RPC gap production facility for CMS and beyond

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May 19, 2026 For Joint Workshop of TYL/FJPPN and FKPPN

FKPPN project

- Title: RPC gap production facility in Korea for experiments in J-PARC
- Collaborators
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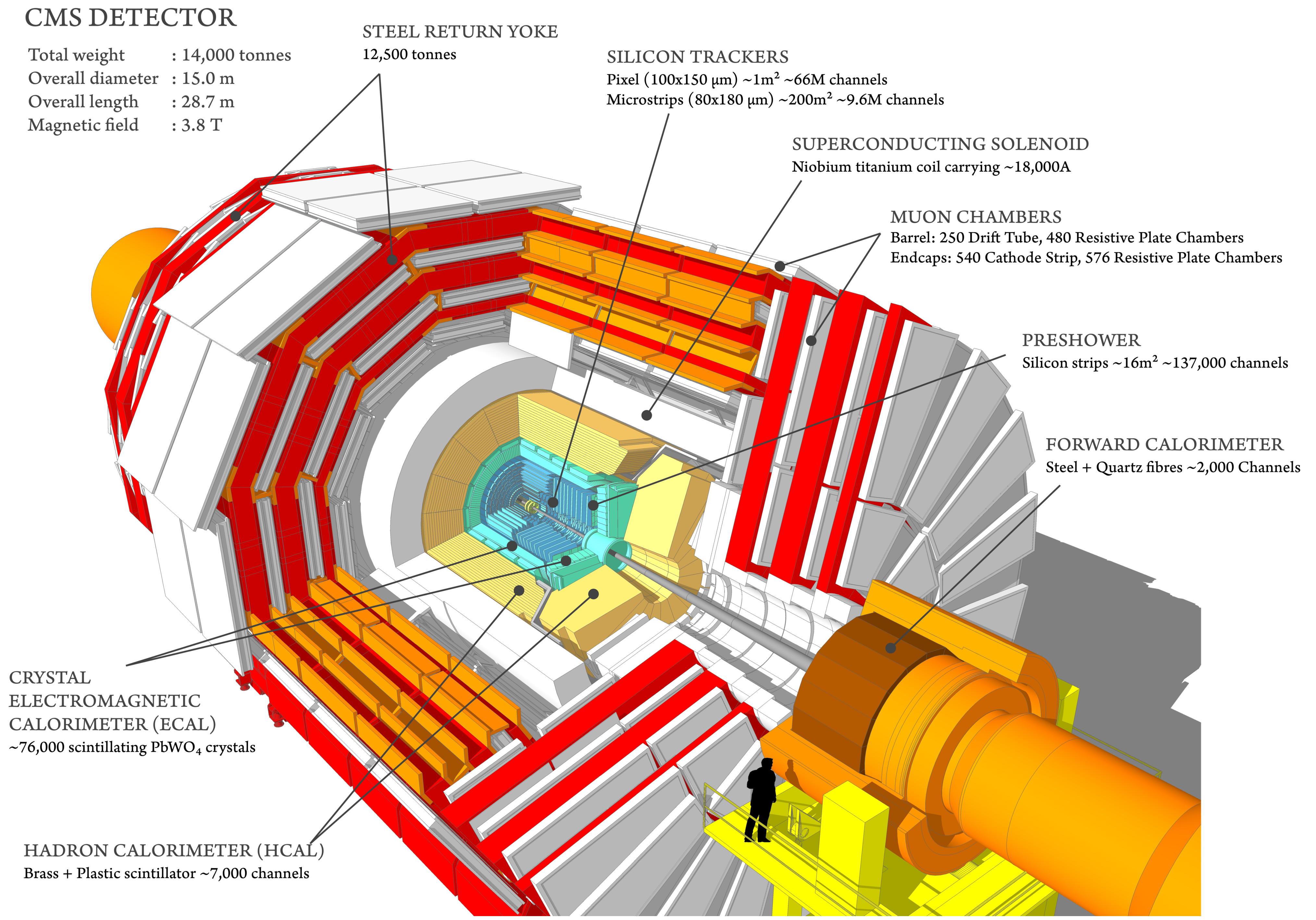
  - **PI:Myeong-Jae Lee (Sungkyunkwan University),** Tae-Jeong Kim (Hanyang)
  - Hanyang: Dr. Kyong-Sei Lee, Minho Kang, Youngmin Jo (two engineers)

CMS (Compact Muon Solenoid)

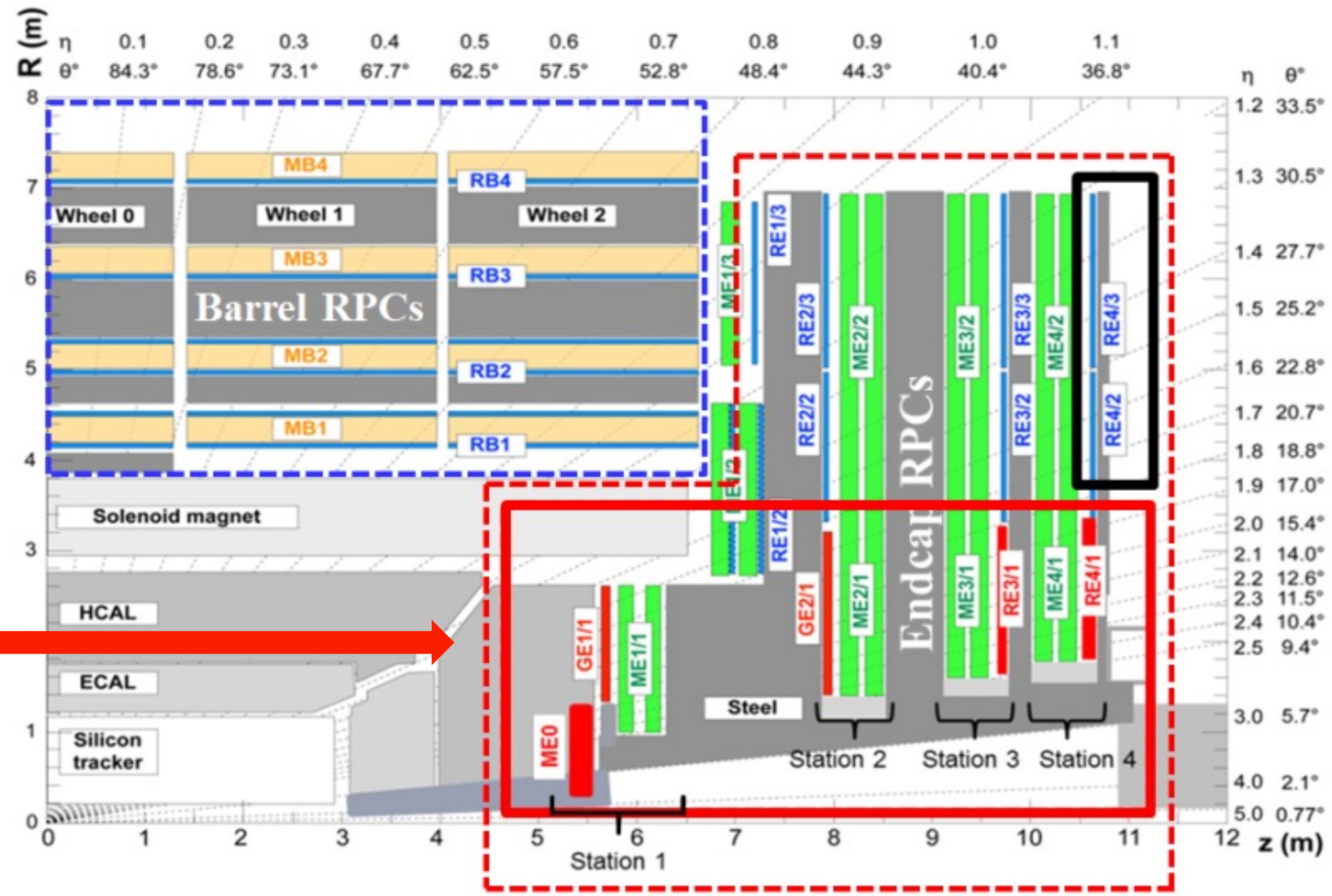


Barrel RPCs

- 6 stations (layers) covering up to $\eta = 0.8$ (partially $\eta = \sim 1.2$)

Endcap RPCs

- 2 wings (RE+, RE-)
- 4 stations (RE1, RE2, RE3, RE4) in each wing
- Covering $0.92 < \eta < 2.1$



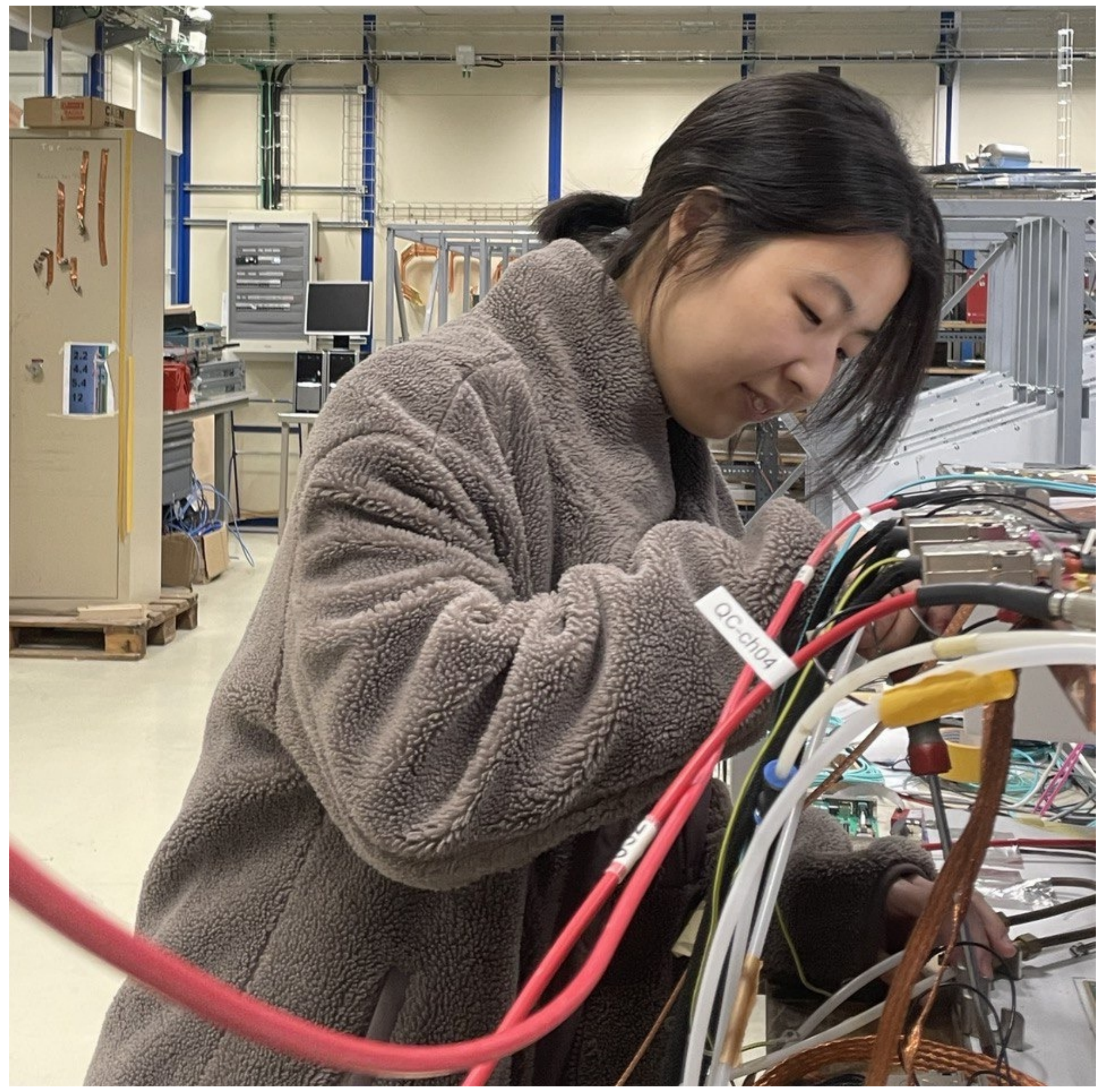
New RPCs for CMS (iRPCs)

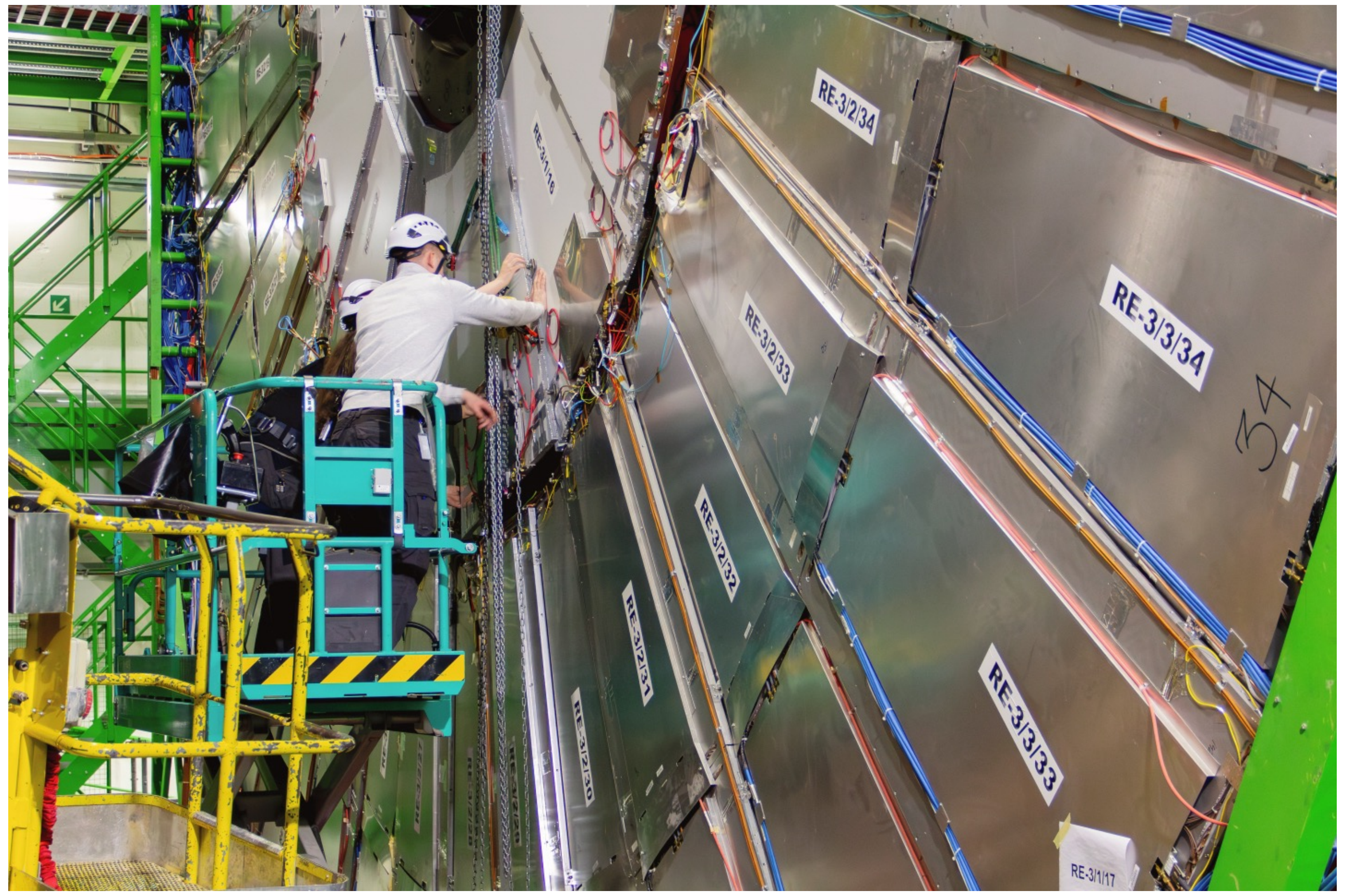
Trigger double-gap RPCs with 2D tracking capability

