Collaboration of Korean HEP community and the capabilities of Korean industry for future experiments

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On behalf of Korea CMS & MECARO

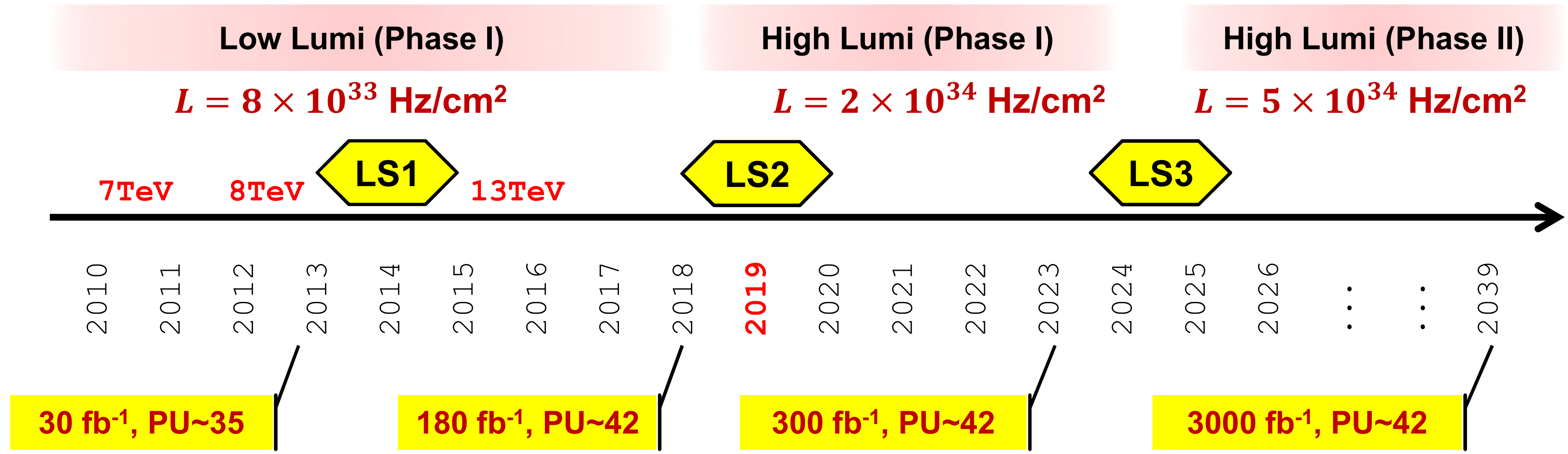
Disclaimer

- The original talk titles were
  - “GEM detector R&D @ Korea CMS”
  - “GEM detector & industrialization in Korea”
- and it was changed accidentally with my agreement
  - “Collaboration of Korean HEP community and the capabilities of Korean industry for future experiments”
    - but, the slides are the same anyway, other than the 1st page

LHC Phase 2 upgrade
& CMS upgrade

LHC upgrade schedule & Muon!

❑3 steps: Energy upgrade & Lumi upgrade



% Charged particles in Muon system

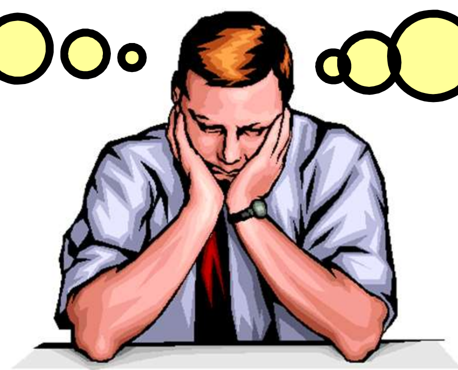
Region	Low Lumi LHC	High Lumi LHC	Phase II
Barrel RPC	10 Hz/cm²	~ 30 Hz/cm²	~ 100 Hz/cm²
Endcap RPC 1, 2, 3, 4 $\eta < 1.6$	30 Hz/cm²	~ 100 Hz/cm²	~ 300 Hz/cm²
Expected Charge in 10 years	0.05 C/cm²	0.15 C/cm²	0.5 C/cm²
Endcap RPC 1, 2, 3, 4 $\eta > 1.6$	500Hz ~ 1kHz	Few kHz	Few 10s kHz
Expected Charge in 10 years	(0.05-1) C/cm²	few C/cm²	Few 10s C/cm²

Muon detector upgrade, Why?

L1 trigger efficiency for $p_T < 25GeV$ is unacceptable after LS2

RPC can not sustain with the phase 2 high rates

There are empty spaces in high eta region

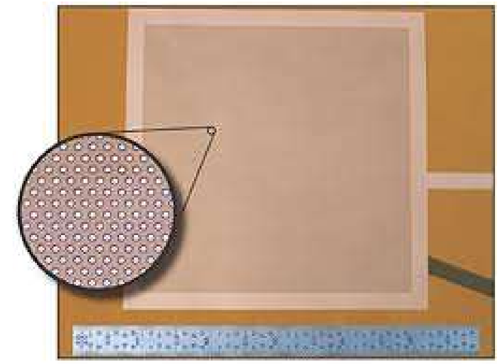


We needs new tech!
- High rate for MHz/cm^2
- Good $\sigma(t)$ trigger
- Good $\sigma(x)$ tracking

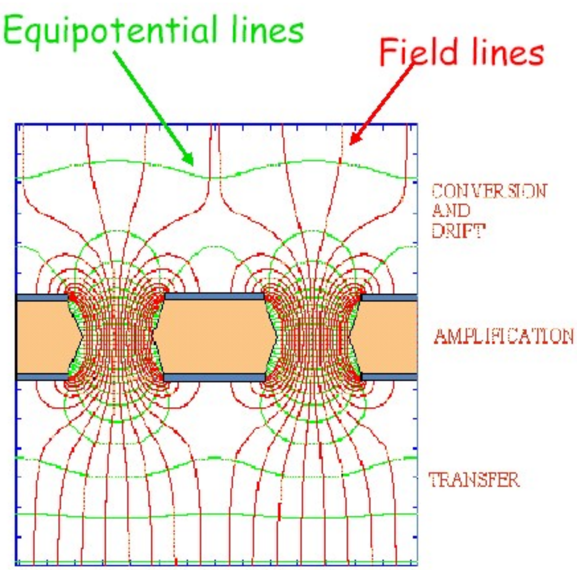
GEM was invented for you!

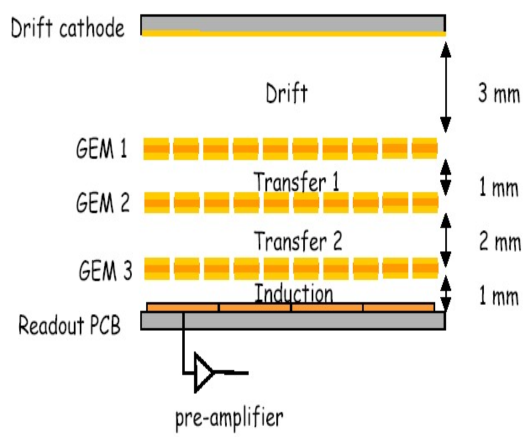
GEM (Gas Electron Multiplier)

A GEM foil

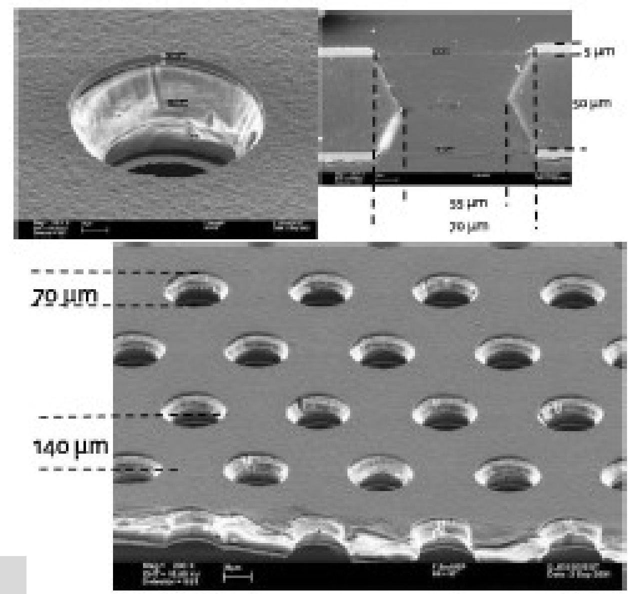


- **Production**
  - PCB manufacturing techniques: lithography + etching
  - Large areas ~1m^2 capability (cost effective)
- **Physical structure**
  - 50μm Polyimide sheet + 5μm double copper layers
  - Typical hole diameter = 70μm, hole pitch = 140μm,
- **Working principle: same as the wire chamber**
  - High field induces electron acceleration & avalanche





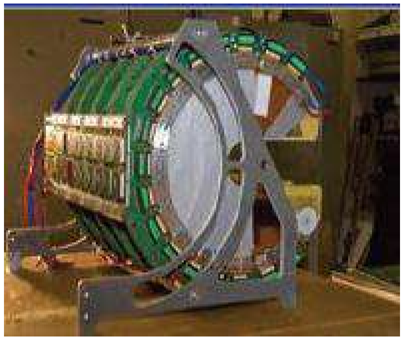
A Triple GEM detector: gain~8000



Experiences with GEM

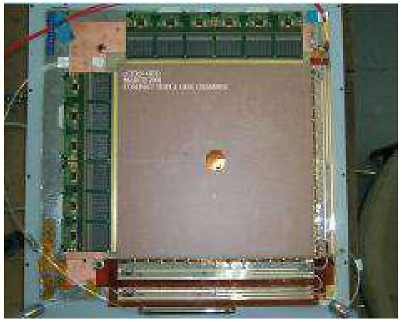
❑ TOTEM

- –Triple-GEM with Ar/CO2 at 5.3 ≤ |η| ≤ 6.5
- –Rate ~ 12MHz/cm2 (1000 x GE1/1 in CMS P2)
  - •No aging effects due to polymerization. No change in material properties



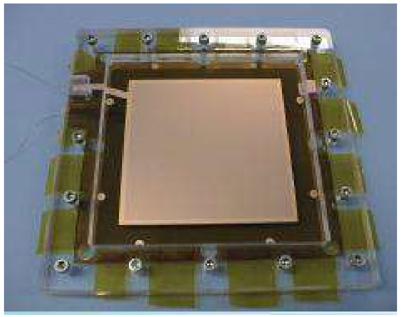
❑ COMPASS

- –Triple-GEM with Ar/CO2
- –Rate ~2.5MHz/cm2 (500 x GE1/1 in CMS P2)
  - •No decrease in gain, efficiency, or deterioration of energy resolution or time resolution up till now



❑ LHCb

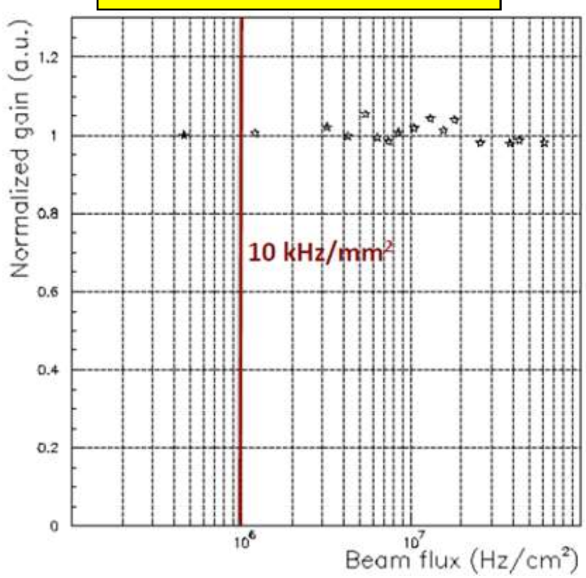
- –Triple-GEM with Ar/CO2 mixture (45/15/40)
- –Rate ~500 kHz/cm2 (50 x GE1/1 in CMS P2)
  - •No decrease in performance after LHCb years



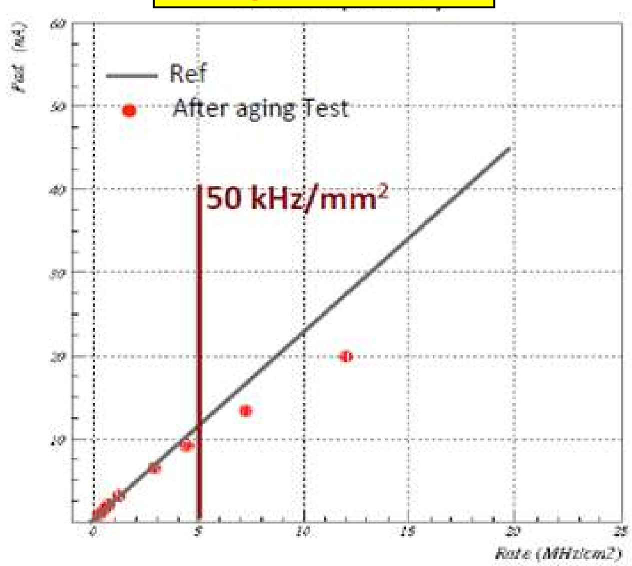
GEM is it!

- Excellent time & spatial resolution: ~5ns, ~100um
- High rate & efficiency: ~1MHz/cm^2, ~ 98%
- Radiation hardness, non-flammable gas (Ar/CO2)

