Aging Effects in COMPASS PixelGEM Detectors

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HadronPhysics I3

Study of Strongly Interacting Matter

MLL

COMPASS at CERN

COmmon **M**uon and **P**roton **A**pparatus for **S**tructure and **S**pectroscopy

- p up to 400 GeV
- secondary hadrons (π, K, ...): $2 \cdot 10^7$/s
- tertiary μ (polarized): $4 \cdot 10^7$/s

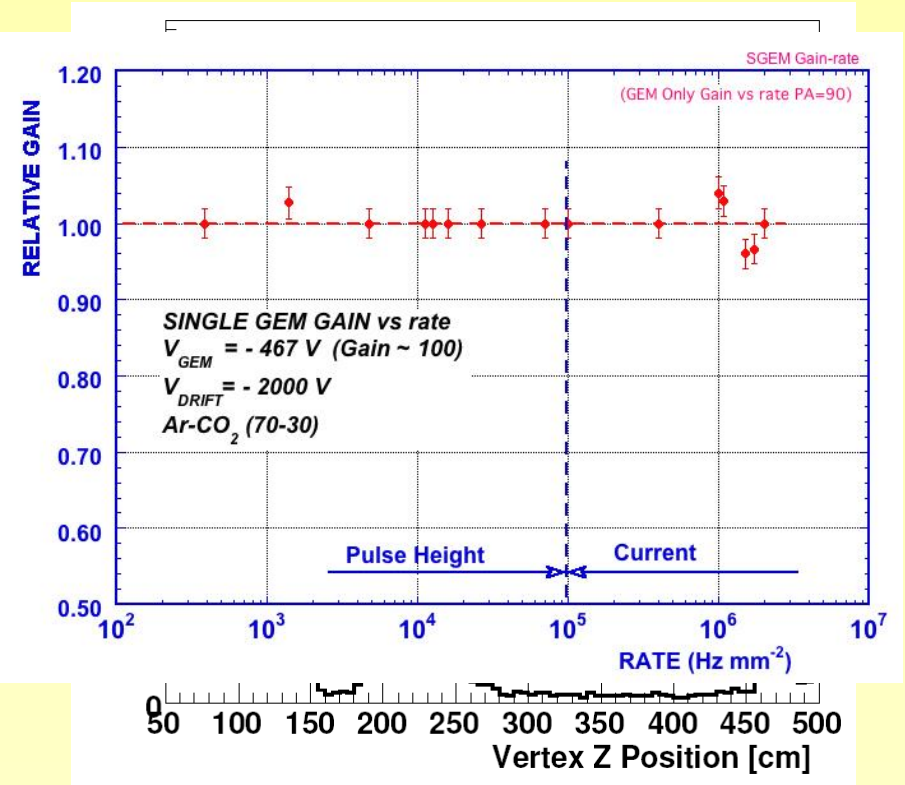
Beam Tracking in COMPASS

Hadron beam:

- Intensity 10^7 s^{-1}
- Local flux density $>10^5$ $mm^{-2}s^{-1}$
- SciFi ⇨ act as secondary target

$x/X_0 = 1.6\% - 2.8\%$

$x/\lambda_I = 0.9\% - 1.5\%$



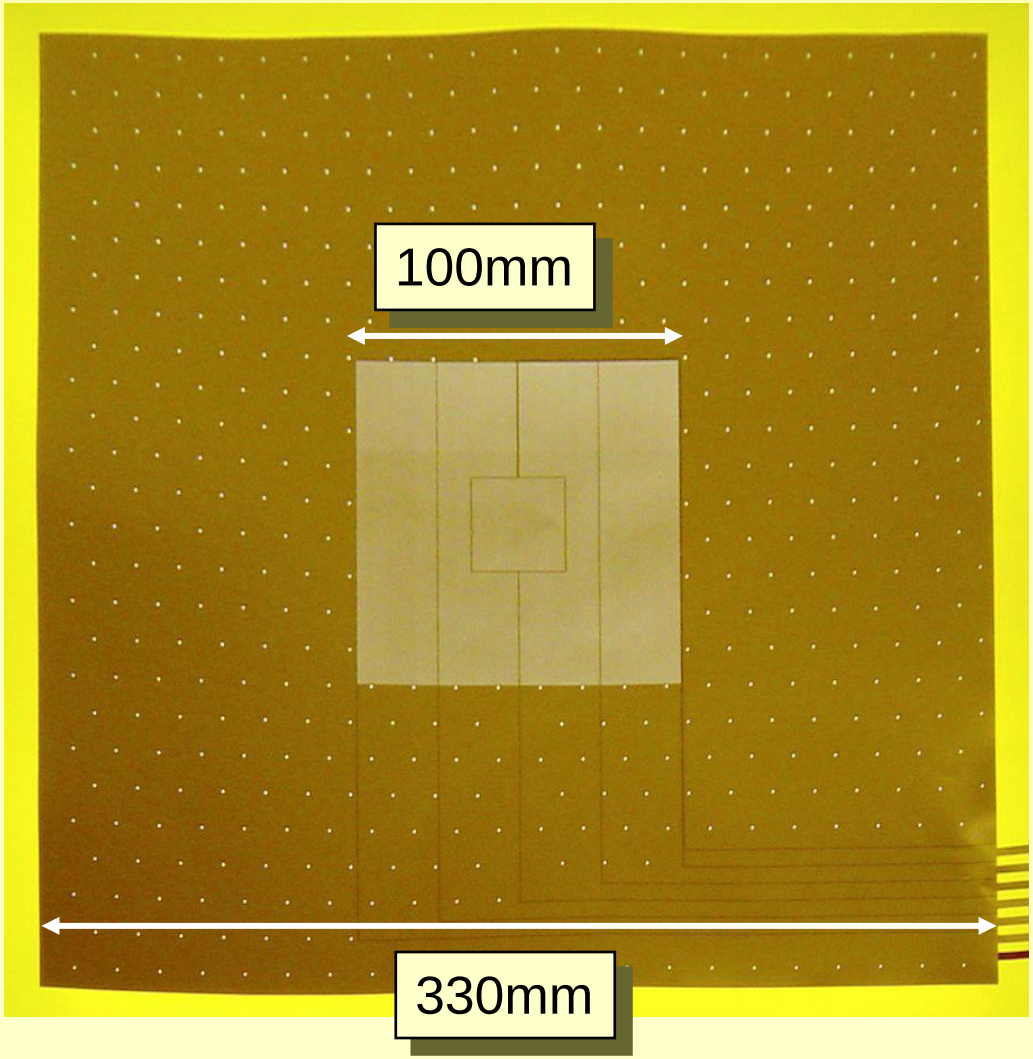
Beam tracking with GEMs?

- GEM material budget 0.4% X_0
- Rate capability > 10^5 $mm^{-2}s^{-1}$
- Strip occupancy too high!

Combined pixel / strip readout

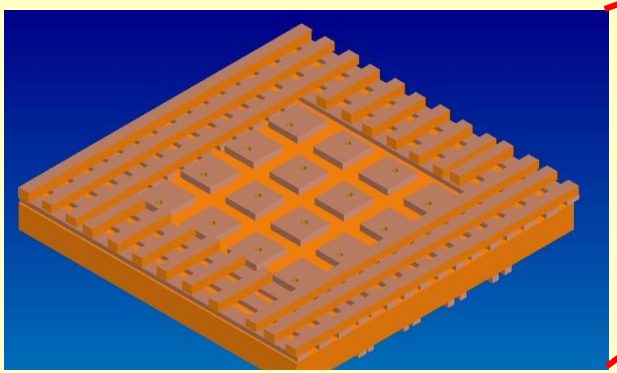
GEM Foils

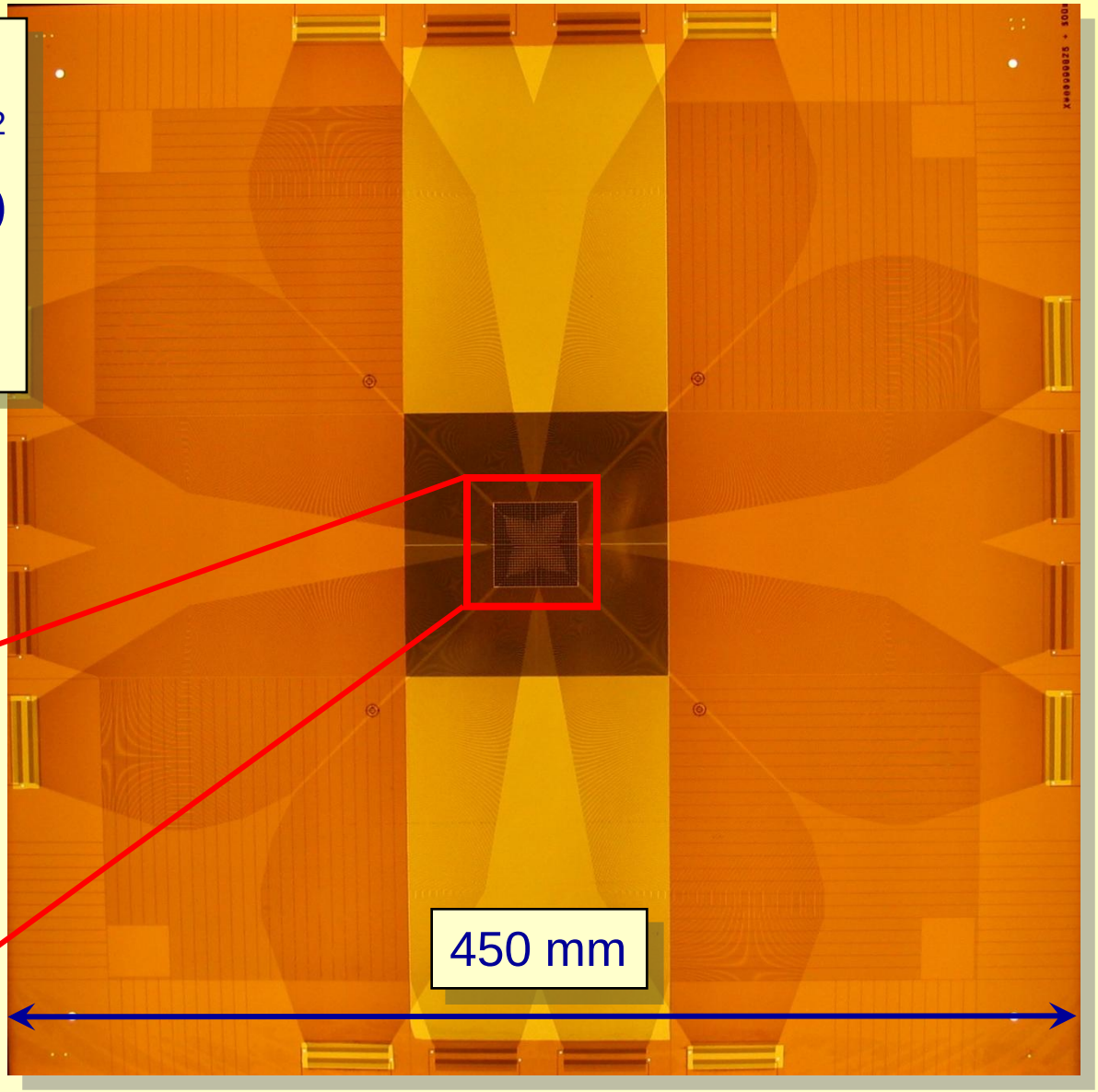
- triple GEM stack
- foils segmented on one side:
  5 sectors
- large holes for gas exchange in outer region, no gas amplification
- Cu thickness reduced to 1-2 μm



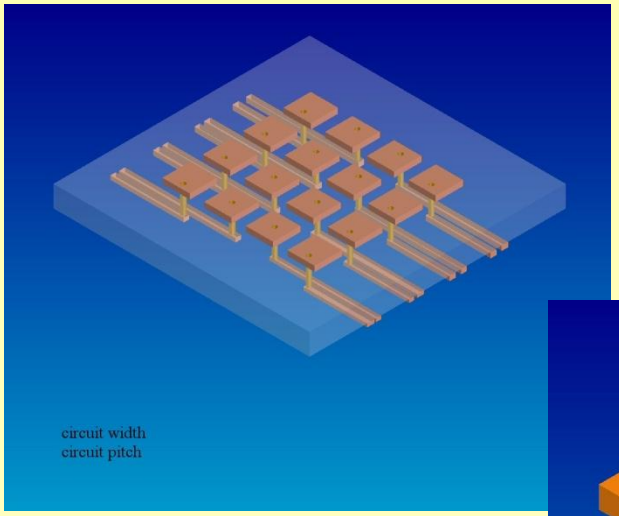
Readout Plane

- Pixel + strip readout
- Center: 32×32 pixels, 1 mm^2
- Periphery: 2×512 strips (2D)
- Readout electronics moved away from the beam

