COMPASS PixelGEM Production

A. Austregesilo, •F. Haas, B. Ketzer, I. Konorov, M. Krämer,
A. Mann, T. Nagel, S. Paul, F. Schneider, S. Uhl

TU München, Physik Department E18

Workshop on GEMs and Micromegas, February 16th 2009

Supported by

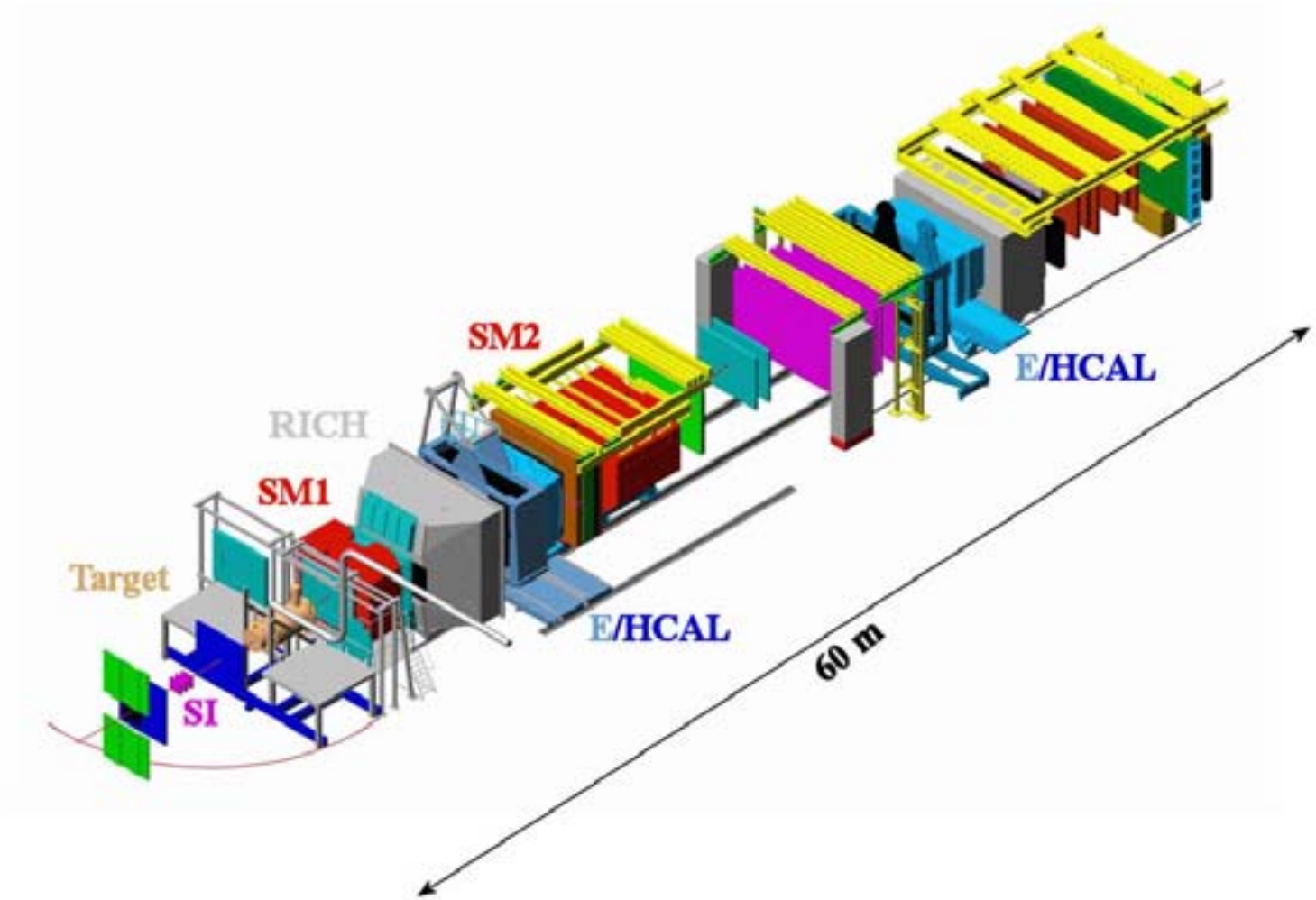
bmb+f - Förderschwerpunkt
COMPASS
Großgeräte der physikalischer Grundlagenforschung

Maier-Leibnitz-Labor
Garching bei München

Excellence Cluster
Universe

Overview

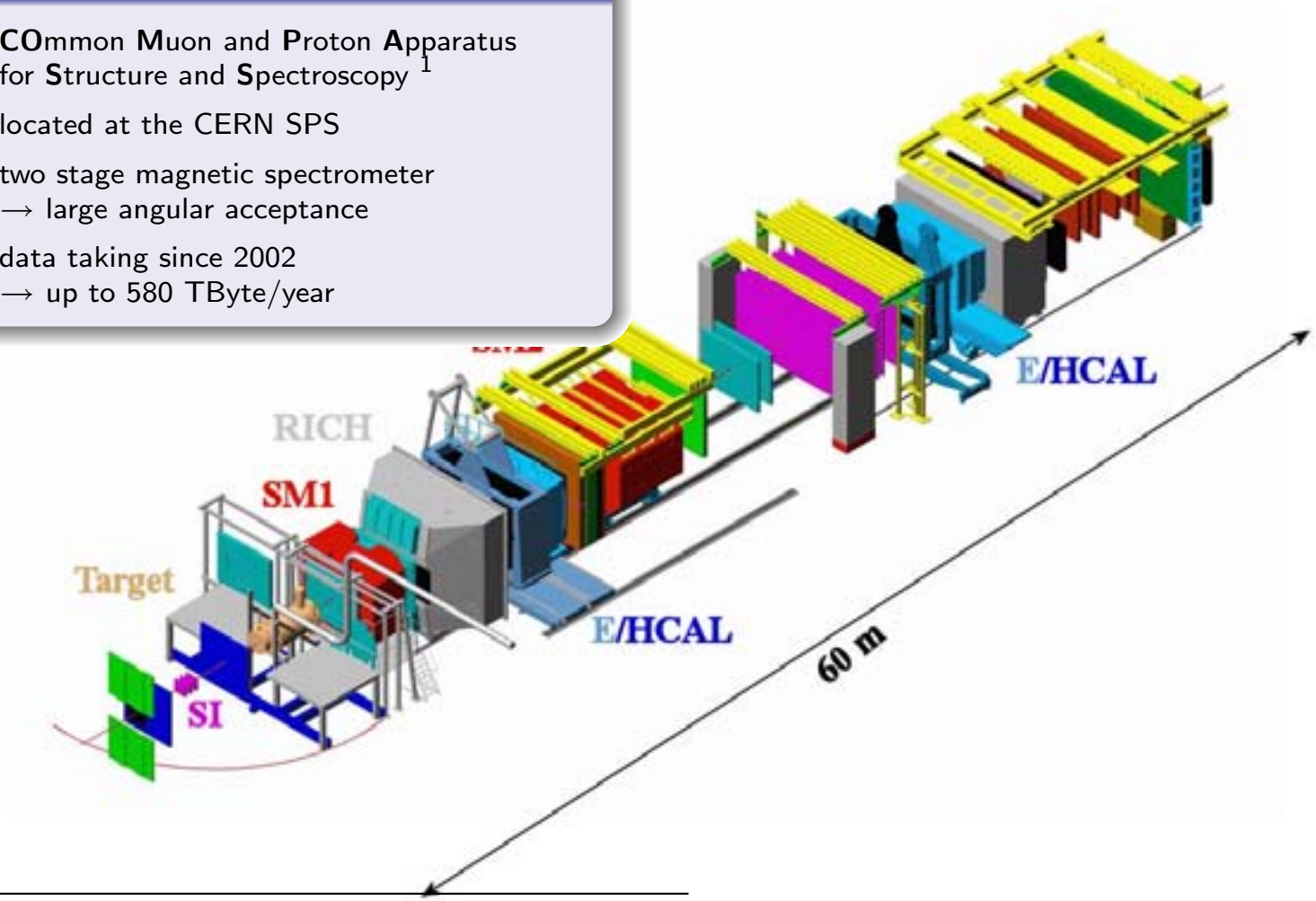
The COMPASS Experiment



The COMPASS Experiment

Overview

- **CO**mmon **M**uon and **P**roton **A**pparatus for **S**tructure and **S**pectroscopy [1]
- located at the CERN SPS
- two stage magnetic spectrometer
  → large angular acceptance
- data taking since 2002
  → up to 580 TByte/year



[1] [Nucl. Instr. and Meth. A 577 (2007) 455]

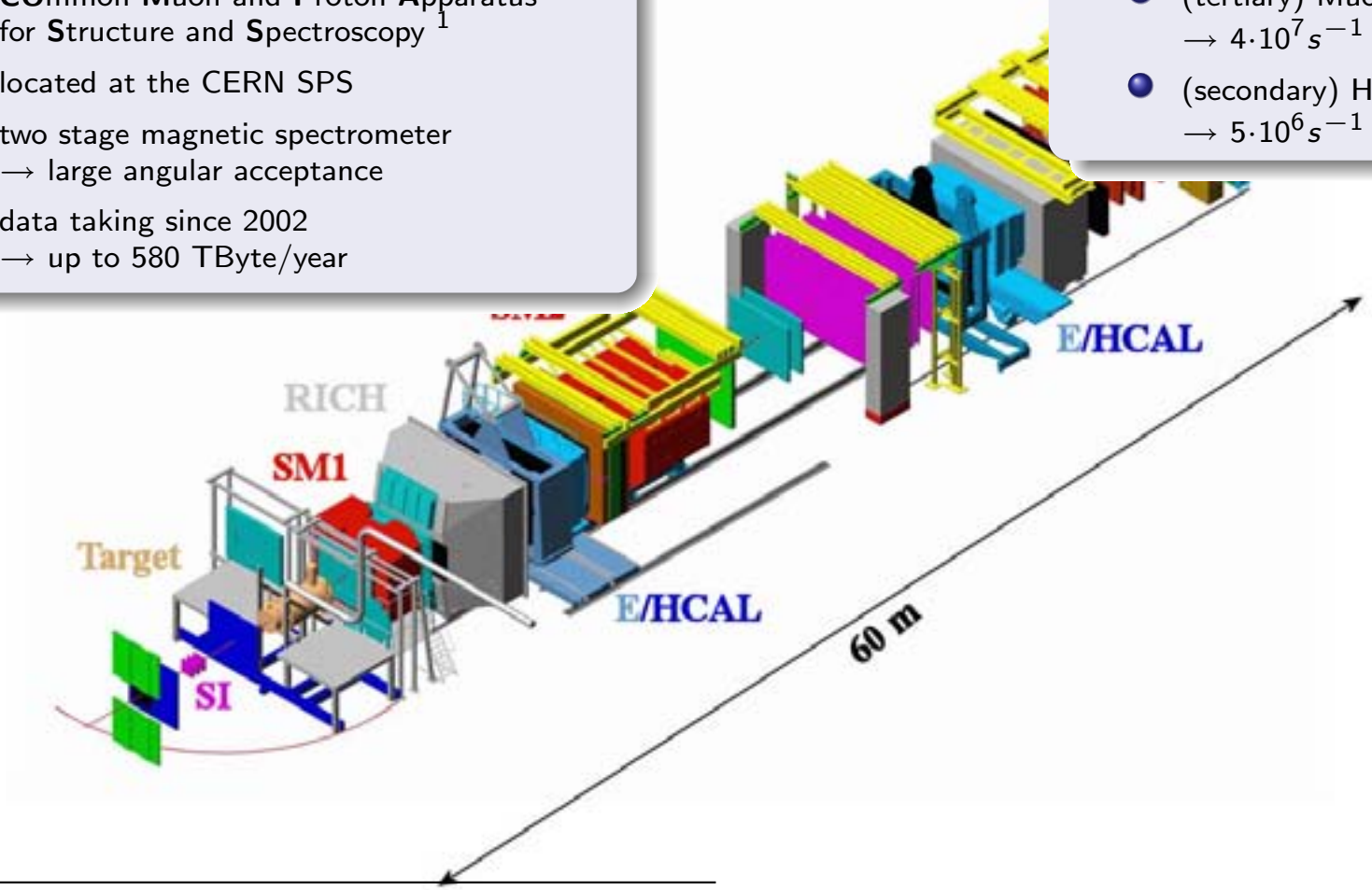
The COMPASS Experiment

Overview

- **CO**mmon **M**uon and **P**roton **A**pparatus for **S**tructure and **S**pectroscopy [1]
- located at the CERN SPS
- two stage magnetic spectrometer
  $\longrightarrow$ large angular acceptance
- data taking since 2002
  $\longrightarrow$ up to 580 TByte/year

Beam Rates

- (tertiary) Muon:
  $\longrightarrow 4 \cdot 10^7 s^{-1}$
- (secondary) Hadron (π, K, ...):
  $\longrightarrow 5 \cdot 10^6 s^{-1}$



[1] [Nucl. Instr. and Meth. A 577 (2007) 455]

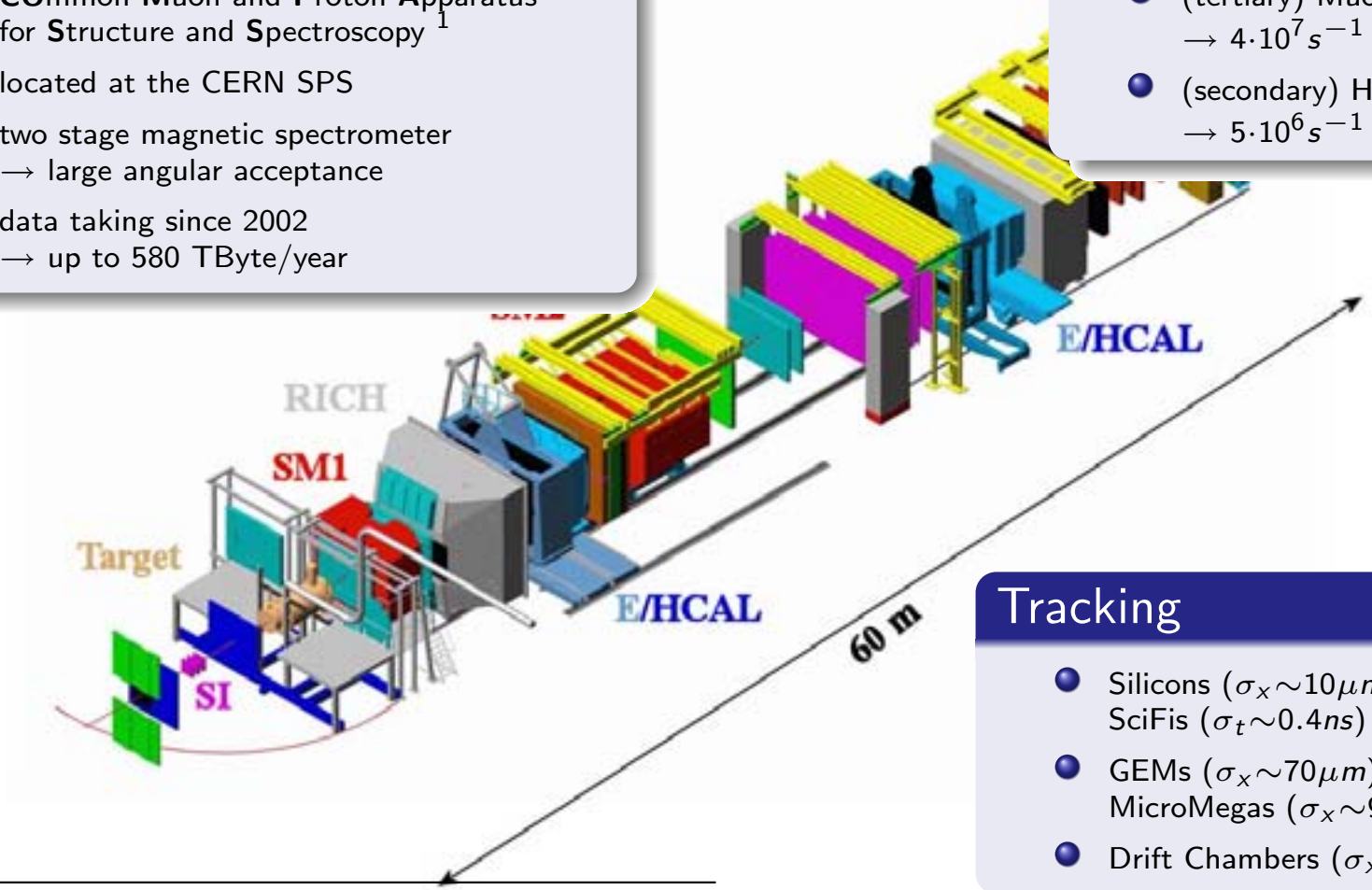
The COMPASS Experiment

Overview

- **CO**mmon **M**uon and **P**roton **A**pparatus for **S**tructure and **S**pectroscopy [1]
- located at the CERN SPS
- two stage magnetic spectrometer
  $\longrightarrow$ large angular acceptance
- data taking since 2002
  $\longrightarrow$ up to 580 TByte/year

Beam Rates

- (tertiary) Muon:
  $\longrightarrow 4{\cdot}10^7 s^{-1}$
- (secondary) Hadron (π, K, ...):
  $\longrightarrow 5{\cdot}10^6 s^{-1}$



Tracking

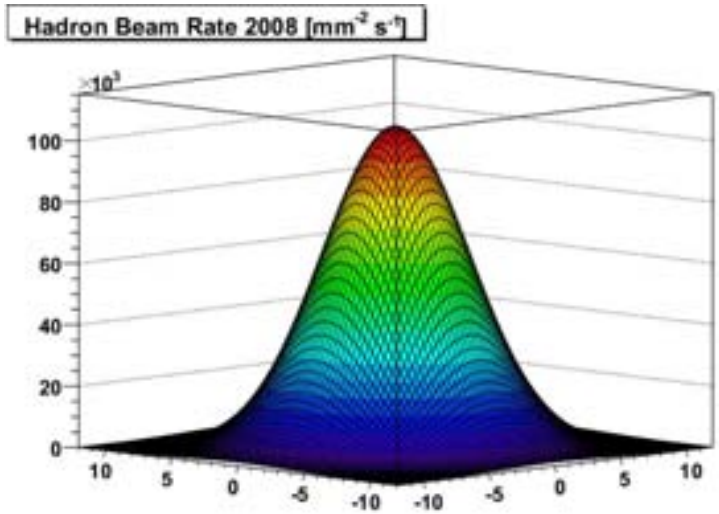
- Silicons ($\sigma_x \sim 10\mu m$),
  SciFis ($\sigma_t \sim 0.4ns$)
- GEMs ($\sigma_x \sim 70\mu m$),
  MicroMegas ($\sigma_x \sim 90\mu m$)
- Drift Chambers ($\sigma_x \leq 200\mu m$)

[1] [Nucl. Instr. and Meth. A 577 (2007) 455]

GEMs for Beam Tracking

Triple-GEM Detectors:

- high rate capability [1,2]
  COMPASS requirements:
  - beam rates: $\lesssim 10^5$ mm^{-2} s^{-1}

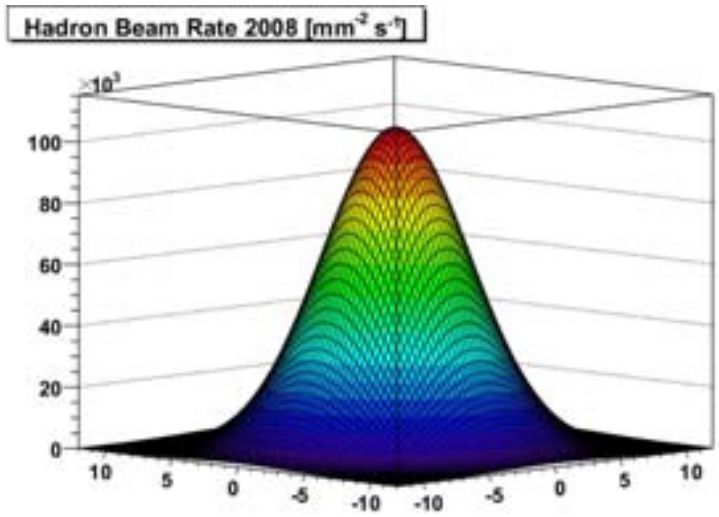


[1] [S. Bachmann, A. Bressan, B. Ketzer et al., Nucl. Instr. and Meth. A 470 (2001) 548.]
[2] [S. Bachmann, S. Kappler, B. Ketzer et al., Nucl. Instr. and Meth. A 478(2002) 104.]

