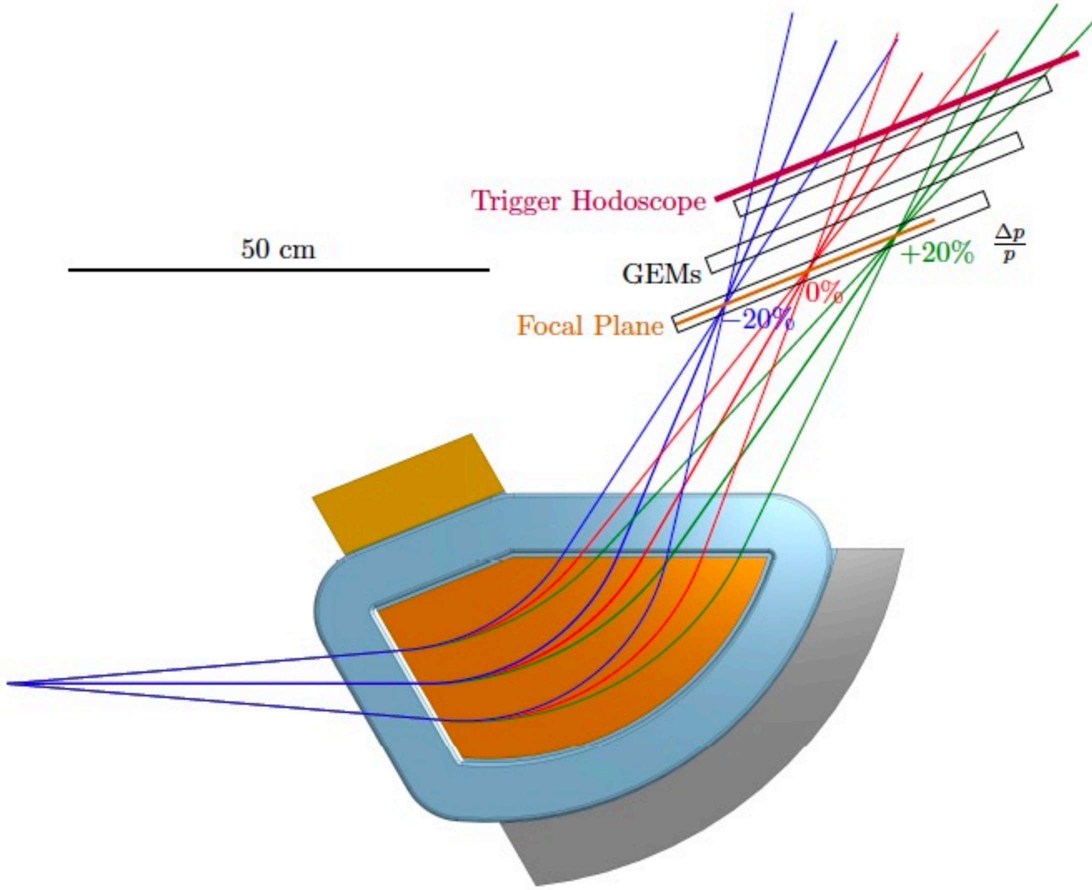
**** Supported by DOE SCGSR and JSA Graduate Fellowships**

DarkLight Phase 1c



- Dedicated search for the 17-MeV fifth-force carrier
- Two-spectrometer solution to detect e^+e^- pair
- DarkLight proposed at LERF (PAC39/2012) (approved)
- Proposed at CEBAF Injector (PAC46/2018, PAC48/2020) (deferred twice)
- Proposed at ARIEL/TRIUMF (PP-EEC 2021, approved)

- New set of GEMs active size: 25x40 cm^2 ; 8 GEM elements
  APV/MPD readout: 400μm pitch, 5+8=13 APVs, 104 APV/8 MPD, ~13k channels

Funded by MRI award 2014-2018

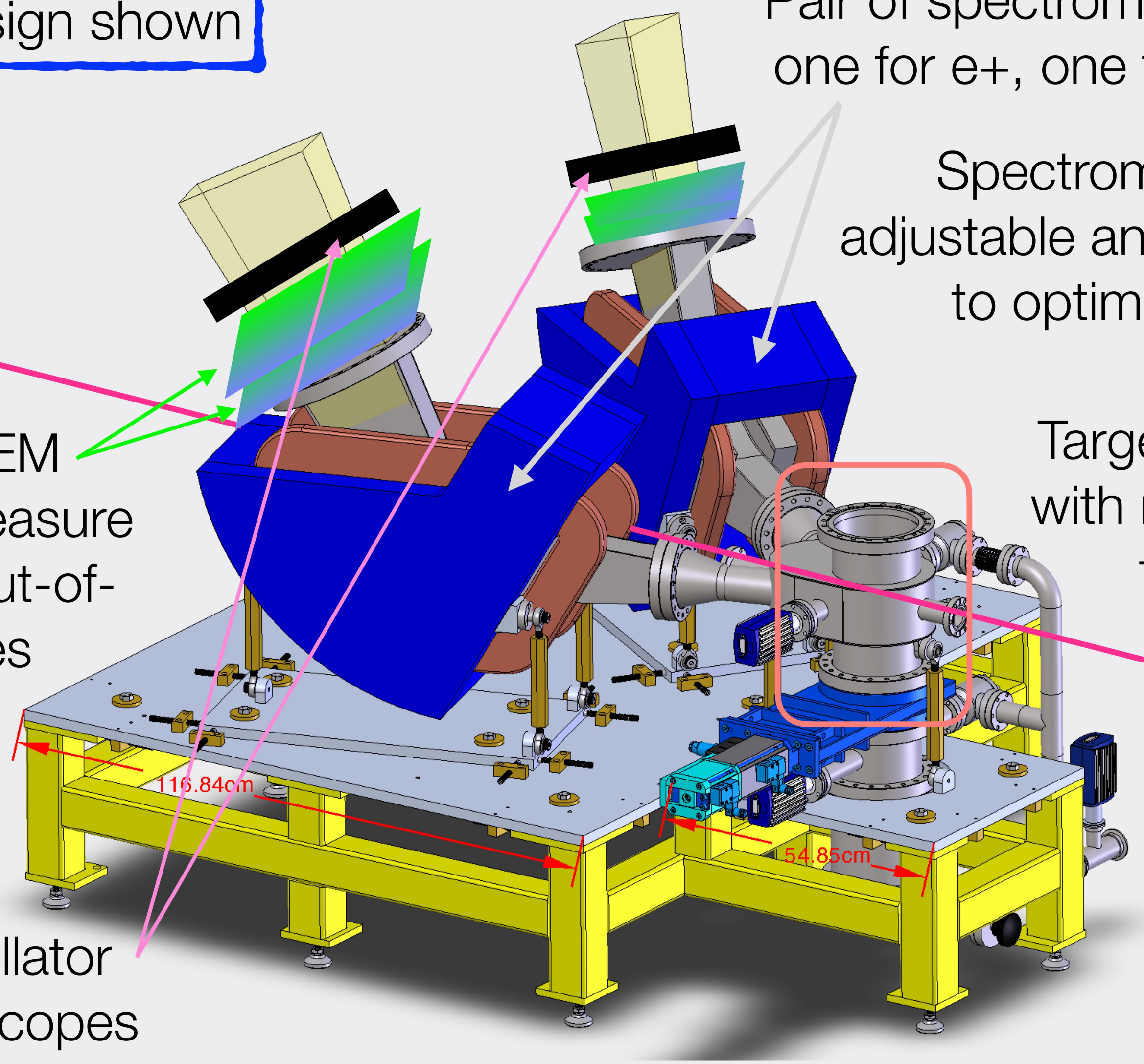
DarkLight at ARIEL (TRIUMF)

Preliminary design shown

Pair of spectrometers:
one for e+, one for e-

Spectrometer arms at adjustable angles: asymmetric to optimise selection

At least 2 GEM detectors to measure in-plane and out-of-plane angles



Target chamber with removeable targets

30 MeV
e- beam

Plastic scintillator trigger hodoscopes

from K. Pachal, PP-EEC 2022

Principle of GEM detectors

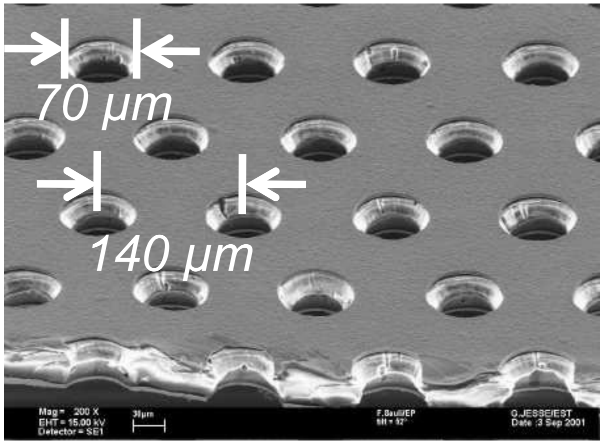
- **GEM = Gas Electron Multiplier**

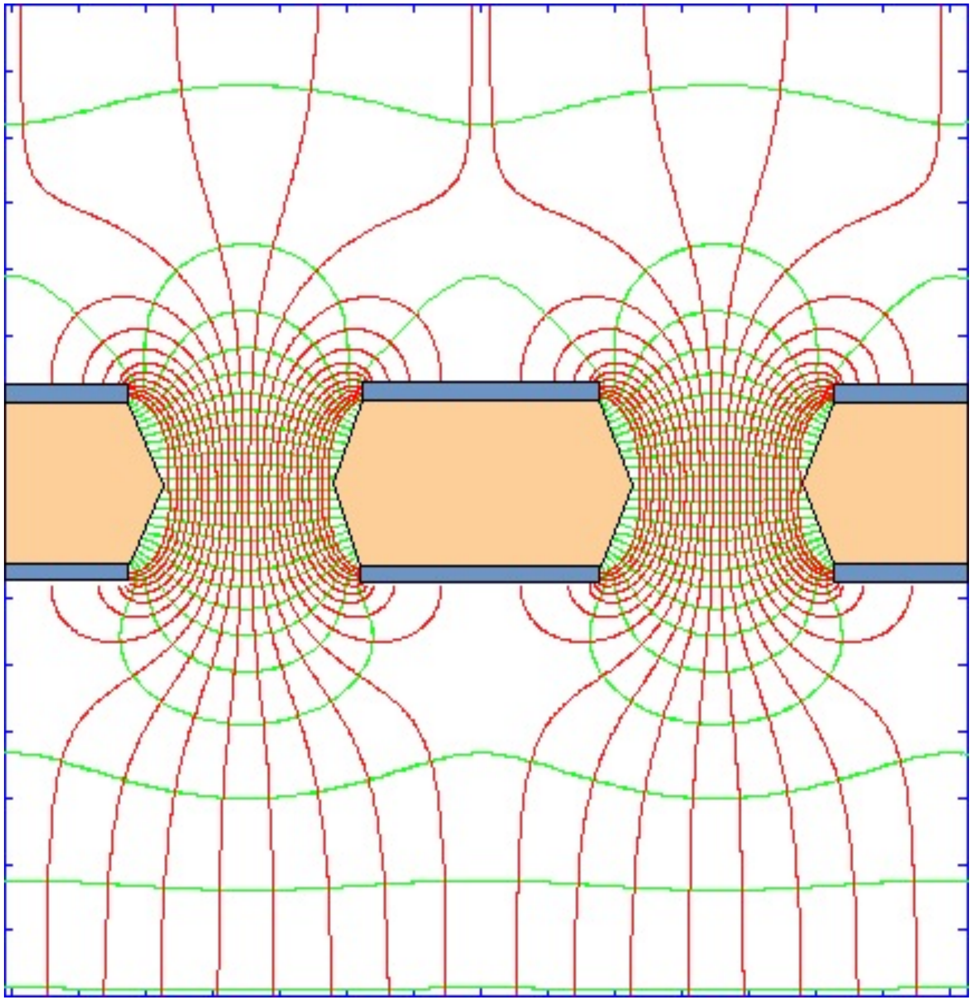
  introduced by F. Sauli in mid 90's, F. Sauli et al., NIMA 386 (1997) 531

- **Copper layer-sandwiched Kapton foil (Apical) with chemically etched micro-hole pattern**

- **Supply ~400V across foil, immersed in Ar:CO_2 (70:30)**

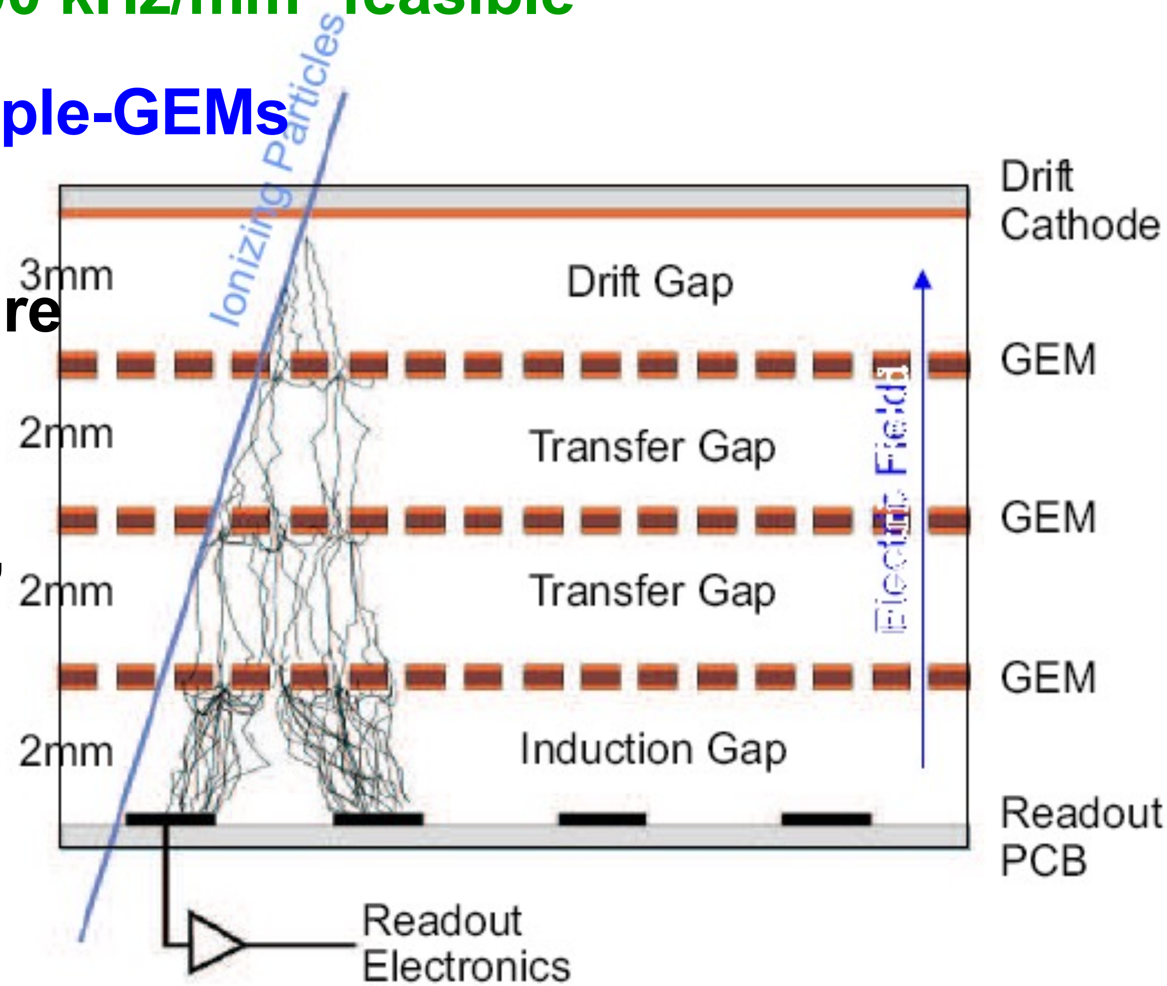
⇨ **gas amplification in the holes**





Properties of GEMs

- Mechanically robust compared to wire chambers
- Fast signals (risetime ~5ns, total signal ~100ns)
- Electron amplification, ions suppressed
- High rate densities 25-100 kHz/mm^2 feasible
- Stacks of double- and triple-GEMs for high MIP efficiency
- Versatile readout structure decoupled from amplification process
- Charge cloud of σ~1mm, centroid to <0.1mm
- Low mass (~0.5% X_0)

