Progress of CMS-GEM Upgrade Project at Peking University

Jiahua Chen
Peking University

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Outline

1. **Overview of CMS-GEM ME0 upgrade project**
   - Layout of CMS-GEM upgrade system
   - CMS GEM detector design
   - Timeline of the ME0 module production
2. **2nd Batch of 10 ME0 GEM assembly and test at PKU**
   - Module Assembly
   - QC Test
   - Troubleshooting
3. **Progress of the test of ME0 GEM electronics board at CERN**
4. **Update of the Performance of ME0 stack at CERN**
5. **Summary**

Part 1

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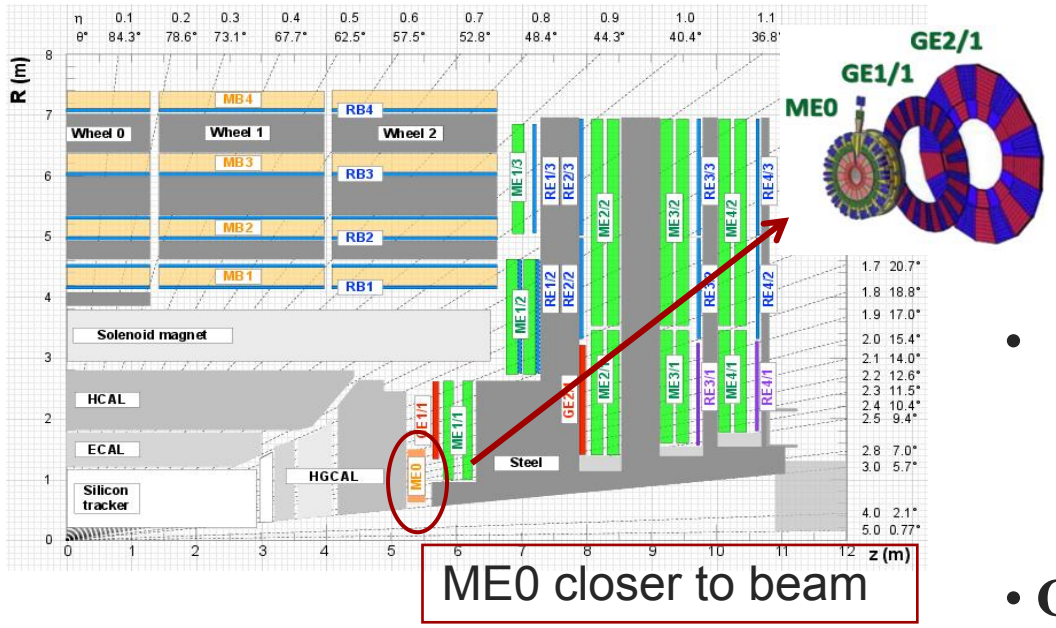
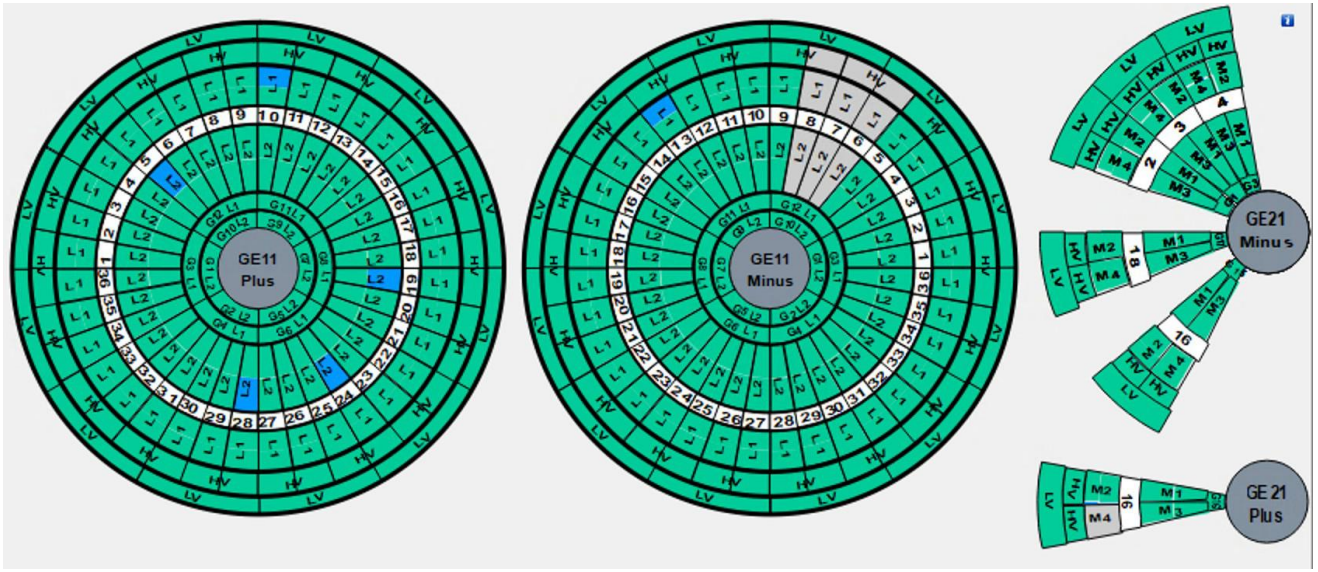
Overview of CMS-GEM upgrade project

- The Gas Electron Multiplier (GEM) in the endcap muon station helps to maintain or even improve the forward muon triggering and track reconstruction.

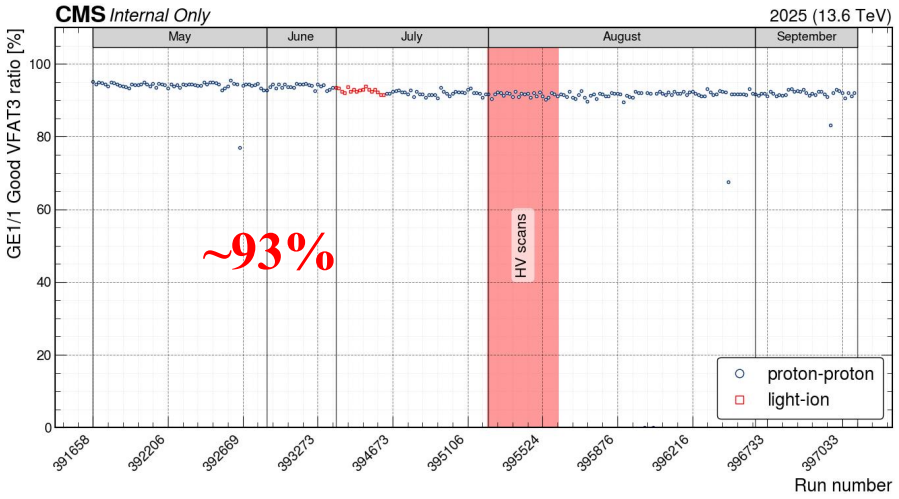


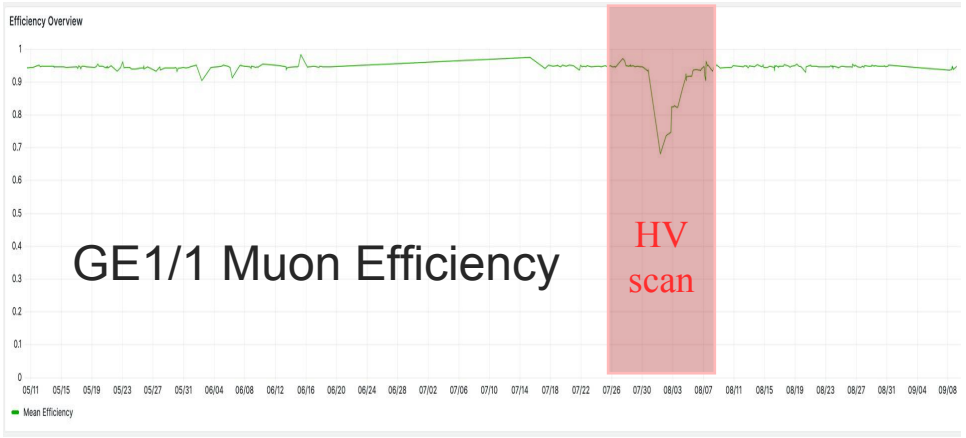


- **GE1/1 detector was installed during LS2:**
  - Total of 144 chambers have been operating since 4 years.
  - Currently, 138 chambers are active; 3 SCs were extracted in YETS 24/25.
- **GE2/1 detector:**
  - Currently only 6 chambers are installed for test commissioning; 5 in GE-2/1 & 1 in GE+2/1

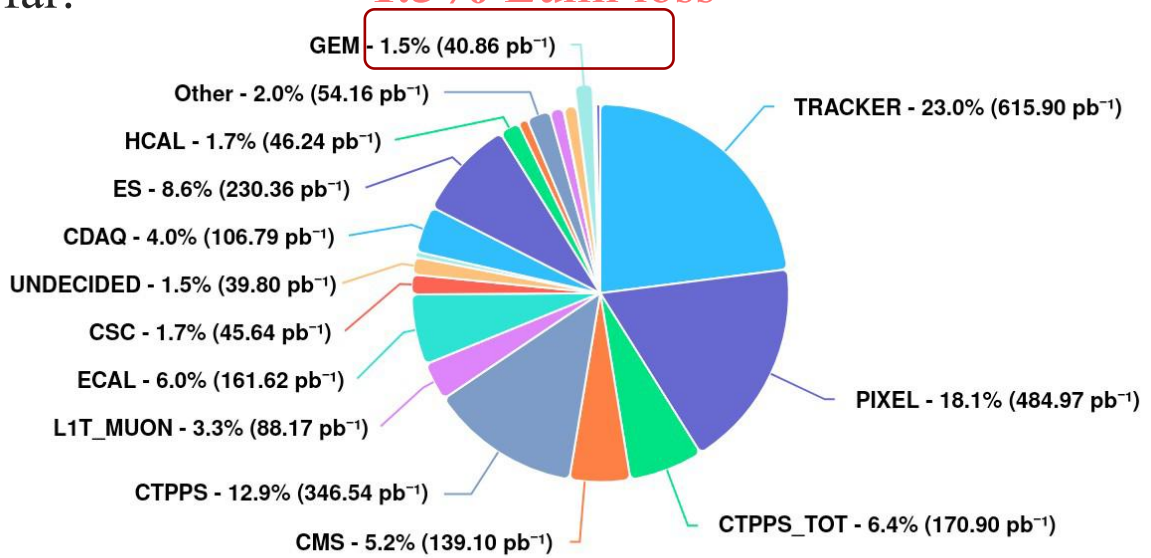
Overview of CMS-GEM upgrade project

- The GE1/1 GEM detectors are running stable so far.
- Active channels(GE1/1): mostly stable





