Highly Pixellated TPC readout
(the “digital” TPC)

CLIC09 workshop – WG1 session

Physics and detectors

15 October 2009

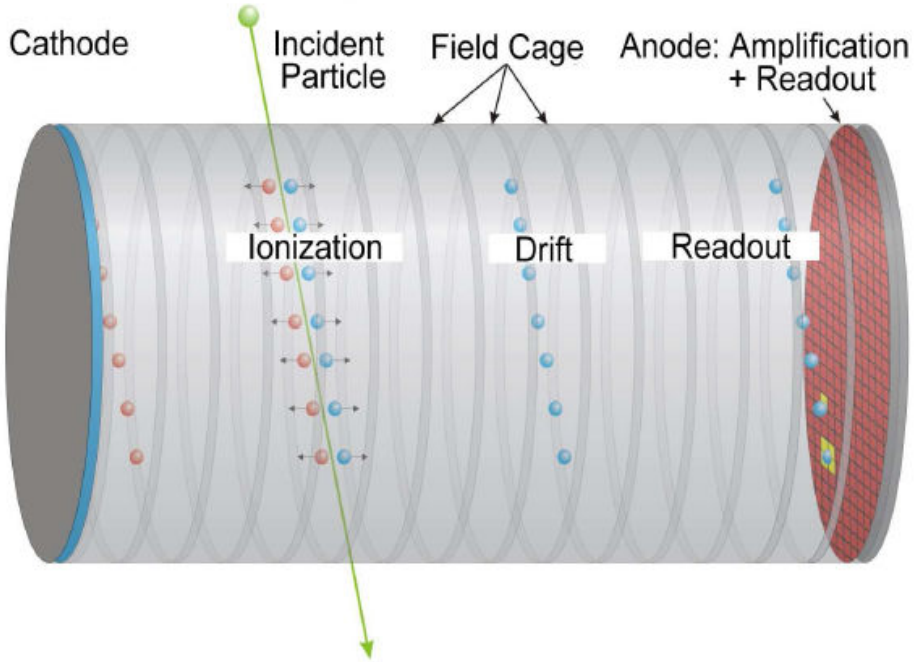
Jan Timmermans - NIKHEF/DESY

Performance goals and design parameters for a TPC with standard electronics at the ILC detector

Size	$\phi = 3.6$m, L = 4.3m outside dimensions
Momentum resolution (3.5T)	$\delta(1/p_t) \sim 9 \times 10^{-5}$/GeV/c TPC only ($\times$ 0.4 if IP incl.)
Momentum resolution (3.5T)	$\delta(1/p_t) \sim 2 \times 10^{-5}$/GeV/c (SET+TPC+SIT+VTX)
Solid angle coverage	Up to $\cos\theta \simeq 0.98$ (10 pad rows)
TPC material budget	$\sim 0.04 X_0$ to outer fieldcage in r
	$\sim 0.15 X_0$ for readout endcaps in z
Number of pads/timebuckets	$\sim 1 \times 10^6$/1000 per endcap
Pad size/no_padrows	$\sim$ 1mm$\times$4–6mm/$\sim$200 (standard readout)
σ_{point} in $r\phi$	$< 100\mu$m (average over $L_{\text{sensitive}}$, modulo track ϕ angle)
σ_{point} in rz	$\sim$ 0.5 mm (modulo track θ angle)
2-hit resolution in $r\phi$	$\sim$ 2 mm (modulo track angles)
2-hit resolution in rz	$\sim$ 6 mm (modulo track angles)
dE/dx resolution	$\sim$ 5 %
Performance	$>$ 97% efficiency for TPC only ($p_t > 1$GeV/c), and
	$>$ 99% all tracking ($p_t > 1$GeV/c) [82]
Background robustness	Full efficiency with 1% occupancy,
	simulated for example in Fig. 4.3-4(right)
Background safety factor	Chamber will be prepared for 10 $\times$ worse backgrounds
	at the linear collider start-up

with MPGD

TPC with MPGD

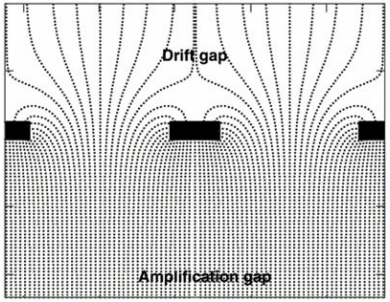


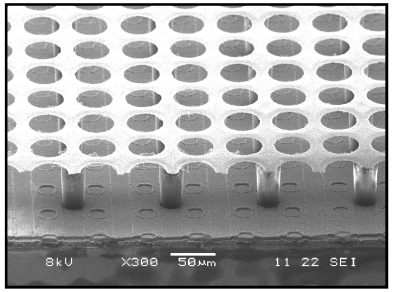
MicroPatternGasDetector

MPGD

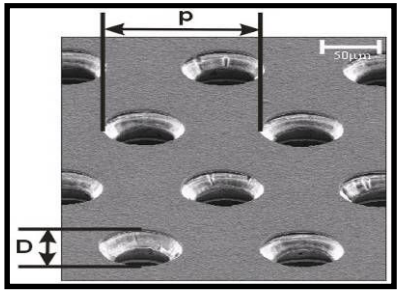
not limited by **E** x **B** effects

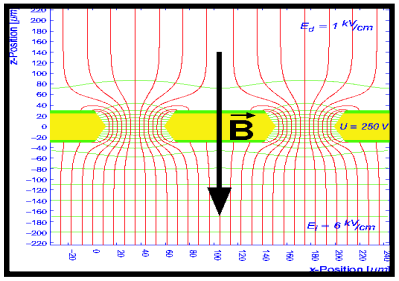
MicroMegas





GEM

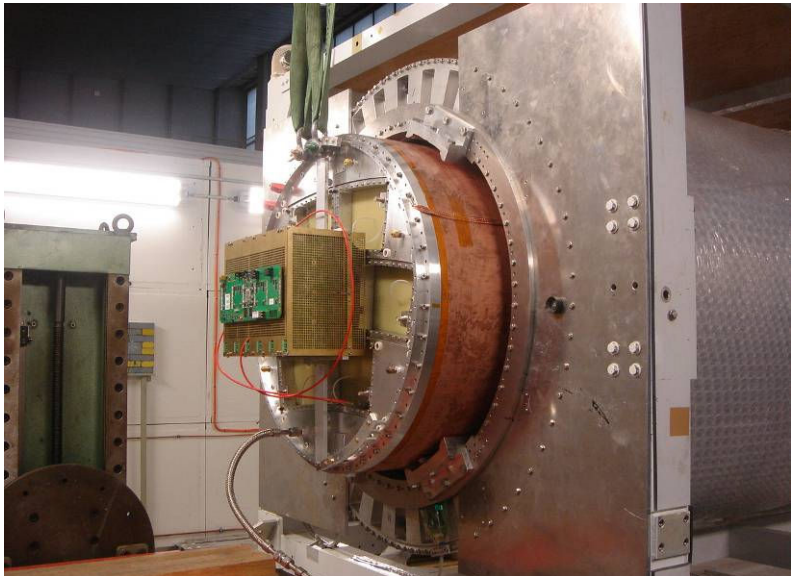




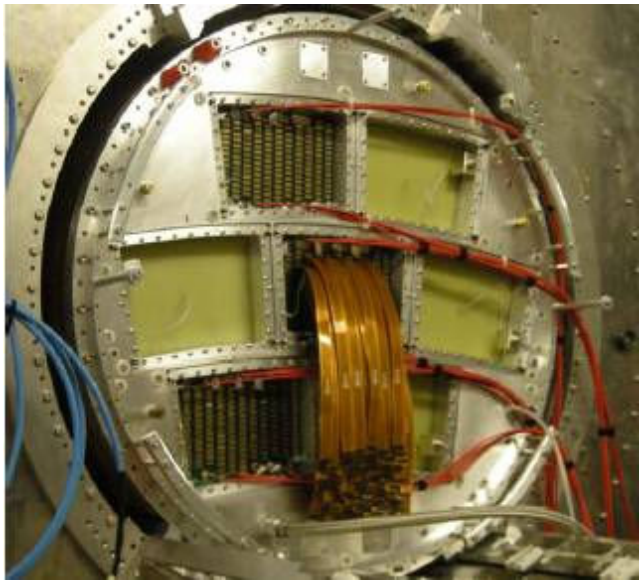
- **Two gas amplifications:**
- **Analog TPC**
  with standard pad readout
  (need signal broadening)