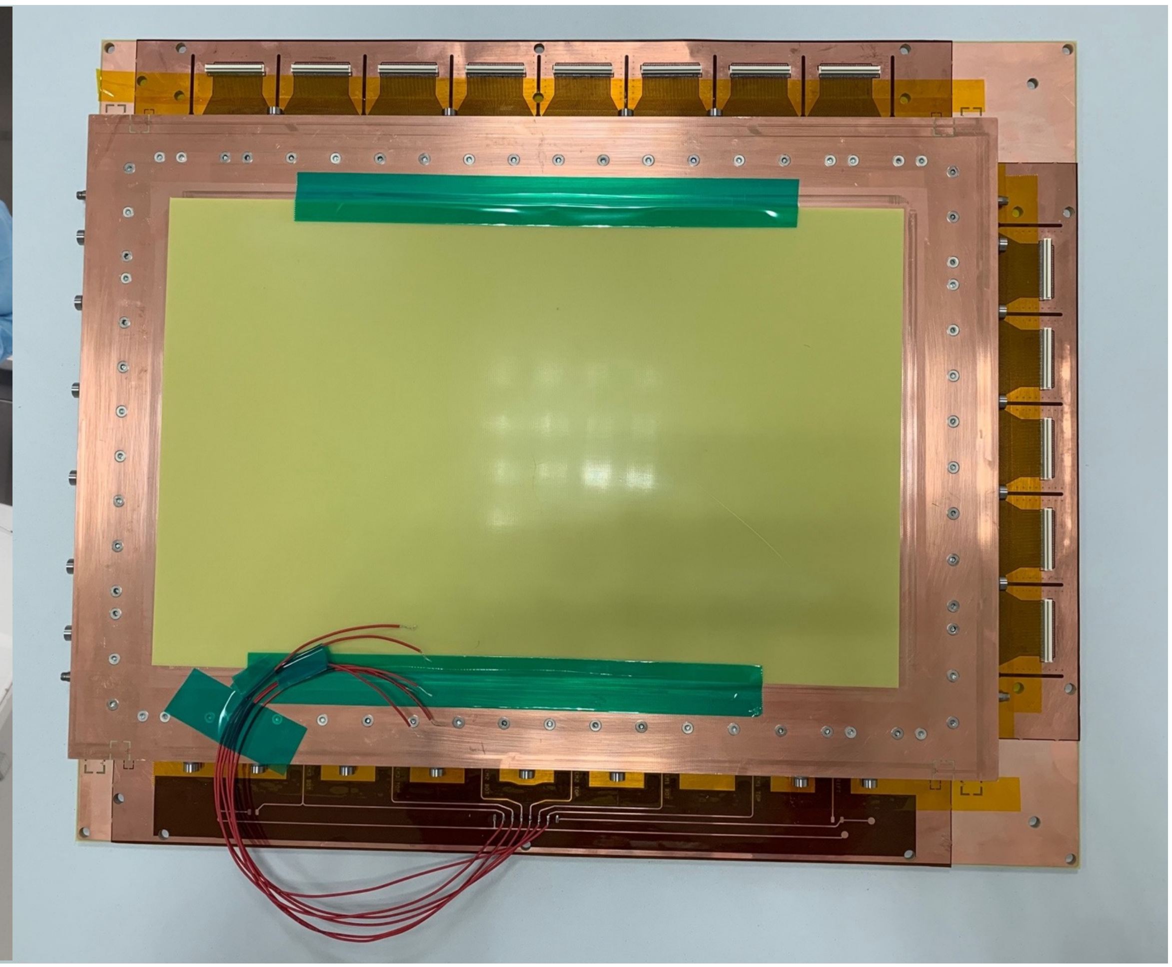


Construction of DarkLight GEM chambers

Constructed new set of 8 GEM elements active size: 25x40 cm^2, outer: 45x55 cm^2
APV/MPD readout: 400μm pitch, 5+8=13 APVs, 104 APVs/8 MPDs, ~13k channels

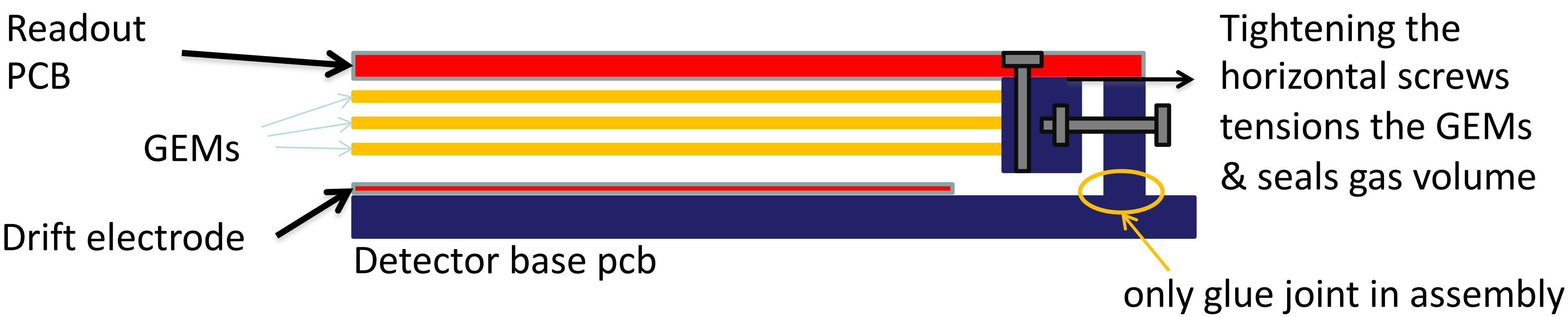
Funded by NSF / MRI award 2014-2018

First GEM chamber assembled Feb. 21, 2019 at CERN, continued in Hampton



NS2 adapted (from CMS Muon Endcap)

Current state-of-the-art: Self-stretching assembly without spacers (CERN)



2012

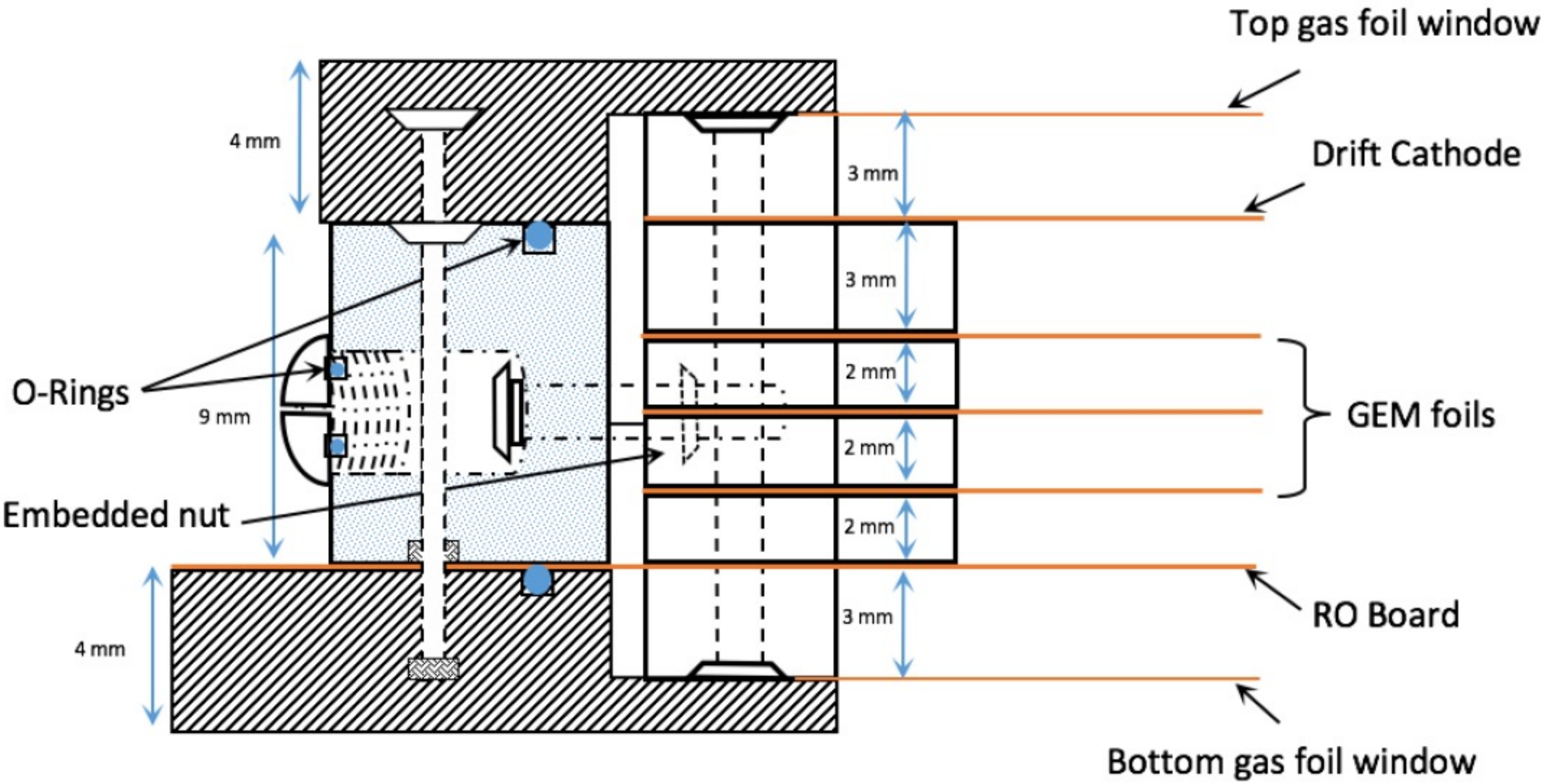
- **No spacers in active area**
- **Assembly time: 2 hours**
- **No gluing, no soldering**
- **Re-opening possible**
- **GEM exchange possible**
- **No stretch degradation with time**
- **Stretching more intense**
- **Base PCB and honeycomb in active area**

NS2 adapted (from CMS Muon Endcap)

5-layer stack clamped and stretched, active area material minimal (~0.5% X_0)

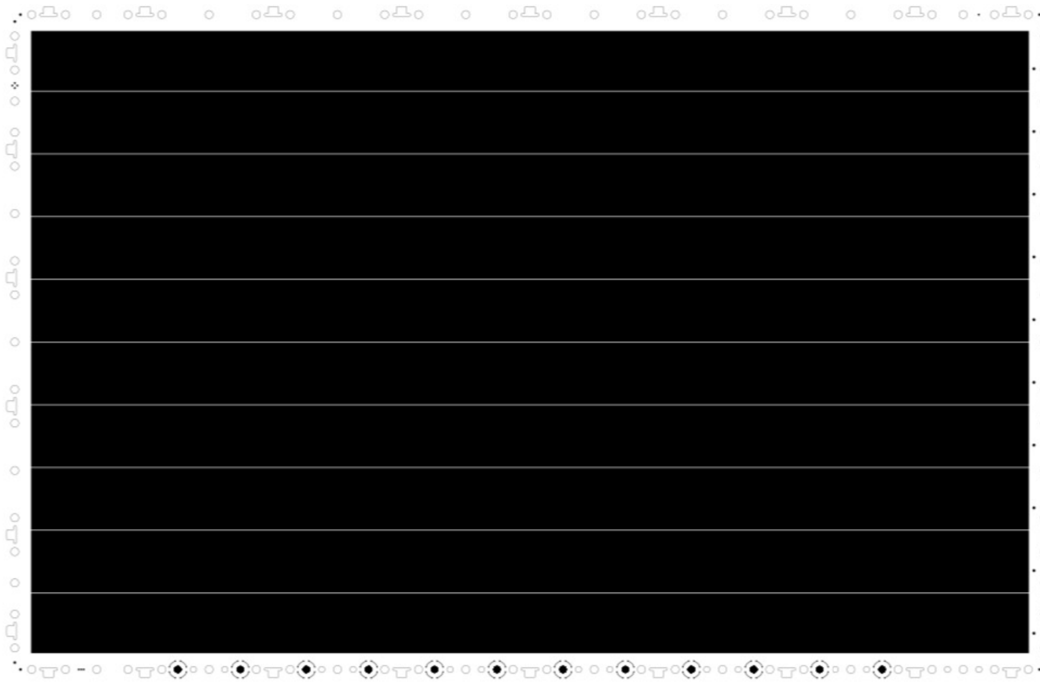
Extending RO layer to exterior along 2 sides for signals, and 1 side for HV

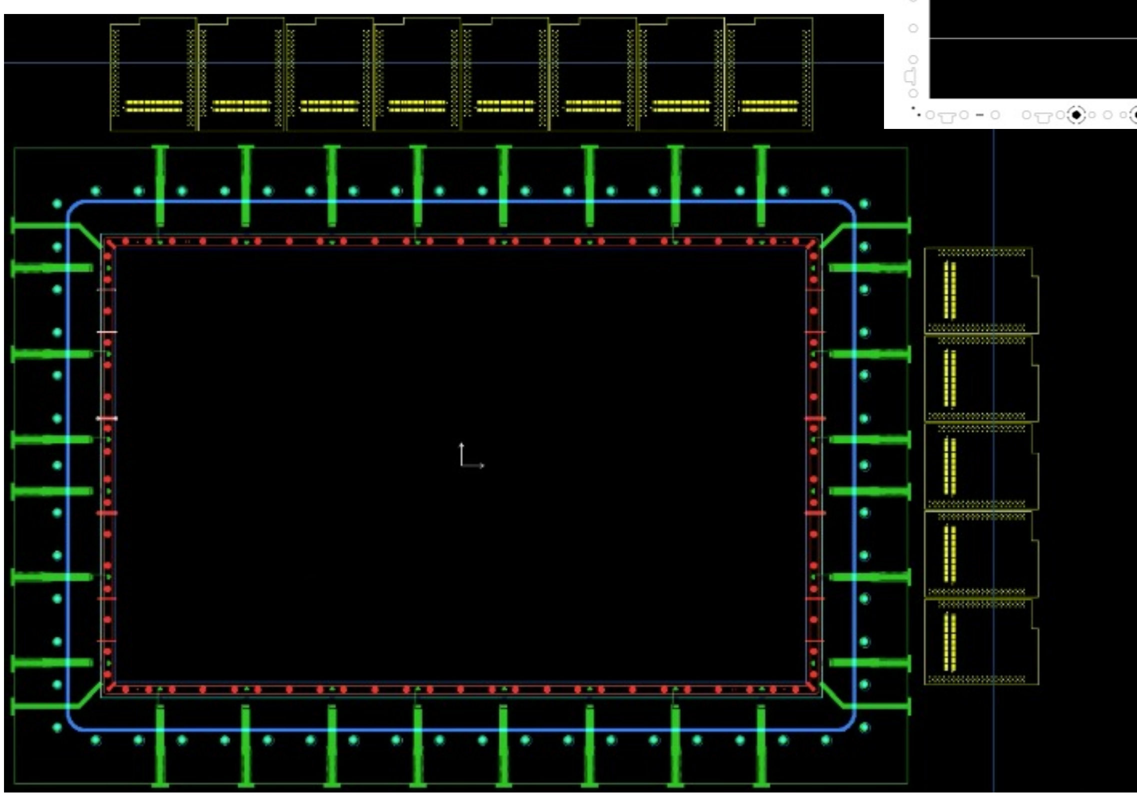
Cr (0.1µm) on Kapton for shielded and grounded Gas Pressure Windows



New GEM chambers under construction

- GEM foils of 25x40 cm^2 segmented to 10 high voltage sectors (100 cm^2) on top side
- One protection resistor (1 MOhm) soldered onto each GEM foil

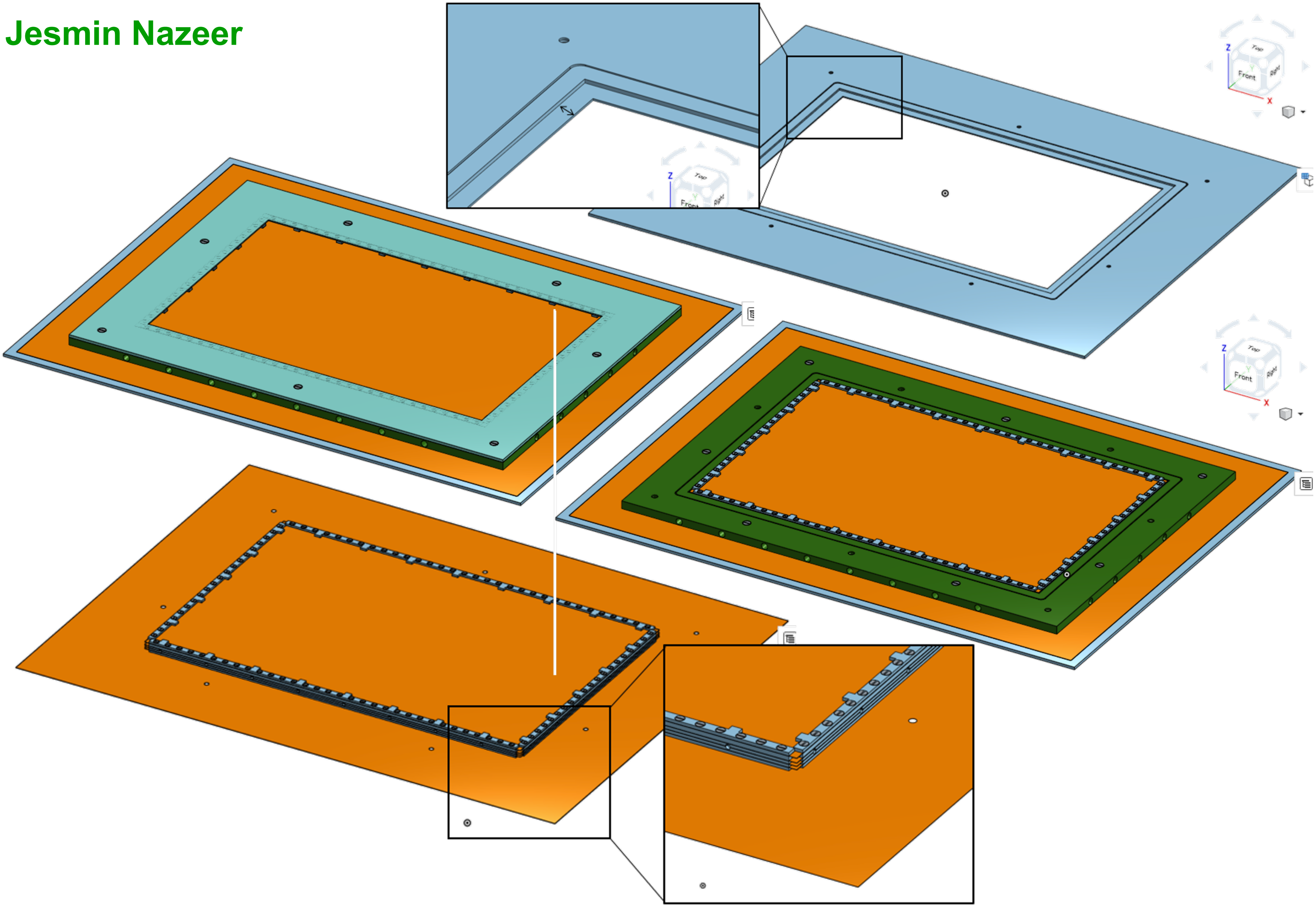




- Two gas inlets and outlets on the short sides for forced gas flow
- In-plane bolts for stretching

