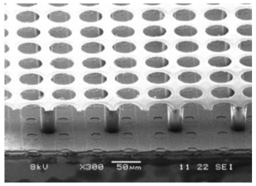

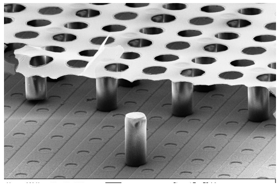

Detecting low energetic X-rays with GridPix Detectors

Jochen Kaminski

University of Bonn

Academia-Industry Matching Event on Photon Detection with MPGDs
CERN
10./11. June 2015

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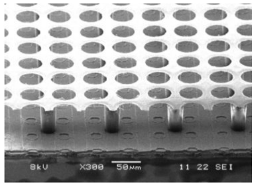
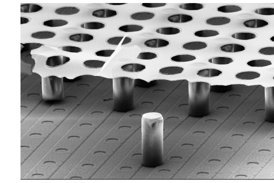
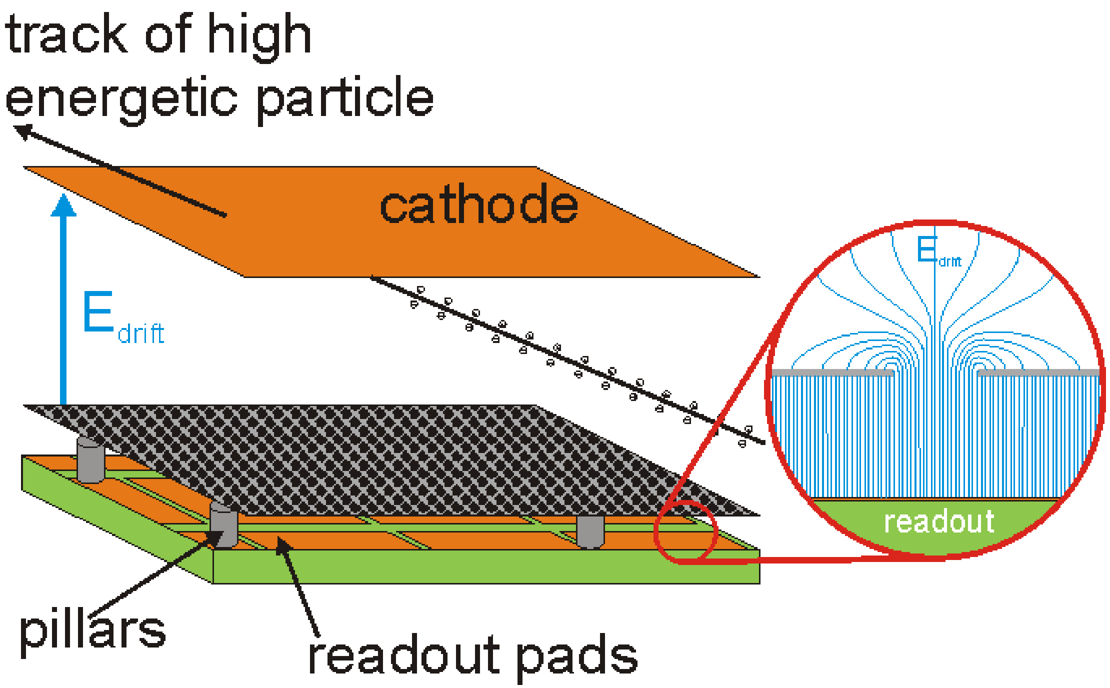


From Micromegas to GridPix



MM invented by Y. Giomataris, et al. (NIMA 376, p. 29-35, 1995)



Two stage parallel plate detector:
- Ionization in drift volume
- Gas amplification in thin gap with high electric field

Standard charge collection:
- Pads of several mm²
- Long strips (l~10 cm, pitch ~200 µm)

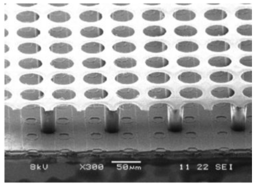
Could the spatial resolution of single electrons be improved?

$Ar:CO_2$ 70:30 → $D_t = 187\ \mu m/\sqrt{cm} \rightarrow \sigma = 21\ \mu m$

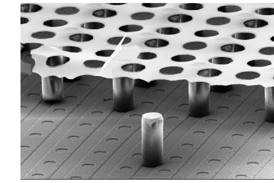
$Ar:CH_4$ 90:10 → $D_t = 208\ \mu m/\sqrt{cm} \rightarrow \sigma = 24\ \mu m$

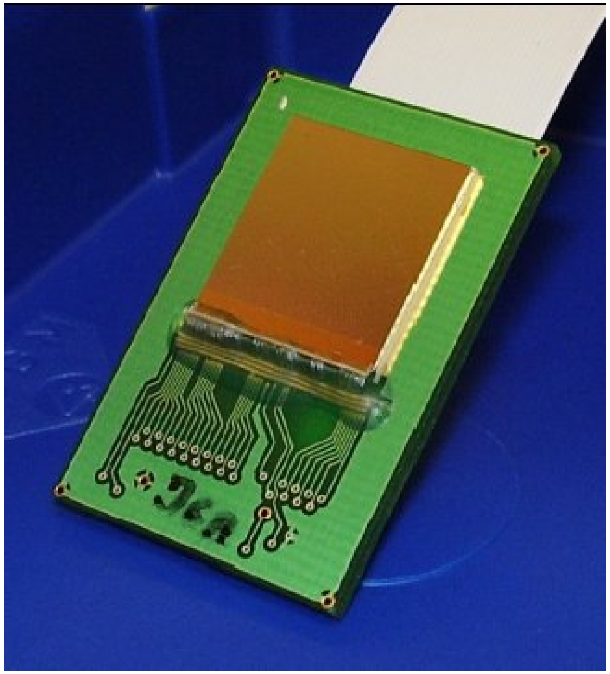
Ar:iButan 95:5 → $D_t = 211\ \mu m/\sqrt{cm} \rightarrow \sigma = 24\ \mu m$

Smaller pads/pixels could result in better resolution!



Timepix Chip

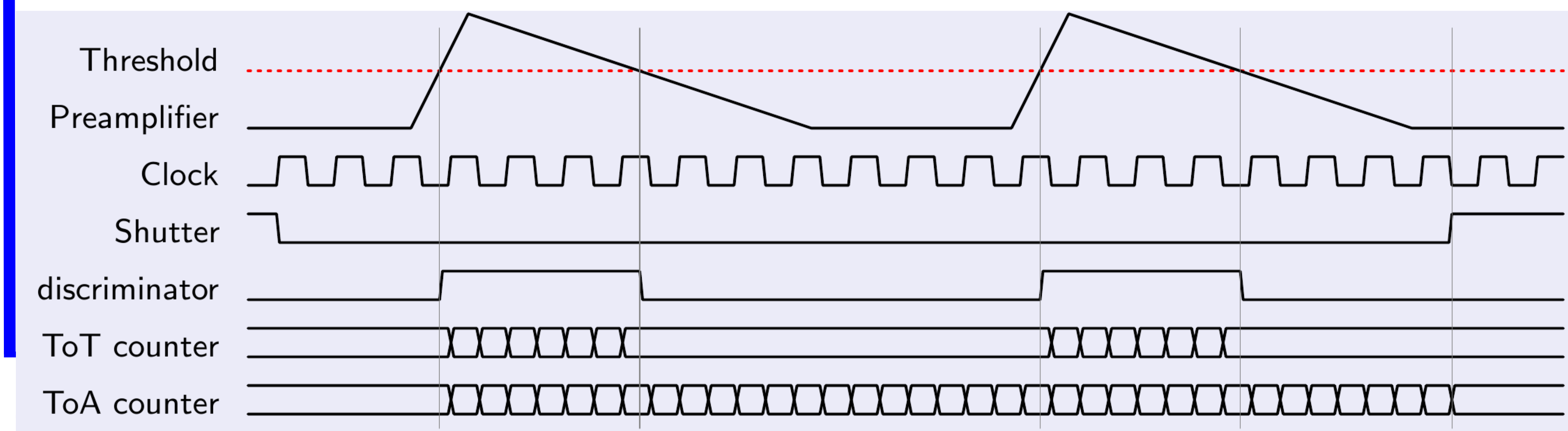




Available for tests since Nov. 2006

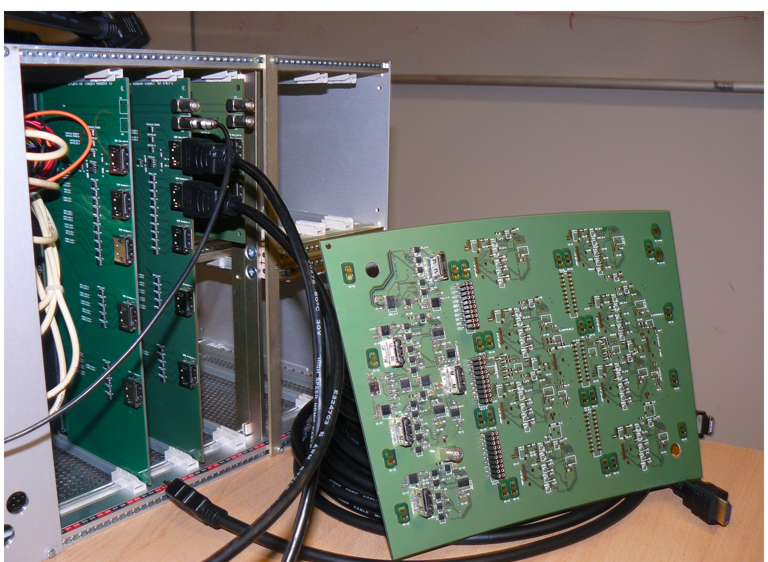
Number of pixels: 256 × 256 pixels
Pixel pitch: 55 × 55 µm²
Chip dimensions: 1.4 × 1.4 cm²
ENC: ~ 90 e⁻

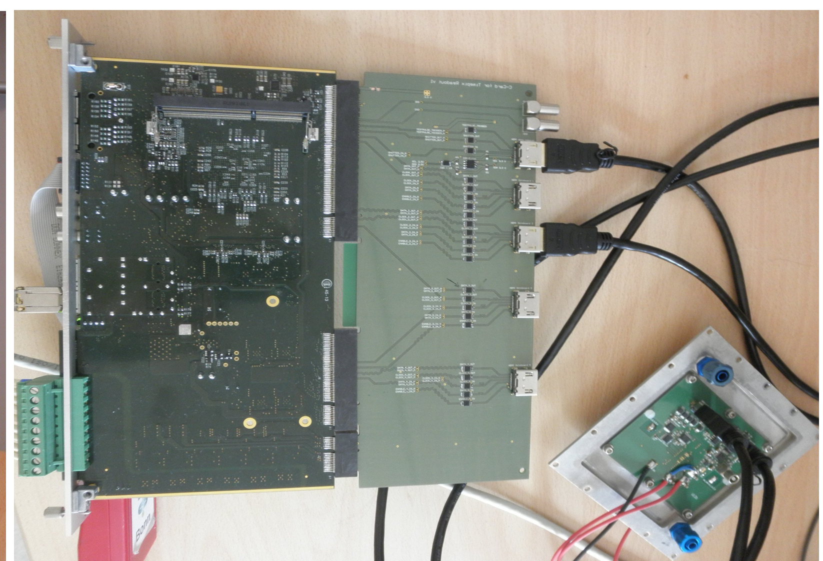
Limitations: no multi-hit capability, charge and time measurement not possible for one pixel.
Each pixel can be set to one of these modes: TOT = time over threshold (charge)
Time between hit and shutter end



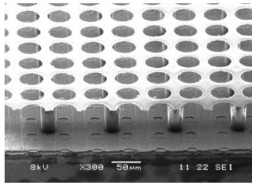
Timepix readout

There are several readout systems optimized for different applications available for purchase. We have built one based on the Scalable Readout System of RD51, because it is easy to scale ☺
and cheap, if you have the main components already.
Idea of SRS: produce a flexible readout electronics, which can handle different chips (new FPGA code, chip carrier), which many groups can use.
New C-Card, intermediate board, and chip carriers were designed for Timepix.
Now up to 32 Timepix chips can be used per FEC/C-card.

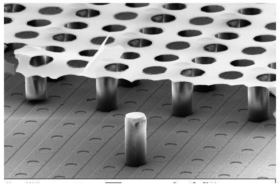




A small-size system using the same FPGA code and most of the hardware can be based on a virtex evaluation board. This is used in CAST.



Protection Layer



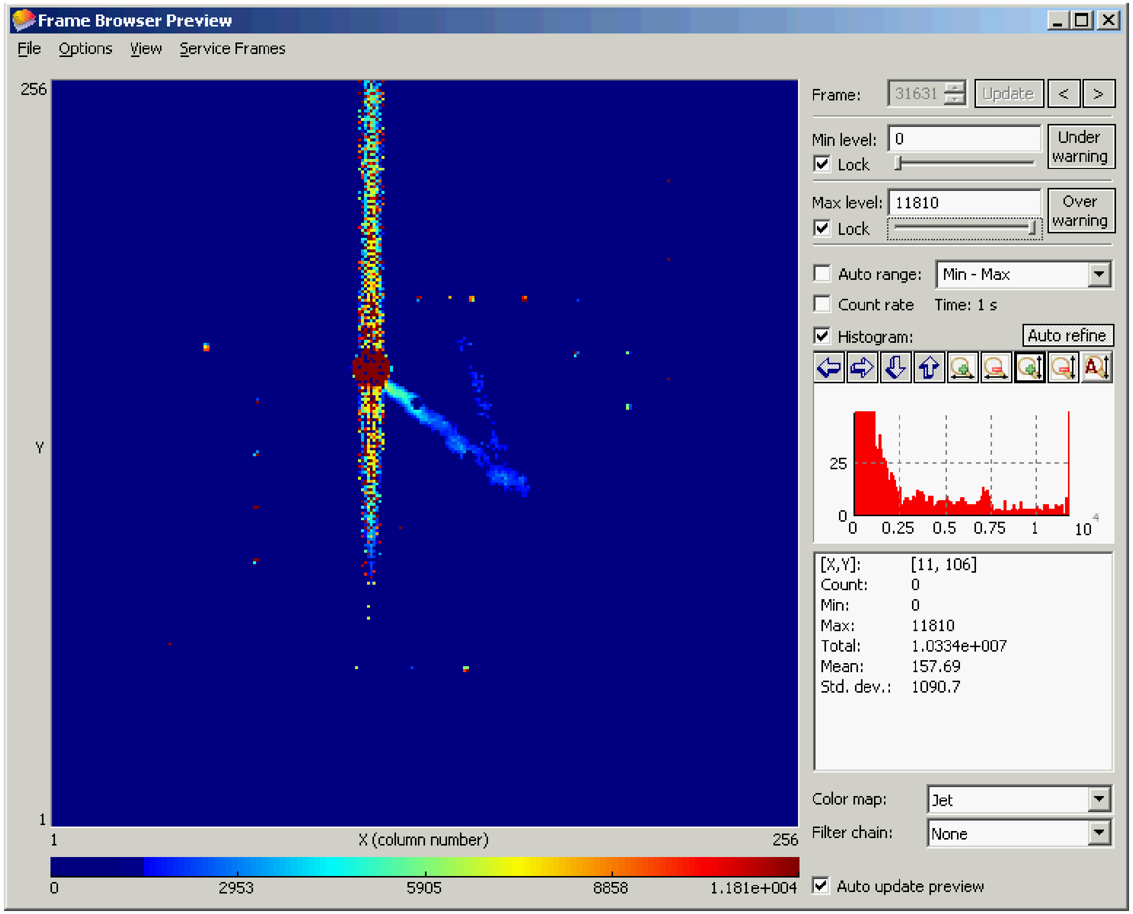
Discharge triggered for example by highly ionizing particles could easily destroy the chip. The charge collected by one pixel was too high.

