GridPix Detectors
Production – Characterization – Applications

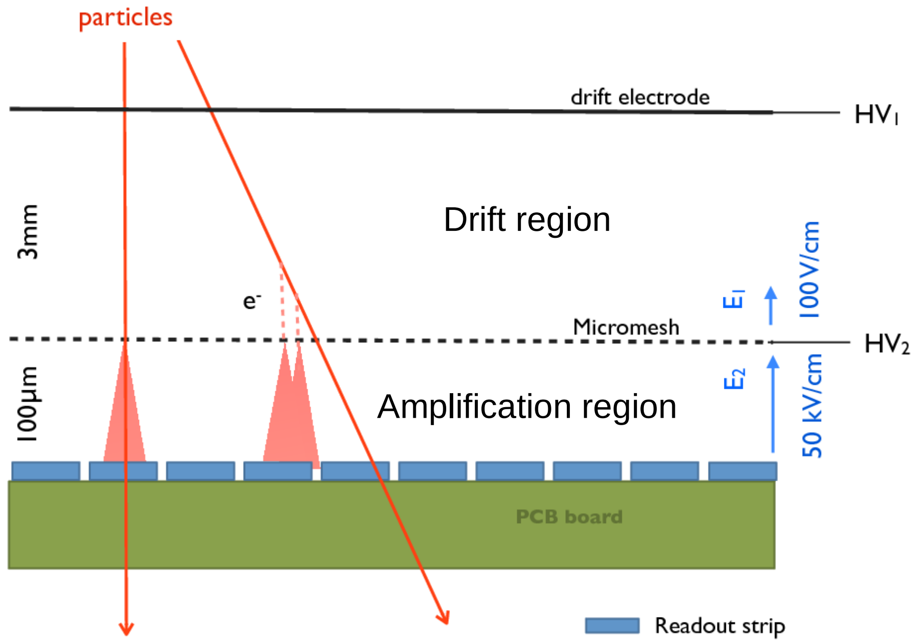
K. Desch – University of Bonn

UNIVERSITÄT BONN

Terascale Detector Workshop
München, 28/02/2018


UNIVERSITÄT BONN
Nikhef
UNIVERSITÄT SIEGEN
Irfu
CEA - Saclay
Fraunhofer
IZM

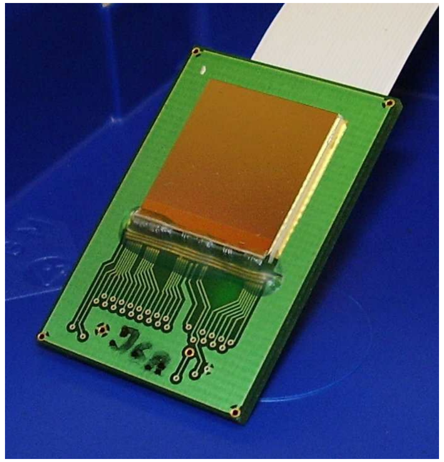
GridPix - InGrid



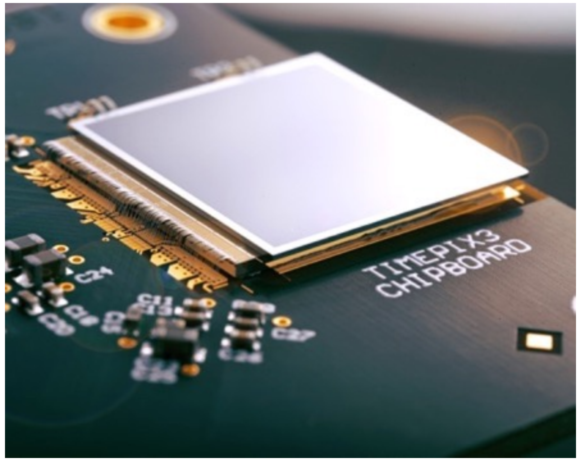
Micromegas mounted on a pixel chip (= „GridPix“)
Via photolithographic post-processing (= „InGrid“)

Pioneered by U Twente&Nikhef&CEA
J. Schmitz, M. Chefdeville et al.

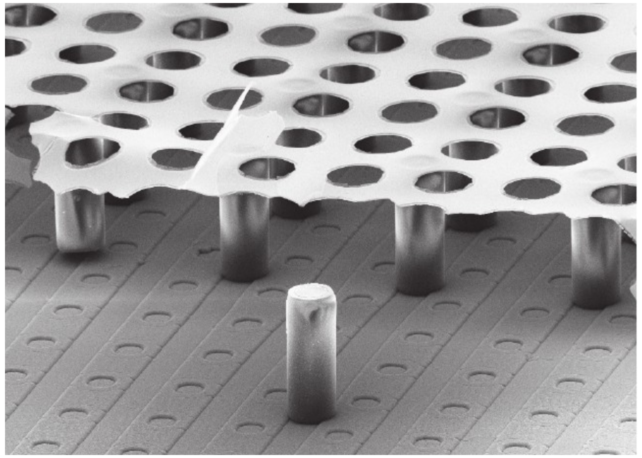
Pixel chip: Timepix / Timepix3
256x256 pixels (55x55 μm^2) ~ 2 cm^2
Typical threshold: few 100 e^-

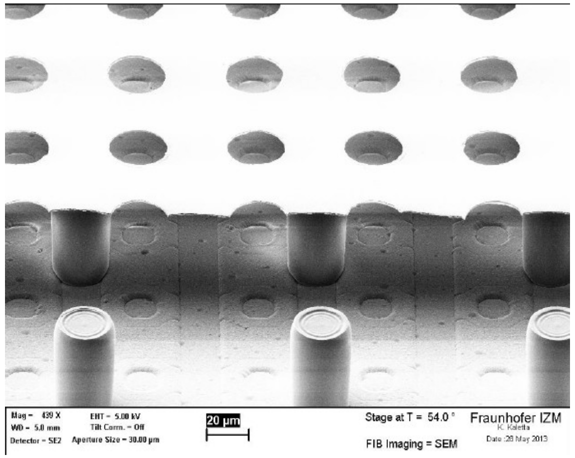


Timepix

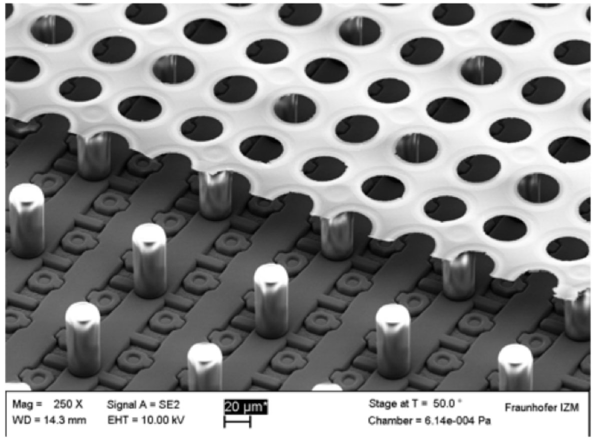


Timepix3





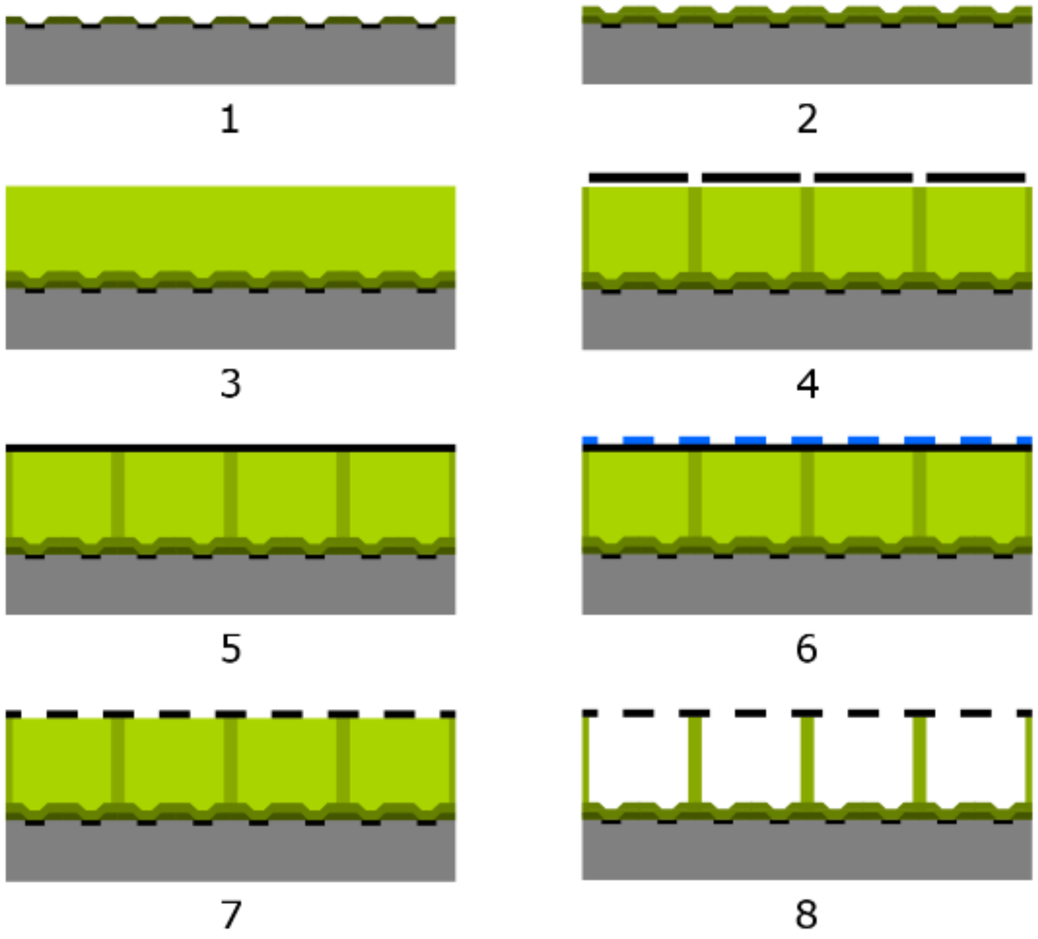
GridPix – InGrid: Features

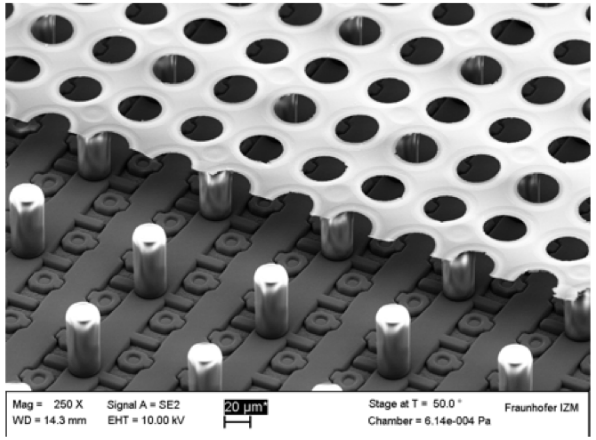


- Perfect alignment of grid holes with pixels
- Typical gas amplification ~2000, typical threshold ~few 100 e-
  → single electron efficiency ~100% 1 primary electron → 1 pixel
- Ultimate spatial resolution for a gaseous detector (limited by diffusion)
- Measurement of deposited energy by pixel counting (E_γ, dE/dx)
- Fully digital – no analog noise, no gain fluctuations in “counting” mode

GridPix – InGrid: production

Rather complex and time-consuming process:



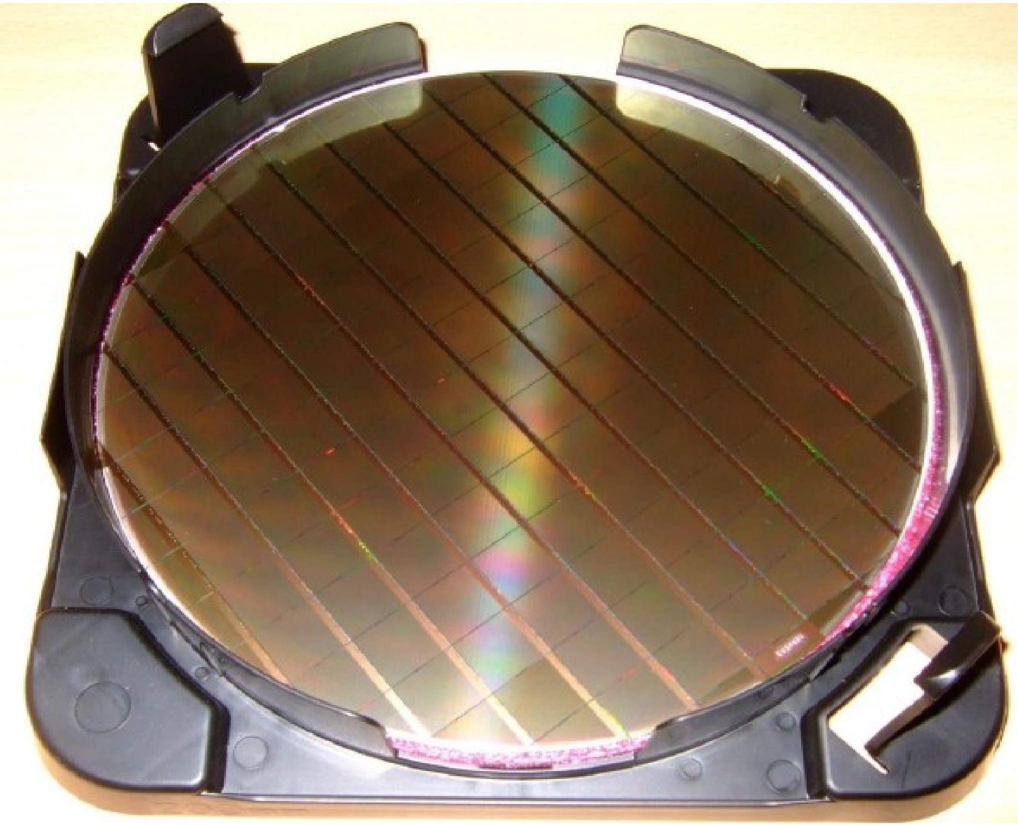


1. Wafer/Chip cleaning
2. PECVD deposition of Si_xN_y layer (4-8 µm)
3. Spin coating of SU-8 photoresist (50 µm)
4. Photolithographic exposure of SU-8
5. Sputtering of Aluminum layer (1 µm)
6. Photoresist application & exposition
7. Wet etching of Al
8. Develop SU-8 → remove unexposed SU-8

RED: very critical!

