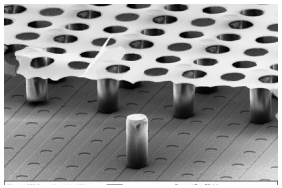
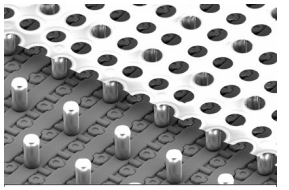




GridPixes and their Application

Jochen Kaminski

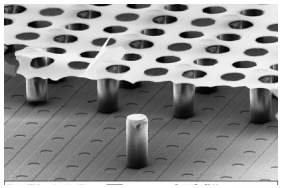
University of Bonn

GEFÖRDERT VOM

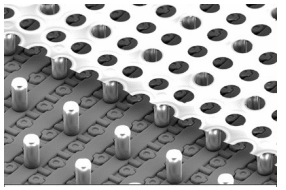
Bundesministerium
für Bildung
und Forschung

MPGD conference
Tel Aviv
13.12.2022

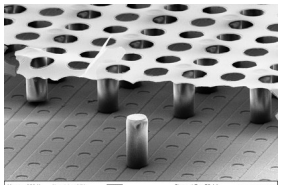
UNIVERSITÄT BONN



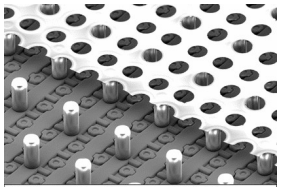
Content

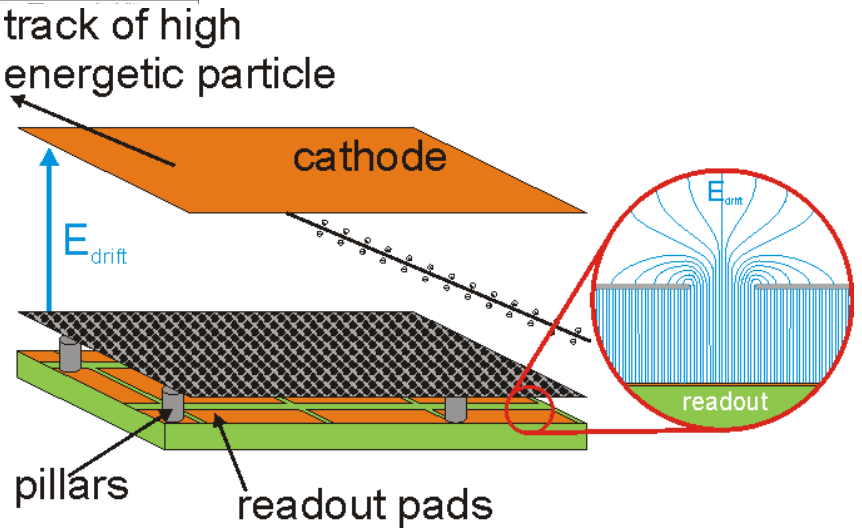


- GridPix Detectors
- X-ray Photon Detector for Axion Searches
- TPC Readout at future Higgs factories
- GridPix for X-ray Polarimetry
- GridPix in Neutron Detectors
- GridPix in a Negative Ion TPC
- GridPix in educational detectors



From Micromegas to GridPix





Could the spatial resolution of single electrons be improved?

Diffusion in amplification region:

$Ar:CO_2$ 80:20 → σ = 11 µm

$Ar:iC_4H_{10}$ 95:5 → σ = 11 µm

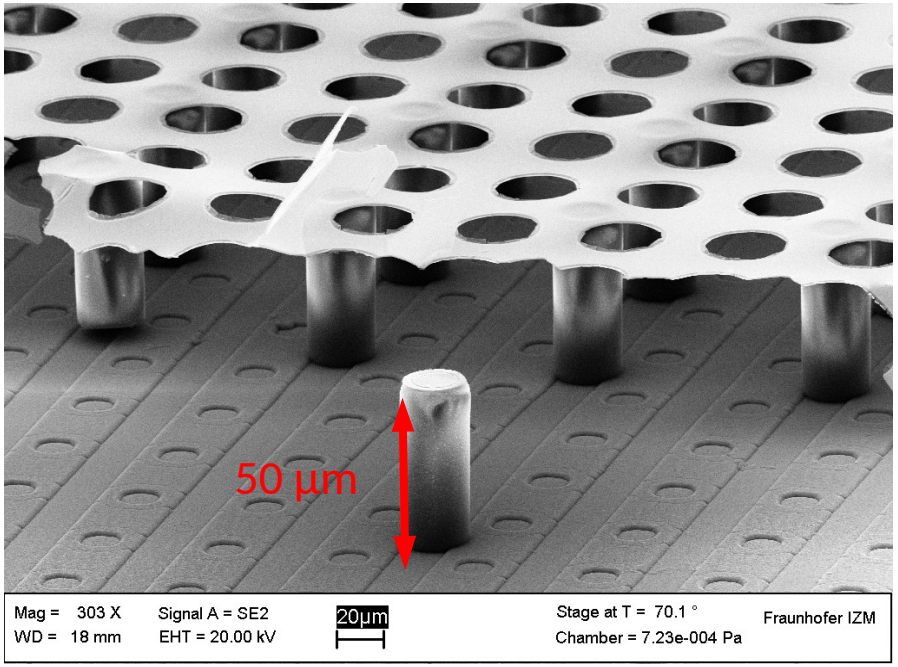
$Ar:CF_4:iC_4H_{10}$ 95:3:2 → σ = 11 µm

Smaller pads/pixels could result in better resolution!

At NIKHEF the GridPix was invented.

Standard charge collection:
Pads / long strips

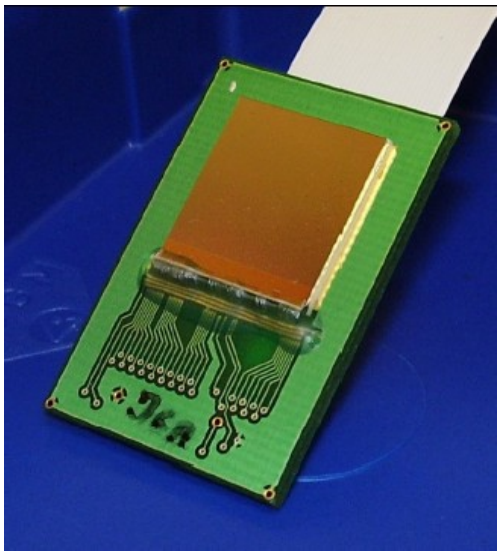
Instead: Bump bond pads are used as charge collection pads.



Charge avalanche is collected by one pixel

→ one hit corresponds to one primary electron

The ASICs - Timepix(3)



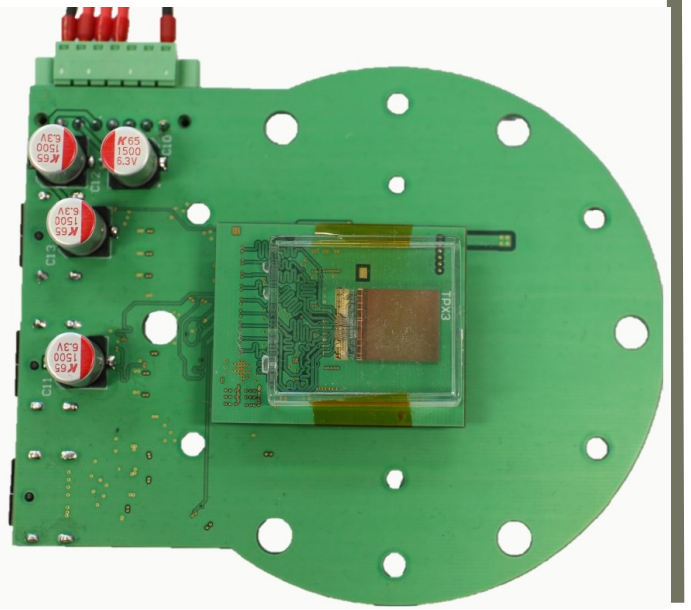
Timepix: Available for tests since Nov. 2006

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

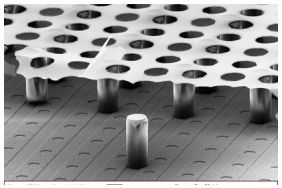
Limitations: no multi-hit capability.
Each pixel can measure either charge or time.

Timepix3: Available for tests since 2012

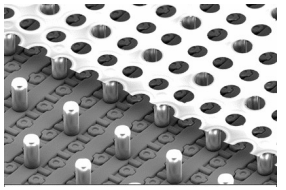
Number of pixels: 256 × 256 pixels
Pixel pitch: 55 × 55 µm²
ENC: ~ 70 e^-



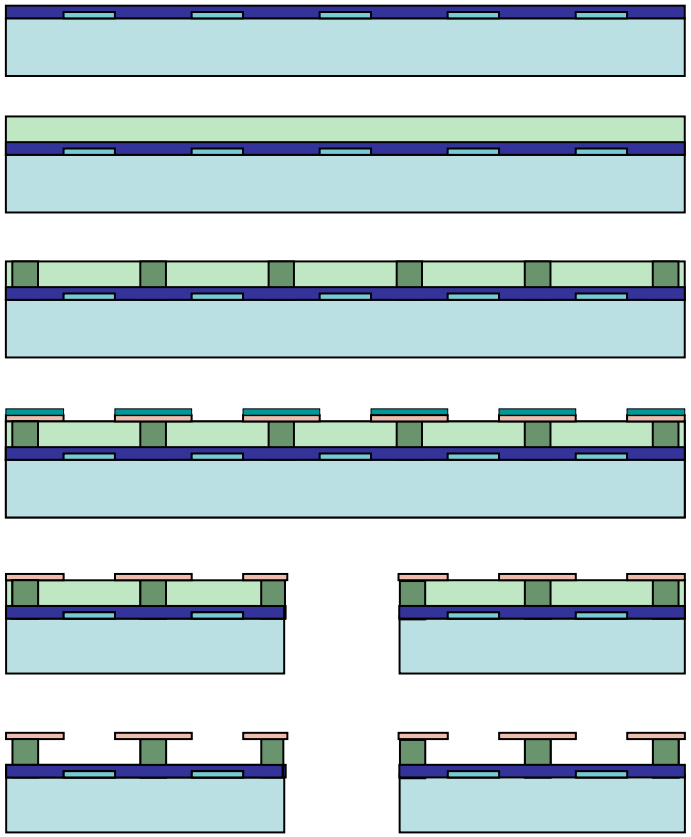
- Charge (ToT) and time (ToA) available for each hit
- Timing resolution: 1.56 ns for duration of ~410 µs
- Zero suppression on chip (sparse readout)
- Multi-hit capable
- Output rate up to 5.12 Gbps



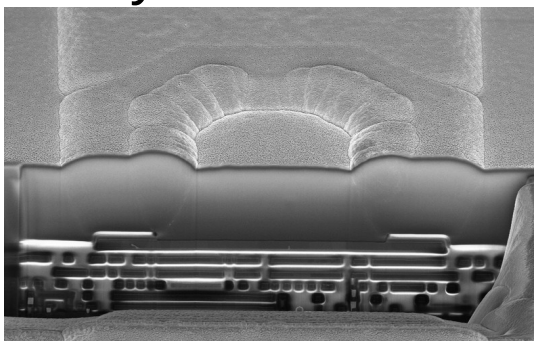
GridPix - Production

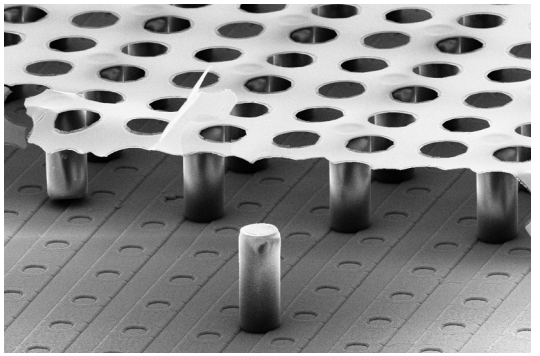


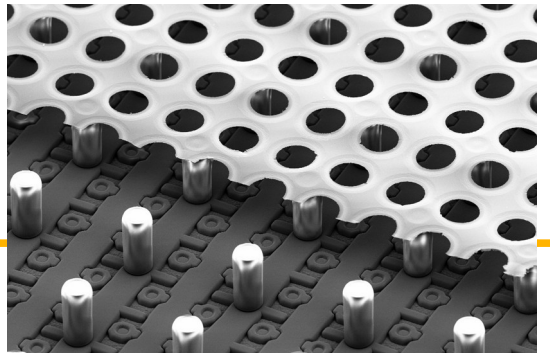
A wafer-based production was set up at the Fraunhofer Institut IZM at Berlin. One wafer (107 chips) is processed at a time.



