The Silicon TPC System (SITPC)

EUDET Annual meeting

9 October 2007

Jan Timmermans

NIKHEF

JRA2 activity/task

- Silicon TPC readout ("SITPC")

  - development MediPix $\rightarrow$ TimePix chip
  - development diagnostic endplate module incl. DAQ

Purpose: a SiTPC based monitoring system

Partners:

ALU Freiburg, Bonn, CEA Saclay, CERN, NIKHEF

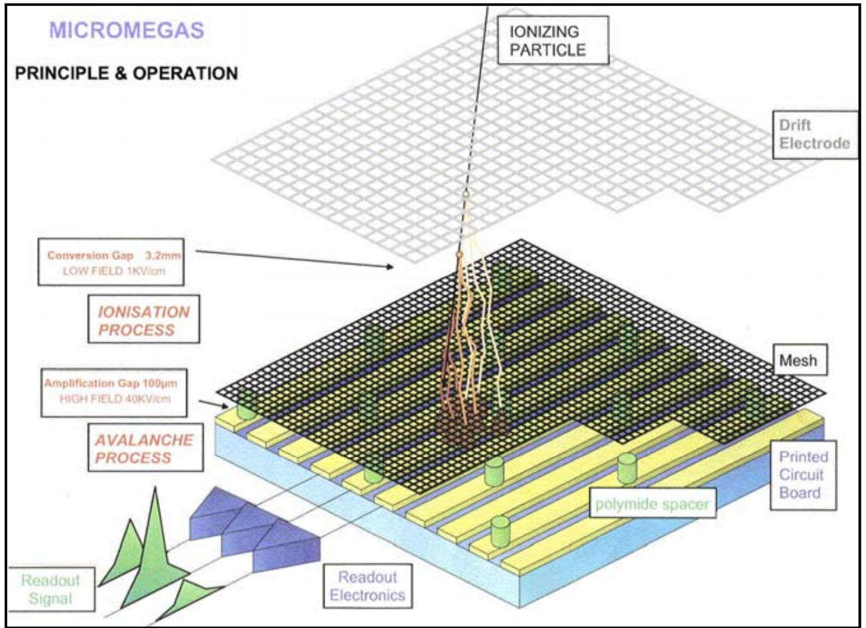
Associate: Bucarest

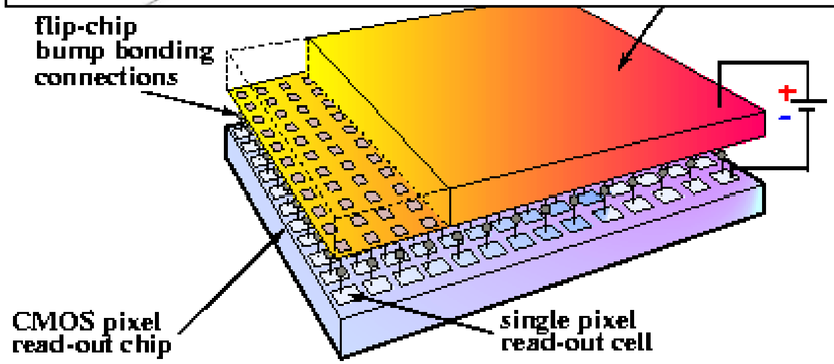
SITPC Tasks:

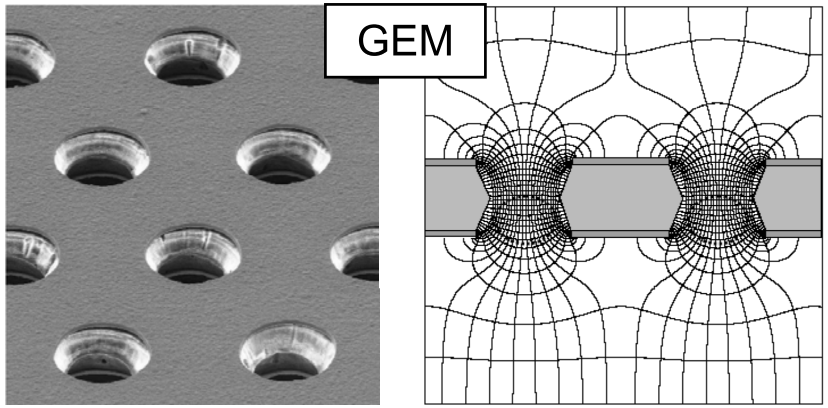
- ✓ Develop the Timepix chip that allows to measure the 3rd coordinate (drift time)
- ✓ Implementation of Timepix together with GEM and Micromegas into diagnostic endplate system (in progress)
- ✓ Performance measurements in test infrastructure at DESY and other places (in progress)
- Develop simulation framework
- Develop DAQ system and integrate in overall DAQ of EUDET infrastructure

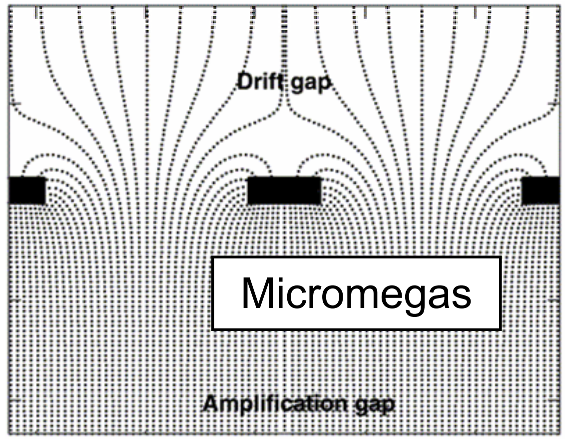
Micro Patterned Gaseous Detectors

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







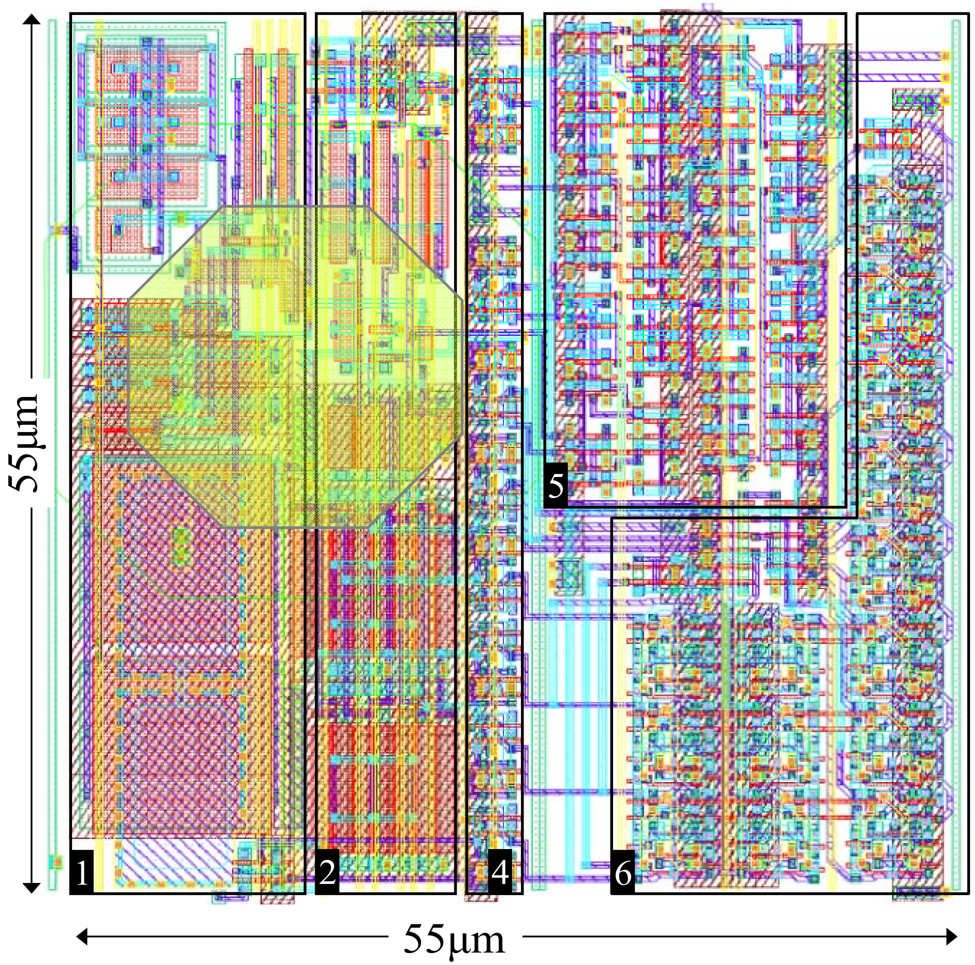


Use 'naked' CMOS pixel readout chip as anode

Timepix pixel

55x55 μm^2

CERN

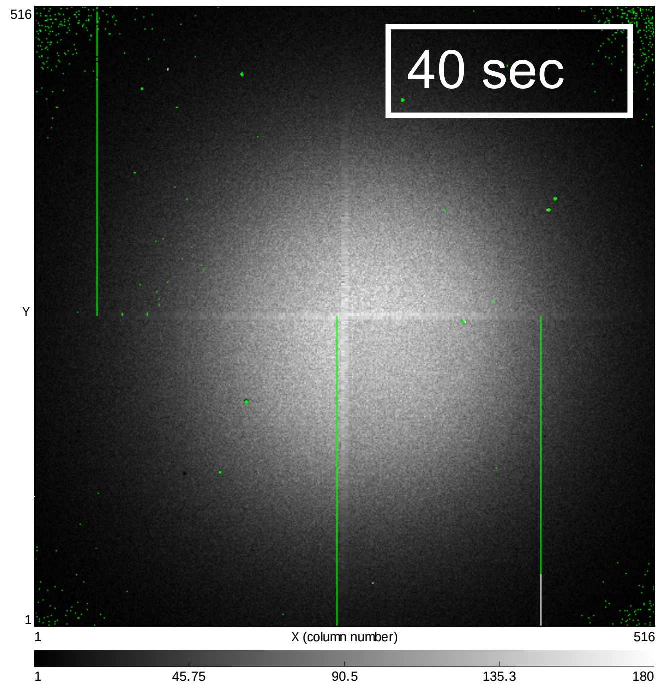


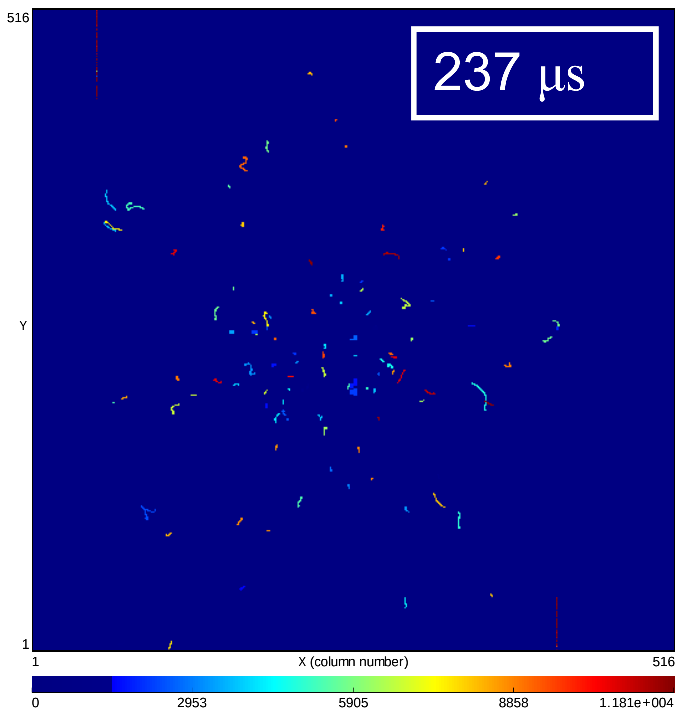
Timepix chip (1st version) produced Sept. 2006

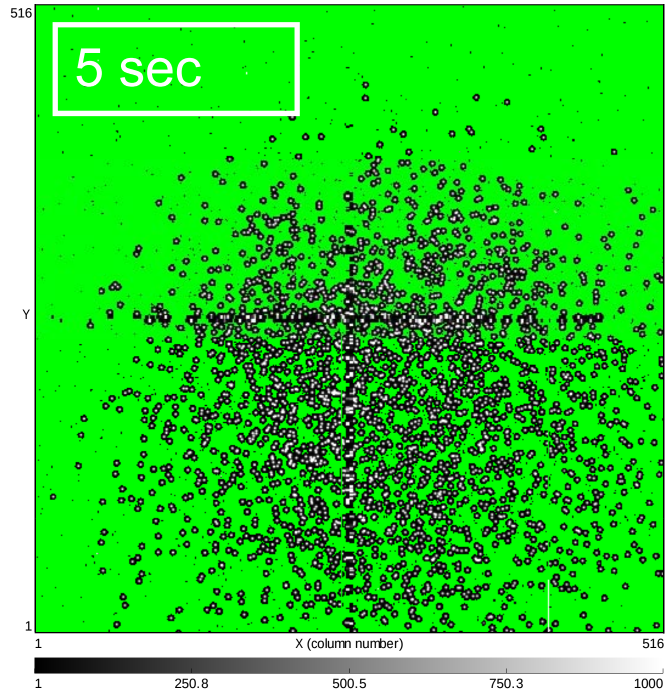
Available for use in detectors since Nov. 2006