GridPix – InGrid: Wafer-based production

[Yevgen Bilevych]



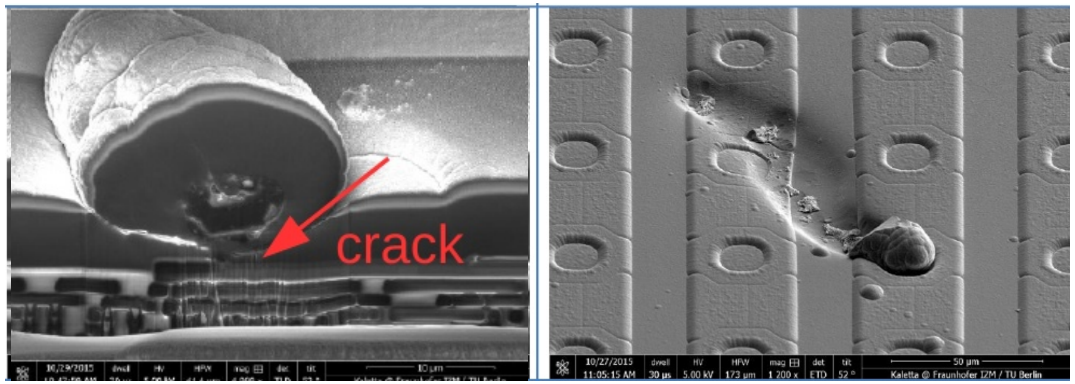
- transferred original single-chip process to a full 8‘‘ wafer
- produce up to 107 InGrids at once at reasonable cost in reasonable time
- technologically more difficult (e.g. SiN layer homogeneity, masking of bonding pads)

Fraunhofer IZM

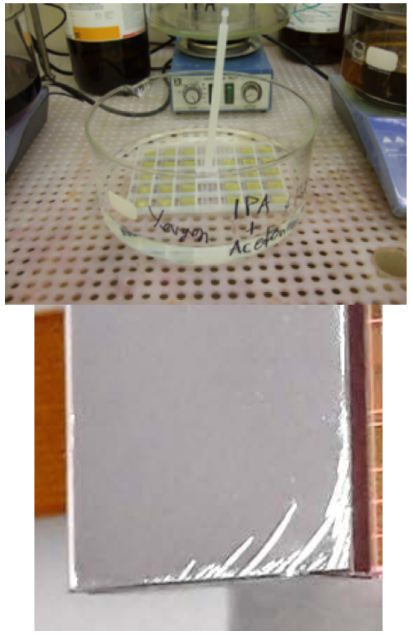
UNIVERSITÄT BONN

[Yevgen Bilevych]

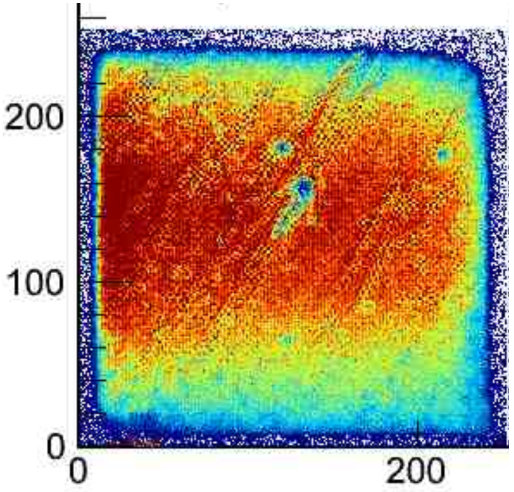
What can go wrong – examples…



Single dust grains or stress in SiN layer can cause cracks in SiN protection layer → Single discharge can kill a chip



Slightly too long development of SU-8 in chemical bath → delamination of Al grid



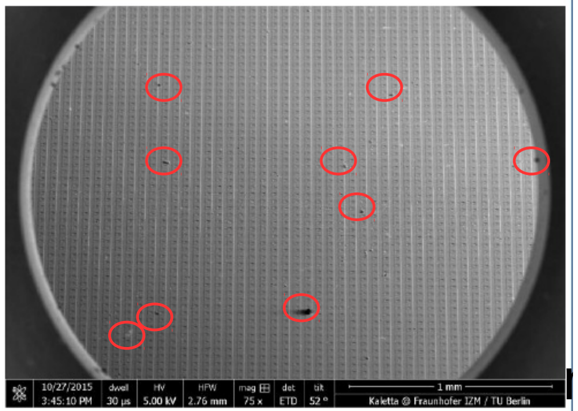
Too high T during Al sputtering
→cross linking of unexposed SU-8
→ remnants of SU-8 underneath the grid

[Jonathan Ottnad]

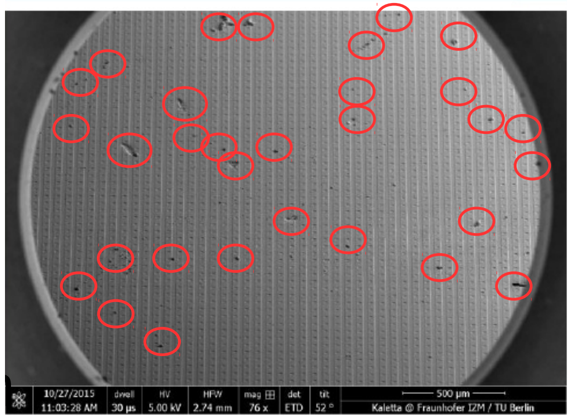
InGrid production

now spark proof

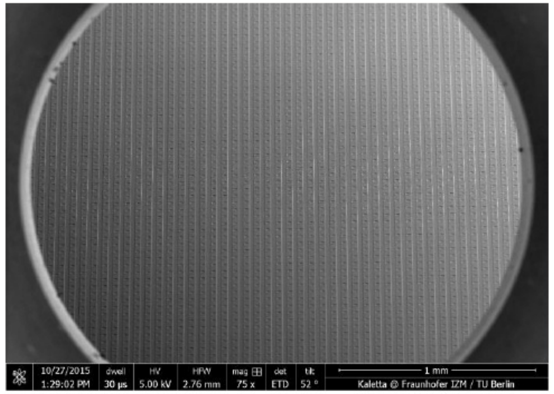
- careful analysis of chip deaths due to discharges (mostly DAC failures)
- significant improvement in cleaning/inspection and SiN deposition (new PECVD machine at IZM)



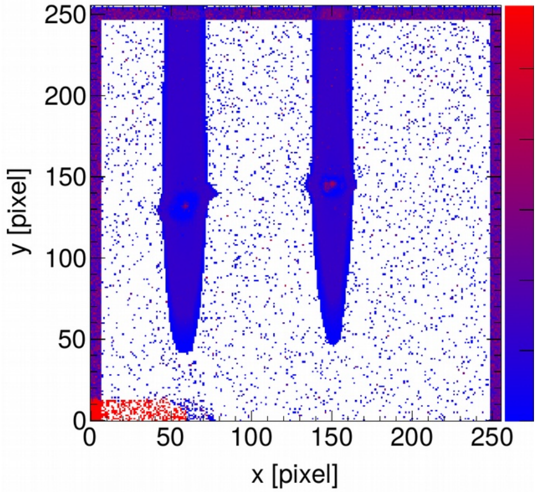
IZM-5



IZM-6



IZM-7



Typical discharge event

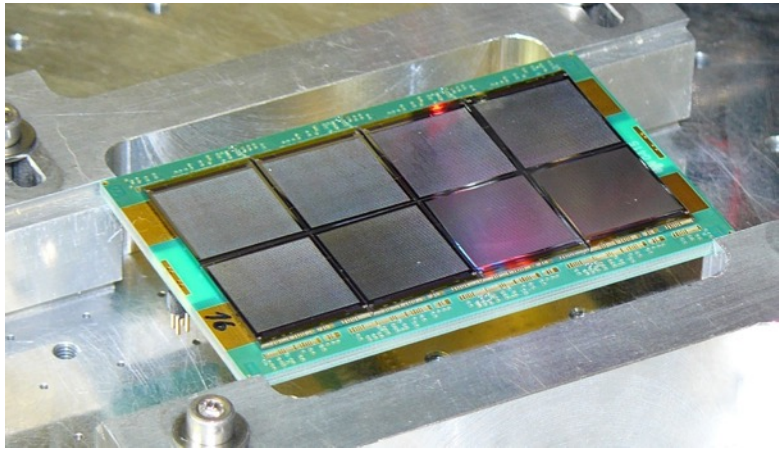
Stress test:

Operation at 550 V → „constant“ discharges

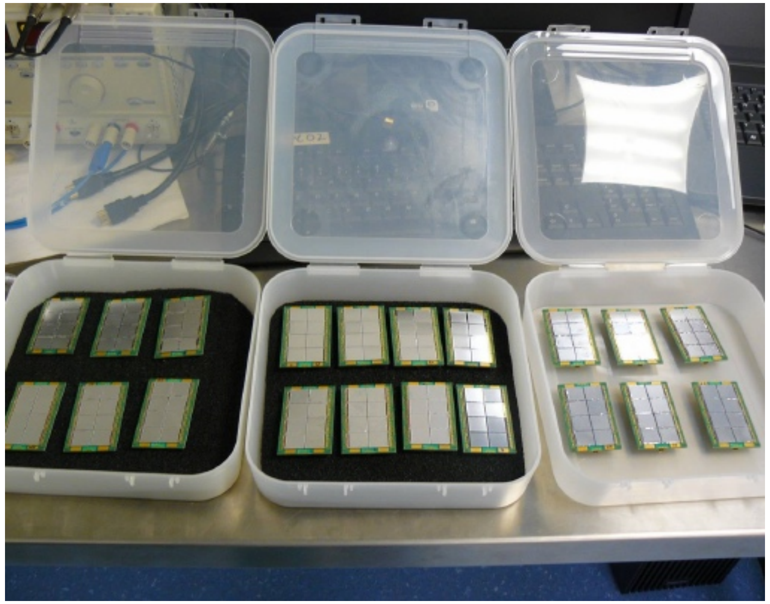
- 10^7 sparks in few hours
- Chips survived
- Still good energy resolution
- But visible damage due to sparks (of course...)

[Lucian Scharenberg et al]

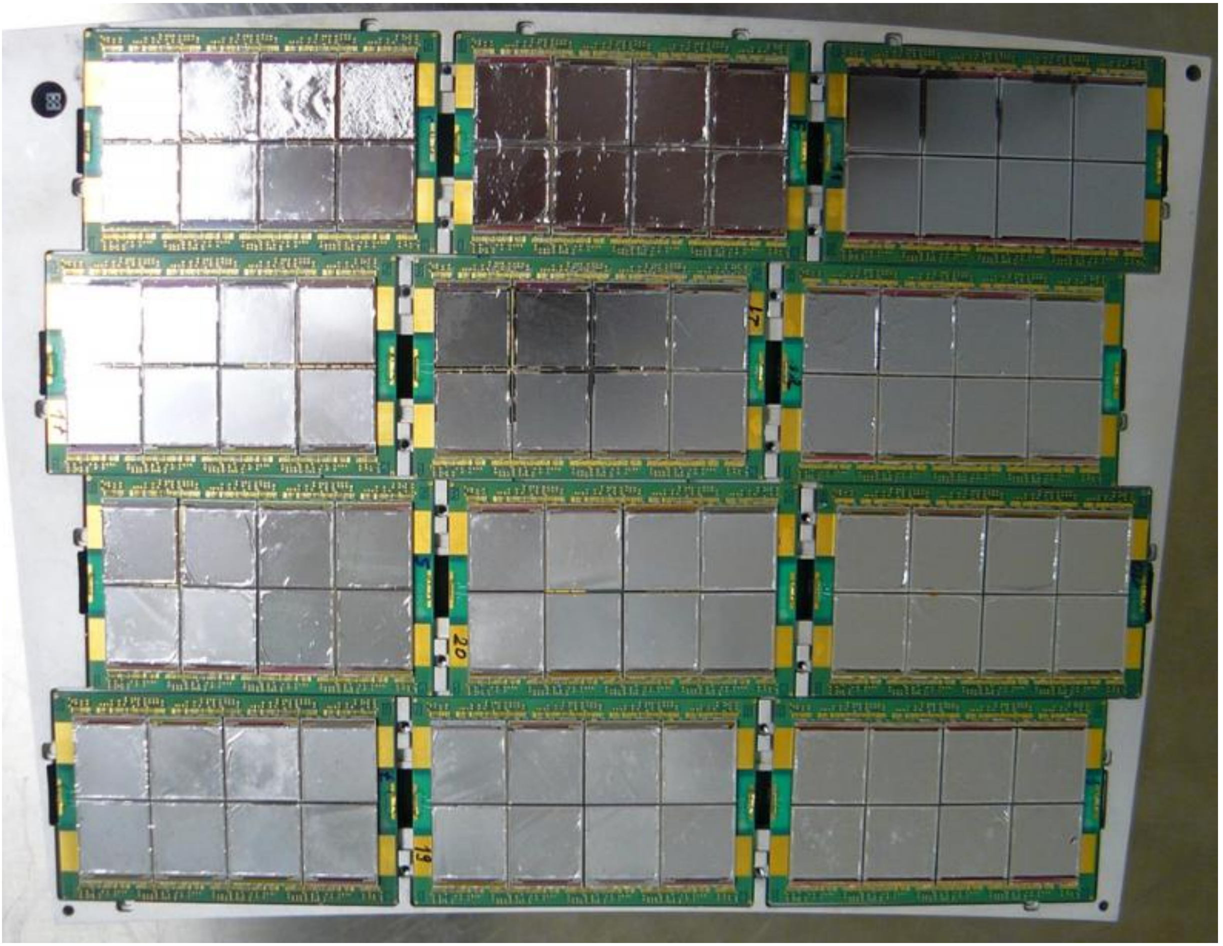
InGrid production



Octoboard



Many Octoboards



1 fully equipped LCTPC module (96 Timepix-GridPixes)
… obviously we didn´t have enough high quality grids...

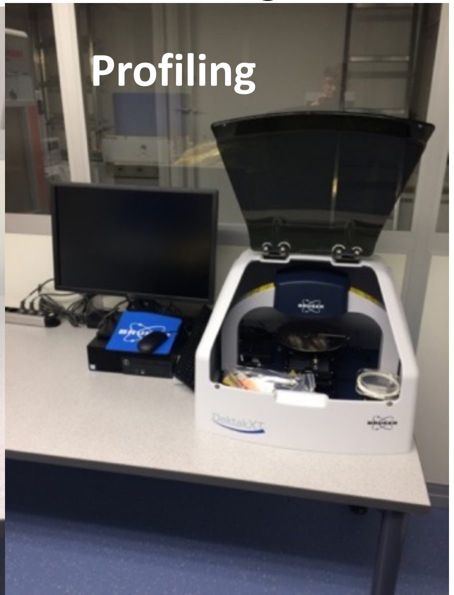
[Jochen Kaminski, Michael Lupberger, et al]

Wafer-based production: future

We soon will have cleanroom infrastructure
for microstructuring capable of producing InGrids

- Sputtering
- PECVD
- RIE
- Mask-less aligner
- Wet chemistry for cleaning/photolithography
- …

Research Building for Detector Physics



Wafer-based production: future

We soon will have cleanroom infrastructure
for microstructuring capable of producing InGrids

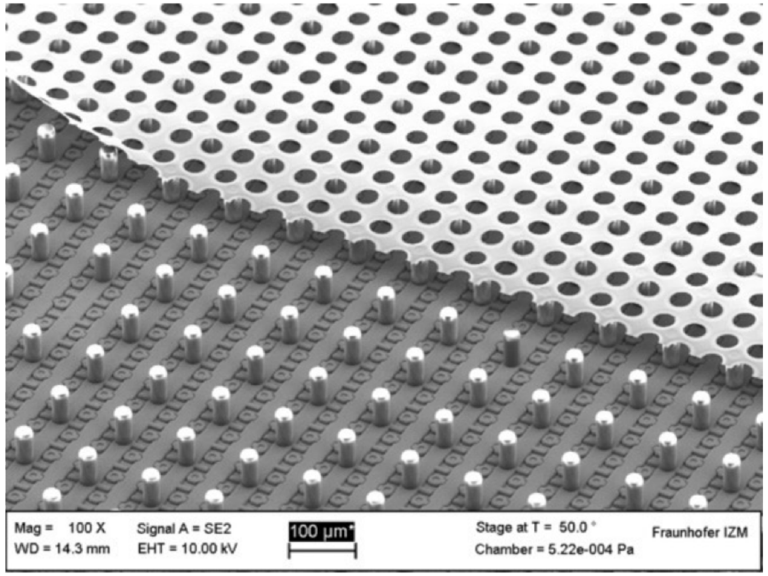
- Sputtering
- PECVD
- RIE
- Mask-less aligner
- Wet chemistry for cleaning/photolithography
- ...

