Silicon Pixel Readout for a TPC

ALCPG 2007 - Fermilab

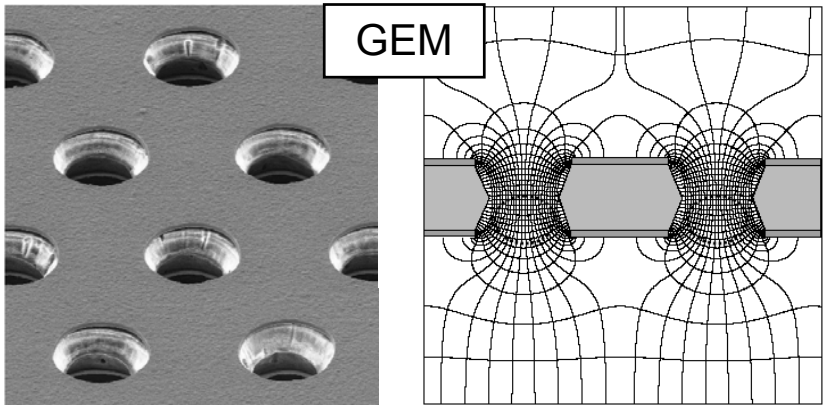
23 October 2007

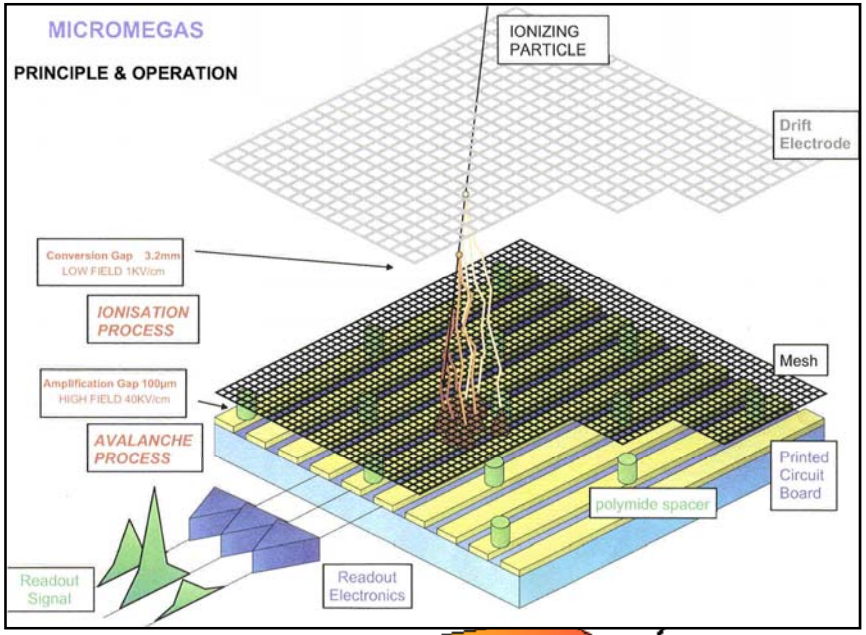
Jan Timmermans

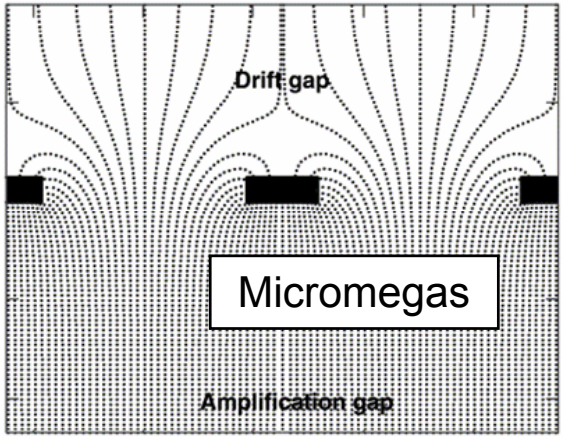
NIKHEF

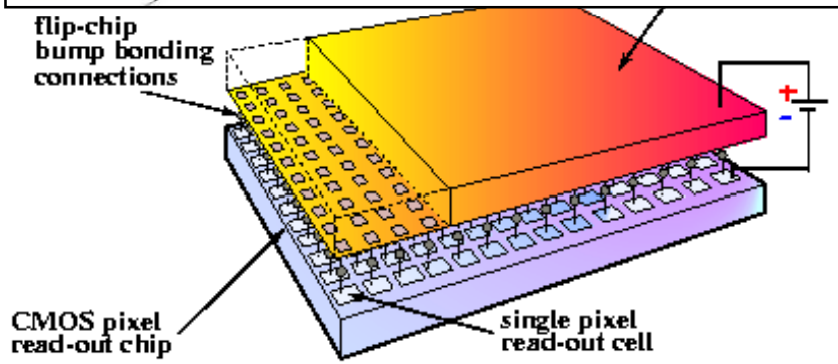
Micro Patterned Gaseous Detectors

- High field created by Gas Gain Grids
- Most popular: GEM & Micromegas





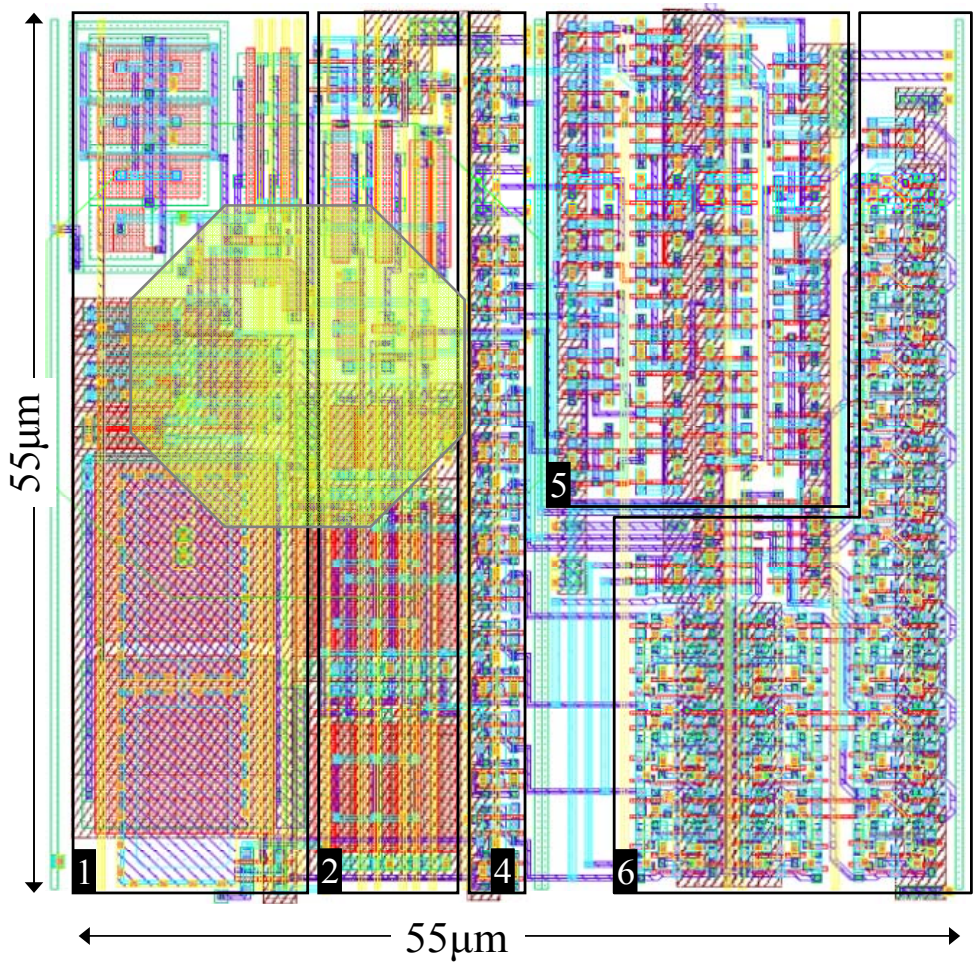




Use 'naked' CMOS pixel readout chip as anode

Timepix pixel

CERN



Timepix chip:

- 256x256 pixels
- pixel: 55x55 µm^2
- active surface: 14x14 mm^2

Timepix chip (1st version) produced Sept. 2006

Available for use in detectors since Nov. 2006

Timepix in gaseous detectors

- With Micromegas grid or GEM stacks
- Wafer postprocessing:
  - Integrated grid (Ingrid)
  - Enlarged pixels
- Discharge protection:

  high-resistive (~10^{11}) Ω·cm amorphous Si layer (20 μm thick) on top of CMOS chip

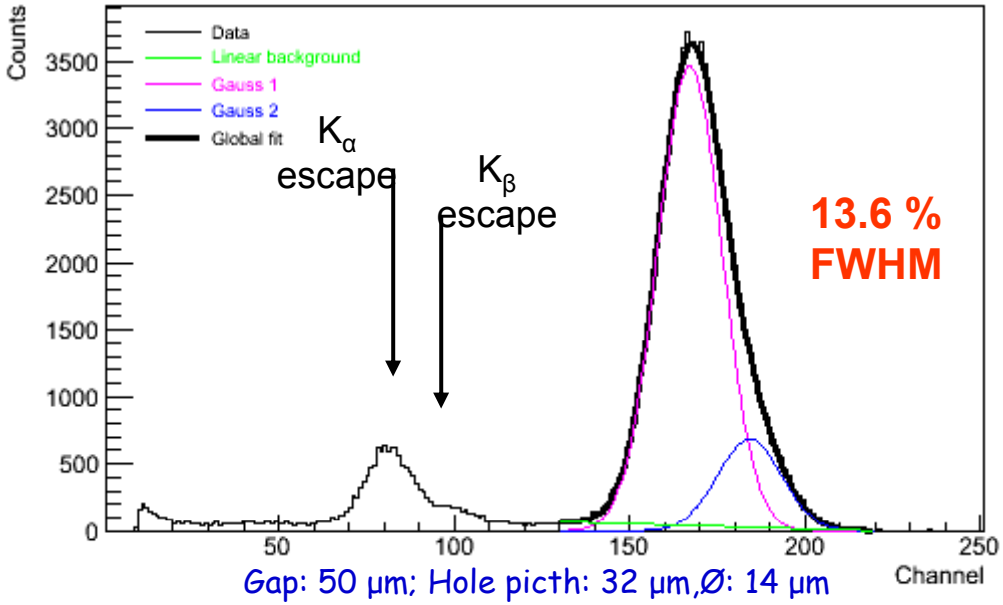
  (later maybe also high-resistive grid)