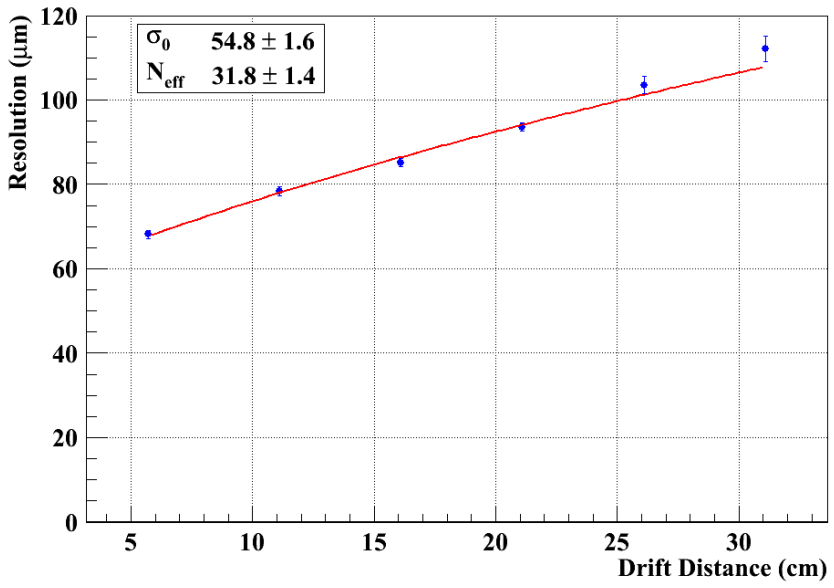
  Digital TPC
  with CMOS pixel readout

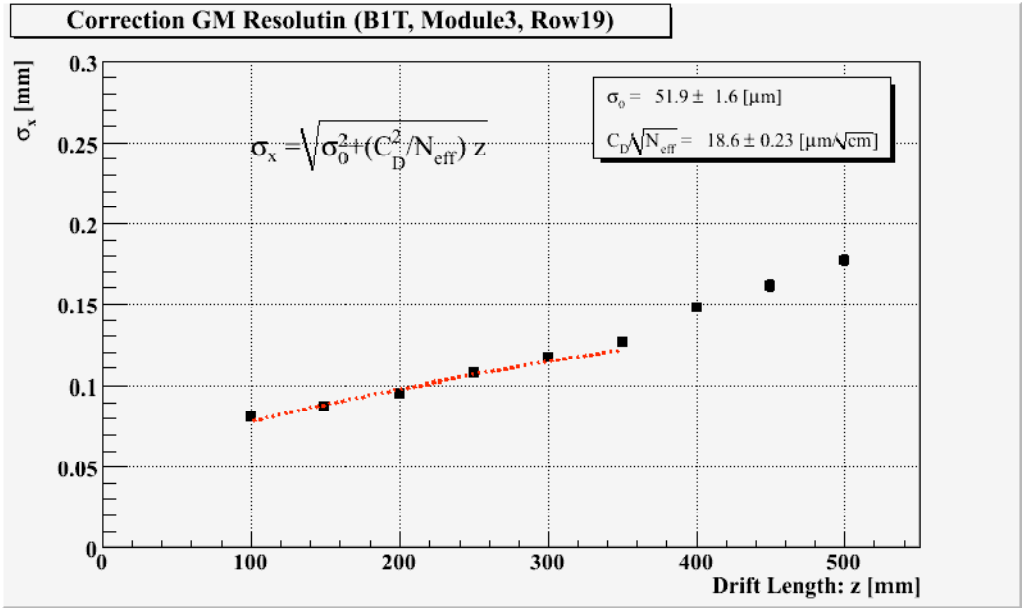
Micromegas (1 module 1700 ch.)



3 double-GEM modules (3300 ch.)





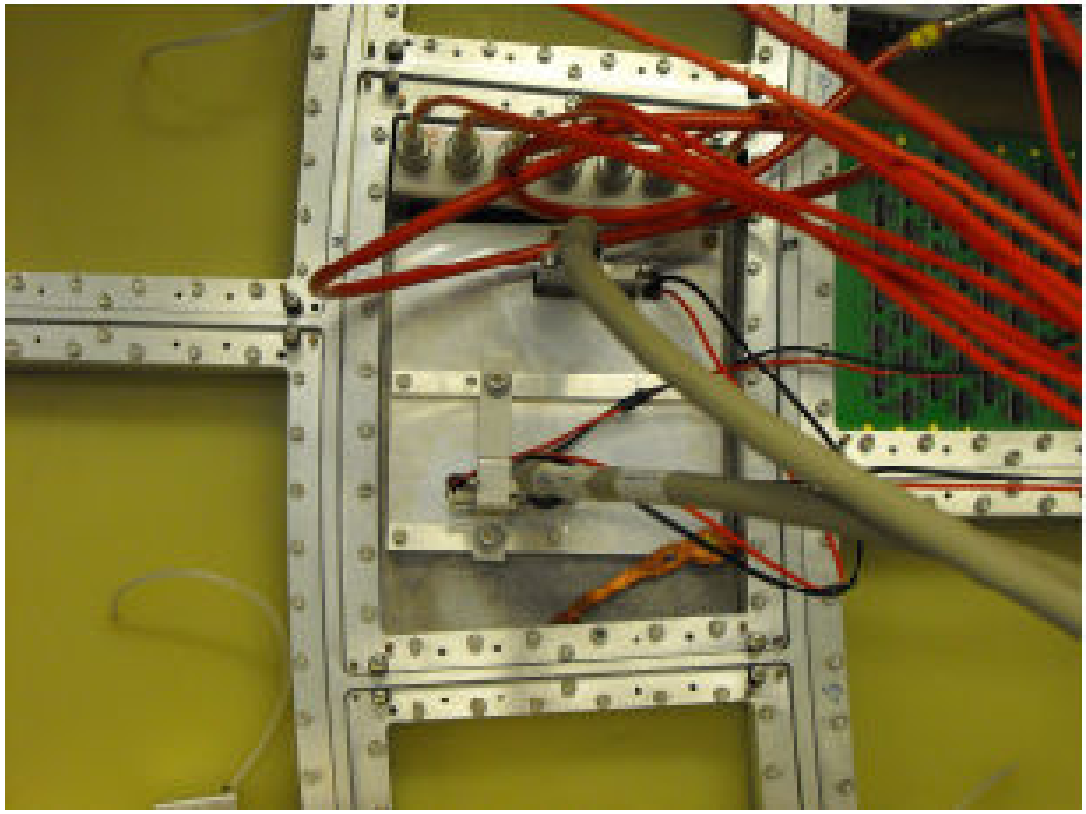


Pad readout vs. Pixel readout

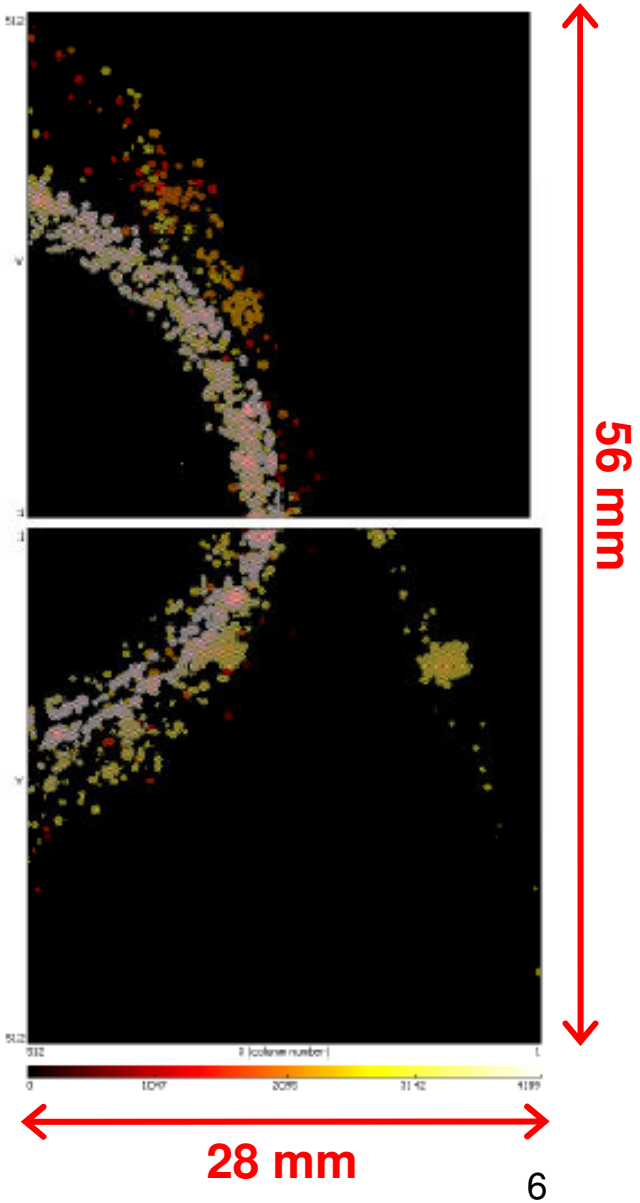
- Pad size ~1x5 mm^2 or ~3x7 mm^2
- Timepix pixel size 55x55 $(\mu m)^2$

- Pad TPC ~ 10^6 pads; several 10^9 3D-voxels
- CMOS pixel readout ~ 2.10^9 'pads' (but 'only' ~ 4.10^4 chips); ~ 10^{12} 3D voxels

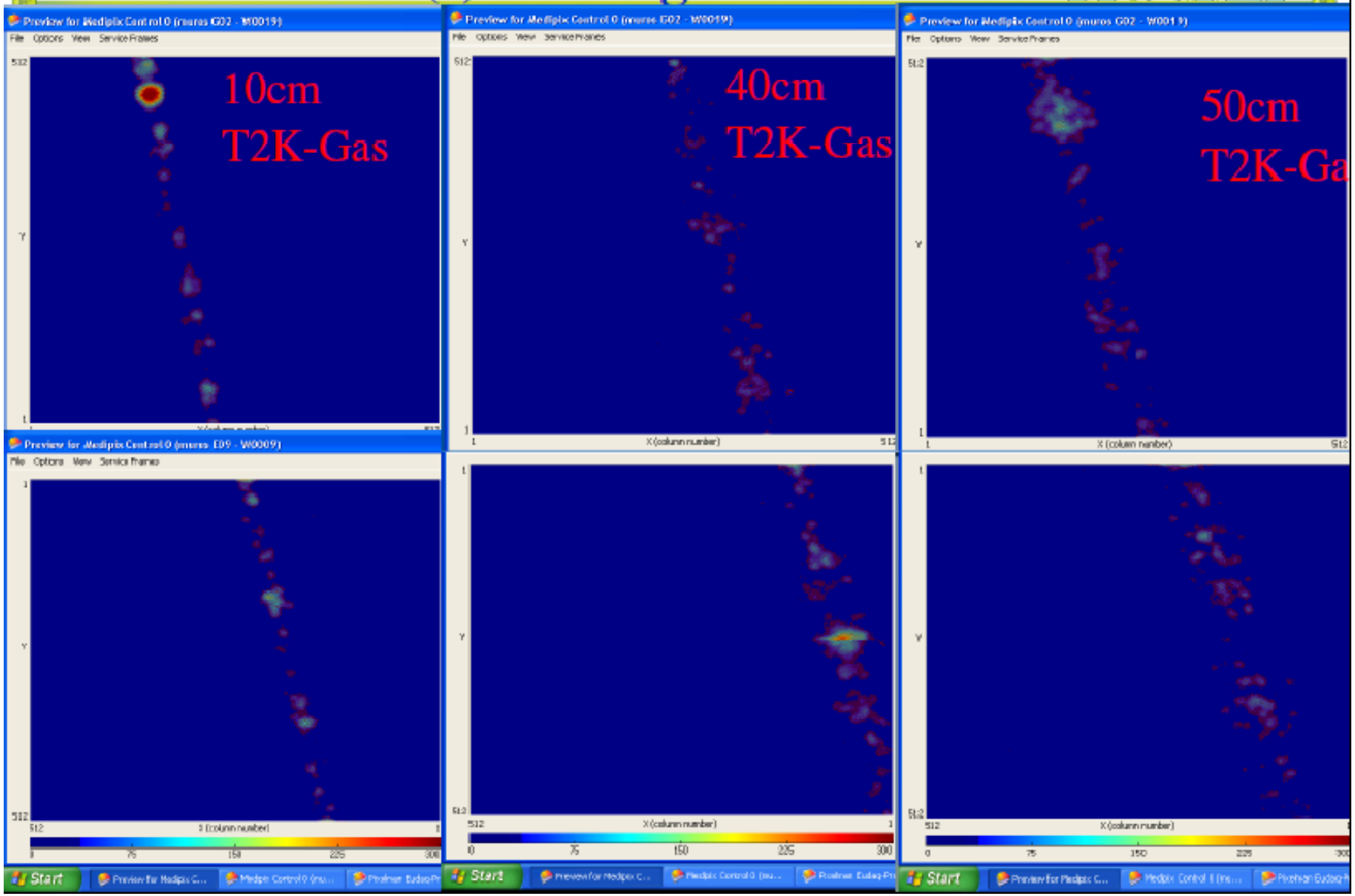
Triple-GEM module with readout by 8 Timepix chips: 16 cm2 active area, 0.5M channels