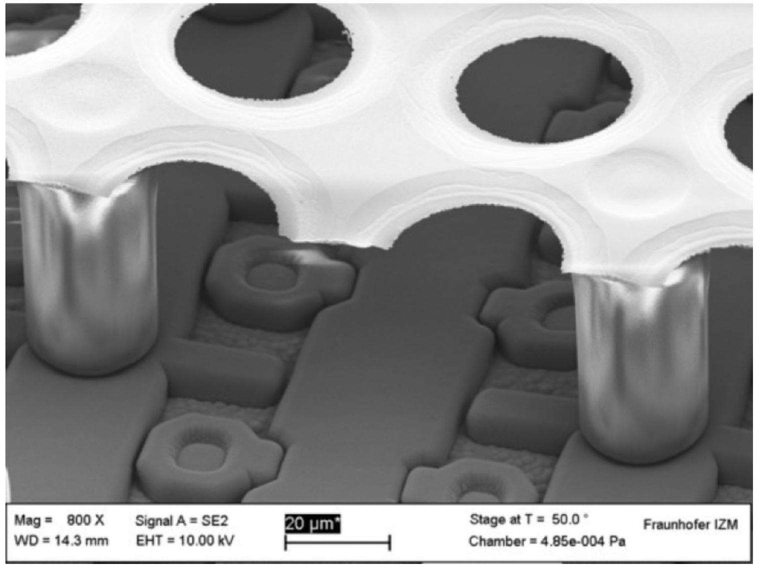
FTD Bonn

Research Building for Detector Physics

Timepix vs. Timepix3

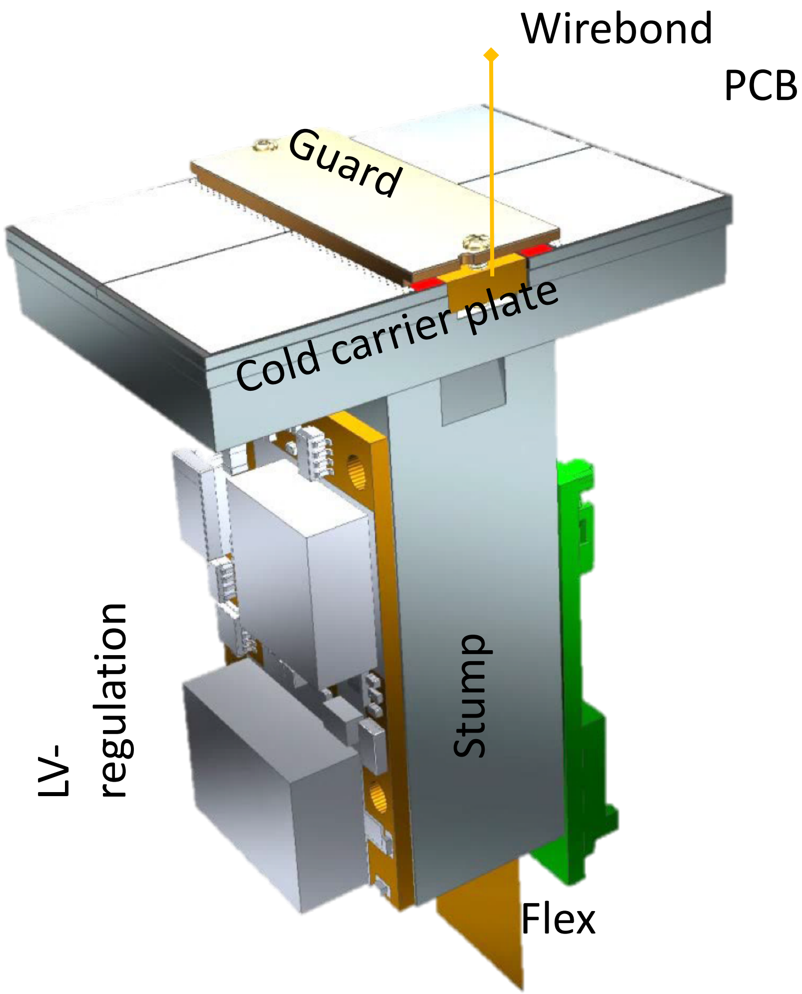
	Timepix	Timepix3
Pixels	256 x 256	256 x 256
Pixelsize	55x55 μm^2	55x55 μm^2
Noise (ENC)	~ 90 e^-	~ 60 e^-
Timing clock	up to 80 MHz	640 MHz
Mode	TOA or TOT	TOA and TOT
Readout	frame-based r/o speed: o(100 Hz max)	data driven 8 x 640MHz serial links r/o speed o(MHz) (occupancy dependent)

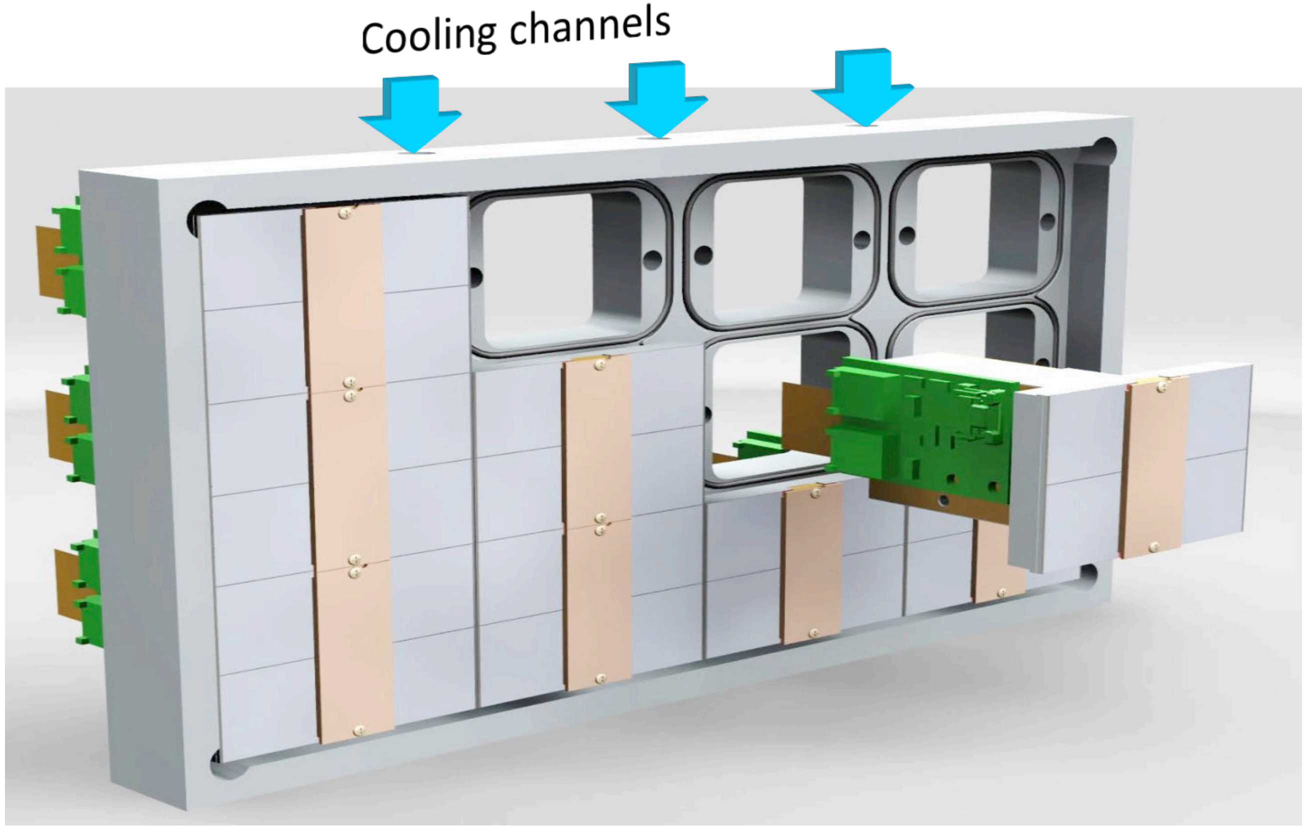


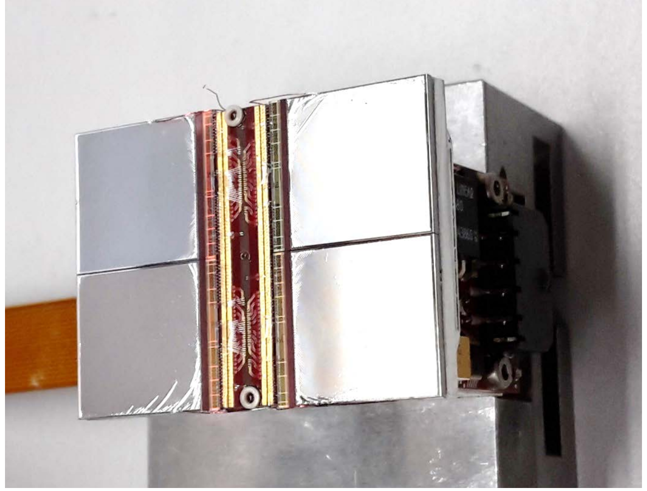


First (low yield) Timepix3 wafer equipped with InGrids

Timepix3 Quad Module







Nikhef Lepcol group [C. Ligtenberg, K. Heijhoff, H. van der Graaf, F. Hartjes, P.M. Kluit, G. Raven, J. Timmermans]

GridPix – Applications

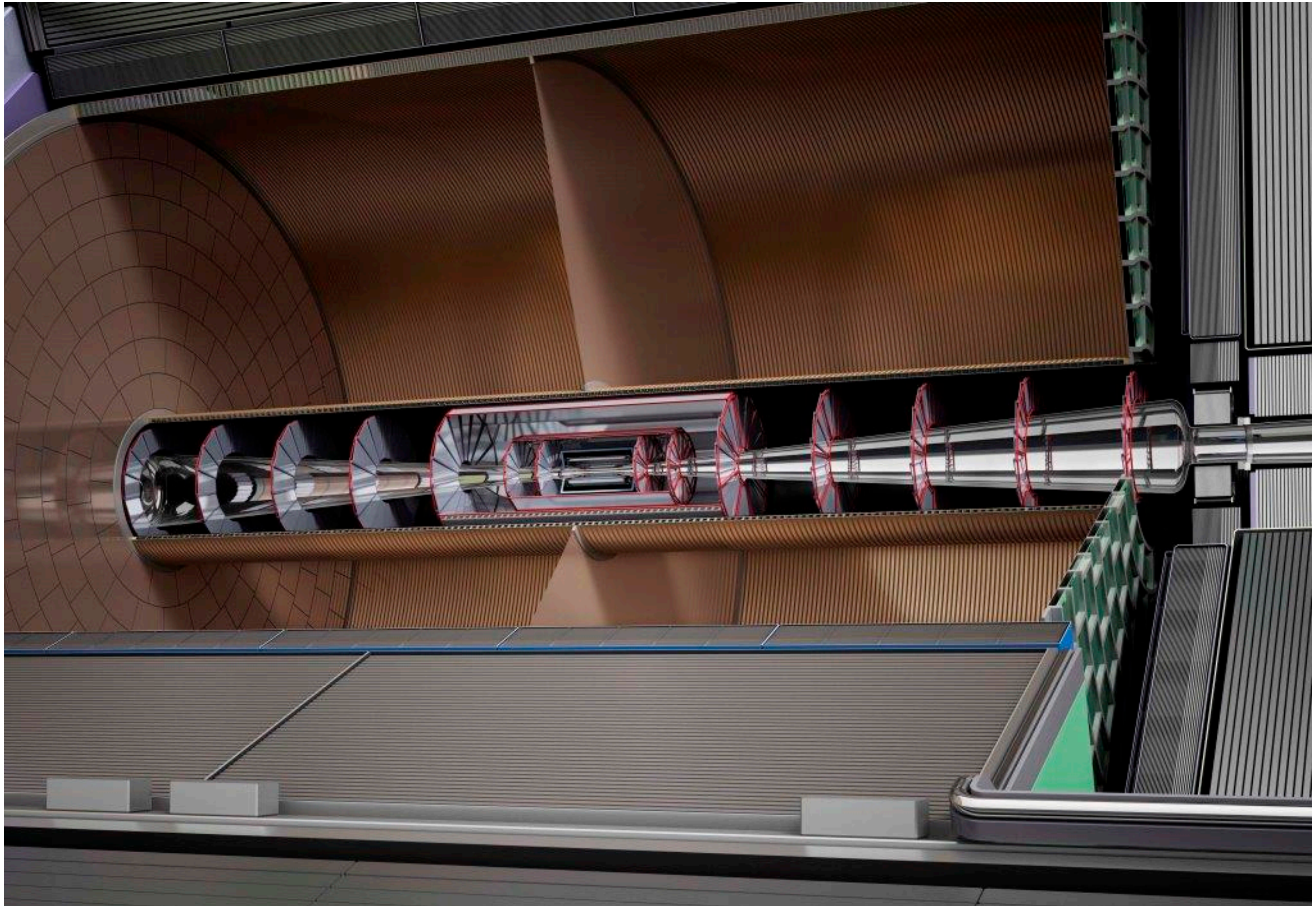
3 examples:

1. Large TPC - Tracking

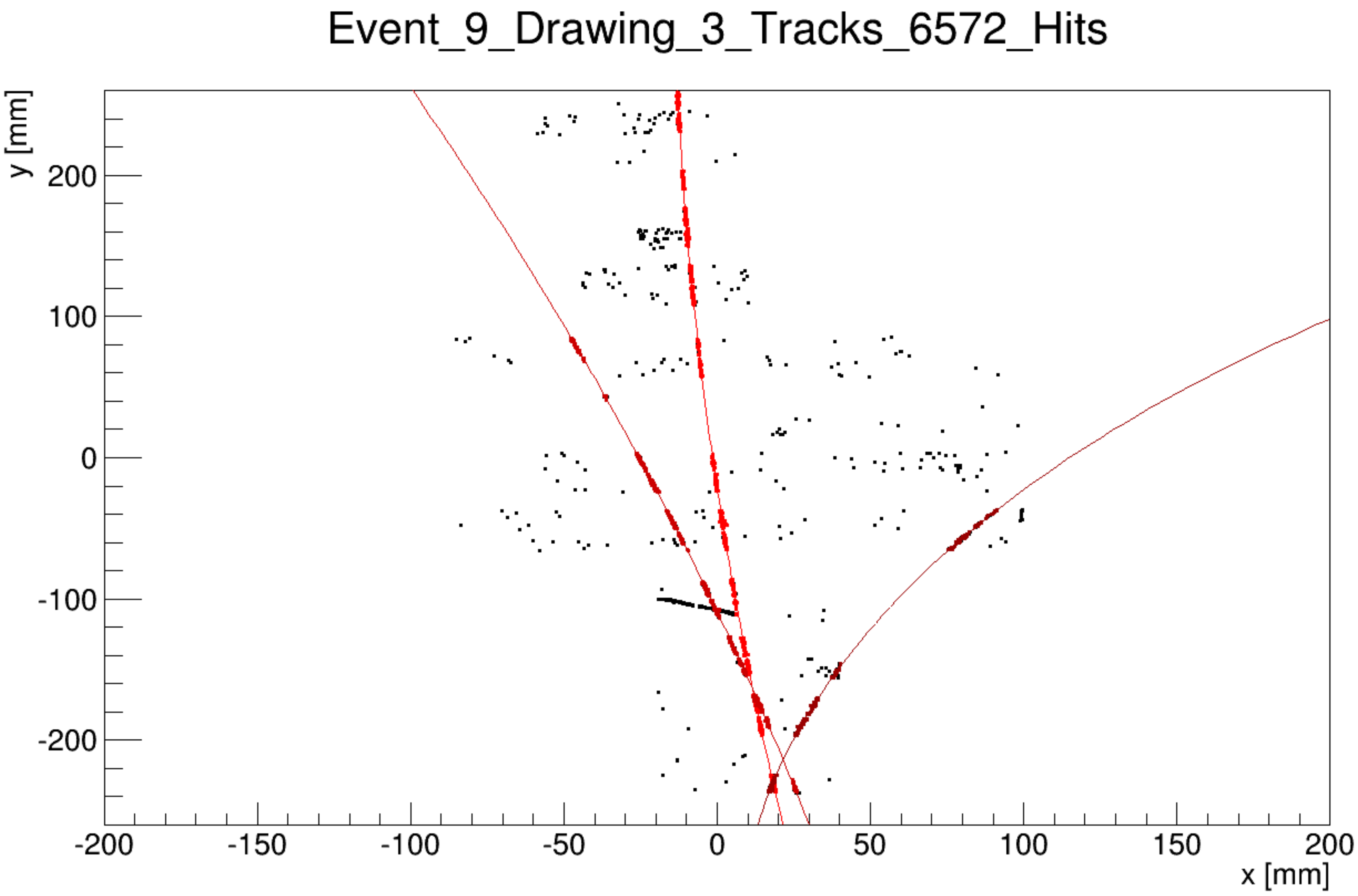
2. Single (soft) X-ray detection

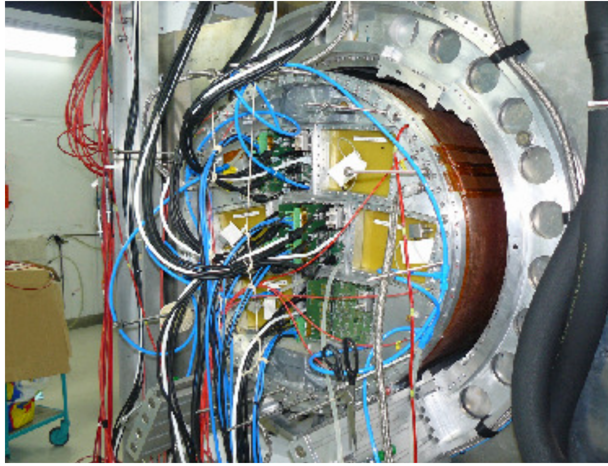
3. Neutron detection

1. GridPix – Large TPC Tracking



1 . GridPix – Large TPC Tracking



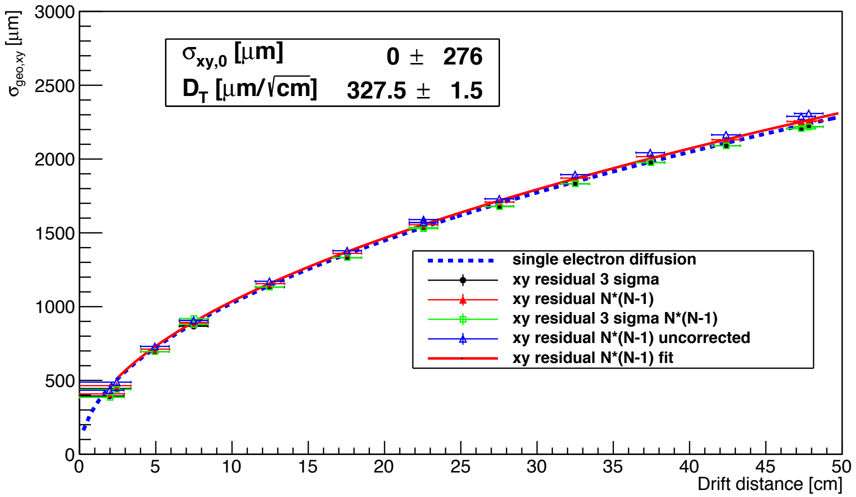


Data from testbeam at DESY (2015) in LCTPC Prototype with B=1T

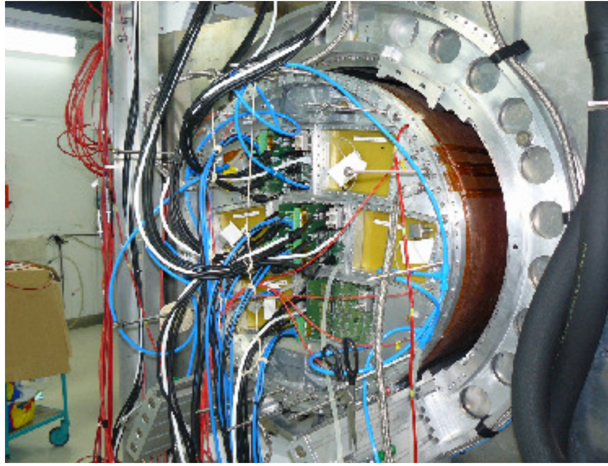
- Tracking possible even in “noisy” environment
- Double track resolution
- δ removal

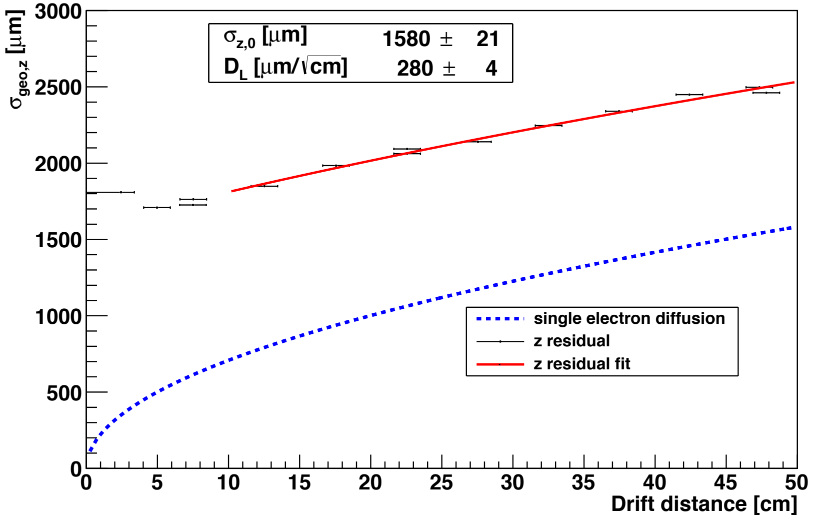
[Amir Noori Shirazi, Siegen]

1. GridPix – Tracking detector



Transverse resolution:
fully limited by single-electron diffusion (can´t get any better)





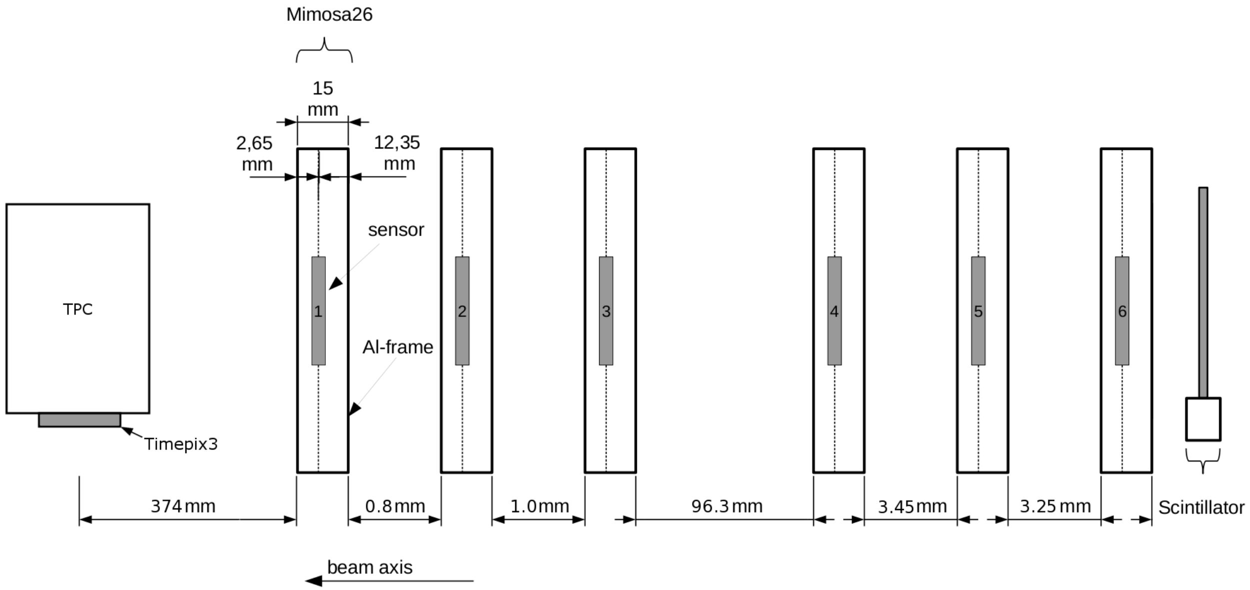
Longitudinal resolution:
limited by slow Timepix clock and <u>Timewalk</u>

→ Huge improvement with Timepix3 possible

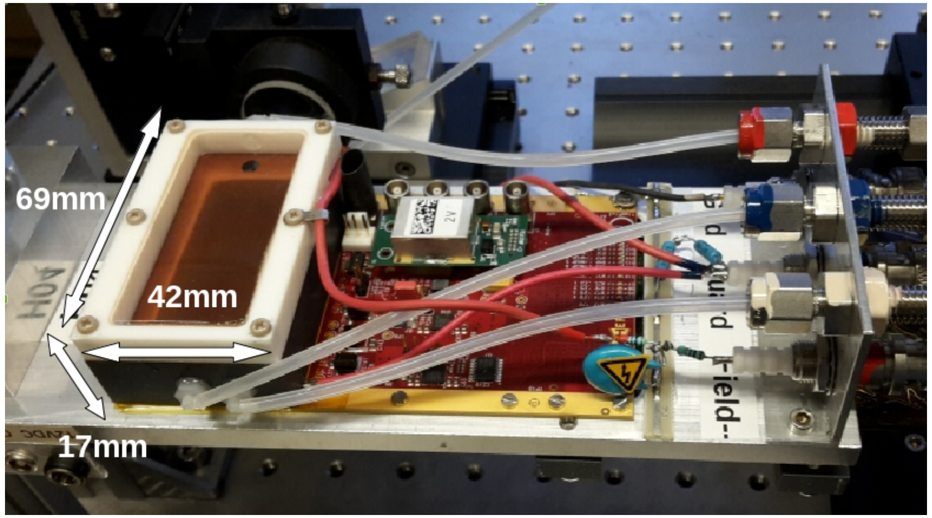
[Michael Lupberger, Bonn]

Timepix-3 Test Beam @ELSA

[Kees Ligtenberg et al]



ANEMONE Mimosa Beam Telescope



2.5 GeV electrons from ELSA (at kHz rate)
Trigger by scintillating plane
6 Mimosa pixel planes as beam telescope

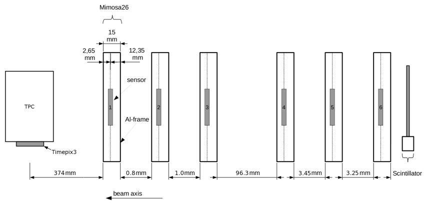
Run 351	
length	6s
triggers	7744
V grid	350 V
E drift	280 V/cm
rotation	17 degree
	0 degree
threshold	700e

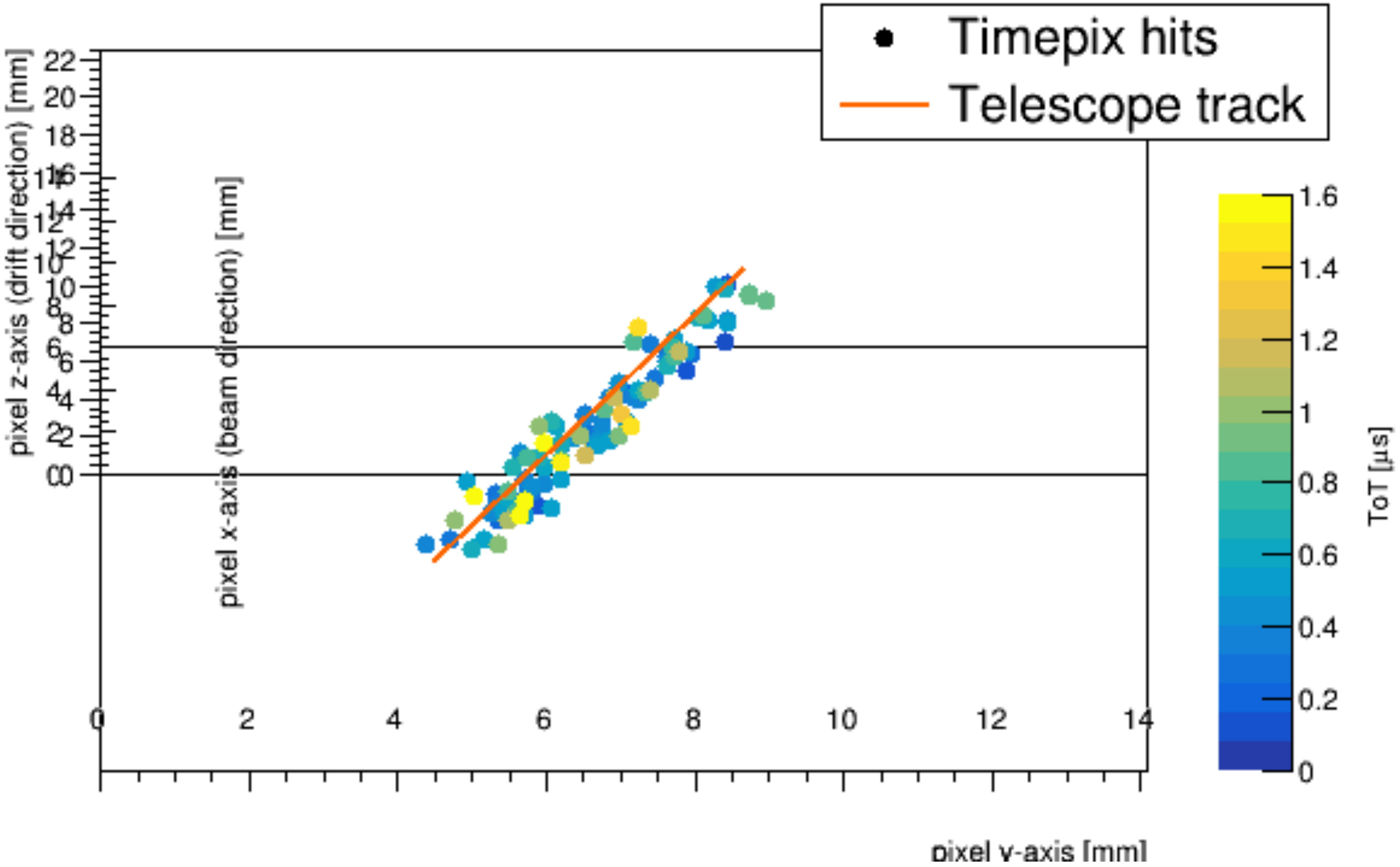
- 6358 triggers with tracks in telescope and timepix
- 5059 matched tracks

Test beams can be fast...

