Controlled Si-Drift Detectors

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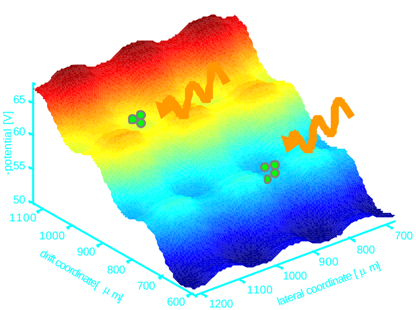
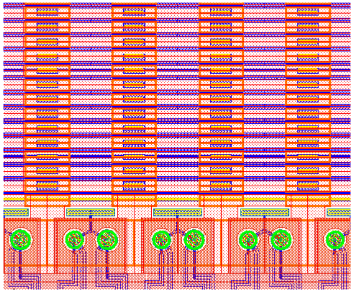


Collaborations:

Sincrotrone Trieste ELETTRA

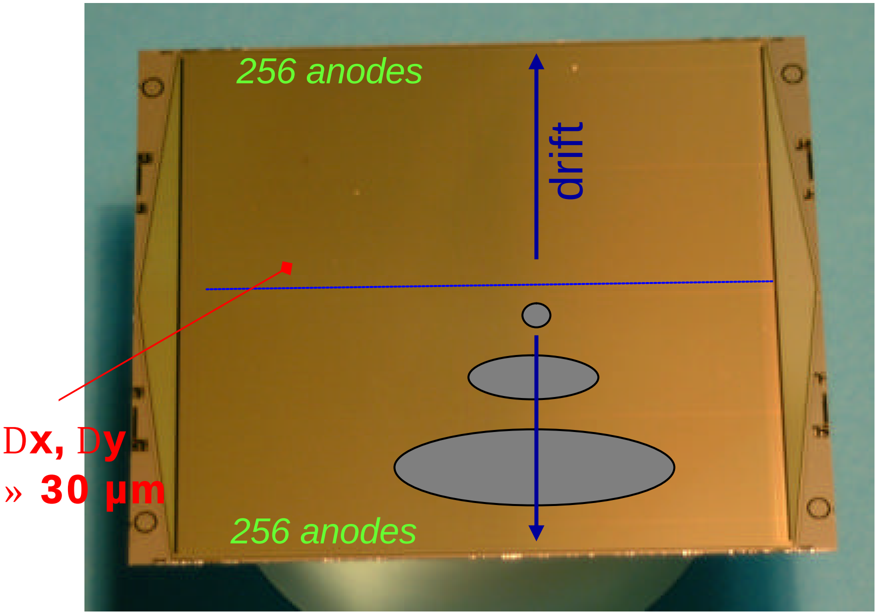
University College London



Int'l Symposium on Detector Development, April 3-6, 2006, Stanford Linear Accelerator Center, USA

Position-sensing with classical *Silicon Drift Detectors*

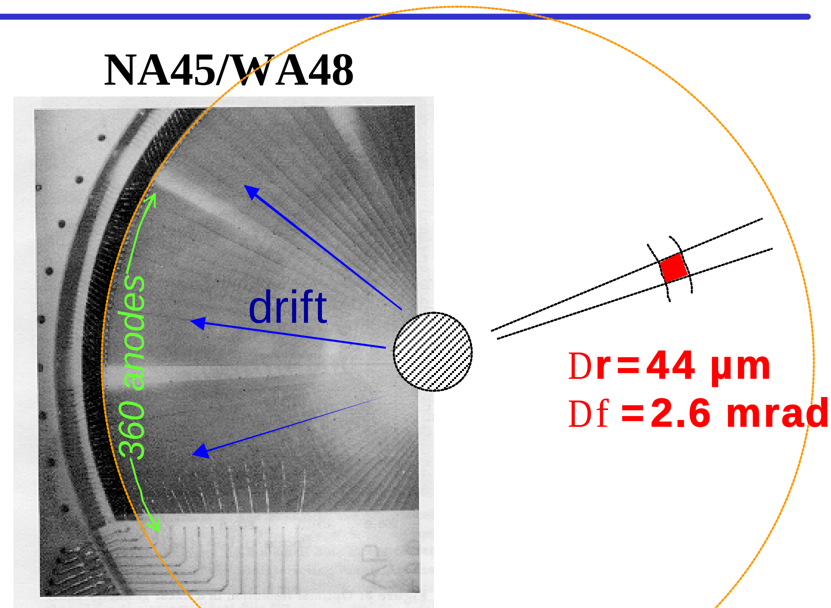
ALICE



Wafer: 5", (NTD) silicon, 3 kΩ·cm resistivity, 300 µm thickness
Active area: 7.02 × 7.53 cm²

~5 Mpixel with
~500 output channels !

NA45/WA48



Wafer: 4" silicon, 300 µm thickness
Active area: 55 cm² (4.2cm radius)

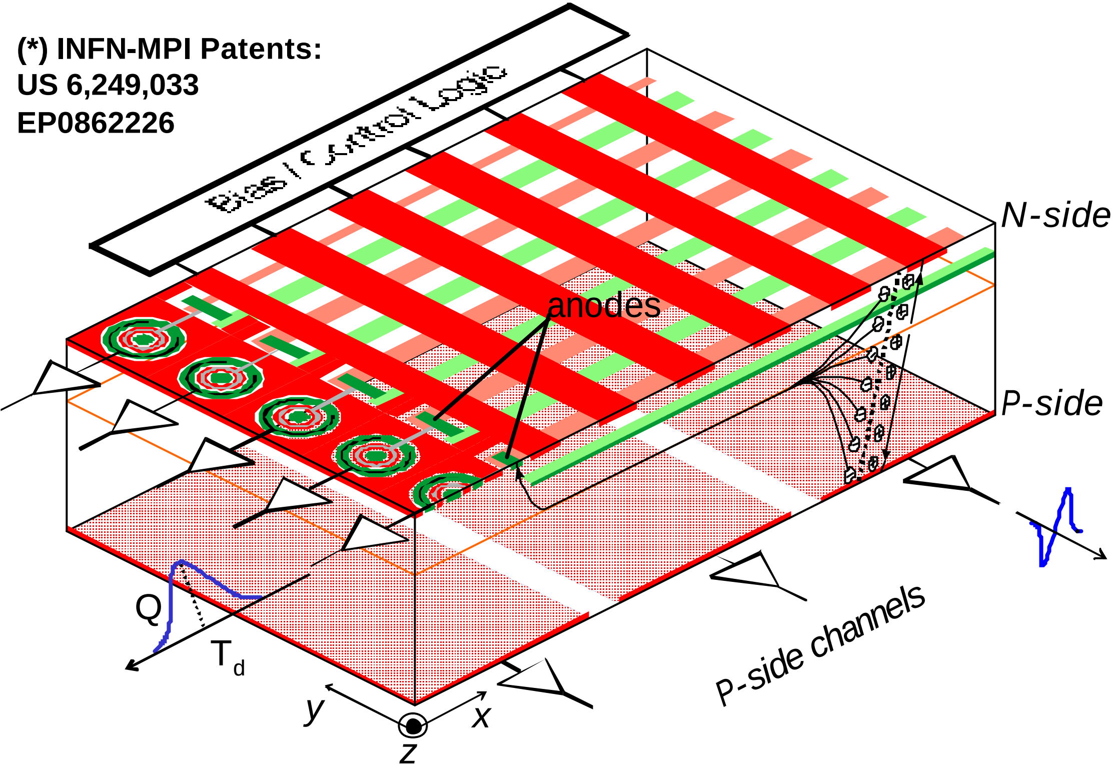
…but…

- **START TRIGGER NEEDED !**
  no imaging of random sources (x/γ/…) !
- **FREE LATERAL BROADENING !**
  → **doping inhomogeneities**
  → **limited spectroscopic performance**
  → **reduction of the event rate**

The *Controlled Drift Detector** (CDD)

A.Castoldi, C.Guazzoni, IEEE TED, 46, 2 (1999)
A.Castoldi, E.Gatti, C.Guazzoni, A.Longoni, P.Rehak, L.Strüder, NIM A439 (2000)

(*) INFN-MPI Patents:
US 6,249,033
EP0862226



Novel features

- potential minimum near top surface

- suppressed lateral broadening

- control of drift field: "integrate-readout" mode

- integrated front-end JFET: high energy/position resol.