A protection layer is placed on the chip to disperse the charge on many pixels and thus lower the input current per pixels. Besides, the charge is removed slowly and thus quenches the discharge.

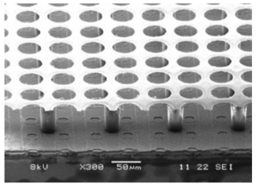
<u>high resistive material</u>

15 µm aSi:H (~10^{11} Ω·cm)

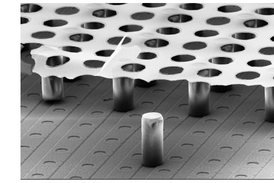
8 µm Si_XN_Y (~10^{14} Ω·cm)



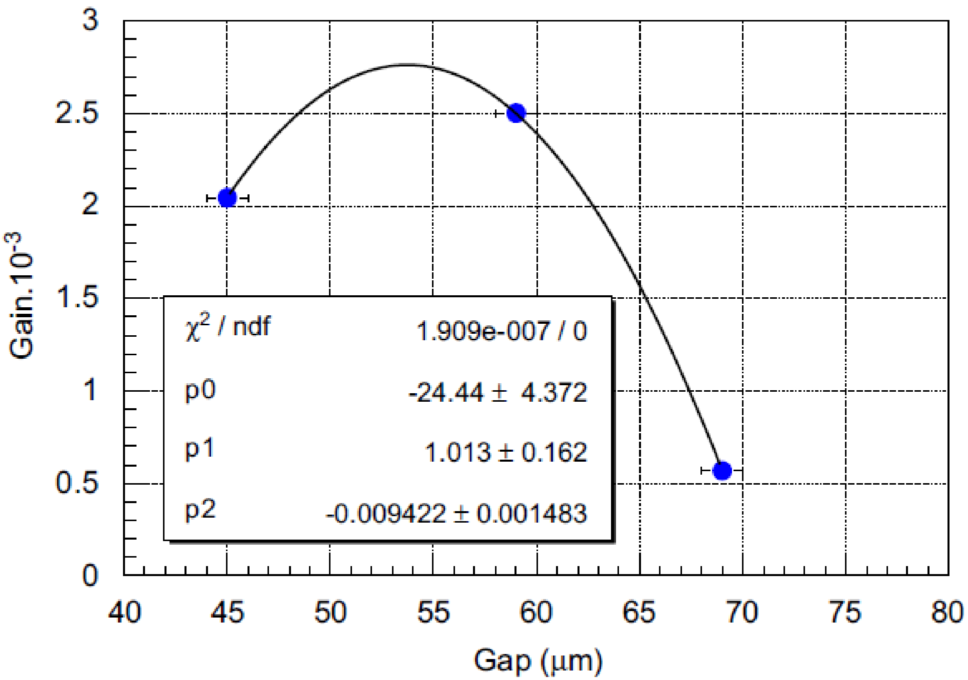
Chips survives several thousand discharges triggered by αs.



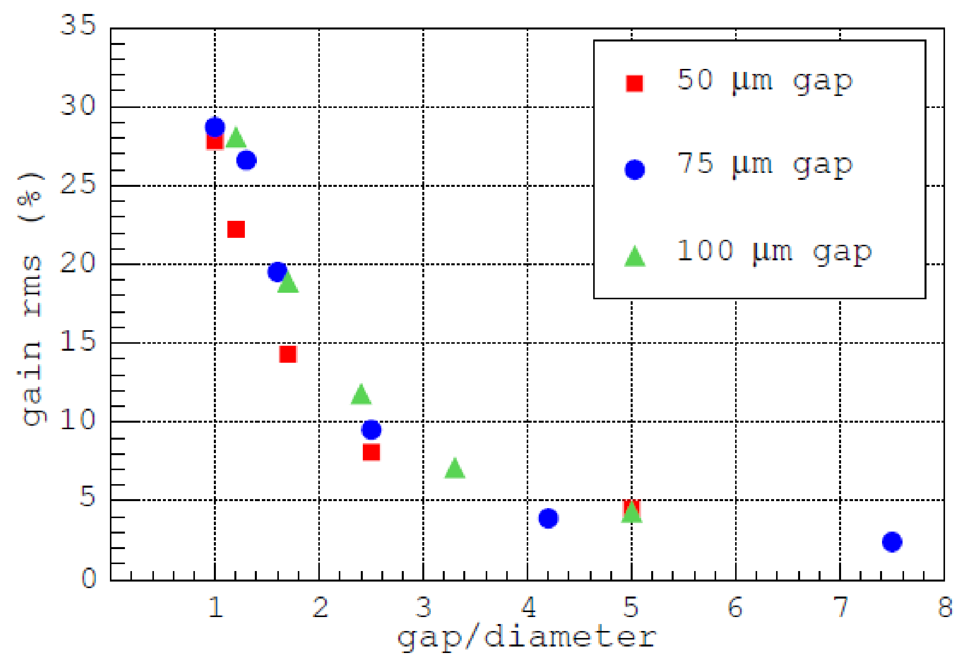
Optimization of InGrids



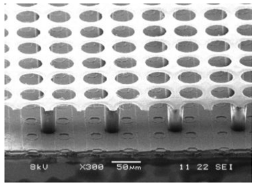
Detailed studies have been performed to optimize the layout of the structure.
(NIMA 591, pp. 147, 2008, PhD. Thesis of M. Chefdeville, NIKHEF)



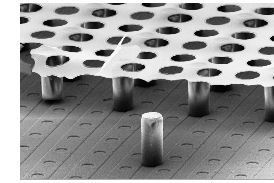
The influence of the gap size and hole diameters on gain, energy resolution, ion feedback and collection efficiency were measured.



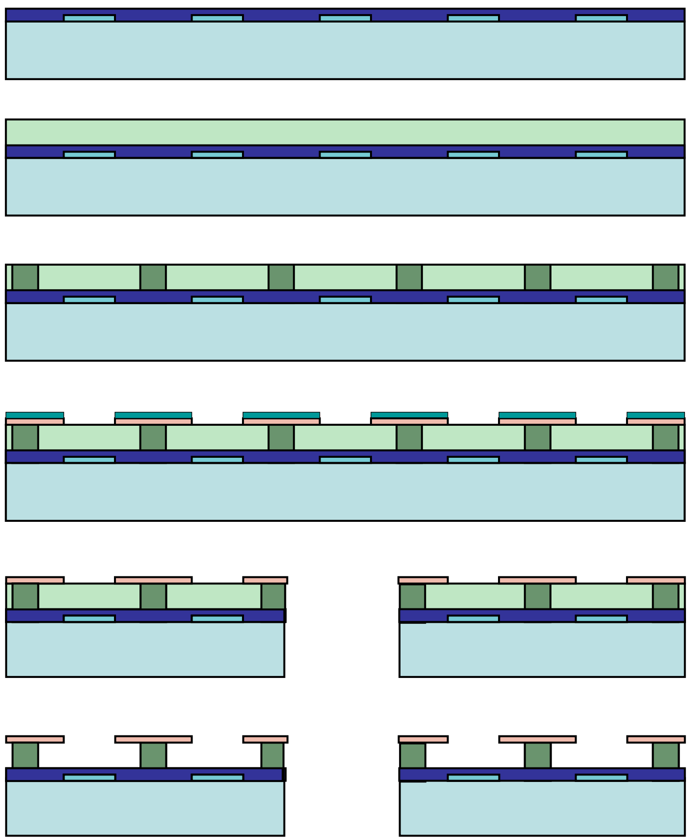
Also the layout of the supporting structures (pillars and dykes) was optimized to give the highest mechanical strength.



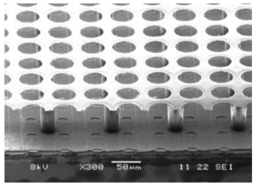
Wafer-based Production



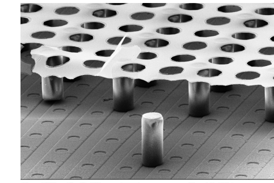
Production at Twente was based on 1 - 9 chips process.
This could not satisfy the increasing demands of R&D projects.
A new production was set up at the Fraunhofer Institut IZM at Berlin.
This process is wafer-based → 1 wafer (107 chips) is processed at a time.



1. Formation of Si_xN_y protection layer
2. Deposition of SU-8
3. Pillar structure formation
4. Formation of Al grid
5. Dicing of Wafer
6. Development of SU-8

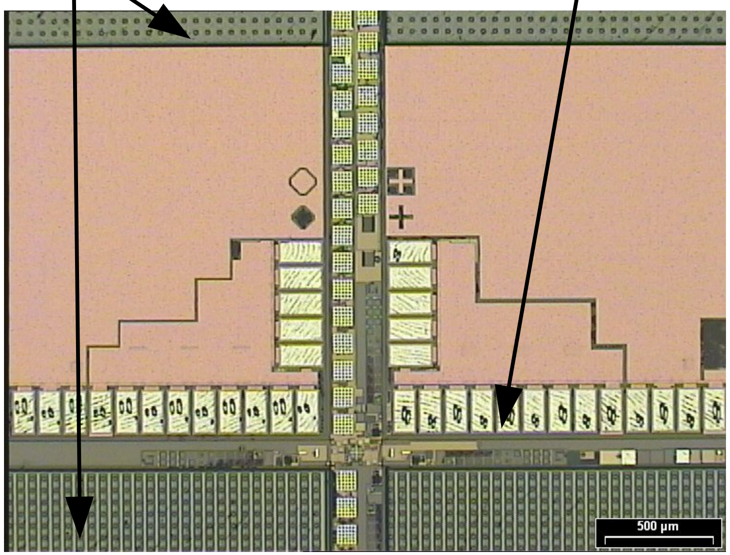


Wafer-based Production



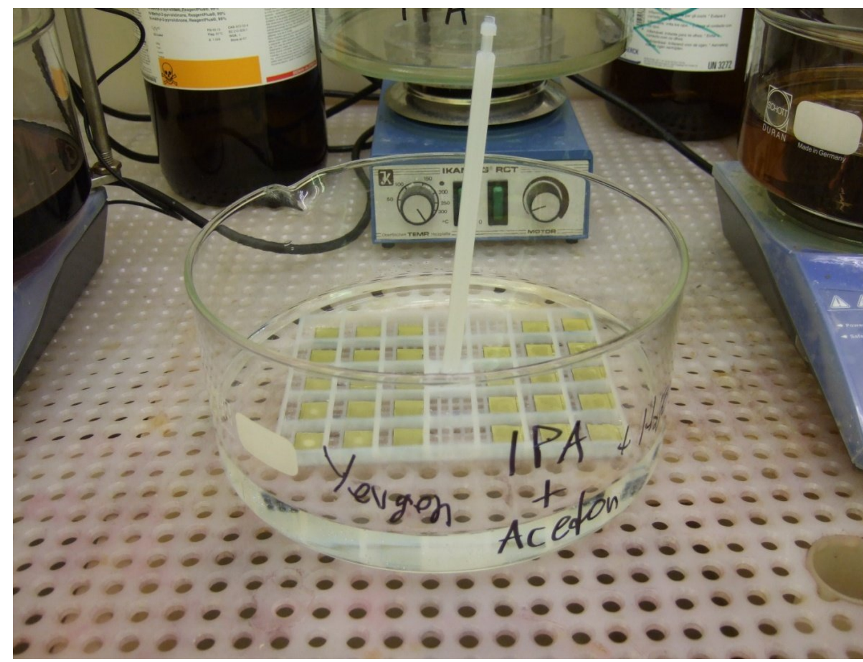
Main challenges:
- Formation of layers, in particular protection layer
- Deposition of Al
- Final development of SU-8 → still chip-based

SiRN should not cover bond pads

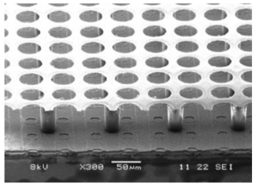


First tests: mechanical mask
→ failed due to thermal stress
Better: poyimide mask chem. removed

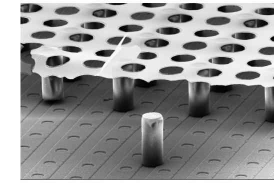
After development of pillars, the grid is too fragile for dicing

