GEM Detectors, Gas System, and Schedule

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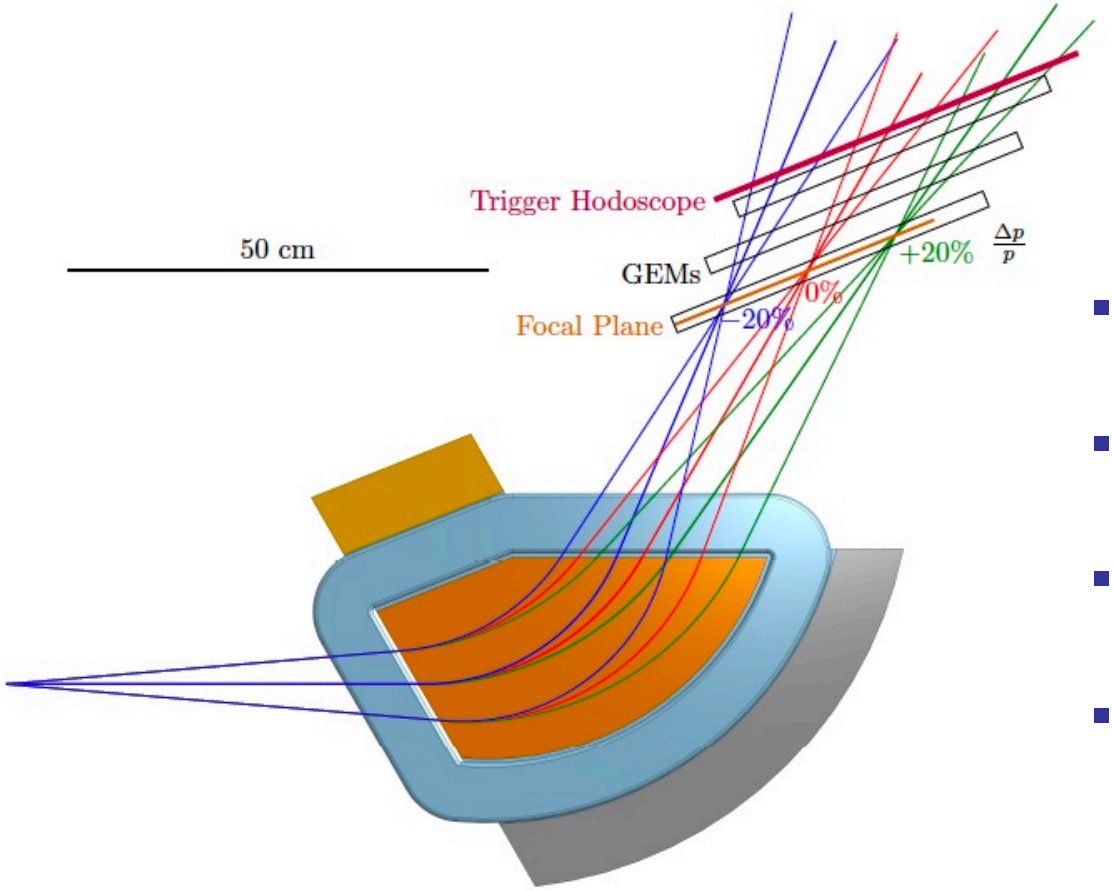
DarkLight



- 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
- Use 4 GEMs for DarkLight@ARIEL (2 per spectrometer arm)

Funded by MRI award 2014-2018

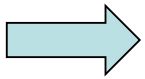
Principle of GEM detectors

- **GEM = Gas Electron Multiplier**

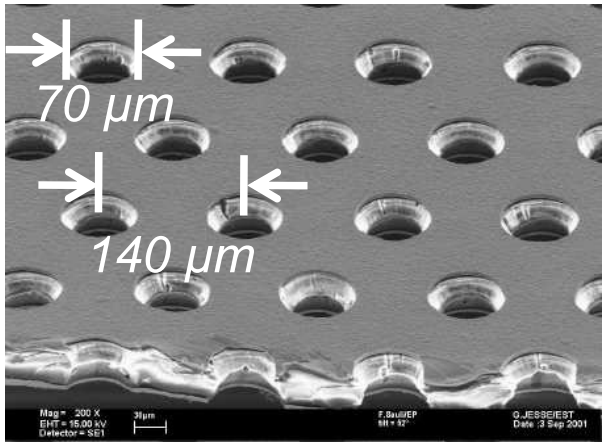
  introduced by F. Sauli in mid 90's, **F. Sauli et al., NIMA 386 (1997) 531**