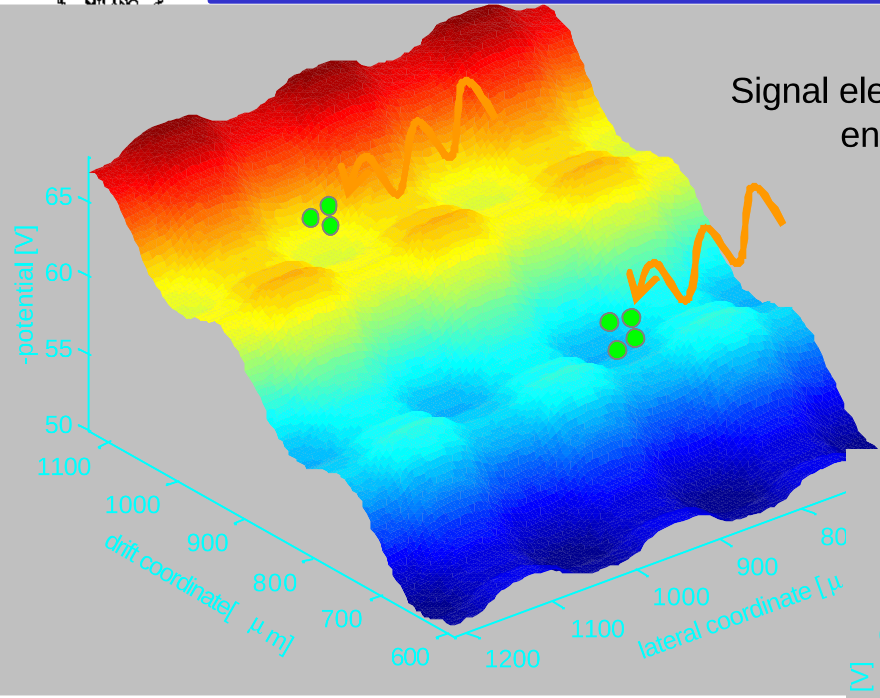
- fast timing signal from back electrodes

• electron packets are drifted at high speed (0.5-1.5 cm/µs) towards point-like anodes (<100 fF)

- deposited energy is obtained from the electron charge (Q)
- interaction position along the drift is obtained from the drift time (T_d)
- interaction position along 2nd coordinate is obtained by anode segmentation

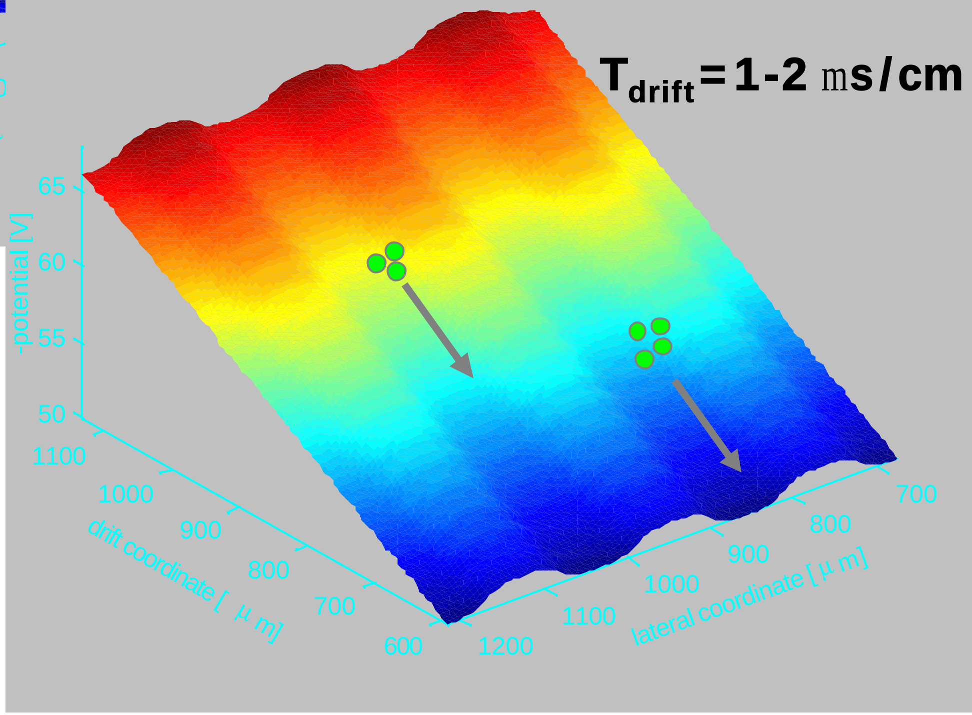
Þ **fast readout, position sensing/reduced no. of channels and spectroscopy of radiation**

CDD working principle: simulation @ z=12 µm



Integration phase:
Signal electrons are collected in suitably engineered potential wells

Readout phase:
A uniform drift field transports the electrons to the readout anodes in <u>few µs</u>.



T_{drift}=1-2 ms/cm

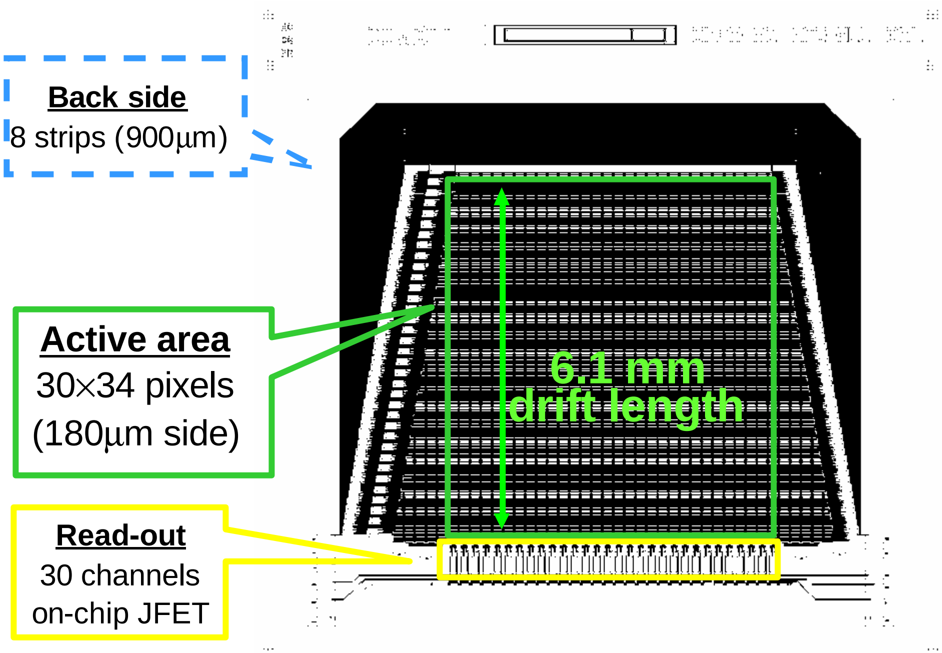
Operating modes:

- <u>**integrate-readout mode**</u>
- <u>**free-running mode**</u> **(self-trig, XFEL)**

Controlled-Drift Detector - Layout and photo

A.Castoldi, A.Galimberti, C.Guazzoni, P.Rehak, L.Strüder, NIM A512, October 2003

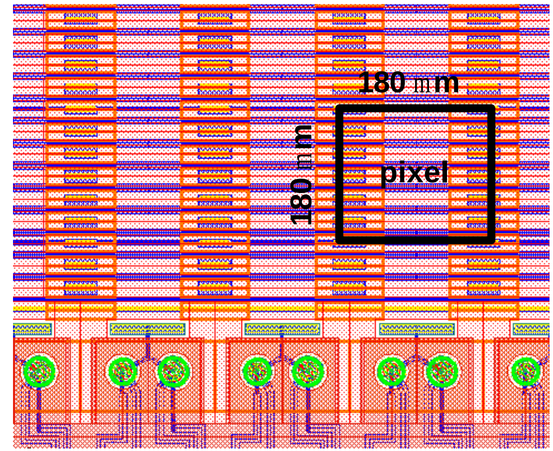
0.3 cm² active area - pixel 120μm/180μm



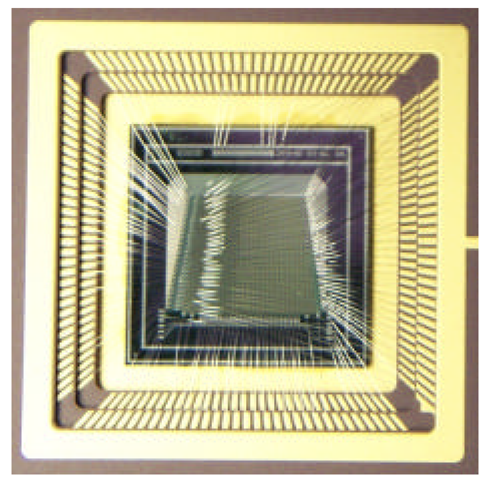
High energy implantation (20 MeV) instead of grown epitaxy ⇒ drift channel is located at about 7 μm from the implanted surface

Designed, layouted and tested at Politecnico di Milano-INFN, Italy
Produced at the Halbleiterlabor of the Max Planck Institut, Munich (D)