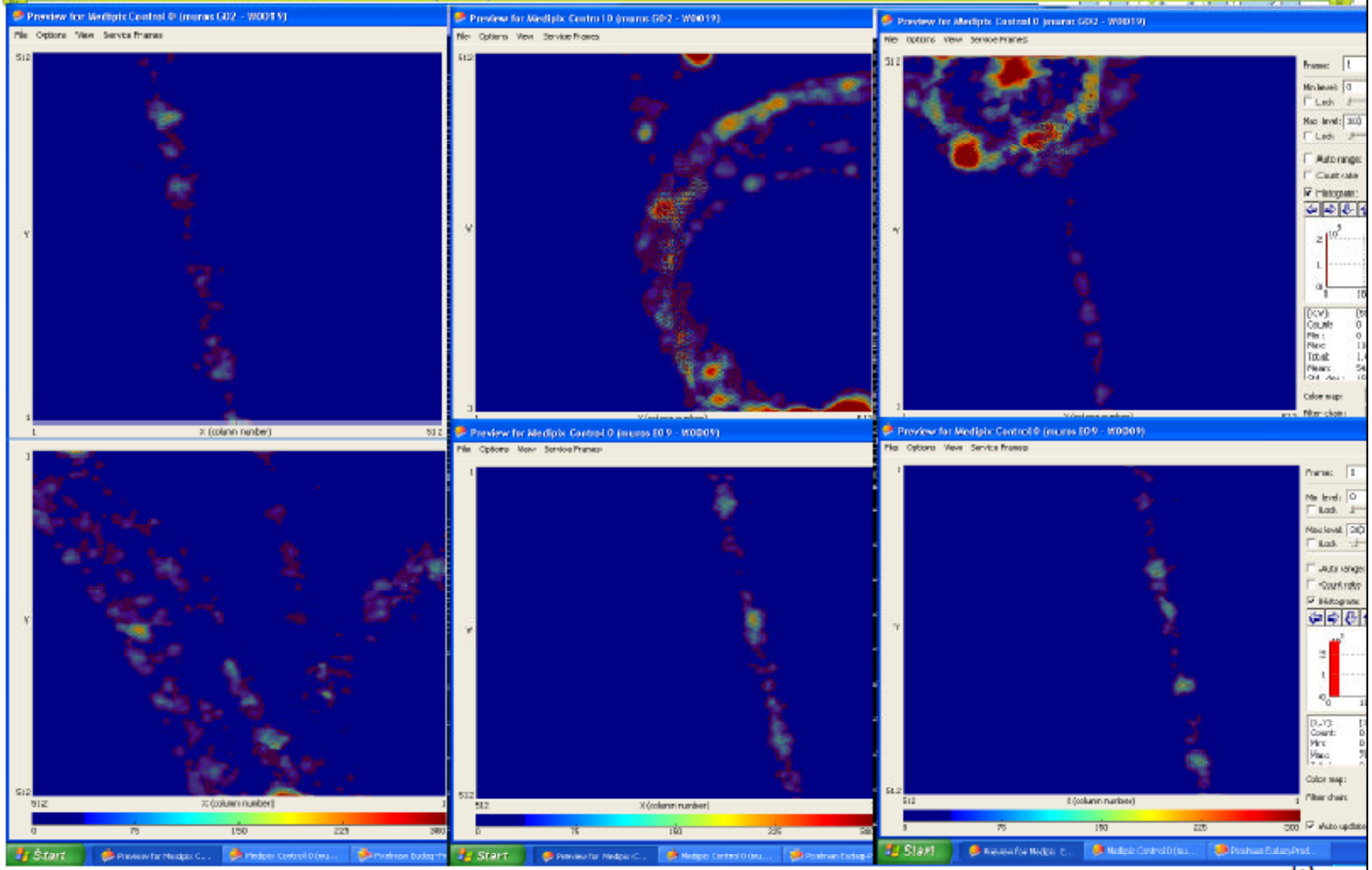
Bonn/Freiburg



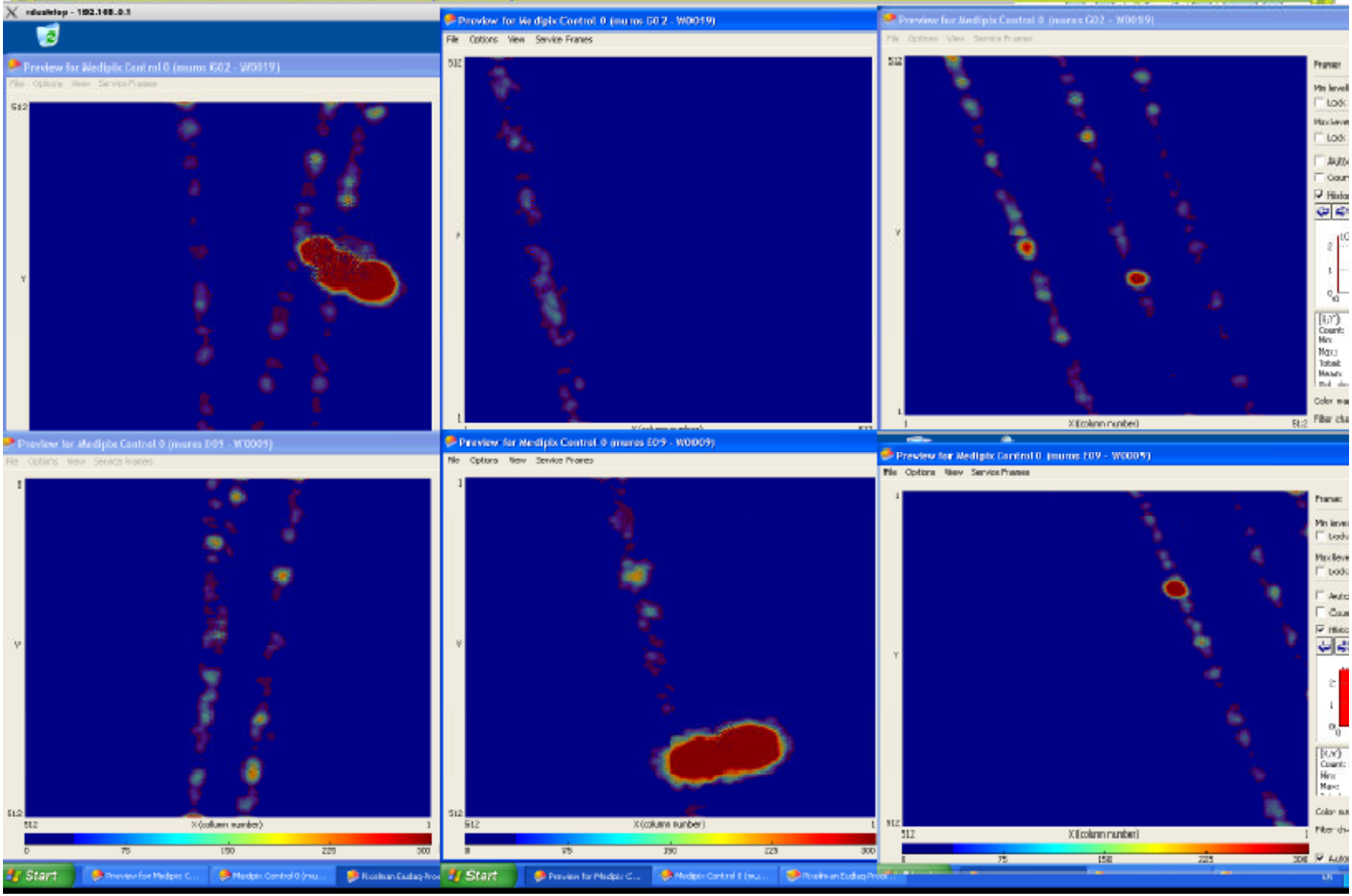
Some Pictures (I) – straight tracks



Some Pictures (II)



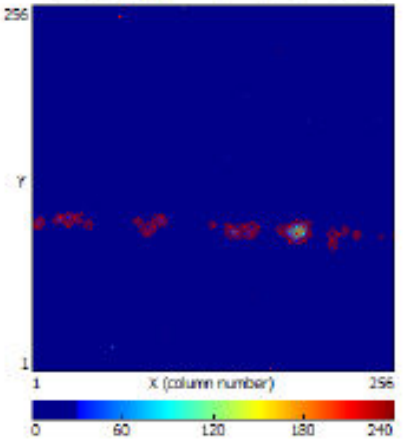
Some Pictures (III)



