Ingrid devicesfor UV photon detection

Joost Melai

MESA+ institute for Nanotechnology, University of Twente, the Netherlands

in collaboration with the Weizmann Institute of Science, Rehovot, Israel

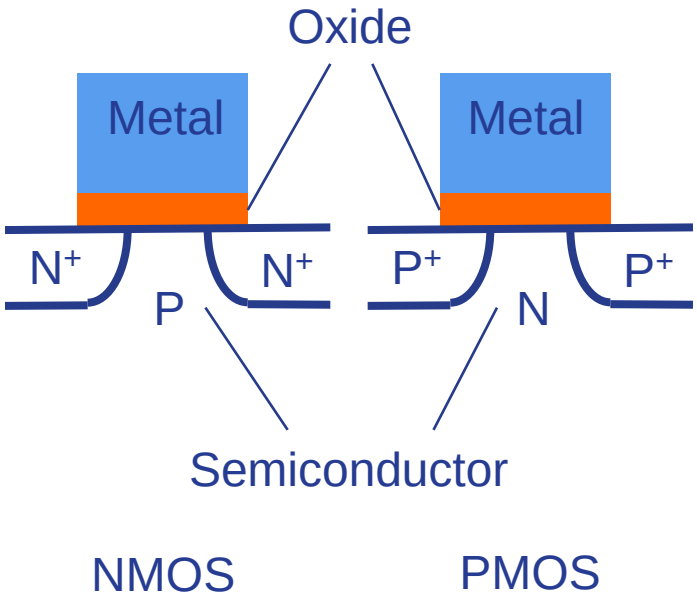
and NIKHEF, Amsterdam, the Netherlands

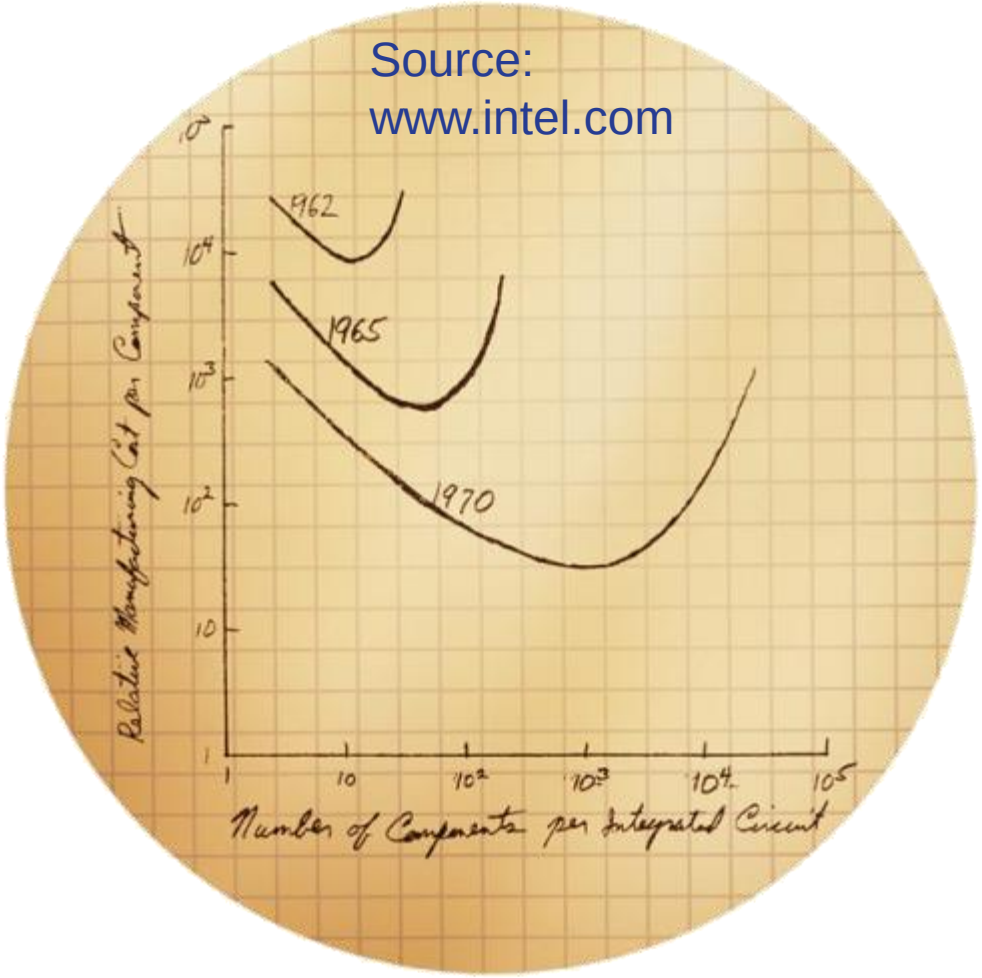
Overview

- Post-Processing on CMOS
- InGrid concept and technology
- InGrid performance
- Photon detection, photocathodes on InGrid
- Experimental results
  - Charge pulses
  - Imaging
- Summary and outlook

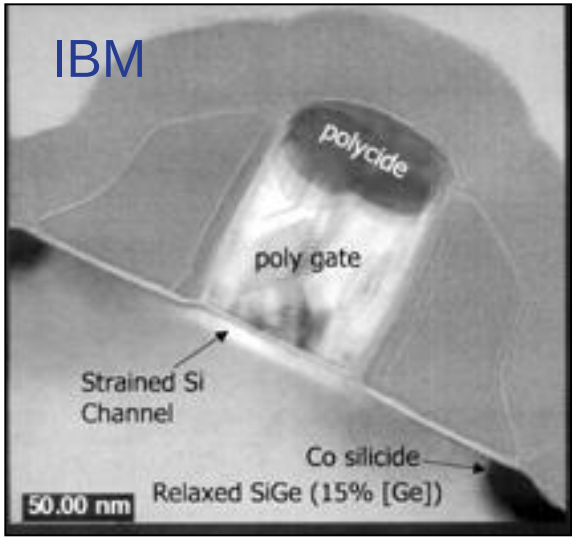
The beginning of Moore's law

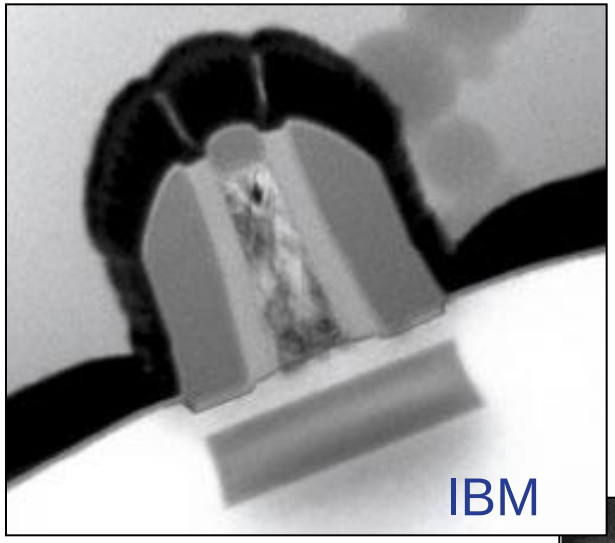
CMOS

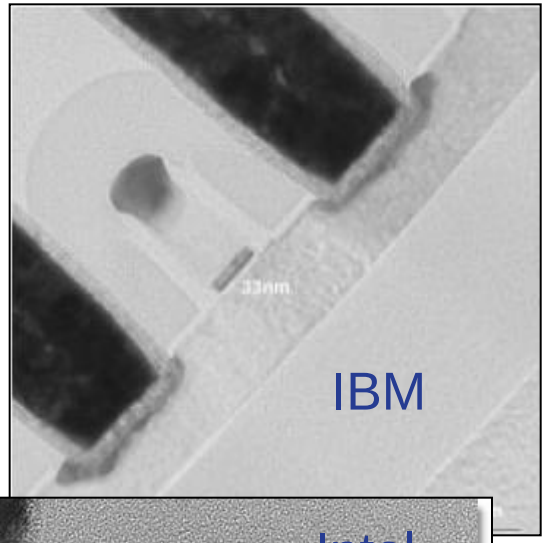


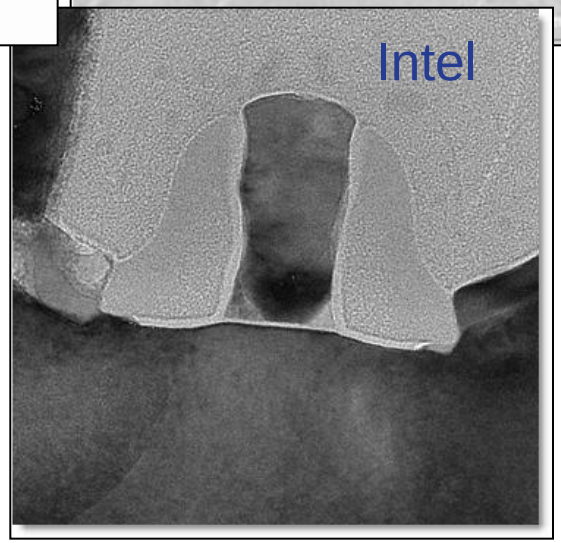


The state of the art: CMOS





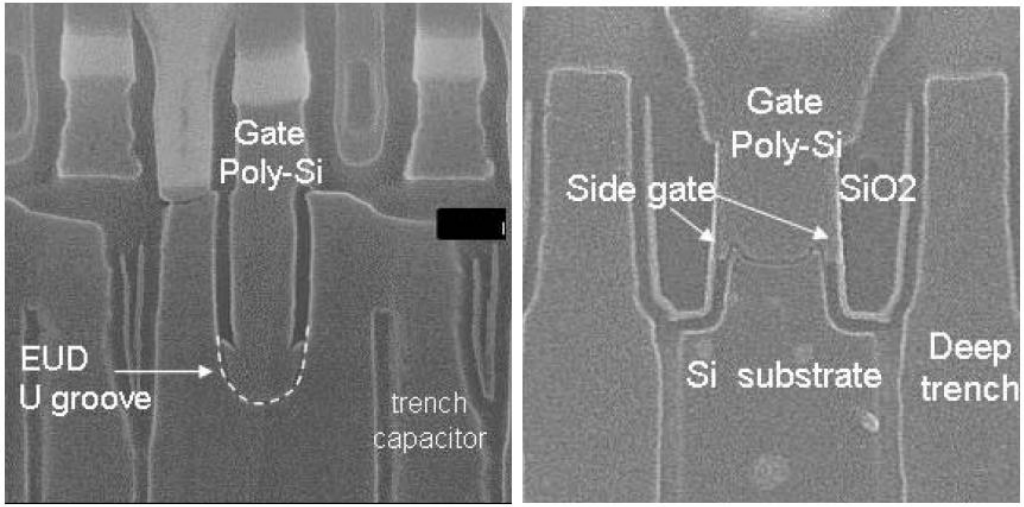




- Nanometer precision
- Sub-ppm materials purity

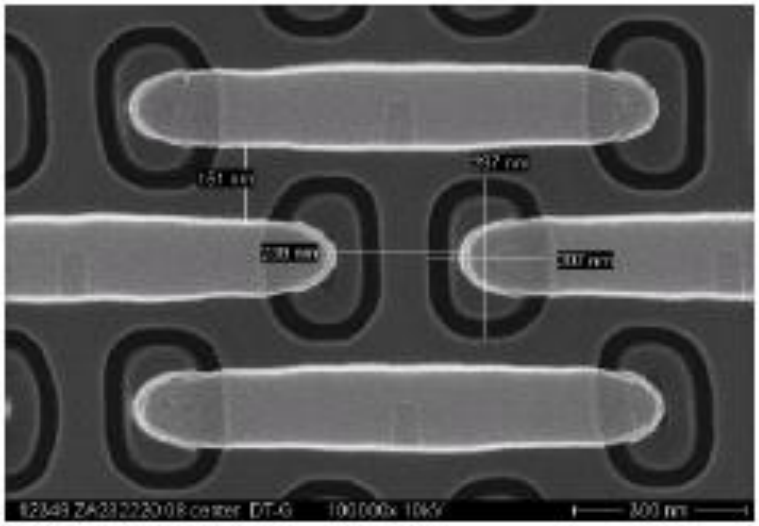
The state of the art: DRAM

- 58-nm DRAM technology



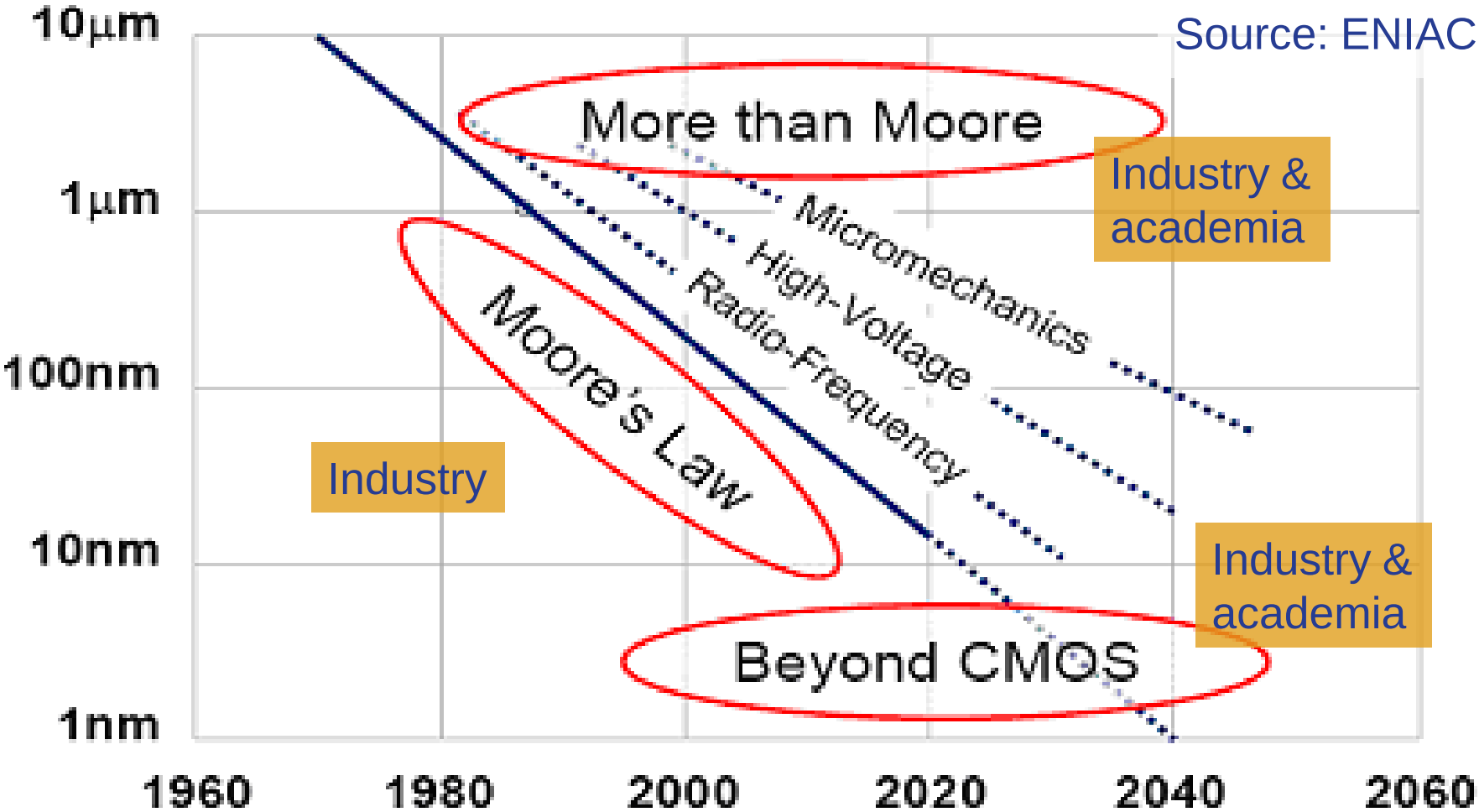
Qimonda (Infineon)

SAMSUNG

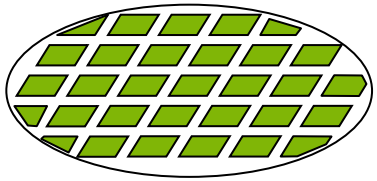


- Nanometer precision
- Sub-ppm materials purity

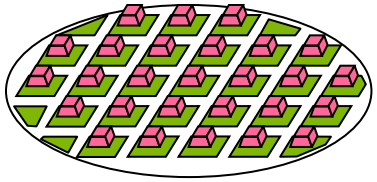
Moore'slaw
More Moore and More than Moore



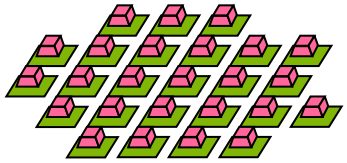
Post-processing CMOS



a. Chip fabrication



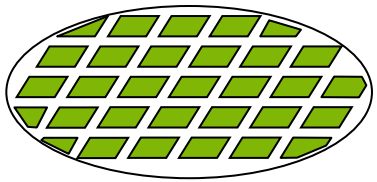
b. Post-processing



c. Wafer dicing

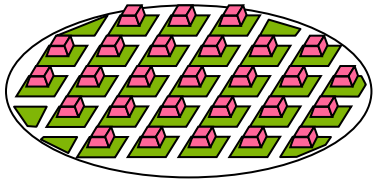
- Chip fabrication: standard, at any regular (CMOS) fab
- Post-processing: special, in a custom CR laboratory
- Wafer dicing, packaging: specialized work like MEMS packaging, e.g. Amkor, Boschman

Pros and cons



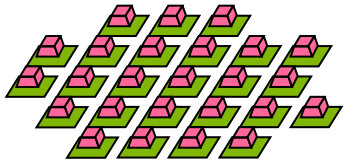
a. Chip fabrication

- We do not interfere with the (CMOS) fab process
- We can buy good quality chips



b. Post-processing

- We can use any lab for this
- We must keep the CMOS intact

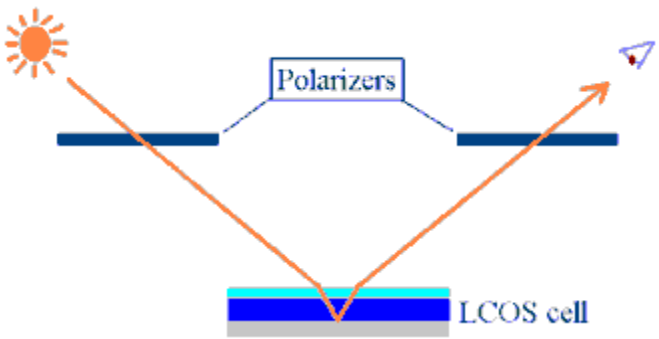


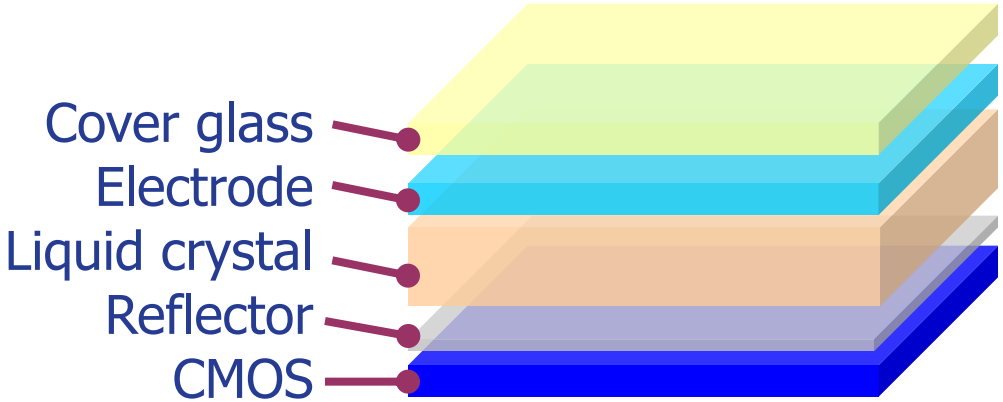
c. Wafer dicing

- We have to think the final stages through very carefully!