3D CAD modeling in OnShape

Jesmin Nazeer

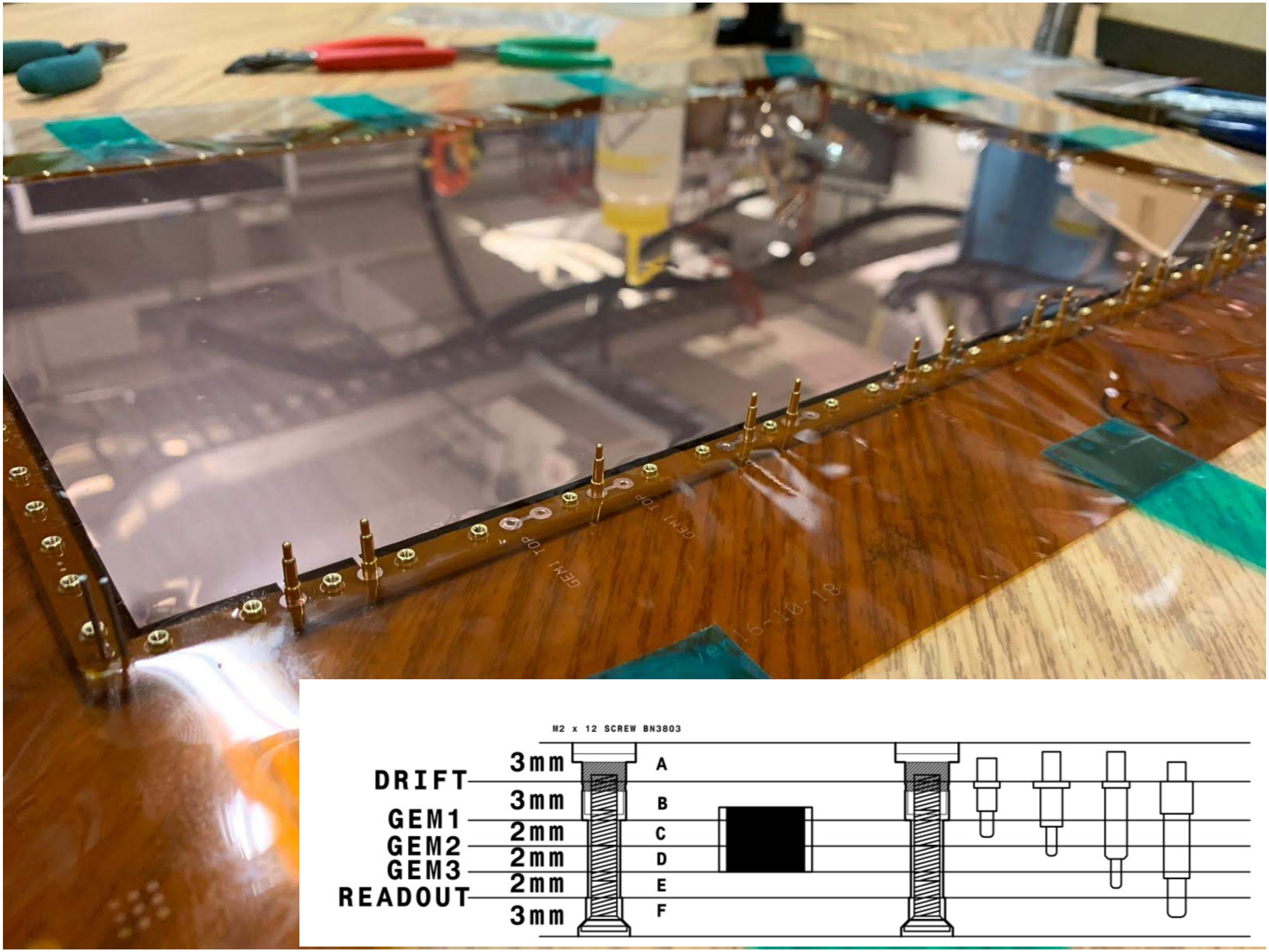


Steps for assembly

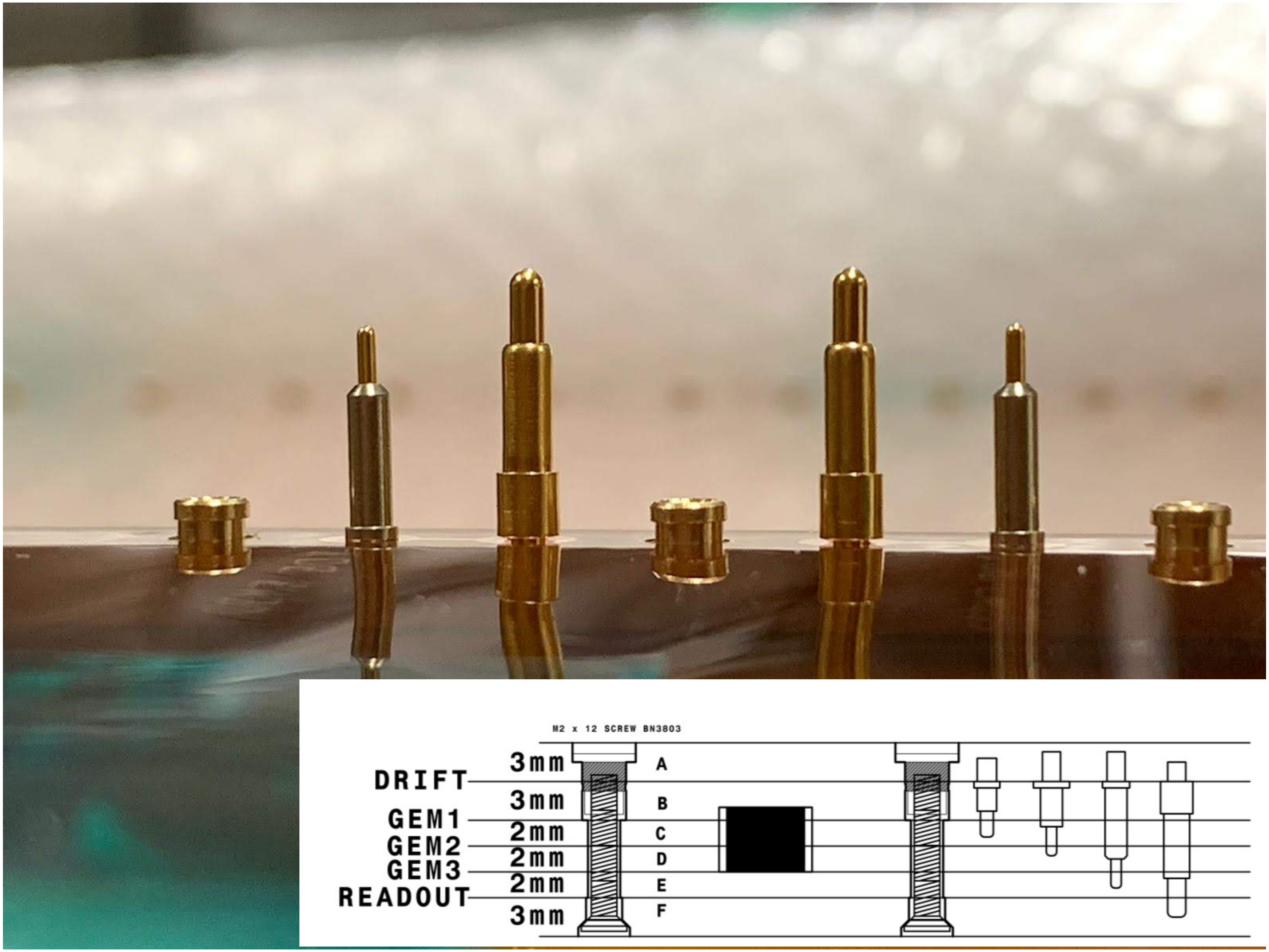
1) Prepare the drift foil: place on base template with dowel pins, solder spring-loaded HV pins
2) Place GEM foils and readout board in canvases
3) Stack up the Drift + 3 GEM foils + R.O., separated by inner frames pieces, and pre-stretch each layer with tape
4) Bolt down the stack to clamp all foils, then release dowel pins
5) Flip the stack over, cut off Drift and GEM foil parts exceeding the inner frame
6) Put on outer frame canvas to surround the stack, and stretch the inner frame stack with horizontal screws
7) Close the chamber with top and bottom gas window covers

- Cleanroom humidity must be <35%
- Clean GEM foils, Drift and RO with a tacky roller to remove dust
- During and immediately after each time of handling a foil, verify that it holds voltage and shows >100 GOhm
- Can go back during 1)-4) in case of any issues