~1.5% Lumi loss

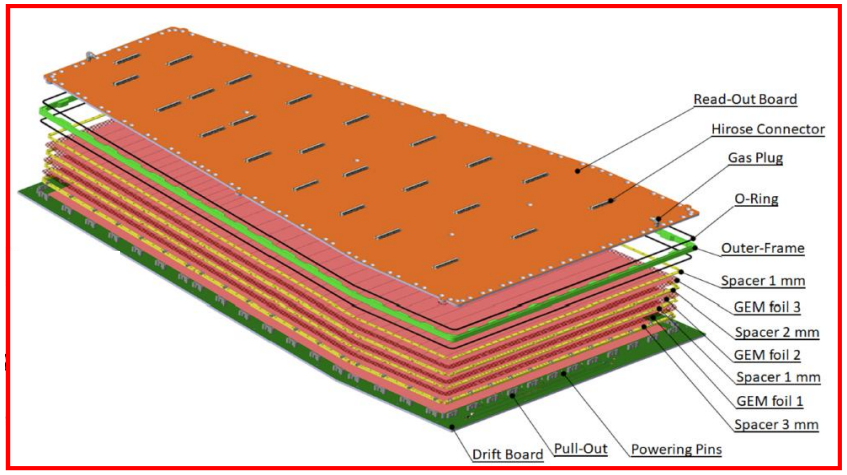


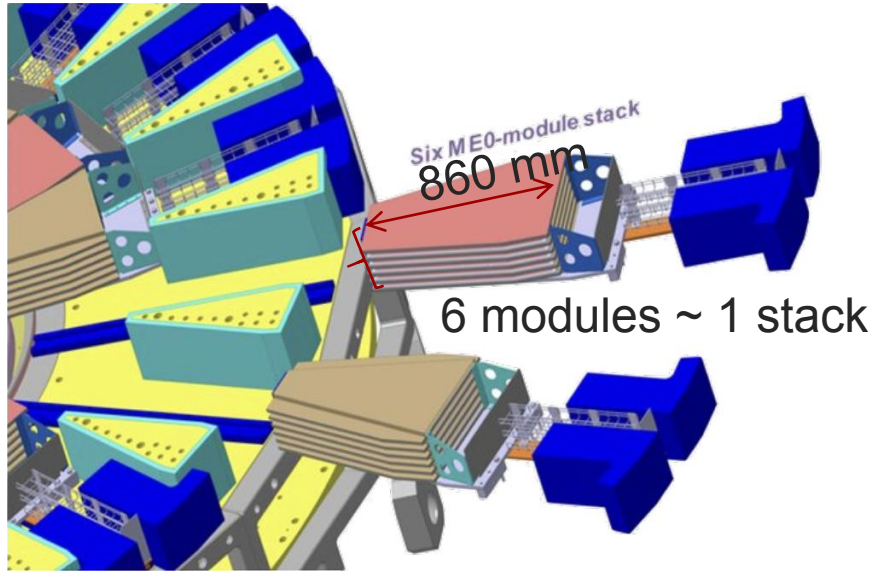
- GE1/1 Chambers are running well with: **~94-95%** efficiency for standalone muons.

CMS-GEM ME0 detector design

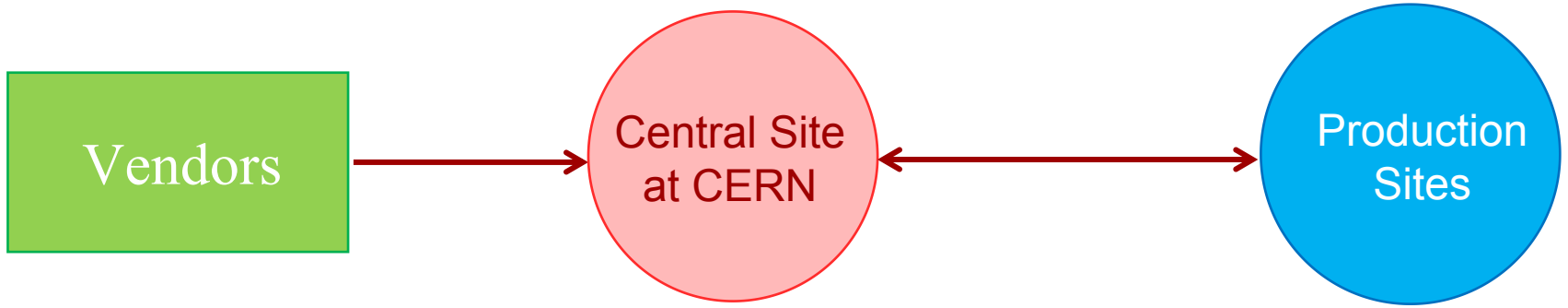
- The full system: 216 ME0 chambers (108 per end-cap)
  - 6 triple-GEM modules per stack
  - 18 stacks per endcap

- Performance Expectations
  - **97% module efficiency**
  - Timing Resolution: 8-10 ns
  - Gain Uniformity: ≤15%
  - Space Resolution: <500 μrad





Timeline of the ME0 Module Production

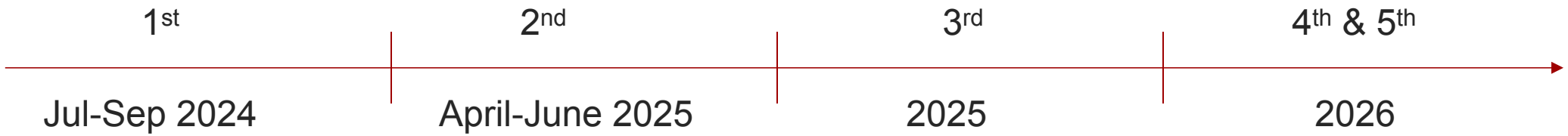


- Vendors
- Manufacturing of the detector components
  Shipment to CERN

- Central Site (at CERN)
- Material inspection (QC1/QC2)
- Pre-assembly work
- Preparation of assembly kits
- Shipment to/back from production sites

- Production Sites
- Module assembly
- QC2-QC5 tests
- Data Base updates

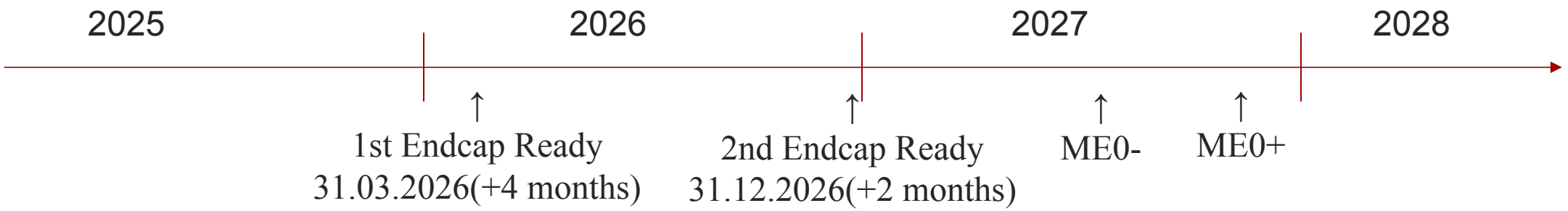
Timeline of PKU Team



2nd batch has been shipped to CERN to do further QC test.

Timeline of the ME0 GEM Installation

Timeline



- According to LS3 schedule (V5) of CMS Technical Coordination (TC), the installation of **ME0-** will be at **Sep-08 2027(+8 months)** and **ME0+ at Nov-29 2027 (+10 months)**.
- With this scenario, there are still 17(11) months of float for the 1st (2nd) Endcap respectively.