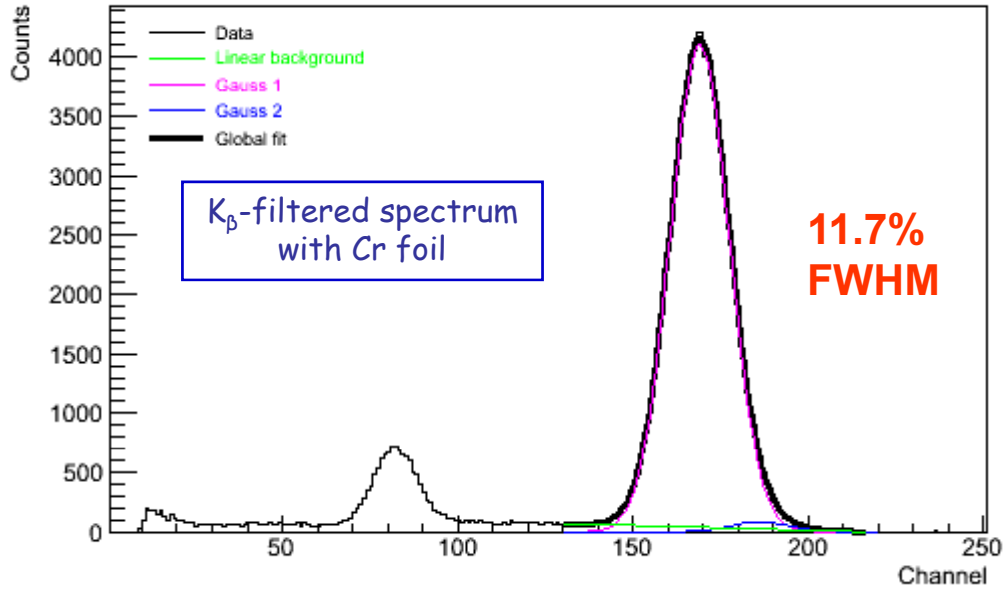
New Ingrid developments and results

- Process improvement: grids much flatter
  - Extremely good energy resolution:
    13.6 % FWHM with ^{55}Fe in P10
  - Removal of K_β 6.5 keV line:
    11.7 % @ 5.9 keV in P10

- New wafer masks:
  hole pitches down to 20 µm
  with various diameters and gaps
  - Investigate Micromegas geometry
  - Test of the ion backflow theory

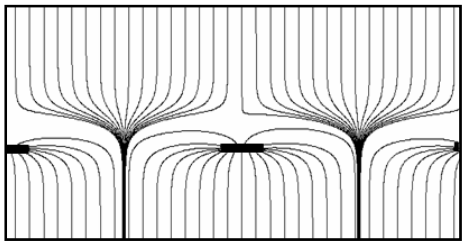
- Until now: 1 µm thin Al
  but can now be increased to 5 µm by electrolysis
  Expect less damaged from sparks

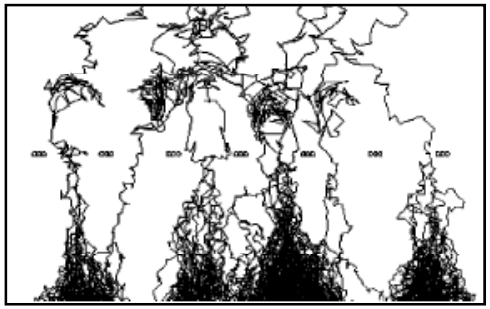


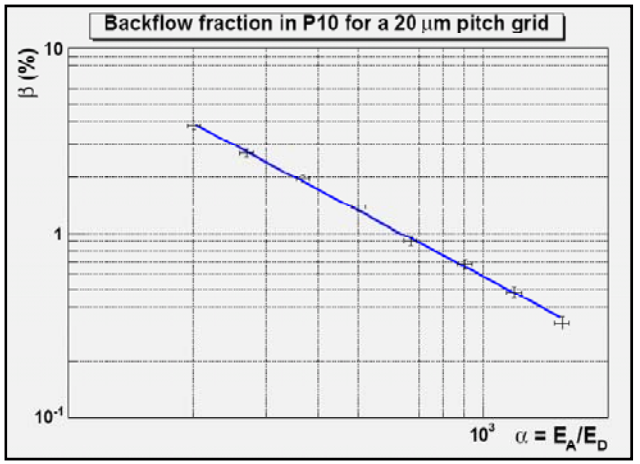


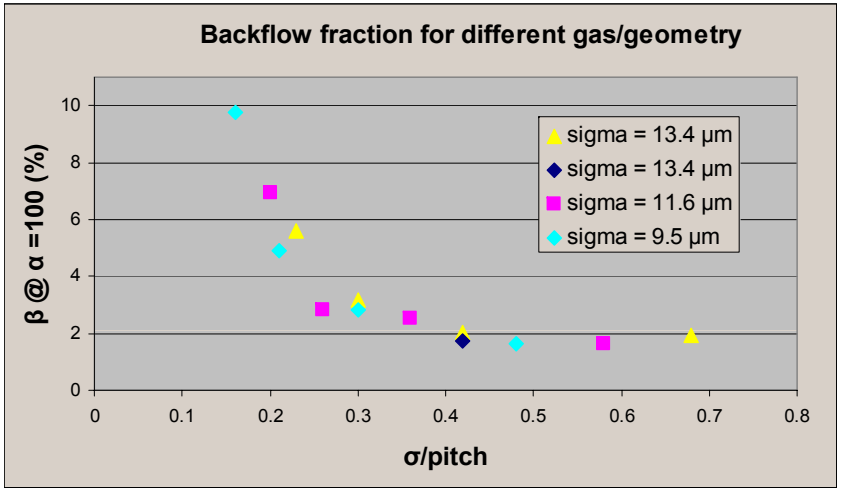
InGrid ion backflow measurements

- Phenomenon depends on:
  - Avalanche charge distribution
  - Funnel size
- therefore on the gas and grid geometry
  - Q density in the funnel decreases with the avalanche transverse diffusion
  - Funnel size decreases with the field ratio and hole pitch
- Backflow fraction reaches a (minimum) plateau
  - Occurs when ions backflow through neighboring holes
  - Simulation predicts this to occur at σ/p = 0.5



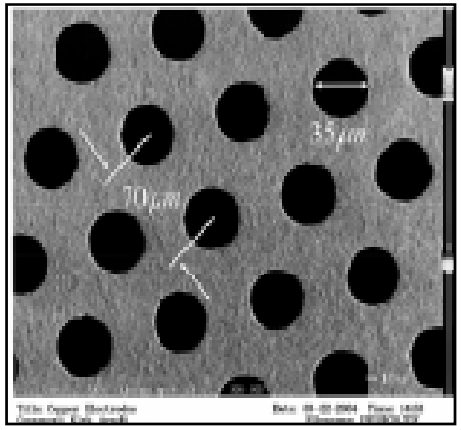


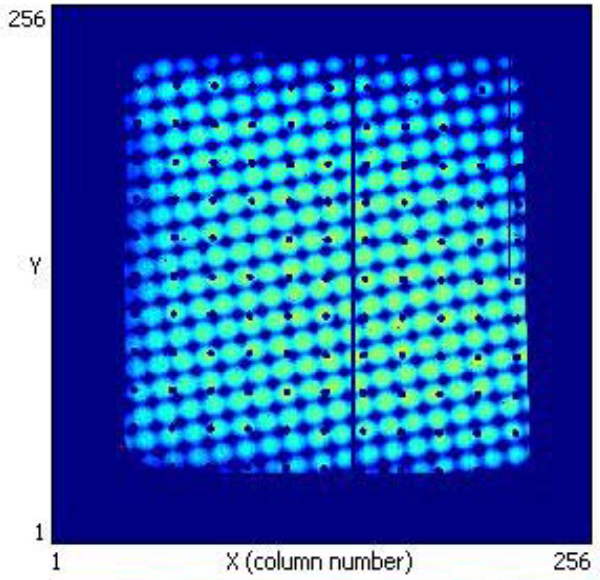




Full post-processing of a TimePix

· Timepix chip + Micromegas mesh:



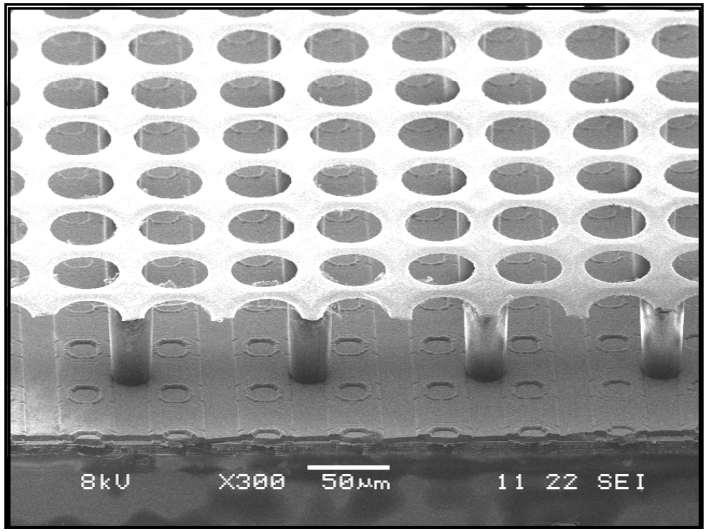


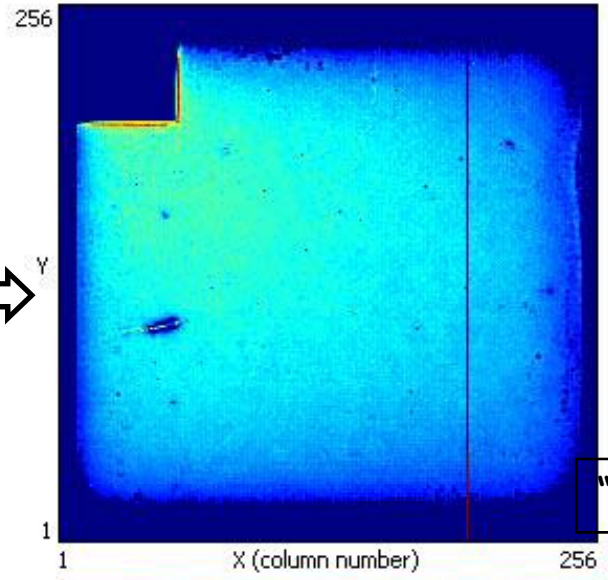
Moiré effects
+ pillars

· Timepix chip + SiProt + Ingrid:

MESA+

IMT
Neuchatel

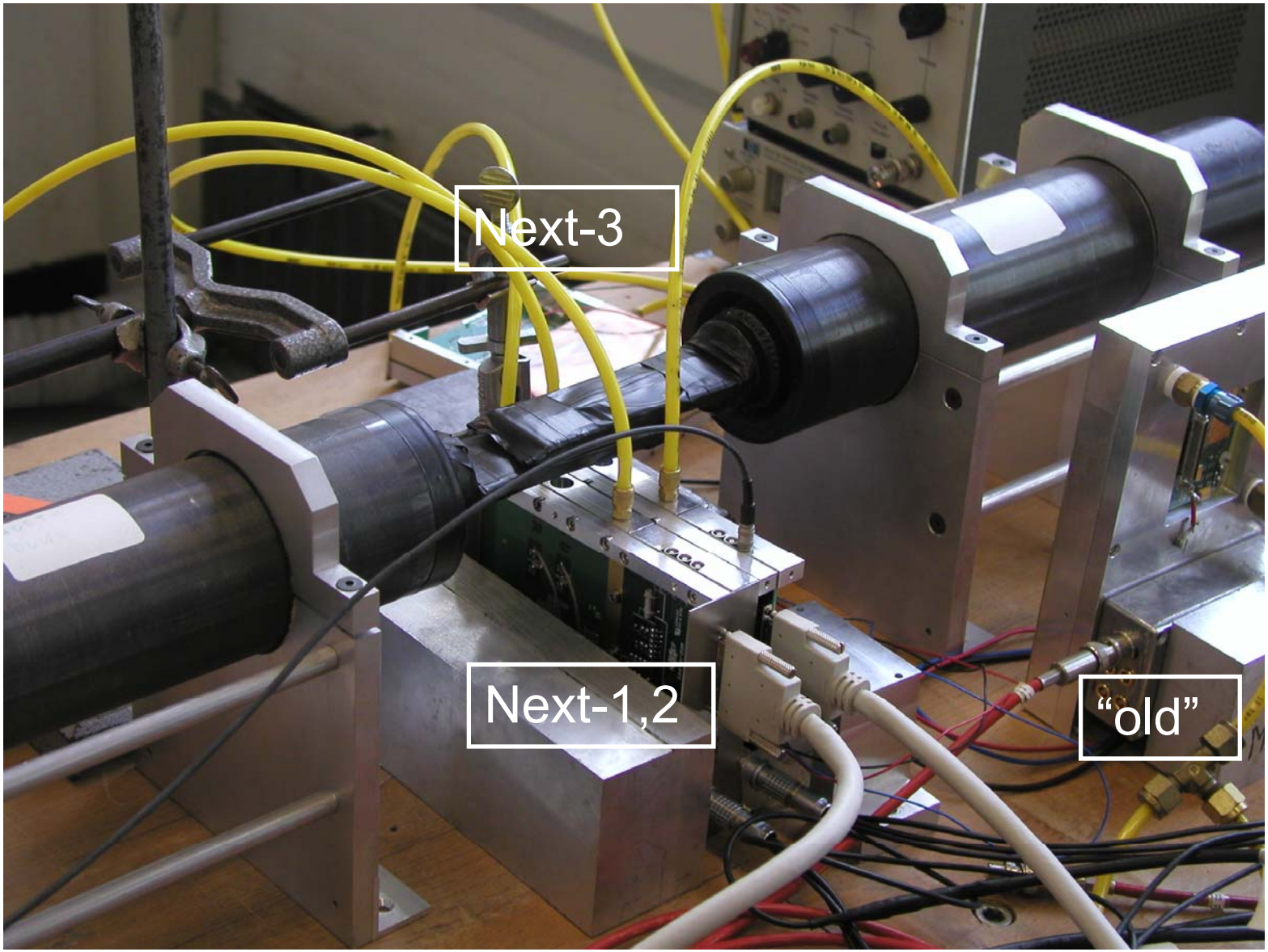




"Uniform"

"counting" mode

NIKHEF setup (> 22 Aug. 2007)



Status of Timepix usage at NIKHEF

13 dec. **B05** with 3 µm SiProt & Micromegas in He 20% iC4H10

24 jan. Switch to Ar 20% iC4H10, chip died after 2 days

TPX operated 1 month in He iC4H10

20 mar. **MediPix2** with 3 µm SiProt & InGrid operated 4 days in He → 1st fully post processed MPX

17 apr. **C08** with 3 µm SiProt & Micromegas & guard electrode (G.E.) in He

25 jul. Stop **C08** after 3 months of continuous operation in He

TPX operated 3 months in He iC4H10

E09 with 20 µm SiProt & InGrid placed in NEXT-1 chamber in He → 1st fully post processed TPX

22 aug. **A06** with 20 µm SiProt & Micromegas placed in NEXT-2 chamber in He

04 sep. Flush NEXT-2 (**A06**) with Ar, stable operation for >40 days!

23 sep. Flush NEXT-1 (**E09**) with Ar, same nice results

TPX operated in Ar iC4H10

26 sep. Introduce Thorium in NEXT-2 (**A06**), provoke discharges
Recording alpha's tracks & even more…

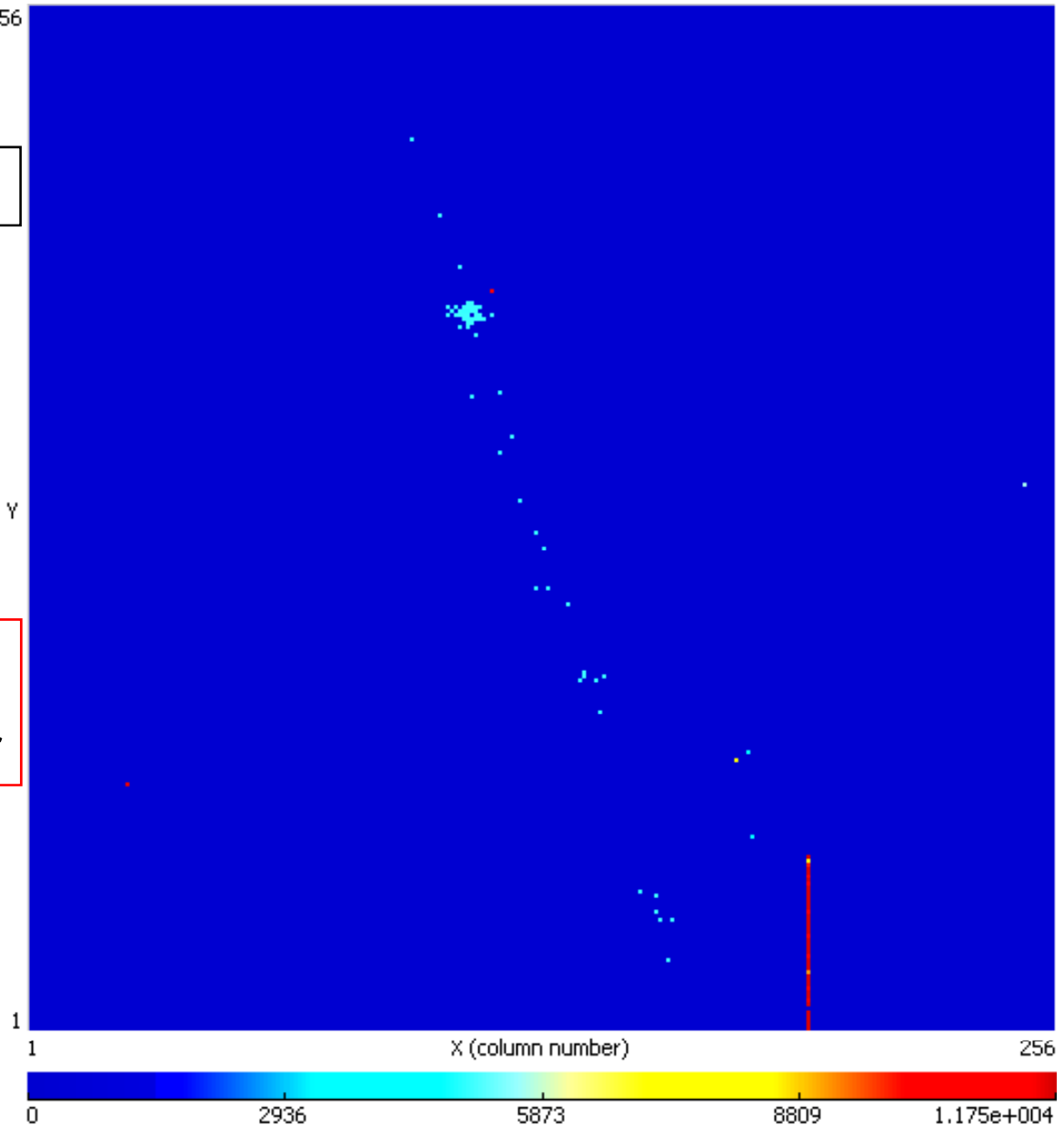
ALL STILL WORKING !!