[Kees Lightenberg, Nikhef et al]

Timepix-3 Test Beam @ELSA

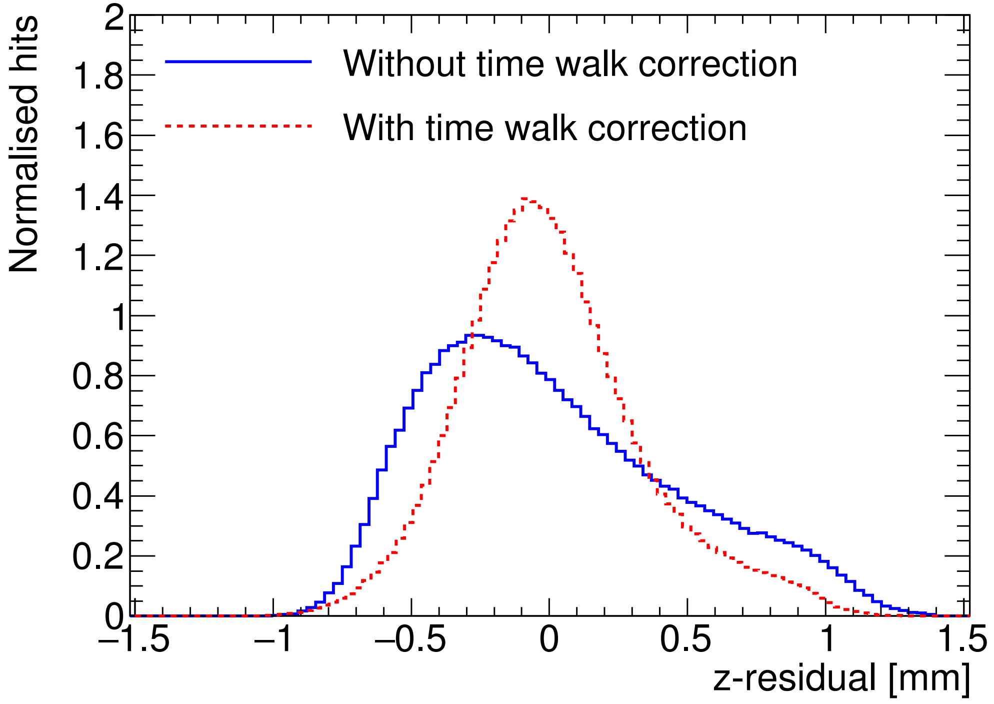


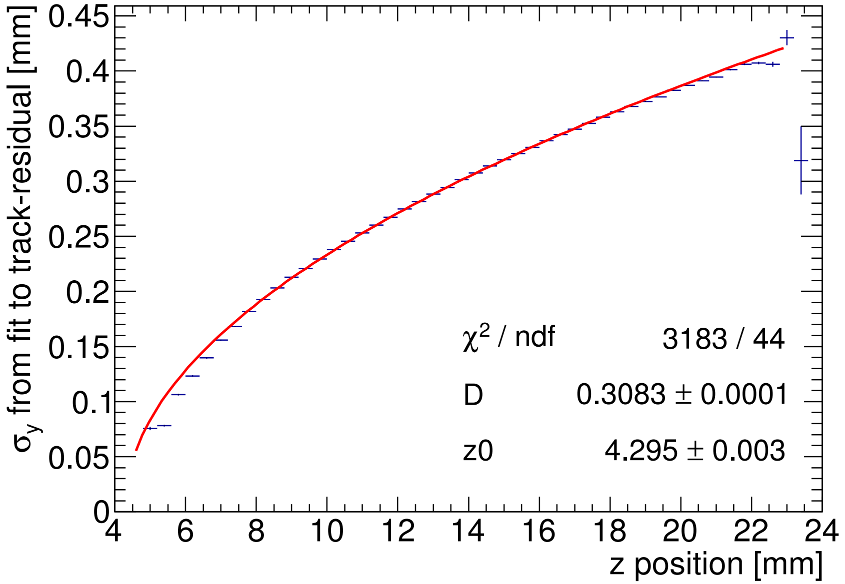


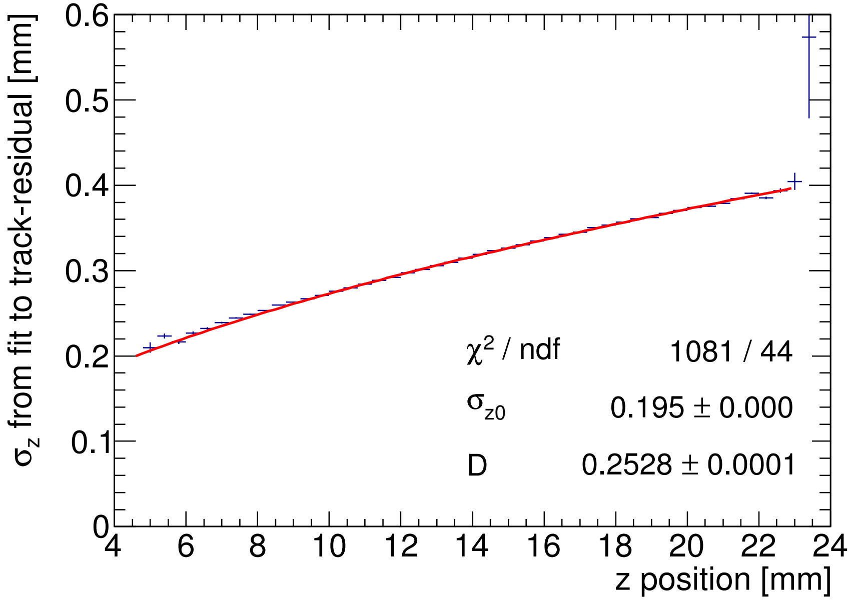
3D tracks at
>kHz readout

Timepix-3 Test Beam @ELSA

Timewalk correction possible
(TOT and Time per pixel in TPX3!)



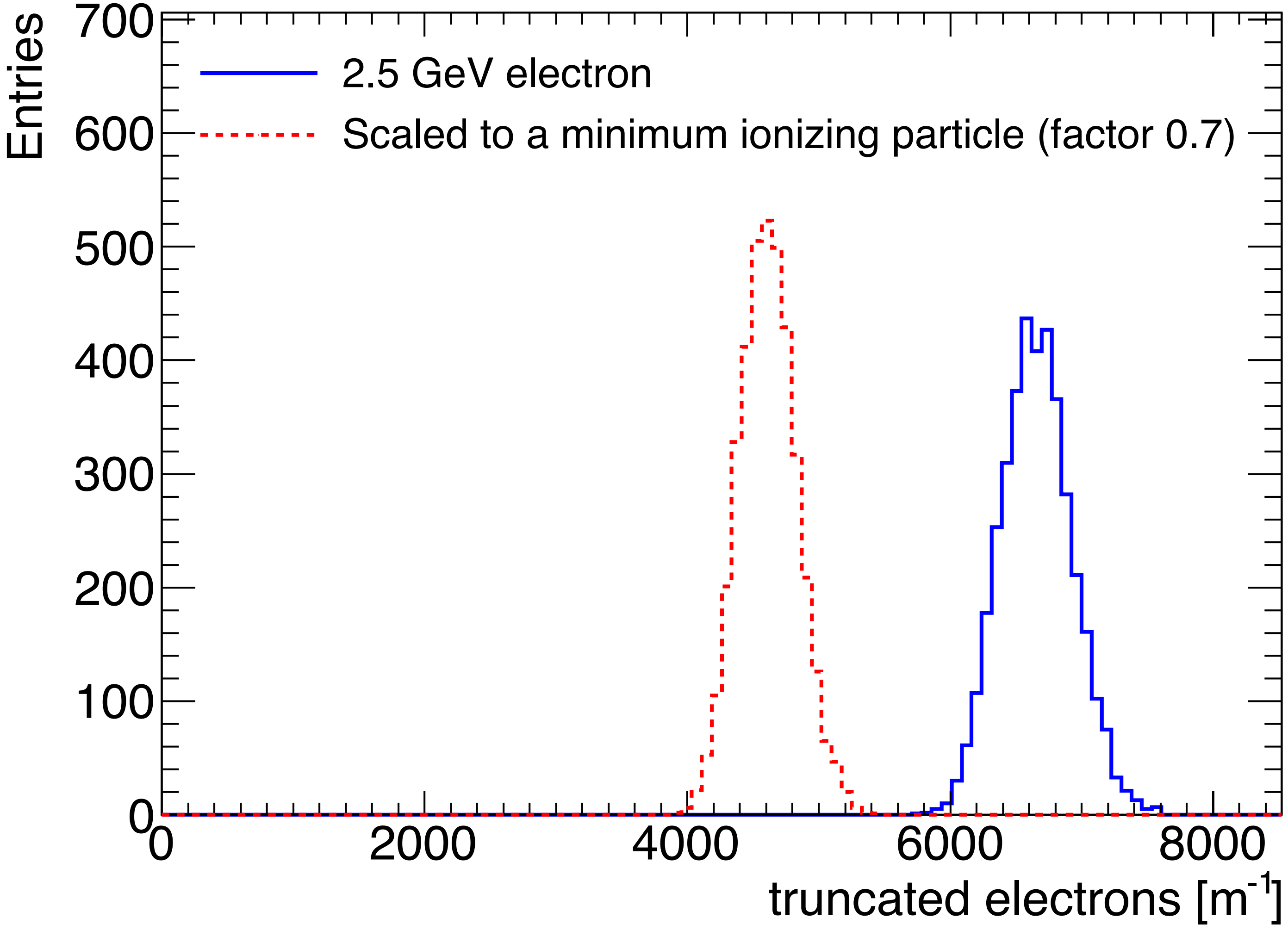




With TPX3 both transverse and longitudinal resolution is dominated by diffusion!

[Kees Ligtenberg, Nikhef et al]

Timepix-3 Test Beam @ELSA



dE/dx resolution

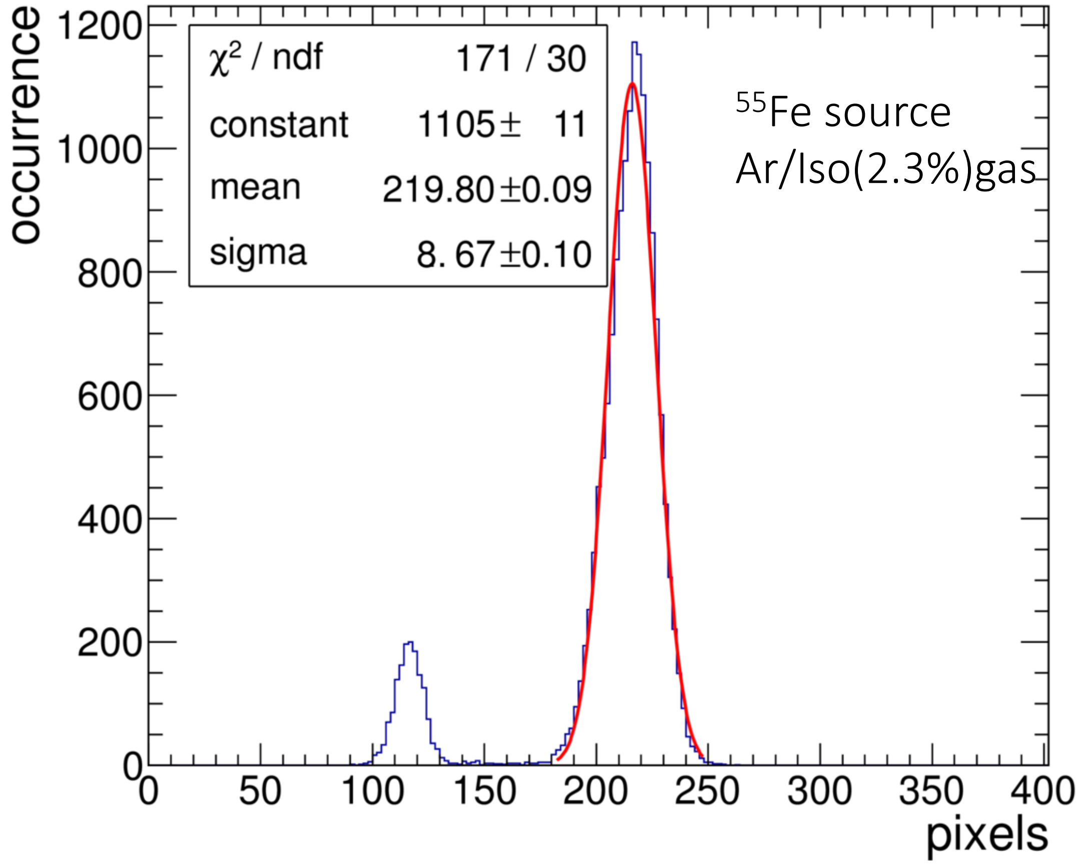
slicing into 1.1mm track pieces
count pixels
truncated mean

→ Resolution 4.1% for electrons
4.8% for MIPs
e/MIP separation 5.9σ for 1m track

[Kees Ligtenberg, Peter Kluit]

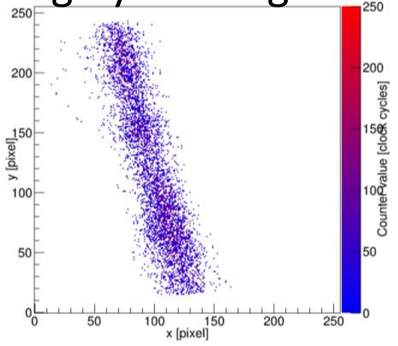
2. GridPix – X-Ray detector

Soft X-Rays (photo effect) produce one electron per 26 eV X-ray energy
→ Count the electrons on the GridPix to measure energy

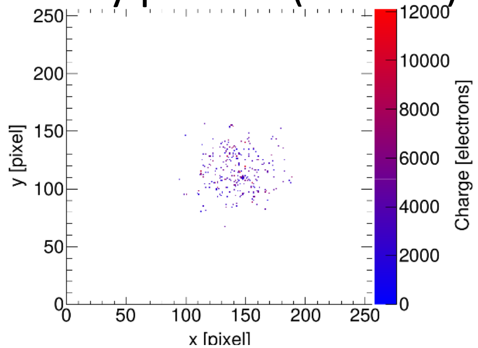


[Christoph Krieger]

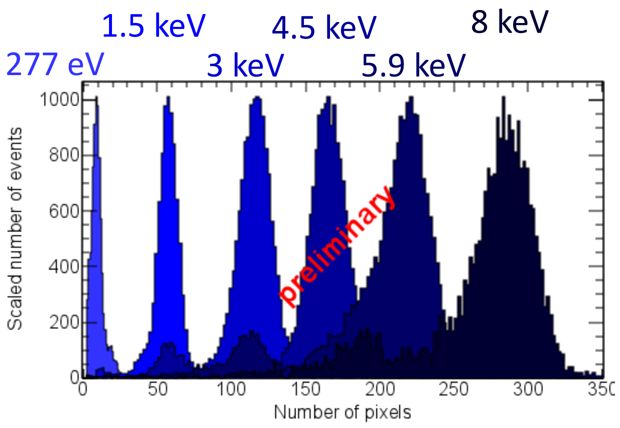
Highly ionizing track



X-ray photon (5.9 keV)