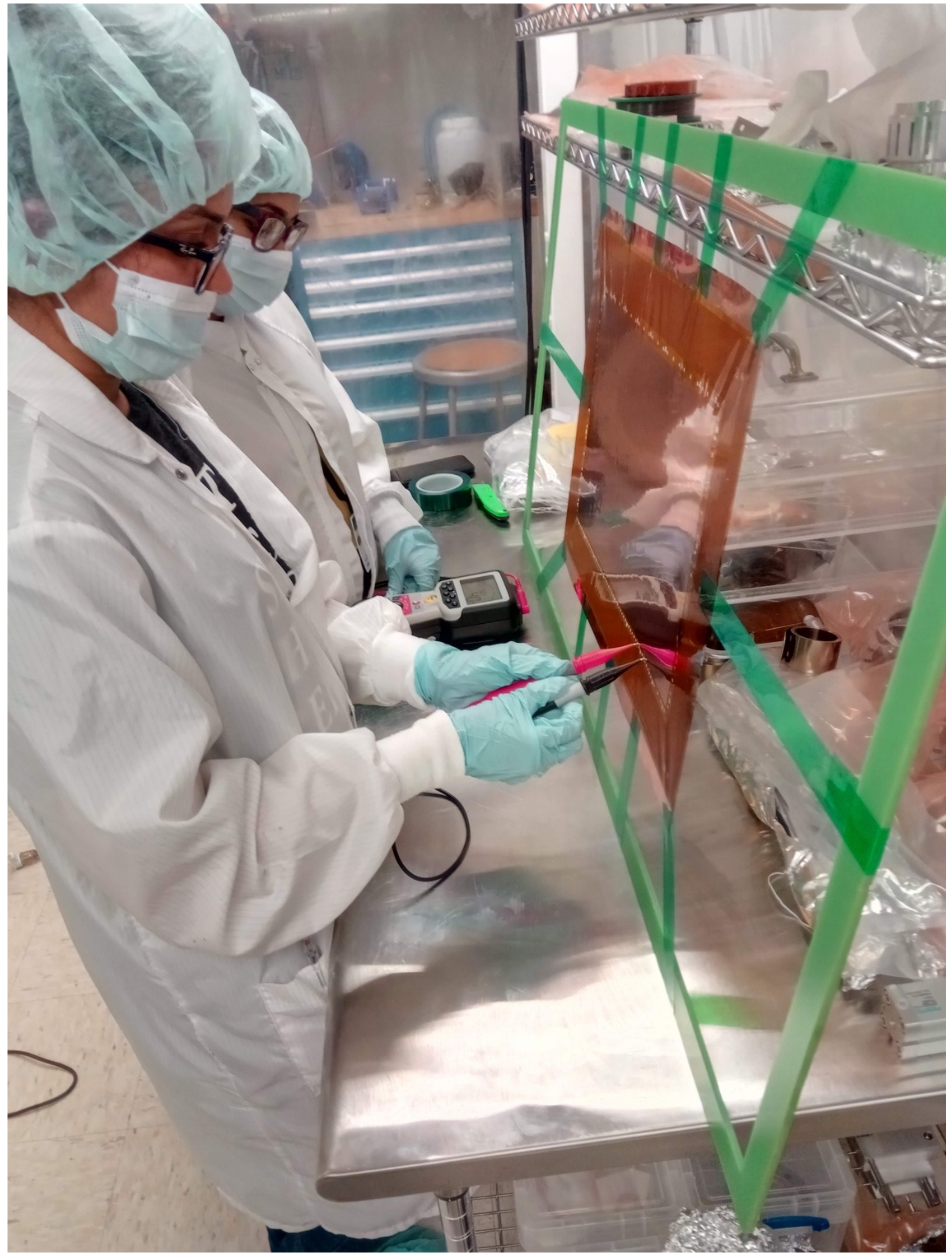
Preparation of Drift foil



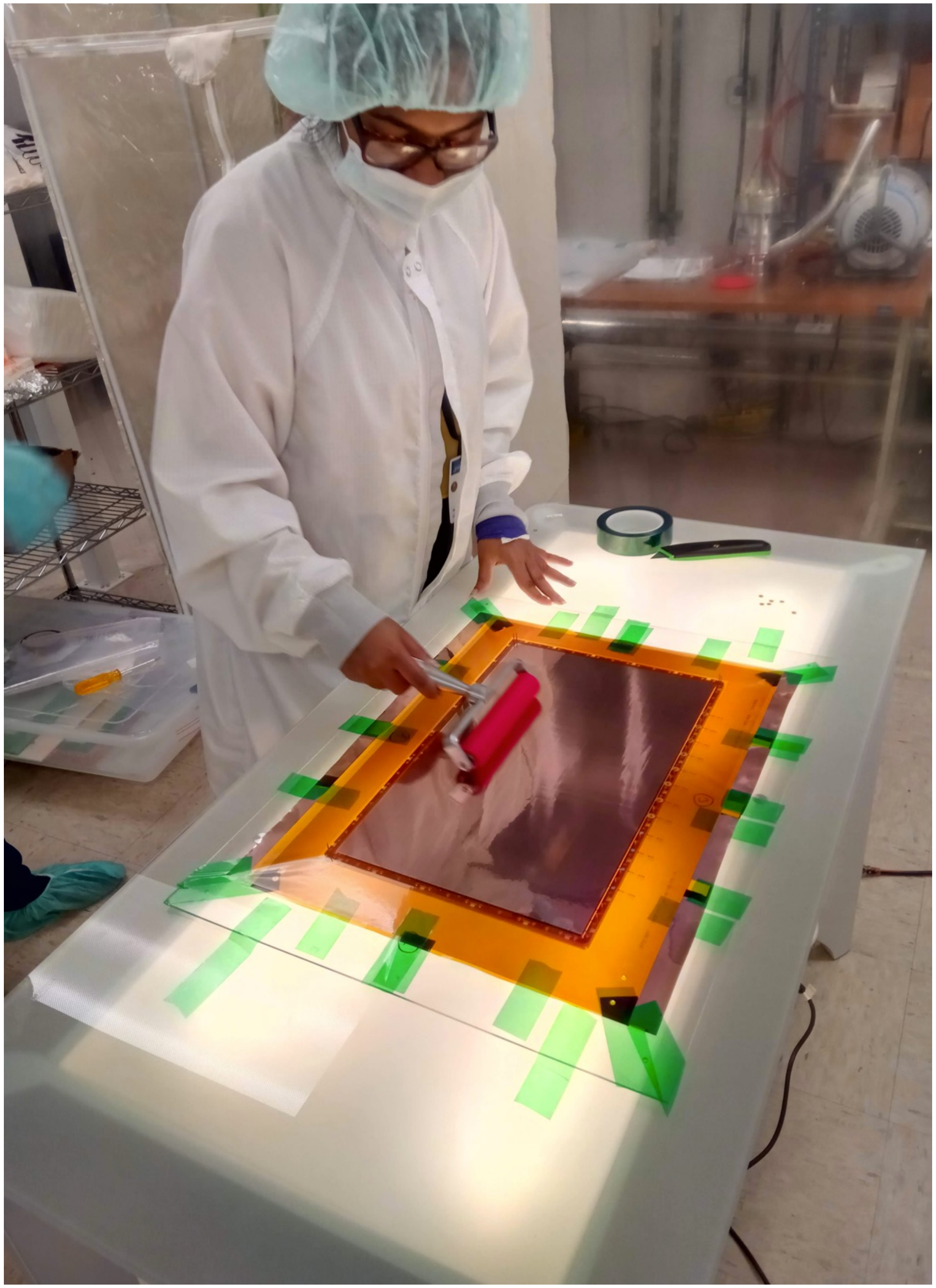
Preparation of Drift foil



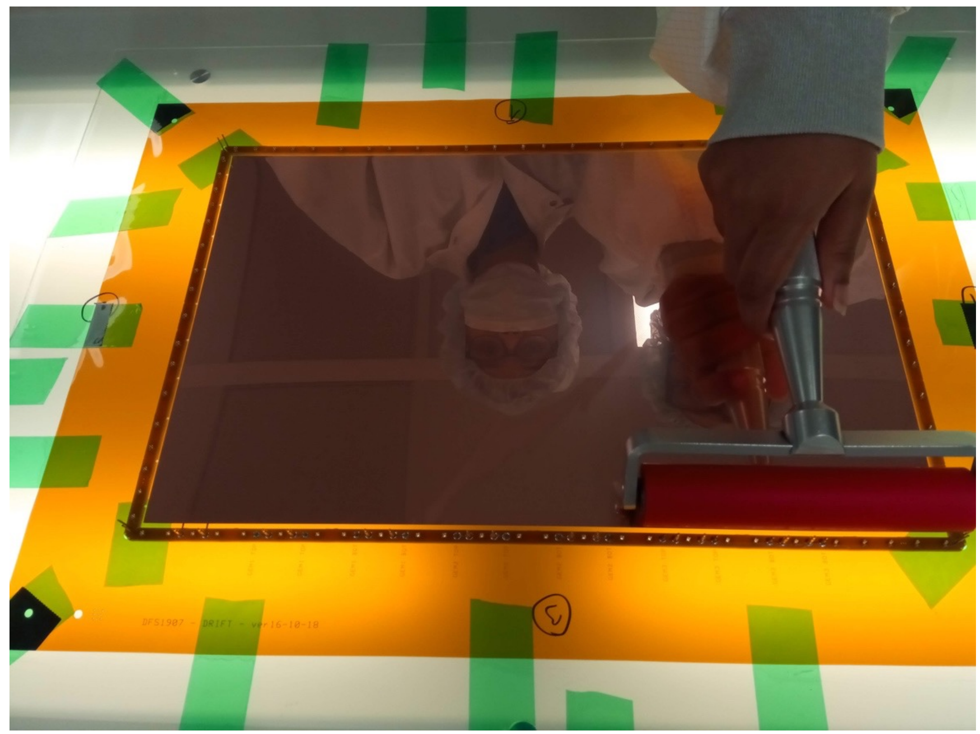
Placing of foils in canvas and HV testing



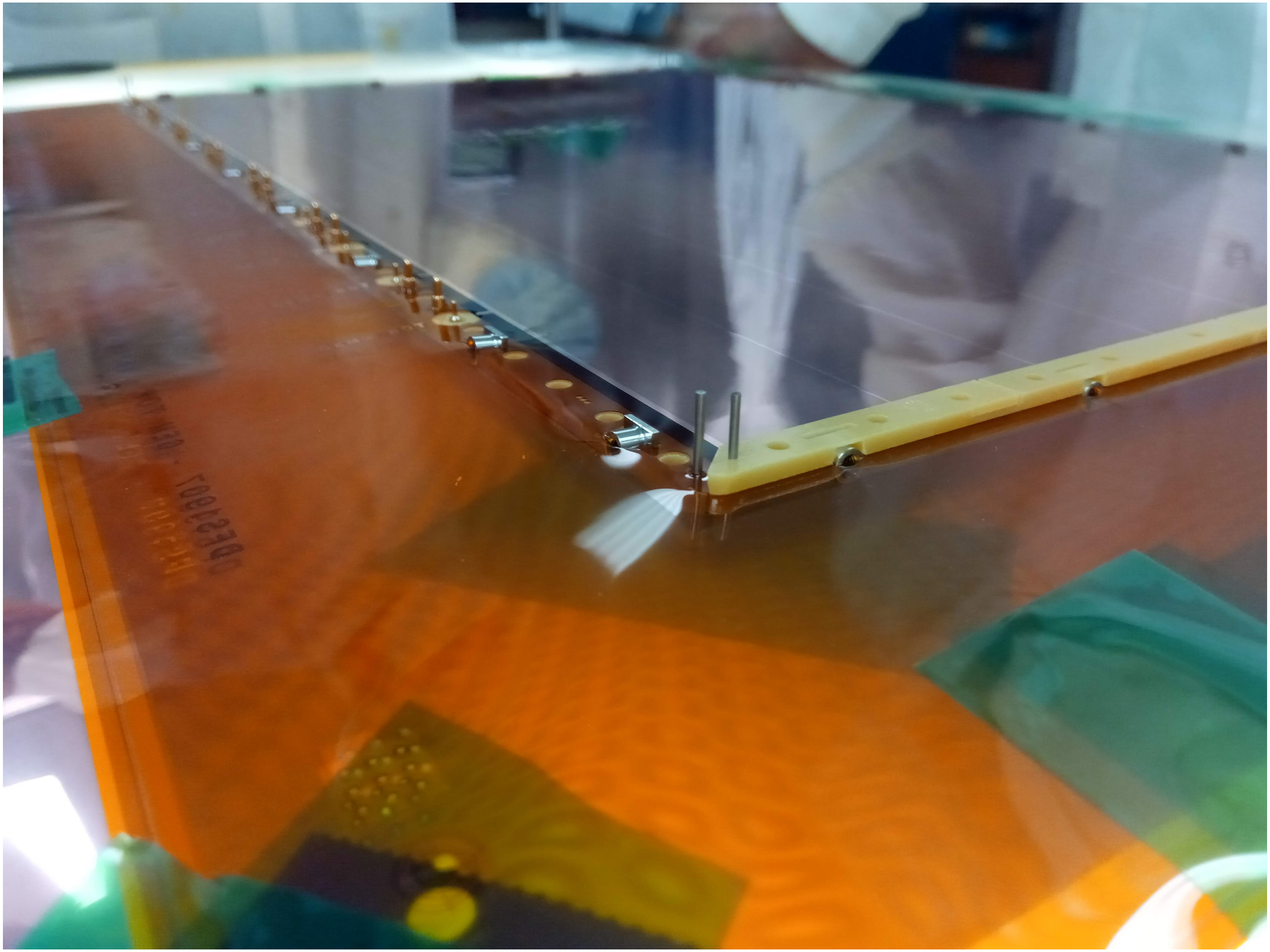
Pre-stretching with tape and rolling



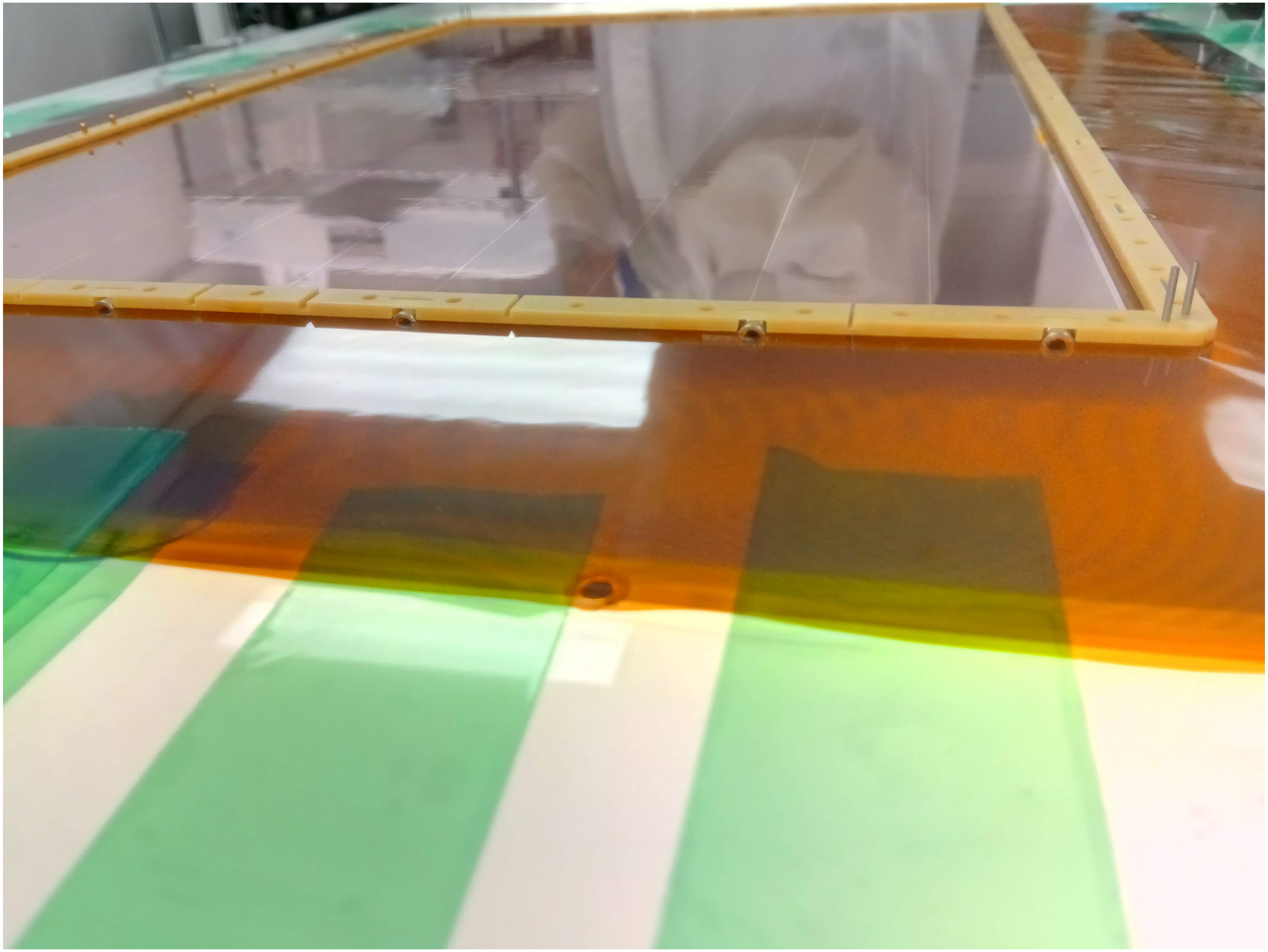
- Tacky roller removes dust and other dirt particles
- Reduces discharges
- Resistance increases significantly
- Can apply frequently
- Minimize exposure time to air