GEMs for Beam Tracking

Triple-GEM Detectors:

- high rate capability [1,2]
  COMPASS requirements:
  - beam rates: $\lesssim 10^5$ mm^{-2} s^{-1}
- small material budget[3]
  center: x/X_0 =0.4 %



[3] [C. Altunbas et al., Nucl. Instr. and Meth. A 490 (2002) 177]

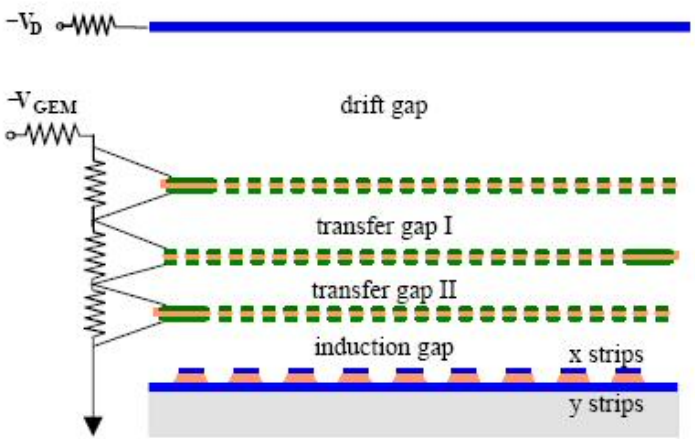
GEMs for Beam Tracking

Triple-GEM Detectors:

- high rate capability [1,2]
  COMPASS requirements:
  - beam rates: $\lesssim 10^5$ mm^{-2} s^{-1}
- small material budget[3]
  center: x/X_0 =0.4 %

Strip Readout

- strip occupancy too high
- no sufficient beam tracking with strip readout



GEMs for Beam Tracking

Triple-GEM Detectors:

- high rate capability [1,2]
  COMPASS requirements:
  - beam rates: $\lesssim 10^5$ mm^{-2} s^{-1}
- small material budget[3]
  center: x/X_0 =0.4 %

Strip Readout

- strip occupancy too high
- no sufficient beam tracking with strip readout

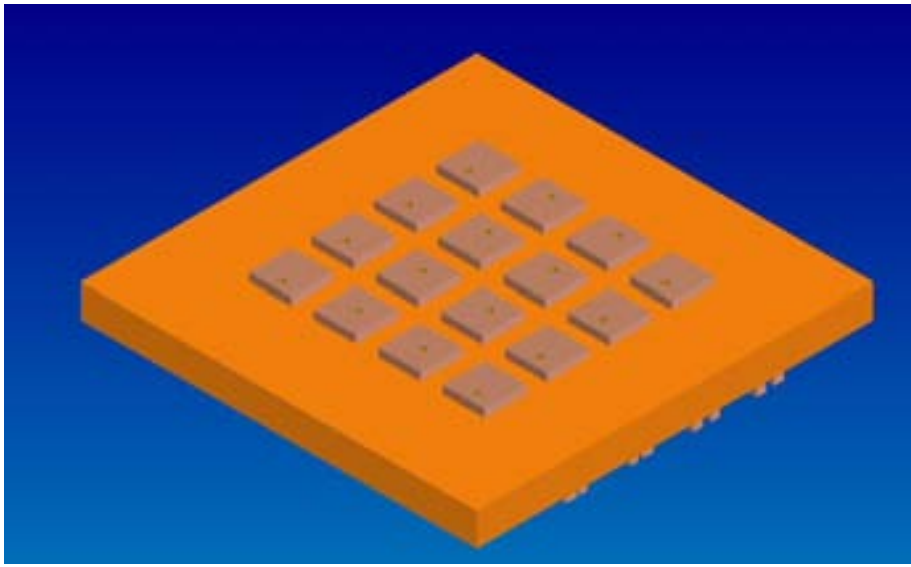
GEM detector with combined pixel/strip readout

The combined Pixel-Strip-Readout

- 3-layer foil
  (base material: Kapton)
- thickness: 100 μm

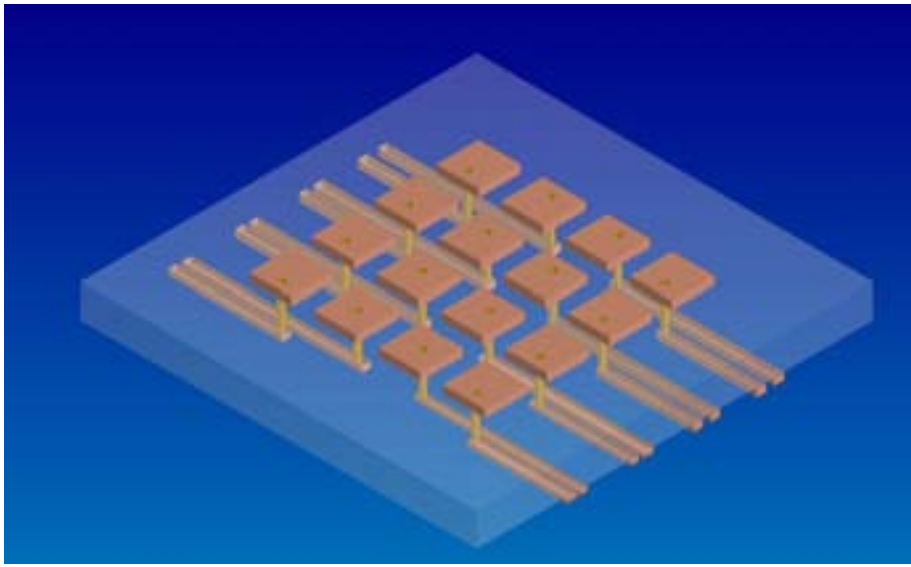
The combined Pixel-Strip-Readout

- 3-layer foil
  (base material: Kapton)
- thickness: 100 μm
- 32 x 32 pixels
- pitch: 1 mm



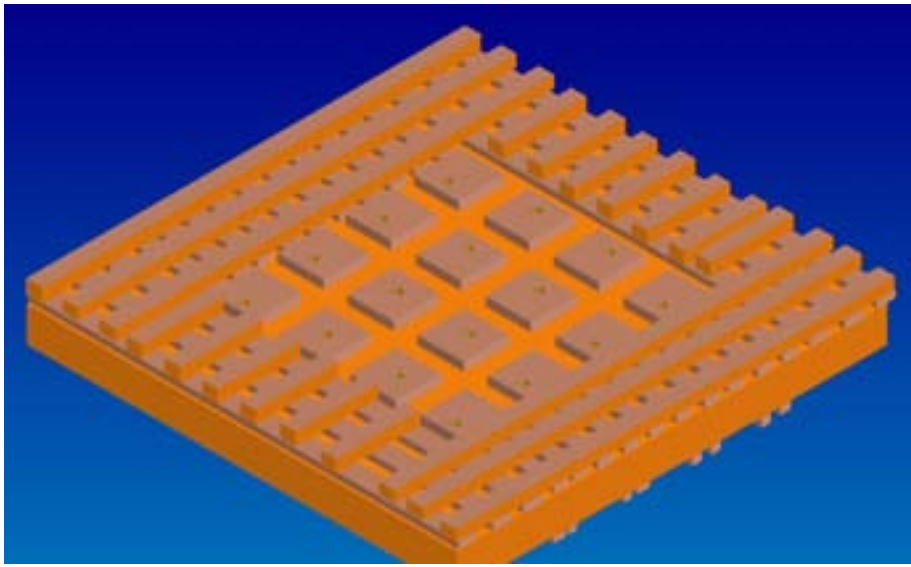
The combined Pixel-Strip-Readout

- 3-layer foil
  (base material: Kapton)
- thickness: 100 μm
- 32 x 32 pixels
- pitch: 1 mm



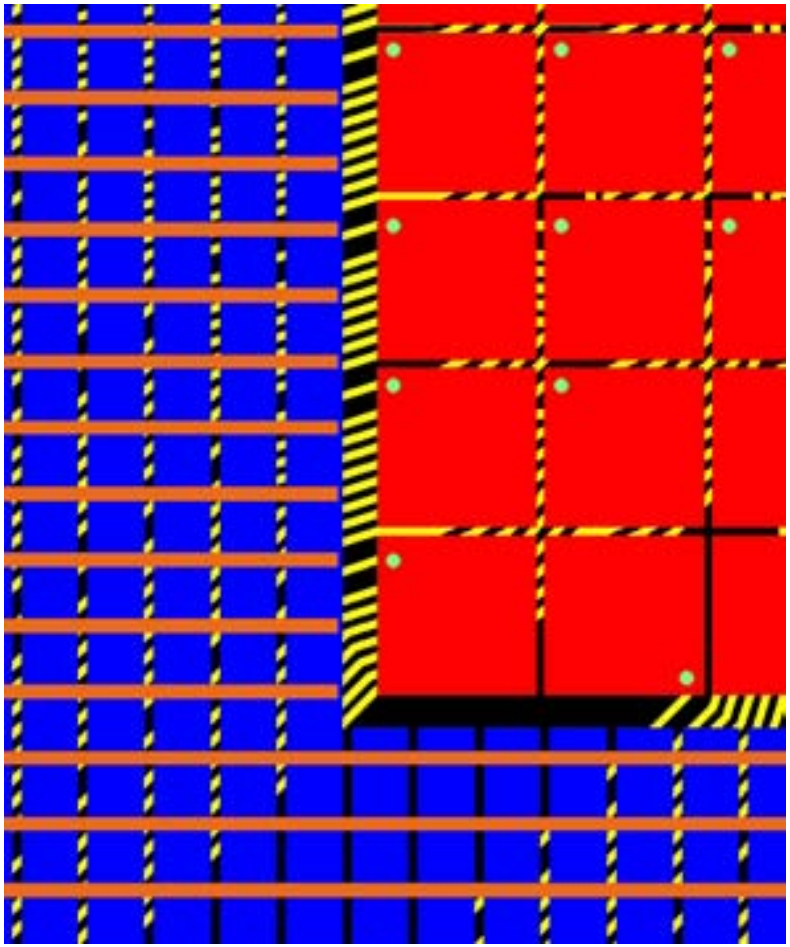
The combined Pixel-Strip-Readout

- 3-layer foil
  (base material: Kapton)
- thickness: 100 μm
- 32 x 32 pixels
- pitch: 1 mm
- 1024 strip channels
  (512 x, 512 y)
- pitch: 400 μm
- equal charge sharing

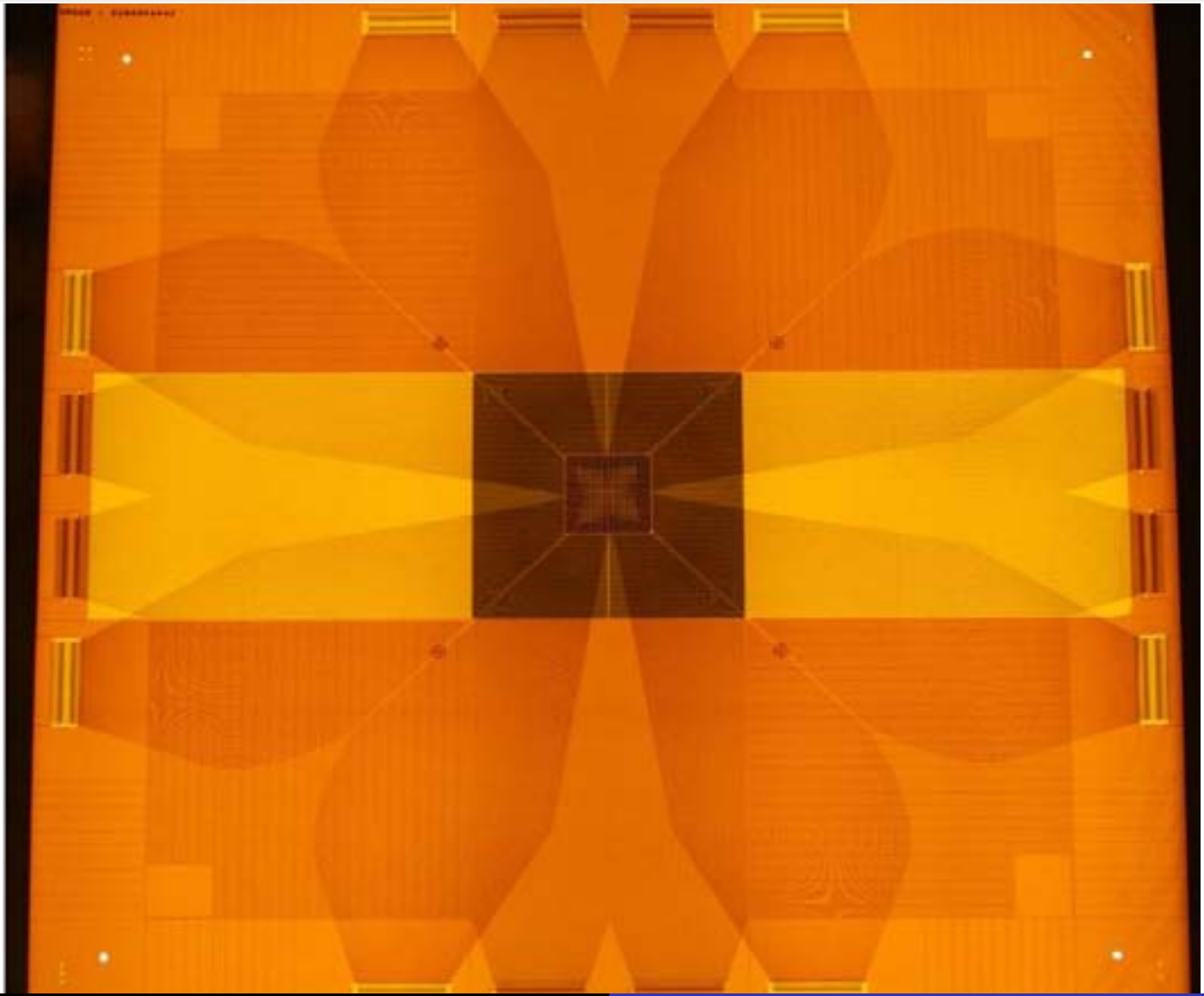


The combined Pixel-Strip-Readout

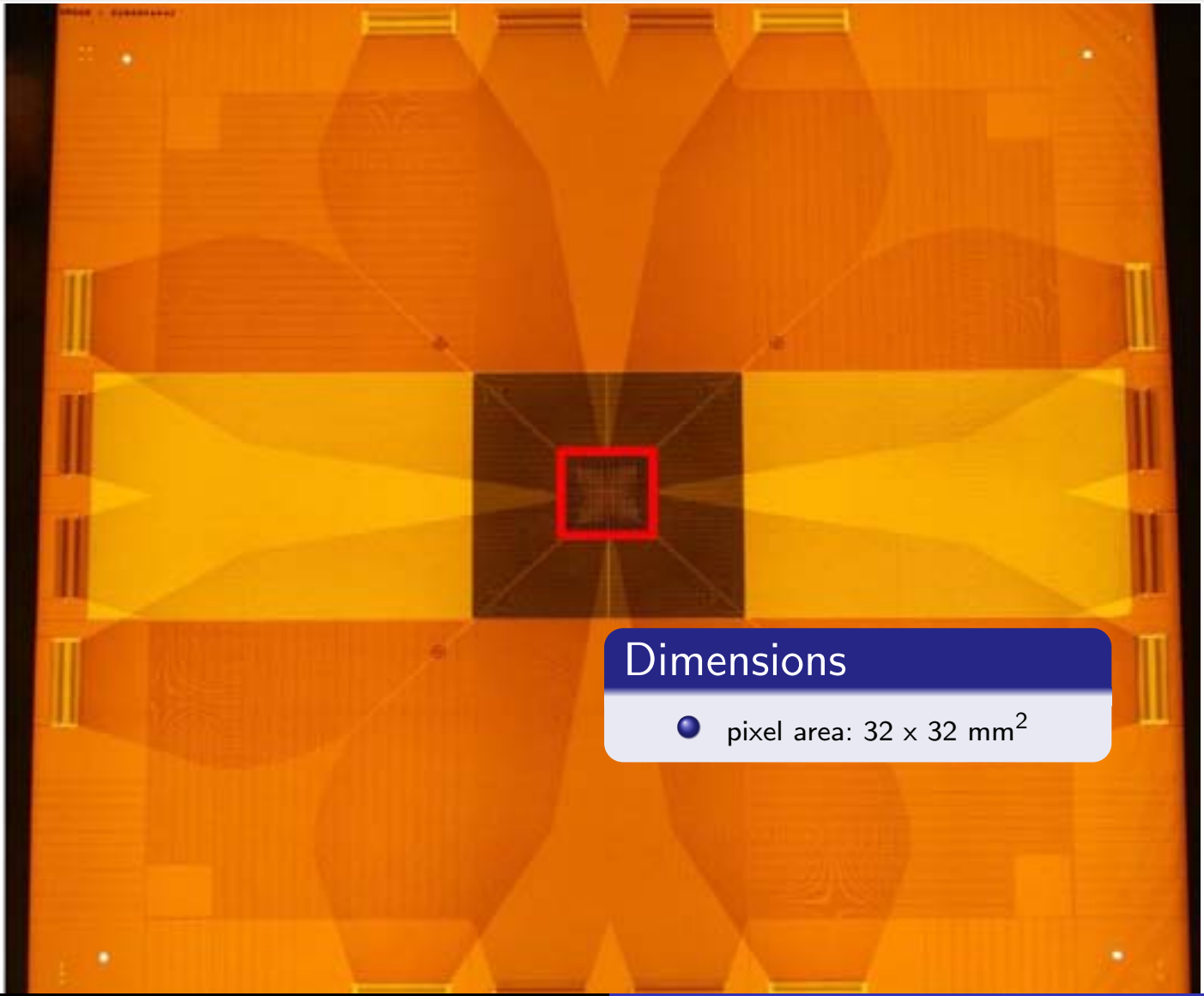
- 3-layer foil
  (base material: Kapton)
- thickness: 100 μm
- 32 x 32 pixels
- pitch: 1 mm
- 1024 strip channels
  (512 x, 512 y)
- pitch: 400 μm
- equal charge sharing