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

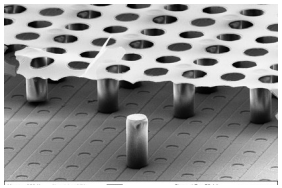




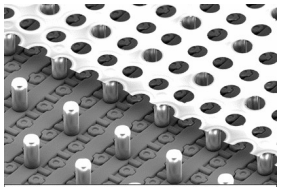


The process will be transferred to the FTD at Bonn in 2023/24.

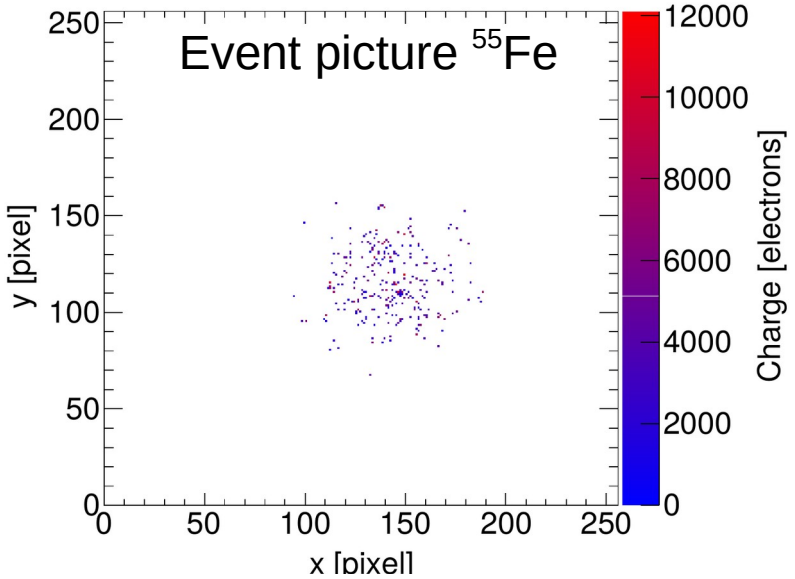
See talk by M. Ball

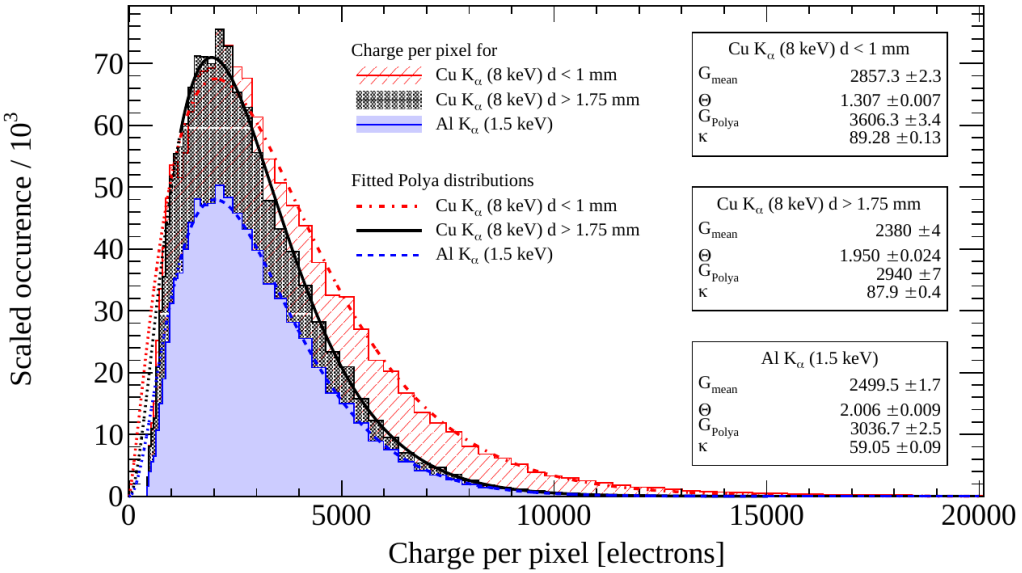


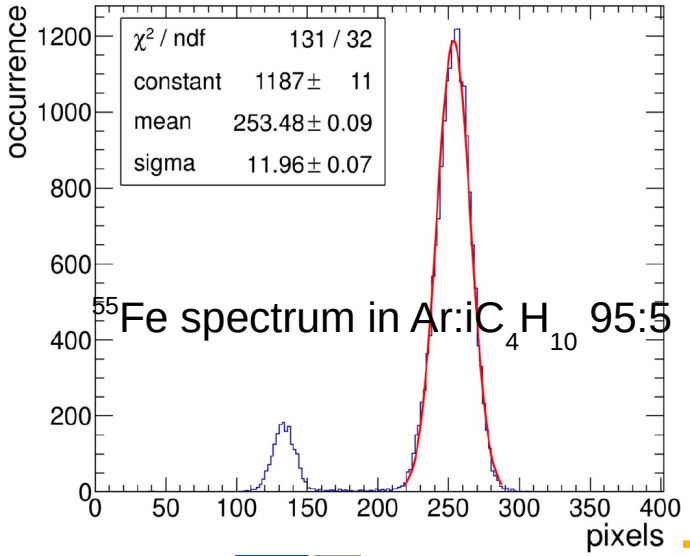
GridPix – Single Primary Electrons



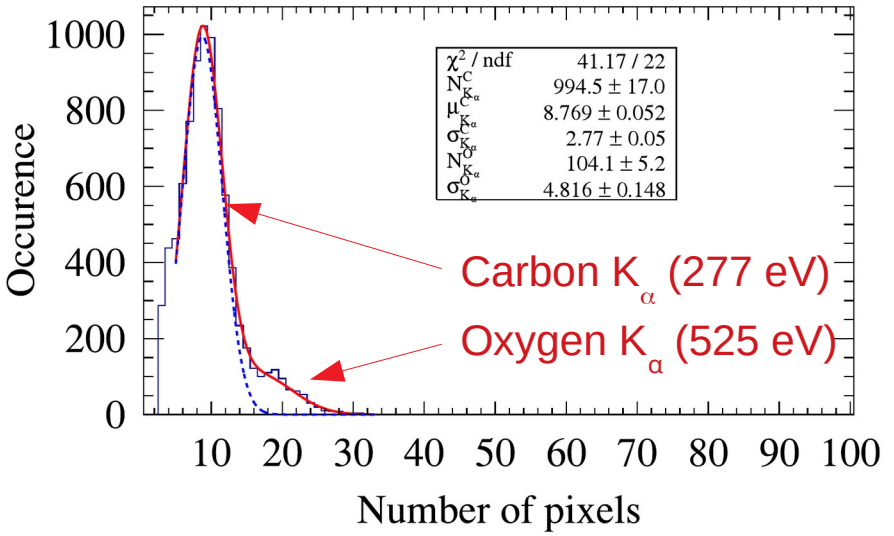
Single primary electrons can be counted leading to excellent energy resolution.



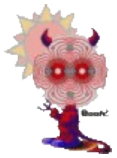


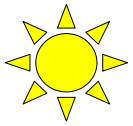


Energy resol. σ_E/E of down to 3.85 % was reached in Ar:iC$_4$H$_{10}$ 90:10 at 5.9 keV.

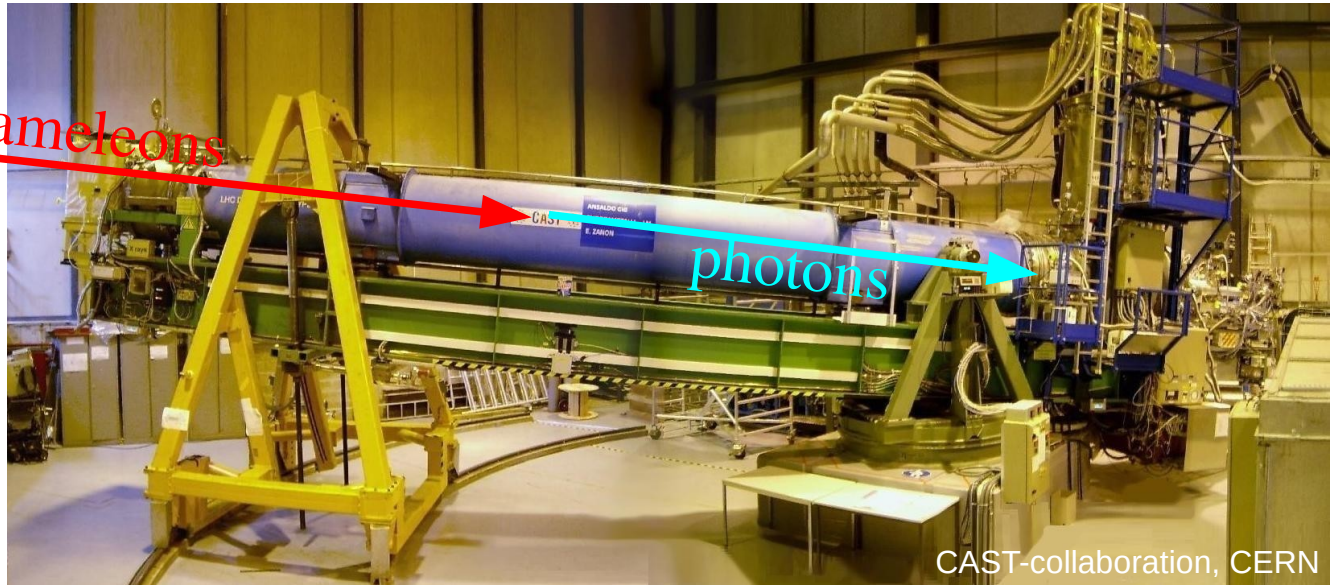


CAST/IAXO – Search for Solar Axions

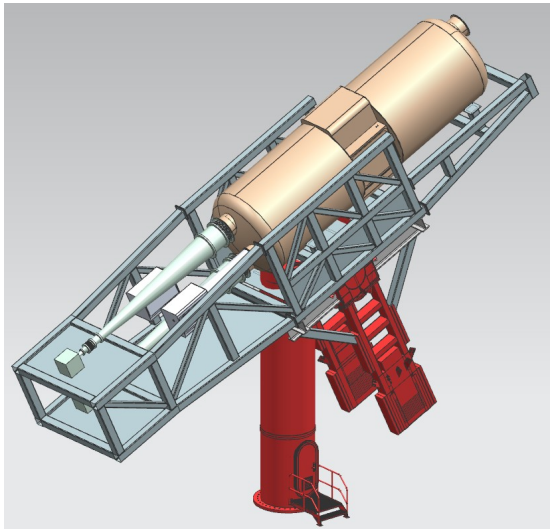




Axions / chameleons



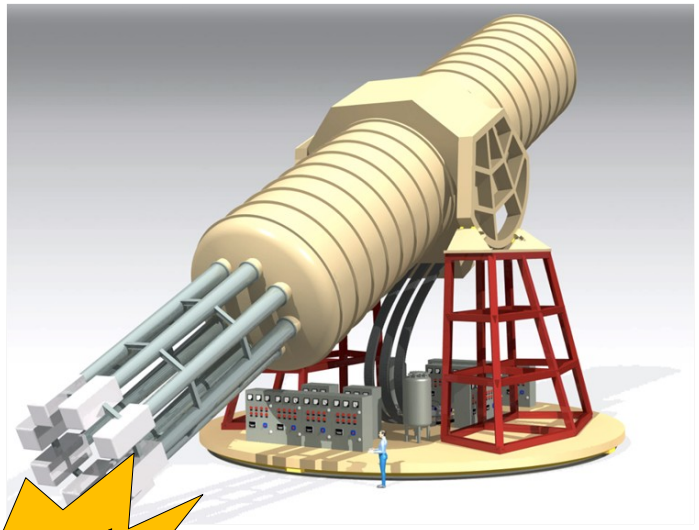
CAST: Decommissioned LHC-magnet is pointed to the Sun. Axions and Chameleons produced in the Sun convert into X-ray photons.