CERN (Xavi Llopart/Michael Campbell): first Timepix quad (+ 300 μm Si sensor)

- Top-right: Medipix counting mode (^{55}Fe)
- Bottom-left: Time mode (^{90}Sr)
- Bottom-right: time-over-threshold (^{241}Am)

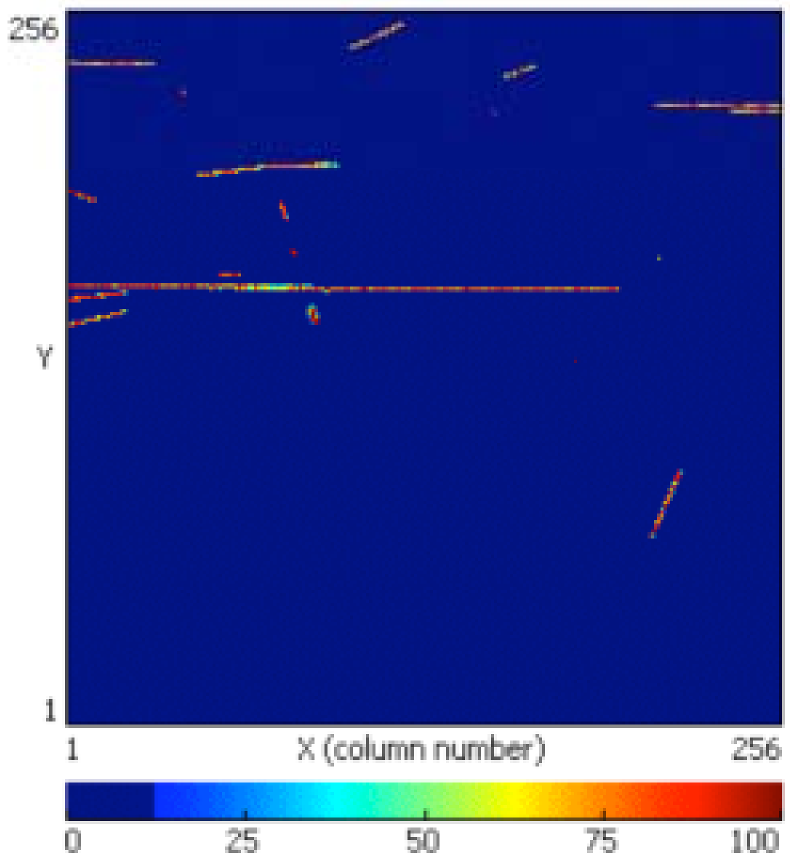






Erik Heijne: Timepix (single chip + Si sensor) parallel to beam

H6 120 GeV/c PION BEAM



ANALOG MODE TOT
TYPICAL SIGNAL ~80 counts

Timepix in gaseous detectors

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

DESY Test Beam June 2007

(before the end of HERA…)

Freiburg (+Bonn)

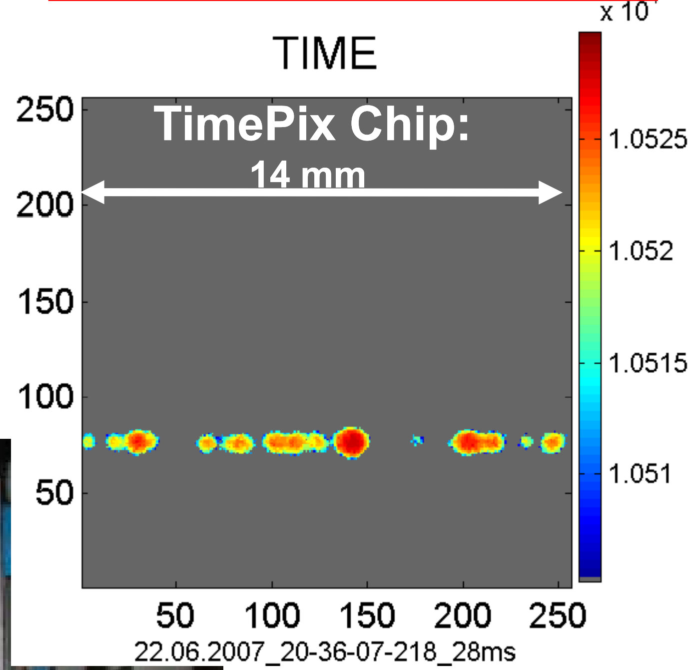
Several mixtures studied:

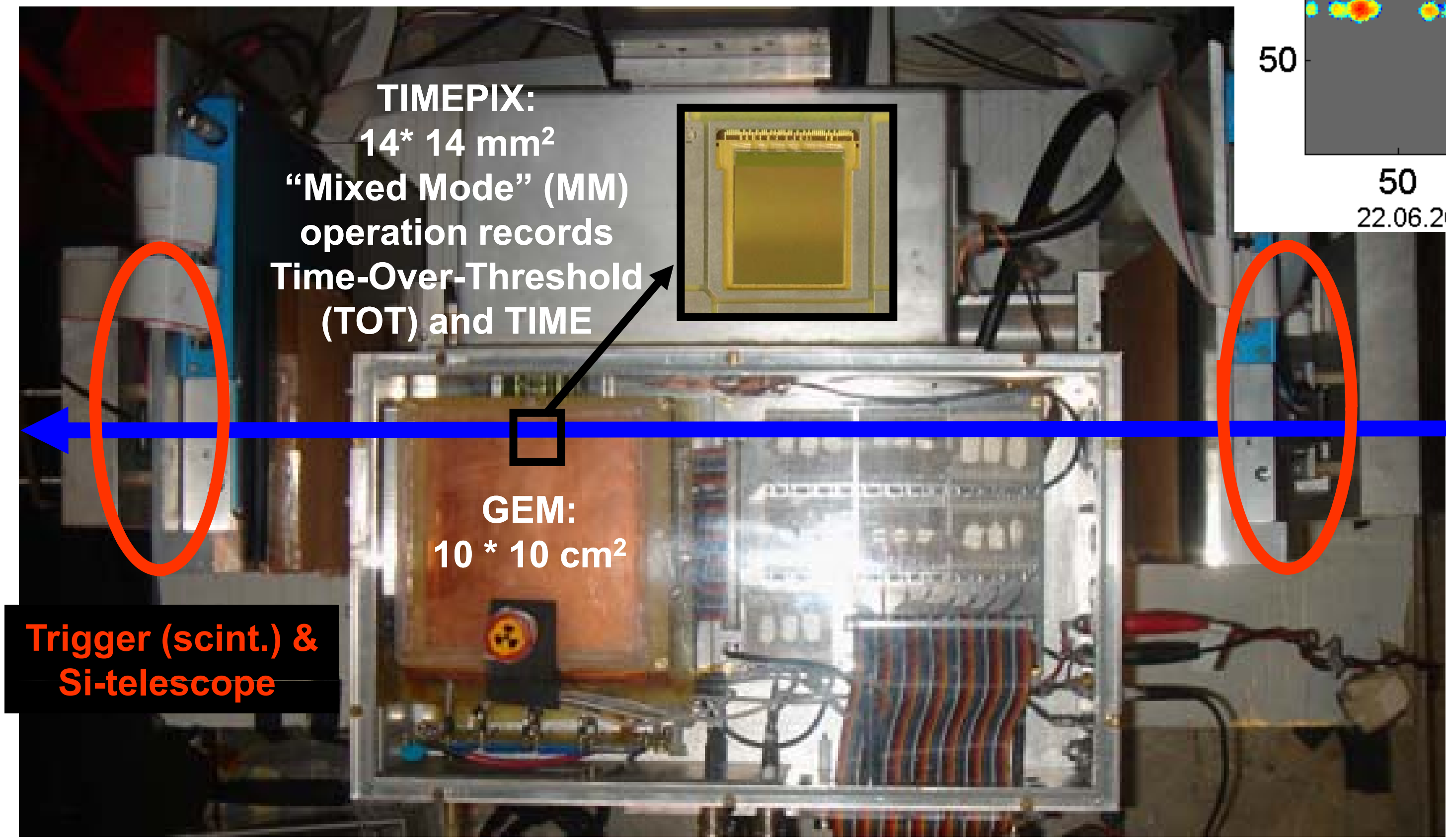
Ar/CO_2 (70:30)
He/CO_2 (70:30)
He/CO_2/C_4H_{10} (68:30:2)
Ar/He/CO_2 (60:10:30)
TDR

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

Resolution studies

Spatial resolution

$$\sigma_{mean}^2 = \sigma_0^2 + \frac{D_t^2 \cdot y}{n_{cl}^{el}}$$

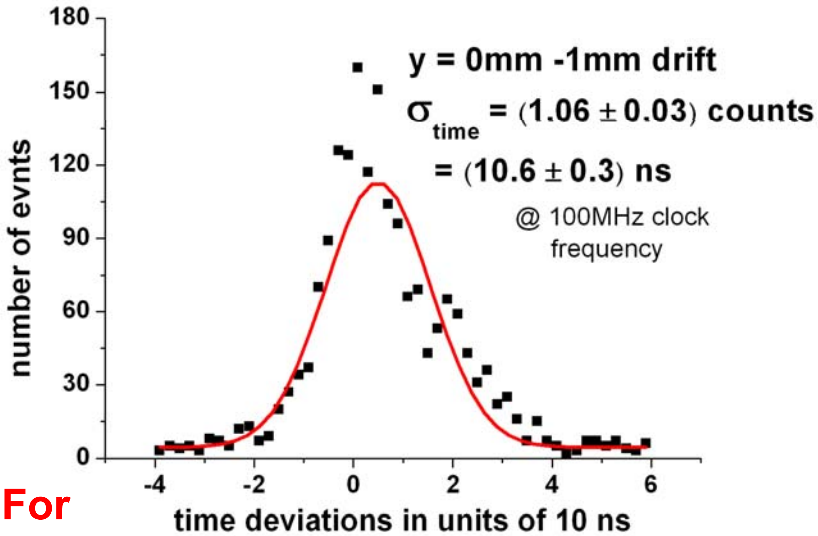
- D_t - transverse diffusion coefficient
- n_{cl}^{el} - number of primary electrons per cluster
- y - drift length
- ***$\sigma_0 \approx$ 15-25µm***

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	-----	-----
"Island"	He/CO_2	25.6 +/-1.0	675 +/-16	-----	-----
"Island"	*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
"Saddle Point"	He/CO_2	27.1 +/-4.9	547 +/-78	19.4 /-4.0	989 +/-54

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.

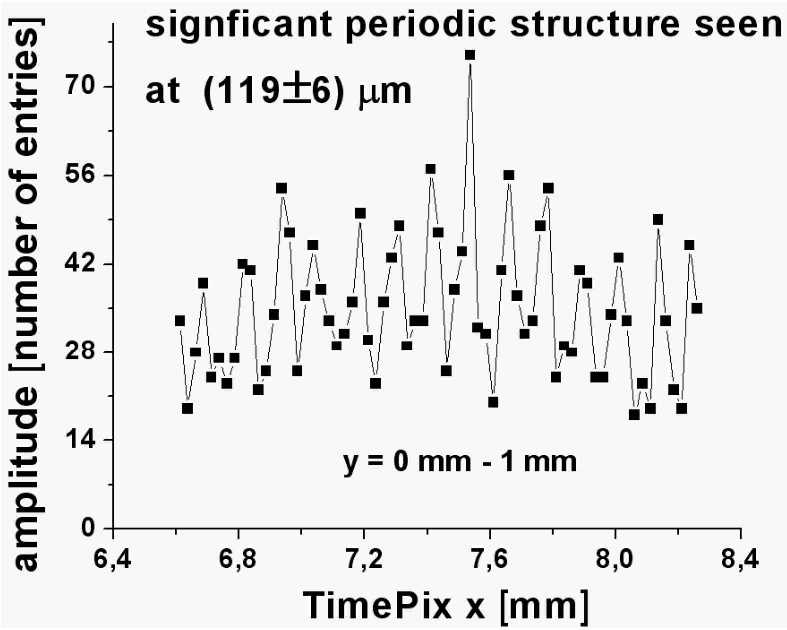
Time resolution

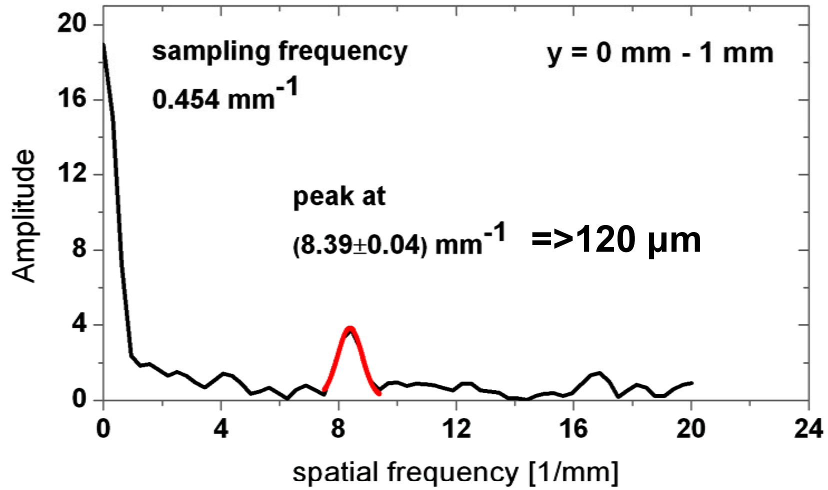
Time resolution was evaluated in MM-operation. A correlation between TOT-maximum and Time was used to correct for time-walk problems (typically 2-3 counts).