The combined Pixel-Strip-Readout



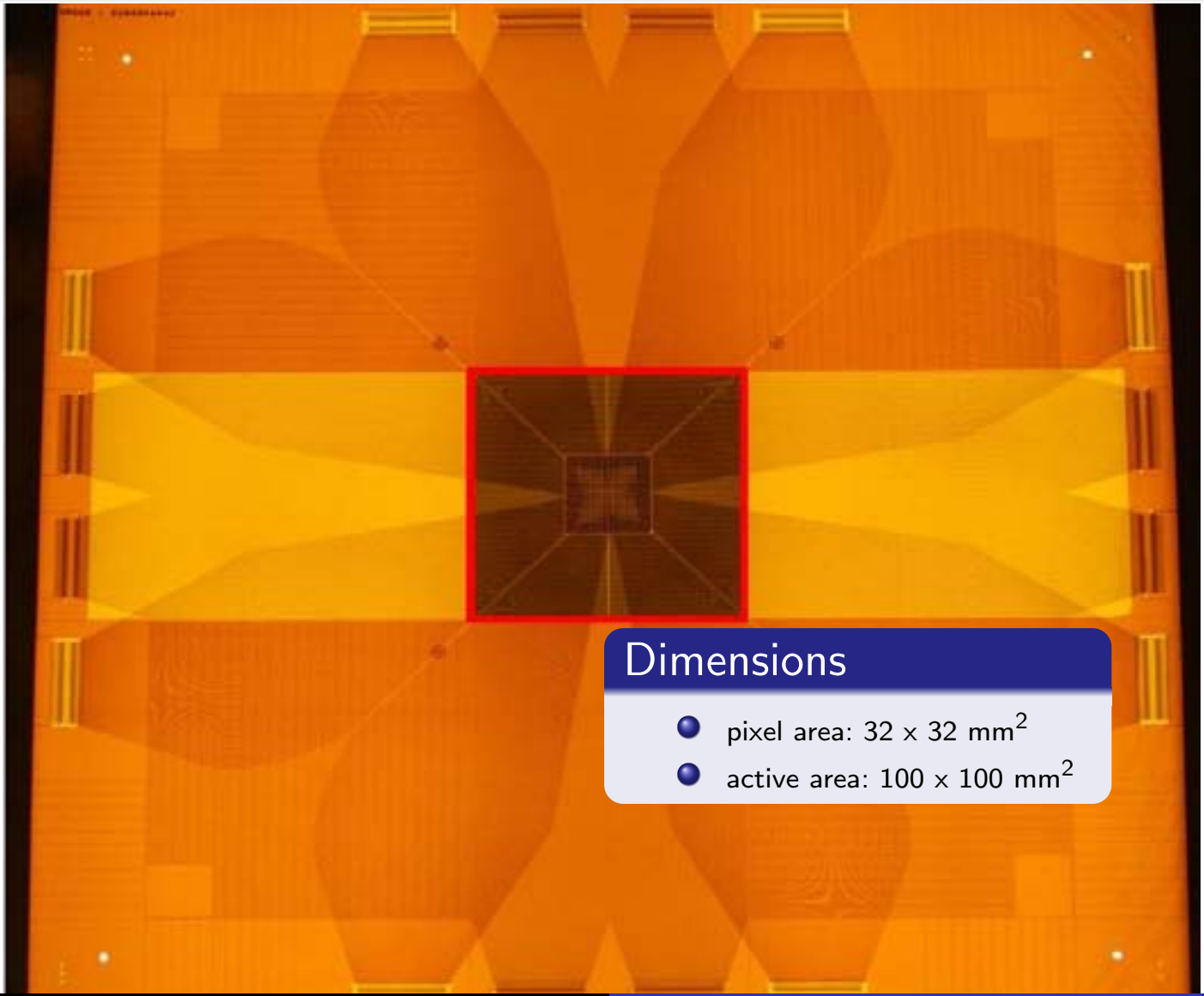
The combined Pixel-Strip-Readout



Dimensions

- pixel area: 32 x 32 mm^2

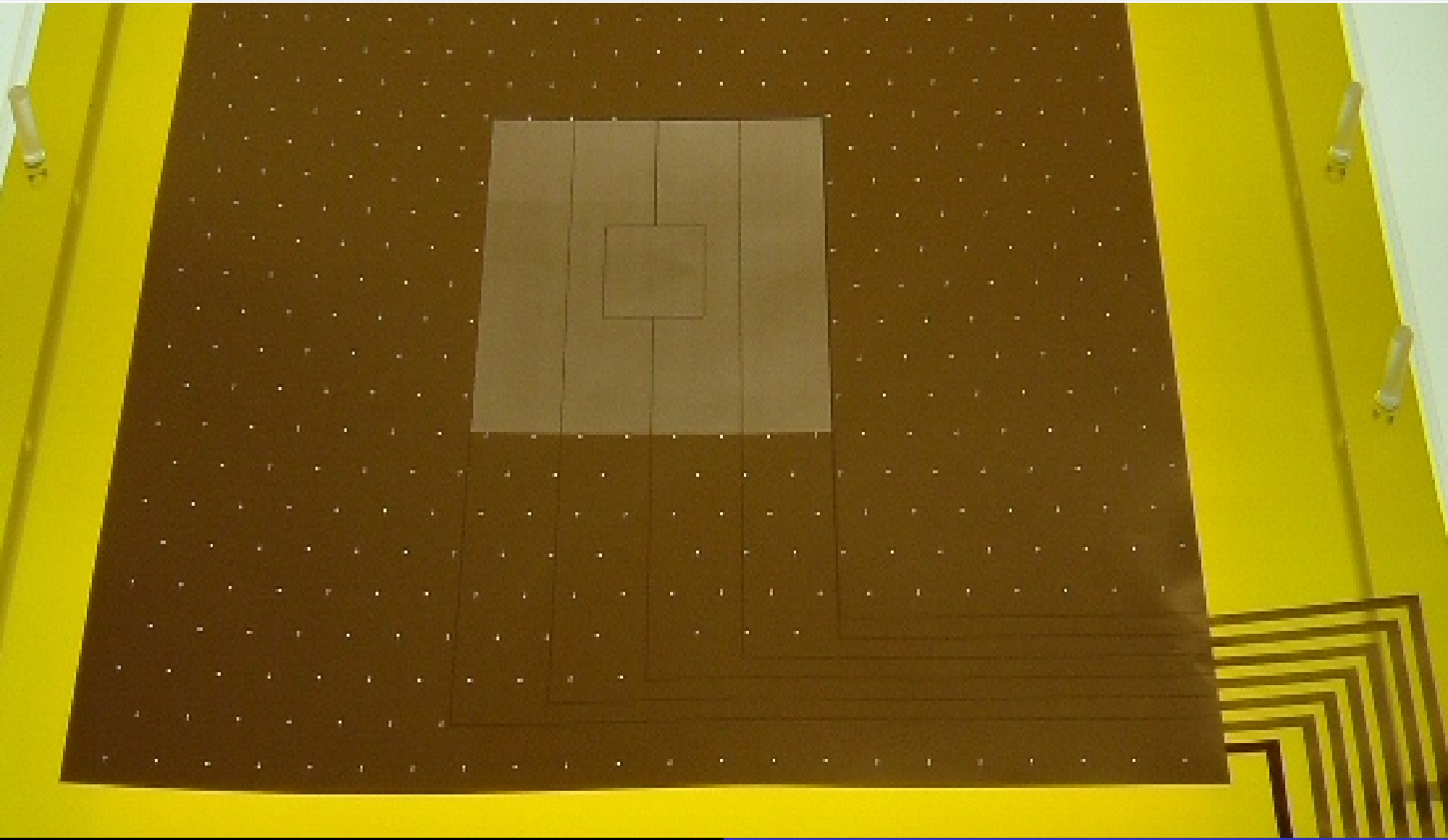
The combined Pixel-Strip-Readout



Dimensions

- pixel area: 32 x 32 mm^2
- active area: 100 x 100 mm^2

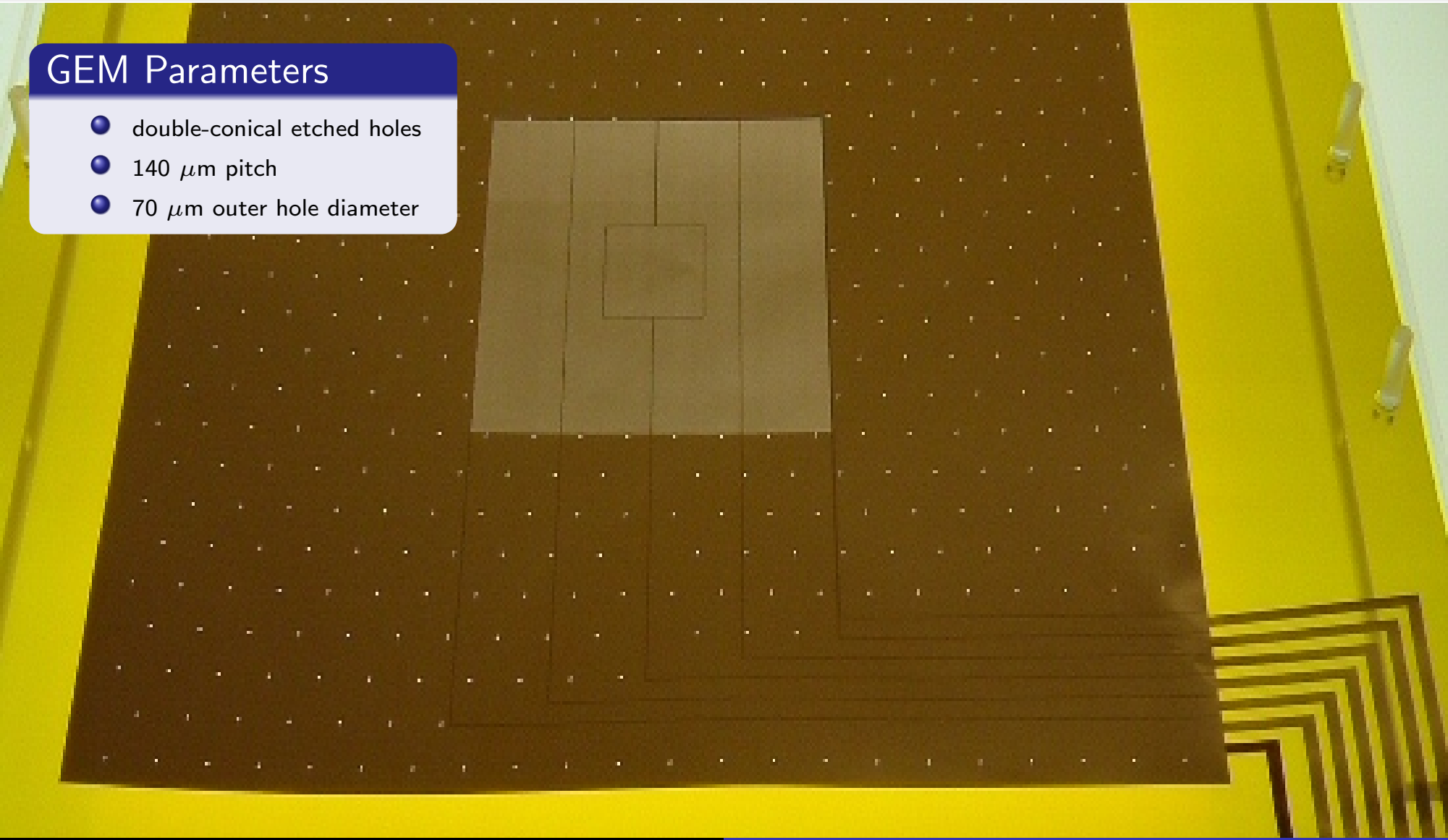
GEM Geometries and Settings



GEM Geometries and Settings

GEM Parameters

- double-conical etched holes
- 140 μm pitch
- 70 μm outer hole diameter



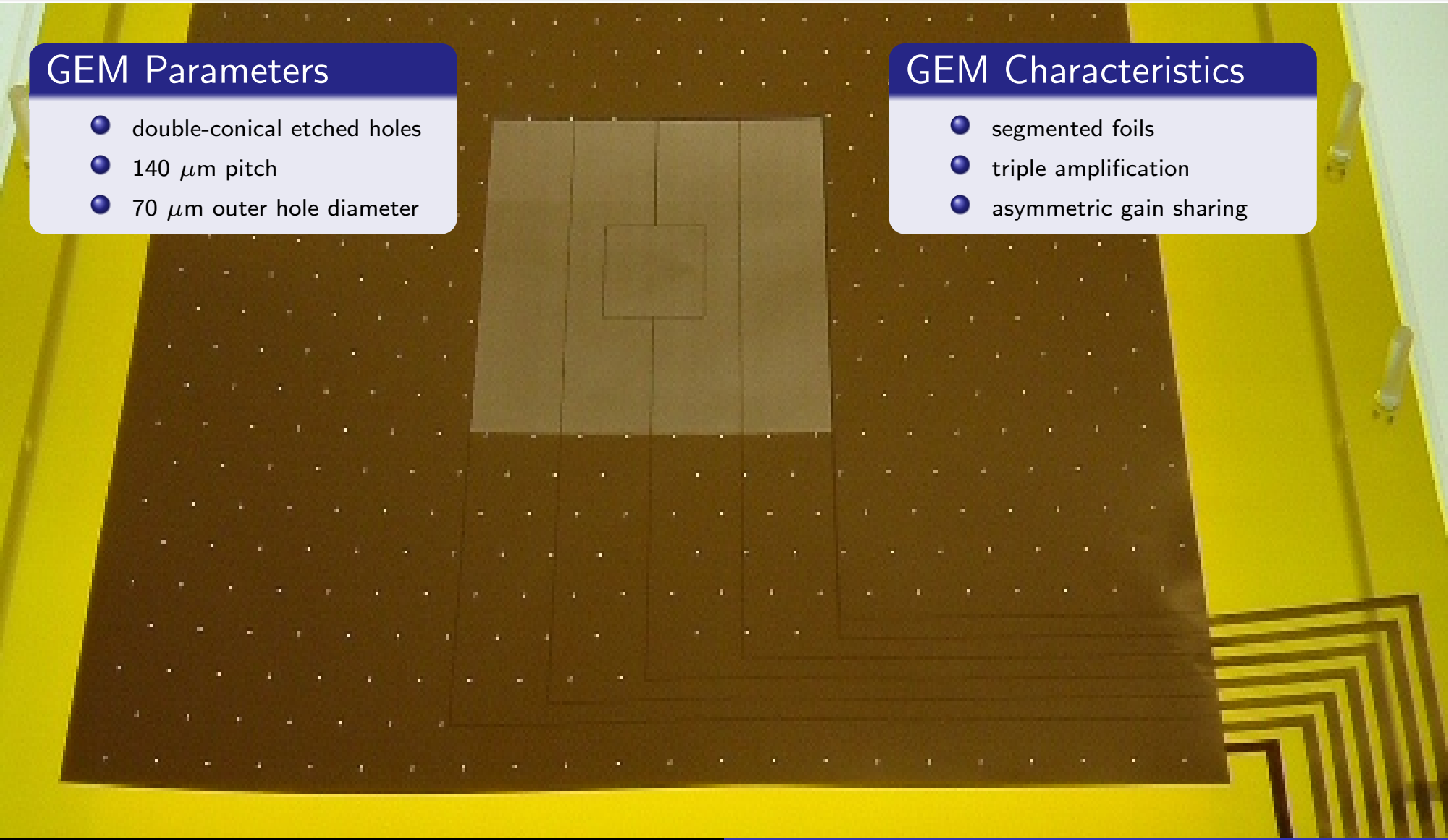
GEM Geometries and Settings

GEM Parameters

- double-conical etched holes
- 140 μm pitch
- 70 μm outer hole diameter

GEM Characteristics

- segmented foils
- triple amplification
- asymmetric gain sharing



GEM Geometries and Settings

GEM Parameters

- double-conical etched holes
- 140 μm pitch
- 70 μm outer hole diameter

GEM Characteristics

- segmented foils
- triple amplification
- asymmetric gain sharing

Foil Properties

- foil size: 330 x 330 mm^2
- no gas amplification in outer region
- big holes ($\varnothing$ 0.5 mm) only for gas exchange

GEM Geometries and Settings

GEM Parameters

- double-conical etched holes
- 140 μm pitch
- 70 μm outer hole diameter

GEM Characteristics

- segmented foils
- triple amplification
- asymmetric gain sharing

Foil Properties

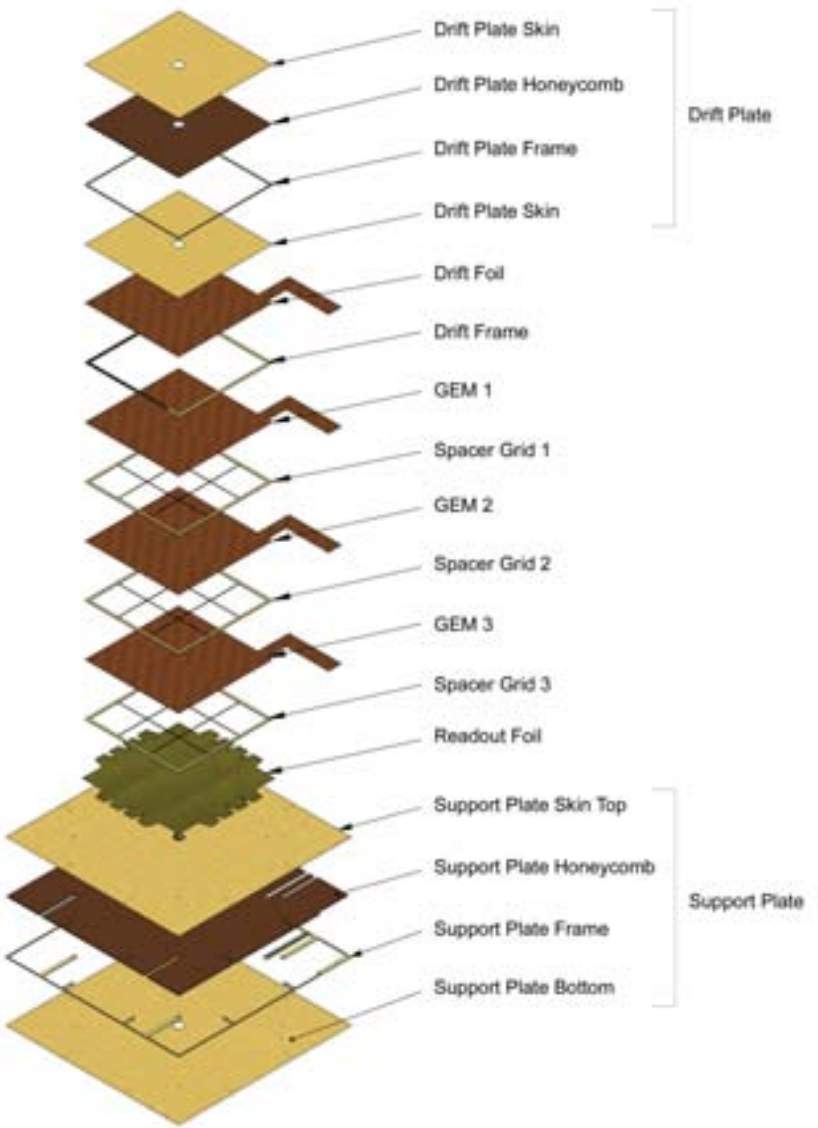
- foil size: 330 x 330 mm^2
- no gas amplification in outer region
- big holes ($\varnothing$ 0.5 mm) only for gas exchange

thin copper

- foils with only 1-2 μm thick copper[1]

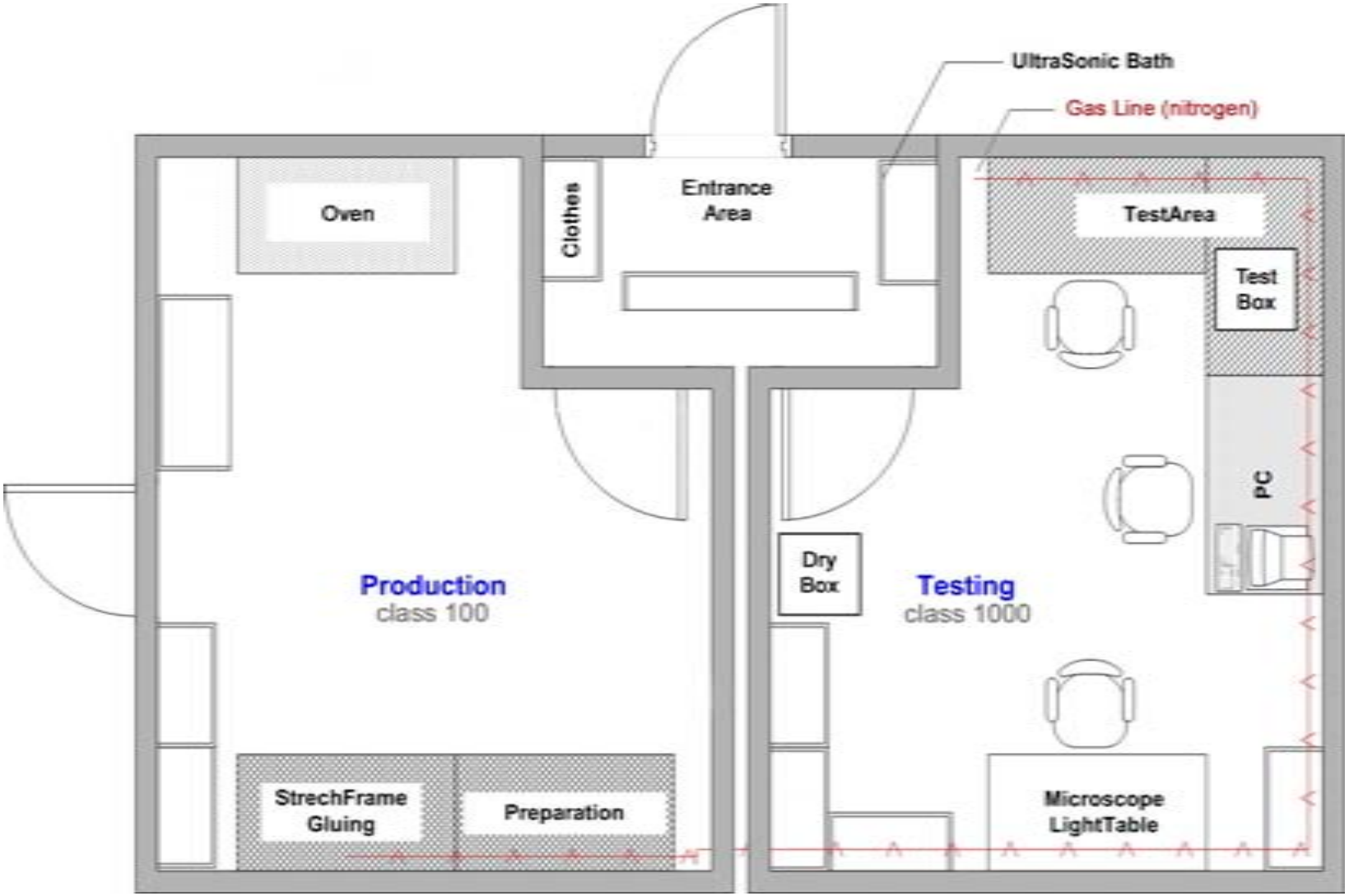
[1] [A. Bondar, et al., Nucl. Instr. and Meth. A 556 (2006) 495]

Assembly



- All constructional drawings done at TU Munich (with advice of CERN engineers)
- The same for the layout of the foils (Gerber files)
- Foils and support structures manufactured at CERN
- Testing, assembly and commissioning done at TU Munich