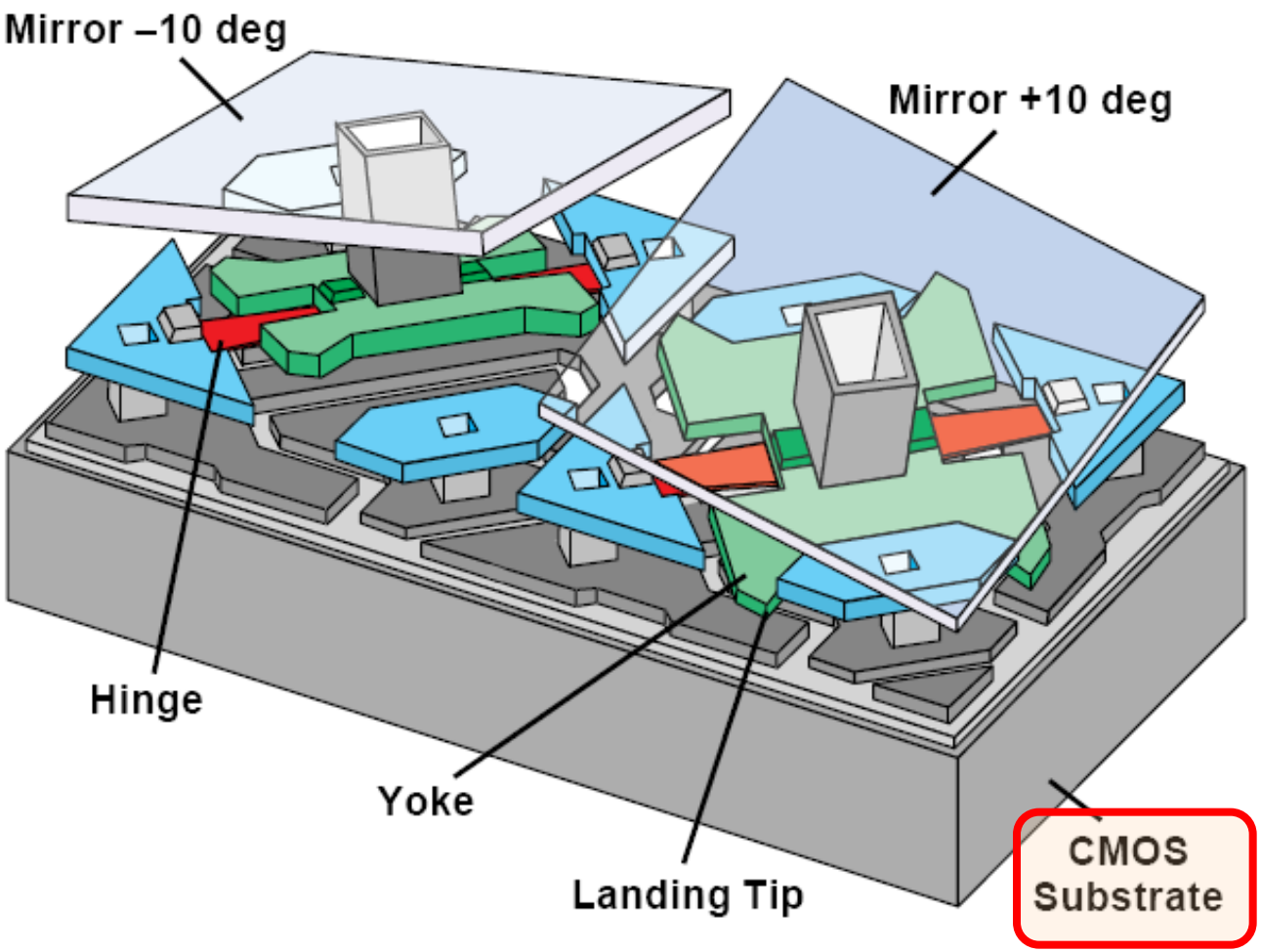
→Flexible for R&D; potential for mass-scale manufacturing

Example: Liquid-Crystal-on-Silicon

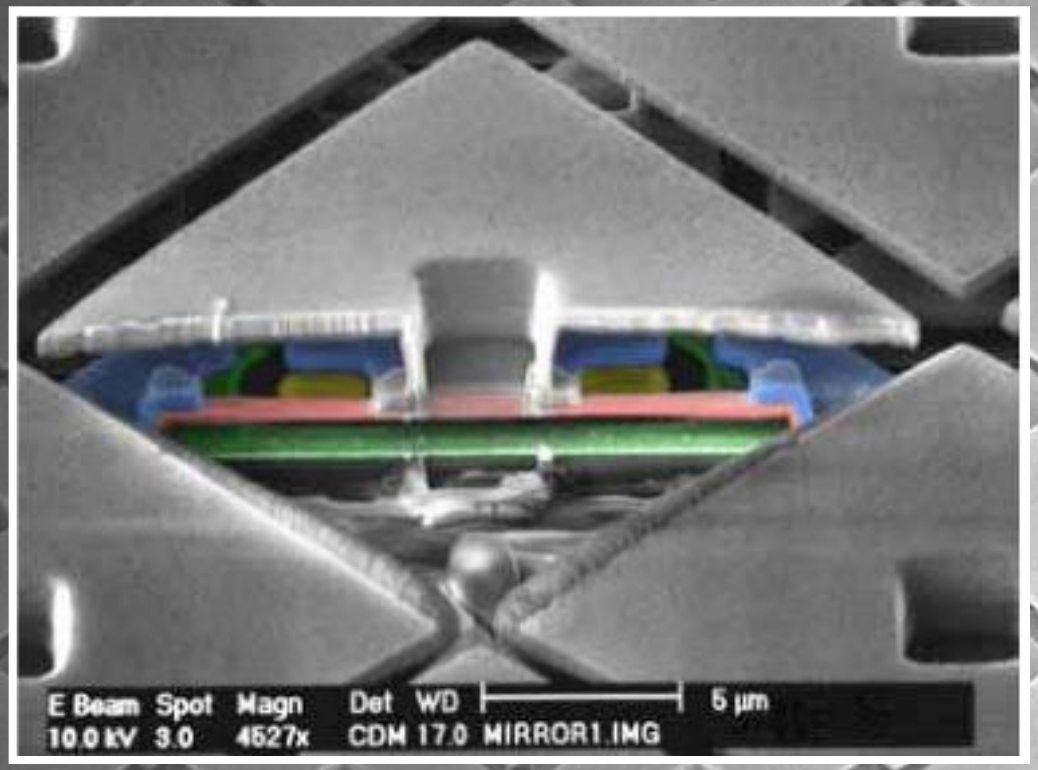




Example: Digital MicroMirror™



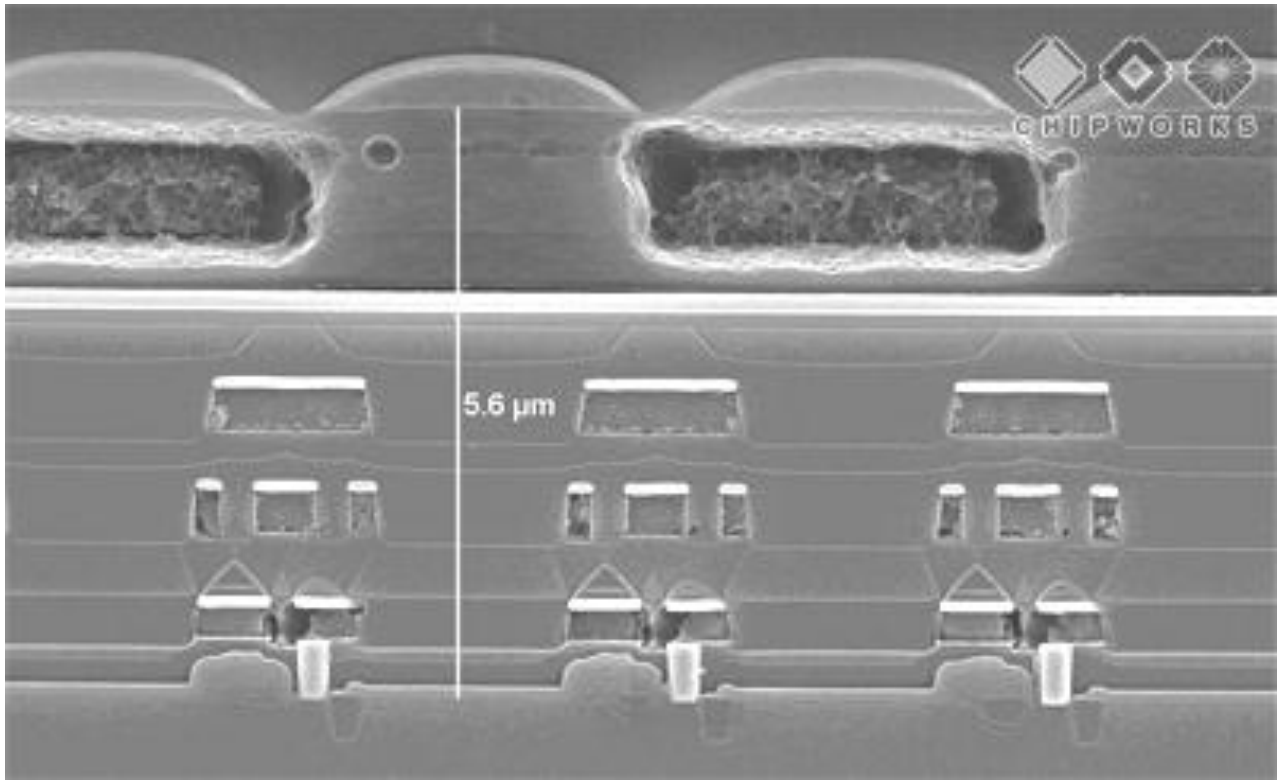
Texas Instruments (1987), used in every DLP projector

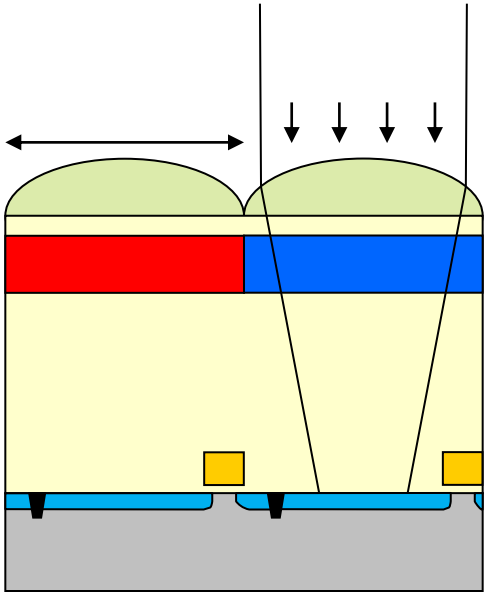


E Beam Spot Magn Det WD 20 µm
8.00 kV 3.0 2563x TLD 4.9 44003 00 04004

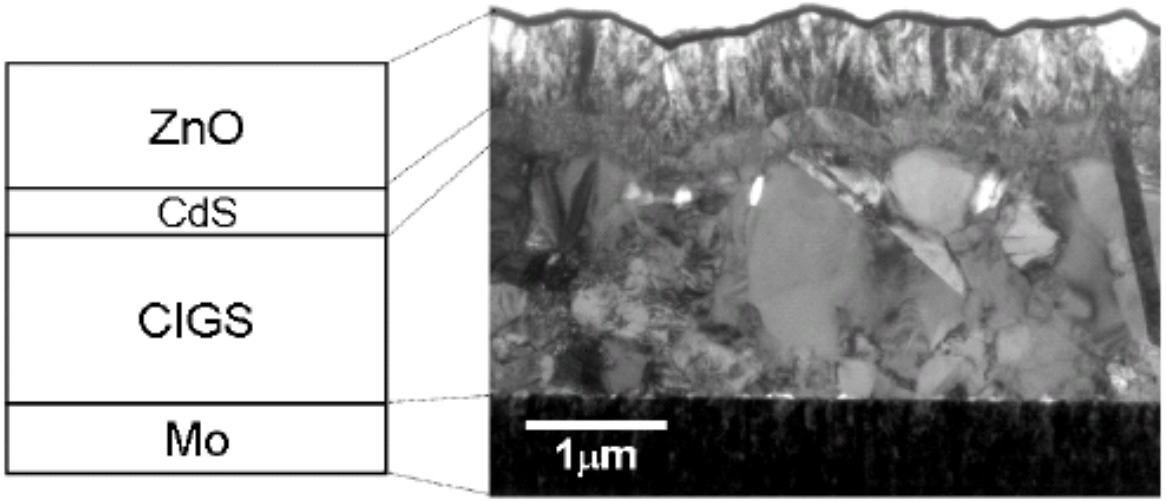
Samsung CMOS image sensor

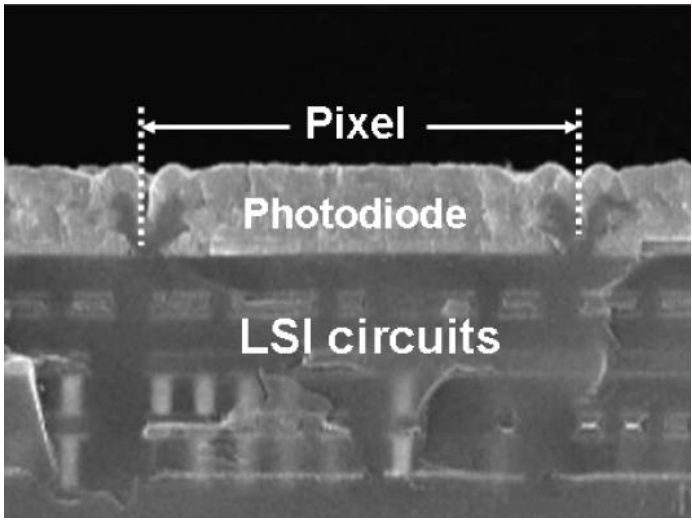
Micro lenses and color filters

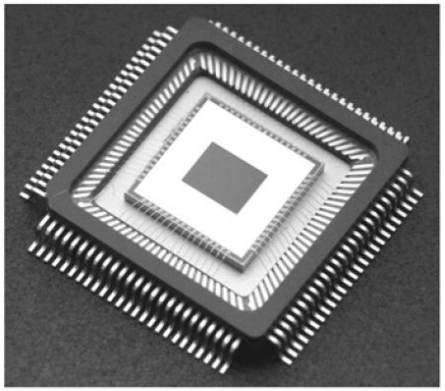




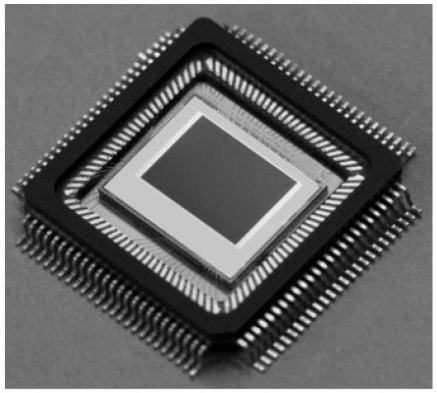
Rohmcorp.: CIGS image sensor on CMOS (IEDM 2008)







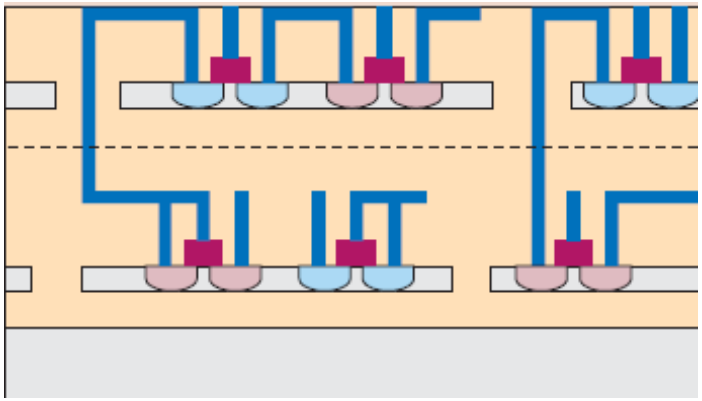
(a) CIF type



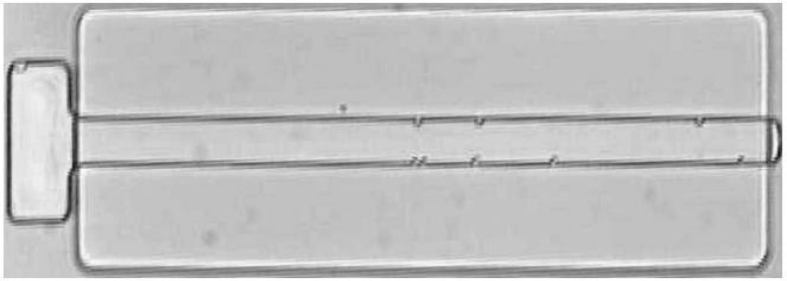
(b) VGA type

CMOS on top of CMOS!
3D integration

T ≤ 450 ° C

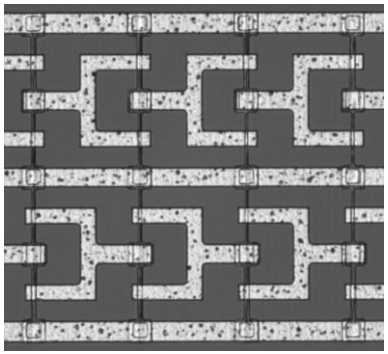


A. W. Topol et al.,
IBM J. Res. & Dev. 50 (4/5) 491



B. Rajendran et al.,
IEEE Trans. El. Dev. 54 (4) 707.

Stacking of activedeviceregions
→new technology



I. Brunets et al.,
IEEE Trans. El. Dev. 56 (8) 1637

CMOS post-processing

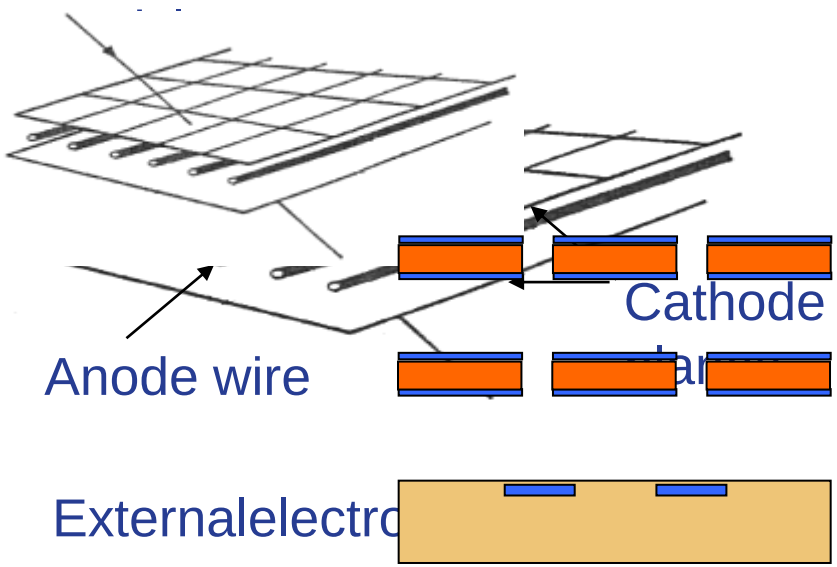
Careful treatment of the underlying CMOS:

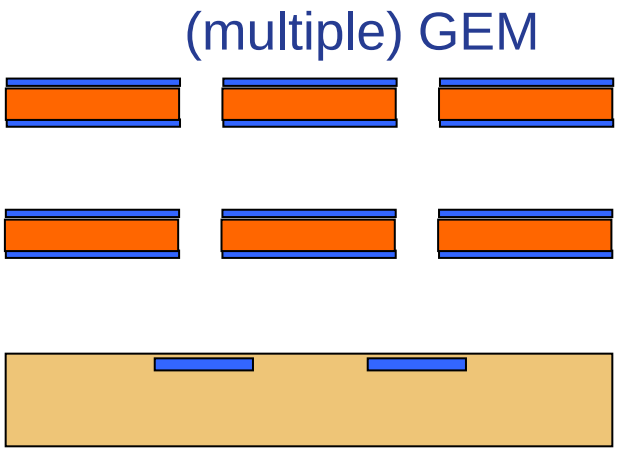
- Temperature ≤ 450 ° C
- Mild (or no) plasmas
- Maintain the H balance in the MOSFET
- Limited mechanical stress
- Prevent material contamination (spec. metals)

The CMOS properties must be unchanged:
then the standard infrastructure can be used

Overview

- Post-Processing on CMOS
  - Can we also miniutarize the MWPC?
  - Can we use CMOS as the readout anode?