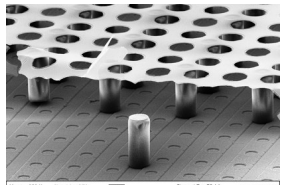
Successor experiment (Baby-)IAXO is planned to be built at DESY.

→ X-ray detectors with

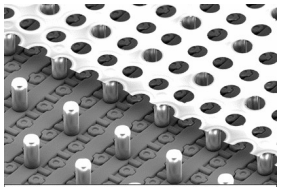
- Low energy threshold
- High spatial resolution
- High radiopurity
- Shielded by lead

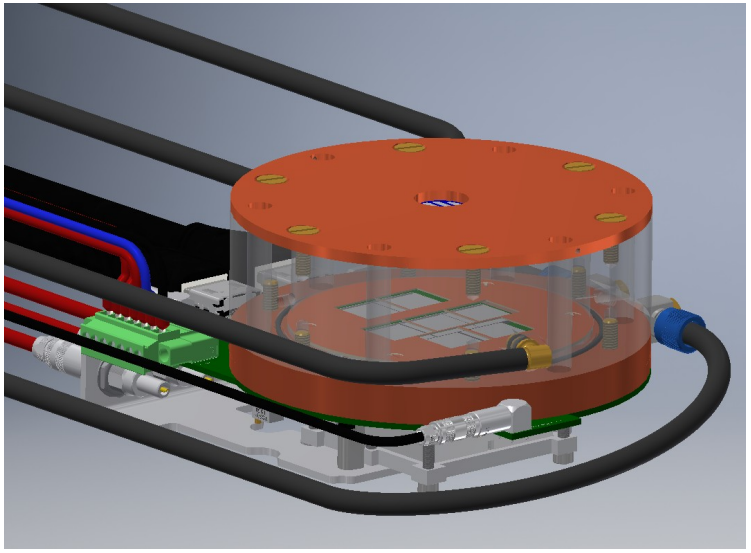


See talk by E.Ferrer Ribas



CAST

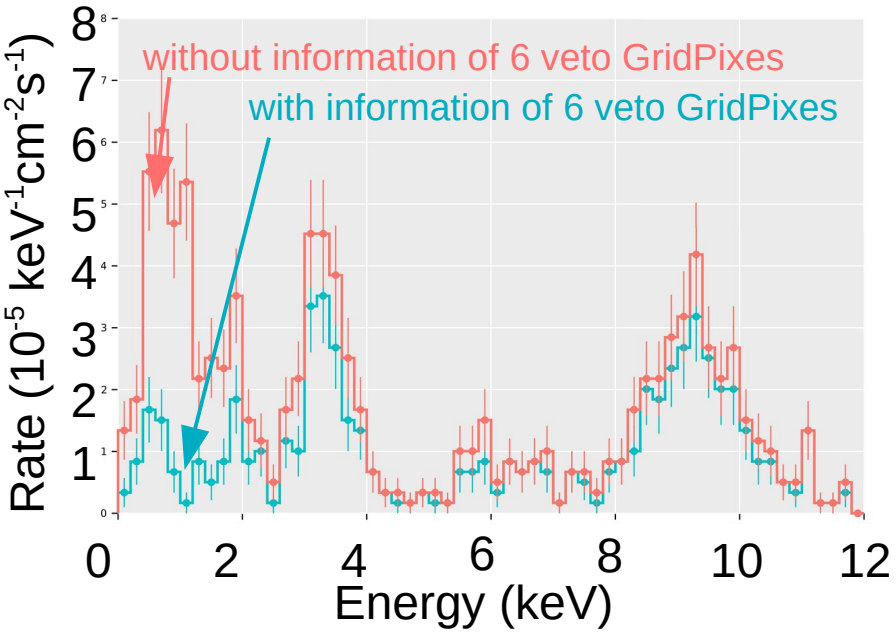


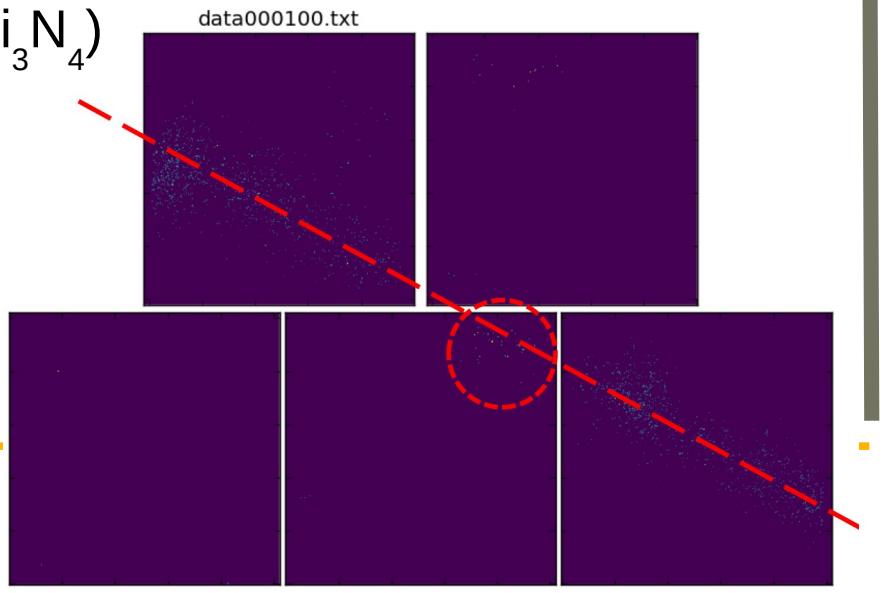


1. data run 2014/15 → Data published
2. data run 2017/18 → Analysis is finalized

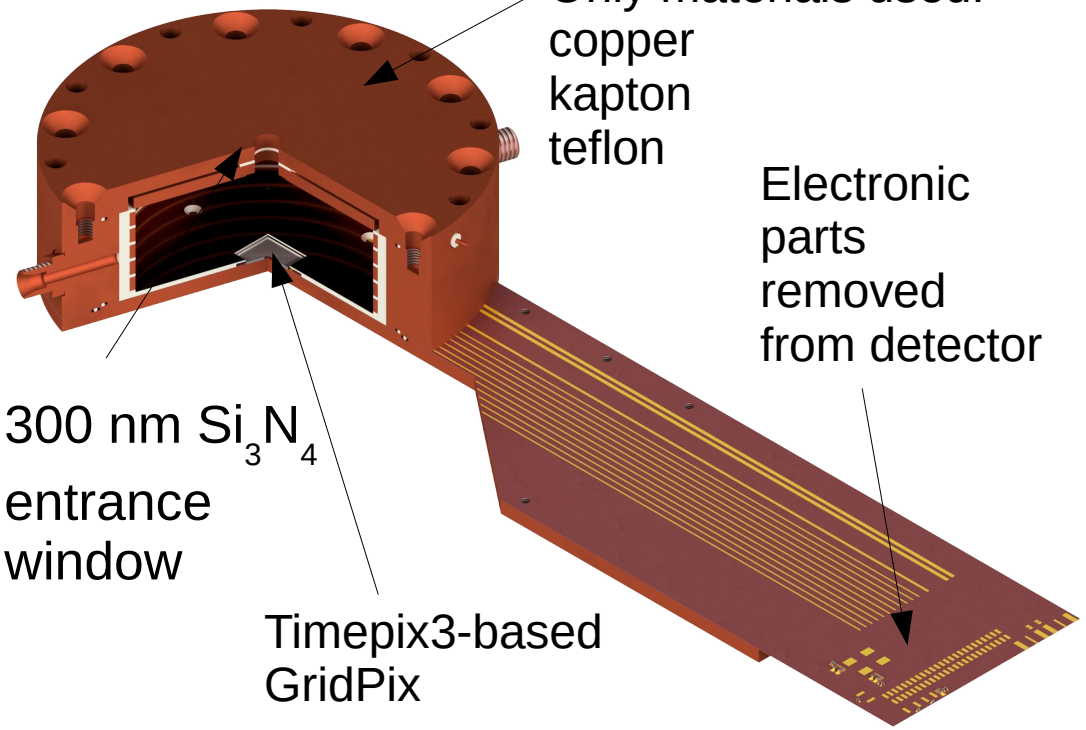
Data Run 2 had several improvements in the detector:

- 7 GridPix arrangement (central main detector + 6 veto detectors)
- Signal decouple from grid and digitized by FADC
- 2 veto scintillators (behind GridPix and on top of lead shielding)
- Low material budget entrance window (300 nm Si_3N_4)





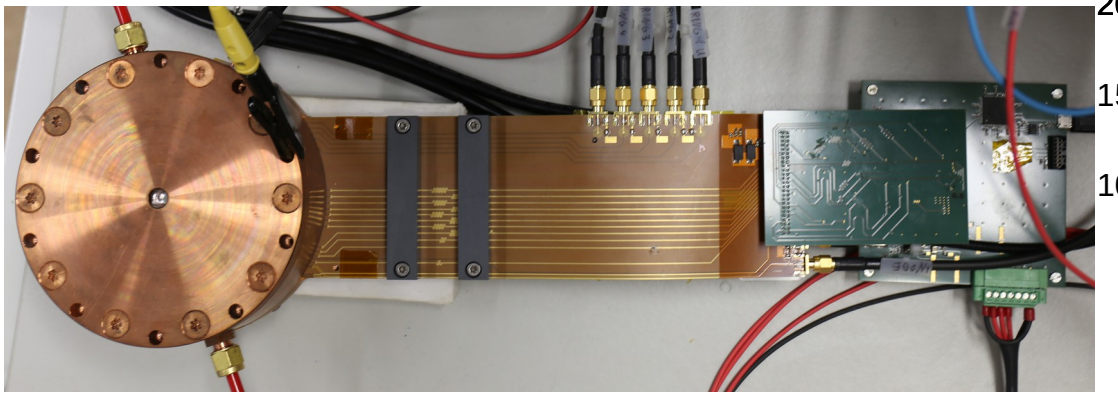
BabyIAXO Prototype Detector

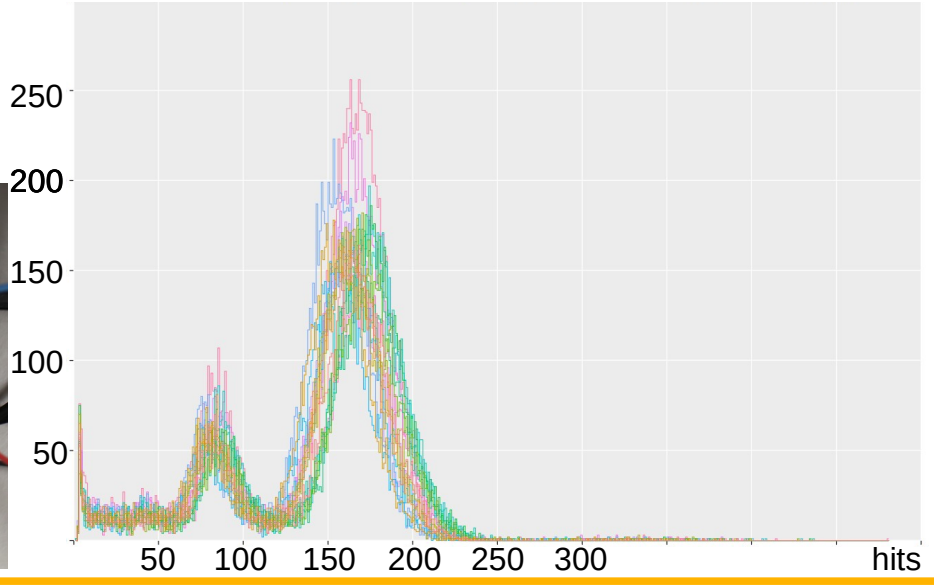


Further improvements of the CAST detector:

- Timepix3 (currently only one)
- Use of radiopure materials only (copper, teflon, kapton)
- Move non-essential parts further away