Topological background discrimation for rare event searches

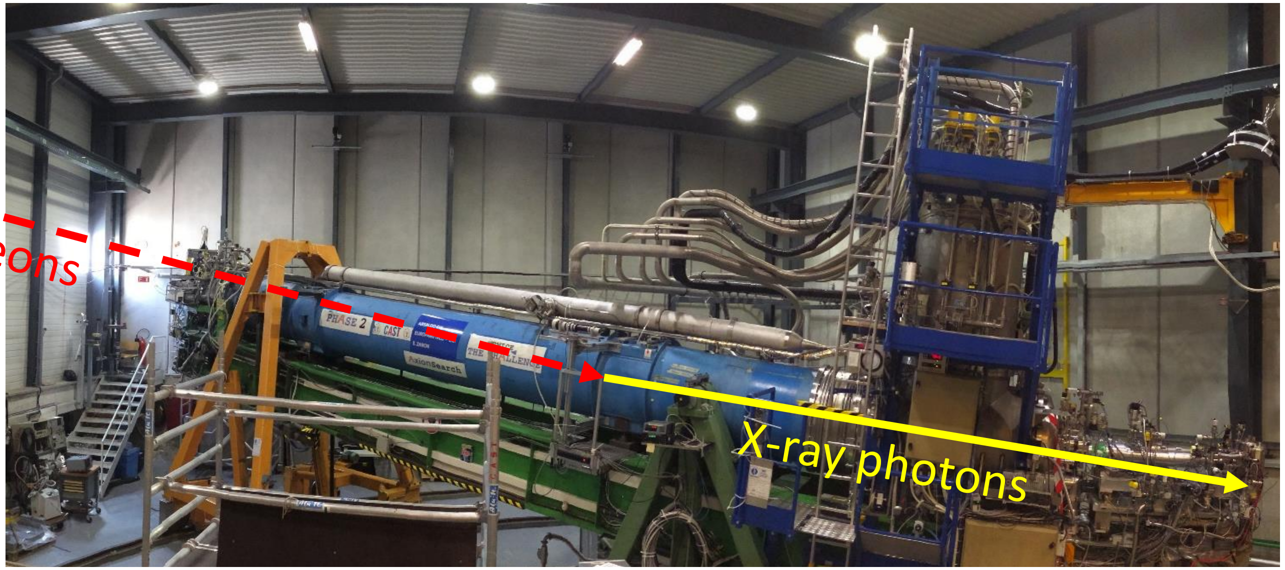


very low threshold

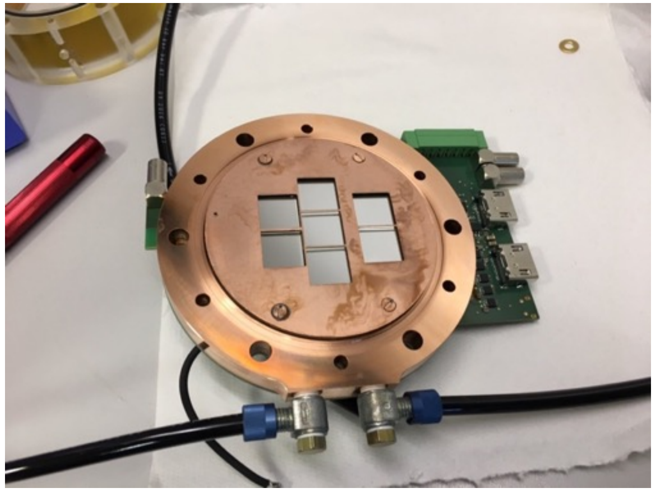
2. Application: solar axion searches

[Christoph Krieger]

CERN **A**xion **S**olar **T**elescope

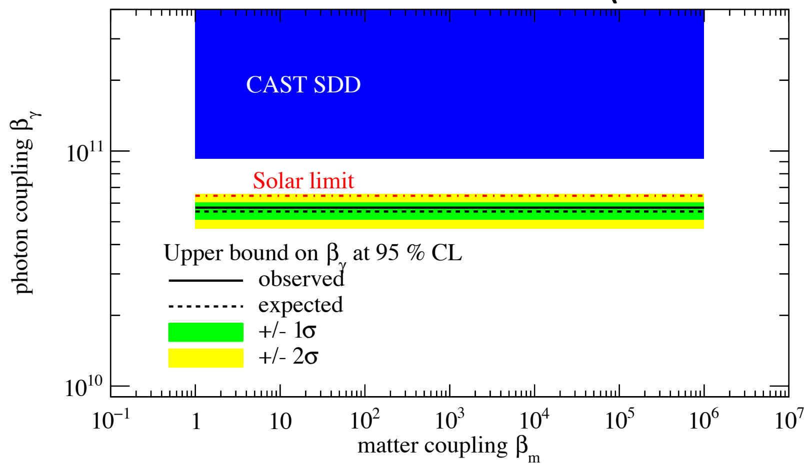


- Axions/chameleons produced in the Sun
- Reconversion to X-ray photons in strong magnetic field (Primakoff effect)



2017 detector with 7 chips

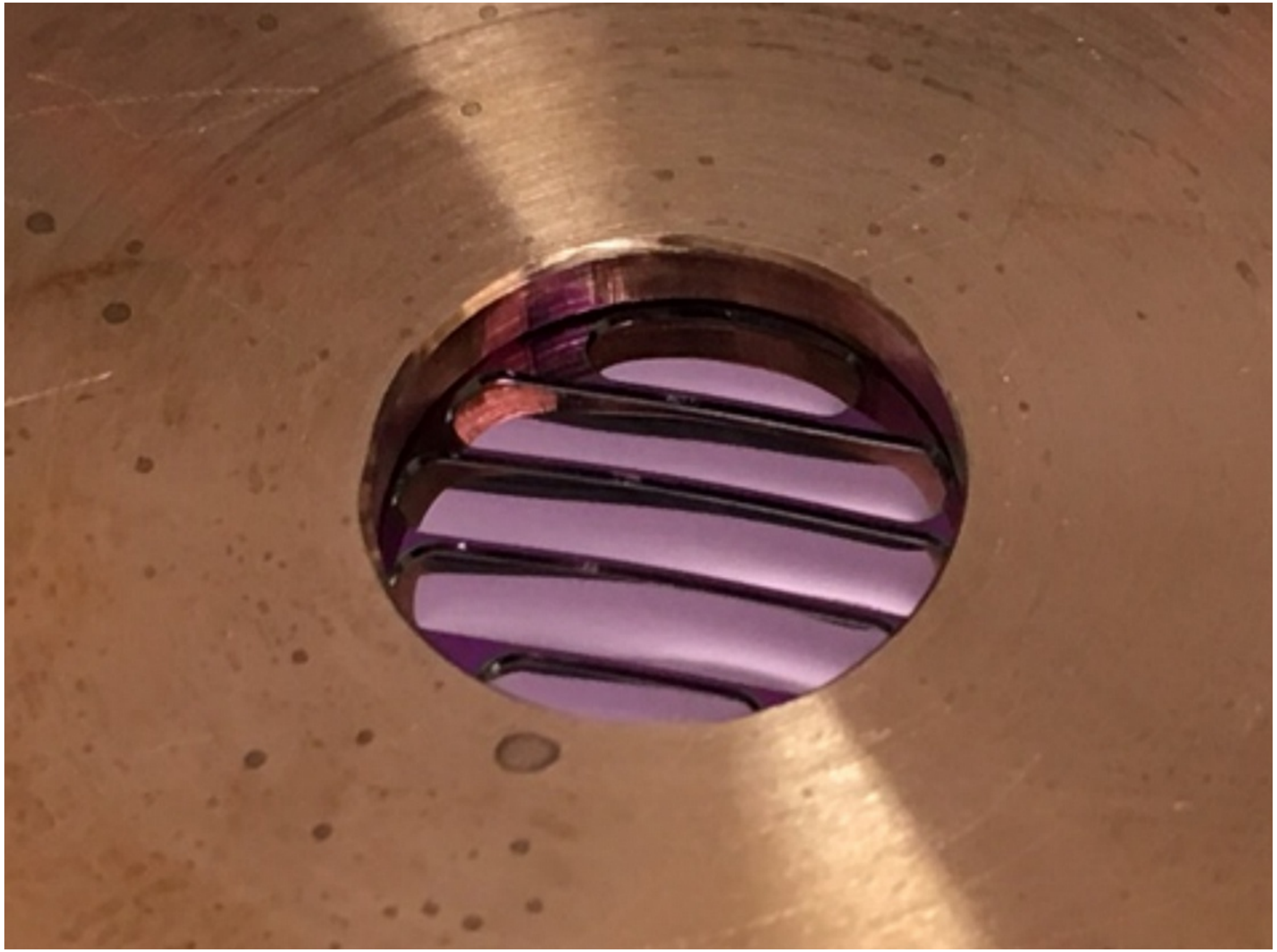
A physics result!
(from 2015 data)



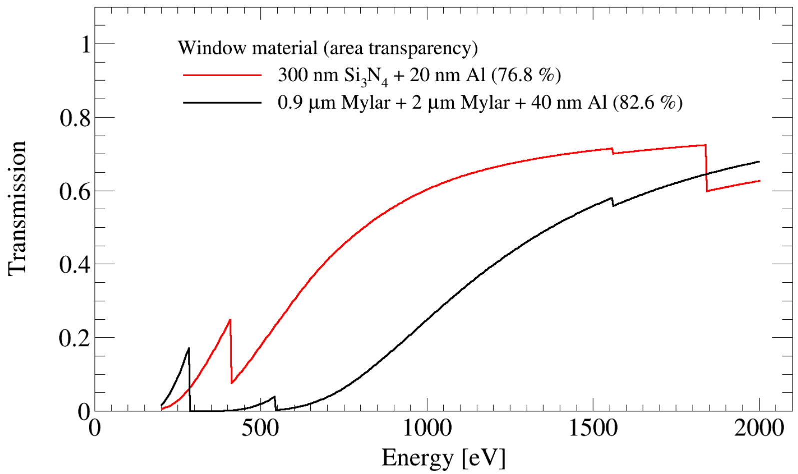
IAXO

[A. Lindner, U. Schneekloth, DESY]

IAXO detectors: X-ray windows



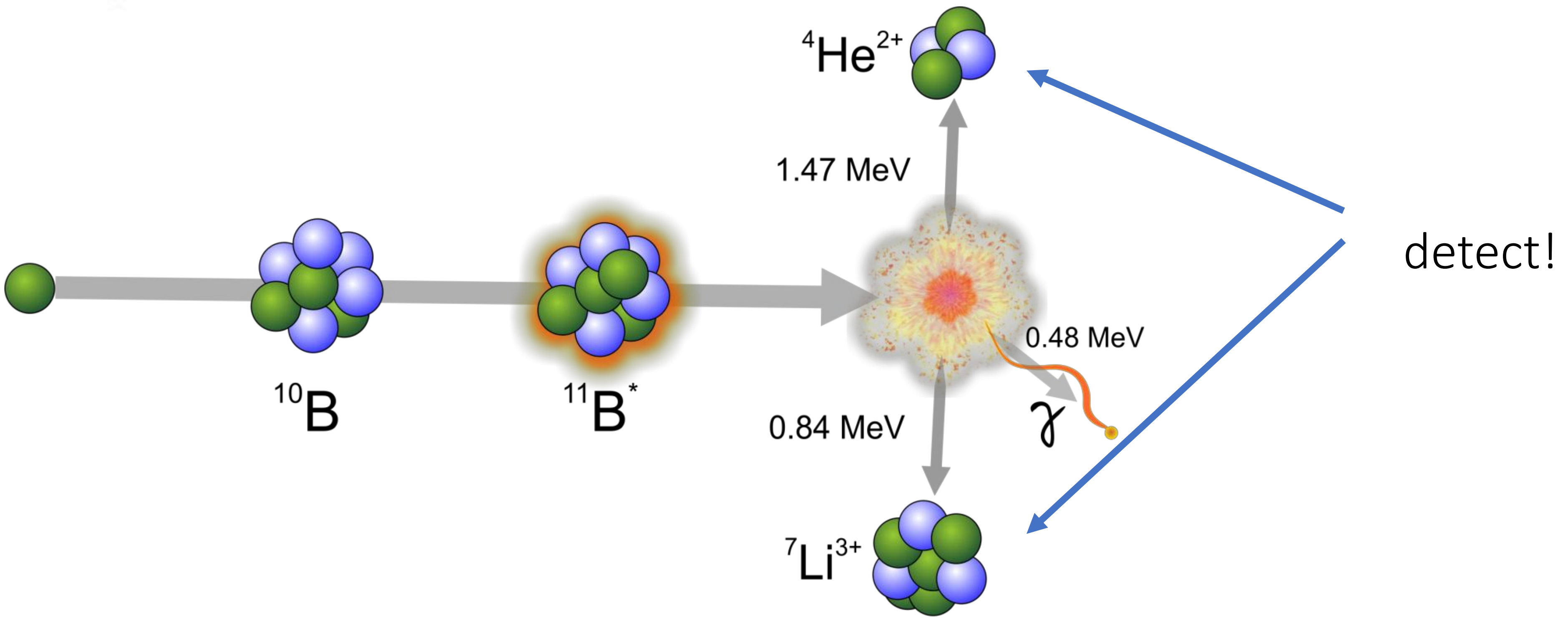
300 nm Silicon-Nitride window at 1.5 bar overpressure



[Krieger, Schiffer et al, Bonn & NORCADA Inc.]