Substructure due to GEM hole pitch

standard GEM





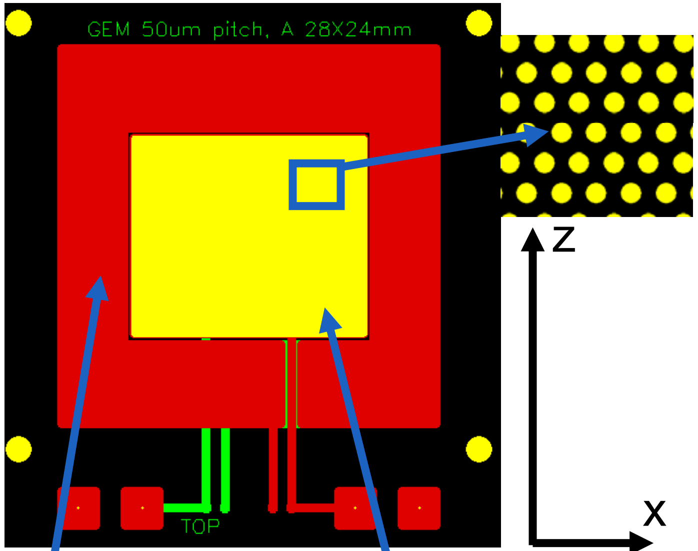
Is the resolution of a cluster yet affected by the finite pitch of the holes?

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.

New Technical Developments

New GEM type

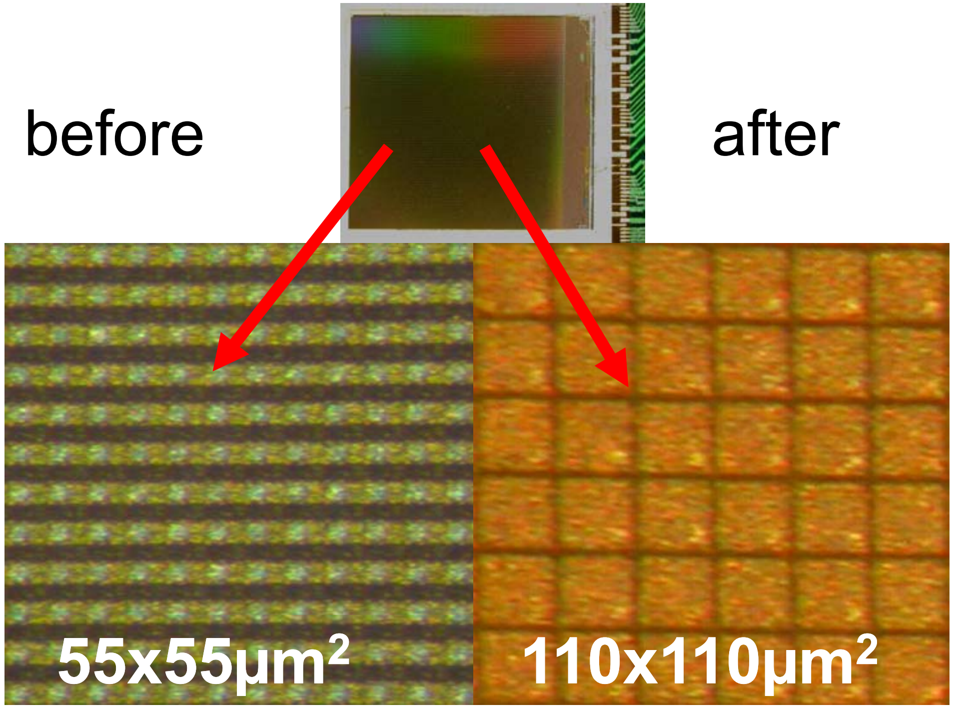


Guard ring (also on lower side)

Active area 28x24mm²

- 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

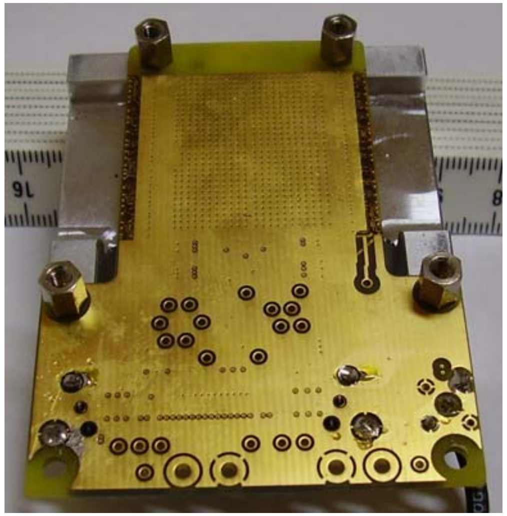
Post processing on a single chip

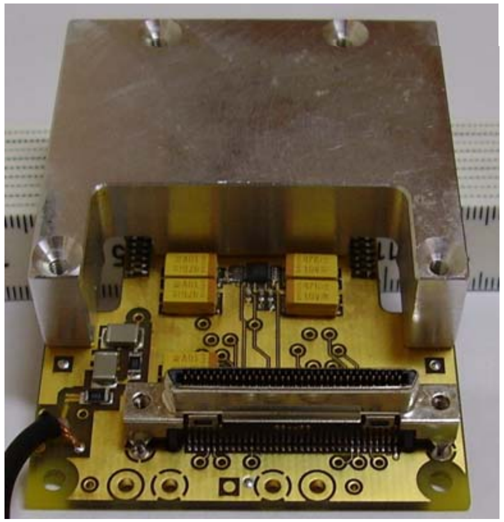


- larger pixels available
- Idea: collect more charge per larger pixel ⇒ reduction of effective threshold expected
- FMF in Freiburg is going to prepare a TimePix after first tests with MediPix2

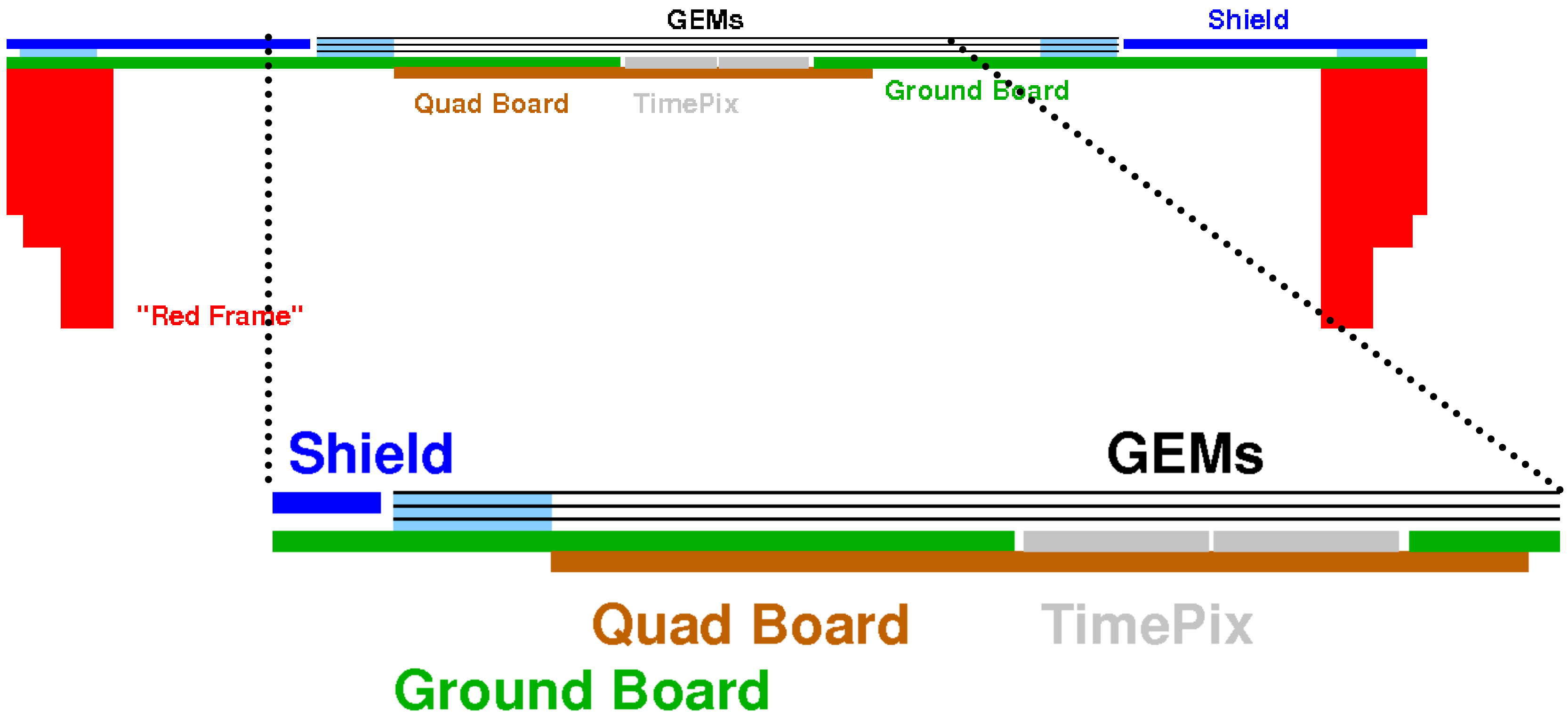
Bonn: TimePix Module for the LP
(deliverable by end 2007)

- Based on Medipix2 QuadBoard designed by NIKHEF
- 2x2 TimePix Chips per QuadBoard
- 2 QuadBoards per Module
- QuadBoards glued into PCB back plane



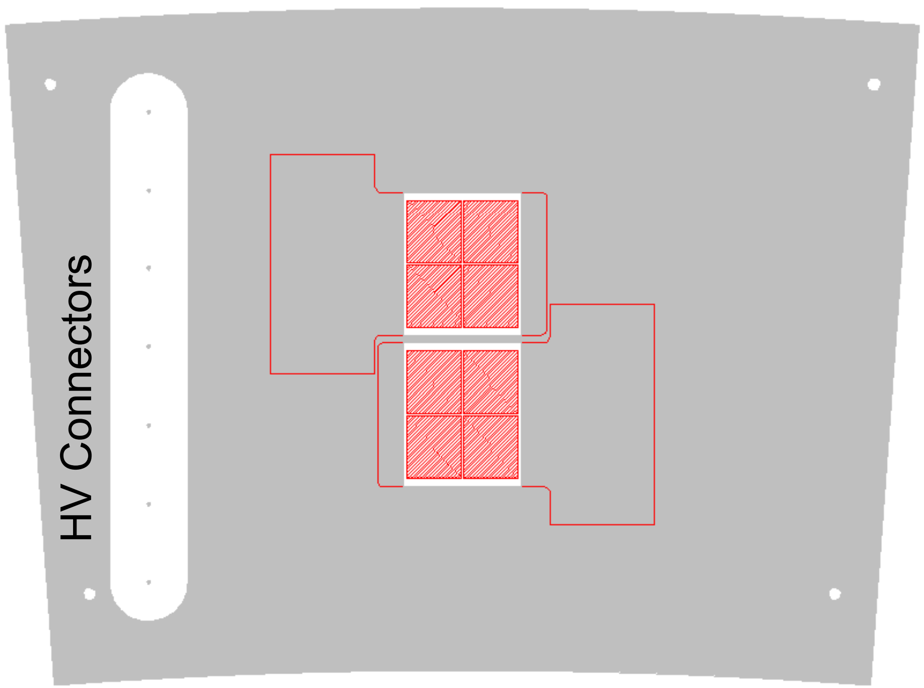


Cross Section

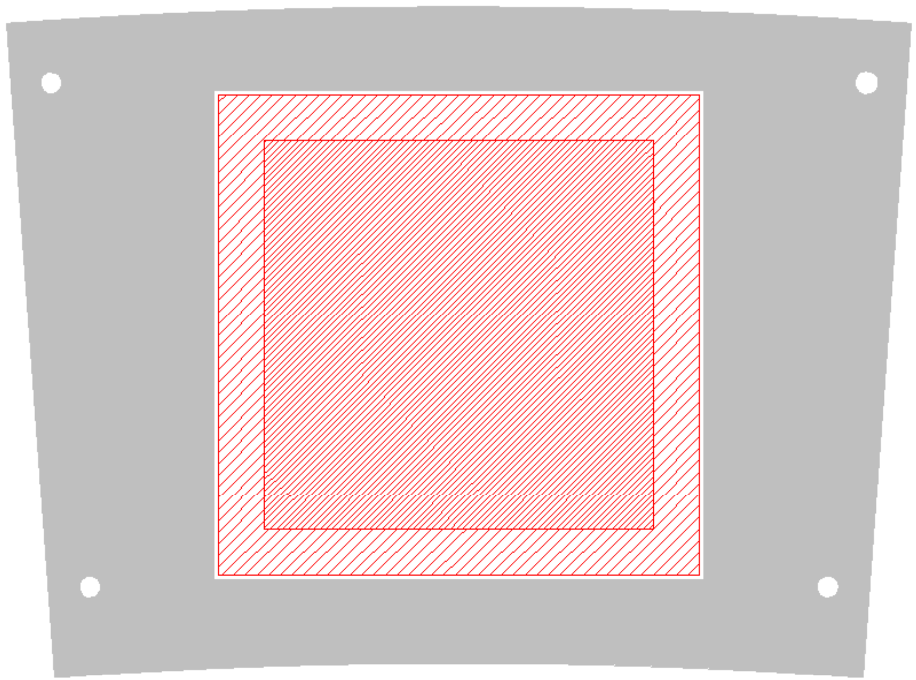


- Three standard CERN GEMs (10x10 mm^2)
- Surrounding shield made from a PCB
- 1mm gap between the GEMs
- Total height of active detector: 6mm + connectors

