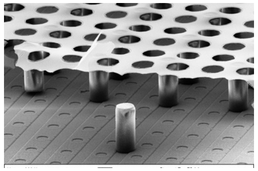

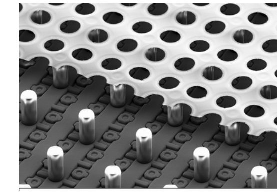

GridPix detector with Timepix3 ASIC

Jochen Kaminski, Yevgen Bilevych, Klaus Desch,
Kevin Heijhoff, Tobias Schiffer
University of Bonn

Fred Hartjes, Peter Kluit, Gerhard Raven,
Jan Timmermans, Harry van der Graaf
Nikhef, Amsterdam

GEFÖRDERT VOM

Bundesministerium
für Bildung
und Forschung

MPGD 2017
Philadelphia
22.-26.05.2017

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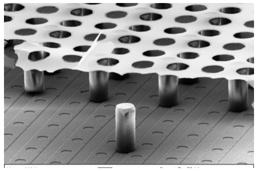
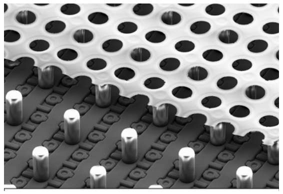
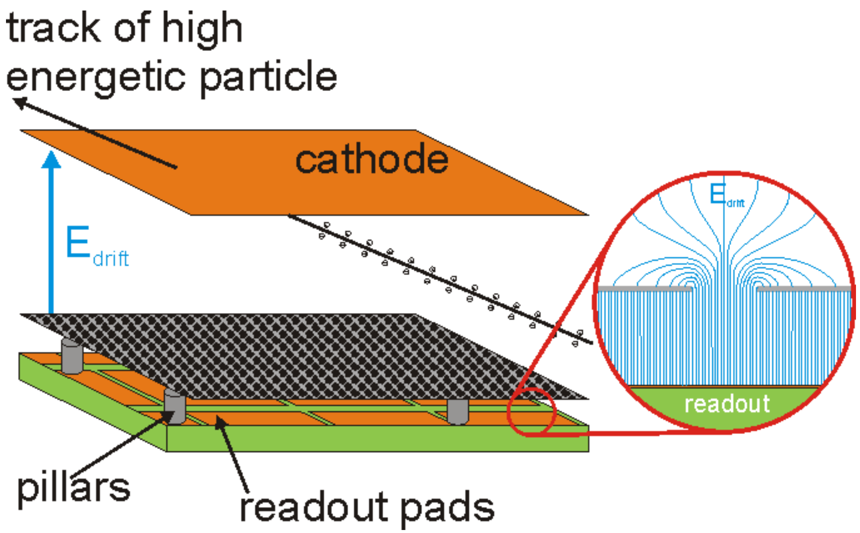
NIKHEF



Improving Micromegas: GridPix





Could the spatial resolution of single electrons be improved?

Ar:CH_4 90:10 → D_T = 208 μm/√cm

→ σ = 24 μm

Ar:iButane 95:5 → D_T = 211 μm/√cm

→ σ = 24 μm

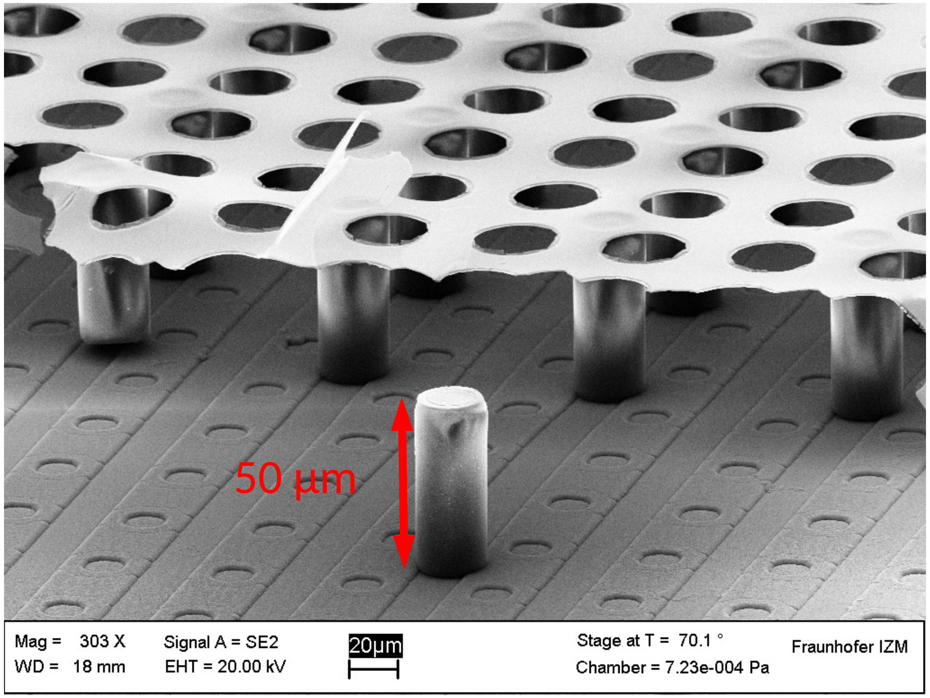
Smaller pads/pixels could result in better resolution!

At Nikhef the GridPix was invented.

Standard charge collection:

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

Instead: Bump bond pads are used as charge collection pads.



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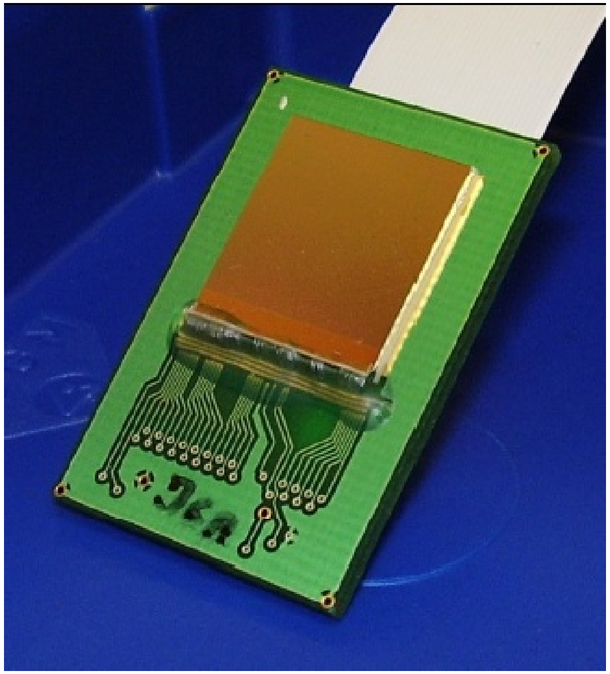
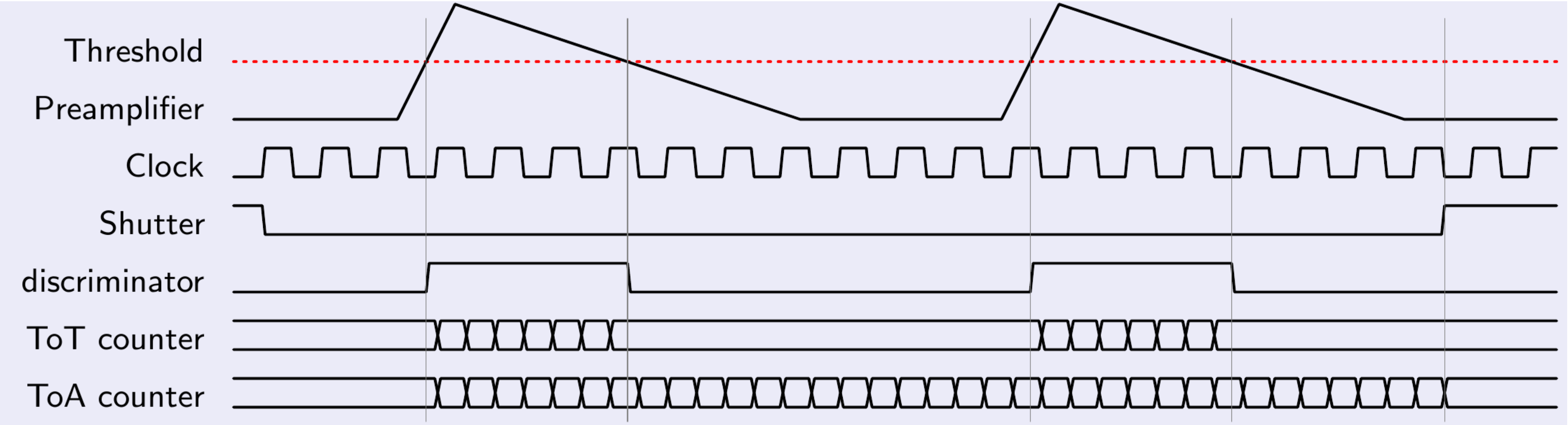
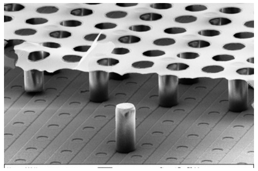
Timepix



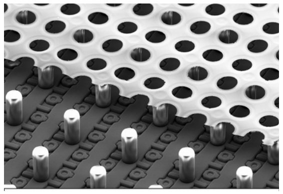
Number of pixels: 256 × 256 pixels
Pixel pitch: 55 × 55 µm²
Chip dimensions: 1.4 × 1.4 cm²
ENC: ~ 90 e⁻

