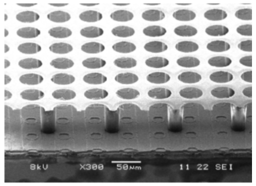

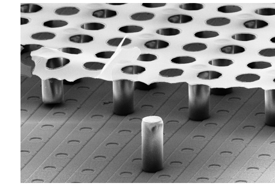

InGrids / GridPixes

Jochen Kaminski

University of Bonn

Industry-Academia Matching Event on MPGD
Annecy
26./27. April 2012

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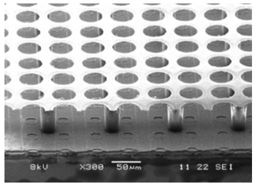
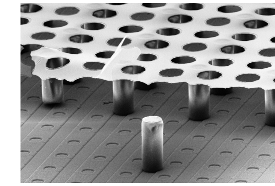


Content



I. What are InGrids, GridPixes, GEMGrids, … ?

From Micromegas to InGrids
The Beginning of InGrids
Nomenclature

II. The Ingredients: Chip, Protection Layer, Grid, Detector, ...

Timepix, Readout Electronics, Software
Production of grids
Protection layer
Some results
Wafer-scale production

III. Application in Academia with performance

CAST - low background, good energy resolution
LCTPC – good spatial resolution

IV. Summary and Acknowledgment

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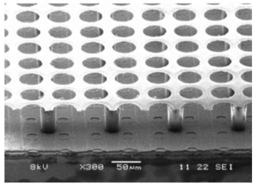
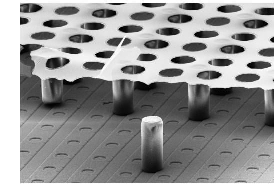
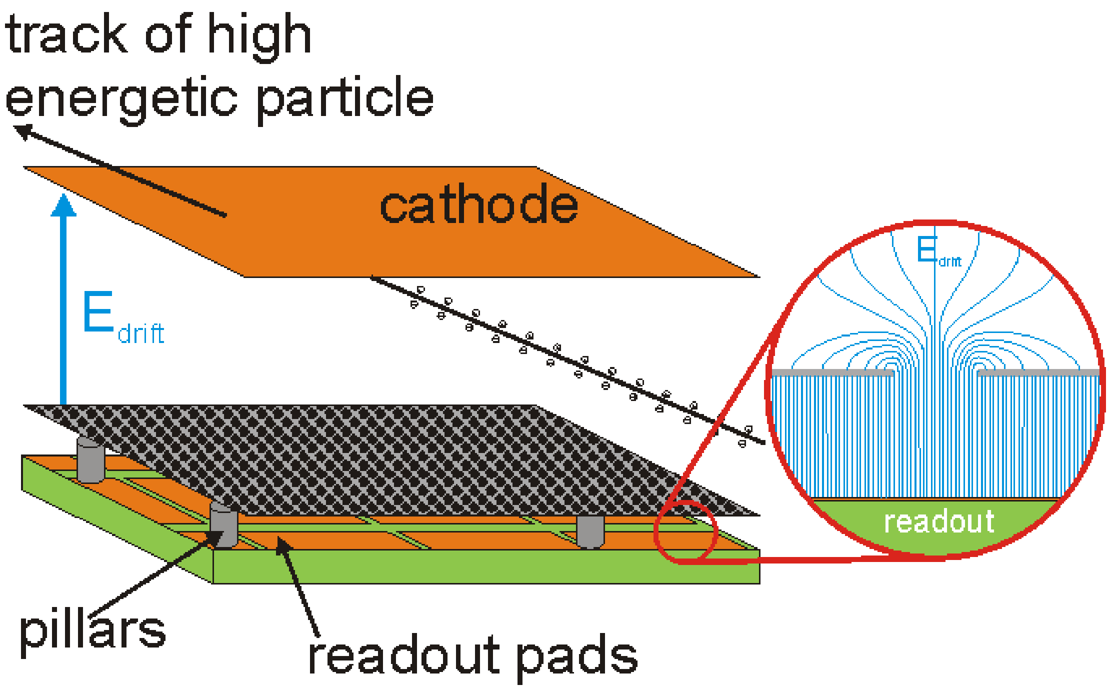


From Micromegas to InGrids



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)

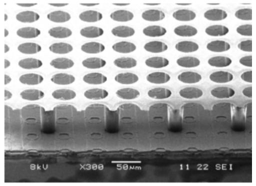
Could the spatial resolution of single electrons be improved?

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

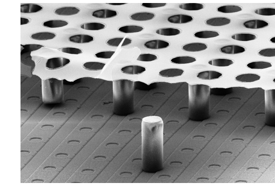
Ar:CH_4 90:10 → $D_t = 208\ \mu m/\sqrt{cm} \rightarrow \sigma = 24\ \mu m$

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

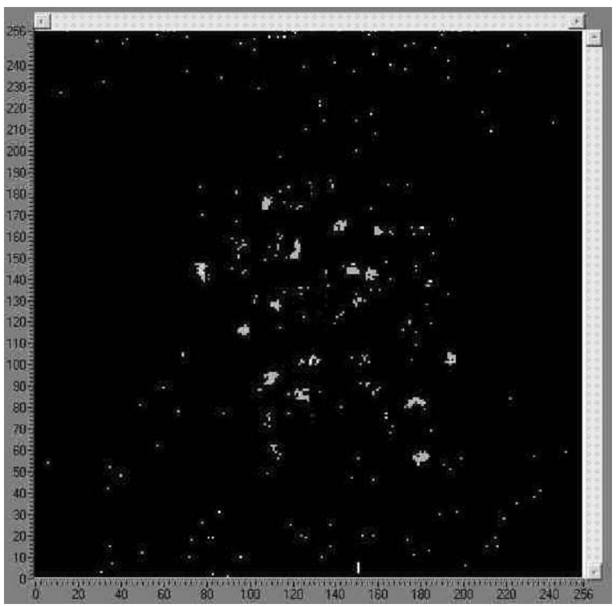
Smaller pads/pixels could result in better resolution!



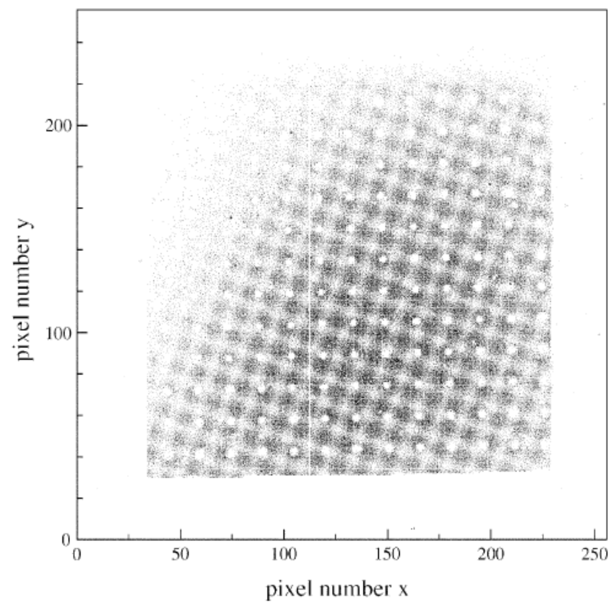
The Beginning of InGrids



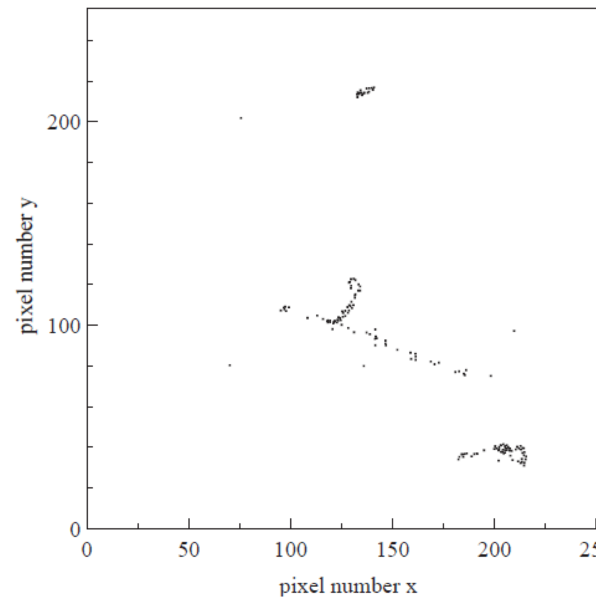
Two groups studied the use of pixel readout chip in MPGDs:
1.) R. Bellazzini, GEMs + VLSI Chip (NIMA 535, pp. 477, 2004)
2.) H. v.d.Graaf, GEMs/Micromegas with Medipix2
(NIMA 535, pp. 506, 2004, NIMA 540, pp. 295, 2005)



Event showing conversions of several γ from ^{55}Fe

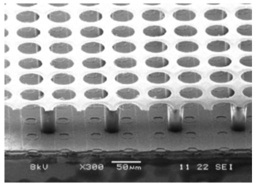


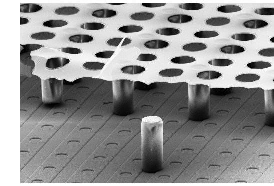
Occupancy showing Moire-effect



Cosmic rays with a δ-electron

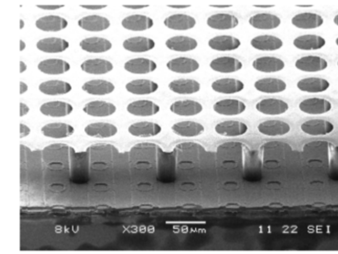
Need better alignment of pixels and grid holes – best: one hole / pixel
Achievable with modern postprocessing methods





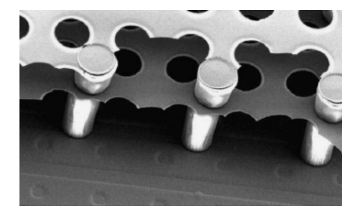
Nomenclature

Timepix / Medipix2: CMOS-ASIC designed by the Medipix collaboration, originally planned as an imaging chip for medical applications (NIMA 581, pp. 485, 2006)

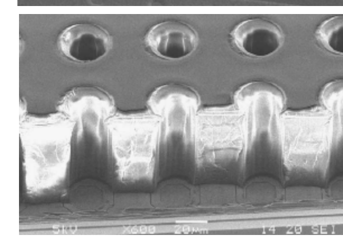


InGrid: Integrated Grid: Micromegas structure built on top of pixel chip with industrial postprocessing techniques (NIMA 556, pp. 490, 2006)

GridPix: complete detector based on InGrids + Pixel chip including cathode, gas volume etc.