^{90}Sr

He/Iso (80:20)

Time mode

118 µs shutter



Timepix
+
20 µm Siprot
+
Ingrid
in Next-1

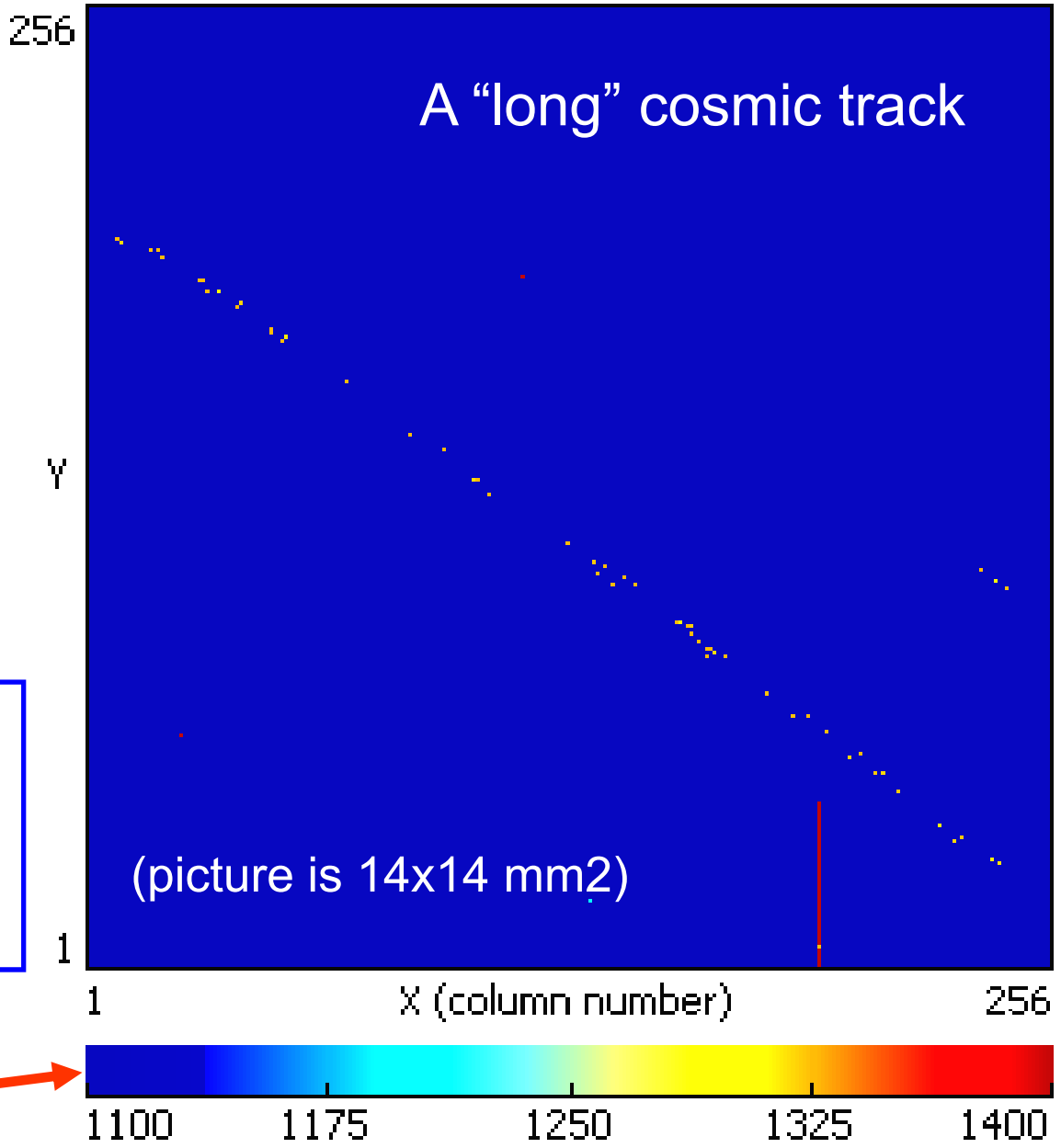
courtesy David Attié

The “typical” track

Timepix
+
20 µm thick Siprot
+
Ingrid

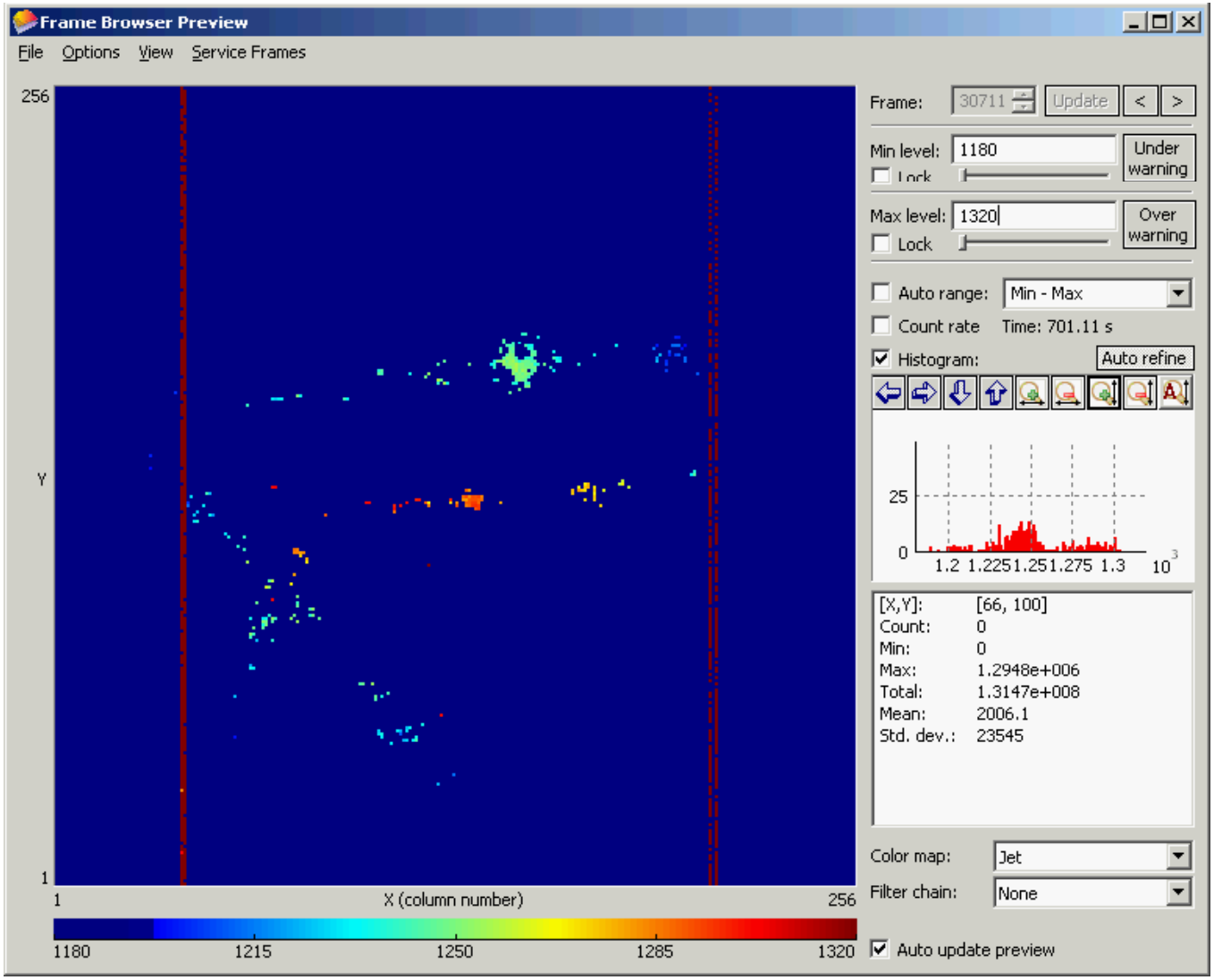
Stable operation in He iC4H10

Will 20 µm SiProt be enough to operate in Ar?



Stable operation in Argon too!