Infrastructure

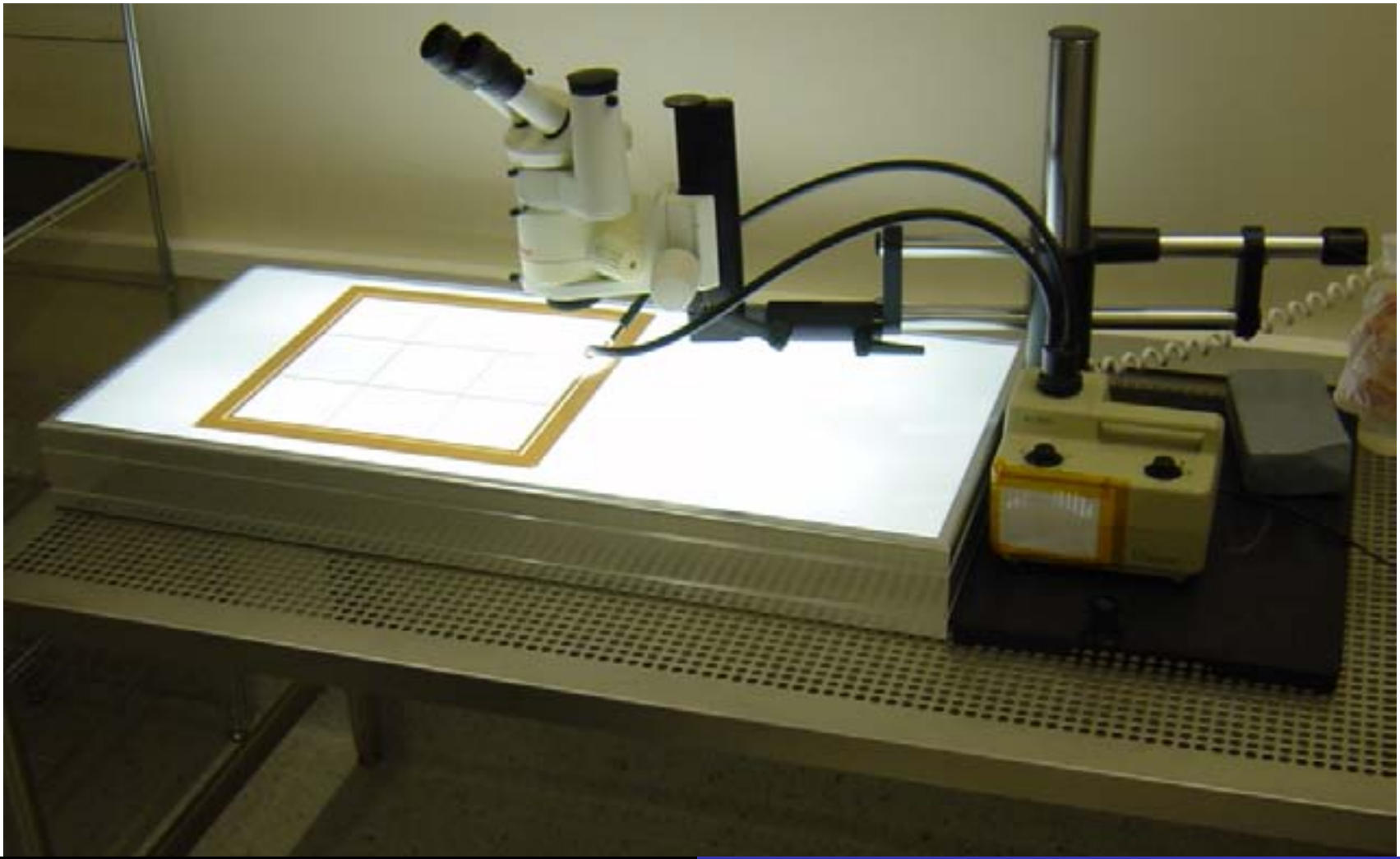


Preparation

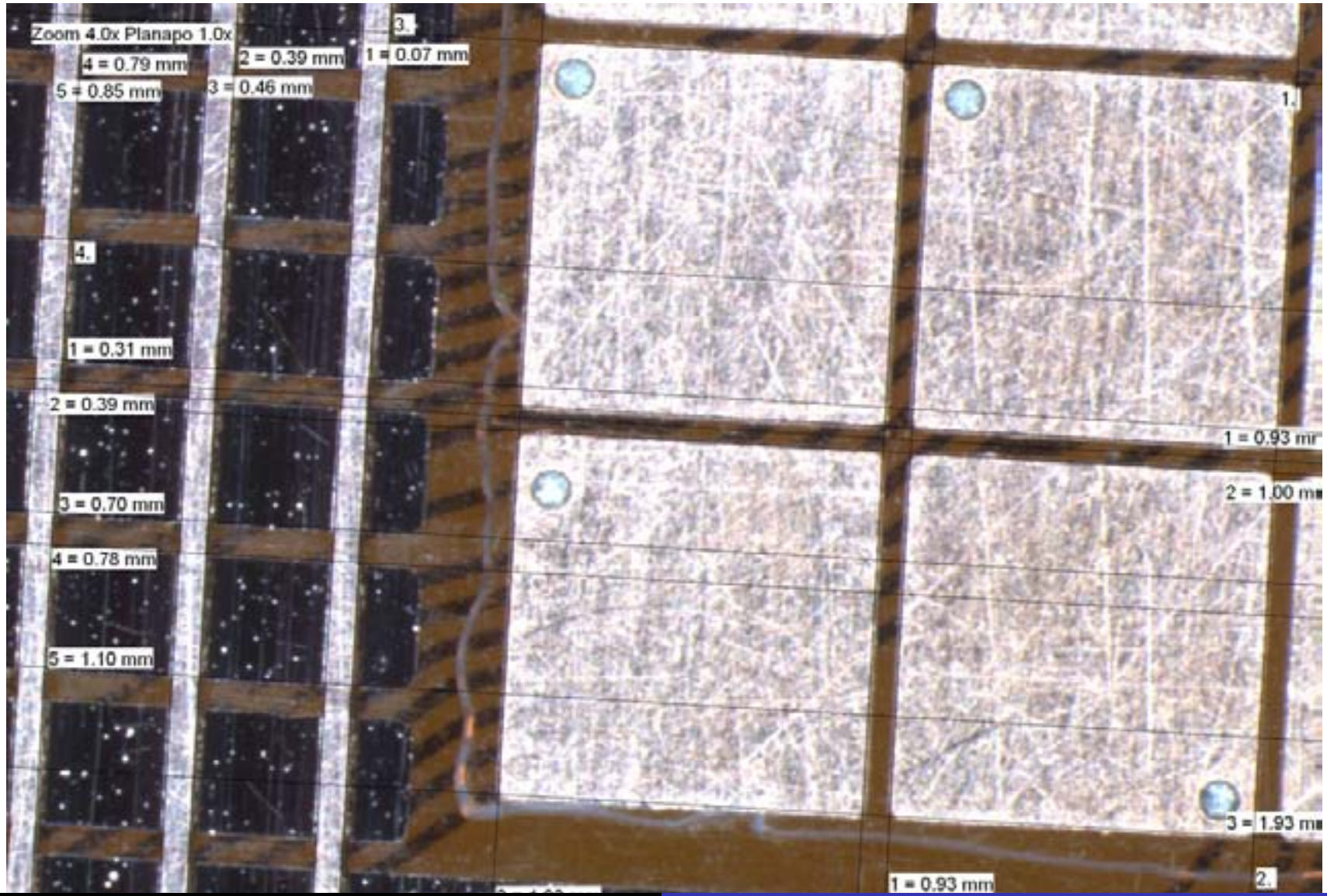
- Sanding of all support frames to remove grouts (danger of shortcuts in the detector)
- Cleaning of components with Isopropanol and demineralized water in ultrasonic bath
- Storage of foils in nitrogen atmosphere to avoid oxidation

After preparation touch components only with gloves
(fingerprint on foils can cause 1 mA leakage current!)

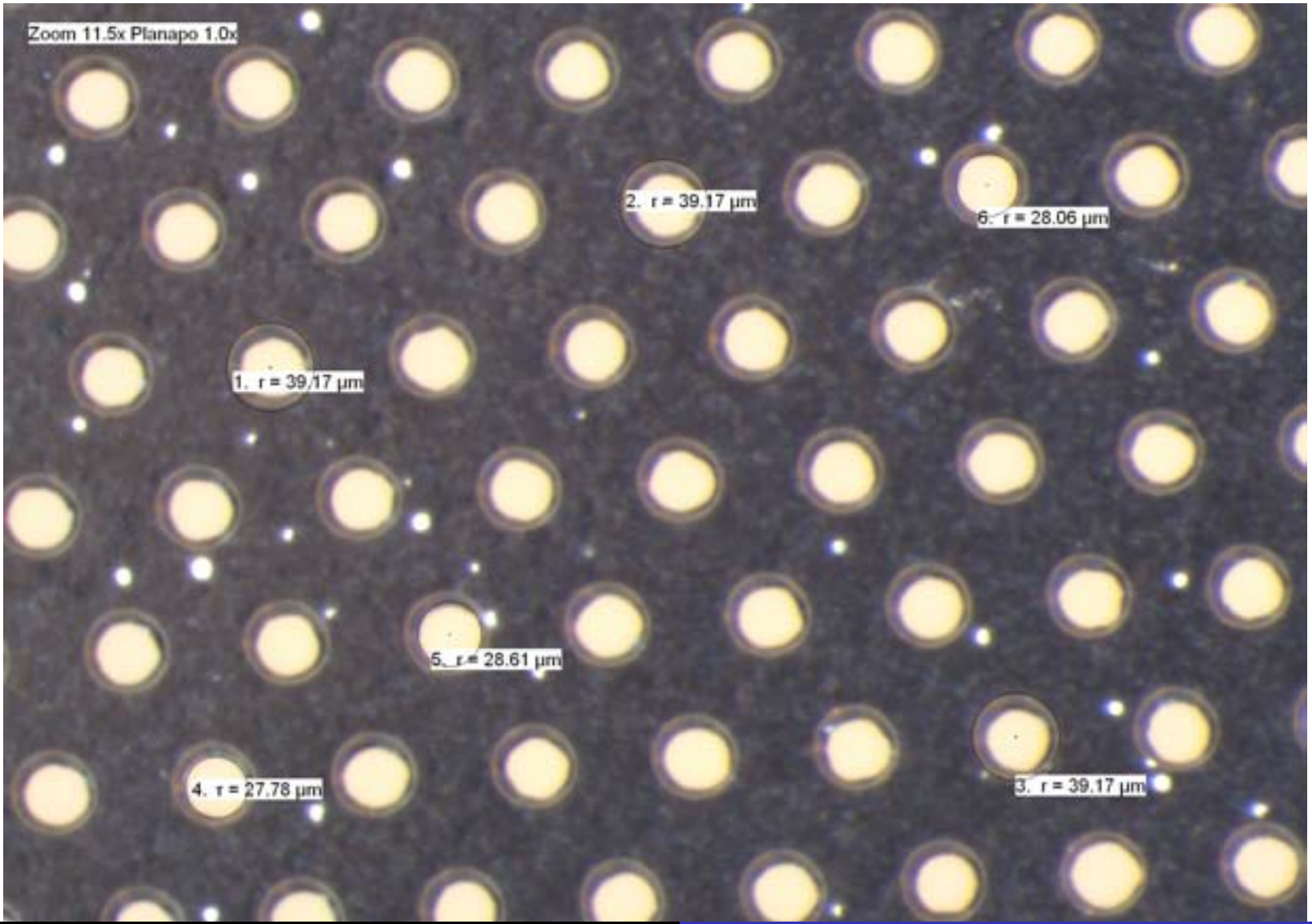
Qualitity Assurance I - Optical Inspection



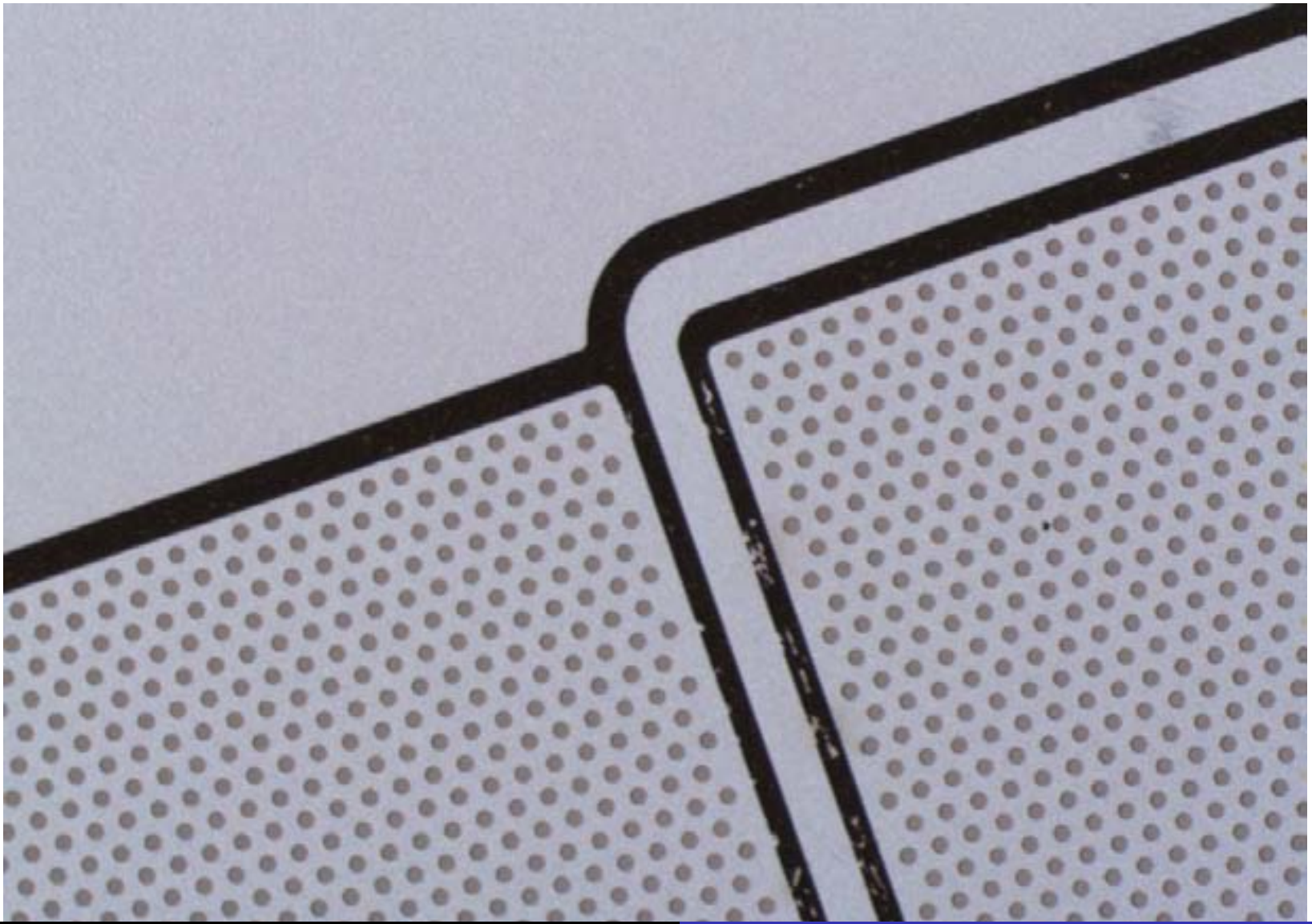
Qualitity Assurance I - Optical Inspection



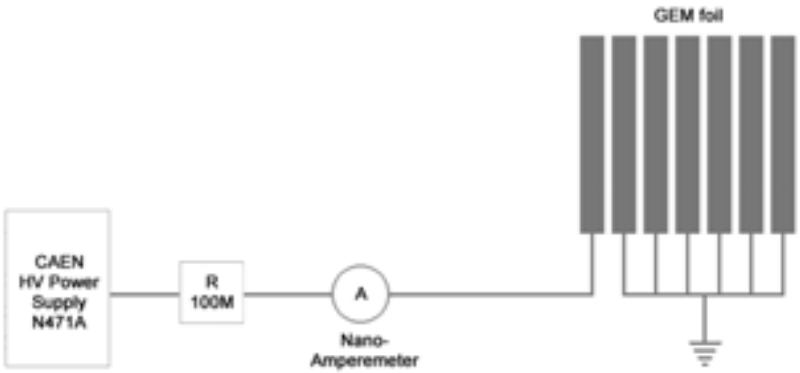
Qualitity Assurance I - Optical Inspection



Qualitity Assurance I - Optical Inspection

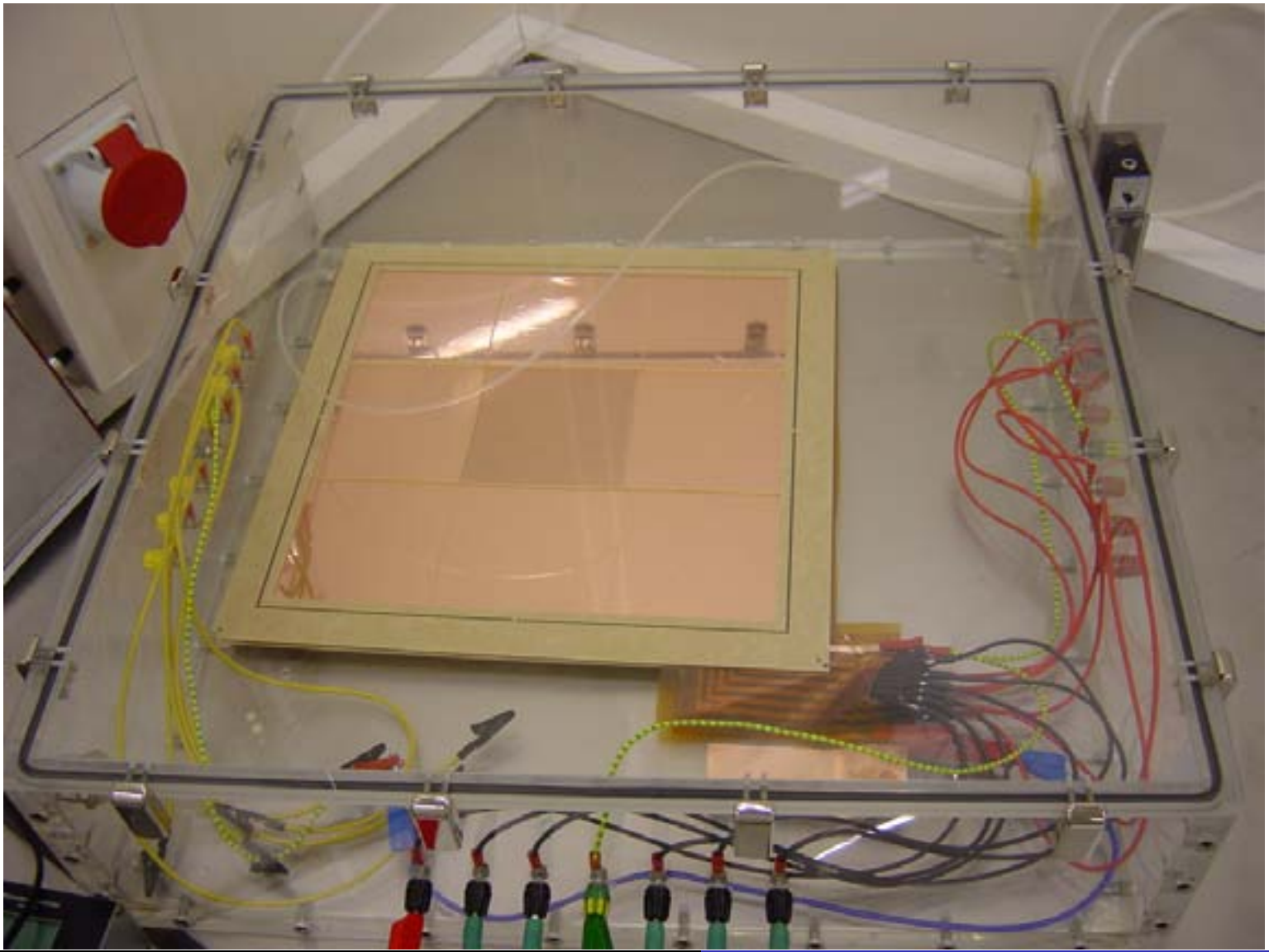


Qualitity Assurance I - HV Tests

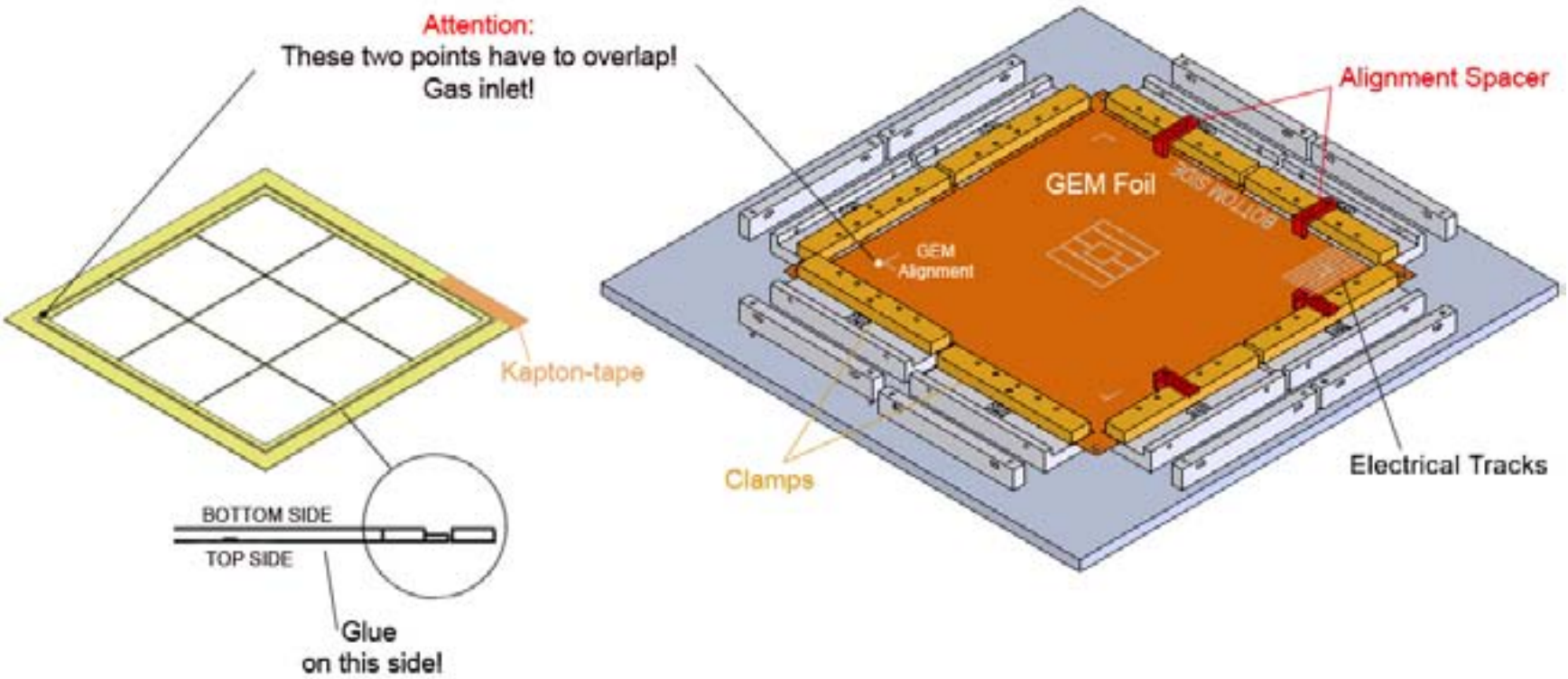


- HV tests for Driftplates, Spacergrids and Driftfoils done by ambient atmosphere
- HV tests for GEM foils under nitrogen atmosphere (no oxygen or water allowed)