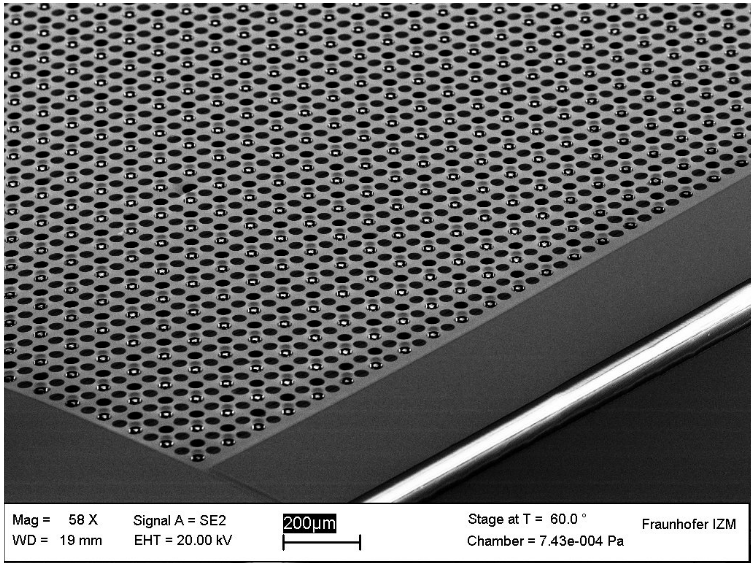


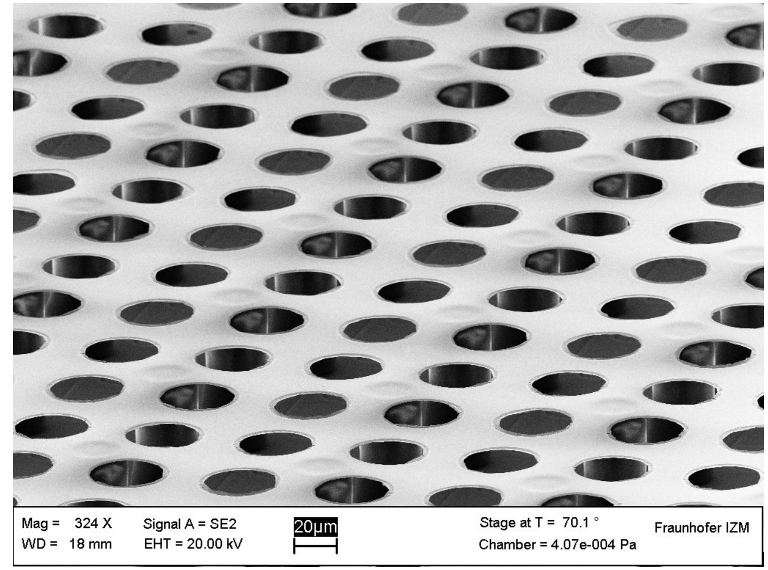
Time consuming

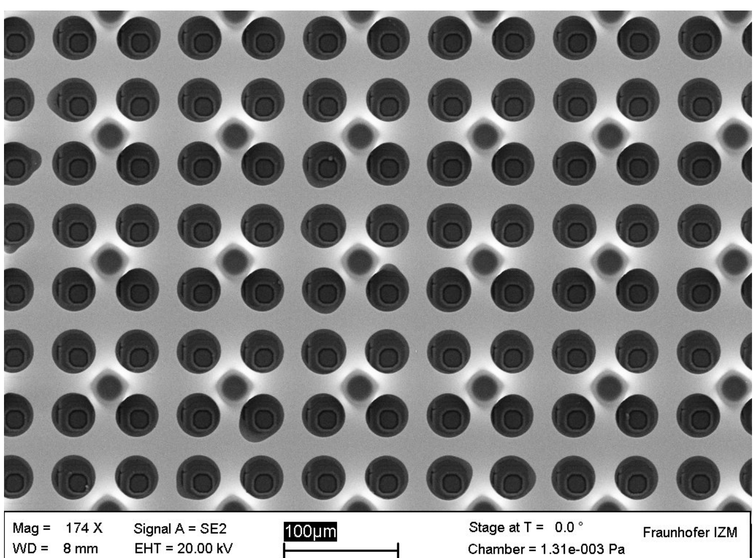


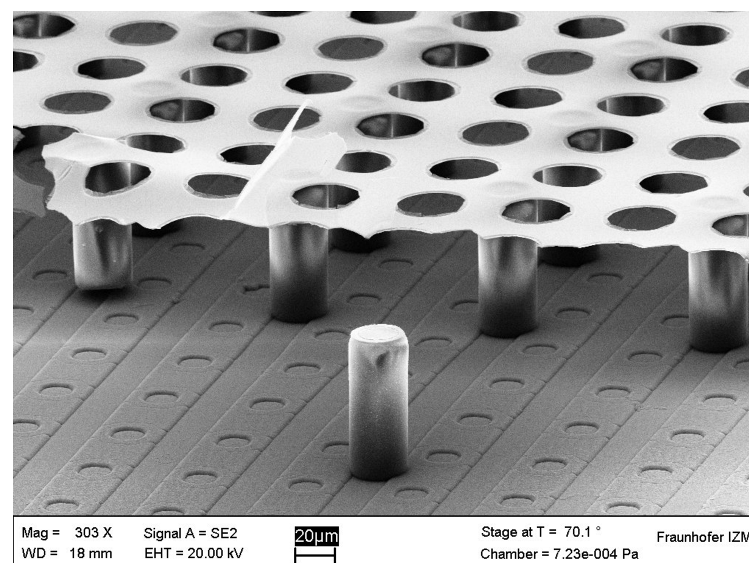
SEM Pictures

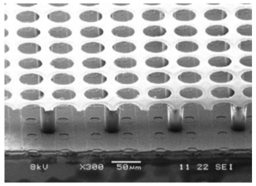


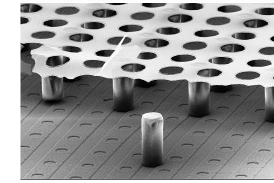






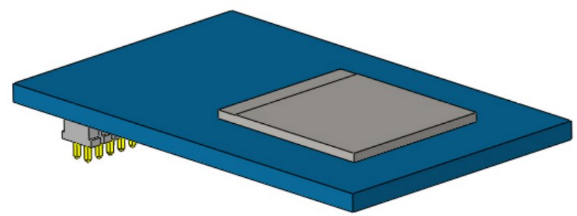


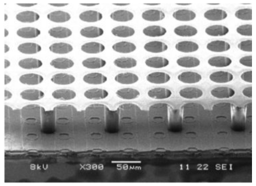


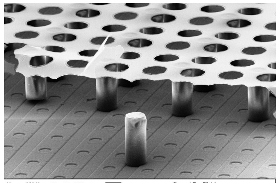


Building an X-ray detector

Timepix with protection layer and InGrid
on a chip carrier



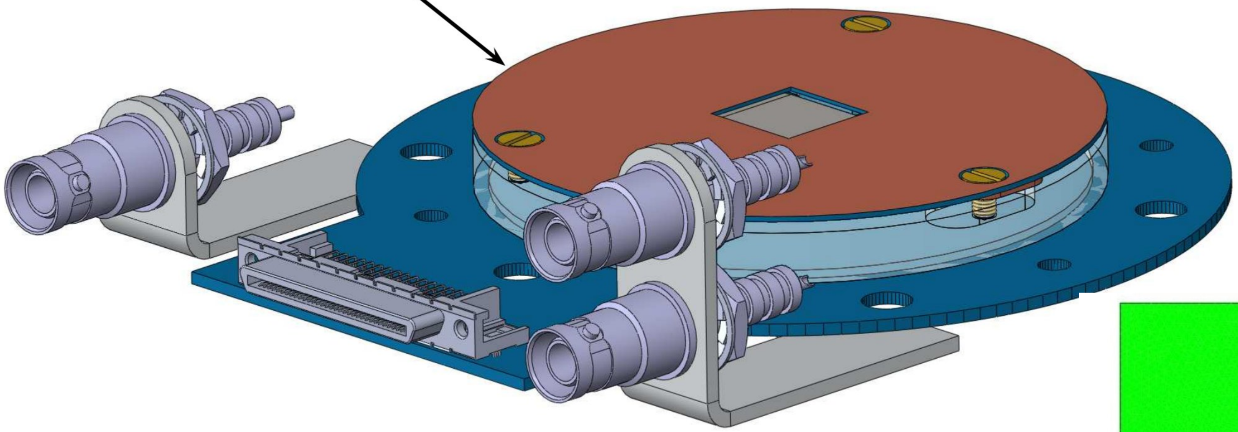




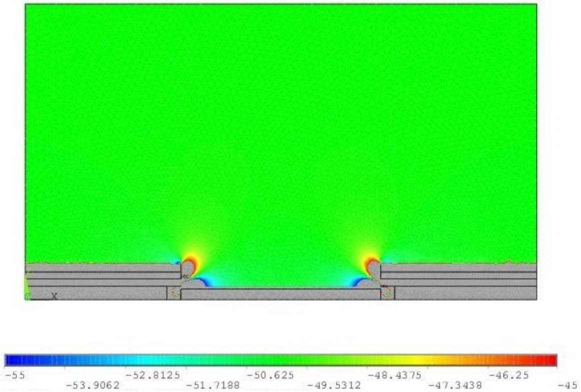
Building an X-ray detector

Readout module

Field shaping electrode (anode)

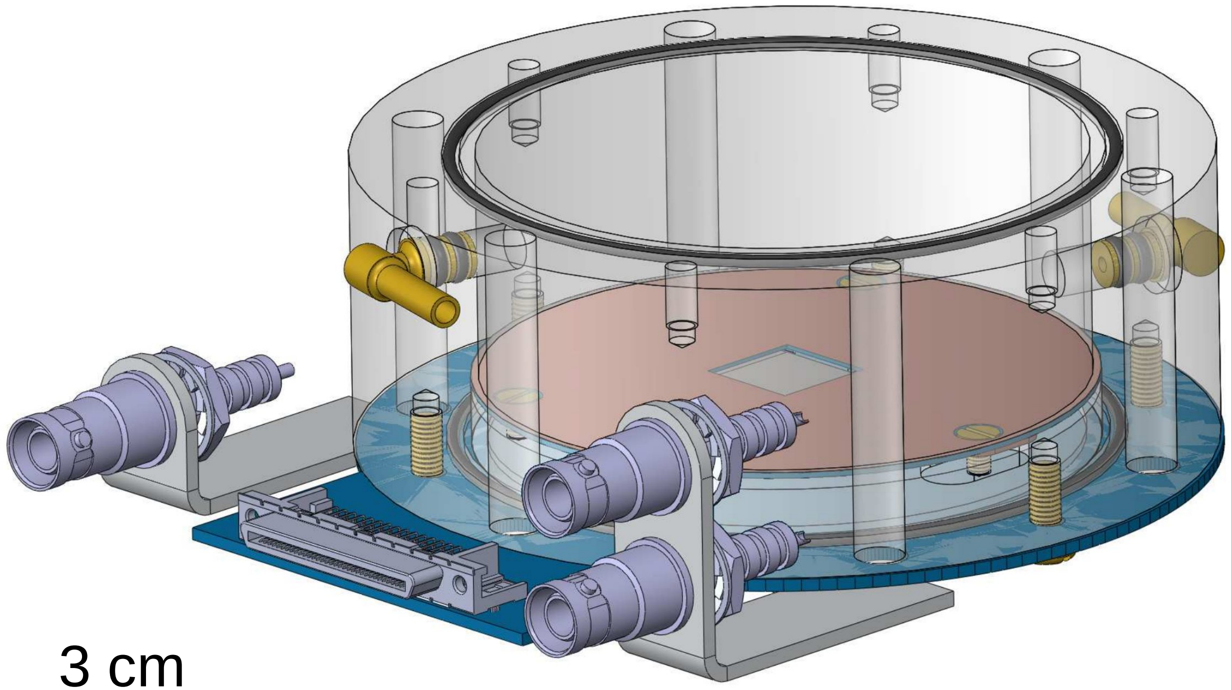


Calculation of field distortions
from nominal 500 V/cm E-field.



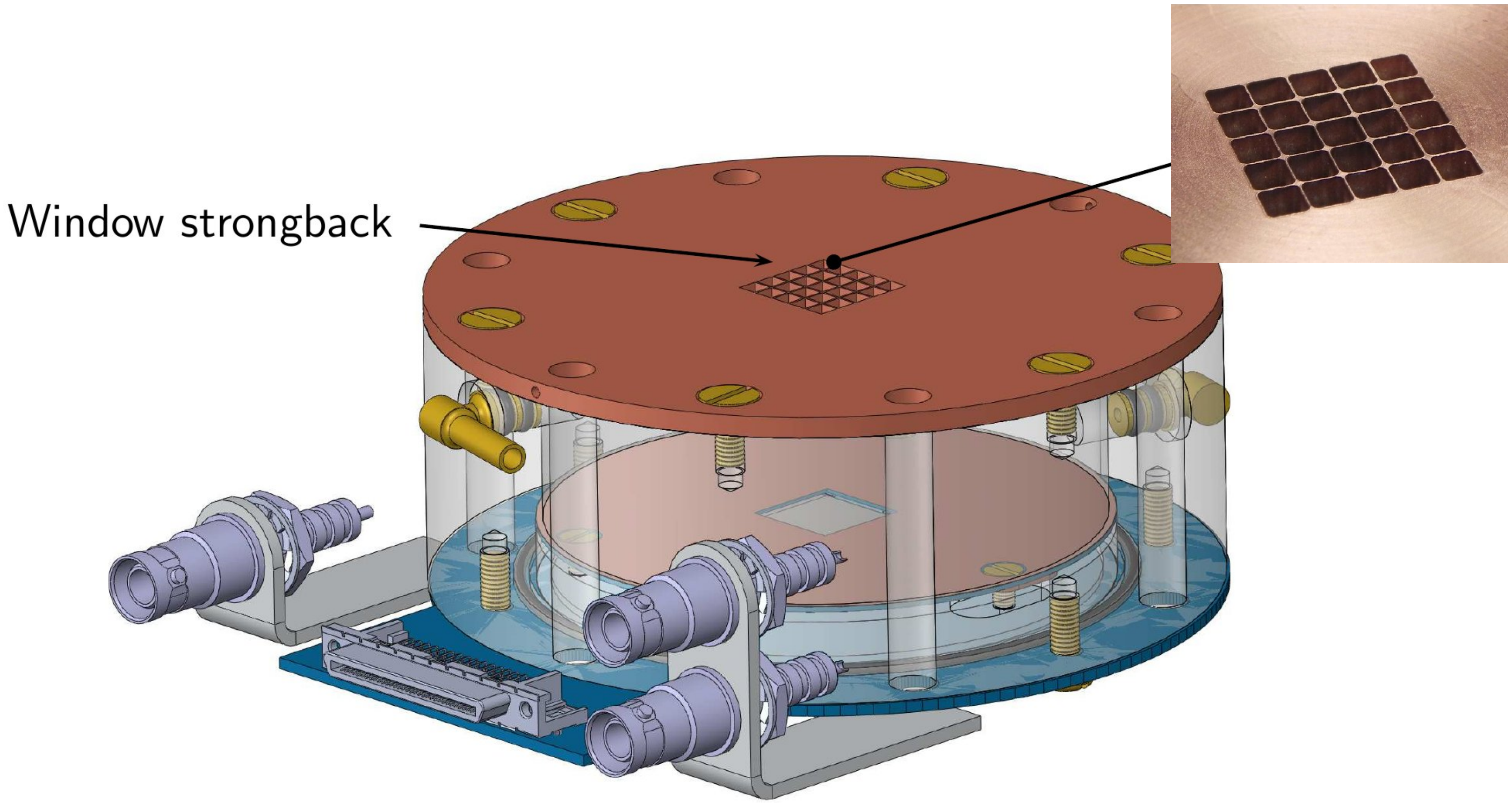
Building an X-ray detector

Drift volume

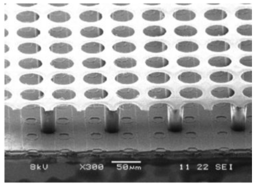


Length: 3 cm
Inner diameter: 8 cm
Electric field: 500 V/cm
Gas: Ar: iC_4H_{10} 97.7:2.3

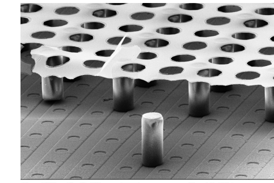
Building an X-ray detector

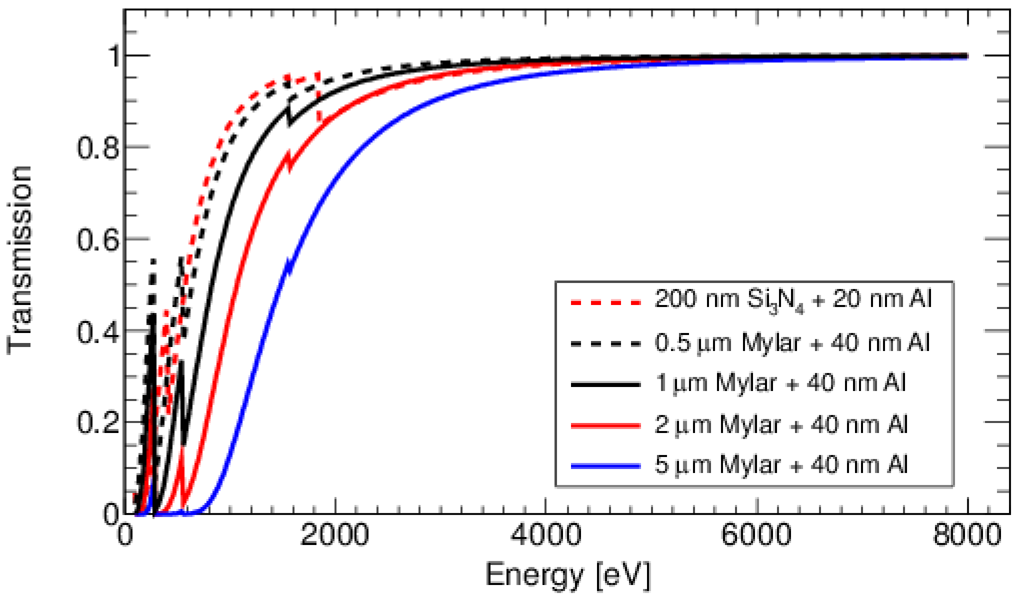


Pressure on outer side of cathode: 10^{-5} mbar
Pressure inside detector: 1050 mbar
Window: 2 µm aluminized Mylar (with strongback)



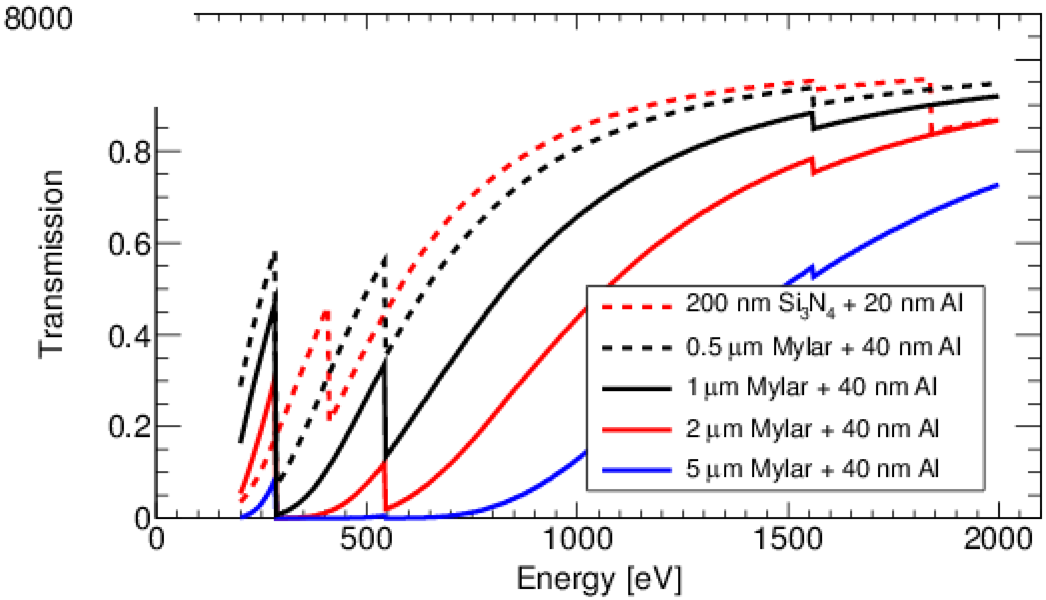
Entrance Window





Because of the strongback, the efficiency is reduced by another factor of ~0.8.
Thinnest foil available is 2 µm aluminized Mylar. Other windows will be investigated soon.