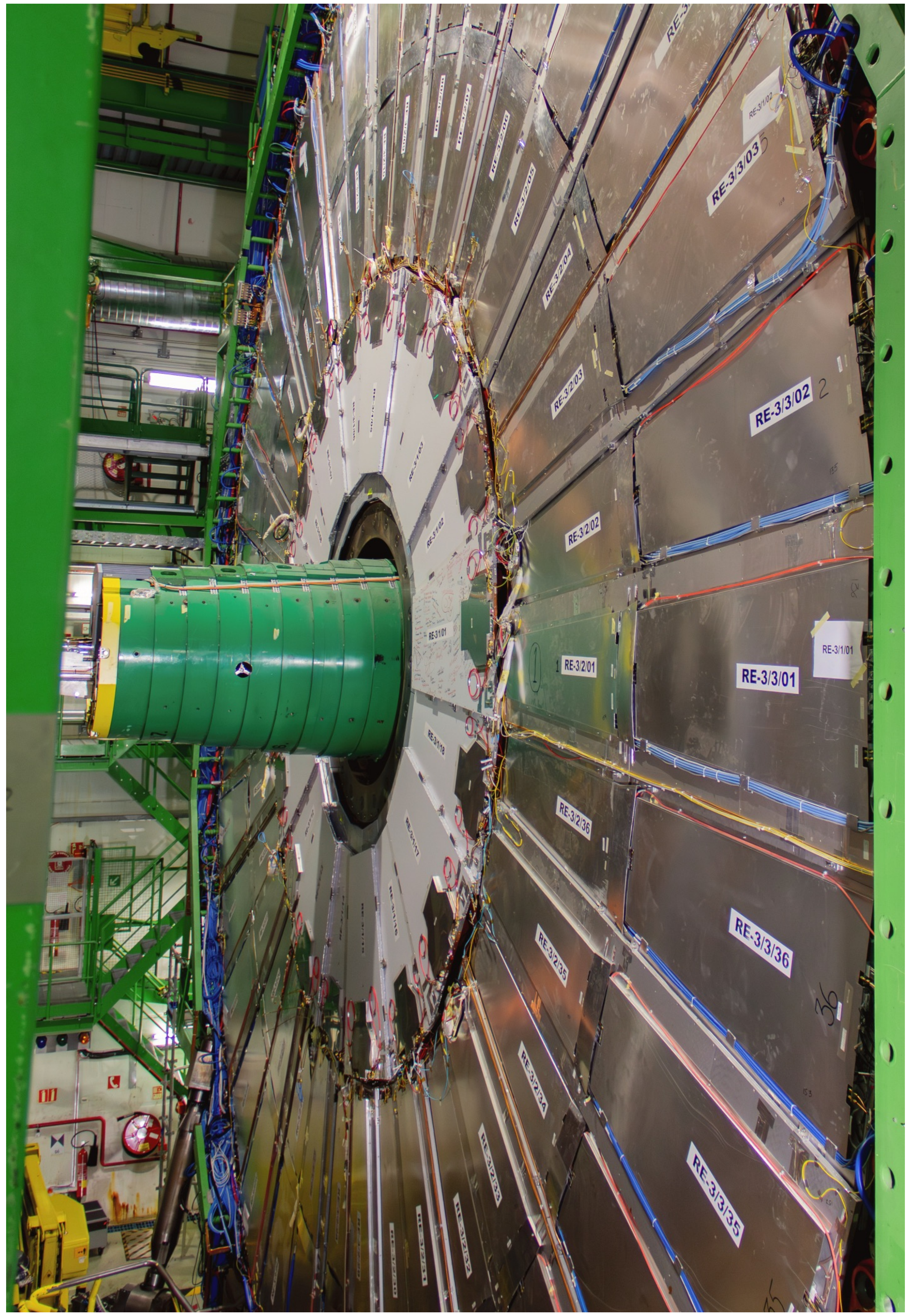
✓Efficiency > 95%
✓Time resolution ~ 400 ps
✓Position resolution in $\varphi \sim 3$ mm
✓Position resolution in $r \sim 2$ cm

Installation of 36 iRPCs at (-) Endcap CMS during YET24-25

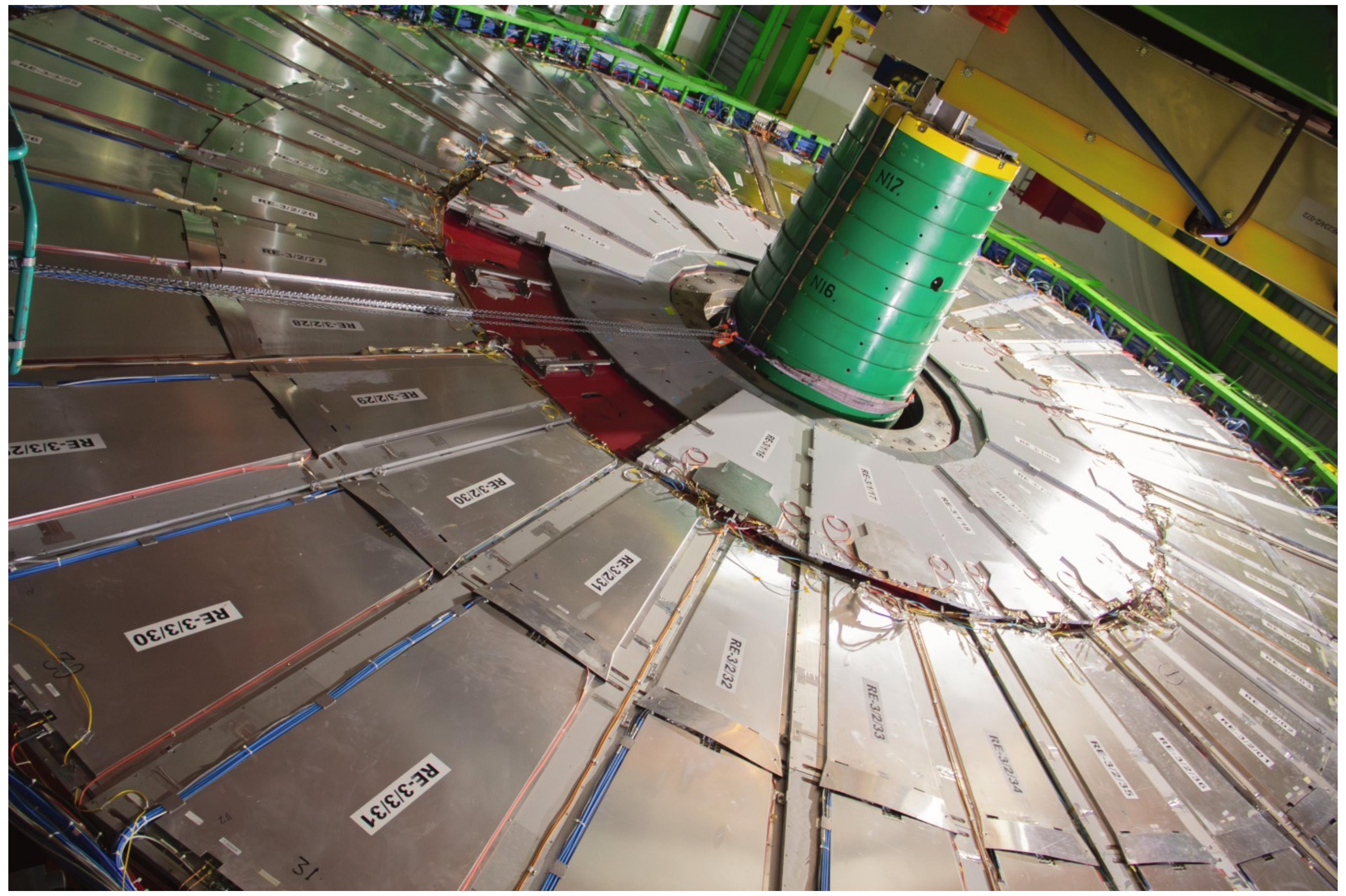
Yeonsu at Hanyang







Maxime at Lyon

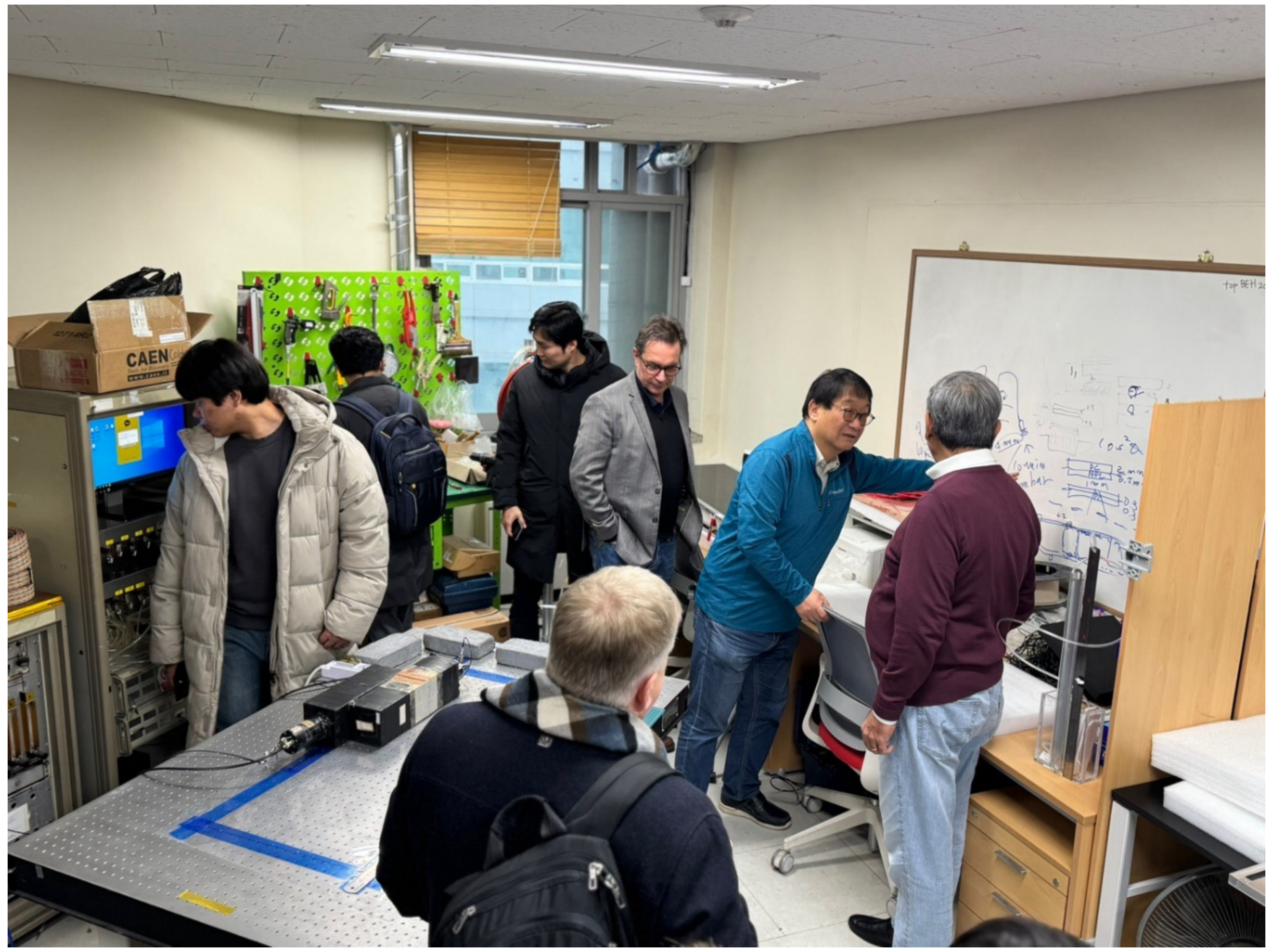


New lab@Hanyang U. and RPC factory@KBSI in Korea U.