Part 2

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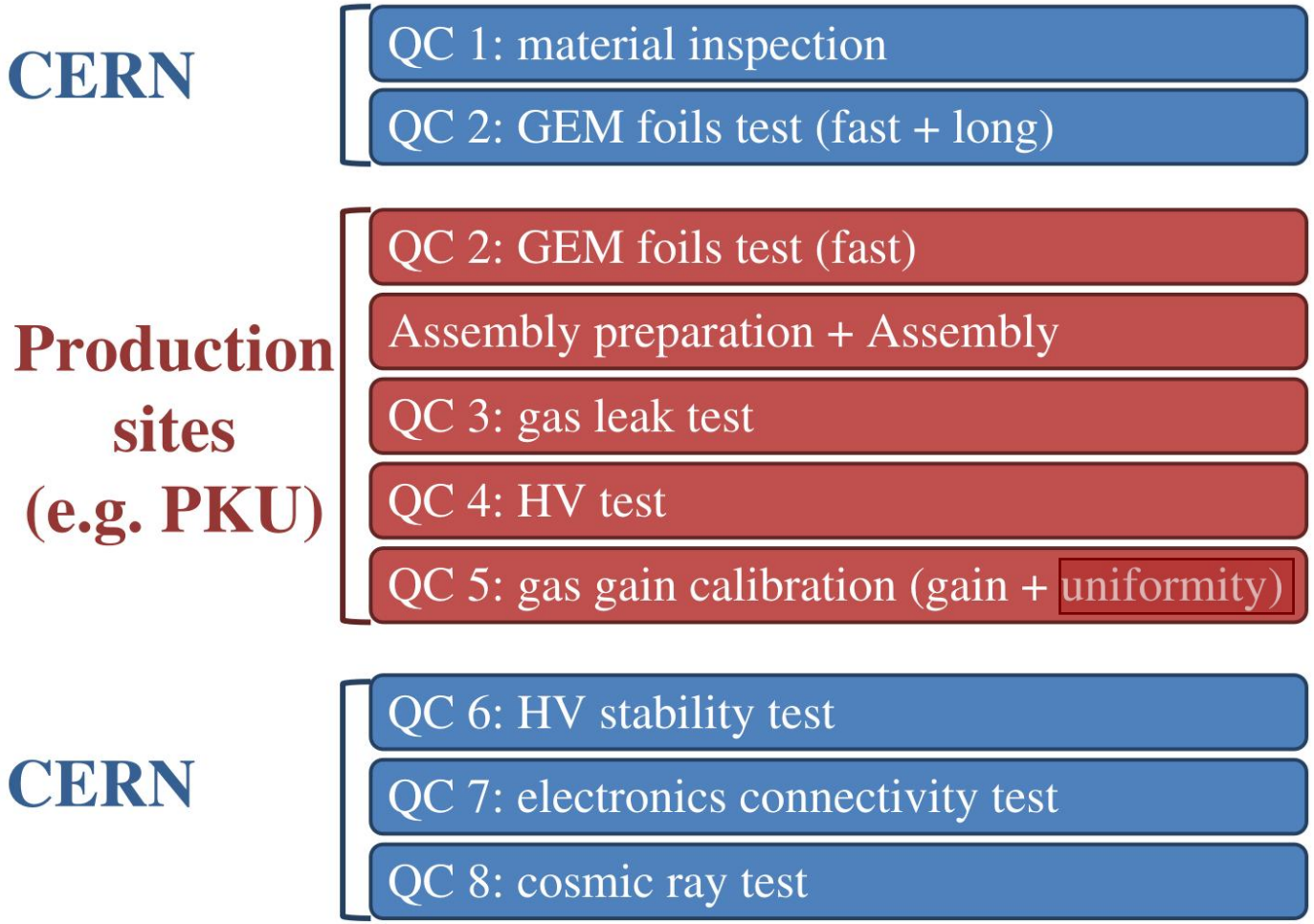
2nd batch of 10 ME0 modules assembly and test

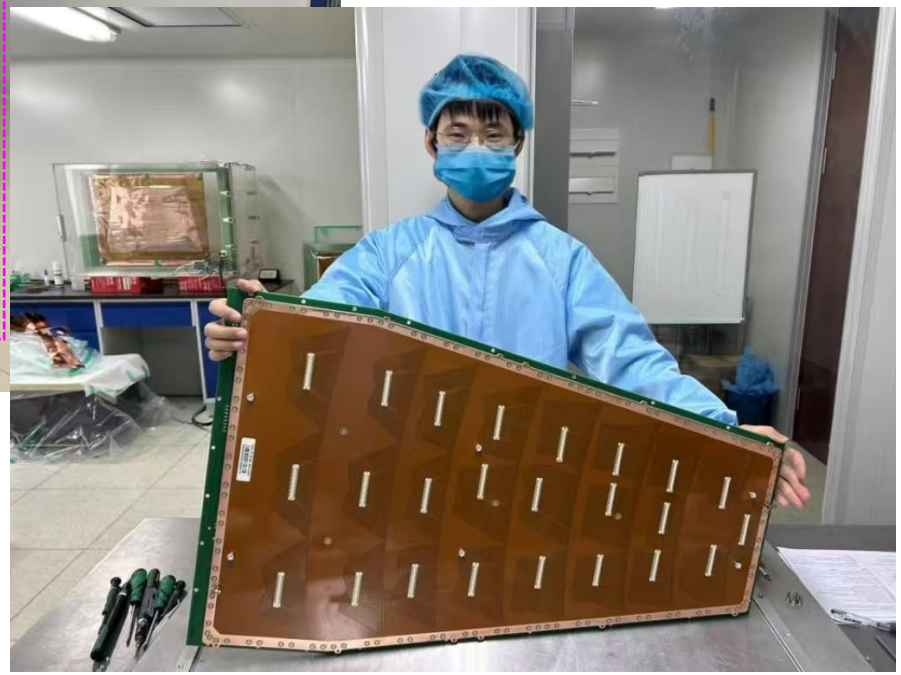
Overall module production strategy of CMS GEM upgrade project:



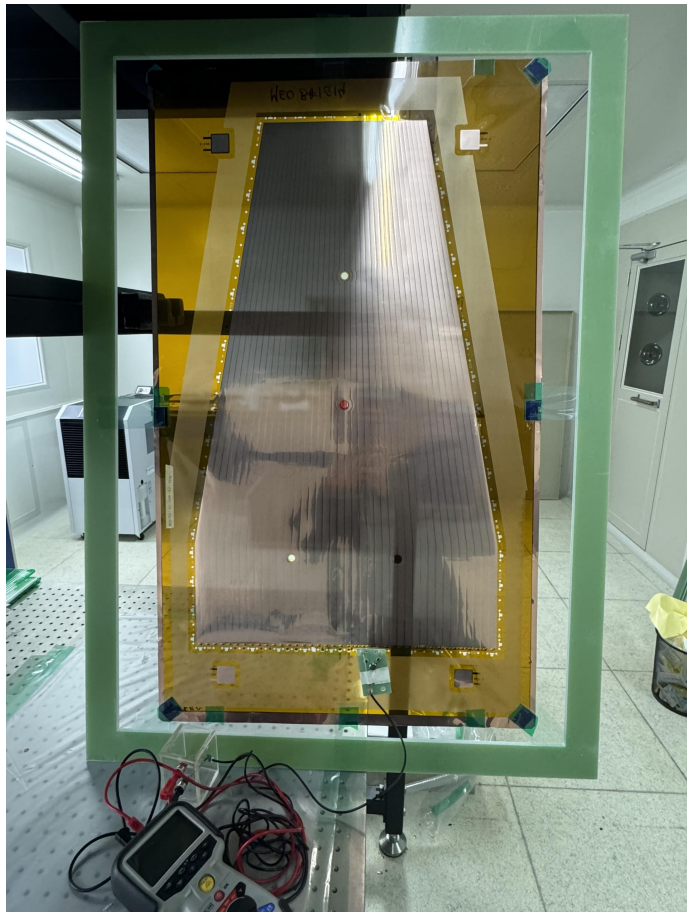
2nd batch of 10 ME0 modules assembly and test

Laboratory for GEM assembly and test at Peking University

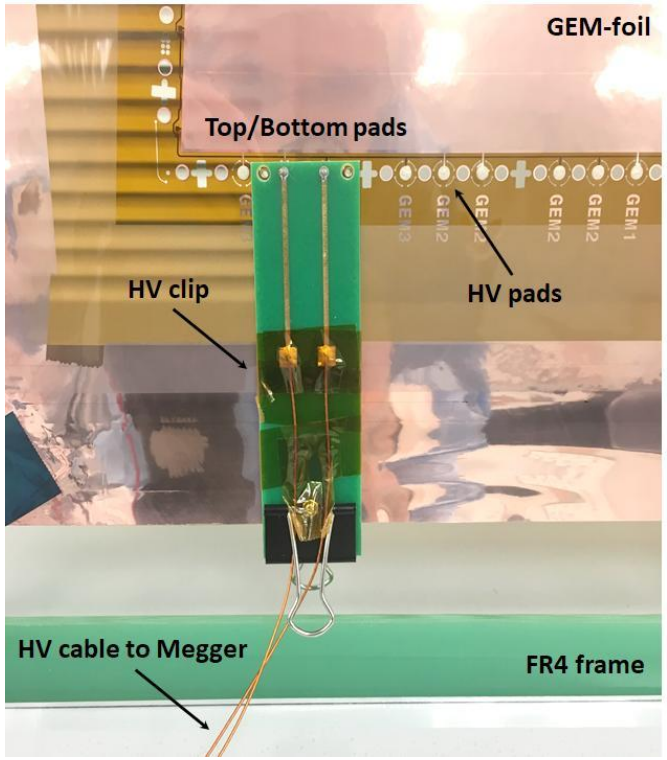
First module of 2nd batch ME0 (April 2025)



QC2: Fast Impedance Test of GEM Foil



Fix the foil to the outer frame with tape

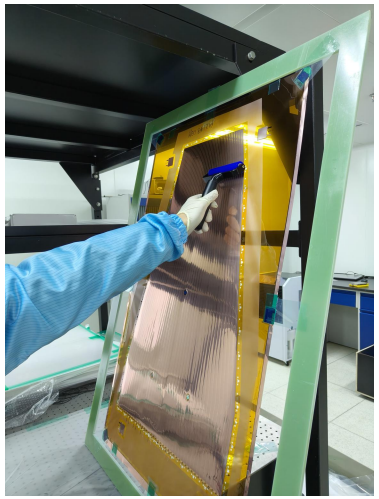


- Test the impedance of the foil by the Megger connected to the HV pads beside the foil.

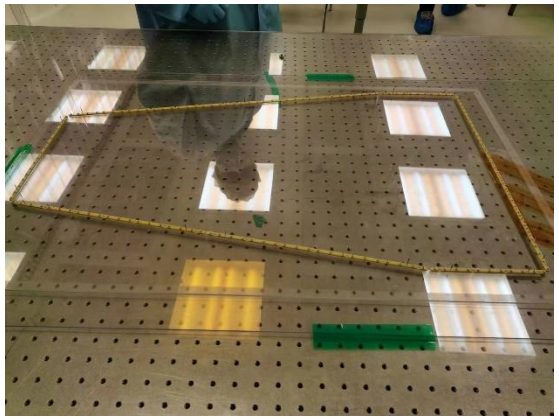
If a short occurs on the foil, use an electrostatic roller to clean the area where the spark appears.