Detail of anode region with integrated front-end JFETs

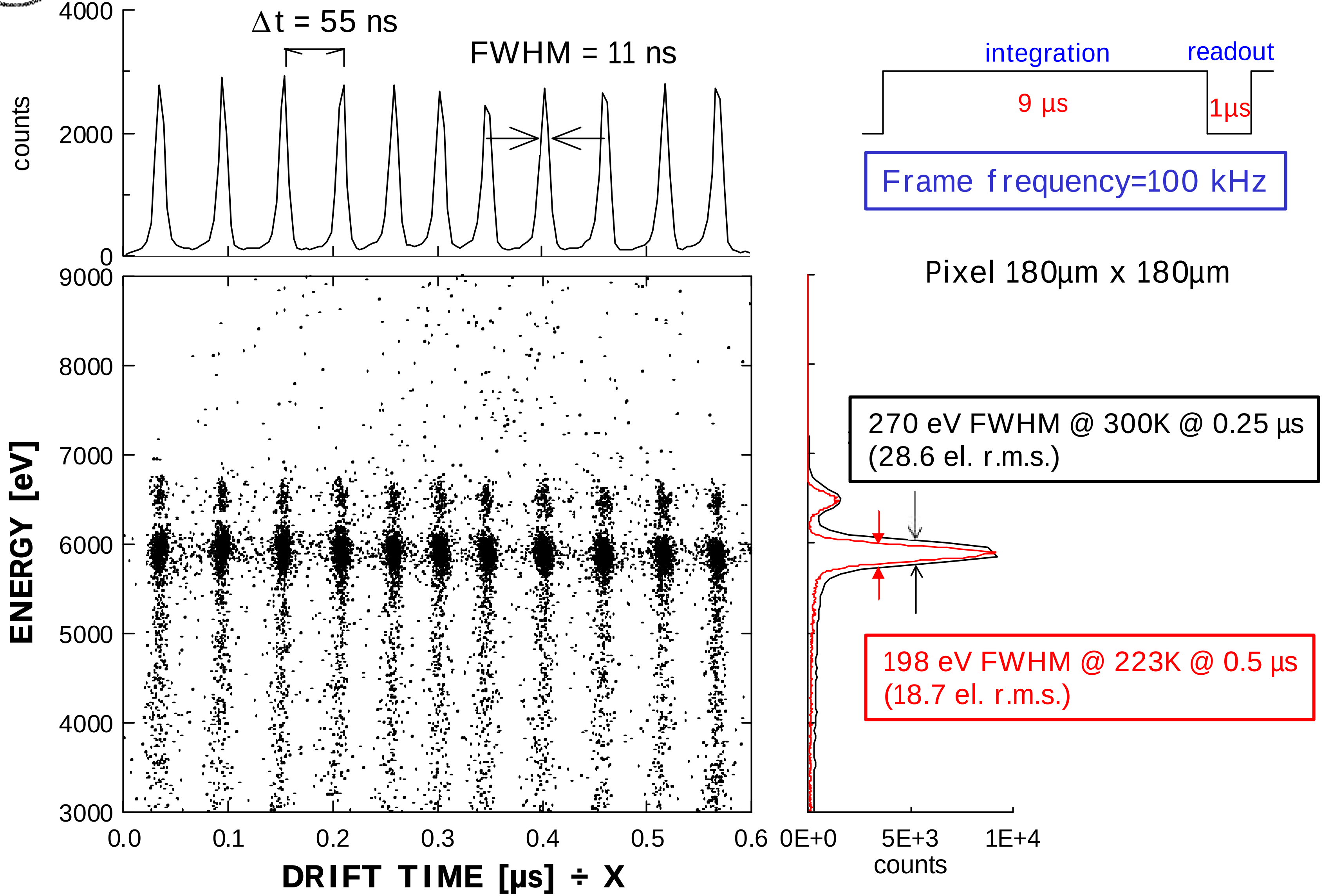


Mounted 6x6 mm² prototype



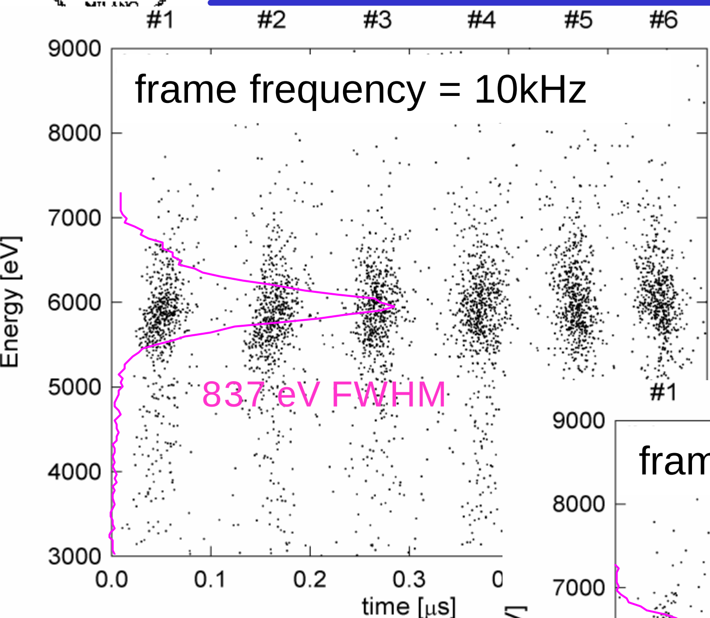
1-D imaging and spectroscopy of a Fe-55 source @ 100 kHz

A.Castoldi, C.Guazzoni, P.Rehak, L.Strüder, et al, Trans. Nucl. Sci. 49 (3) June 2002