- Two VME TDCs and DAQs
- VME and NIM electronics for comic ray triggers
- VME power supplies
- Gas system
- Dark current reader

CMS spokesperson team and RPC team visit

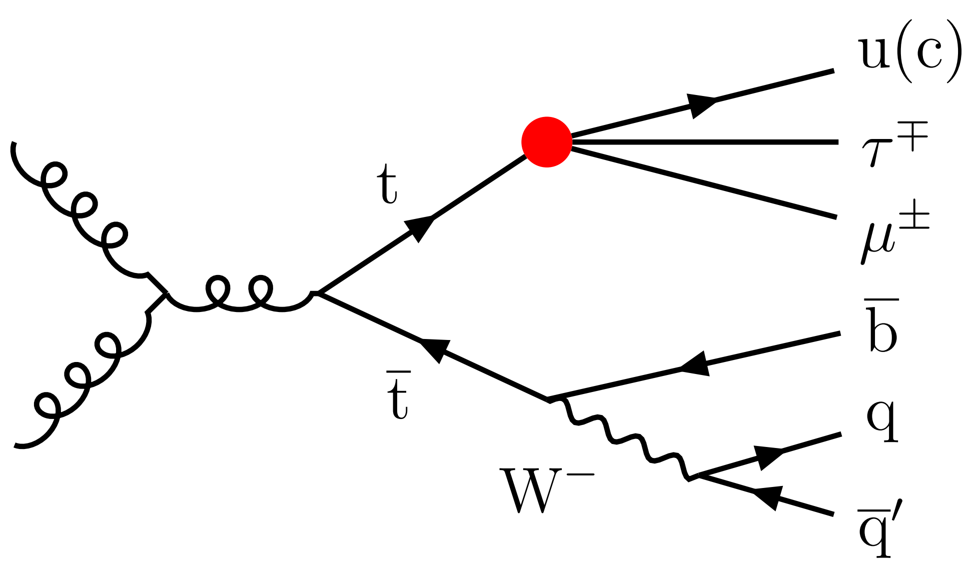
- During the CMS week in December last year (2025)



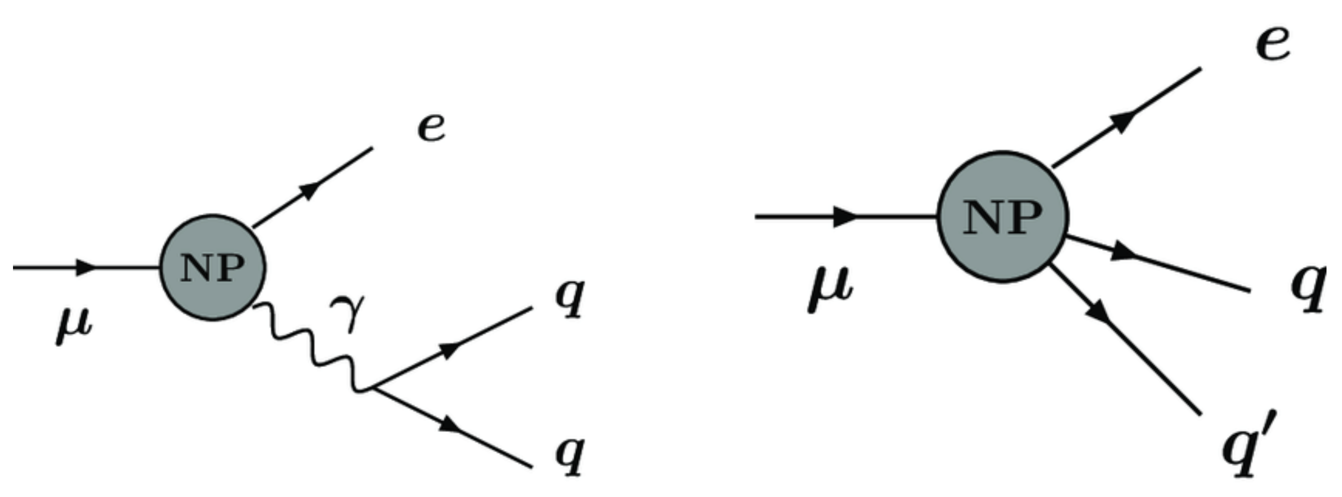
From CMS to COMET experiment

- Made a proposal (Basic Research Laboratory) **to preserve and transfer the know-how to future experiments**

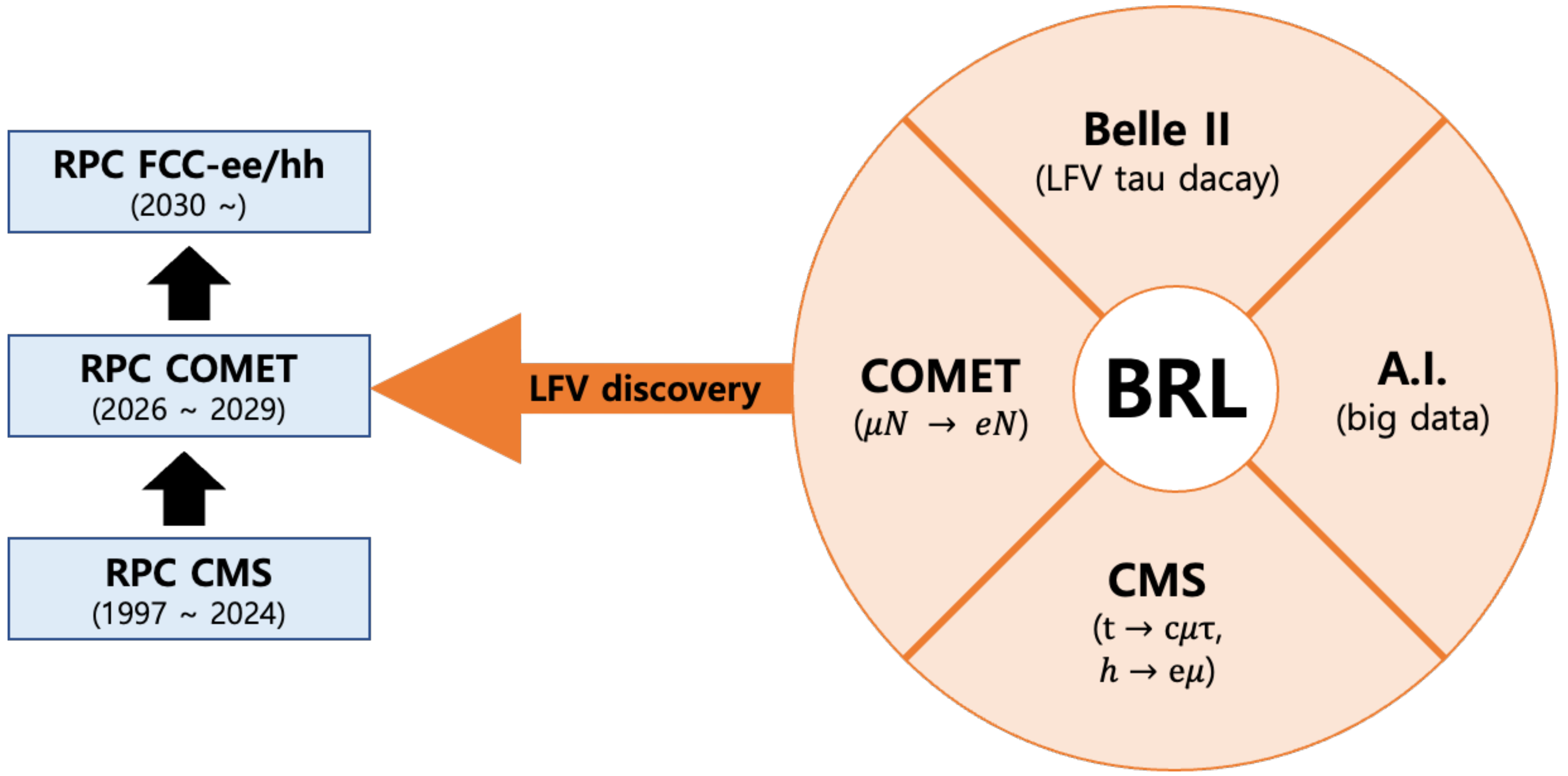
- Common Physics Motivation (CMS, Belle II, COMET): Search for Lepton Flavor Violation
  - For CMS: in the EFT framework, searching for the three-body top decay ($t \rightarrow c\mu\tau$)
  - Belle II : LFV tau decay (e.g. $\tau \rightarrow l\eta$)
  - COMET: searches for μ → e conversion in muonic atoms, $\mu^- + N(A,Z) \longrightarrow e^- + N(A,Z)$



CMS



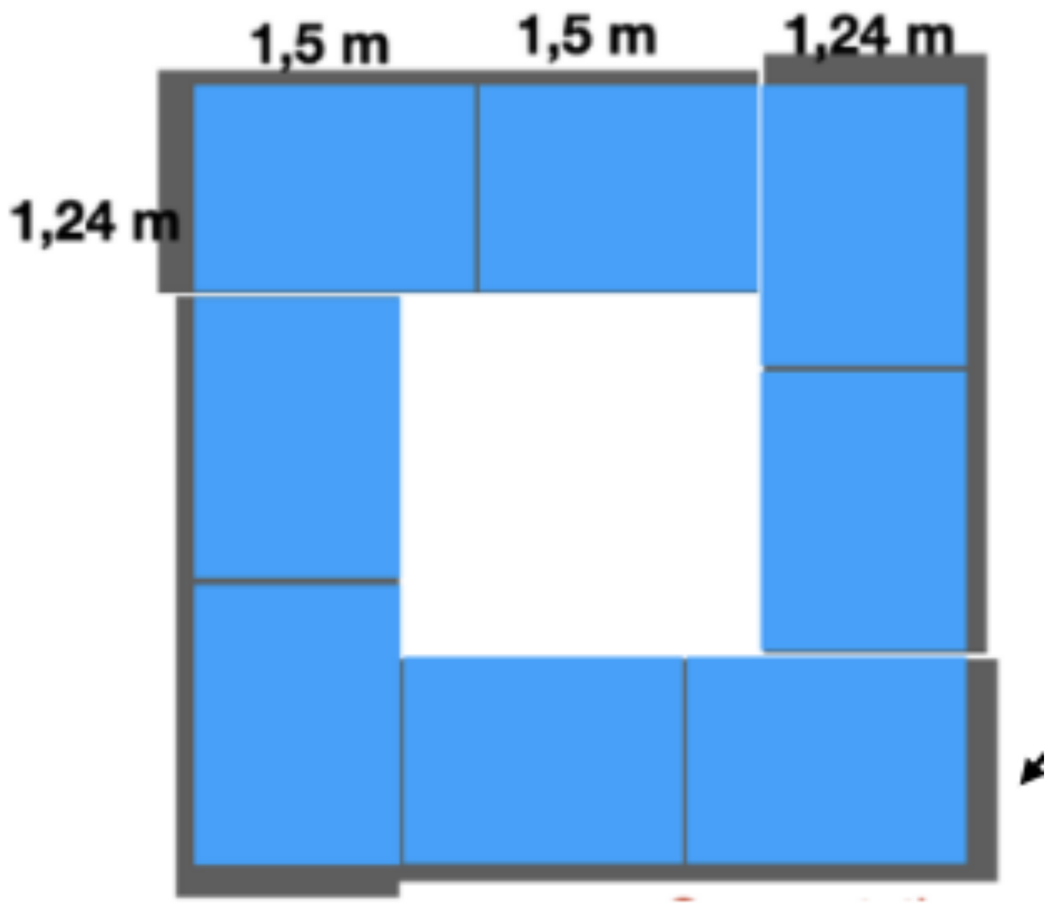
COMET

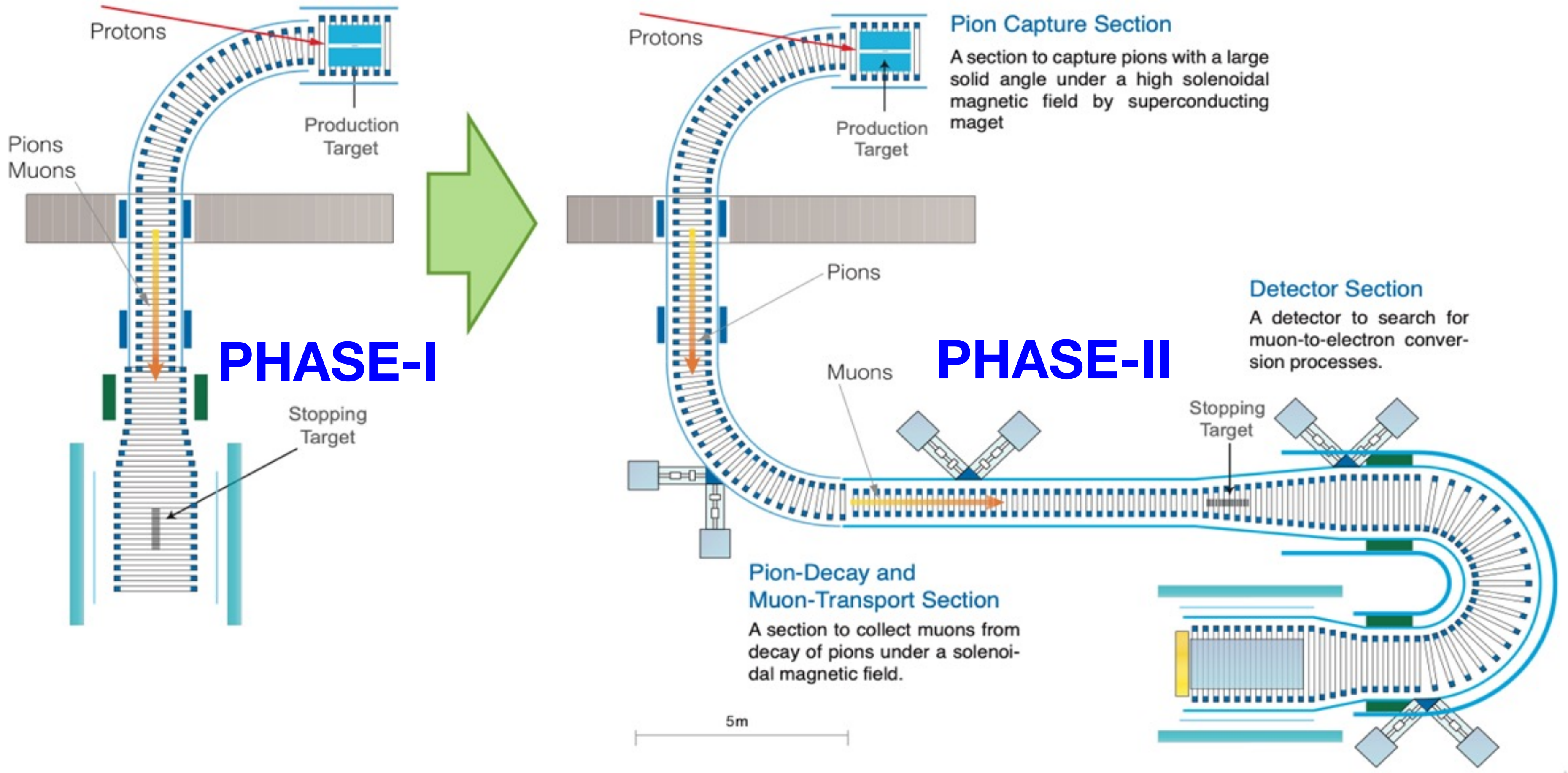


RPCs for COMET

See the talk from Natsuki in parallel session!