If no vacuum requirements are given, thinner windows could be used.



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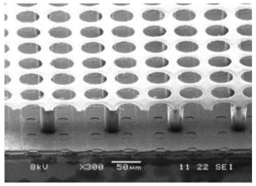
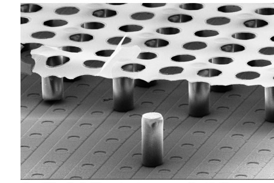




Working Principle

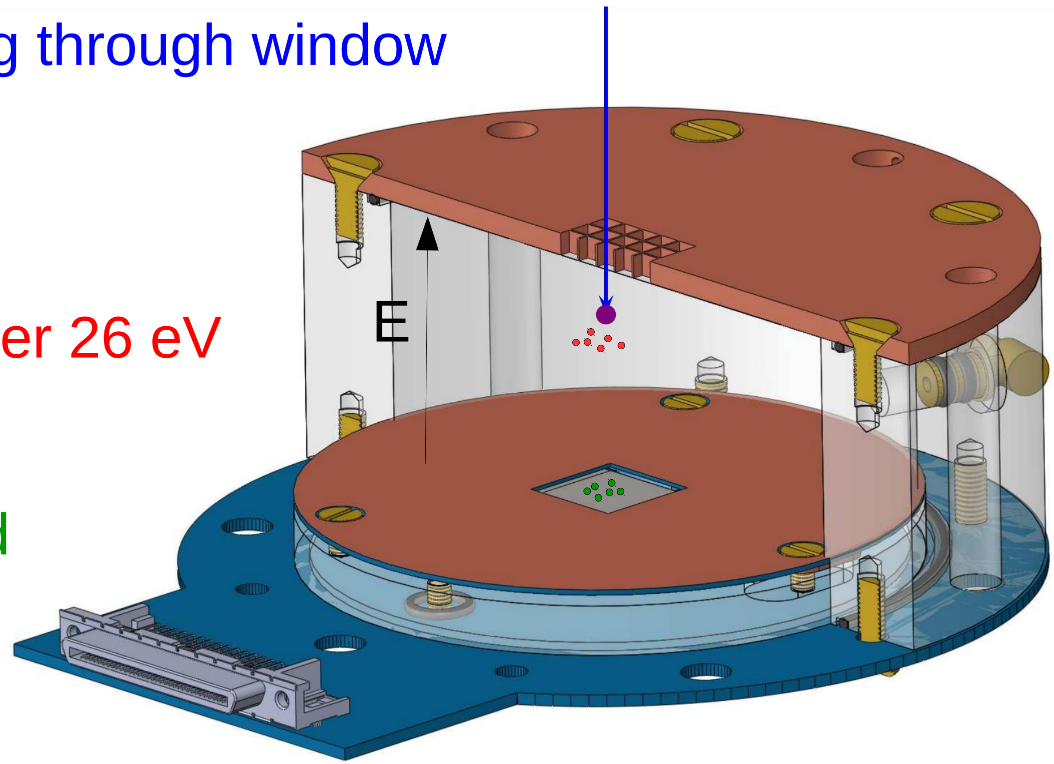
X-ray photon entering through window

Hitting a gas atom

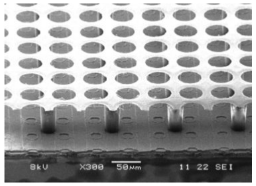
Primary electrons 1 per 26 eV

Drift in E field

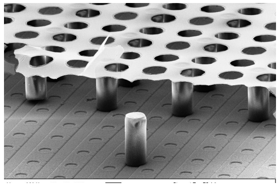
Gas amplification and electron detection

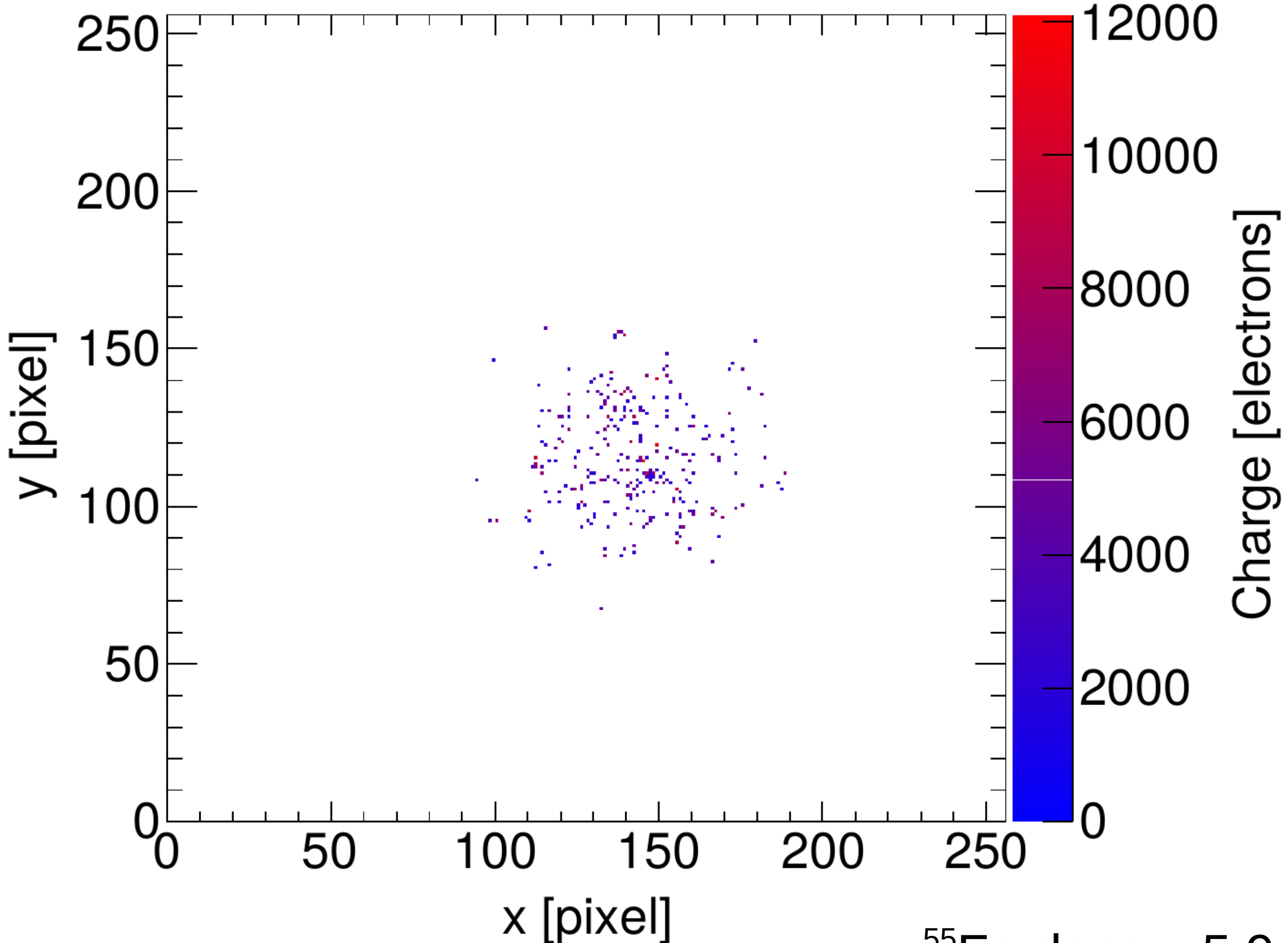


In principle photons of energy ~26 eV could be detected. But single pixels could be mistaken for noise → three pixels close by are probably enough.
But photons of 78 eV do not pass through the window.
They have to be produced internally.

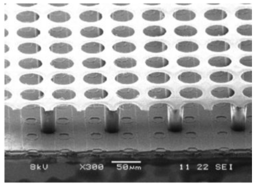


1 Event

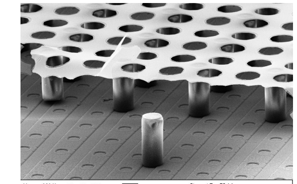




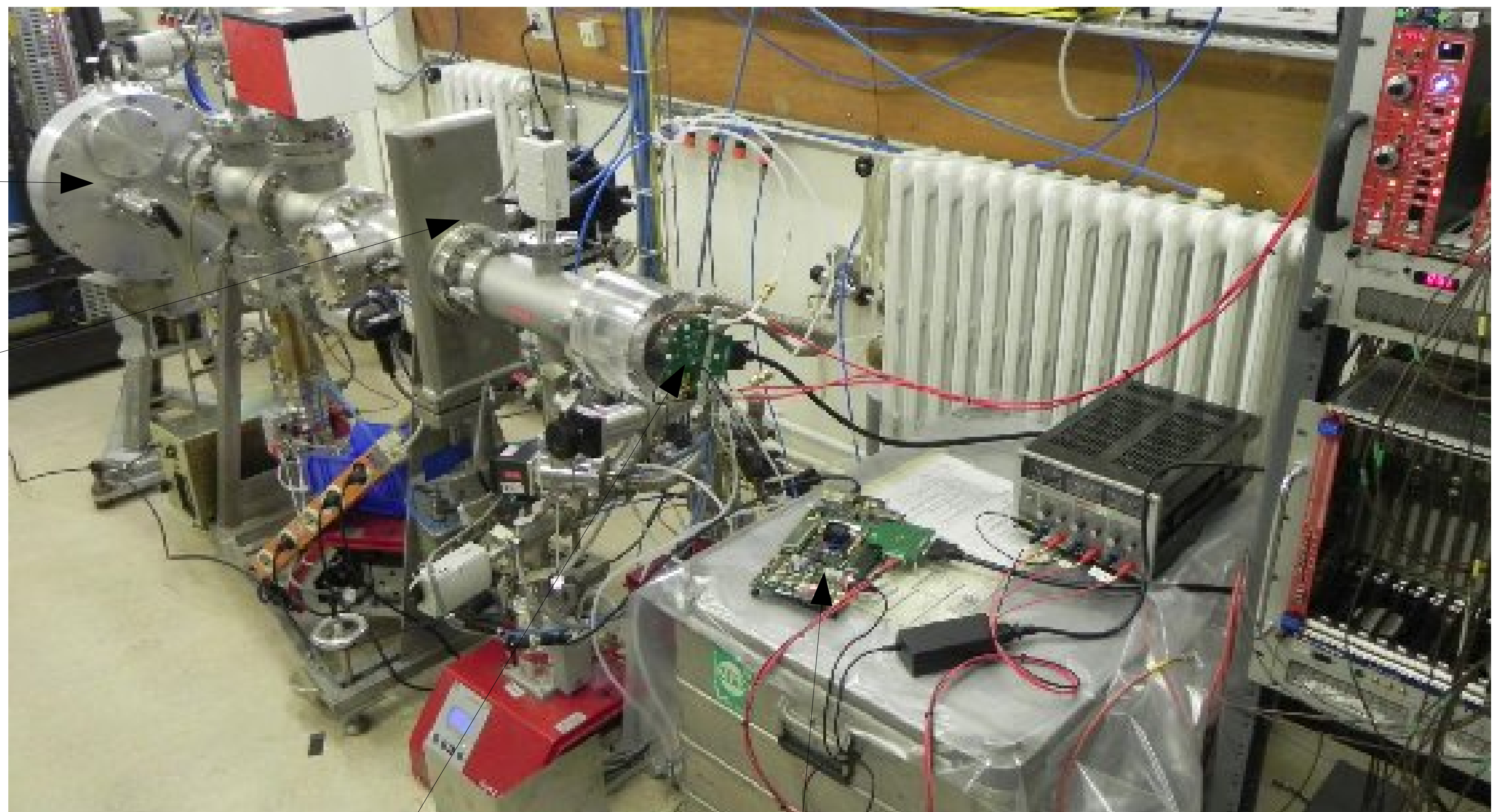
^{55}Fe decay: 5.9 keV photon
→ ~225 electrons

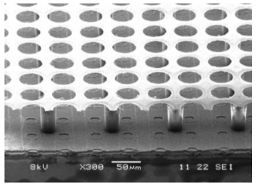


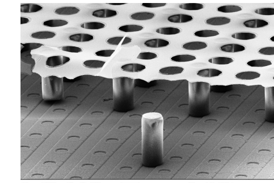
Tests with variable X-ray generator



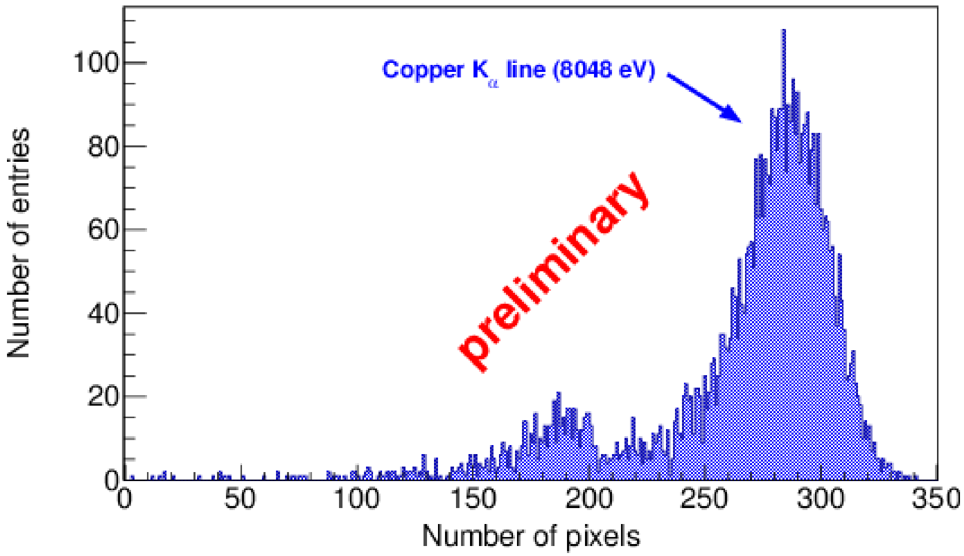
CAST Detector Lab has an X-ray tube with exchangeable targets and filter wheels. => monochromatic X-ray lines down to few hundred eV.
Vacuum system allowing for differential pumping