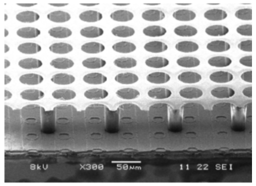


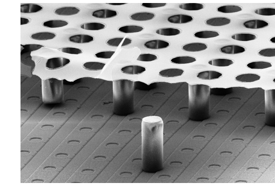
TwinGrid: two grids on top of each other (NIMA 610, pp. 644, 2009)



GEMGrid: Same as InGrid, but grid rests on solid layer with holes, instead of pillars (NIMA 608, pp. 96, 2009)

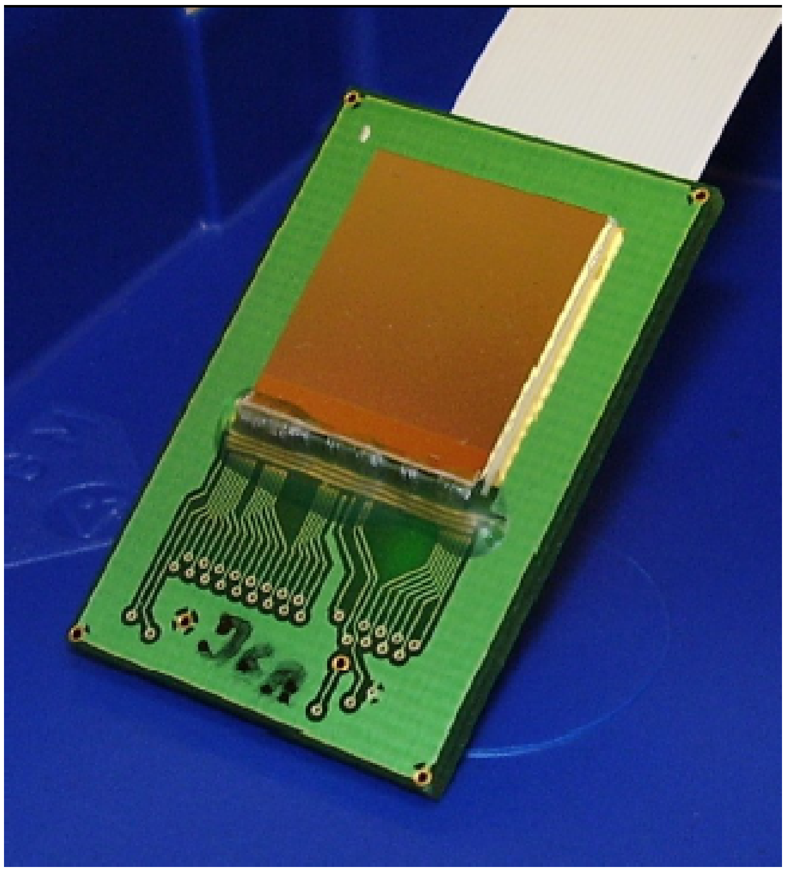
Gossip: Gas On Slimmed Silicon Pixels, a very thin GridPix detector with minimal material budget, e.g. 1 mm of gas gap, thinned ASIC





Timepix Chip

Timepix chip (1st version) derived from MediPix-2



Available for tests since Nov. 2006

Number of pixel: 256 × 256 pixel
Pixel pitch: 55 × 55 μm²
Chip dimensions: 1.4 × 1.4 cm²
ENC: ~ 90 e^-

Each pixel can be set to one of these modes:

- Hit counting
- TOT = time over threshold gives integrated charge
- Time between hit and shutter end
- Hit/no-hit

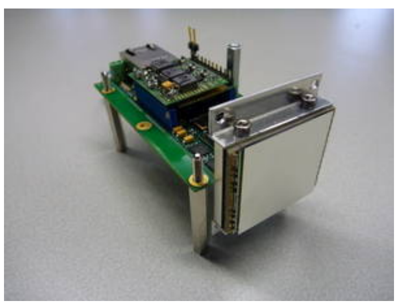
Limitations: no multi-hit capability, charge and time measurement not possible for one pixel

The successor Timepix-3 is being designed and will be submitted soon.

Readout Electronics

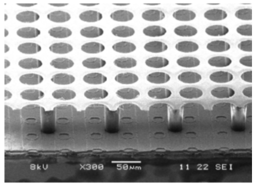
MUROS 2.1 designed at NIKHEF - still in wide use today, but not in production anymore, can handle up to 8 chips, needs outdated NI card

USB interface designed by TU Prague
very easy to handle/transport
but limited speed and functionality

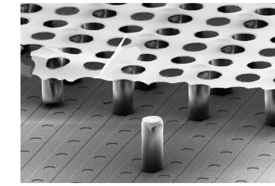


ReLaXd designed at NIKHEF – fast readout for 4 Medipix/Timepix chips

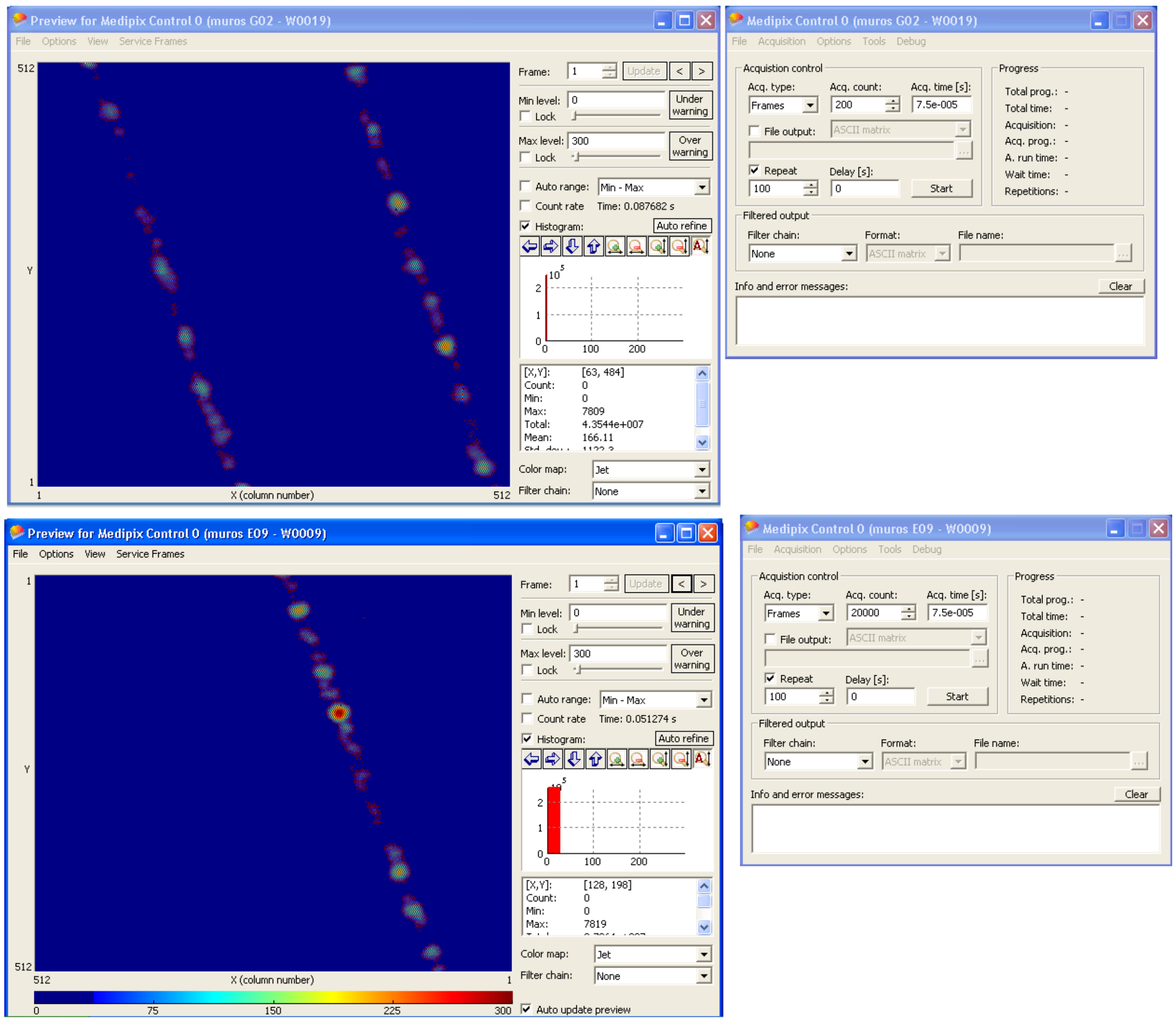
FITPix improved version of the USB-interface designed by TU Prague
can handle up to 16 detectors

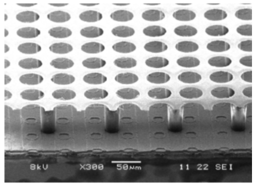


Software

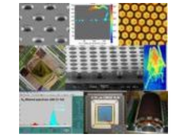
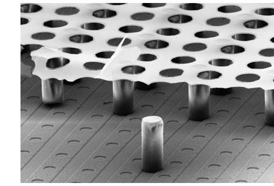


Most systems are operated by the Pixelman software developed at the TU Prague.