- Share the same detector technology with iRPC or consider glass RPC
  - Cosmic muon VETO with ~ 3 mm tracking resolution
  - Muon tracking to eliminate the neutron background
- Possibly assemble 80 (8 chambers per layer, 2 gaps per chamber, 5 layers) RPC gaps for COMET experiment in case the iRPC is finally chosen for COMET phase 1

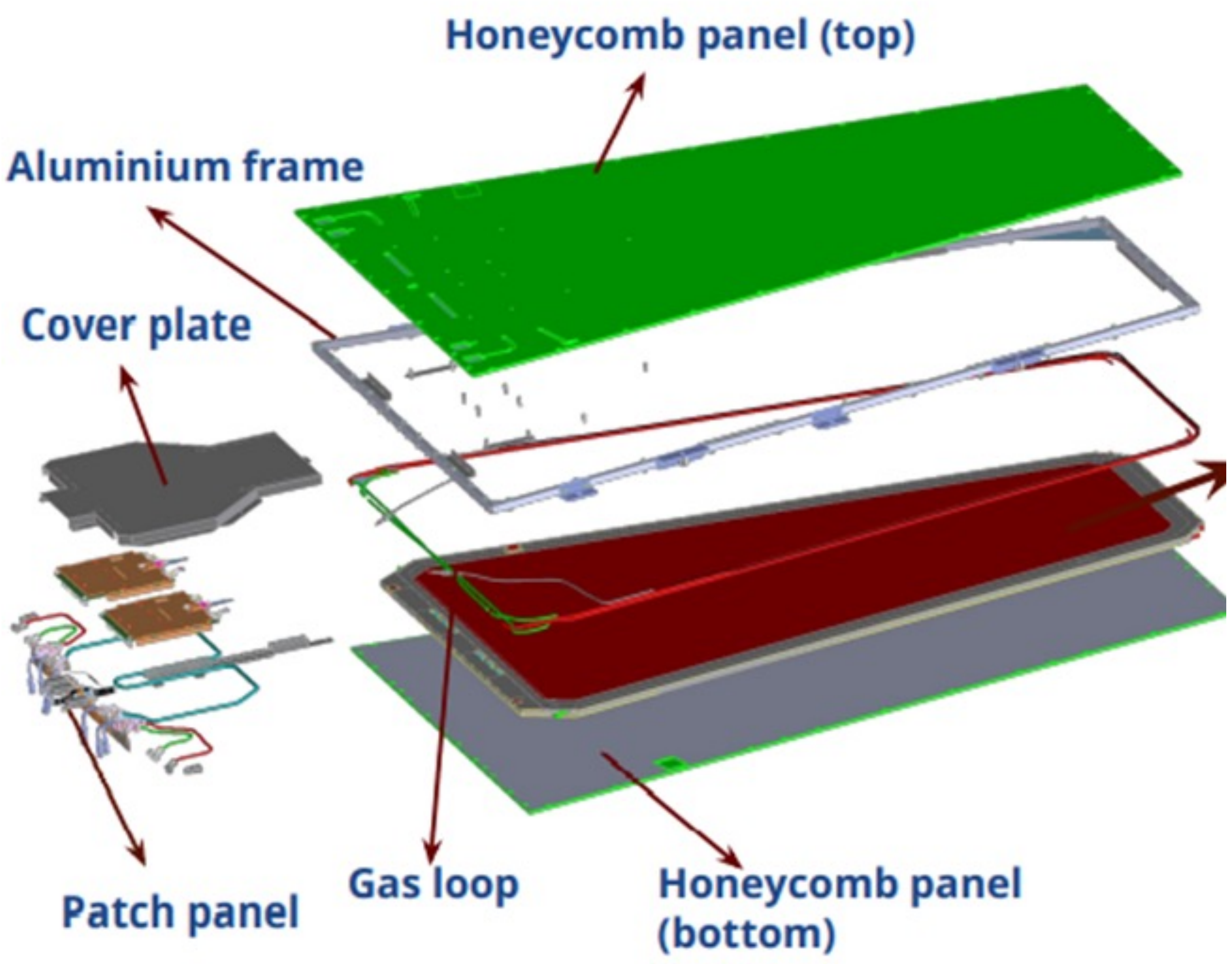




iRPC for HL-LHC

- **What are the difference of the iRPCs compared to the existing CMS RPCs?**
  - **Thickness of gas volume as well as the HPL thickness: 2 mm → 1.4 mm**
    - Higher rate capability more than 2 kHz / cm^2
    - Improving time resolution as good as 400 ps (PETIROC electronics ~25ps)
    - Accommodate lower digitization thresholds: 150 ~ 170 fC (RPCs) → 36 ~ 50 fC (iRPCs)
    - Use smaller avalanche charge with lower threshold
  - **2D RPC trigger/tracking with better position resolutions in both r and φ directions**
    - 1D readout with 3 η divisions (RPCs) → 2D readout (iRPCs)
    - Strip pitch: 2.0 ~ 3.8 cm (RPCs) → 0.58 cm ~ 1.1 cm

Both CMS RPCs and new CMS iRPCs are double-gap (double-gas volume) RPCs



For CMS RPCs, the RPC electrodes are made of Bakelite (Phenol type High Pressurized Laminate)

Pros:

- Rate capability is high (proven up to a few kHz cm^{-2}).
- Productivity of RPC gap is high.

Cons:

- Relatively high noise rate is a drawback when utilized for VETO detectors.
- Aging problem
- Bakelite contains hydrogen (proton) and is sensitive to fast neutrons.

  → (due to np capture and proton knockout reactions)

What if we use glass instead of Bakelite?

Pros:

- The glass is much less sensitive to fast neutrons.
- The low neutron sensitivity will mitigate the data load for the trigger system.

Cons:

- The rate capability of glass RPCs is in general lower than that of Bakelite RPCs.

But neutrons induce much less charged signal in glass than in Bakelite. So, at the end Glass can have higher rate capability → Could reduce the neutron and gamma background to the whole detector system in addition to the proposal of insulating the target and beam line by using gadolinium powder

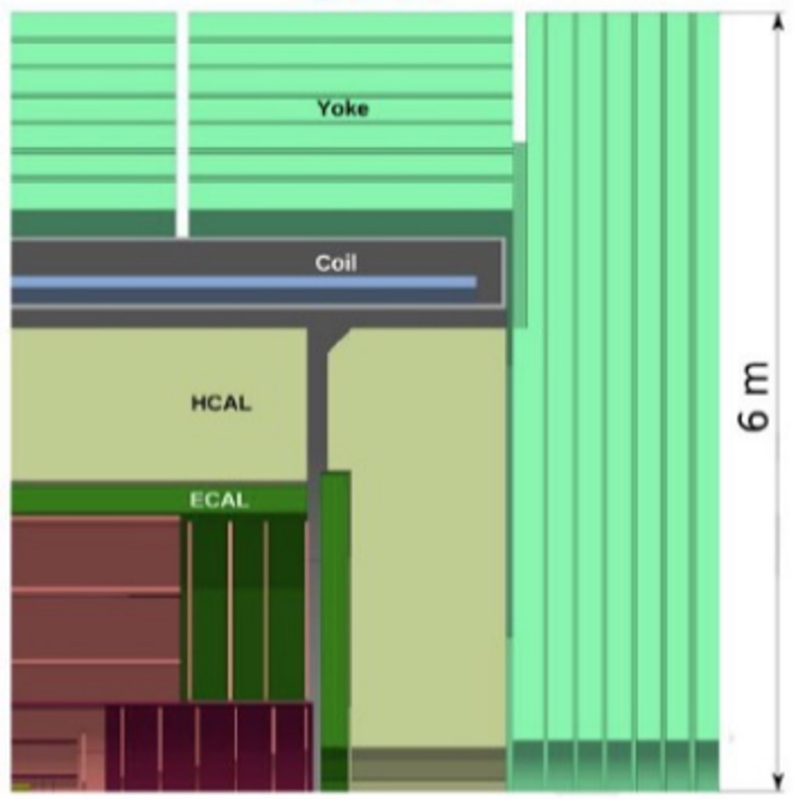
FCC and DRD1 contribution

- For precise measurement:
  - Aiming for less than 300 ps timing resolution and < 1 mm spatial resolution
- Propose a timing RPC detector for better timing resolution for FCC-ee
  - Good for searching for heavy stable charged particle or long lived particle
- Mircro Strip RPC is motivated for large coverage and low cost

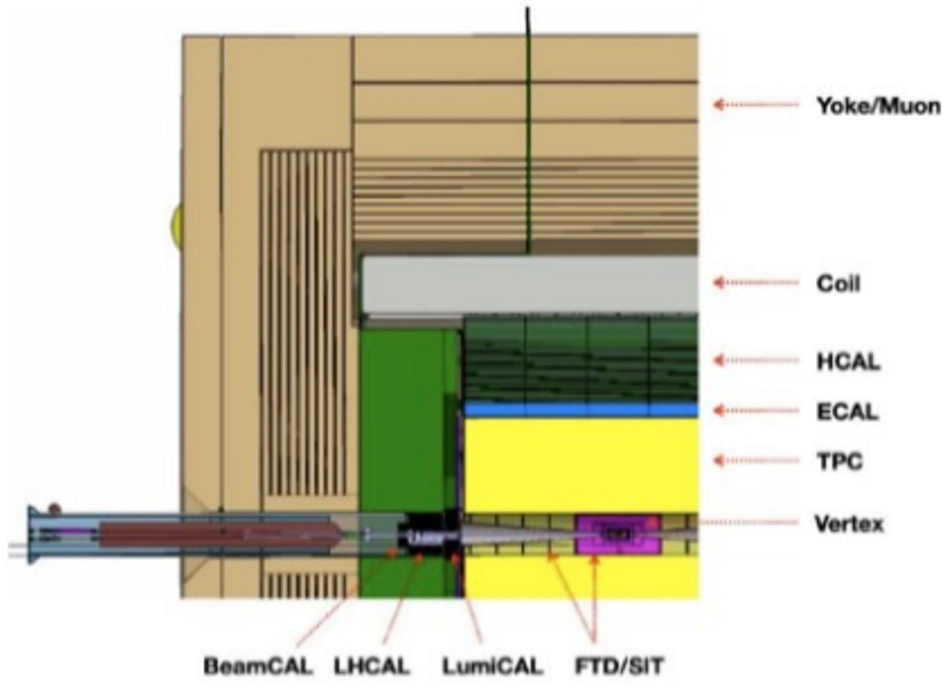
Slide From FCC muon sub-group meeting

Overview on the FCC detectors

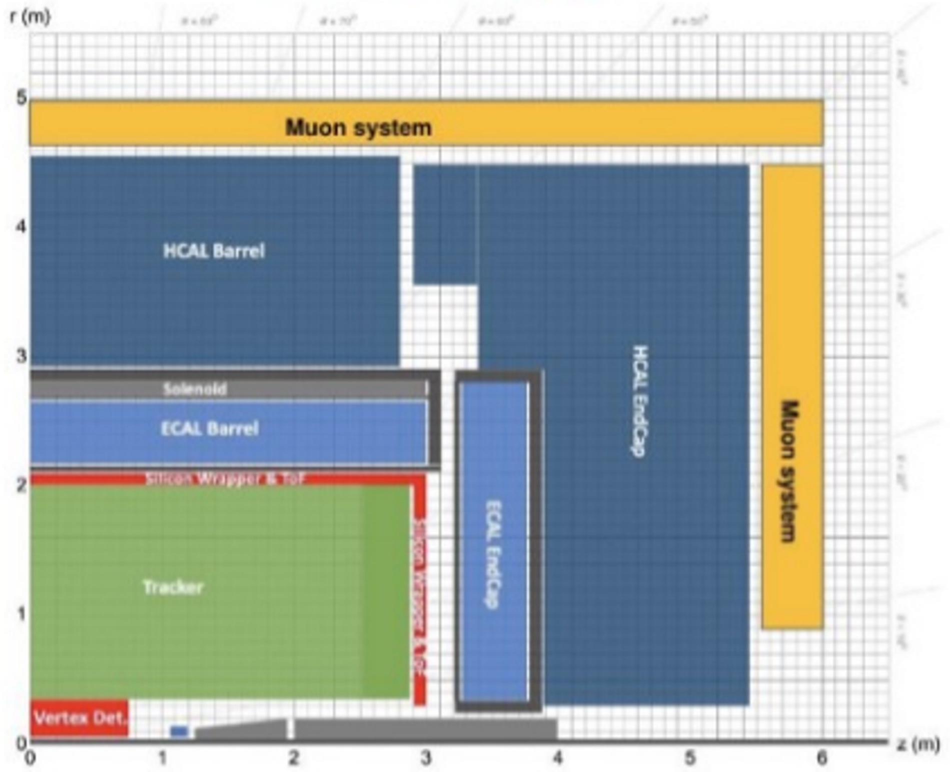
CLD



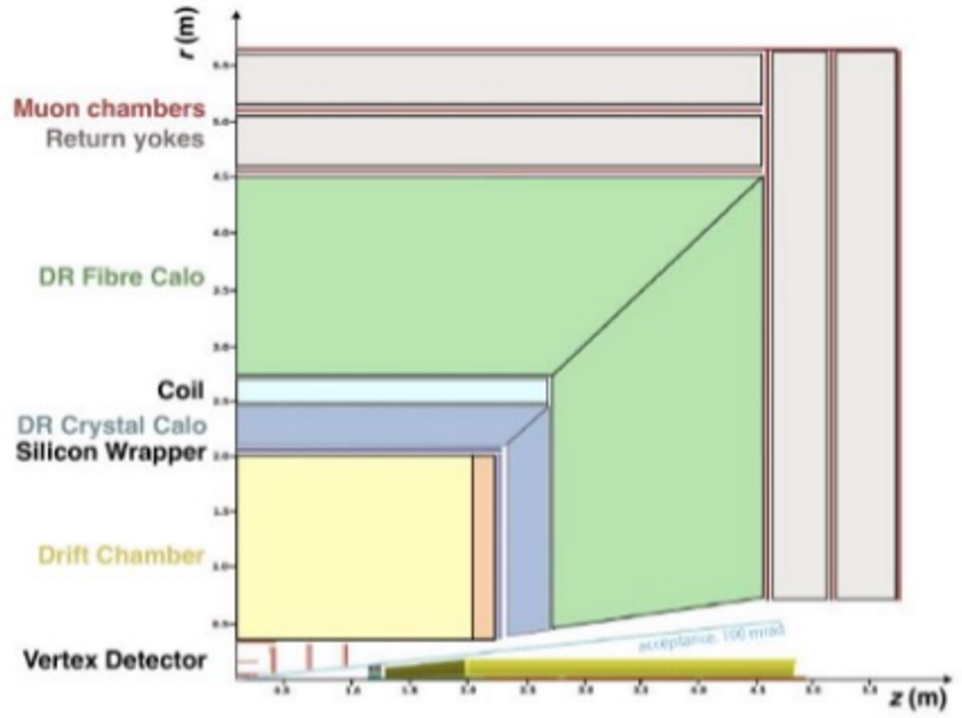
ILD



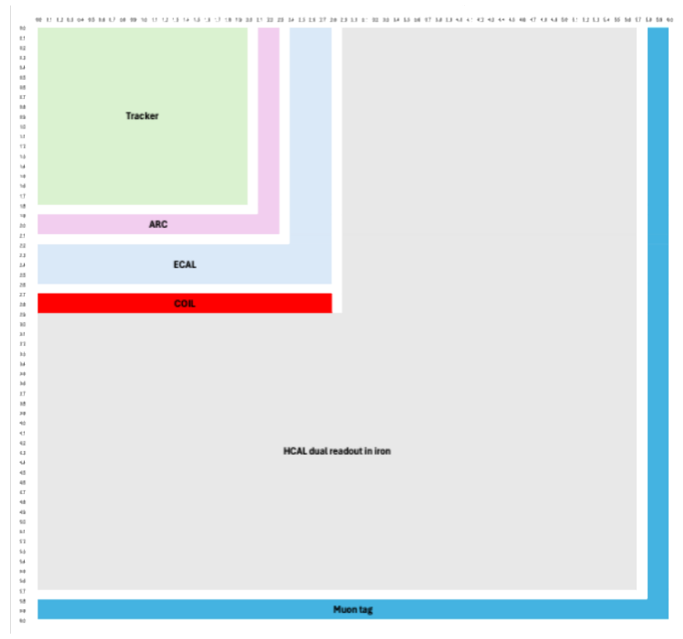
ALLEGRO



IDEA



ALPF



Subsystem	CLD	ILD	ALLEGRO	IDEA
ID	All-silicon tracker	Silicon vertex detector TPC	Options considered initially: Silicon vertex detector Low X_0 drift chamber or straw tracker Silicon wrapper BUT: Open for other technologies	Silicon vertex detector Low X_0 drift chamber
ECAL	High-granularity silicon-tungsten		High-granularity lead/noble liquid	Dual read-out calorimeter Lead-scintillating/Cherenkov fibres
HCAL	High-granularity scintillator-steel		Several options, no baseline yet	
Muon	Steel-yoke instrumented with RPCs		Several options, no baseline yet	Return yokes with μRwell chambers