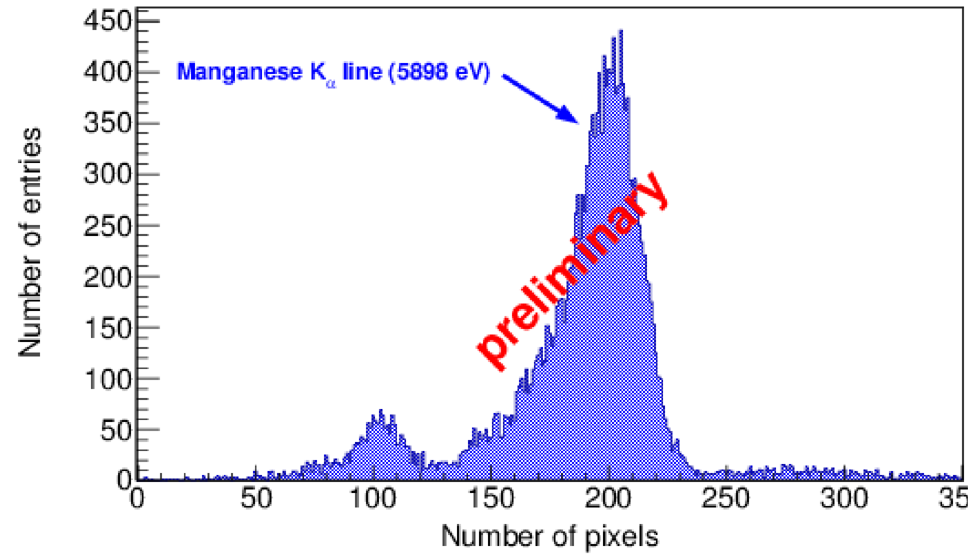


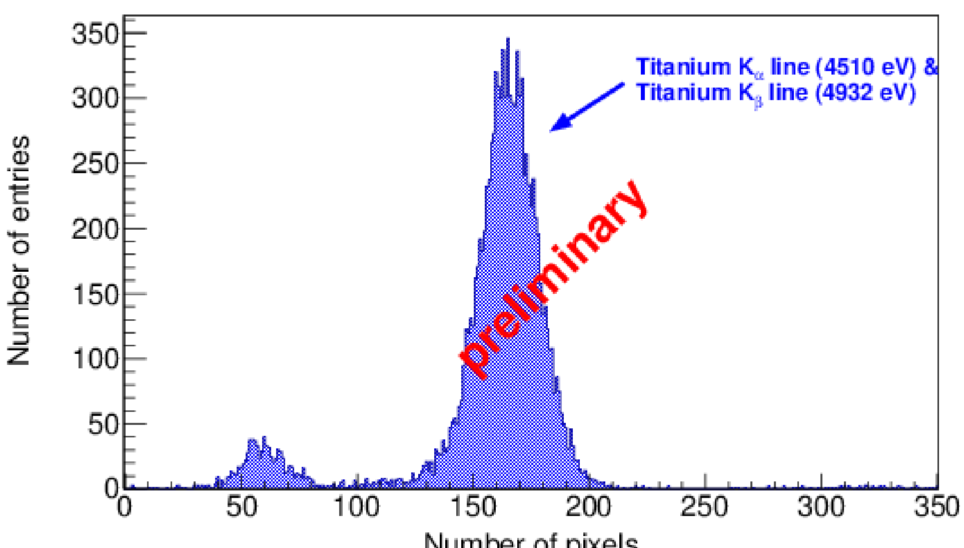


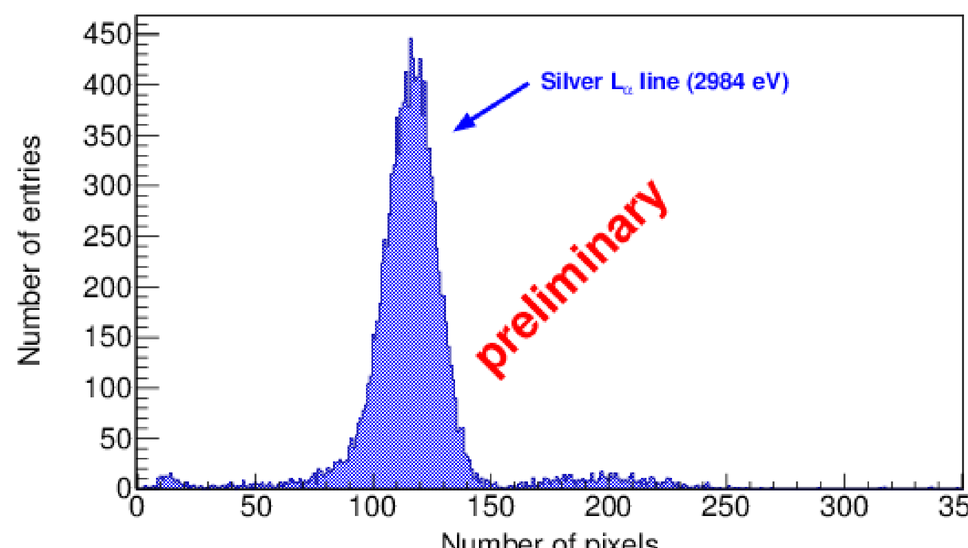


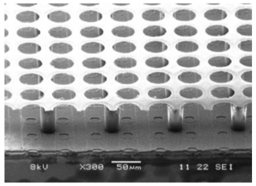
Some X-ray Lines



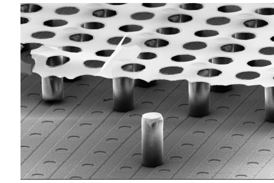


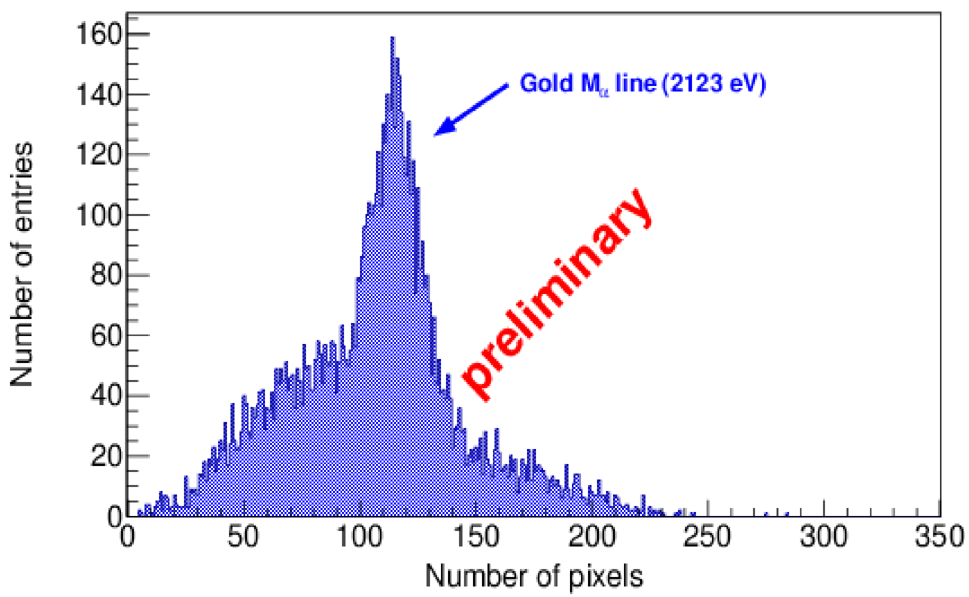


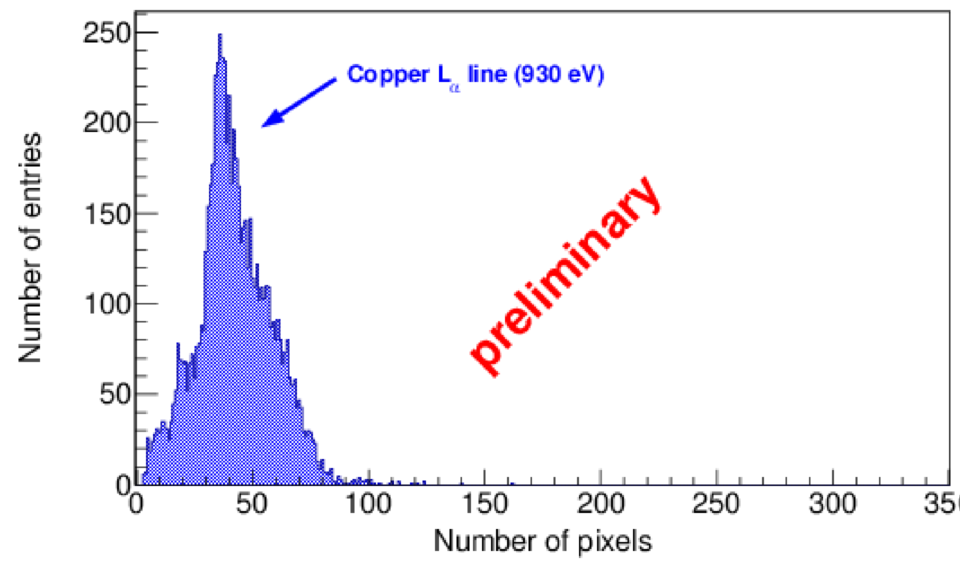


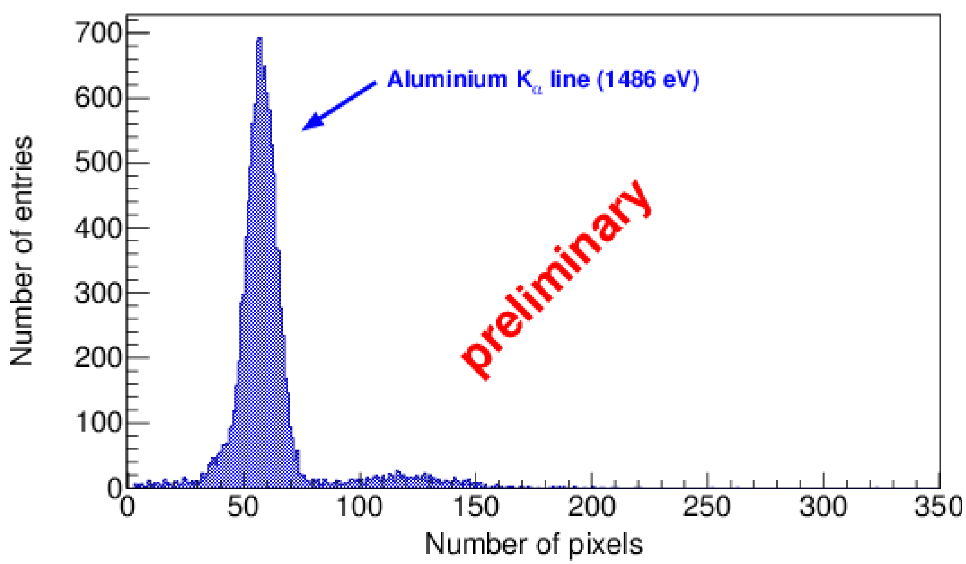


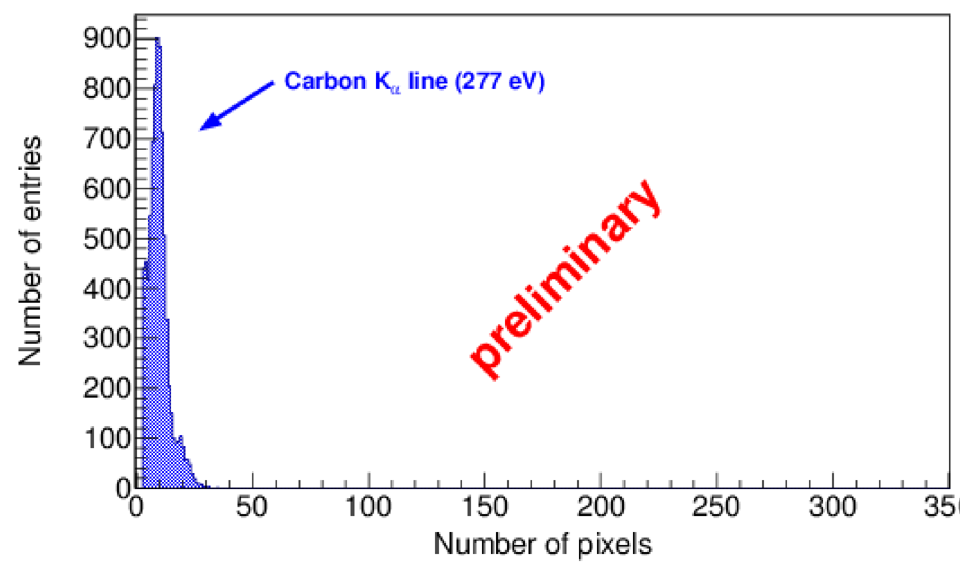
More X-ray Lines

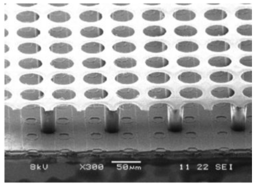




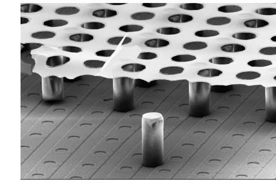




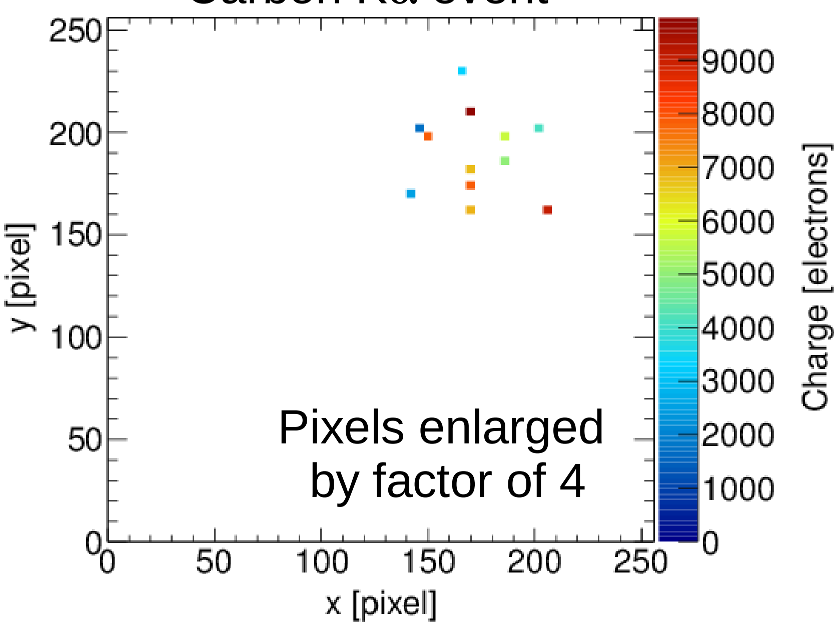


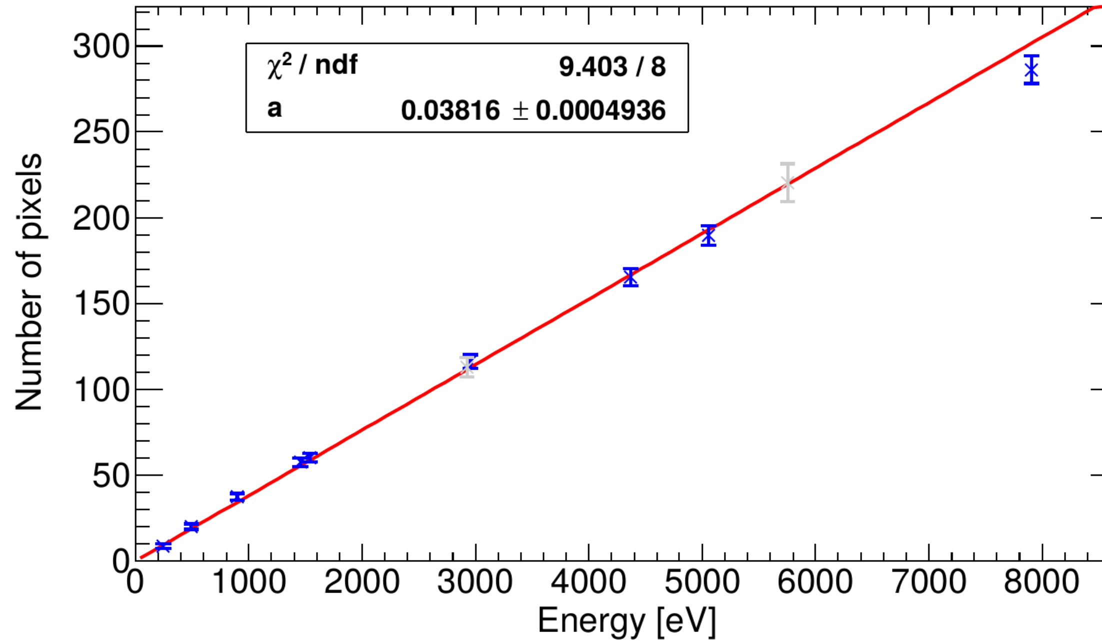


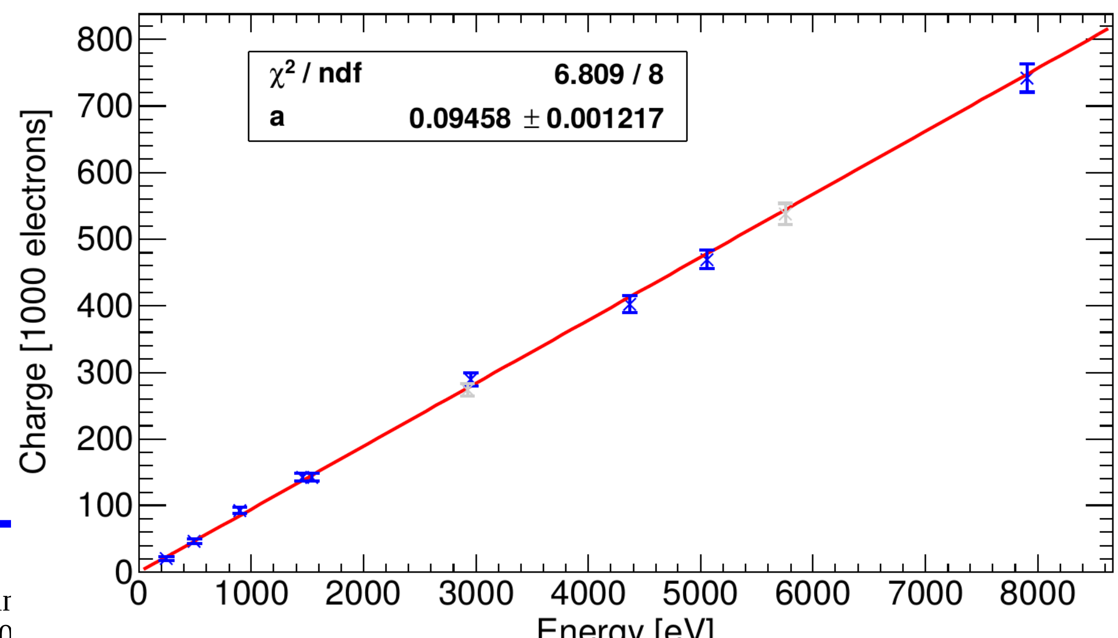
Energy calibration



Pixel counting starts failing, if diffusion is not large enough and more than 1 electron ends up on a pixel.
Energy measurement based on collected charge still works fine.