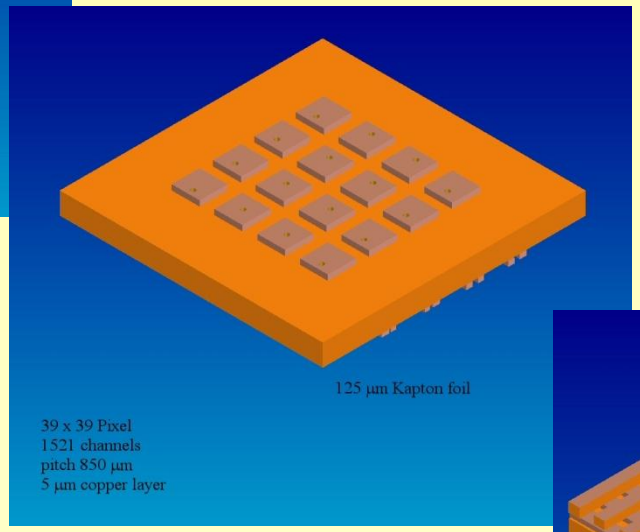


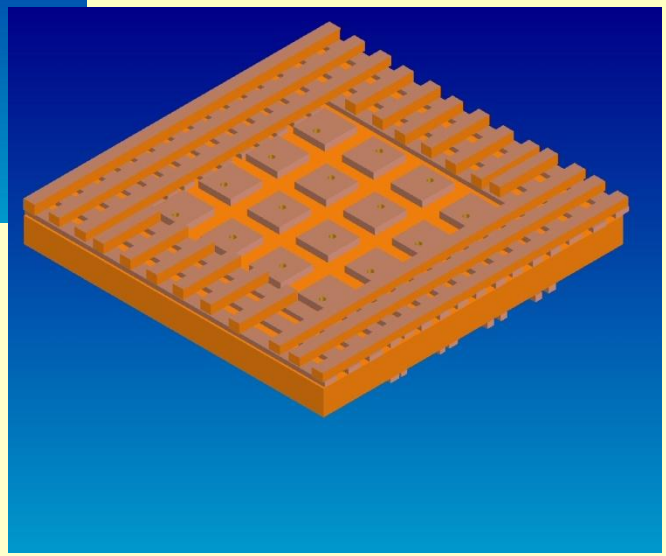


Readout Plane

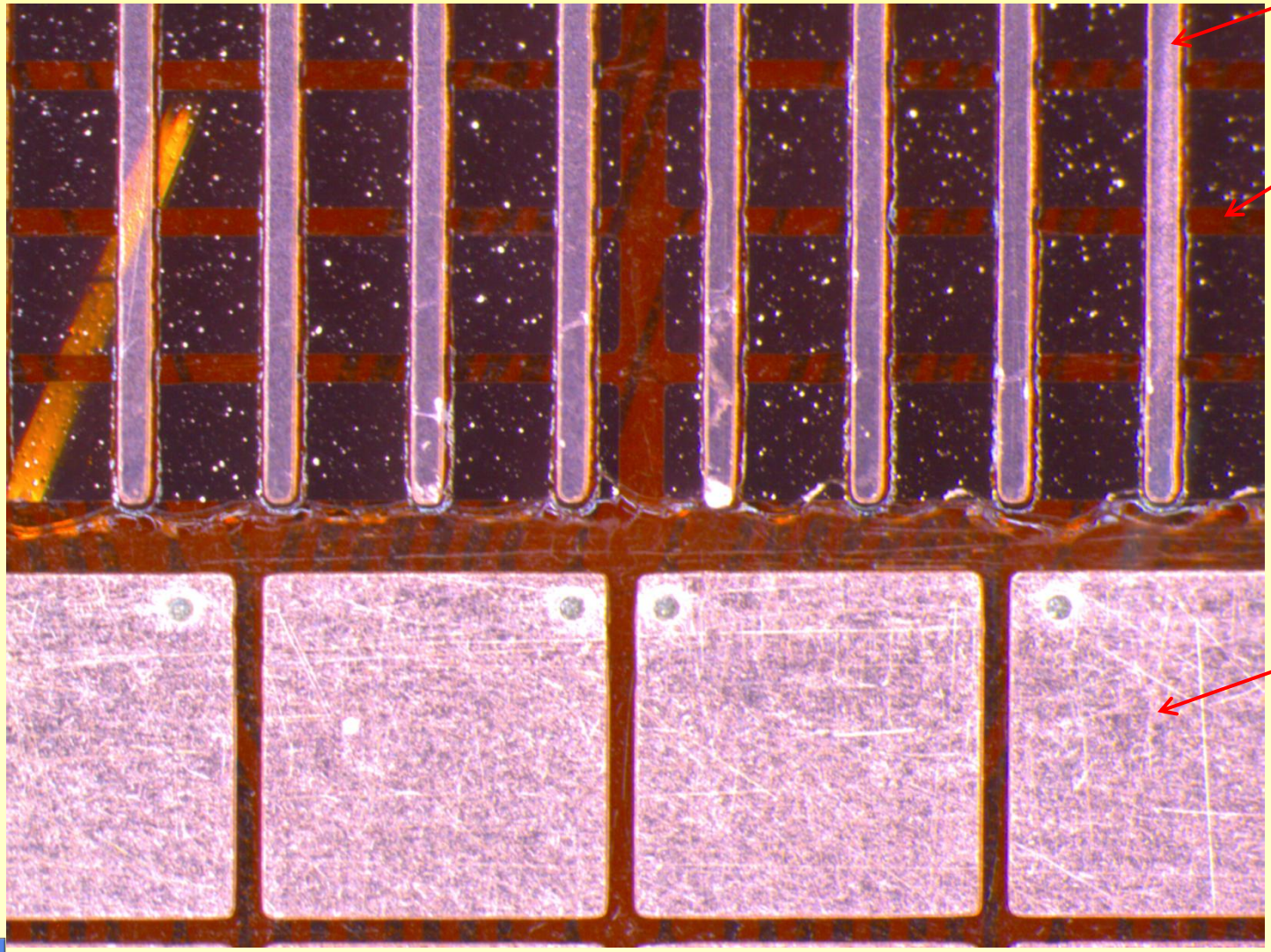


- Pixel plane: 2 layers (50µm)
- Strip plane: 2 layers (50µm)

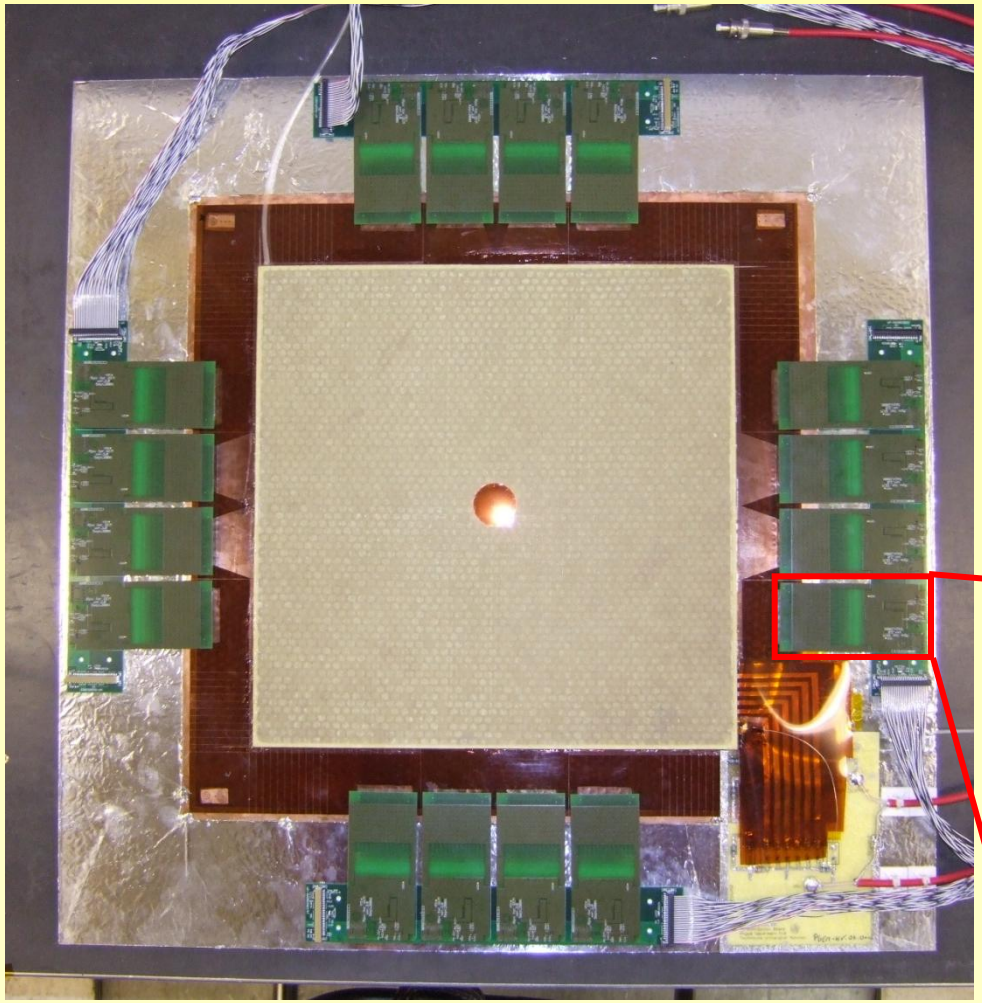




Readout Plane



PixelGEM Detector



Gas: Ar/CO_2 (70/30)

Discharge prevention:

triple GEM

asymmetric gain sharing

segmented GEM foils

Readout: analog sampling

APV25 + 10-bit ADC

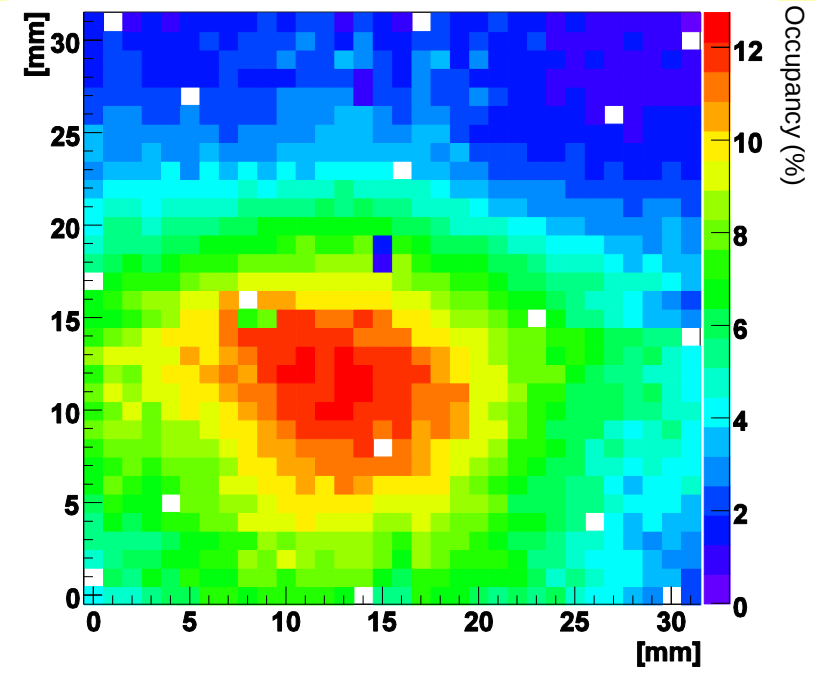
Material Budget

	Center x/X_0 (‰)	Periphery x/X_0 (‰)
Honeycomb support	0	2.94
Drift foil (5μm Cu / 1μm)	0.53 / **0.25**	
3 GEM foils (5μm Cu / 1μm)	2.09 / **0.75**	
Readout circuit	1.00	1.34
Gas	0.06	
Shielding	0.16	
Total	3.84 / **2.22**	7.09 / **5.48**

30% less interactions in passive material with **1μm Cu** layer

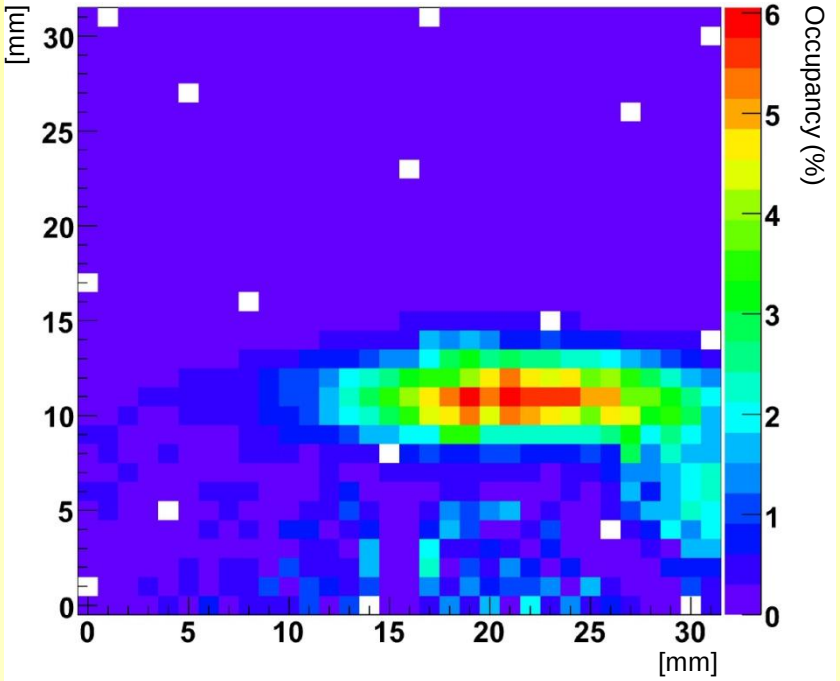
Beam Profiles

Muon Beam



- 160 GeV/c μ
- Intensity $4.2 \cdot 10^7$/s
- up to $1.2 \cdot 10^5$ /mm²/s

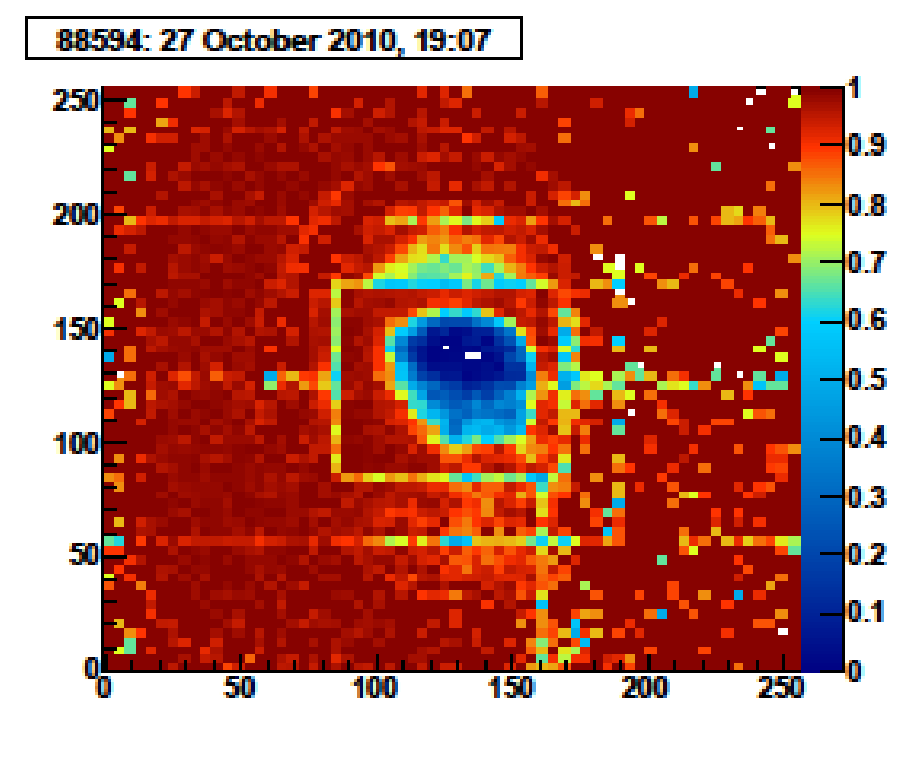
Hadron Beam



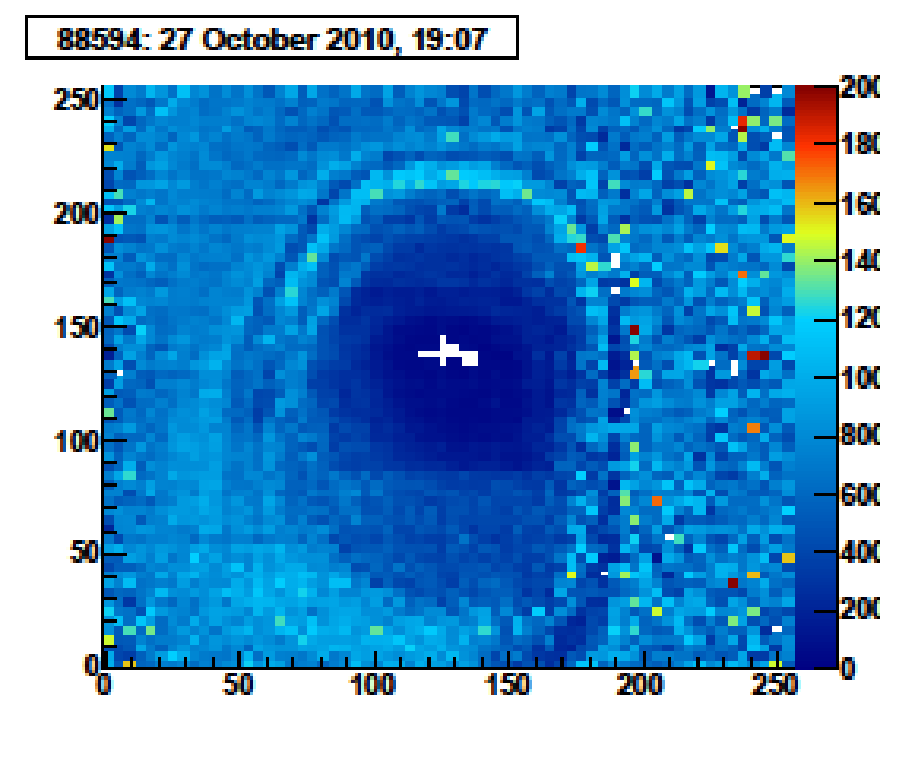
- 190 GeV/c π
- Intensity 10^6/s
- up to $1.2 \cdot 10^4$ /mm²/s

Efficiency GP03XY

Efficiency



Cluster amplitude

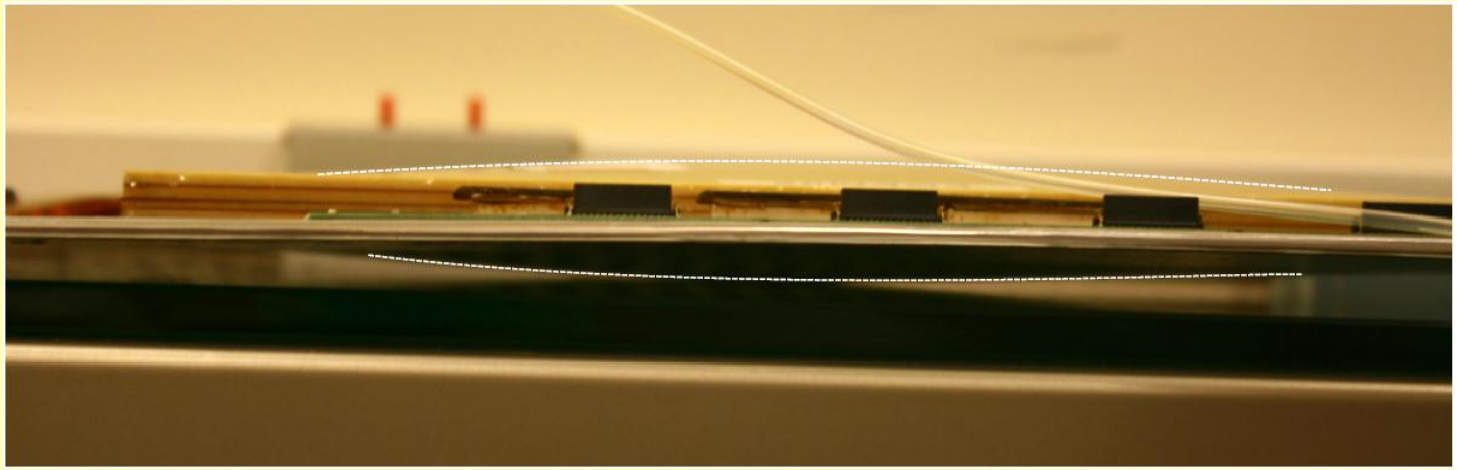


Total charge:

- 2008/2009 (π beam): (500 $\pm$20) mC/cm^2
- 2010/2011 (μ beam): (1000$\pm$20) mC/cm^2

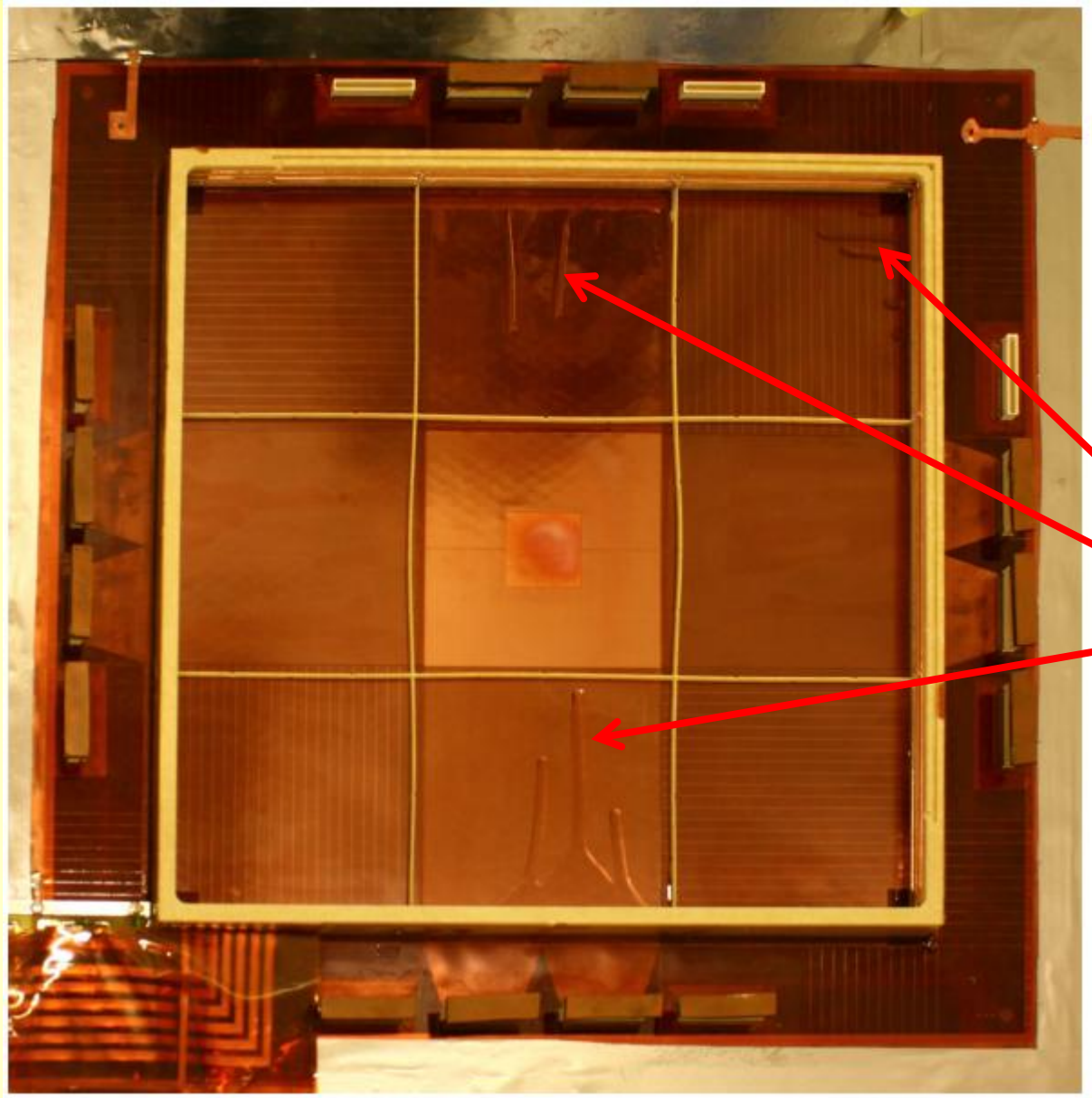
Opening of GP03XY

Inflating the detector…

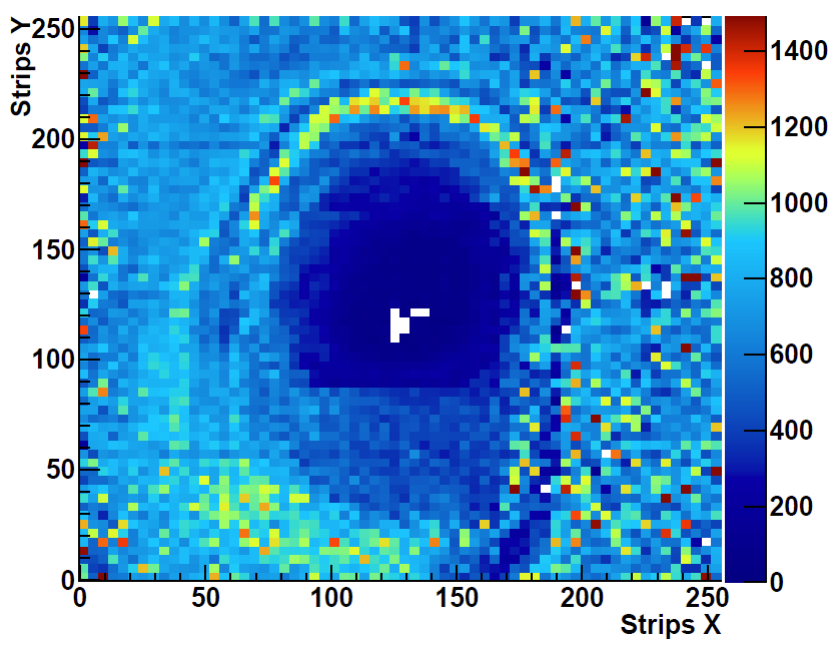


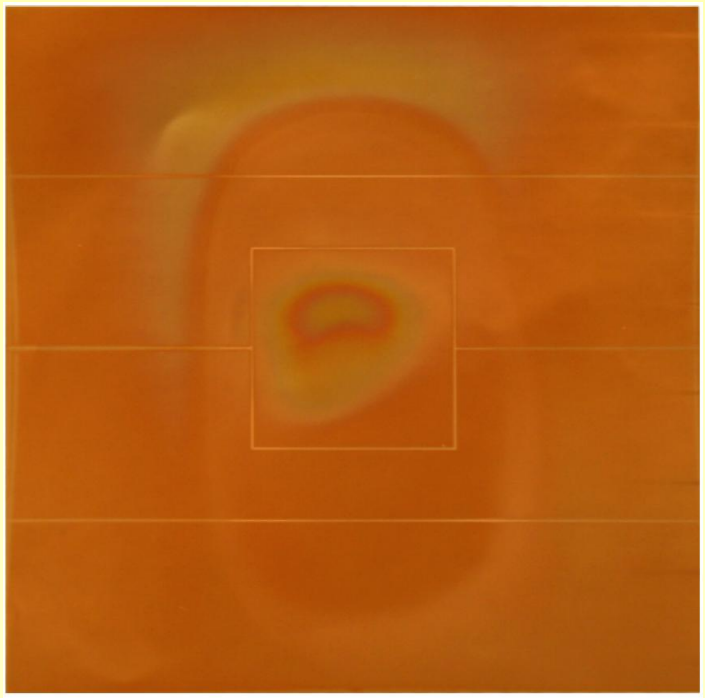
…and opening it

A Surprise

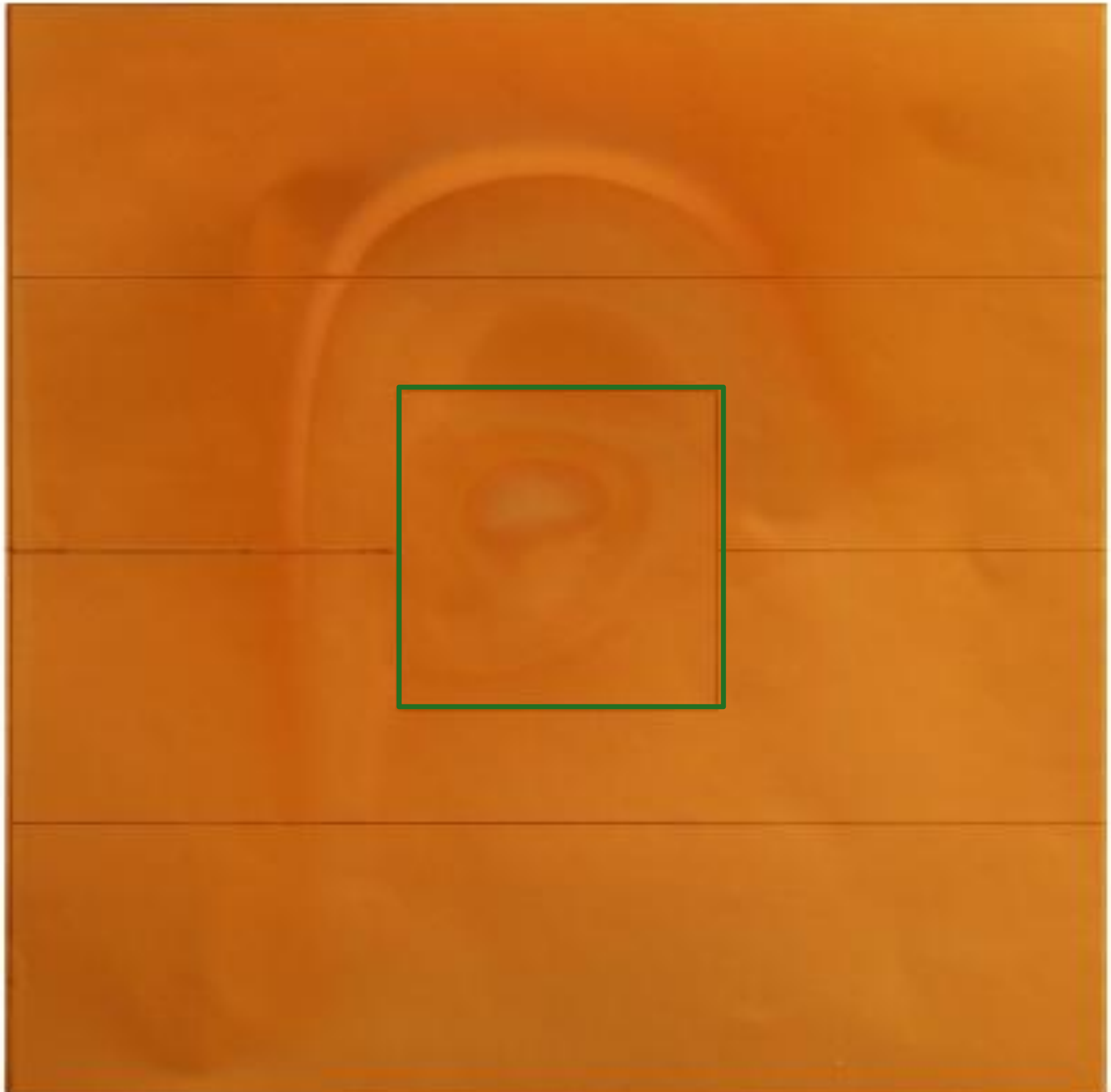


Reason for Inefficiency





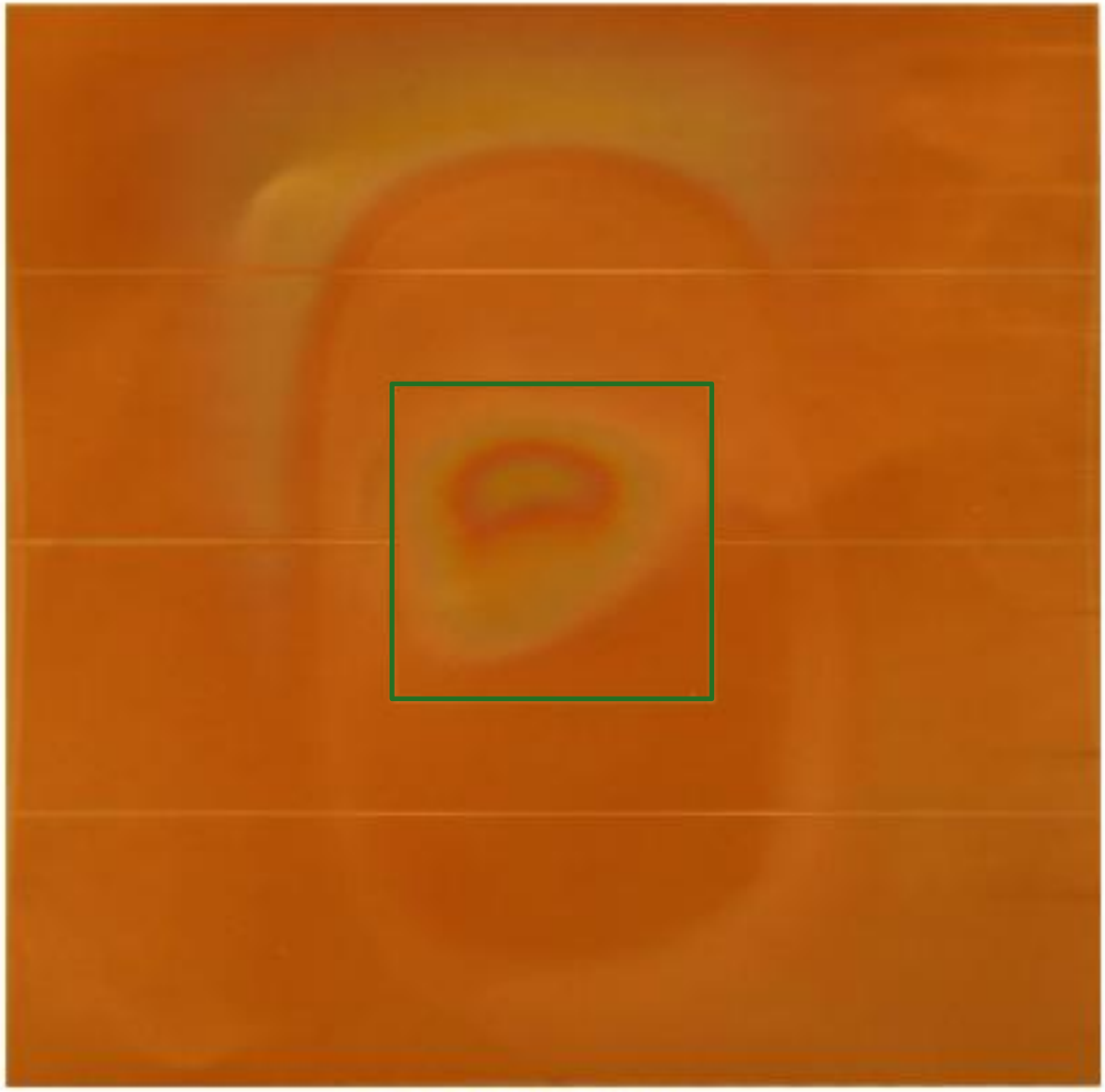
(c) GEM2 top



(e) GEM3 top