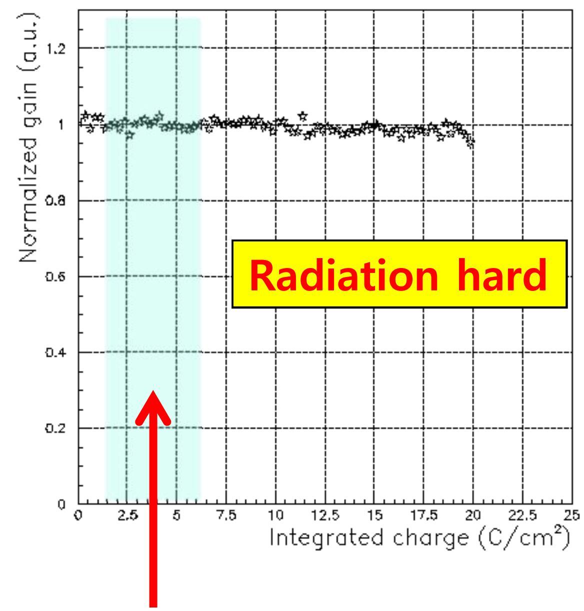
Gain vs beam flux



No gain drops



10 years @LHCb → 13 C/cm²
50MHz/cm² X-ray → 20 C/cm2

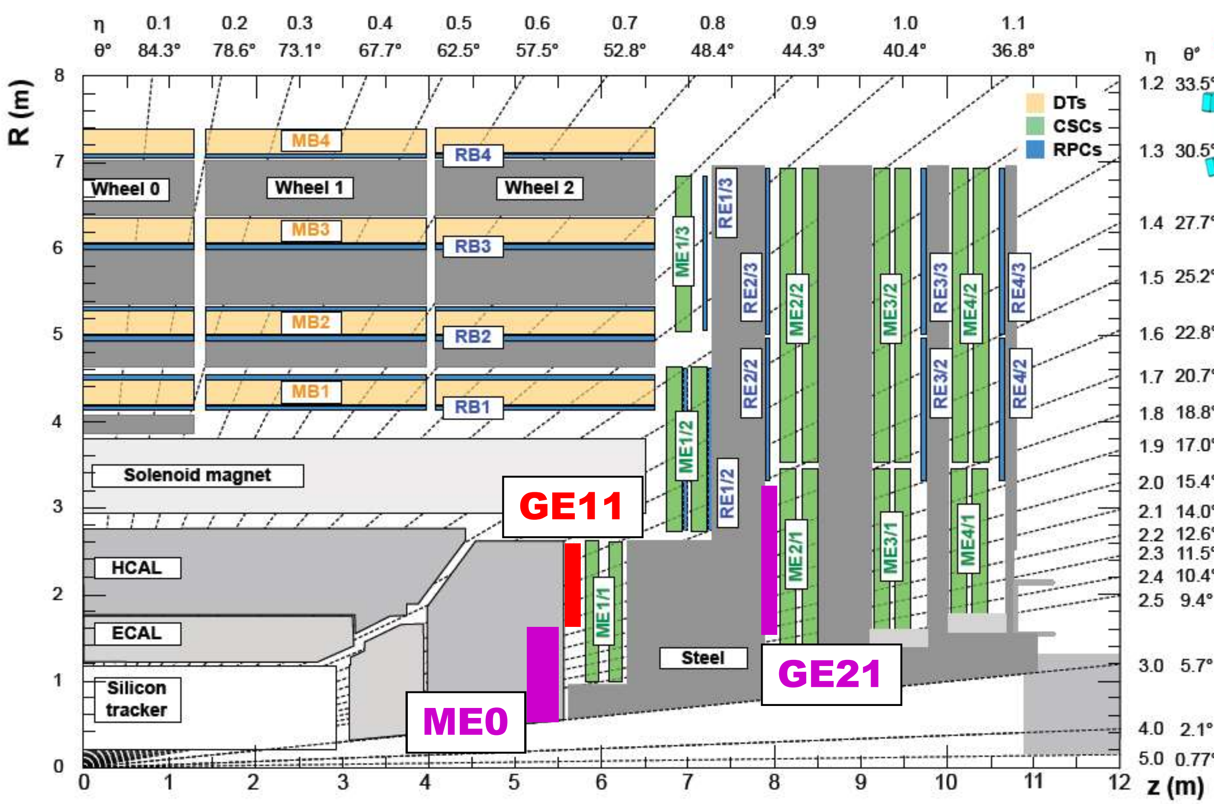


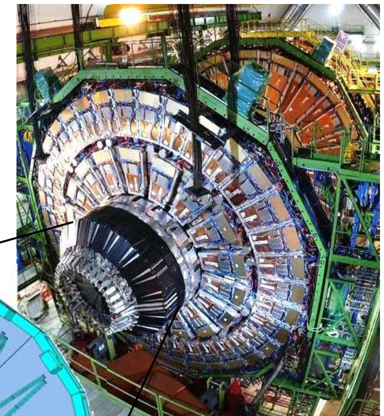
% M. Alfonsi et al. 2004

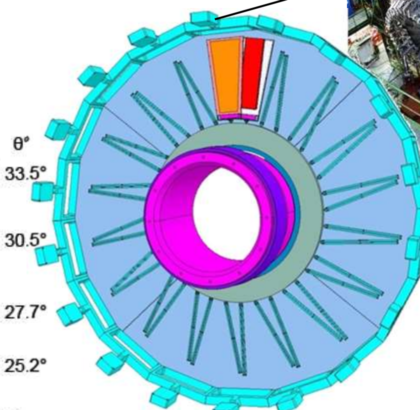
CMS high η - maximum integrated charge

GEM Endcap (GE) Project

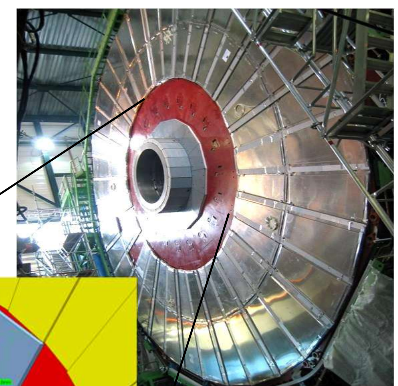
- GE11 (1.6 < |eta| < 2.2) : LS2
- GE21 (1.6 < |eta| < 2.45) : LS3
- ME0 (2.0 < |eta| < 3.5): LS3

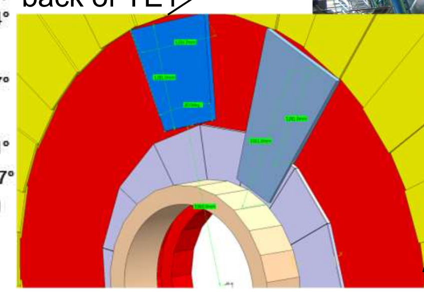






GE1/1 in YE1 nose

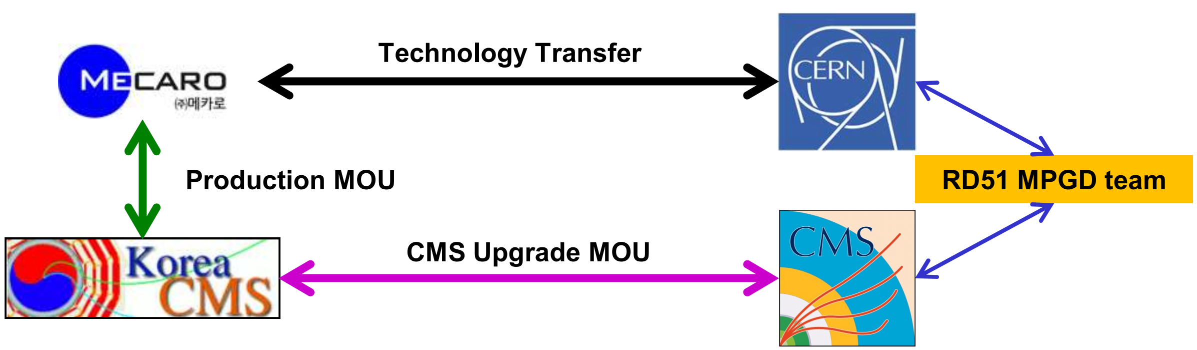




GE2/1 on back of YE1

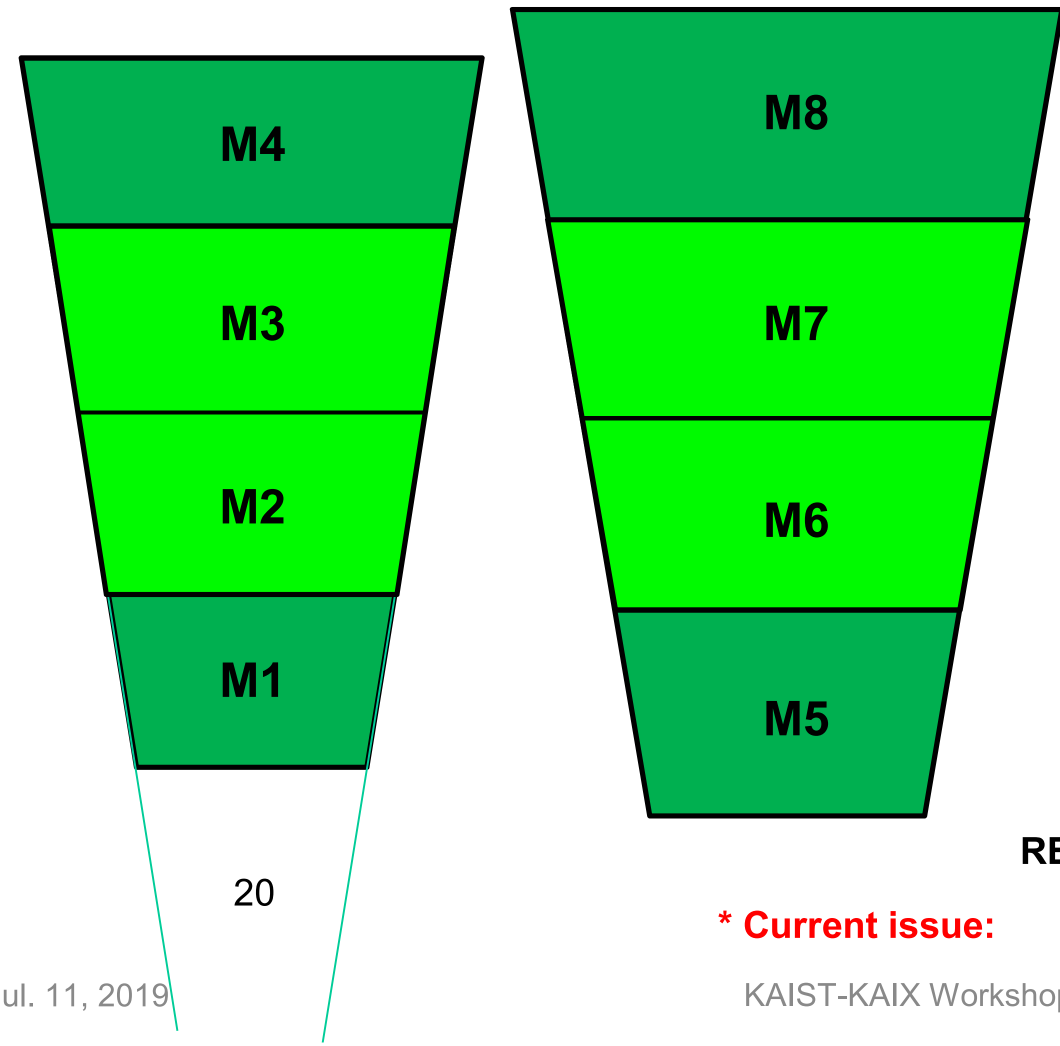
History of Korea GEM involvement

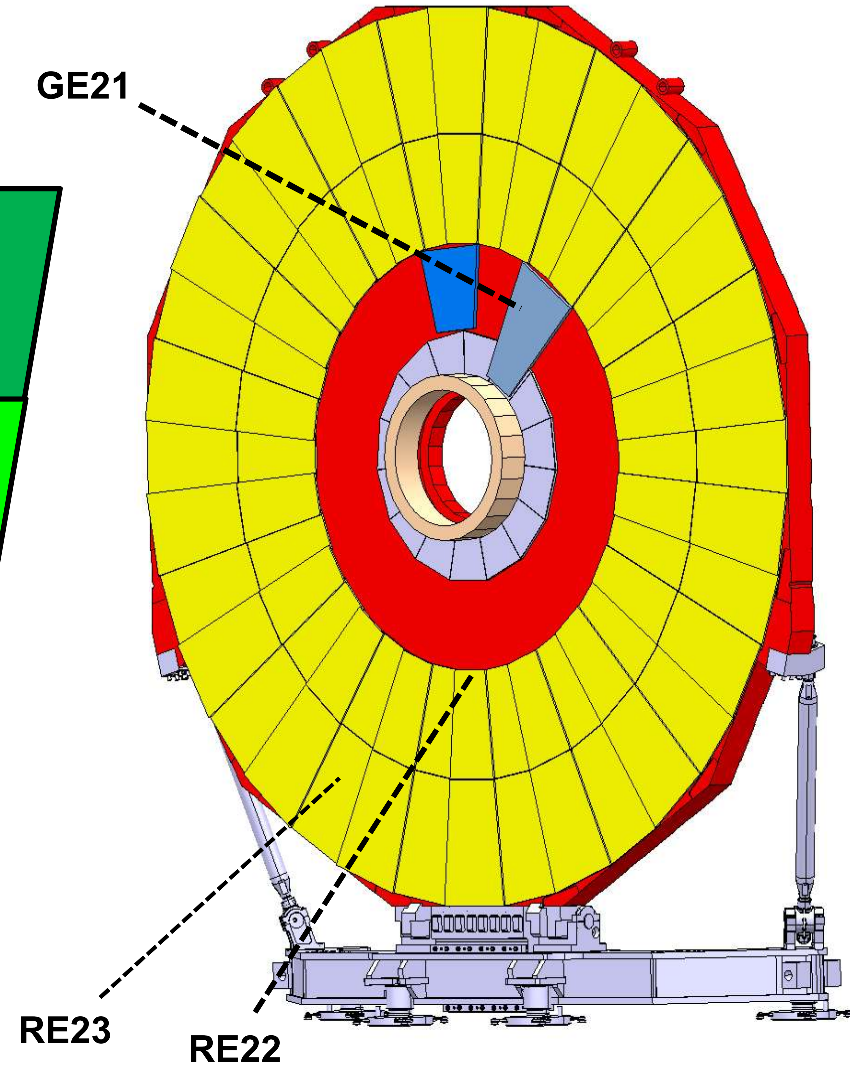
- **2012: MOU between Korea CMS and MECARO for the industrialization of GEM foil production**
  - **Technology transfer agreement with CERN**
- **2013-2016: 1st 3-year NRF funding (~$2M) for facility set-up**
- **2016-2019: 2nd 3-year NRF funding (~$2M) for the large GEM foil development & test production**
- **2019-2022: GE21 & ME0 production**



GE21 production in Korea

2 endcaps x 18 sectors x 3 foils = 108 foils, + 10 foils for test + 6 foils for extra = 124 foils for each module of GE21, x 4 modules (M2,M3,M6,M7) = 496 foils in total

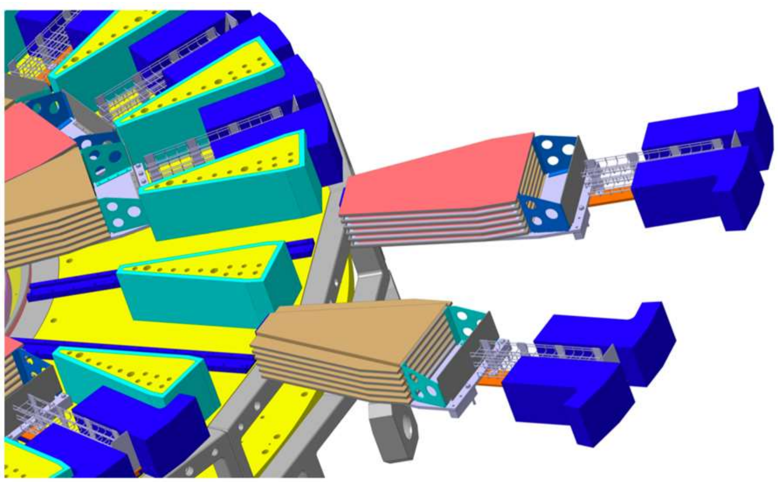


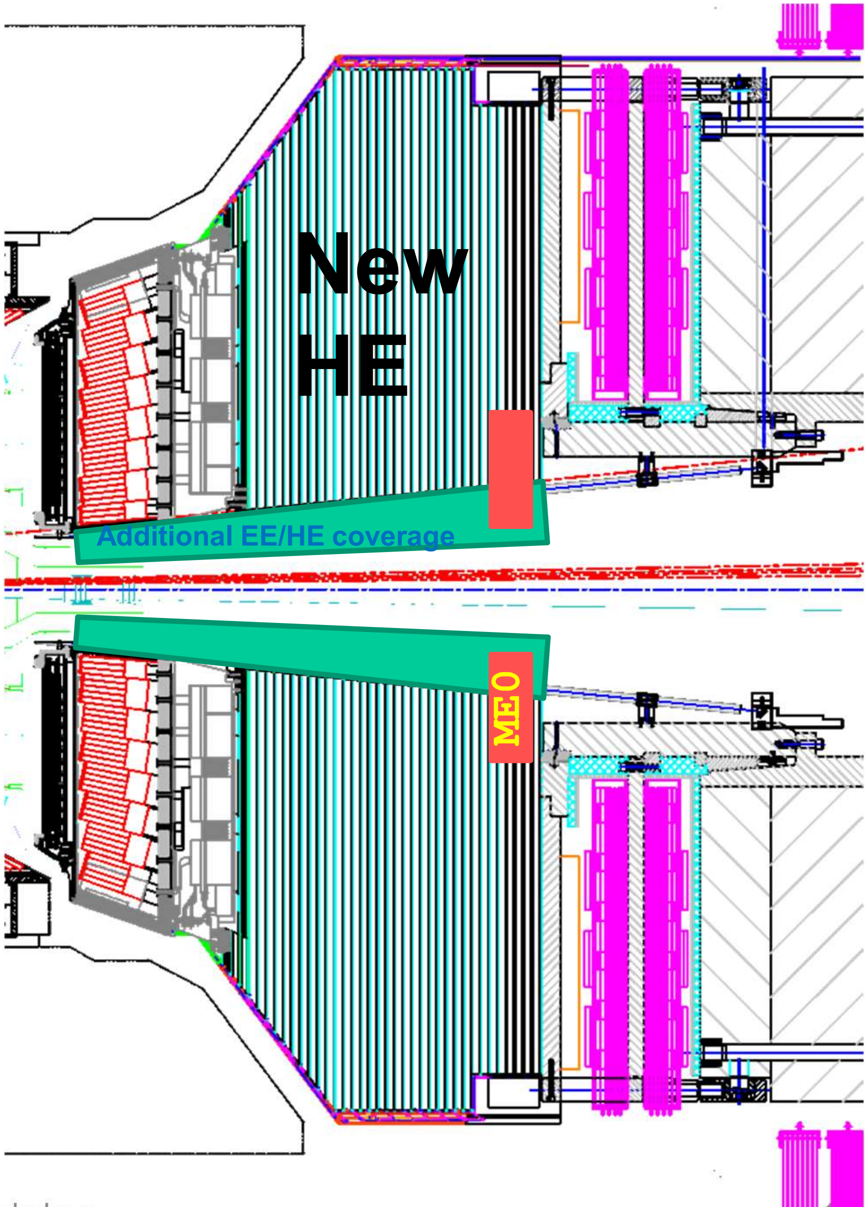


* Current issue:

MEo production in Korea

2 endcaps x 18 sectors x 6 layers = 216 chambers, x 3 foils = 648 foils, + 9 for 3 test chambers + 9 for extra = 666 foils in total





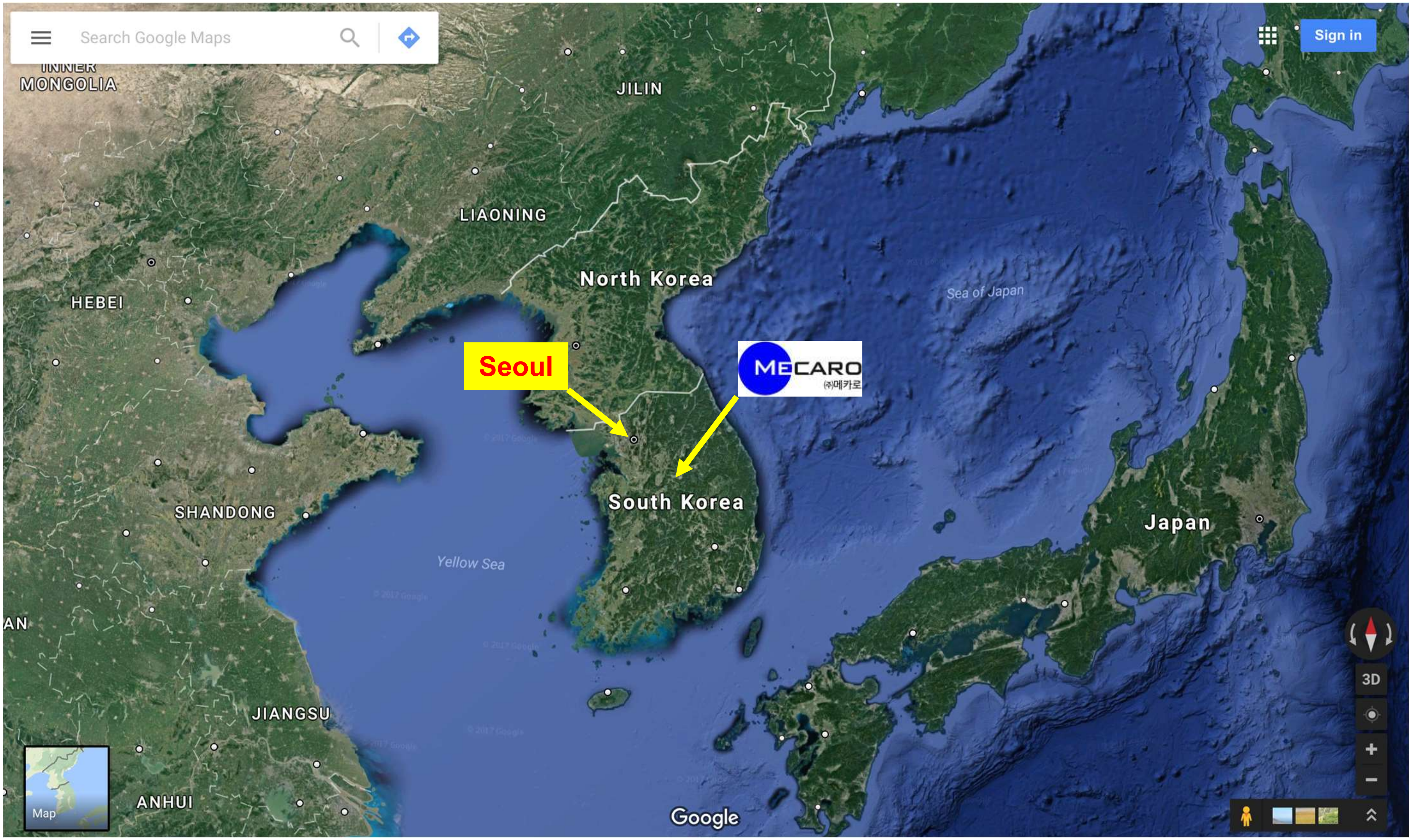
Cern-Korea Committee 2019

In-kind contribution of 1162 GEMs ~ 2.3MCHF equivalent

Industrialization

(site & production facilities)

Industrialization site: MECARO



Company details

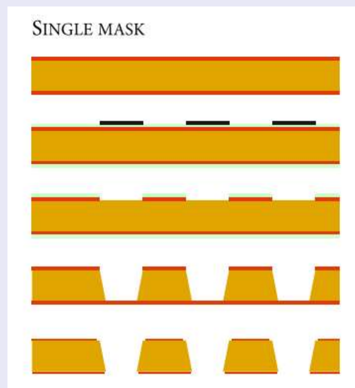
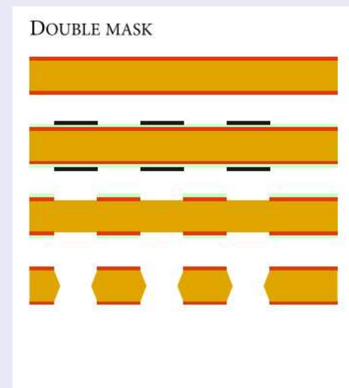
Mecaro Co., Ltd is No.1 Best Semiconductor parts company authorized in parts area by producing optimal semiconductor part of equipment through ceaseless technology development and research for about 15 years.

- Company Name : Mecaro CO., Ltd.
- Foundation Date : 2000. 11
- CEO : Jaejung, Lee
- Business Field : Semiconductor Heater Block, Semiconductor Chemical Source, GEM Foil, Etc.

Eumsung factory

- R&D and Production
- Clean room : 1300 m^2
- GEM foil production site

Single-mask vs Double-mask

	Single-mask	Double mask
Infrastructure	Cheap	Expensive
Mask alignment	No need (film)	Crucial (Glass only)
Pros & Cons in size	Large size capable	Limited in size
Production method		
Production process	Complicate	Simple
Production time	Long	Fast
Labor cost	Expensive	Cheap

GEM production line at MECARO

DFR Film coater

Large Bipolar Exposure

DFR Film Developer

Cu layer etcher

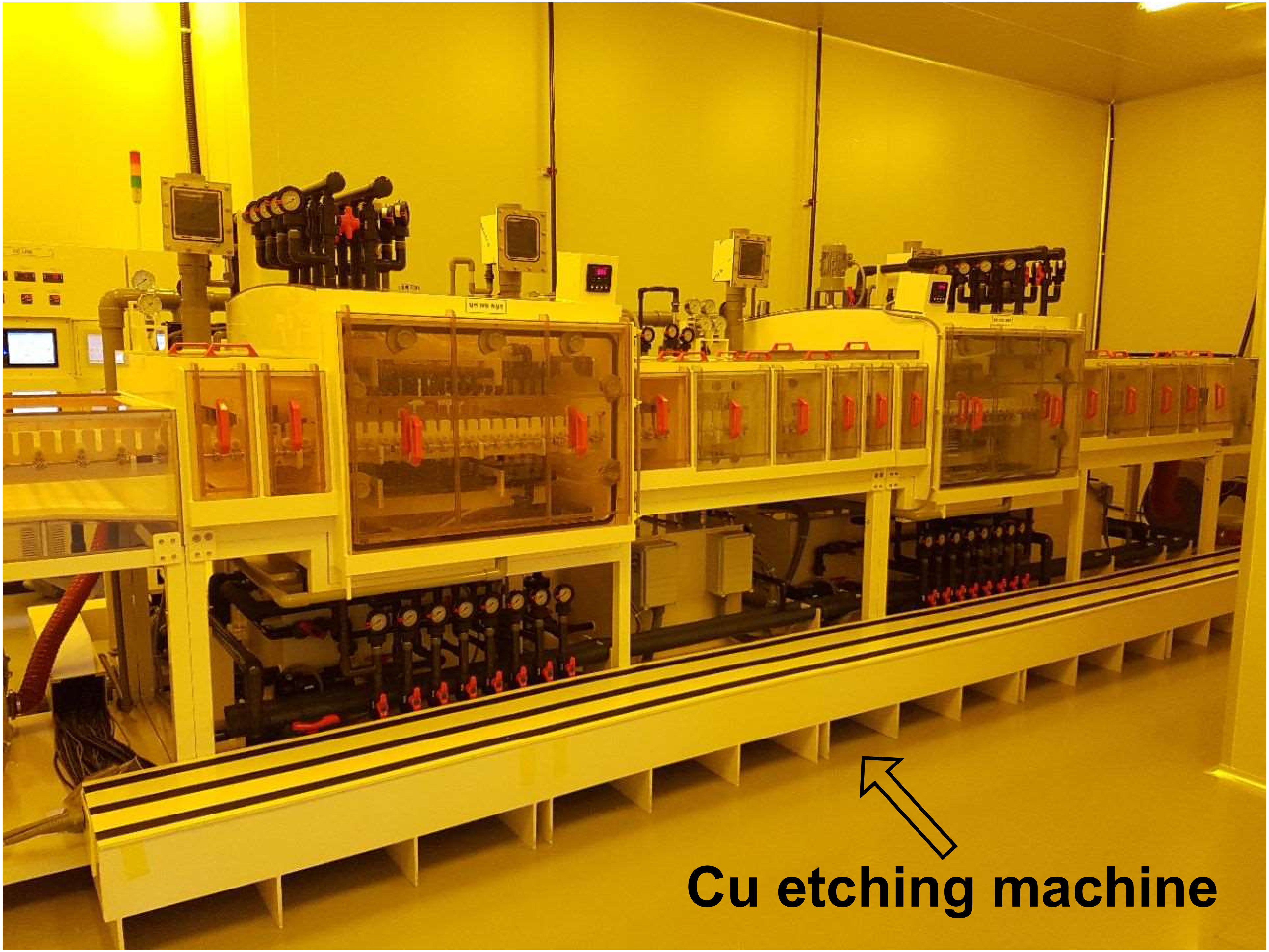
Cleaner & Dryer

PI etching machine

Cleaner & Dryer

Inspection & QC

Large Bipolar Exposure


Cu etching machine

GEM Production Facilities: Production room

Small size etching bath

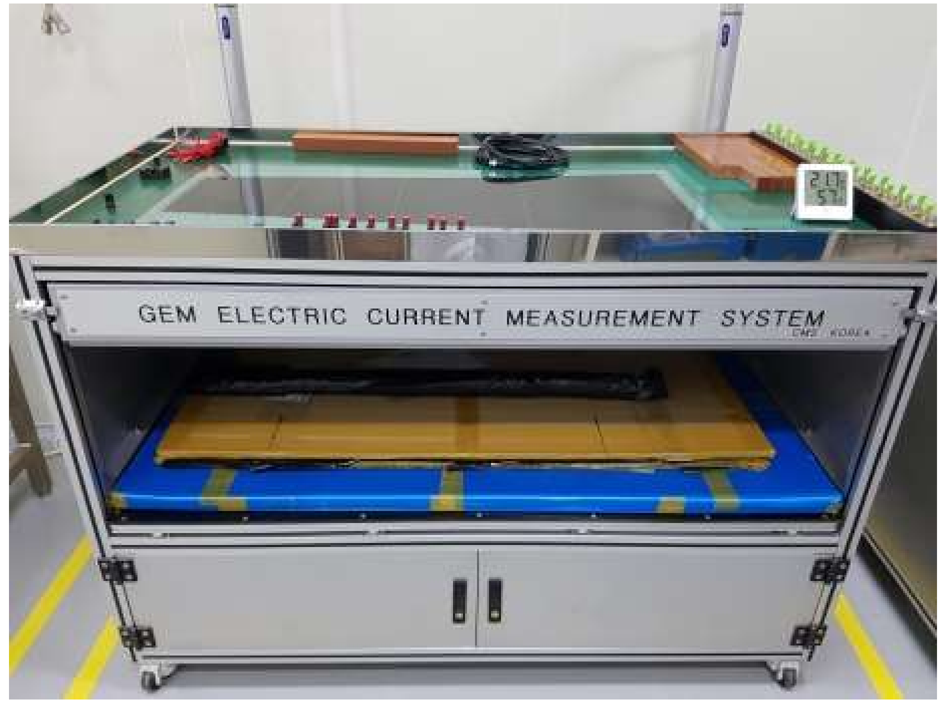
Mid size etching bath

Large size etching bath

- **Multiple etching baths are ready for various sizes of GEMs**
  - **Small: 10cm x 10cm, 30cm x 30cm**
  - **Middle: 50cm ~ 1m**
  - **Large: > 1m**

GEM Production Facilities: QC

Small size leakage current test

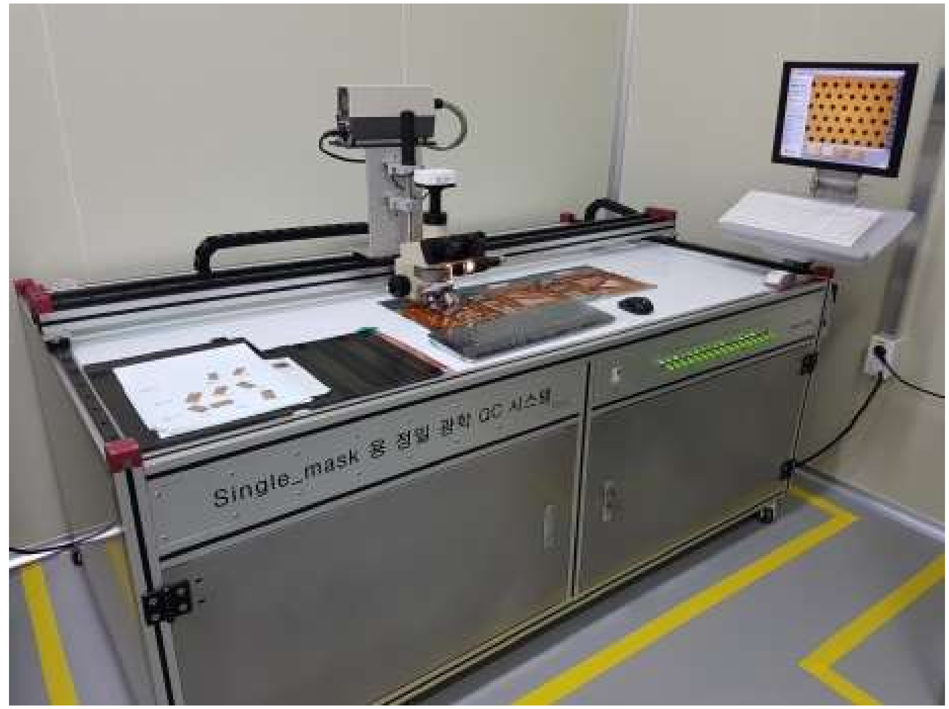


Large size leakage current test

- ❑Leak current measurement with/without gas system
  - –Small: 10cm x 10cm, 30cm x 30cm
  - –Middle: 50cm ~ 1m
  - –Large: > 1m