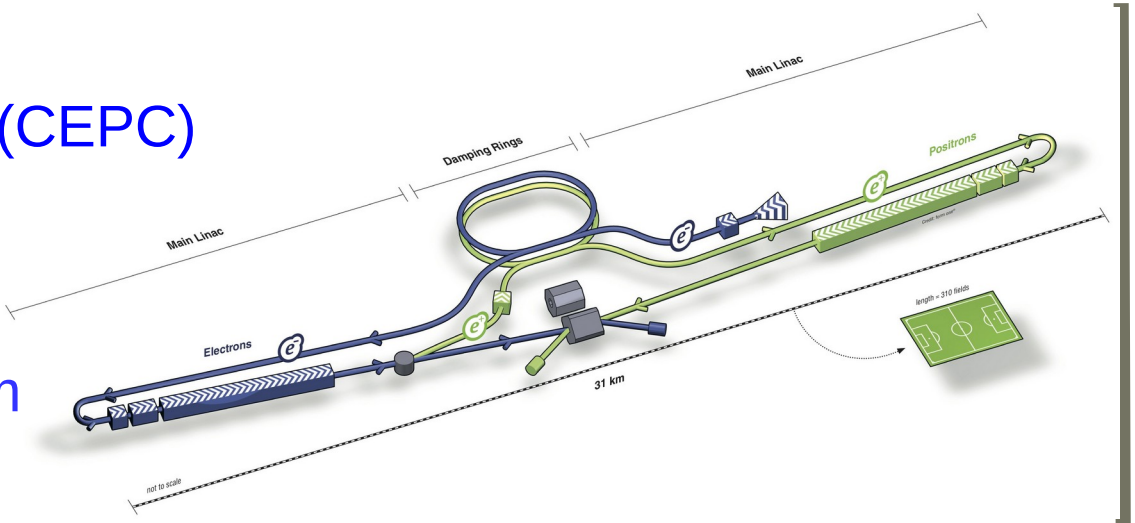
Currently first prototype without radiopure copper/cleaning.





Tracker for Future Higgs Factories

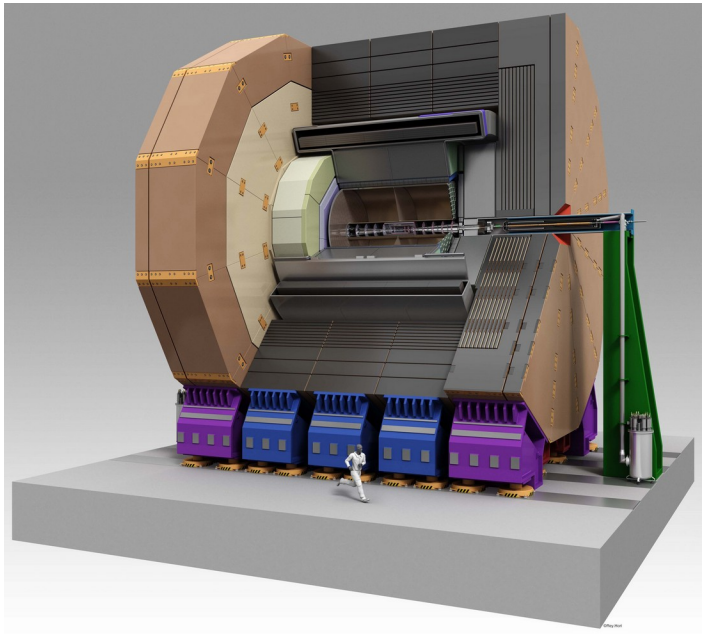
International Linear Collider (ILC) /
Chinese Electron Position Collider (CEPC)
Future Circular Collider (FCCee)
are e^+e^- colliders with:
$\sqrt{s}$ = 90 GeV – 1 TeV / 90-240 GeV
Overall length of 21-50 km / 100 km



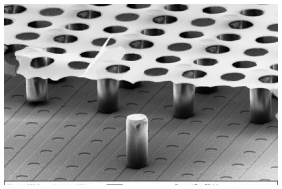
Requirements of TPC from
ILC TDR vol. 4

Parameter			
Geometrical parameters	r_{in}	r_{out}	z
	329 mm	1808 mm	$\pm$ 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 μm for zero drift, $<$ 100 μm 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)		

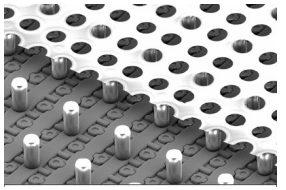
In addition: very high efficiency for particle of more than 1 GeV.



International Large Detector
- Standard layout HEP detector with improved performance
- TPC as main tracker

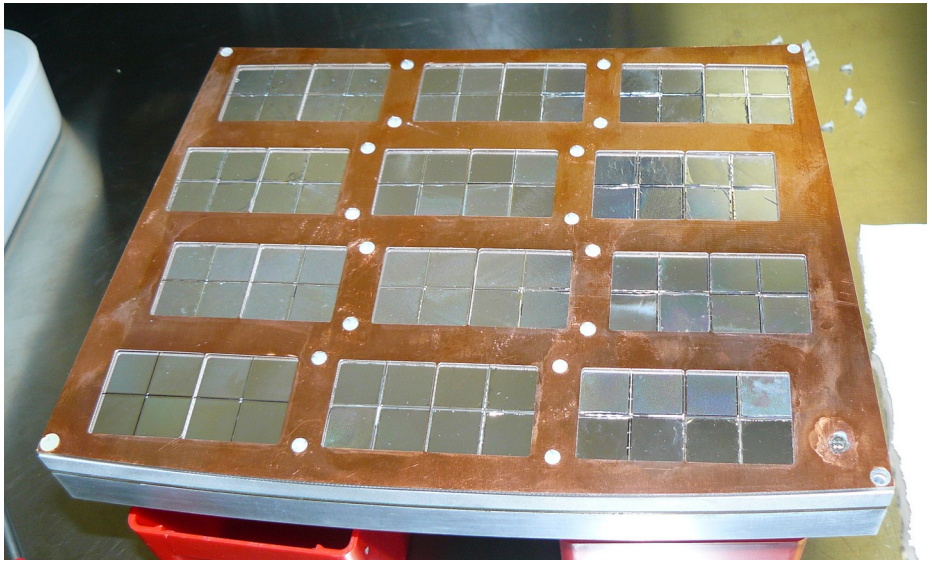


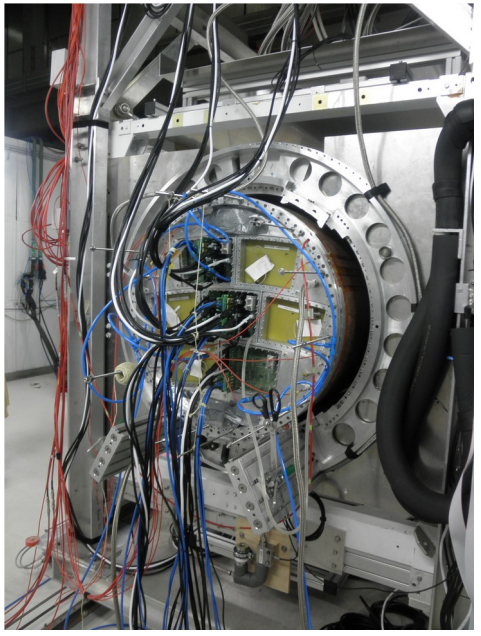
PixelTPC for tracking at Colliders

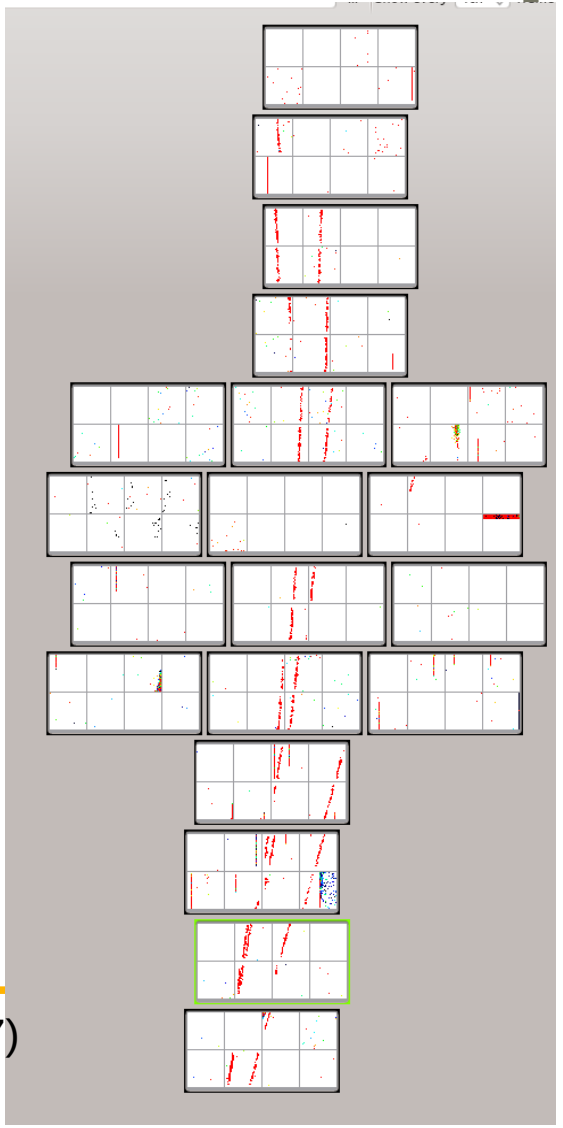


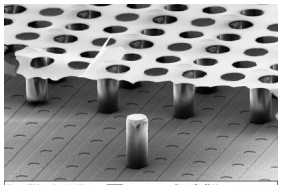
A pixelTPC has some advantages compared to a conventional pad TPC
- Lower occupancy → easier track reconstruction at higher backgrounds
- Improved dE/dx: <4% seems possible with electron or even cluster counting
- Removal of δ-rays and kink removal
- No angular pad effect

To readout a large TPC:~50000 GridPixes needed
→ Demonstrator with 160 GridPixes (Timepix) in 2015
Central module with 96 GridPixes (coverage 50%)
2 weeks of successful test beam.