Ground plate with TimePixes

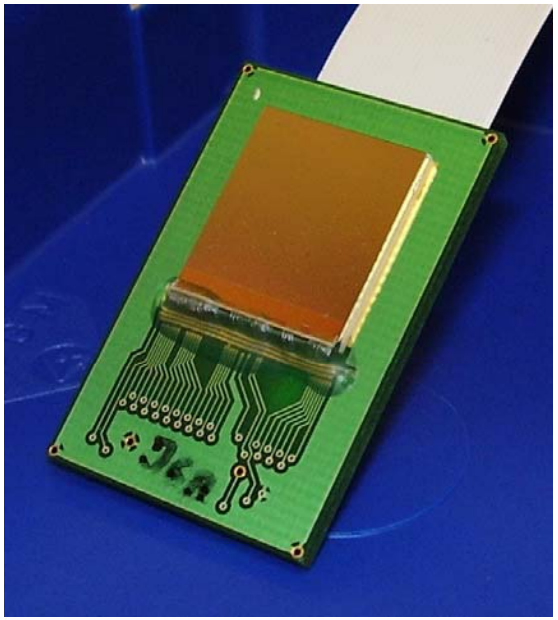


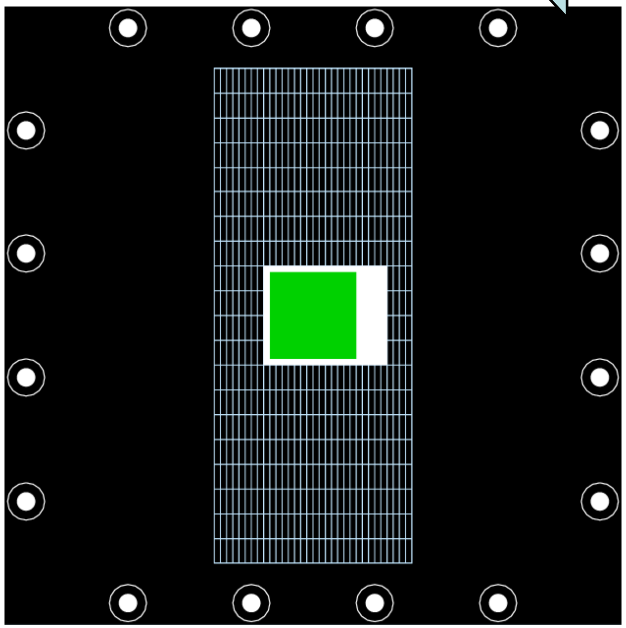
Shield with GEM

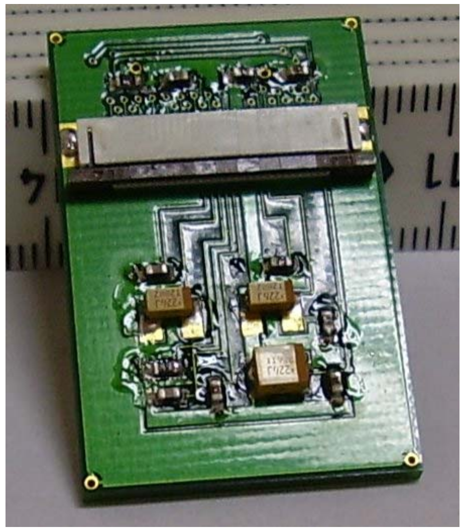


Also: Single Chip Board

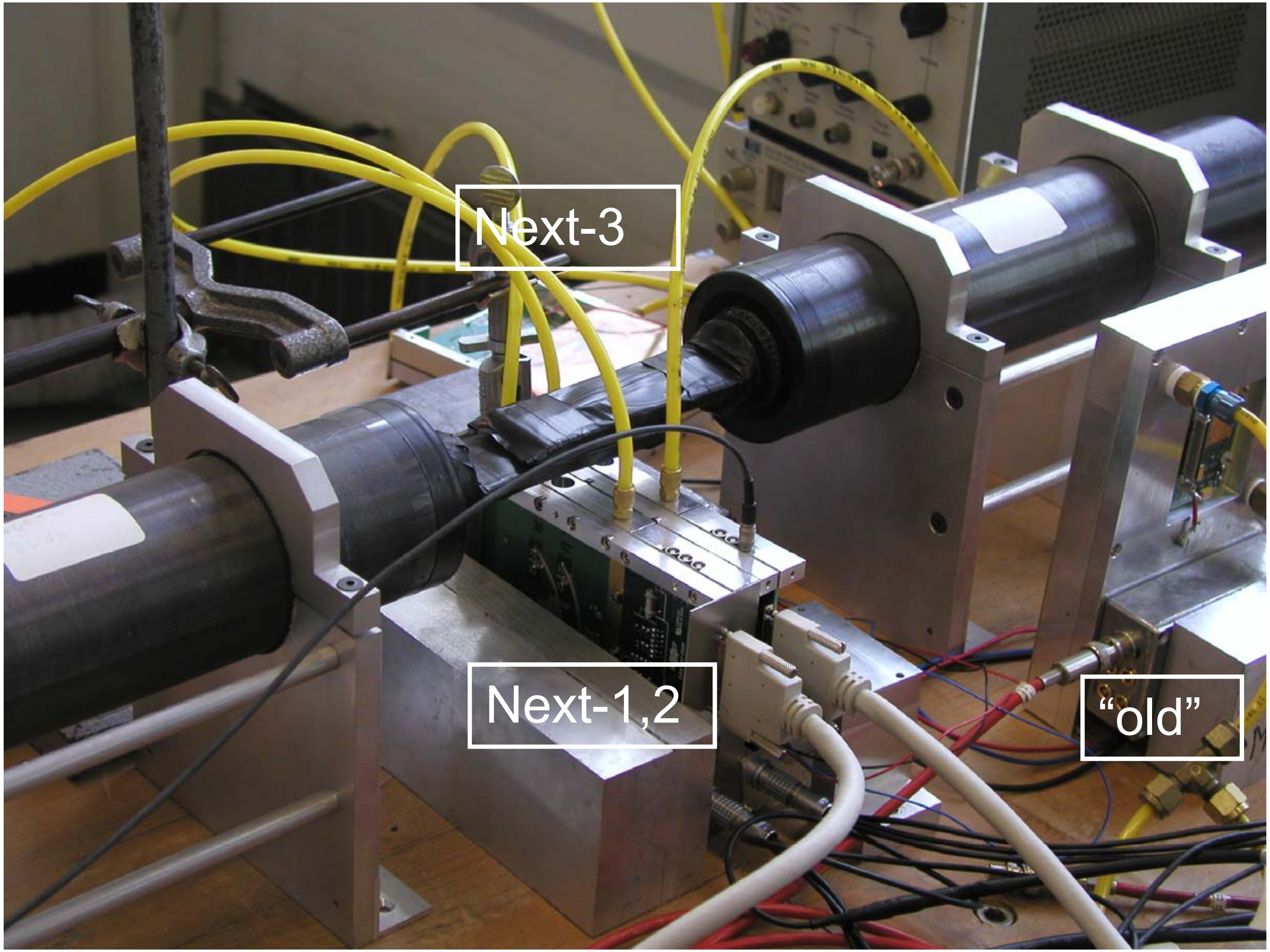
- Designed to be as small as possible: Resistors mounted behind the chip
- For use in board together with pads







NIKHEF setup (on 24 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 >20 days!

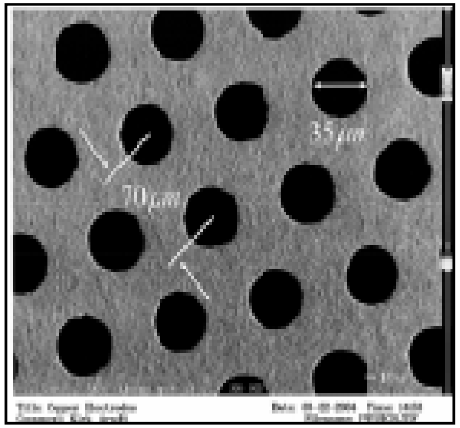
23 sep. — Flush NEXT-1 (**E09**) with Ar, same nice results

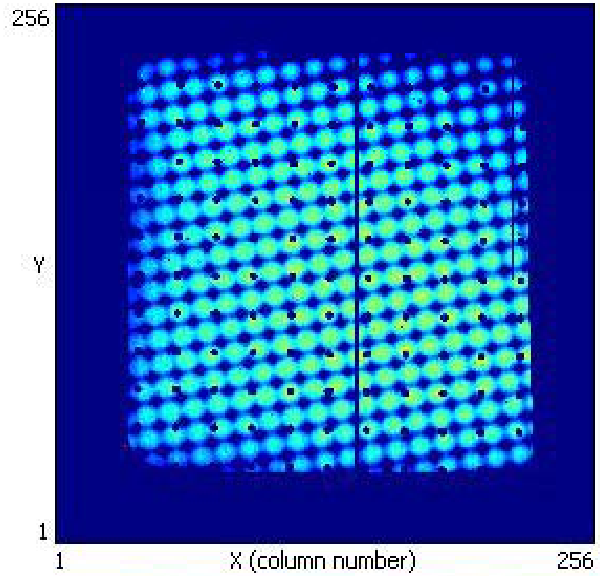
26 sep. — Introduce Thorium in NEXT-2 (**A06**), provoke discharges
Recording alpha's tracks & even more…

TPX operated in Ar iC4H10

Full post-processing of a TimePix

- Timepix chip + Micromegas mesh:



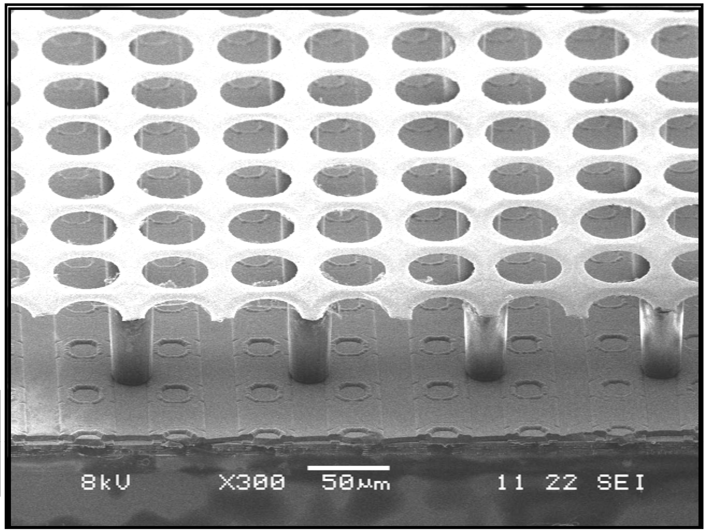


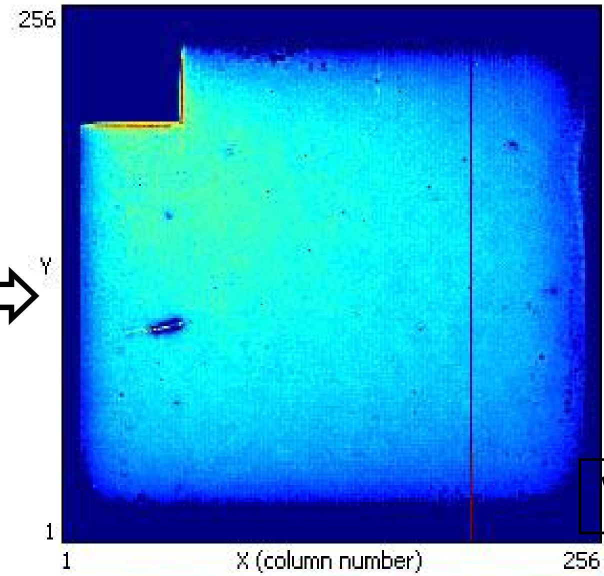
Moiré effects
+ pillars

- Timepix chip + SiProt + Ingrid:

MESA+

IMT Neuchatel





"Uniform"

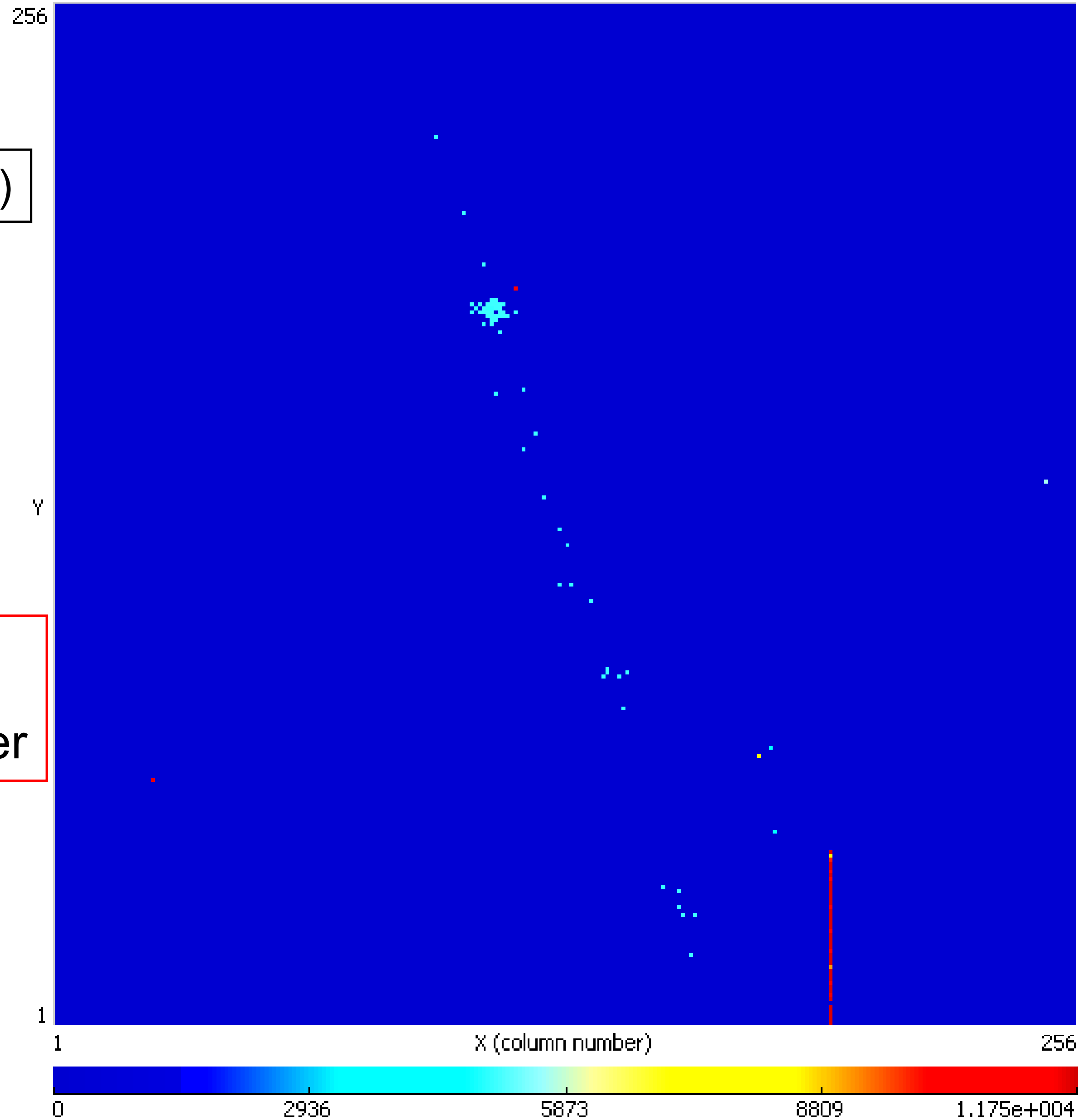
"counting" mode

^{90}Sr

He/Iso (80:20)

Time mode

118 μs shutter

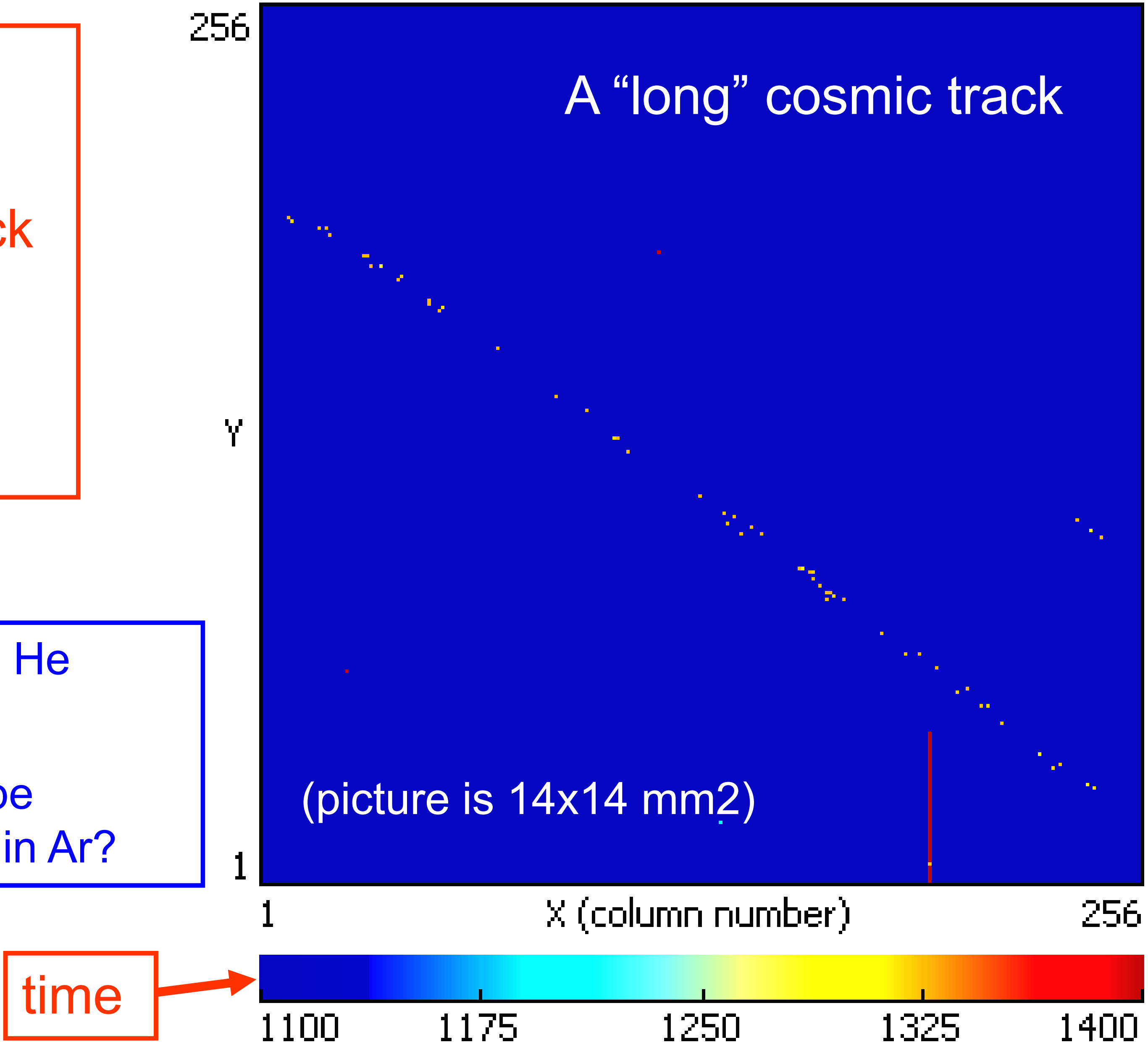


Timepix
+
20 μm Siprot
+
Ingrid
in Next-1

courtesy David Attié

The "typical" track

Timepix
+
20 µm thick Siprot
+
Ingrid

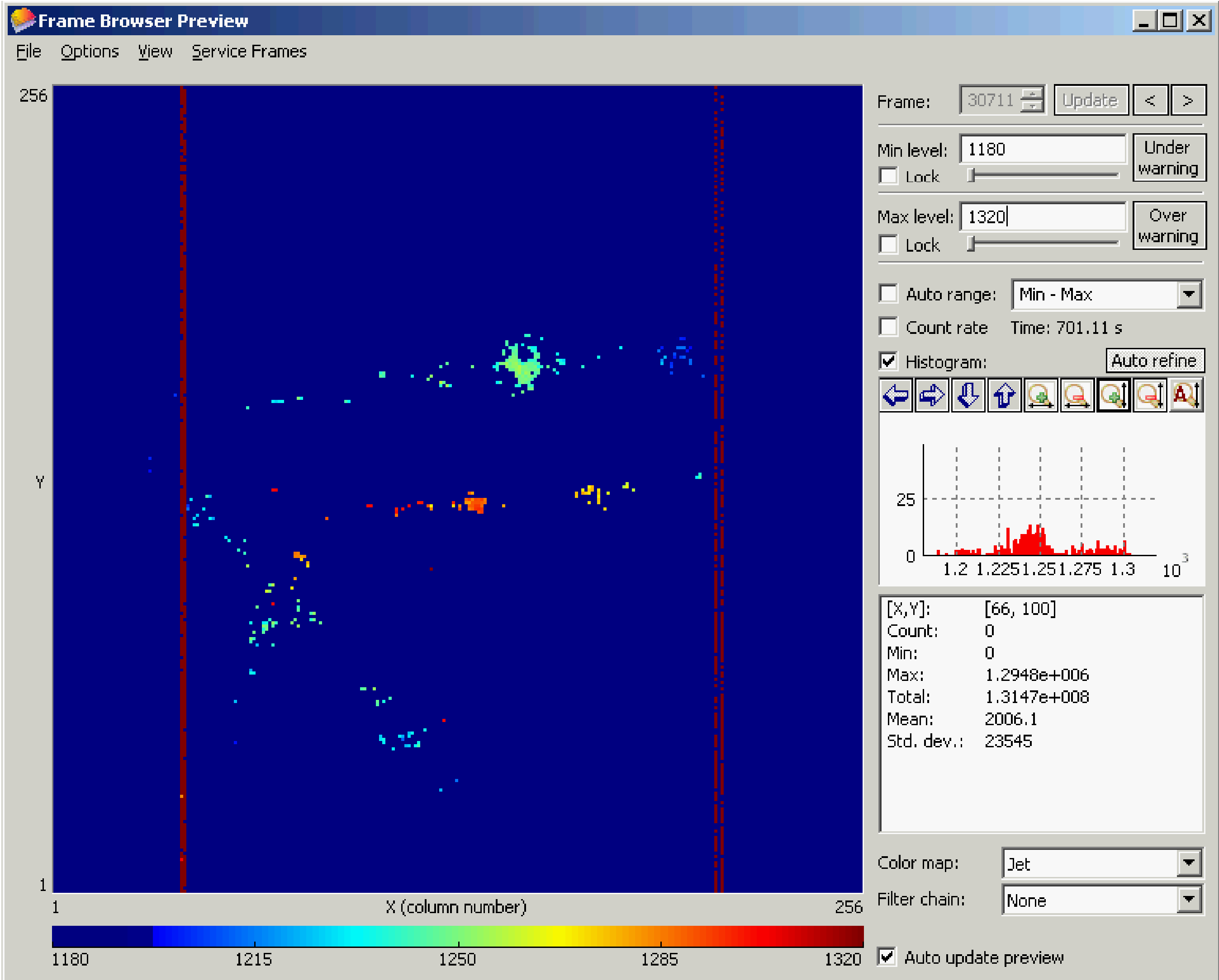


Stable operation in He iC4H10

Will 20 µm SiProt be enough to operate in Ar?

Stable operation in Argon too!