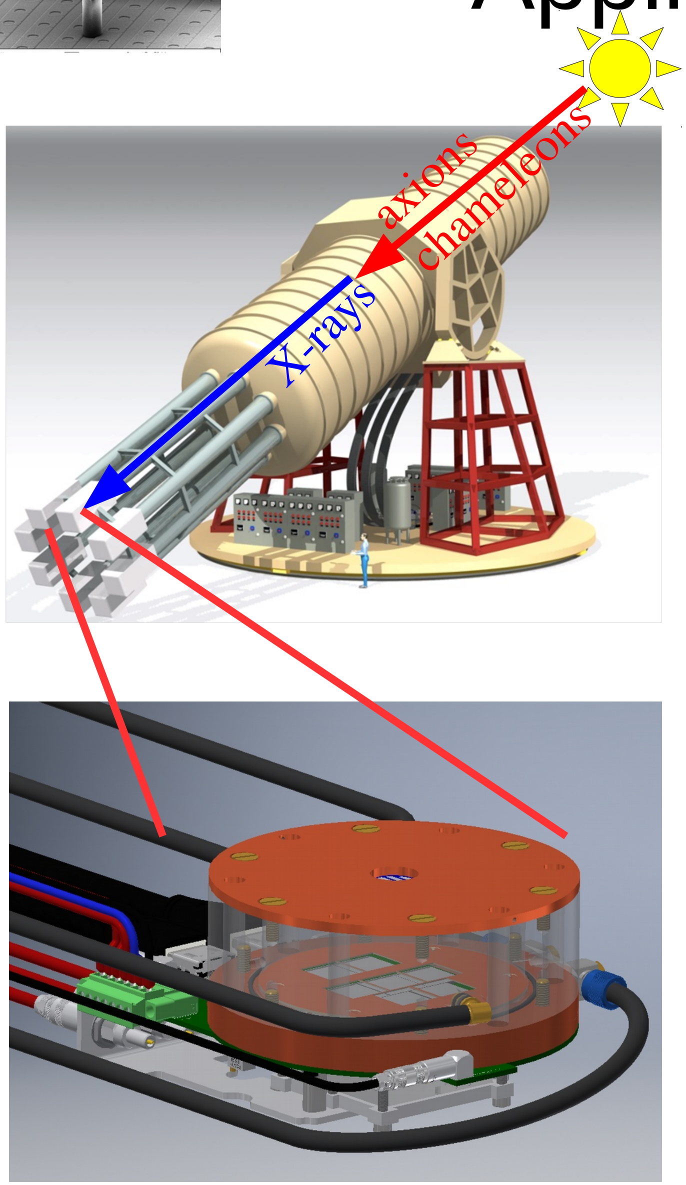
Limitations: no multi-hit capability, charge and time measurement not possible for one pixel.
Each pixel can be set to one of these modes: TOT = time over threshold (charge)
Time between hit and shutter end.





Application IAXO/CAST





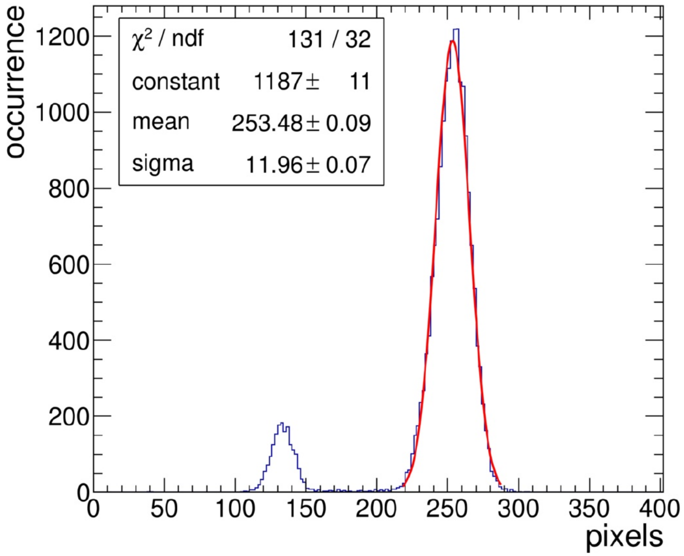
Magnet is pointed to the Sun. Axions and chameleons produced in the Sun convert into X-ray photons.

Detector requirements:

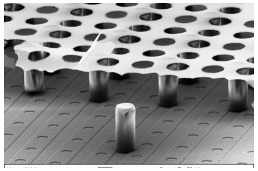
- Radiopure materials
- Good background separation (distinguish round X-rays and longer tracks)
- Good energy resolution
- Very low dead time

=> Detector optimized for spatial and energy resolution:

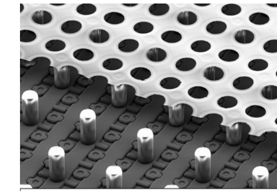
- Gas mixture ($Ar:iC_4H_{10}$: 97.7:2.3)
- Electric fields (E_{drift} = 500 V/cm)
- Gas gain (G~ 2500) and
- Analysis (pixel counting).



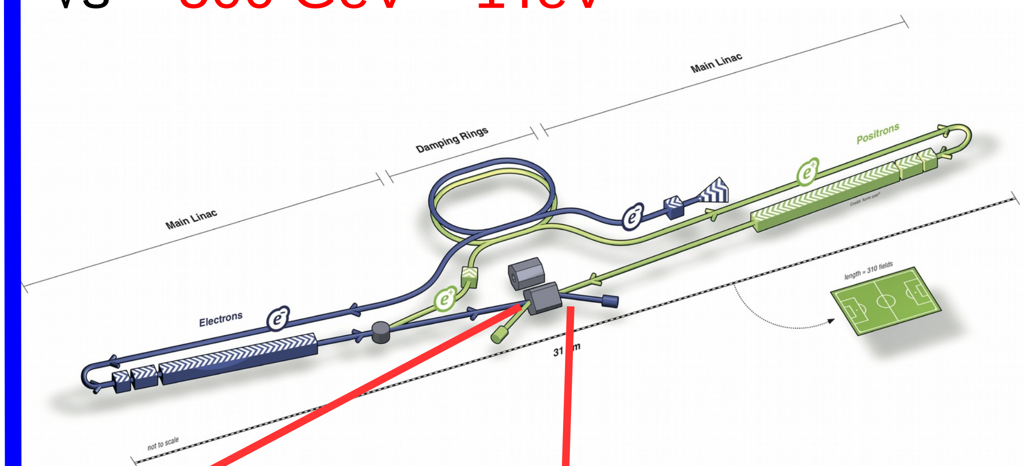
During the study energy resolutions of $\sigma_E/E=3.85\%$ for the photopeak of ^{55}Fe could be reached.

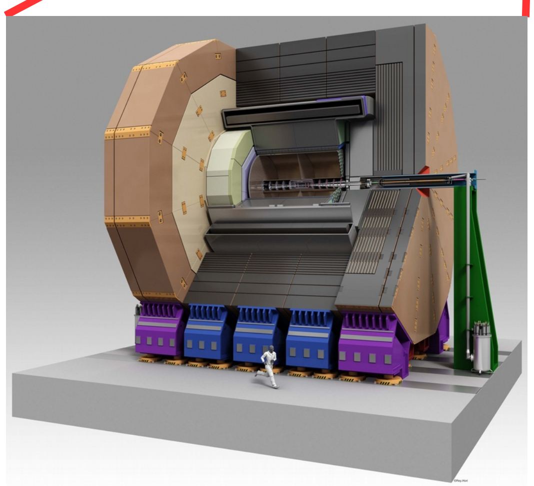


Application: ILC



International Linear Collider (ILC)
is a linear e^+e^- colliders with
$\sqrt{s}$ = 500 GeV – 1TeV





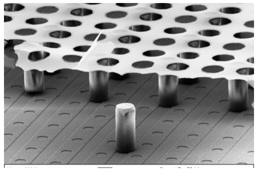
International Large Detector
- Standard HEP detector
- TPC as main tracker

TPC Requirements :

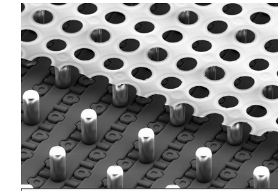
Parameter	
Geometrical parameters	r_{in} 329 mm, r_{out} 1808 mm, z $\pm$ 2350 mm
Solid angle coverage	up to $\cos\theta \simeq 0.98$ (10 pad rows)
TPC material budget	$\simeq 0.05\ X_0$ including outer fieldcage in r
	$< 0.25\ X_0$ for readout endcaps in z
Number of pads/timebuckets	$\simeq$ 1-2 $\times 10^6$/1000 per endcap
Pad pitch/ no.padrows	$\simeq 1\times 6\ mm^2$ for 220 padrows
σ_{point} in $r\phi$	$\simeq 60\ \mu m$ for zero drift, $< 100\ \mu m$ overall
σ_{point} in rz	$\simeq 0.4 - 1.4$ mm (for zero – full drift)
2-hit resolution in $r\phi$	$\simeq 2$ mm
2-hit resolution in rz	$\simeq 6$ mm
dE/dx resolution	$\simeq 5$ %
Momentum resolution at B=3.5 T	$\delta(1/p_t) \simeq 10^{-4}$/GeV/c (TPC only)

Benefits of GridPix readout:
- Lower occupancy → better track finding
- Identification/removal of δ-rays/kinks
- Improved dE/dx → primary e^- counting

But to readout the TPC with GridPixes:
~100-120 chips/module 240 module/endcap (10 m²)
→50k-60k GridPixes

