Gaseous detectors for synchrotron radiation

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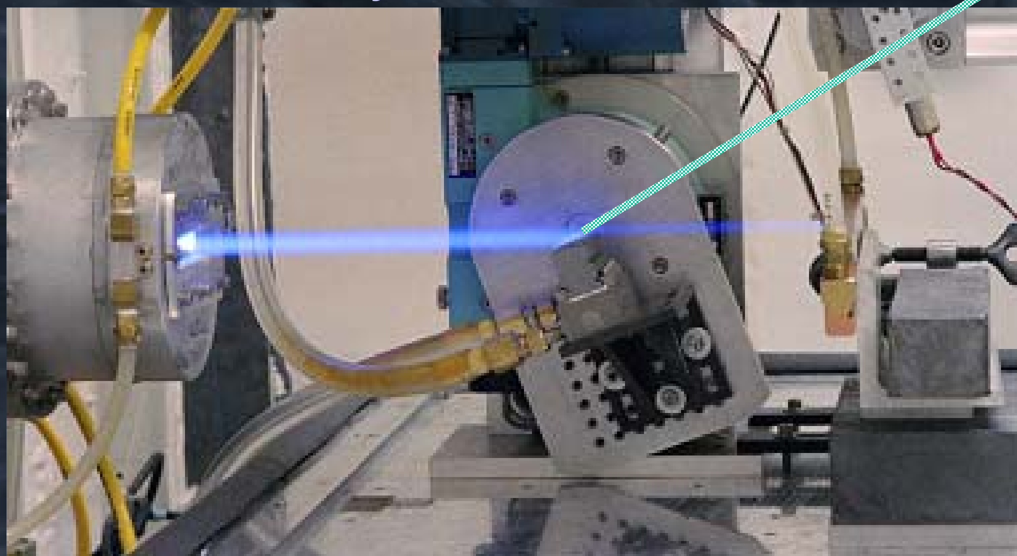
The European Commission
Community Research
Improving Human Research Potential & the Socio-economic Knowledge Base