Assembly Procedure

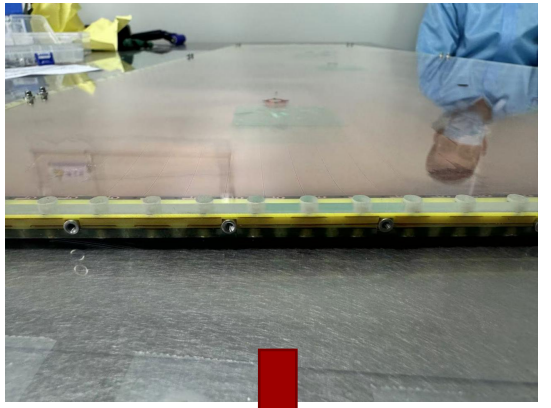
Use scroll to clean foil



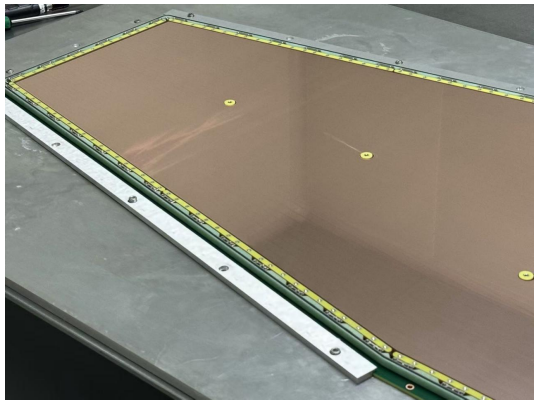
Set up internal frames and pillars



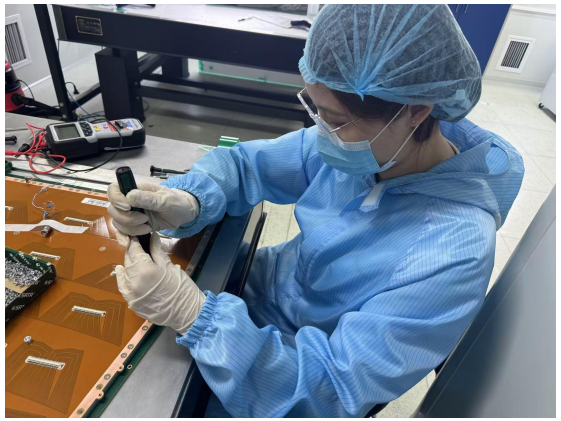
Components installation to get triple-GEM



Set up Drift Board(DB) and move GEM foil stack on it



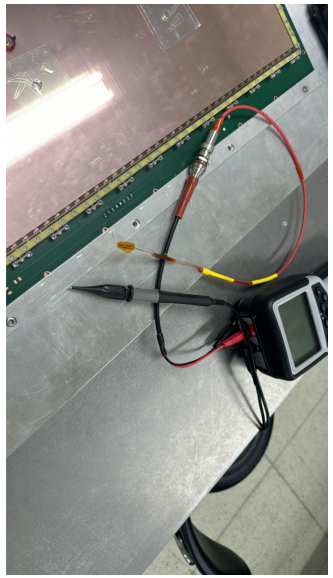
Install external frame with O-rings



Install Readout Board(RB)

Troubleshooting

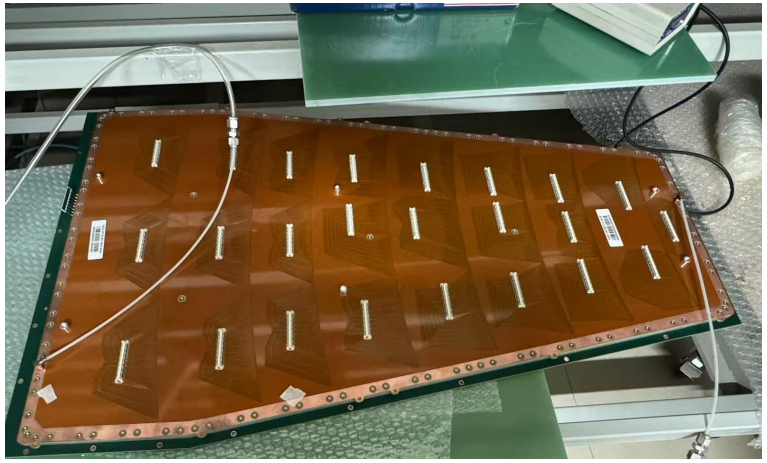
- **Short after the assembly**
  - It is likely that the dust has fallen onto the foil
  - If the short is on the 3rd foil (close to the RB), remove the RB and **use a scroll to clean the foil**
  - If the short is on the 1st or 2nd foil, remove the RB, then use a hook to apply high voltage to the affected sector.



- **Gas leak**
  - Use a mini-tracer to confirm where the gas leak is
  - Replace the screw with the washer
  - Apply more AB glue around the gas connector

QC3: Gas Leak Test of the module

- Pressurize the detector with pure CO_2 to 25 mbar above atmospheric pressure while recording the internal pressure per minute, along with associated environmental variables.
- If the gas leakage results in a pressure change is less than 7 mb/h, the new module will pass QC3.



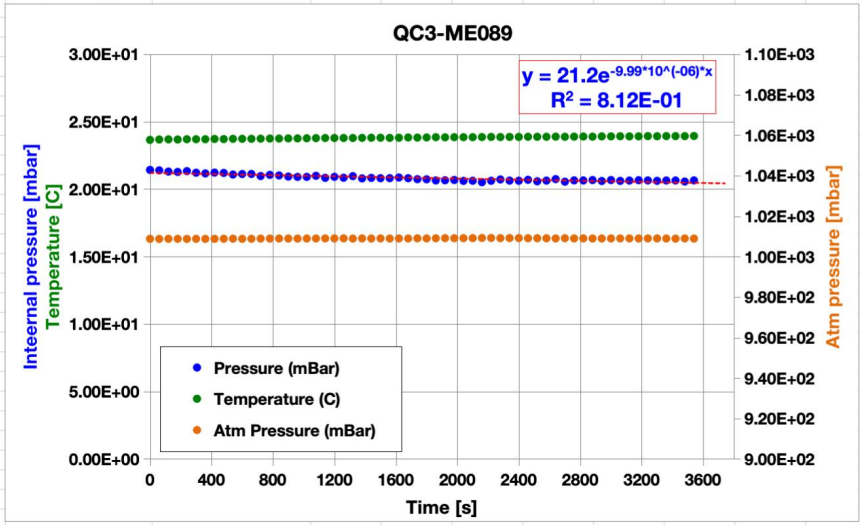
original data

Temperature

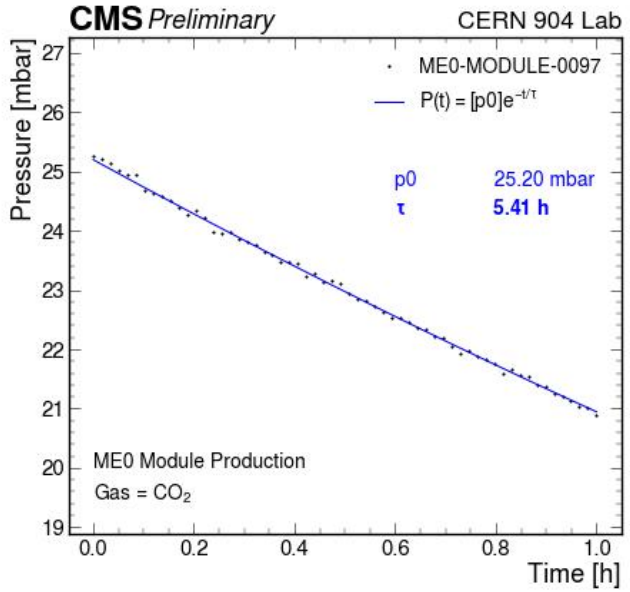
Environment pressure

Time	Seconds	(mBar)	Temperature (C)	(mBar)
9:41:15	0.00	2.14E+01	2.37E+01	1.01E+03
9:42:15	60.00	2.14E+01	2.37E+01	1.01E+03
9:43:15	120.00	2.13E+01	2.37E+01	1.01E+03
9:44:15	180.00	2.13E+01	2.37E+01	1.01E+03
9:45:15	240.00	2.13E+01	2.37E+01	1.01E+03
9:46:15	300.00	2.12E+01	2.37E+01	1.01E+03
9:47:15	360.00	2.12E+01	2.37E+01	1.01E+03
9:48:15	420.00	2.12E+01	2.37E+01	1.01E+03
9:49:15	480.00	2.12E+01	2.37E+01	1.01E+03
9:50:15	540.00	2.11E+01	2.37E+01	1.01E+03
9:51:15	600.00	2.11E+01	2.37E+01	1.01E+03
9:52:15	660.00	2.11E+01	2.37E+01	1.01E+03
9:53:15	720.00	2.10E+01	2.37E+01	1.01E+03
9:54:15	780.00	2.11E+01	2.38E+01	1.01E+03
9:55:15	840.00	2.10E+01	2.38E+01	1.01E+03
9:56:15	900.00	2.09E+01	2.38E+01	1.01E+03
9:57:15	960.00	2.09E+01	2.38E+01	1.01E+03
9:58:15	1020.00	2.09E+01	2.38E+01	1.01E+03
9:59:15	1080.00	2.10E+01	2.38E+01	1.01E+03
10:00:15	1140.00	2.08E+01	2.38E+01	1.01E+03
10:01:15	1200.00	2.09E+01	2.38E+01	1.01E+03
10:02:15	1260.00	2.08E+01	2.38E+01	1.01E+03
10:03:15	1320.00	2.10E+01	2.38E+01	1.01E+03
10:04:15	1380.00	2.08E+01	2.38E+01	1.01E+03
10:05:15	1440.01	2.08E+01	2.38E+01	1.01E+03
10:06:15	1500.01	2.08E+01	2.38E+01	1.01E+03
10:07:15	1560.01	2.08E+01	2.38E+01	1.01E+03
10:08:15	1620.01	2.09E+01	2.38E+01	1.01E+03
10:09:15	1680.01	2.08E+01	2.38E+01	1.01E+03
10:10:15	1740.01	2.07E+01	2.38E+01	1.01E+03
10:11:15	1800.01	2.07E+01	2.38E+01	1.01E+03
10:12:15	1860.01	2.06E+01	2.39E+01	1.01E+03
10:13:15	1920.01	2.07E+01	2.38E+01	1.01E+03
10:14:15	1980.01	2.07E+01	2.39E+01	1.01E+03