Time mode

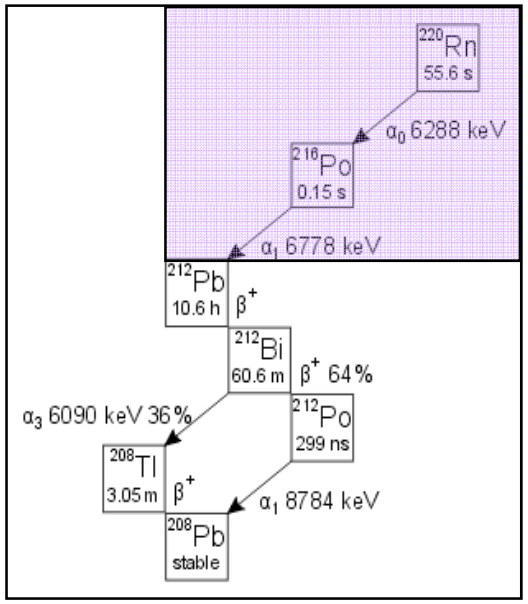


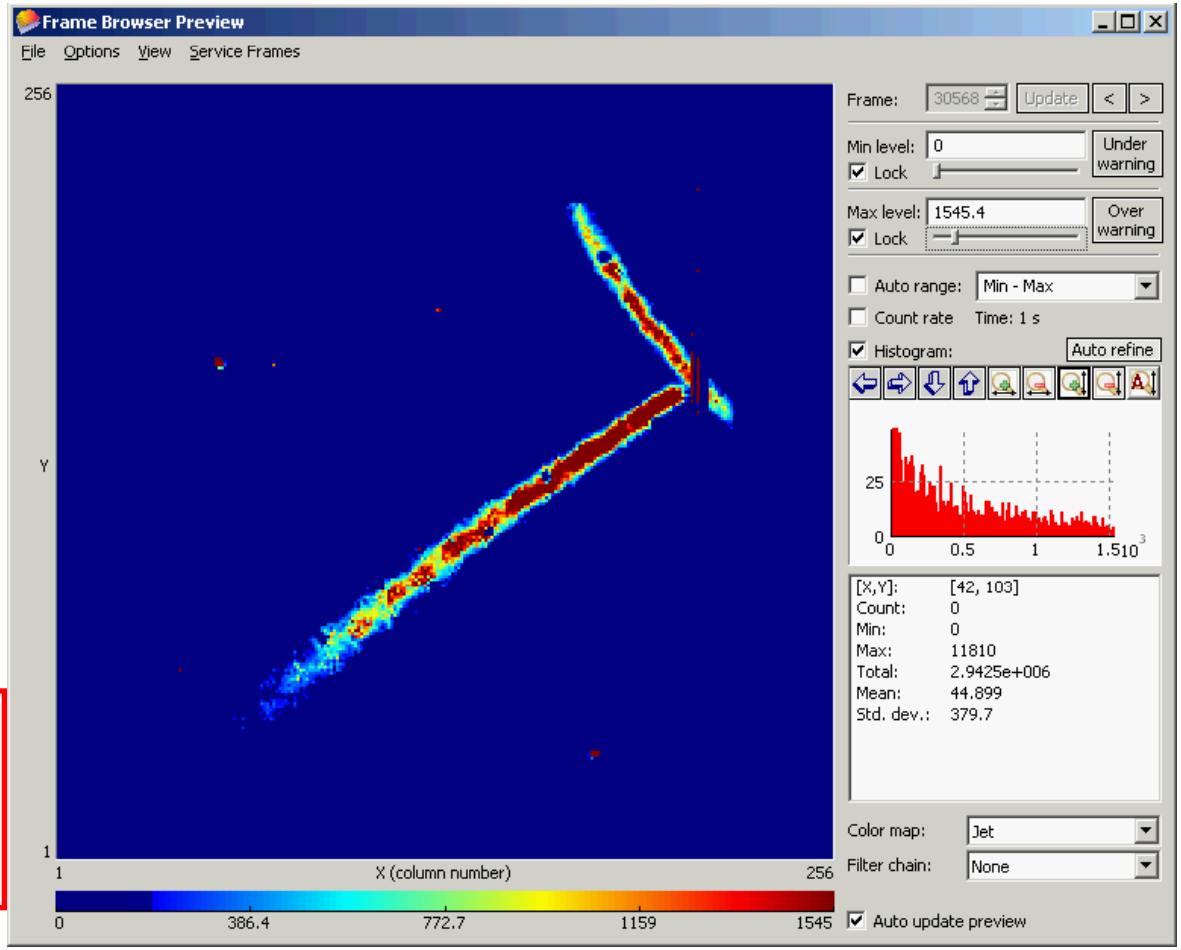
After 2 weeks of cosmic event recording, it was time for a definitive assessment whether 20 µm SiProt is enough to protect against discharges…

Final assessment: spark-proofness

- Provoke discharges by introducing small amount of Thorium in the Ar gas
  - Thorium decays to Radon 222 which emits 2 alphas of 6.3 & 6.8 MeV
  - Depose on average $2.5.10^5$ & $2.7.10^5$ e- in Ar/iC_4H_{10} 80/20 at -420 V on the grid, likely to trigger discharges

Charge mode





During ~3 days, some 5.10^4 alpha events recorded in 1% of which …

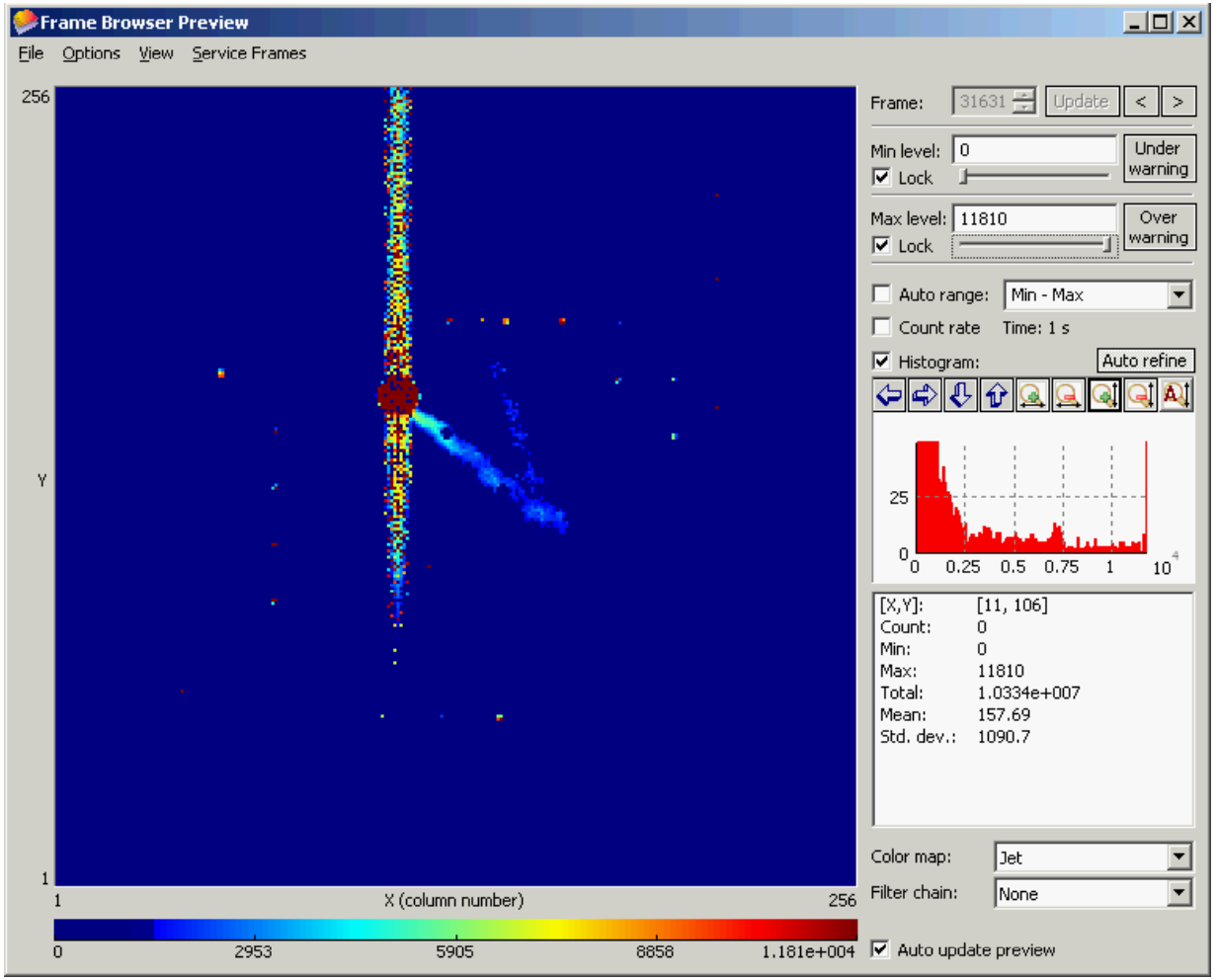
… discharges are observed !

For the 1st time: image of discharges are being recorded

Round-shaped pattern of some 100 overflow pixels

Perturbations in the concerned column pixels
- Threshold?
- Power?

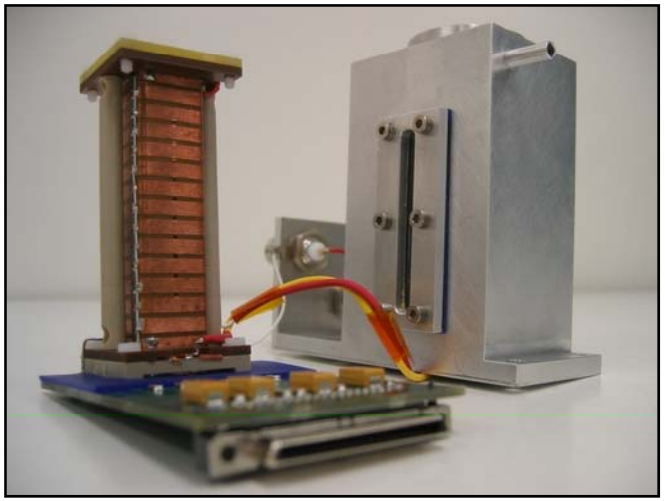
Chip keeps working !!