Energy resolution vs. frame frequency

A.Castoldi, C.Guazzoni, P.Rehak, L.Strüder, IEEE TNS **48** (4), August 2001

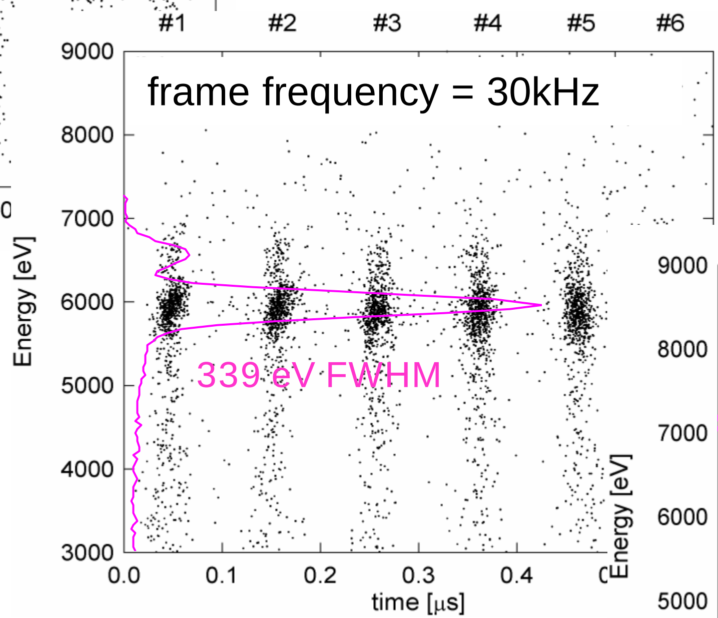


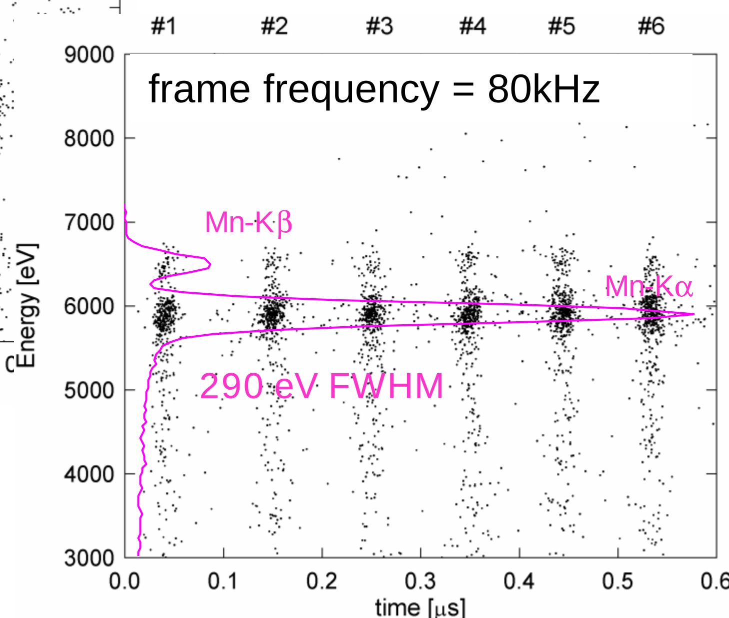
^{55}Fe radioactive source

E_{drift} = 300V/cm

ΔV = 2V

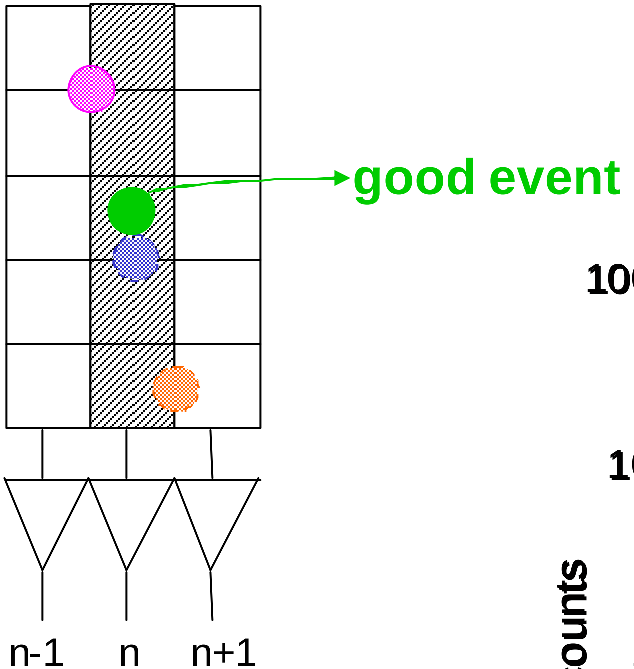
T = 300K





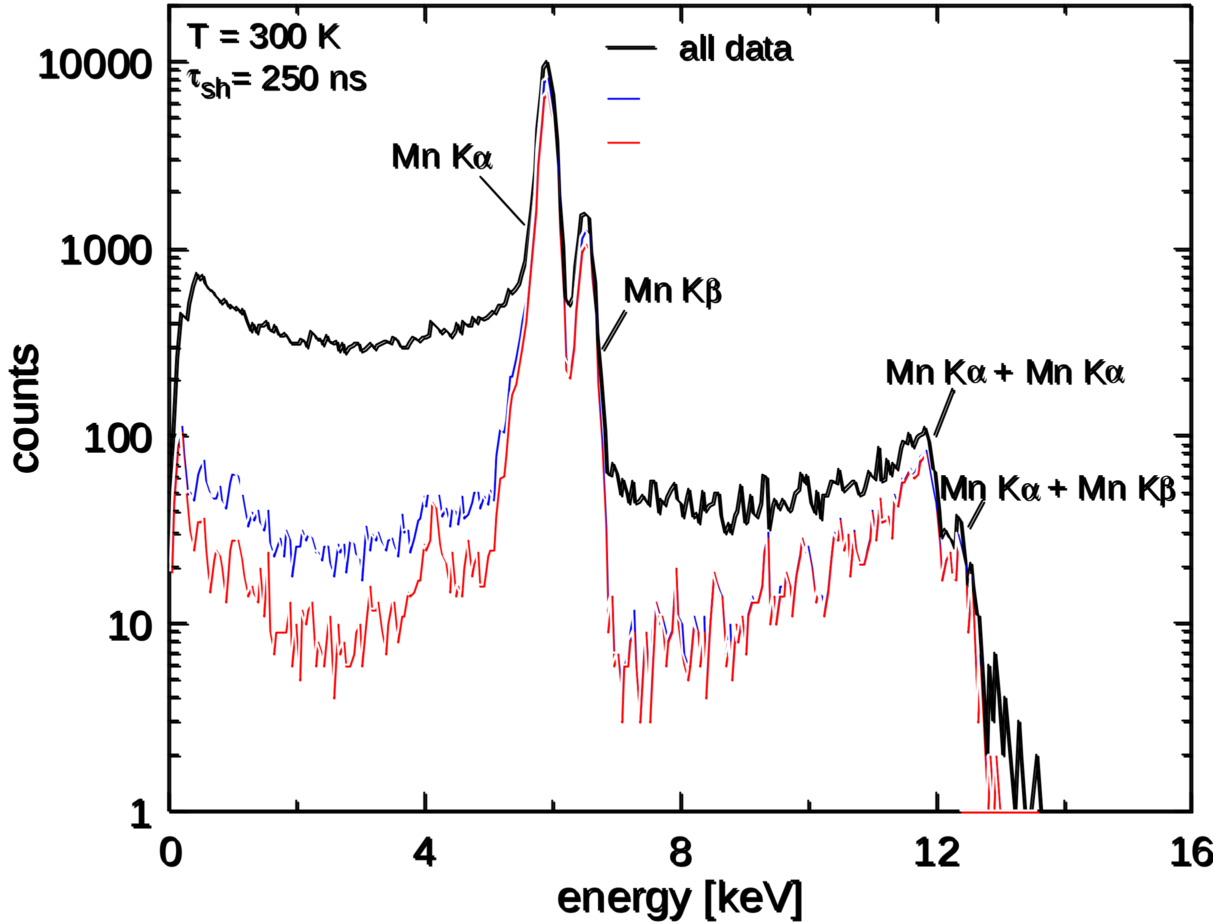
"Electronic" collimation

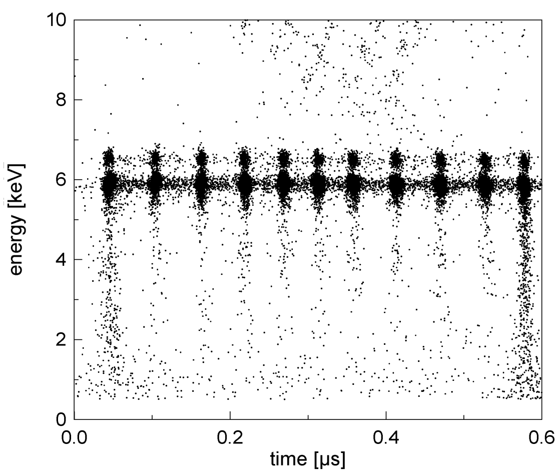
A.Castoldi, G.Cattaneo, A.Galimberti, C.Guazzoni, P.Rehak, L.Strüder, IEEE TNS **49** (3), June 2002



^{55}Fe radioactive source

f_{frame} = 100kHz
E_{drift} = 300V/cm
ΔV = 2V
T = 300K





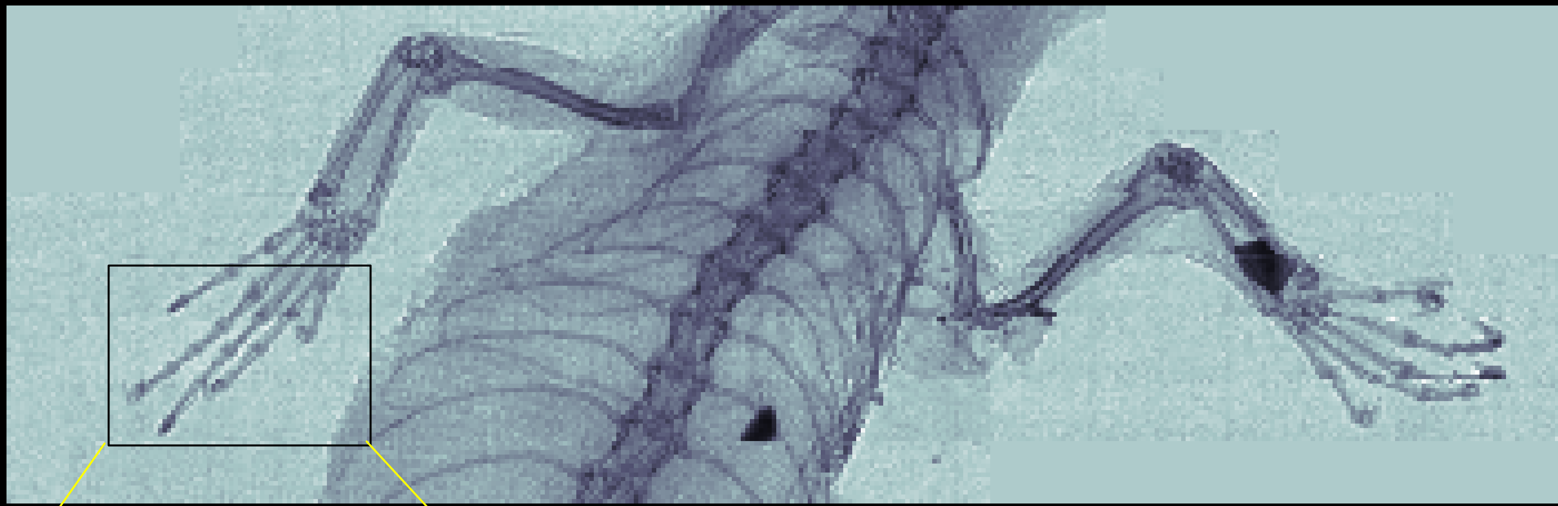
2-D *spectroscopic* imaging of X-rays with CDDs

Exp. CODERA (2003) - INFN - Sezione di Milano - Gruppo V

A.Castoldi, G. Cattaneo, A.Galimberti, C.Guazzoni, P.Rehak, L.Strüder, IEEE TNS 49, 3 (2002)
A.Castoldi, A.Galimberti, C.Guazzoni, P.Rehak, L.Strüder, NIM A512 (2003)