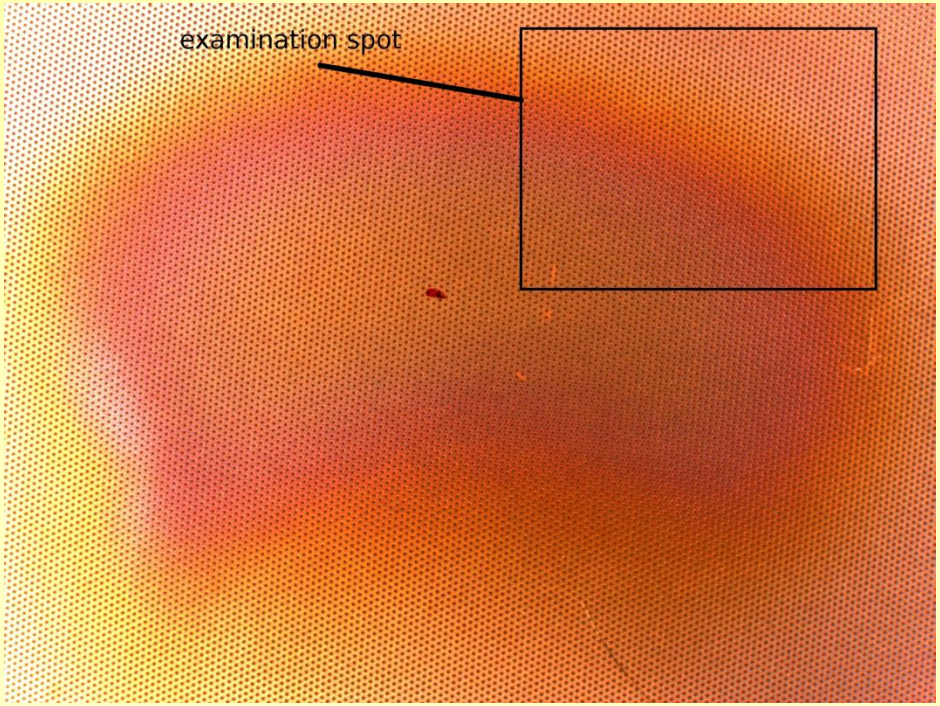
B. Ketzer

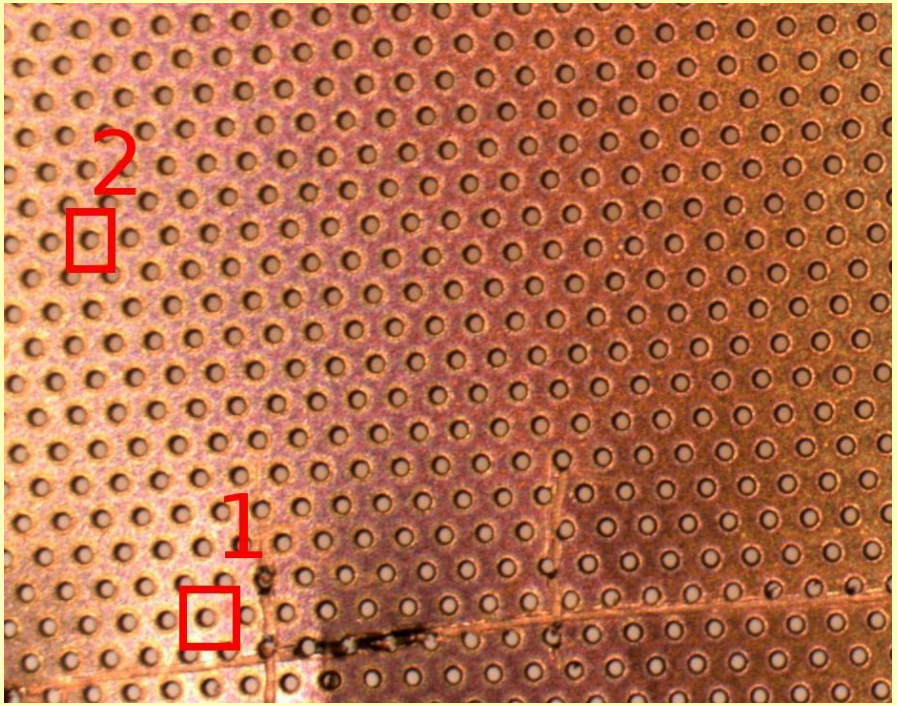
(d) *GEM2 bottom*



(f) *GEM3 bottom*

Optical Microscope

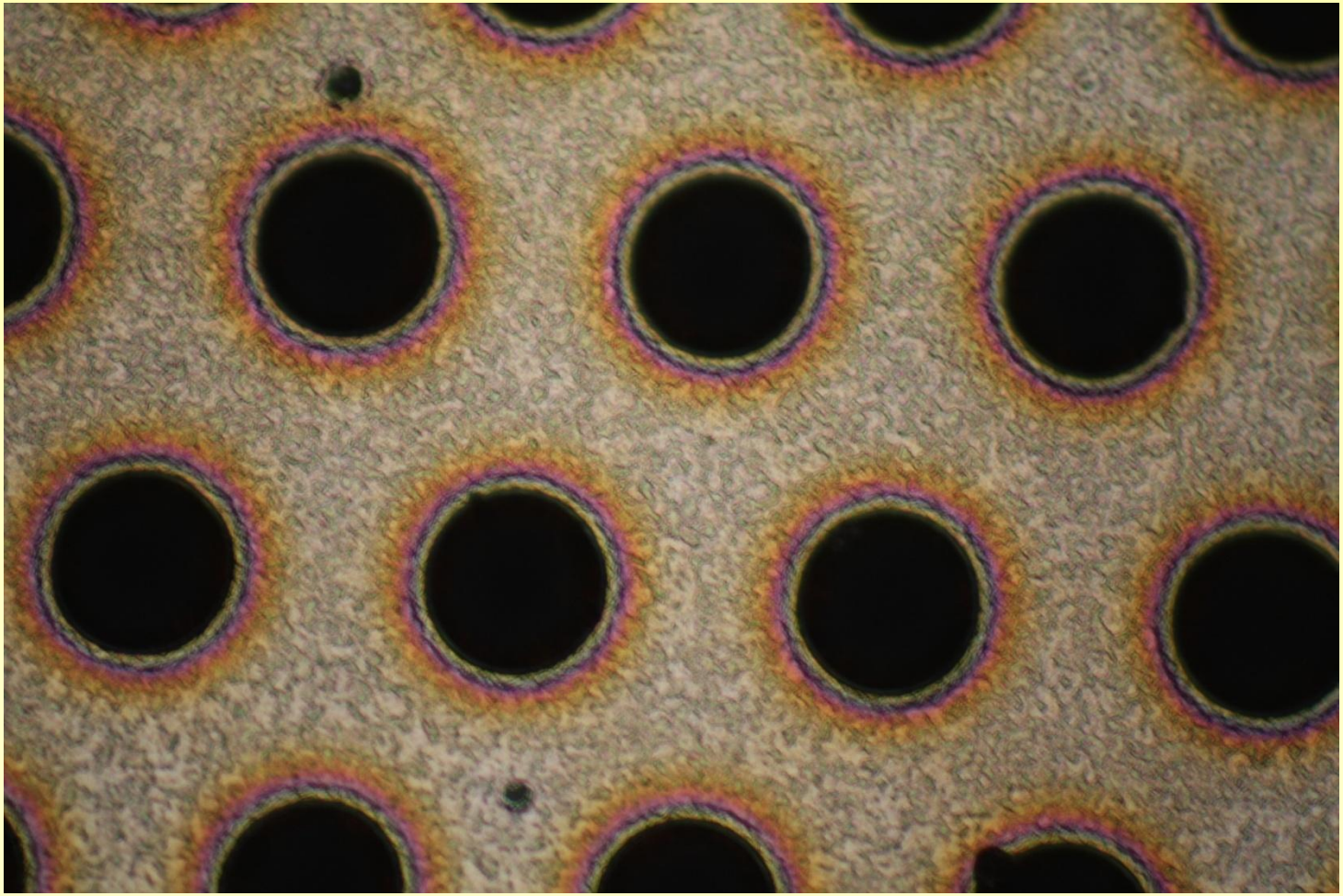




Optical Microscope

Zeiss optical microscope

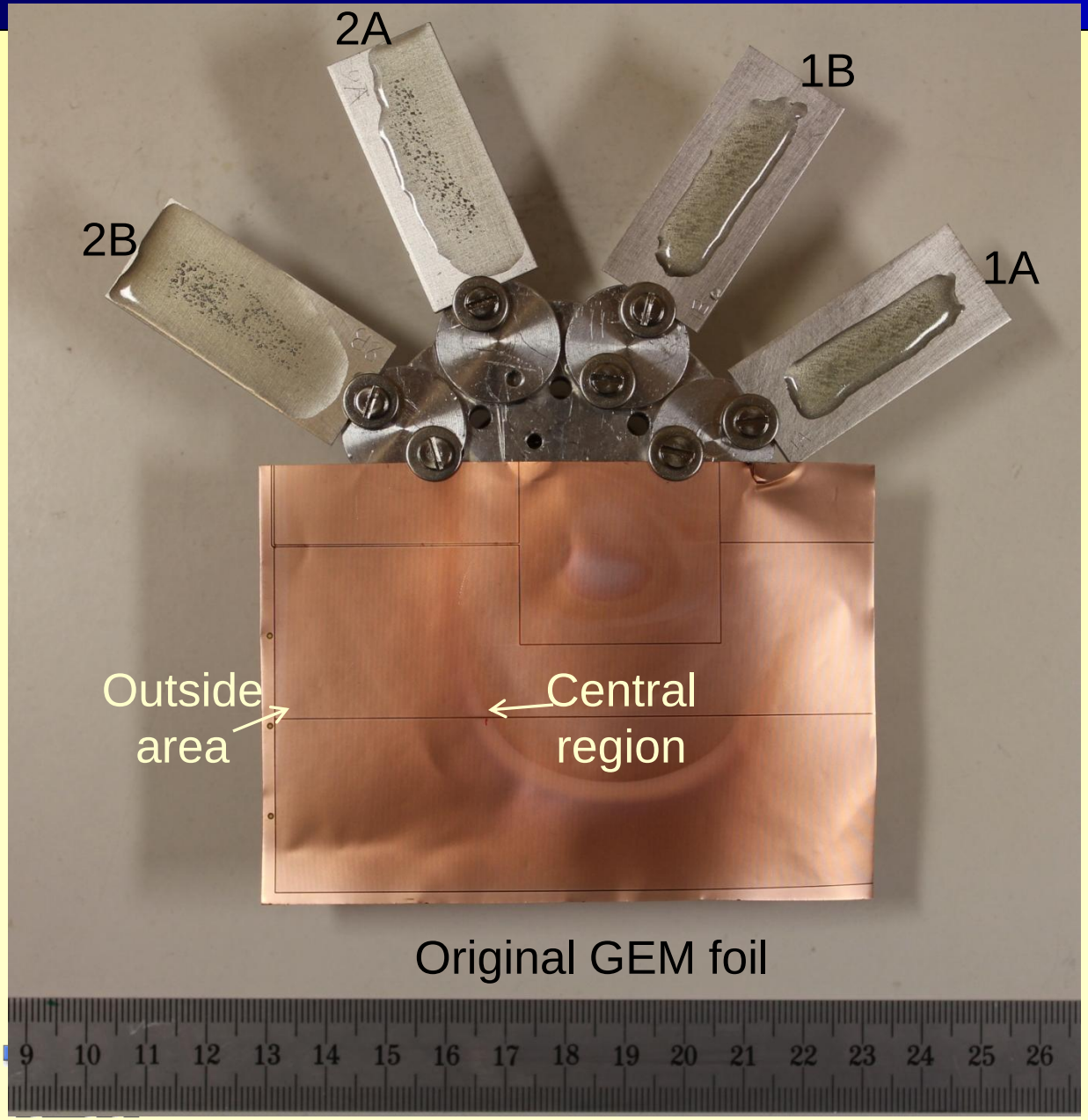
Sample 1

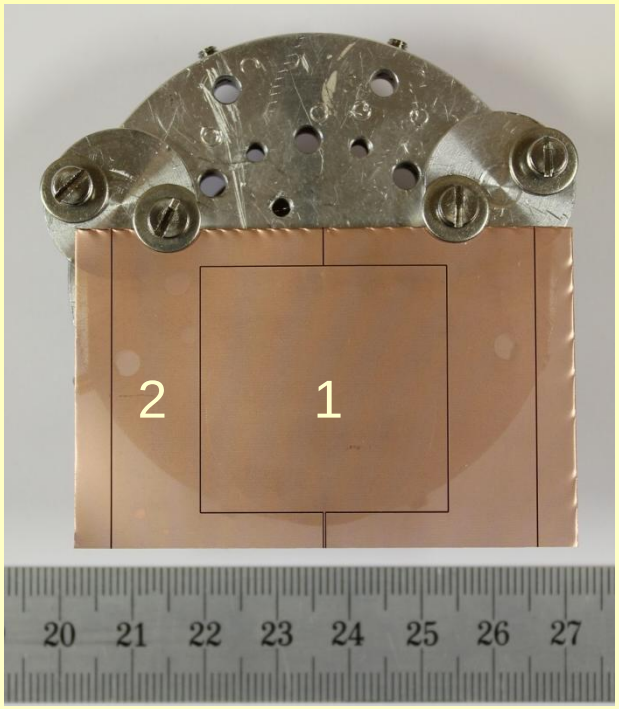


Scanning Electron Microscope

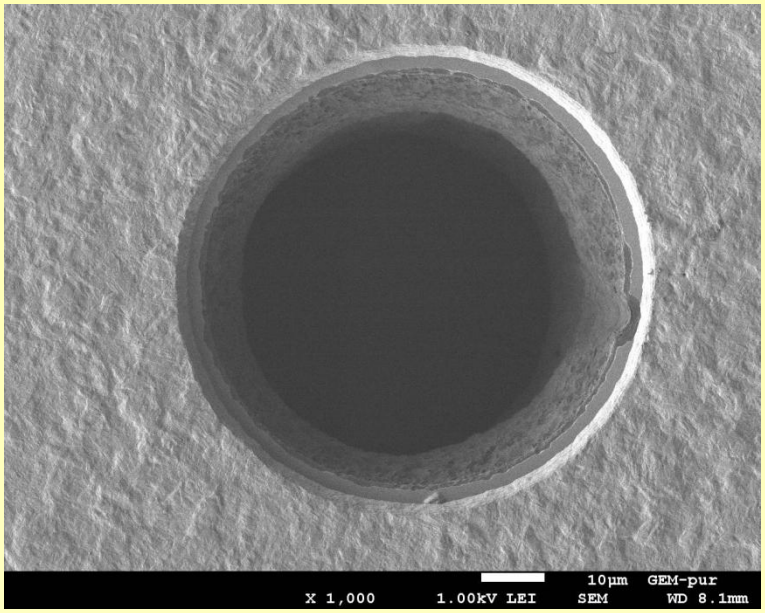
Zeiss SEM:

Pictures of the samples

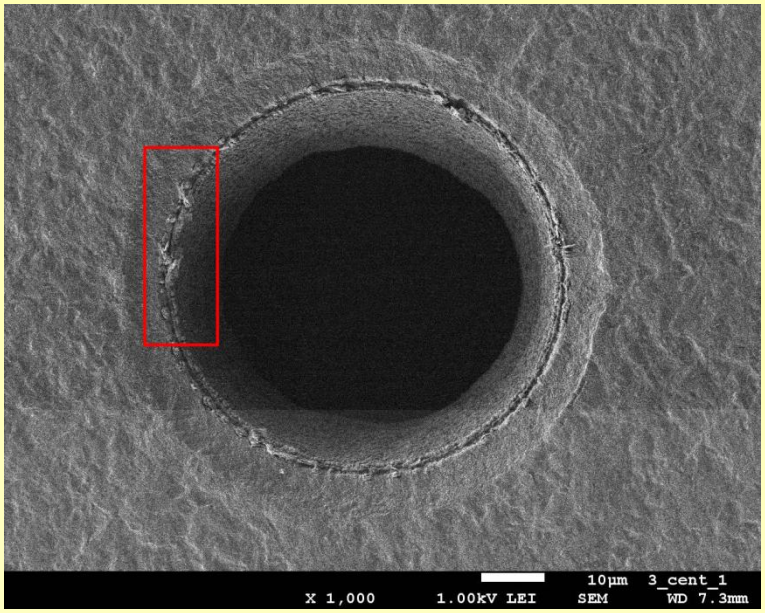




SEM



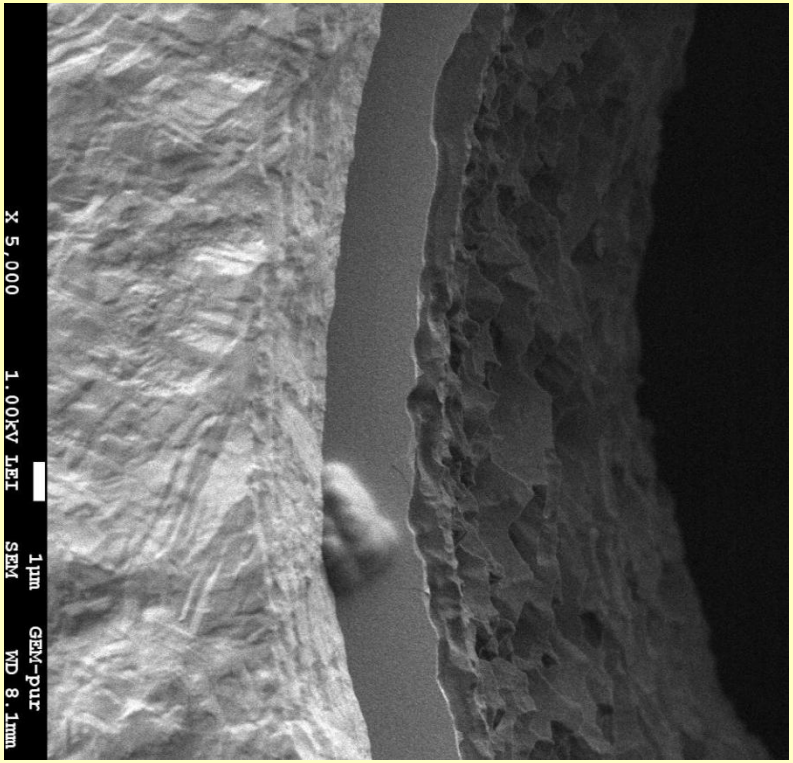
Unused GEM foil



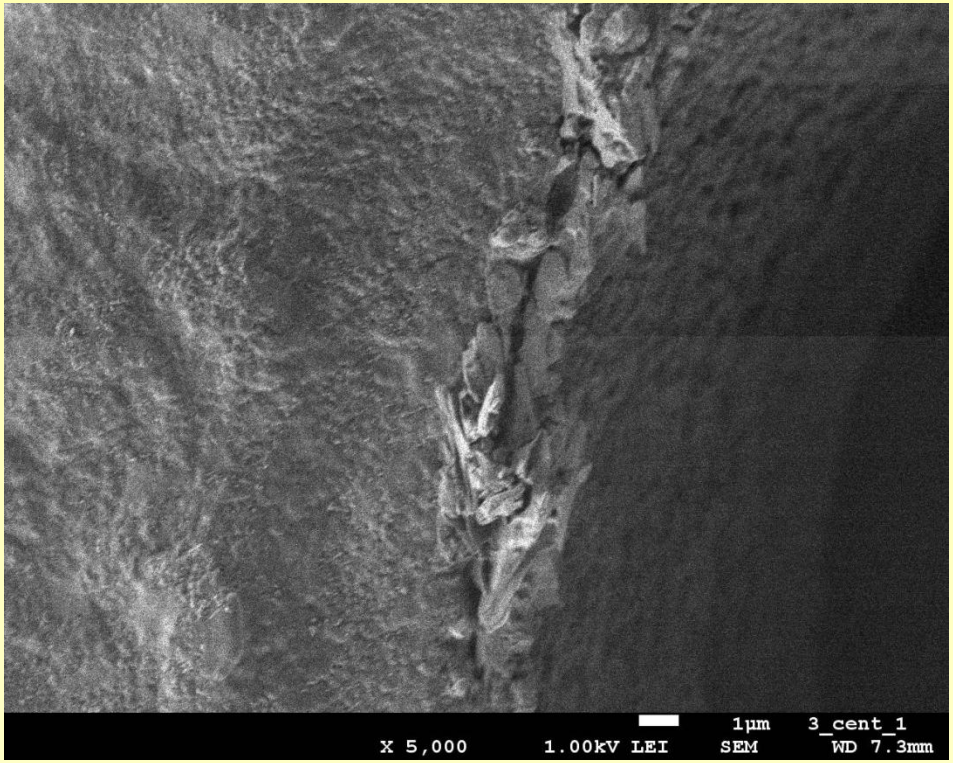
Aged foil, central region
Third GEM, position 1

- Larger rim
- Depositions around the edge of the hole and inside the hole

SEM



Unused GEM foil

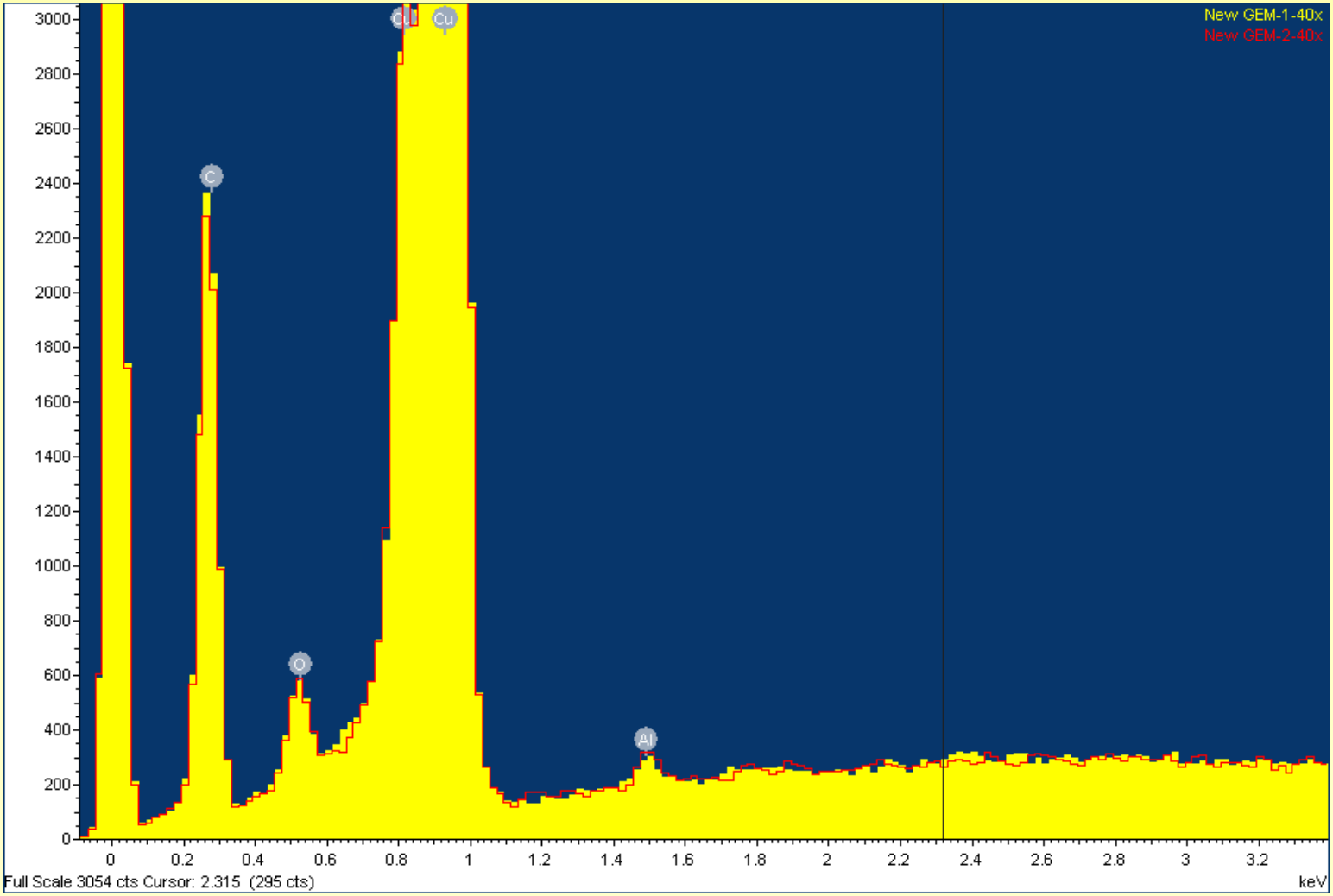


Aged foil, central region
Third GEM, position 1

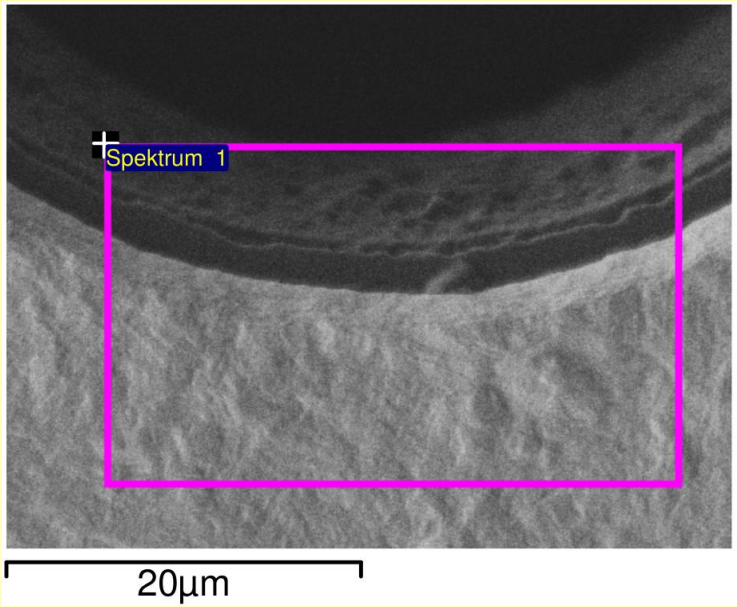
What are the depositions?

⇨Energy-dispersive X-ray spectroscopy (EDS)

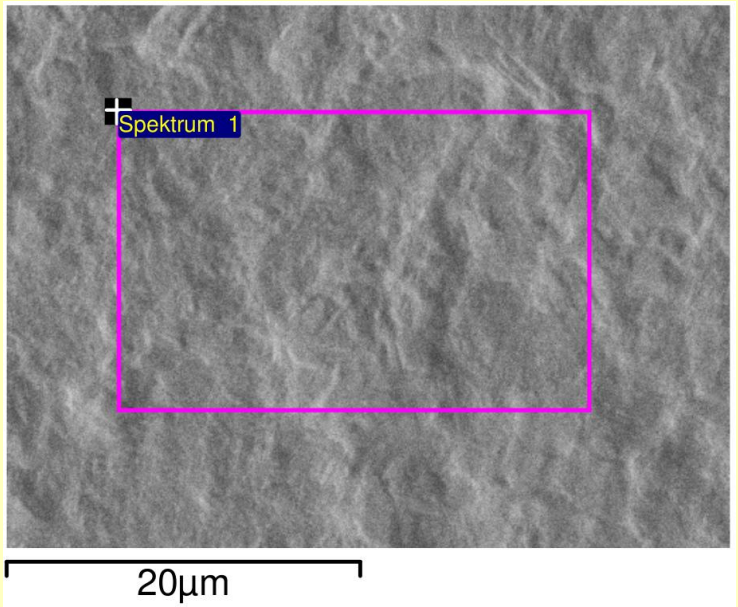
EDS analyses of new GEM foil



EDX Analysis



Edge of hole

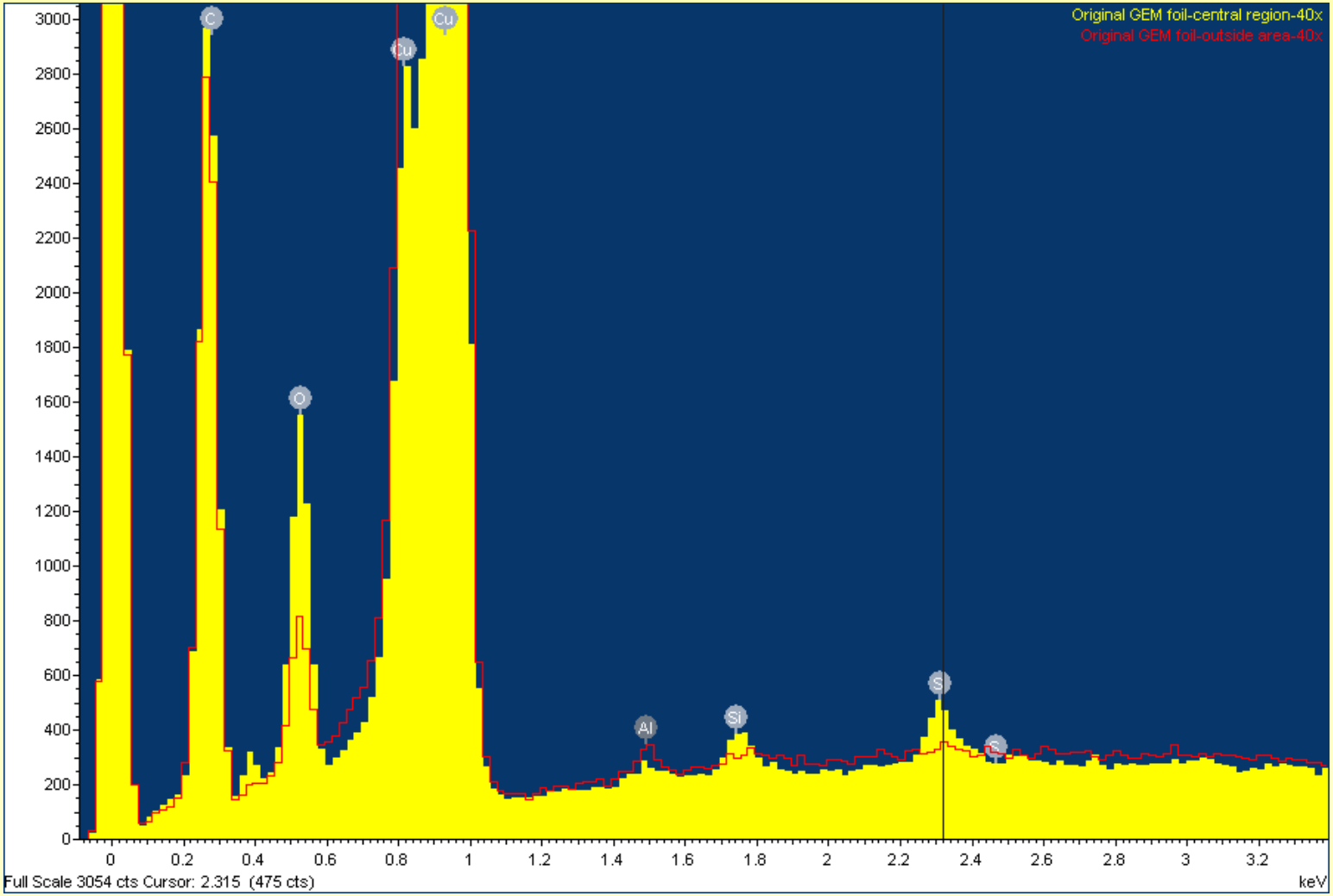


Between holes

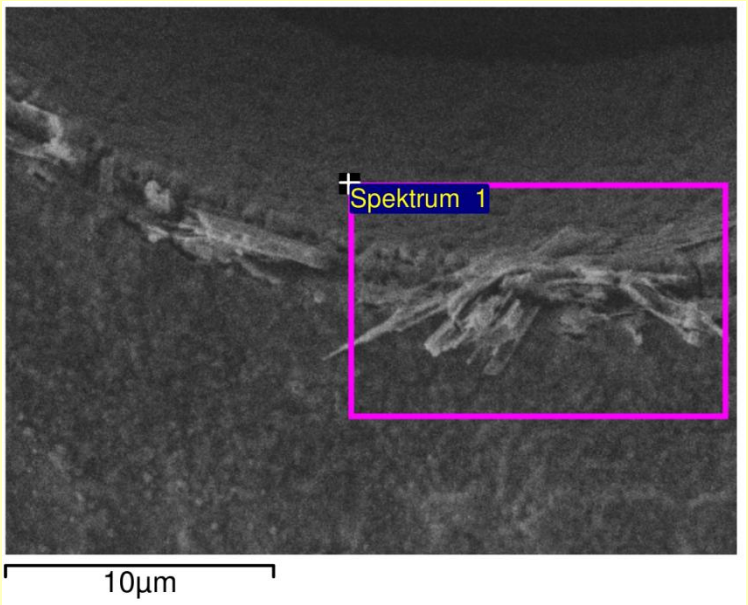
Atomic composition:

Ort	Cu	C	N	O
Lochrand	31.65%	57.96%	0%	10.39%
Zwischenregion	100%	0%	0%	0%

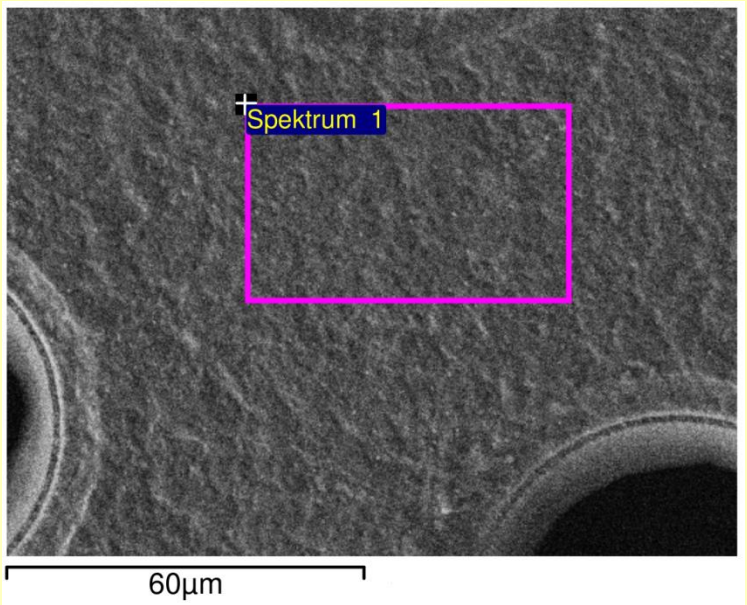
EDS analyses of original GEM foil



EDS Analysis



Edge of hole, old foil

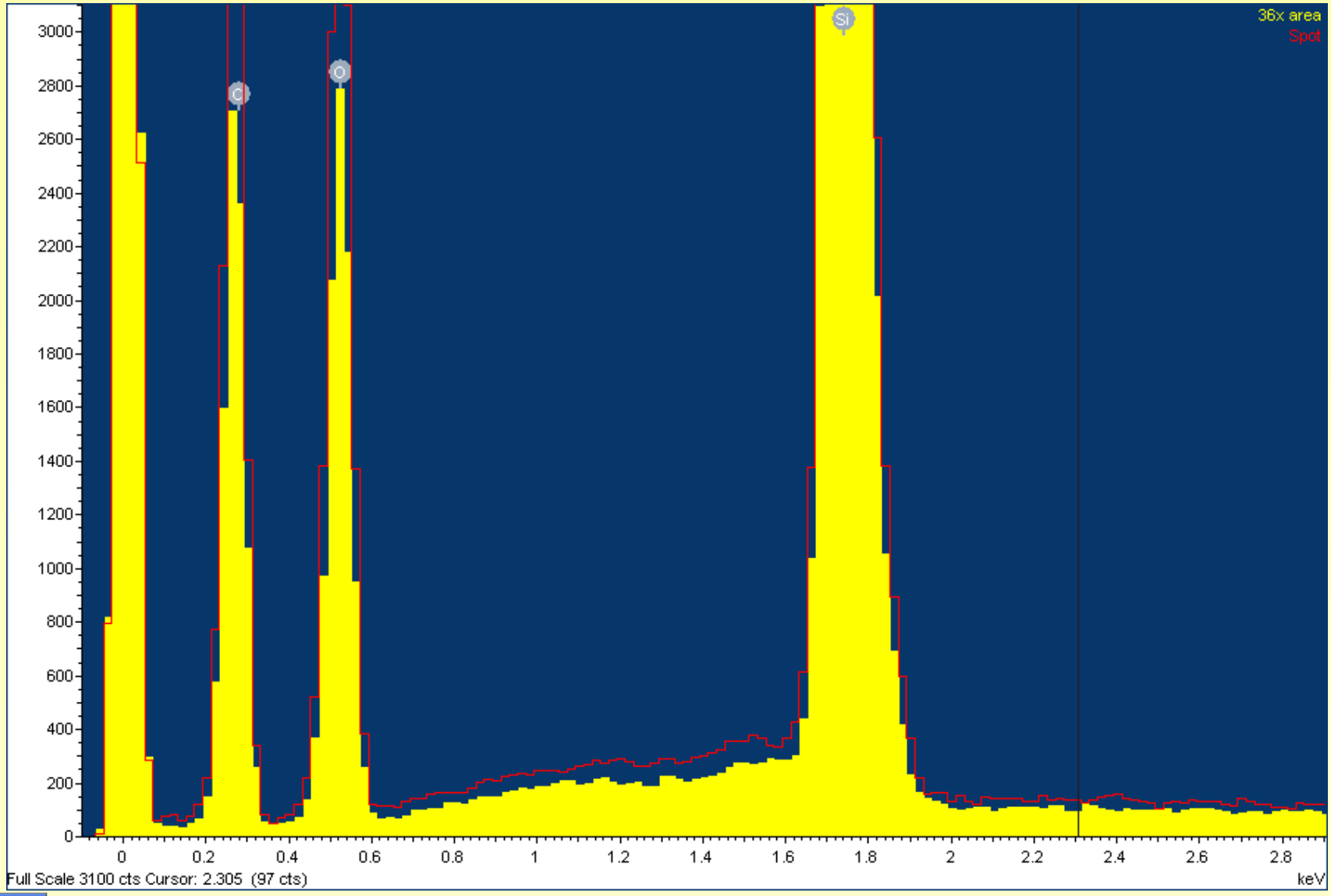


Region between holes, old foill

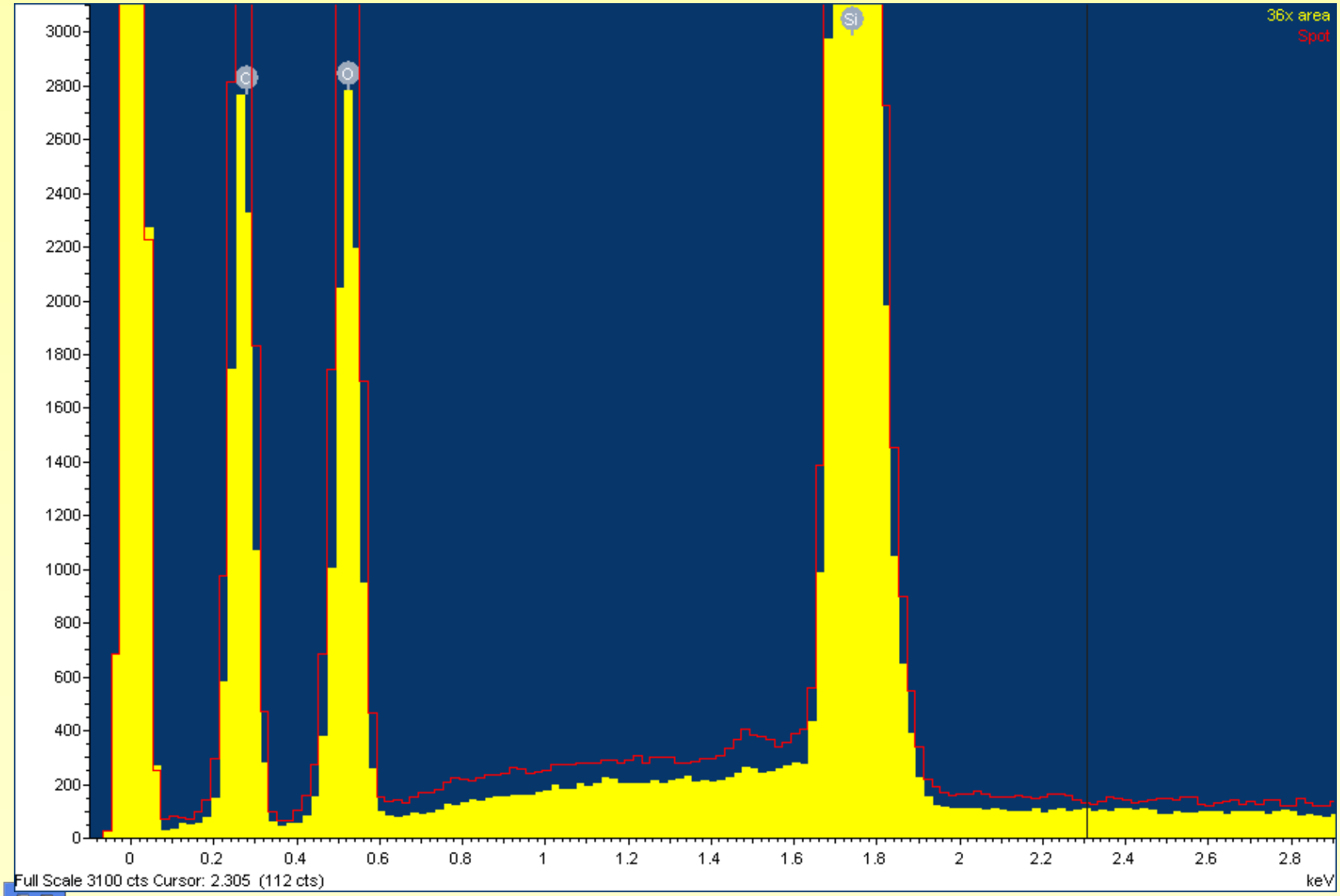
Atomic composition:

Ort	Cu	C	N	O	Si	S
Whiskers	6.39%	51.78%	0%	35.09%	1.46%	5.29%
Zwischenregion	13.51%	51.98%	0%	30.60%	0.80%	3.11%