GEM Production Facilities: QC

UV light system



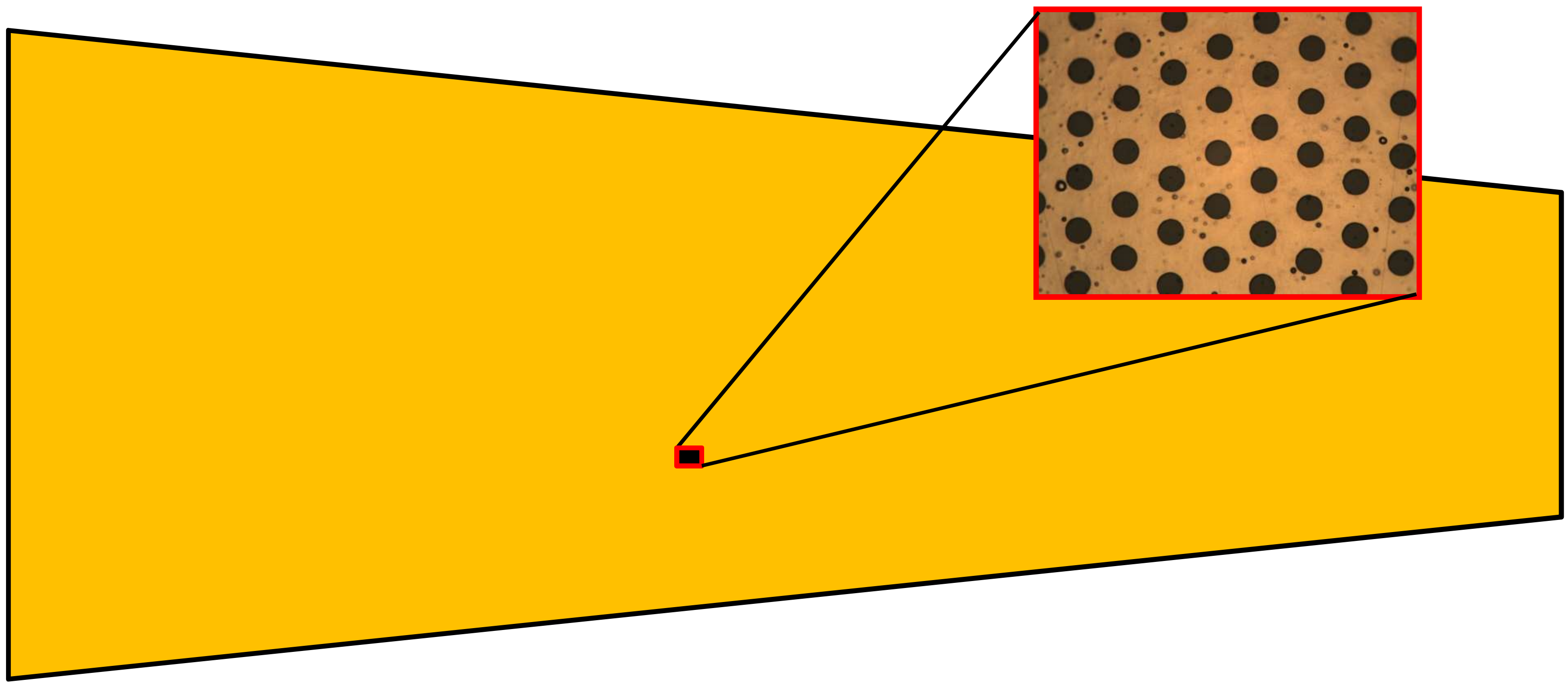
Optical inspection table

- UV curing facility, Semi-automatic Optical inspection
  - for all sizes
  - fully automatics whole area scanning will be available

Large GEM foil production

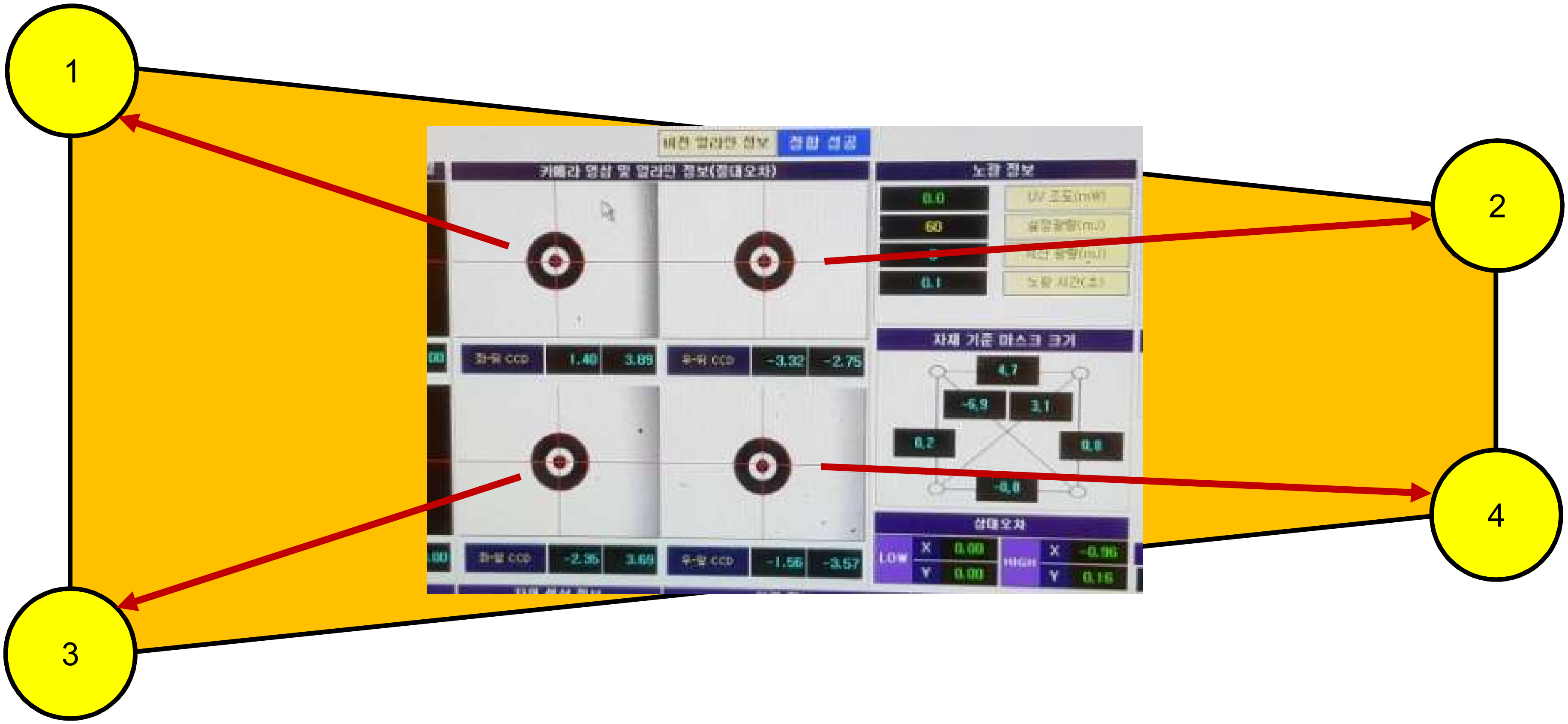
Critical obstacle & Breakthrough

- hole diameter = 70µm, hole pitch = 140µm over 100m x 50cm ~ 20M holes
  - All top & bottom holes must be perfectly aligned



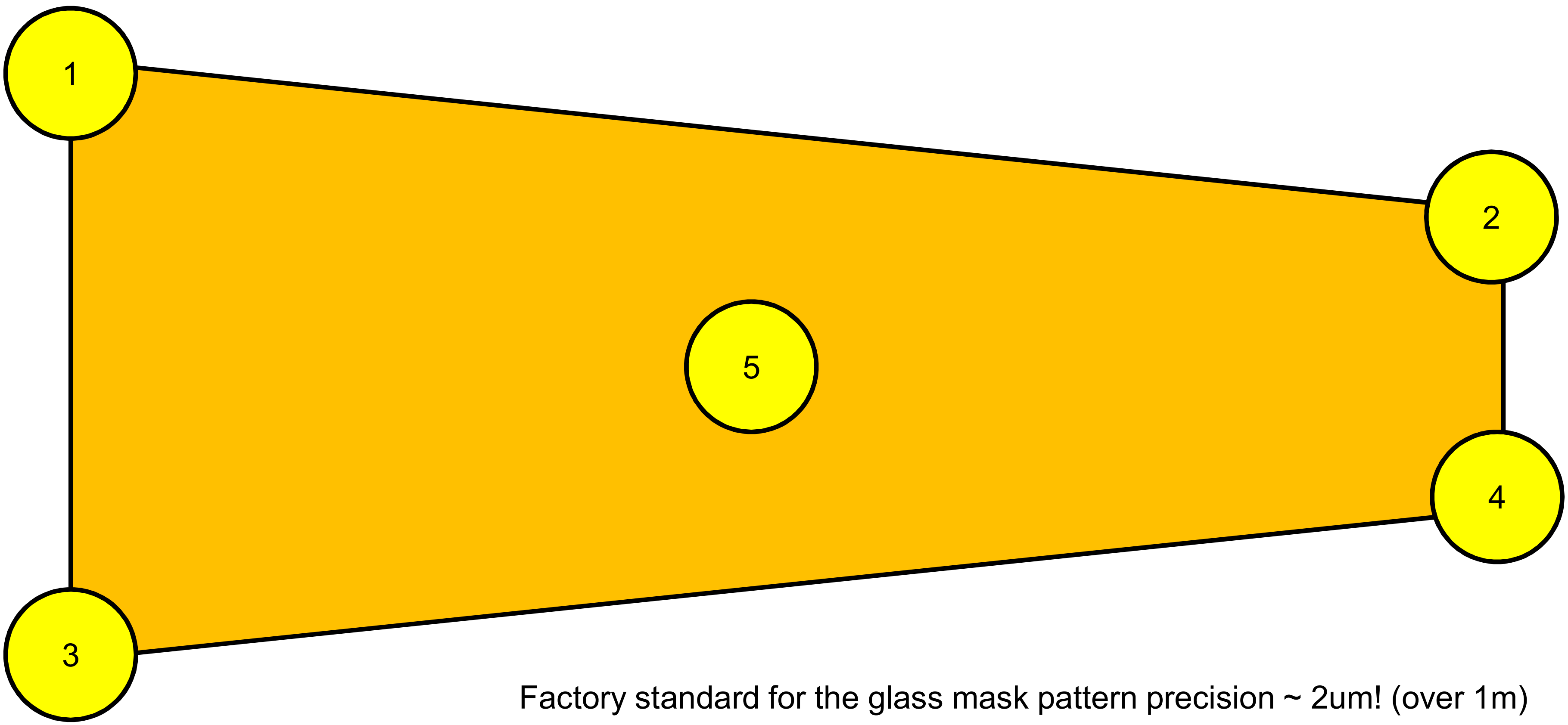
Top & bottom mask alignment

- 4-view bifocal microscope is used to align the top & bottom masks



Mask alignment results

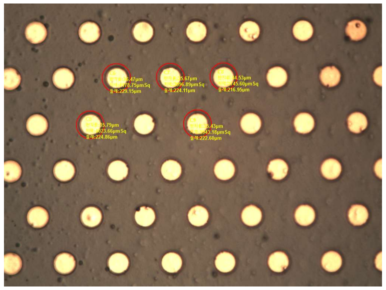
- 1,2,3,4,5 are aligned almost perfectly
  - residual misalignment is less than 3 micron
    - hard to identify any misalignment in microscope image.



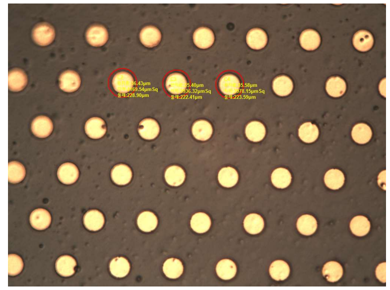
Factory standard for the glass mask pattern precision ~ 2um! (over 1m)