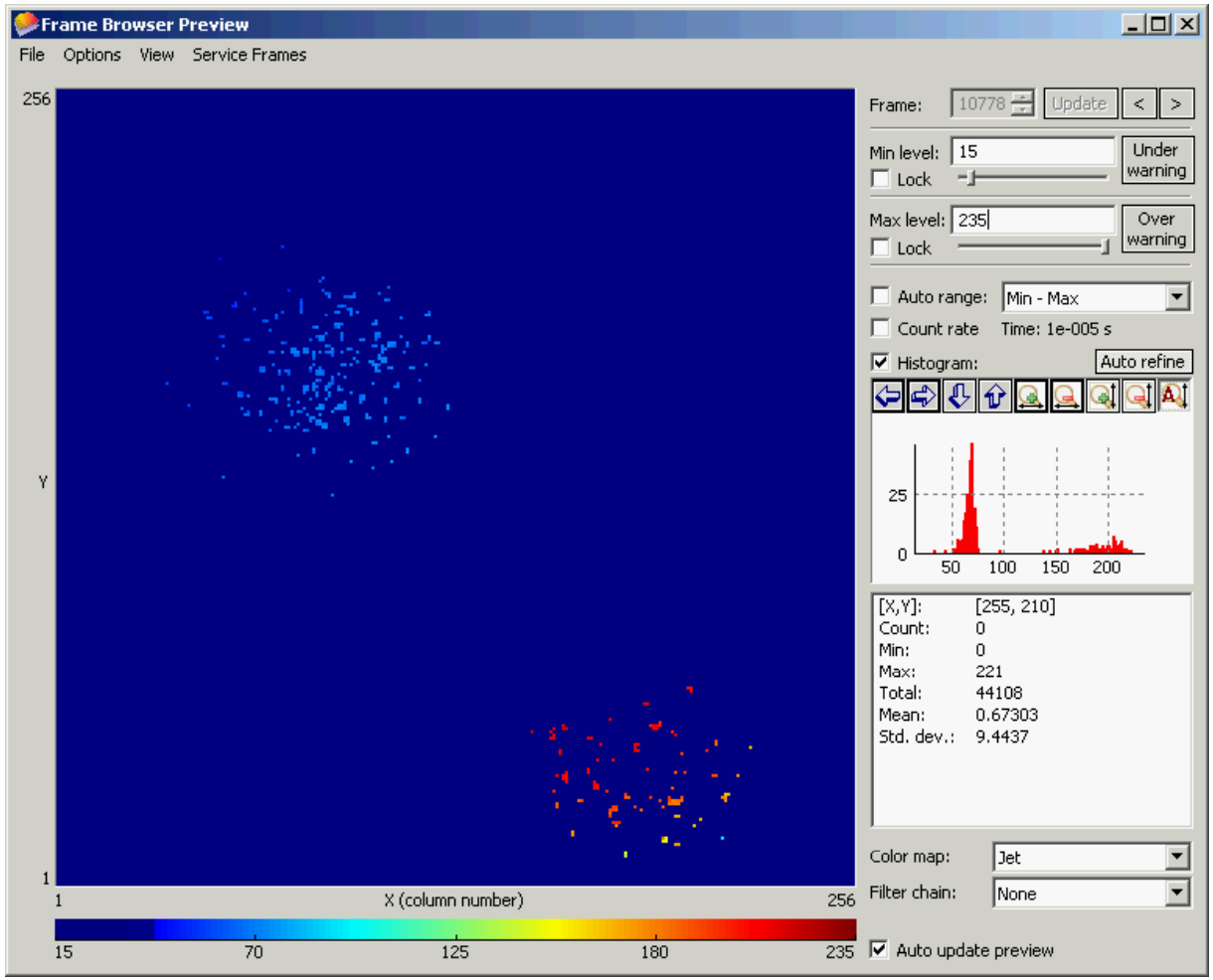
TimePix/Micromegas chamber: first light at Saclay

(D. Attié, P. Colas, E. Delagnes, M. Riallot, A. Giganon)

- Small TPC chamber with a 6 cm height field cage
- Timepix chip
  - + SiProt 20 µm
  - + Micromegas
- Ar/Iso (95:5)
- Time mode



^{55}Fe, z = 25 mm



DESY Test Beam June 2007

(before the end of HERA…)

Freiburg (+Bonn)

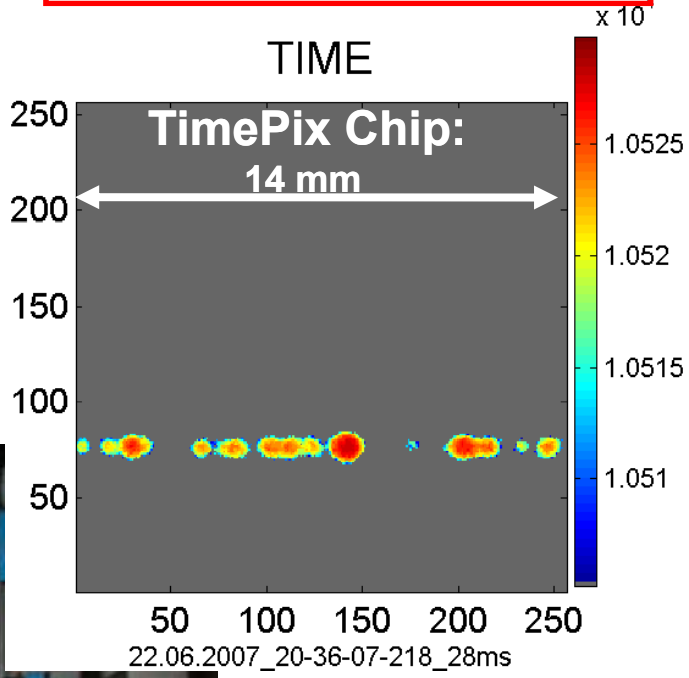
Several mixtures studied:

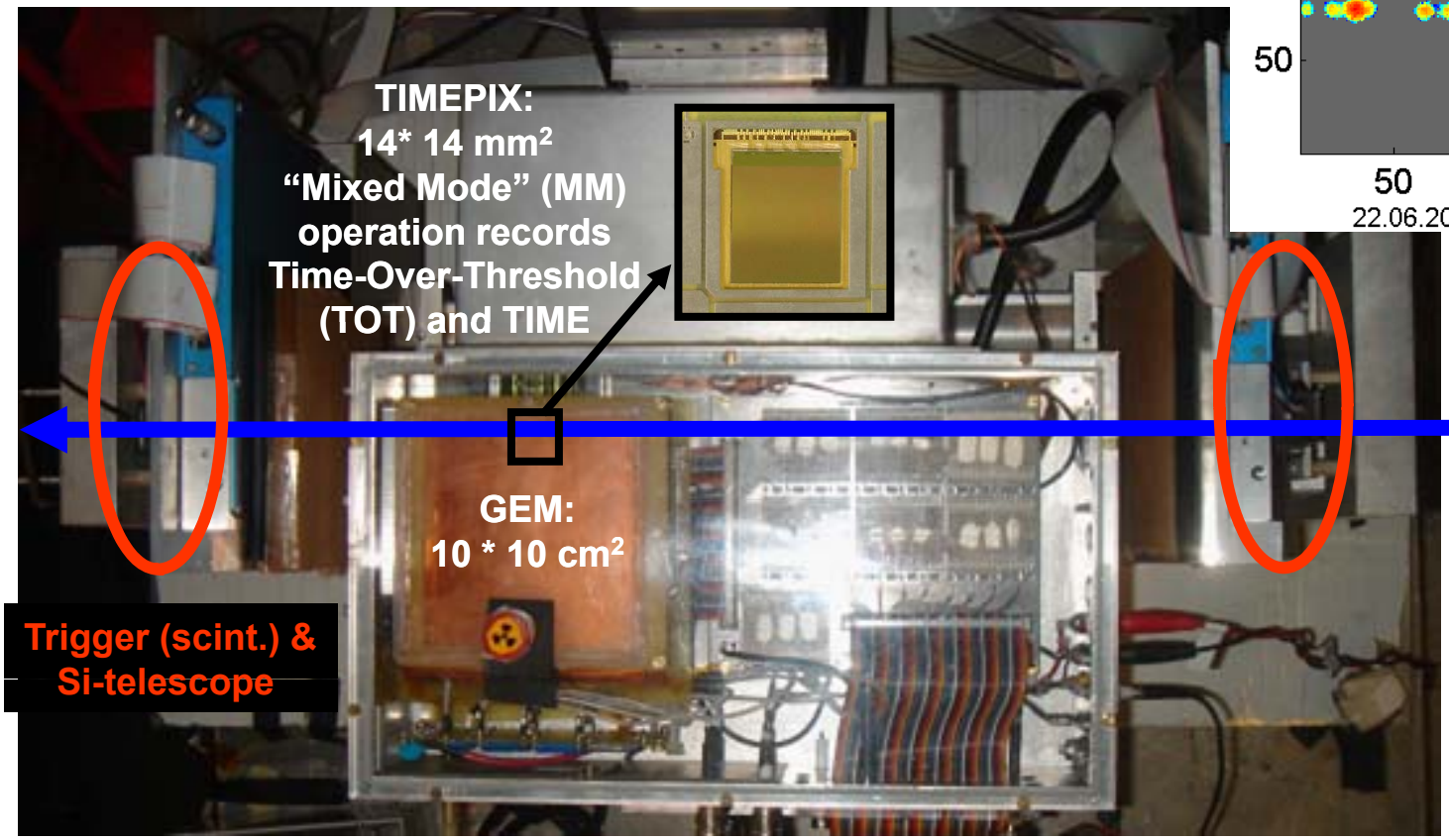
Ar/CO_2 (70:30)
He/CO_2 (70:30)
$He/CO_2/C_4H_{10}$ (68:30:2)
$Ar/He/CO_2$ (60:10:30)
TDR

Two different GEM types tested:

Standard 100x100mm² GEMs with 140µm hole pitch

New 24x28mm² GEMs with 50µm hole pitch

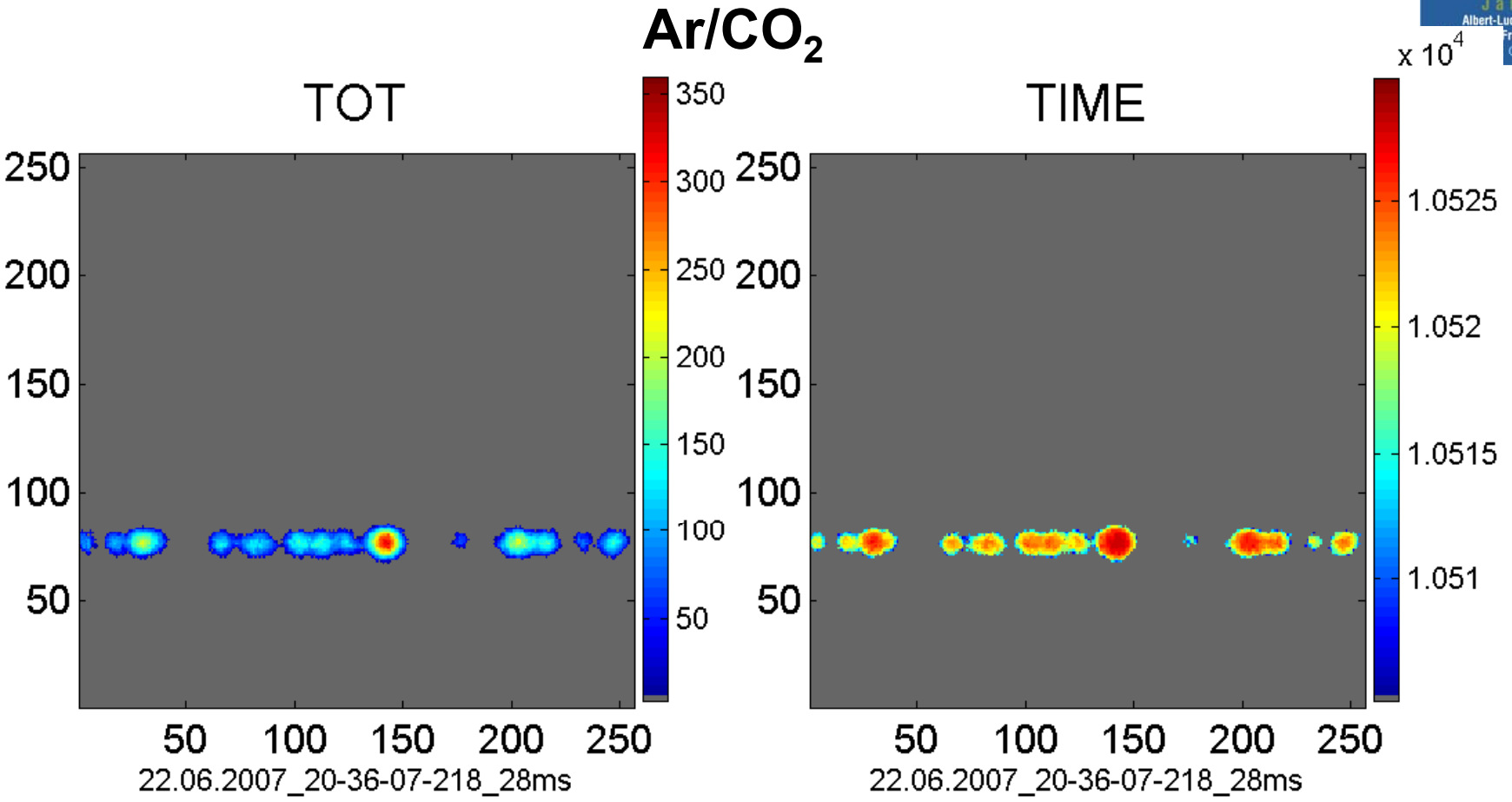




e- beam DESY II

AGAIN VERY ROBUST (TIMEPIX) OPERATION FOR BOTH GEM TYPES

TRACKS RECORDED WITH SMALL PITCHED GEMS



Gain with small pitched GEMs at $\Delta V_{GEM} \approx 346V$ comparable to $\Delta V_{GEM} \approx 403V$ with standard GEMs.

Resolution studies

Spatial resolution

$$\sigma^2_{mean} = \sigma^2_0 + \frac{D_t^2 \cdot y}{n^{el}_{cl}}$$

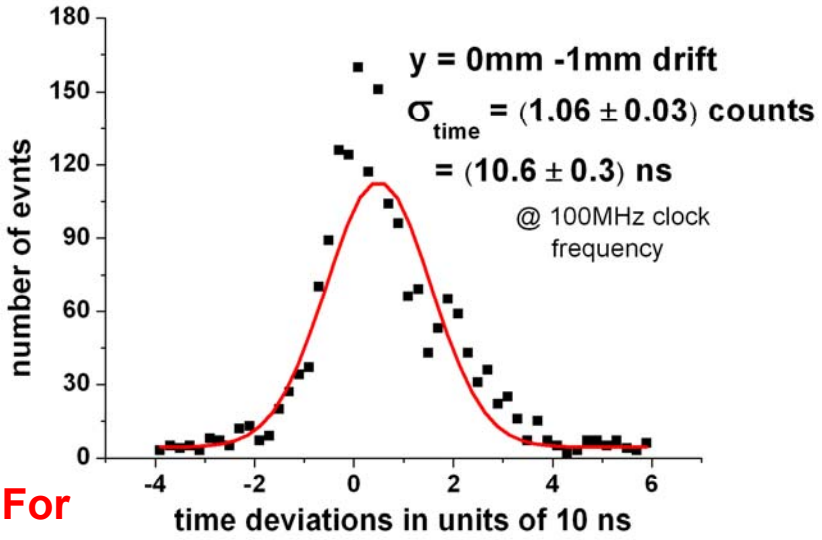
- D_t - transverse diffusion coefficient
- n^{el}_{cl} - number of primary electrons per cluster
- y - drift length

Clustering method	Gas	DATA σ_0	DATA D_t^2/n^{el}_{cl}	Simu-lations σ_0	Simu-lations D_t^2/n^{el}_{cl}
"Island"	Ar/CO_2	21.7 +/-0.5	519 +/-12	-----	-----
	He/CO_2	25.6 +/-1.0	675 +/-16	-----	-----
	new GEM type Ar/CO_2	15.4 +/-0.4	405 +/10	-----	-----
"Saddle Point"	Ar/CO_2	18.4 +/-2.7	467 +/-36	15.2 +/-3.8	726 +/-41
	He/CO_2	27.1 +/-4.9	547 +/-78	19.4 /-4.0	989 +/-54

- $\sigma_0 \approx$ 15-25µm

Time resolution

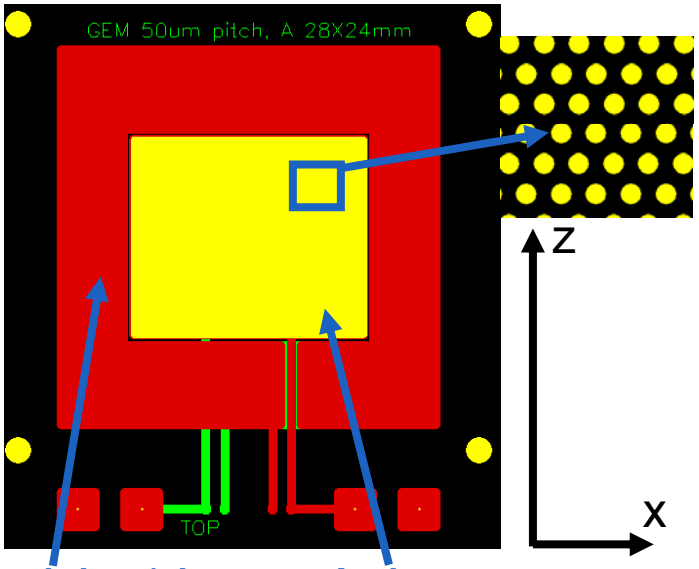
Time resolution was evaluated in MM-operation. A correlation between TOT-maximum and Time was used to correct for time-walk problems (typically 2-3 counts).



Proves robustness of cluster separation algorithms. For σ_0 good agreement between experiment and simulations. D_t^2/n^{el}_{cl} is in fair agreement.

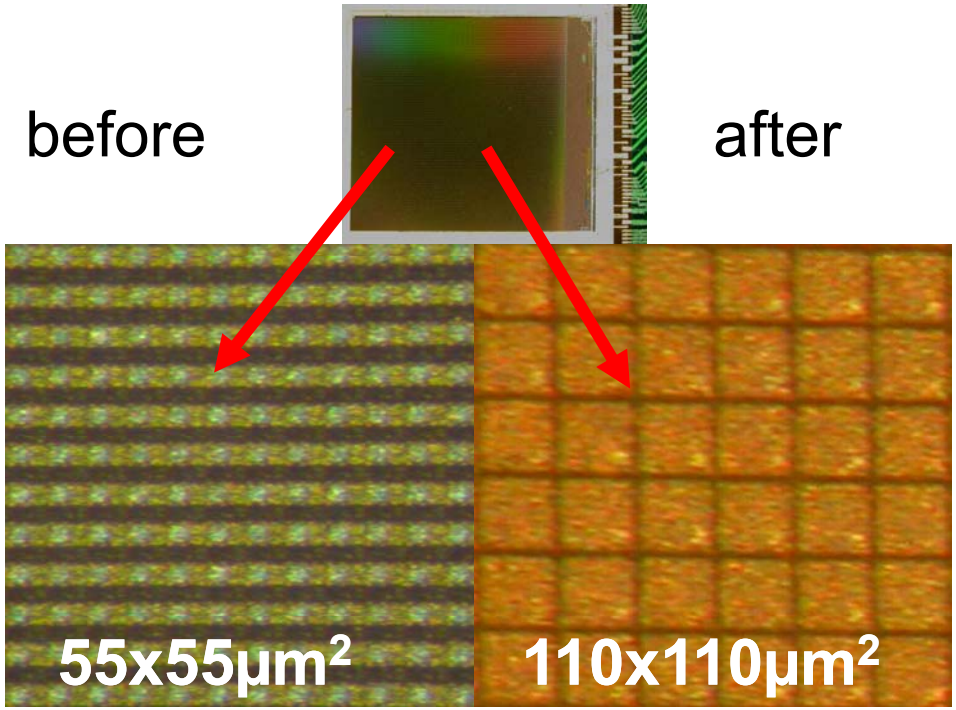
New Technical Developments

New GEM type (Bellazzini)