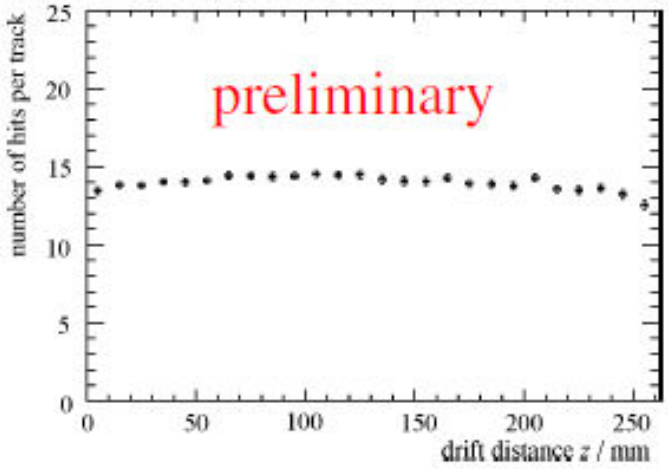
High Magnetic Fields

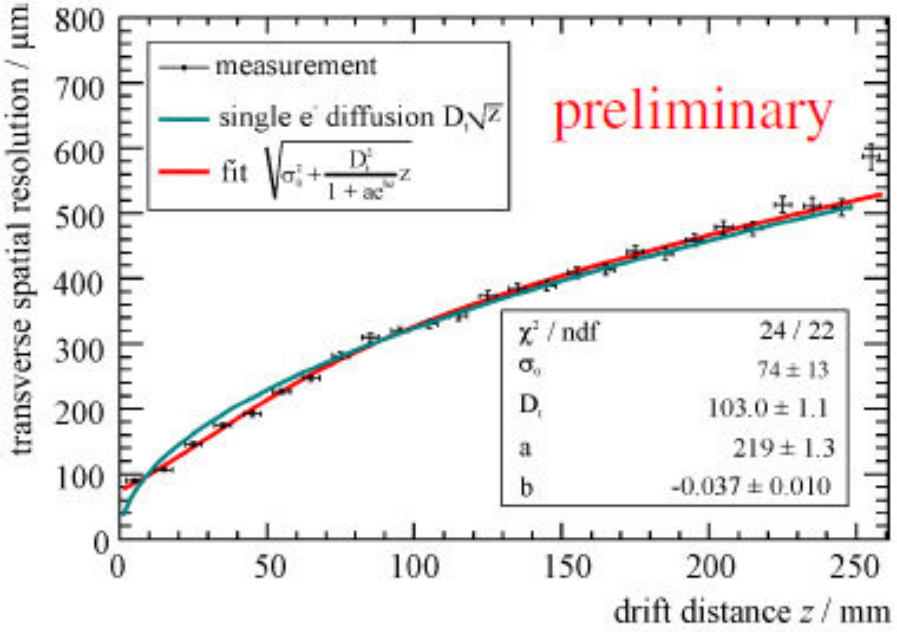
old ZEUS compensation magnet
supraconducting solenoid
reaches up to 5 T

detector is operated in magnet
first results with low statistics



$He:CO_2$ 70:30
at 4T





Full post-processing of a TimePix

· Timepix chip + SiProt + Ingrid:

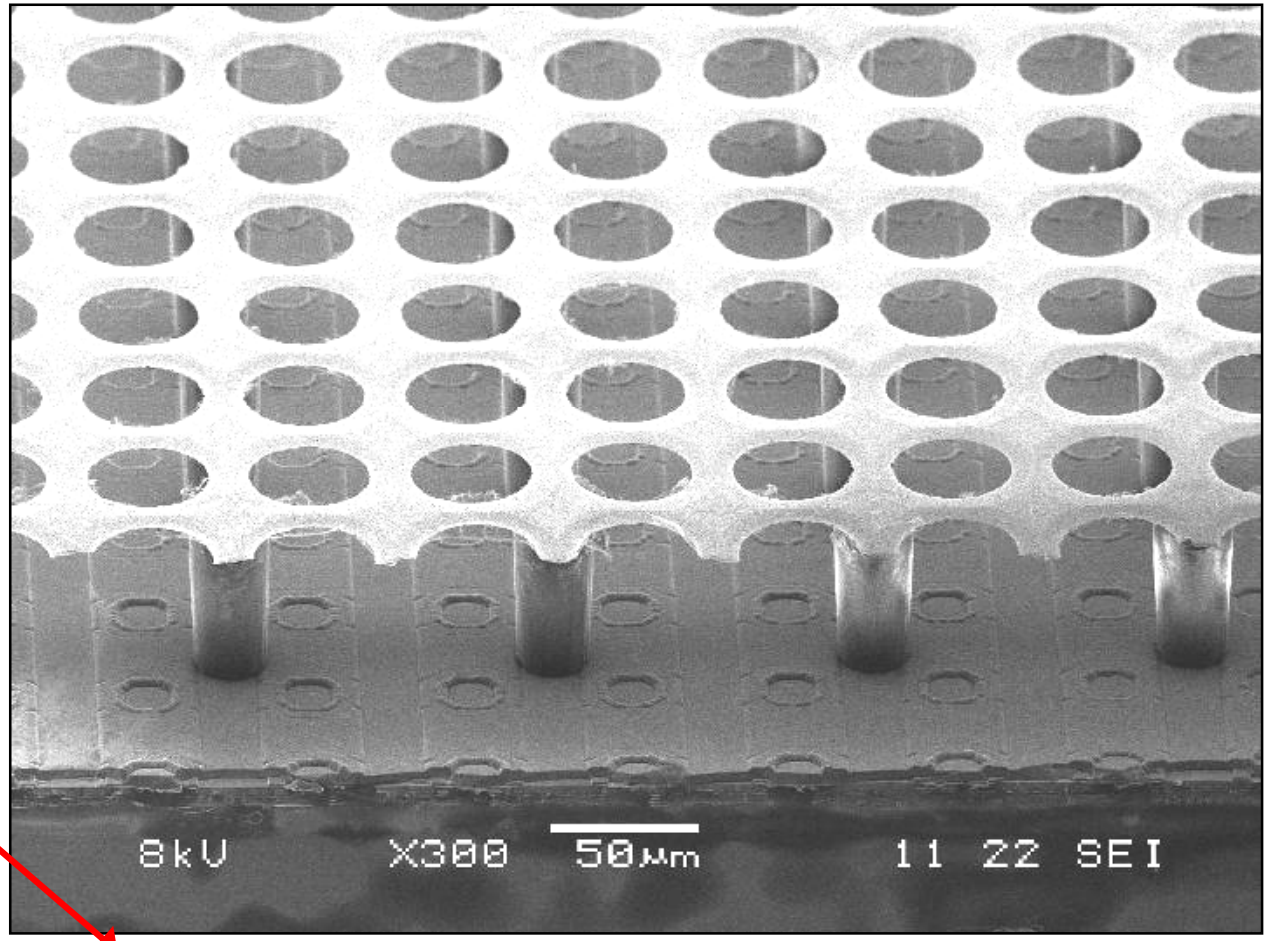
Timepix chip:

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

MESA+: Ingrid

IMT Neuchatel:

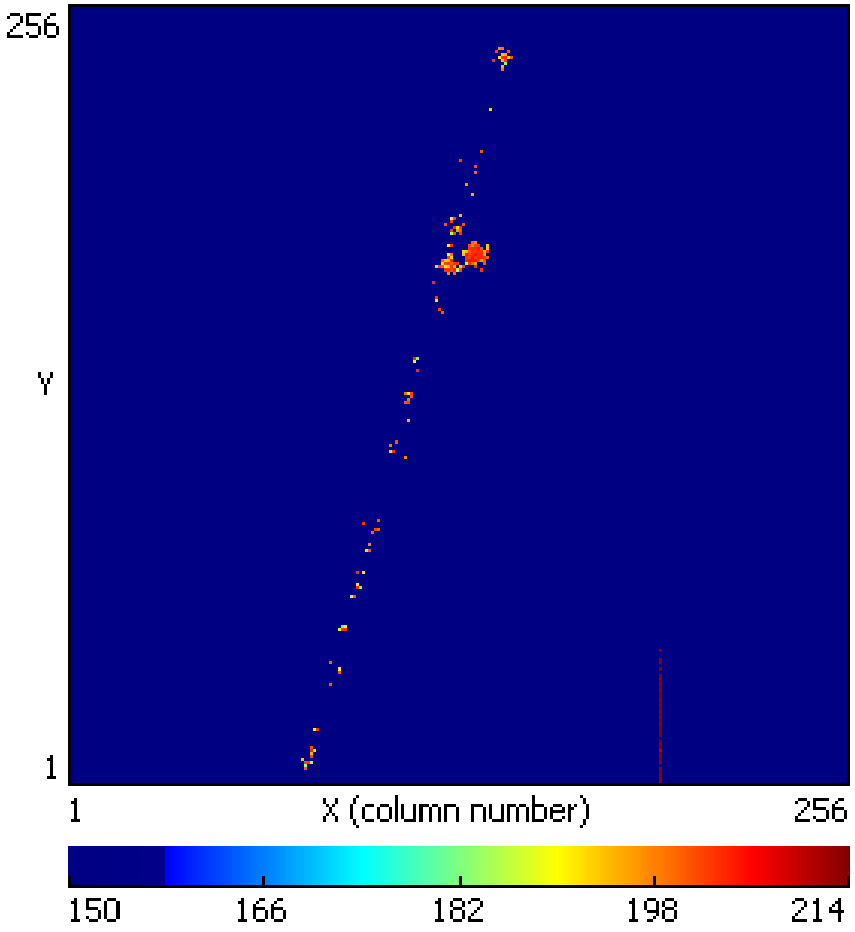
15 or 20 µm highly resistive aSi:H protection layer