→InGrid concept and technology

→InGrid performance

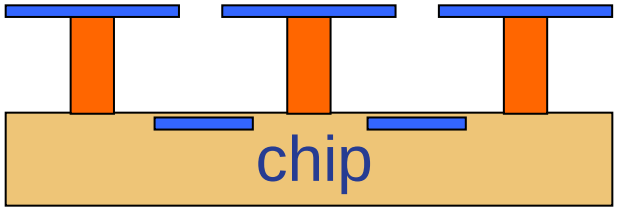
Overview

- Post-Processing on CMOS
  - Can we also miniutarize the MWPC?
  - Can we use CMOS as the readout anode?

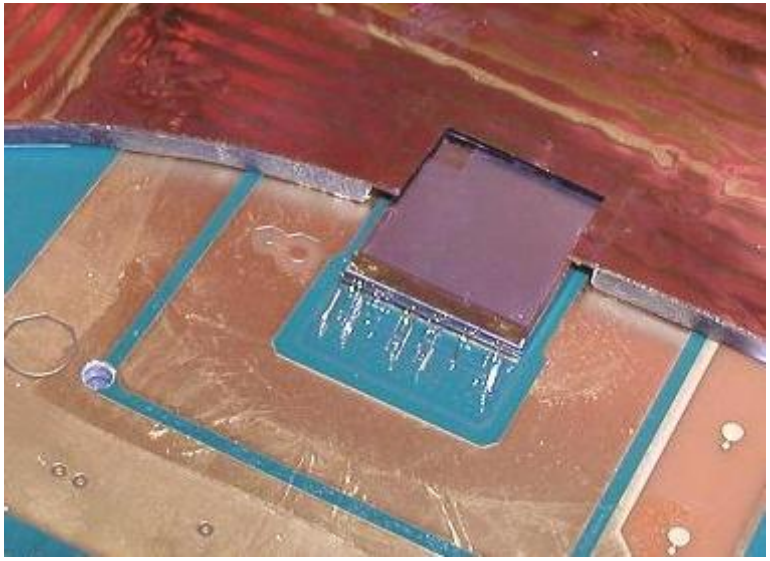
→InGrid concept and technology

→InGrid performance

IntegratedMicromegas



- Detector elements
  - The chip: Timepix
  - The MPGD: grid and pillars

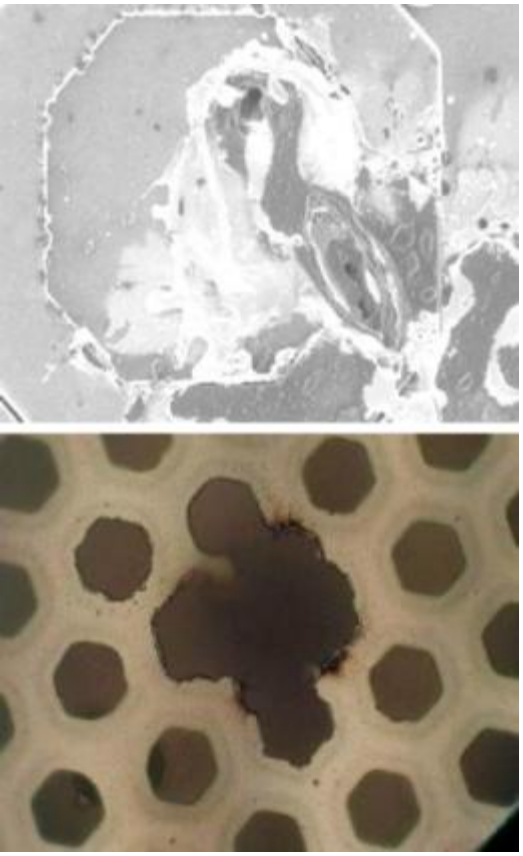


TimePix

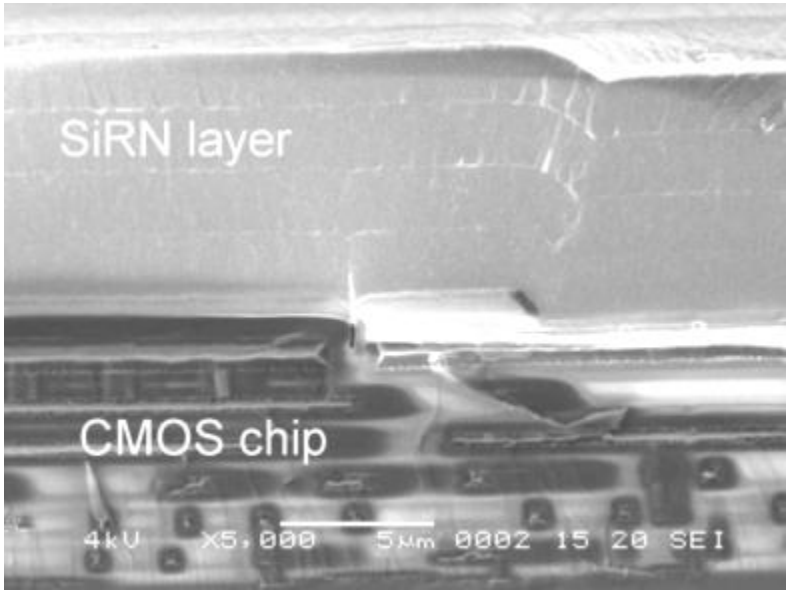
variation of Medipix2, designed by the Medipix2 collaboration headed by CERN

- 256 × 256 pixels of 55 × 55 μm^2, charge sensitive
- Different readout modes:
  - MediPix mode: nr of hits per pixel
  - TimePix mode: time of arrival within shutter window
  - TOT mode: estimation of total charge per pixel
- 0.25 μm CMOS, size 14 × 16 mm
- Post-processing done on chip level or multi-chip cluster level

SiRN:New anti-spark material

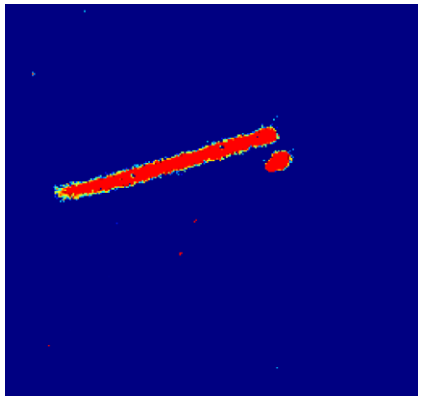


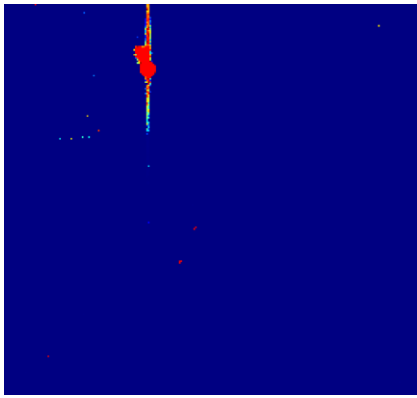
- Sparks cause permanent damage
- Originally a-Si:H, now Si-rich Nitride
- Si_3N_4typical anti-scratch layer on CMOS
- SiRN, excess of Si to tune resistivity and mechanical stress
- Deposited by PECVD at 300 ° C or lower



Spark protection

- Protection layer quenches discharges, removing the built up E-field
- Signal still fast by induced mirror charge
- Timepix with 7.2 μmSiRN + InGrid
- Operation in Ar/Iso 80/20,withalphaparticles→ induce sparks
- No damage observed, spark protection is effective

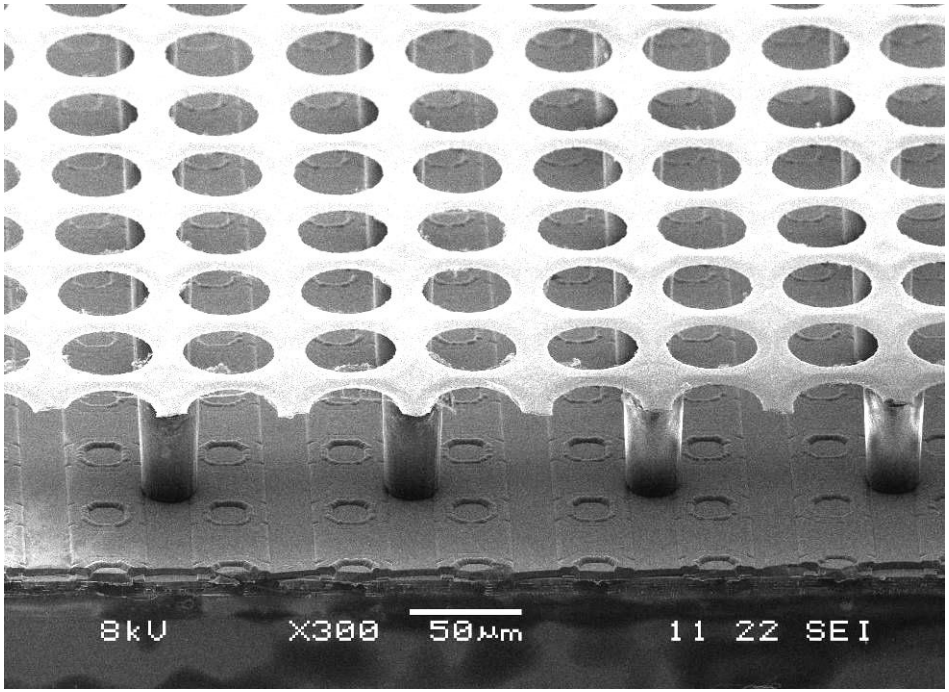


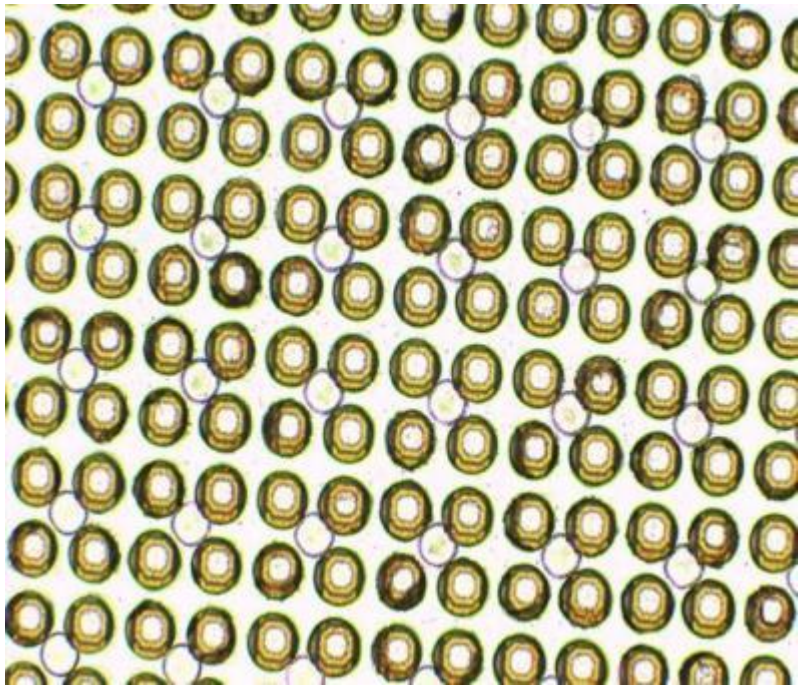


Courtesy of Victor Blanco Carballo

InGrid: postprocessedMicromegas

- Metal grid (Al) supported by insulating pillars (SU-8)
- Pillars in the middle of four pixels
- Perfect alignment hole to pixel, pillar to pixel
- Arbitrary hole geometry
- Integrated MPGD: Micro Patterned Gaseous Detector

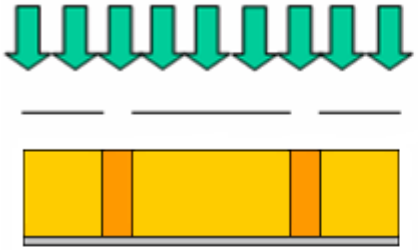




InGrid: Integrated Grid

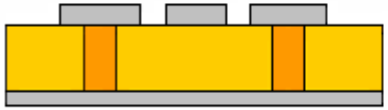
1) Pre-process chip

2) Spin SU-8

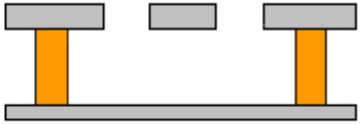


3) UV exposure

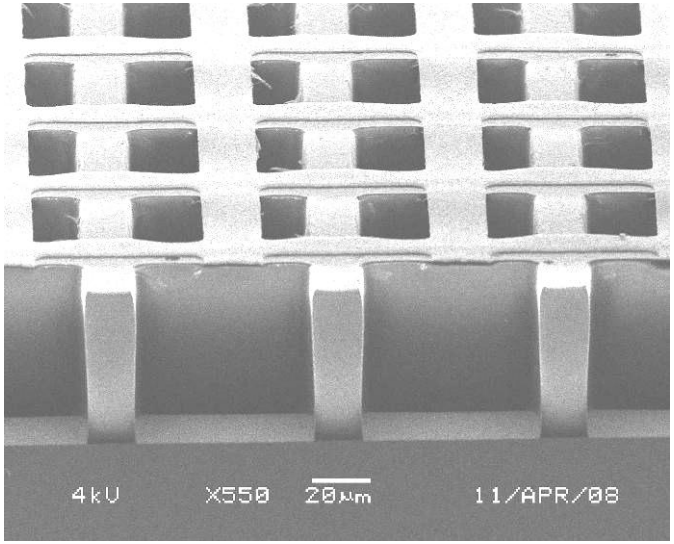
4) Deposit metal

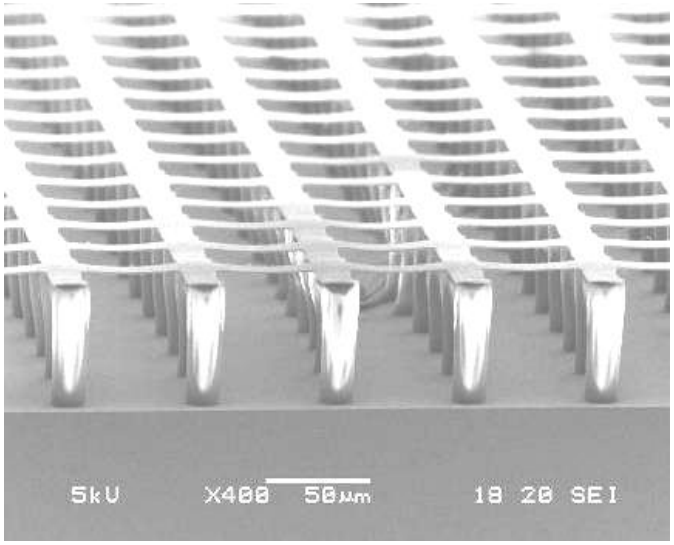


5) Pattern metal



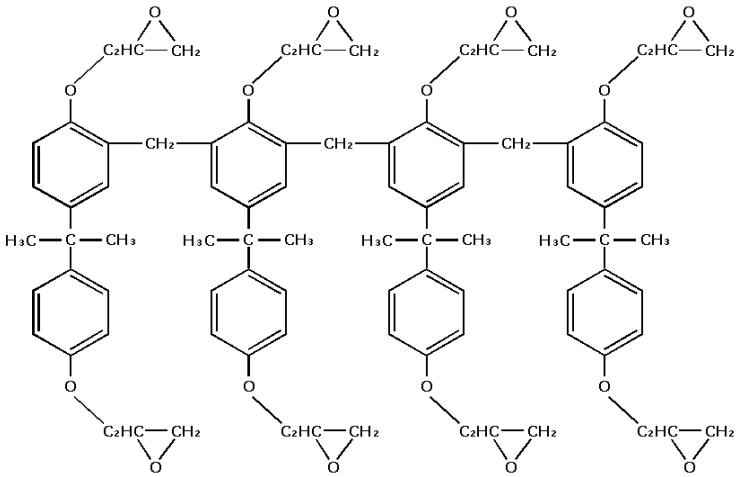
6) Develop resist





SU-8 material

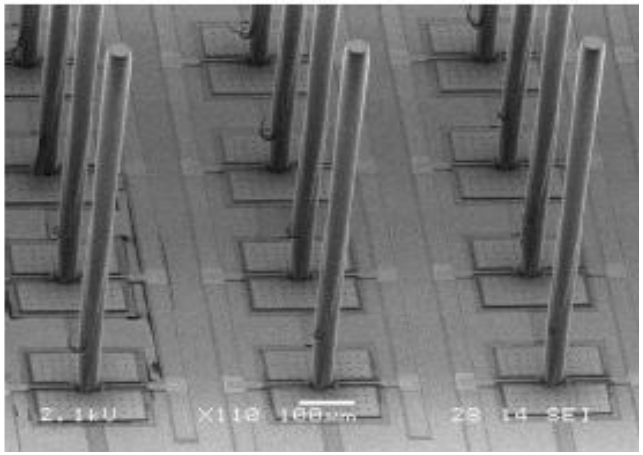
- Negative tone photoresist (developed by IBM Research)
- Polymer based (EPON SU-8 from Shell Chemical)

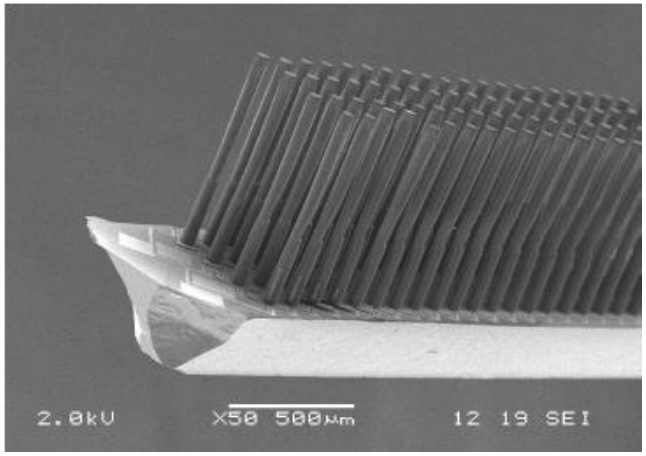


- Available in many viscosities
- Thickness ranges from **1 to 1000 µm**
- Processing similar to normal UV lithography

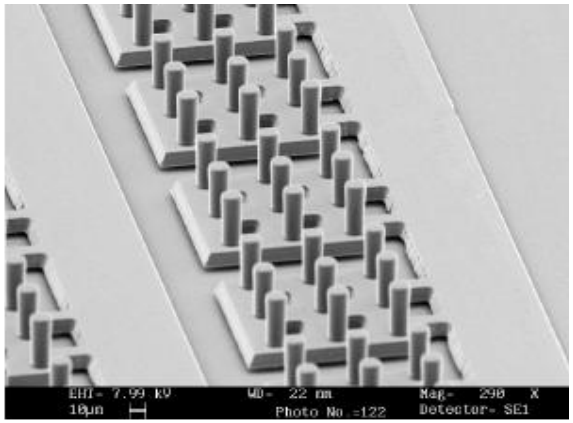
Examples of SU-8 use

- Permanent, high aspect ratio structures





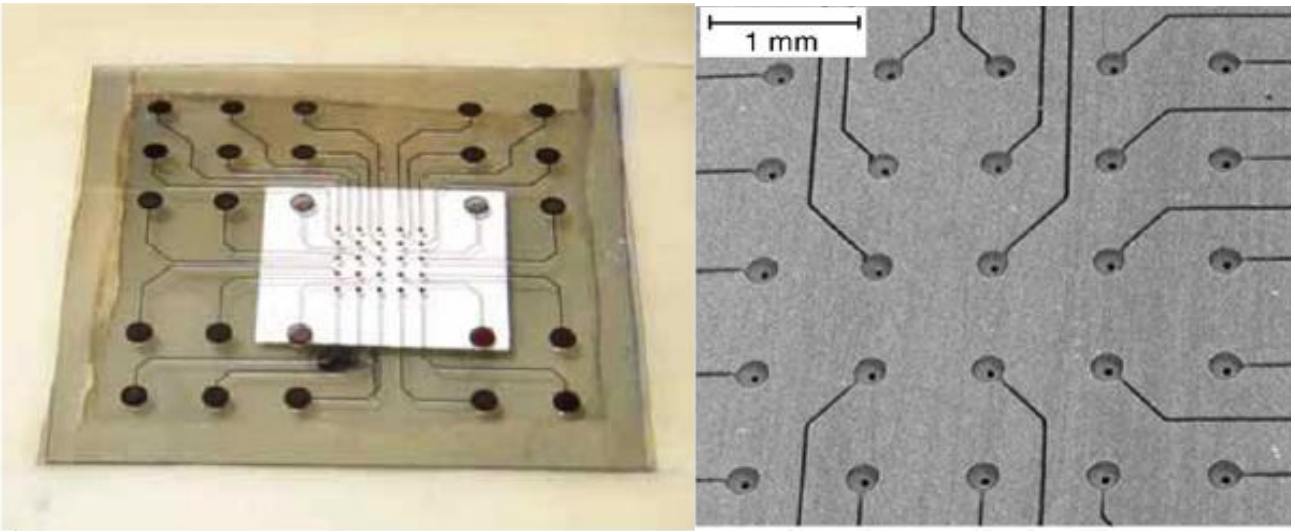
Krijnen *et al.*,
MESA+, UT



Conradie *et al.*,
(Cambridge univ.)
J. Micromech. and
Microeng. 12 (2002)