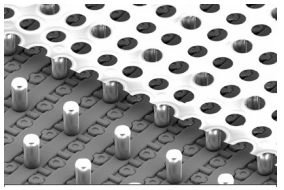




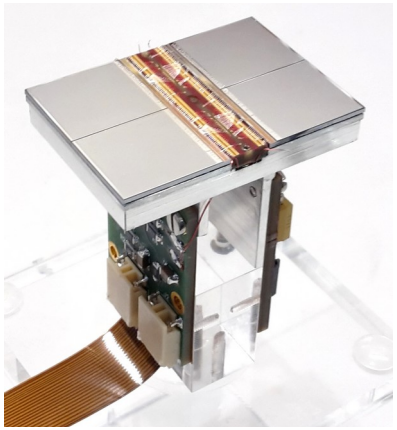


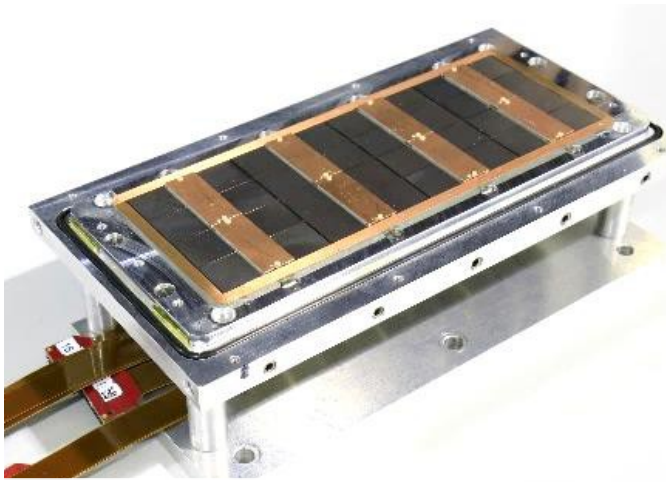


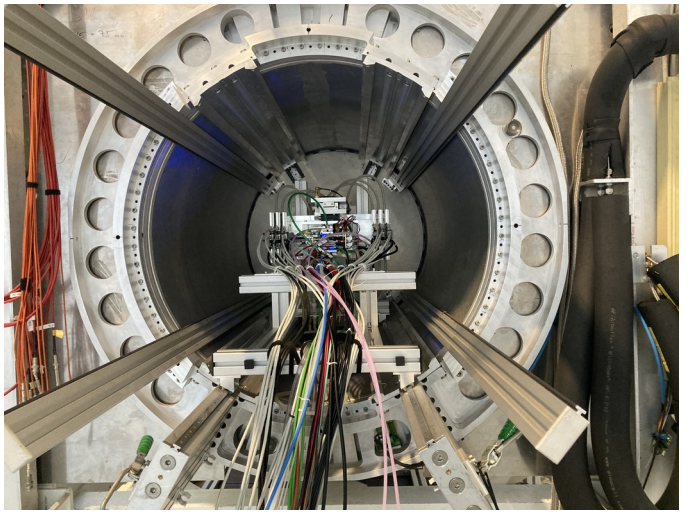
Tracking with Timepix3



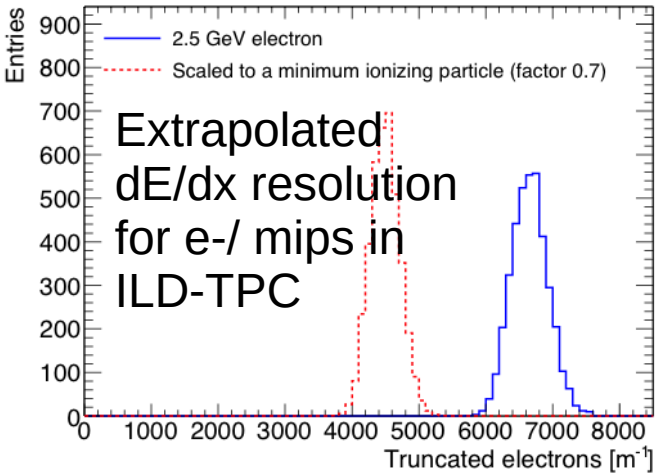
New effort to build larger modules with Timepix3 based GridPixes:
First single chip (2017), then quads (2018), finally 8 quads (June 2021).

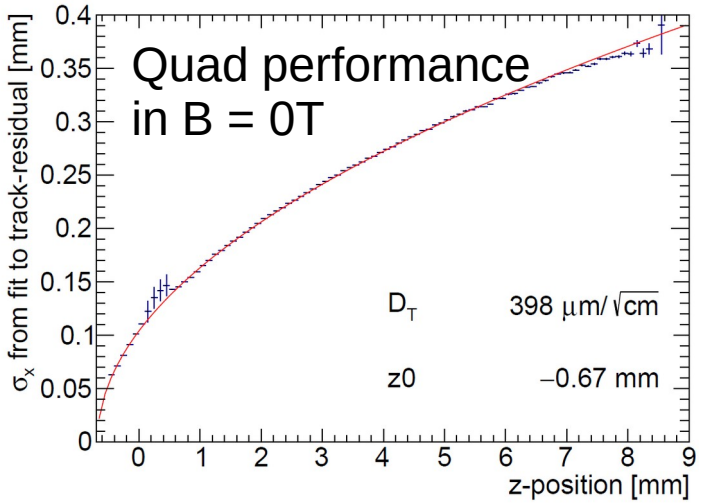


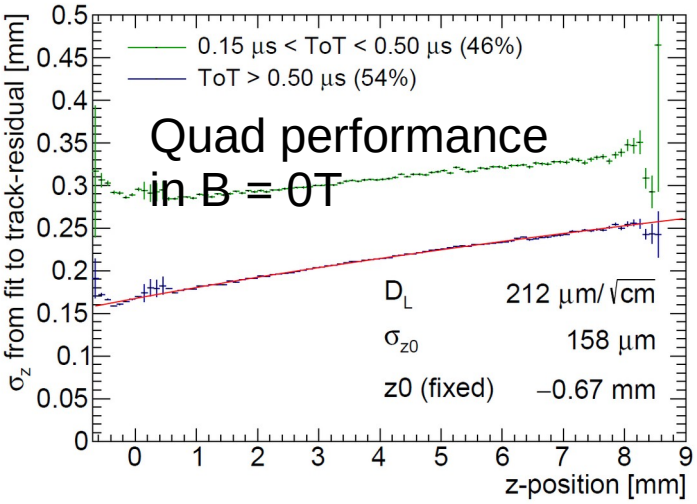




Quad coverage: 68.9 %

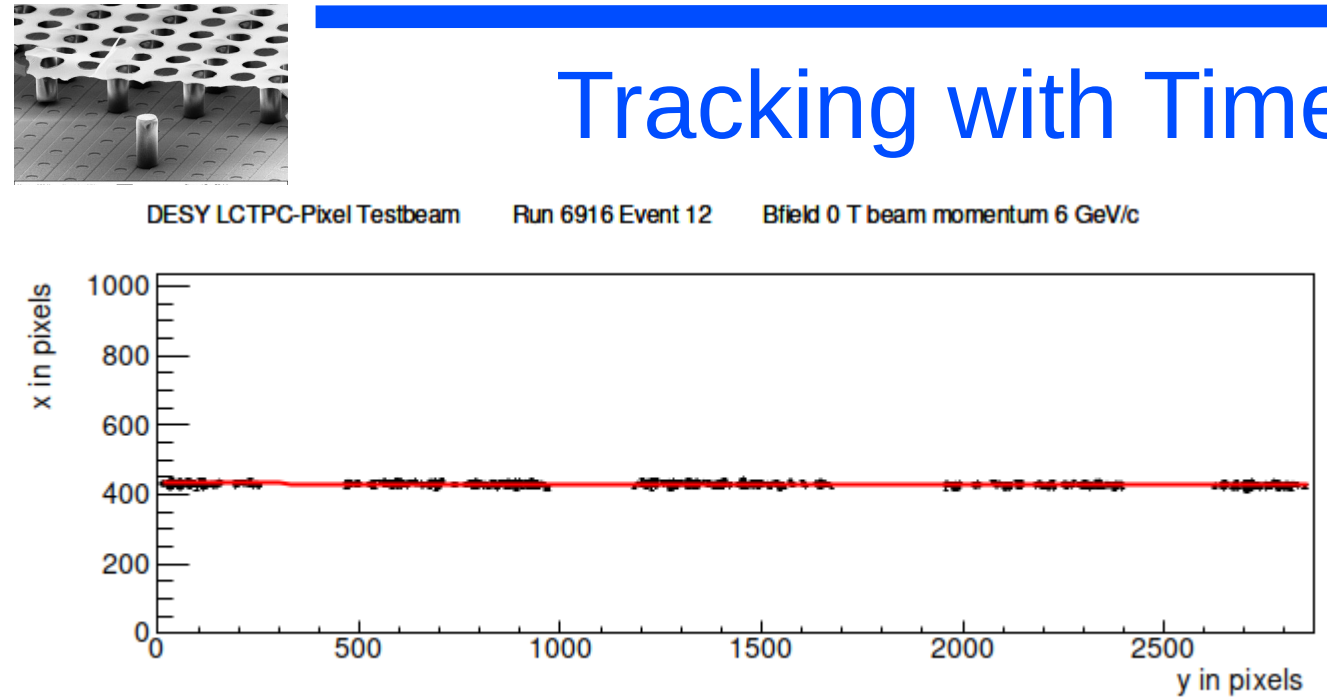


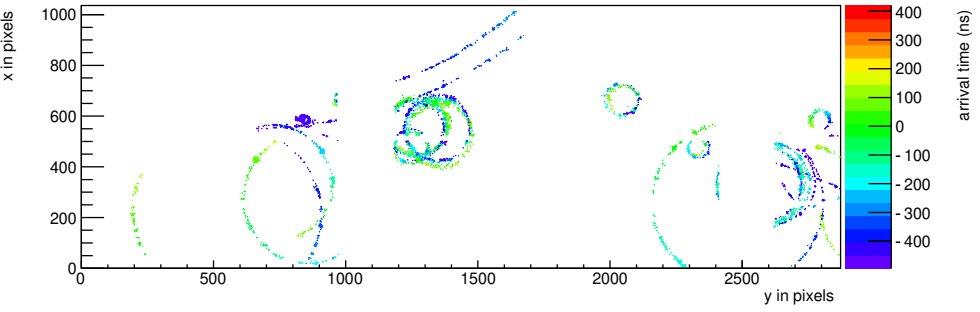




NÌM A908 (2018) 18-23
NIM A956 (2020) 163331

Tracking with Timepix3





Track with 1050 hits:

$\chi^2_{xy} = 912/1048$

$\chi^2_{z} = 1740/1048$

No asymmetric tail (z time slewing) or outlier removal applied yet.

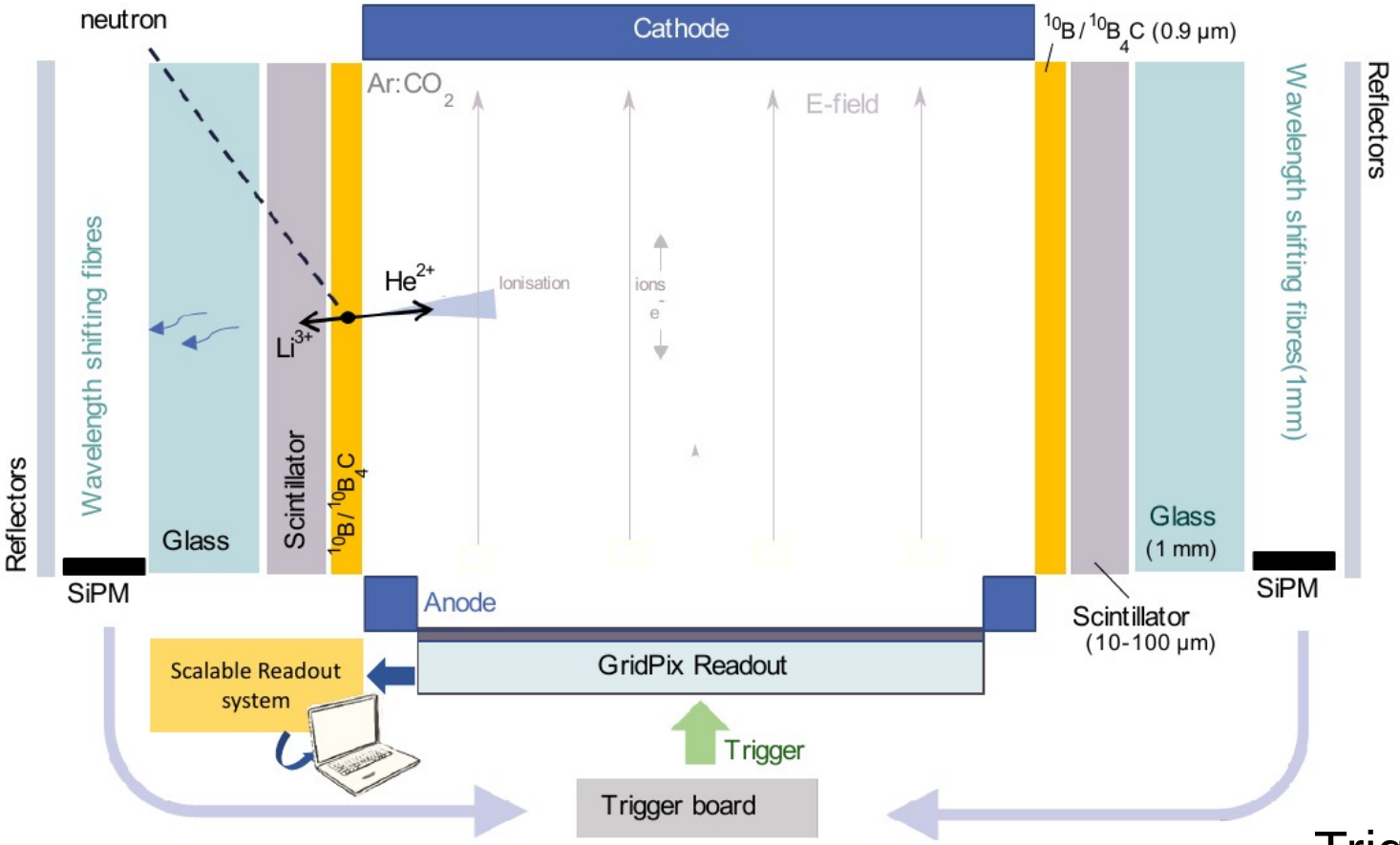
Many tests performed
in B = 0/1 T
with various beam energies
with various rates
with various angles
For the complete data taking a high precision external tracker was available