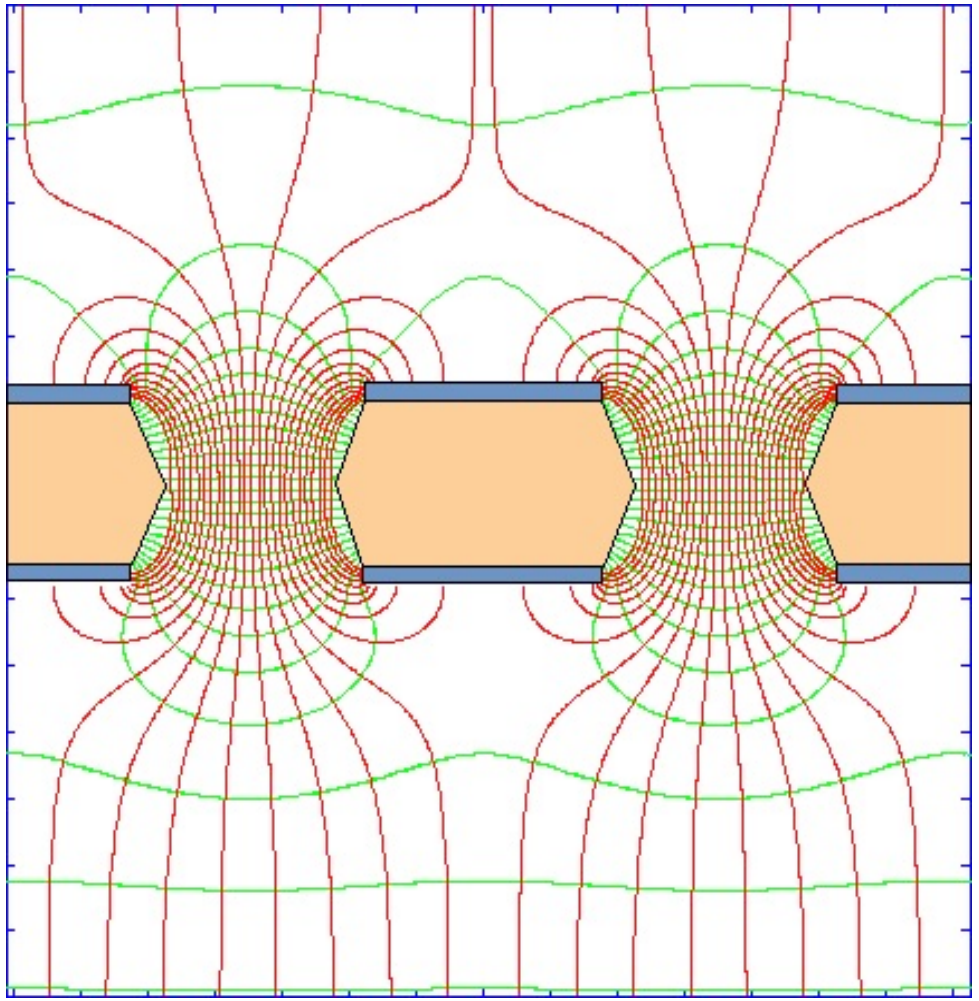
- **Copper layer-sandwiched Kapton foil (Apical) with chemically etched micro-hole pattern**

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



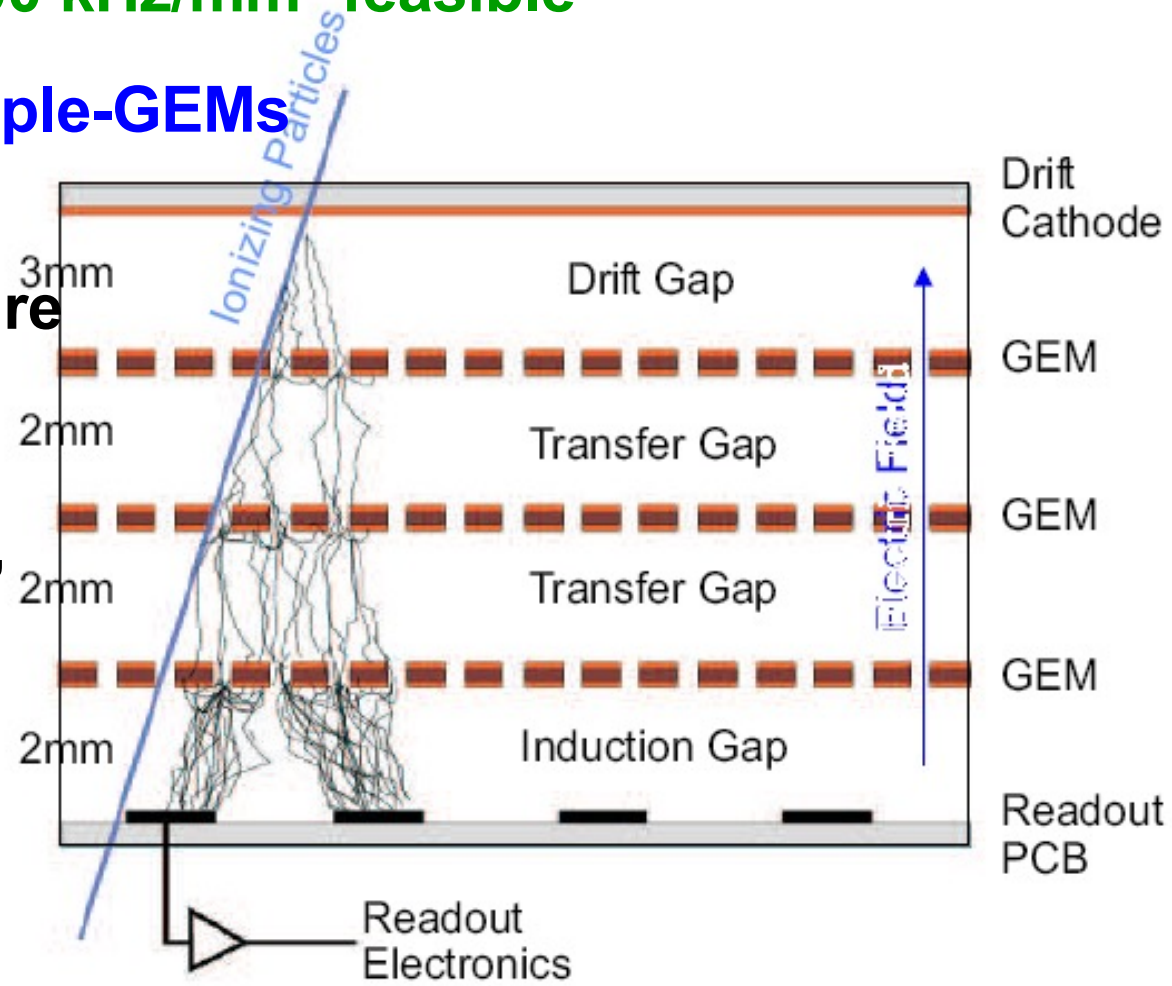
gas amplification in the holes





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)