Examples of SU-8 use

- Bio compatibility: lab-on-a-chip applications

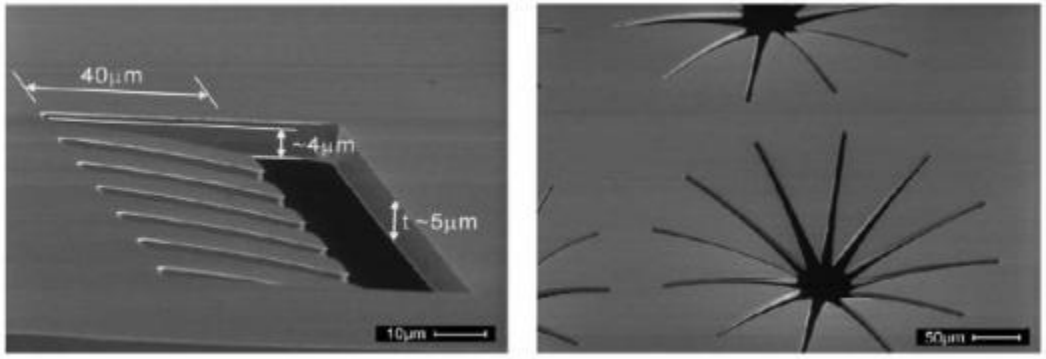


B. Xu*et al.*, (Univ. Shanghai) Sensors and Actuators A 132 (2006)

- Multiple layers of patterned SU-8 alternative to bonding

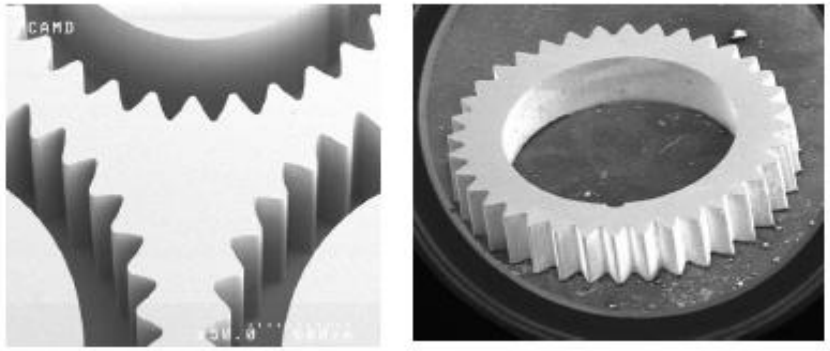
Examples of SU-8 use

- SU-8 removal using a lift-off layer
- A stencil mask made in SU-8



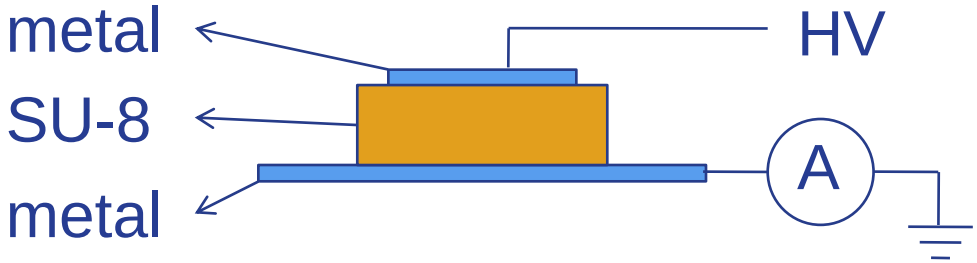
G. Kim *et al.* (MESA+, UT), Sensors and Actuators A 107 (2003)

- SU-8 as plating mold → cheap, fast, UV LIGA

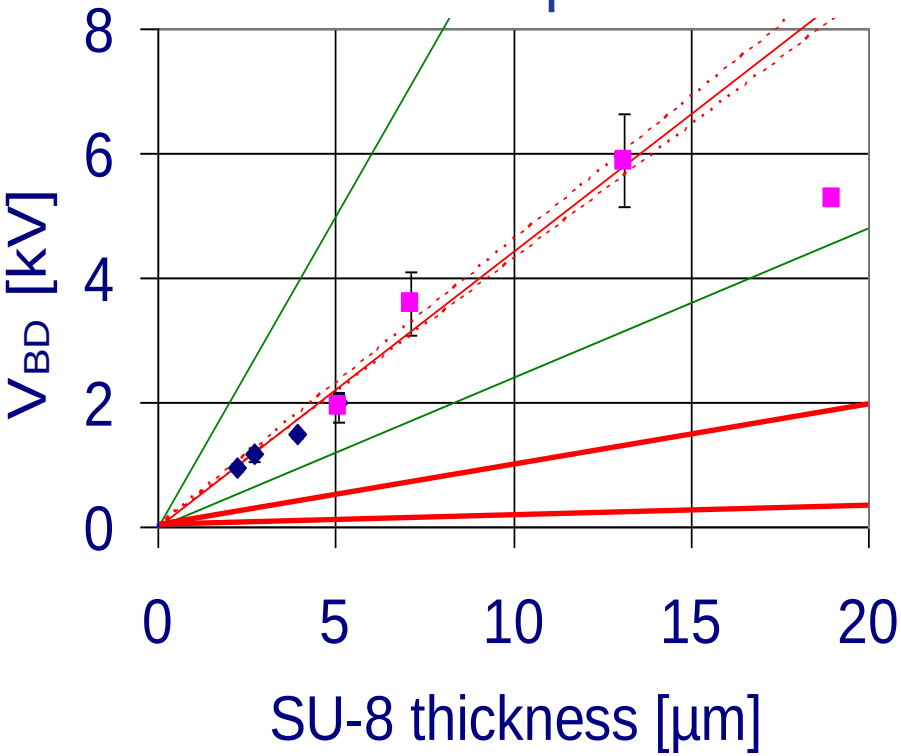


L. Jian *et al.* (Louisiana State Uinv.), SPIE vol. 4979 (2003)

DS of SU-8 mesa capacitor structures



SiO_2:
0.8–1 kV/µm



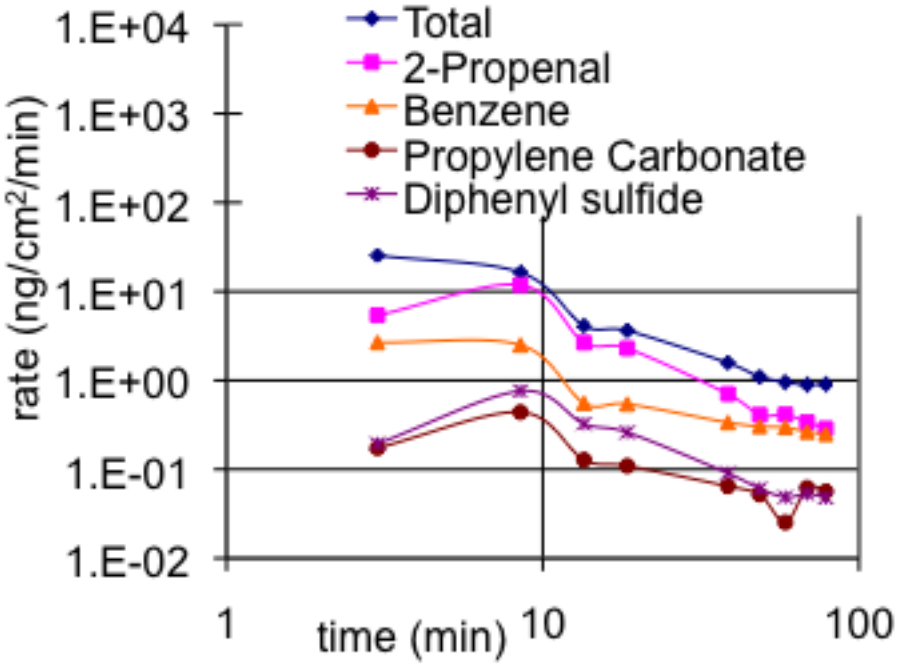
SU-8: 443 ± 16 V/µm

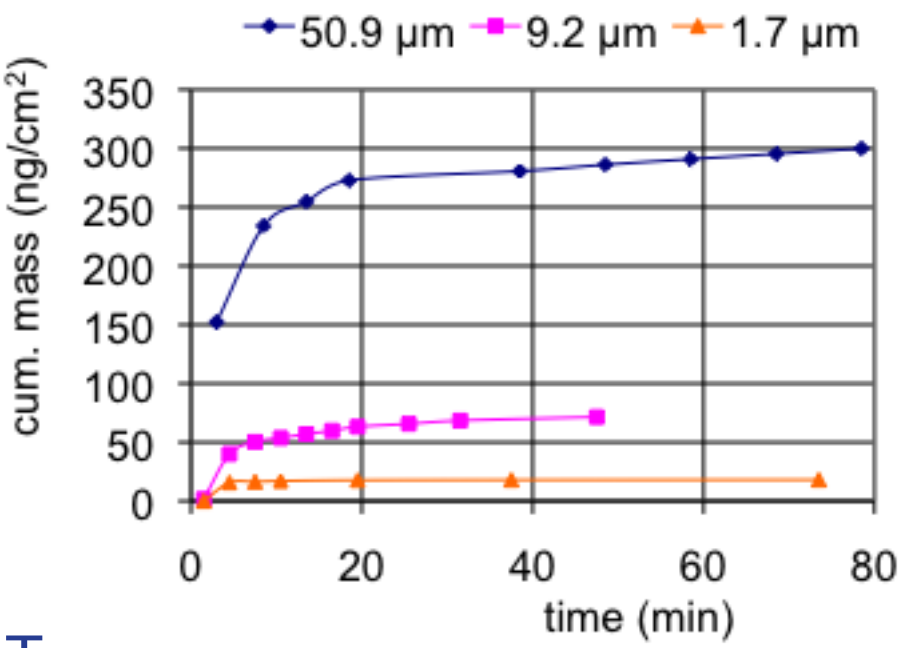
Kapton-N: 270 V/µm

MCP: ≤ 100 V/µm

MPGD: ≤ 10–20 V/µm

Outgassing from SU-8



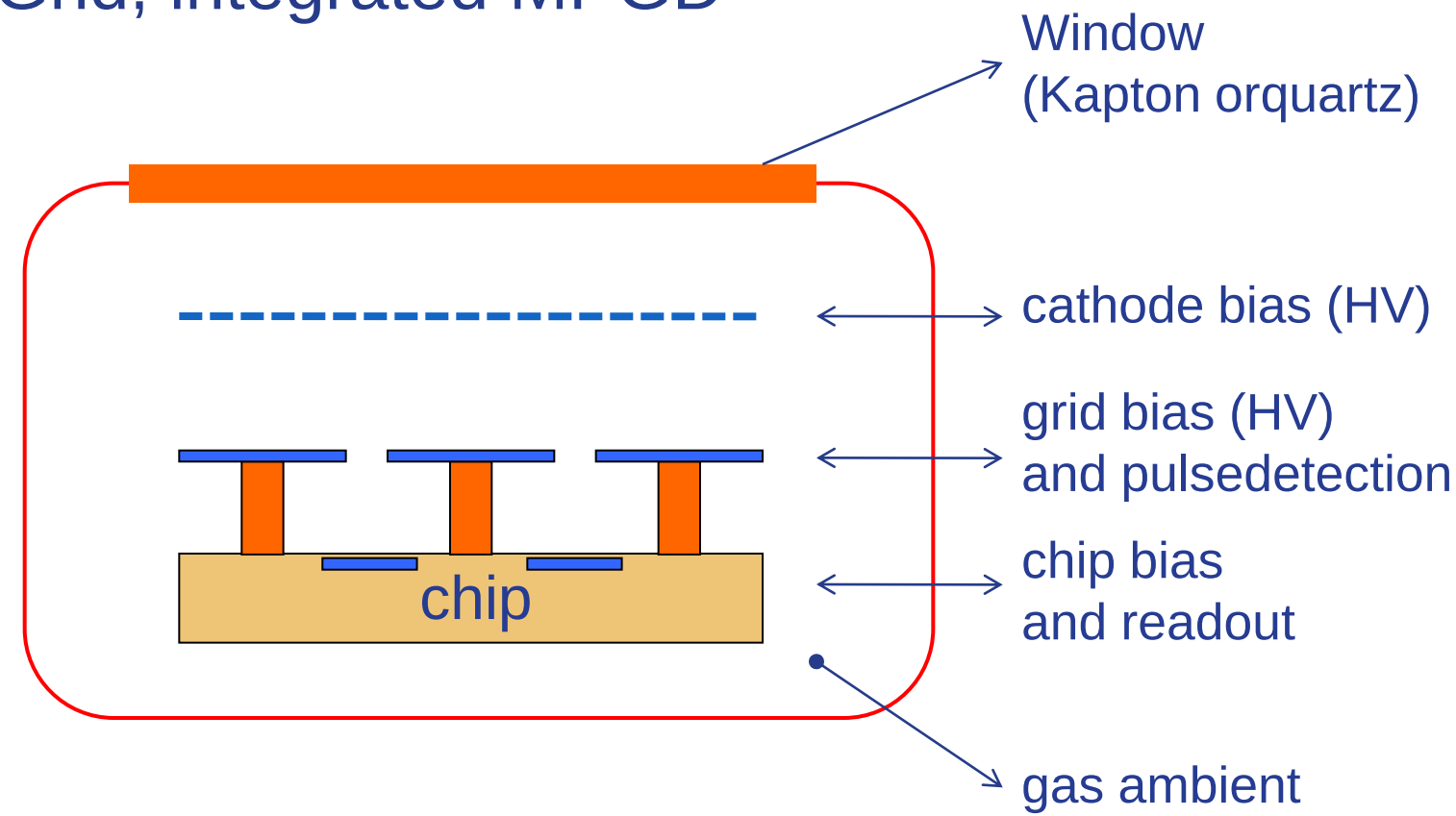


T =150 ° C

- Outgassing rate comparable to Kapton
- 20–30 min Hard-Bake →efficient pre-conditioning
- Components directly linked to resist formulation

Overview

- InGrid, integrated MPGD

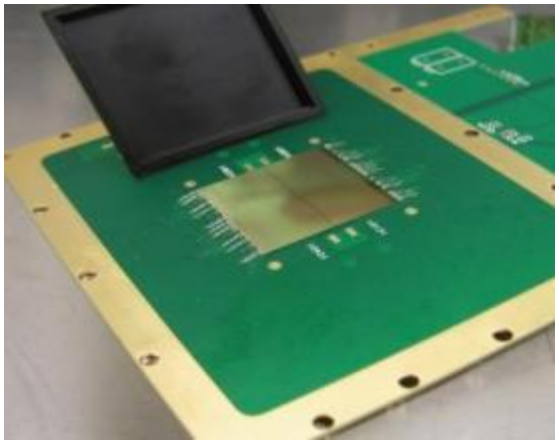


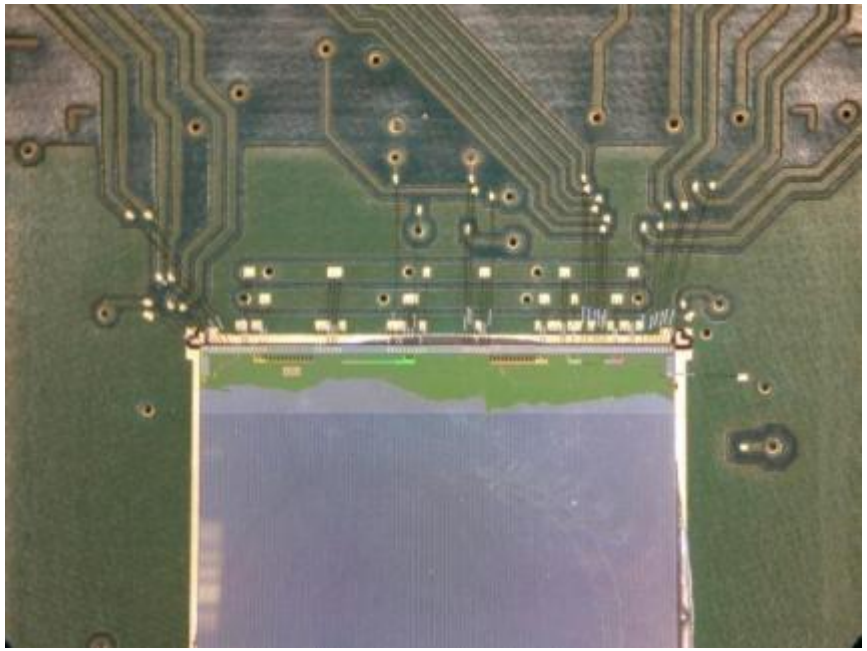
→Capabilities of InGrid

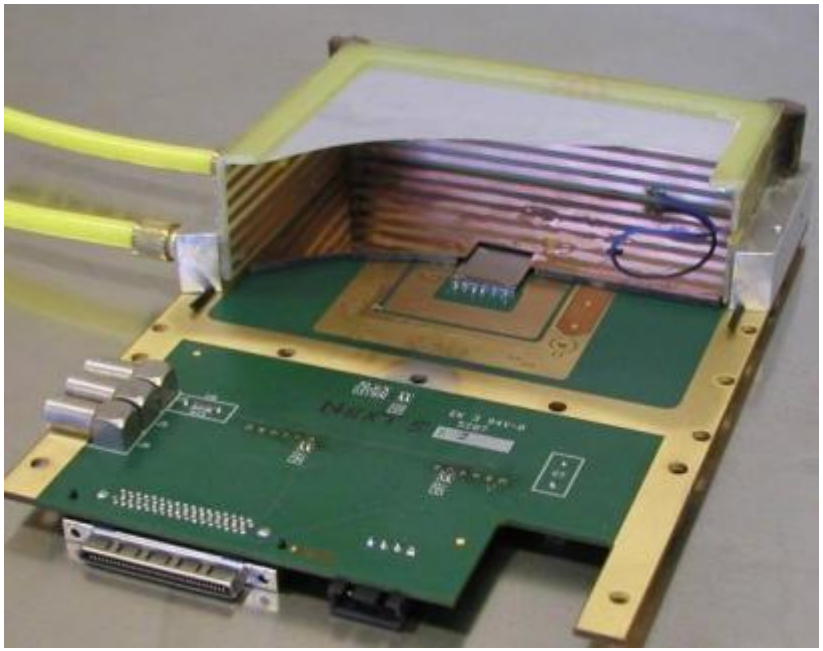
→InGrid for photon detection

Chip bonding

- Finish post-processing
- Attach chip (w/ InGrid) to board
- Wirebonding of connections
- Mount chamber onto board