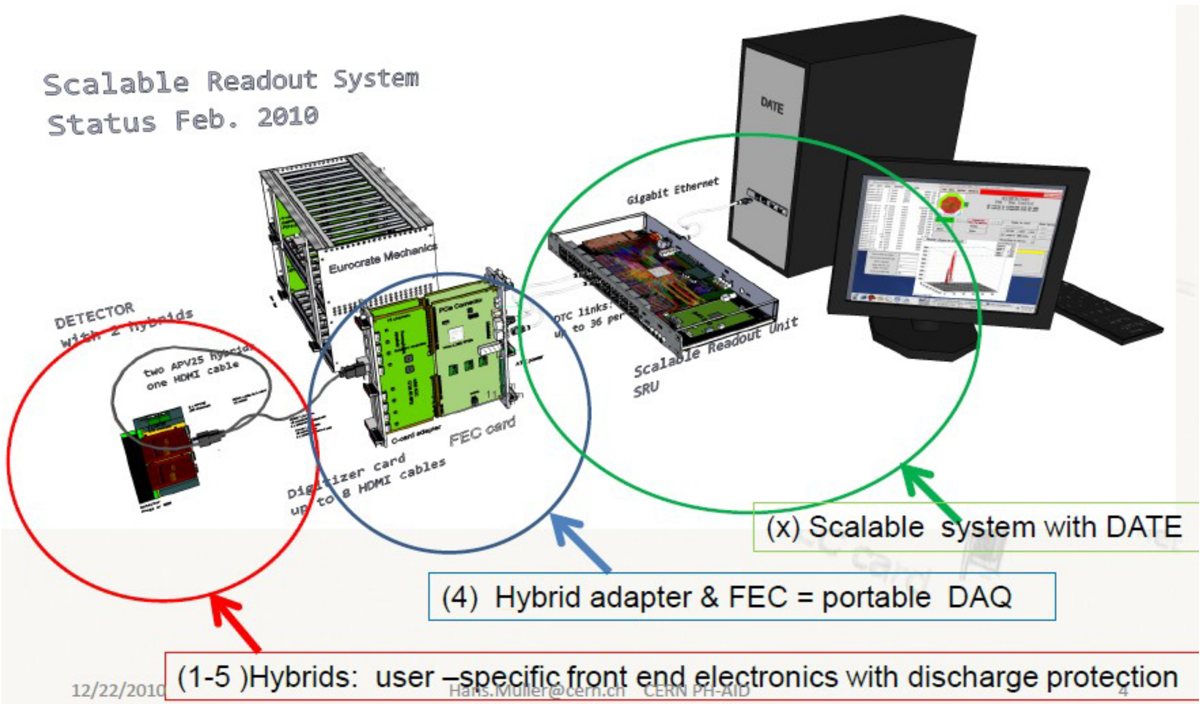


Timepix readout with SRS

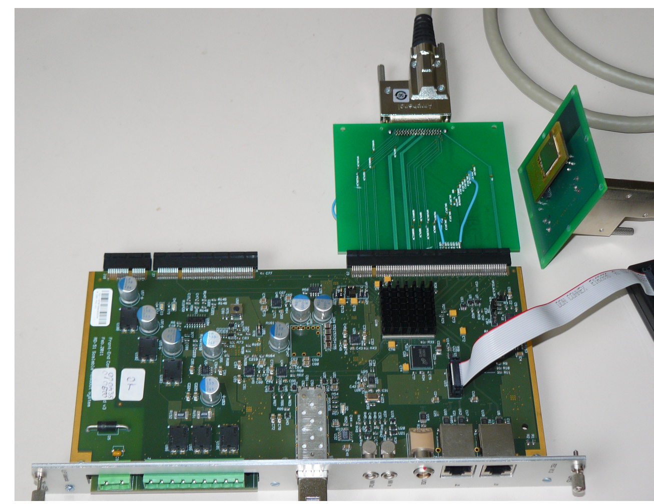



The Scalable Readout System is designed by the RD51 collaboration with CERN as a main developer. → See presentation/demonstartion of H. Muller

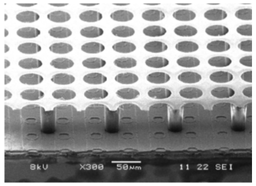
Idea: produce a flexible readout electronics, which can handle different chips (new FPGA code, chip carrier), which many groups can use



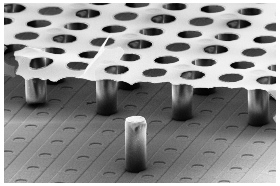
U. Bonn and U. Mainz are developing a readout for the Timepix chip



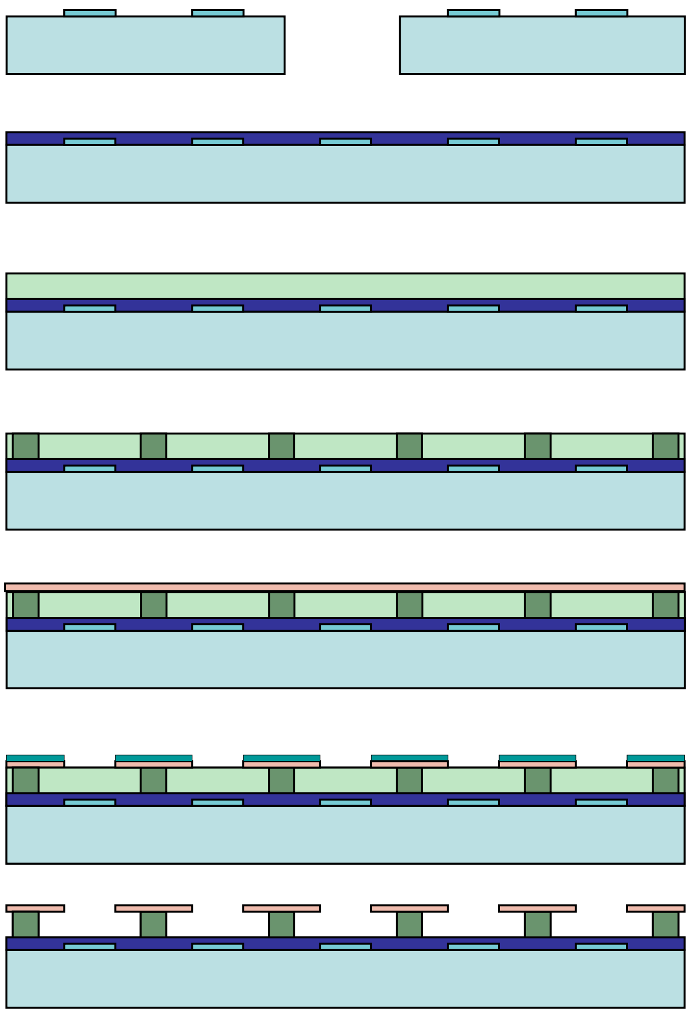
Operation has been demonstrated for a single chip, more functionality has to be added. Aim is to operate ~100 chip in 2013.



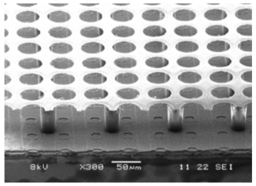
Production of InGrids



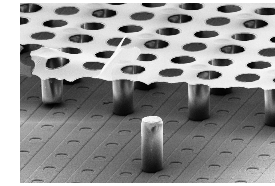
The production of InGrids was pioneered by the University of Twente/MESA+.



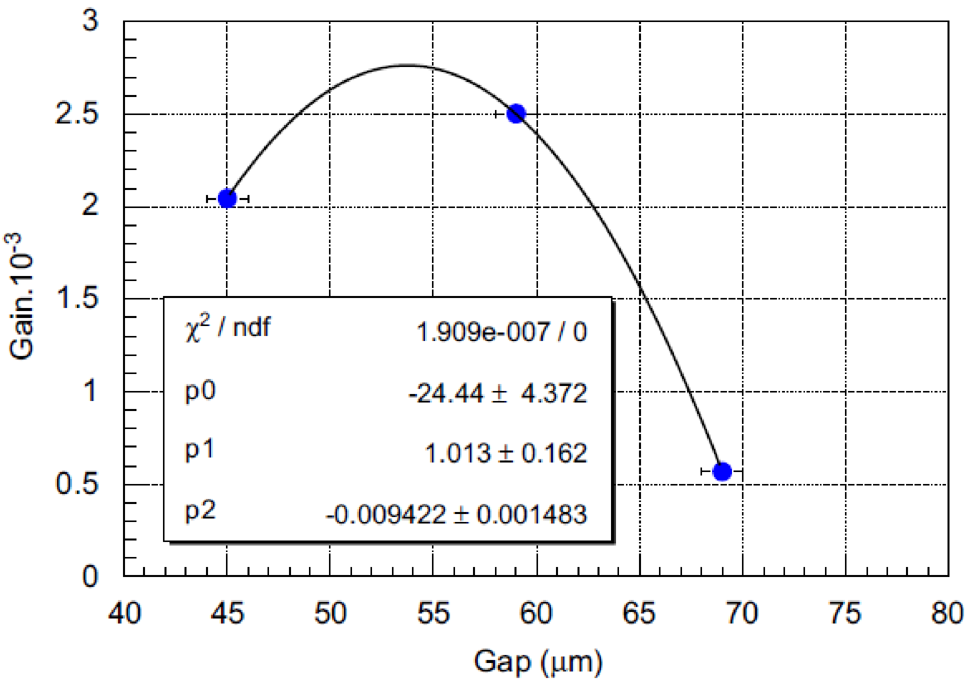
1. Dicing of Wafer
2. Formation of Si_xN_y protection layer
3. Deposition of SU-8
4. Pillars-like structure formation
5. Deposition of thin Al layer
6. Formation of Al grid
7. Development of SU-8



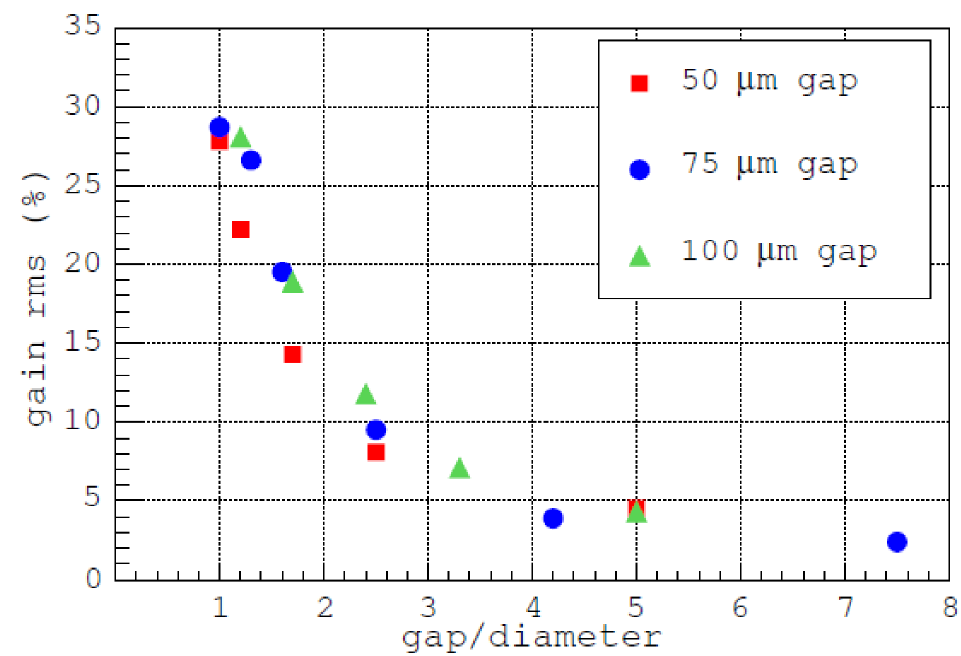
Optimization of InGrids



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.