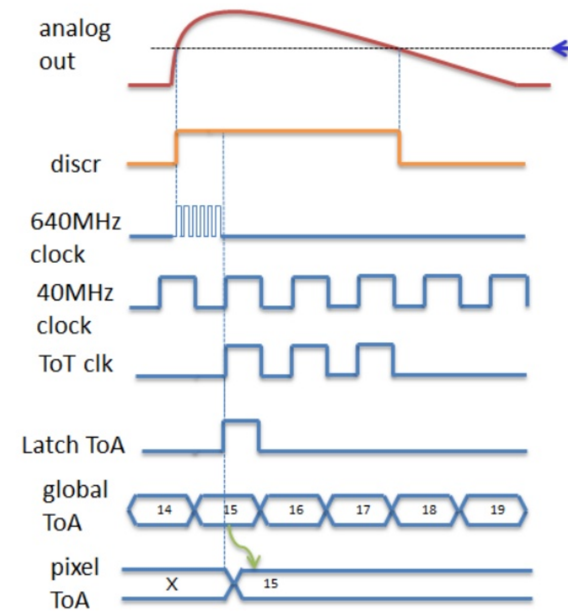


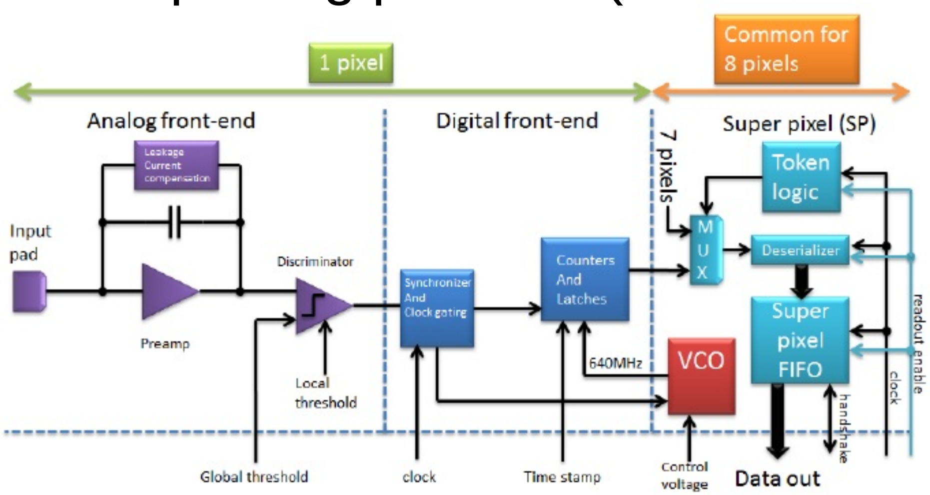
Timepix3

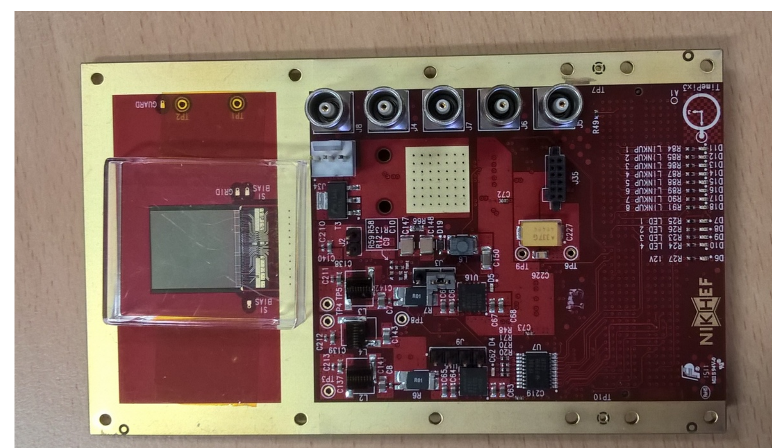


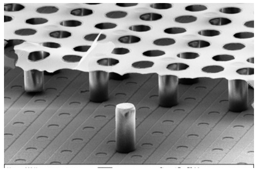
- Number of pixels: 256 × 256 pixels
- Pixel pitch: 55 × 55 µm²
- ENC: ~ 60 e$^-$
- Charge (ToT) and time (ToA) available for each hit
- Timing resolution: 1.56 ns for duration of ~410 µs
- Zero suppression on chip (sparse readout)
- Multi-hit capable (pixels sensitive after t_{ToT}+475 ns)

  Super-pixels store hits for some time
- Output rate up to 5.12 Gbps
- Power pulsing possible (800 ns for start up)

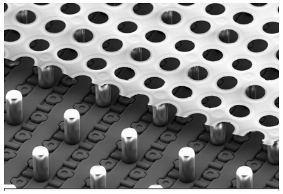




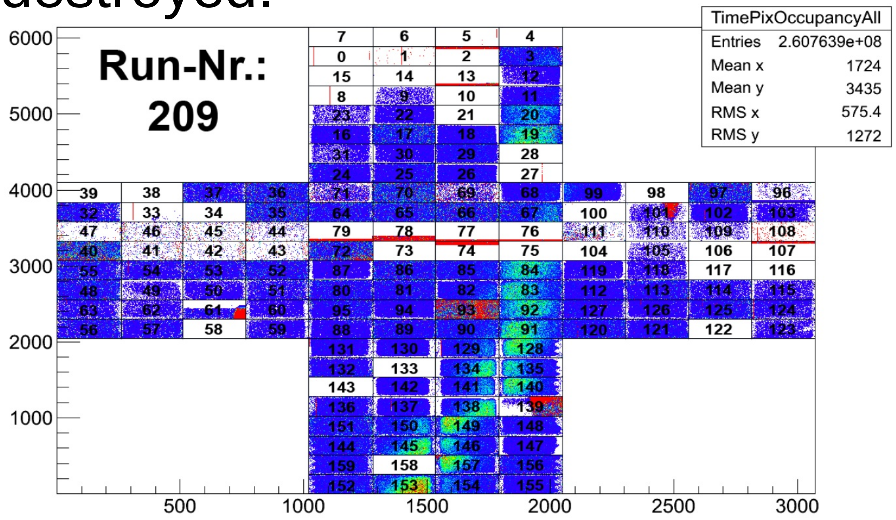


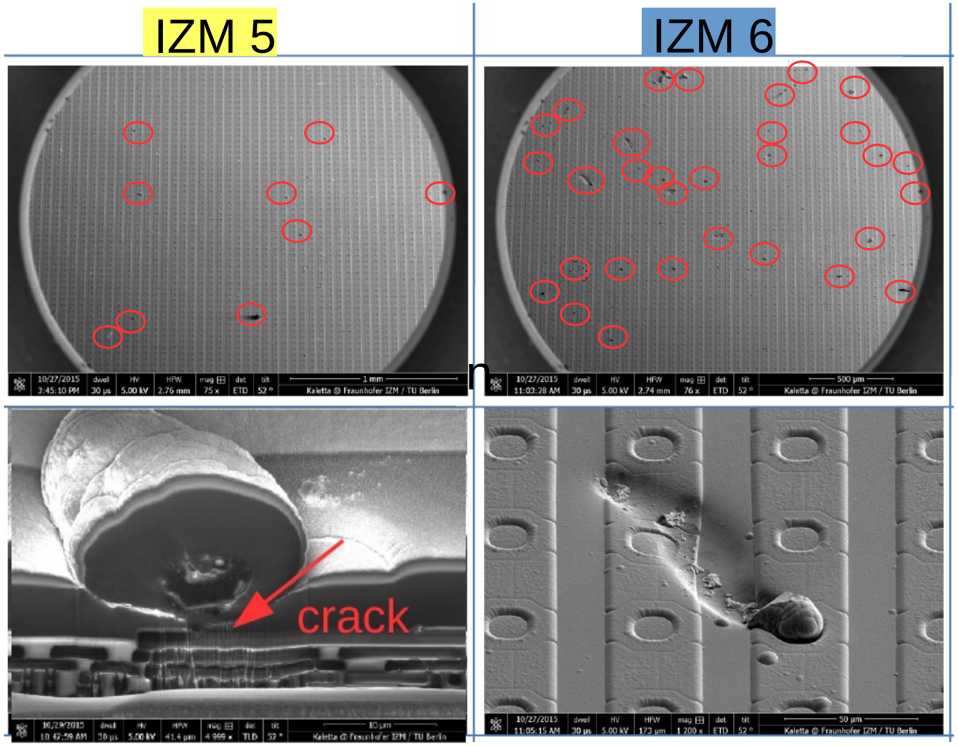


Protection Layer



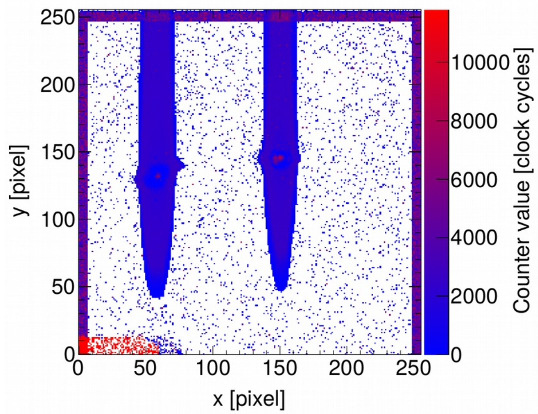
During a 2 week test beam (5 GeV e^-) about 18 out of 160 chips were destroyed.



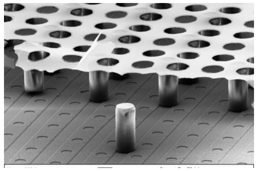


<u>Reason identified:</u> Machine depositing Si_xN_y caused defects in the protective layer during growths.