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

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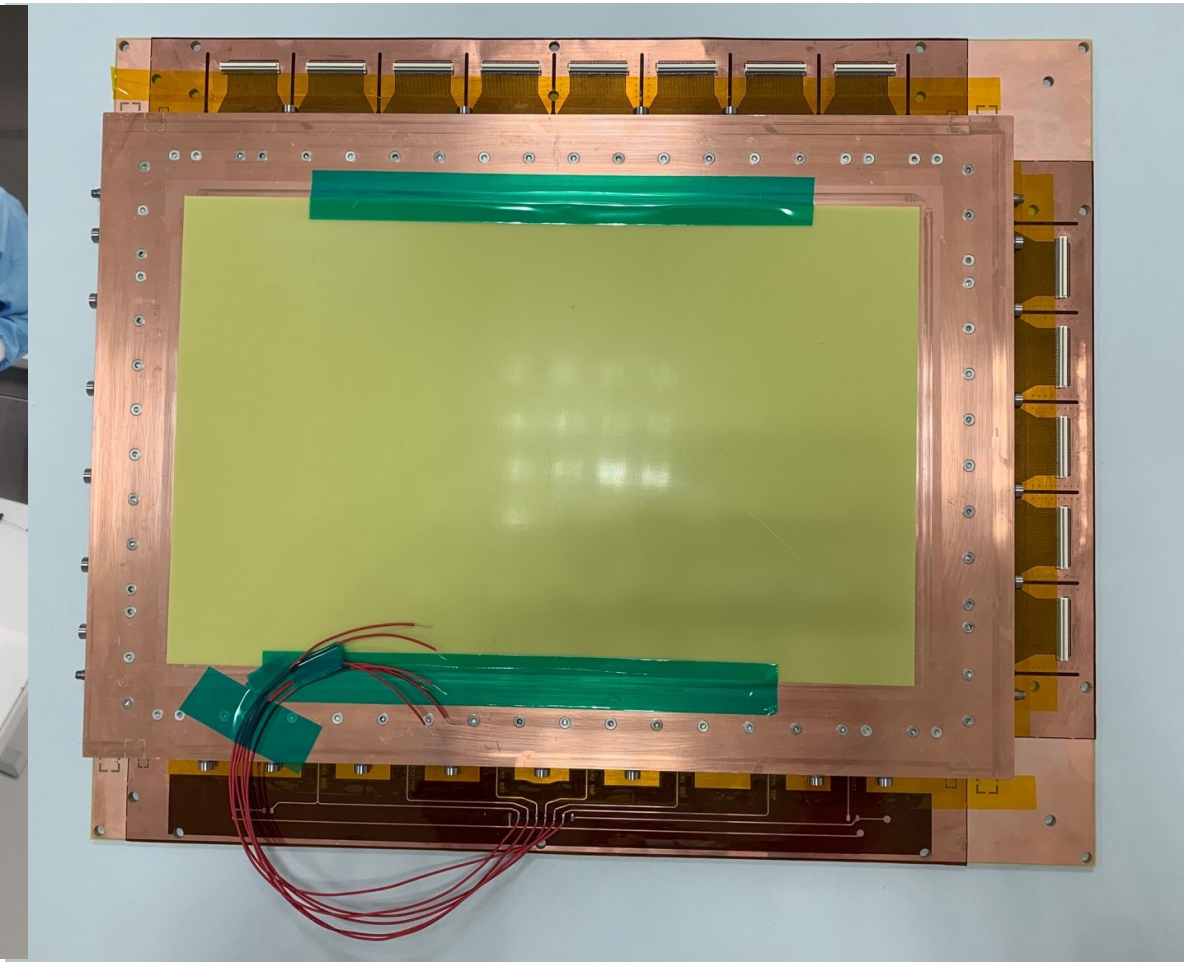
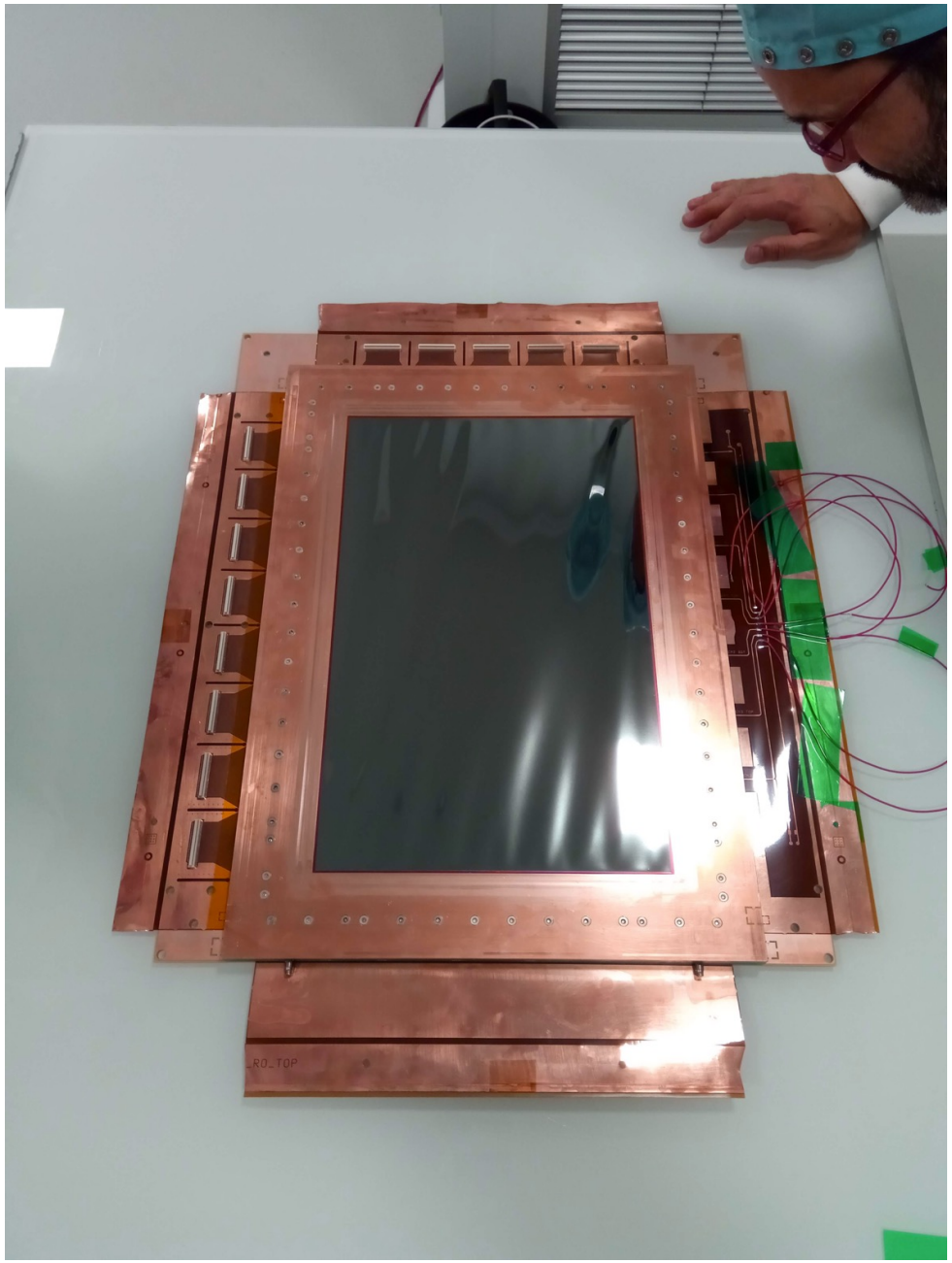
First GEM chamber assembled Feb. 21, 2019 at CERN, continued in Hampton