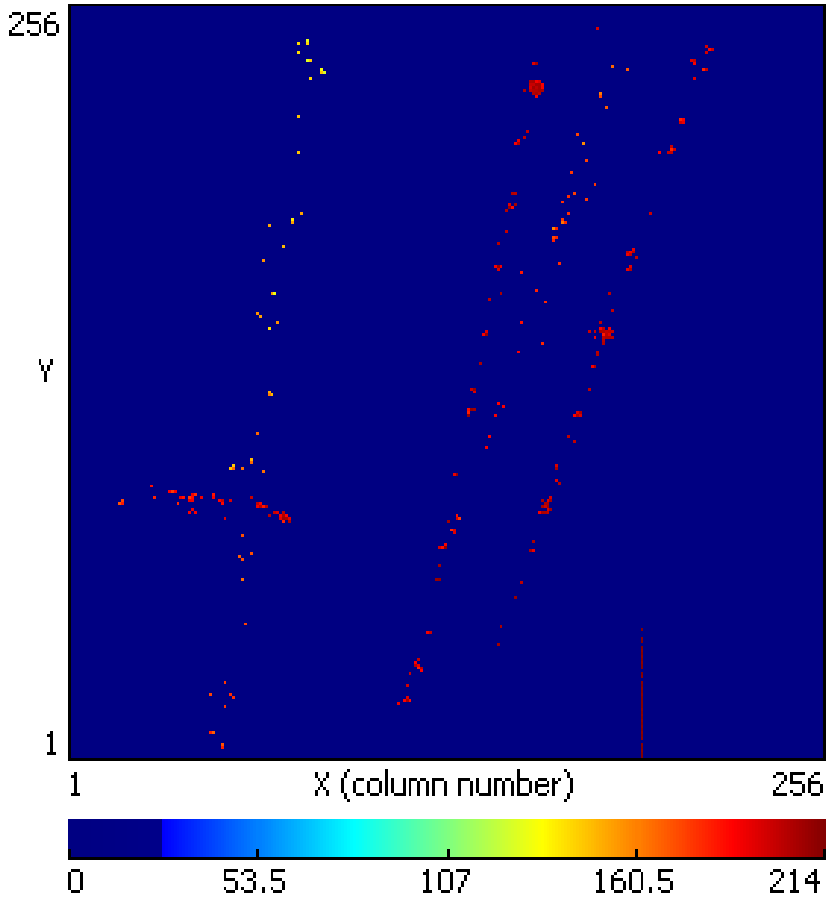


Now also Si_3N_4 protection layers (7 µm)

Some tracks

(with Ingrid in 5 GeV CERN T9 testbeam)



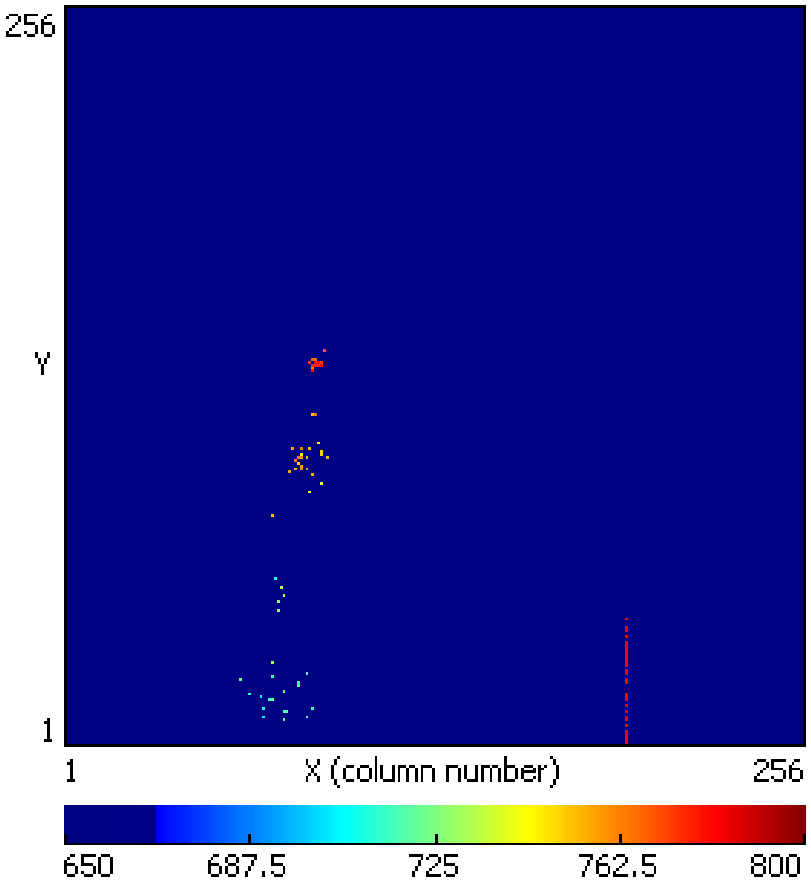


Colour code is drifttime

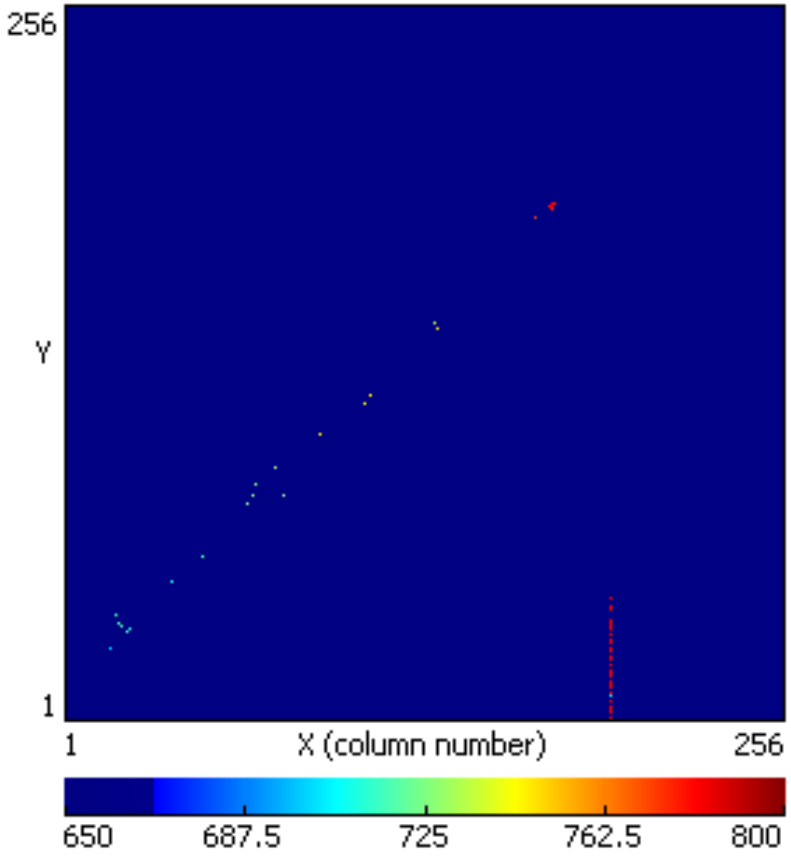
Cosmic tracks traversing ~ 30 mm drift space

Ingrid and Ar-CF4-iC4H10 (95/3/2%)