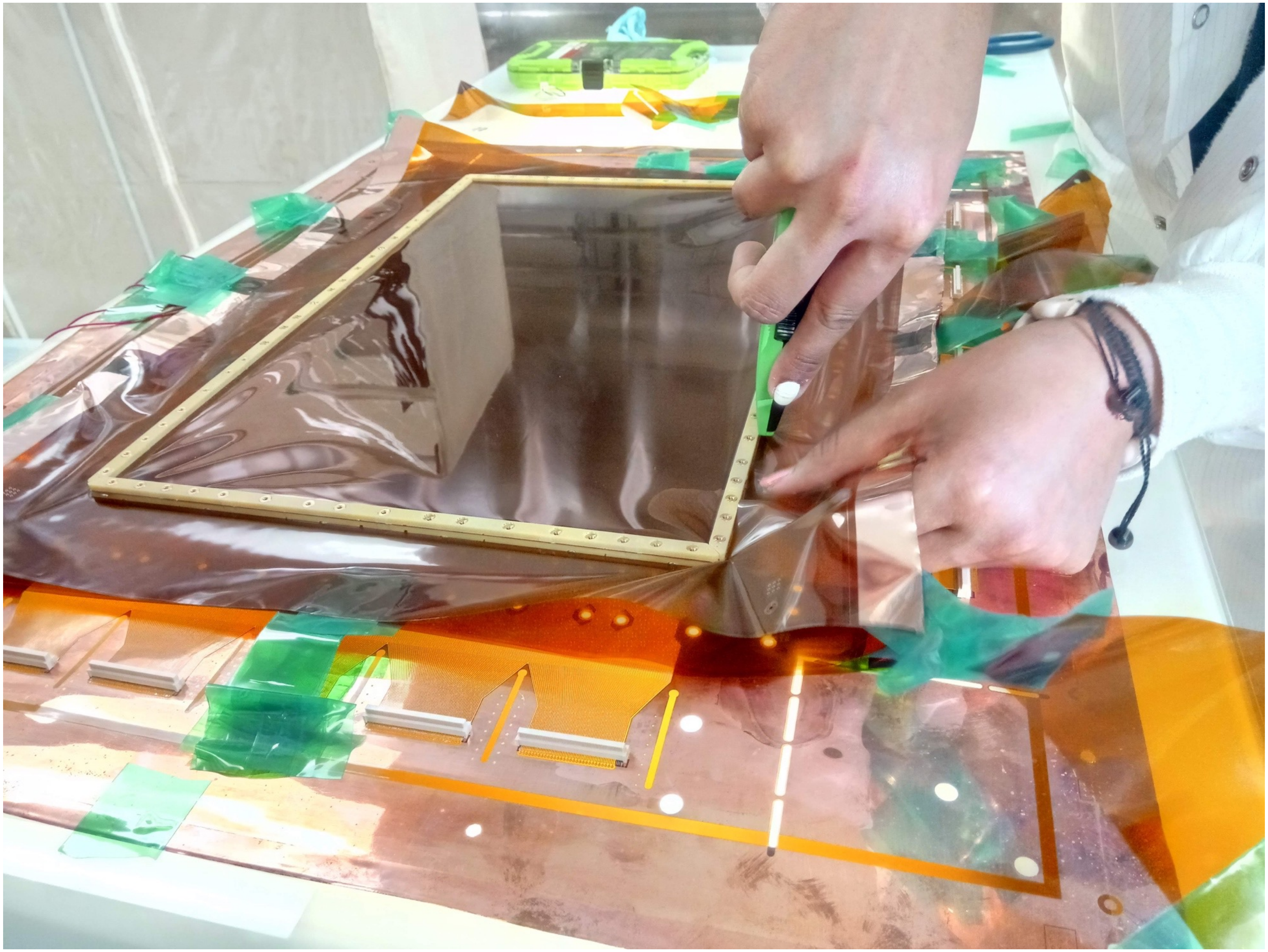
Stacking up with embedded hardware



Stacking up with embedded hardware

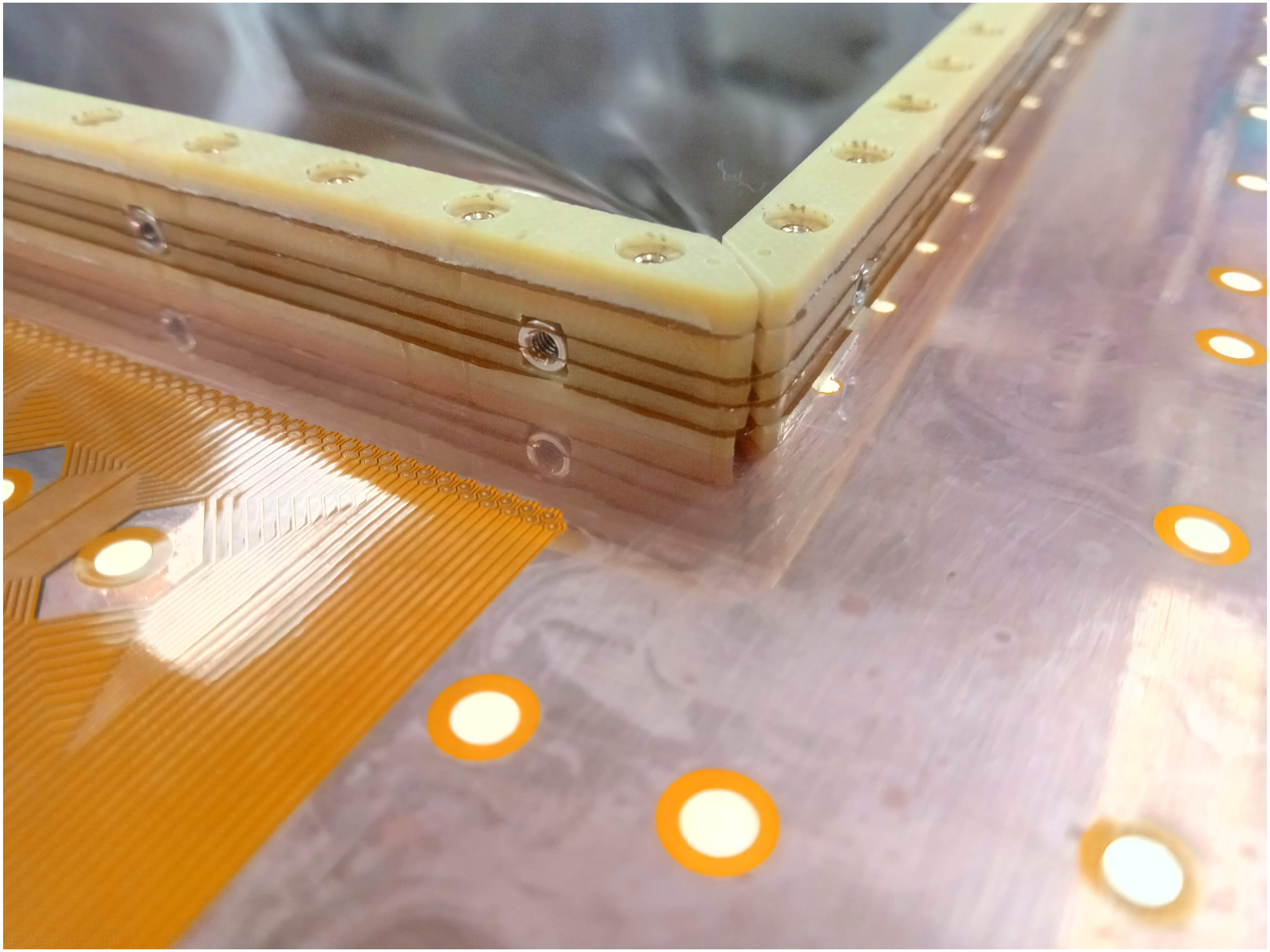


Cutting of excess foils



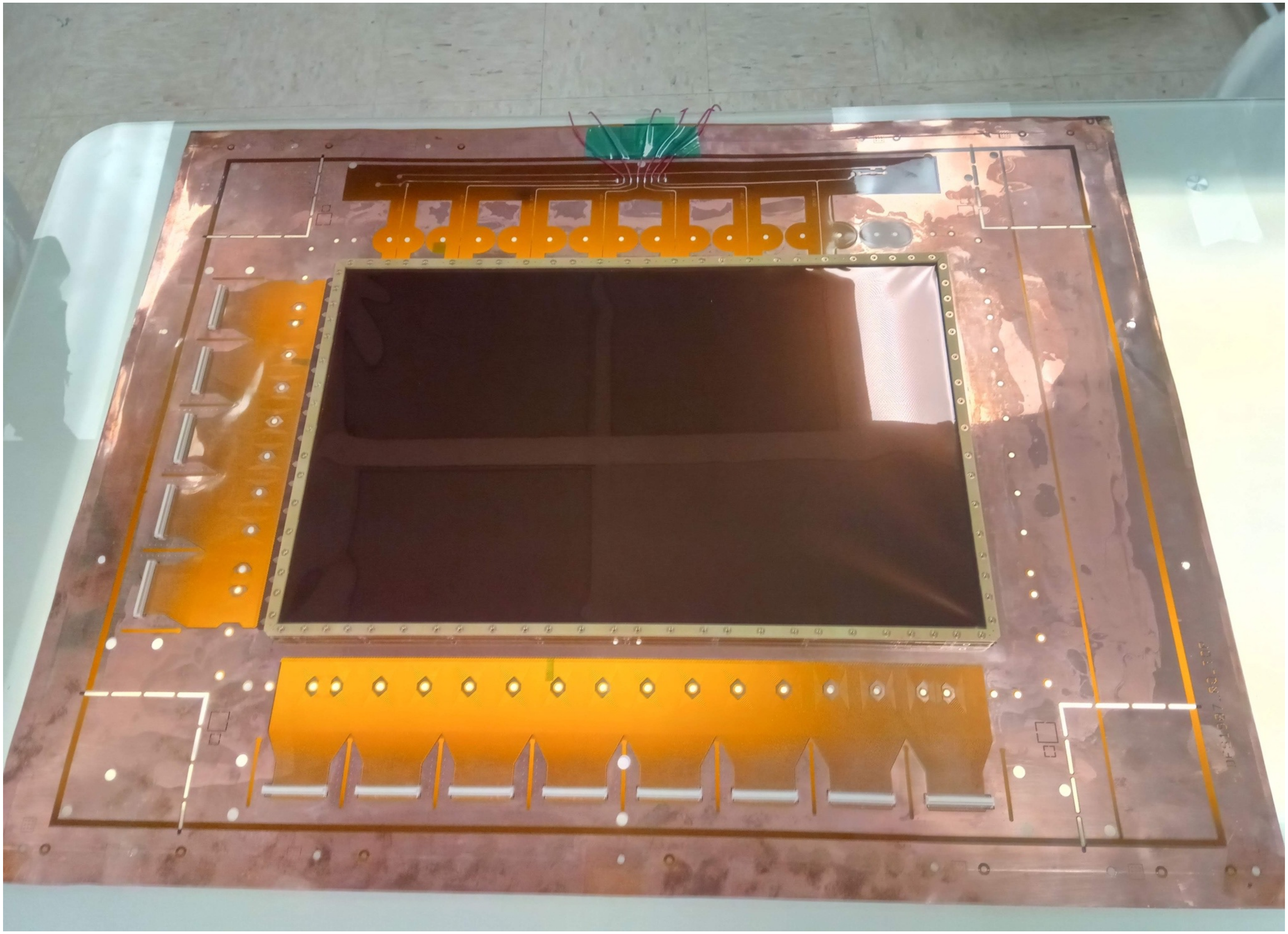
- **Tension released from pre-stretching after removal of dowel pins**

Cutting of excess foils



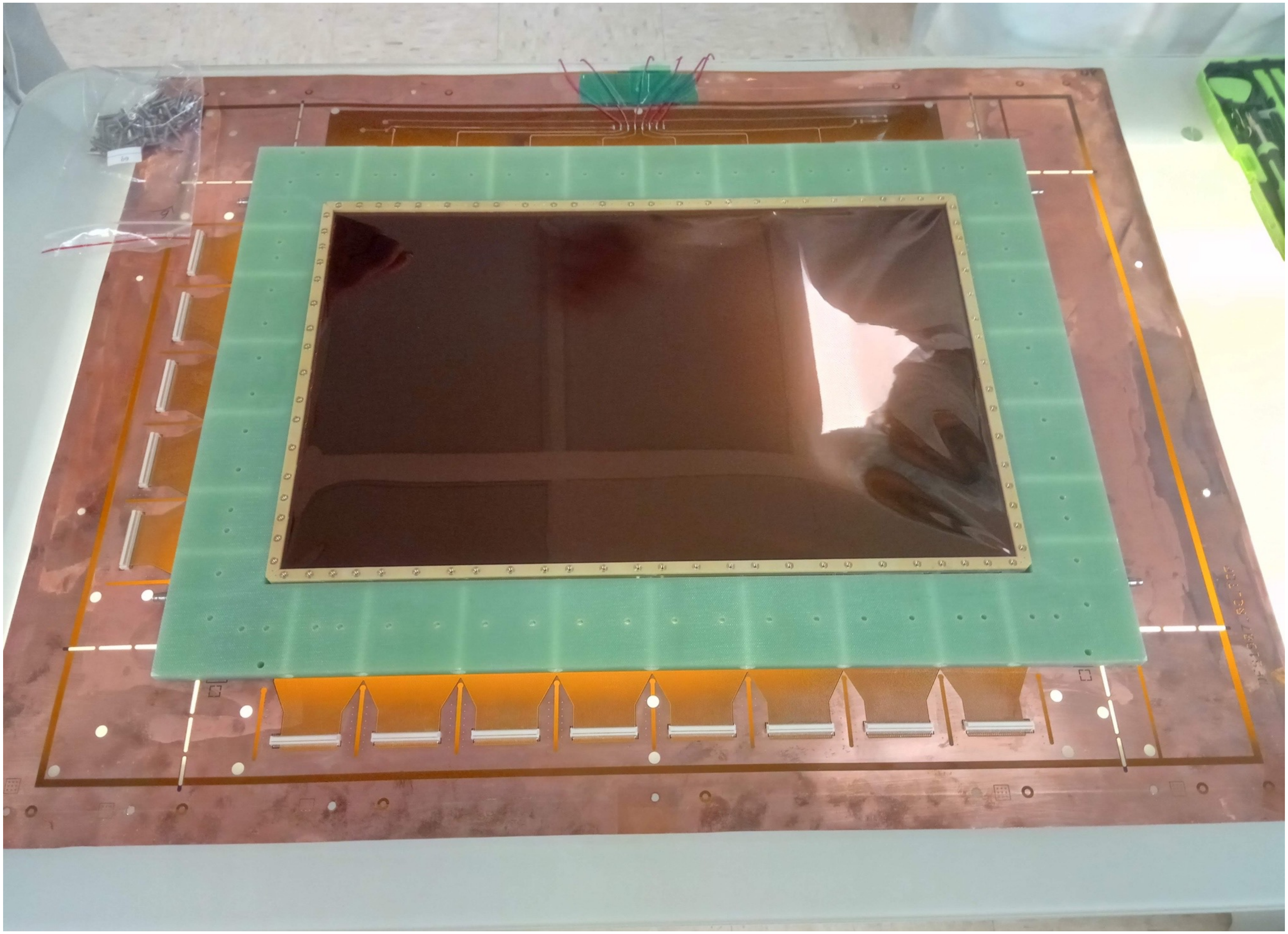
- **Tension released from pre-stretching after removal of dowel pins**

Inner frame stack before stretching



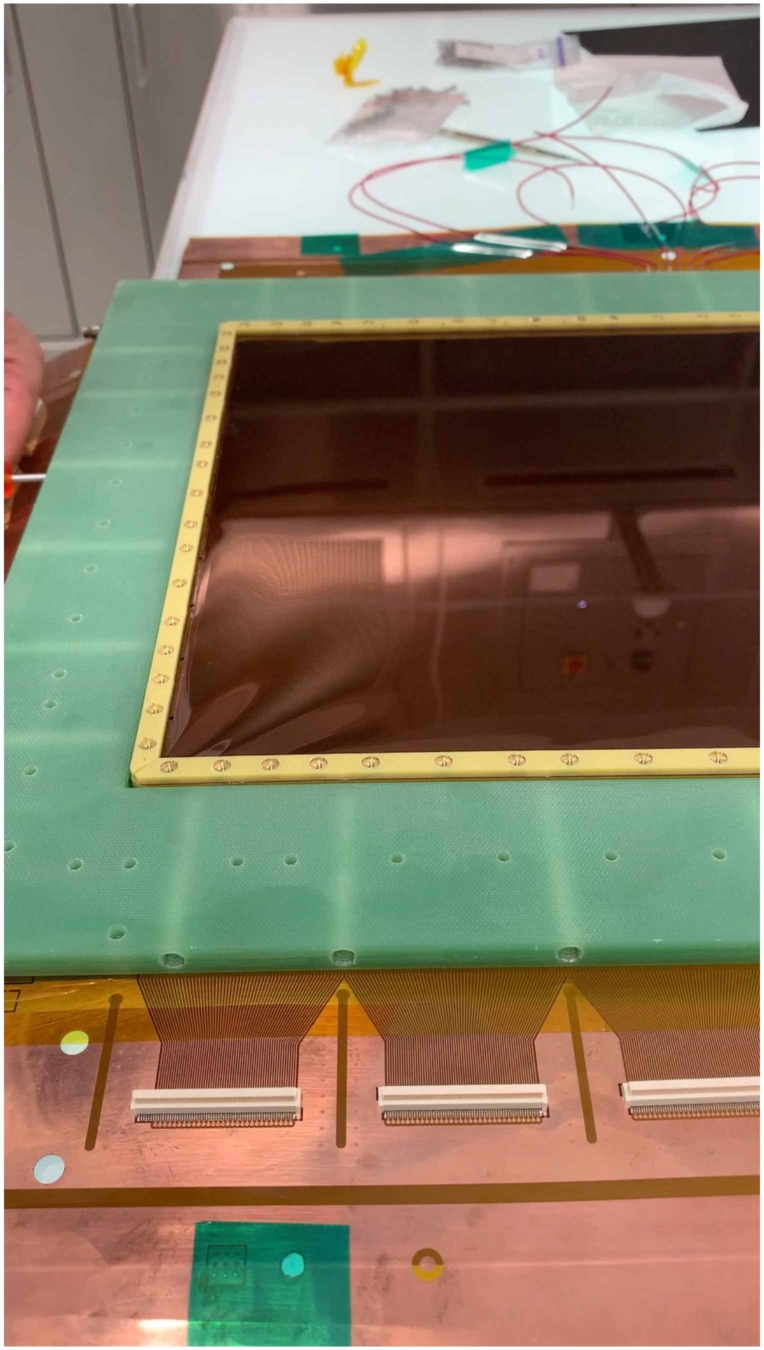
- **Tension released from pre-stretching after removal of dowel pins**