Qualitity Assurance I - HV Tests

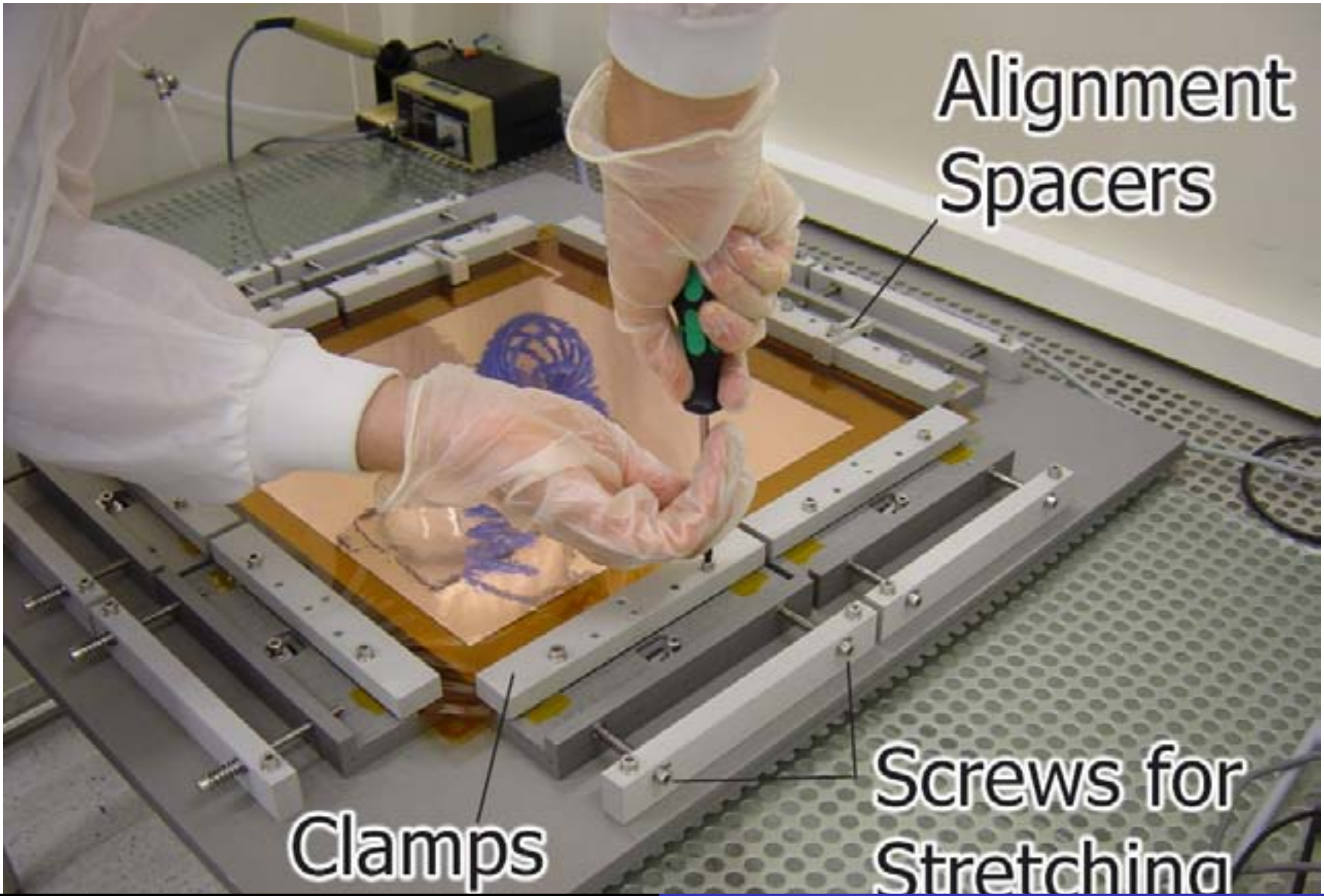


Gluing

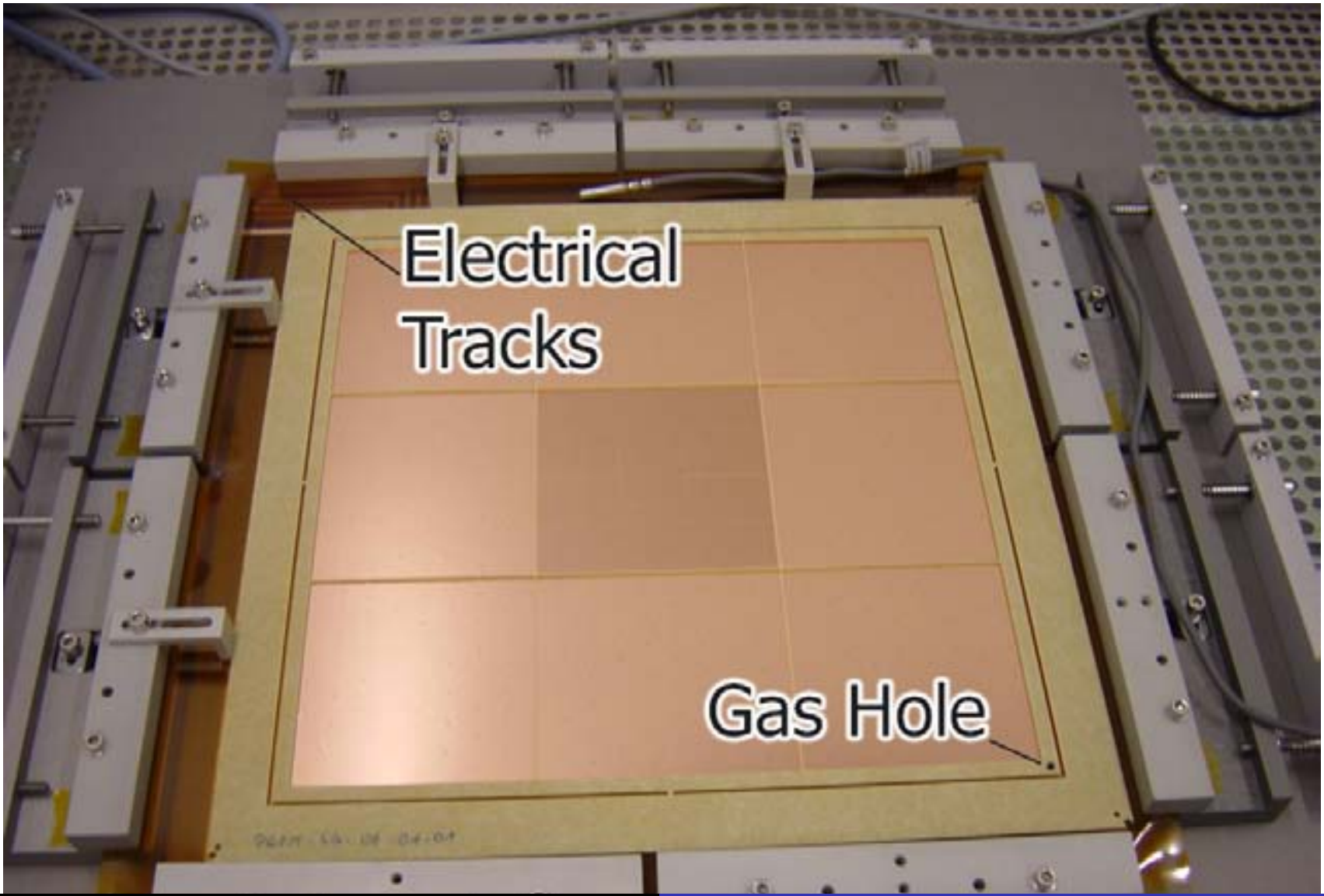


Stretching frame for fixation and flattening of GEM foils during gluing process

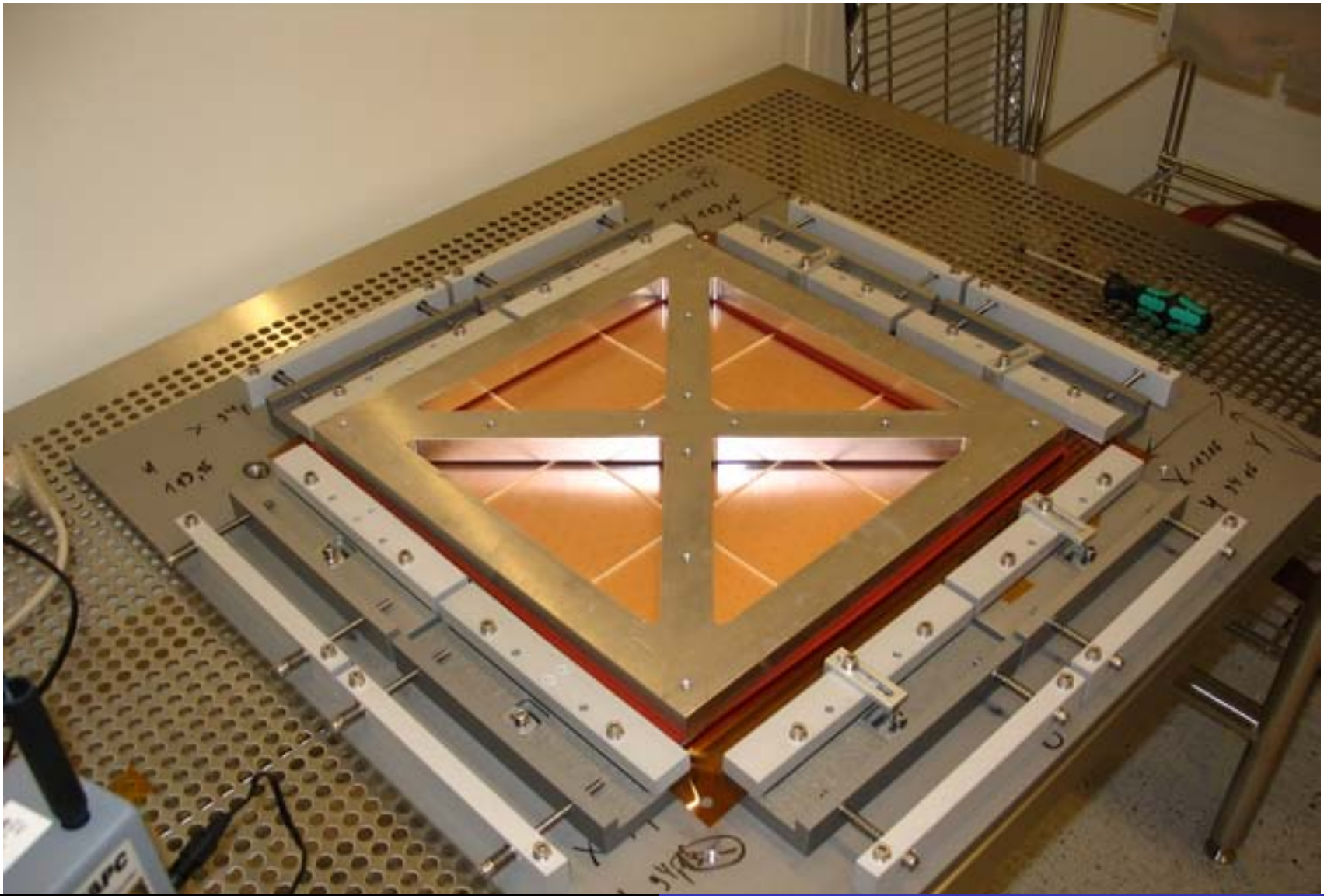
Gluing



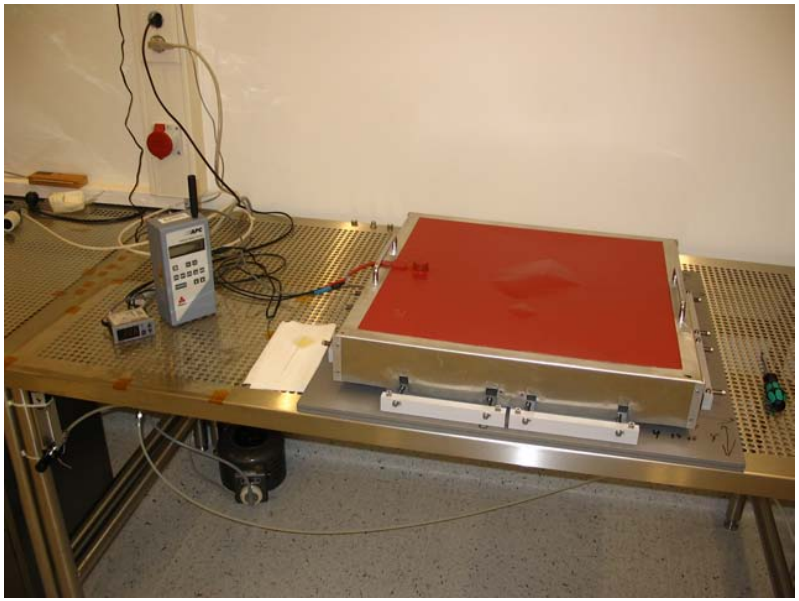
Gluing



Gluing

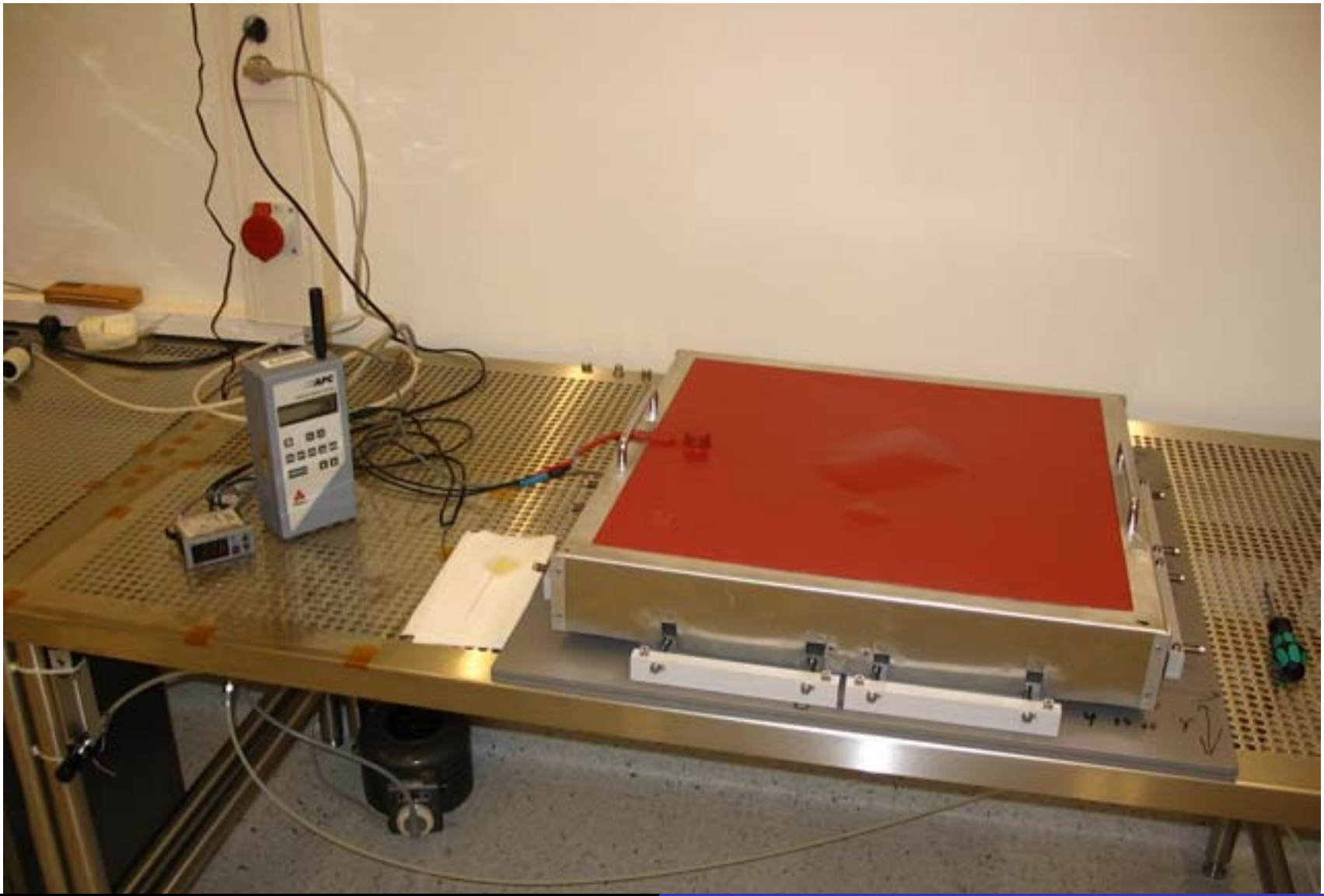


Gluing

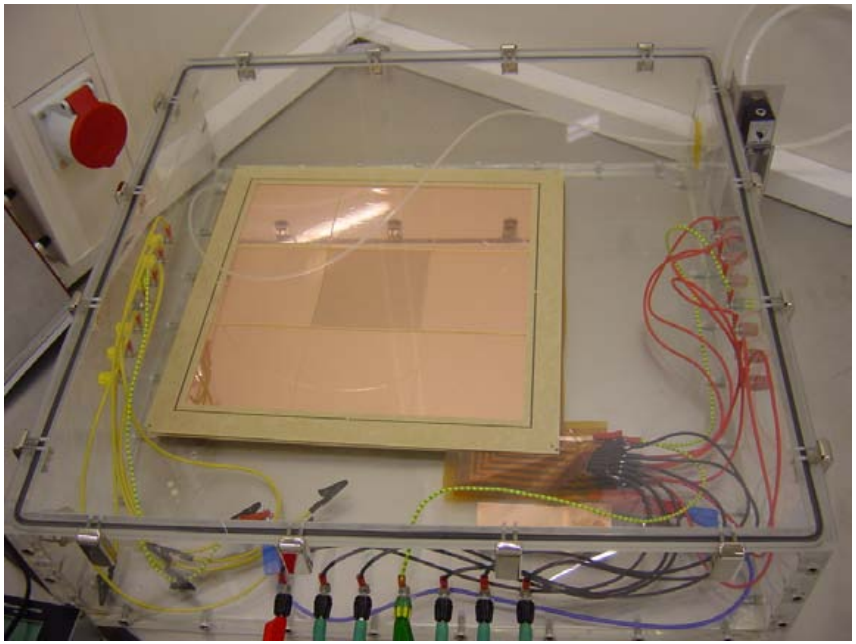


- monitoring of environmental conditions during each production step
- complete polymerization of glue important
  $\longrightarrow$ constant, defined temperature for several hours

Gluing

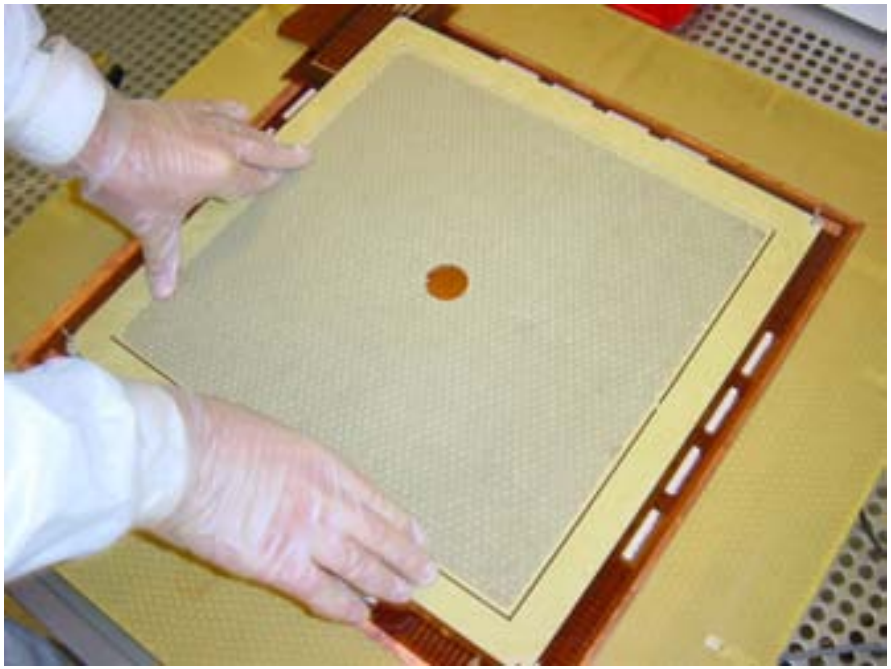


Qualitity Assurance II



- After each production step the components have to be tested for their stability and functionality

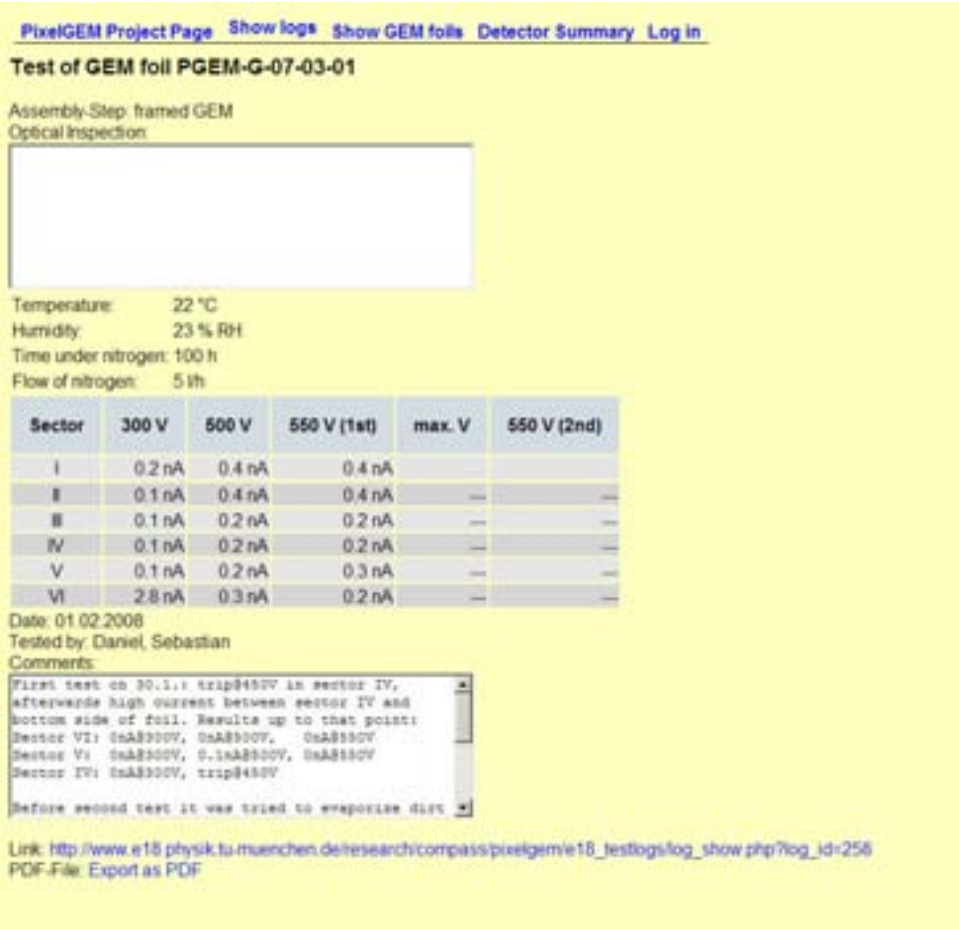
Assembly



Complete assembly in two steps

- Step1: Gluing the GEM stack, consisting of 3 GEM foils - Spacergrid pairs and Driftfoil glued on Driftplate
- Quality control
- Step 2: Gluing tested GEM stack on Readout