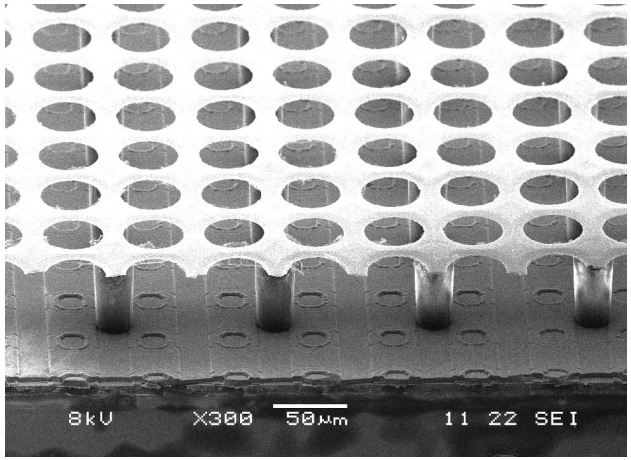


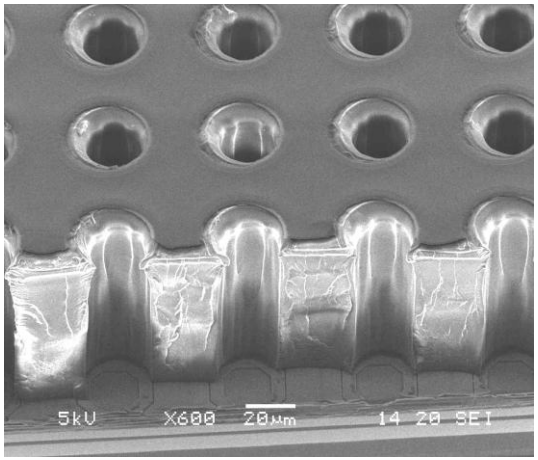


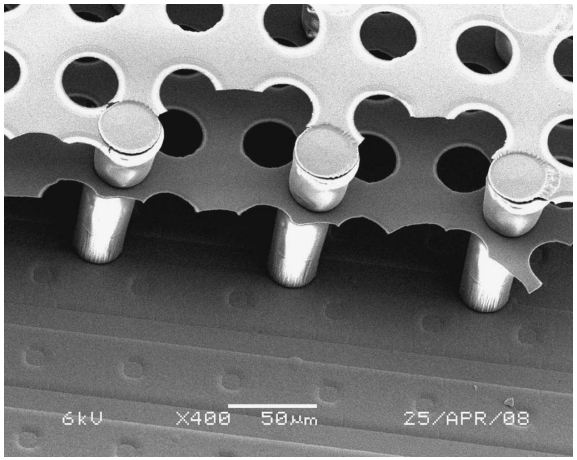


InGrid performance

- High single e^- collection efficiency (> 90% at $G=10^4$), set by field-ratio
- Good energy resolution (11.7% FWHM for ^{55}Fe in Ar/CH_4)
- 2D and 3D tracking of MIPs etc
- Different device designs, Micromegas, GEM, multiple electrodes

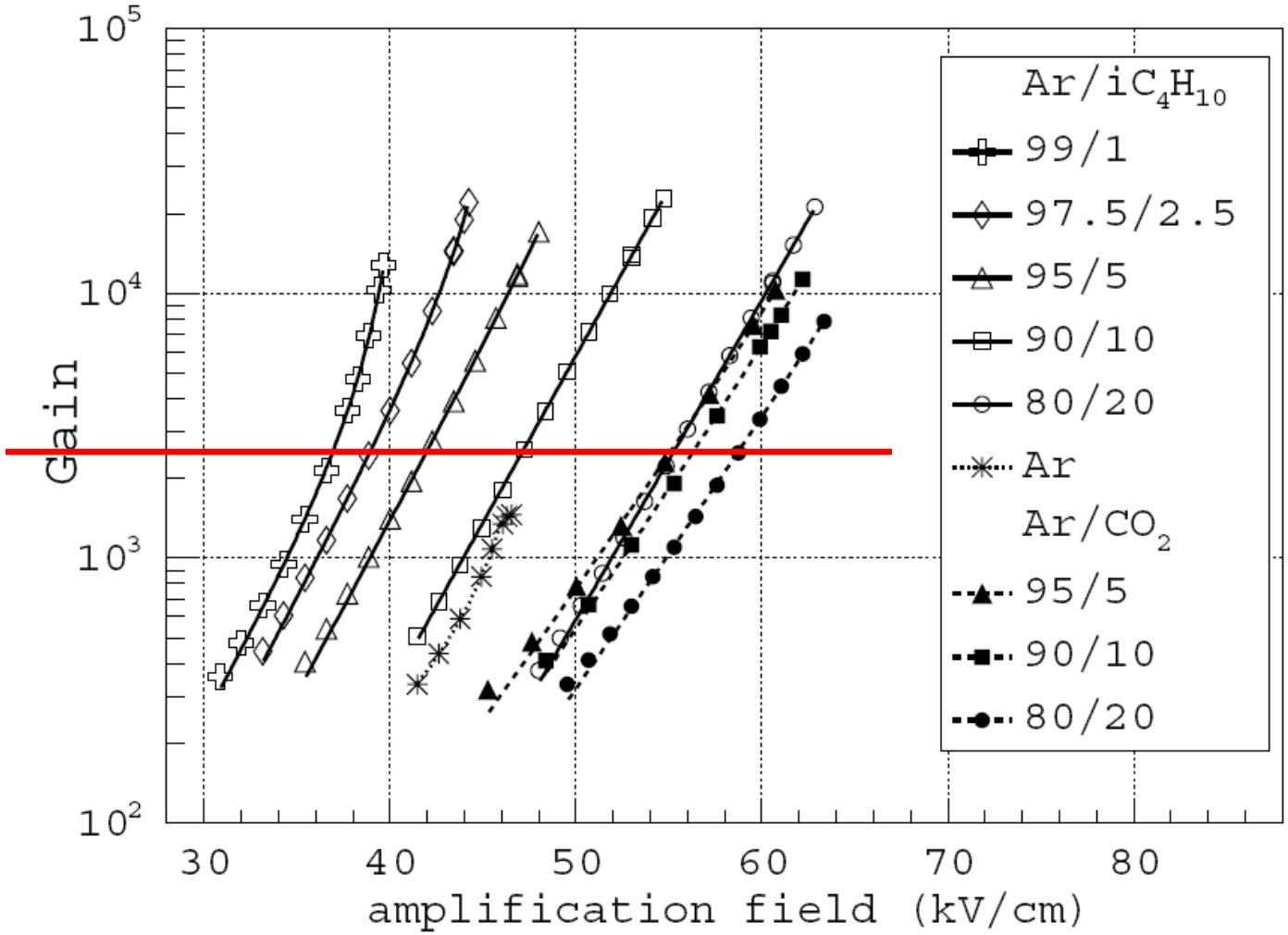






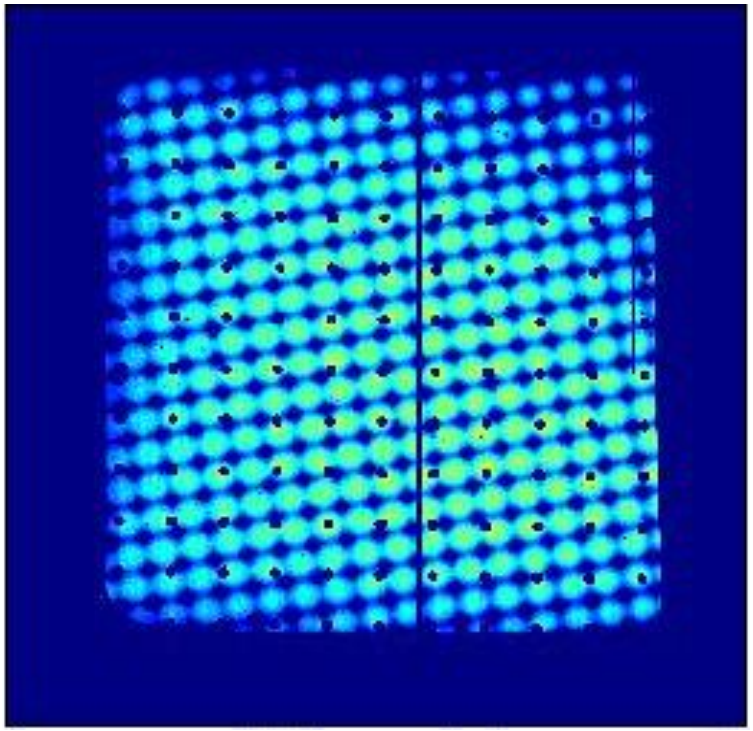
Gain in Ar/iso-Butane mixtures

Typical threshold level, $2–3 \cdot 10^3$

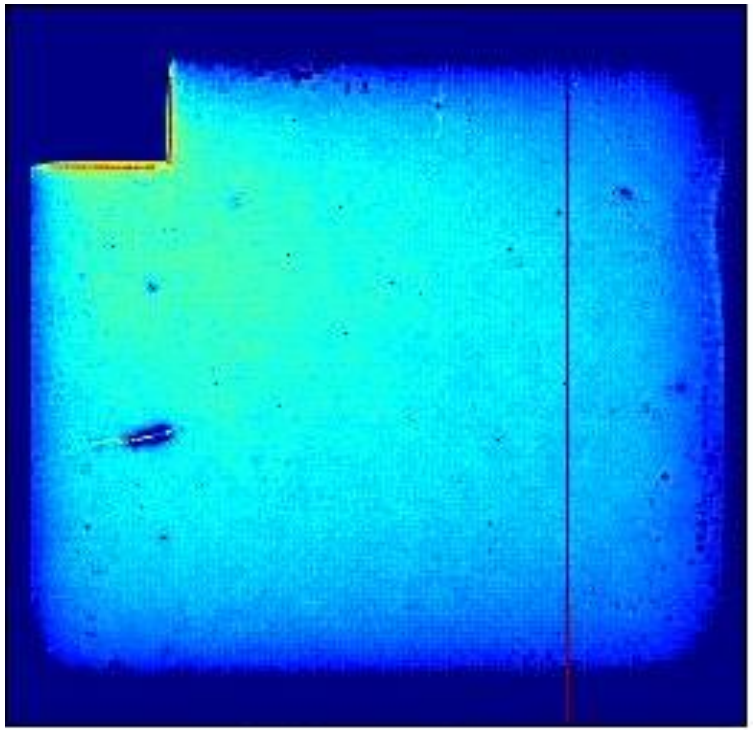


From the thesis of Max Chefdeville (NIKHEF)

Homogeneous response



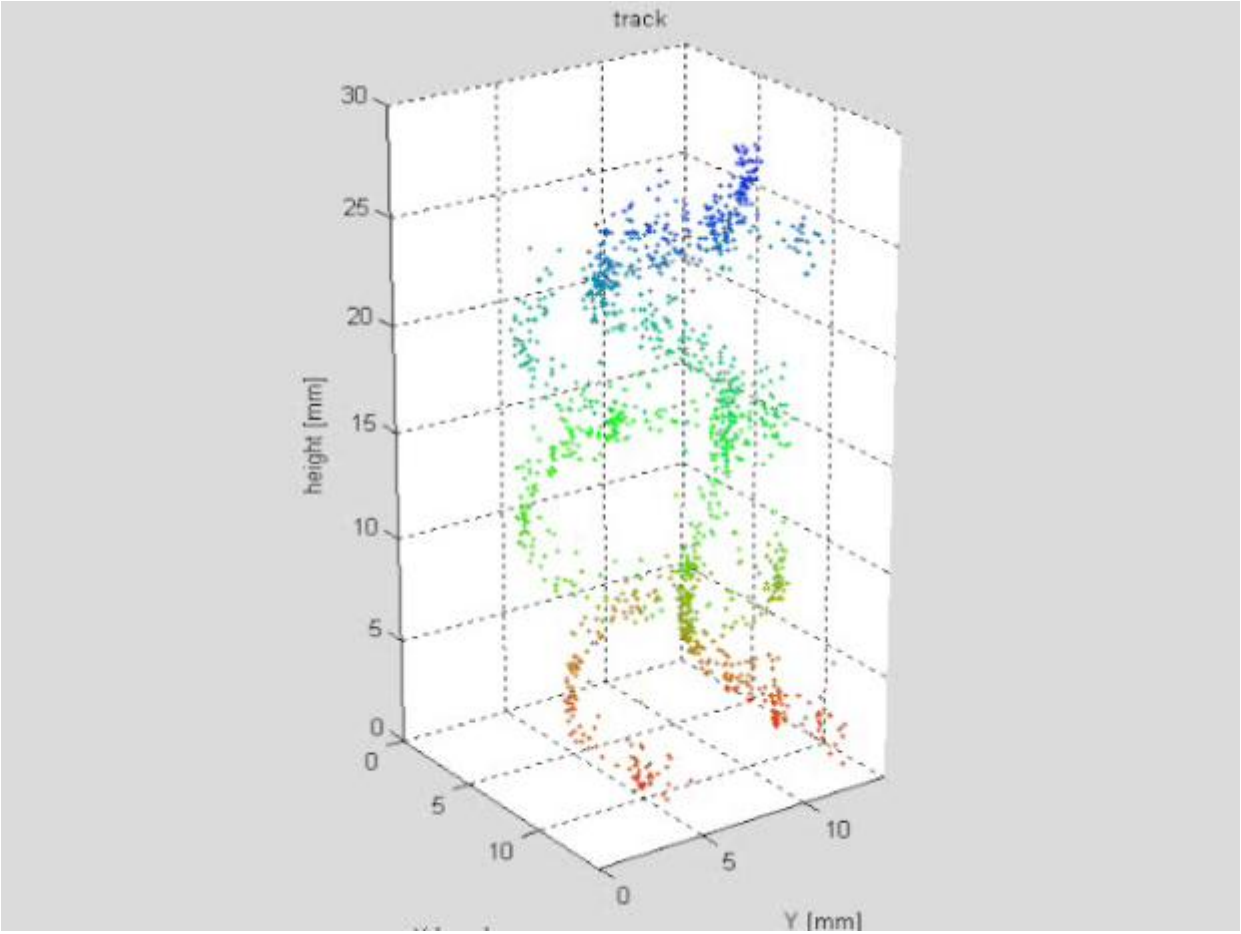
SeperatleymountedMicromegas



Post-processedInGrid

Microlithography → alignment tolerance (few µm)
→ alignment between pixels and grid (55 µm pitch)
→ no more Moiré patterns

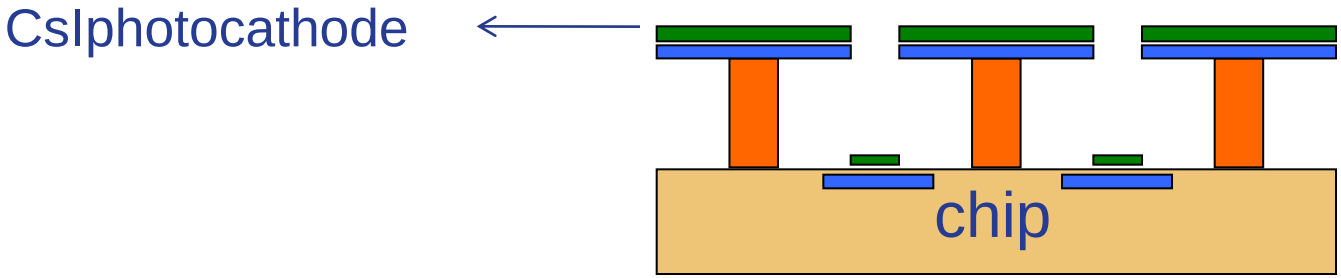
Two ^{90}Sr tracks in a B field Recorded with a 3 cm Timepix TPC



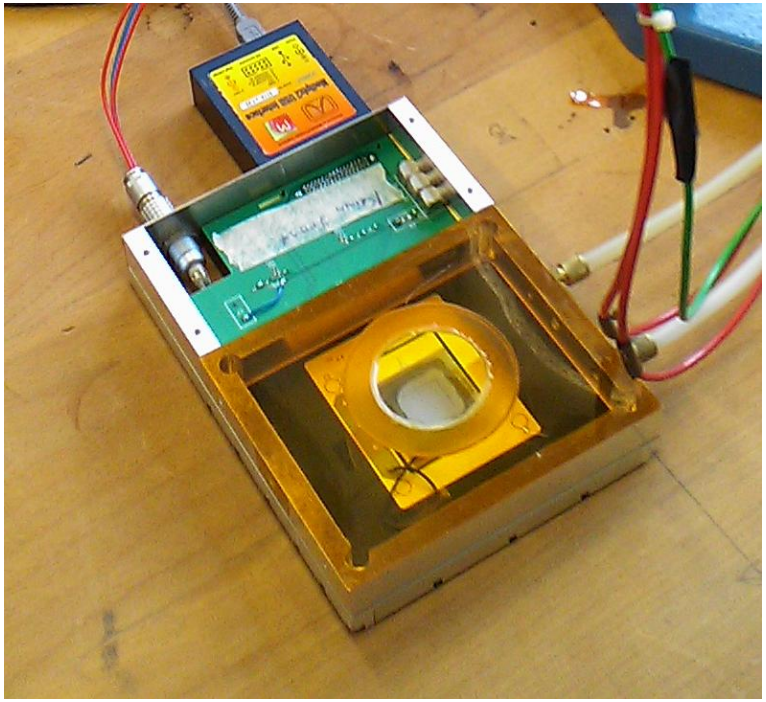
Courtesy: Martin Fransen and Lucie de Nooij, NIKHEF

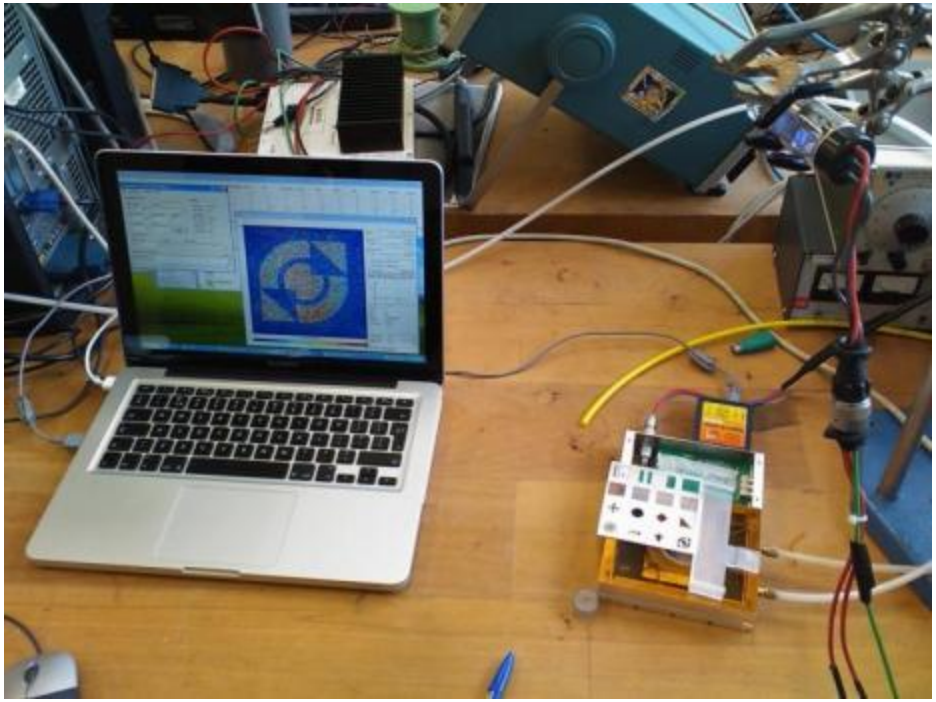
InGrid for photon detection

- Aim: complete integration of a UV photon sensitive detector
- Based on InGrid technology
- High resolution, high sensitivity, high rate
- Photocathode deposited after chip bonding