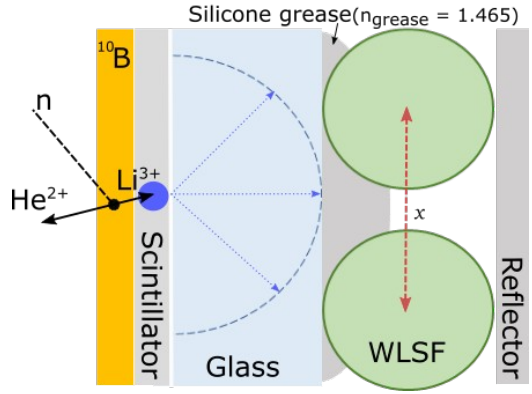
Neutron TPC

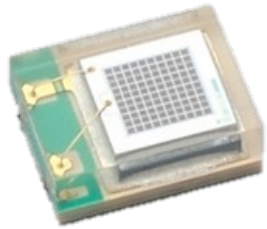
TPC with solid state converter on side walls

$^{10}B + n \rightarrow {}^{7}Li + \alpha$ => two fragments: trigger + tracking

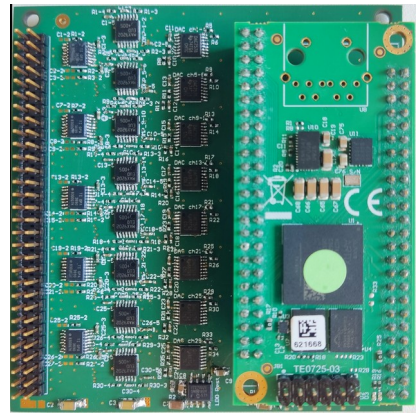
Side walls: ^{10}B, scintillator, glas, WLSF





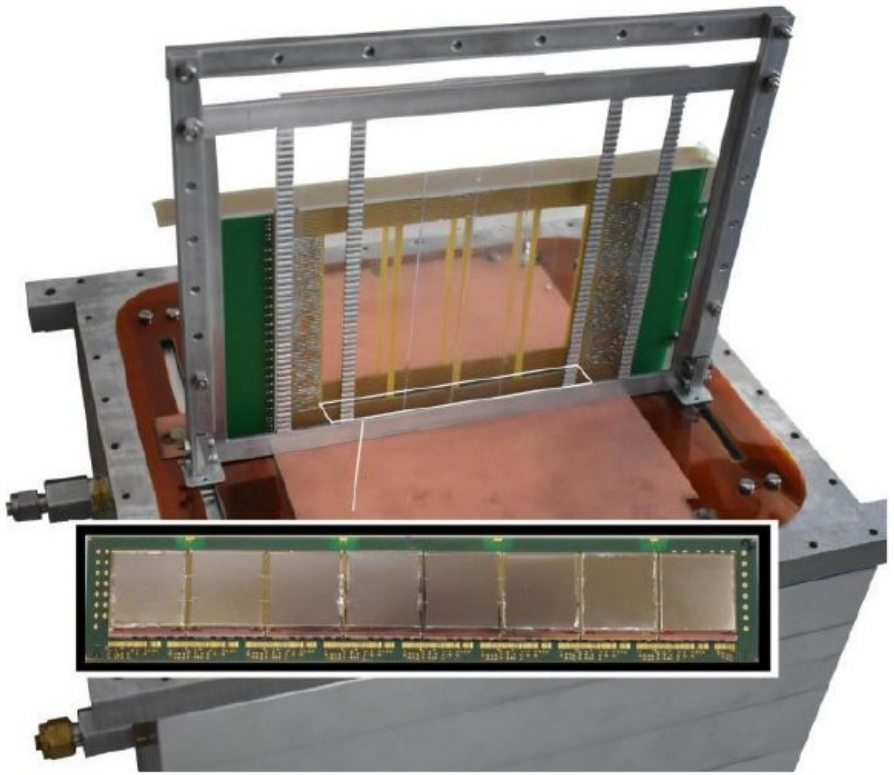


MPPC S13360-1375PE

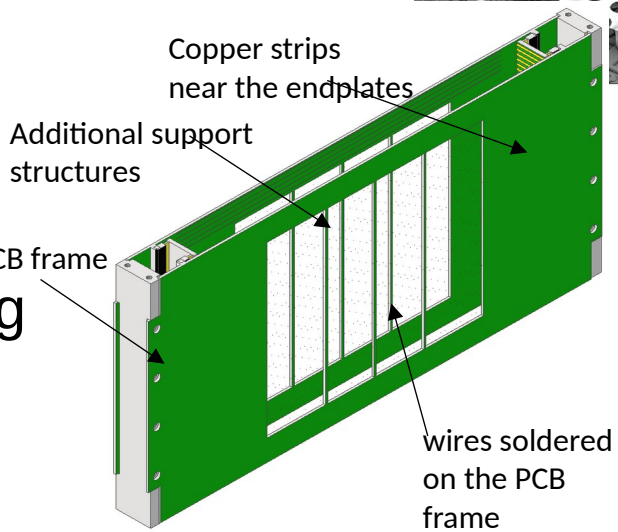


Trigger board for 30 SiPMs

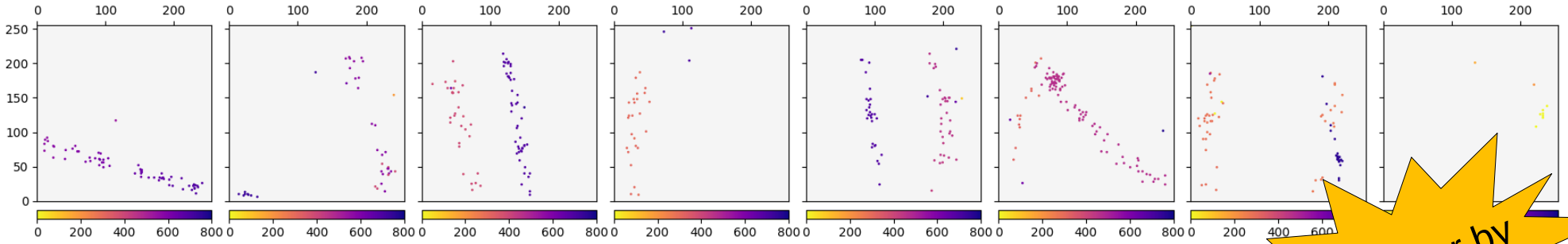
Neutron TPC



Current field cage: 30 µm thick wires with a spacing of 2 mm soldered on PCB.

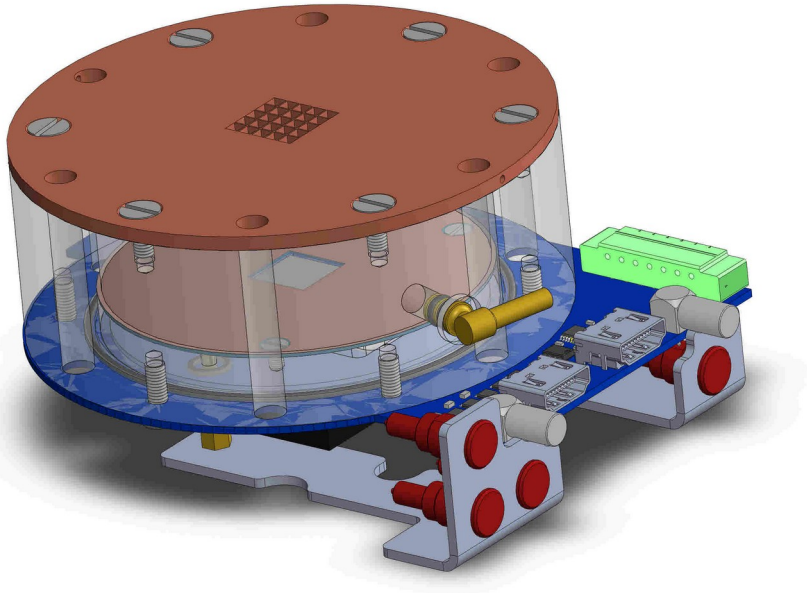


First tracks of cosmic muons recorded with the TPC and external trigger. Analysis shows, that there are no track distortion in the xy-plane seen. Some distortions in the drift direction are seen close to the wires.



See poster by M. Lupberger

X-ray Polarimetry



- CAST type detector with 3 cm drift
- Different He-based gas mixtures with CO_2 or DME
- Test beam at PETRA III (DESY) and KARA (KIT)
- Beam energies 4-11 keV
- Beam is >95 % linearly polarized

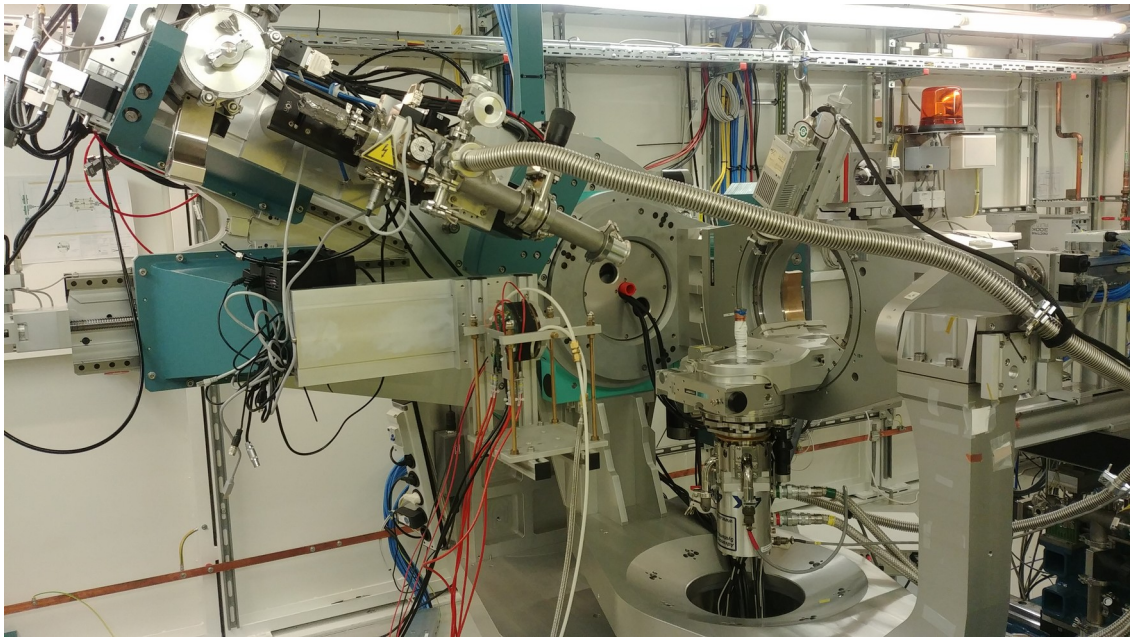
→ reconstructed polarization 76% (sofar)

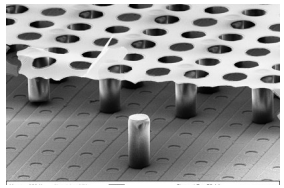
Polarization is interesting to measure, since it gives information about materials or physical processes.