Imaging set up

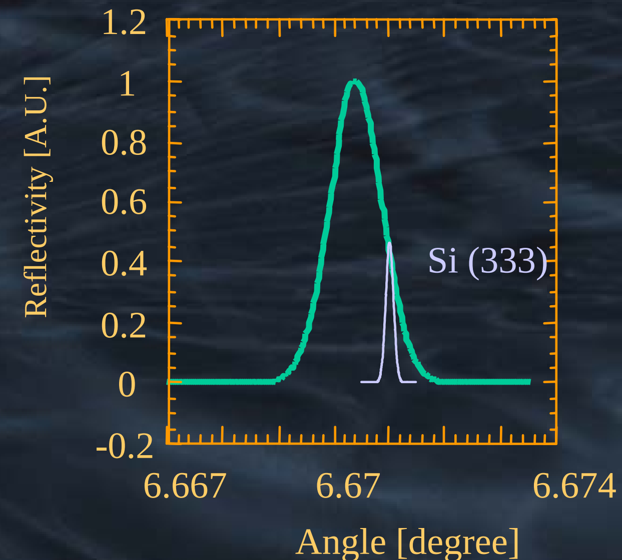
Credit: NSLS

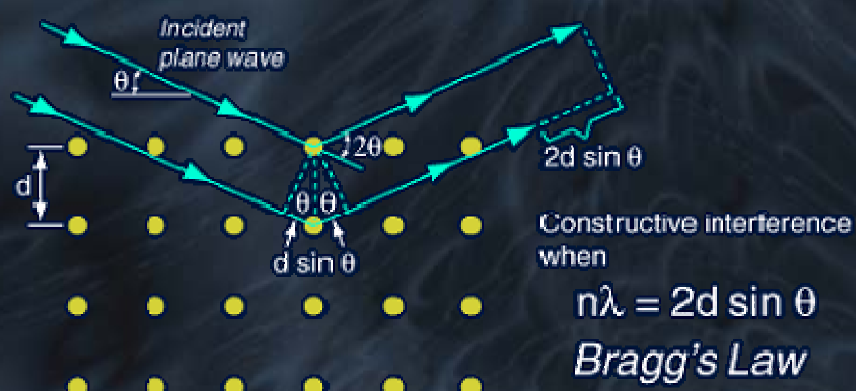
Dose rate 13000 Gy/s

Dose rate <100 Gy/s



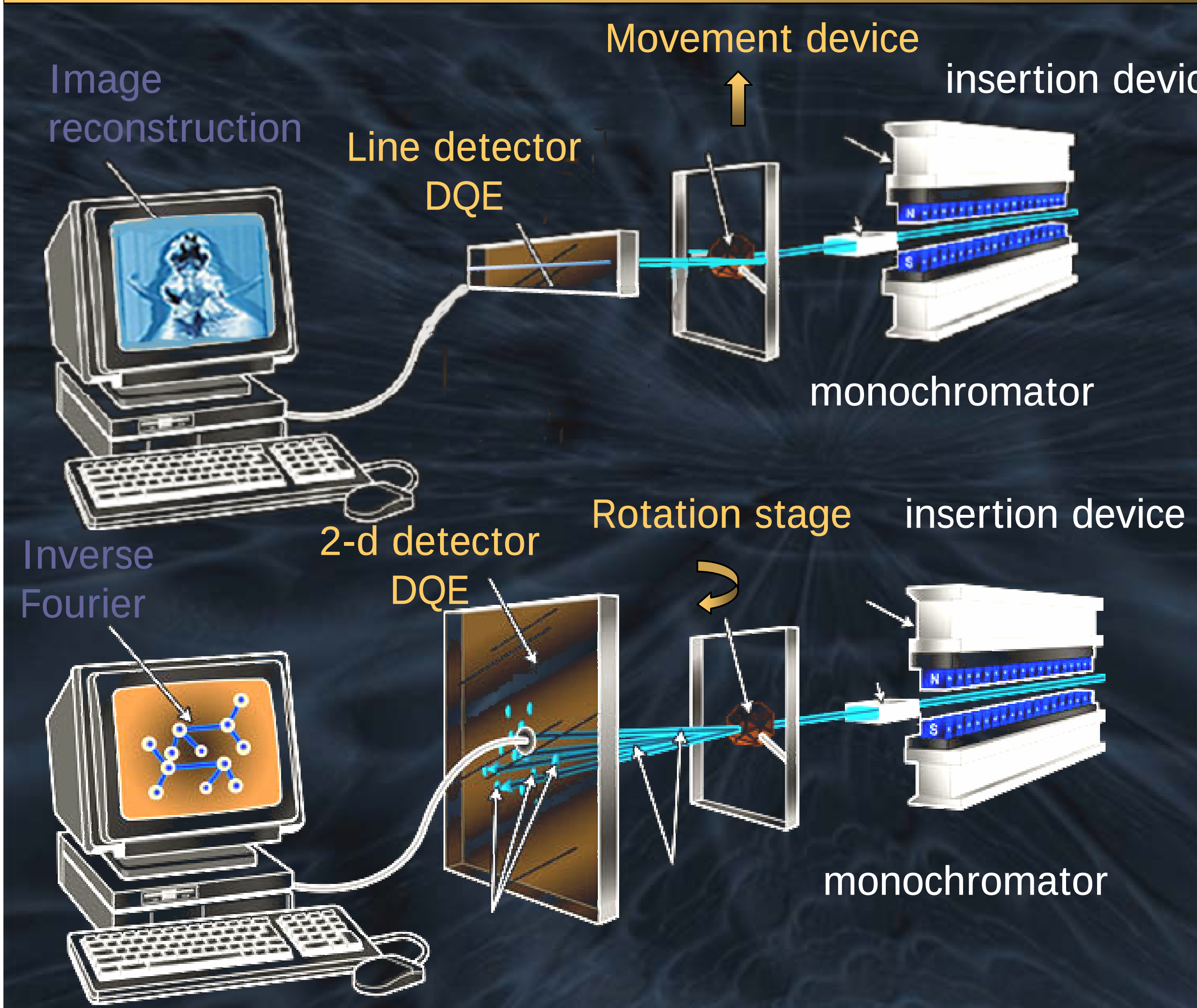
Si (111) perfect crystal at 17 keV
width ~ 20 μrad