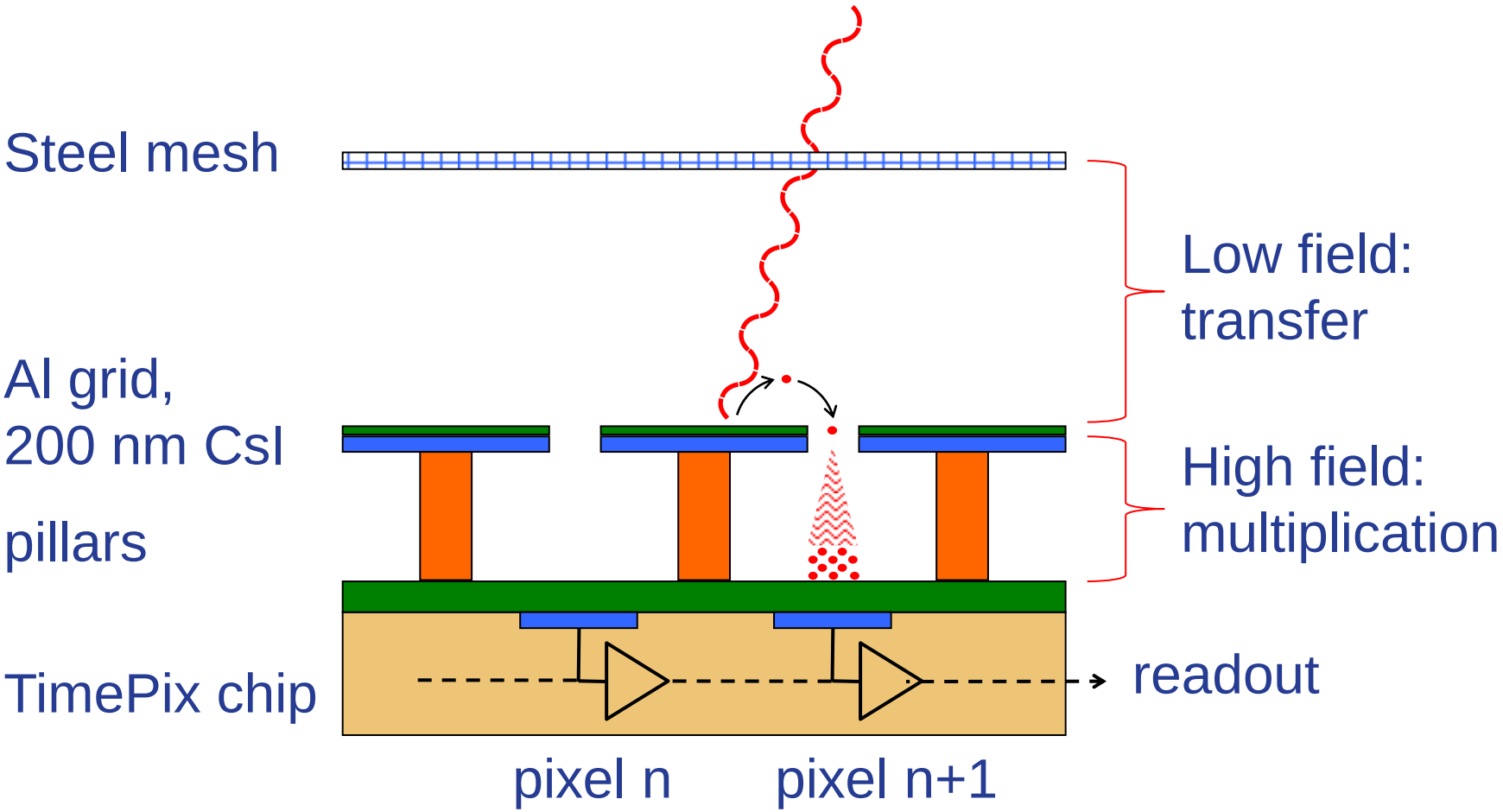
Set-up for photon detection



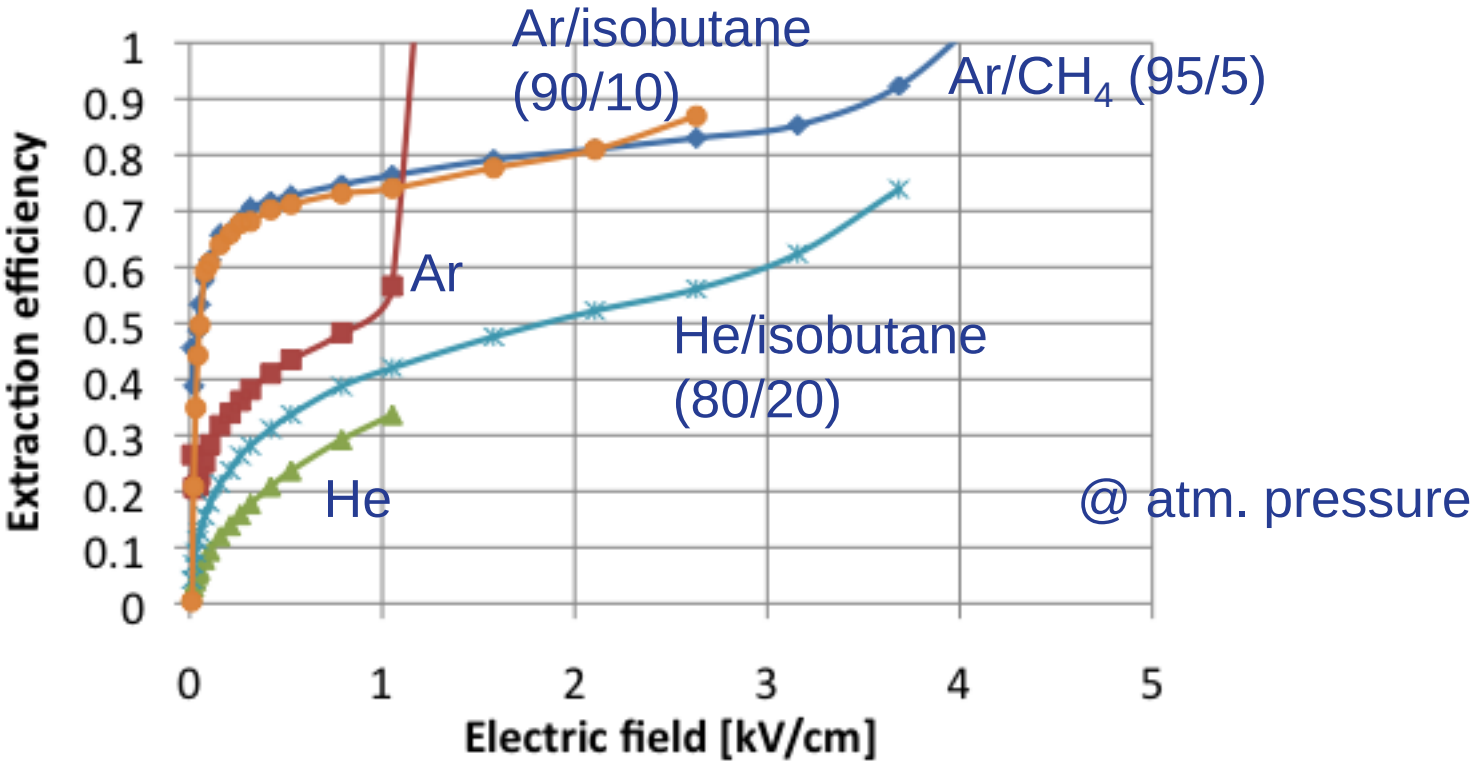


- Si-nitride spark protection of 8 µm
- Typical InGrid: 80 µm gap, 25 µm holes (OT: 19%)
- GOSSIP/NEXT chamber, USB readout
- CsI is deposited by thermal evaporation, after chip is processed and mounted on board

Operation principle of a light sensitive InGrid

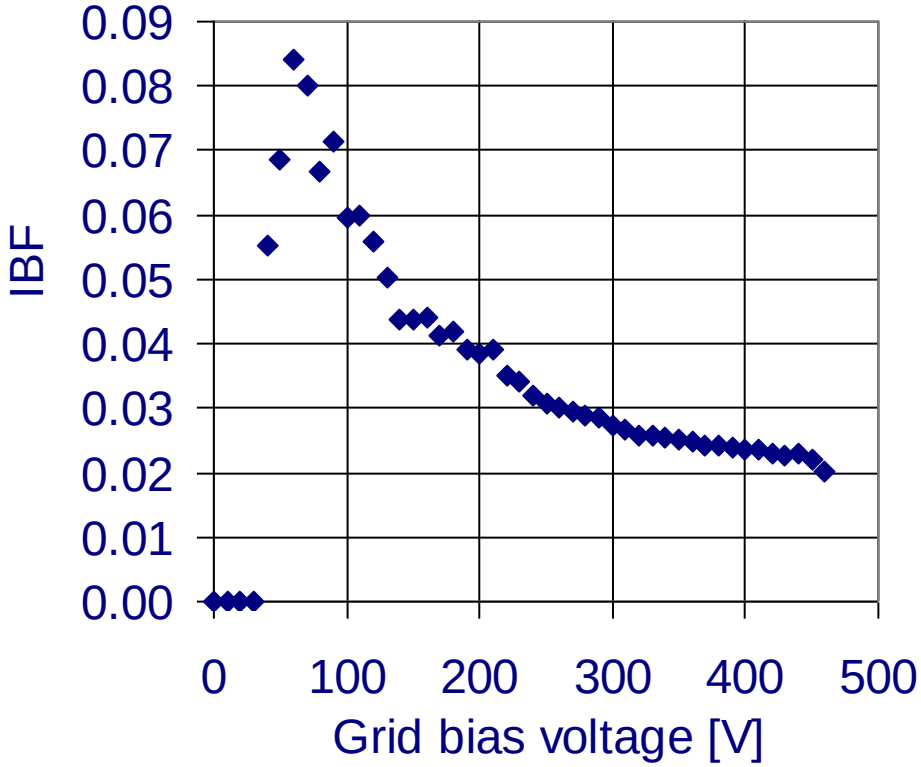


Extraction of primary electrons into He/isobutane



- He shows increased backscattering (compared to Ar)
- Addition of quencher (isobutane) restores yield (partially)
- High concentration of isobutane leads to UV absorption

Ion Back Flow (IBF) measurement



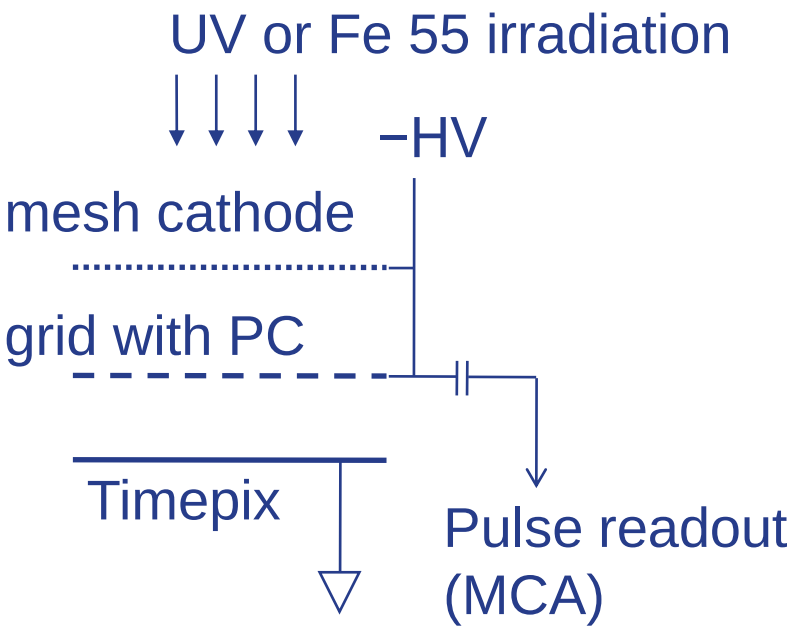
IBF:
Fraction of anode current that flows back to cathode (as ions)

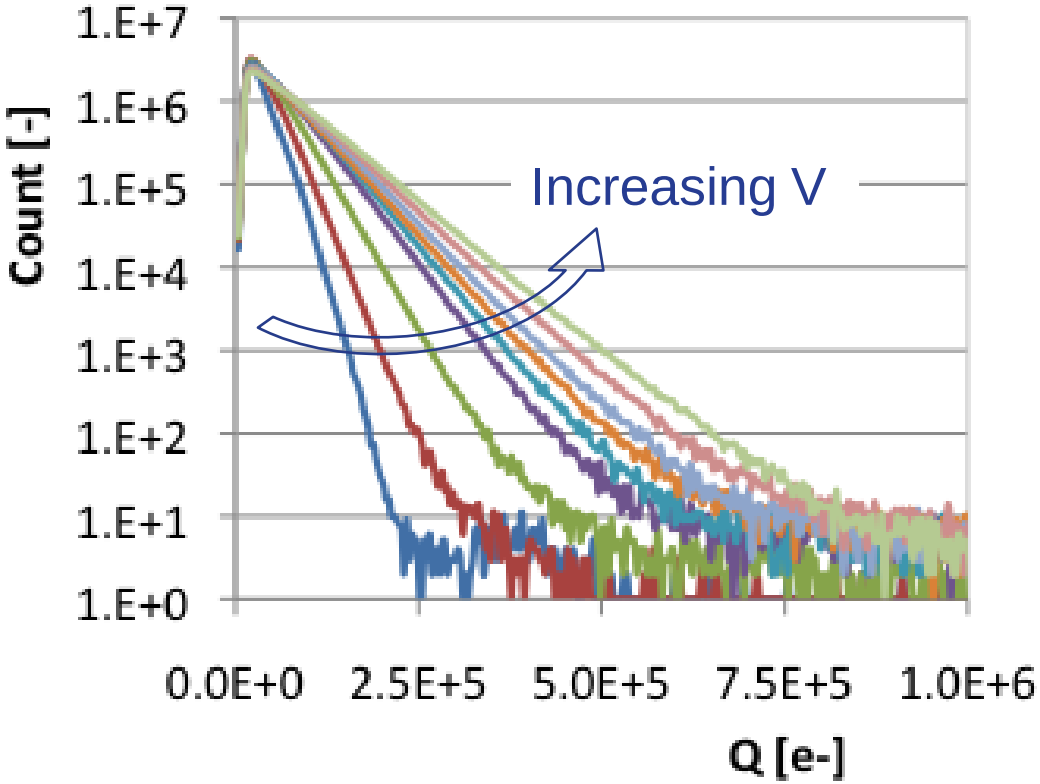
Ions can damage photocathode (surface reactions)

Options for reduction

- Optimization of geometry, field ratio, gas
  Saclay (Colas et al.) reported IBF ~ 0.001
- Multistage structures (IBF not known)

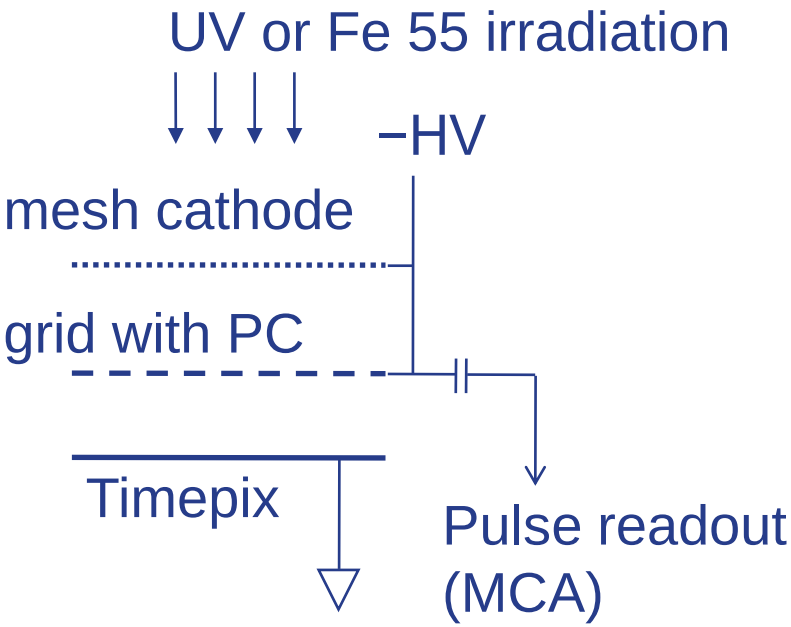
UV pulses measured on grid

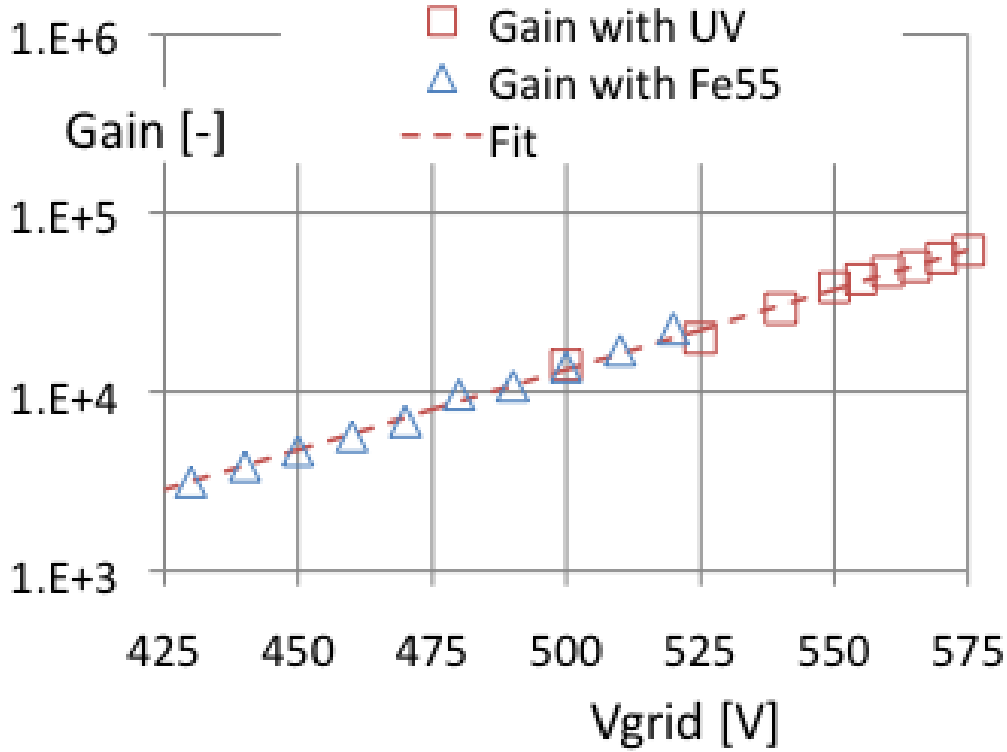




- He/isobutane (80/20), Al grid with 200 nm CsI
- Distribution $G(Q) \propto C \cdot 1/G \cdot \exp(-Q/G)$
- Fit to distribution → extract G(V)