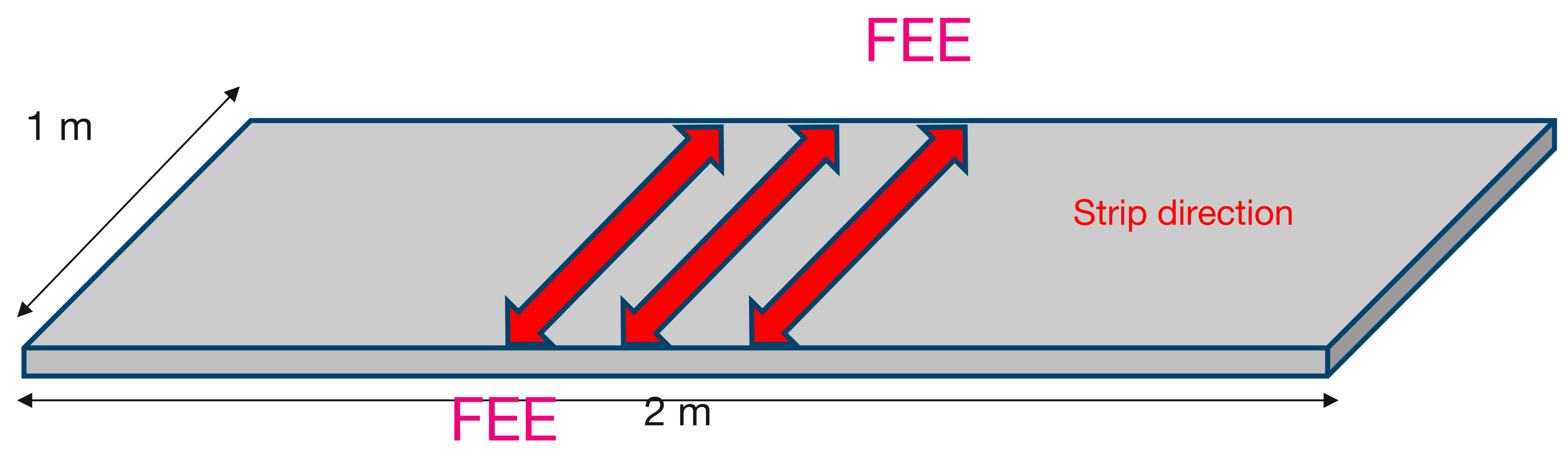
- High-performance all-MAPS Tracker
- ARC (**A**rray of **RI**CH **C**ells)
  - Good particle ID over large momentum range
- ECAL based on GRAiNITA
  - Excellent energy (and position) resolution at an affordable cost
- Coil for 3T field
  - ~ 3T seems plausible
  - Dimensions are reasonable
- Dual Readout HCAL in iron
  - Best option for hadronic energy resolution
  - Iron absorber keeps the overall detector dimension reasonable
    - Dimensions shown may be somewhat overdone
  - **Nobody has ever built a dual readout HCAL!**
    - *18 M fibers cast in iron?!?*
- Muon tag
  - No muon tracking beyond the Tracker - to be discussed
  - Maybe it's not a bad idea to have *one* subdetector simple and affordable…

- CLD (eg barrel): in yoke, 7 layers of RPCs. x*y square readout (3x3 cm2). Calorimeter-type sensitive action. Integrated in Pandora reconstruction (used for muon-ID of tracks from inner detectors)
- ILD_FCCee (eg barrel): in yoke, 14 layers of scintillator, 3x3 cm2 cells. Calorimeter-type sensitive action. Integrated in Pandora reconstruction
- IDEA (eg barrel): in yoke, 3 layers of mu-Rwells. Square readout cells with strip pitch = 1.4 mm. Tracker-like action. Standalone track reconstruction under development for e.g. LLPs

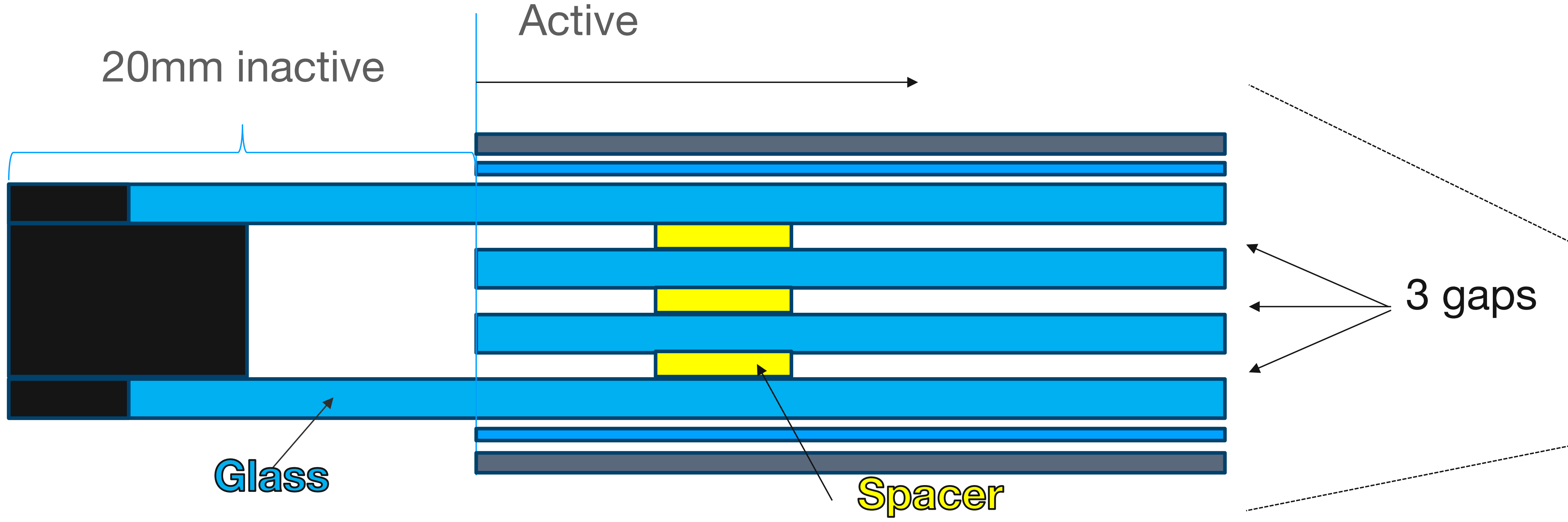
FCC muon group conveners ⟶ Riccardo and Taejeong - May 4th, 2026 - FCC-PED Muon detector subgroup status and plan

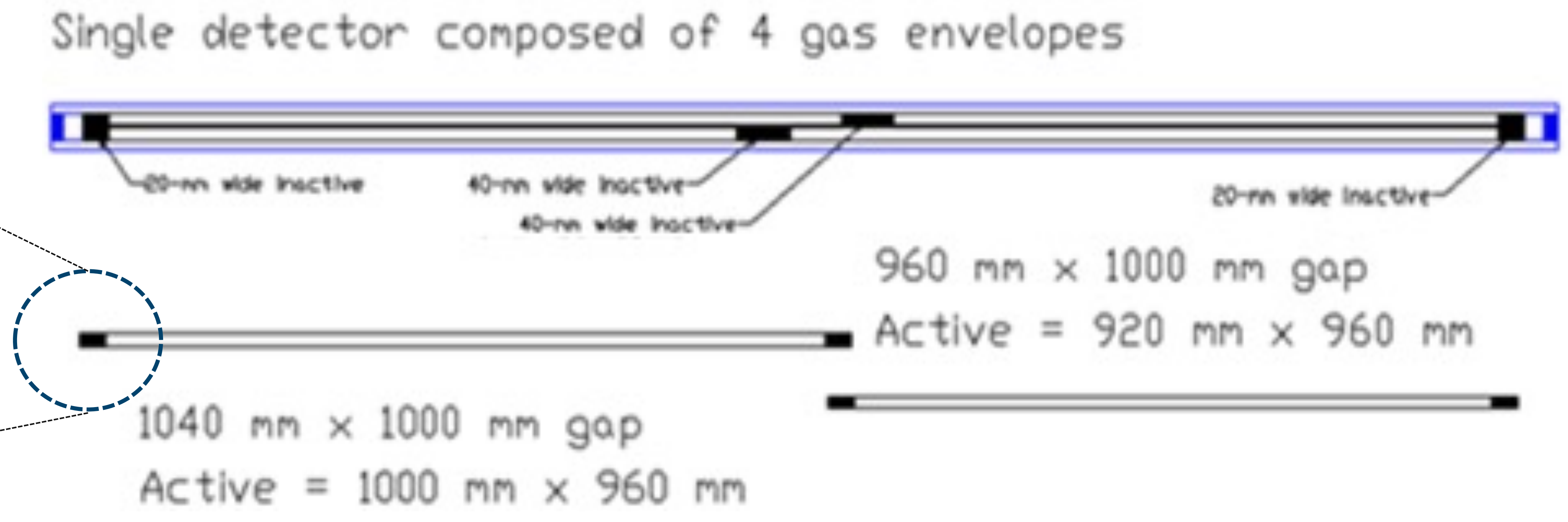
Glass Multi-Gap RPC (MRPC) for FCC-ee

- GOAL: Large size timing RPCs (glass electrode) to meet the physics requirement of heavy stable charged particles at the muon detector
  - Time resolution: ~ 150 ps
  - Position resolution: 3~5 mm (2D readout)
  - Working Efficiency ~ 98% (current CMS double gap RPC~95%)
- Use thin spacers for proper gas circulation and to prevent aging



- Maximum ~ 1 m long strips to allow dispersion of signals ~ 50 ps
- Can reach σ_t ~ 150 ps with 300-µm six gaps