Documentation



PixelGEM Project Page Show logs Show GEM foils Detector Summary Log in

Test of GEM foil PGEM-G-07-03-01

Assembly-Step: framed GEM
Optical Inspection:

Temperature: 22 °C
Humidity: 23 % RH
Time under nitrogen: 100 h
Flow of nitrogen: 5 l/h

Sector	300 V	500 V	550 V (1st)	max. V	550 V (2nd)
I	0.2 nA	0.4 nA	0.4 nA		
II	0.1 nA	0.4 nA	0.4 nA	–	–
III	0.1 nA	0.2 nA	0.2 nA	–	–
IV	0.1 nA	0.2 nA	0.2 nA	–	–
V	0.1 nA	0.2 nA	0.3 nA	–	–
VI	2.8 nA	0.3 nA	0.2 nA	–	–

Date: 01.02.2008
Tested by: Daniel, Sebastian
Comments:

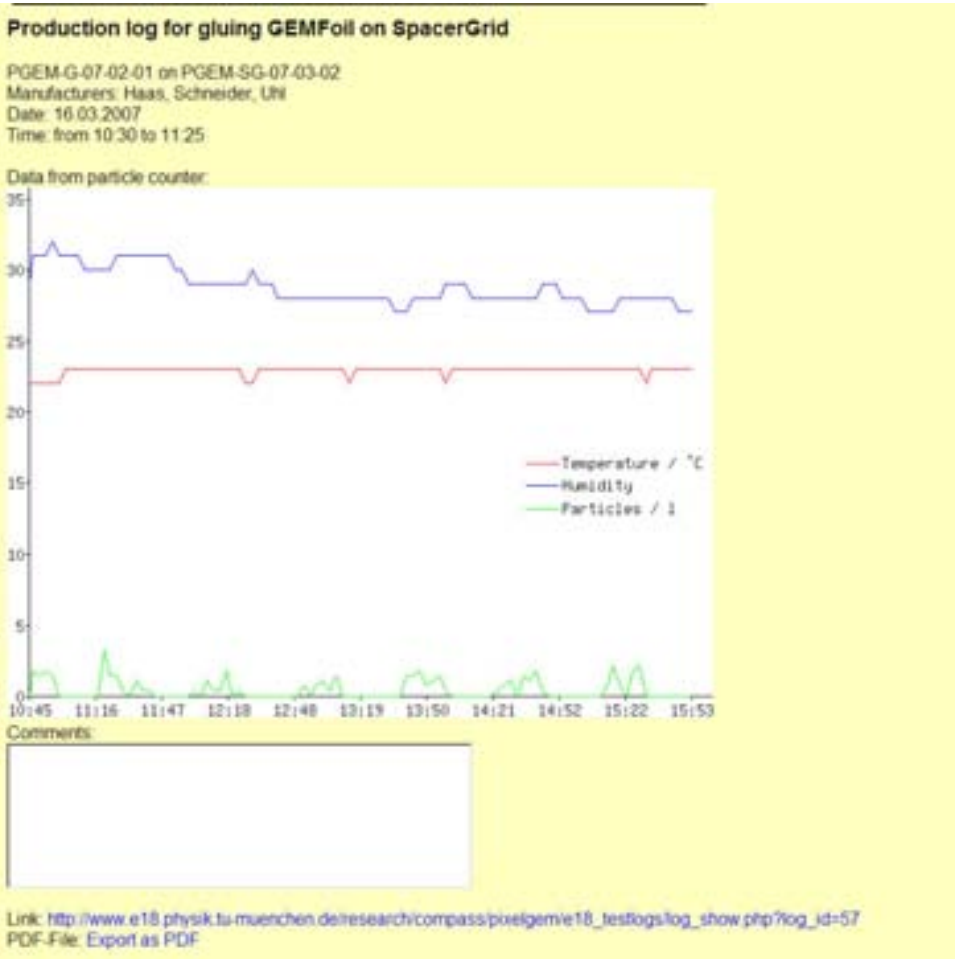
First test on 30.1.: trip@450V in sector IV, afterwards high current between sector IV and bottom side of foil. Results up to that point: Sector VI: 0nA@300V, 0nA@500V, 0nA@550V Sector V: 0nA@300V, 0.1nA@500V, 0nA@550V Sector IV: 0nA@300V, trip@450V

Before second test it was tried to evaporize dirt

Link: http://www.e18.physik.tu-muenchen.de/research/compass/pixelgem/e18_testlogs/log_show.php?log_id=258
PDF-File: Export as PDF

- Each production step, from the preparation to the last commissioning must be documented

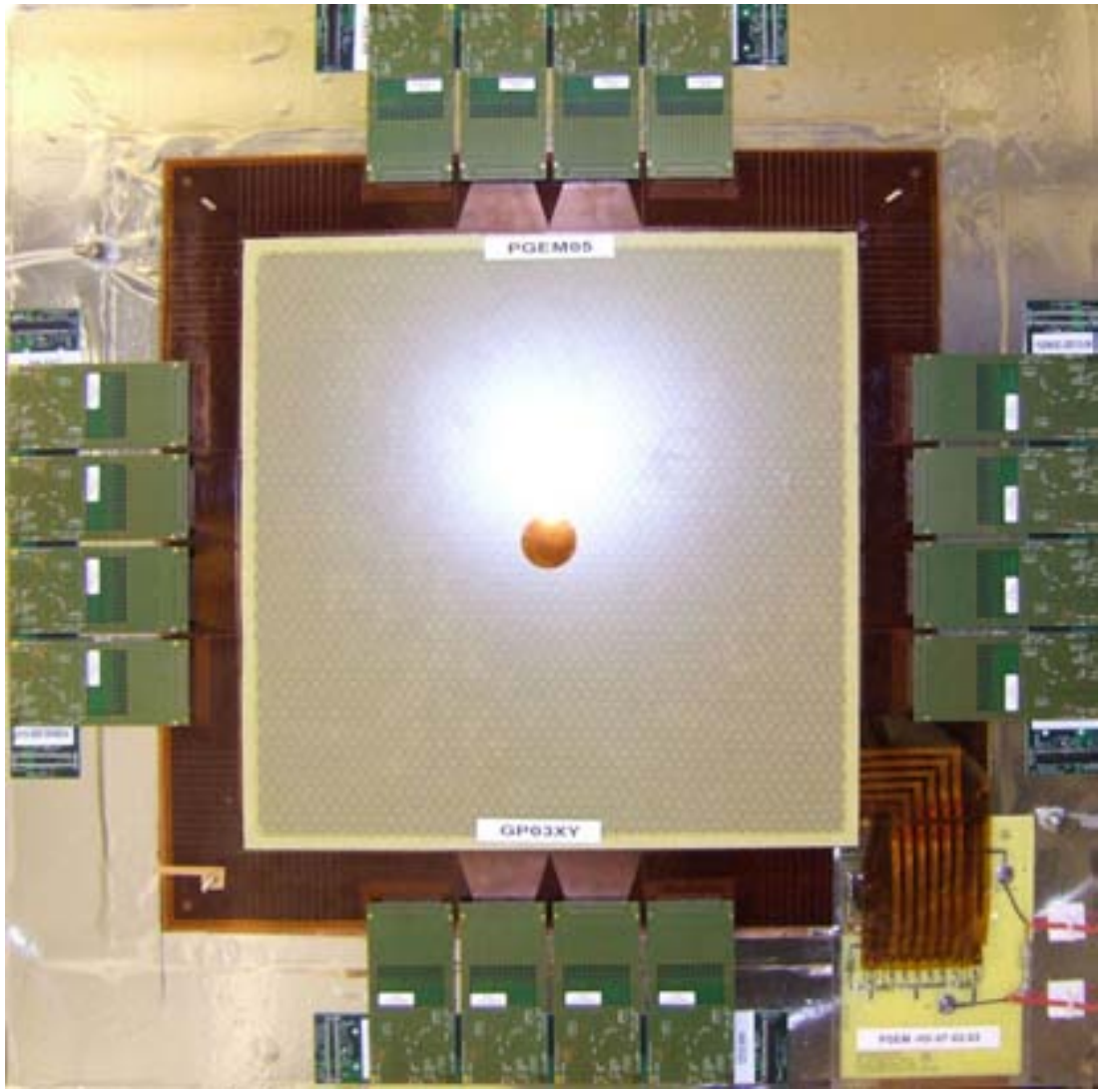
Documentation



- Each production step, from the preparation to the last commissioning must be documented
- Webbased MySQL database including
  - Photos
  - Quality tests
  - Production logs
  - Environmental data

  for each production step
- For each detector complete summary available (PDF or online)

Complete Detector

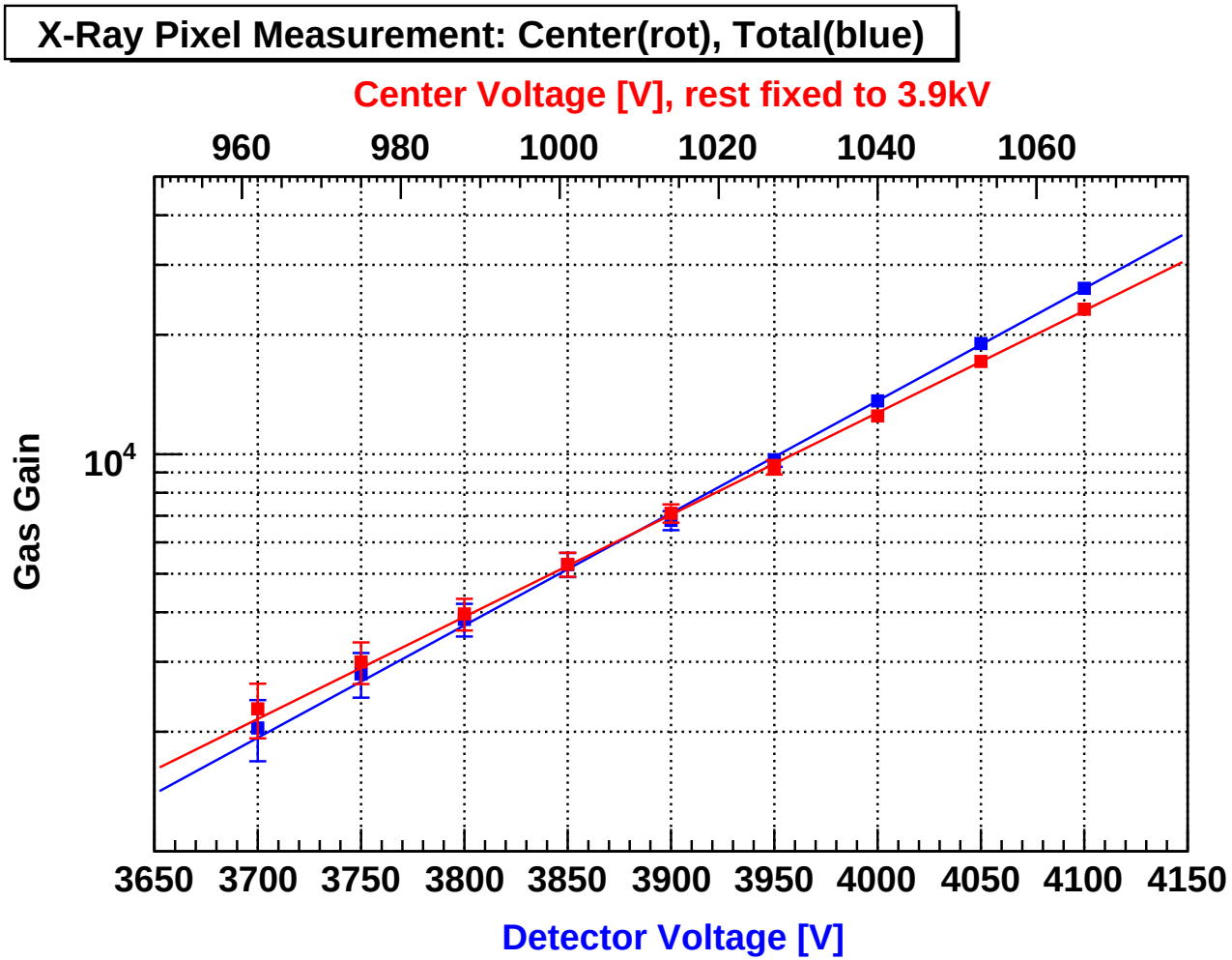


For detailed procedure steps and further commissioning see production guide[1] at
www.e18.physik.tu-muenchen.de

[1] Construction and Test of PixelGEM Tracking Detectors

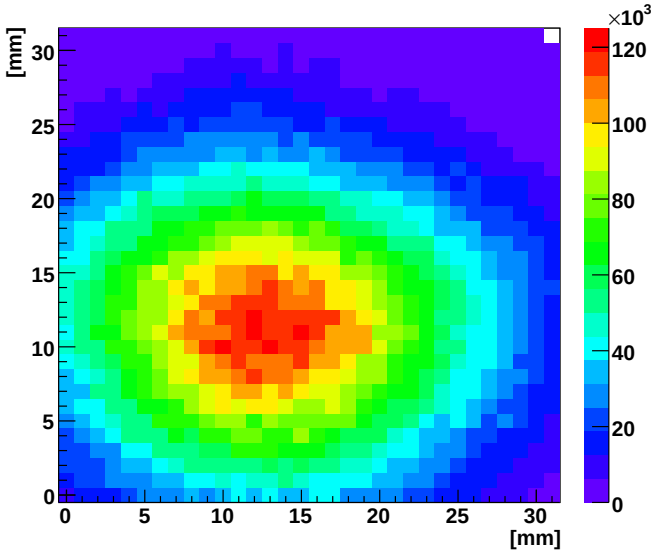
Detector Performance

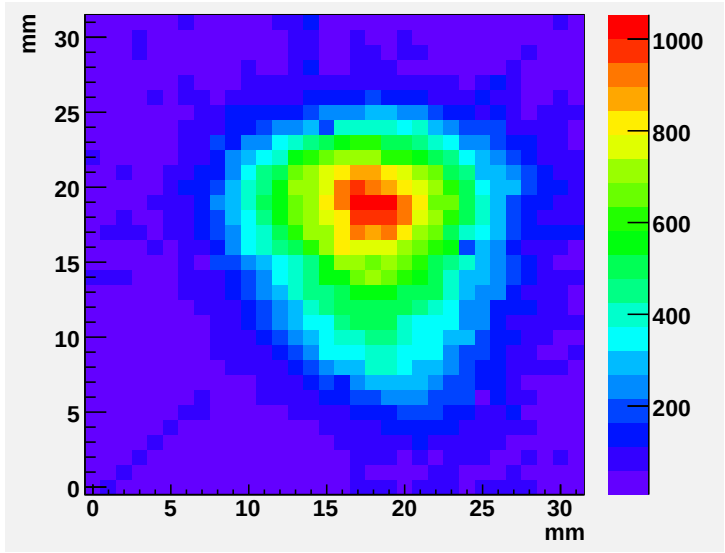
Gain


X-Ray Pixel Measurement: Center(rot), Total(blue)
Center Voltage [V], rest fixed to 3.9kV
960
980
1000
1020
1040
1060
Gas Gain
10^4
3650
3700
3750
3800
3850
3900
3950
4000
4050
4100
4150
Detector Voltage [V]

Beam Intensities

Estimations of particle flux in the pixel region





Myon beam

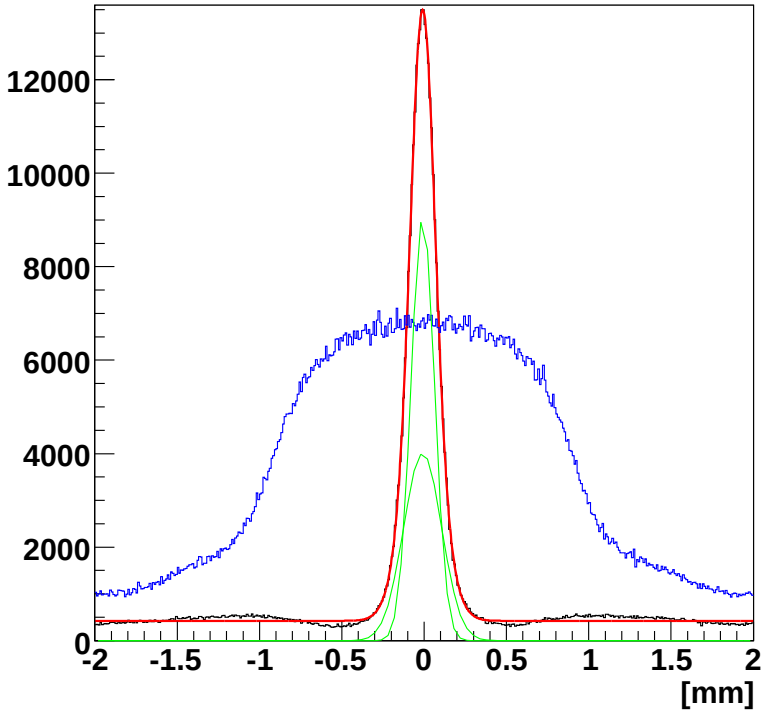
- $4.8 \cdot 10^7 / s$
- $\leq 1.2 \cdot 10^5 / s / mm^2$