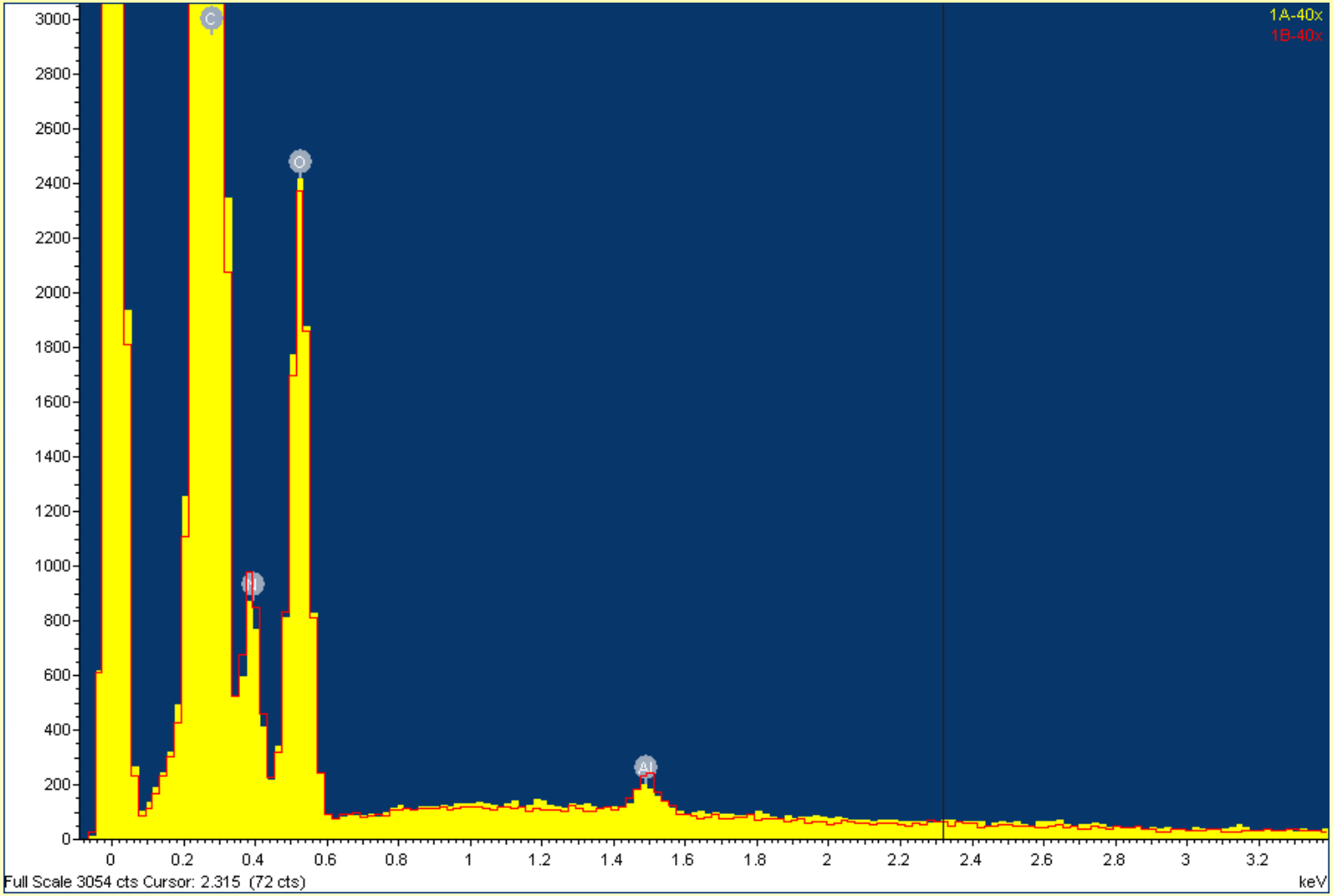
EDS analyses of Dow Corning RT



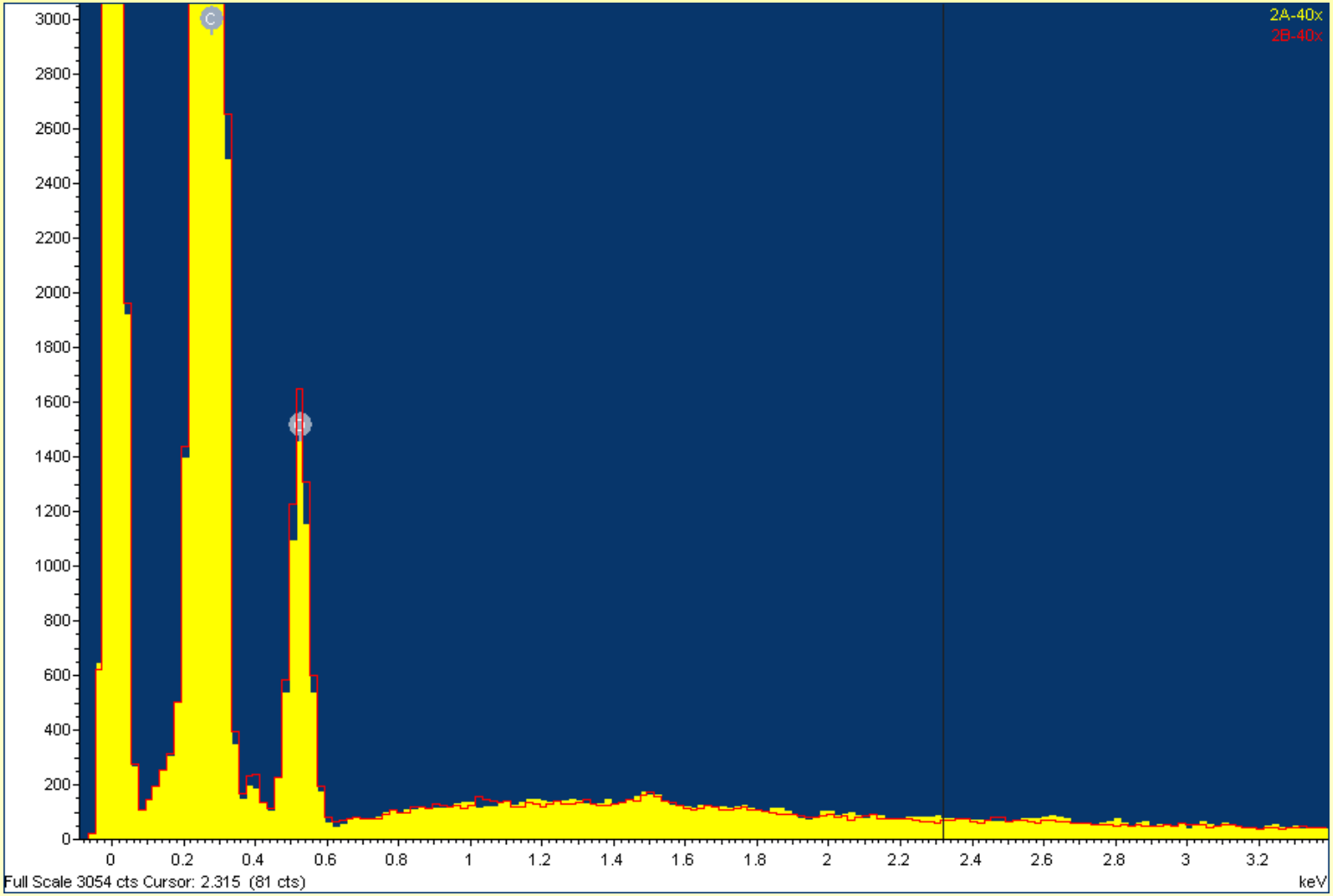
EDS analyses of Dow Corning 50°C



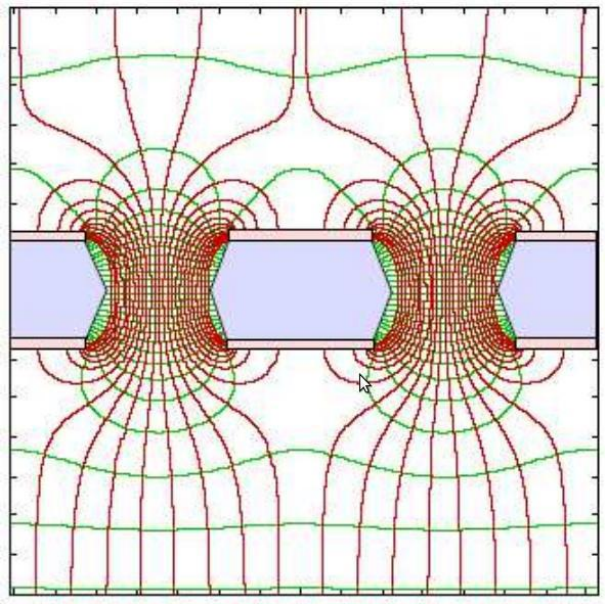
EDS analyses of Araldite RT

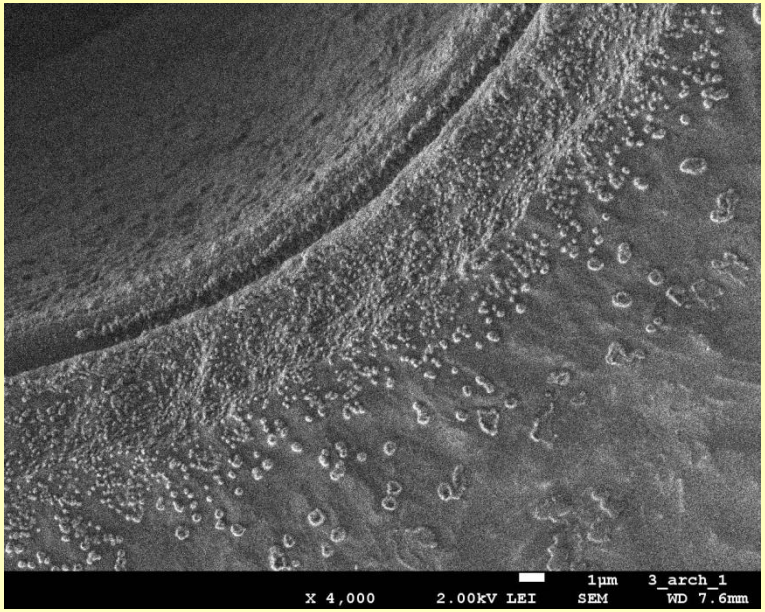


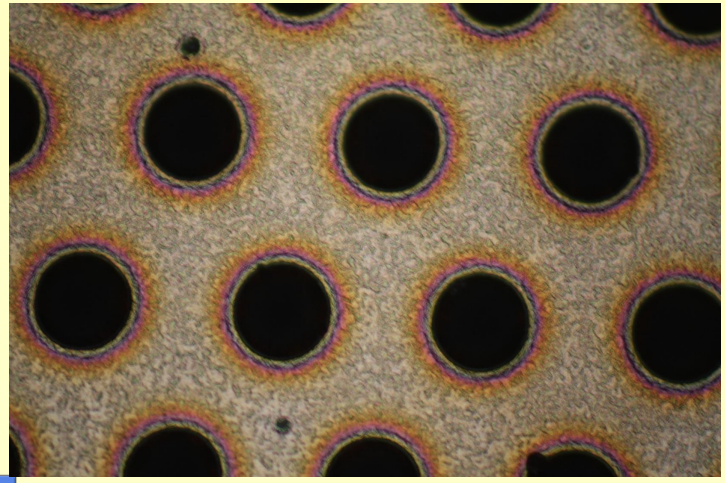
EDS analyses of Araldite 50 °C

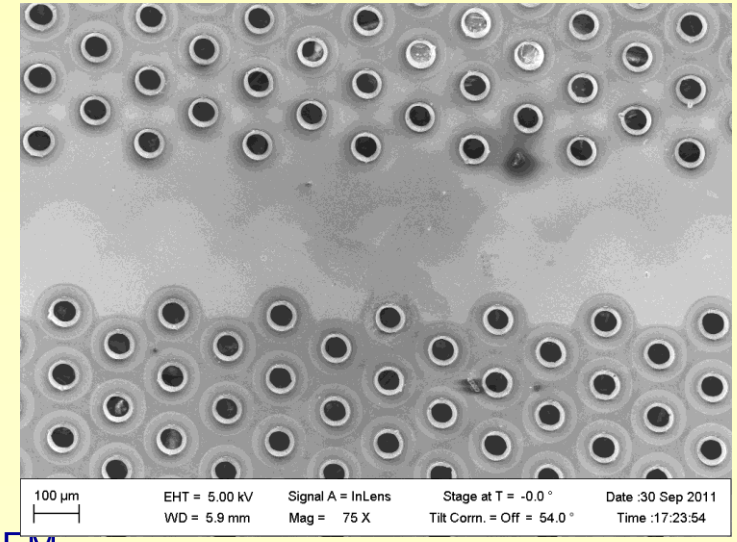


Depositions

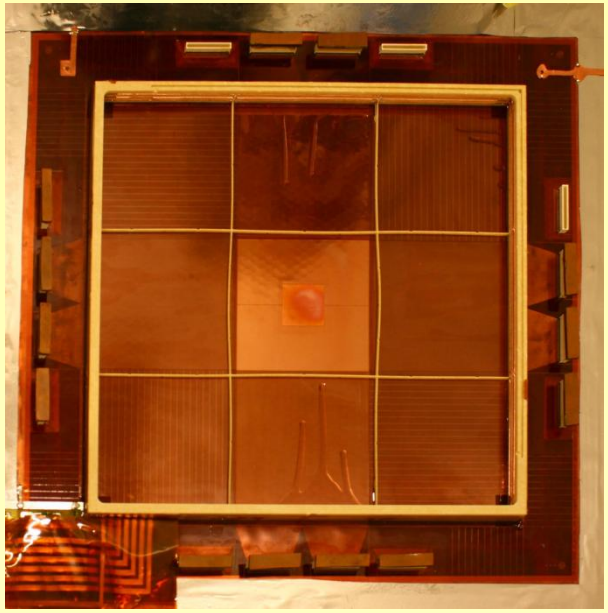


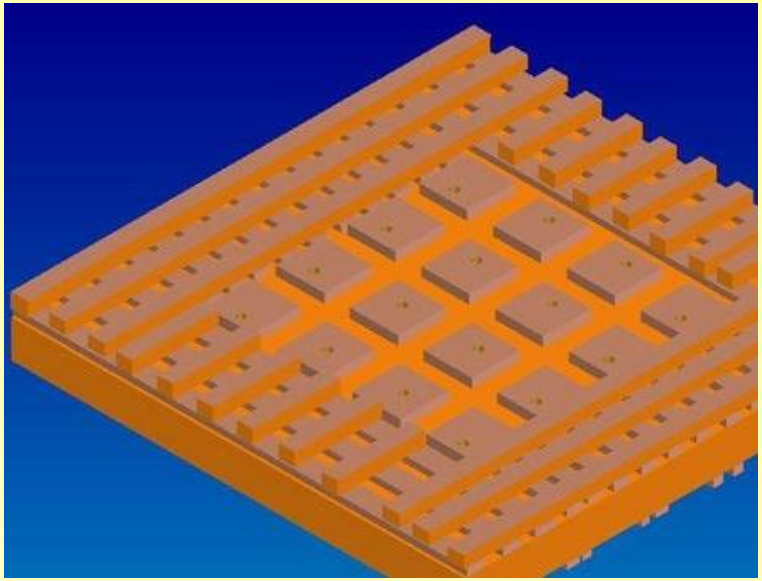




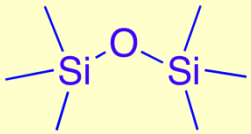


Depositions



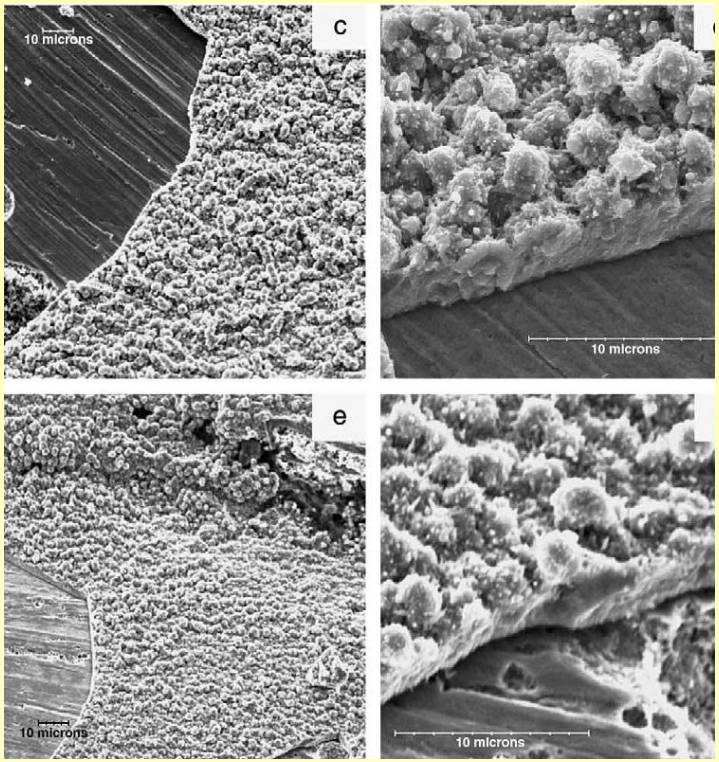


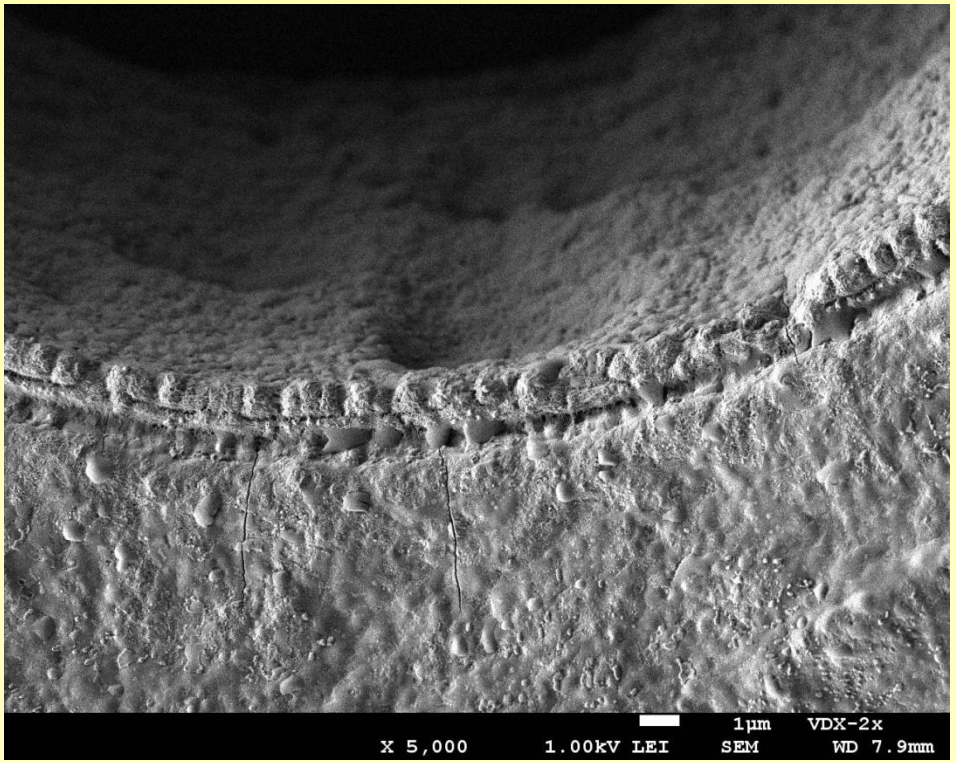
Sealing of Detector:
Dow Corning 1-2577
Conformal Coating
Siloxane $R_3Si\text{-}O\text{-}SiR_3$



Removal of glue during production:
H_2SO_4

Source of Aging?