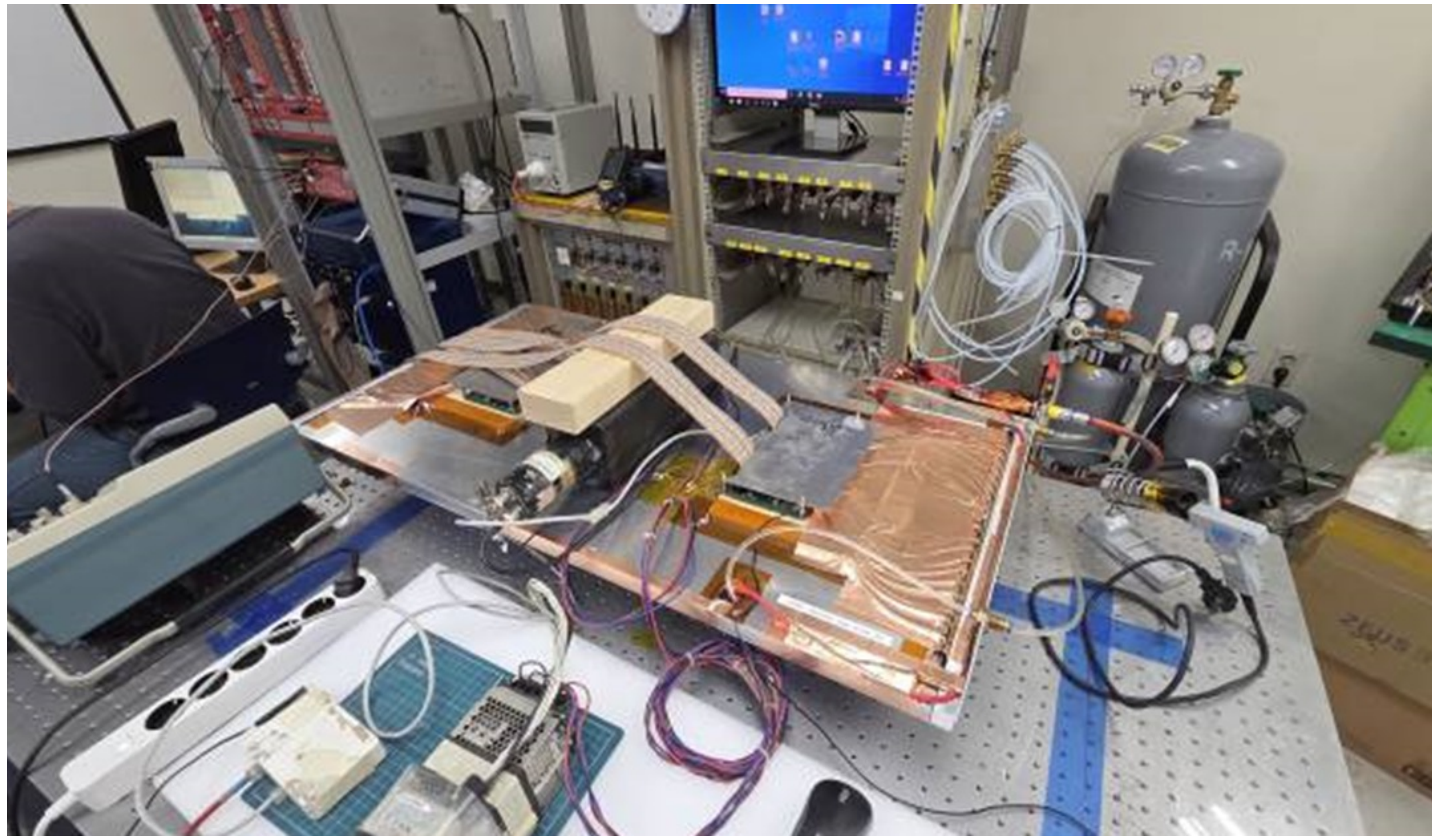




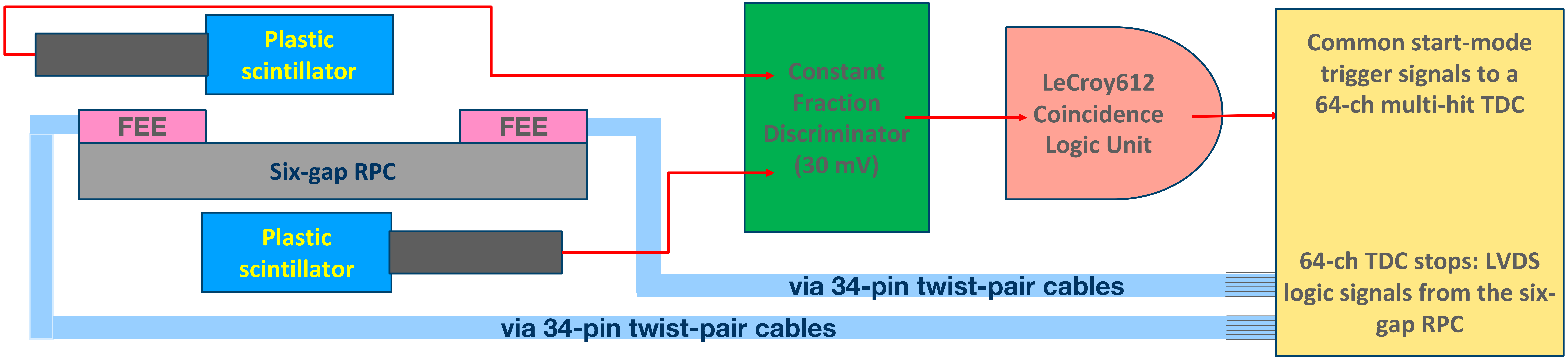
Prototype RPC Construction and Test

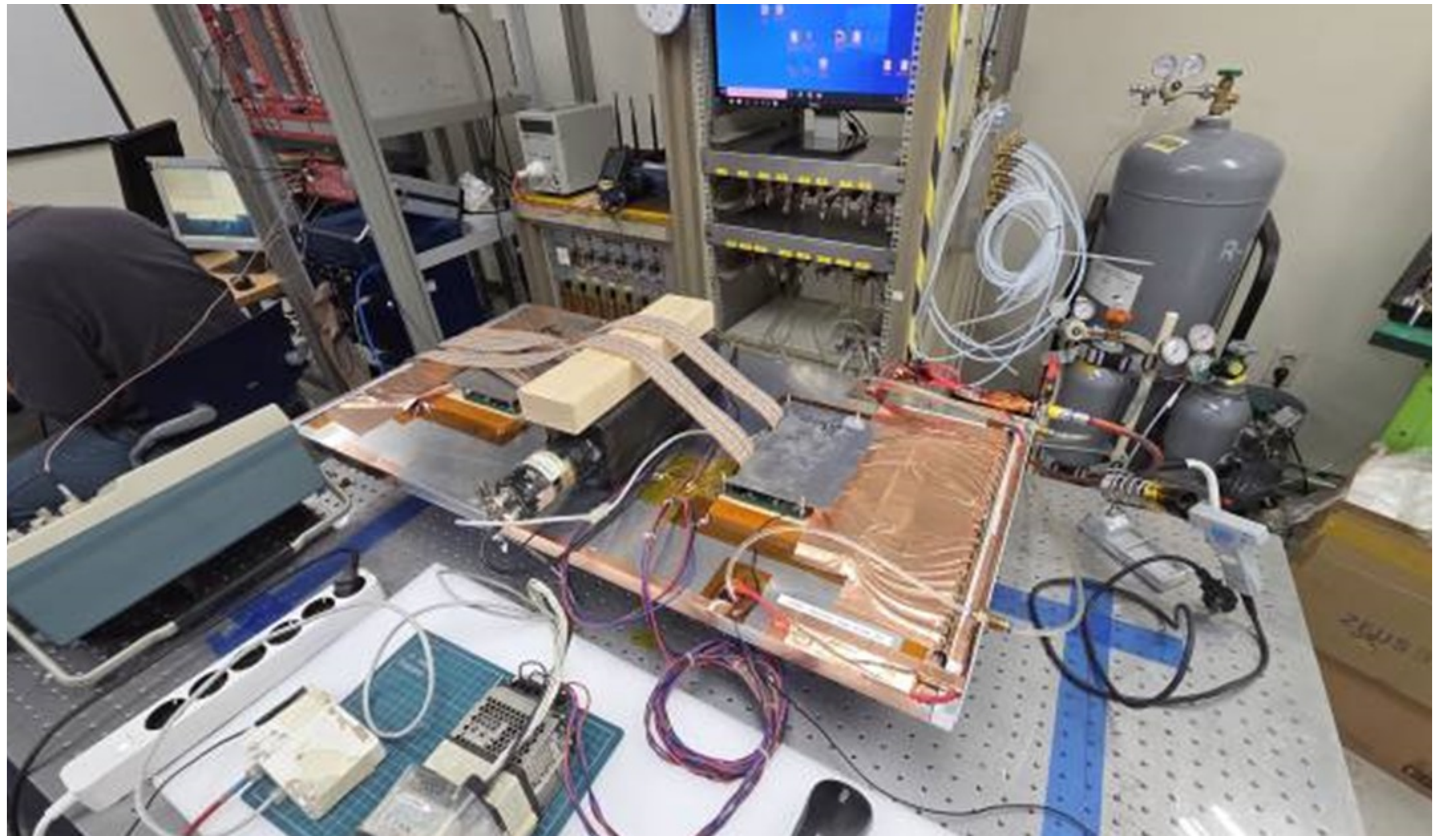
- Triple gas gap design (thickness = 0.5 mm)
- gas: 93.5% $C_2H_2F_4$ + 4.5% C_4H_{10} + 2.0% SF_6
- Tight gas sealing: expect much lower gas circulation rate, better for gas recuperation, low gas flow of R-134a Freon

- Six (double-triple)-gap RPC (100cm x 50cm)
- Total thickness ~ 3 cm, Strip pitch = 20 mm (impedance ~ 22 Ω)
- Used old KODEL FEBs with threshold ~ 0.9 mV (~100 fC in charge mode)



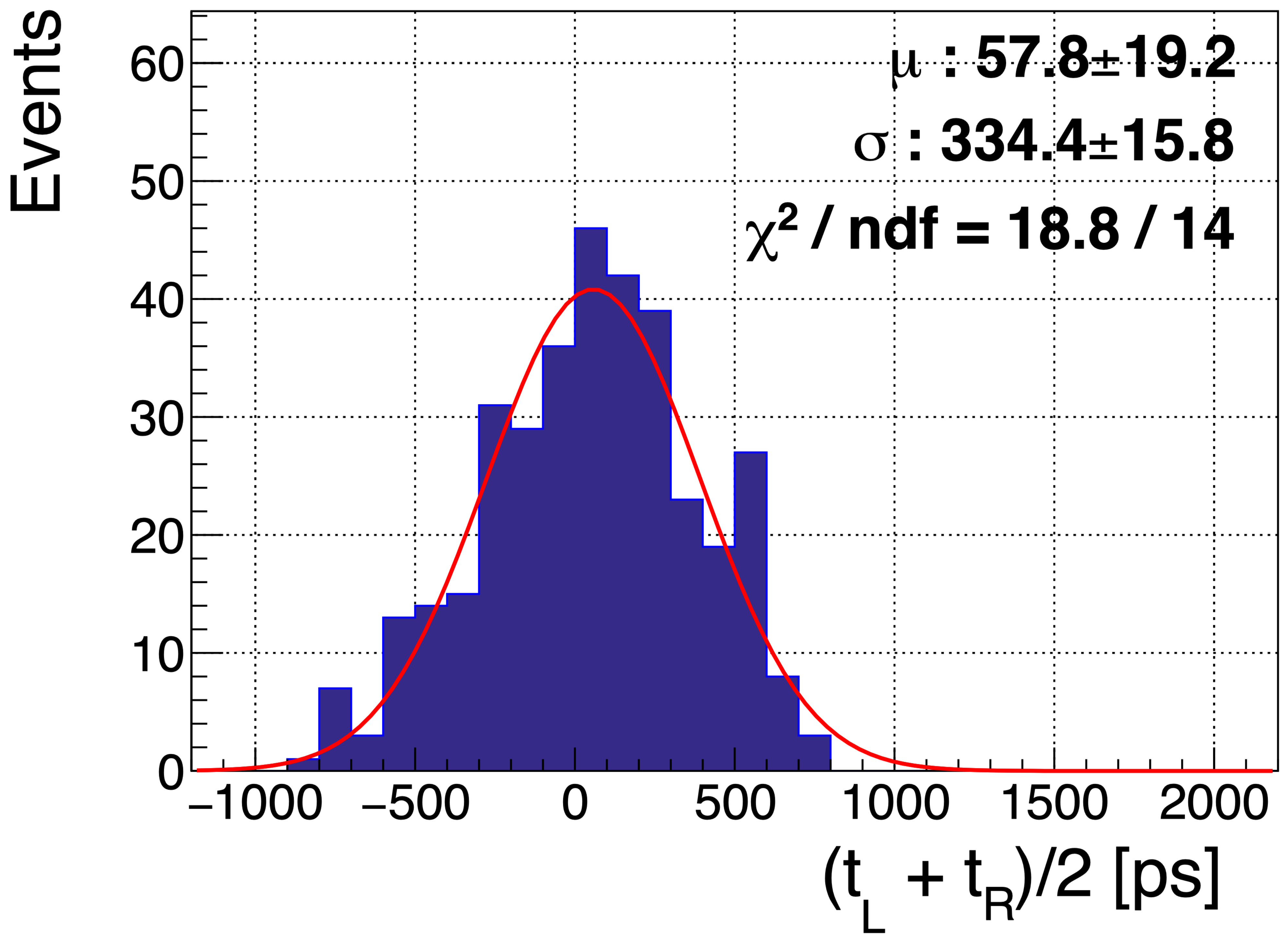
Construction and Test at Handel



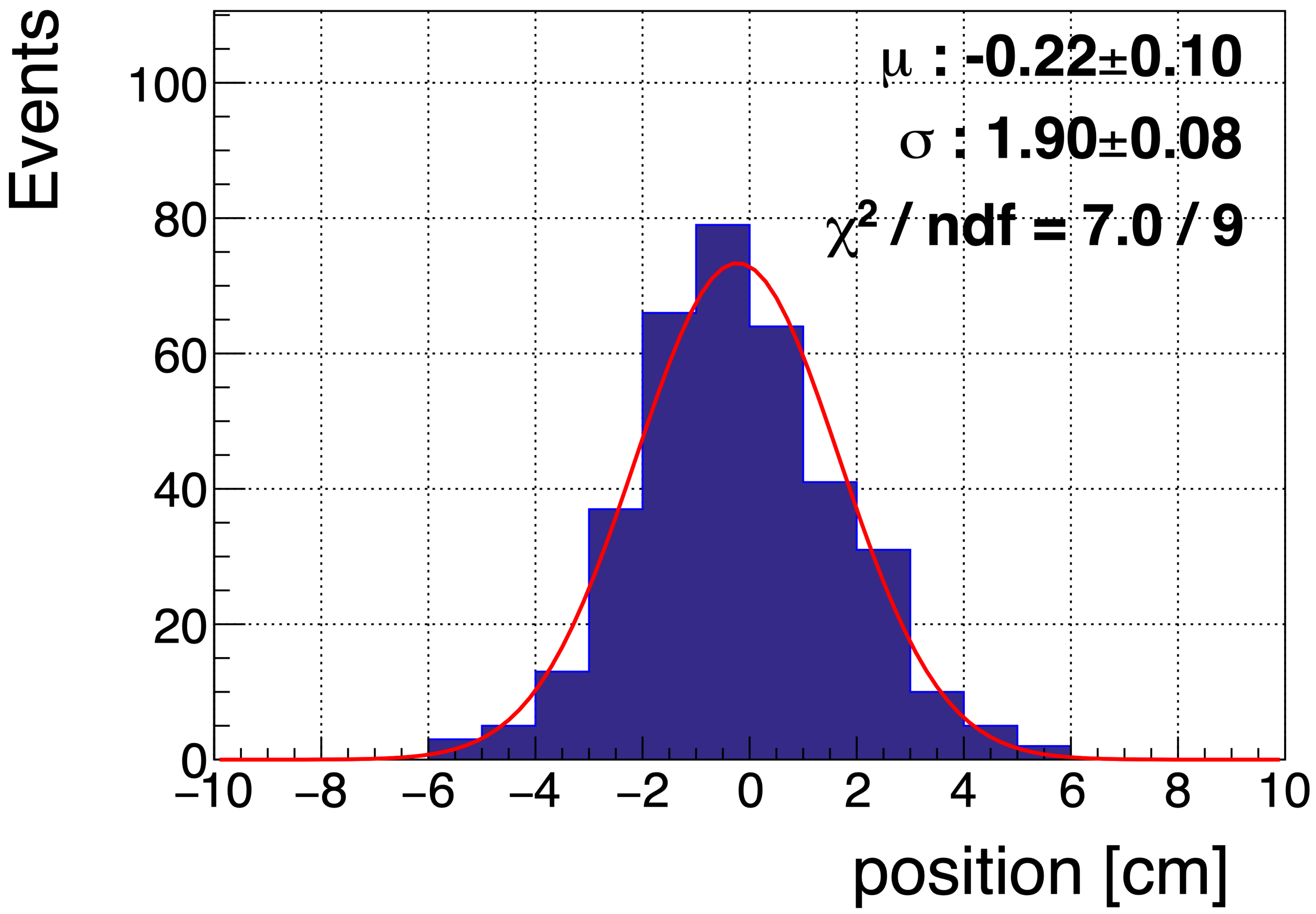


Timing and Position resolution

- Timing resolution
  - $\sigma_{t,RPC+FEE+Trigger}$ = 334 ps ($\sigma_{t,Trigger}$=300 ps)
  - $\sigma_{t,RPC+FEE}$ = 259 ps ($\sigma_{t,FEE}$ = 164 ps)