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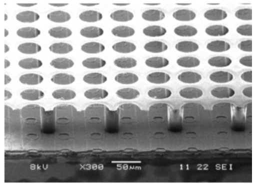
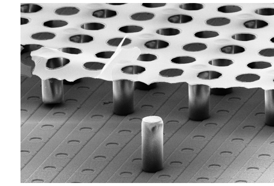


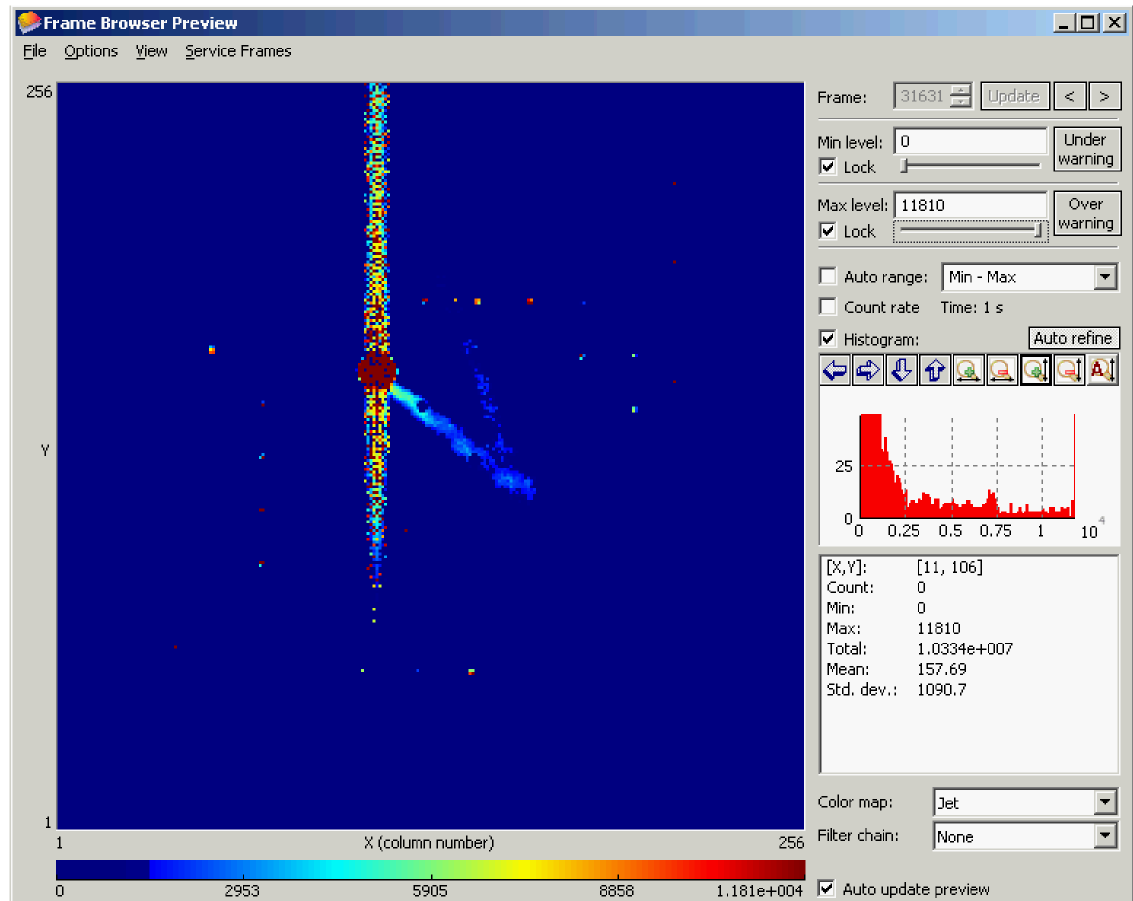


Protection Layer

NIKHEF
MESA+ Institute for Nanotechnology

Discharge triggered for example by highly ionizing particles could easily destroy the 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.

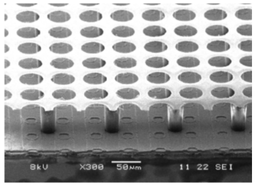


<u>high resistive material</u>

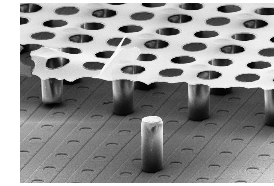
15 µm aSi:H (~10^{11} Ω·cm)

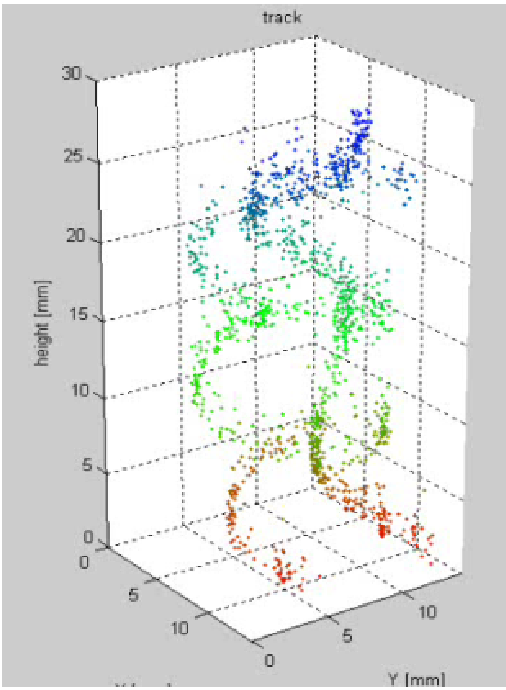
8 µm Si_XN_Y (~10^{14} Ω·cm)

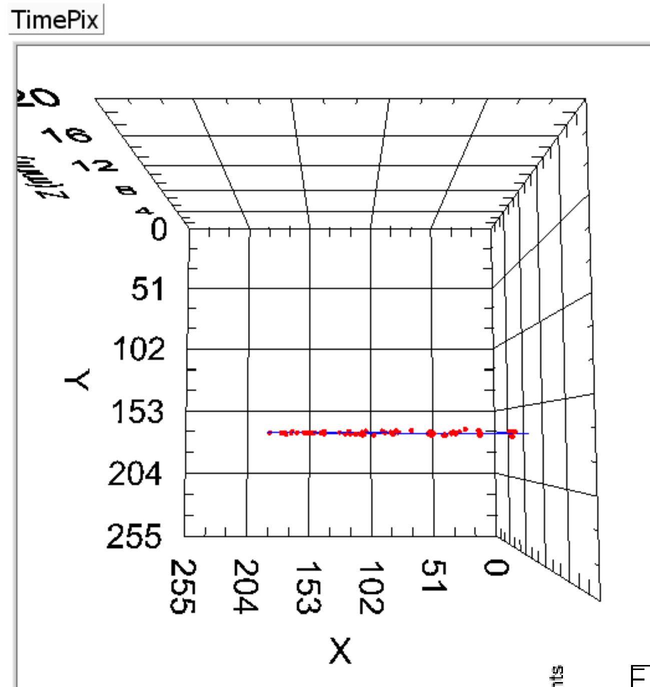
Chips survives several thousand discharges triggered by αs.

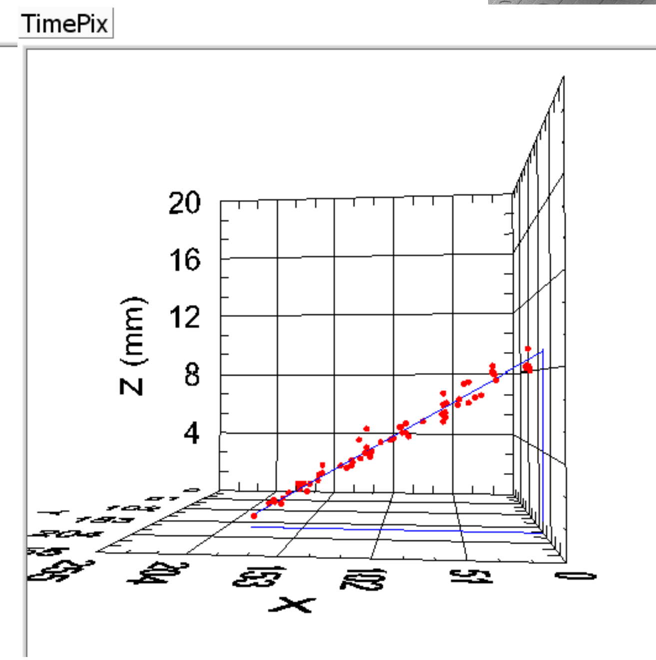


Some Results









2 electrons of a ^{90}Sr source in B = 0.2 T

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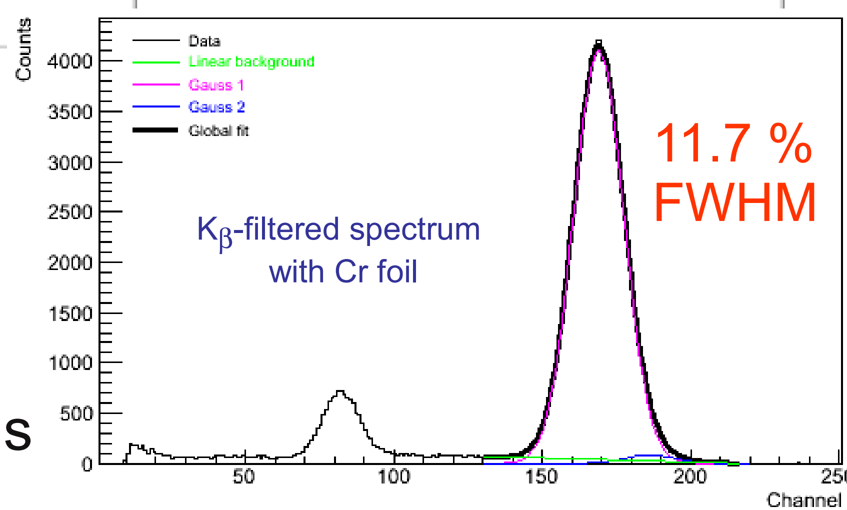

^{55}Fe spectrum in Ar:CH_4 90:10

InGrids show for example:
- extremely good energy resolution
- high detection efficiency of single electrons (up to 98 % were reached)