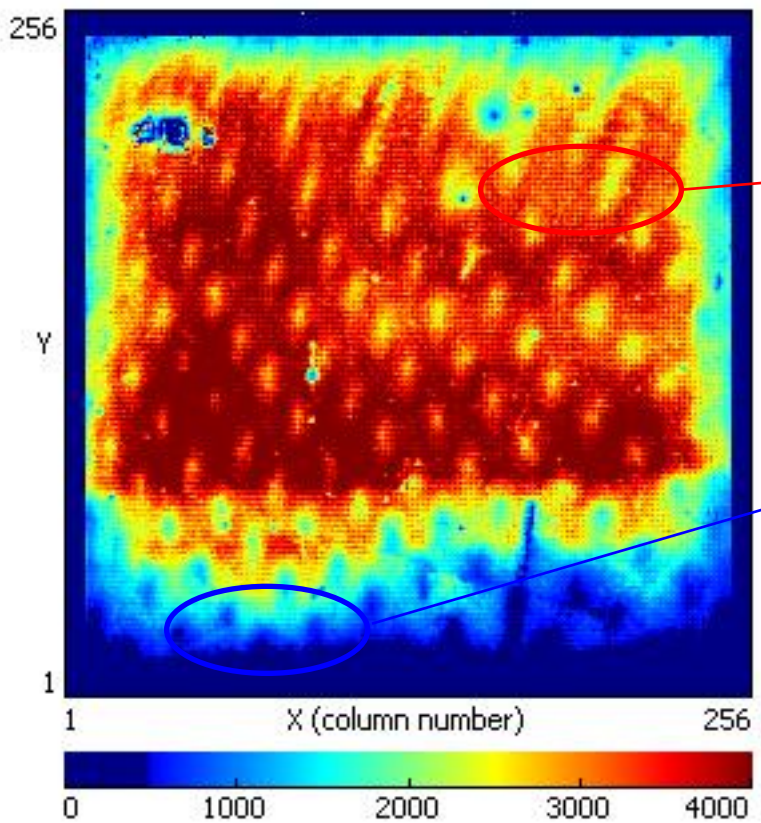
Gain of InGrid device with PC

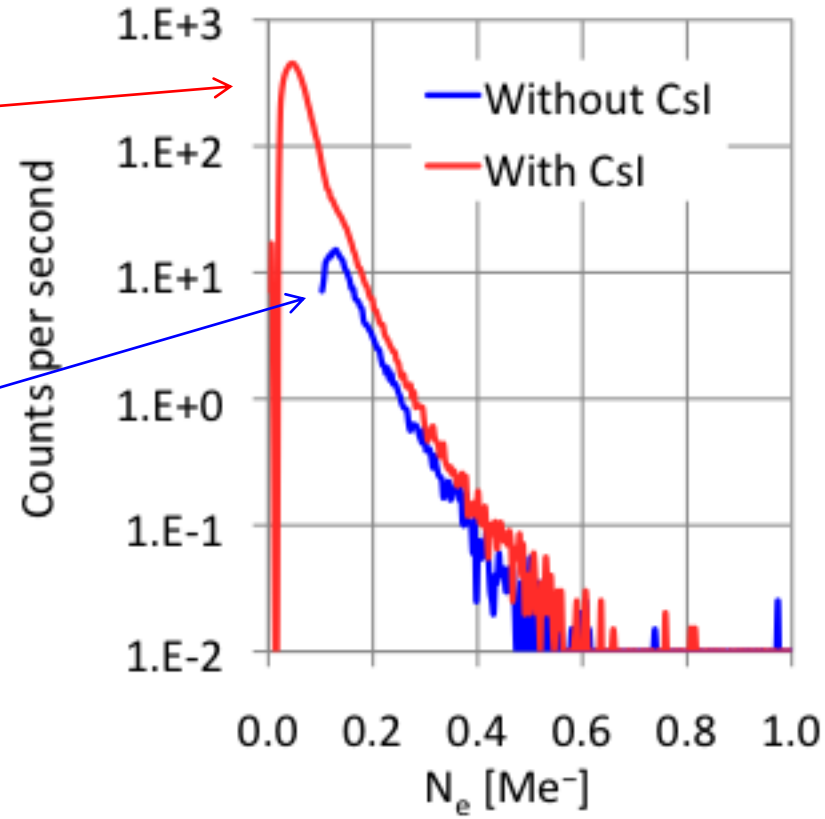




- He/isobutane (80/20),Al grid with 200 nm CsI, 80 µm gap height, 25 µm hole size
- slope ≈ 100–110 V/dec, max. gain ≈ $7 \cdot 10^4$

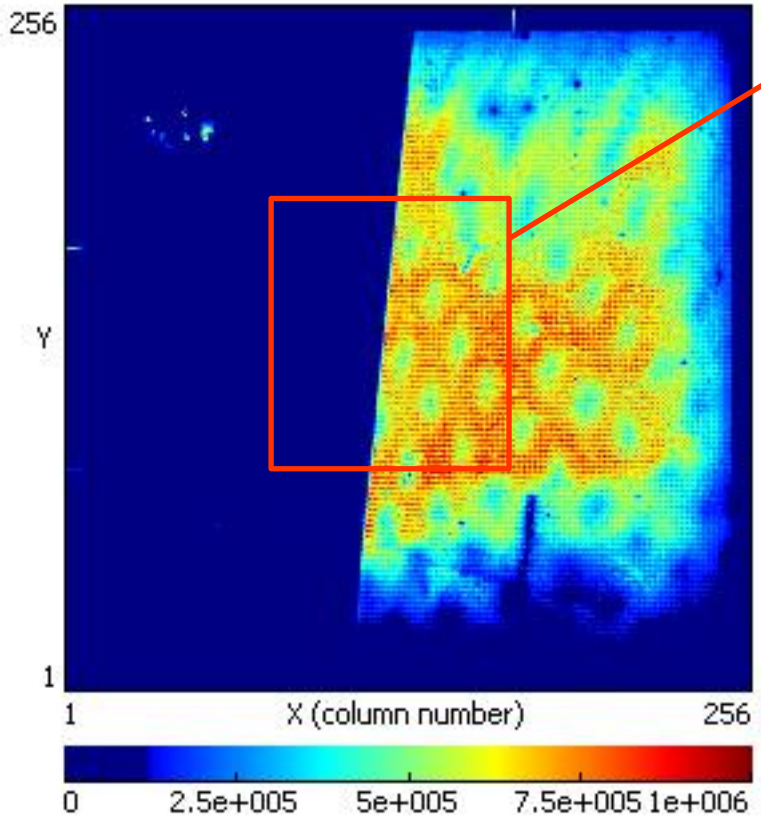
Spectra with and without CsI





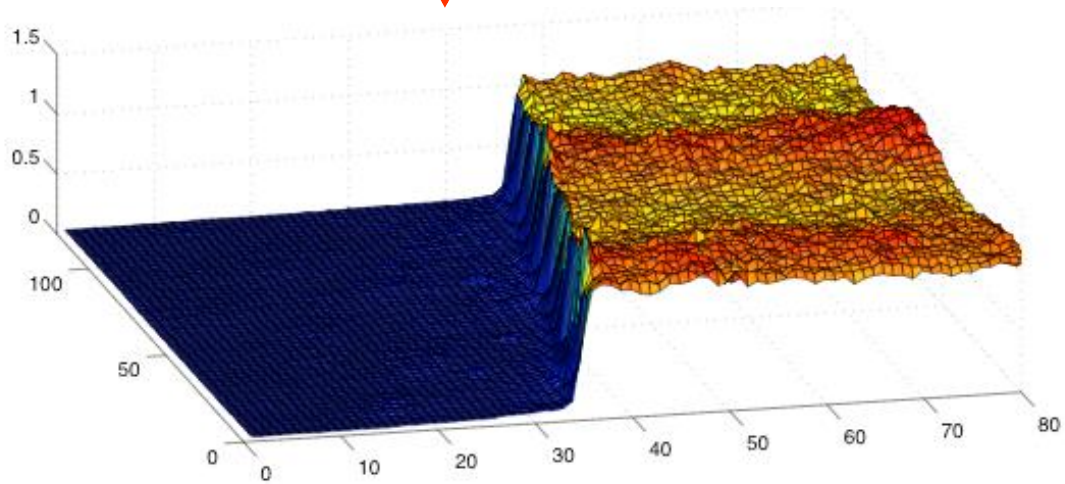
→ No increase in (photon) feedback

Determining spatial resolution using slanted edge method

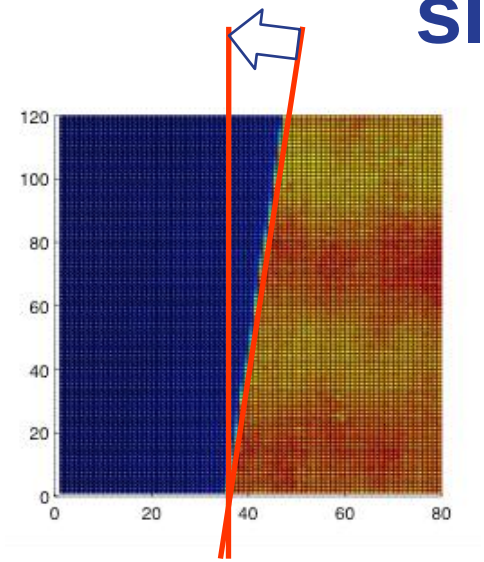


Select ROI

Correct using open frame



Determining spatial resolution using slanted edge method

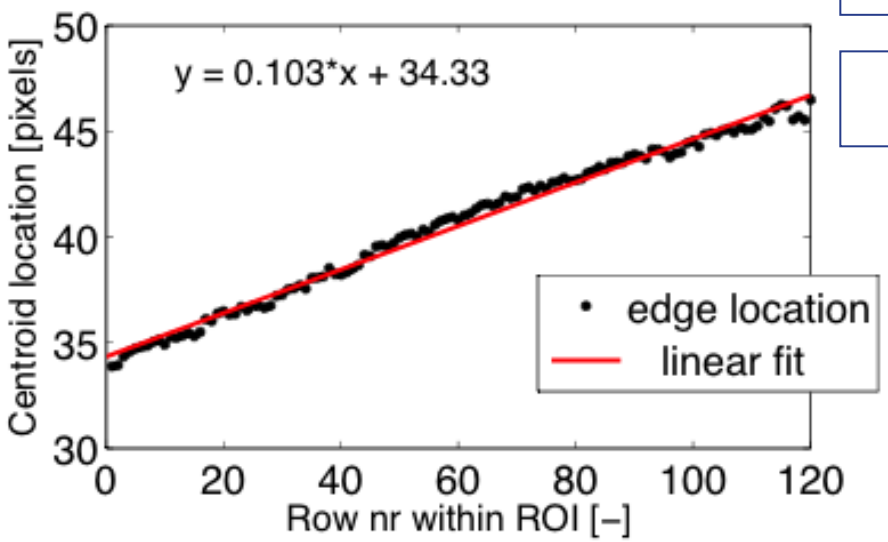


Select ROI

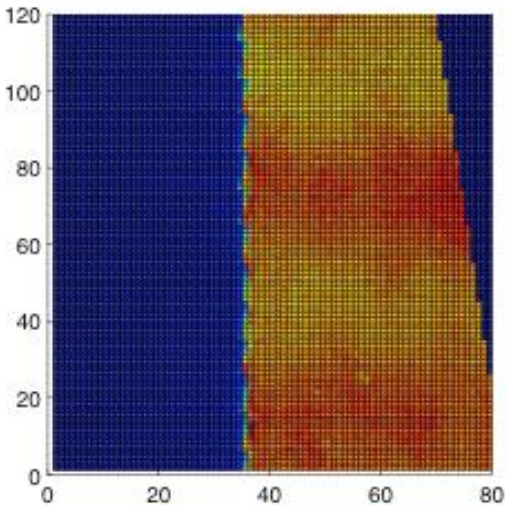
Correct using open frame

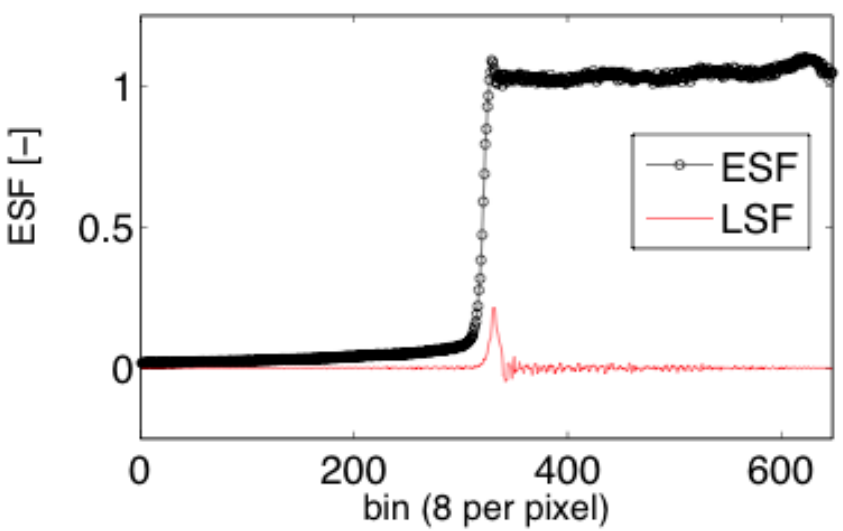
Find edge using derivation for all lines and fit a line

Shift line data accordingly



Determining spatial resolution using slanted edge method





Select ROI

Correct using open frame

Find edge using derivation for all lines and fit a line

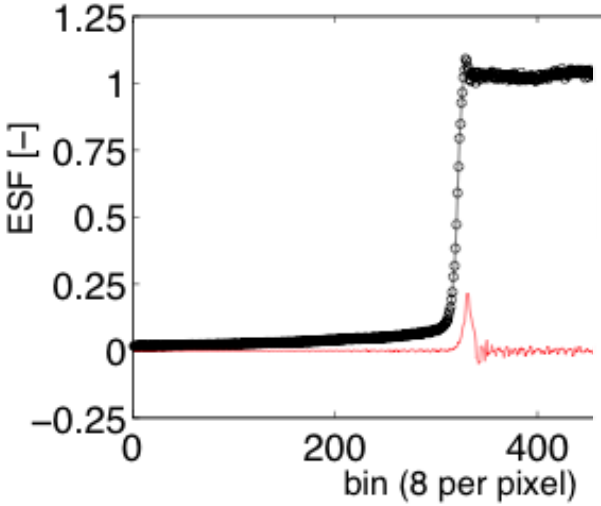
Shift line data accordingly

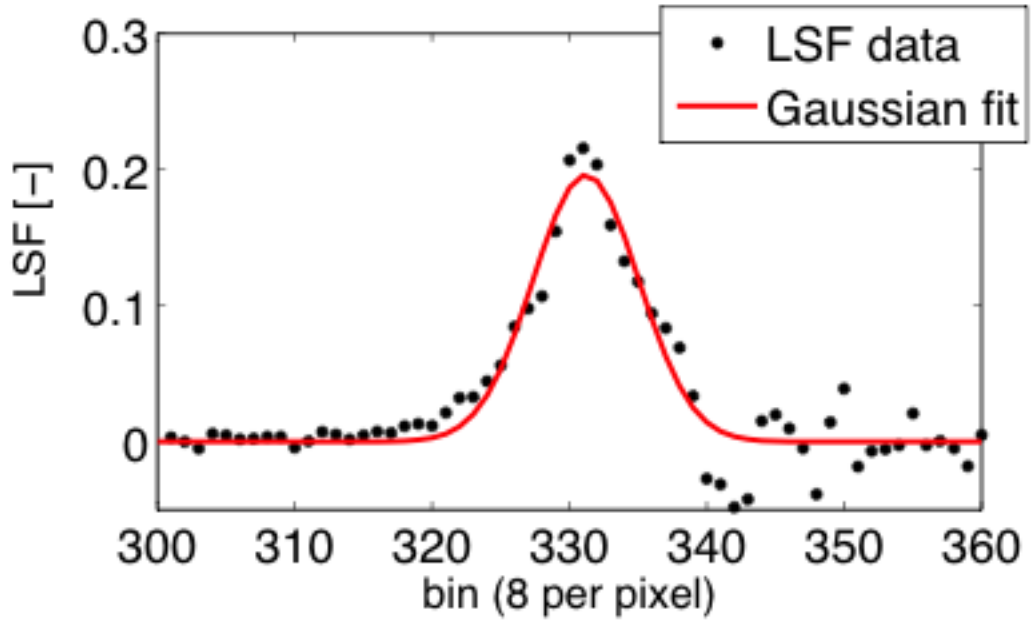
Resample into 1 ESF

Calculate LSF

Determine resolution

Determining spatial resolution using slanted edge method



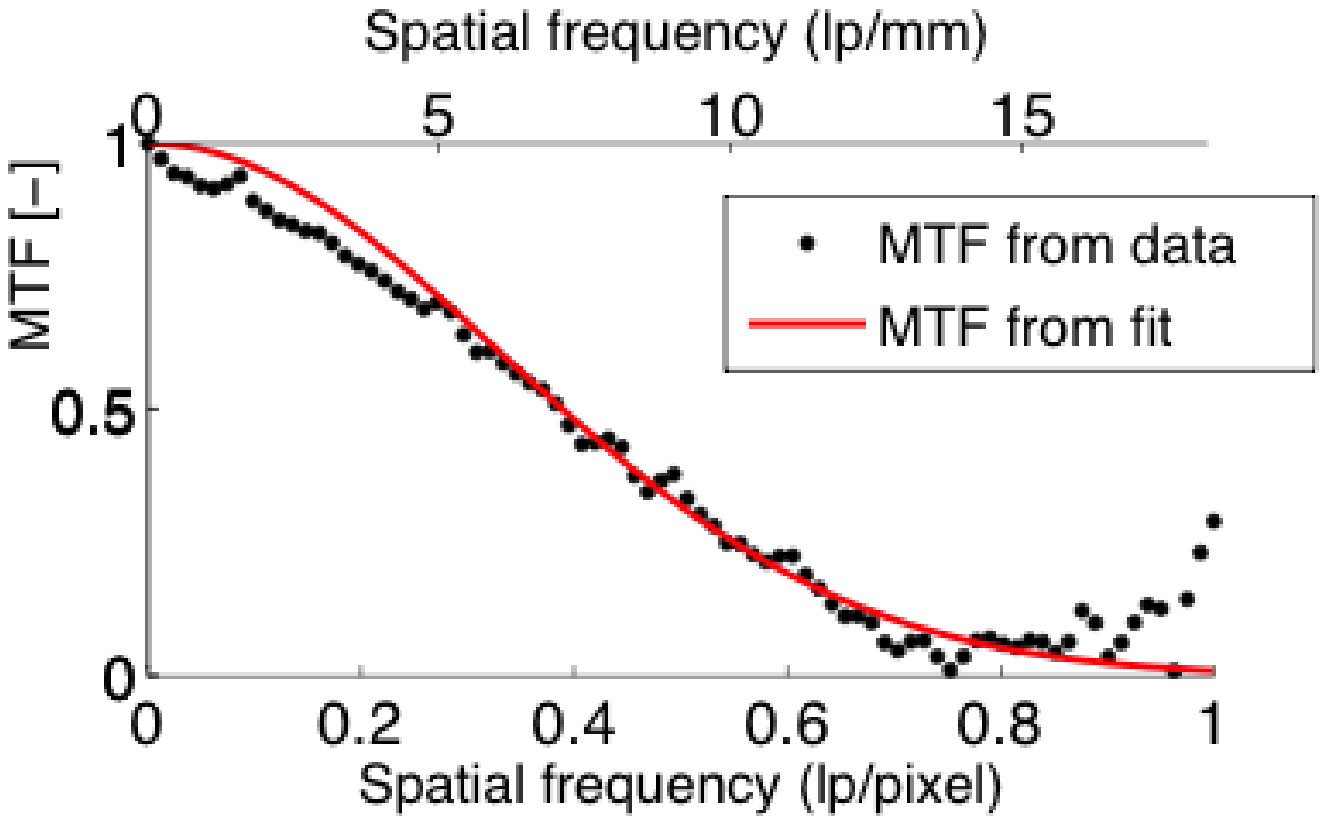


Fit to LSF:

- Gaussian with σ = 0.48 pixel = 26.4 μm
- FWHM = 1.13 pixel = 62.2 μm

Fourier transformation of LSF → MTF

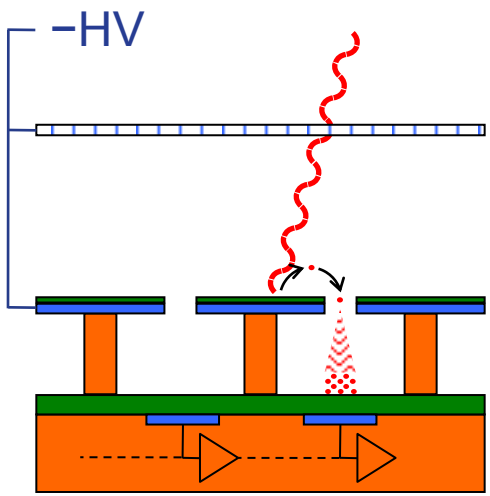
MTF calculated from LSF



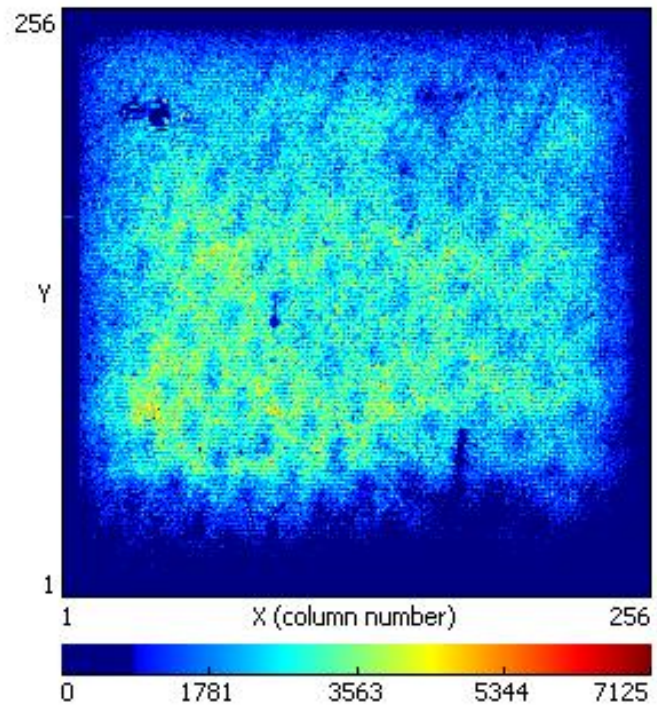
- MTF50 = 0.4 lp/pixel (≈ 7 lp/mm)
- Limit ≈ 0.8 lp/pixel (≈ 14 lp/mm)
- Resolution < pixel size (MTF = 0.32 @ $f_{Nyquist}$)