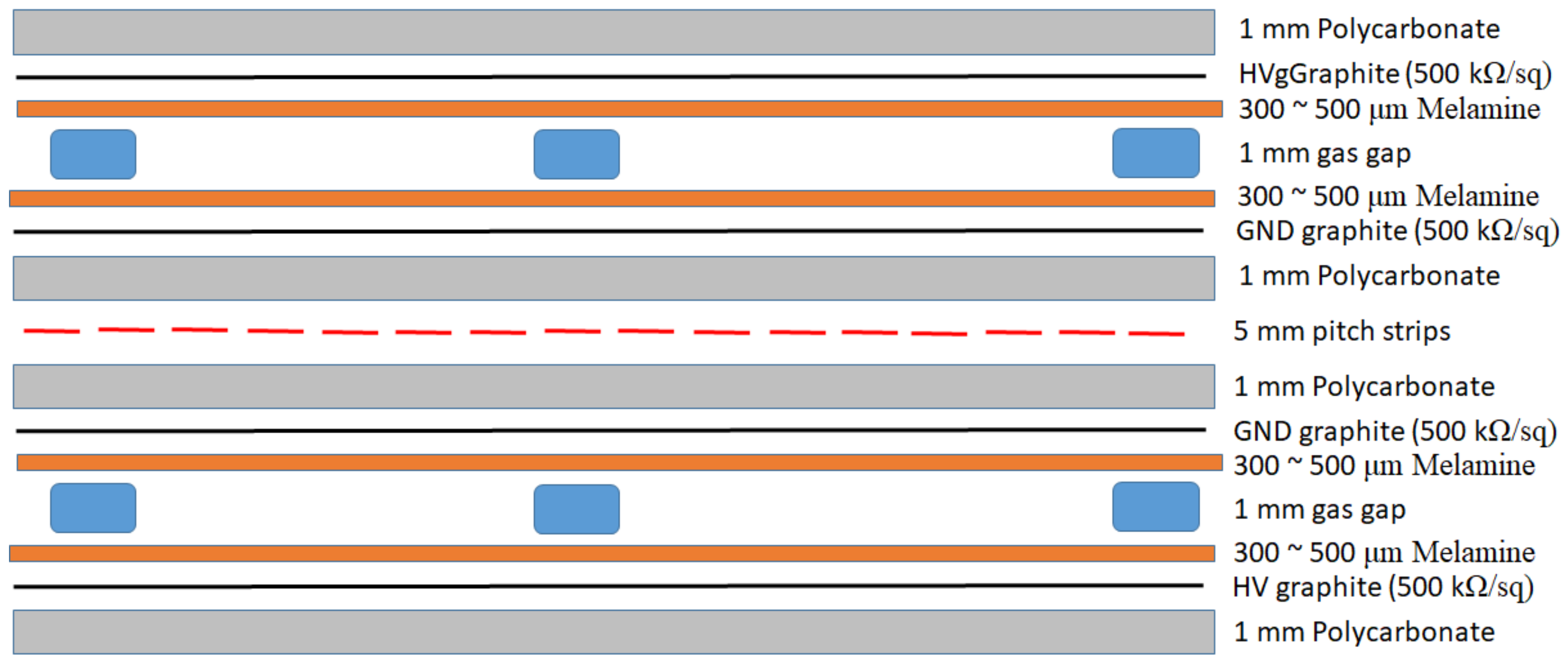
- Position resolution
  - σ_{position} = 1.90 cm (along the strip)
  - v_s = 16.03 cm/ns on ~ 22-Ω impedance strips

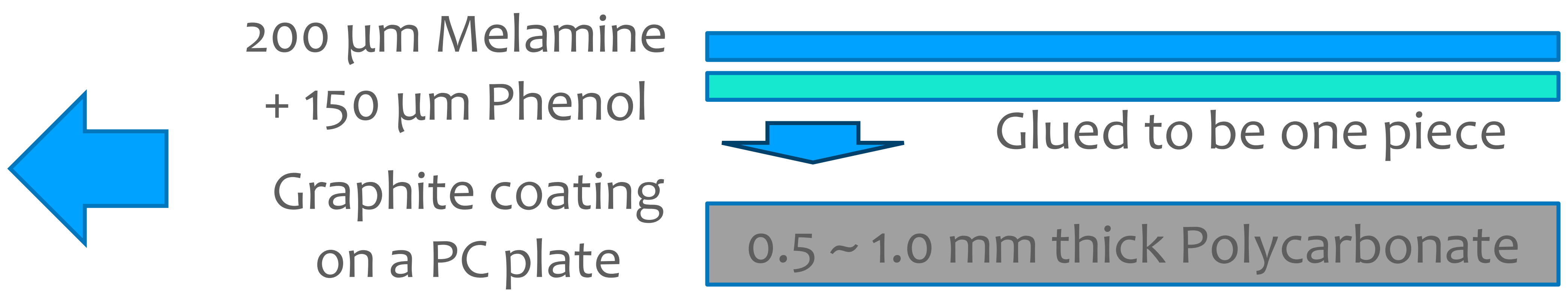


New R&D item #2

Micro Strip RPC model with thin HPL-based electrodes for a higher rate capability

- Goals: Development of trigger as well as tracking RPCs like MPGDs (resolution for muon p_T is most important for the Higgs factory program)
  - Time resolution ~ 300 ps with a 1-mm thick gas gap thickness
  - Position resolution ~ 500 μm (with simple digitization using 2 mm pitch strips)
  - Rate capability better than 5 kHz cm^{-2}
- Use thin melamine-based HPL electrodes (0.35 and 0.5 mm)
  - Double-gap RPCs with 1-mm gaps for time resolution (~ 300 ps)
  - Use thinner anode-side electrodes to lower lateral dispersion of signals
  - Oil varnishing required for low noise and better longevity (aging)
  - Thin melamine-Phenol electrodes + PC support → better stiffness and then uniformity of gas gaps