Top view

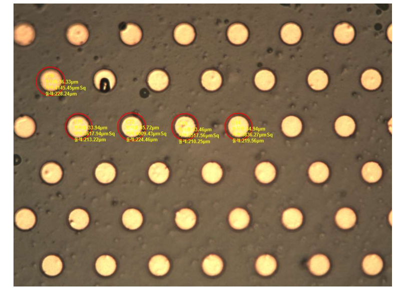
After DFR film development



left

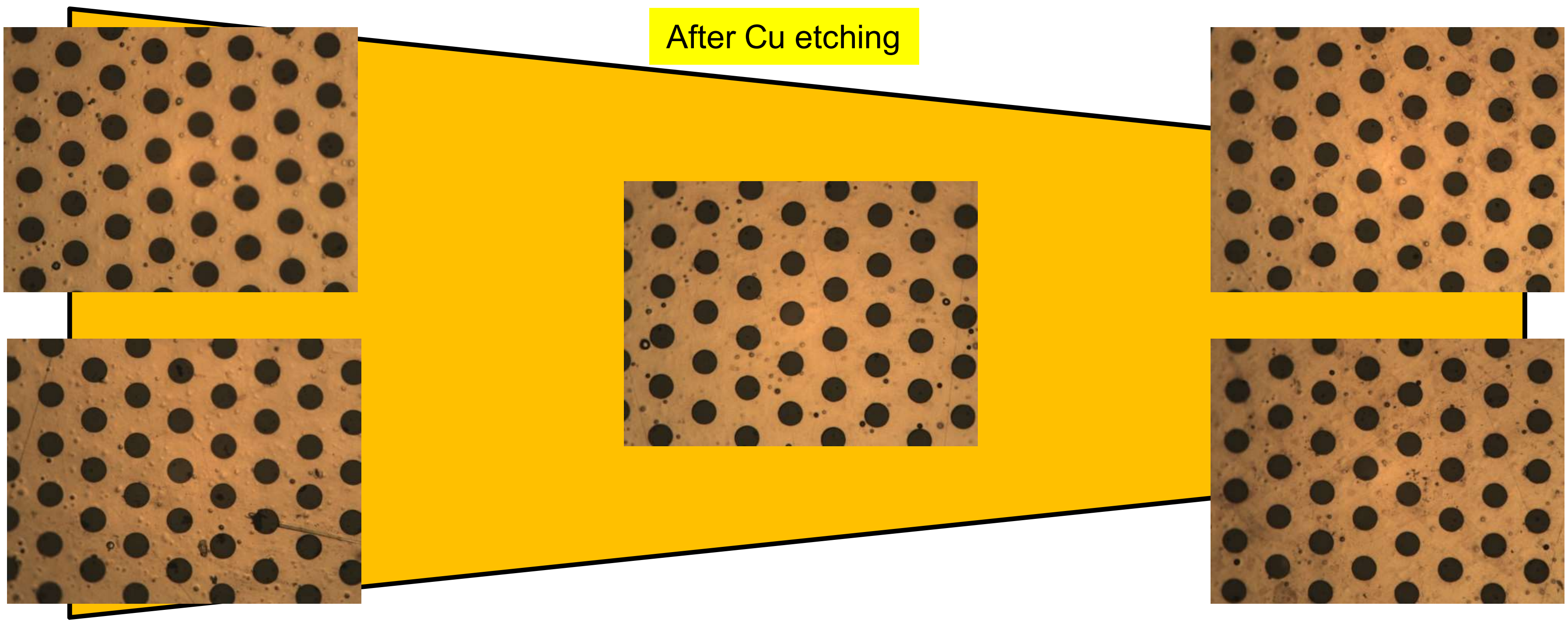


center

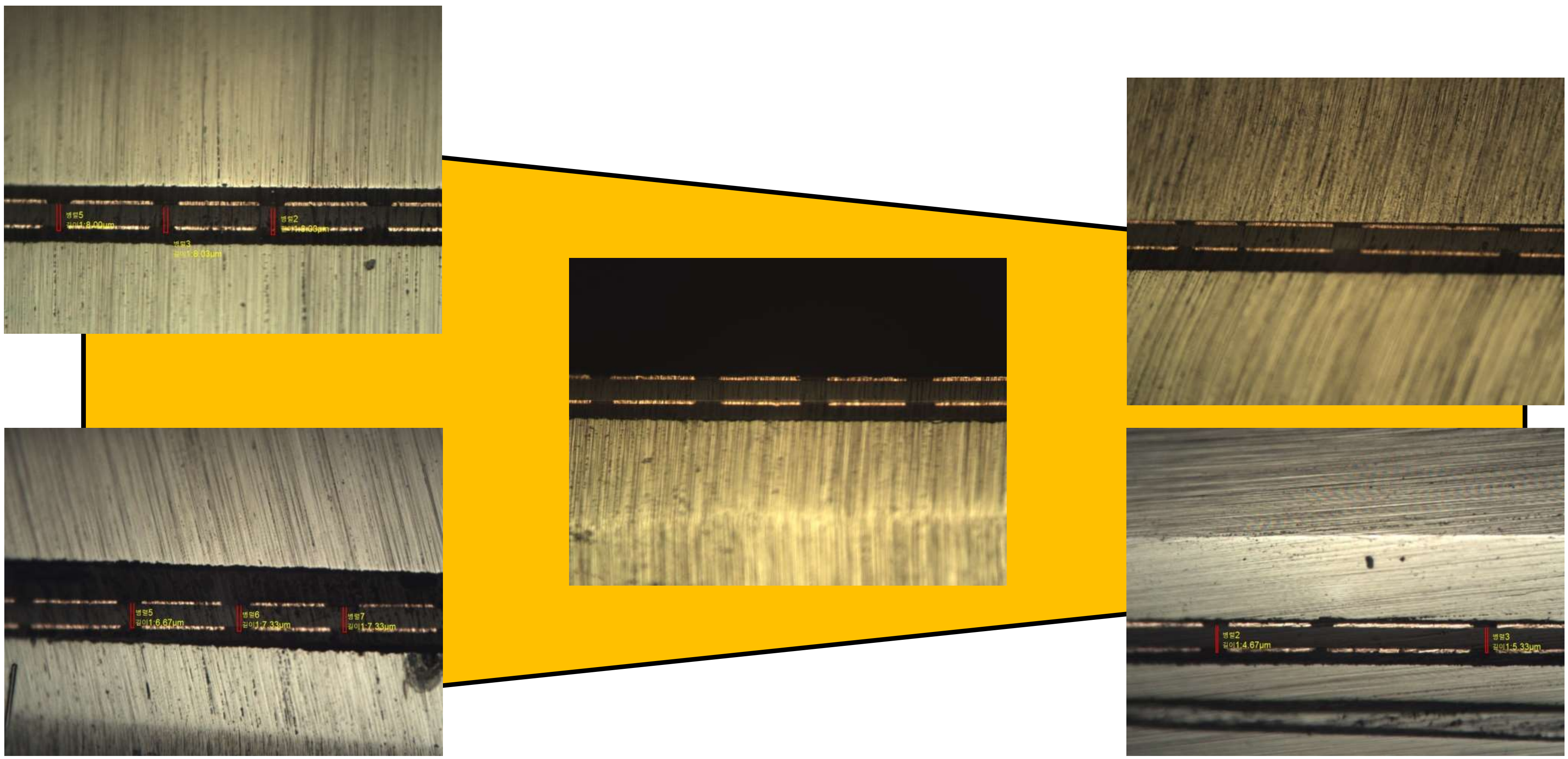


right

After Cu etching



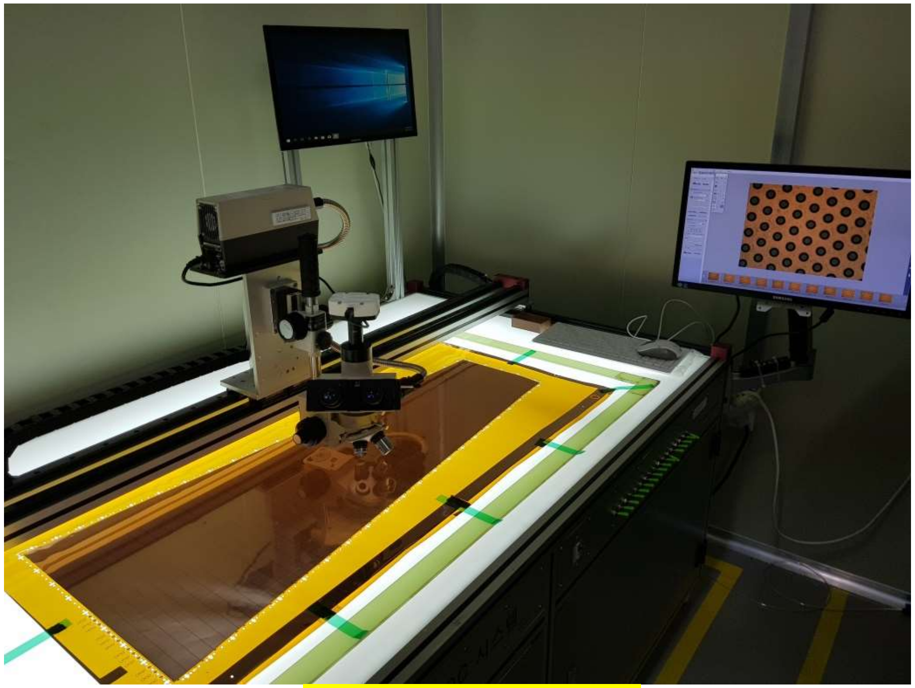
cross-sectional view



QC at MECARO


RH: 45%, HV: 507V
Impedance: 10.5 Gohm
507
10.5
25.2℃
45
TEST
Megger MIT410/2

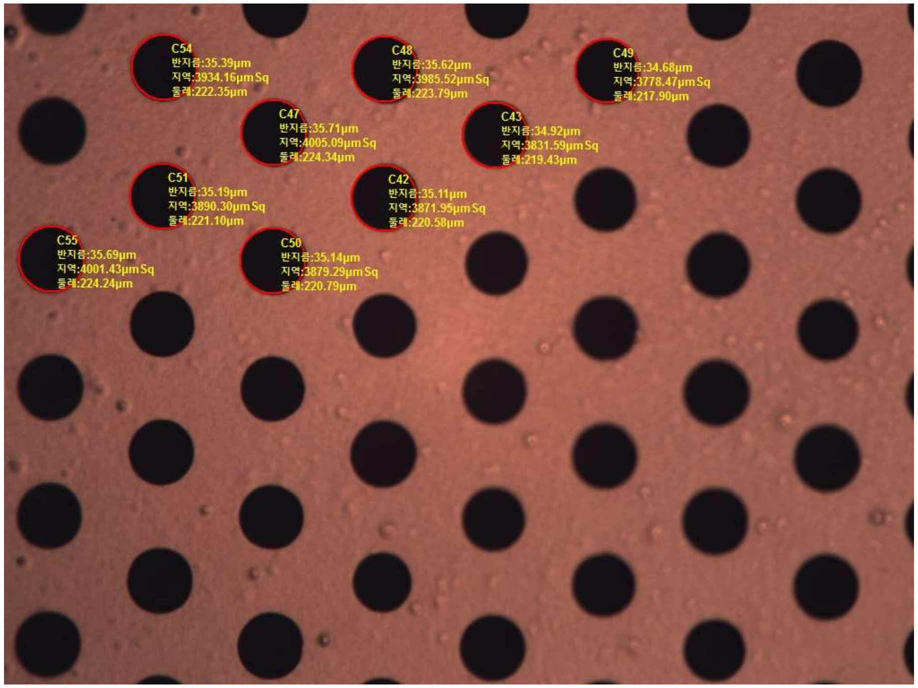
Final QC before shipping

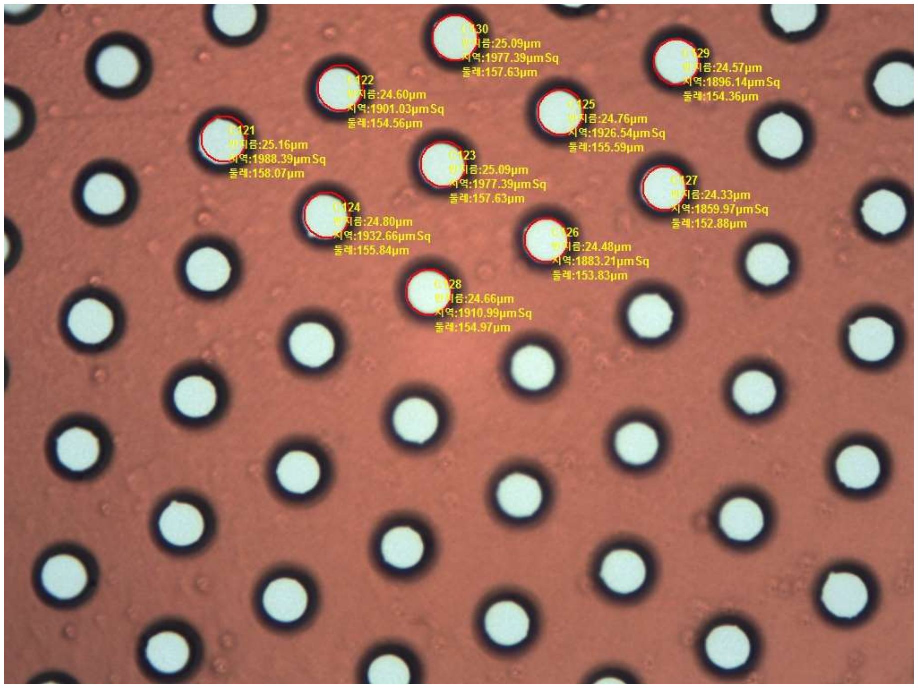


Optical Inspection

Leakage current measurement

QC1: Optical inspection





- **Outer hole sizes are 68 ~ 72 um. (goal was 70um)**
- **Inner hole size are 48 ~ 52 um. (goal was 50 um)**

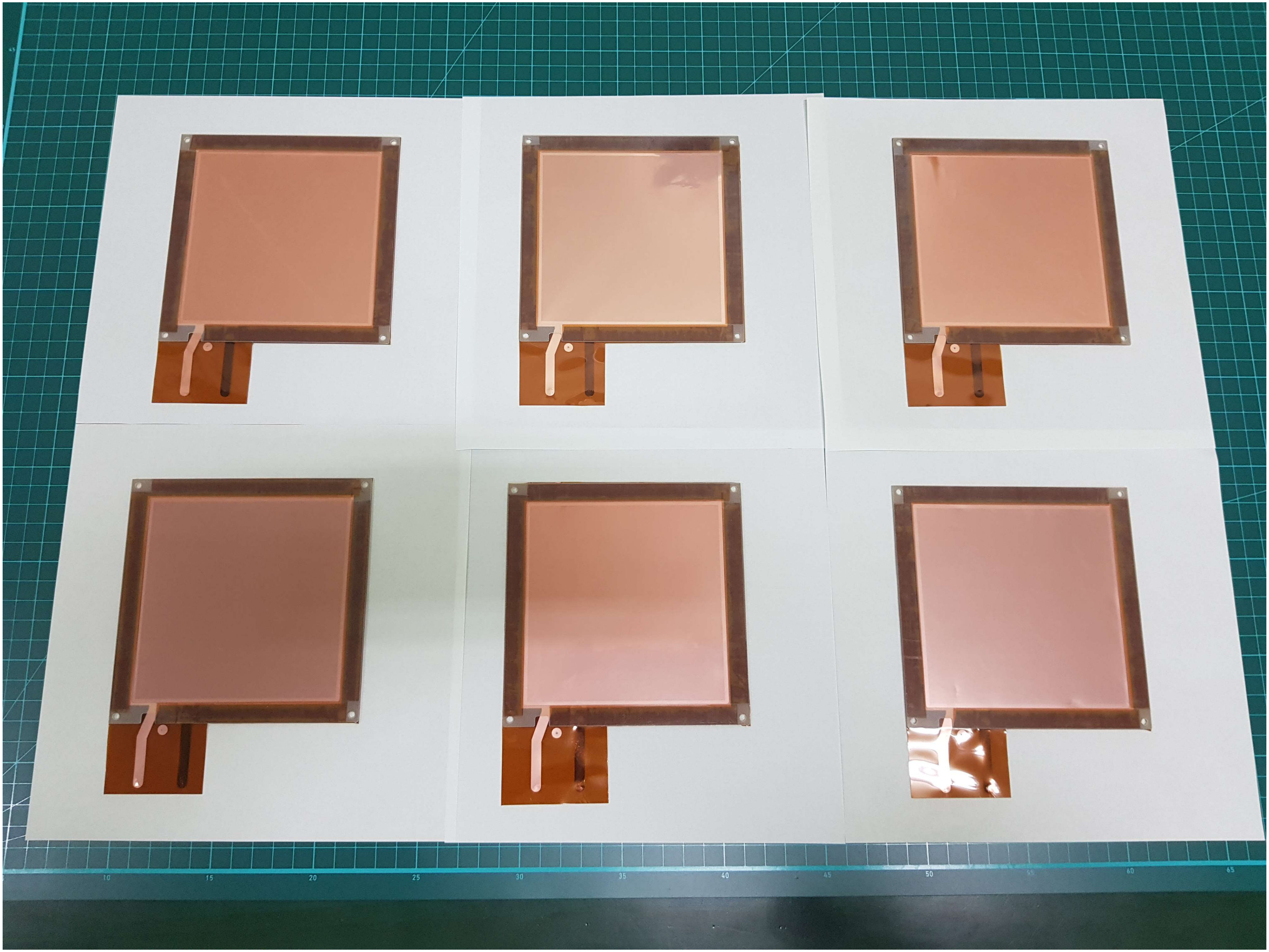
QC2: Leakage current test

SAMPLE NAME	VOLTAGE	IMPEDENCE (HUMIDITY)	LEAKAGE CURRENT	HOLE SIZE (OUTER/INNER)	NB
A	500V	20~21 Gohm (45%)	23~24 nA	70um / 50um	
B	500V	24~25 Gohm (45%)	20 nA	70um / 50um	
C	500V	27~28 Gohm (45%)	17~18 nA	70um / 50um	
D	500V	13~15 Gohm (45%)	30~40 nA	70um / 50um	
E	500V	13~15 Gohm (45%)	30~40 nA	70um / 50um	
F	500V	13~15 Gohm (45%)	30~40 nA	70um / 50um	
G	500V	13~15 Gohm (45%)	30~40 nA	70um / 50um	
H	500V	13~15 Gohm (45%)	30~40 nA	70um / 50um	
I	500V	13~15 Gohm (45%)	30~40 nA	70um / 50um	
J	500V	13~15 Gohm (45%)	30~40 nA	70um / 50um	
K	500V	10~11 Gohm (45%)	45~50 nA	70um / 50um	
L	500V	13~15 Gohm (45%)	30~40 nA	70um / 50um	Over Cleaning
M	500V	13~15 Gohm (45%)	30~40 nA	70um / 50um	1 Section Defect
N	500V	2~3 Gohm (45%)	150~200 nA	70um / 50um	1 Section Defect

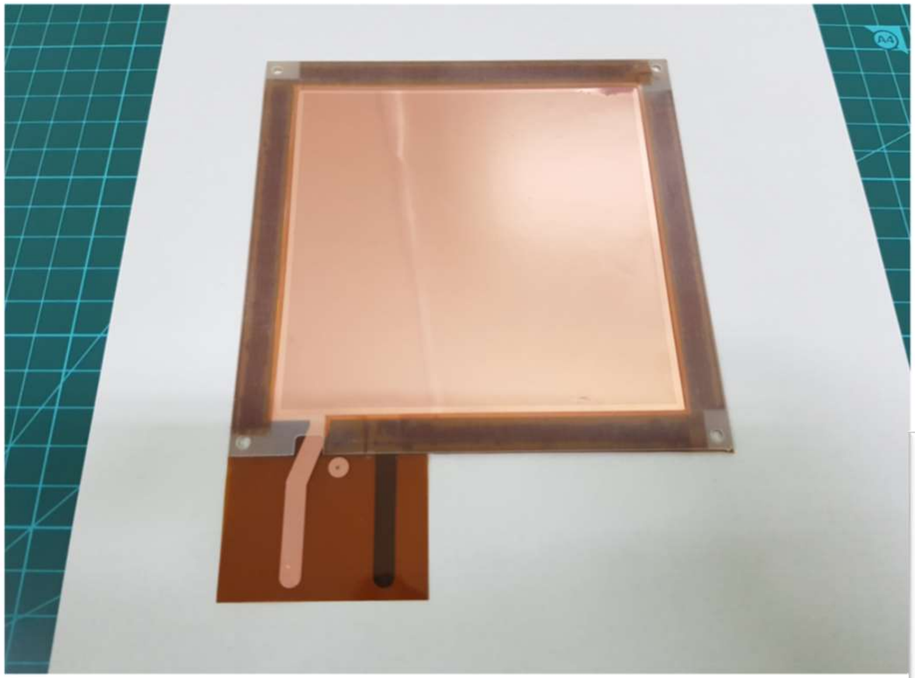
Package and ship to CERN

- **Hard cases were used, between GEM sheets and seats, anti-static film, shock absorber and polycarbonate.**