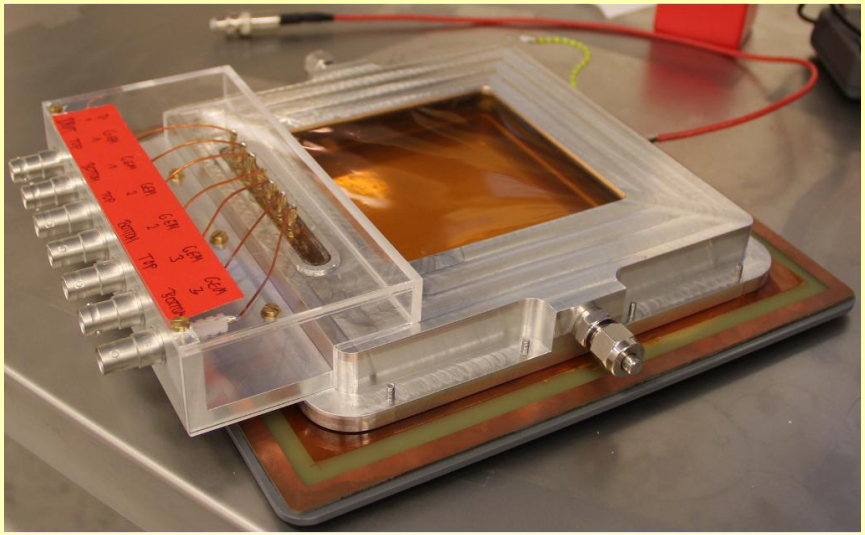


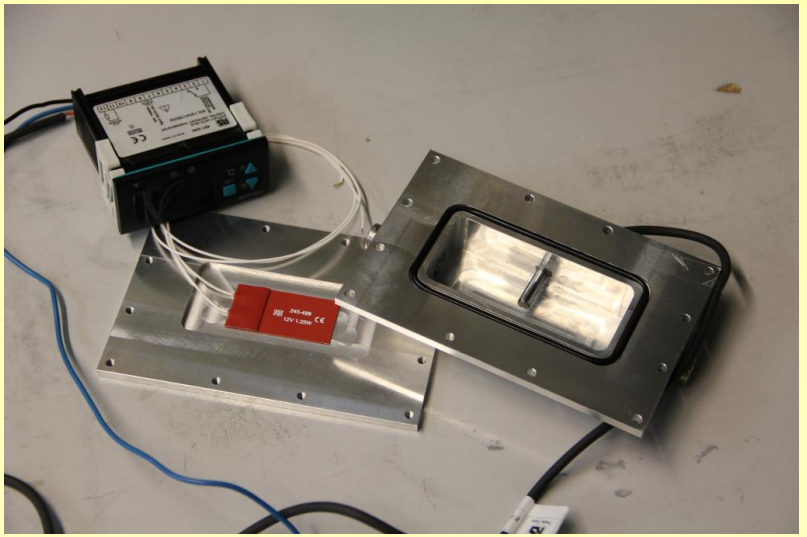
Cu exposed to H_2S
[T.T.M. Tran et al., Corrosion Science 45, 2787 (2003)]

Summary of the observations

- The original GEM foil clearly is coated with Si and S in the damaged regions, not outside
- A new GEM foil does not contain any Si or S
- Araldite does not contain any sulfur, only carbon, nitrogen and oxygen at room temperature and carbon and oxygen at 50 °C in an oven
- Dow Corning contains Si, but no S
- S may come from H_2SO_4 used during production
- Reason for outer ring not yet understood

Test Setup



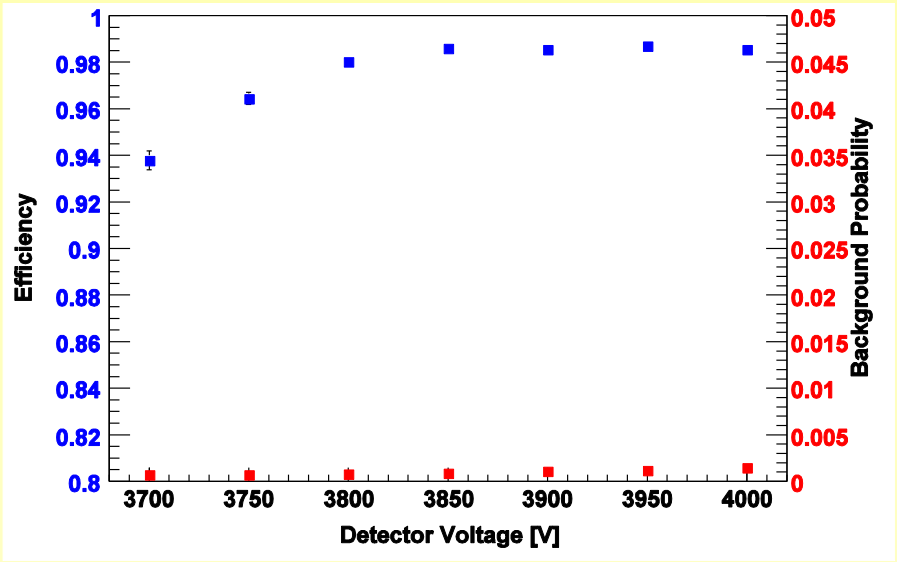


- Long term measurements
- Heatable box for outgassing tests
- Amptek Mini X-ray
- Single wire counter for stability monitoring

Spare Slides

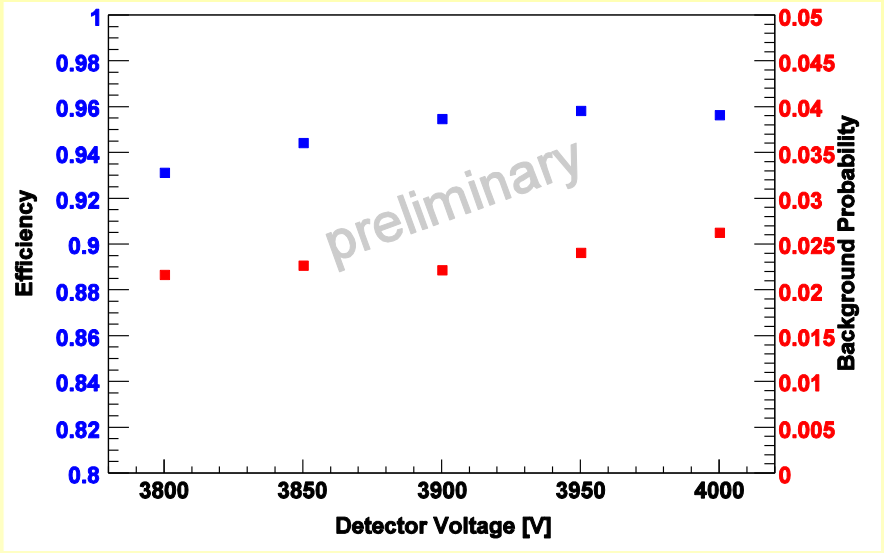
Efficiency

Low intensity μ beam: $4 \cdot 10^6$ s^{-1}



- Plateau: 98.5% at G~5000
- Background prob. per pixel: 0.1%
- Roadwidth: 0.6 mm

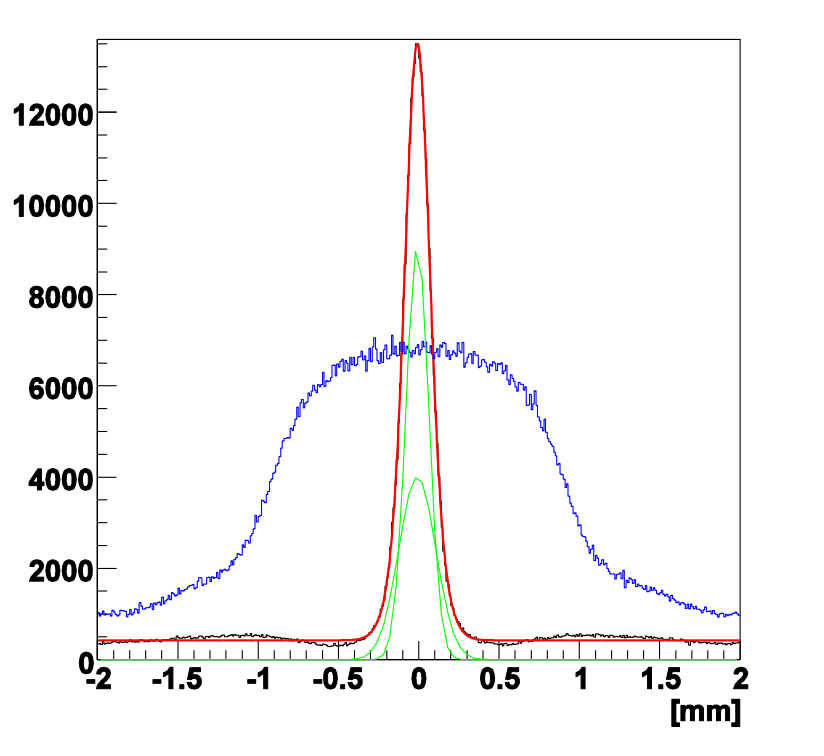
High intensity μ beam: $2 \cdot 10^8$ s^{-1}



- Plateau: 96% at G~7500
- Background prob. per pixel: 2.5%
- Roadwidth: 1.0 mm

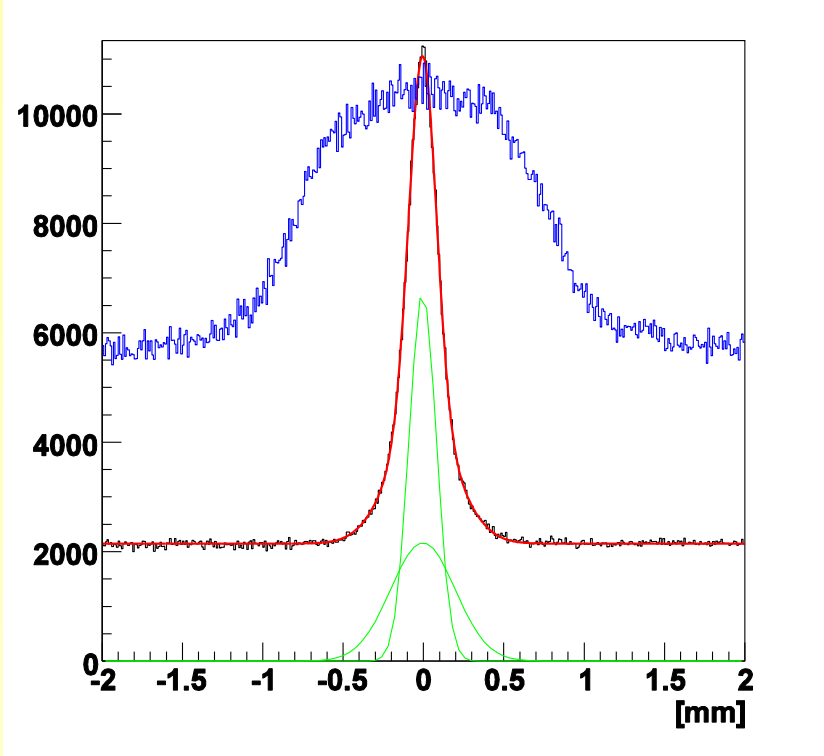
Spatial Residuals

Low intensity: $4 \cdot 10^6\ s^{-1}$



Weighted mean: $\sigma_x = 90\mu m$

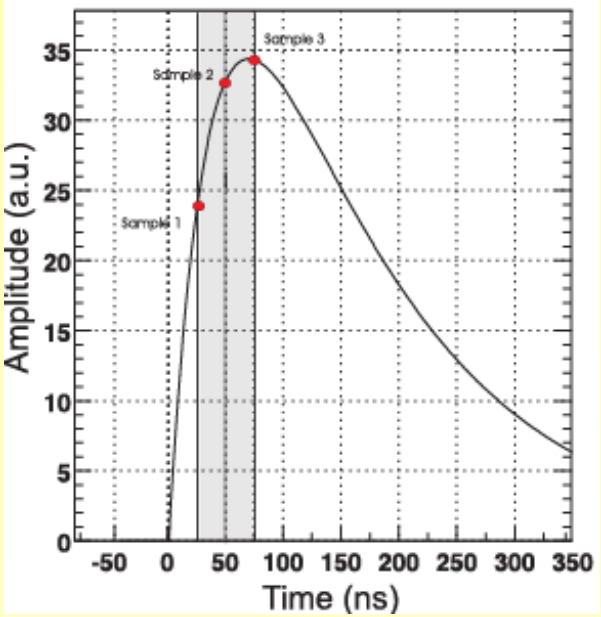
High intensity: $2 \cdot 10^8\ s^{-1}$



Weighted mean: $\sigma_x = 135\mu m$

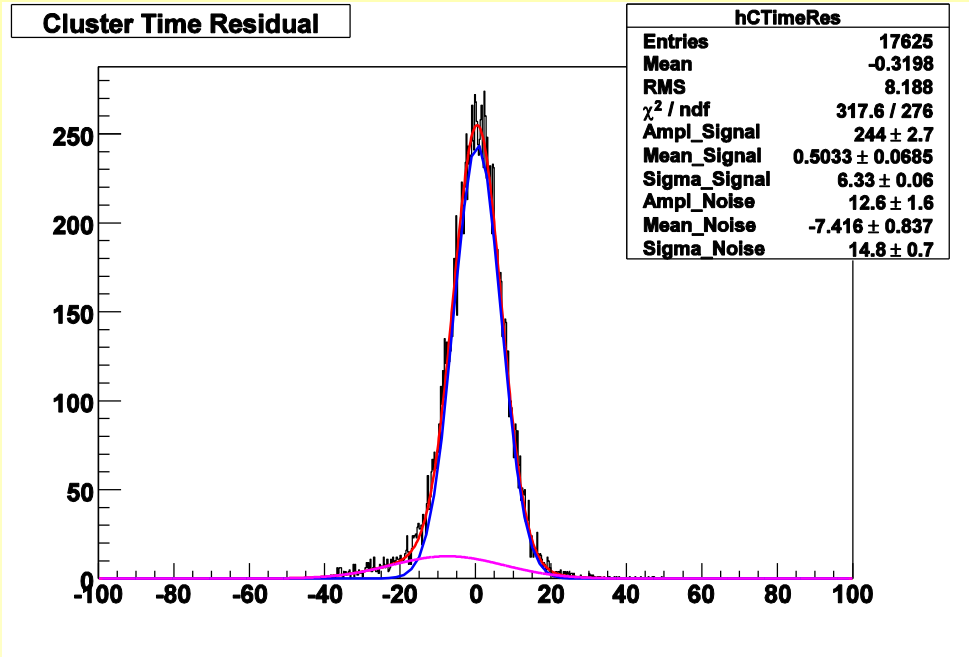
Time Residual

Principle



- 3 analog samples per trigger
- Timing: rising edge of signal
- Reconstruct t_0 from known pulse shape

Low intensity: $4 \cdot 10^6\ s^{-1}$

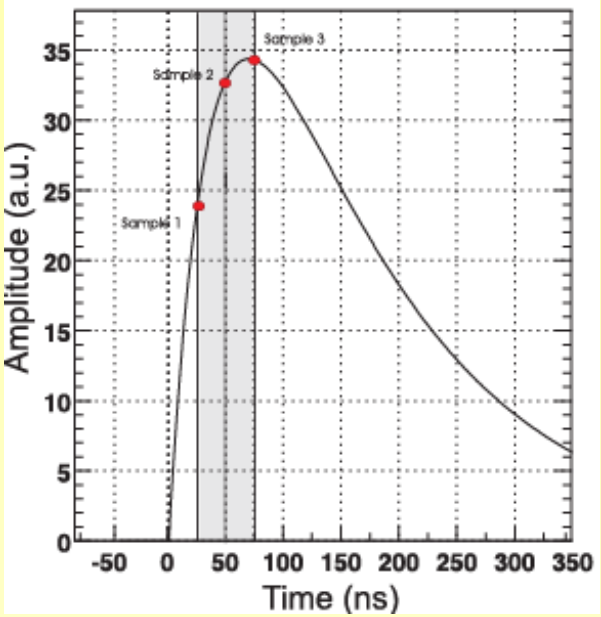


$\sigma_t = 6.3$ ns

Limit: $\sigma_t = \frac{1}{n \cdot u} = 4.6$ ns

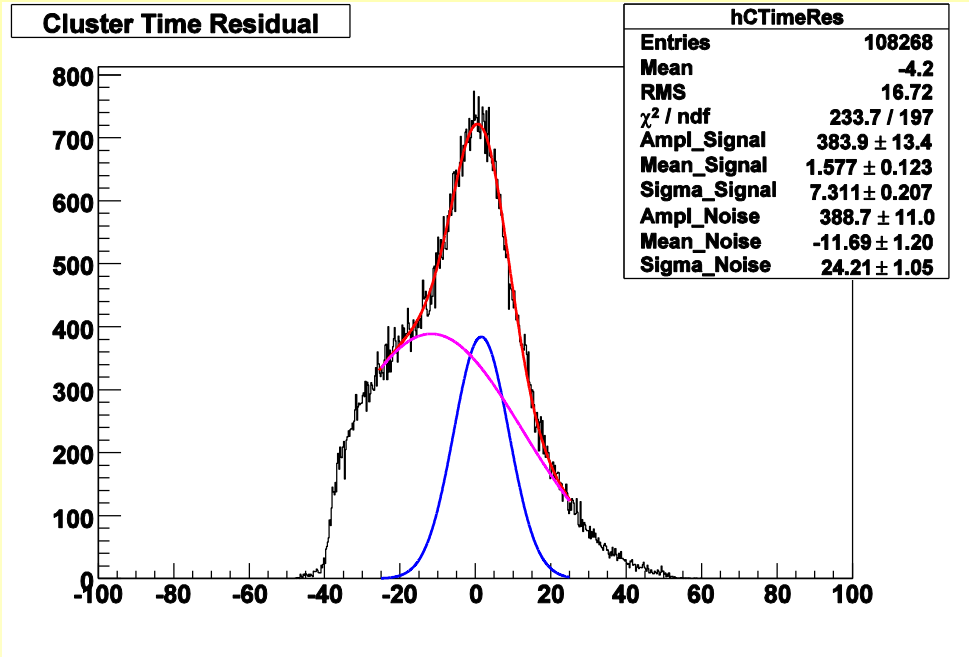
Time Residual

Principle



- 3 analog samples per trigger
- Timing: rising edge of signal
- Reconstruct t_0 from known pulse shape

High intensity: $2 \cdot 10^8\ s^{-1}$



$\sigma_t = 7.3\text{ns}$