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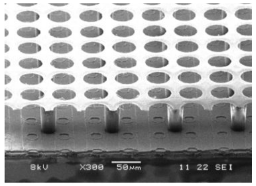
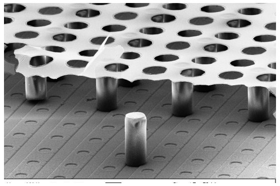
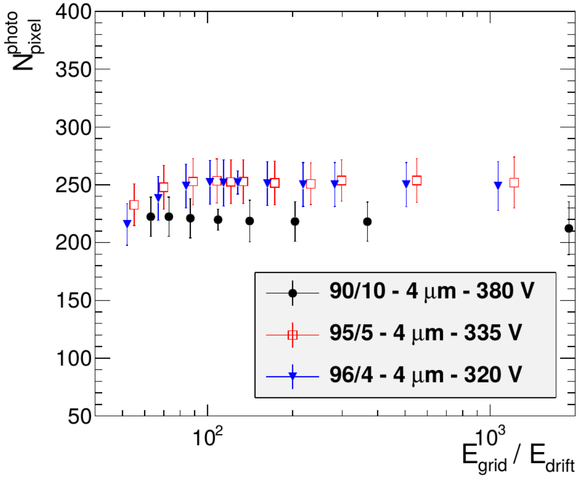
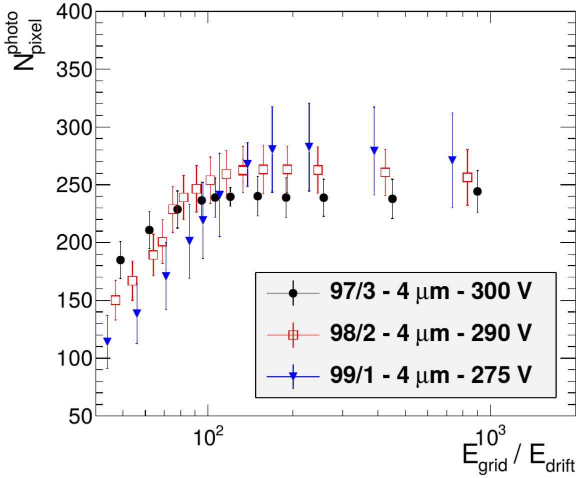


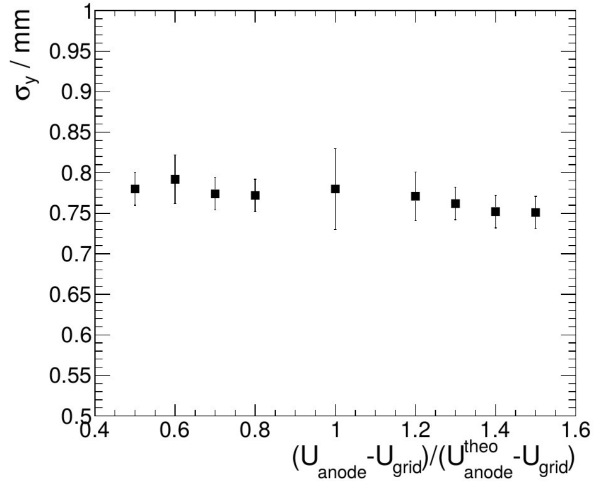
Energy resolution

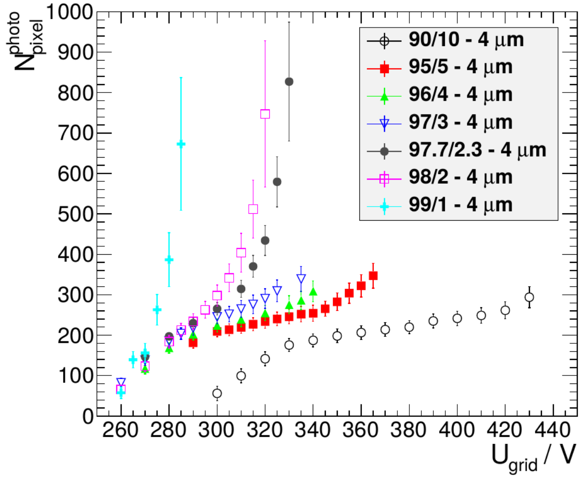


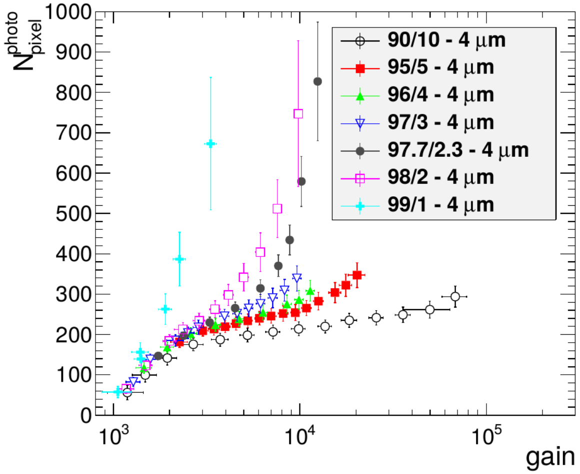
Different gas mixtures, electrical fields and gas gains were studied and good setting for the energy resolutions were found.

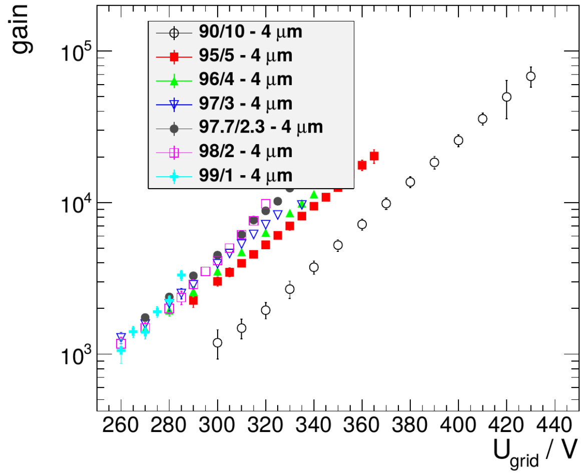


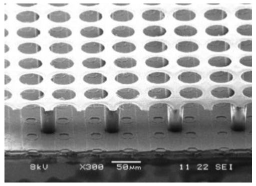




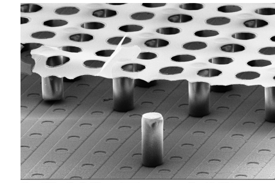




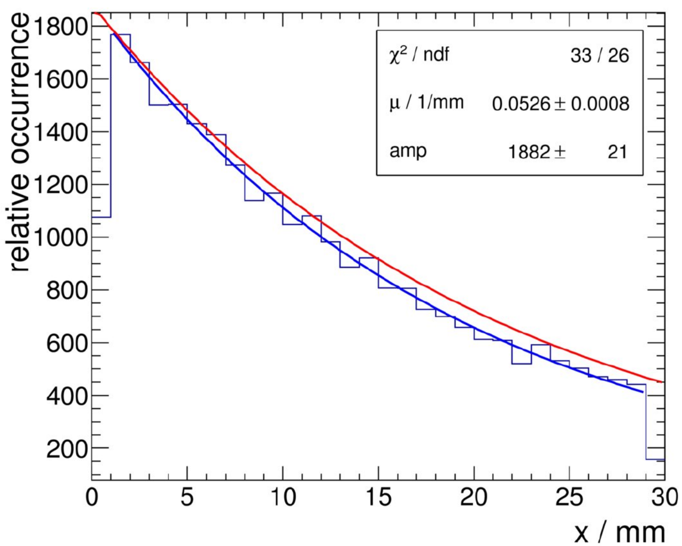


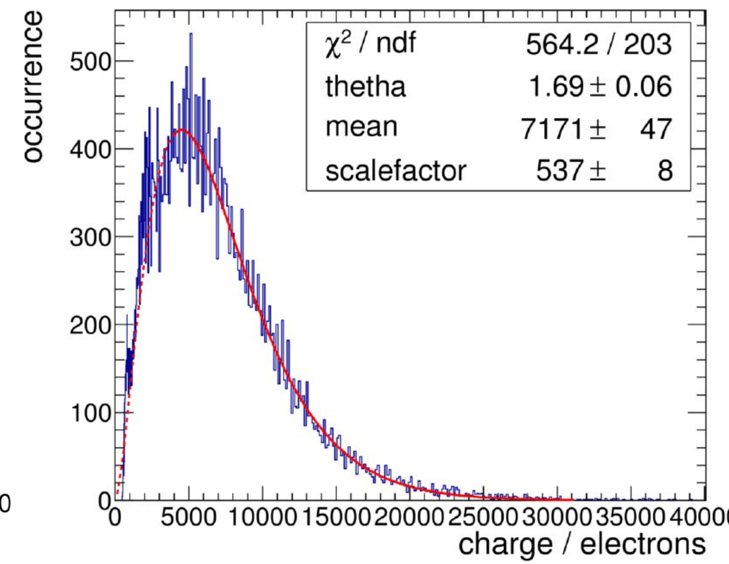


Energy resolution



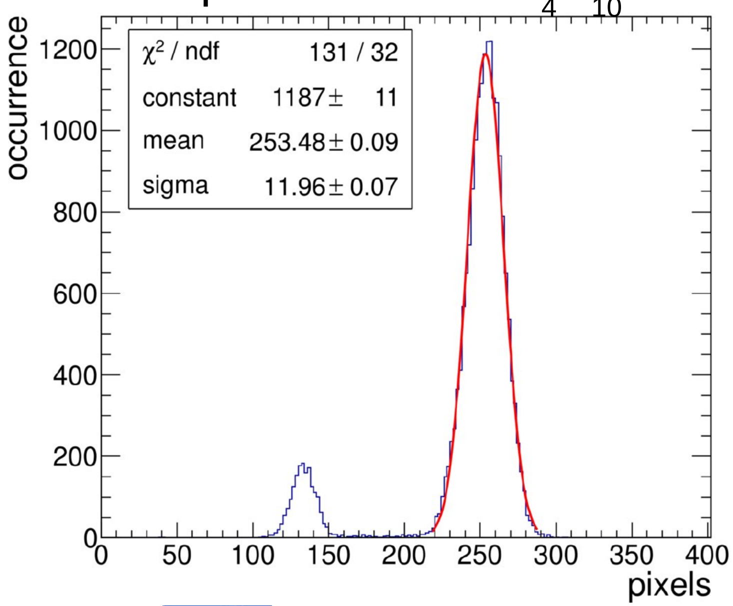
Measurement of absorption length by using cluster sizes as a measure of drift length.