Date	17/12/2019
Name	hjma
Detector ID	1
Duration (h)	1



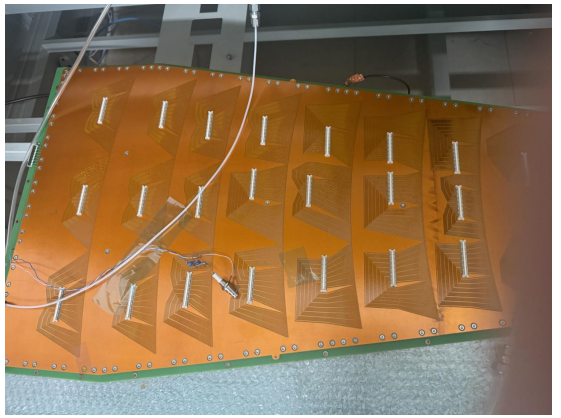
Summary		Error
Temperature (C)	23.82	0.0787824
Atm Pressure (mBar)	1008.96055	0.11571869
Initial pressure (mBar)	21.4237	



QC4: HV Test of the module

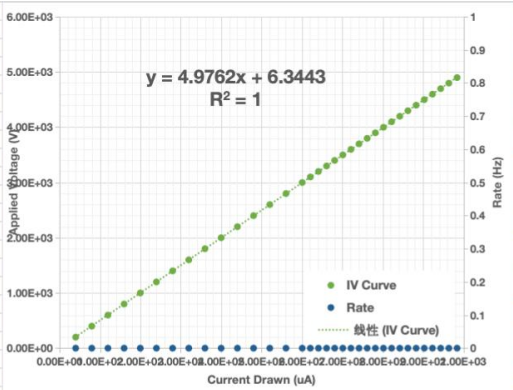
To acquire the spurious signal (or noise) rate on the **characteristic I-V curve** of the detector from 200 V to 4900 V while operating the detector with pure CO_2.

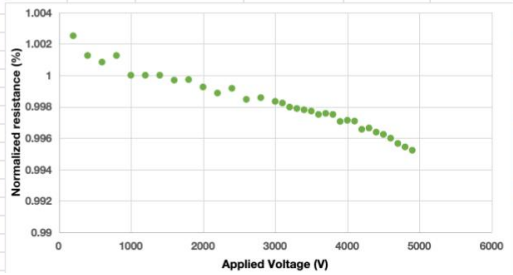
- From 200 V to 3000 V this is measured at 200 V increments and from 3000 V to 4900 V this is measured at 100 V increments.
- A linear I-V curve describes the ohmic relation between the applied HV and measured current of the resistive divider.



QC4 HV test

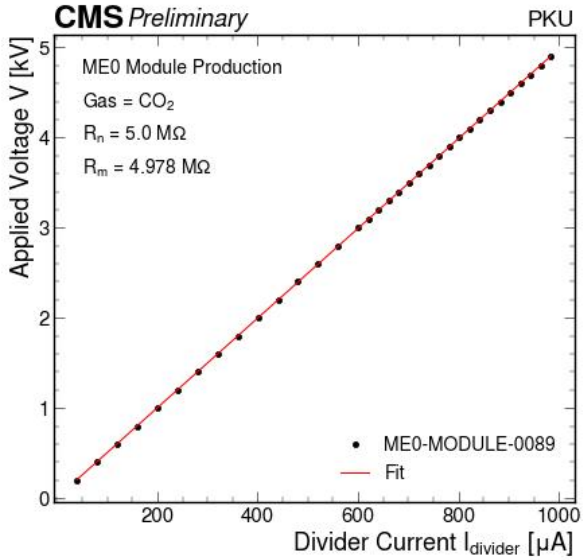
Vset	Vmon	Iset	Imon	R calc	R norm	Counts	Rate	Rate Err
(V)	(V)	(uA)	(uA)	(Mohm)	(Mohm)		(Hz)	(Hz)
200	2.00E+02	40	######	5.01256294	1.0025126		#VALUE!	#VALUE!
400	3.99E+02	80	######	5.006273714	1.0012547		#VALUE!	#VALUE!
600	5.99E+02	120	######	5.004177235	1.0008354		#VALUE!	#VALUE!
800	8.00E+02	160	######	5.006261835	1.0012524		#VALUE!	#VALUE!
1000	9.99E+02	200	######	4.999999925	1		#VALUE!	#VALUE!
1200	1.20E+03	240	######	4.999999937	1		#VALUE!	#VALUE!
1400	1.40E+03	280	######	5.000000107	1		#VALUE!	#VALUE!
1600	1.60E+03	320	######	4.998437105	0.9996874		#VALUE!	#VALUE!
1800	1.80E+03	360	######	4.998611111	0.9997222		#VALUE!	#VALUE!
2000	2.00E+03	400	######	4.996250862	0.9992502		#VALUE!	#VALUE!
2200	2.20E+03	440	######	4.994322189	0.9988644		#VALUE!	#VALUE!
2400	2.40E+03	480	######	4.995836061	0.9991672		#VALUE!	#VALUE!
2600	2.60E+03	520	######	4.992315082	0.998463		#VALUE!	#VALUE!
2800	2.80E+03	560	######	4.992865001	0.998573		#VALUE!	#VALUE!
3000	3.00E+03	600	######	4.991677863	0.9983356		#VALUE!	#VALUE!
3100	3.10E+03	620	######	4.991141698	0.9982283		#VALUE!	#VALUE!
3200	3.20E+03	640	######	4.989859594	0.9979719		#VALUE!	#VALUE!
3300	3.30E+03	660	######	4.989411768	0.9978824		#VALUE!	#VALUE!
3400	3.40E+03	680	######	4.98898993	0.997798		#VALUE!	#VALUE!
3500	3.50E+03	700	######	4.988592699	0.9977185		#VALUE!	#VALUE!
3600	3.60E+03	720	######	4.987524092	0.9975048		#VALUE!	#VALUE!
3700	3.70E+03	740	######	4.987862441	0.9975725		#VALUE!	#VALUE!
3800	3.80E+03	760	######	4.987526418	0.9975053		#VALUE!	#VALUE!
3900	3.90E+03	780	######	4.985292084	0.9970584		#VALUE!	#VALUE!
4000	4.00E+03	800	######	4.985660848	0.9971322		#VALUE!	#VALUE!
4100	4.10E+03	820	######	4.985403381	0.9970807		#VALUE!	#VALUE!
4200	4.20E+03	840	######	4.982787132	0.9965574		#VALUE!	#VALUE!
4300	4.30E+03	860	######	4.983188406	0.9966377		#VALUE!	#VALUE!
4400	4.40E+03	880	######	4.981875917	0.9963752		#VALUE!	#VALUE!
4500	4.50E+03	900	######	4.981173865	0.9962348		#VALUE!	#VALUE!
4600	4.60E+03	920	######	4.97996324	0.9959926		#VALUE!	#VALUE!
4700	4.70E+03	940	######	4.978274819	0.995655		#VALUE!	#VALUE!
4800	4.80E+03	960	######	4.977175932	0.9954352		#VALUE!	#VALUE!
4900	4.90E+03	980	######	4.976122679	0.9952245		#VALUE!	#VALUE!





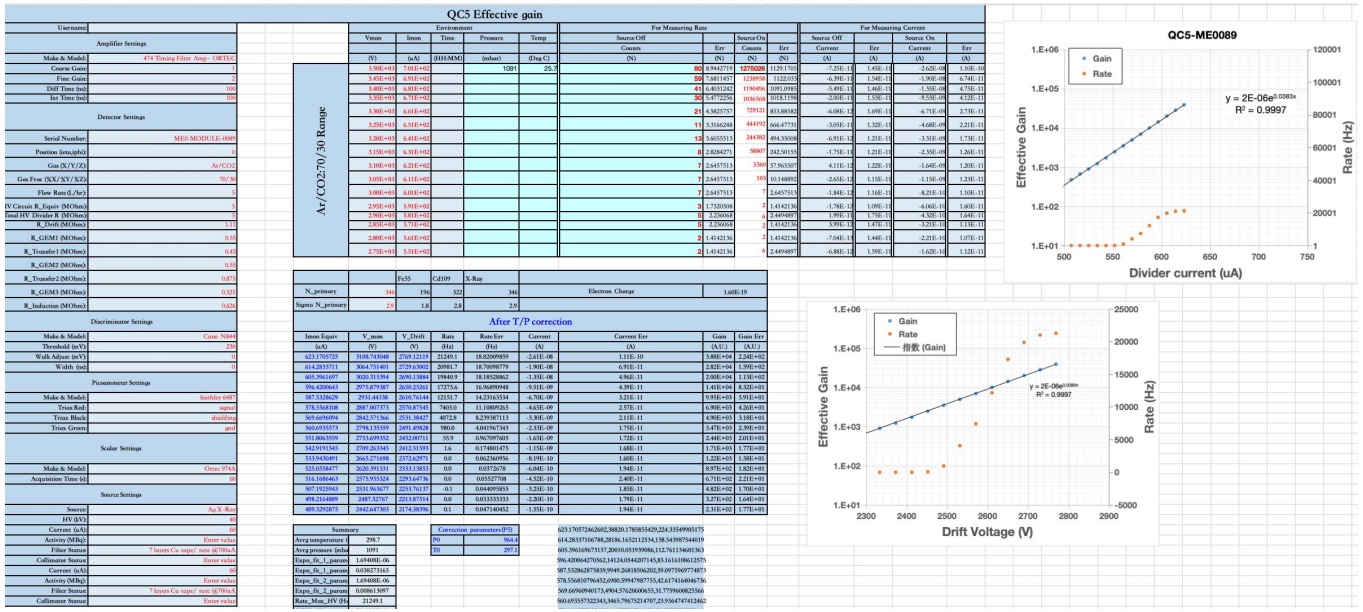
HV Circuit	
R_Equiv (Mohm)	5
Preamplifier	
Make & Model	User Provides
	User Provides
Amplifier	
Make & Model	User Provides
Coarse Gain	User Provides
Fine Gain	User Provides
Int. Time (ns)	User Provides
Diff Time (ns)	User Provides
Discriminator	
Make & Model	User Provides
Threshold (mV)	User Provides
Scalar	
Make & Model	User Provides
Acquisition Time (s)	User Provides

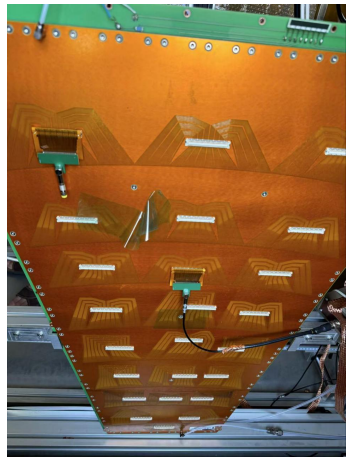
Summary	
V_Max (V)	4897.5
Vdrift_Max (V)	4625.740056
I_Max (uA)	984.200012
R_Equ_MSRD (Mohm)	5
R_Equ_Slope (Mohm)	4.976215426
R_Diff (%)	0.475691483
SPR_Signal_Rate (Hz)	#VALUE!
SPR_Signal_Rate_Err (Hz)	#VALUE!