→ Difficult to measure at low X-ray energies with standard techniques

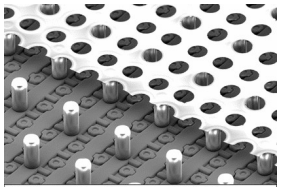
Photoelectrons follow E-field of polarization

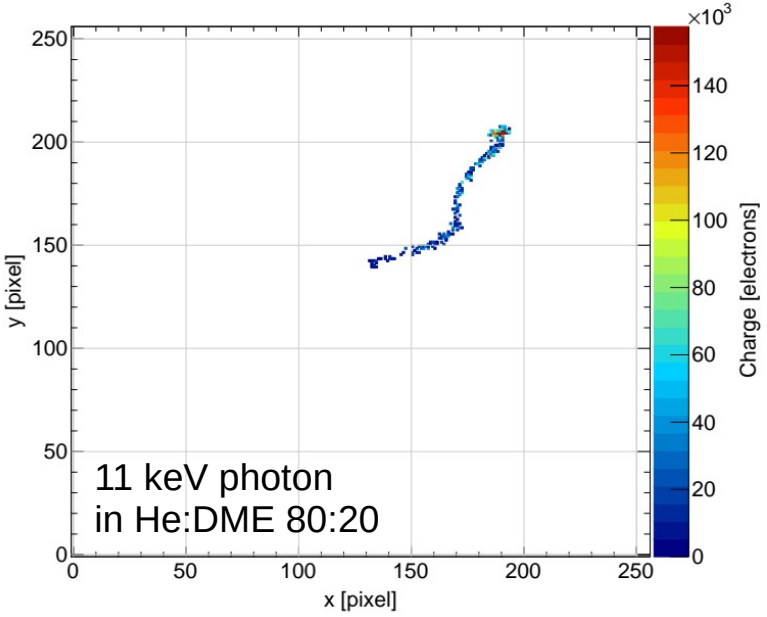
=> need gaseous detectors with high resolutions (GridPixes)





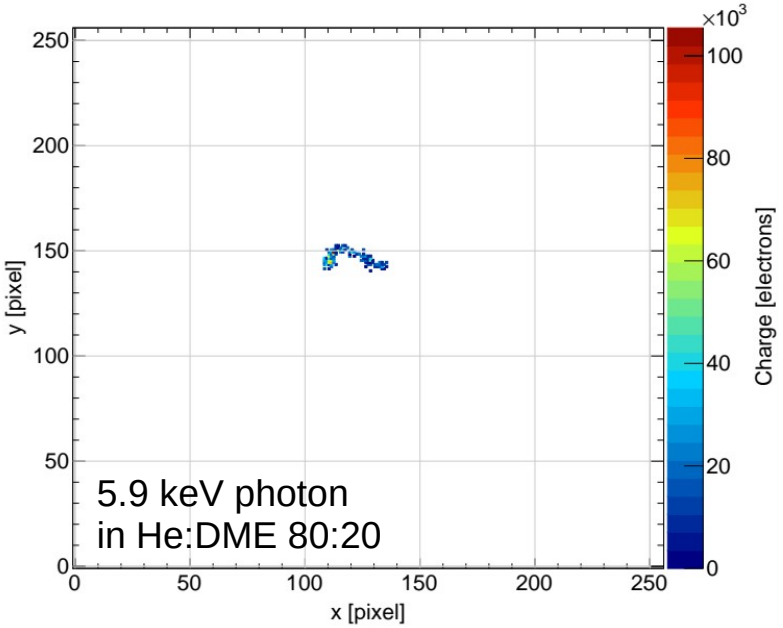
X-ray Polarimetry

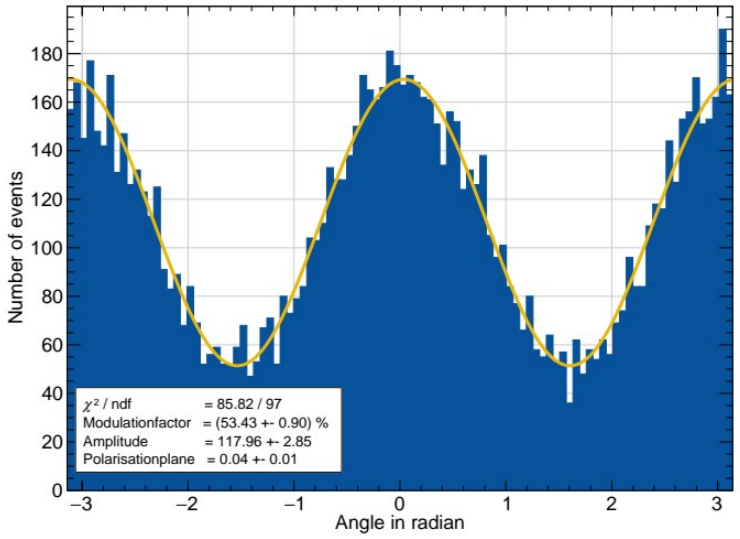


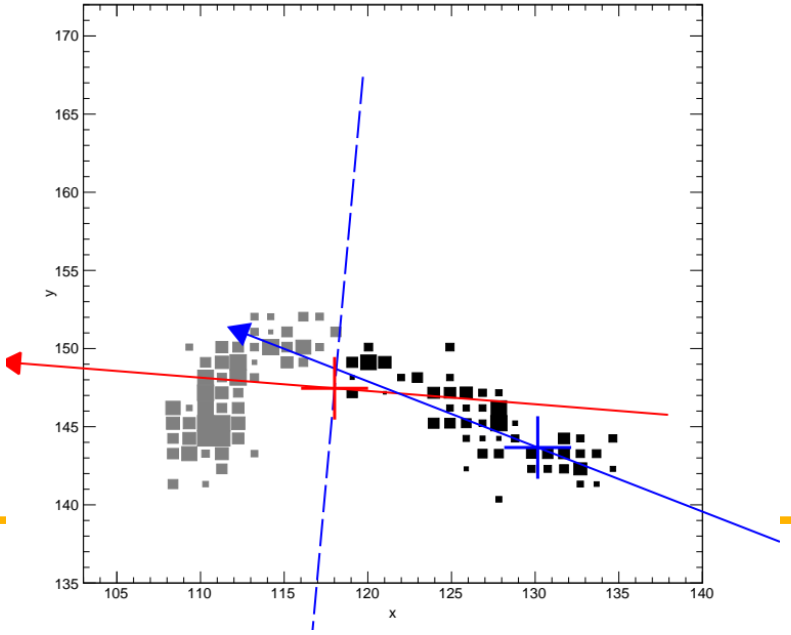


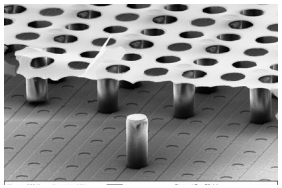
Reconstruction:

- Find center of event
- Split track
- Find end with higher ioniz.
- Reconstruct the other end
- Determine direction

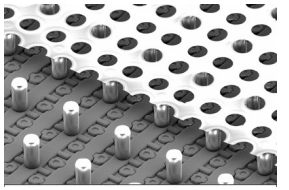






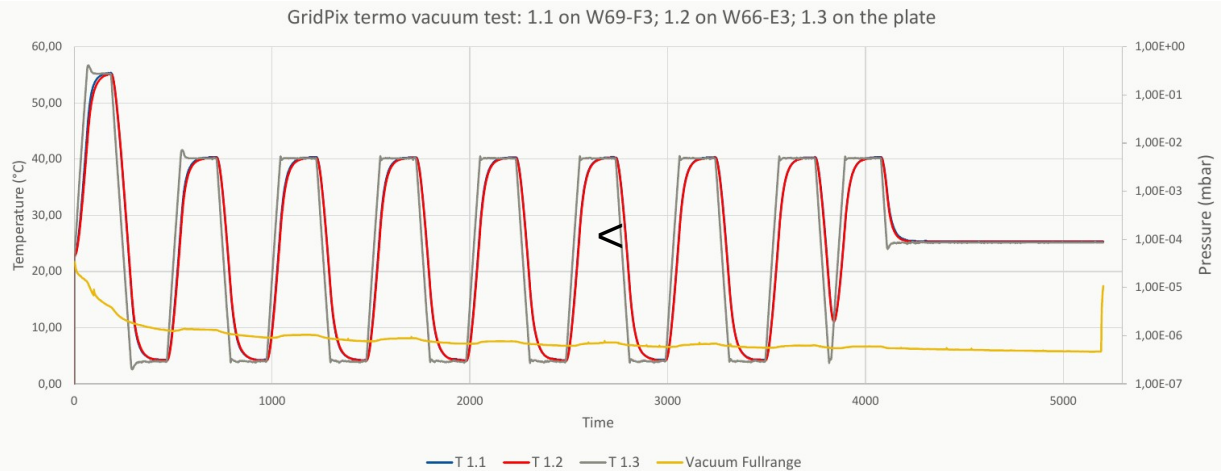


X-ray Polarimetry in Astrophysics



Project by the X-ray polarimetry group at INAF-IAPS (lead by Paolo Soffitta).
Idea is to prepare and propose a follow-up mission of the IXPE satellite, potentially using a GridPix instead of a Gas Pixel Detector.
Important first tests have been performed with 2 standard GridPixes:

1.) Thermo vacuum tests

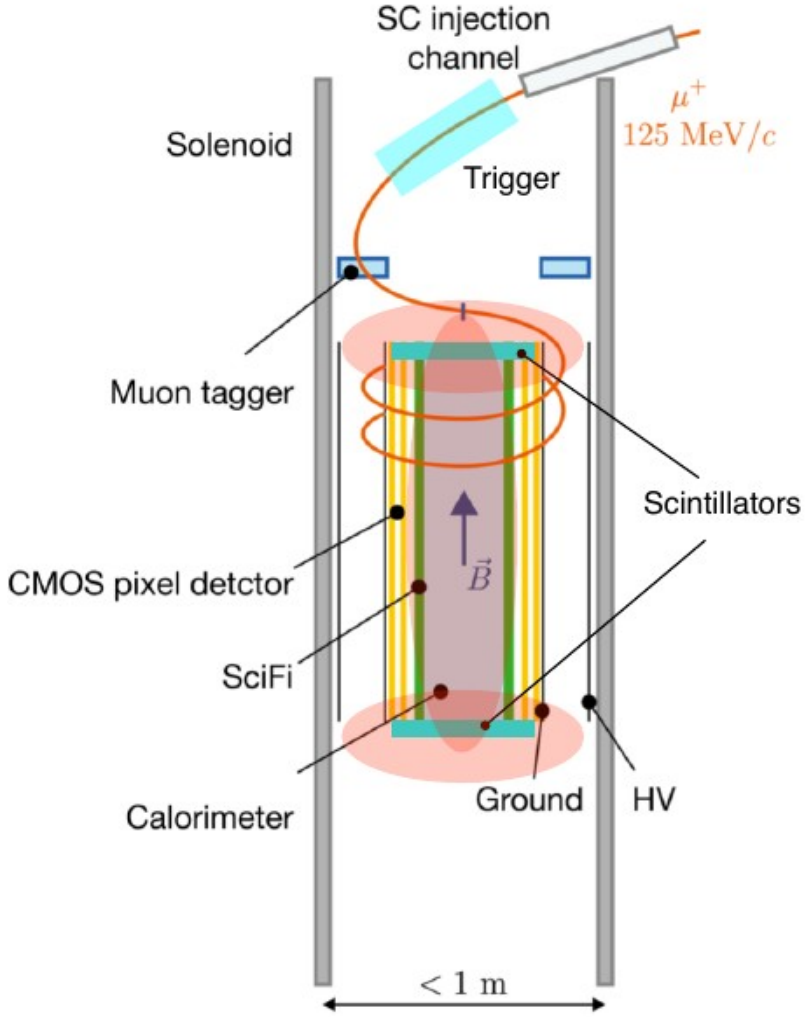


2.) random vibration test → no resonances found up to 2 kHz

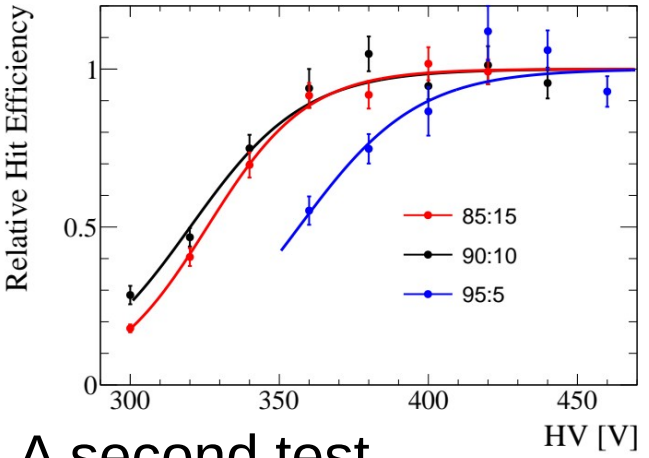
Before and after the two environmental tests high resolution pictures of the grid were taken and the ASICs were tested electronically → no differences were found

Muon EDM at PSI

A new project for a dedicated measurement of the muon EDM

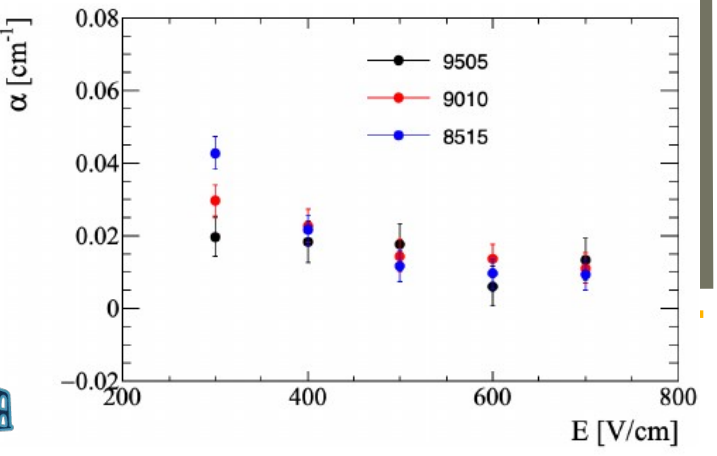


First tests to evaluate GridPix-TPC (F. Renga, INFN Roma) to characterize the muon beam during the commissioning of the phase-I experiment (2025-2026). Test beam with different mixtures of $He:iC_4H_{10}$ (95:5, 90:10, 85:15)



Rich study of gas parameters: V_{drift}, D_T, D_L, attachment α

A second test beam with $He:CO_2$ mixtures just took place.