0 T

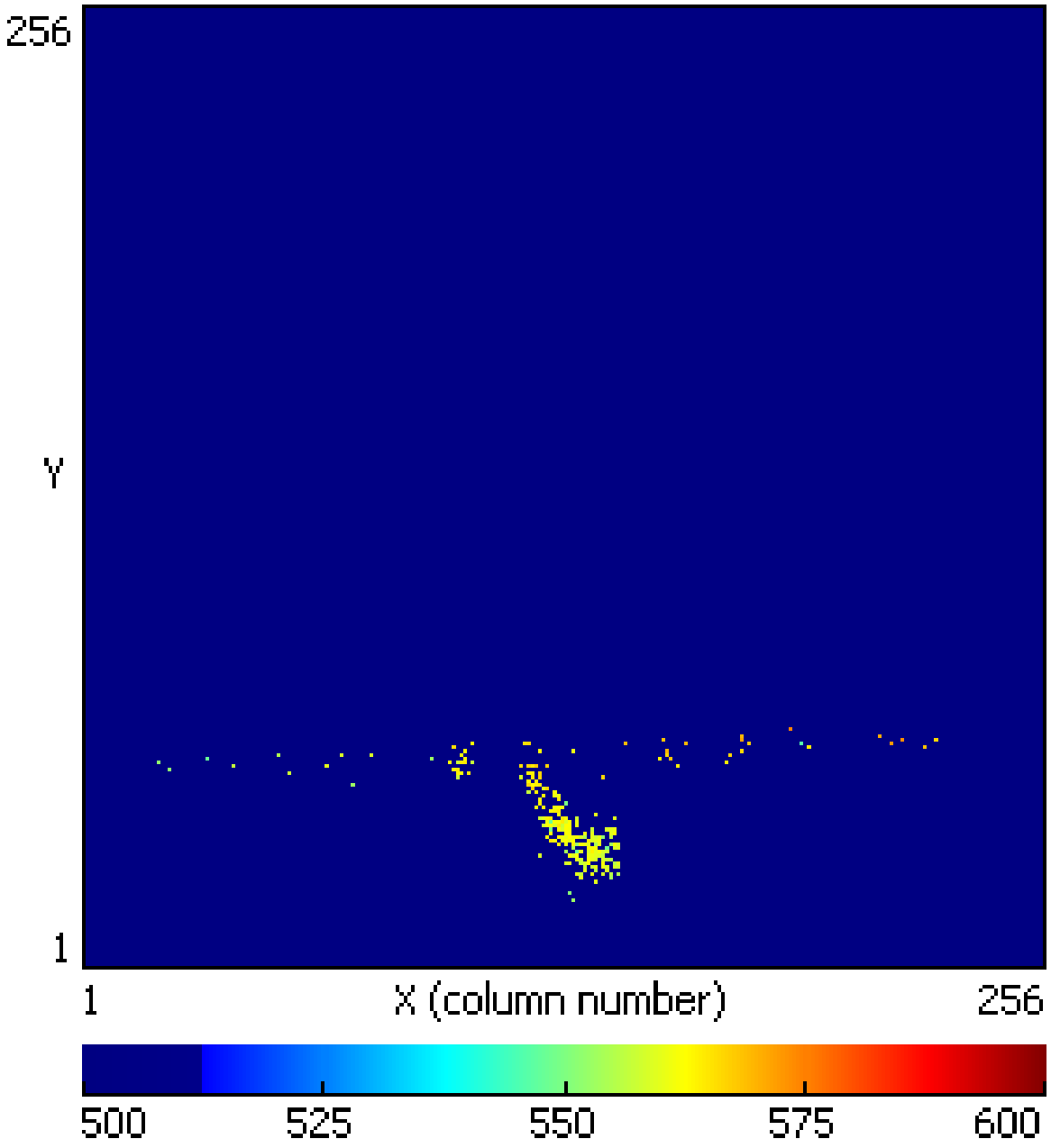


1 T

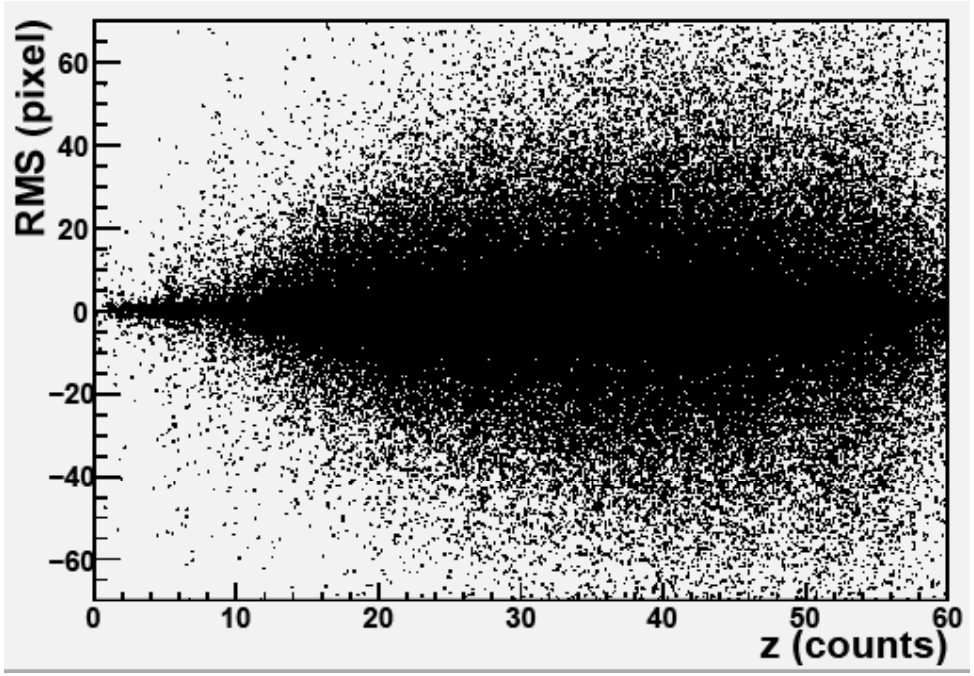


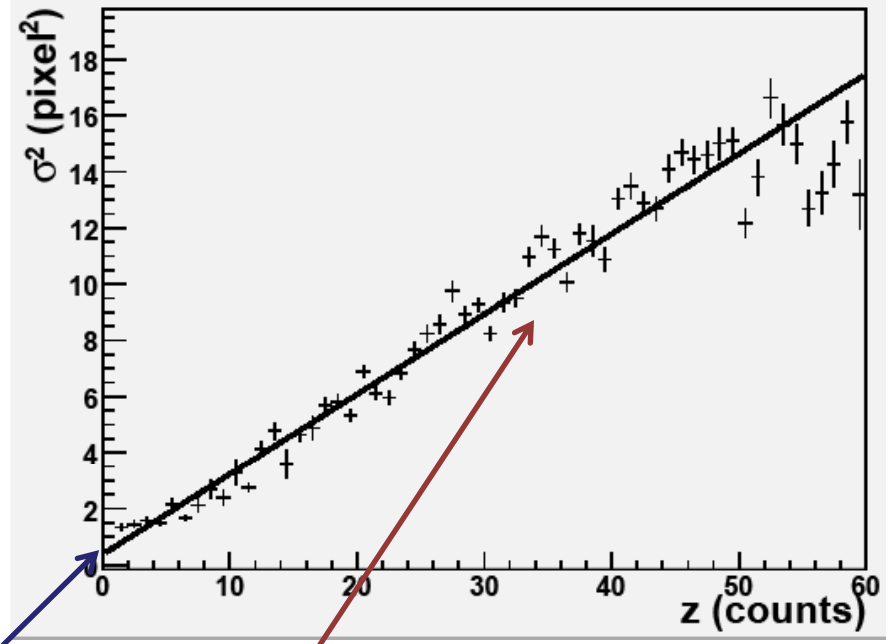
"large" diffusion

"little" diffusion


256
Y
1
1
X (column number)
256
500
525
550
575
600

Fit Slices





intersection

slope

$$res^2 = \frac{pixel^2}{12} + D_t^2 z$$

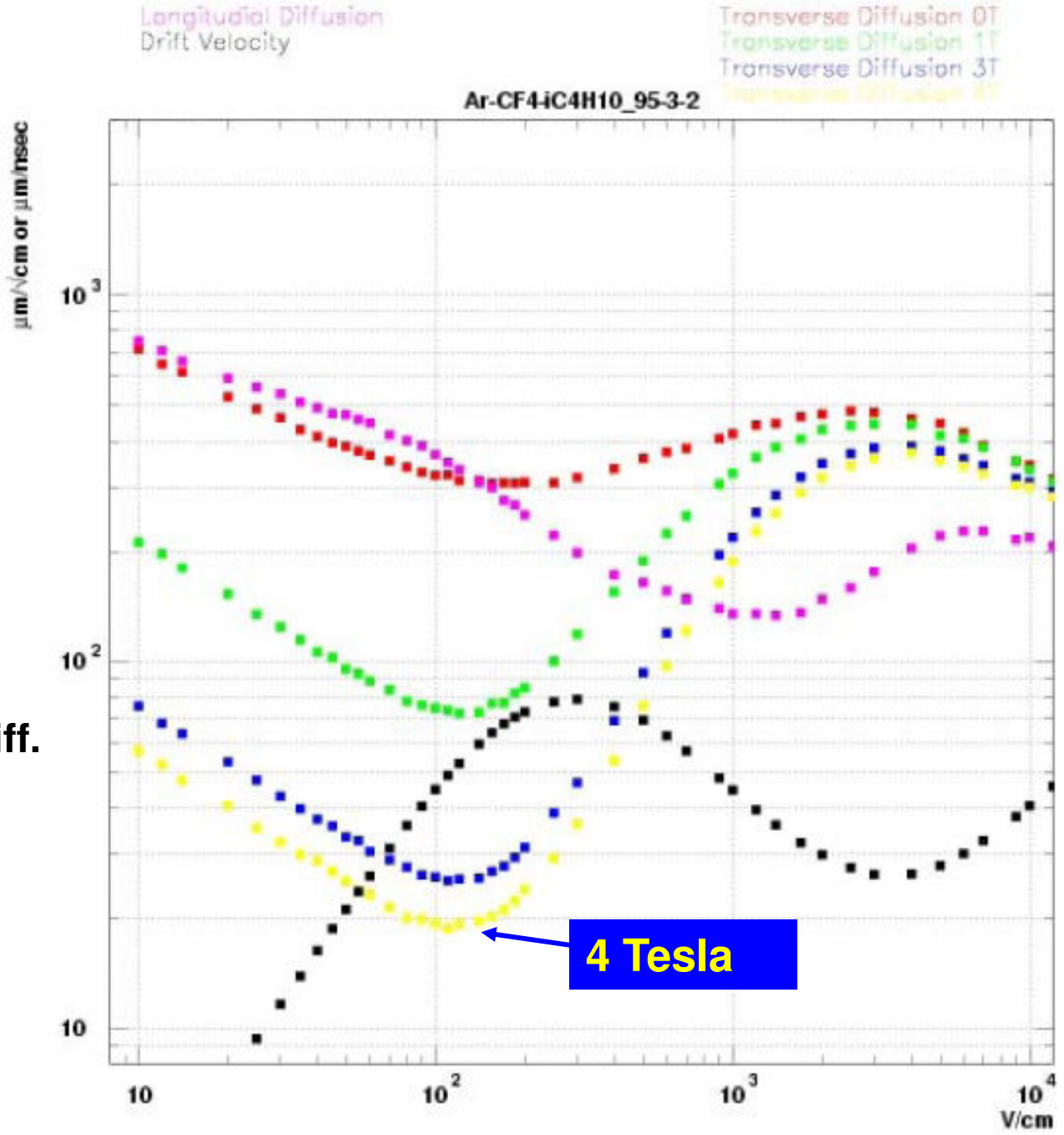
- $N_{eff} = 1$,
- but many separate points
- Single e- efficiency ~90%