Imaging with SR

Piazza Unita, Trieste



Direct imaging

Length scale

0.5 μm – 30 cm

most of pixels see approx same photon

~ 10^4 for 0.1%

Fourier indirect imaging

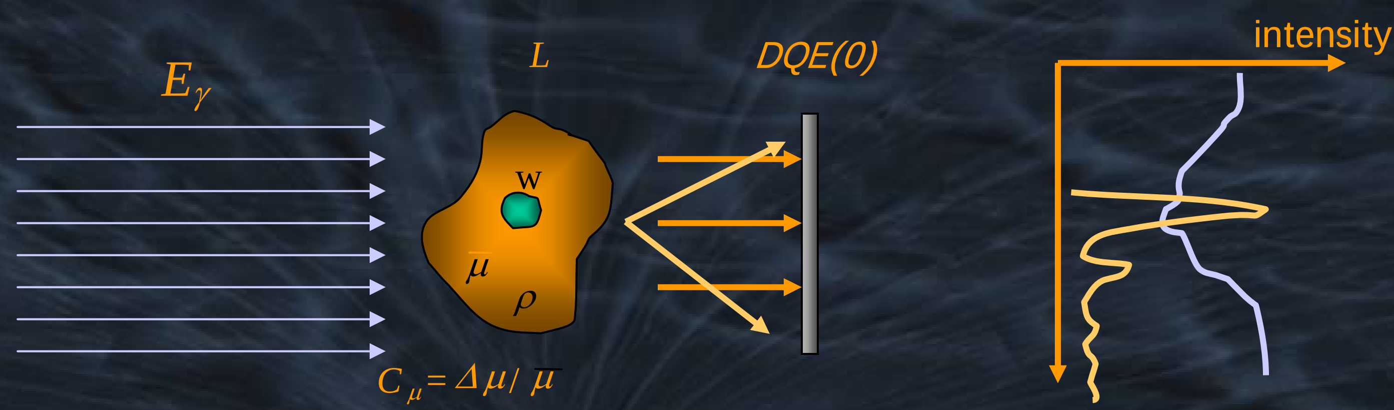
Length scale

15 Å –5000Å

most of pixels see ~ 0 photons


DOSE
Golf of Trieste

Dose considerations



Direct Imaging

$$D_{skin} = \frac{2 \cdot L \cdot e^{\mu \cdot L} \cdot SNR_{out}^2}{DQE(f) \cdot \mu^2 \cdot w^4 \cdot C_\mu^2} \cdot E_\gamma \cdot \left(\frac{\mu}{\rho}\right)$$

$$D_{sample} = \frac{\mu \cdot P \cdot h \cdot \nu}{DQE(f) \cdot \rho^2 \cdot w^4 \cdot \lambda^2 \cdot r_e^2}$$

$$\left.\begin{matrix} D_{skin} \\ D_{sample} \end{matrix}\right\} \approx \frac{1}{w^4 \cdot DQE(f)}$$