Time mode

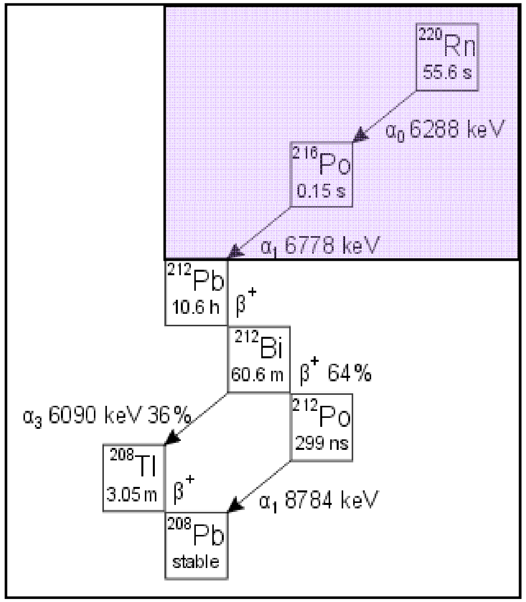


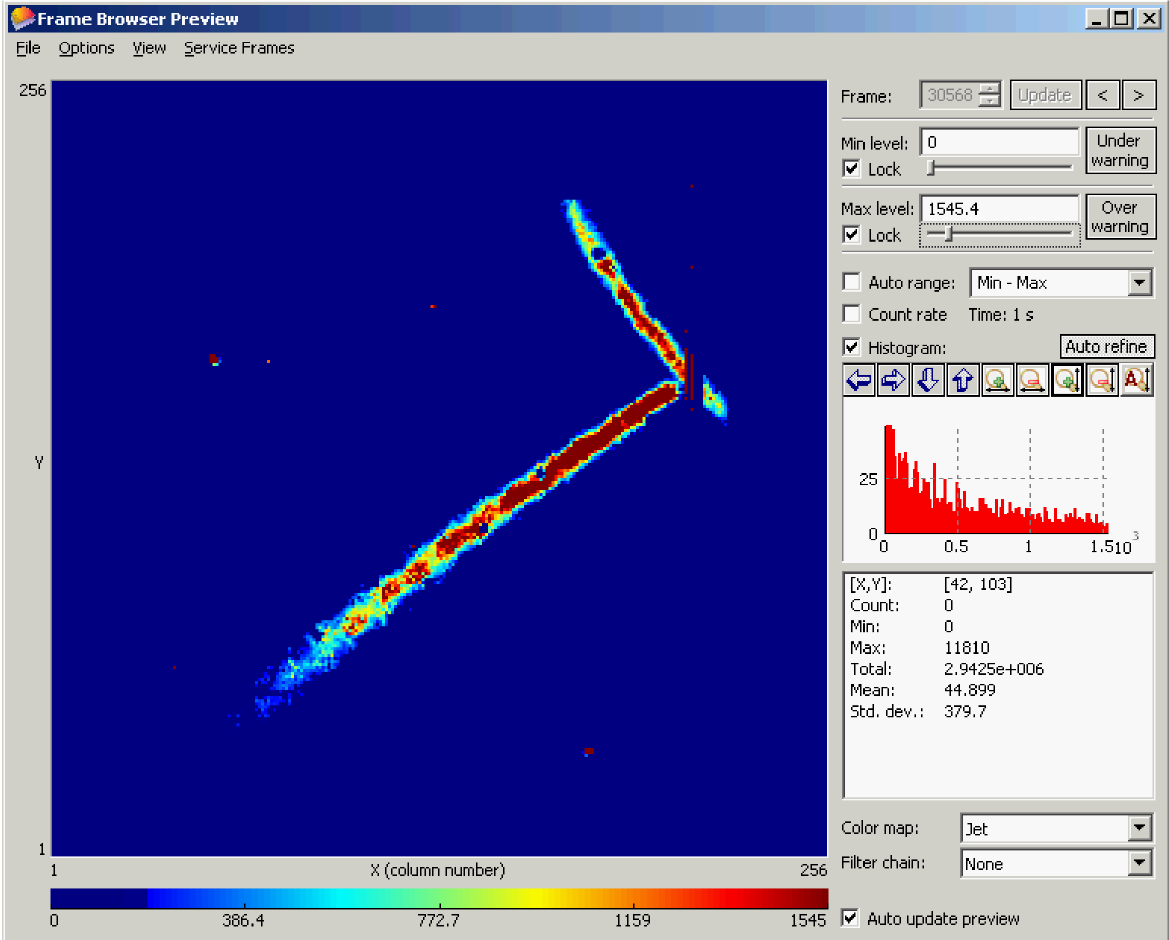
After 2 weeks of cosmic event recording, it was time for a definitive assessment whether 20 µm SiProt is enough to protect against discharges…

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





Since 1 week, some 5.10^4 alpha events recorded in 1% of which …

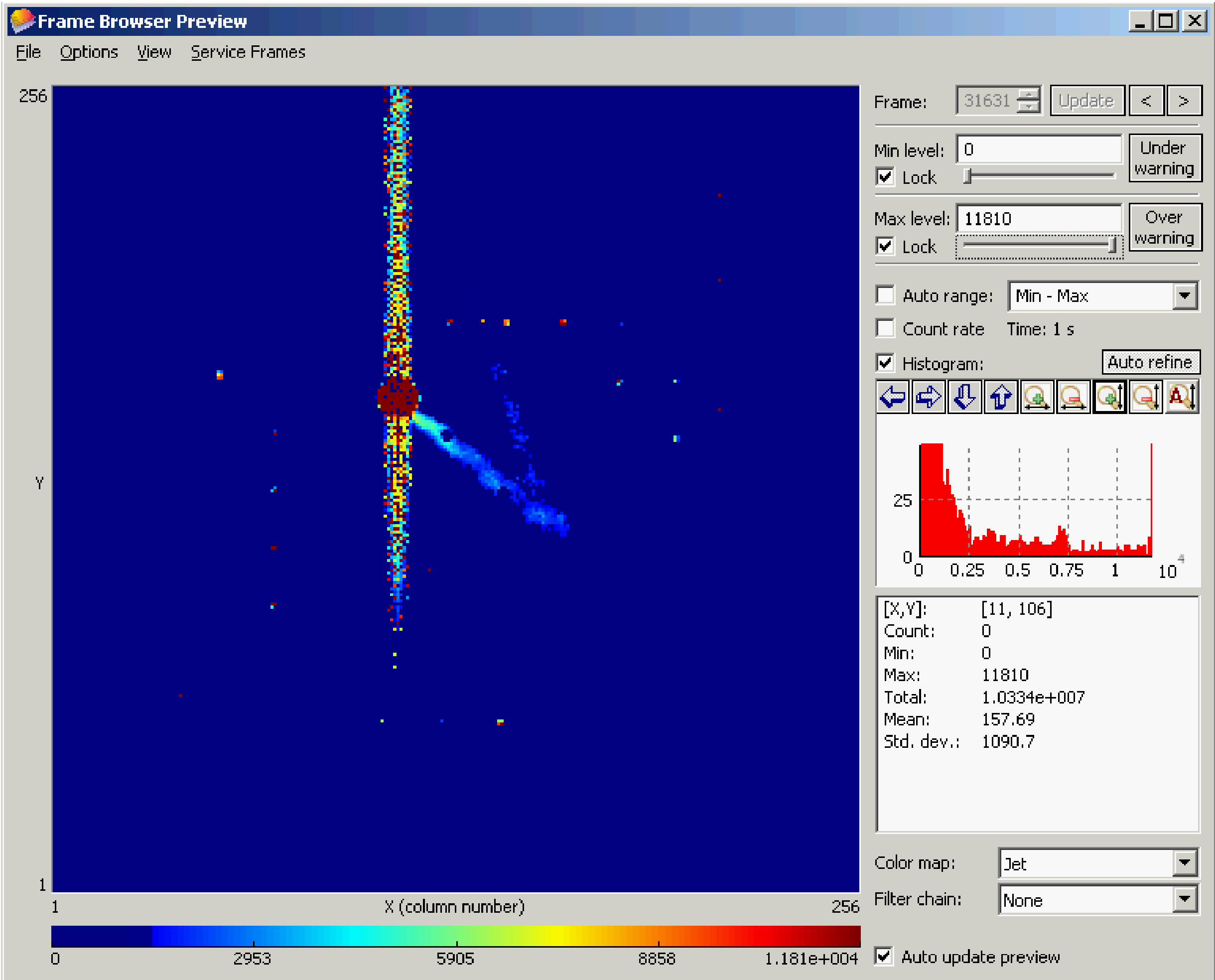
… discharges are observed !

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 wafer tests at CERN (together with Freiburg, NIKHEF)

Class

(green)	A	No dead columns
(light green)	B	1 dead column
(yellow)	C	2 dead columns
(orange)	D	>2 dead columns
(dark orange)	E	Bad DACs
(dark orange)	F	Bad Digital Test
(dark orange)	Fnt	Not tested

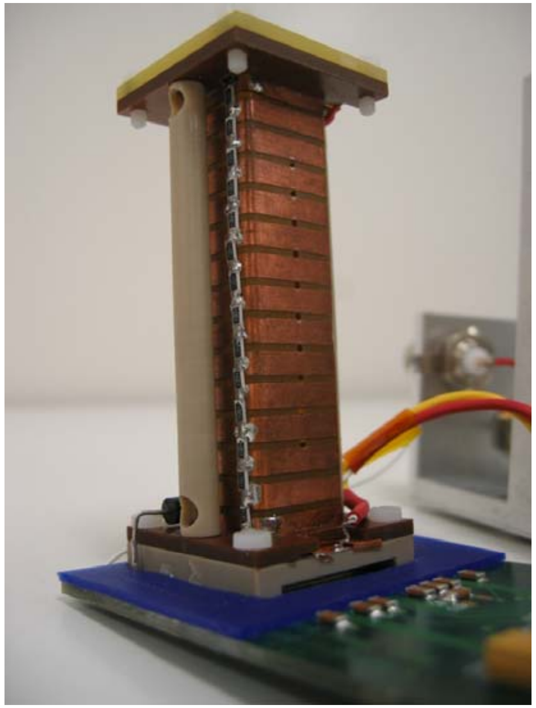
20 wafers from the first run tested

→ ~ ~~66%~~ of chips are usable

72.9% yield (A+B+C)