- Nominal outer hole diameter 30μm in copper
- Inner hole sizes are as small as 17μm-21μm in the Kapton
- Pitch of holes 50μm
  - Projected in x ≈ 43μm
  - Projected in z ≈ 25μm

Post processing on a single chip



- larger pixels available
- Idea: collect more charge per larger pixel ⇒ reduction of effective threshold expected
- FMF in Freiburg is going to prepare a TimePix after first tests with MediPix2

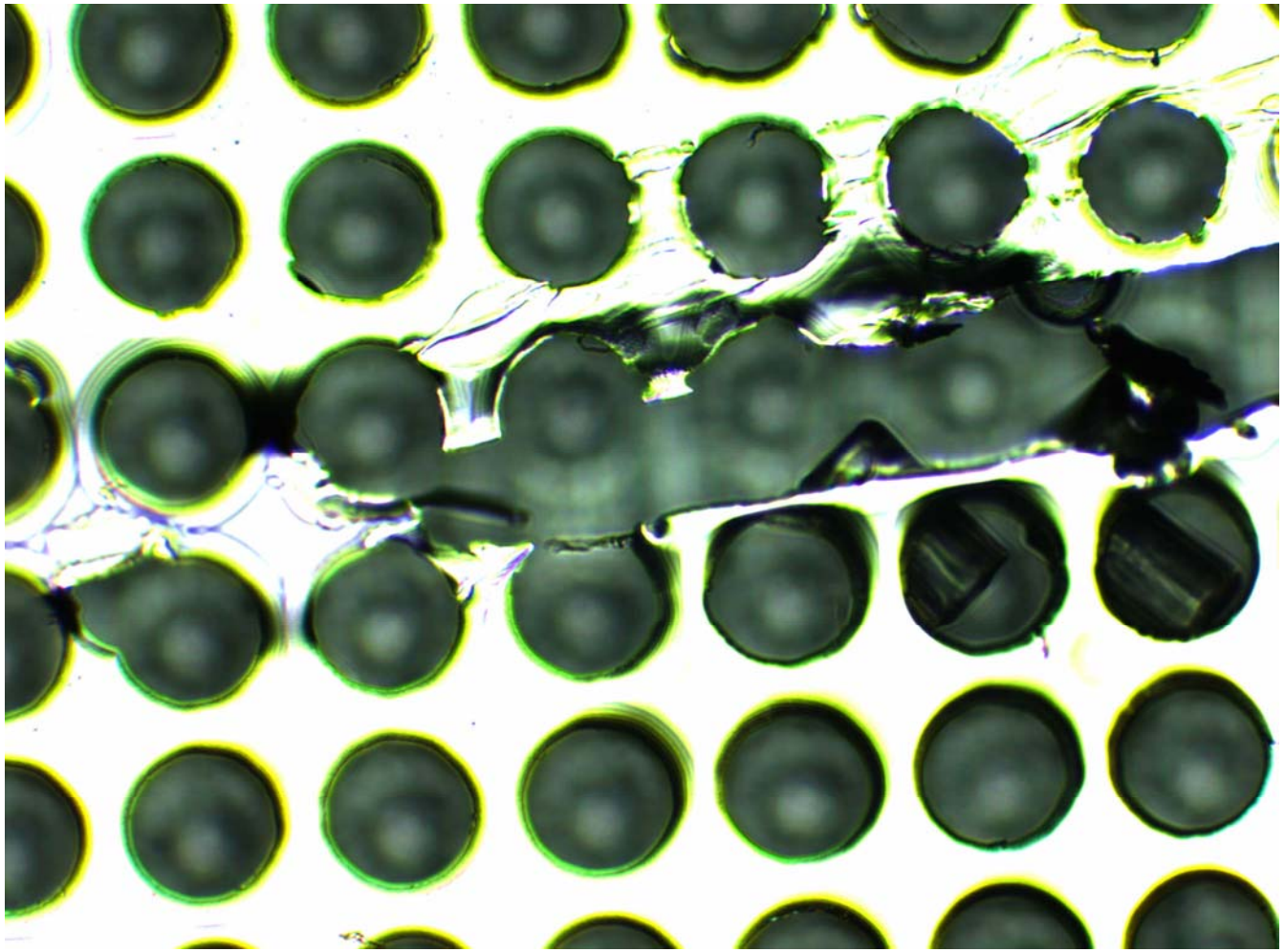
Summary

- A lot of progress made in last ‘year’; not mentioned many details on track resolution studies and on signal development
- Part of the technology is ready:
  - Very good energy resolution for Ingrid devices
  - Ion backflow at the few per-mil level at high field ratio
- Discharge protection seems working for Ingrid devices
- Robust operation with GEM devices (without protection)

Next:

- Build larger multi-chip detector systems with fast readout

Backup slides



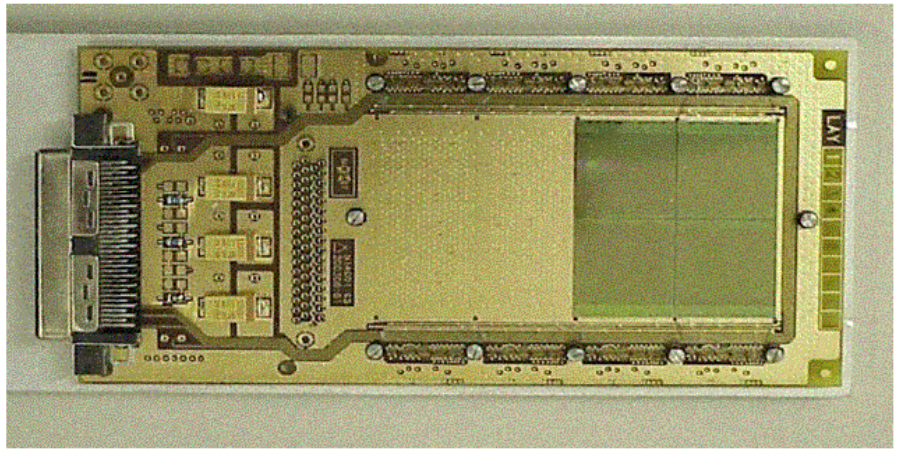
A “scratch” occurred during production Ingrid;

Loose parts removed. Ingrid working!

Further Developments

RELAXD project (Dutch/Belgian)
NIKHEF,Panalytical,IMEC,Canberra:

- Chip tiling: large(r) detector surfaces
  (2x2, 2x4 chips)
- Through Si connectivity: avoiding bonding wires
- Fast readout technology
  (~5 Gb/s)

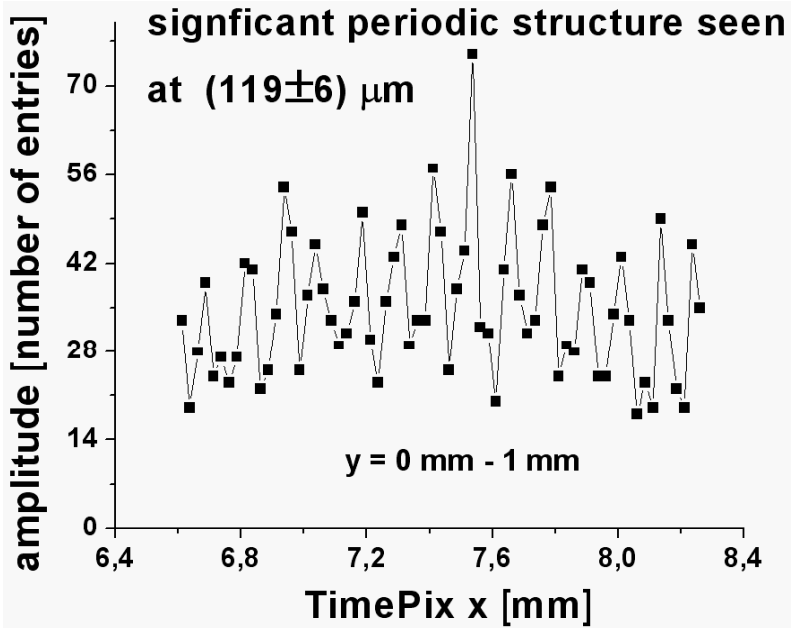


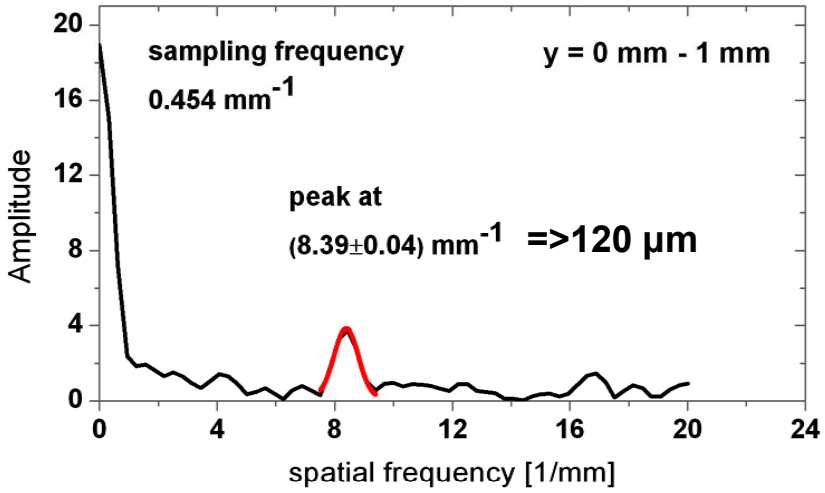
Somewhat slower progress than expected:

Still hope for “through Si vias” (with Medipix chips) later this year!

Substructure due to GEM hole pitch

standard GEM





Is the resolution of a cluster yet affected by the finite pitch of the holes?

Test runs are taken recently with different orientation with respect to the track and with smaller pitched GEMs (80μm).

Results are expected to be available soon.