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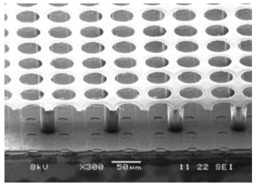
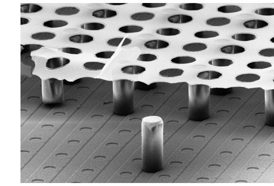
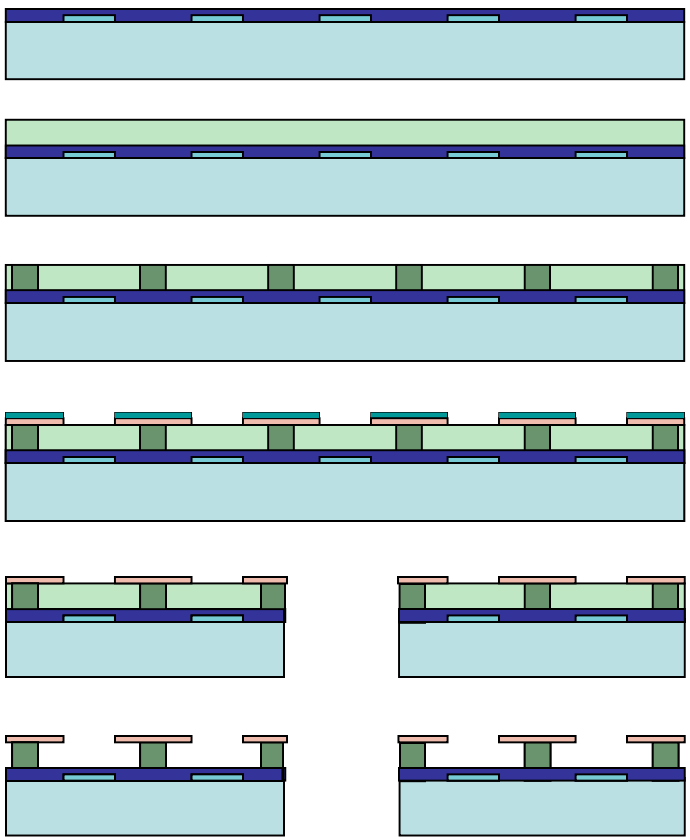


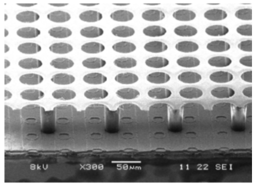
Wafer-based Production



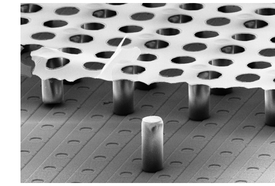
Production at Twente was based on 1 - 9 chips process.
This could not satisfy the increasing demands of R&D projects.
New production set up at the Fraunhofer Institut IZM at Berlin.
This process is wafer-based → 1 wafer (107 chips) is processed at a time.



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

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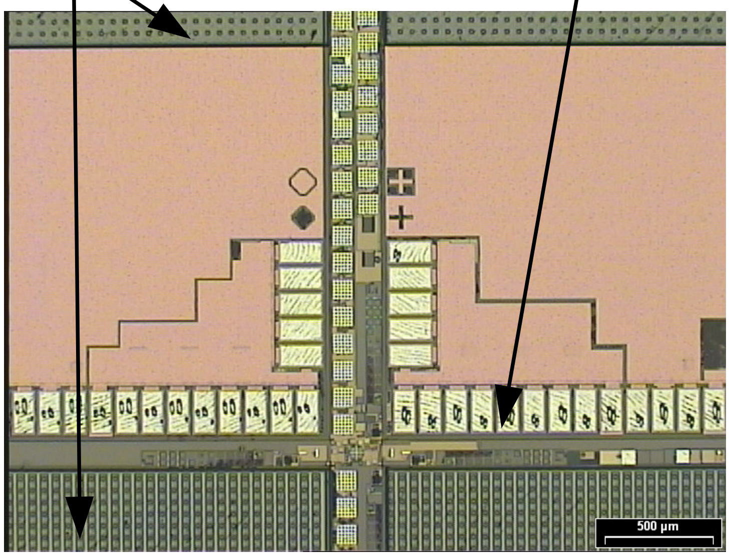
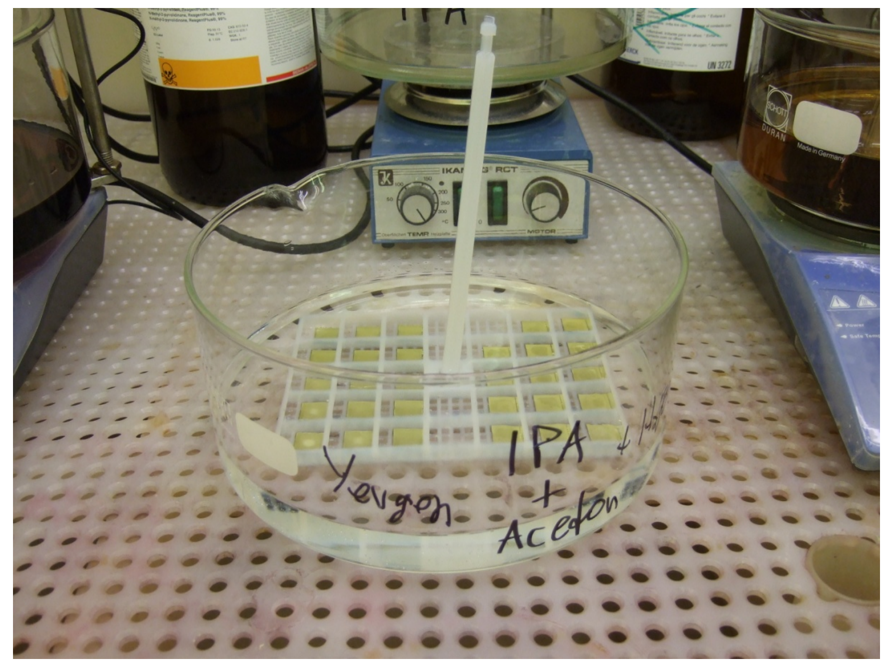
SiRN should not cover bond pads

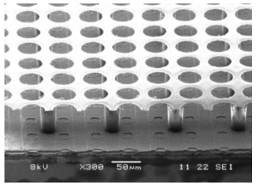


First tests: mechanical mask
→ failed due to thermal stress
Better: poyimide mask chem. removed