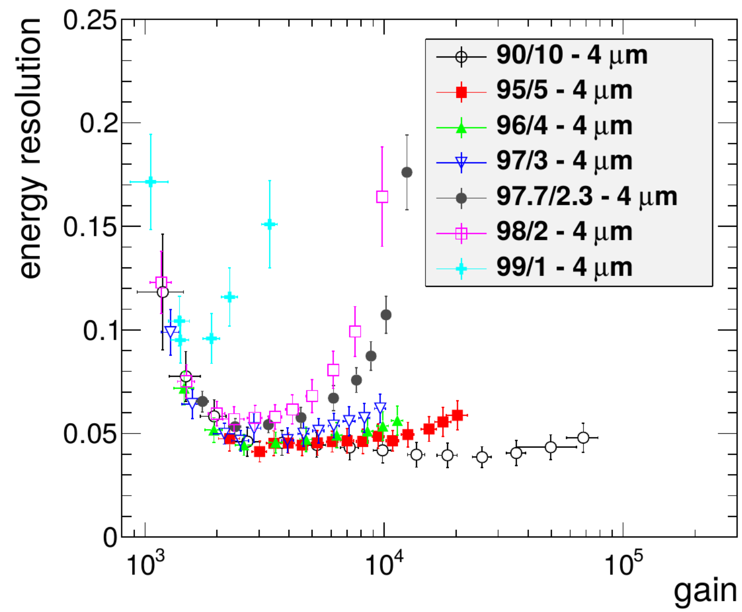




Charge collected by single pixels → Polya distribution of gas gain

^{55}Fe spectrum in Ar:iC_4H_{10} 95:5





Energy resolution of 5.9 keV photons in various Ar:iC_4H_{10} mixtures.

Energy resolution σ_E/E of down to 3.85 % were reached.

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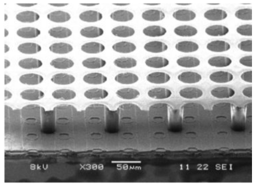
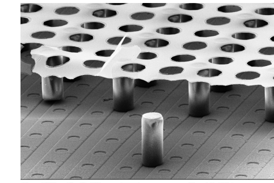
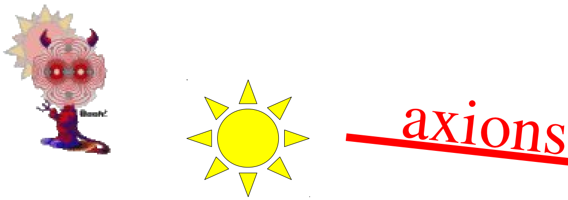
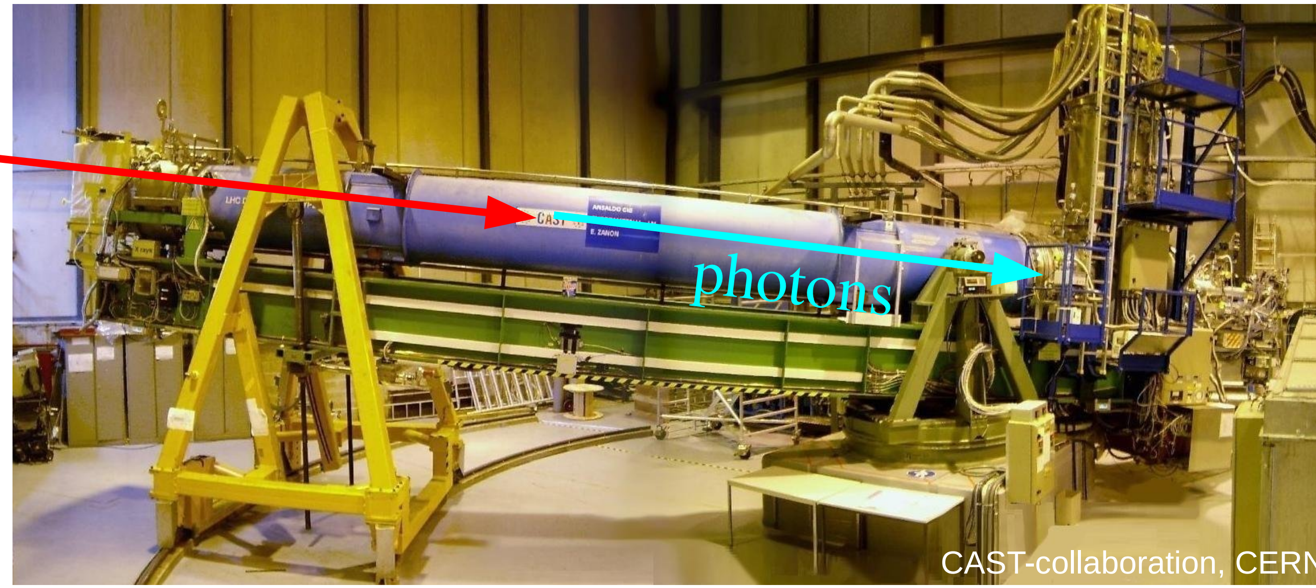
Application CAST

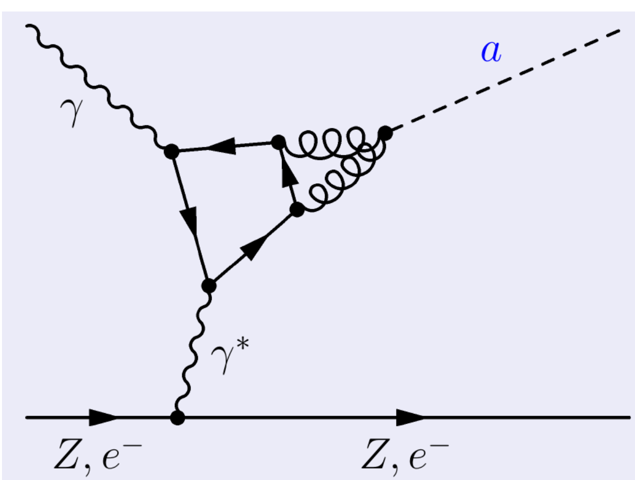






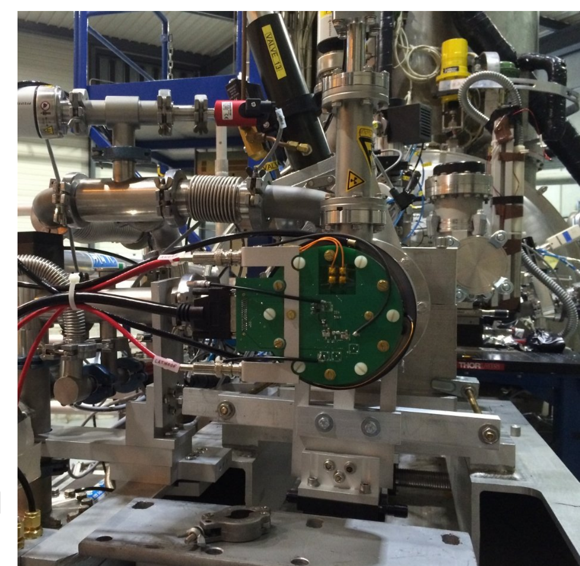


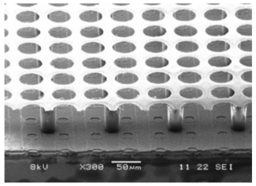
Decommissioned LHC-magnet is pointed to the sun. Axions produced in the sun convert into X-ray photons.



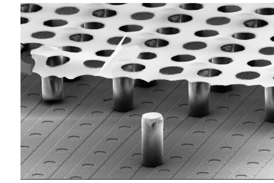
Detect X-rays with high efficiency.
→ Ar-mixture, 1 bar, 3 cm conversion volume

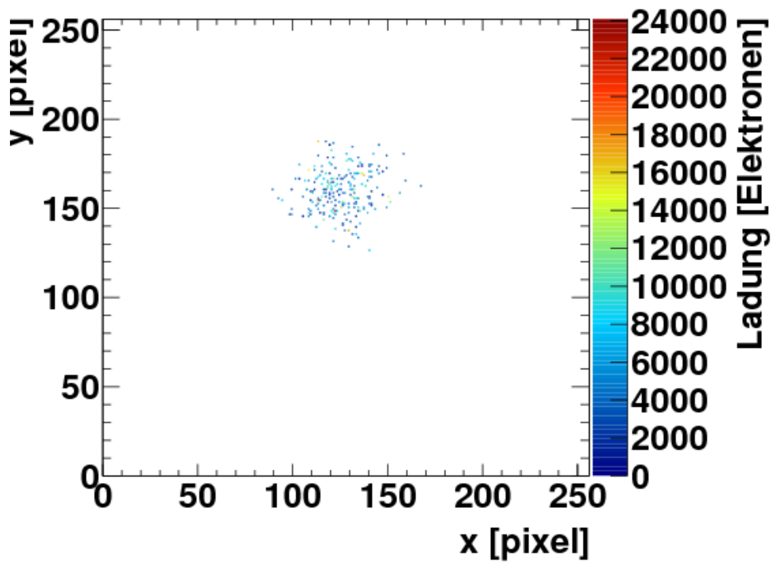
Suppress background as much as possible
→ radiopure material lead absorber, distinguish tracks from γs



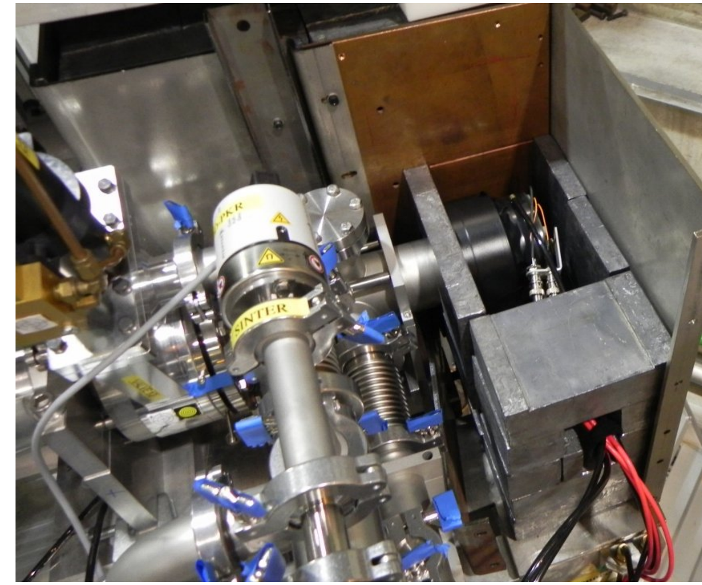


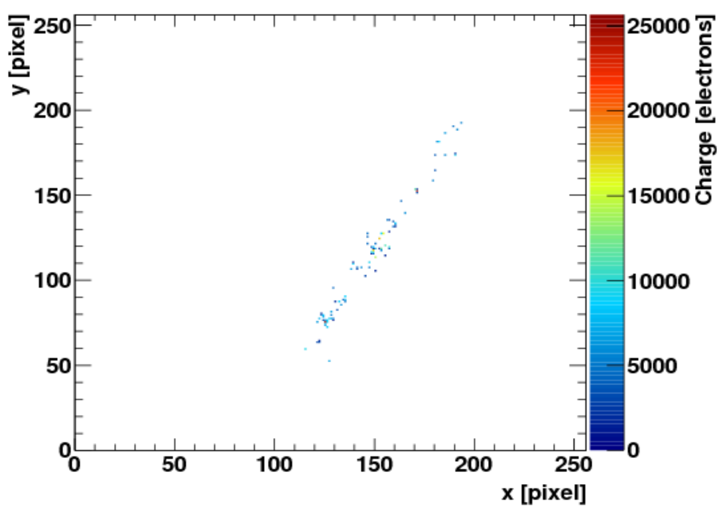
Application CAST

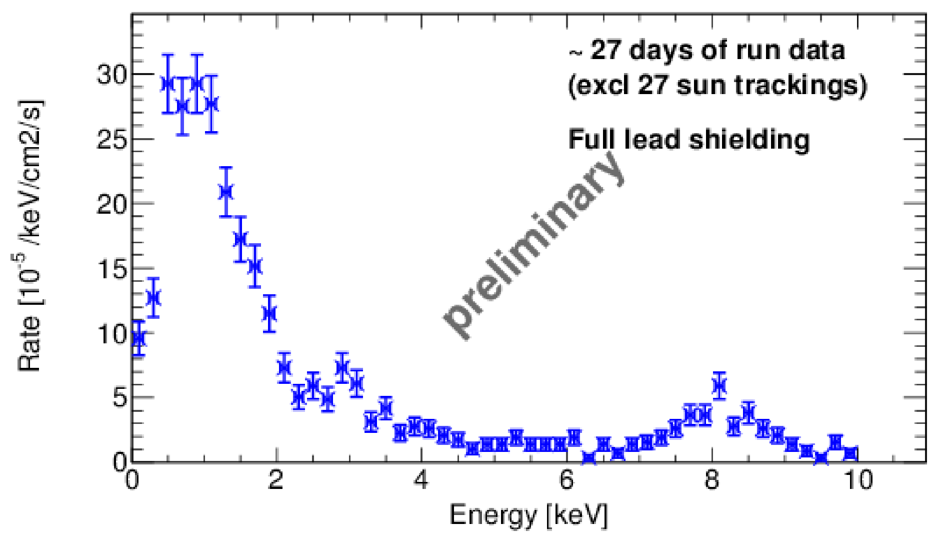




Lead shielding and likelihood ratio algorithm suppress back-ground down to 10^{-5} keVcm^{-2}s^{-1}







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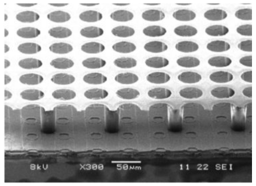
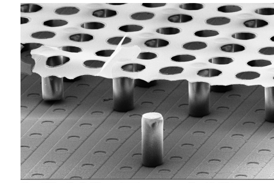


Application LCTPC



The ILC or CLIC are possible successors of the LHC colliding e^+ and e^- at 300 GeV – 3 TeV. One of the two detector concepts foresees a large Time Projection Chamber as a central tracking device.

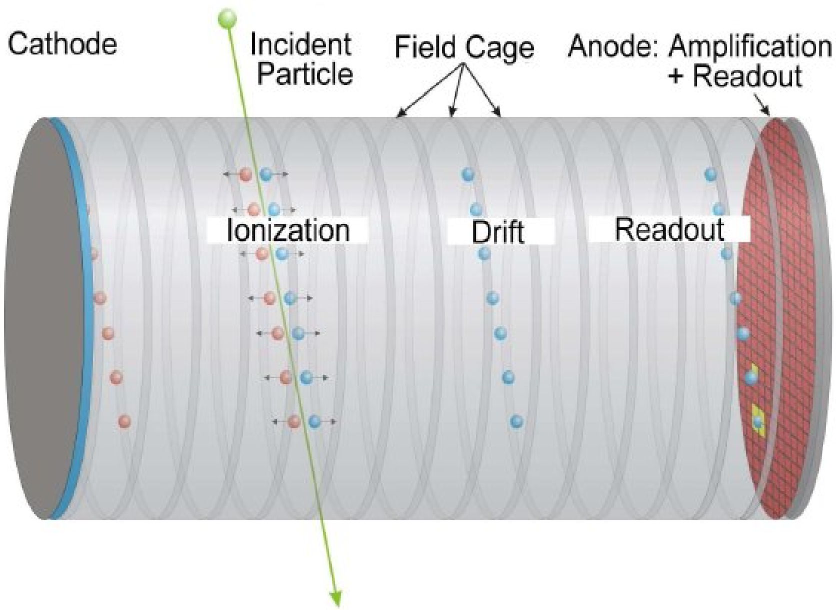
Micropattern gas amplification stages are needed to fulfill requirements.