Inner frame stack before stretching

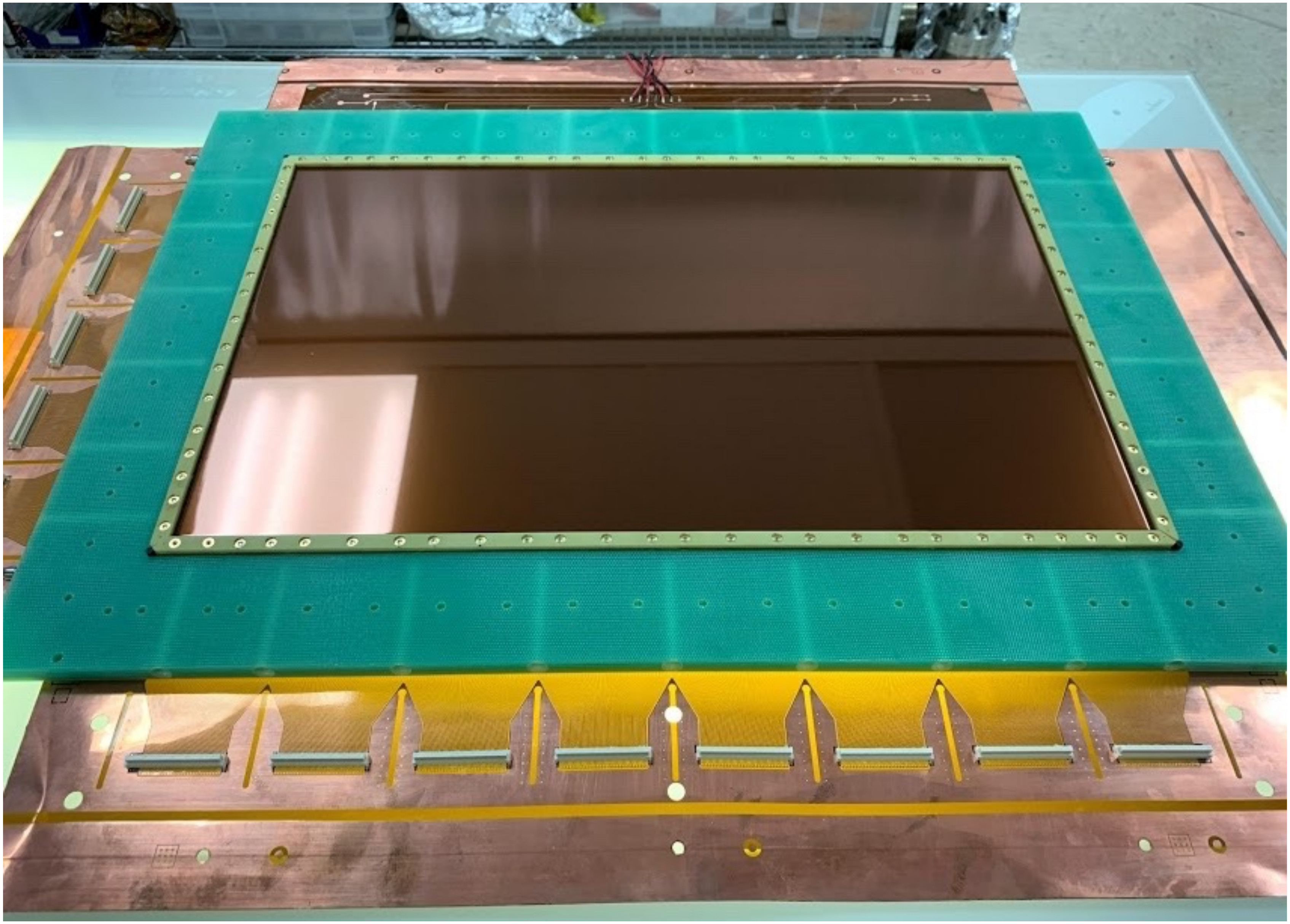


- **Green canvas placed centered over stack for stretching**

Stretching

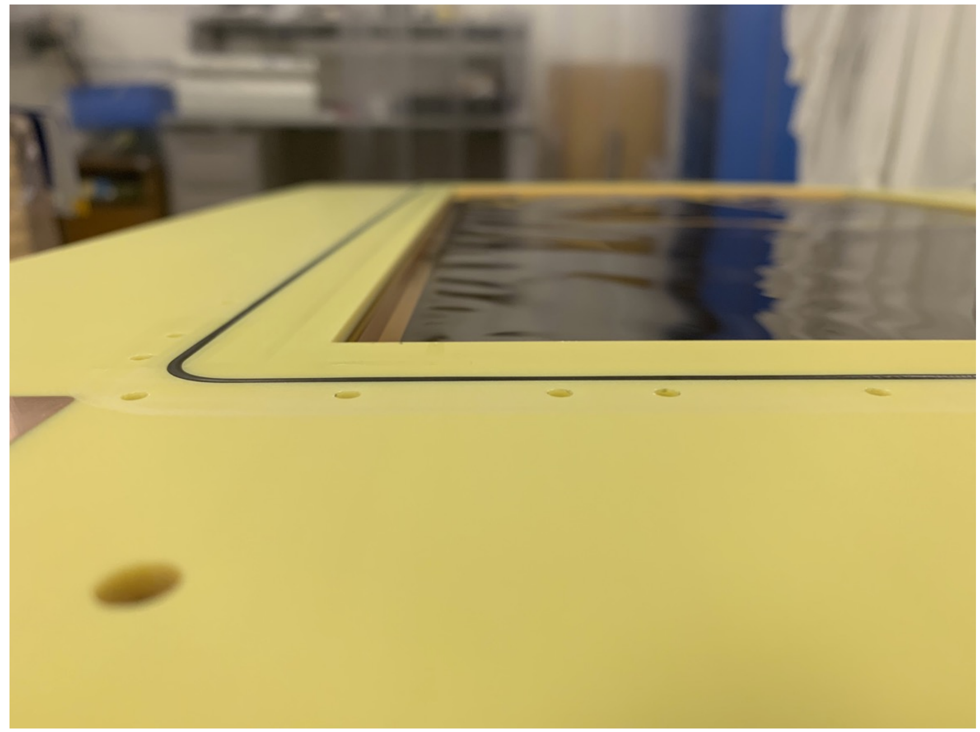


Inner frame stack after stretching



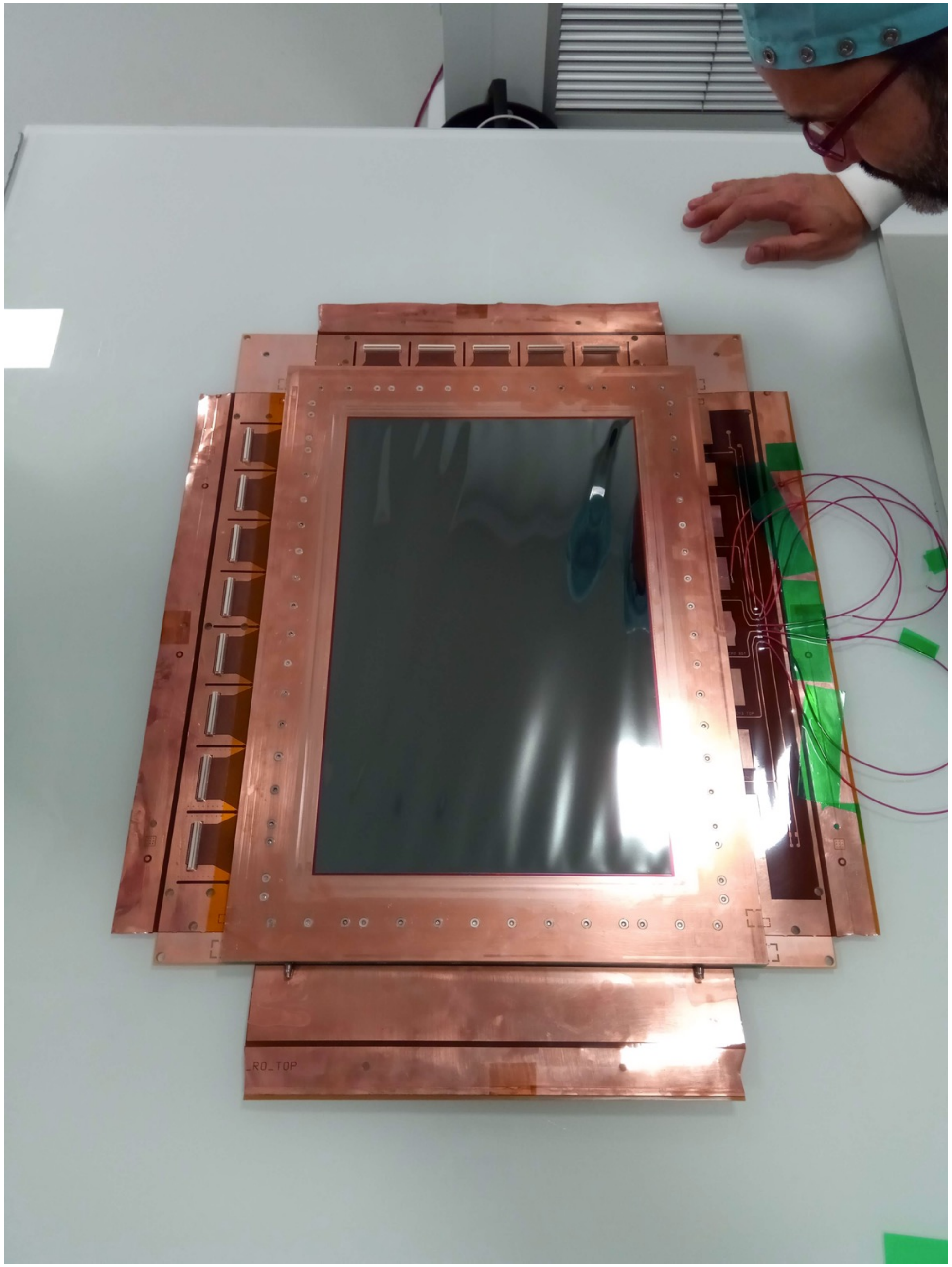
- **Stretching of stack with screws through horizontal channels**

Window cover with O-ring



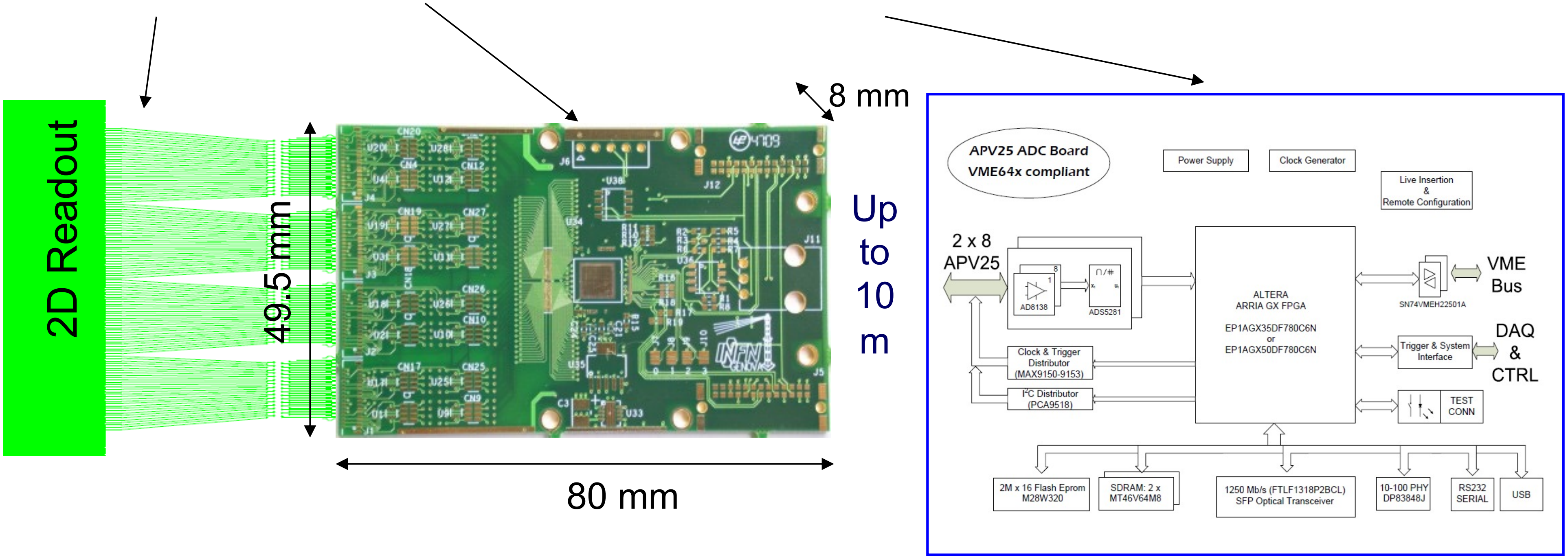
- Top and bottom covers to sandwich the stack with O-ring seal
- Can re-open to access stack and to replace GEM and drift foils

A fully assembled new GEM chamber



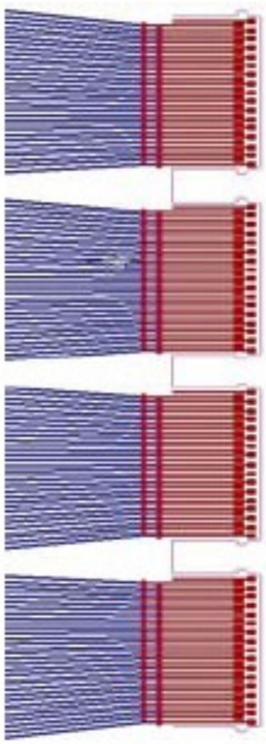
Readout electronics (INFN Rome)

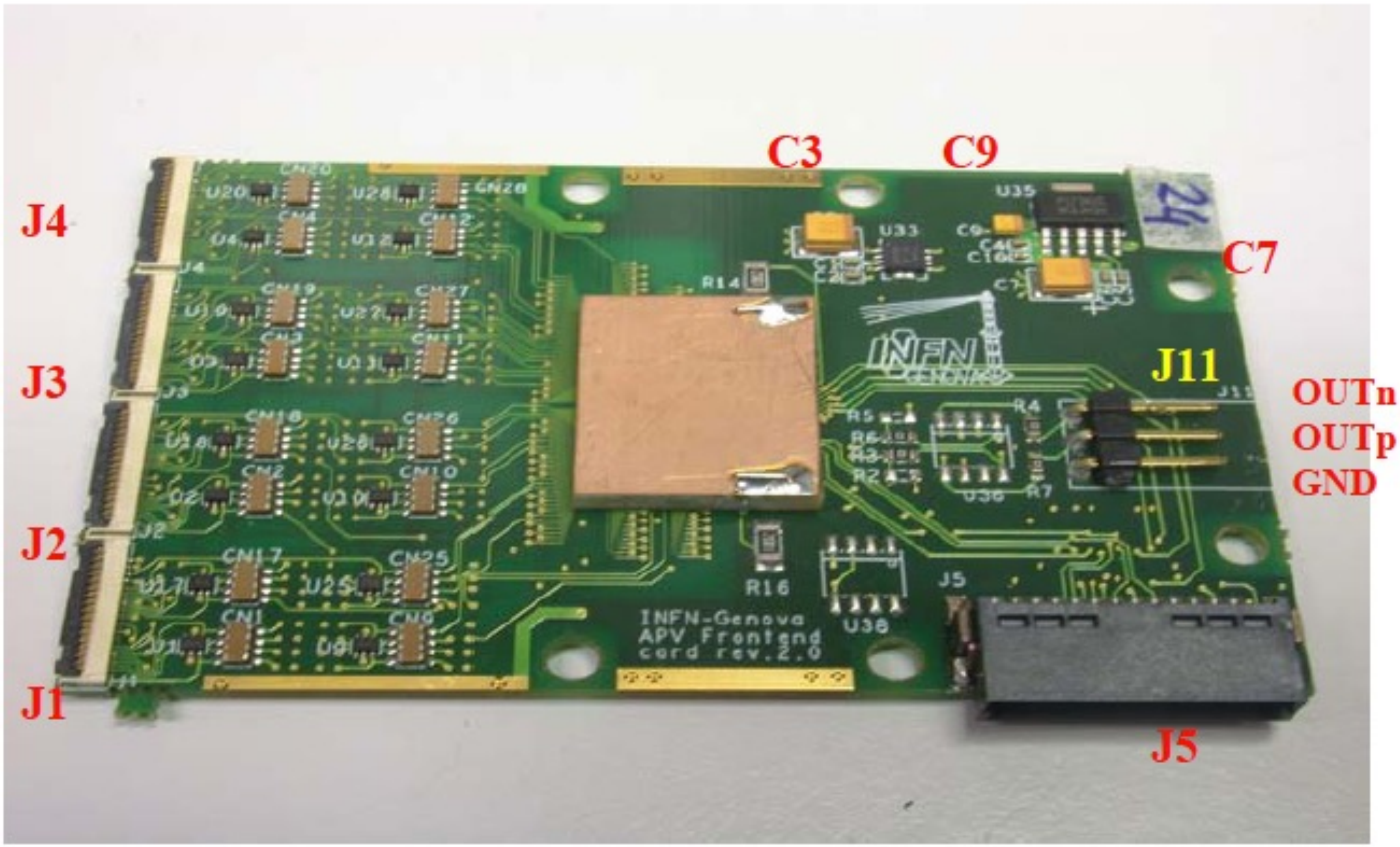
GEM ⇒ FEC ⇒ ADC+VME Controller ⇒ DAQ



- **Frontend card and controller (APV + VME) by INFN Rome, Jlab/SBS project S. Frullani, E. Cisbani, P. Musico**
- **APV rev. 3.0/3.1 (MUSE) and rev. 4.1 (DarkLight)**
- **MPD upgraded to rev. 4.0 for operation in DarkLight and MUSE**

Analog Pipeline Voltage (APV) frontend card





APV Frontend card rev. 2.0

Multi-purpose digitizer (MPD)

MPD rev. 3.0

rev. 4.0

2019: GEM tracker (re-)purposing

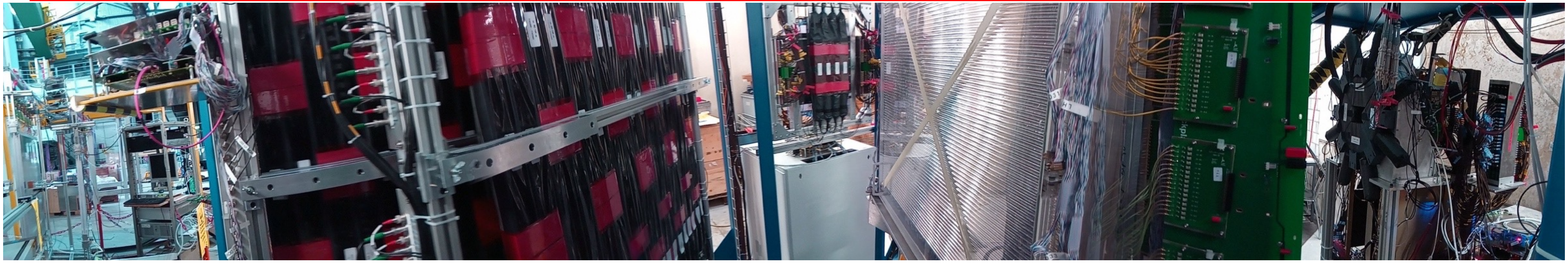
→ Original purpose: Use 2x3 GEM elements at DL Phase 1c (X17 search)
- 2018 PAC46 / 2020 PAC48 proposals for DarkLight at CEBAF deferred
- 2022+ new program of DL at ARIEL taking off

→ Use 3 GEM elements at ULQ2@ELPH (Started commissioning in Fall 2019)
- 3 GEM planes: Position + ghost suppression + efficiency
- To characterize spectrometer optics and for tracking

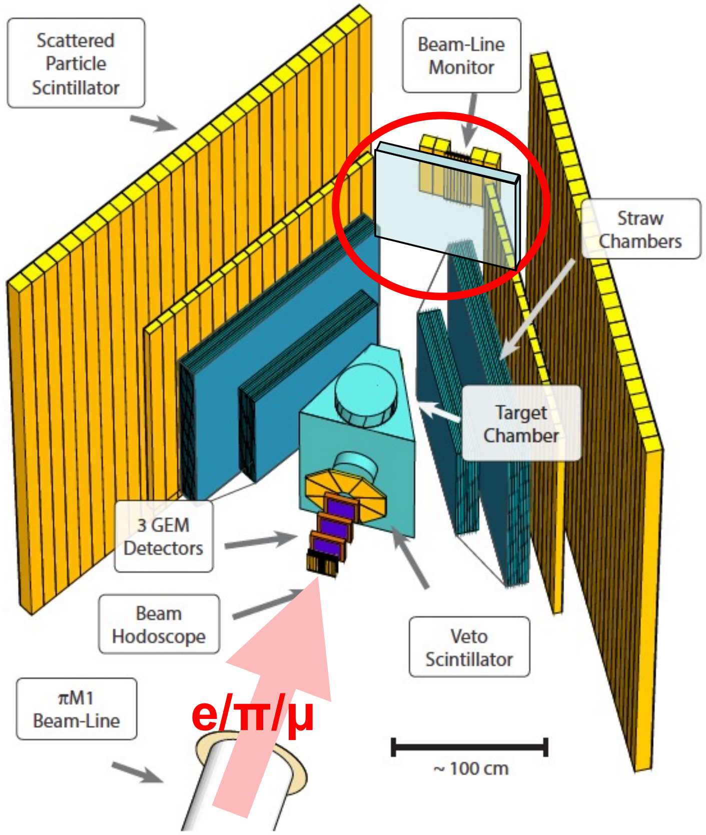
→ Also considered (but then shelved): Use 4 GEM elements at MUSE@PSI
- 4 planes as forward tracker
- SSP readout with zero suppression