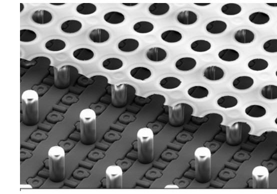
Process has been switched to a different machine.
→ no defects anymore



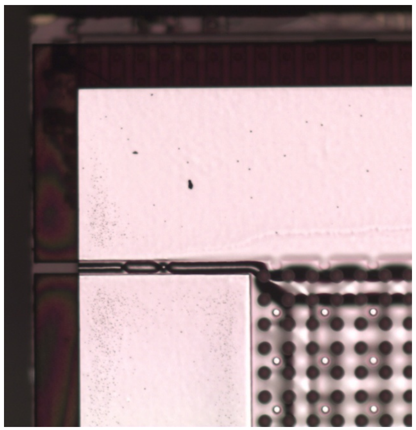
Detector at 550V shows constant discharges: $>10^7$ discharges in a few hours
→ Detector still works and shows good σ_E/E afterward

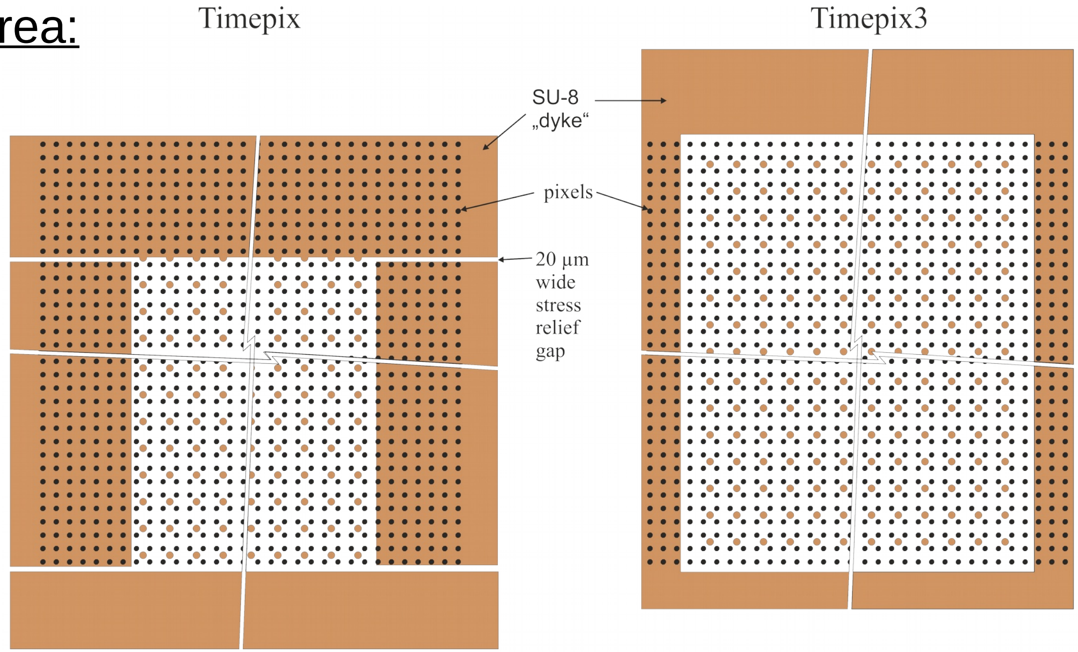


New Grid Design



Increase sensitive area:



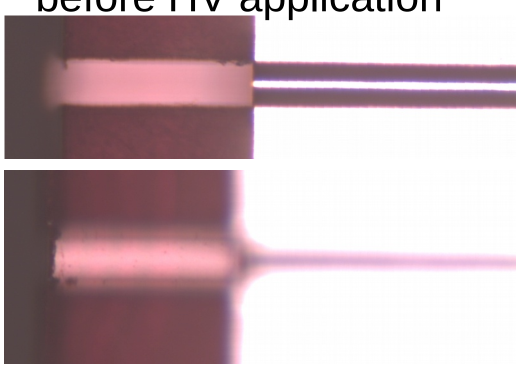


5762 of 65536 pixels covered => loss of 8.7 % of active area

1536 of 65536 pixels covered => loss of 2.3 % of active area

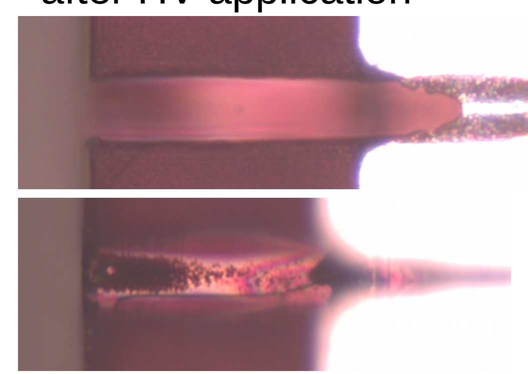
Remove stress relief gaps:

before HV application



Grid sags in the stress relief gaps.
At high gains these places are prone for discharges.
=> gaps have been removed

after HV application



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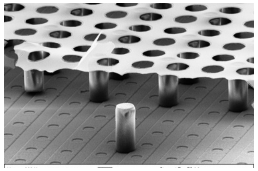
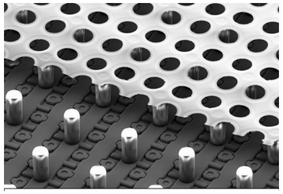
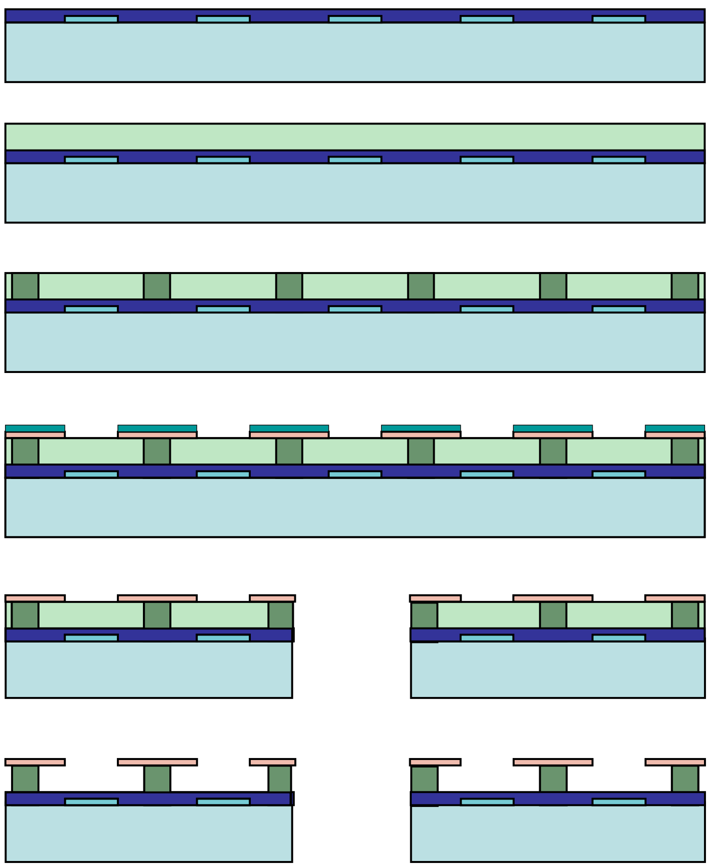


Production at IZM



Production was set up at the Fraunhofer Institut IZM at Berlin.
This process is wafer-based → batches of up to 4 wafers (105 chips each) at a time.



1. Formation of Si_xN_y protection layer (to protect chip from discharges)
2. Deposition of SU-8
3. Pillar structure formation
4. Formation of Al grid
5. Dicing of wafer
6. Development of SU-8

Fraunhofer IZM

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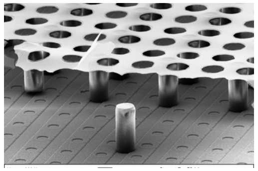
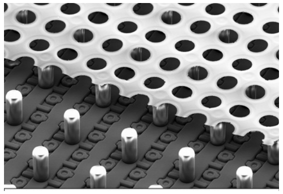
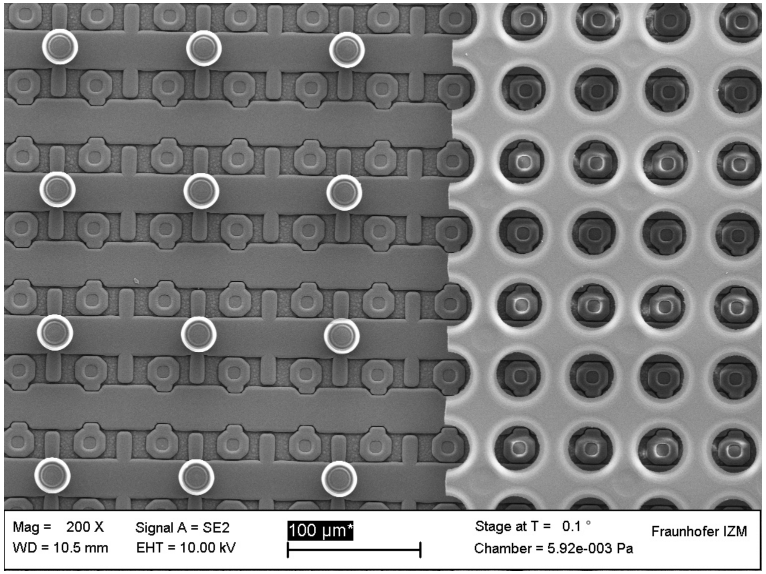
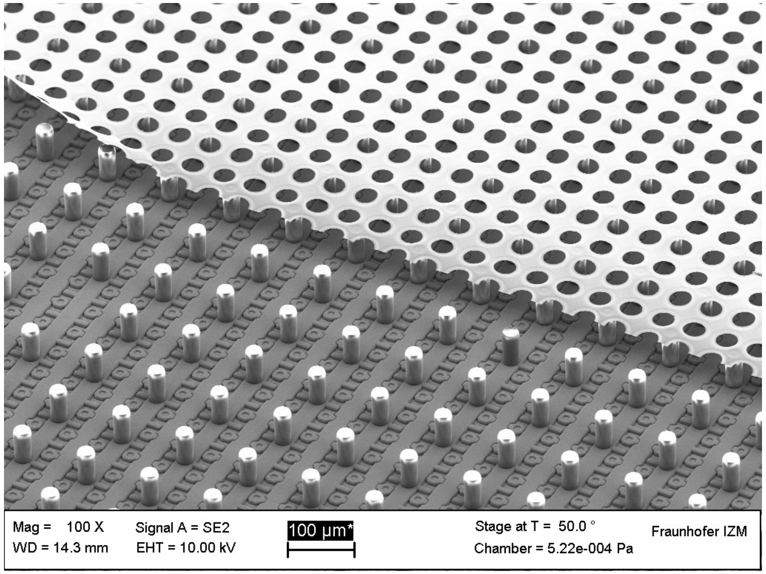