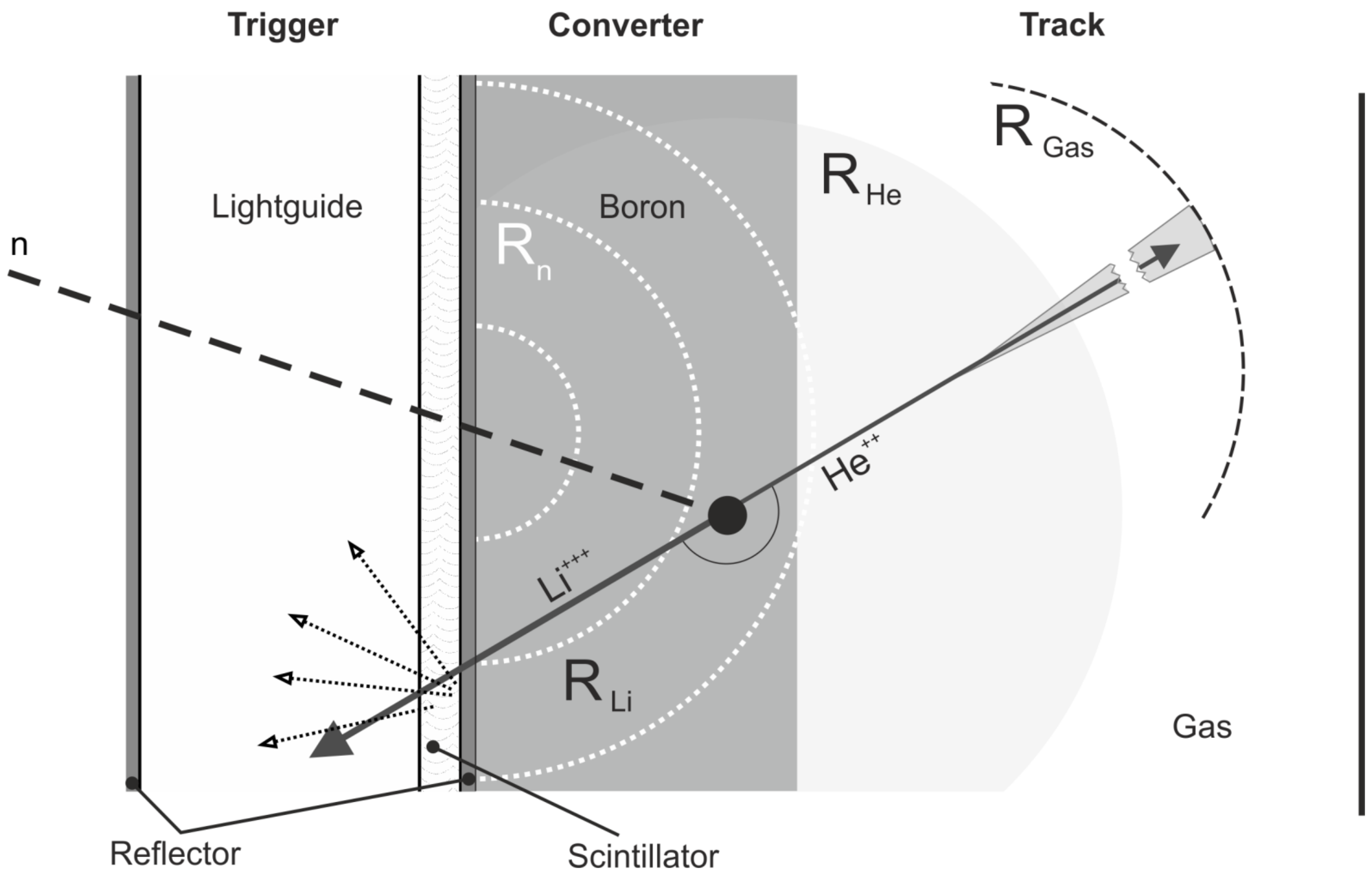
3. GridPix – Neutron detector

^{3}He crisis, many new neutron facilities (ESS!)
→ need for alternative detector for slow neutrons.



3. GridPix – Neutron detector

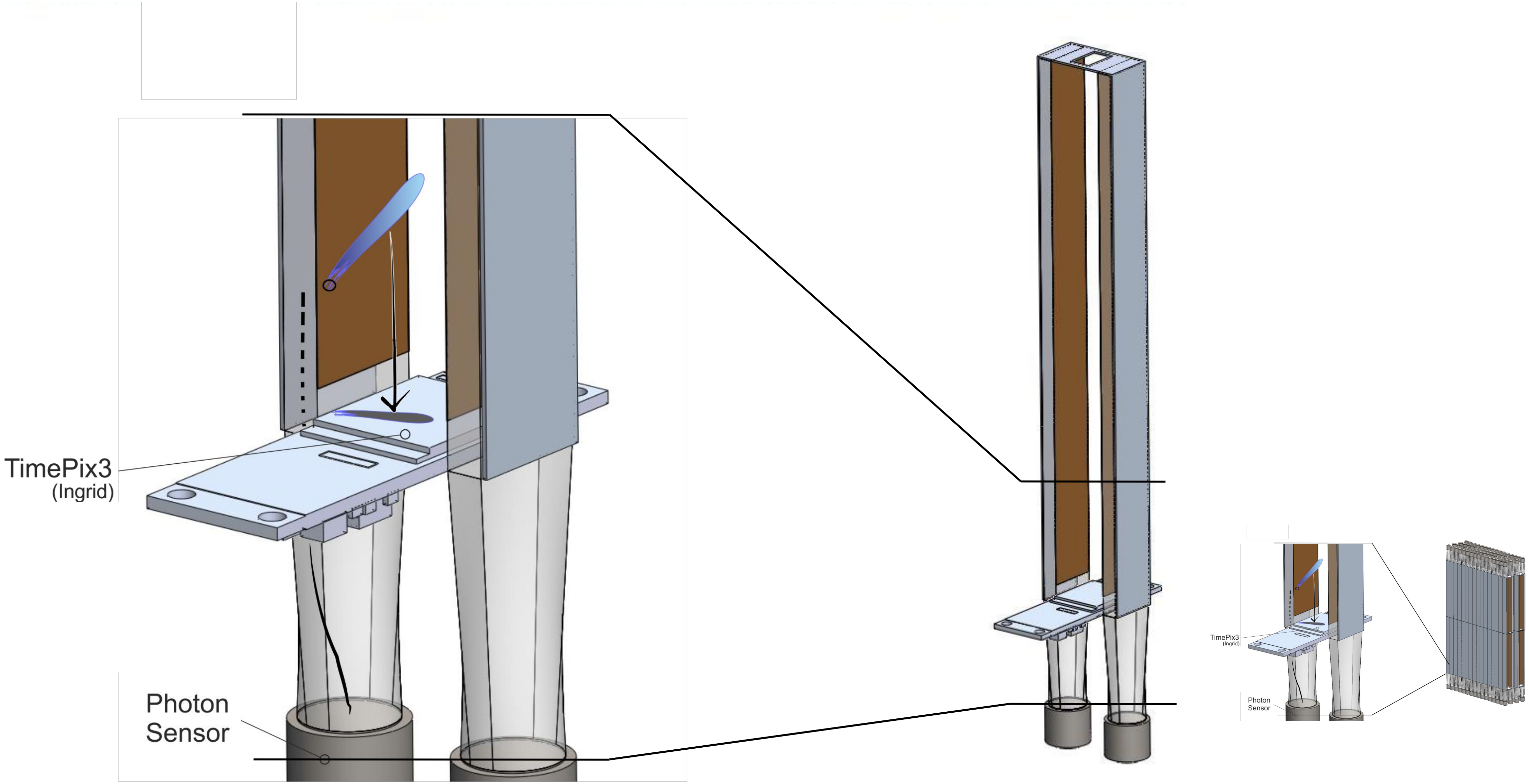
Idea: use one nucleus for t_0 , the other for (x,y,z) (TPC)



[Markus Köhli, Jochen Kaminski, Fabian Schmidt et al]

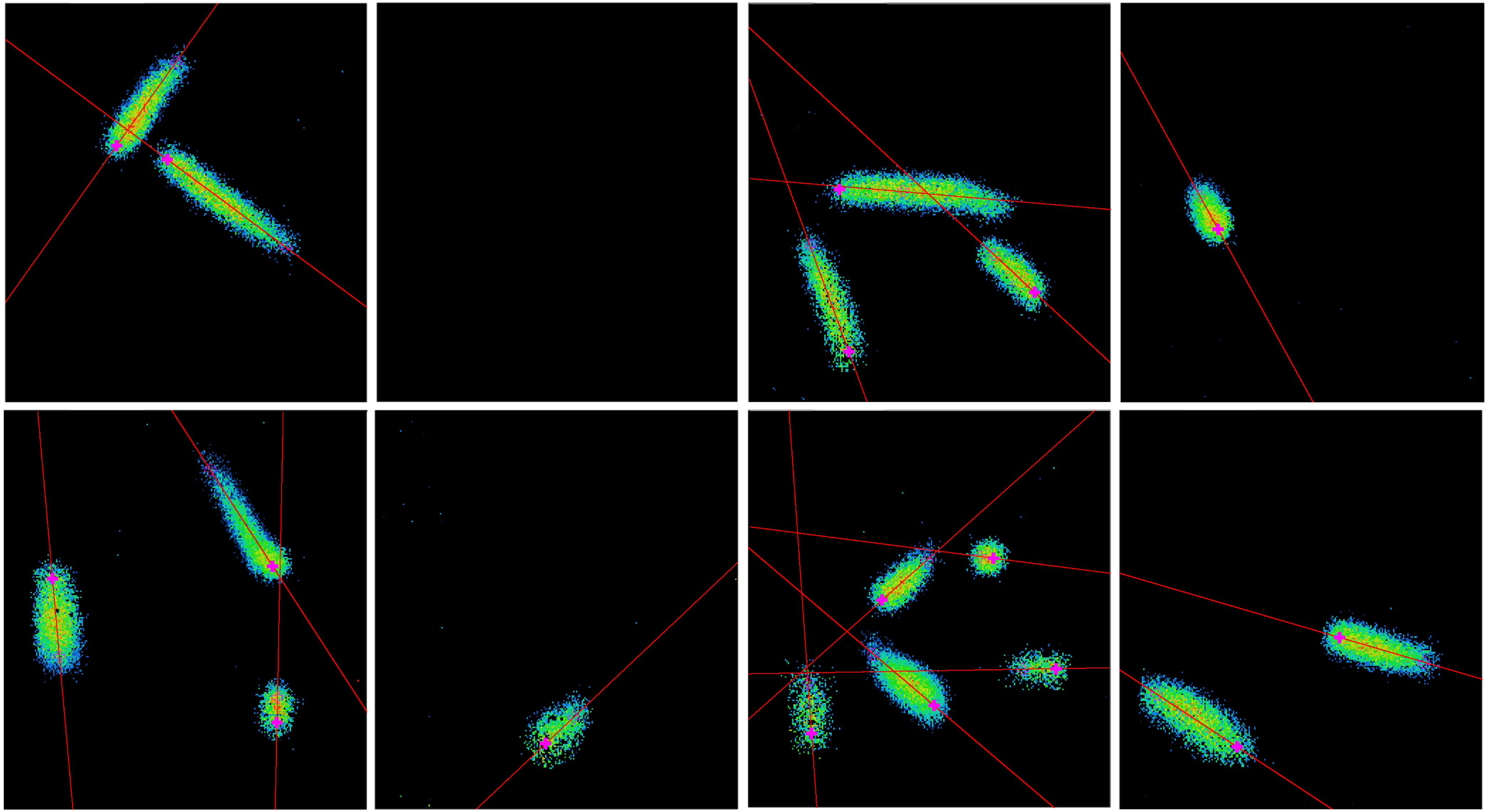
3. GridPix – Neutron detector

BODELAIRE (M. Köhli, J. Kaminski)



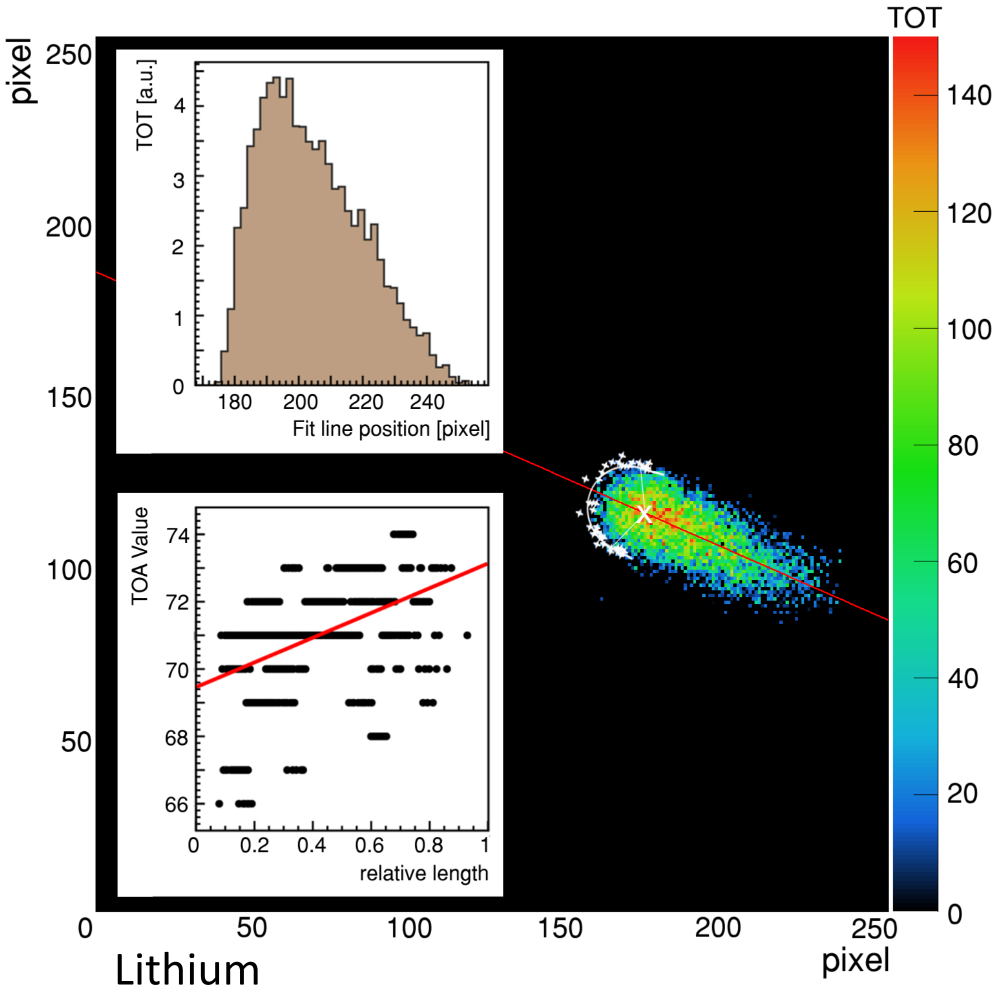
GridPix – Neutron detector

$^{4}He^{2+}$, $^{7}Li^{3+}$ Ions seen by GridPix

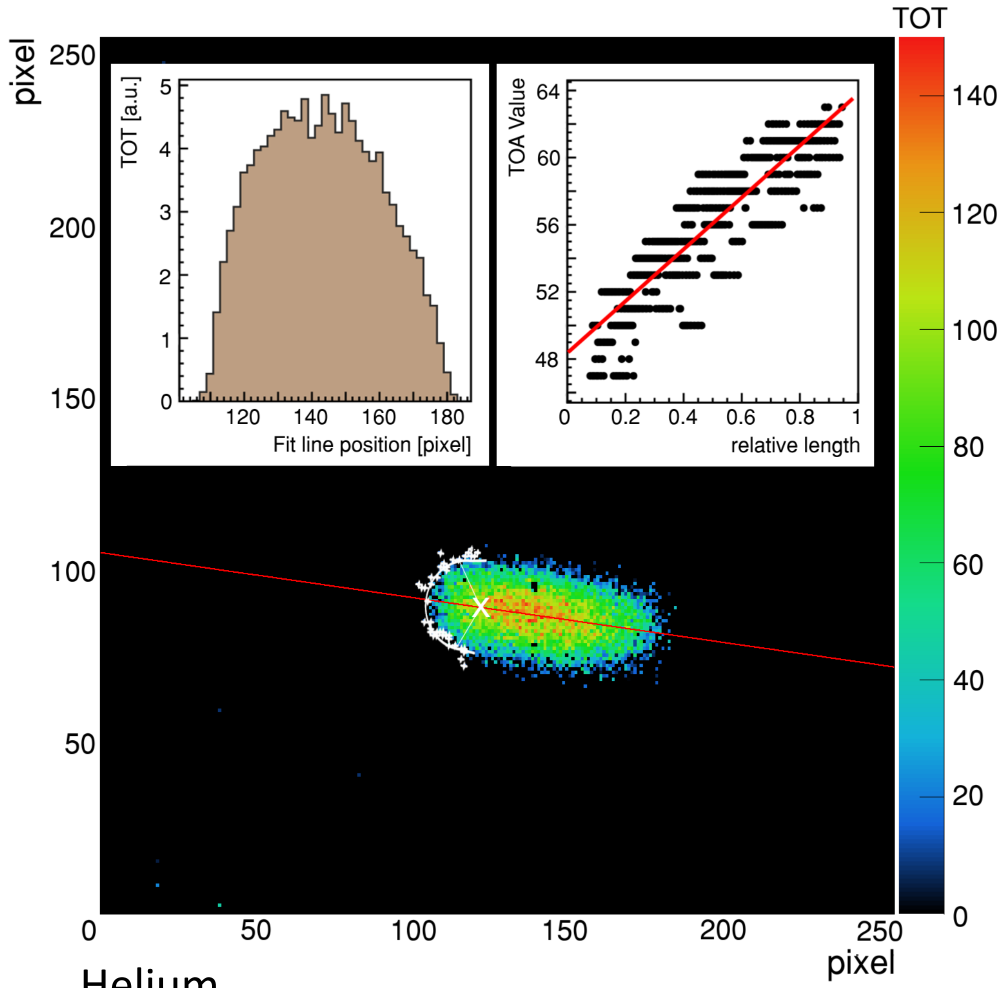


[Markus Köhli, Jochen Kaminski, Fabian Schmidt et al]