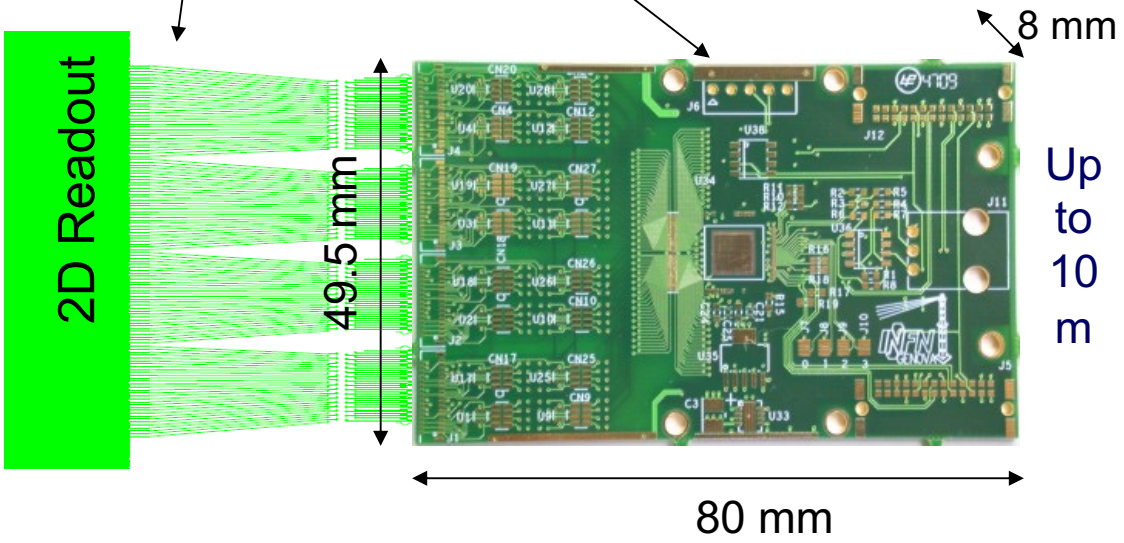


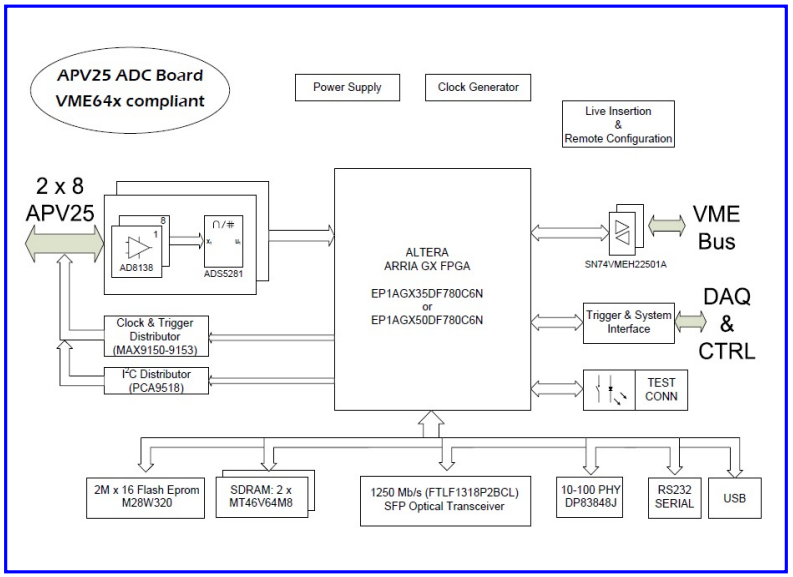
A fully assembled new GEM chamber



Readout electronics (INFN Rome)

GEM ⇒ FEC ⇒ ADC+VME Controller ⇒ DAQ





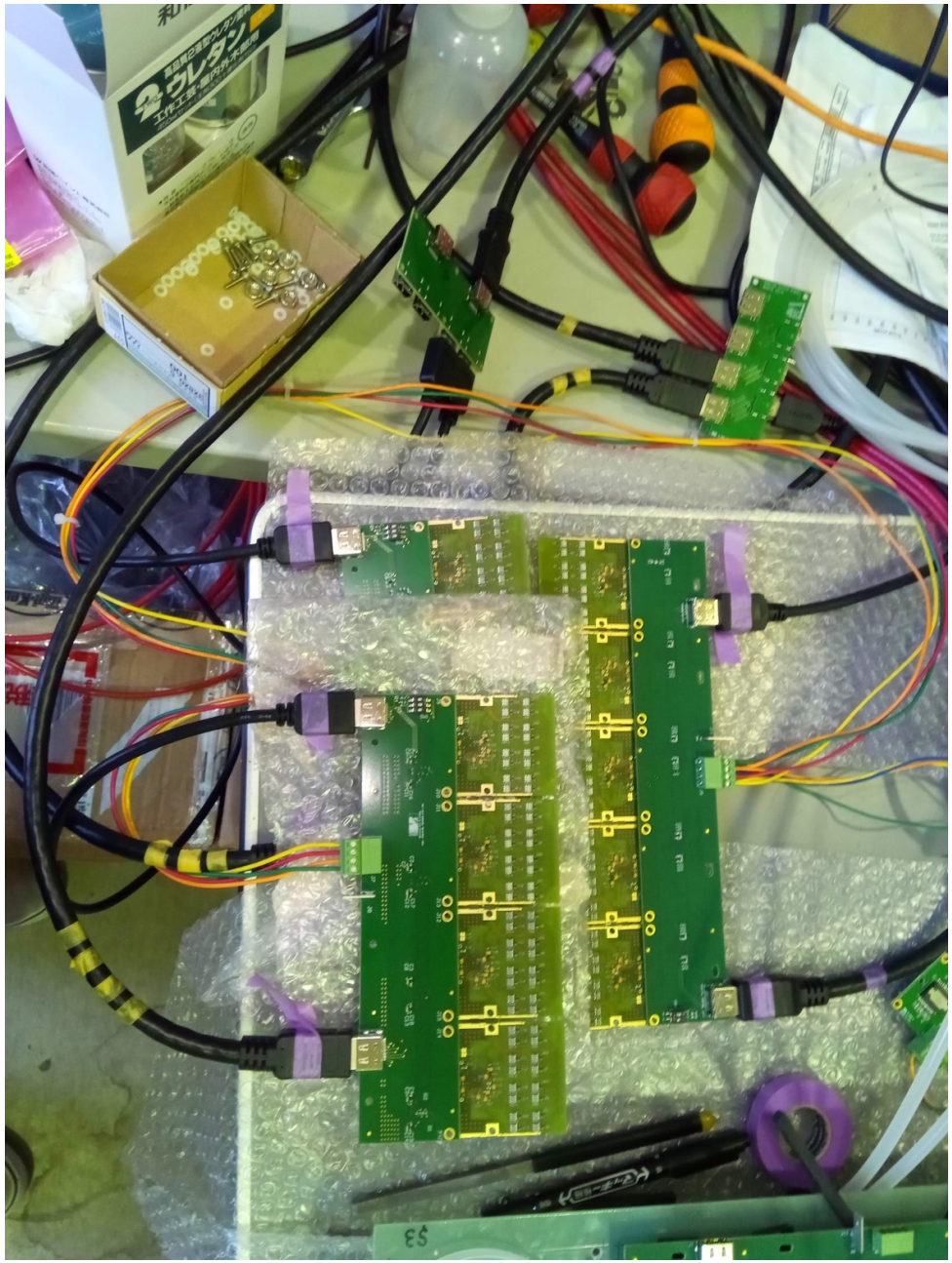
- Frontend card and controller (APV + VME) by INFN Rome, Jlab/SBS project S. Frullani, E. Cisbani, P. Musico
- APV rev. 3.0/3.1 (MUSE) and rev. 4.1 (DarkLight)
- MPD upgraded to rev. 4.0 for operation in DarkLight and MUSE