Standard size (100 x 100)
GEM foil production & tests



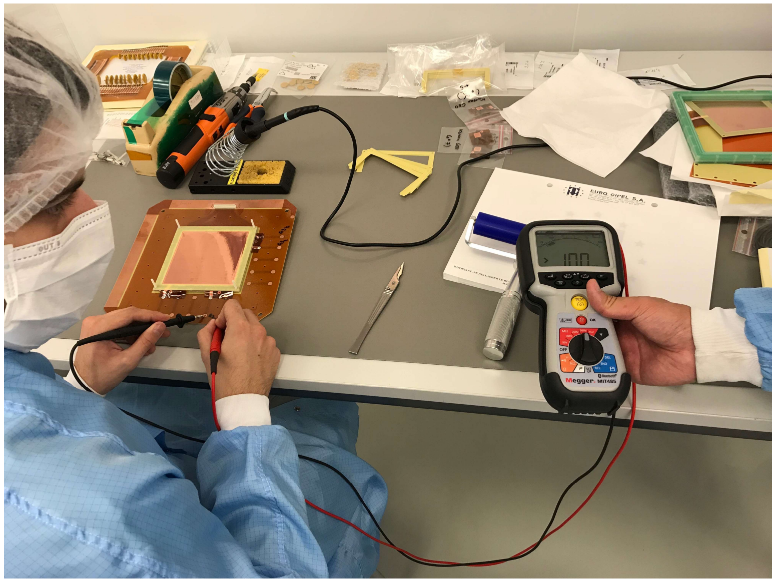
Mass production is ready

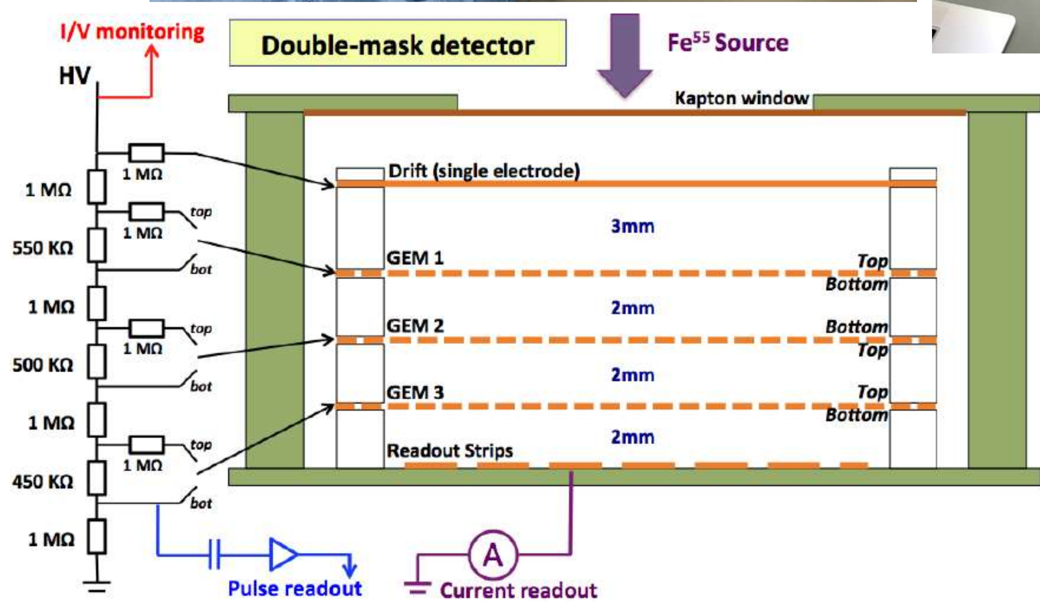


Stacking 5 GEMs

Packing for a set of 5 GEMs

Chamber assembly & test

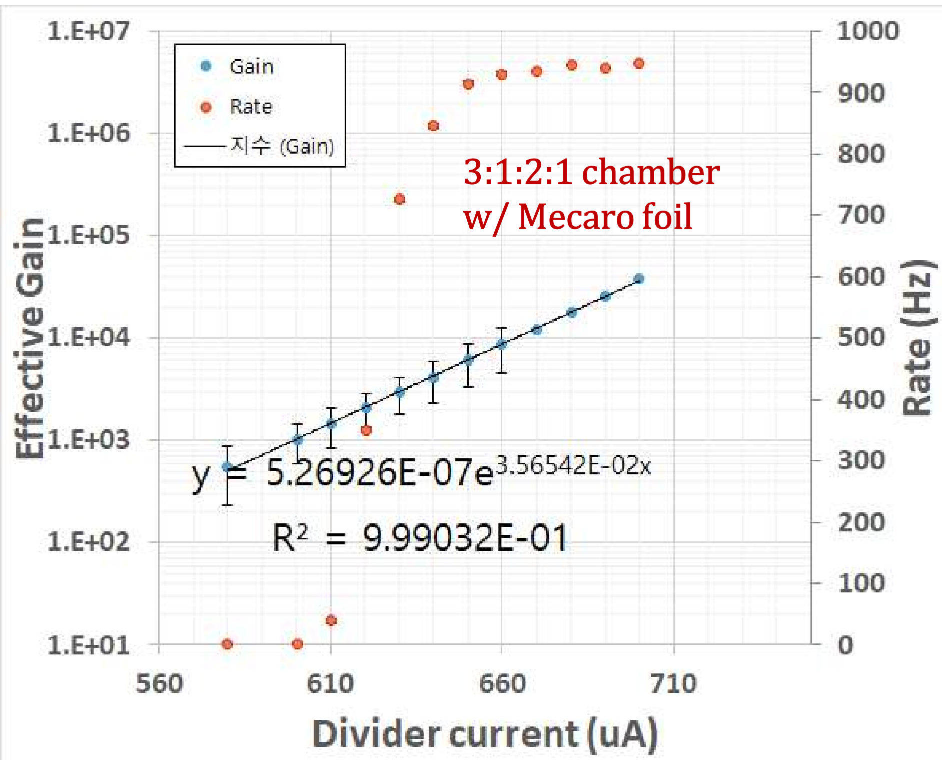


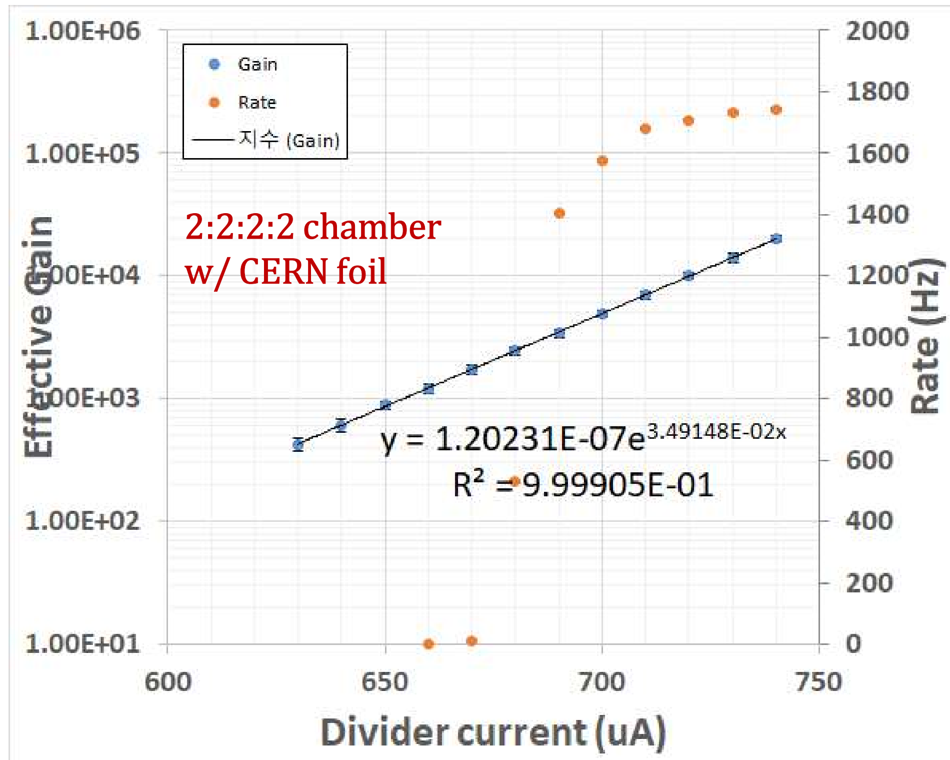


*GEM foils produced in 2015

Gain measurement

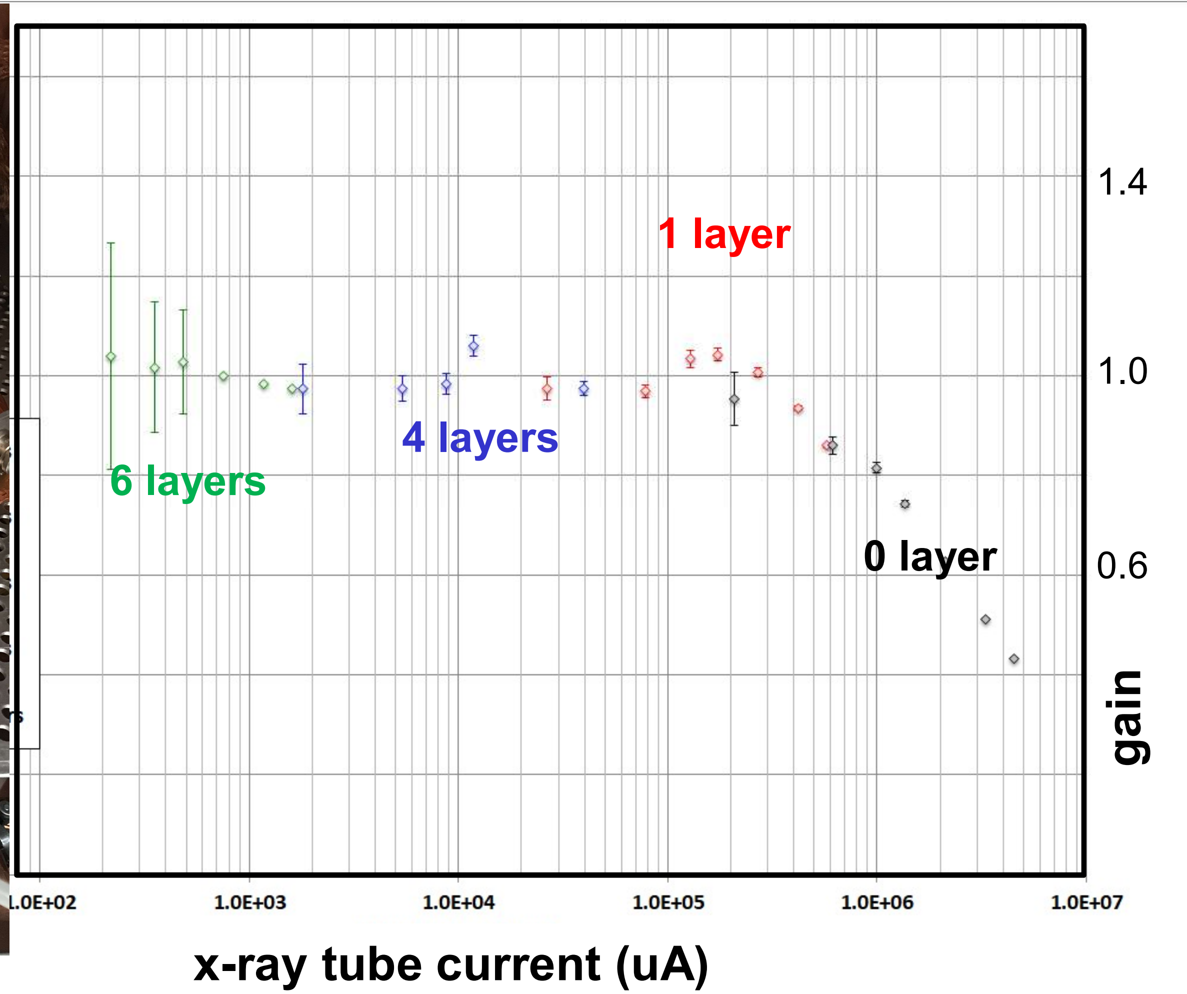
- ❑ **MECARO foil chamber (3mm:1mm:2mm:1mm)**
  - ○ **Gain** ~ 10^4 **at** $V_{GEM} = 330\ V$
- ❑ **CERN foil chamber (2mm:2mm:2mm:2mm)**
  - ○ **Gain** ~ 10^4 $V_{GEM} = 360\ V$





Rate test

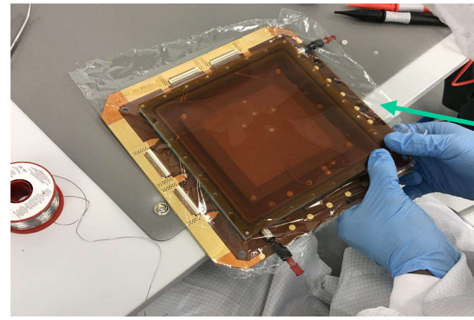
Rate capability is the most important factor of GE11 project, as the GE11 will be installed in high flux region around beam pipe. Maximum expected rate can be $\mathbf{5 \times 10^1} \boldsymbol{Hz\ mm^{-2}}$