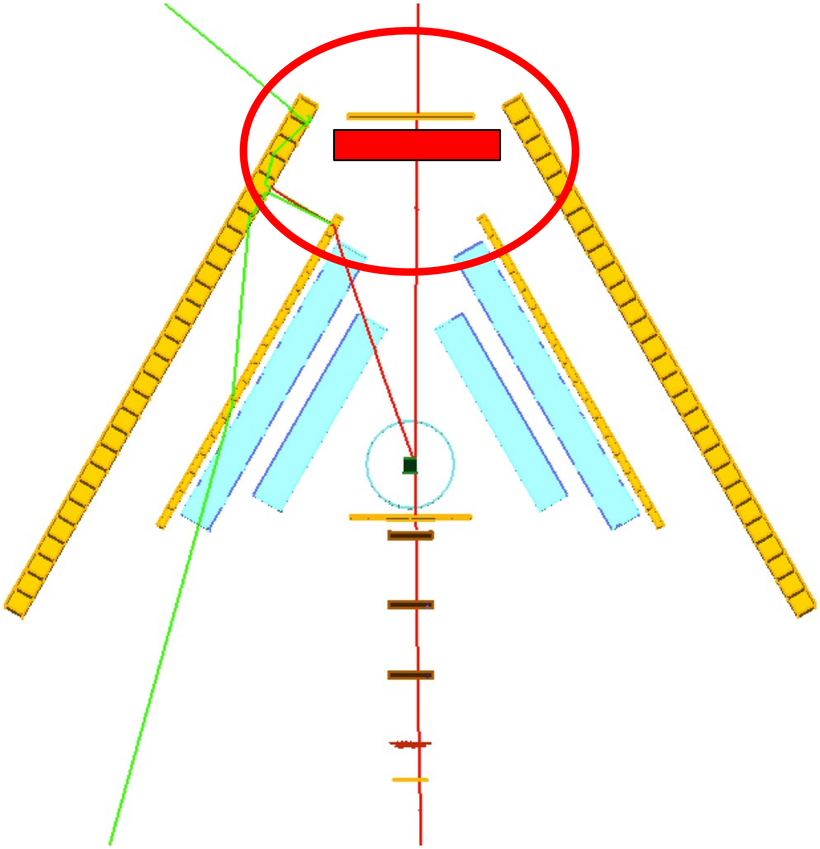
→ Using 100 APV cards + 7 MPDs for GEn-RP experiment with SBS@Jlab (was planned for Fall 2021 – Spring 2022; now considered Summer 2023)

Forward GEM tracker for MUSE



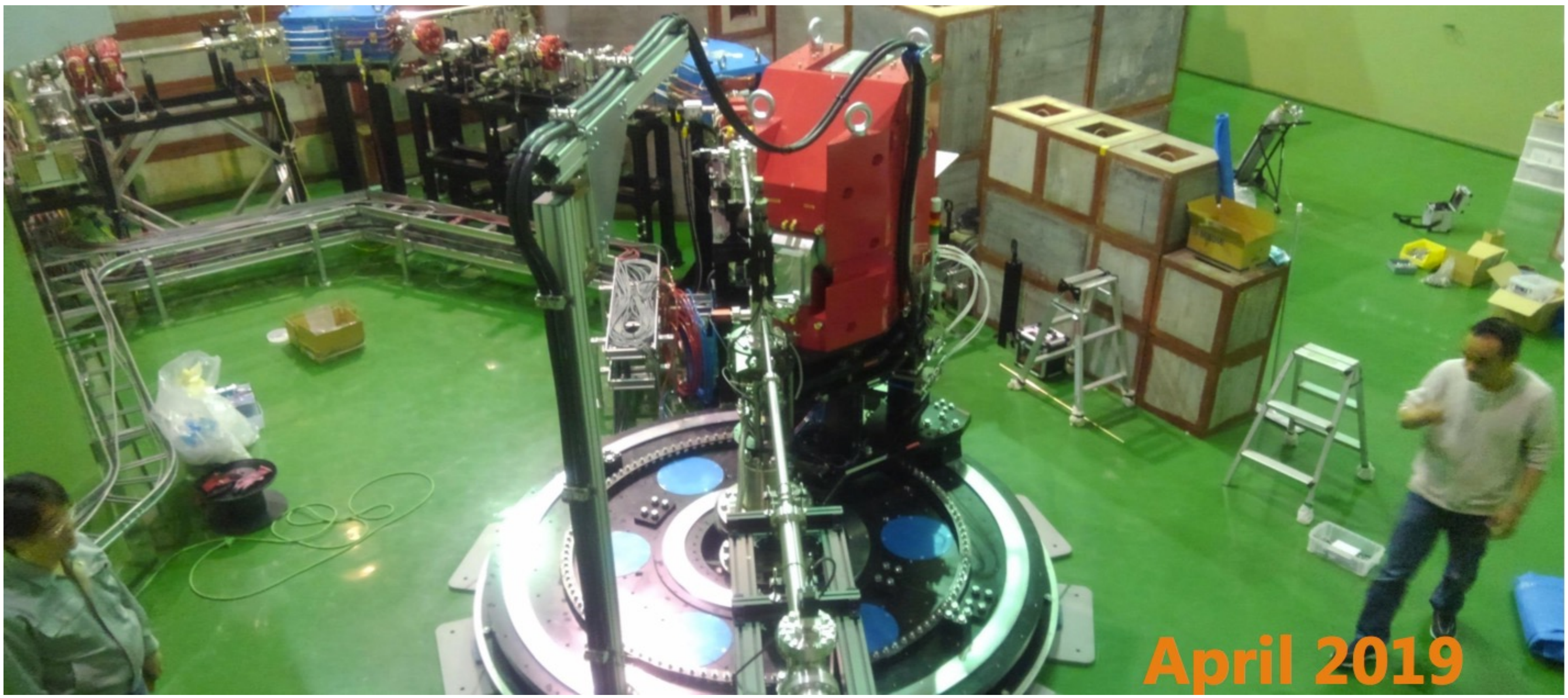
→ **Use 4 GEM elements at MUSE@PSI downstream in front of beam monitor as forward tracker (implement in Spring 2020)**
Package size for 4 GEMs incl. readout: H x W x D = 55 x 65 x 10 cm^3





ULQ2 @ ELPH (Tohoku U.)

- ULQ2: E_0 ~ 20–60 MeV; θ_e ~ 30°–150°; Q^2 ~ 3–8 x10^{-3} $(GeV/c)^2$
- New spectrometer to be instrumented
- 3 GEM planes: Position + ghost suppression + efficiency
- Resolution ~100 μm, efficiency >98%
- Shipped 3 elements to Tohoku for tests in Fall 2019



Status of the GEM detectors

- **All 8 new GEM elements have been produced**
  (Rui, Michael, Ishara, Tanvi, Jesmin, Bishoy, Thir and Malinga)
- **3 GEMs were shipped to ELPH (Rui, Ishara, Bishoy) in Aug 2019**
  (Rui and Ishara repaired at CERN and received back at HU 2021)
- **Cosmic ray test stands at LERF (in prep.) and at ELPH (operated)**
- **Gas tightness tests, high voltage tests with nitrogen**
- **Electronics testing (APVs, patch panels, LV regulators, MPDs)**
- **Operation of GEMs with cosmic rays and Sr-90, readout via VME**
- **Support structure for GEM stack and frontend electronics**

ULQ2 @ ELPH (Sendai):

- **Beam test Dec 16-17, 2019**
- **Plan to mount in ULQ2 spectrometer to characterize optics and focal plane (2022/23)**

Commissioning at Jlab; DAQ development

- **Standard readout (APV/MPD) via VME bus**
- **Procured SSP for optical readout and zero suppression (aligned with strategy pursued at Jlab/SBS)**

Status of GEMs at ELPH

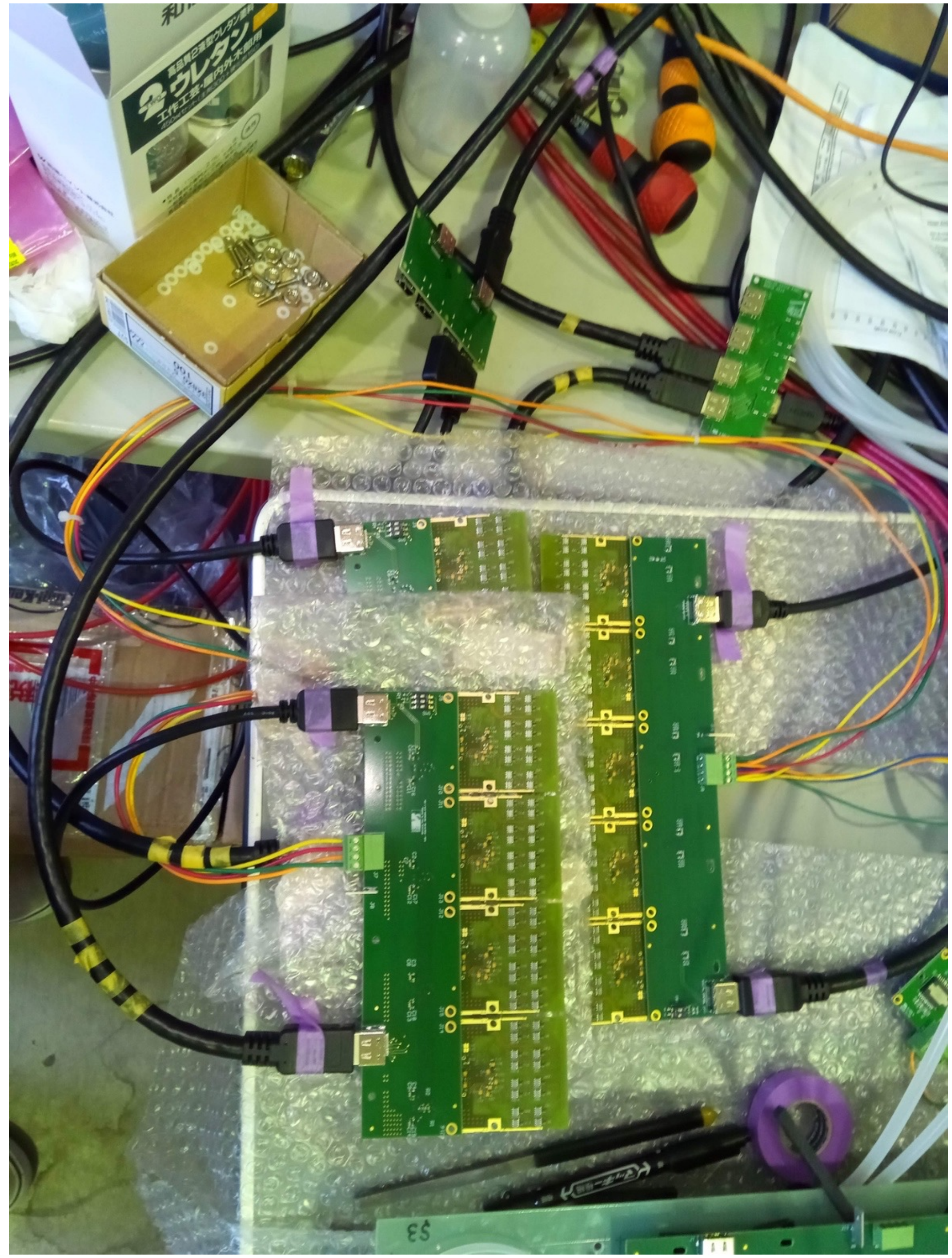
- M.K. Fall 2019 JSPS invitational fellowship and sabbatical at Tohoku, Sendai
- VME crate with controller for MPDs and GEM HV
- Three GEMs ("Bishoy", "Ishara", and "Rui")
- Identified and fixed all leaks
- Passed individual high voltage tests of foils, operate with N_2 at 4,300 V
- Prepared setup for electronics testing (APV, backplanes, patch panels, HDMI cables, MPD, VME), 10Hz pulser
  Histogramming mode ok
  Event mode with standalone program ok
  Addressing, configuration and mapping of APVs ok

- Preparation of support plates for frontend electronics
- Preparation of outer support frame
- Set up trigger scintillator, DAQ and analysis computer
- DAQ implementation with MIDAS and busy inhibit
- Adjusted Cooker analysis package

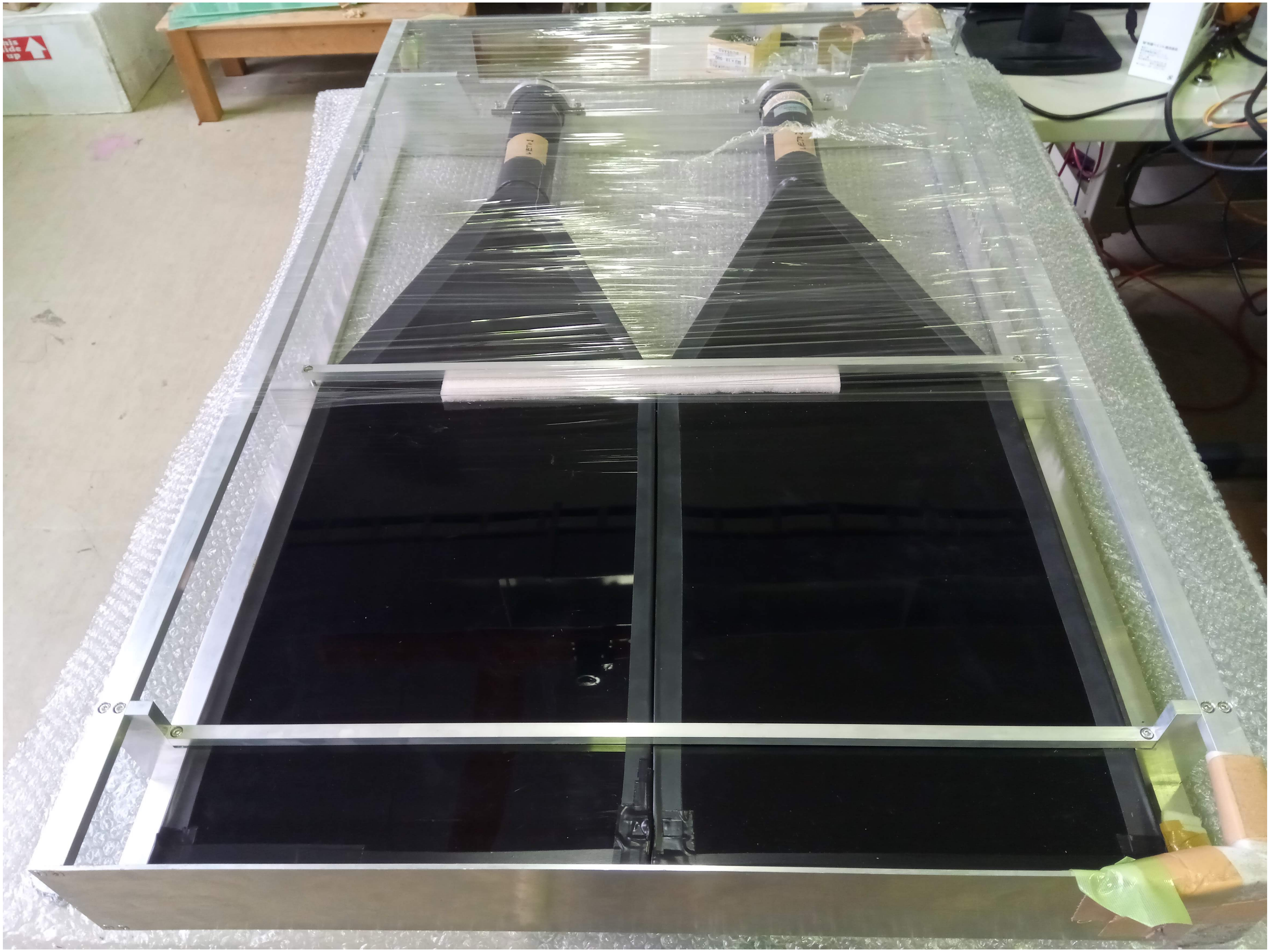
- November 2019: Rui shorted upon turning on HV with Ar:CO_2
- December 16-17, 2019: Beam test with Ishara and Bishoy
  Ishara shorted, good data taken with Bishoy