Influence of cathode mesh

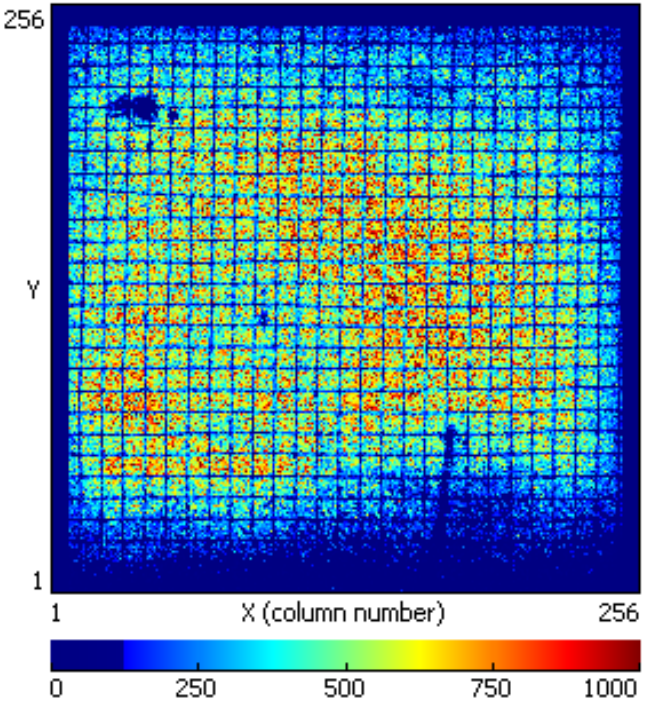
Mesh modulates light → non-uniform response,
but also indication of resolution



Pixel pitch = 55 µm



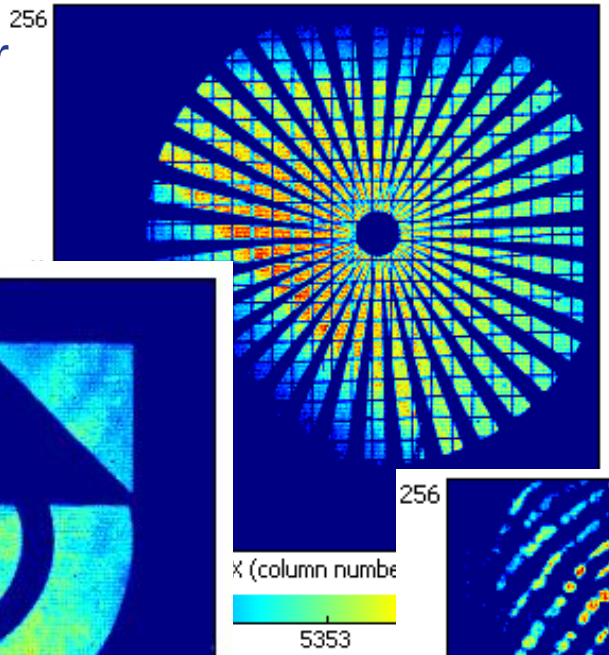
Fine mesh (56 µm)
→ Moiré pattern



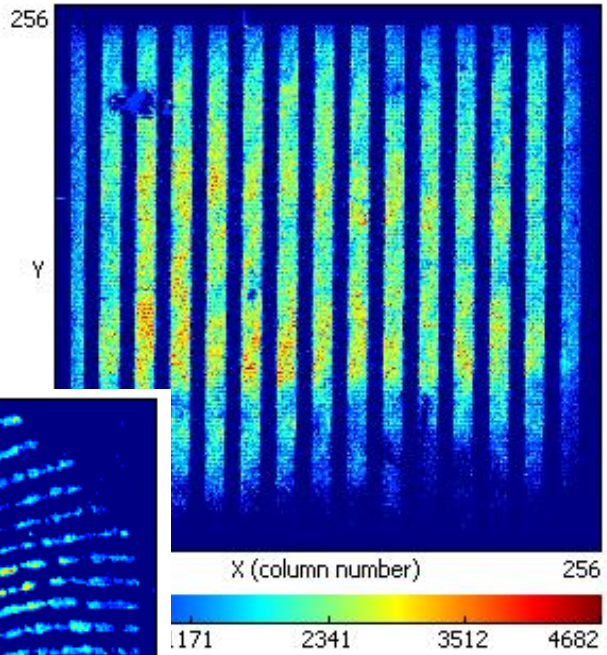
Coarse mesh (500 µm)
→ Mesh is imaged

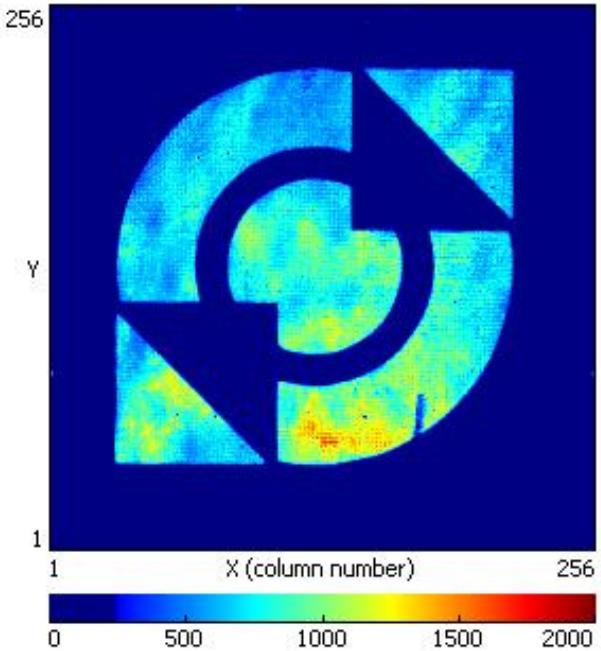
More images

Siemens star

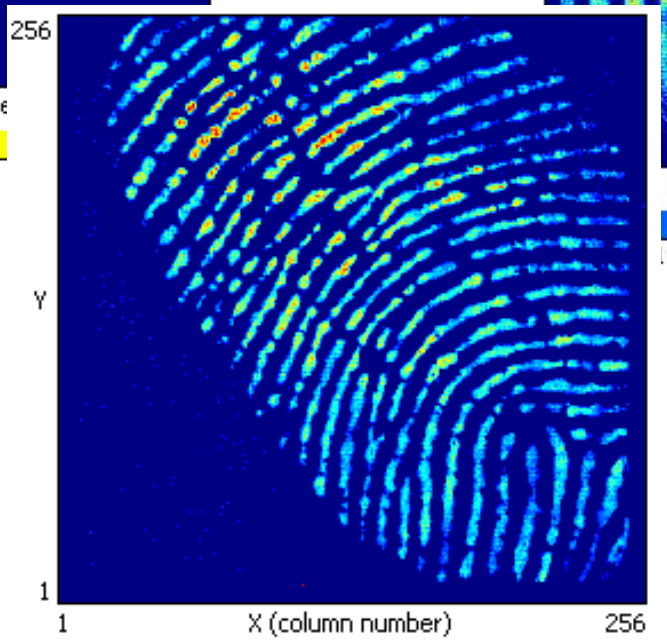


Vertical stripes





Logo of the University of Twente



Fingerprint on window

Conclusions

- Post processing combines CMOS strengths with MEMS flexibility
- SU-8 pillars and Al grid allow integration of MPGD on CMOS readout
- CsIdeposition on InGrid successful, CsIPC works on InGrid
- Timepix fully operational with PC

Conclusions

Successful integration of MPGD and PC on CMOS imaging chip:

- No photon feedback observed
- IBF ≈ 0.02
- Max gain ≈ $7 \cdot 10^4$
- UV photon imaging capability demonstrated, external cathode mesh
- Spatial resolution is very good, FWHM of LSF is 62 μm, resolution limit above $f_{Nyquist}$

Outlook

- Qualitative measurement of QE
- Multistage structures for better IBF
- Otherphotocathodes
- Spectroscopic capabilities of Timepix TOT readout-mode
- Other grid materials (spark protection)
- Technological limits, alignment and feature size

Acknowledgement

Weizmann Institute of Science, Rehovot, Israel:
Amos Breskin, Marco Cortesi, Moshe Klin and AlexeyLyashenko

NIKHEF, Amsterdam, the Netherlands:
Victor Blanco Carballo, YevgenBilevych, Max Chefdeville, Martin Fransen, Harry van derGraaf, Fred Hartjes, JoopRövekamp, Jan Timmermans and Jan Visschers

MESA+, University of Twente, the Netherlands:
Cora Salm, Jurriaan Schmitz, Sander Smits, and Rob Wolters

This project is sponsored by Dutch Technology Foundation STW

Questions

UNIVERSITY OF TWENTE.

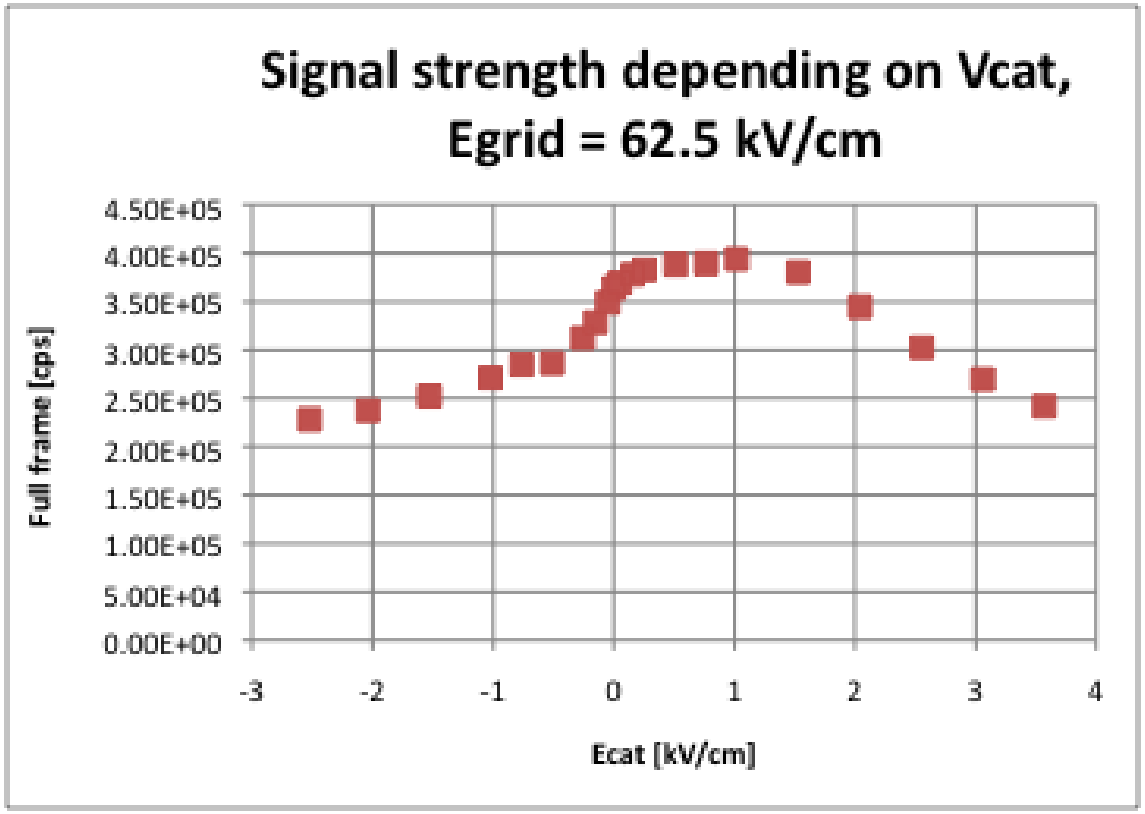
MESA+ Institute for Nanotechnology

NIKHEF

מכון ויצמן למדע
WEIZMANN INSTITUTE OF SCIENCE

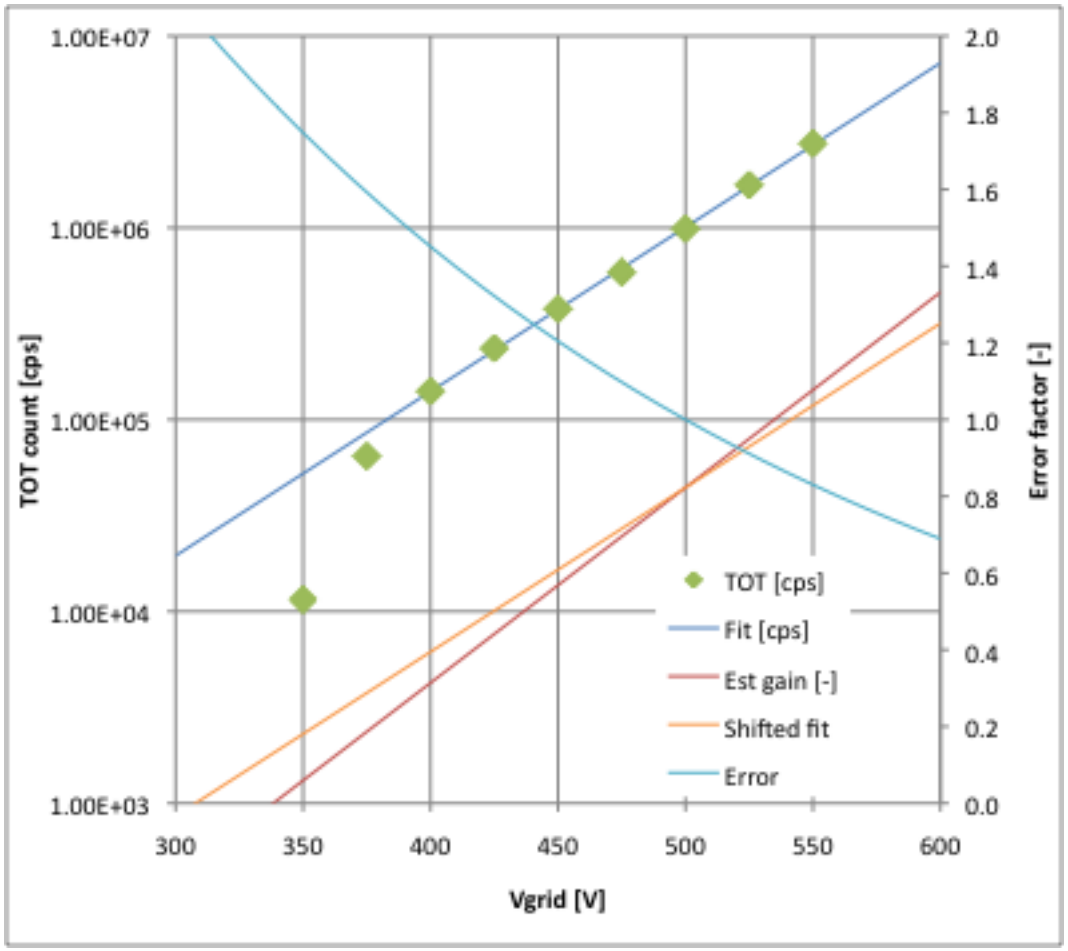
stw

Dependence on drift field



- TOT count of full frame (in cps)

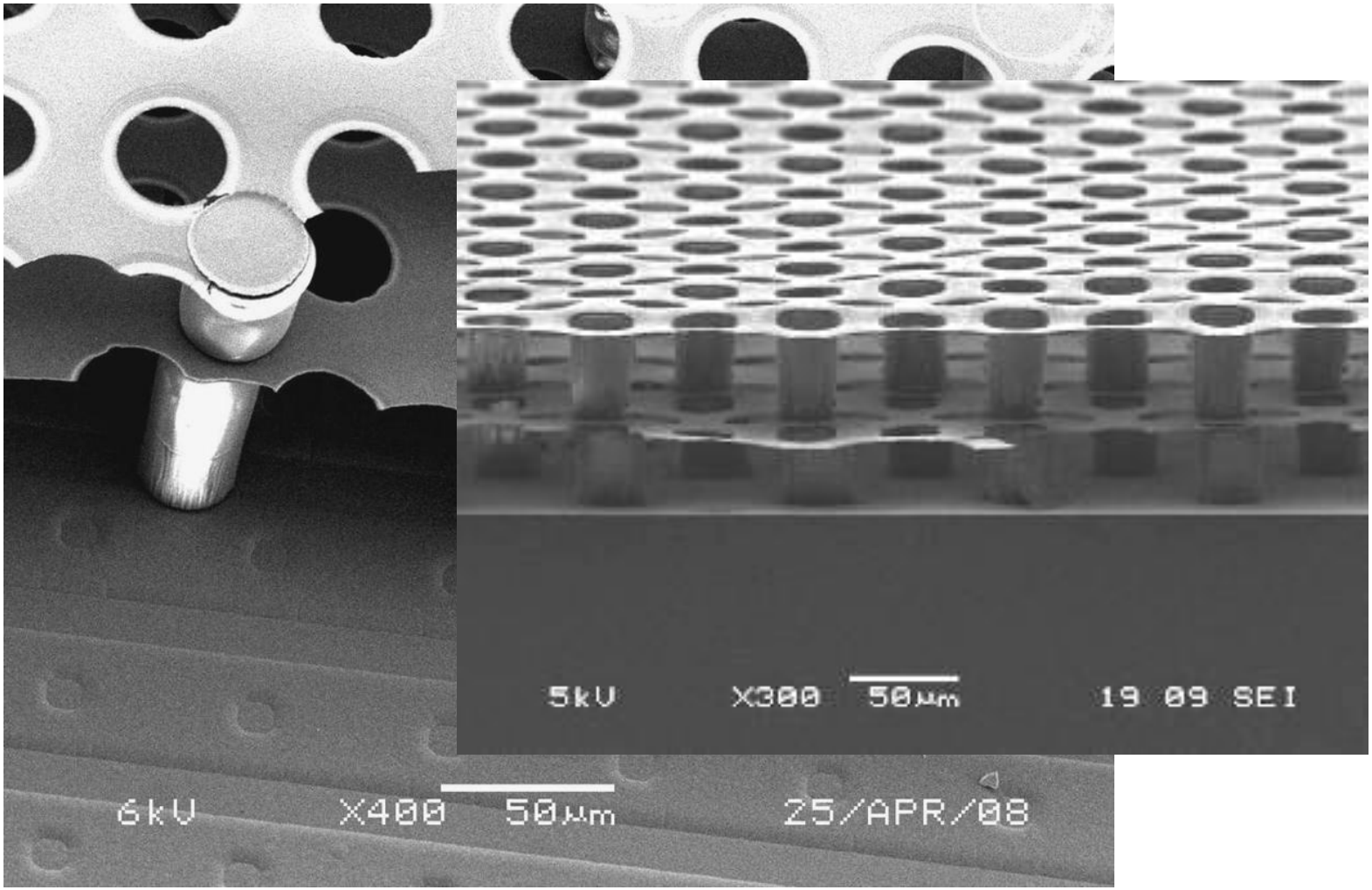
Gain curve based on TOT count



- Fe55: 99 V/dec; TOT: 117 V/dec

TwinGrid

multistage structure to reduce IBF, increase gain



Detector geometries

- Hole pitch variation:
  20 - 32 - 45 - 58 µm
- 20 & 32 µm pitch: pillars inside holes
- 45 & 58 µm pitch: pillars between holes
- Hole pitch/diameter variation:
  ratio 1.5 - 2.0 - 3.0
  (hole sizes from 7 - 38 µm)
- Amplification gap set by SU-8 thickness, variable with spin speed