Pion beam

- $5 \cdot 10^6 / s$
- $\leq 1.6 \cdot 10^4 / s / mm^2$

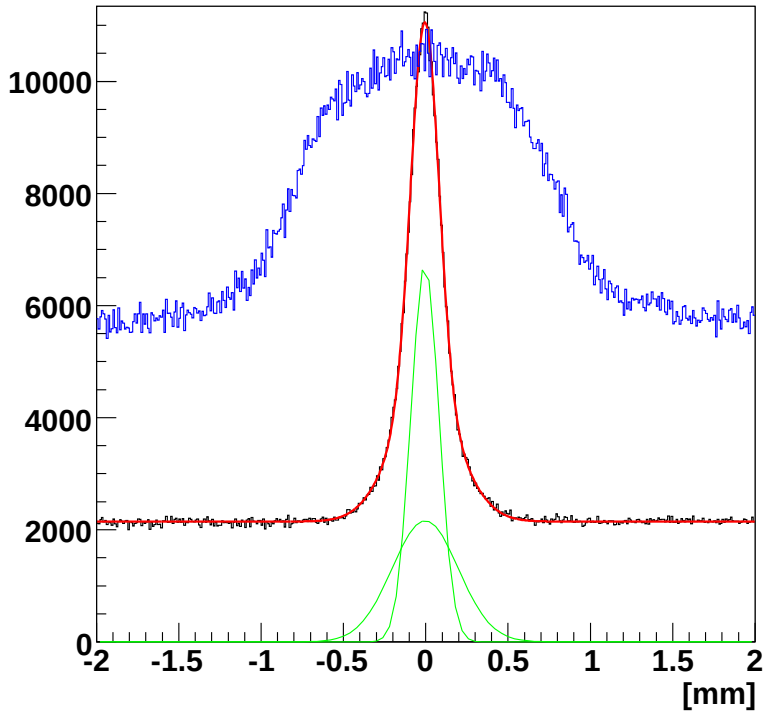
Spatial Resolution

Low Intensity: $\leq 2{\cdot}10^3/\mathrm{s/mm^2}$



$\bar{\sigma} = 90\mu\mathrm{m}$

High Intensity: $\leq 1{\cdot}10^5/\mathrm{s/mm^2}$

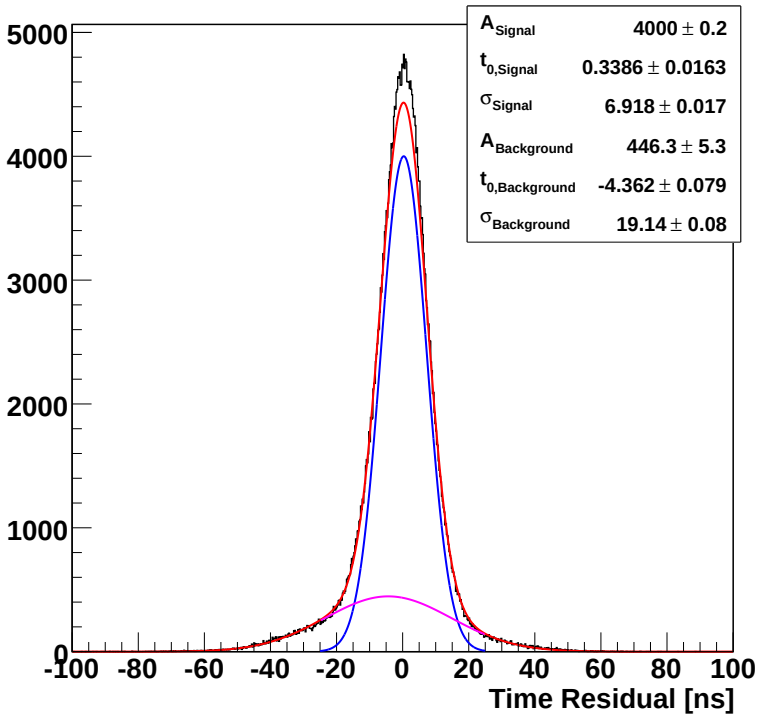


$\bar{\sigma} = 135\mu\mathrm{m}$

with/without Clustering, green: Gauss fit components

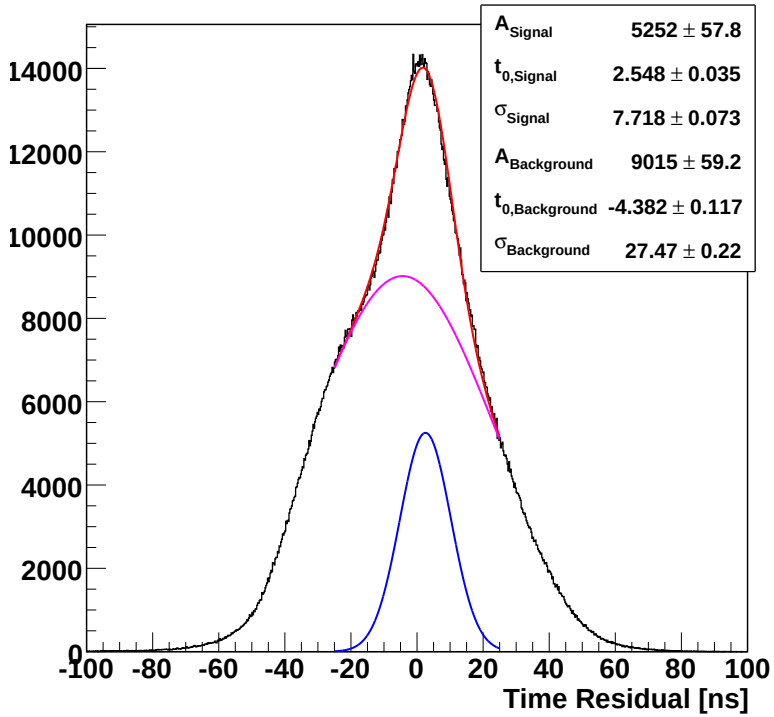
Time Resolution

Low Intensity: $\leq 2 \cdot 10^3 / s / mm^2$



$\sigma_t \leq 7ns$

High Intensity: $\leq 1 \cdot 10^5 / s / mm^2$

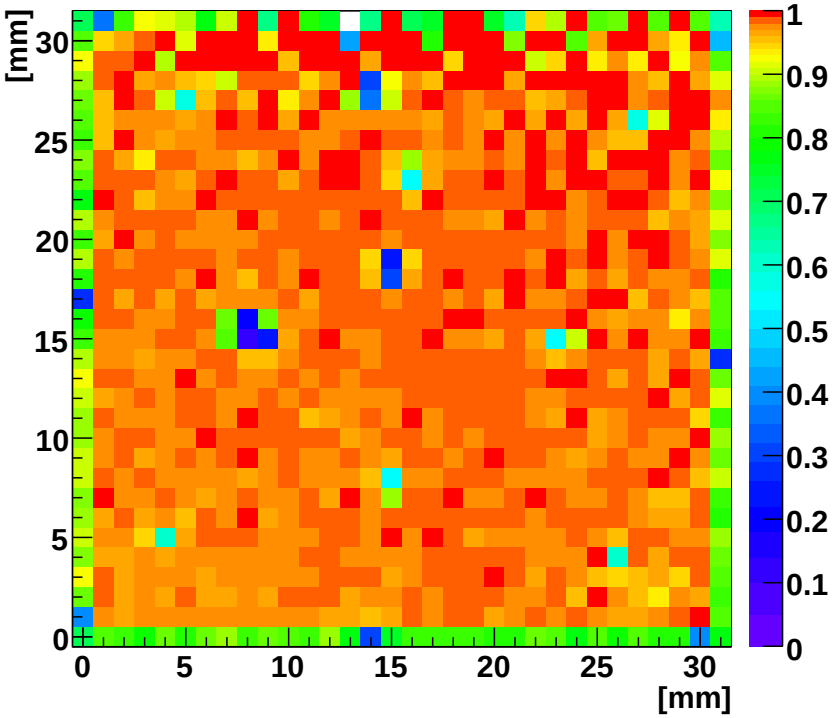


$\sigma_t \leq 8ns$

blau: Signal, magenta: Underground

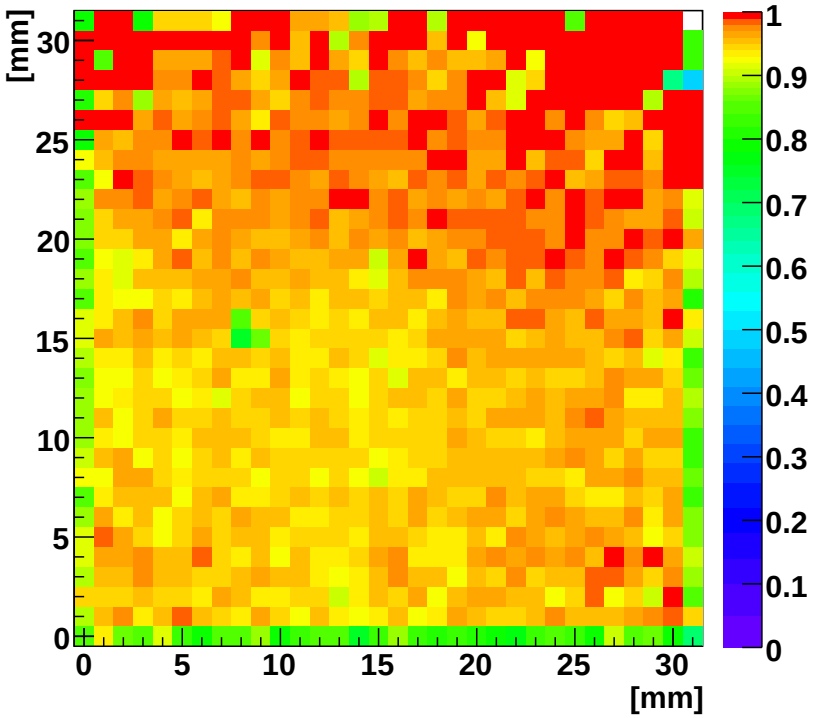
Detector Efficiency

Low Intensity: $\leq 2 \cdot 10^3 / s / mm^2$



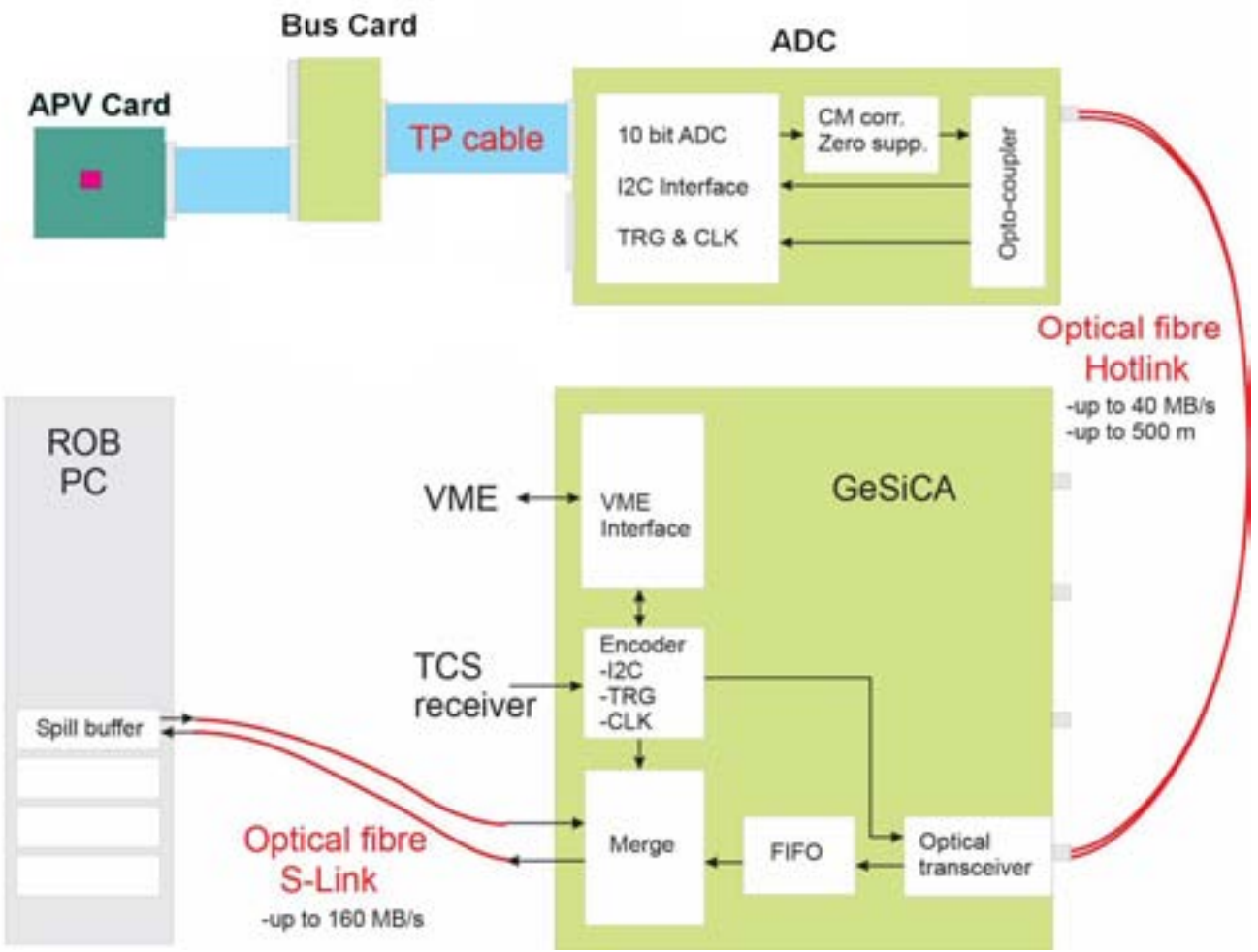
Mean Efficiency $\approx 99.3\,\%$

High Intensity: $\leq 1 \cdot 10^5 / s / mm^2$



Mean Efficiency $\approx 95.5\,\%$

Readout Chain



Spatial/Time Resolution COMPASS Triple GEM Detectors

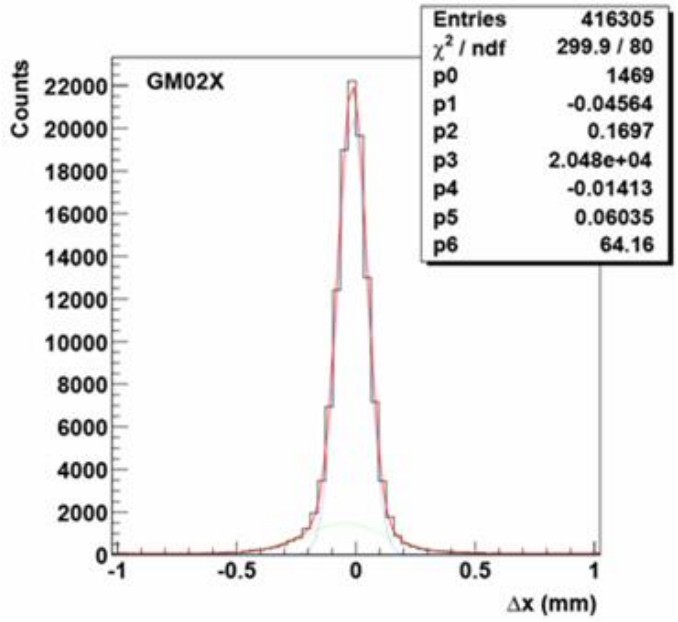
Spatial resolution

- Test beam/low intensity:

$$\langle \sigma_x \rangle \approx 50 \mu m$$

- Standard physics run: $4 \cdot 10^7$ μ^+/s:

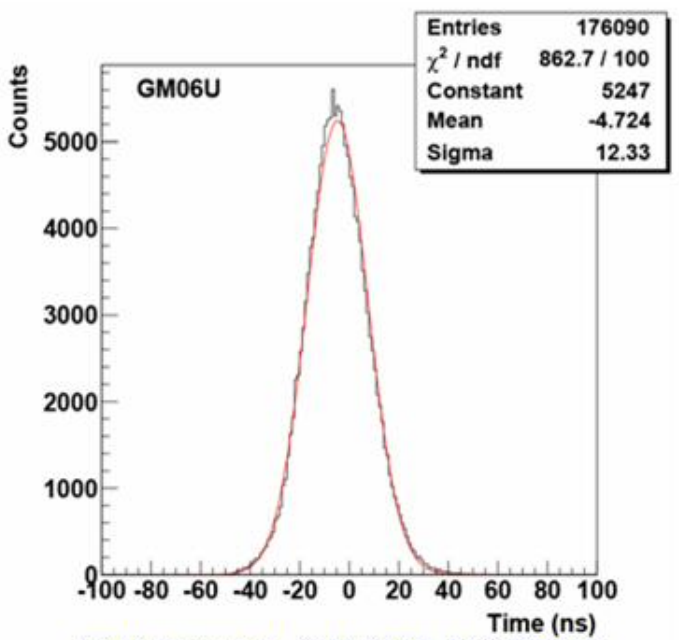
$$\langle \sigma_x \rangle \approx 70 \mu m$$



Time resolution

- 3 analog samples per trigger
- Rising edge of signal
- Reconstruct t_0 from known pulse shape

$$\langle \sigma_t \rangle \approx 12 ns$$



[B. Ketzer et al., NIM A535, 314 (2004)]

Efficencies COMPASS Triple GEM Detectors

Low intensity beam: $5 \cdot 10^6$ μ^+/s

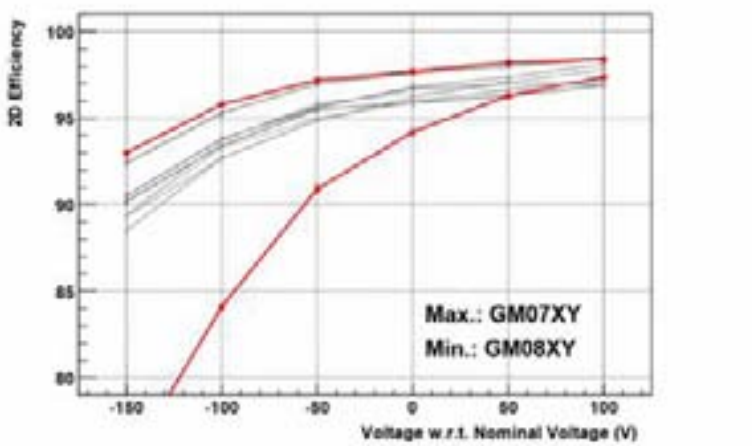
- All detectors reach plateau (ε>98%)
- Gain ~8000
- SNR ~18
- Losses due to spacer grid: 1.2-1.5%

Standard physics beam: $4 \cdot 10^7$ μ^+/s

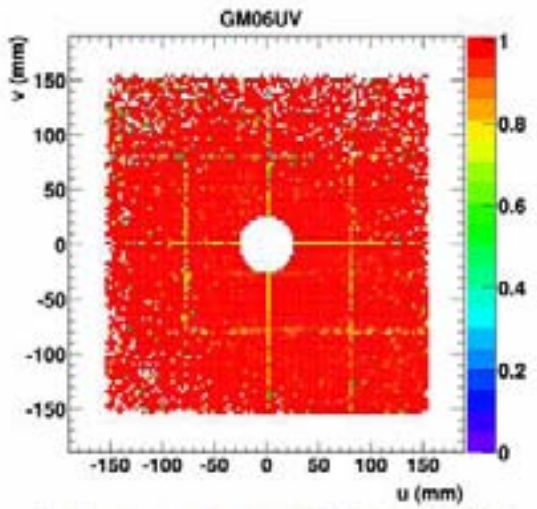
- Background correction

$$\varepsilon_{app} = \varepsilon + (1-\varepsilon) \cdot b$$

- Single plane: $\langle \varepsilon_{1D} \rangle = 97.2\%$
- 2D (space point): $\langle \varepsilon_{2D} \rangle = 95.6\%$



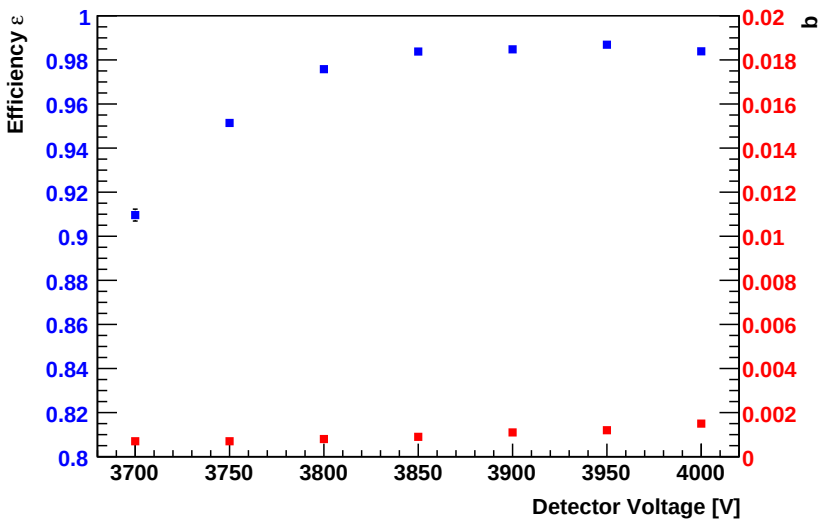
[B. Ketzer et al., Nucl. Phys. B 125C, 368 (2003)]



[B. Ketzer et al., NIM A535, 314 (2004)]

Efficiency Plateau

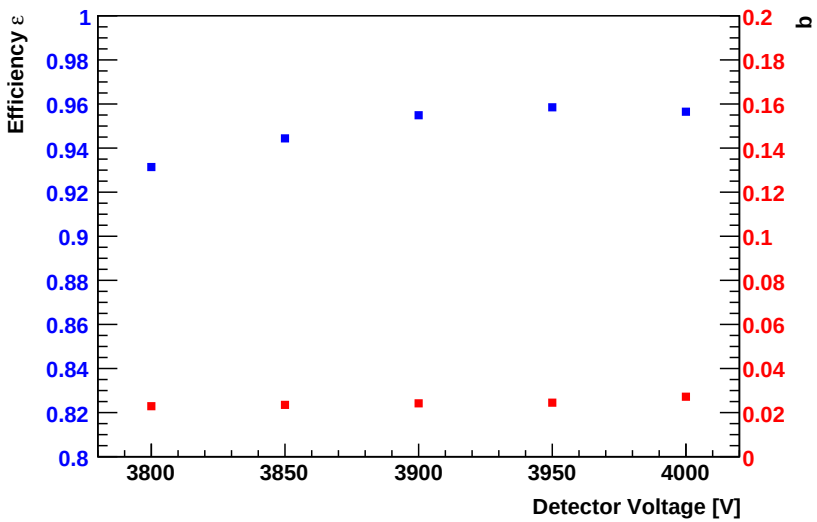
Low Intensity: $\leq 2 \cdot 10^3 / s / mm^2$



Efficiency Plateau: 98.5 %

Background per pixel: ≤ 0.1 %

High Intensity: $\leq 1 \cdot 10^5 / s / mm^2$



Efficiency Plateau: 95.5 %

Background per pixel: ≈ 2 %

Background: probability to find uncorrelated clusters within a certain roadwidth around a track

FrontEnd-Electronics

- APV25 S1 ASIC[1]
- 128 channels per APV
- 160 samples pipeline
- 40 MHz sampling frequency
- average noise:
  $\sim$ 1300 - 1500 electrons
- used for Silicon, GEM and RICH at COMPASS