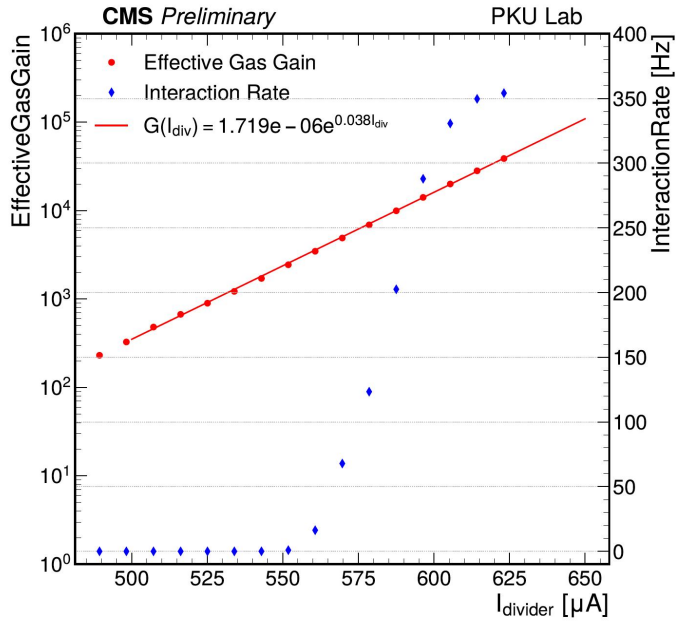


QC5-1: Effective Gas Gain Test with X-ray

- A measurement of **the effective gas gain** as a function of the HV both with and without a radiation source using a gas mixture of 70% Ar and 30% CO_2.
- The effective gas gain is calculated from the count rate and current measurements.





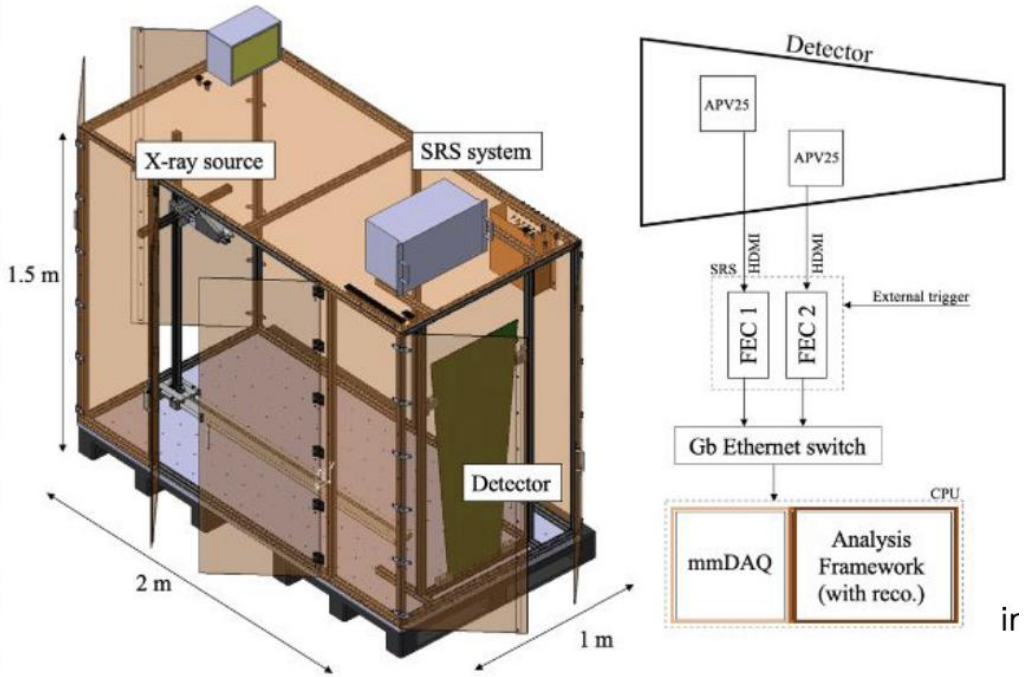


QC5-2: Gain Uniformity Measurement

(Gain uniformity test is performed at CERN)

signal->APV25->ADC->FEC->DAQ

- APV: Analog Pipeline Voltage mode
- ADC: Analog-to-Digital Converter
- FEC: Front-end concentrator cards
- DAQ: Data Acquisition



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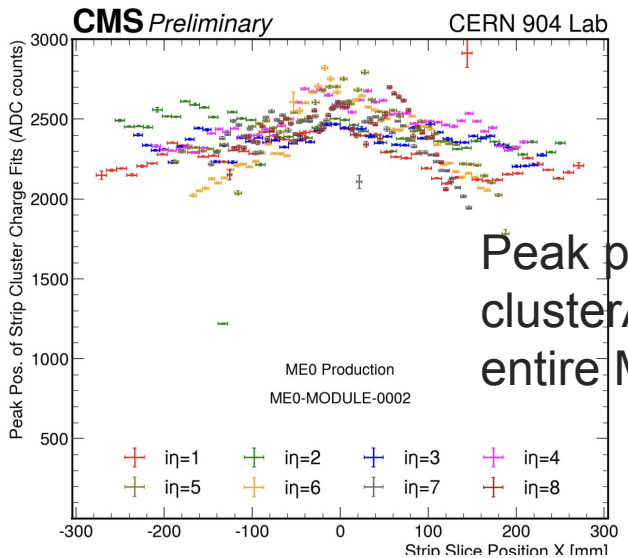
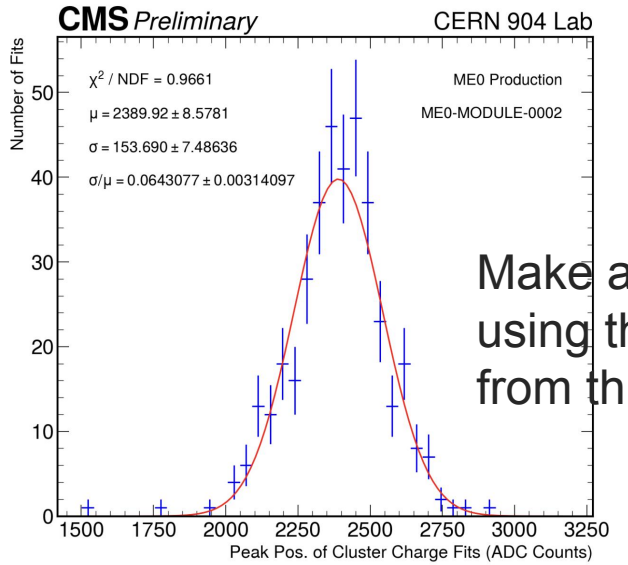


Peak position of clusterADC over the entire ME0 detector

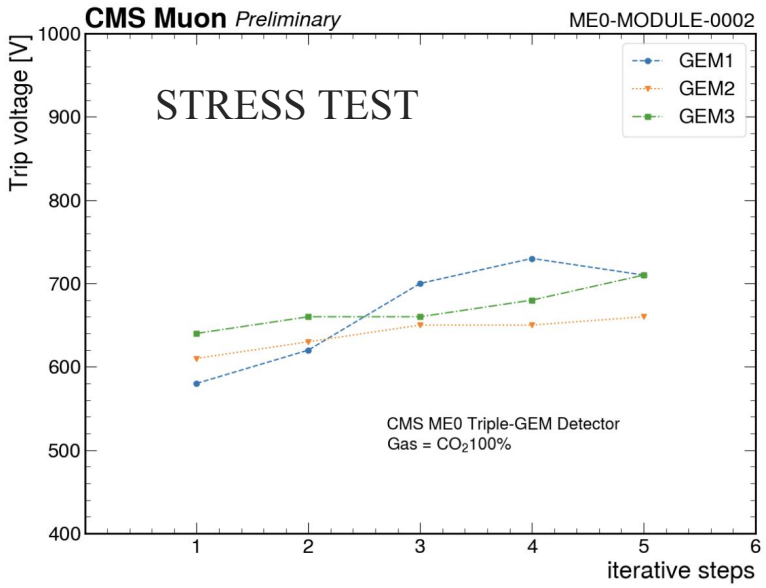


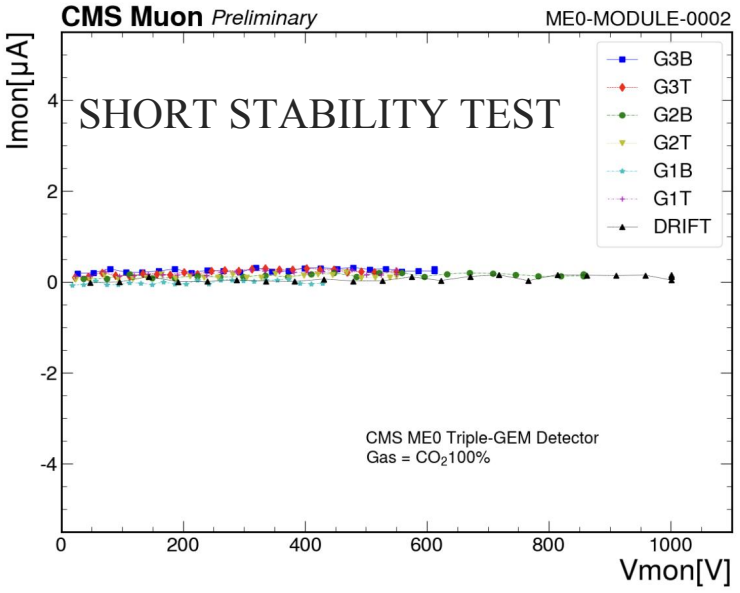
Response Uniformity = 100 * σ/μ %
must < 15%