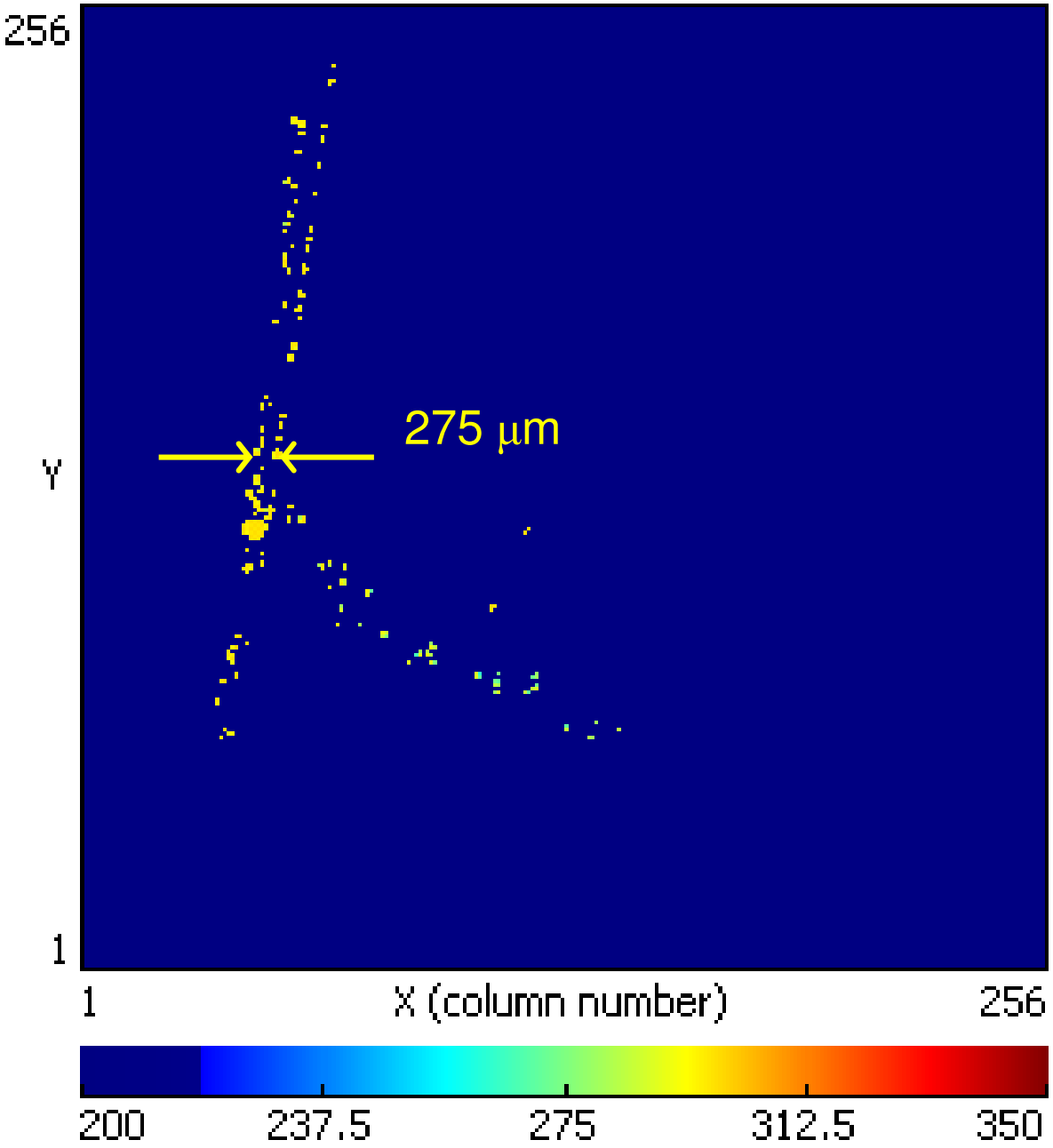
Results single point resolution

gas	E_{drift} (V/cm)	D_t exp ($\mu m/\sqrt{cm}$)	$\sigma_{xy,0}$ (μm)
Ar 3% CF_4 2% IsoBut	200	290	35±11
Ar 30% CO_2	470	148	24±7
Xe 30% CO_2	1000	185	30±15
Xe 30% CO_2	1400	103	23±11
Xe 30% CO_2	1900	110	17±14
He 20% IsoBut	560	175	27±14

Master thesis Lucie de Nooij (NIKHEF)

Error includes (syst.) error due to T-zero (extrapolation to z=0)


Longitudial Diffusion
Drift Velocity
Transverse Diffusion 0T
Transverse Diffusion 1T
Transverse Diffusion 3T
Ar-CF4-iC4H10_95-3-2
µm/√cm or µm/√nsec
10 3
10 2
10
10
10 2
10 3
10 4
V/cm
Long. Diff.
Transv. Diff.
Drift vel.
4 Tesla



Two-track separation:

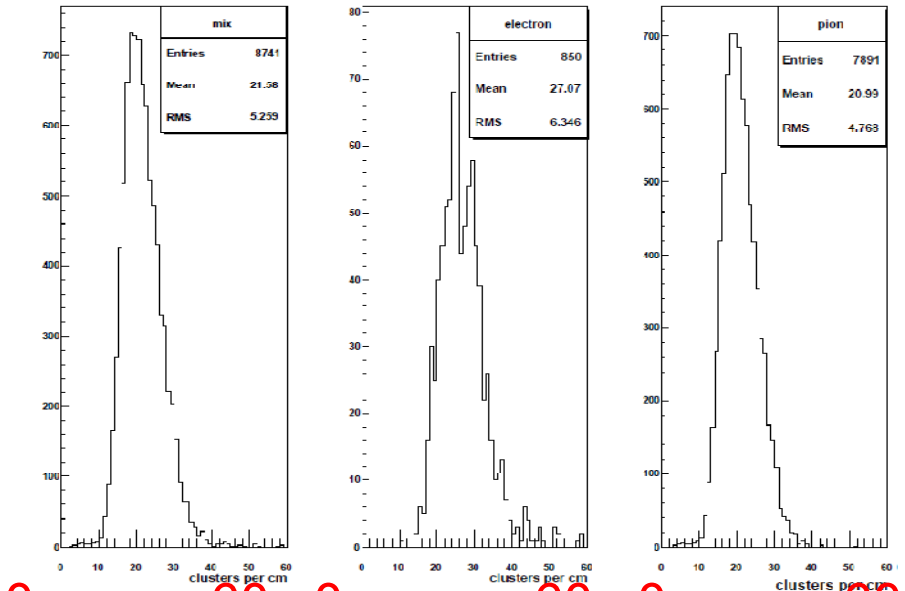
- Will be diffusion limited
- In this example:

5 pixels = 275 μm

Diffusion at 4T in Ar/CF4/iC_4H_{10} is

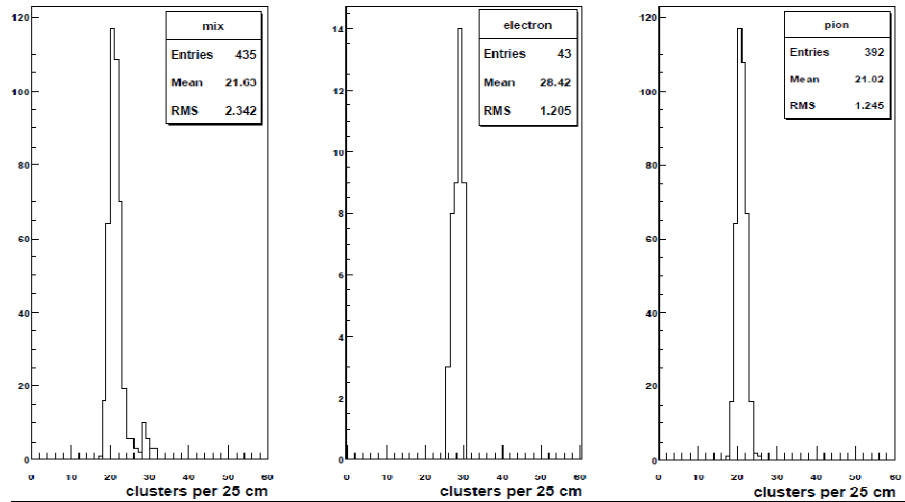
~ $20\sqrt{200}$ = 300 μm

Cluster counting distribution in He/iC4H10



0 60 0 60 0 60

all electrons pions



0 60 0 60 0 60

- Using 1 cm tracklength

Electrons:

Avg=27.1/cm rms=6.3

Pions: 21.0/cm 4.8

- Using 25 cm tracklength

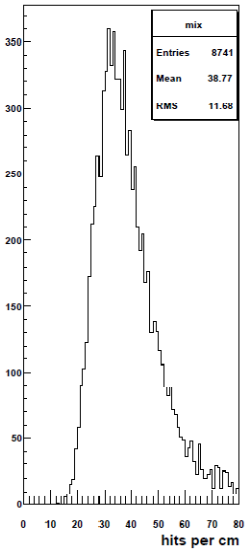
Electrons:

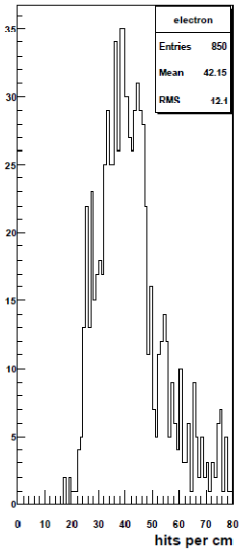
Avg=28.4/cm rms=1.2

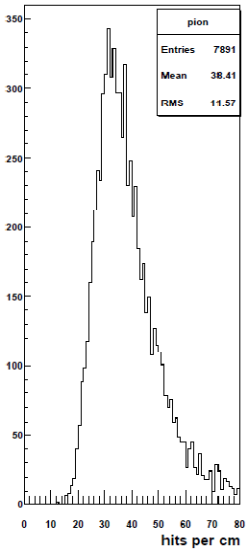
Pions: 21.0/cm 1.2

4.4 σ difference

Single hits counting distribution in He/iC4H10

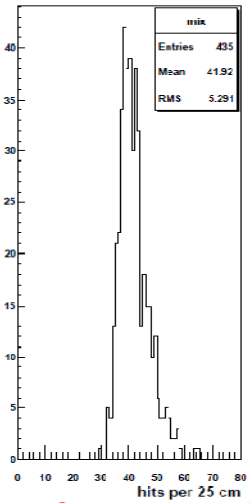


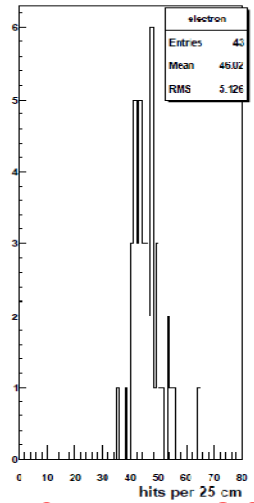


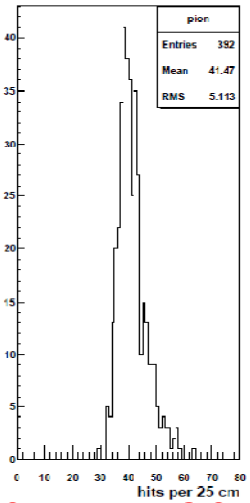


0 80 0 80 0 80

all electrons pions







0 80 0 80 0 80

- Using 1 cm tracklength

Electrons:

Avg=42.2/cm rms=12.1

Pions: 38.4/cm 11.6

- Using 25 cm tracklength

Electrons:

Avg=46.0/cm rms=5.1

Pions: 41.5/cm 5.1

0.6 σ difference

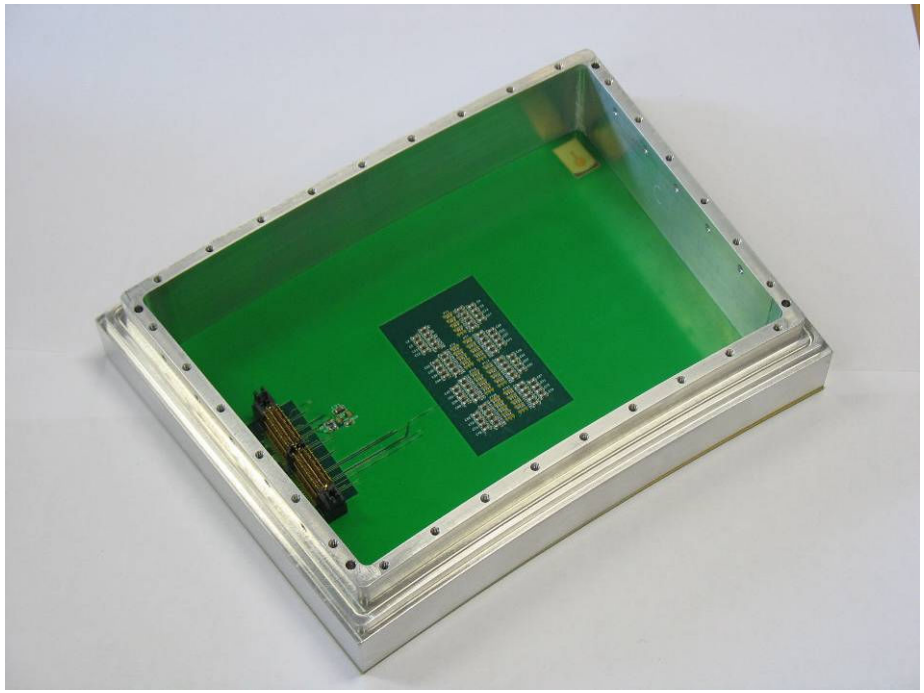
Summary

- Pixel readout very promising technique
- Issues are (still) robustness, large(r) detectors

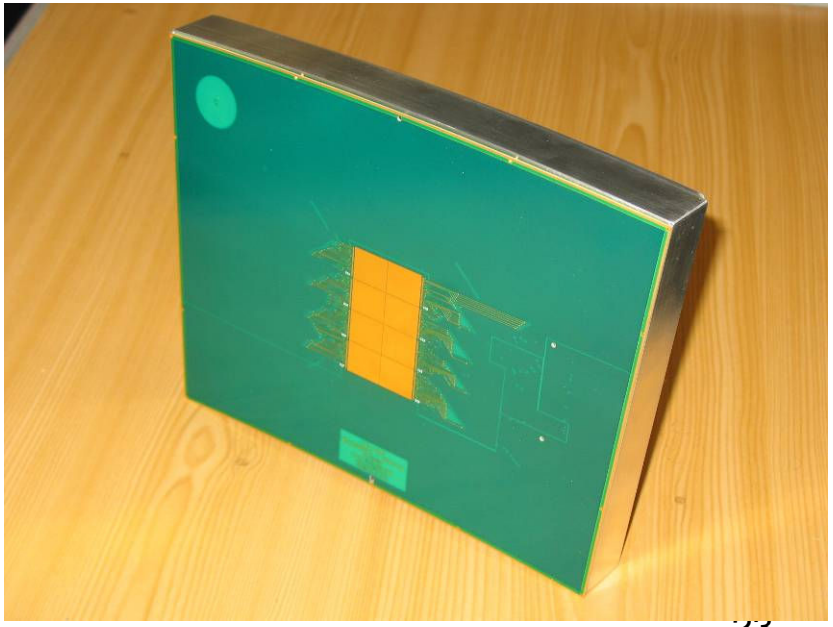
- Should lead to improved RΦ resolution
- Better two-track separation (< 1 mm possible)
- Possibility of cluster counting (dE/dx)

Backup

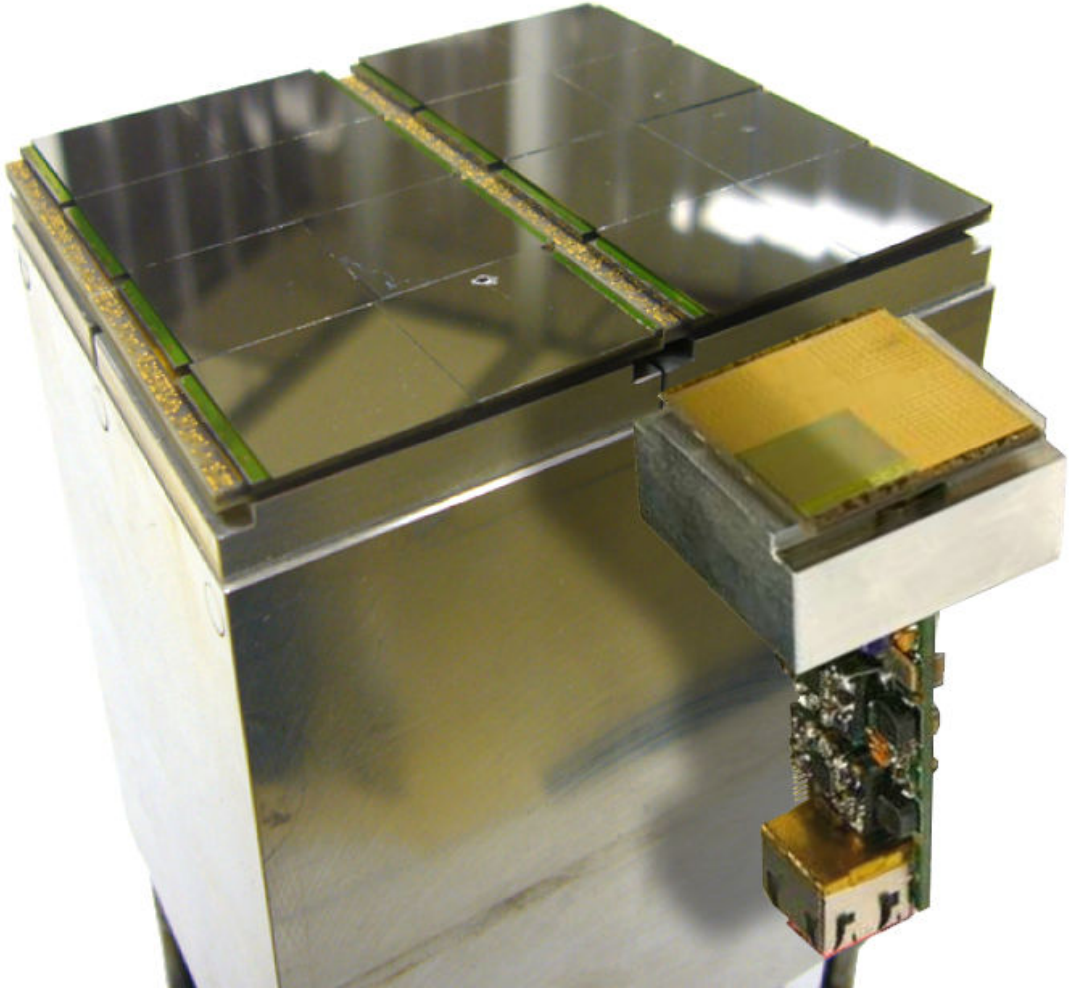
Saclay



- 8 Timepix chips
- bug in Pixelman software fixed
- Now waiting for Ingrids from Nikhef/Twente
- Expect module for test in fall 2009



NIKHEF

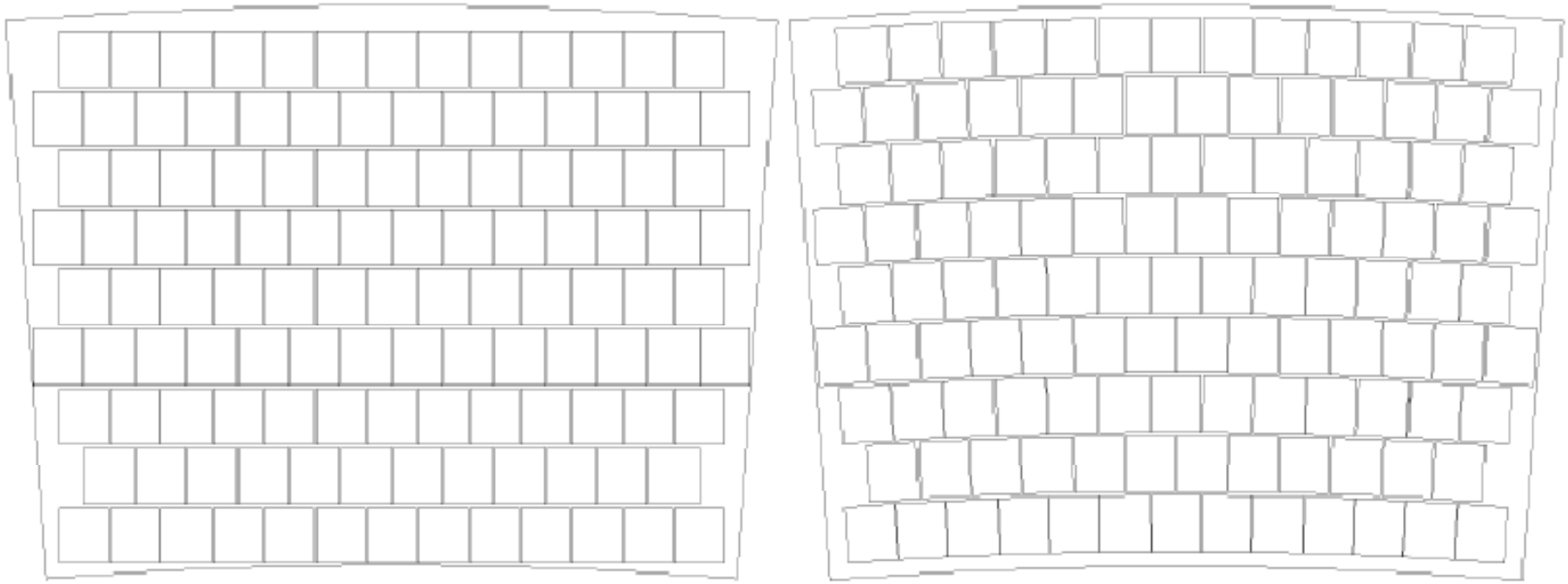


- within Relaxd project: 4x4 Medipix chips in compact mounting
- Will evolve in 8x8 Timepix chips for EUDET/LCTPC

'Long-term' plans (end 2010)

LP1 module covered completely with Timepix modules

First ideas: 119 Timepix chips (more than 1 wafer, $\approx 7.8 \cdot 10^6$ channels)



Gas amplification: triple GEM, possibly also InGrids

Readout electronics: 'Scalable Readout System' developed at CERN in the framework of RD-51

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