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

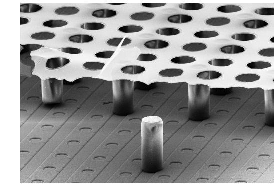


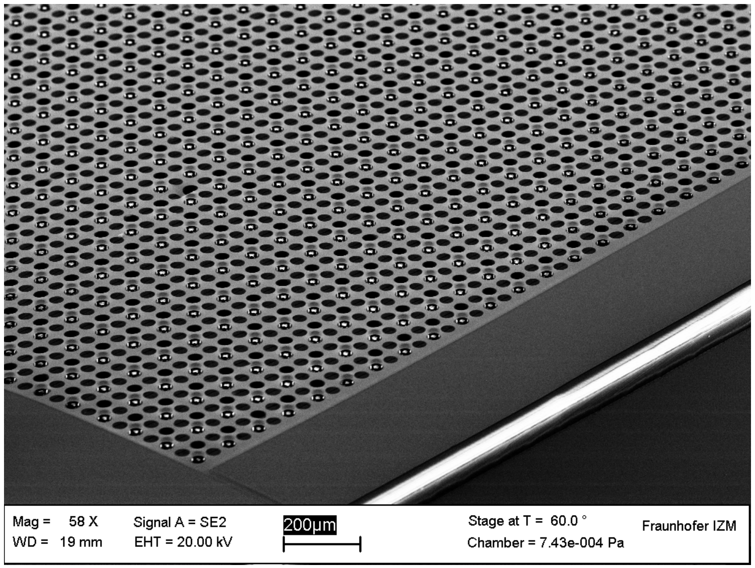
Time consuming

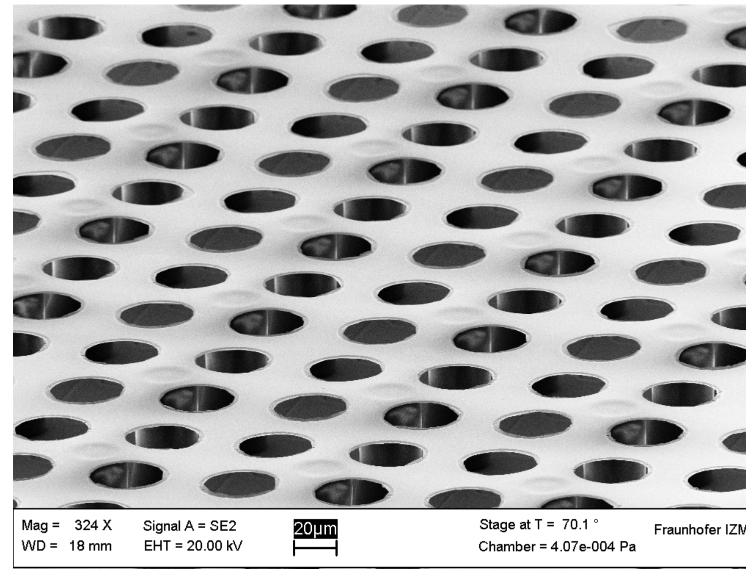


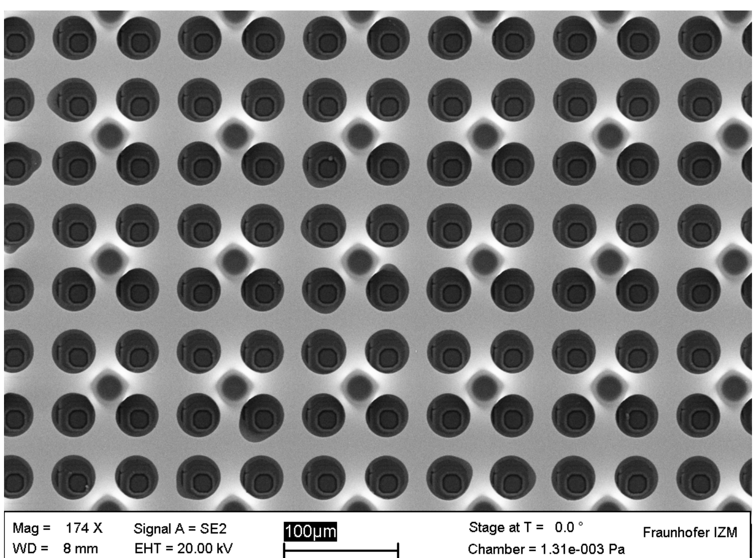
SEM Pictures

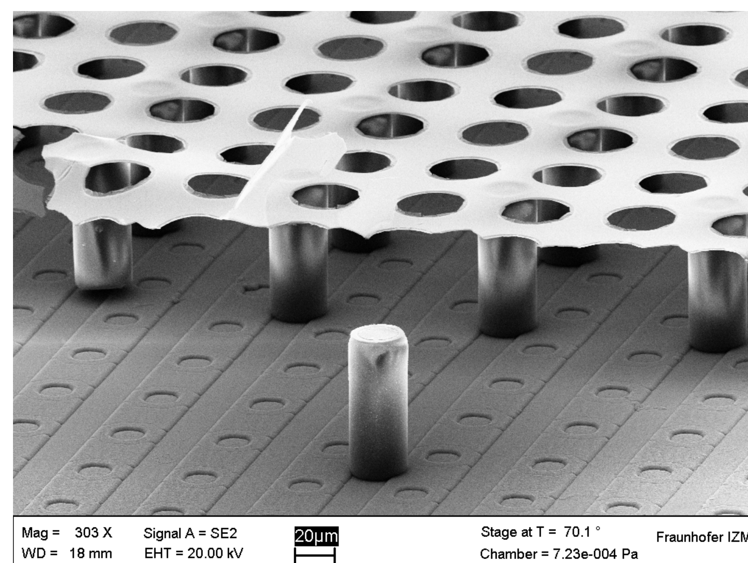
Fraunhofer IZM

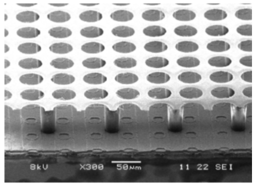




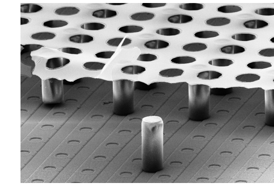








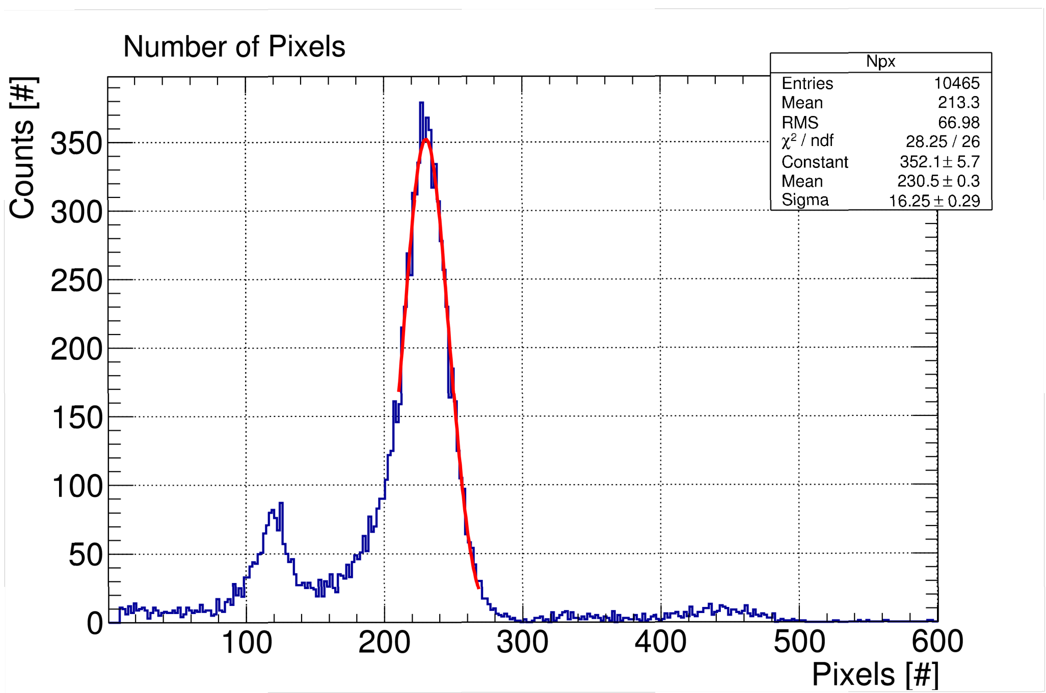
Performance

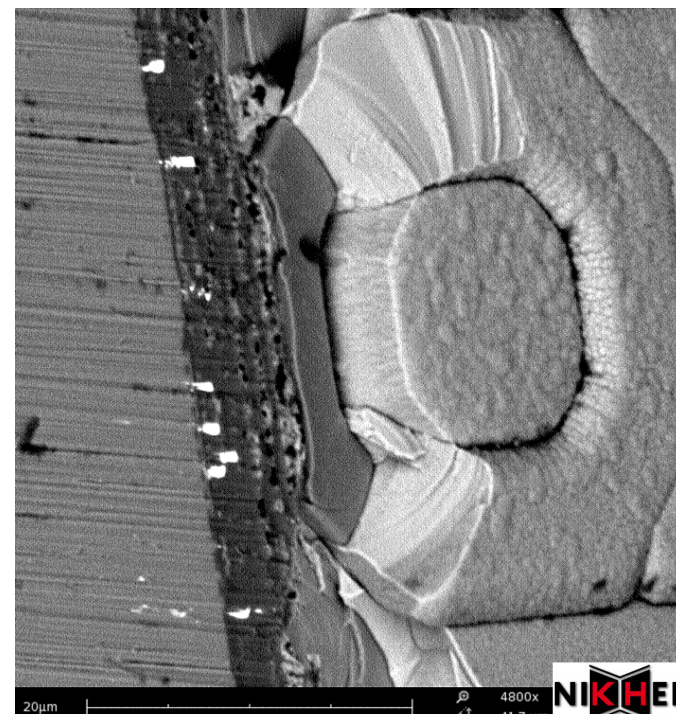


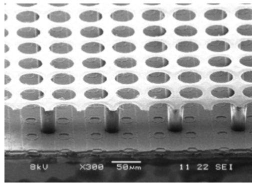
First batch (10/2011): Problems with resistive layer and Al-grid

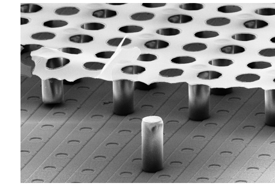
Second batch (12/2011):
- Very good optical results, InGrids work well
- Good energy resolution ($\sigma_E/E \sim 7\%$) and homogeneity
- Pillars higher than expected (70-80 μm)
- Resistive layer needs optimization (chips die after 2 weeks)

Third batch: in preparation

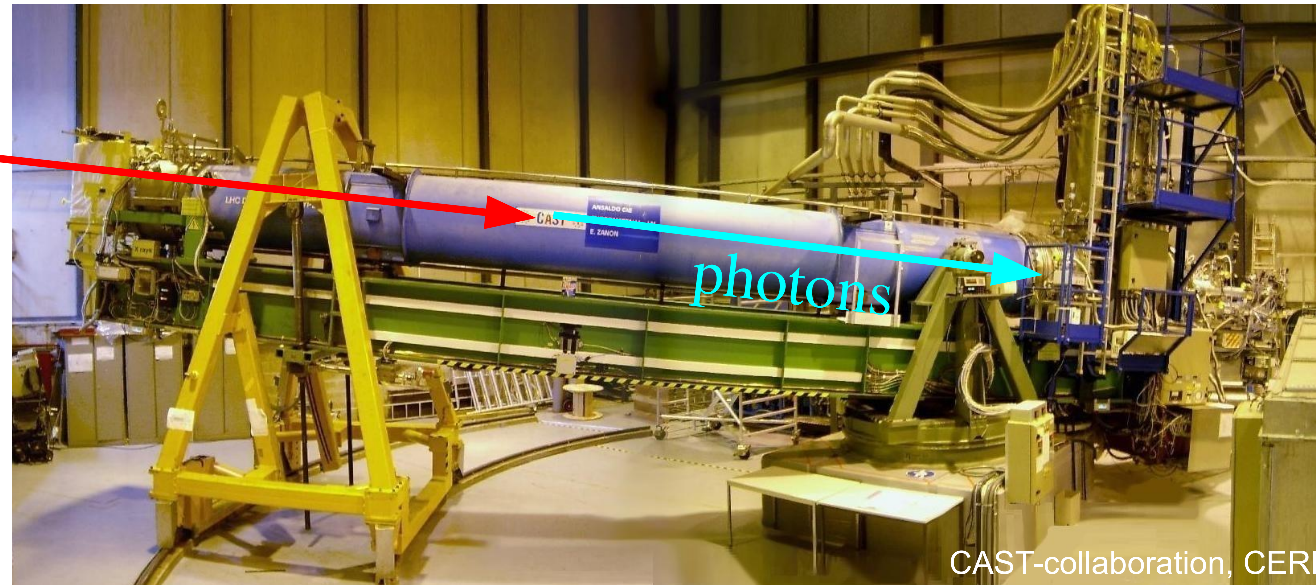




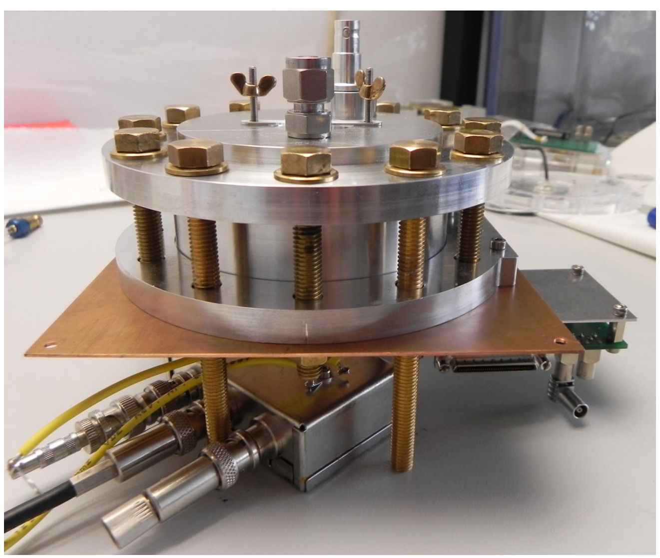




Application CAST

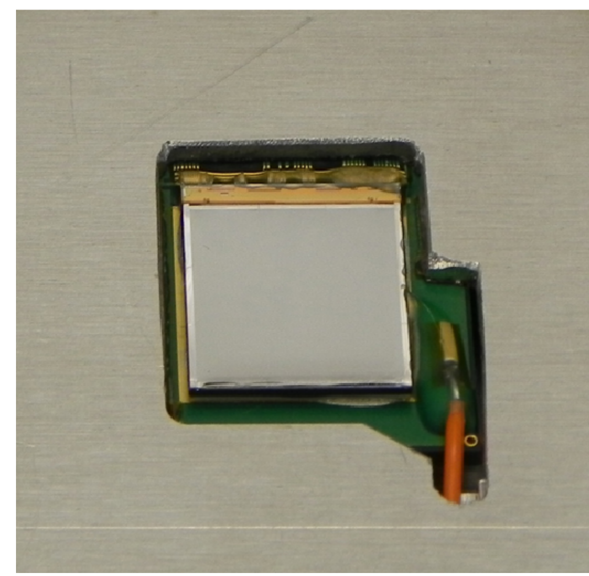


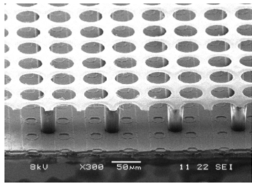
Decommissioned LHC-magnet is pointed to the sun. Axions produced in the sun convert into X-ray photons.