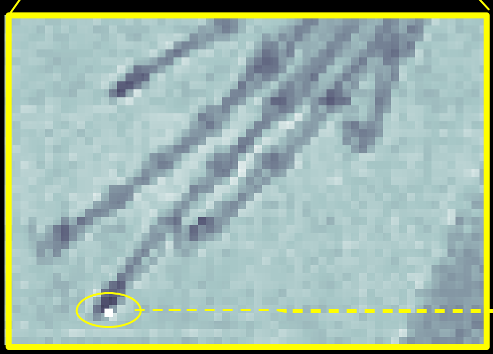
Radiographic image of a lizard*...

pixel 120μm, 10^5 frame/s, 15 keV x-rays, T=300K

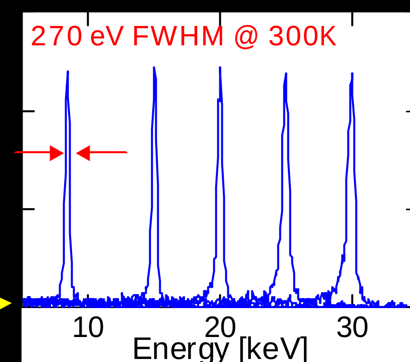


* no animal was killed or suffered for this measurement

Sincrotrone Trieste – SYRMEP beam line



... and spectroscopic analysis of each pixel

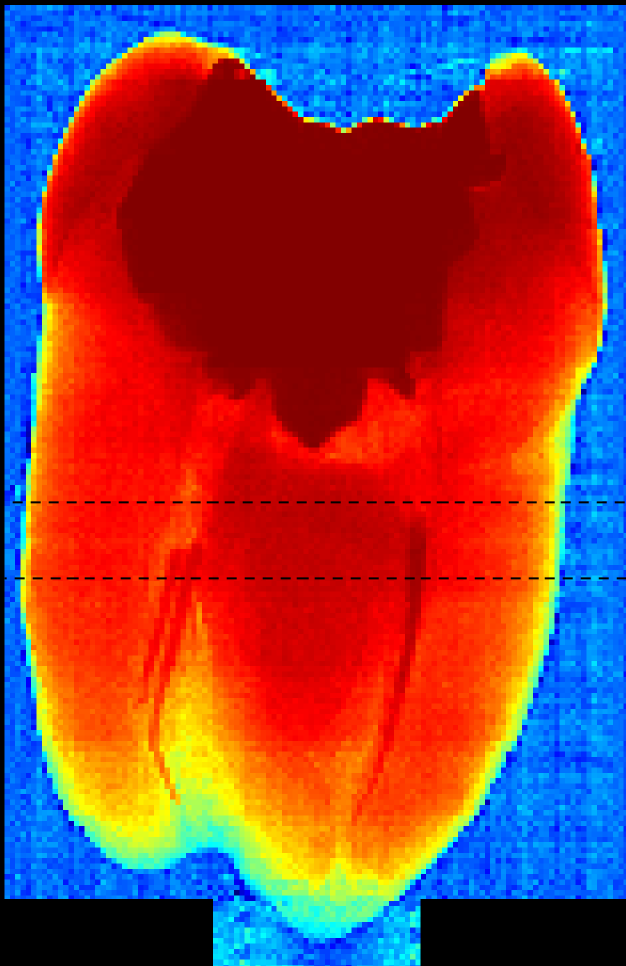


2D/3D tomographic imaging at 100 kHz frame rate

A. Castoldi, A. Galimberti, C. Guazzoni, L.Strüder, *"New Silicon Drift Detectors for Synchrotron Radiation Applications"*, Nuclear Science Symposium Conference Record, 2004 IEEE, 16-22 Ottobre 2004, Roma, Italia.

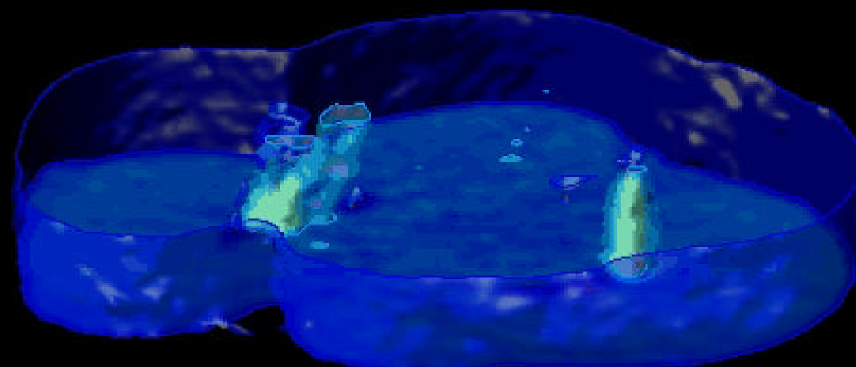
pixel 120mm, 28 keV x-rays (0.44 Å), 10^5 frame/s, T=300K

Sincrotrone Trieste – SYRMEP beam line



Digital radiography of a wisdom tooth

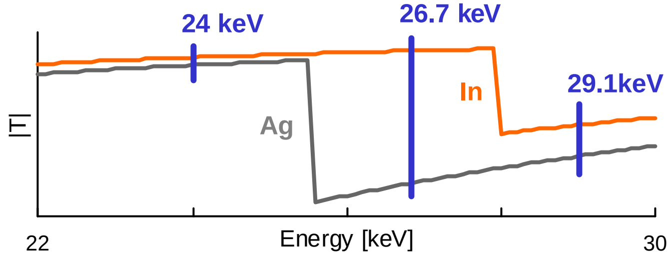
2D projections of a tooth section of 1.7 mm



3D reconstruction

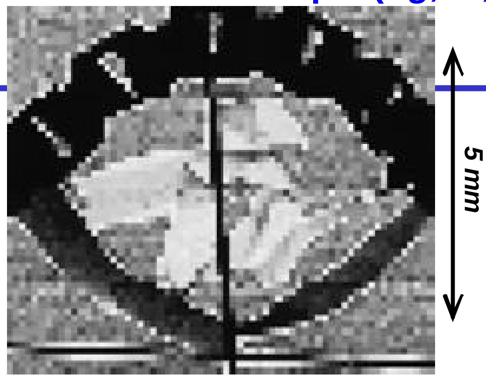
2D Elemental mapping by K-edge subtraction imaging

K-edge subtraction imaging (dual energy technique)

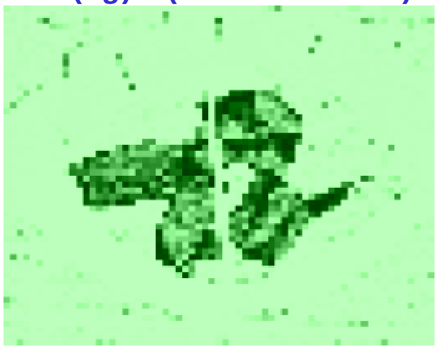


The distribution of a known element (i.e. silver) in the sample is obtained by imaging the sample in two X-ray windows, one below and the other above the K-edge of silver, and looking at the image difference.

Multi-element sample (*Ag*, *In*, etc.)

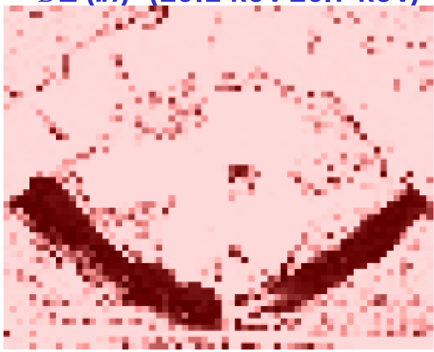


ΔE (*Ag*) = (26.7 keV-24 keV)



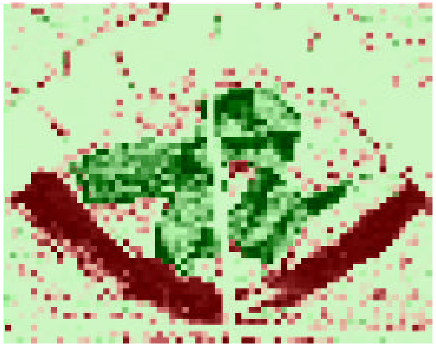
***Ag* distribution**

ΔE (*In*)=(29.1 keV-26.7 keV)



***In* distribution**

2D elemental mapping (*Ag, In*)



pixel 120x120µm

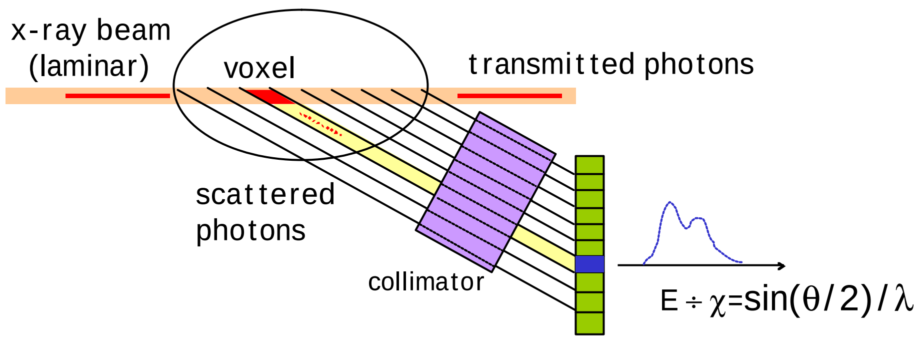
The spectroscopic capability of the CDD allows mapping of principal elements in the sample with ~100µm position resolution from a <u>single image acquisition</u> (i.e. multiple-energy technique)