Multi-purpose digitizer (MPD)

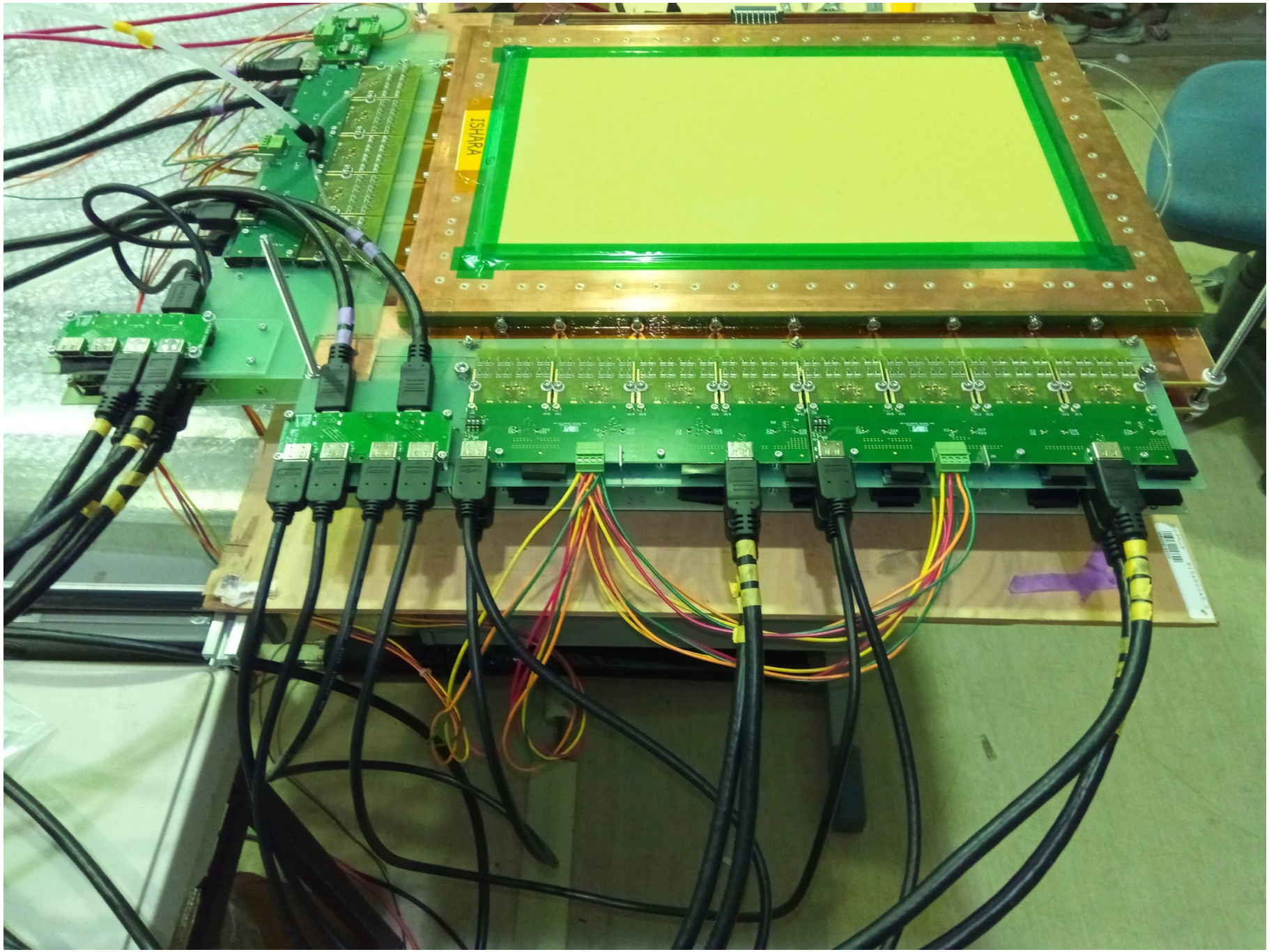
MPD rev. 3.0

rev. 4.0

VME based MPD + APV frontend readout



First commissioning



GEM gas

- Pre-mixed Ar:CO2 from 70:30 to 80:20, non-flammable
- Cylinder: 200 bar * 50 L = 10,000 L
  3 bubbles/s ~= 3 cm^3/s ~= 10 L/h per GEM
  → 40 L/h f. 4 GEMs → 500h/cylinder = 20 days/cylinder
- Small total flow not posing any ODH hazard
- Two-cylinder storage outside hall, with one supply line to DL
- Mechanical flow meters, operate at 1.5-2 bar input pressure
- Gas distribution panel with 4 flow meters (1 per GEM)
- GEMs operated near atmospheric pressure, over-pressured only due to flow conductance and exhaust bubblers
- Plastic hosing (1/4”), split to 1/8” / 3mm inlets
- 2 inlets, 2 outlets per GEM
- No gas recovery or chimney required. Pressure after bubbler should be atmospheric, or controlled at mbar level (1.000 bar). Existing chimney pressure can be << 1 bar, a risk for GEMs!