- Rui and Ishara shipped to CERN for repairs Jan'20, received at HU in Oct'21

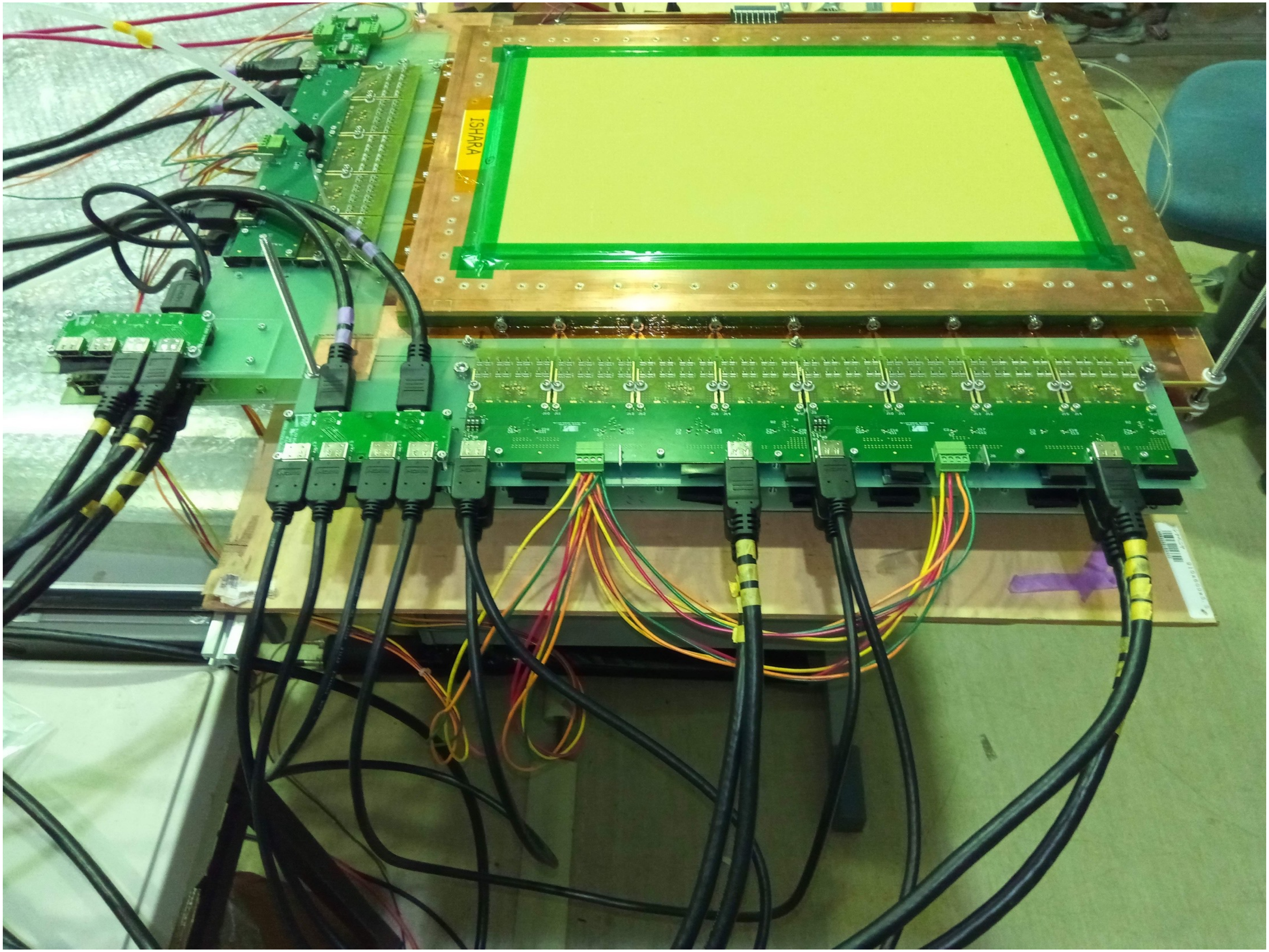
VME based MPD + APV frontend readout



Trigger paddles

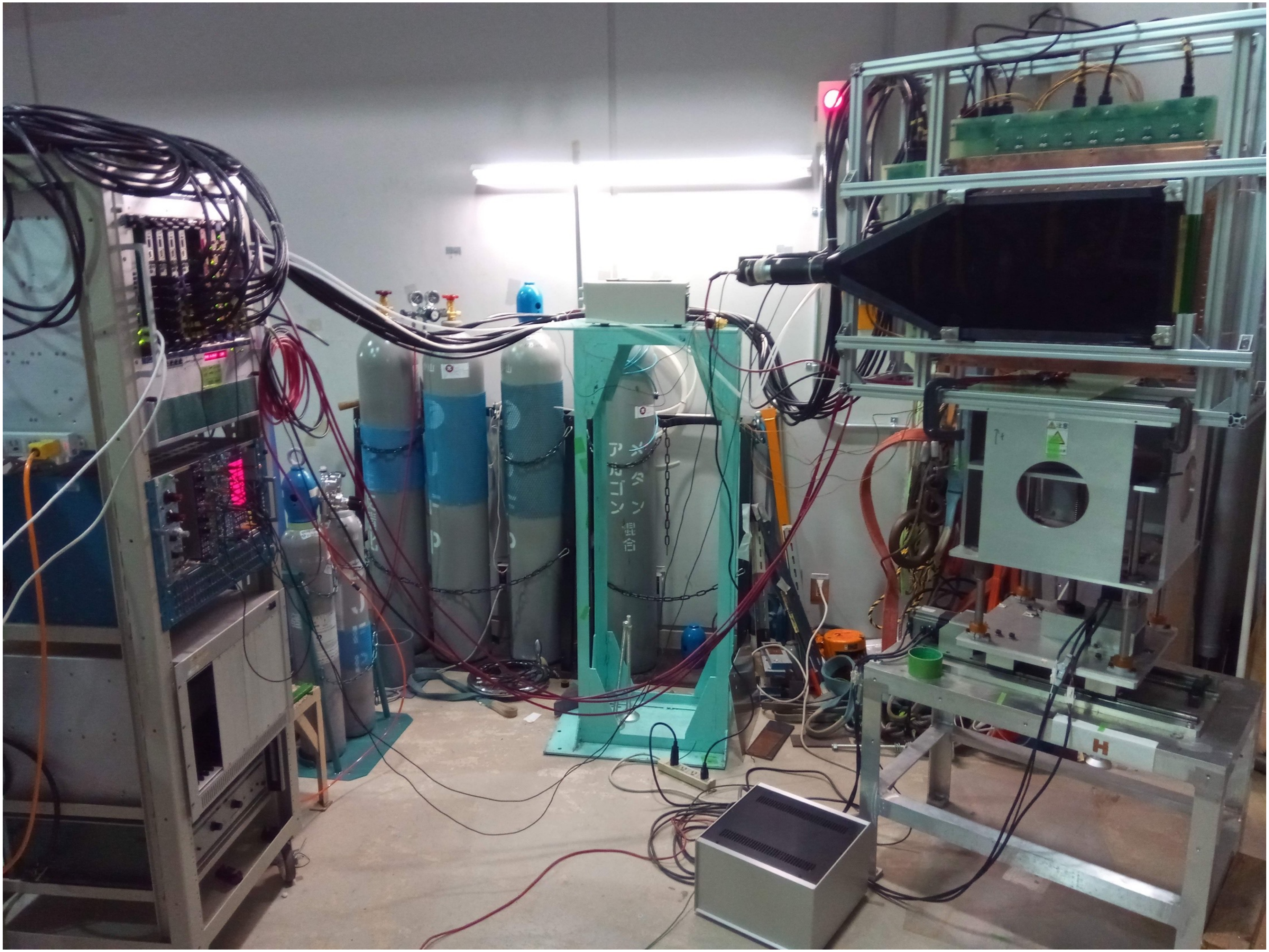


First commissioning

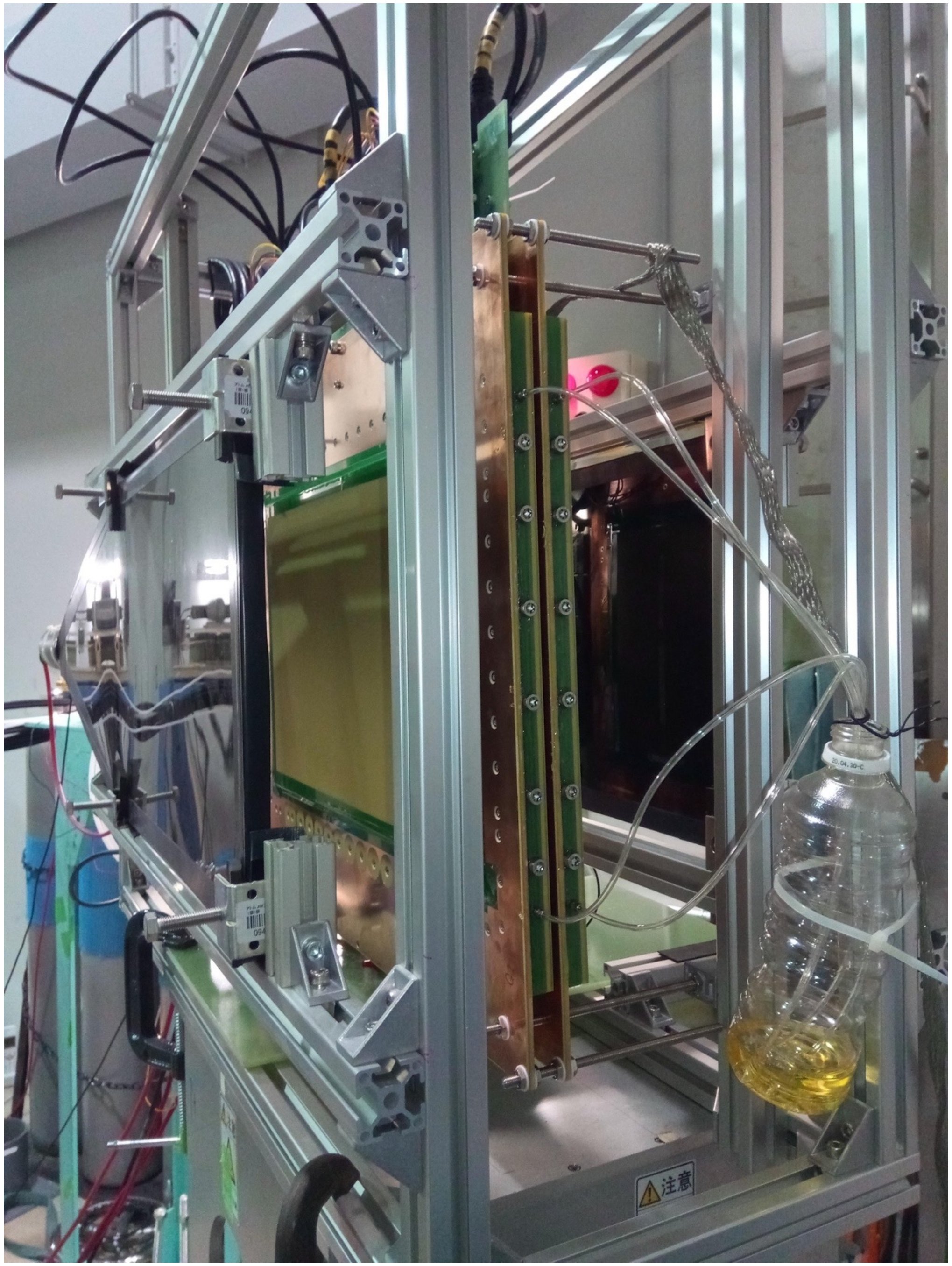


ELPH beam test (Dec. 2019)

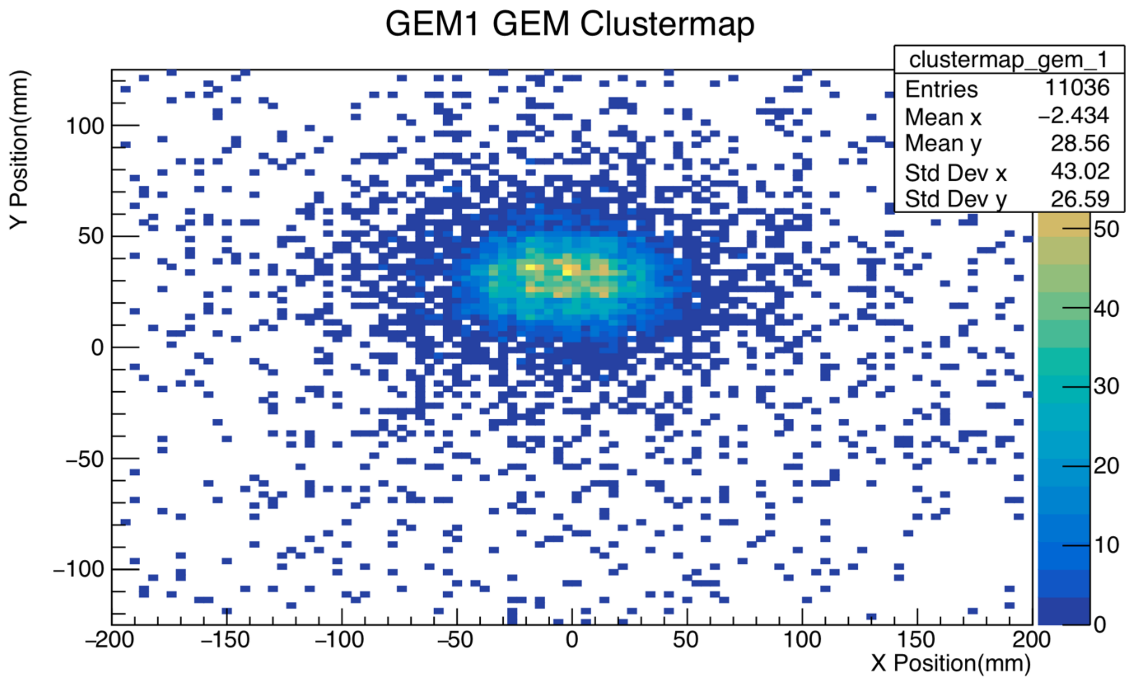
ELPH beam test (Dec. 2019)



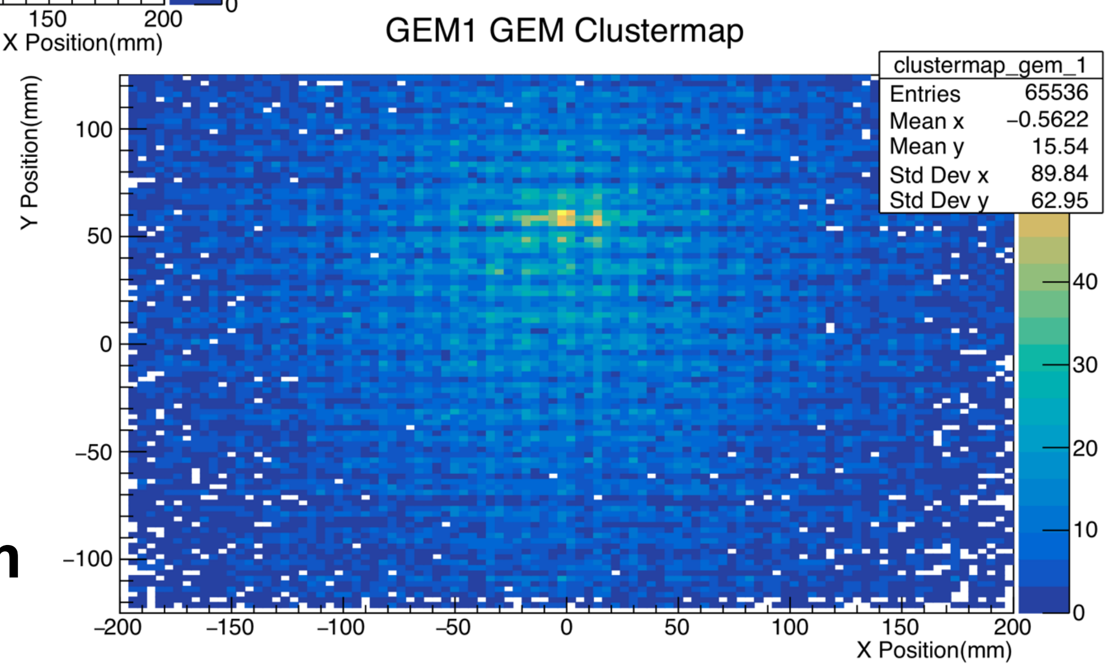
ELPH beam test (Dec. 2019)



Cluster maps of “Bishoy”



with focused beam



with defocused beam

Updated planning

Spring / Summer / Fall 2022

- Commissioning of 7 elements with Sr-90 and cosmic rays at LERF (Michael, Tanvi, Jesmin, Thir and Malinga, plus the repaired Ishara and Rui)
- DAQ with SSP

Spring / Summer / Fall 2023

- Ready for routine operations from Spring 2023
- Continue testing at ELPH/ULQ2 (M.K. Fellowship at Tohoku U. 2022/23)
- Available for DarkLight at ARIEL from Summer 2023
- Full electronics available again from Fall 2023

LERF User Lab 1

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THANK YOU!

DARKLIGHT