Exp. CODERA - Gr. V - INFN Sez. Milano

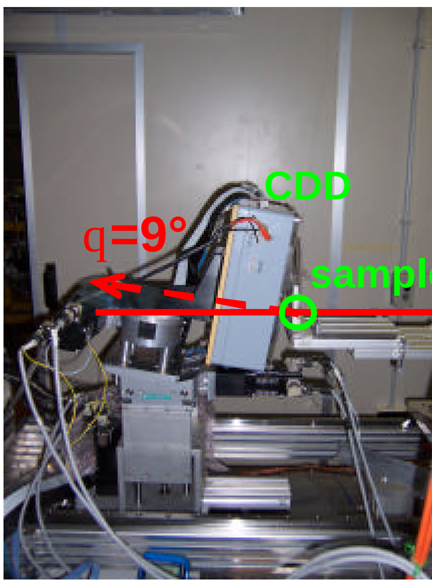
A.Castoldi, A.Galimberti, C.Guazzoni, P.Rehak, L.Strüder, R.Menk, NIM. A510 (2003) 57-62.

Diffraction Enhanced Breast Imaging (DEBI)

Scattered intensity vs. momentum transfer
-> LAXS signature for tissue/material analysis

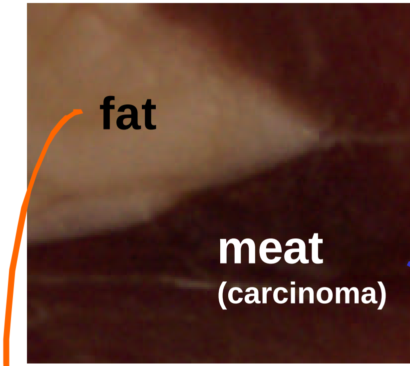


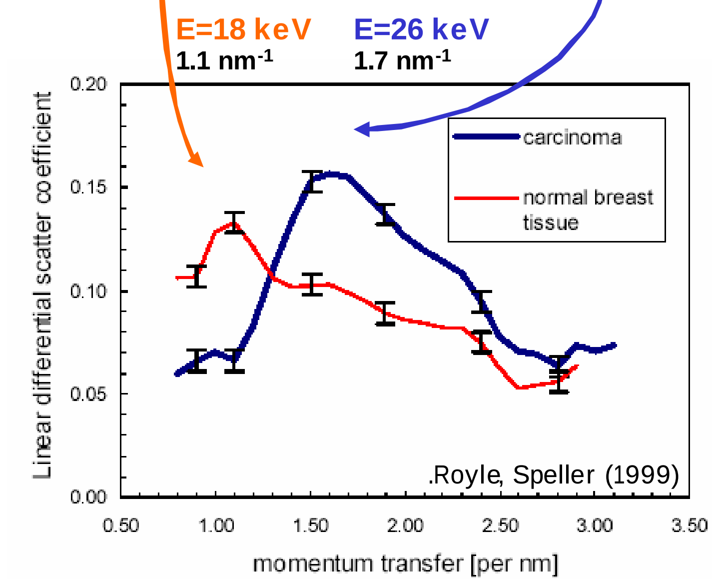
Exp. set-up at fixed angle (9°)
mechanical collimator Ø0.5mm



Sincrotrone Trieste (SYRMEP)

biological tissue (pork)





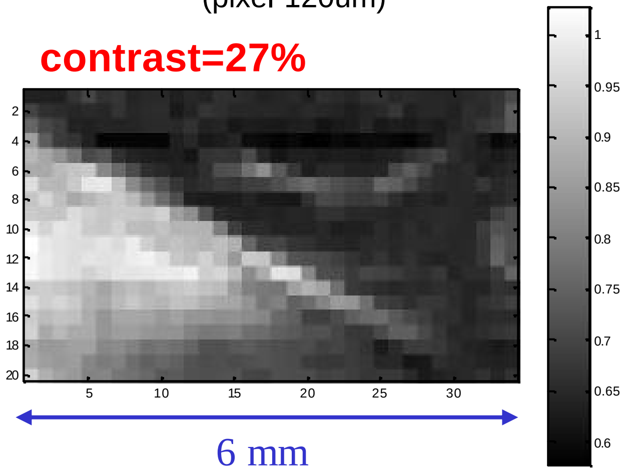
$\chi = \sin(\theta/2)/\lambda$

Experimental results on tissue: contrast and specificity

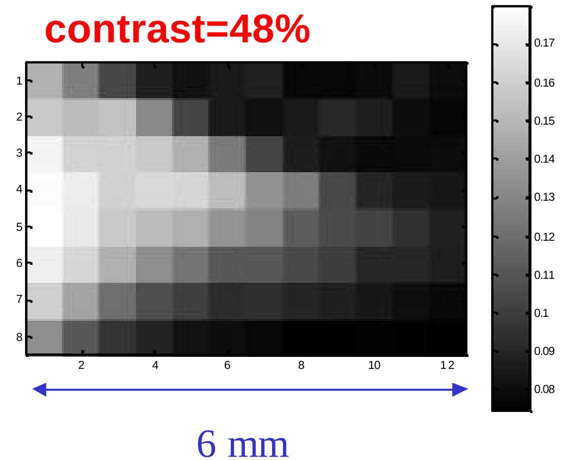
transmission images:
(pixel 120um)

diffraction images:
(pixel 500um)

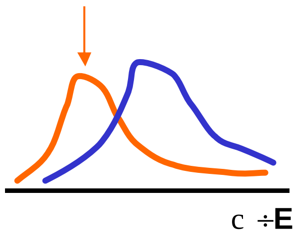
contrast=27%



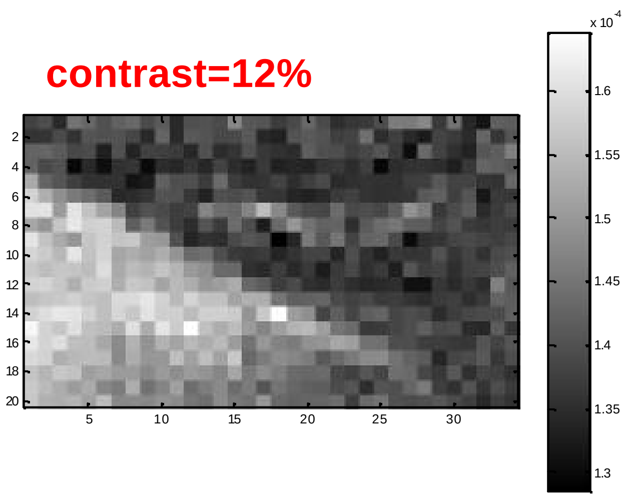
contrast=48%



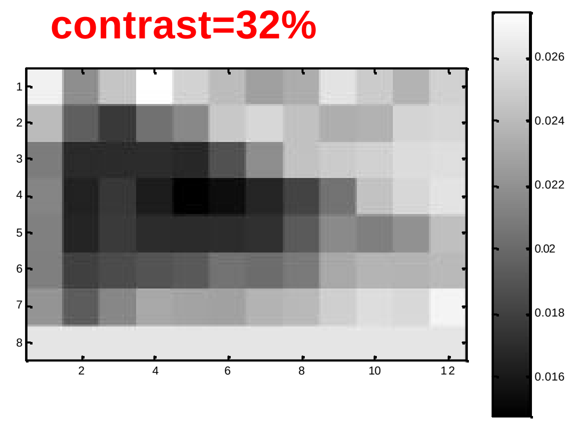
E=18 keV



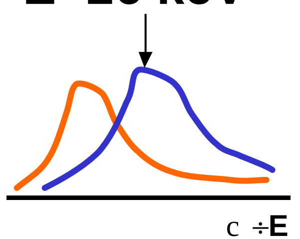
contrast=12%



contrast=32%



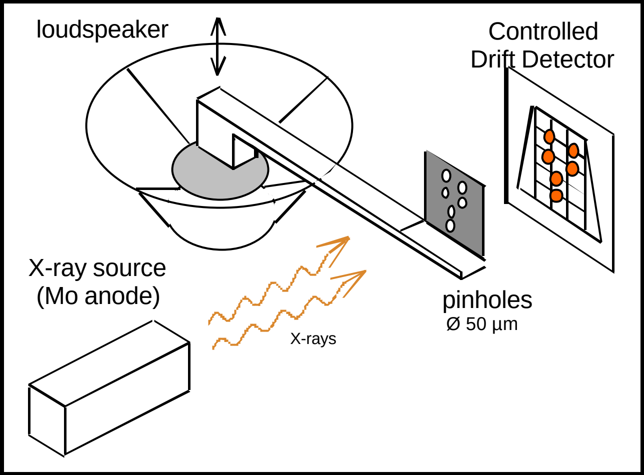
E=26 keV



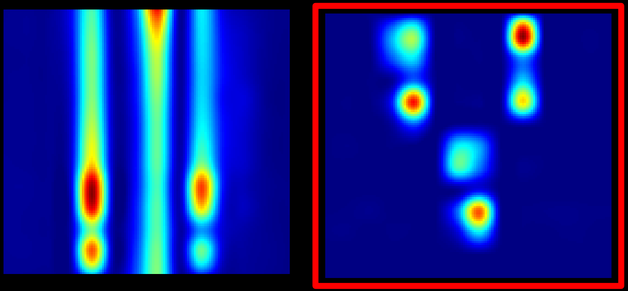
Time-resolved X-ray imaging of repetitive processes