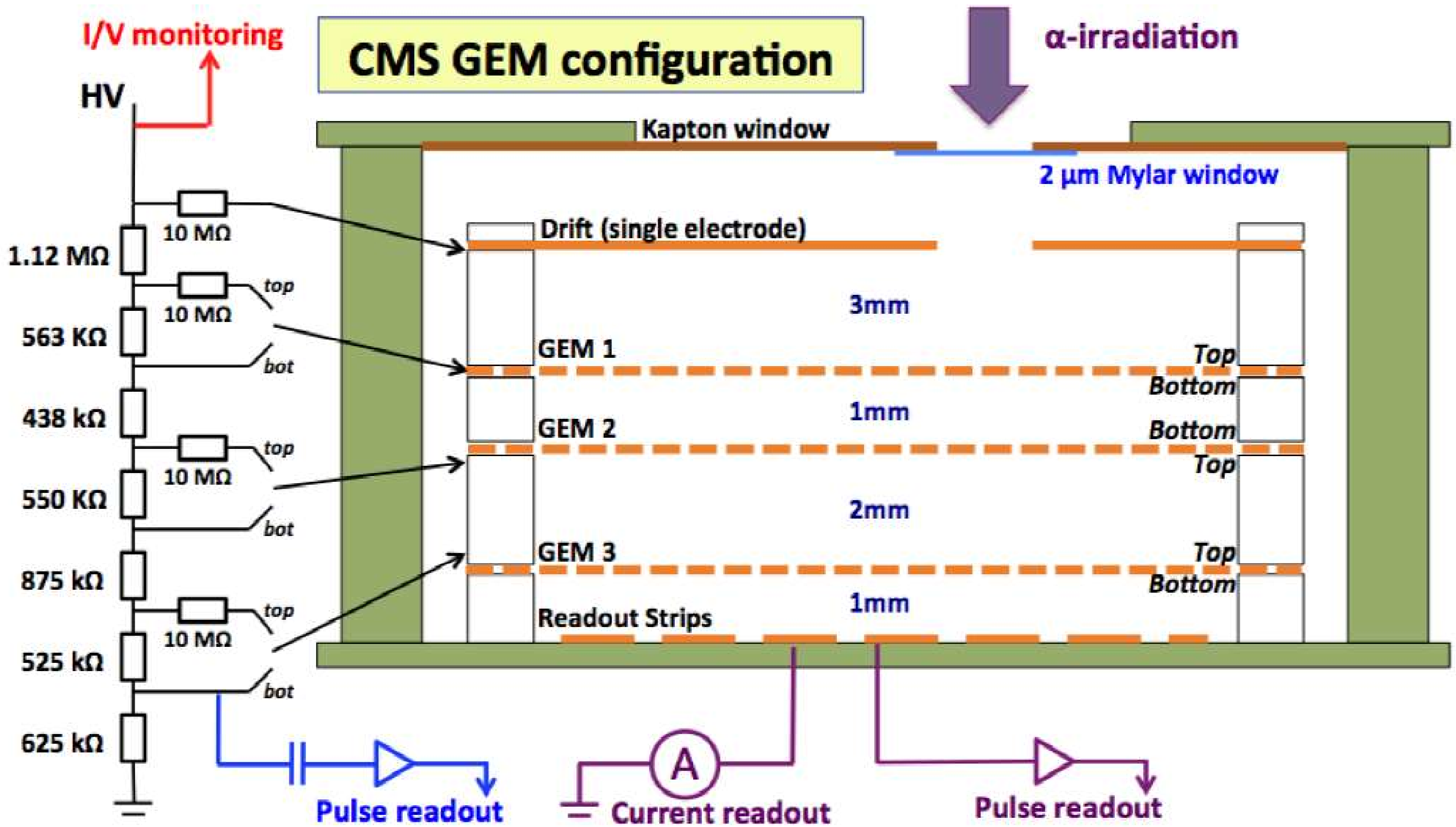


Flux = counts/60 s/3.14 mm^2

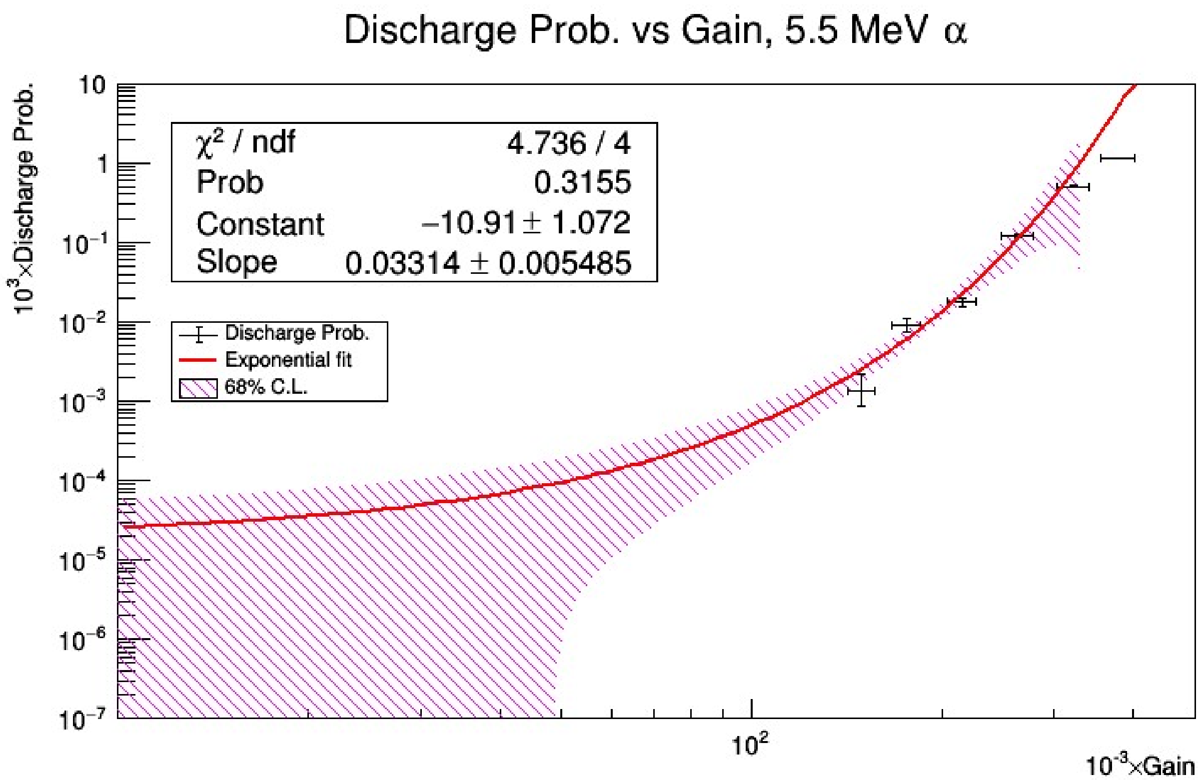
Discharge test

To make intentional discharge, α from ^{241}Am is irradiated to the chamber





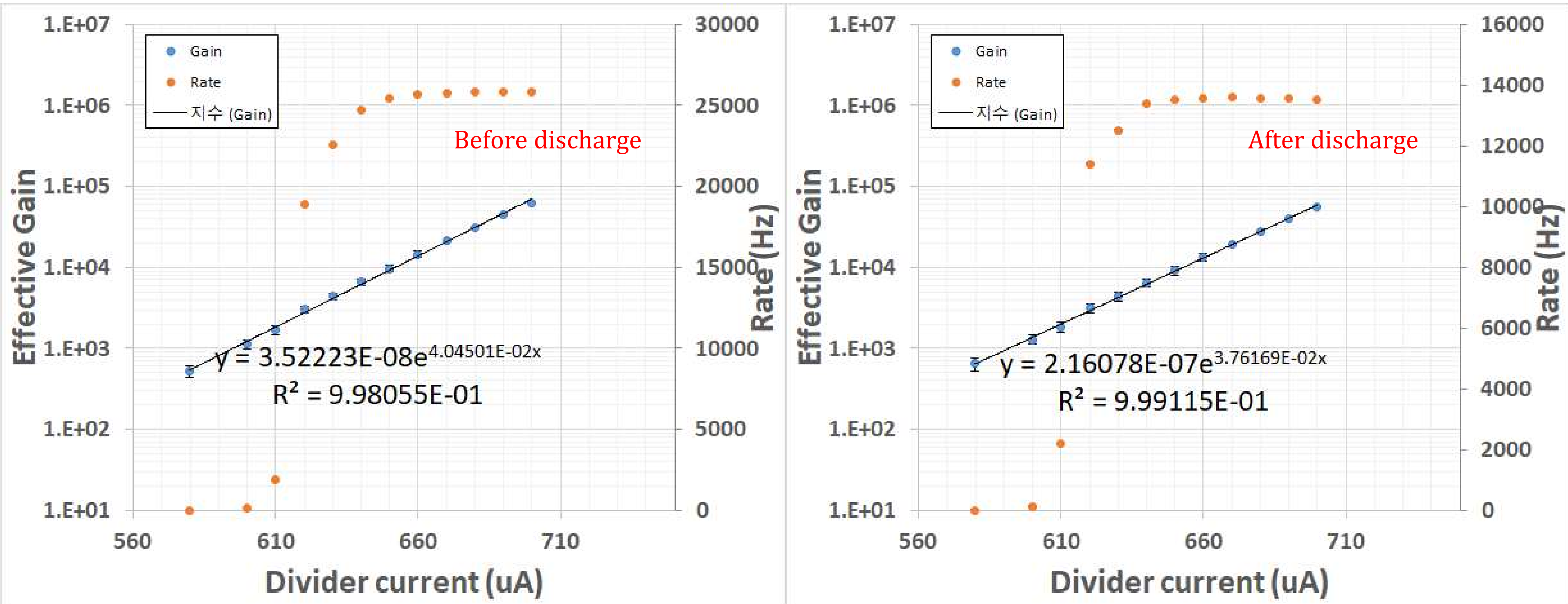
Chamber tests at CERN



At $\boldsymbol{gain = 1 \times 10^4, Prob. = 2.5 \times 10^{-5} + 3.2 \times 10^{-5}}$
At $\boldsymbol{gain = 2 \times 10^4, Prob. = 3.5 \times 10^{-5} + 4.2 \times 10^{-5}}$

For MIP, discharge Prob. is 1/100 times smaller

gain degradation before/after discharge

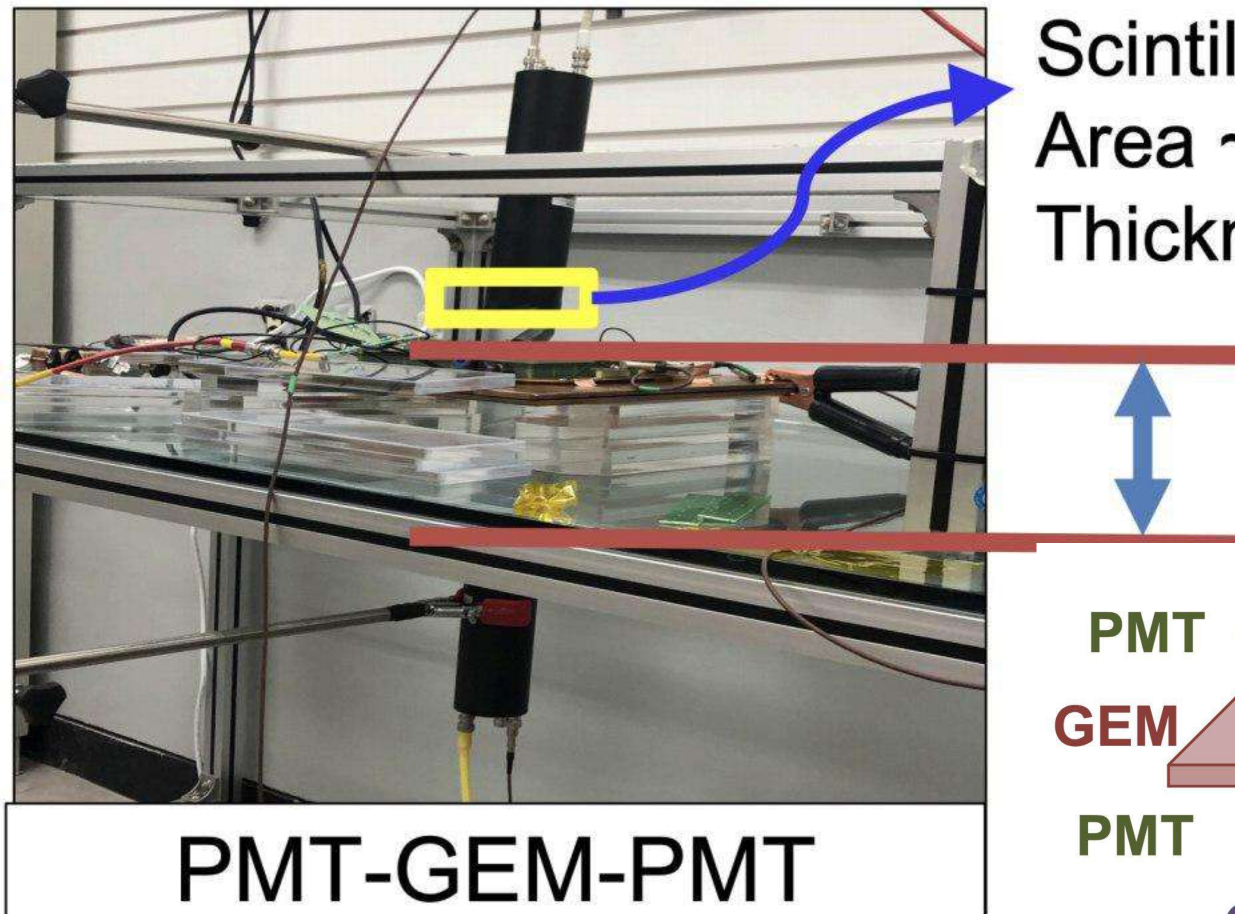


During the measurement, we've observed at least 15,000 discharges.
However no degradation of chamber performance is observed.

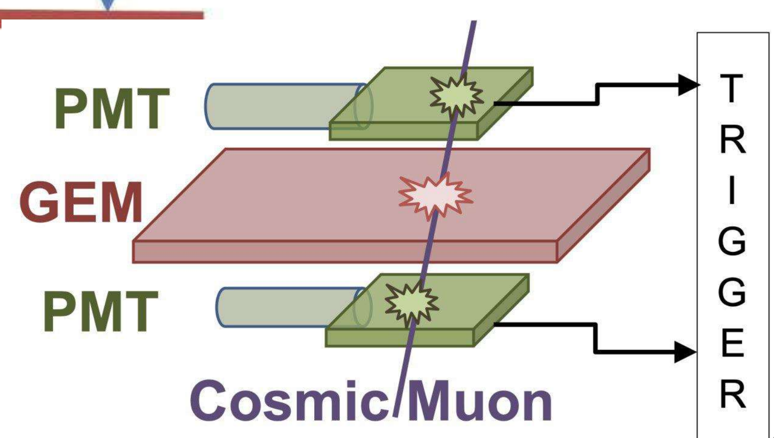
Local lab activities
(mostly student projects)

Cosmic muon efficiency

- **Efficiency ~ 80% (>95% with PreAmp)**
  - **need to fix light shielding, ground, etc. to reach 98%**