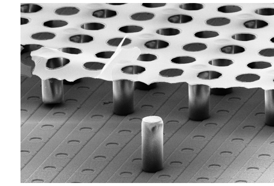


Detect X-rays with high efficiency.
→ Ar-mixture, 1-2 bar, 2 cm conversion volume

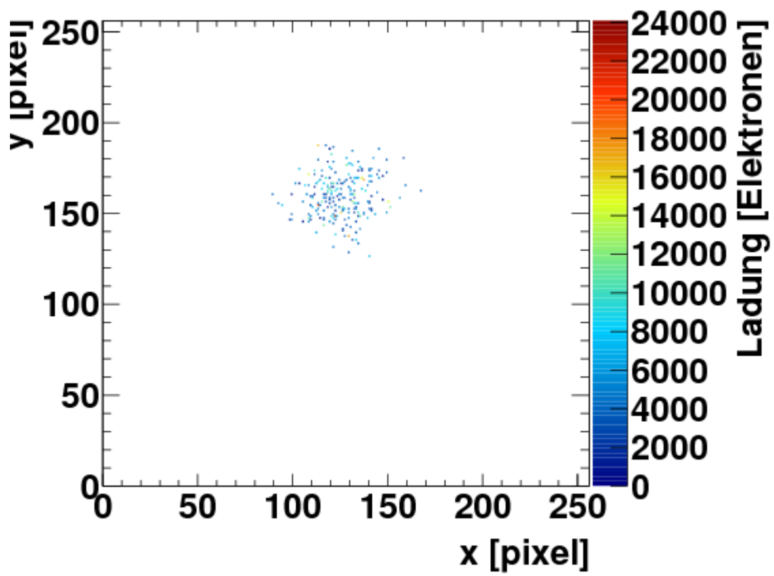
Suppress background as much as possible
→ radiopure material lead absorber, distinguish tracks from γs



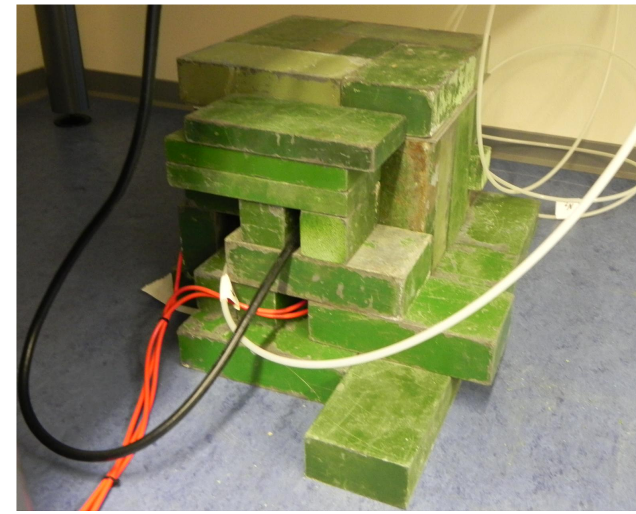


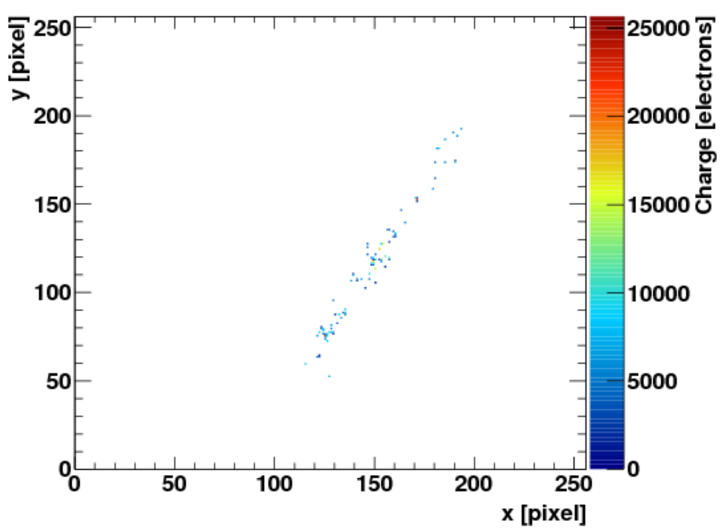


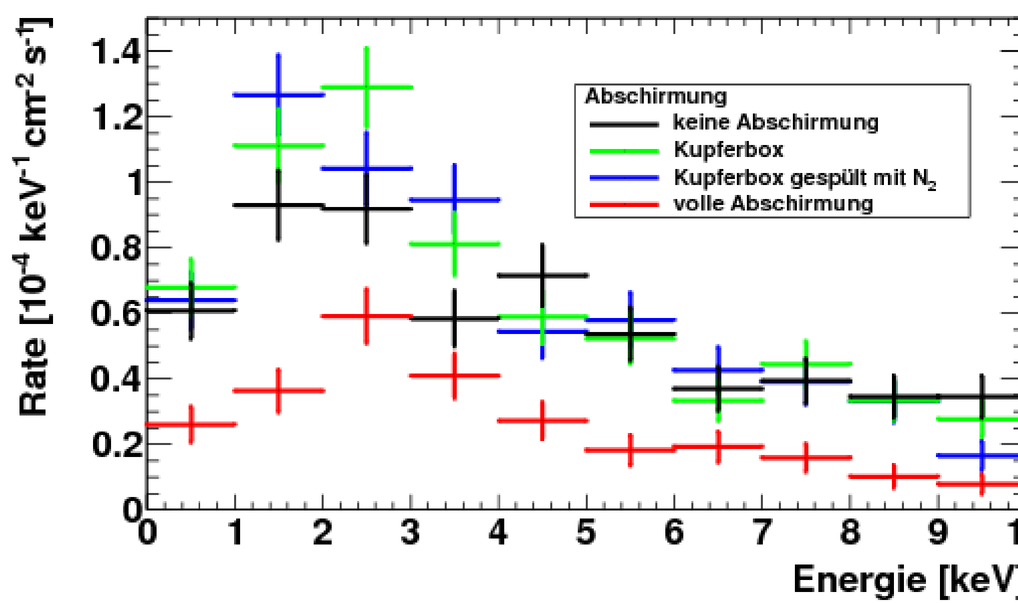
Application CAST



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







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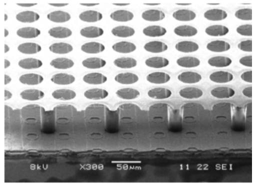
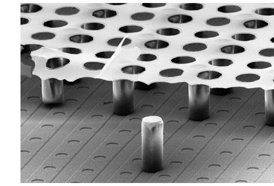
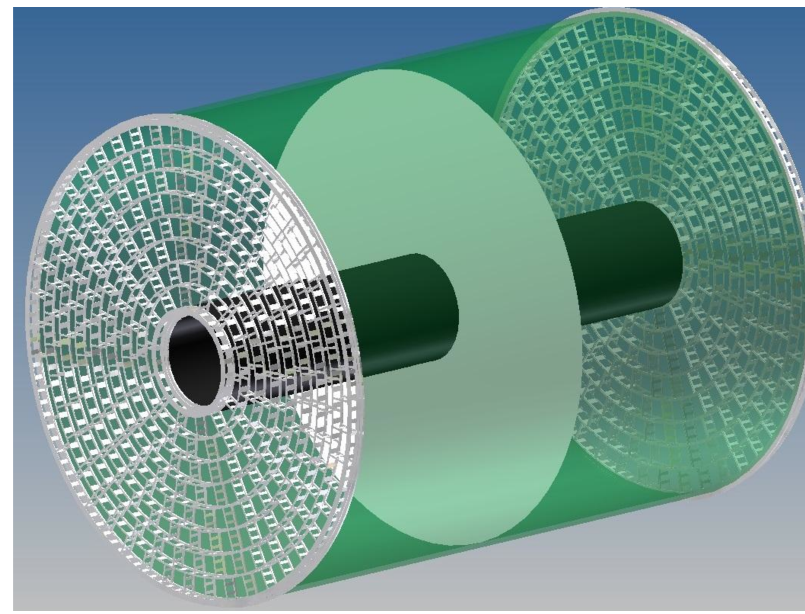


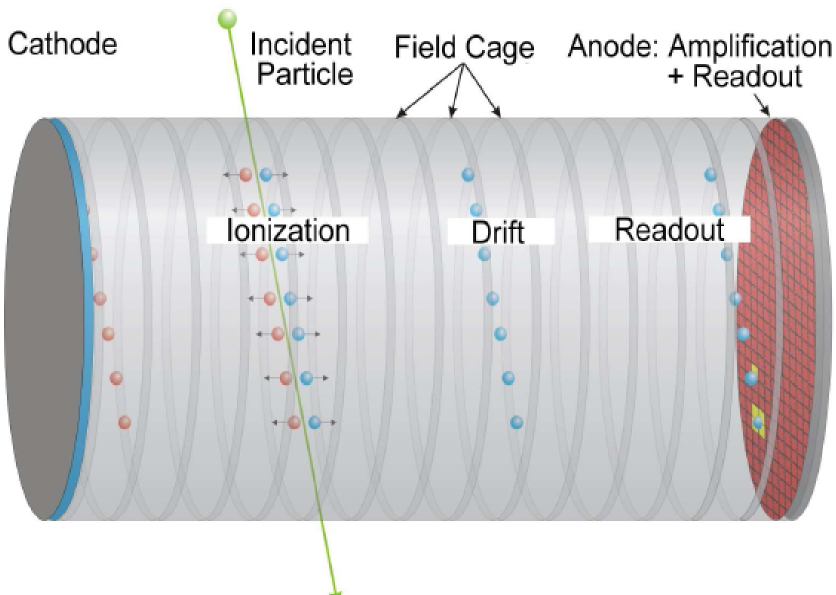
Application LCTPC



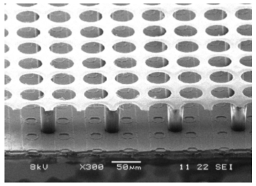
The ILC or CLIC are possible successors of the LHC colliding e^+ and e^- at 300 GeV – 3 TeV. One of the two detector concepts foresees a large Time Projection Chamber as a central tracking device.
Micropattern gas amplification stages are needed to fulfill requirements.

size of endcaps ~10 m^2
8 rows of MPGD detector modules;
module size ~17×22 cm^2
240 modules per endcap

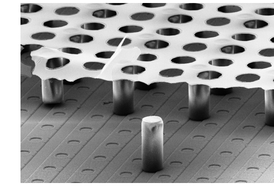




To readout TPC with InGrids,
one needs ~100 chips per module
→ 2000-2500 per endcap