Experimental setup:
CDD operated at 100 kHz
drift field 400 V/cm, T=300 K

Input signal: 219 Hz sine wave
Mask displacement: 2.3 mm p-p



Acquired time-sliced X-ray images (integrate-readout, 100kHz)



¥

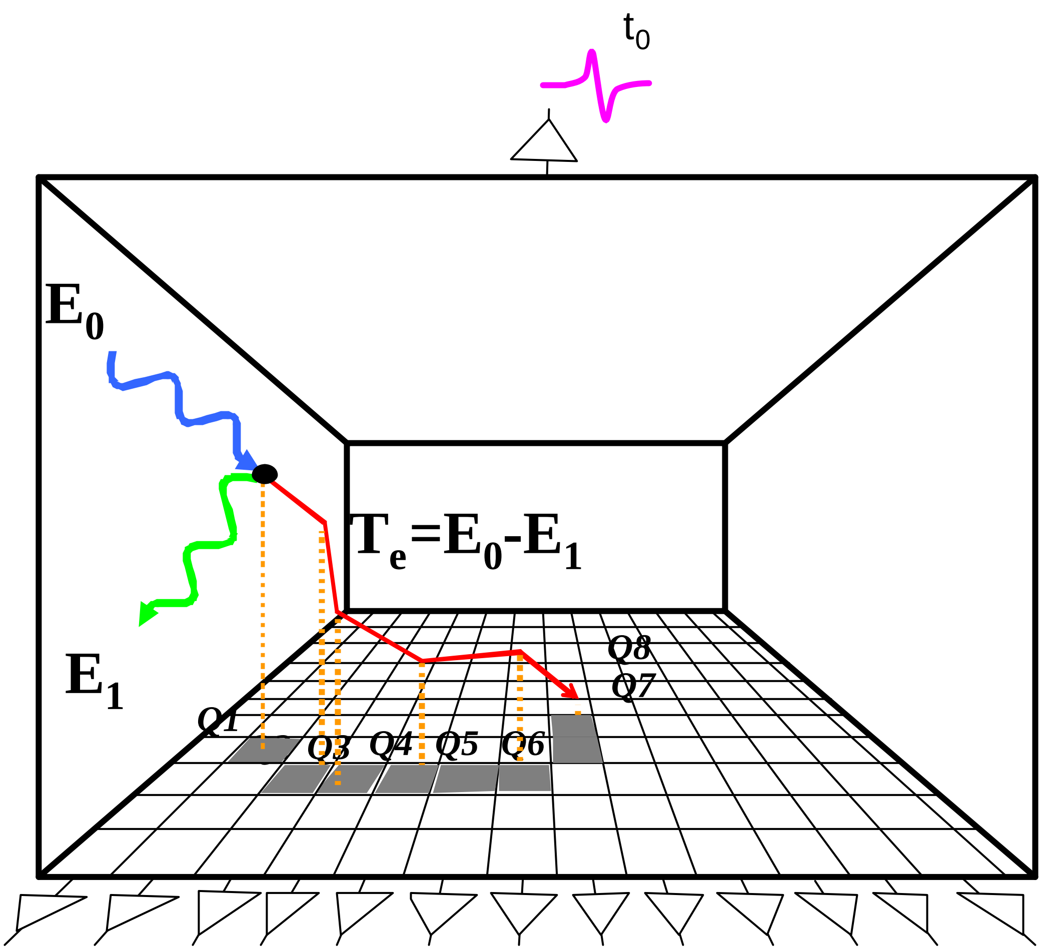
20 µs
time slice

1 µs resolution in free-running mode

Þ *pump-and-probe* techniques

Compton electron tracking

A. Castoldi, A. Galimberti, C. Guazzoni, P.Rehak, R-Hartmann, L Strüder, A. H. Walenta, *"Multi-linear Drift Detectors for X-ray and Comtpon Imaging", 10° European Symposium on Semiconductor Detectors, Wildbad-Kreuth, June 12-16 2005 (NIM)*



Silicon CDD scatter detector

Electron tracking of the *first* Compton scatter can significantly increase sensitivity of Compton telescopes:

Approximate determination of dE/dx from experimental data:

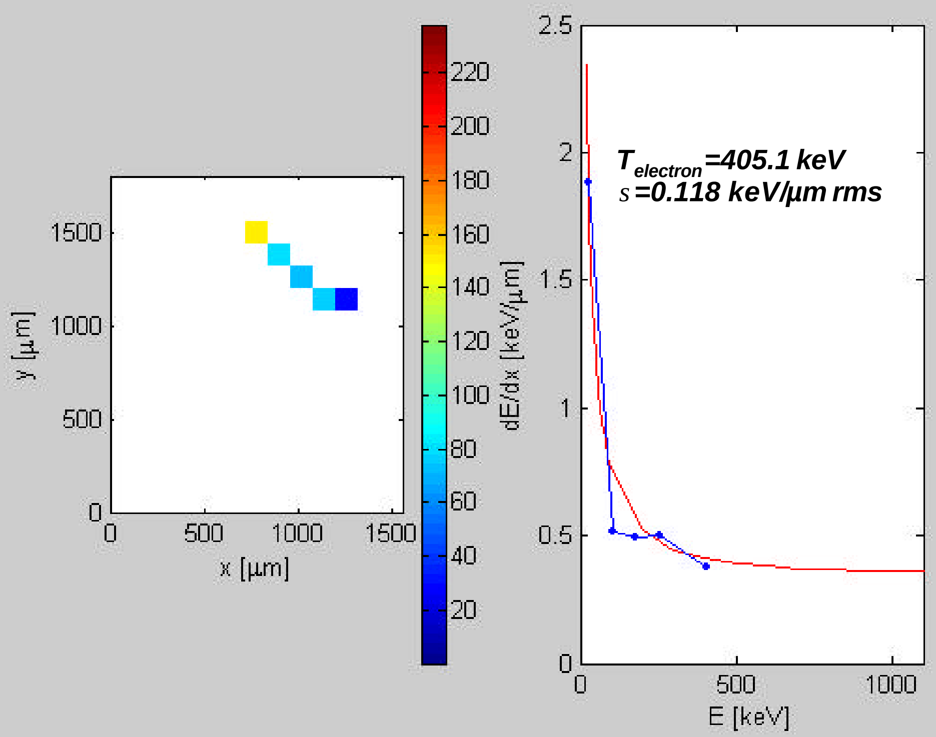
- direction of recoil electron

- data fitting: recoil electron energy, deposited energy, escape energy

- *analysis of back signals may provide Depth-Of-Interaction information*

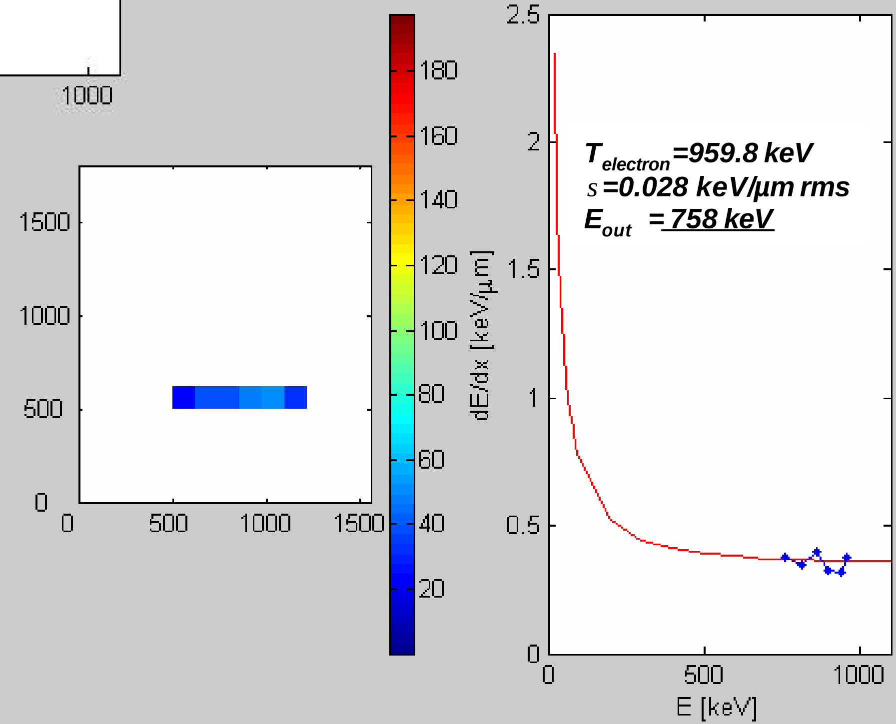
Electron tracks

Na-22 source, T=300K



internal absorption

Z-exit

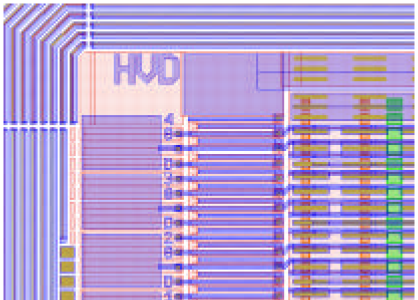


2D imager based on 3´1 cm^2 CDDs

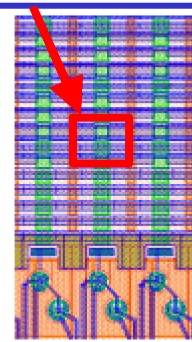
(project#1: x-ray imaging, project#2: Compton scatter detector)