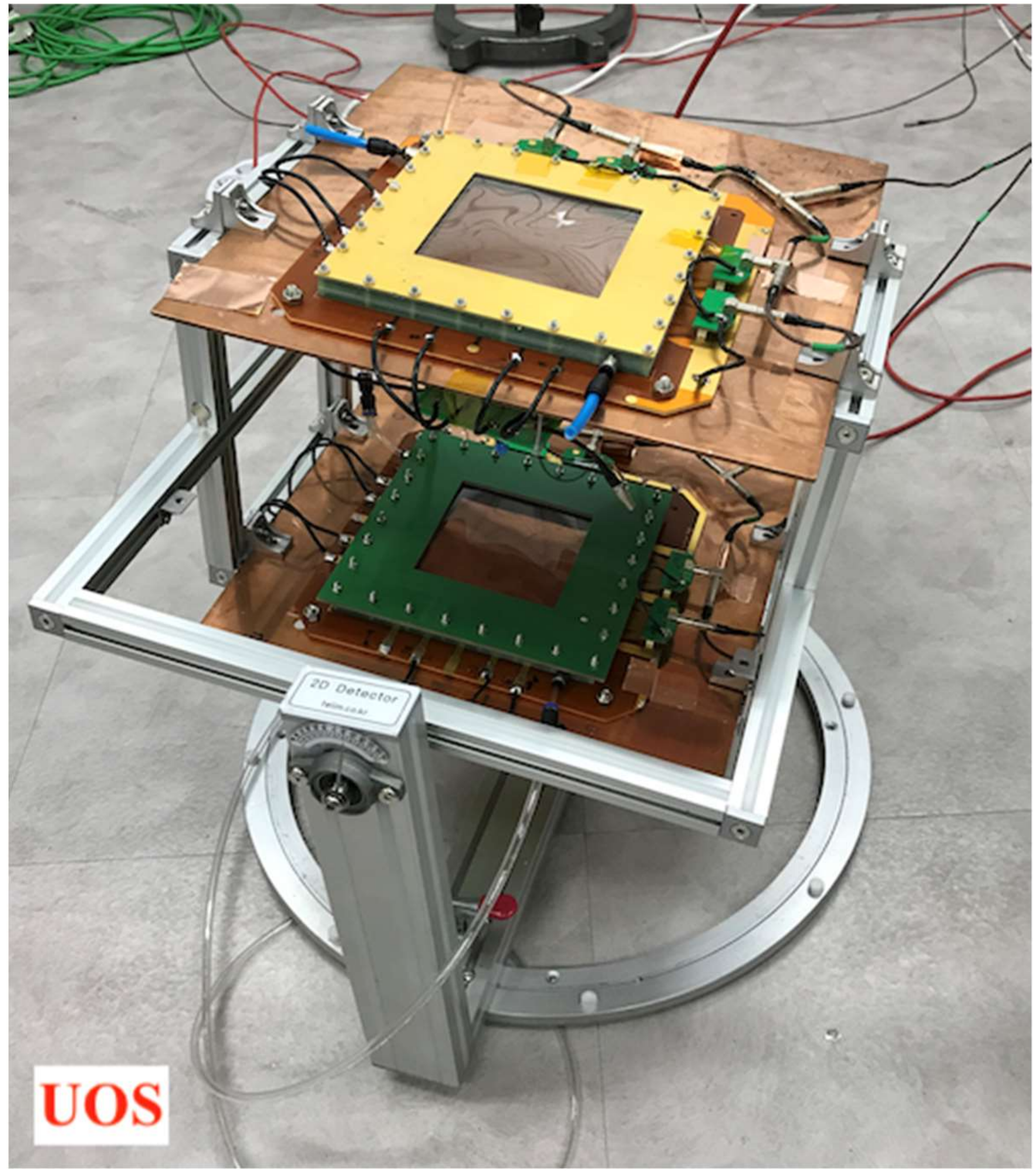


Scintillator
Area ~ 40 cm^2
Thickness ~ 1.5 cm



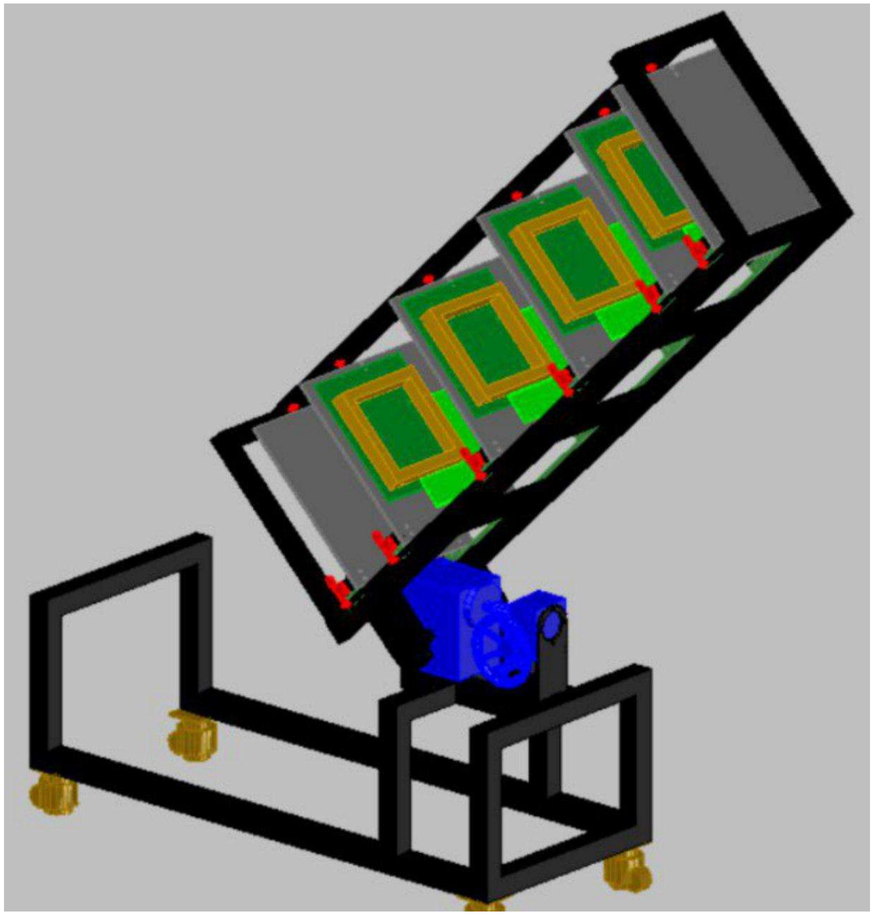
Student project: Cosmic ray scanner

- **Double layer 2D-GEM detector**
  - **2d-strip readout (x,y)**
  - **measuring θ and ϕ**
    - **prove $\cos^2\theta$ distribution**

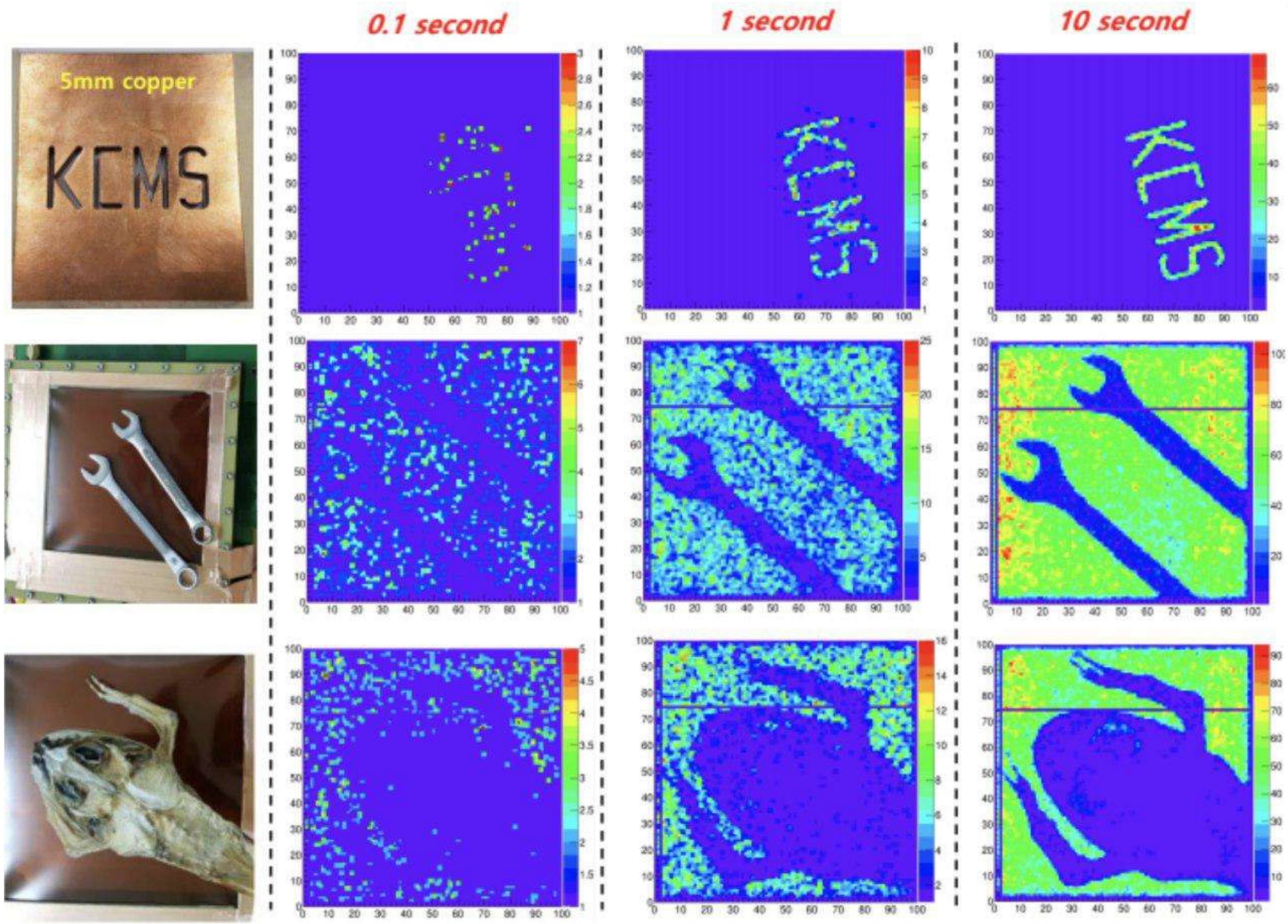


Muon telescope & scanner

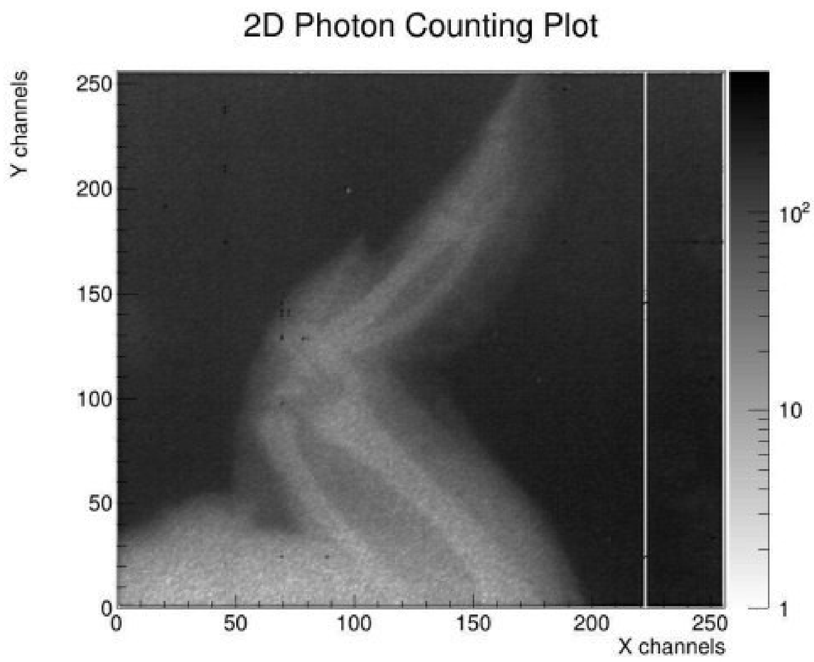
- Aiming for
  - volcano scanning for Mt. Bakdu
  - muon scan for nuclear reactor watch



X-ray imaging (using Fe55 source)



More X-ray imaging

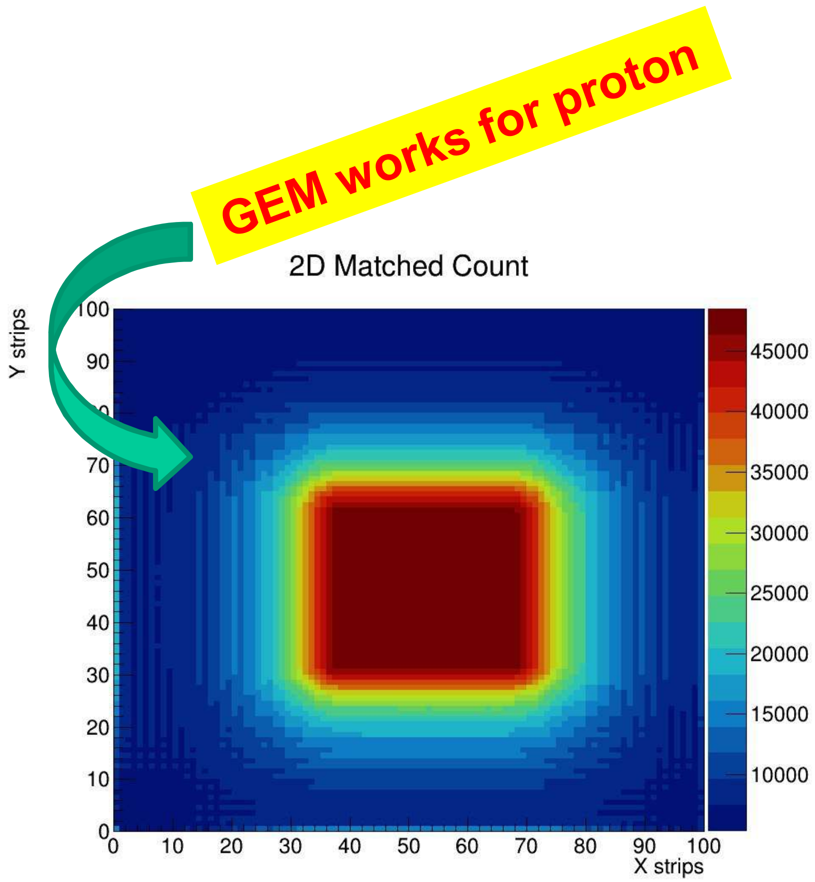


- KCMS + MECARO engineers made a fully functional X-ray imaging GEM camera.

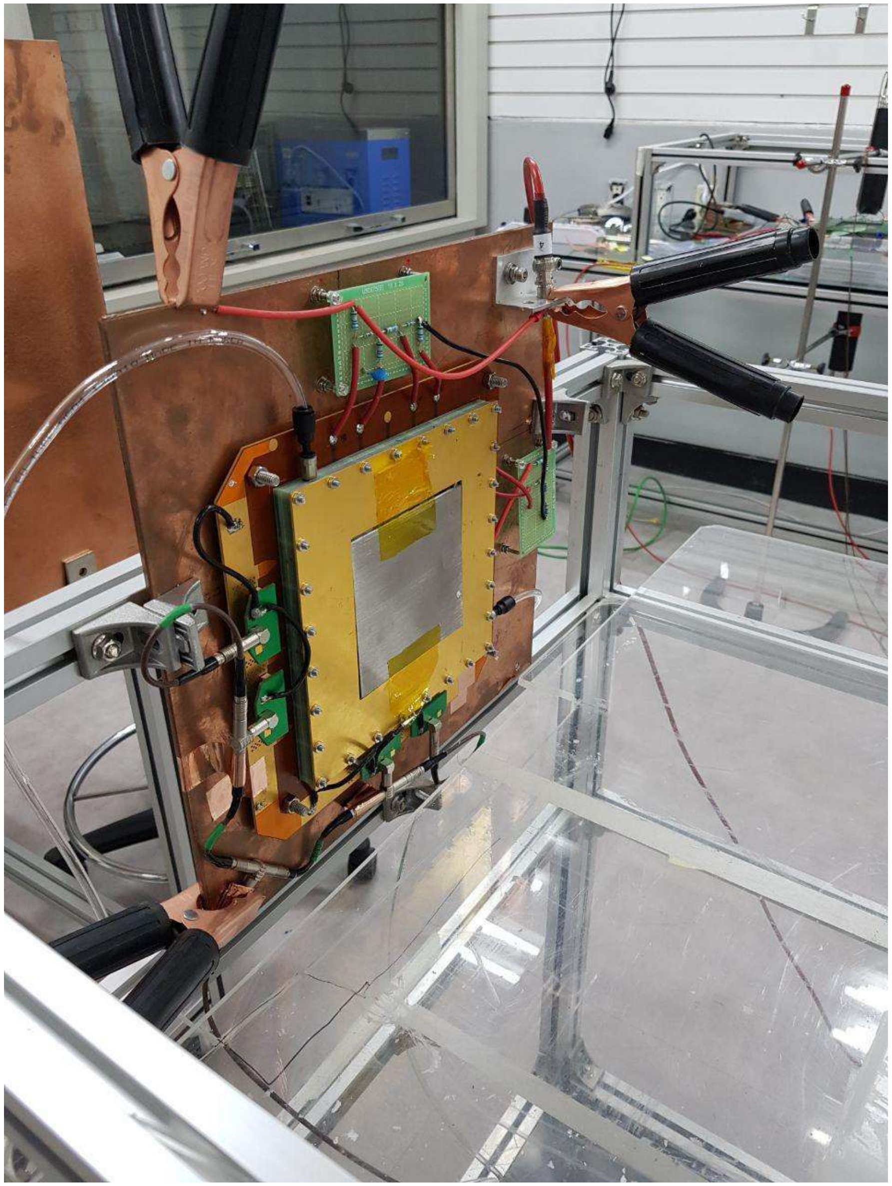
Proton beam monitor

❑ Work with National Cancer Center of Korea

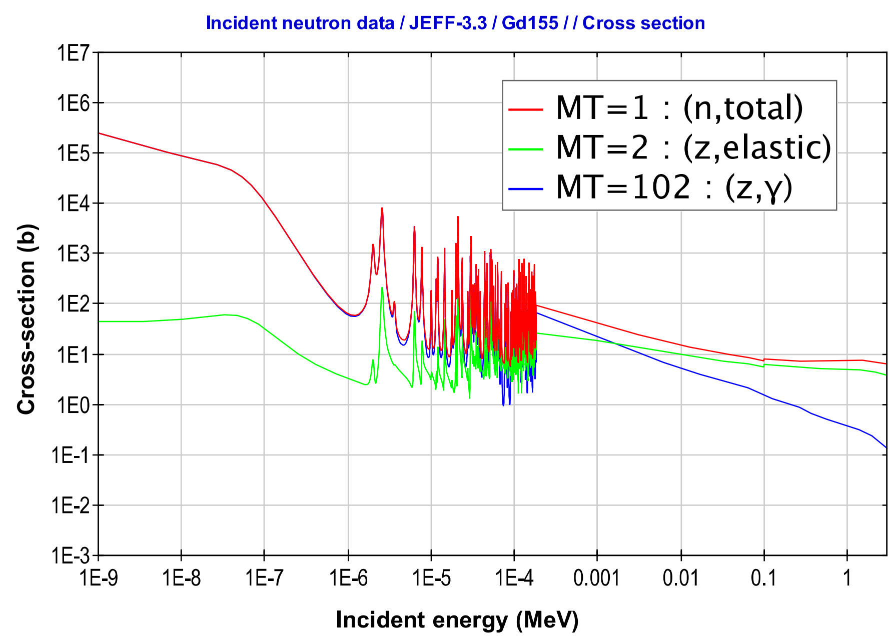
- proton beam QC
  - 230 MeV proton beam



Neutron detector (Gd plate converter)



- **Gd plate cathode**
  - **cold neutron sensitive detector**
    - **need neutron source!**



backup