Pictures

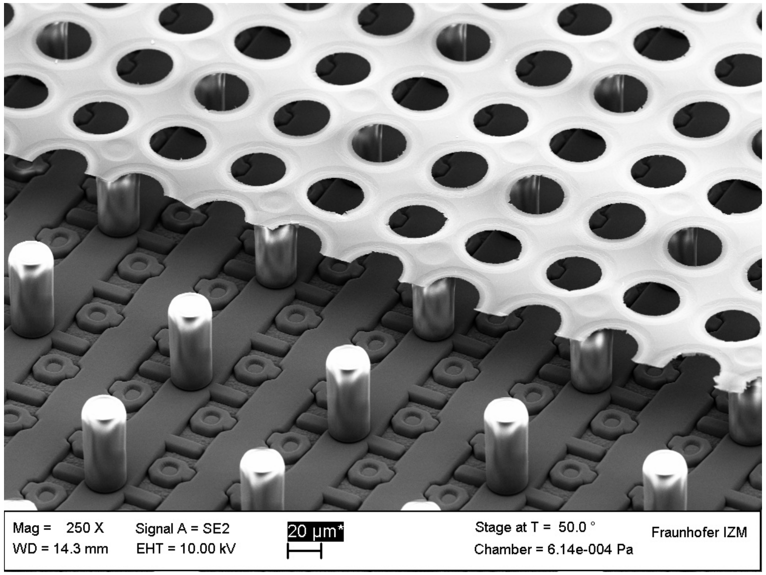




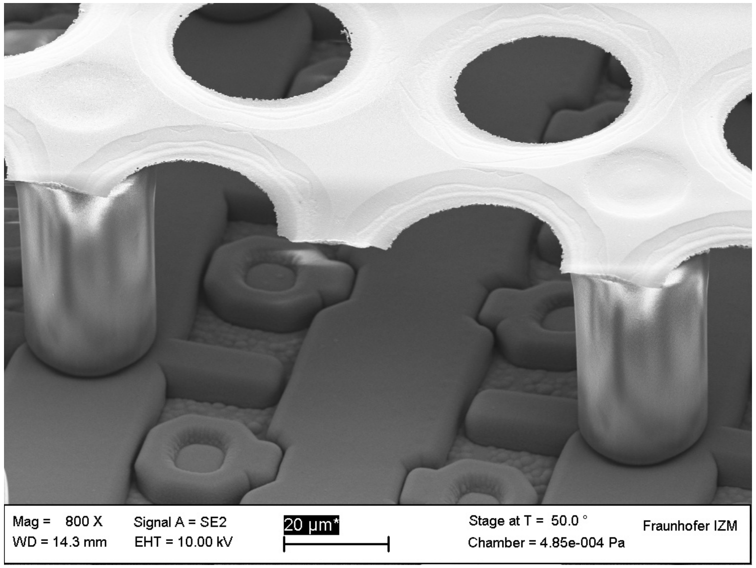
Mag = 200 X
WD = 10.5 mm
Signal A = SE2
EHT = 10.00 kV
100 µm*
Stage at T = 0.1 °
Chamber = 5.92e-003 Pa
Fraunhofer IZM



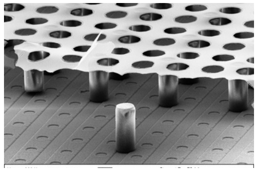
Mag = 100 X
WD = 14.3 mm
Signal A = SE2
EHT = 10.00 kV
100 µm*
Stage at T = 50.0 °
Chamber = 5.22e-004 Pa
Fraunhofer IZM



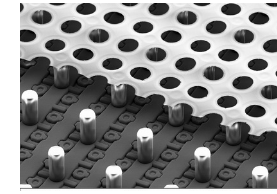
Mag = 250 X
WD = 14.3 mm
Signal A = SE2
EHT = 10.00 kV
20 µm*
Stage at T = 50.0 °
Chamber = 6.14e-004 Pa
Fraunhofer IZM

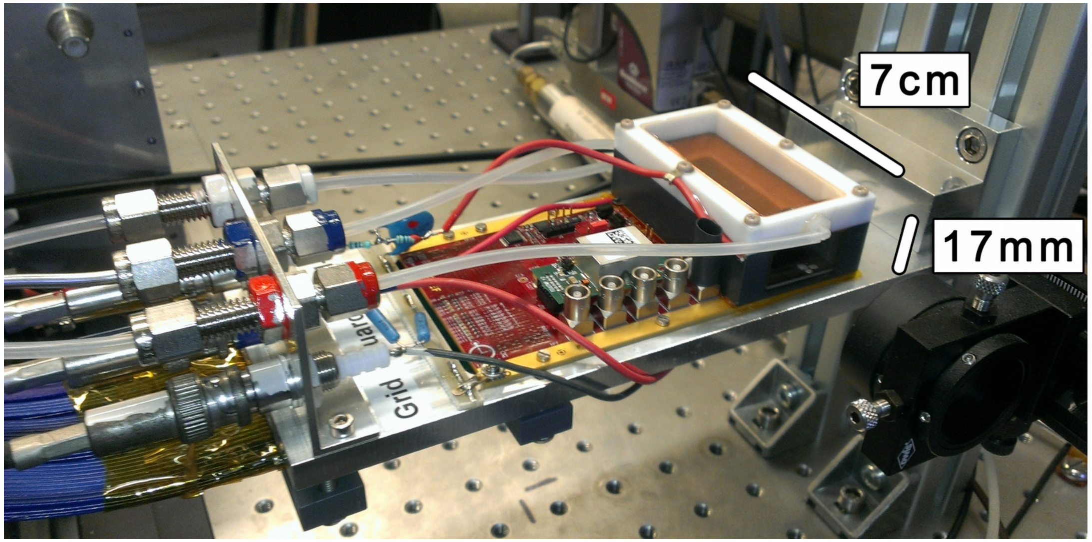


Mag = 800 X
WD = 14.3 mm
Signal A = SE2
EHT = 10.00 kV
20 µm*
Stage at T = 50.0 °
Chamber = 4.85e-004 Pa
Fraunhofer IZM