APVs and MPDs

- Analog Pipeline Voltage (APV) frontend chips from CMS provide preamplification+shaping, sampling, serializing 128ch
- Analog data frames are sent on external trigger via twisted pair to Multi-Purpose Digitizer (MPD) for digitization and recording through VME system.
- One twisted pair per APV. Four (4) shielded twisted pairs per HDMI cable for up to 4 APVs per HDMI cable.
- 4 HDMI slots per MPD, using one MPD for 13 APVs per GEM
- MPD has FPGA with firmware to communicate with APVs; using single-board VME controller (CPU) to control MPD
- Frontend APVs are not radiation hard for operation, can lose configuration
- No direct exposure to particle flux (in shadow of yokes) ok
- Inside spectrometer shielding house proven ok
  Successful operation in Hall A (Super-Bigbite)

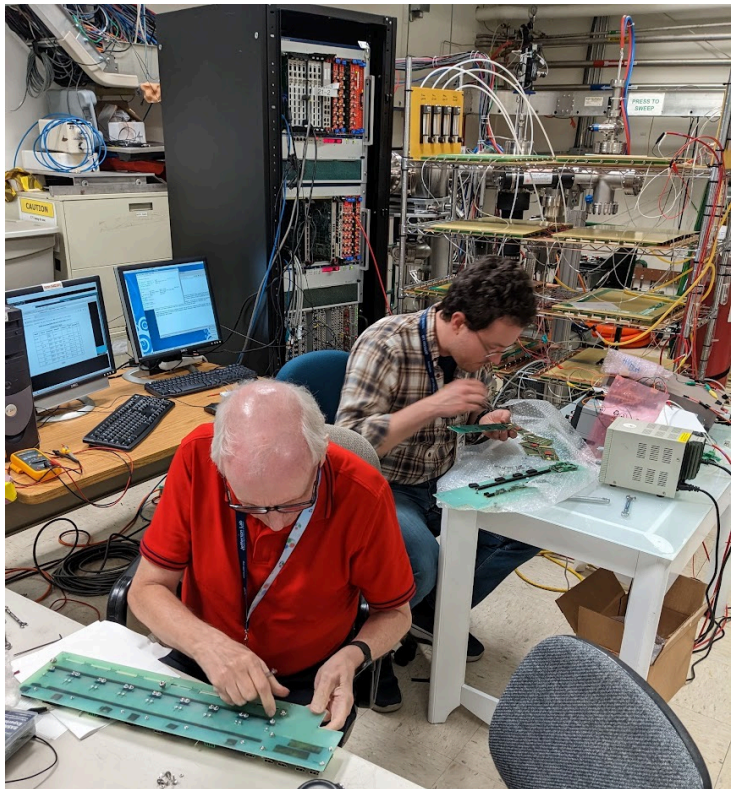
VME and HDMI

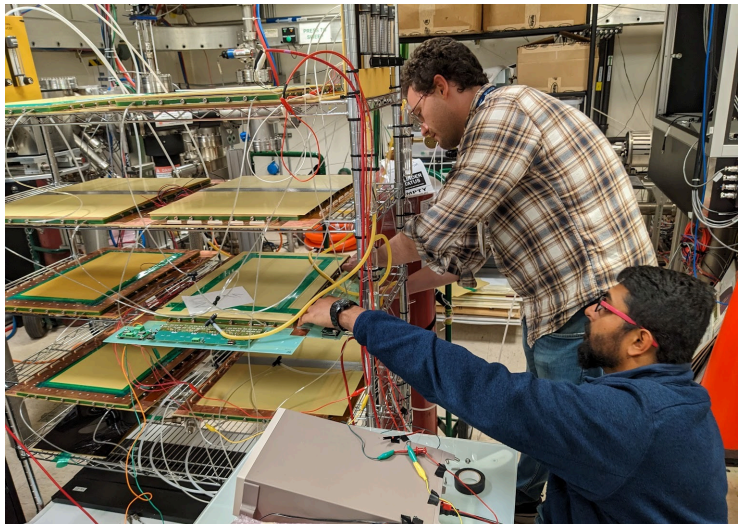
- APV frontend cards connected to backplanes with HDMI slots, six (6) HDMI cables between VME and GEM APV frontend (2x digital, 4x analog)
- Designed for 10m, previously operated at up to 20m length
- VME crate (Wiener 64x, Jlab-style) is hosting:
  1x Intel controller (Abaco XVB602) for MPD/APV configuration and VME readout of triggered event data, 1 Gbps ethernet link
  1x Multi-purpose digitizer (MPD) per GEM → 4 MPDs total
  2x CAEN V6533
- Upgrade path for higher readout speed (2024):
  (VME: 1 Gbps / 100 MB/s limit)
  → Use VME only to power MPD; read out optically;
  process MPD data with VTP or SSP on VXS crate, 10 Gbps
  can run 4 MPDs / 6 samples at few kHz w/o zero-suppression
  Event size: 13*6*128*(32/2)*4 = 640 kb → 5 kHz = 3.2 Gbps