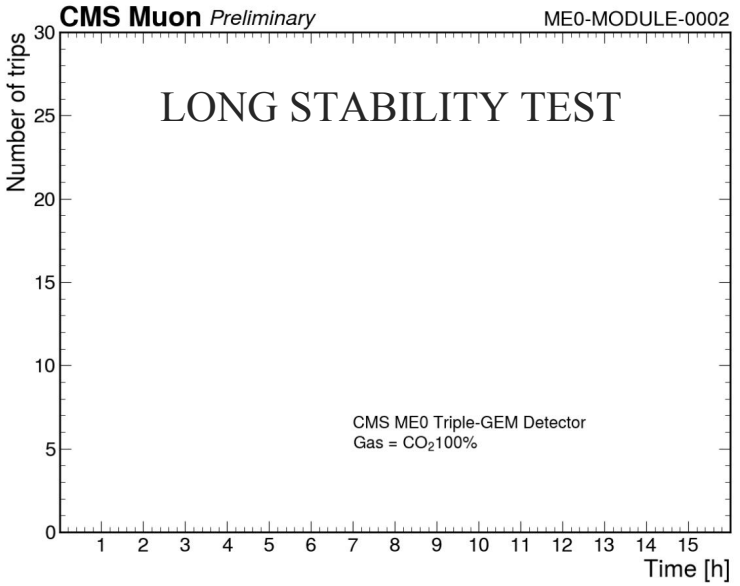
Make a histogram using the data points from this distribution

QC6: HV Stability Test (at CERN)

- To clean and characterize the GEM foils in order to ensure the stability of the high voltage
  1. **STRESS TEST:** record the maximum voltage supported by each GEM foil
  2. **SHORT STABILITY TEST:** to determine the current-voltage curve for all the GEMs foils and DB of the detector
  3. **LONG STABILITY TEST:** keep all the GEM foils at 580 V for 15 hours or longer if needed and check the stable operation of the GEM foils. The number of trips of the power supply are registered.

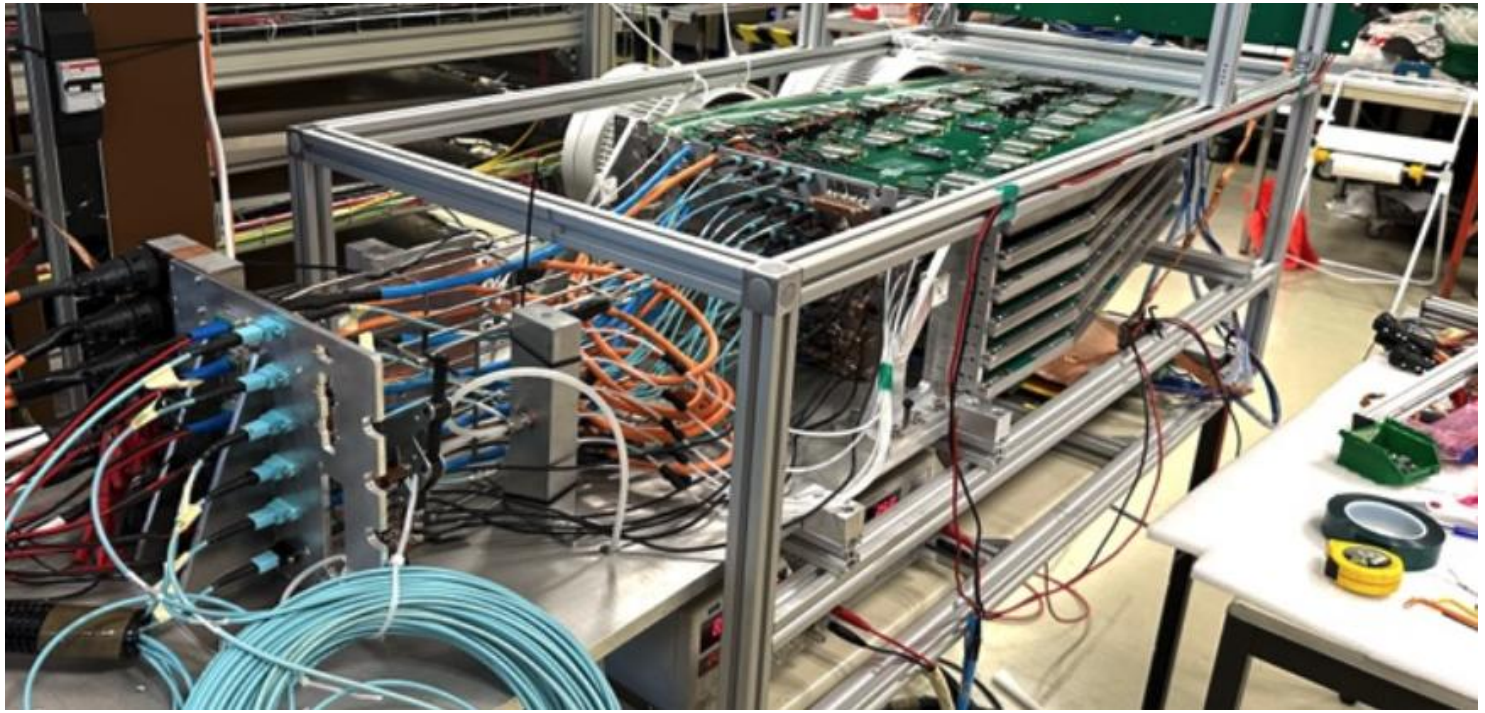






QC7: Electronics Integration Test (at CERN)

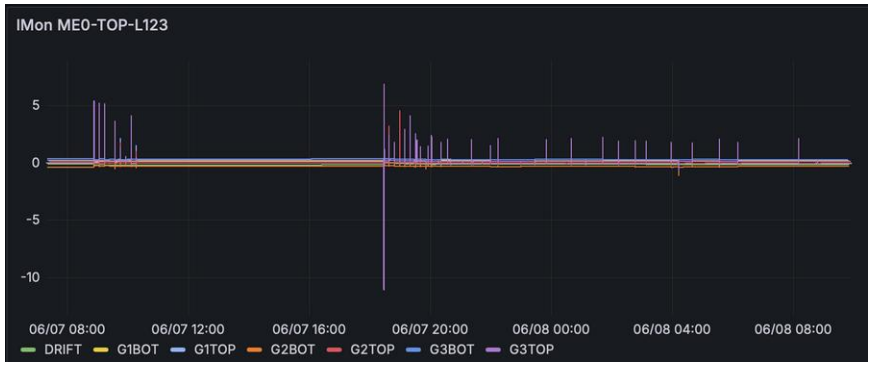
This step revolves around making sure that the signal is high. Having virus in the signal will destroy everything that has been previously done with quality control process and assembly.



- The ME0 modules will be arranged in stacks of **six layers**.

QC8: Cosmic Test of the Chambers (at CERN)

The main aim of doing the cosmic test of the chambers is carrying out experiments with a cosmic stand to measure the efficiency of chambers.



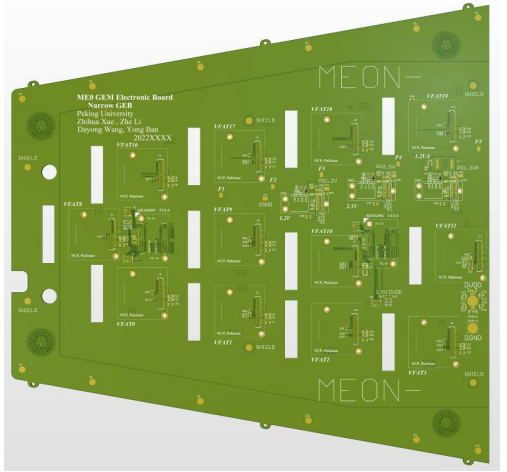
Part 3

1. **Overview of CMS-GEM ME0 upgrade project**
   - Layout of CMS-GEM upgrade system
   - CMS GEM detector design
   - Timeline of the ME0 module production
2. **2nd Batch of 10 ME0 GEM assembly and test at PKU**
   - Module Assembly
   - QC Test
   - Troubleshooting
3. **Progress of the test of ME0 GEM electronics board at CERN**
4. **Update of the Performance of ME0 stack at CERN**
5. **Summary**

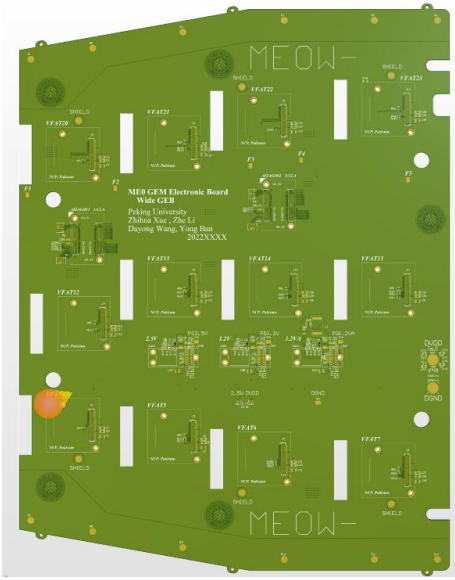
Progress of GEM electronics board for ME0

- GEB: front-end electronics board of GEM detector for upgraded CMS muon system (GE1/1, GE2/1, ME0)

- **Function of GEB:**
  - Carrier of front-end and back-end electronics system
  - Front-end signal transmission carrier
  - Provide direct shielding for GEM detectors