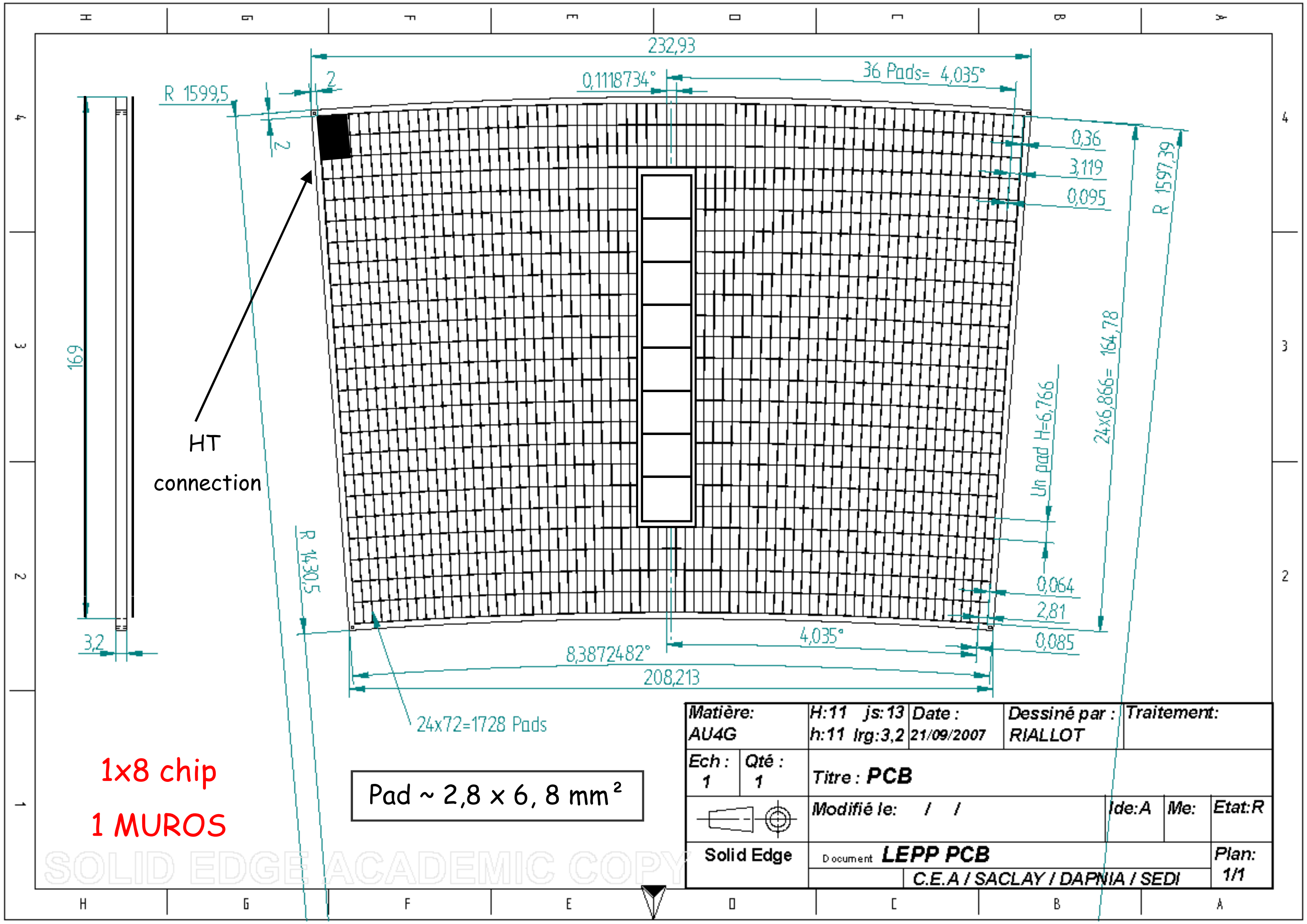
		TimePix classification							Total	
Wafer n°	**Location**	**A**	**B**	**C**	**D**	**E**	**F**	**Fnt**	**Wafer**	**A+B**
8_A9FWR6X	CERN	31	27	6	11	12	20	0	107	58
9_ACFWR3X	CERN	42	15	13	10	9	17	1	107	57
10_A6FWQ5X	CERN	40	27	7	12	11	9	1	107	67
11_ATFWTLX	CERN	54	18	7	6	14	8	0	107	72
12_ASFWTMX	CERN	45	21	7	2	18	13	1	107	66
13_ARFWTNX	CERN	15	18	14	27	17	16	0	107	33
14_A5FWQTX	Diced	44	26	3	6	8	20	0	107	70
15_AQFWTPX	VTT	55	20	10	6	9	7	0	107	75
16_GX11ILX	CERN	44	27	8	10	13	5	0	107	71
17_G111GIX	CERN	41	31	8	7	14	6	0	107	72
18_GG11G3X	CERN	58	26	5	4	9	5	0	107	84
19_GF11G4X	CERN	49	30	9	6	9	4	0	107	79
20_GV11INX	CERN	51	23	15	13	3	2	0	107	74
21_GV11GPX	CERN	49	27	8	9	9	5	0	107	76
22_GZ11H2X	CERN	48	25	9	7	14	4	0	107	73
23_GU11H7X	CERN	58	26	2	3	12	6	0	107	84
24_GY11IKX	CERN	47	23	8	6	18	5	0	107	70
25_GW11H5X	CERN	46	18	8	15	2	18	0	107	64
26_GS11H9X	CERN	35	39	7	8	11	7	0	107	74
27_GH11G2X	CERN	56	27	5	4	13	2	0	107	83
TOTAL		**908**	**494**	**159**	**172**	**225**	**179**	**3**	**2140**	**1402**
(%)		42,4	23,1	7,4	8,0	10,5	8,4	0,1	100	65,5

TimePix/Micromegas chamber at Saclay



- The field cage is ready to work in He/Iso 80/20 (6 kV on the cathode)
- 1 TimePix dead by HV accident
- 2 TimePix Chip don't show the same behavior after putting up the micromegas mesh
- Several chips with Siprot now available

Deliverable endplate with TimePix

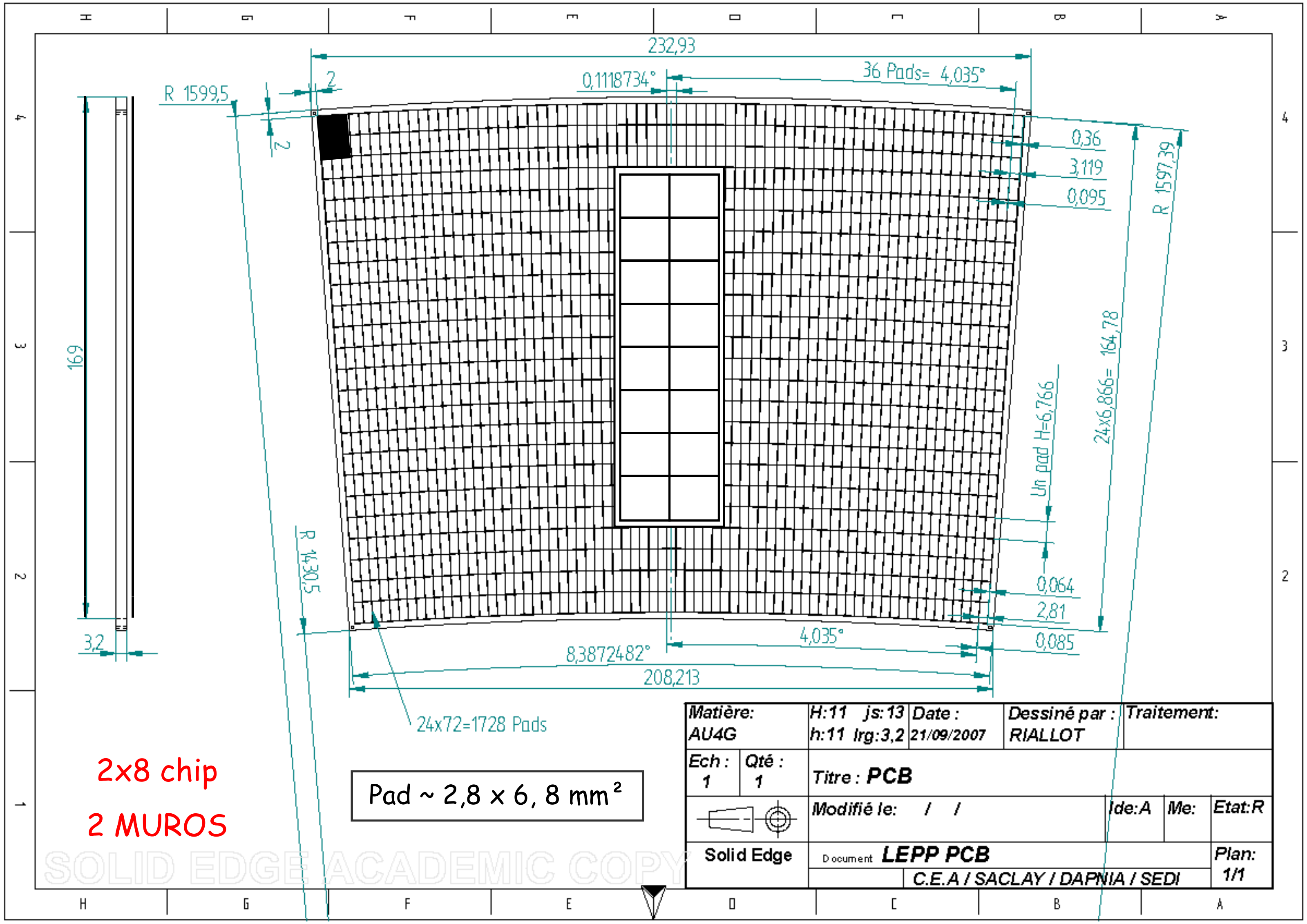


1x8 chip

1 MUROS

Pad ~ 2,8 x 6, 8 mm²

Large Prototype Endplate



Summary

- A lot of progress made in last year; not mentioned many details on track resolution studies, reconstruction software development, signal development
- Part of the technology is ready
- Discharge protection seems working

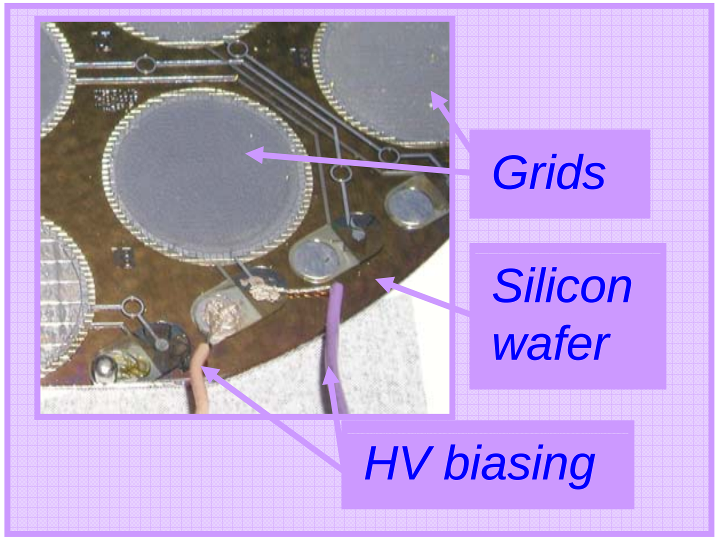
Next:

- Build larger detector systems with fast readout; first step ("deliverable") endplate structure end of 2007 (few 1-2 months later)
- Further beam tests (and in B field)
- Assess track and dE/dx resolutions

Backup slides

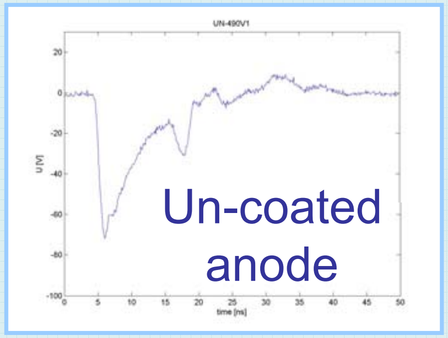
Wafer post-processing(s)

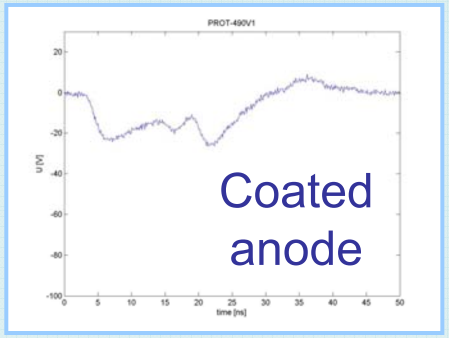
- Idea: use micro-electronic techniques to optimize CMOS pixel chip performances
  - Gas amplification structures
  - Current limiting coatings



- InGrid: a Grid integrated on Si
  - Maximize detection efficiency
    - alignment holes/pads
  - Minimize dead areas
    - small pillars Ø, full pixel area coverage

- SiProt: a low T deposited aSi:H layer
  - Up to 30 μm thick films, ~10^{11} Ω.cm
  - Attenuate discharge current