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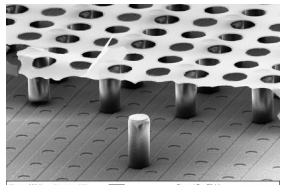
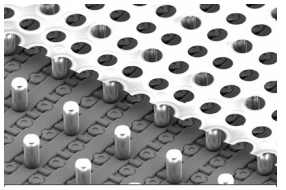
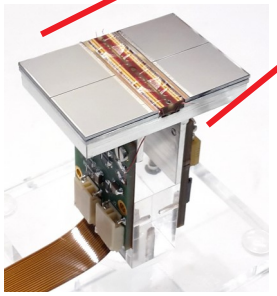
INFN Istituto Nazionale di Fisica Nucleare Sezione di Roma

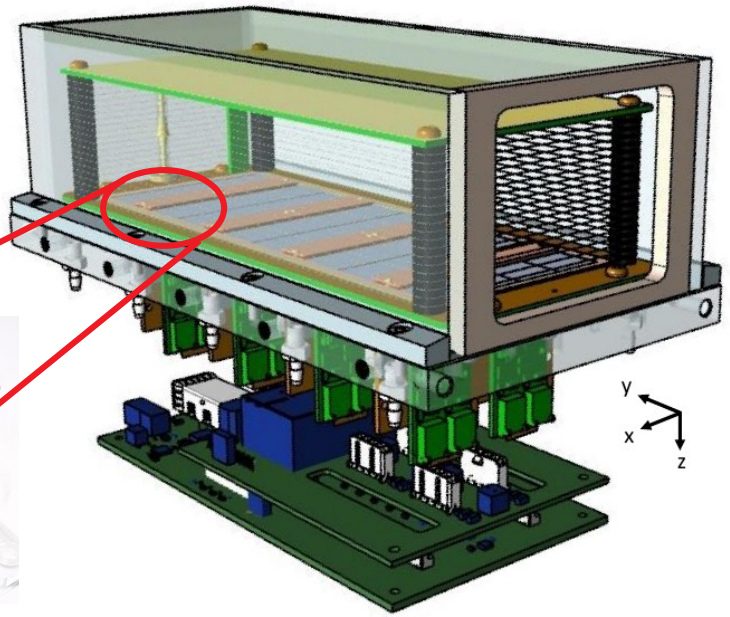


Negative Ion TPC



quad





Detector with 32 GridPixes based on Timepix3

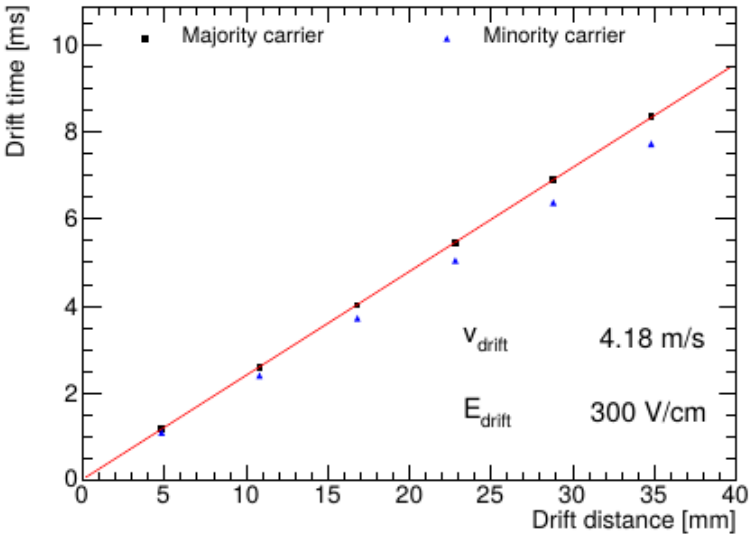
UV laser (337nm) used to generate tracks.

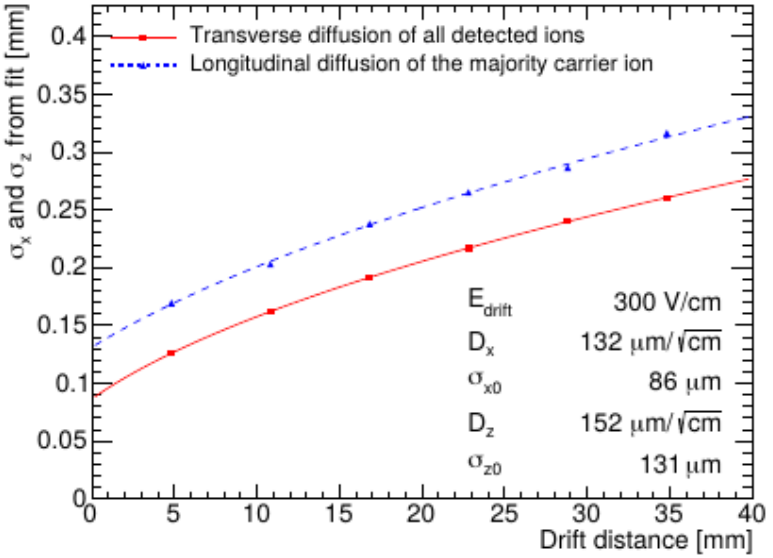
<u>Gas mixtures:</u>

$Ar:iC_4H_{10}:CS_2$ 93.6:5.0:1.4

+ O_2 (650-1150 ppm) -minority carrier

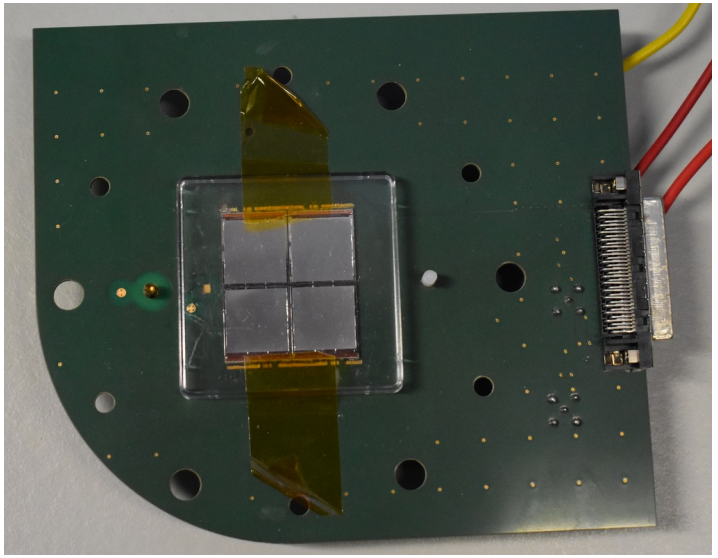
+ TMPD (to enhance sensitivity to laser)

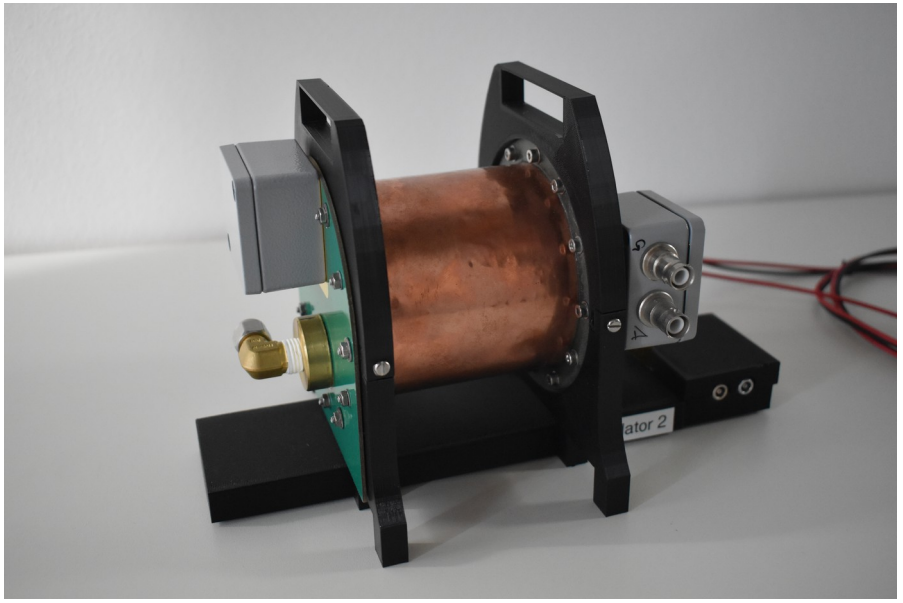




- Gas at atmospheric pressure
- Both majority (CS_2) and minority (O_2) carriers observed
- Transverse diffusion at thermal limit
- Have to optimize gas mixture.

SchulTPC

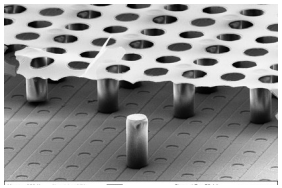




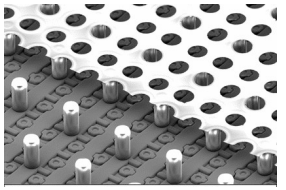
Compact, flexible and mobile detector for educational purposes such as:
exhibitions, school projects, workshops at schools

Setup consists of (partially planned)

- TPC: 10 cm length, 8 cm inner diameter
- 4 GridPixes
- Compact readout system (FitPix)
- 2 trigger scintillators
- Possibly small, compact HV supply
- Operated with welding gas (cheap)
- Currently developing an educational concept for schools
- Thinking about a small magnet



Summary and Outlook

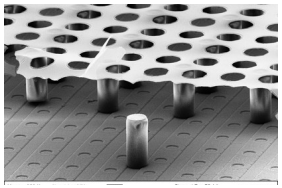


GridPixes are seeing a transition from Timepix to Timepix3.

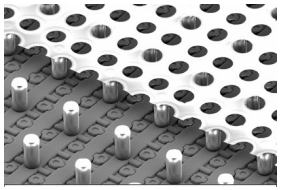
The grid production can soon be done in Bonn, which will open possibilities for new ideas and R&D.

More projects are becoming interested in testing the devices and evaluate them for their applications.

There is quite a large interest in the possible PID performance of GridPixes in particular if cluster counting can be exploited.



Acknowledgment



This is of course the work of many people.

In Bonn these are:
Yevgen Bilevych (who builds the InGrids)
Christoph Krieger, S. Schmidt, T. Schiffer, J. von Oy (CAST/IAXO),
M. Lupberger, D. Danilov, A. Hamann (LCTPC).
M. Gruber (Polarimetry)
M. Köhli, D. Pal (Neutron TPC)
and of course Klaus Desch.

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At Nikhef:
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and even more on smaller projects.