[1] M.J. French, et al. Nucl. Instr. and Meth. A 466 (2001) 359

Front-End Electronics

Readout Scheme

- 16 front-end cards per detector
- bus-cards to 12 bit ADC

3 Sample Amplitude Information

⇒ clustering
⇒ time reconstruction

Front-End Electronics

Readout Scheme

- 16 front-end cards per detector
- bus-cards to 12 bit ADC

3 Sample Amplitude Information

⇒ clustering
⇒ time reconstruction

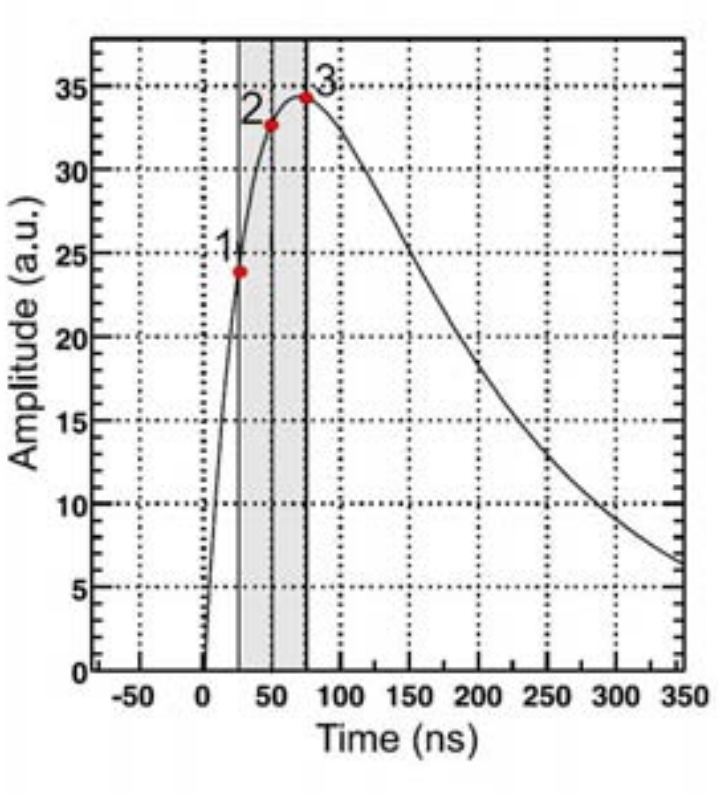
Front-End Electronics

Readout Scheme

- 16 front-end cards per detector
- bus-cards to 12 bit ADC

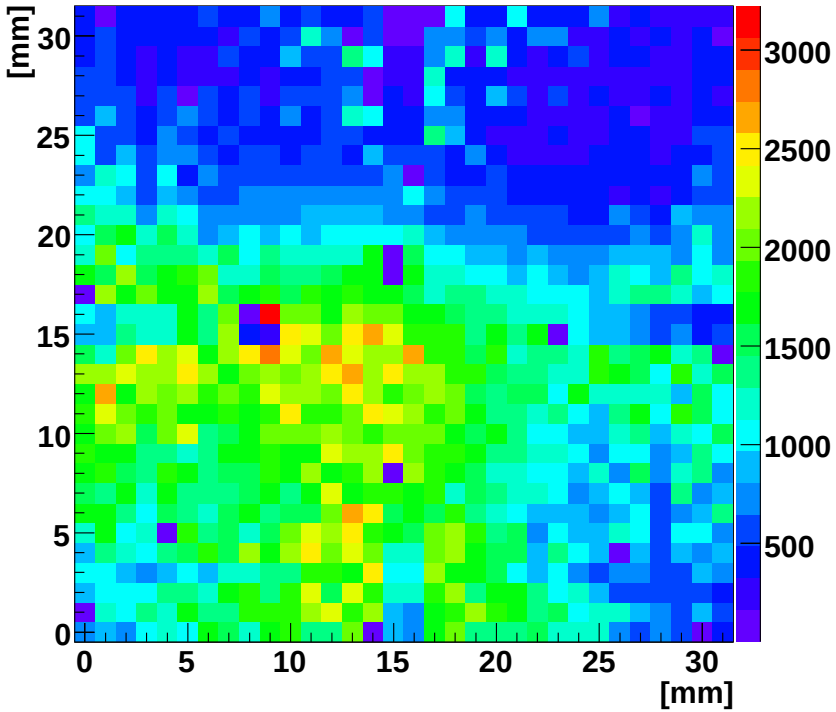
3 Sample Amplitude Information

⇒ clustering
⇒ time reconstruction

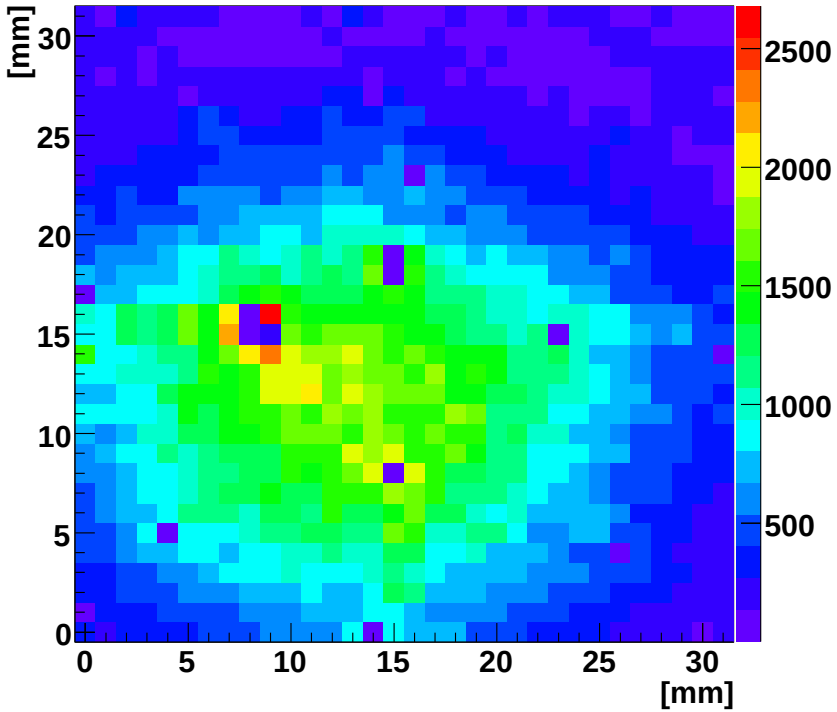


crosstalk suppression

beamspot with crosstalk



crosstalk suppressed



- tag channels with high-amplitude neighbours
- after clustering: remove clusters containing mostly tagged pixels

Material Budget

	Centre $[X_0/1000]$	Periphery $[X_0/1000]$
Support	0.0	2.9
Driftfoil	0.5	0.5
3 GEM-Foils	2.1	2.1
Readout Foil	1.0	1.3
Shielding	0.2	0.2
Gas	0.1	0.1
Sum	**3.9**	**7.1**

Centre: $r < 15\,\text{mm}$, Periphery: $r > 15\,\text{mm}$

Cu layer $5\,\mu\text{m}$

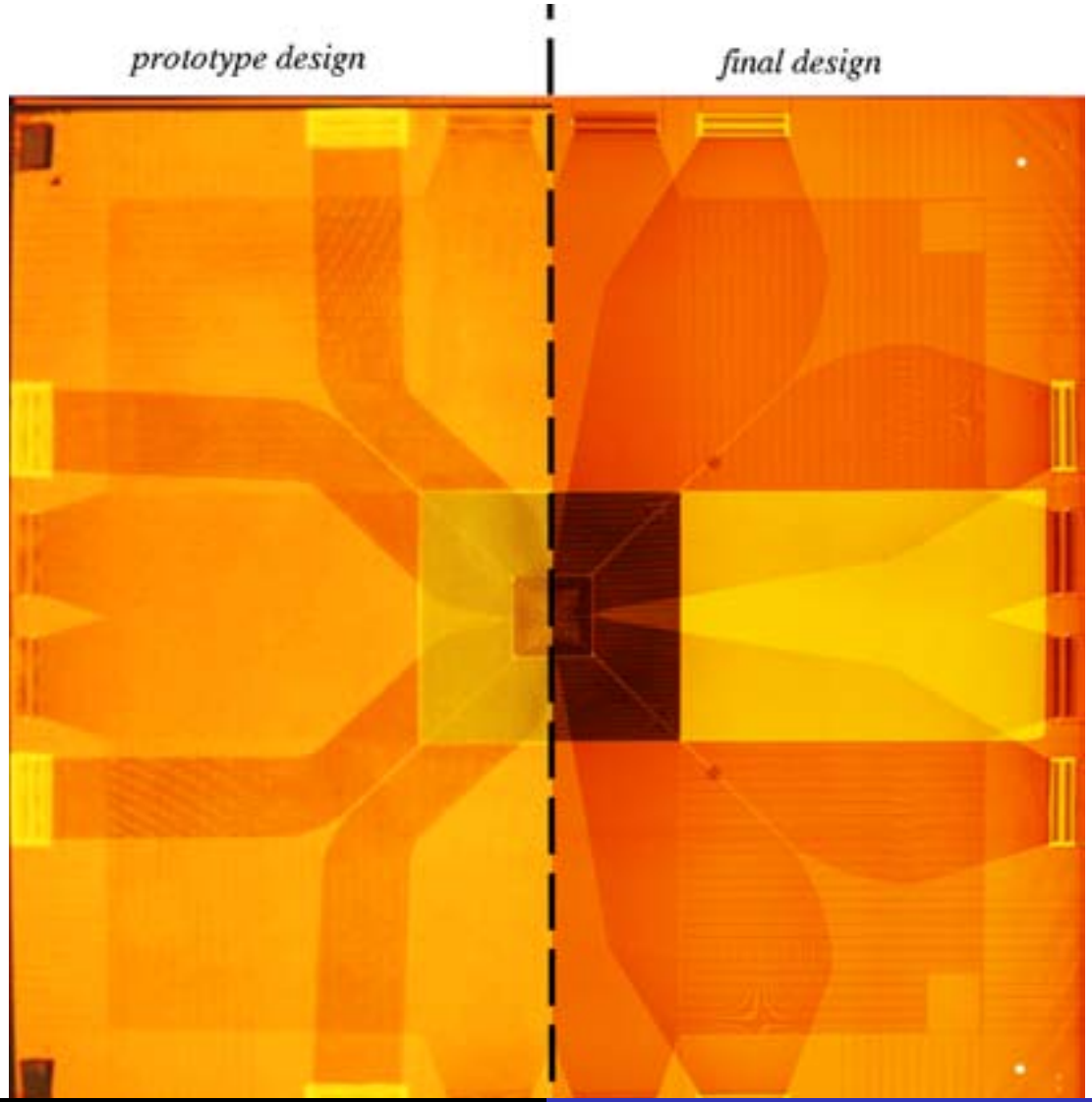
Material Budget

	Centre $[X_0/1000]$	Periphery $[X_0/1000]$
Support	0.0	2.9
Driftfoil	0.5 / 0.3	0.5 / 0.3
3 GEM-Foils	2.1 / 0.8	2.1 / 0.8
Readout Foil	1.0	1.3
Shielding	0.2	0.2
Gas	0.1	0.1
Sum	**3.9 / 2.4**	**7.1 / 5.6**

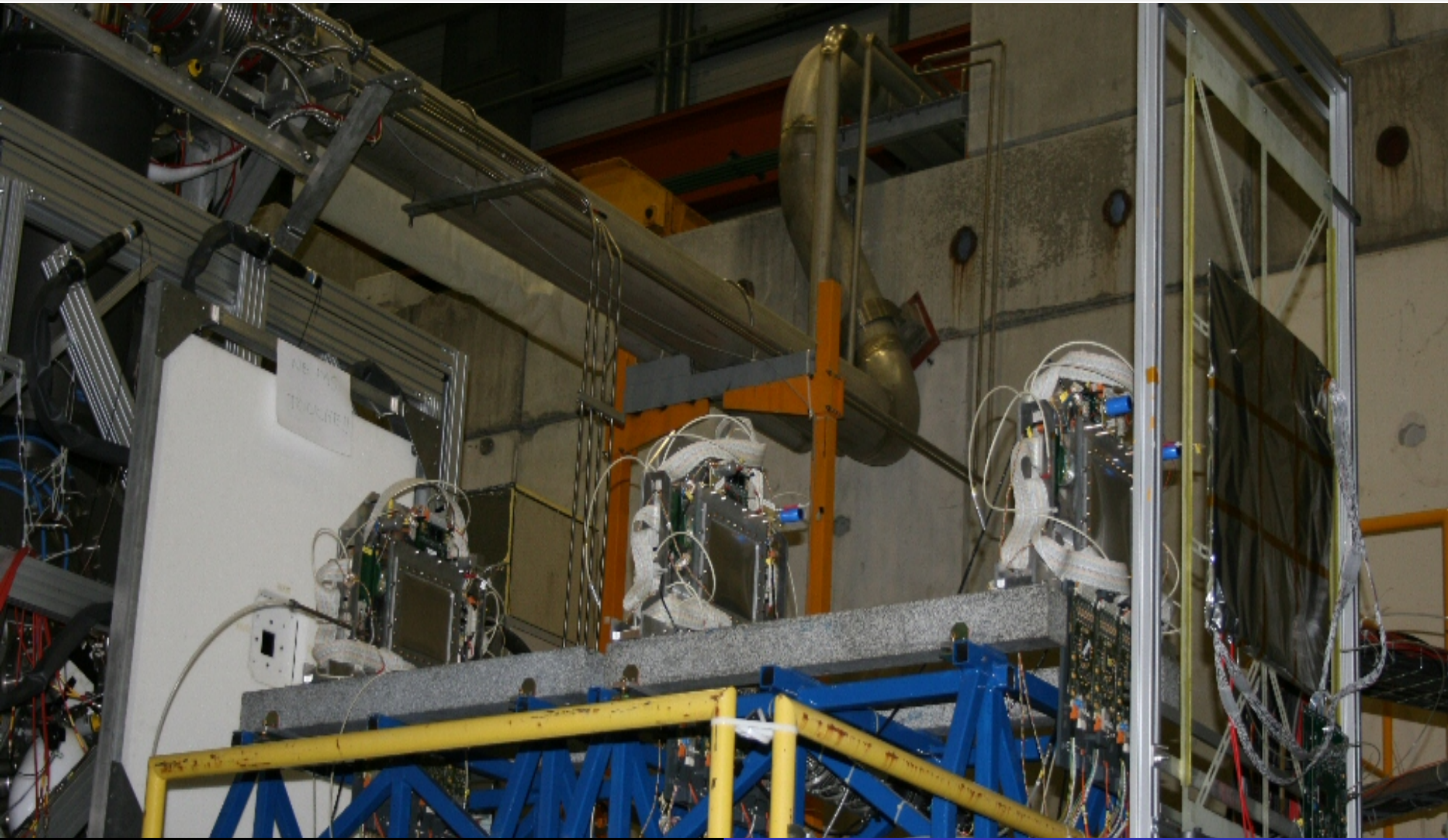
Centre: $r < 15\,\text{mm}$, Periphery: $r > 15\,\text{mm}$

Cu layer $5\,\mu\text{m}$ / $1\,\mu\text{m}$

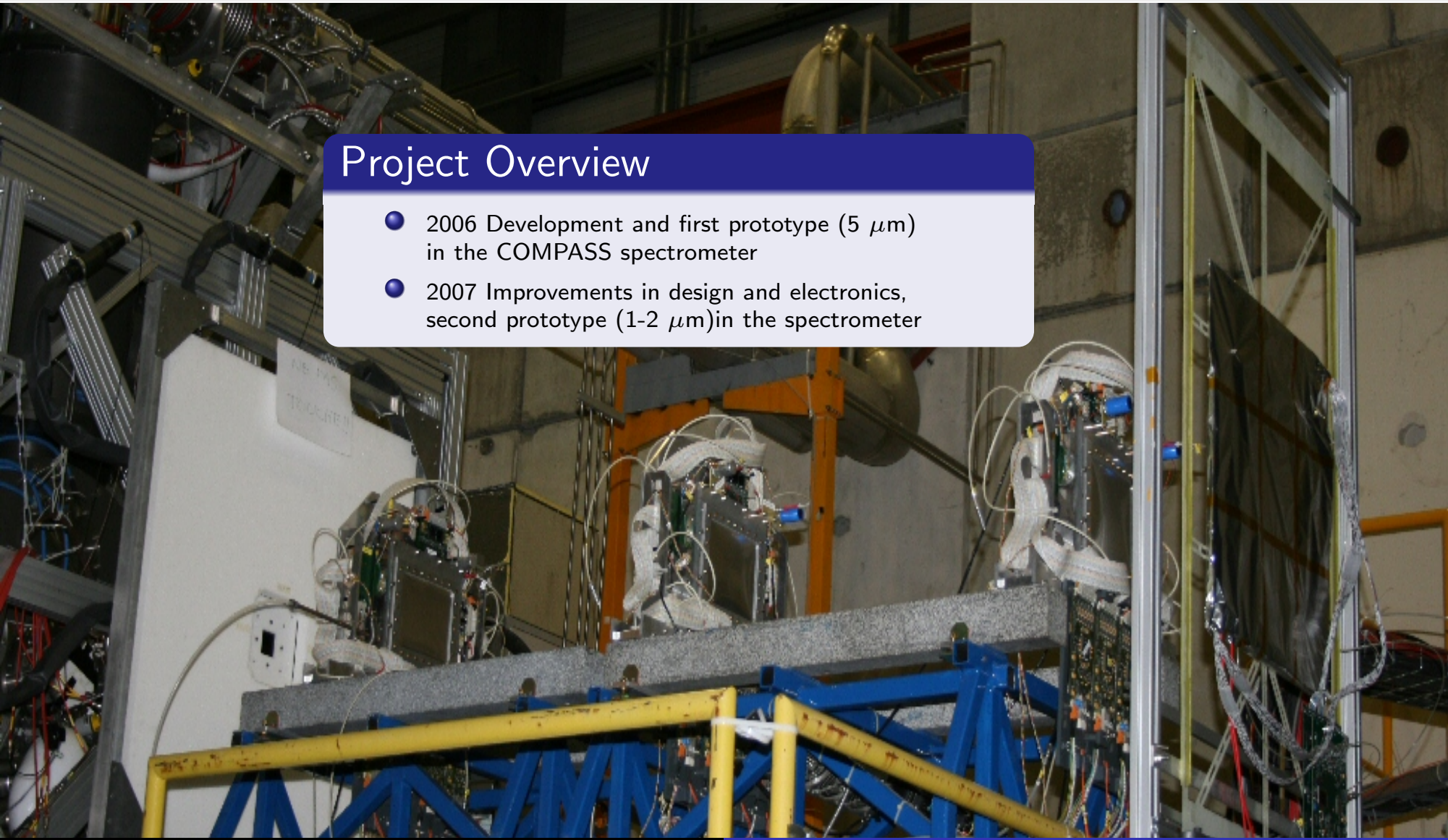
Modifications Prototype - Prototype II



The PixelGEM Project



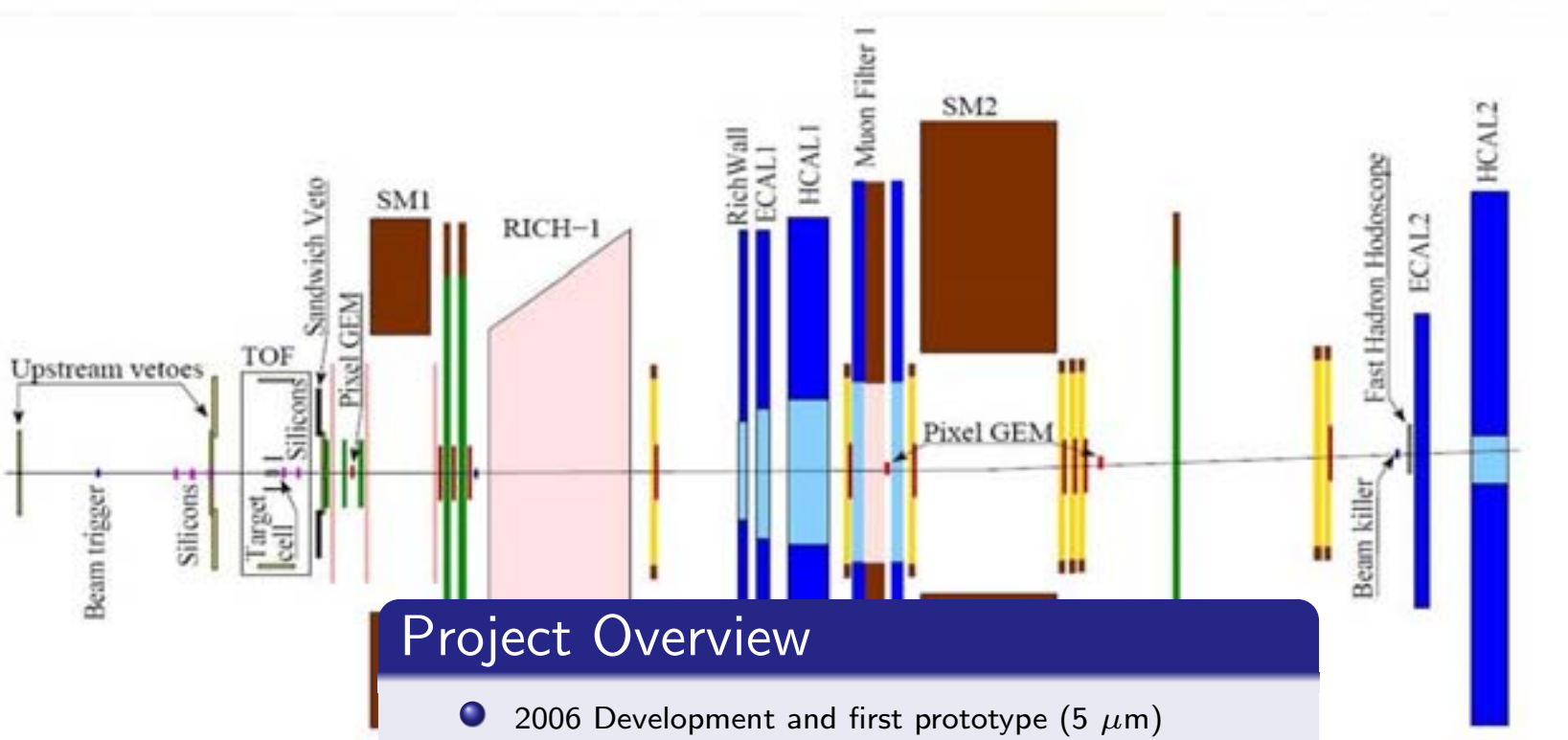
The PixelGEM Project



Project Overview

- 2006 Development and first prototype (5 μm) in the COMPASS spectrometer
- 2007 Improvements in design and electronics, second prototype (1-2 μm)in the spectrometer

The PixelGEM Project



Project Overview

- 2006 Development and first prototype (5 μm) in the COMPASS spectrometer
- 2007 Improvements in design and electronics, second prototype (1-2 μm)in the spectrometer
- 2008 Five PixelGEMs installed