COMPTON (2004-2006) - INFN - Sezione di Milano - Gruppo V

HV region

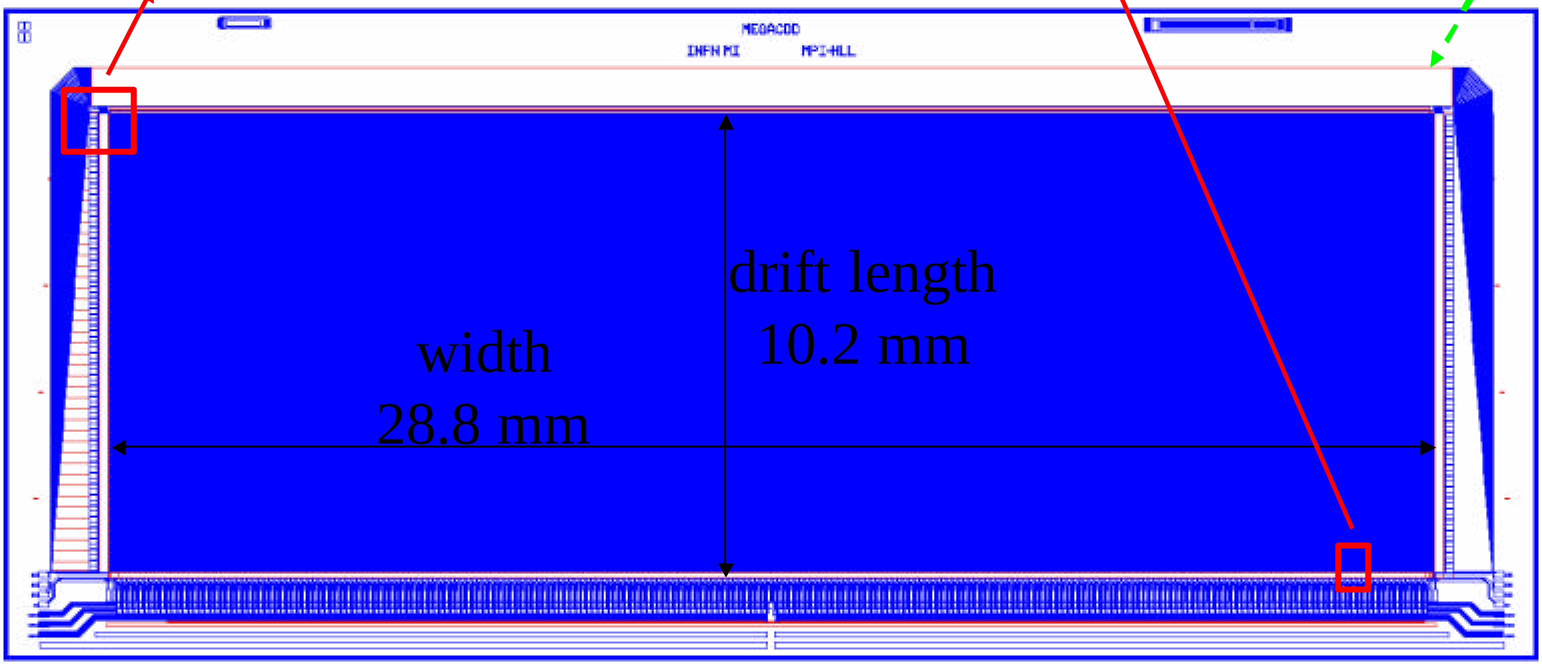


Pixel size (120µm) and readout section



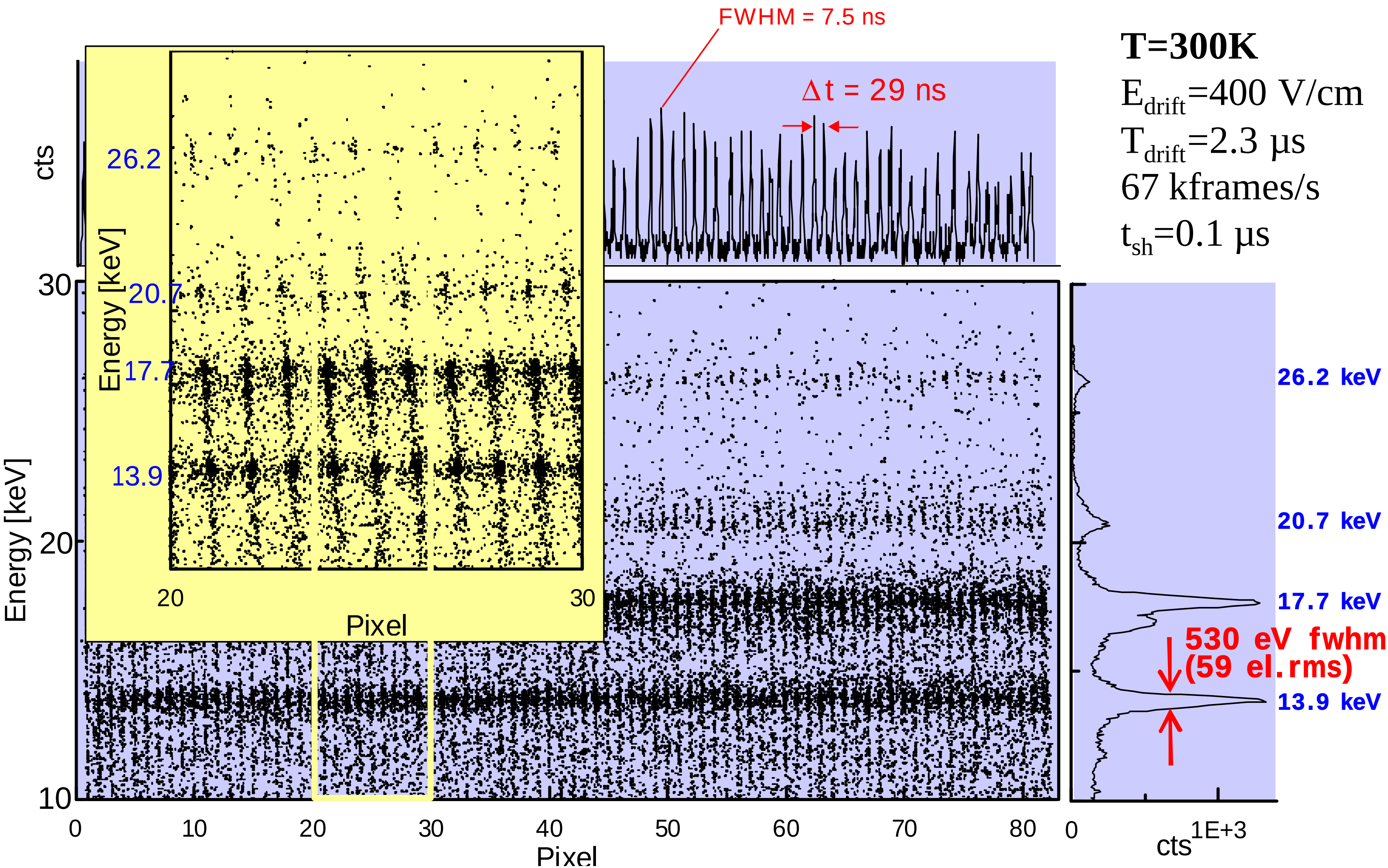
P-side: 15 strips (pitch 780µm)

240 x 84 pixels



Scientific collaboration with MPI Munich for technology develop./detector production (2005)

Preliminary tests with Am-241 (march '06)



T=300K

E_{drift}=400 V/cm

T_{drift}=2.3 μs

67 kframes/s

t_{sh}=0.1 μs