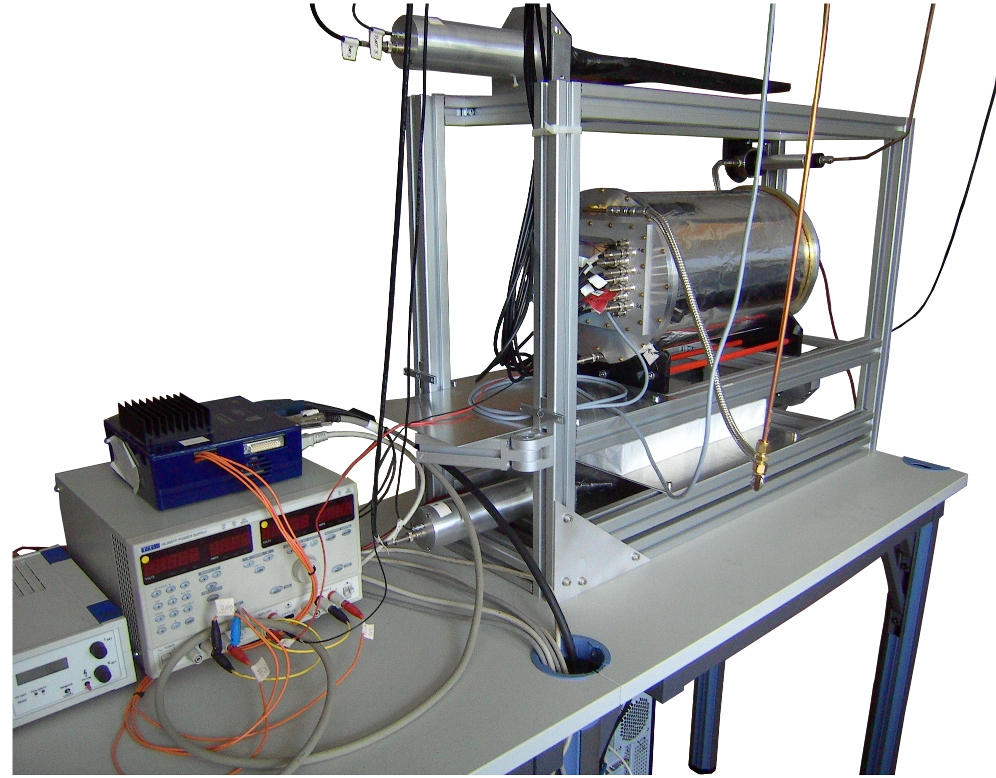


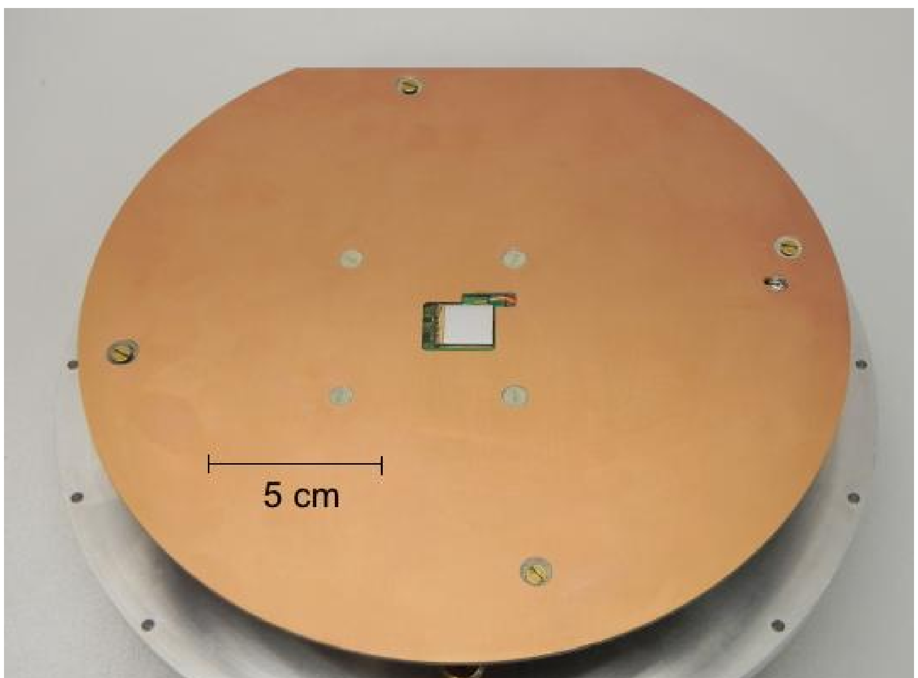
Application LCTPC



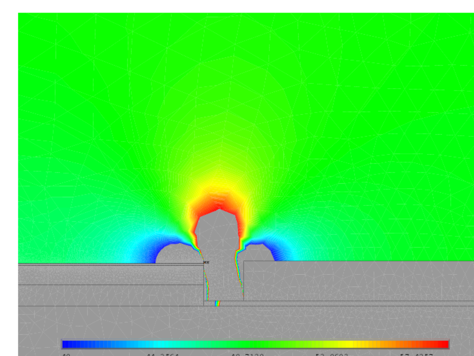
<u>Test setup at U. of Bonn</u>

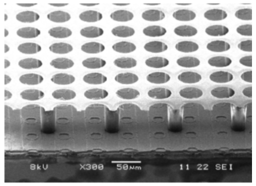
Triggered by two scintillators
Max. drift length: 26 cm
Measures cosmic muons
Drift field: 450 V/cm
Gas: He:CO_2 (70:30)



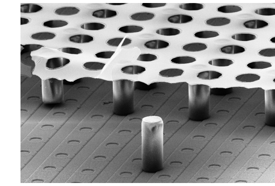


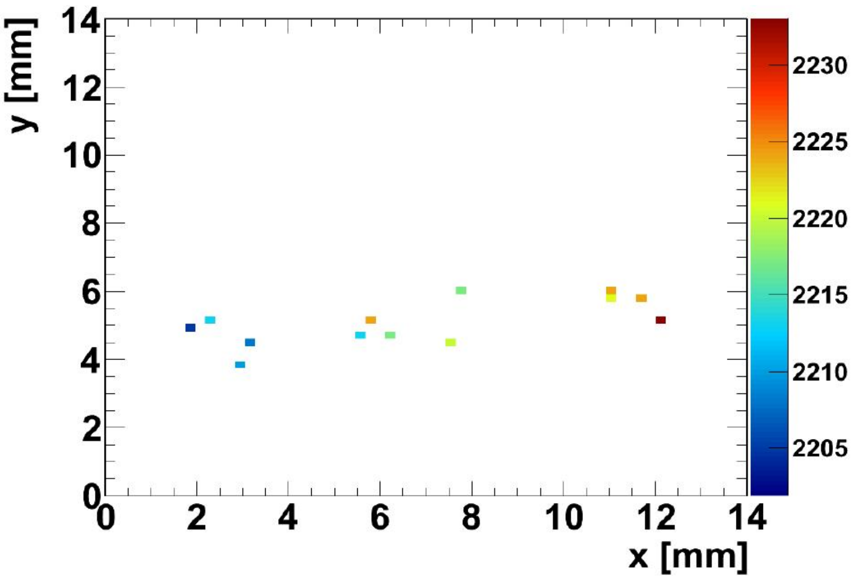
Field distortions originating from gap between chip and termination plate





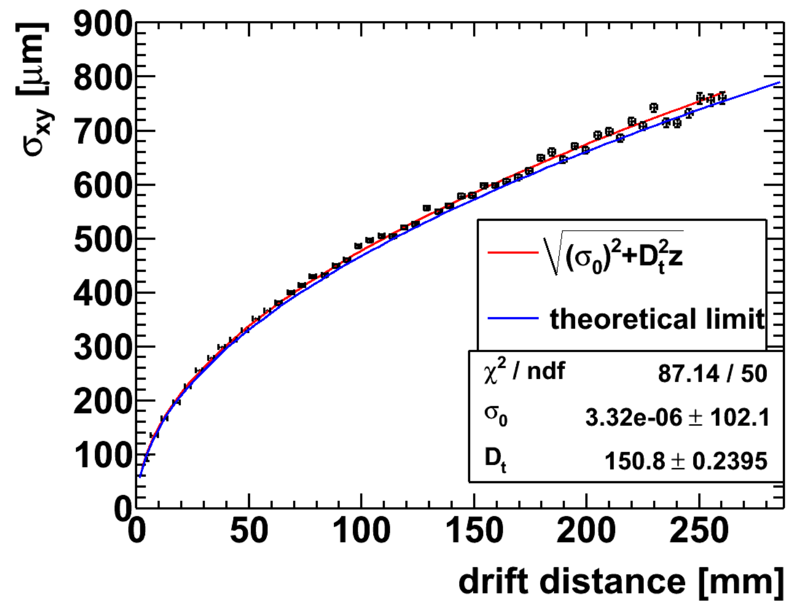
Application LCTPC





For the analysis only the area with no field distortions was used.
Larger areas, first an 8 chip module then an100 chip module are planned.
The gaps between chips must be made smaller in these modules.

Transverse spatial resolution right on diffusion limit of single electrons.
Theoretical limit:
$\sigma = D_t \sqrt{z}$
with diffusion coefficient
D_t calculated with Magboltz.



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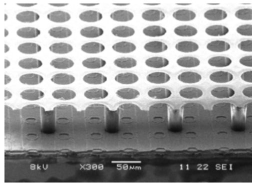
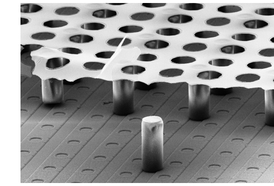
J. Kaminski
Industry-Academia Matching Event on MPGD,
26.4.2012, Annecy



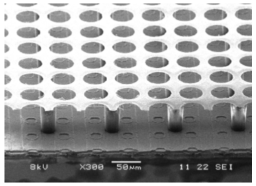
Industrial Application



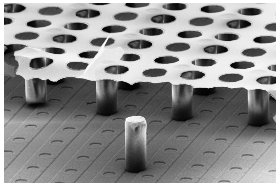
Still struggling on the academic level ☺,
but there is already one idea for industrialization:

A demonstrator TPC for educational purposes (for example schools)
This model could be based on 4 InGrids
read out with the ReLaXd electronics
a 5-10 cm drift volume
with Scintillator as triggering device
- possibly a magnetic field by permanent magnet

But this project needs funding!
- Needs one or two people to work full time (PhD.)
A first try for funding from the Dutch government was done by NIKHEF and U. Twente - but failed.



Summary and Outlook



- InGrids have shown excellent performance:
  - Energy resolution of $\sigma_E/E \sim 5\%$ (at 5.9 keV)
  - Spatial resolution only limited by diffusion.
  - High efficiency for single electron detection.
- Production techniques are well advanced, a few details (protection layer in particular) have to be optimized.
- Several readout systems optimized for compactness, speed or large systems have been developed and are commercially available.
- Large systems (~100 chips) will be operated next year
- Further R&D on InGrids are planned (resistive grid, all ceramic,...)
- New Timepix-3 should be available next year.

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
Cristoph Krieger, whose detector is used in the demonstration.