Narrow board



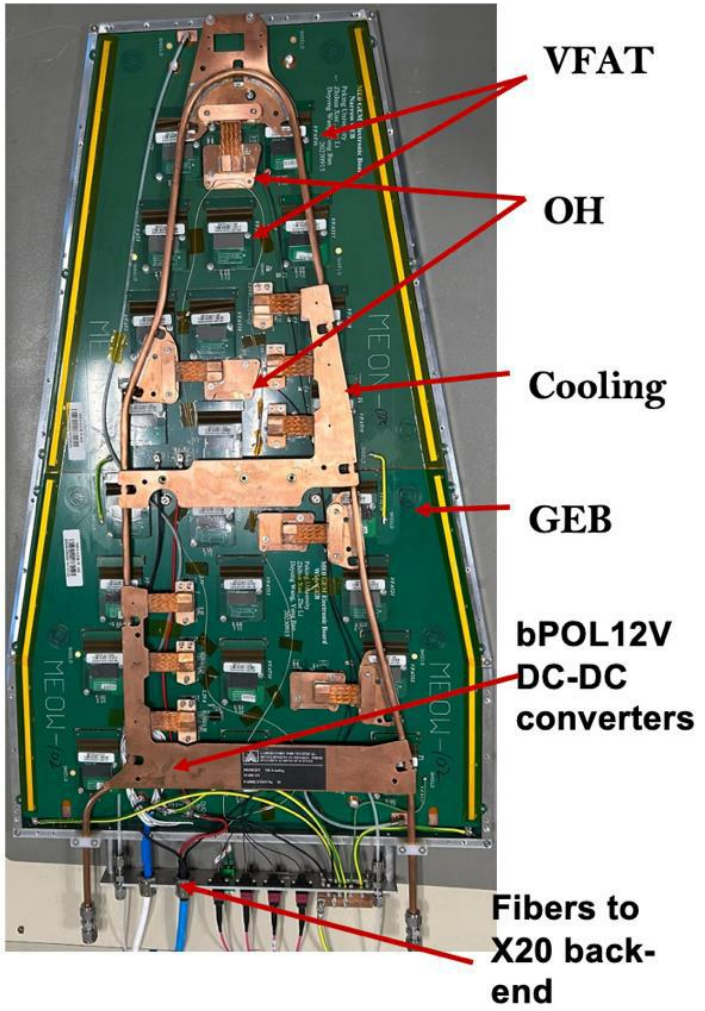
Wide board

Progress of GEM electronics board for ME0

Works of CMS China group:

- Production and test of GE1/1 GEB
- Design, production and test of all GE2/1 and ME0 GEBs
- Development of automatic tester

- 456 ME0 needed for 36 + (2 spares) stacks
- 510 ME0 GEBs produced in total at Sinafast Ltd. in Shenzhen and were shipped to 904 lab at CERN
- Acceptance test at CERN: PKU team finished 1st batch check work(222 GEBs, Feb 2025) and is performing the test of 2nd batch, expected to be completed by early next year



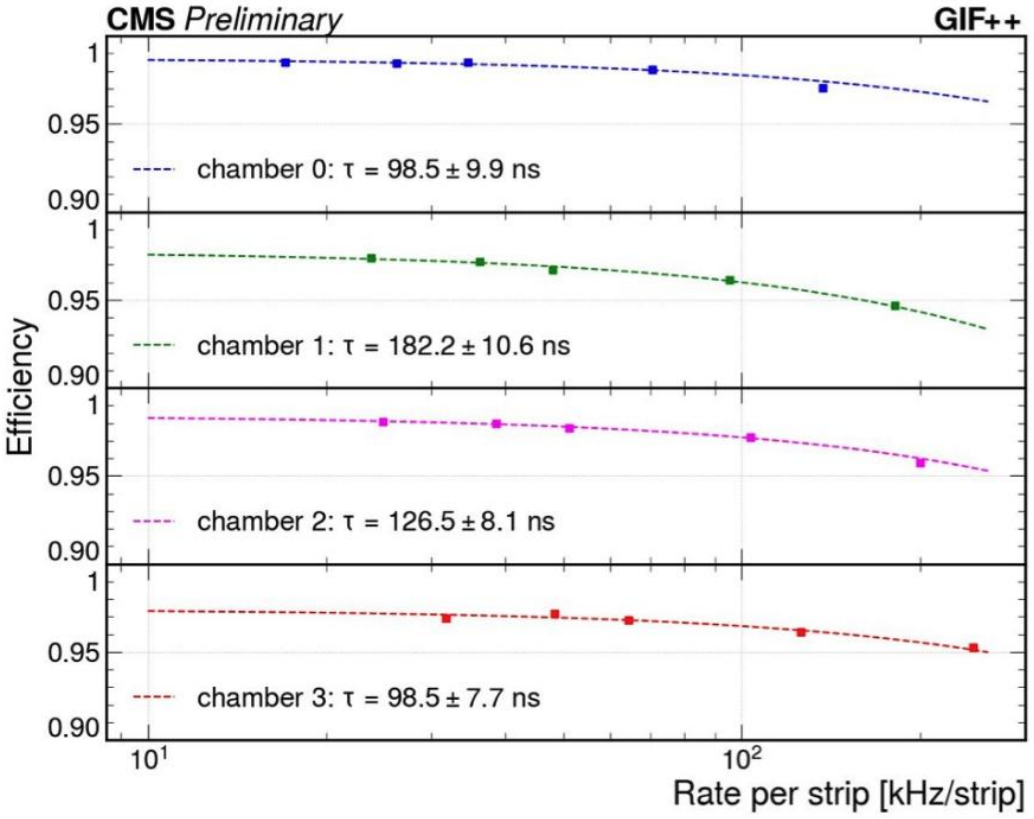
Part 4

1. Overview of CMS-GEM ME0 upgrade project
    - Layout of CMS-GEM upgrade system
    - CMS GEM detector design
    - Timeline of the ME0 module production
2. 2nd Batch of 10 ME0 GEM assembly and test at PKU
    - Module Assembly
    - QC Test
    - Troubleshooting
3. Progress of the test of ME0 GEM electronics board at CERN
4. **Update of the Performance of ME0 stack at CERN**
5. Summary

Test for the Chambers--Rate Capability Study

Beam test was performed at GIF CERN, with a test beam about 2 MHz per sector

- 80 GeV muons
- a low-energy gamma background from ^{137}Cs to simulate the expected background



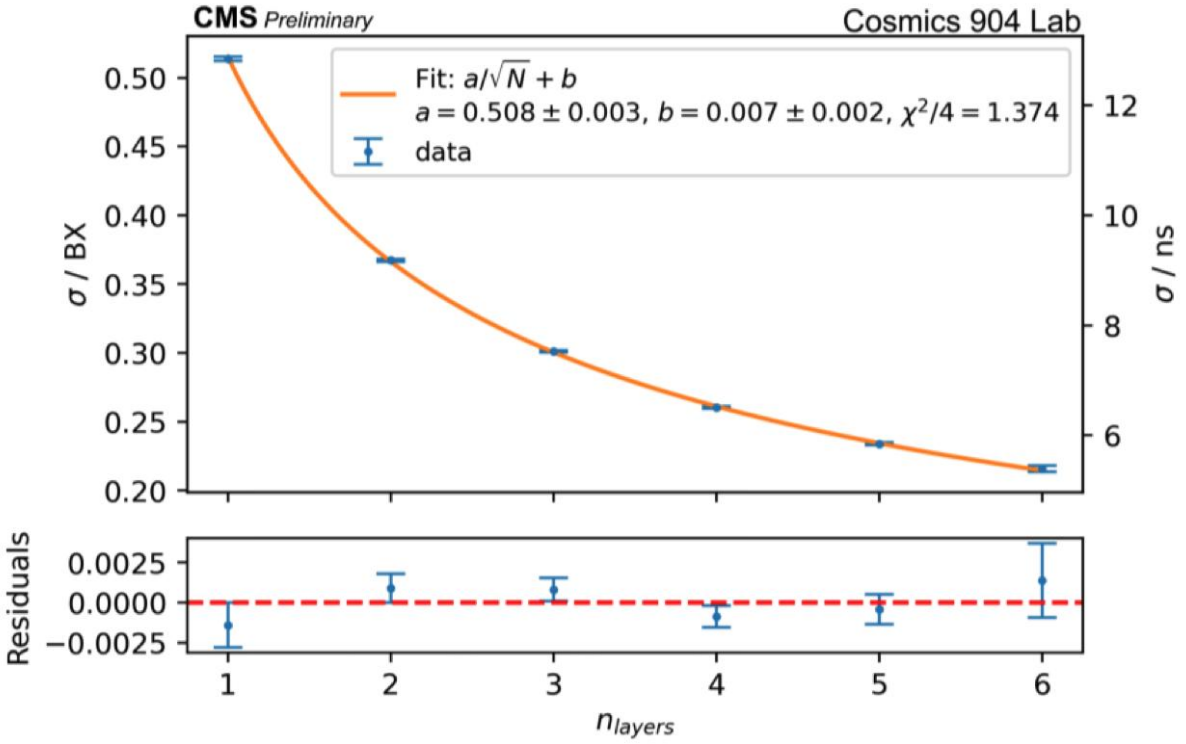
- efficiency loss around **2.5%** per chamber
- due to **redundancy** provided by the six chambers in each stack

  => approximately **1%**

Test for the Chambers--Time Resolution

The full 6-layer stack time resolution

- use cosmic rays as the uncertainty on the average arrival time of the track segments



- Average time resolution as a function of the number of ME0 chambers (layers)
- For 6-layer segments, the time resolution is 0.21 BX (left y-axis) corresponding to **5.4 ns** (right y-axis).
- A more precise measurement is ongoing

Summary

- Progress and status of CMS-GEM upgrade project:
  - GE1/1: Overall smooth operations with only small lumi loss & very good muon detection efficiency (stable & ~95%).
  - GE2/1: On hold, perhaps postponed to 2029
  - ME0: module production on schedule, expect to be completed by end of next year
- The China group has completed the 2nd batch of 10 ME0 GEM module assembly and test, shipped to CERN and passed further tests. Preparation for the 3rd batch of ME0 module production is going on.
- All ME0 GEBs produced in China have been shipped to CERN, half of them passed the acceptance test with no failure found, part of the GEBs have been already assembled on ME0 modules. The acceptance test is still going on at CERN.

— THANKS —

Back up