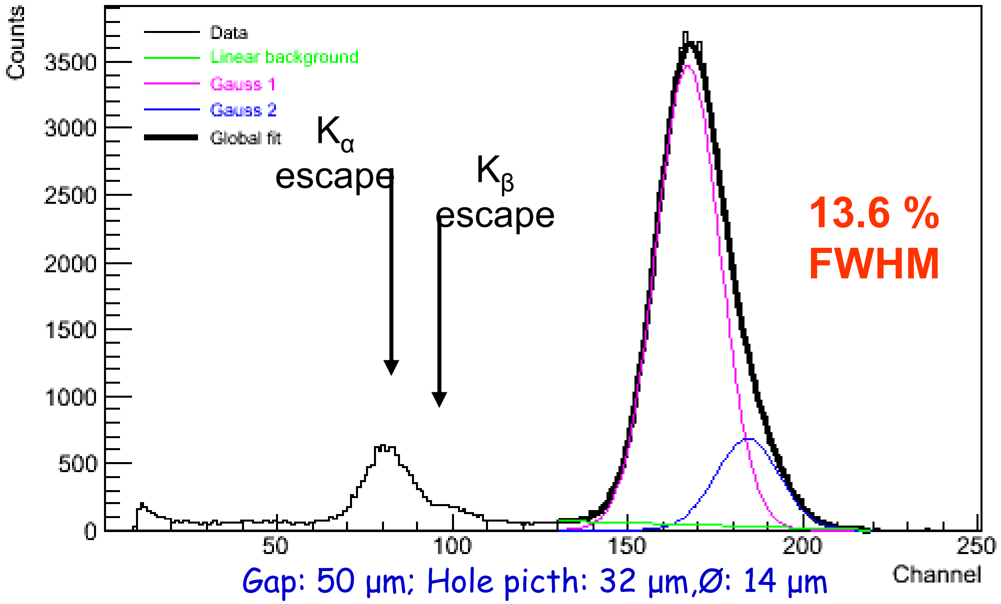


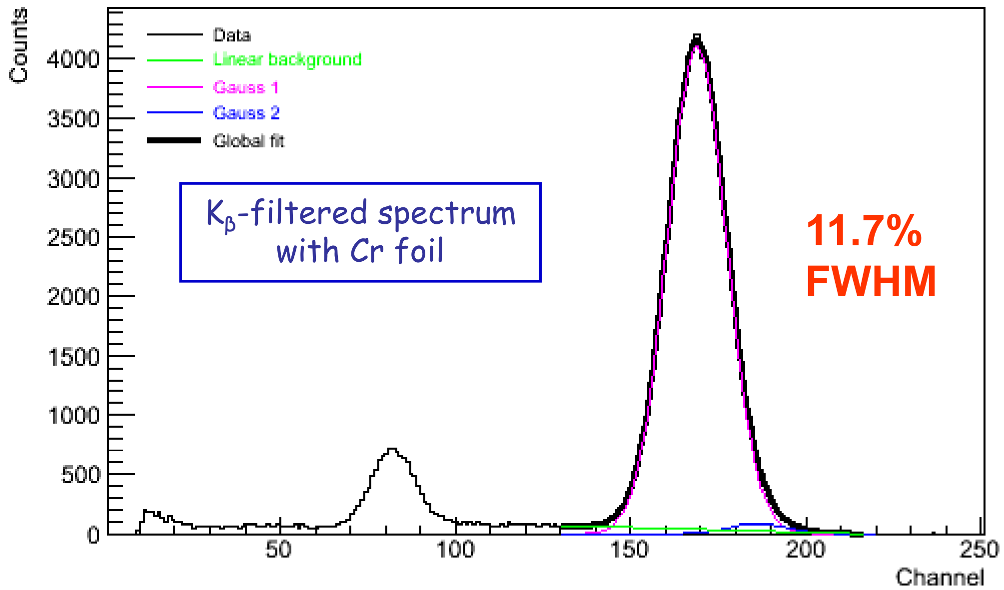
New Ingrid developments and results

- 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

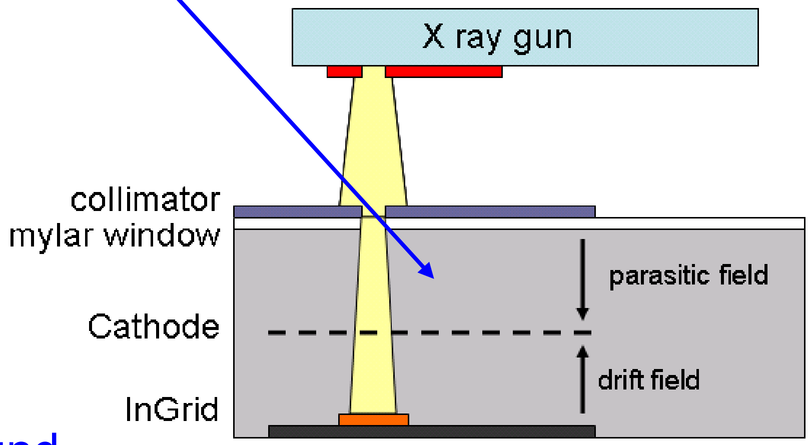
- Until now: 1 µm thin Al but can now be increased to 5 µm by electrolysis
  Expect less damaged from sparks





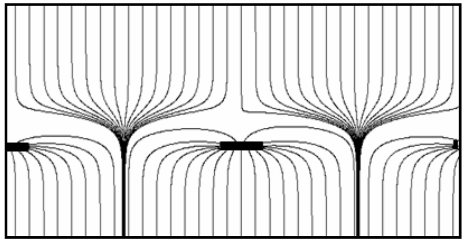
InGrid ion backflow measurements (I)

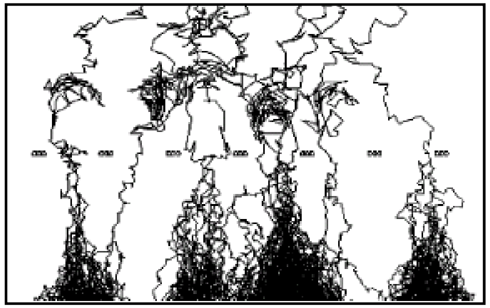
- Measurements started in Saclay with D. Attié & P. Colas
- Main issues encountered:
  - Gas gap between detector window & cathode
    - "Parasitic" field
      Unwanted contribution to primary current
  - Small grid area
    - high X flux for significant primary current (recombination problem @ low drift field)
    - bad collection of "long" range photoe-



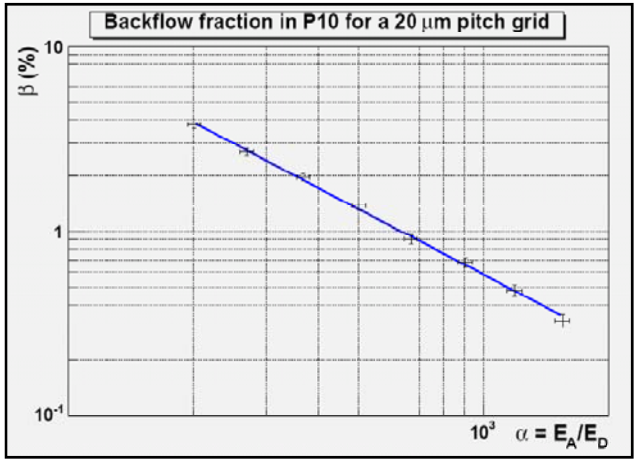
- Solutions:
  - Operate the detector with cathode at ground
  - Reduce X-ray energy (~ 9 keV) and flux
- Now:
  - measurements of the primary and backflow currents accurate to the pA!
  - Good measurements up to field ratio of 1000:
    backflow fraction of few 10^{-3} in P10 gas.

InGrid ion backflow measurements (II)

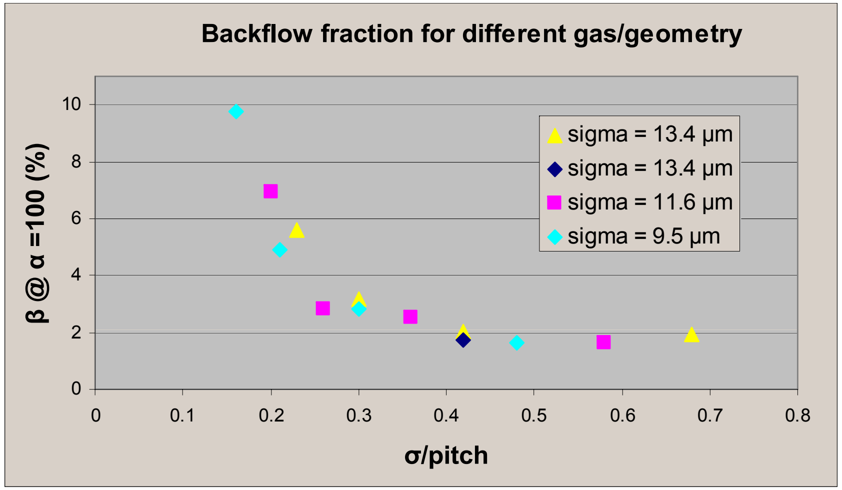




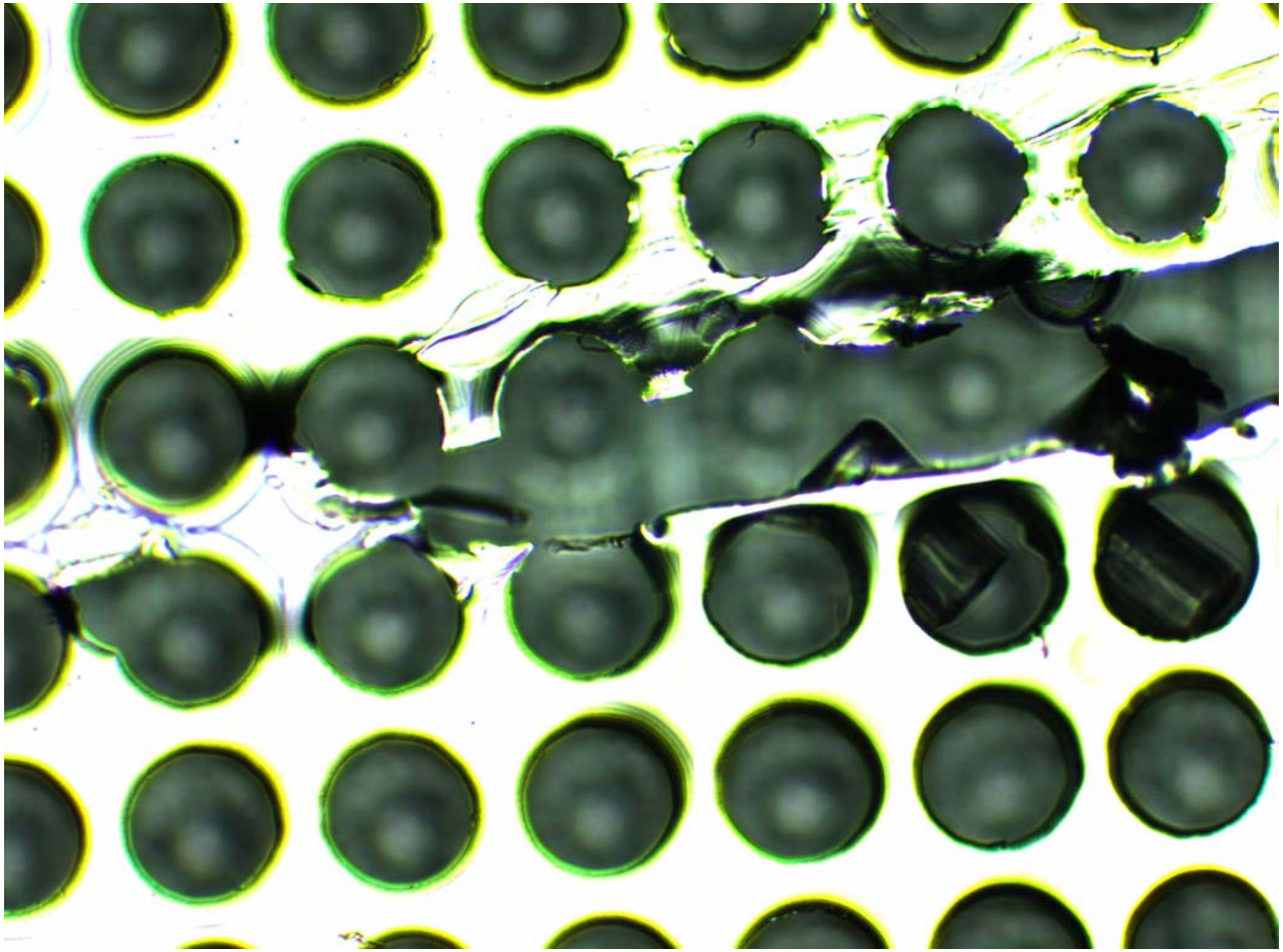
- Phenomenon depends on:
  - Avalanche charge distribution
  - Funnel size



- 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 $\sigma/p = 0.5$



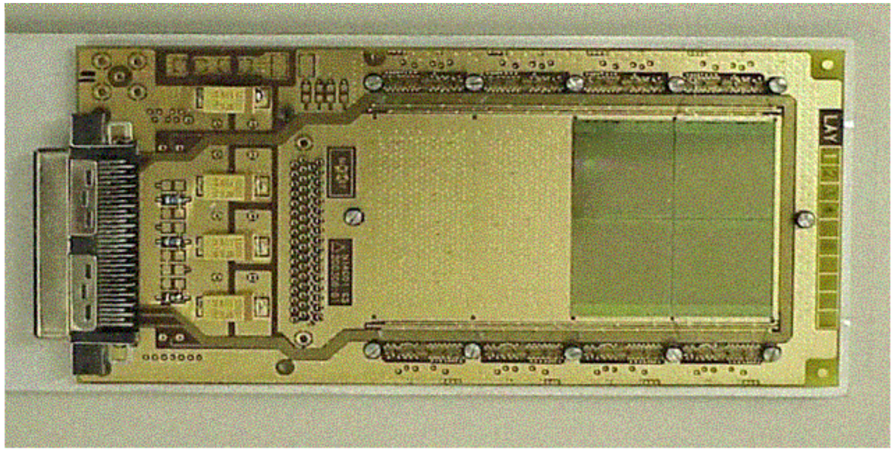
A “scratch” occurred during production Ingrid;

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!

summary timetable

- ✓ 1st version Timepix operational: ~~1/2007~~ 9/2006
- ✓ First m.i.p. signals with Timepix: ~~~4/2007~~ 11/2006
- Gain experience with Timepix during 2007
- Development 2nd iteration Timepix ~~during 2007~~

  $\rightarrow$ 3/2008
- Endplate infrastructure: 1/2008
- Full SITPC infrastructure incl. DAQ available:

  1/2009

TimePix Reconstruction

Data Structure	Processor Name	Collection Name
`TrackerRawData`		TimePixRawData
	TimePixZeroSuppressionProcessor	
`TrackerRawData`		TimePixZeroSuppressedRawData
	TimePixClusterFinderProcessor	
`TrackerHit`		TimePixHitCandidates
	TimePixClusterProjectionSeparatorProcessor	
`TrackerHit`		TimePixSepHitCandidates
	TimePixHitCenterCalculatorProcessor	
`TrackerHit`		TimePixHits