First GridPix-Detector with TP3





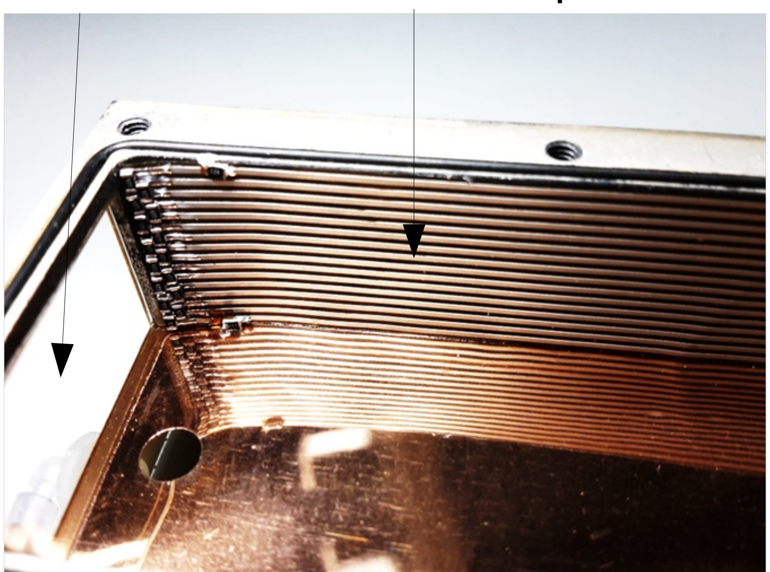
Gas: Ar:CF_4:iButane 95:3:2

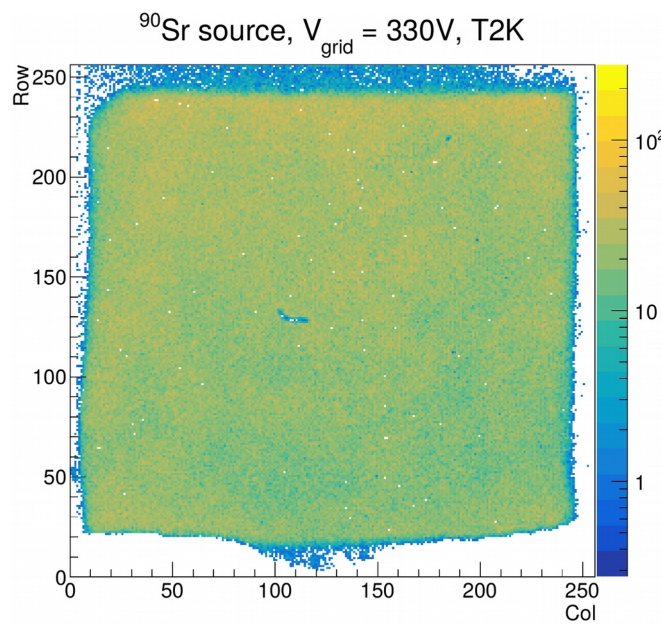
E_{drift}: 200 V/cm

d_{max}: 17 mm

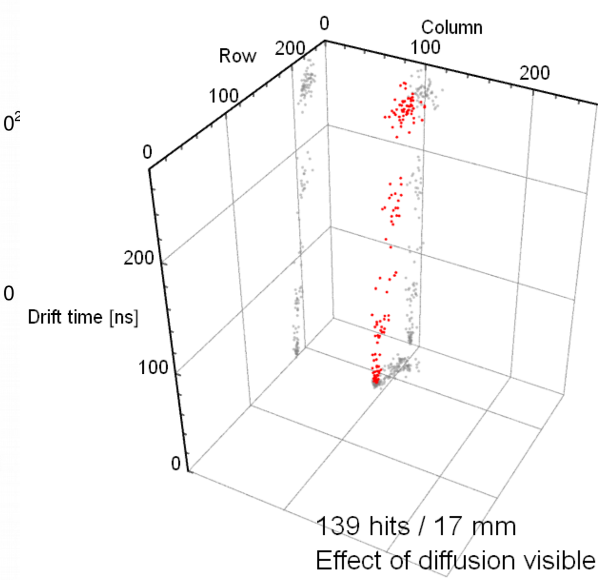
window

Field shaper

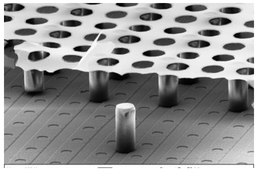


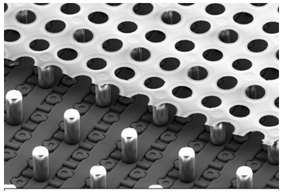


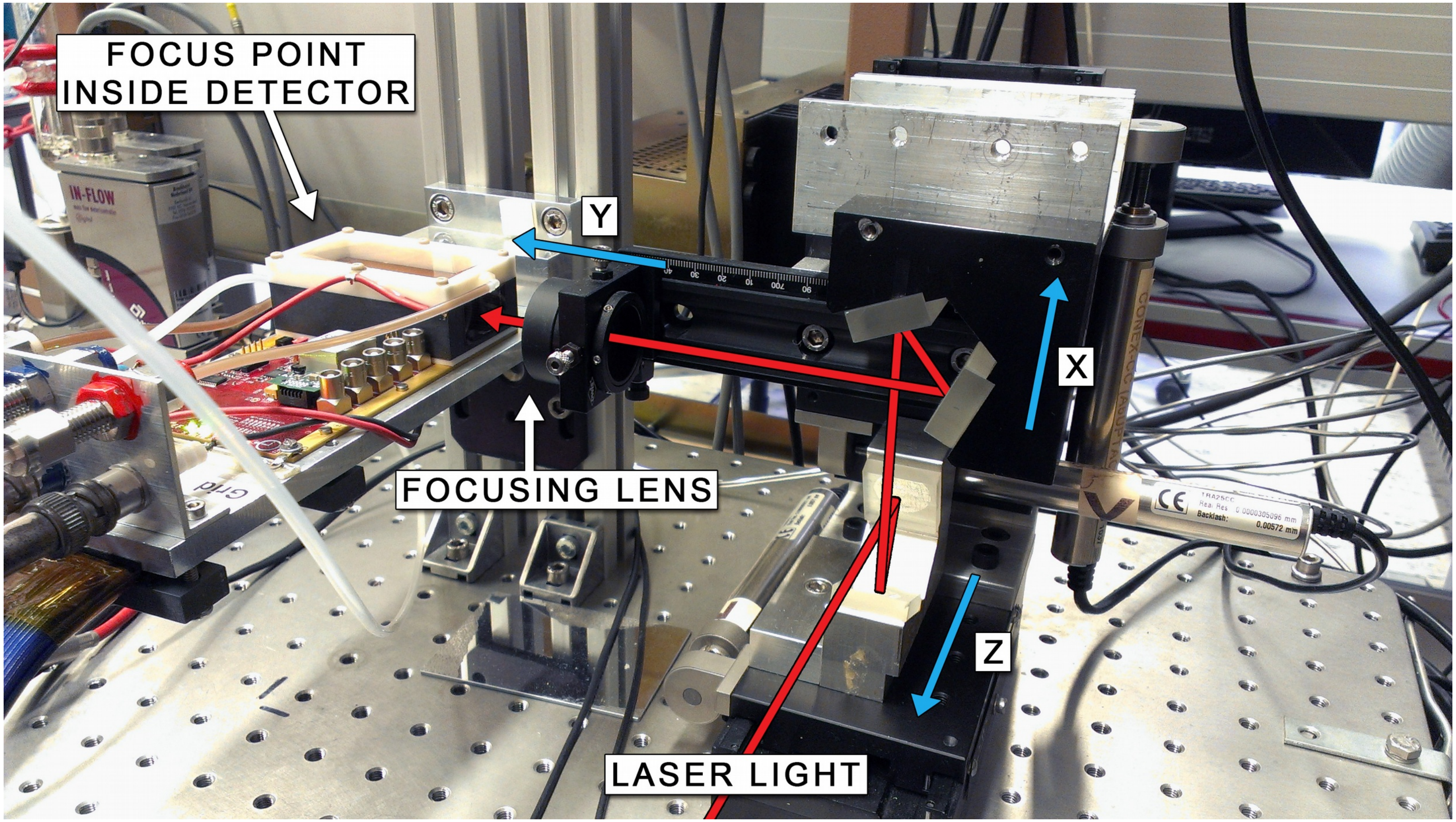
Cosmic muon



Laser Setup at Nikhef

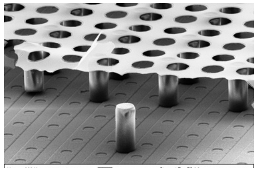




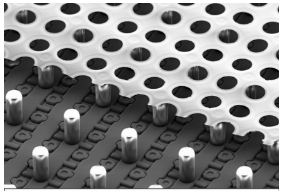


- pulsed UV nitrogen laser
  λ = 337 nm
- duration:
  1 ns
- energy:
  few µJ

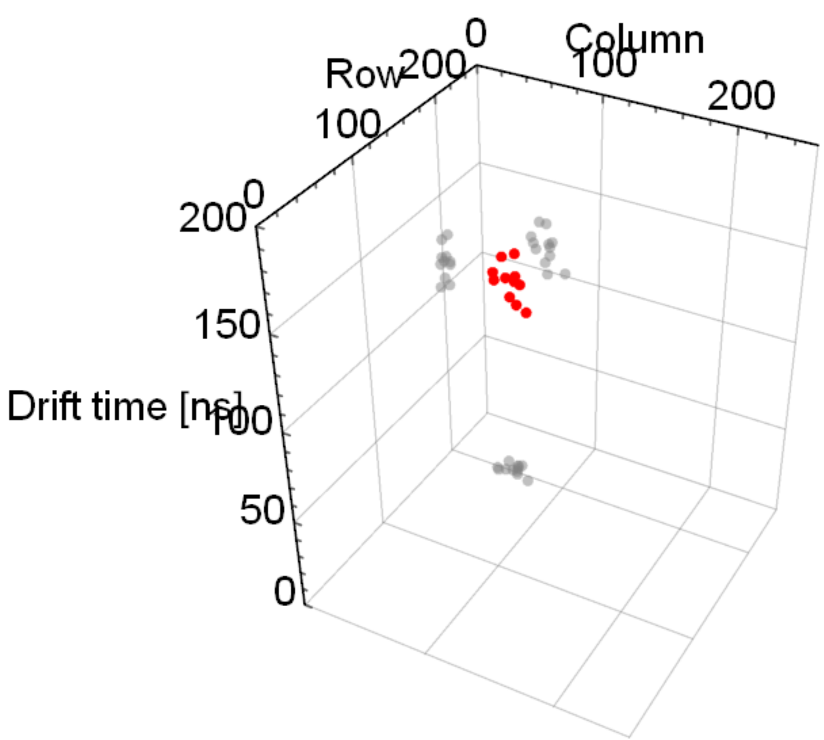
- divergence: near diffraction limit
- double photon absorption, ionization enhanced by traces of TMPD
  => ionization is merely confined to the focal point