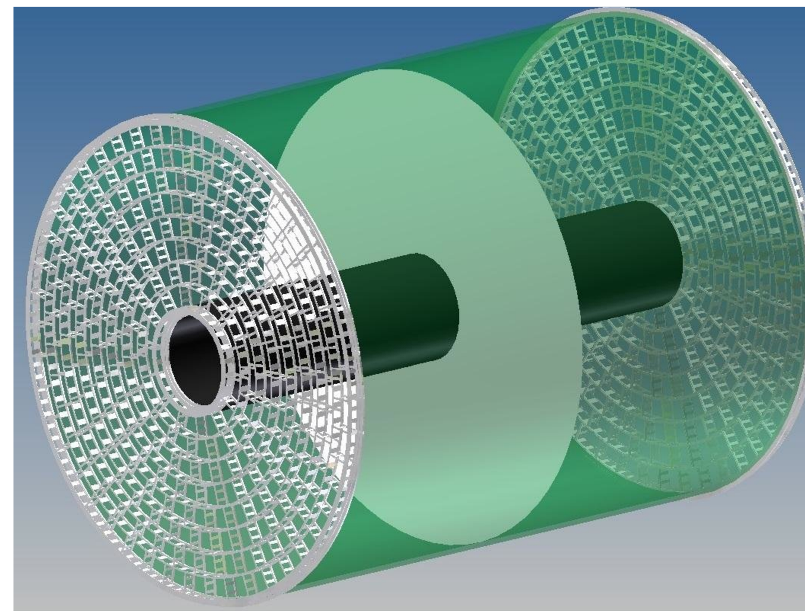
size of endcaps ~10 m^2

8 rows of MPGD detector modules;

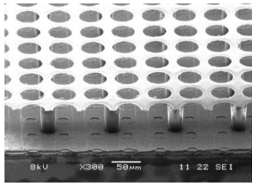
module size ~17×22 cm^2

240 modules per endcap

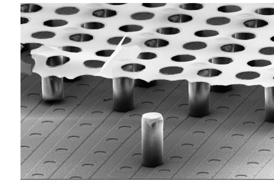


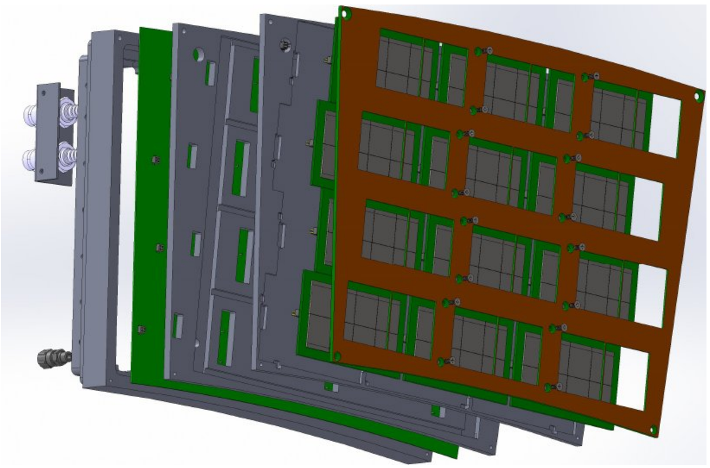


To readout TPC with InGrids,
one needs ~100 chips per module
→ 2000-2500 per endcap



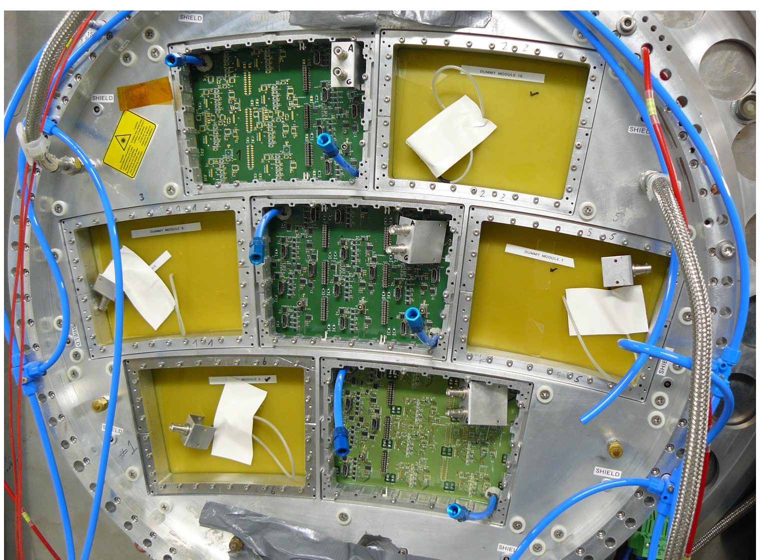
Test with 160 GridPix detectors

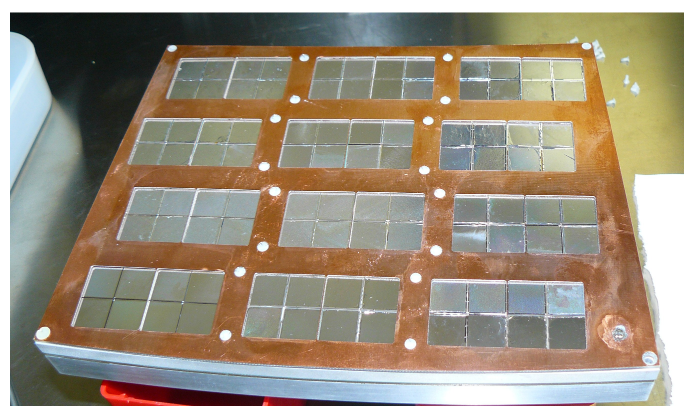


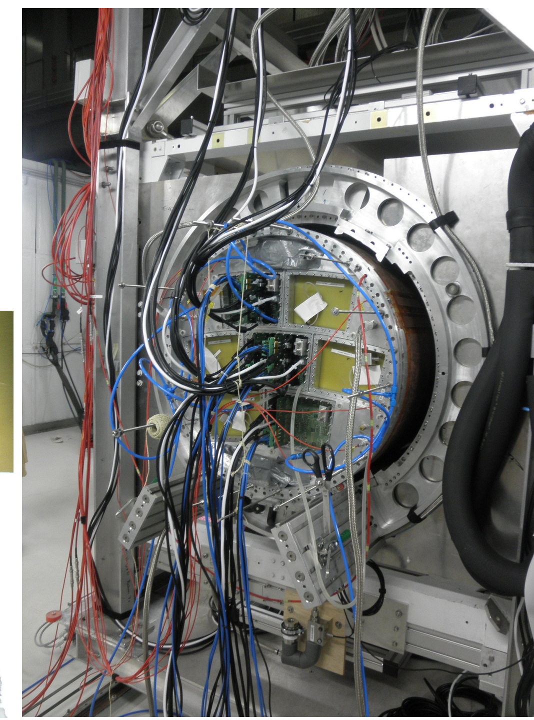


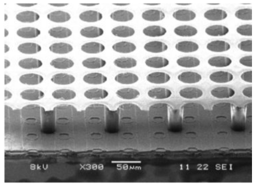
3 module with 20 Octoboards (160 chips) were constructed,
- central module with 96 chips
- 2 outer modules with 32 chips each

Some of the challenges are:
- LV distribution possibly up to 85 A @ 2.2 V
- Cooling
- InGrid production
- Bonding on boards
- Synchronized readout

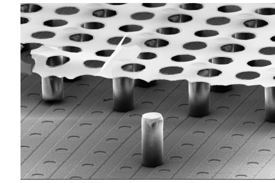








Test Beam Results



~ 10^6 frames recorded at 5 Hz in $Ar:CF_4:iC_4H_{10}$ 95:3:2, B = 0/1 T

Test beam program:

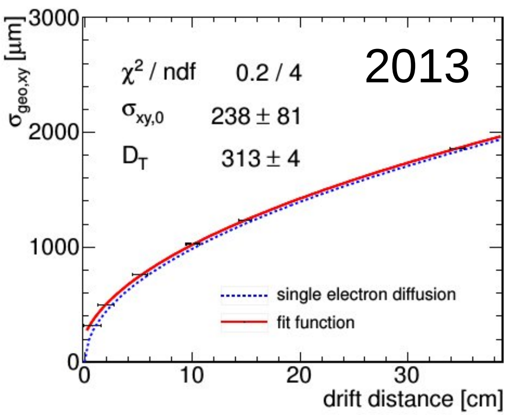
– Voltage scans (gas gain)

– z-scan, momentum scan

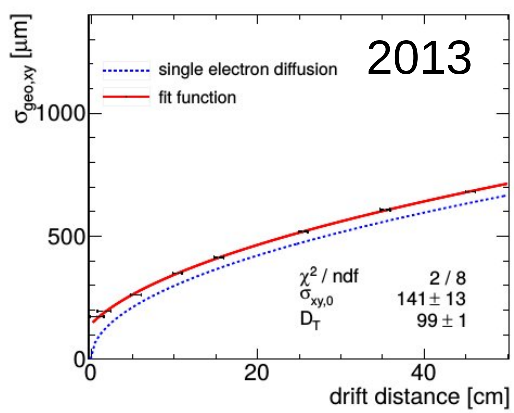
– Different angles

The analysis has started

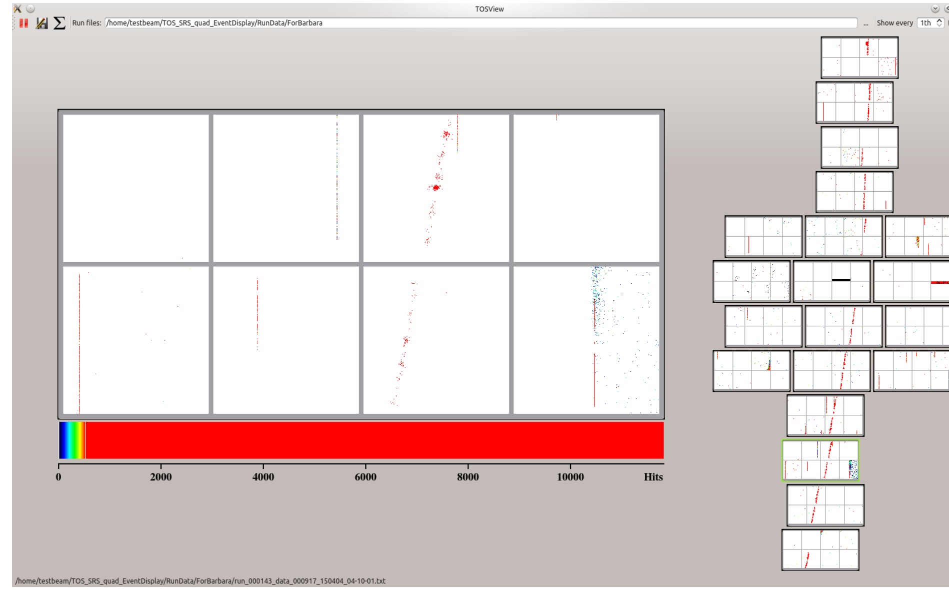
Previous test beam results have shown, that the spatial resolution is dominated by diffusion only

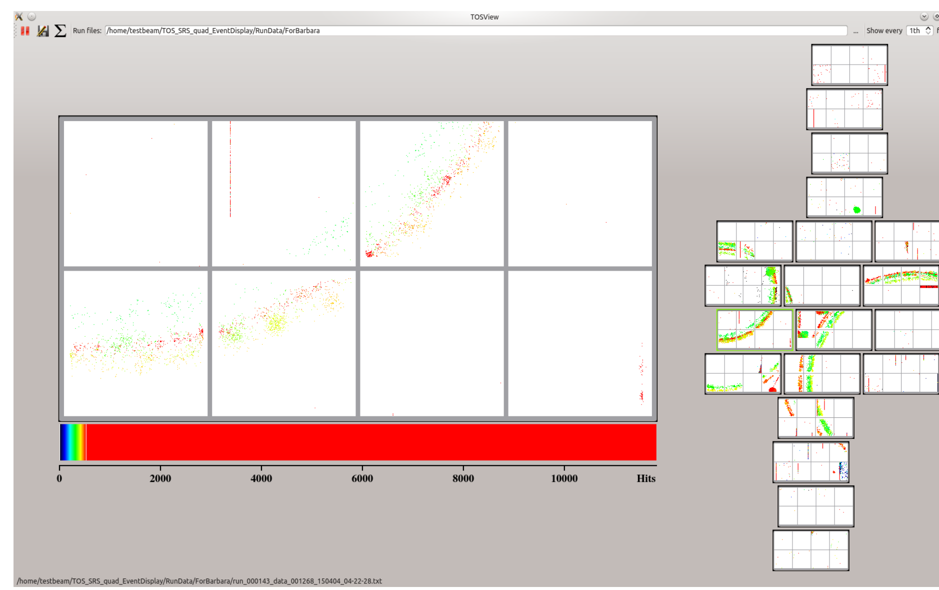


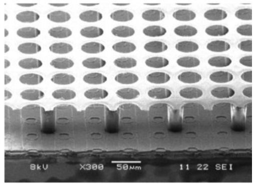
(a) xy resolution $B = 0\,T$



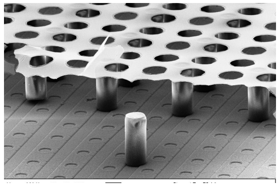
(b) xy resolution $B = 1\,T$

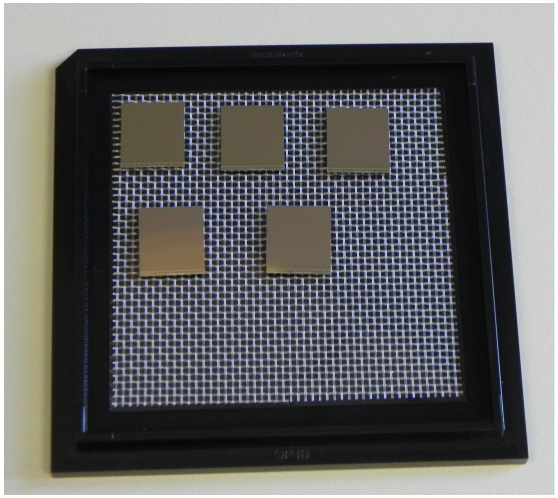






Outlook





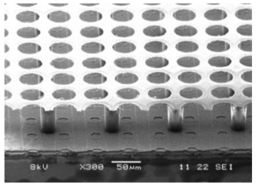
Timepix3 is available and is expected to give much better results than Timepix:

- Better time resolution (1.7 ns)
- Multi-hit capable
- Can measure time and charge for each pixel
- Much higher rate
- Ready for Through-silicon-vias

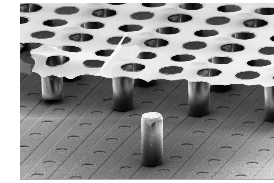
NIKHEF has developed a readout system for single Timepix3 chips (SPIDR).
First tests with standard Micromegas on top were successful.
Implementation in SRS is planned within AIDA2020.

Further R&D:

- Pillars made of ceramics (e.g. SiO) for sturdier structure.
- Grids made of resistive materials for higher spark protection
- Through-silicon-via technology to reduce dead area between chips.



Summary



InGrids have shown excellent performance:

Energy resolution of $\sigma_E/E \sim 3.85$ % (at 5.9 keV)

Spatial resolution only limited by diffusion.

High efficiency for single electron detection.

Production techniques are well advanced, a few details have to be improved.

Several readout systems optimized for compactness, speed or large systems have been developed and are commercially available.

Large systems (~160 chips) have been operated with a new readout system in a test beam earlier this year.

Further R&D on InGrids are planned (resistive grid, all ceramic,...)

New Timepix-3 is available and shows good results.

Acknowledgment: This presentation shows the work of many people
at NIKHEF, U. Twente/MESA+, U. Bonn, IZM, CEA Saclay.
I would like to mention in particular:
Yevgen Bilevich, who makes the InGrids, and
Christoph Krieger, whose detector the largest part of the talk is based on.