LERF User Lab 1

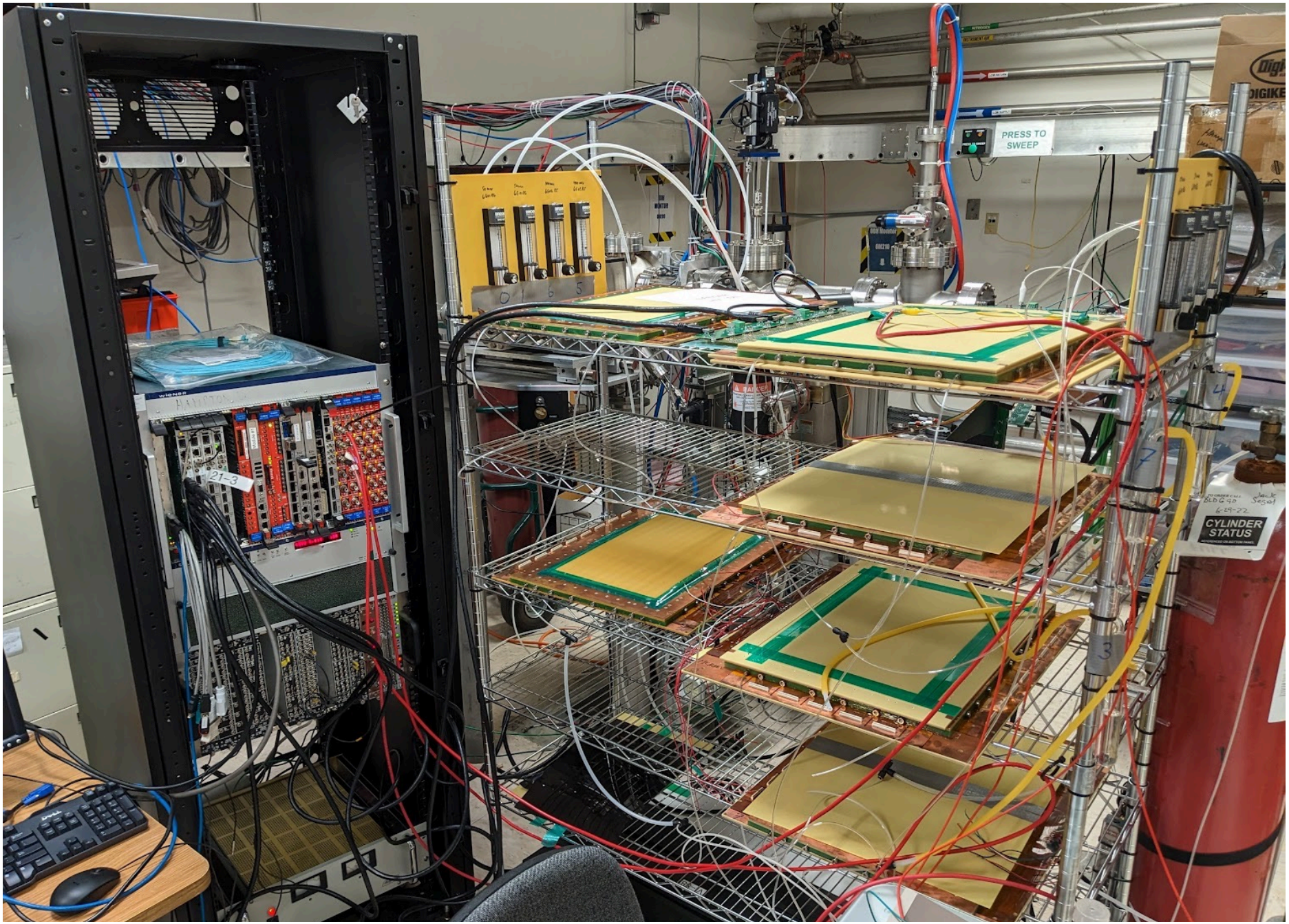
External volunteers

- D.H and E.C. visited LERF from 4/24-5/4, to work 16-hour days
- Flushing GEMs with nitrogen
- Doing HV tests of individual GEM foils, and with HV divider
- Tests of APV electronics
- 4 GEMs working (enough for DarkLight), 4 having issues: 3 with high dark current, one with a shorted sector
- Repairs ($0) possible by shock-ramping, by-passing protection resistors, to clear from resistive dirt and to burn off the short.
  If it fails, must replace foils.
  Costs: $20k for 4 GEMs





External volunteers



However, we also had some fun …

Electronics and Schedule

- 2 GEMs, 1 set of electronics (13 APVs, 2 MPDs, 1 VME crate, 1 XVB602, HDMI and LV cables) now at MIT, to be shipped to TRIUMF in July
- 2 GEMs, 1 set of electronics, now hooked up at LERF, set up in June for testing with cosmics in July-Aug; ship to TRIUMF in September/October
- Expect additional 26 APVs (2 sets) to become available for DarkLight, of 100 lent to SBS. E.C. identified 13 good cards from stack of 20 questionable cards. Another 20 to be tested.
- UVA/JLAB to place order for ~100 new APV cards, ~6 months lead time. Additional 112 cards needed for SBS before Jan 2024. Could be reduced by 88 if GEn-RP is descoping partial setup. Still, more spares are desired for MOLLER.
  May come back to D.H.'s offer to donate APV chips, for a total order of ~200 cards. In that case some, or all, lent ones could be received back even before SBS GEn-RP and GEp-V in 2024

THANK YOU!

High voltage

- Up to 4,300V @ 1mA supplied to passive HV divider on GEM
- Negative HV, from Cathode layer to readout at ground level
- CAEN V6533N VME based (6 channels)
- 9W power limit → use only 2 channels per module;
  Use 2 CAEN modules for 4 GEMs
- SHV cables from VME to GEMs, 1 per GEM

Low voltage

- APV frontend cards require 2.5 V + 1.25 V operating voltages, provided by power regulator chip, one per GEM
- LV (4.5-5 V) is supplied to LV regulator board
- 1 regulator per GEM to power 13 APVs (8+5)
- 13 APVs per GEM draw <20A; total setup <100A @ 5V
- Need low-gauge LV cabling (10-12 AWG) to avoid LV drop

- Can TRIUMF provide LV power?