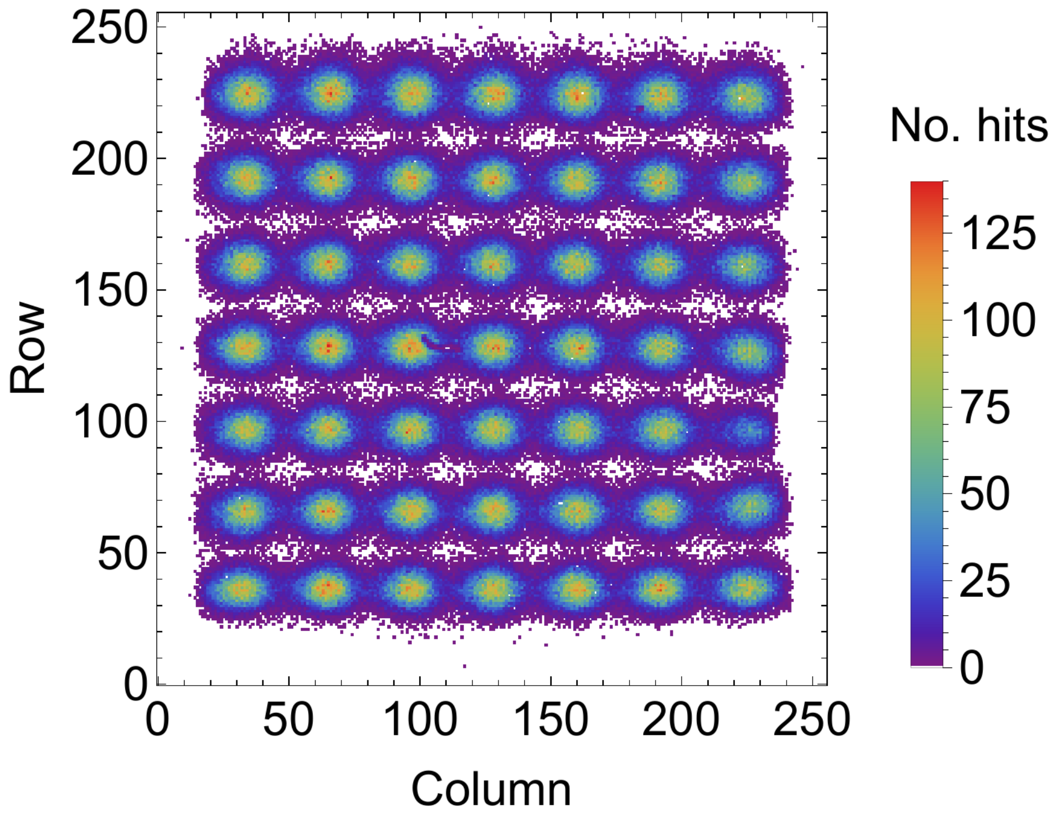


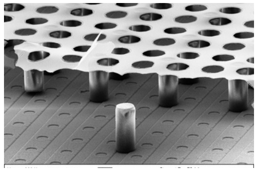
Events



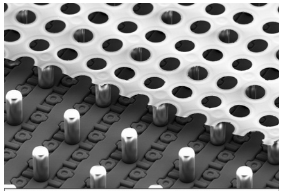
- About 10 hits per laser pulse
- 960 laser pulses per spot
- Measured spot size dominated by diffusion. About 5 pixels (standard deviation) in the example on the right.







Gas Parameters

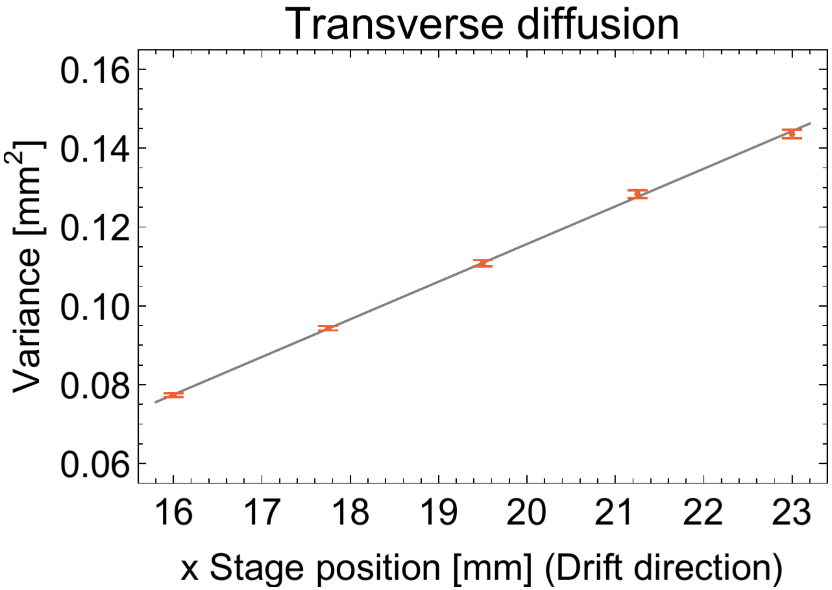


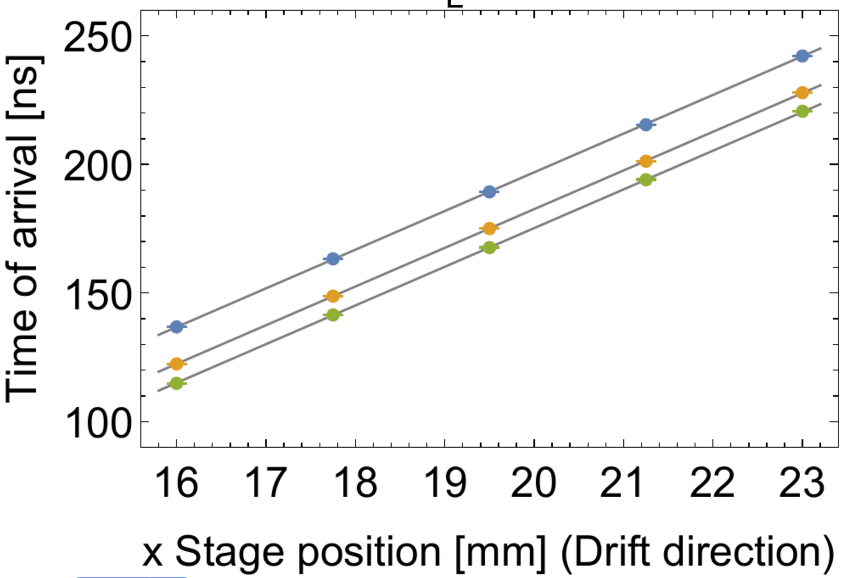
Absolute position of laser not known
→ use differences of two laser positions

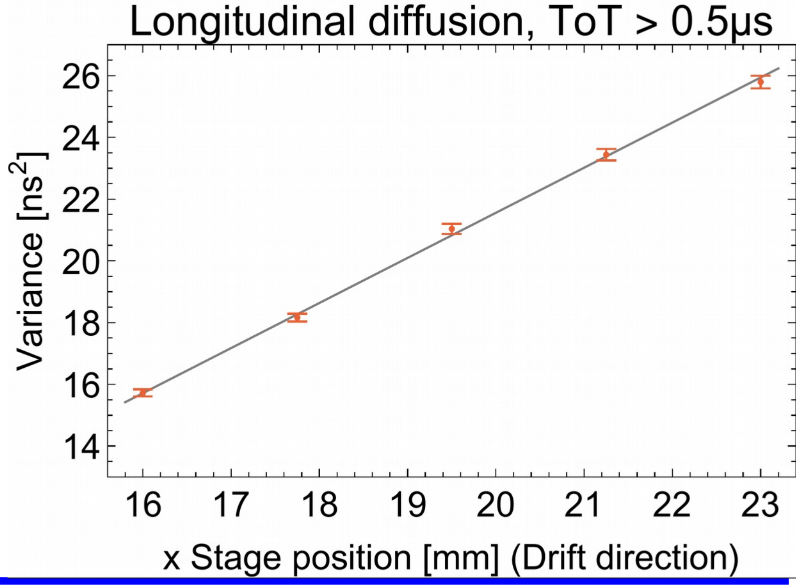
Drift velocity: 6.6480±0.007 cm/μs
Because of time walk: split data according to collected charge

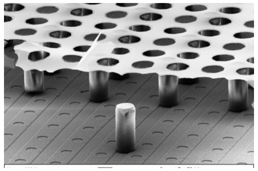
Spatial variance of charge distribution:
Transverse diff. $D_T = 309.0 \pm 2.2\ \mu m/\sqrt{cm}$

Time variance of charge distribution:
Longitudinal diff. $D_L = 254.1 \pm 2.7\ \mu m/\sqrt{cm}$