Neutron detector



Lithium

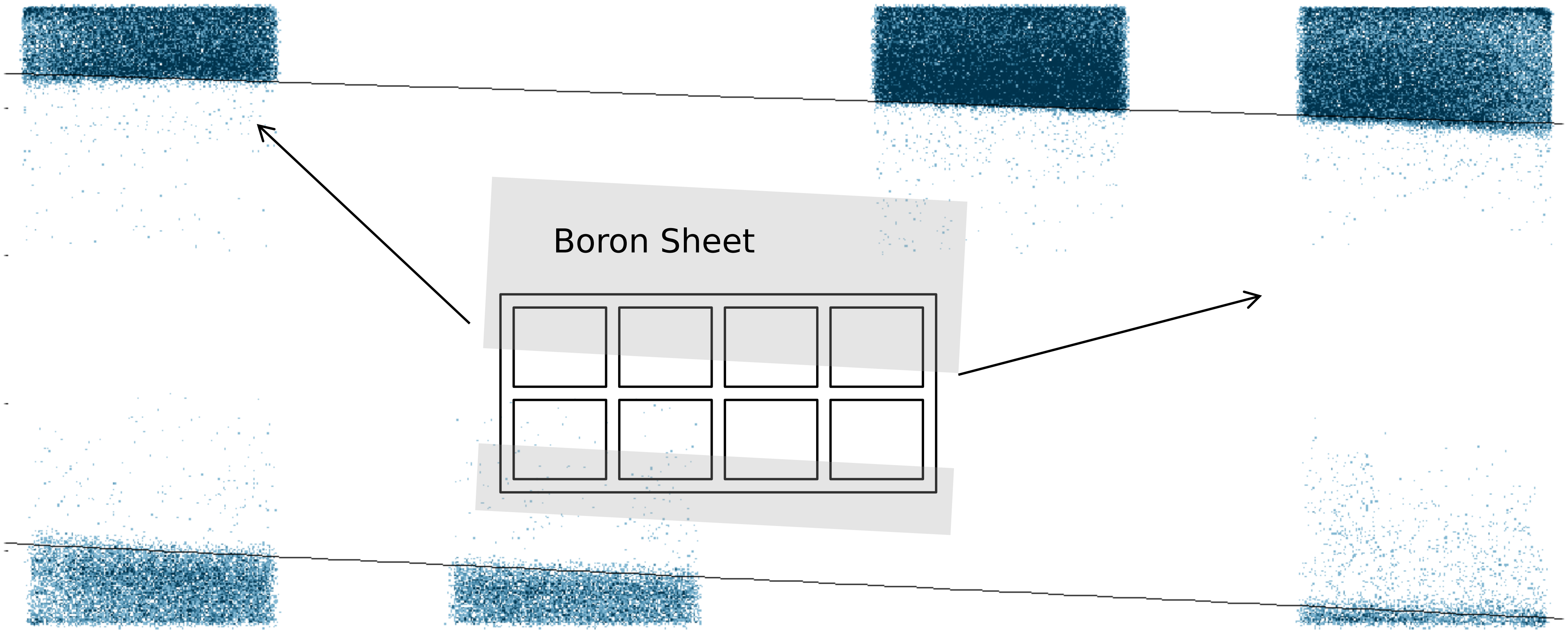


Helium

Use Timepix timing to determine start/end of track

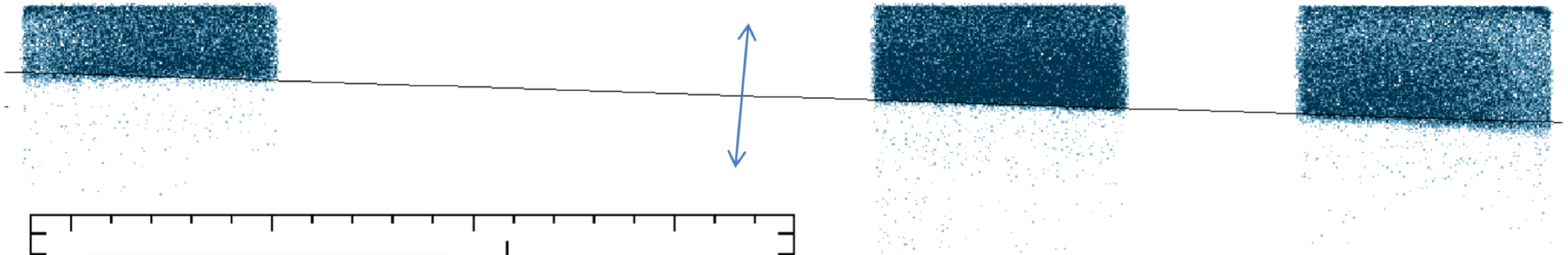
[Markus Köhli, Jochen Kaminski, Fabian Schmidt et al]

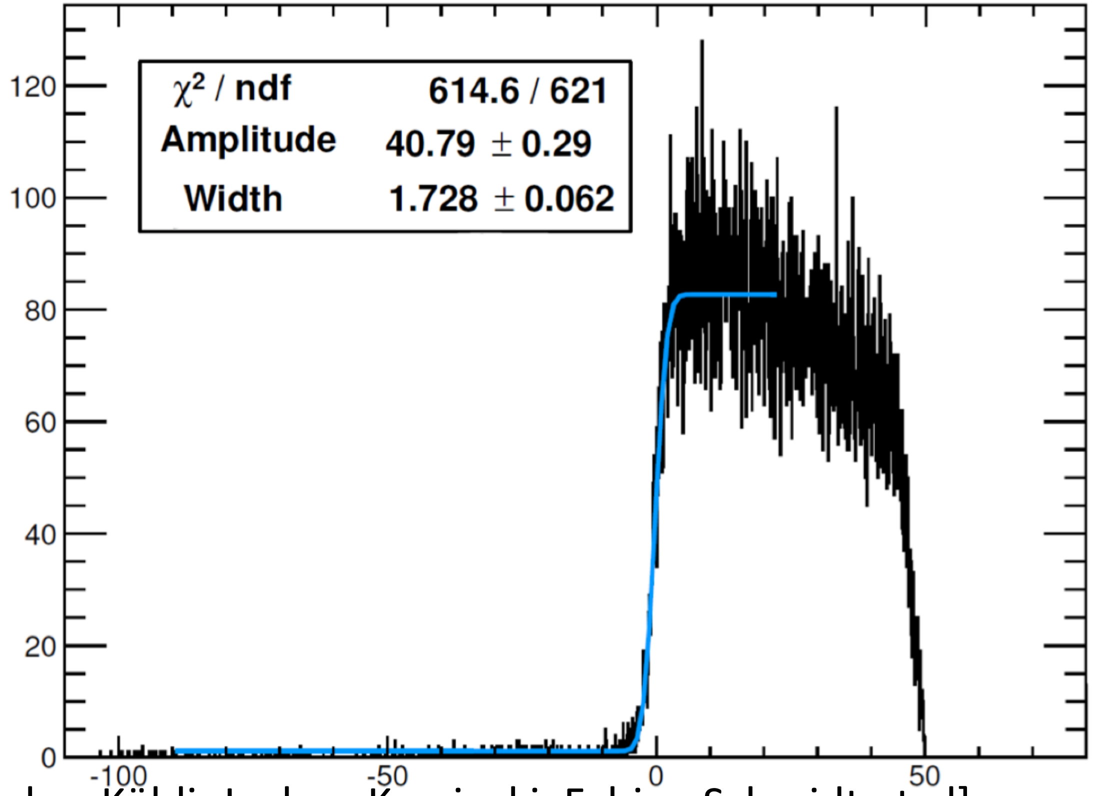
Neutron detector – position resolution



[Markus Köhli, Jochen Kaminski, Fabian Schmidt et al]

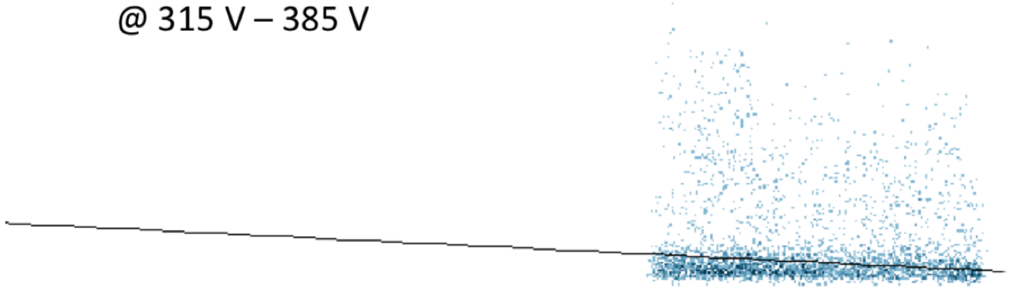
Neutron detector – position resolution





Spatial Resolution σ
(95 +/- 4) µm

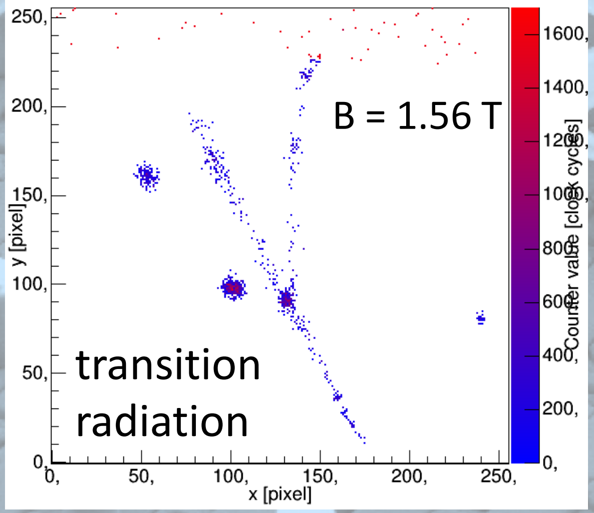
@ 315 V – 385 V



[Markus Köhli, Jochen Kaminski, Fabian Schmidt et al]

Summary & Conclusions

- GridPix detectors combine advantages of gaseous detectors with highest possible resolution
- Production technology is becoming (more) mature
- Various applications (TPC tracking, X-rays, neutrons, and more …)

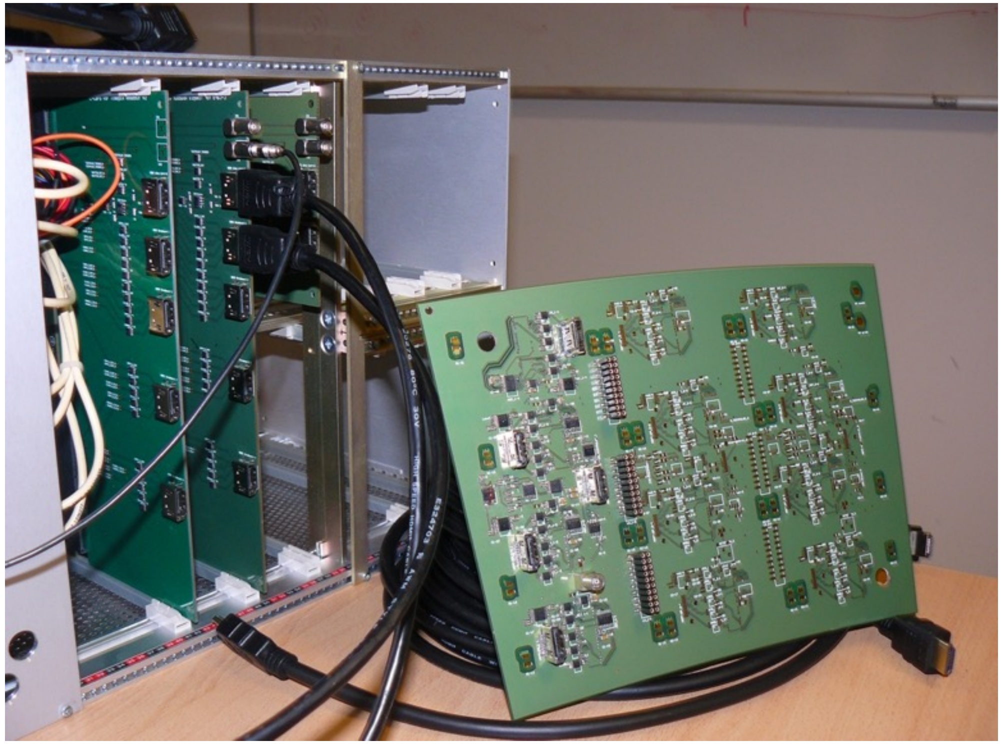


Backup

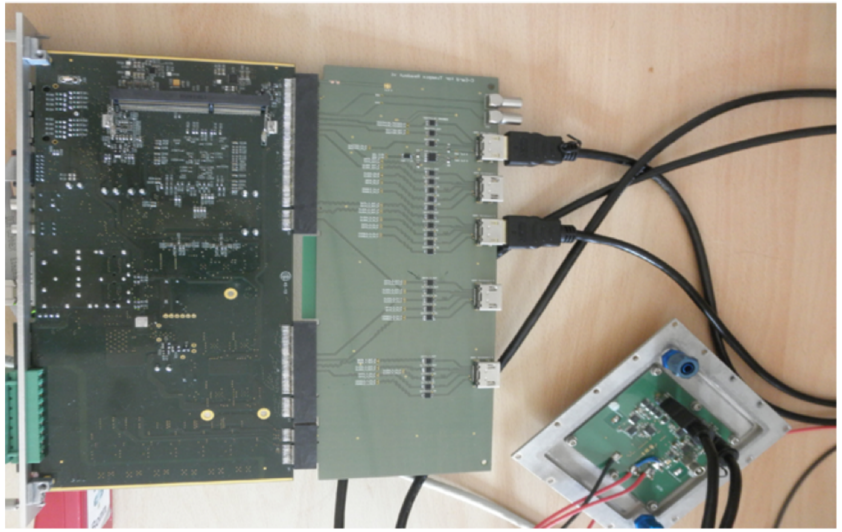
SRS Readout

Developed Timepix readout system customized for HEP applications

- based on „Scalable readout system“ (SRS) developed in RD51
- zero suppression on FPGA
- maximum readout speed
- up to 32 Timepix / SRS-FEC
- easy to synchronize >1 FECs



intermdiate board to host 12 x 8 Timepix chips



„small“ readout based on FPGA development board (used e.g. in CAST)

Neutron detector