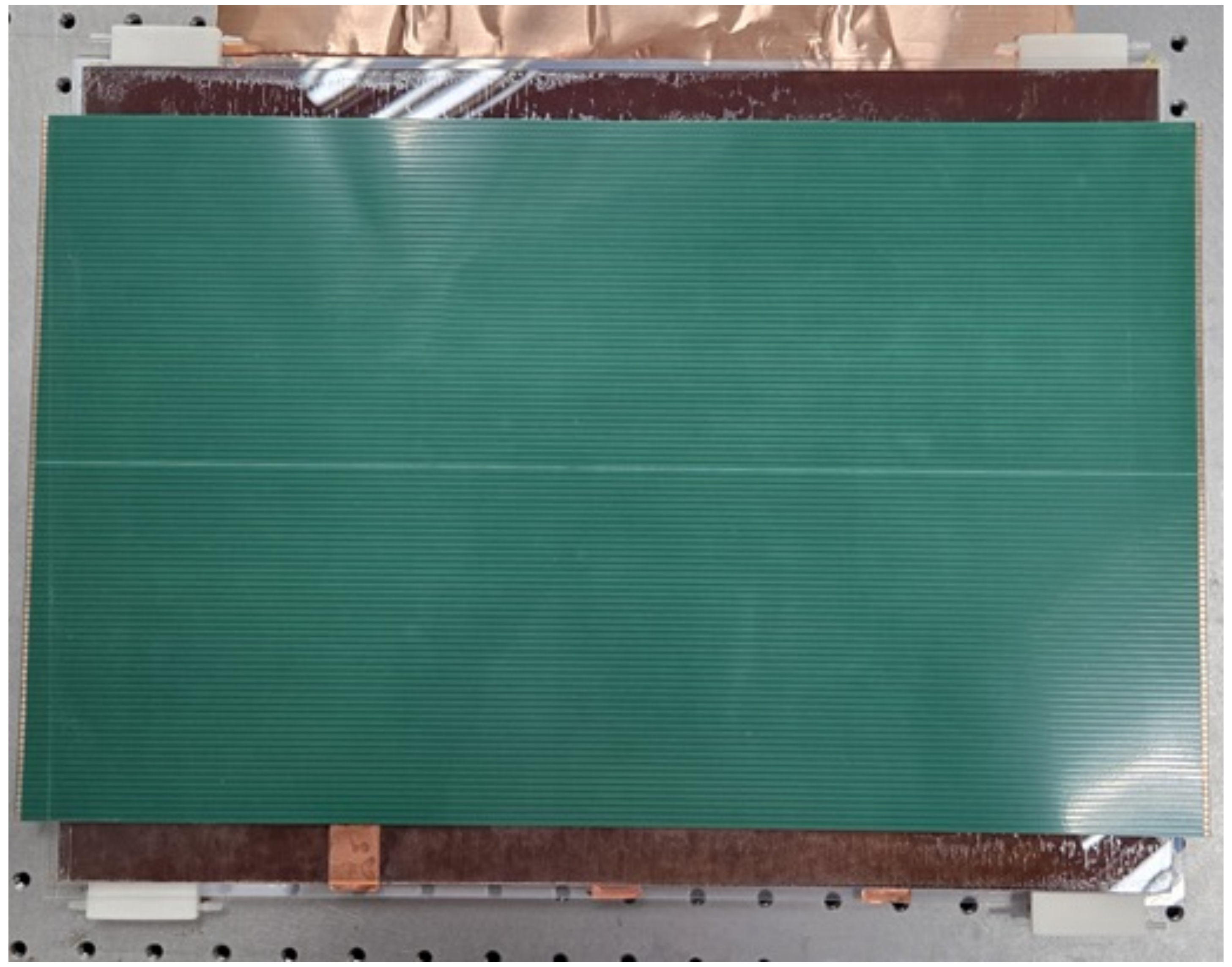


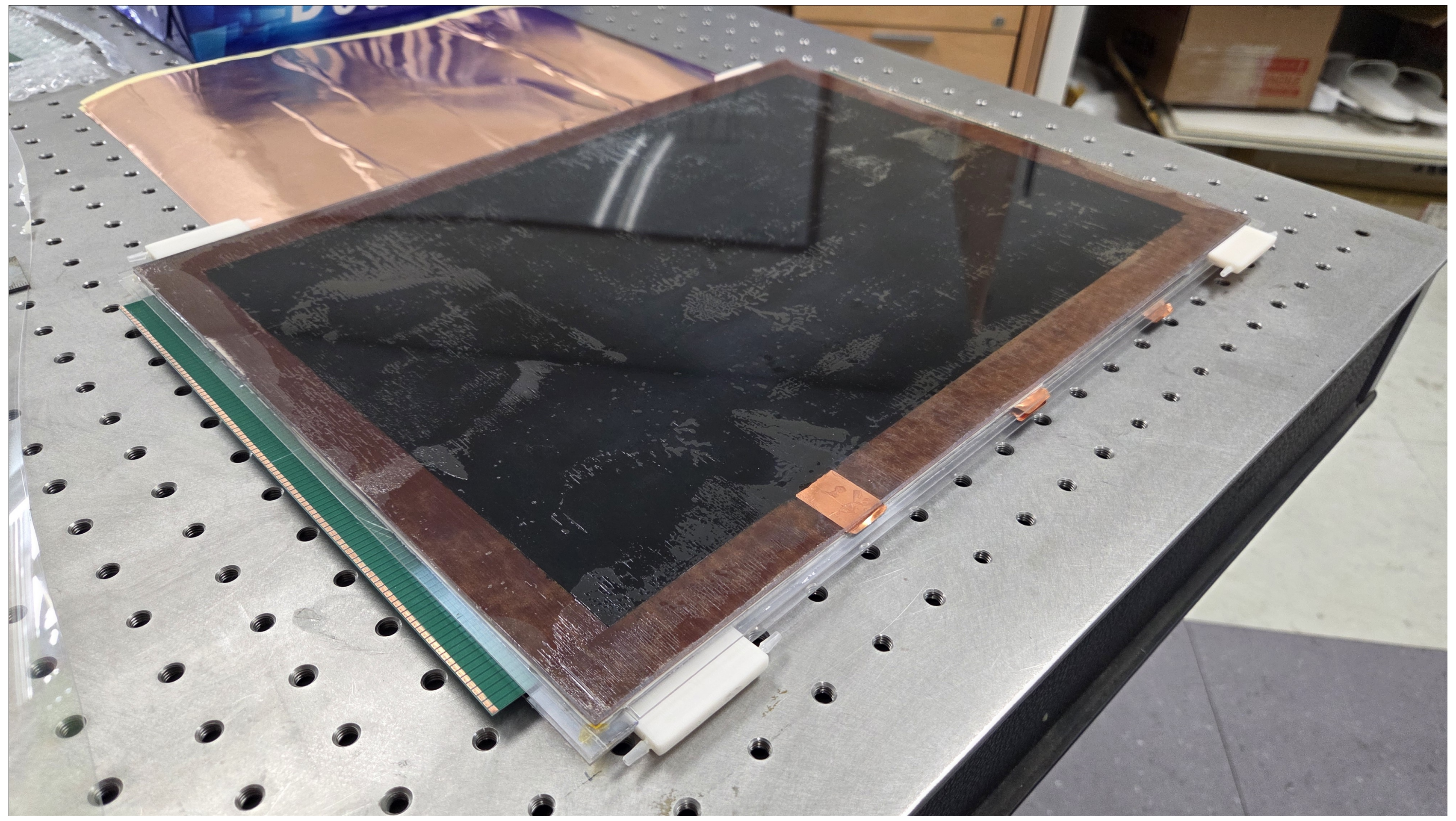


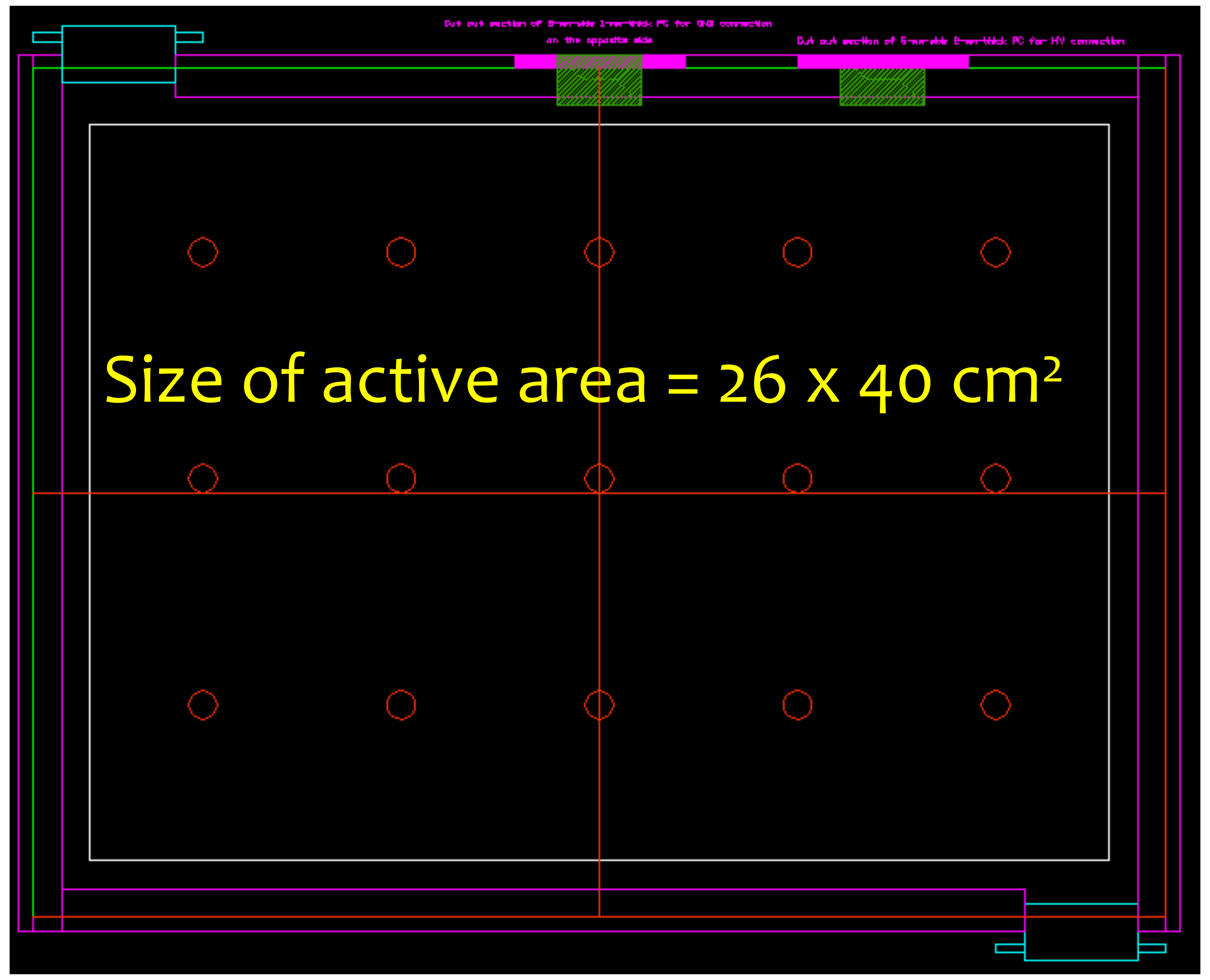
Published NIMA 1082 170983 (February 2026)

Plan:Micro Strip RPC

- New prototype R&D for micro-strip double-gap RPCs
- Plan to build 3 small chambers for minimal tracking using cosmic muons
  - 2.5 mm strip pitch for < 1-mm resolution
  - Use 350 µm thick HPL with 500 µm thick PC support for anode electrodes and 550 µm thick HPL with 2 mm thick PC for cathode electrodes
  - Digitization threshold ~ 50 fC (old KODEL front-end electronics used)





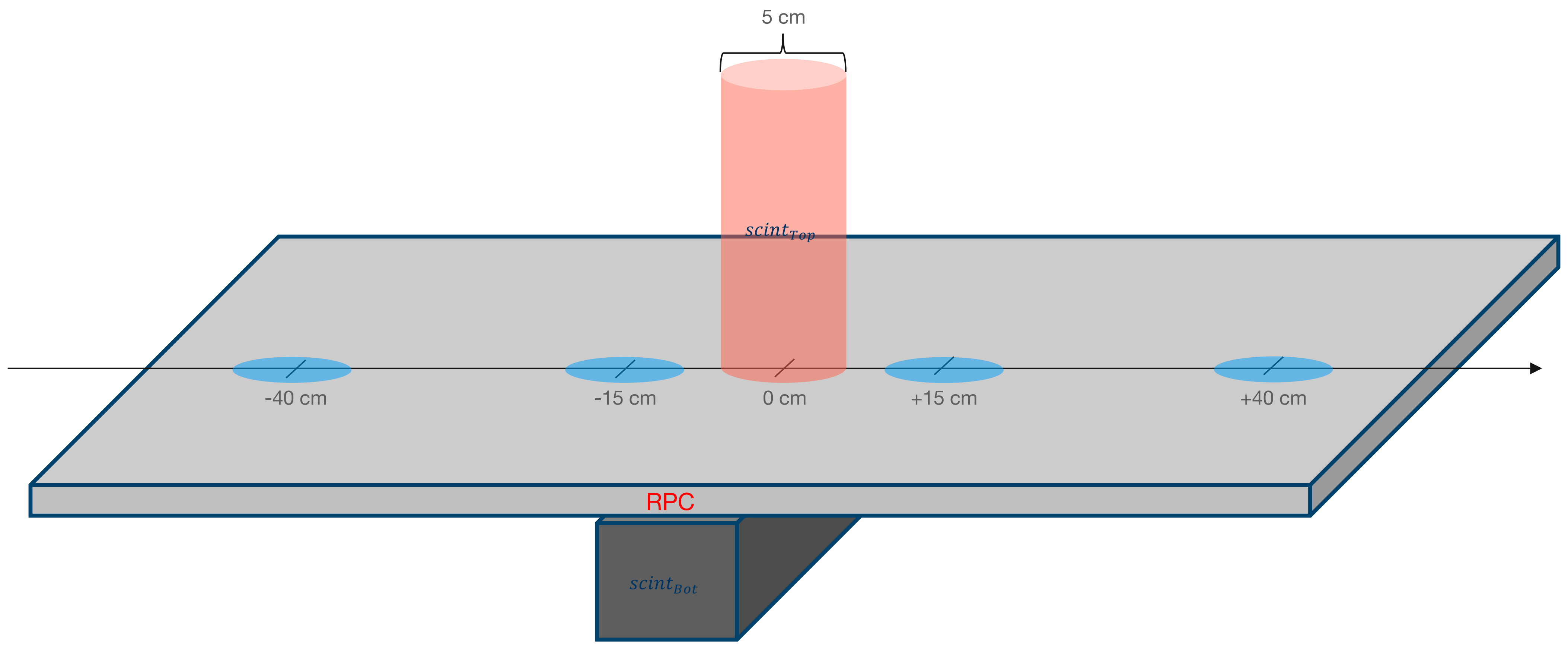


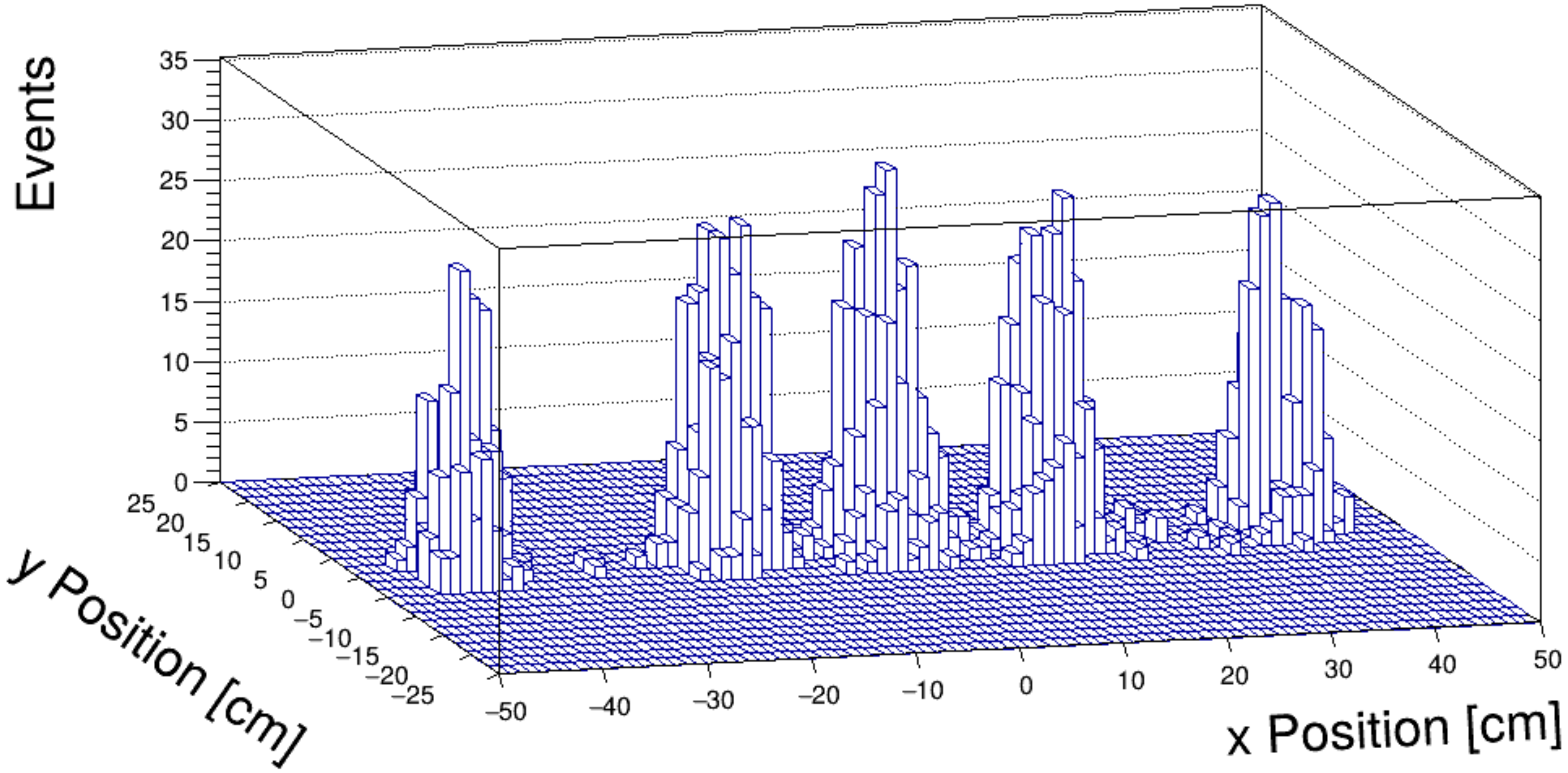
Conclusion

- After completing the contribution for CMS HL-LHC, we relocated the RPC facility to Hanyang University and KBSI@Korea University
- While we still repair some of the existing iRPC for CMS, we started R&D for the future experiments
- This is mainly to preserve the know-how (20 years of experience) and transfer the knowledge to future experiments
- Conceivable to contribute to COMET in near future and FCC for the longer term

Test condition

- Trigger: 5 cm diameter disk-type scintillator
  - Position: [-40, -15, 0, 15, 40] cm
- Detector : Gas : 93.5% $C_2H_2F_4$ + 4.5% C_4H_{10} + 2.0% SF_6 at HV 9.7 kV
- Hit position = $\frac{1}{2}v_s(t_L-t_R)$, v_s=16.03 cm/ns and t_L,t_R : TDC from left/right FEE

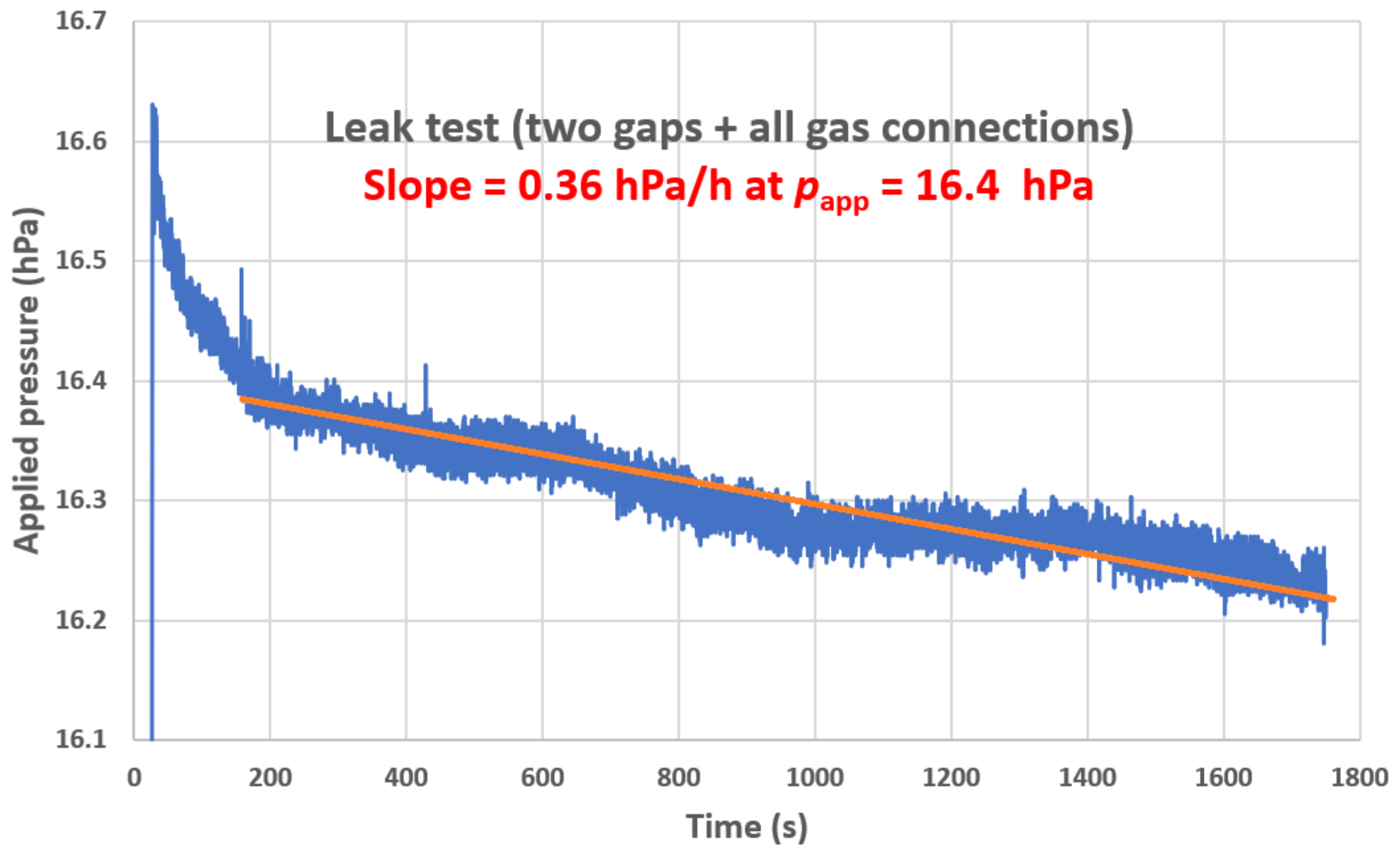




Result

Gas leak test for the prototype chambers using an ADC logger

- Applied pressure = 16.5 hPa
- Pressure drop ~ 0.15 hPa for 25 mins → a factor 8 tighter than iRPC chambers



Max efficiency = 99.2%