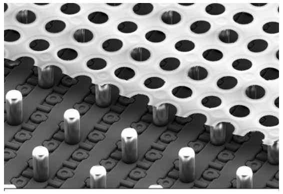




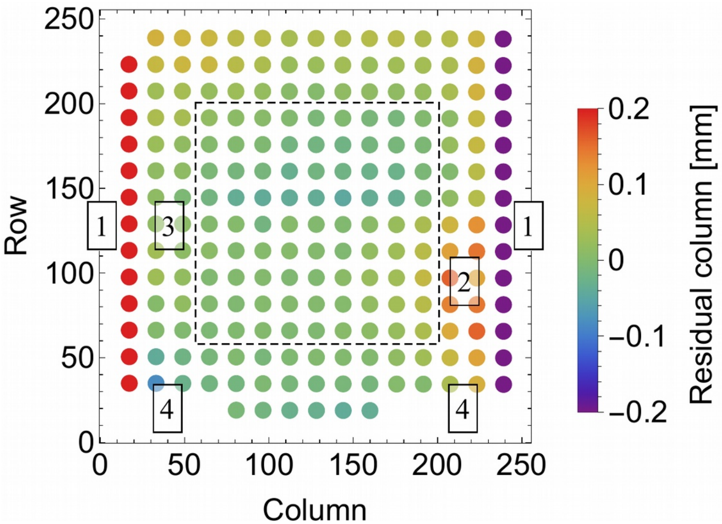


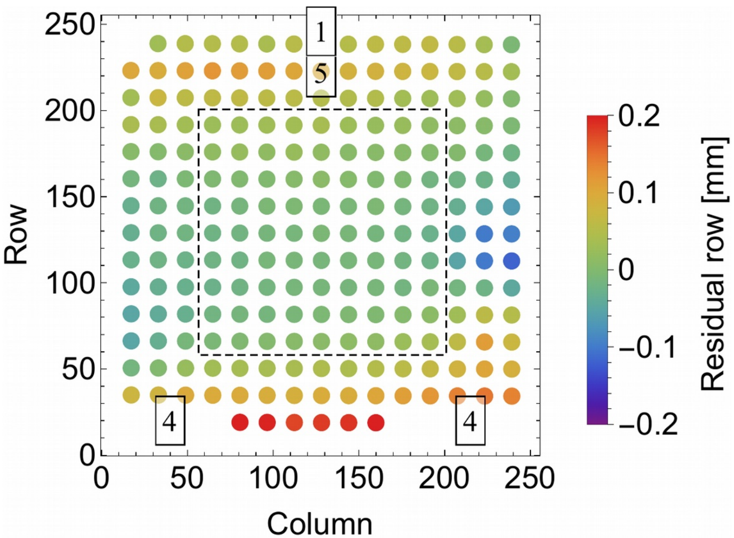


Spatial Resolution



Residuals in x and y of each laser dot



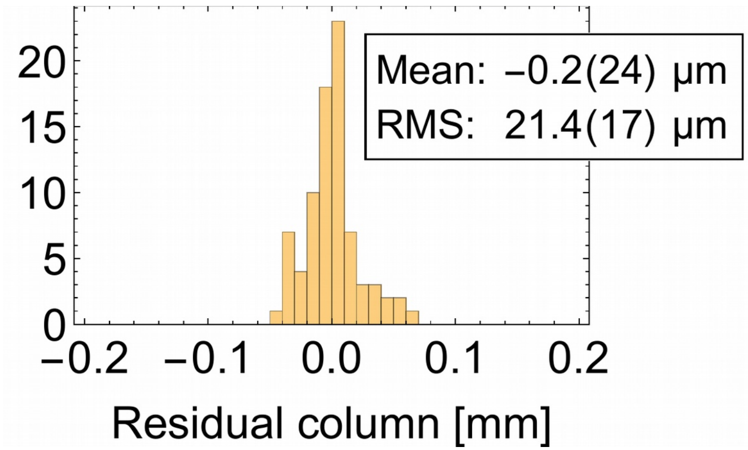


Outer part of detector shows larger residuals because of field distortions and grid inefficiencies. Central part has a very small residual distributions.

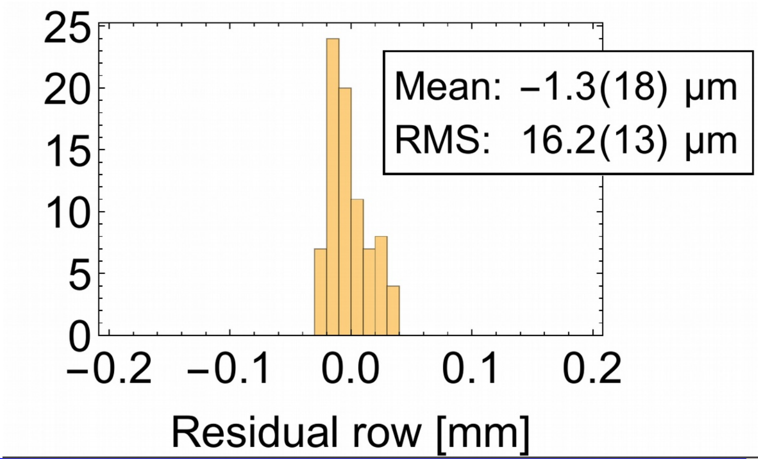
d = 7.6 mm

N_{pulses} = 960

=> spatial res. ~ 20 µm



1. partially contained dots
2. low efficiency pixels
3. field distortions due to field cage
4. grid peeling off
5. guard electrode distorted



Plans New Module

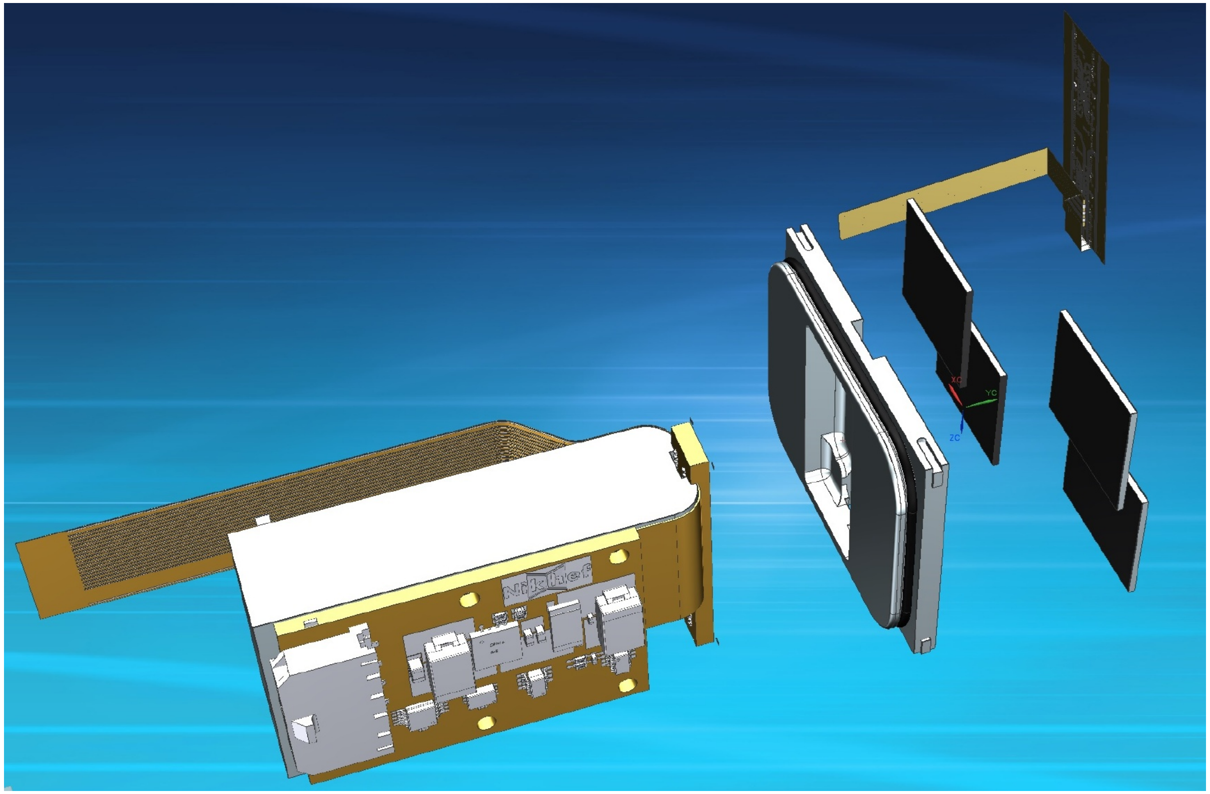
Longterm plan: built a LCTPC – module with about 100 GridPixes

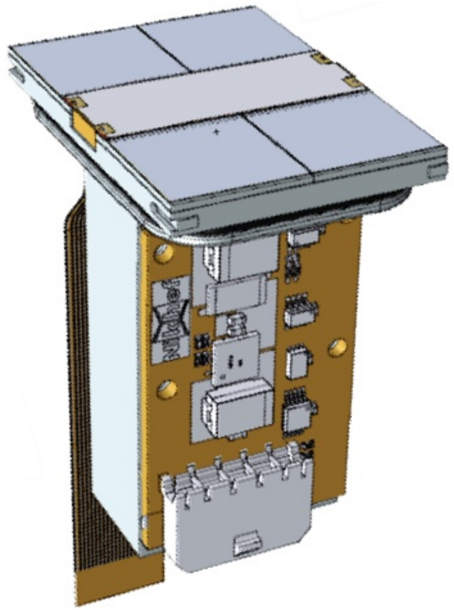
Module size: 22×17 cm² – keystone shaped

GridPixes are grouped into smaller units (4-8 GridPixes)

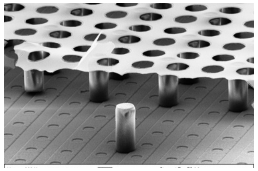
Short term plan: start with a module equipped with 1 or 2 of the small units

Currently: Quads, designed to minimize the dead area

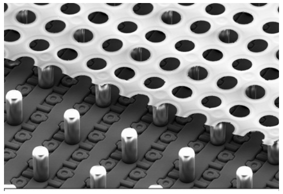




Quad assembly



Summary



GridPix based on Timepix has demonstrated good performance in several applications. But limited because of Timepix performance.

New ASIC, Timepix3, has been developed which has multi-hit capability, a time resolution of 1.56 ns, gives charge and time information for each pixel and has a continuous readout.

InGrids have been built on top of Timepix3 forming new GridPixes. For this
- the quality of the protections layer has been improved
- the grid layout has been modified to decrease the covered pixels from 8.7 % to 2.3 %.

A detector has been built and tested with a laser setup.
Good performance could be demonstrated at the center of the chip.
E-field distortion expected from detector design.

First test beam with Timepix3 detector at 3 GeV e^- facility at Bonn in June.

New larger area detectors are in preparation.