Indirect imaging

DQE

Integrating detectors

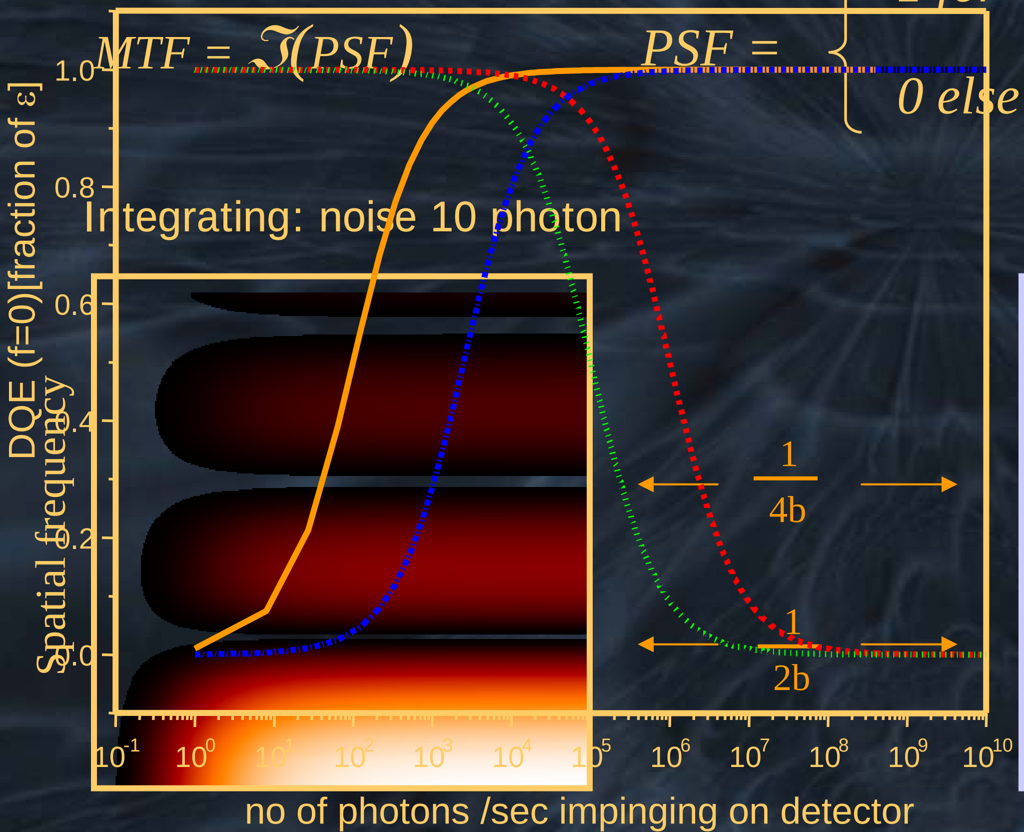
$$SNR^2_{measure} = DQE \cdot SNR^2_{Poisson}$$

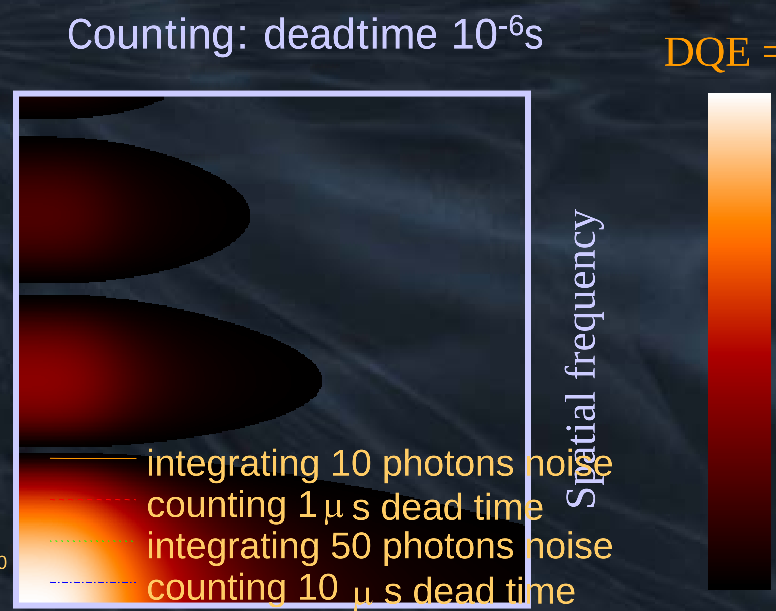
$$DQE = \frac{\varepsilon}{1+\frac{\sigma^2_{add}}{\varepsilon \cdot N}} \cdot |MTF|^2$$

Counting detectors

$$DQE = \frac{\varepsilon}{1+R\cdot\tau} \cdot |MTF|^2$$

$$MTF = \Im(PSF) \qquad PSF = \begin{cases} 1 \text{ for } -b/2<x<b/2 \\ 0 \text{ else} \end{cases} \quad => MTF \sim \frac{Sin(x)}{x}$$





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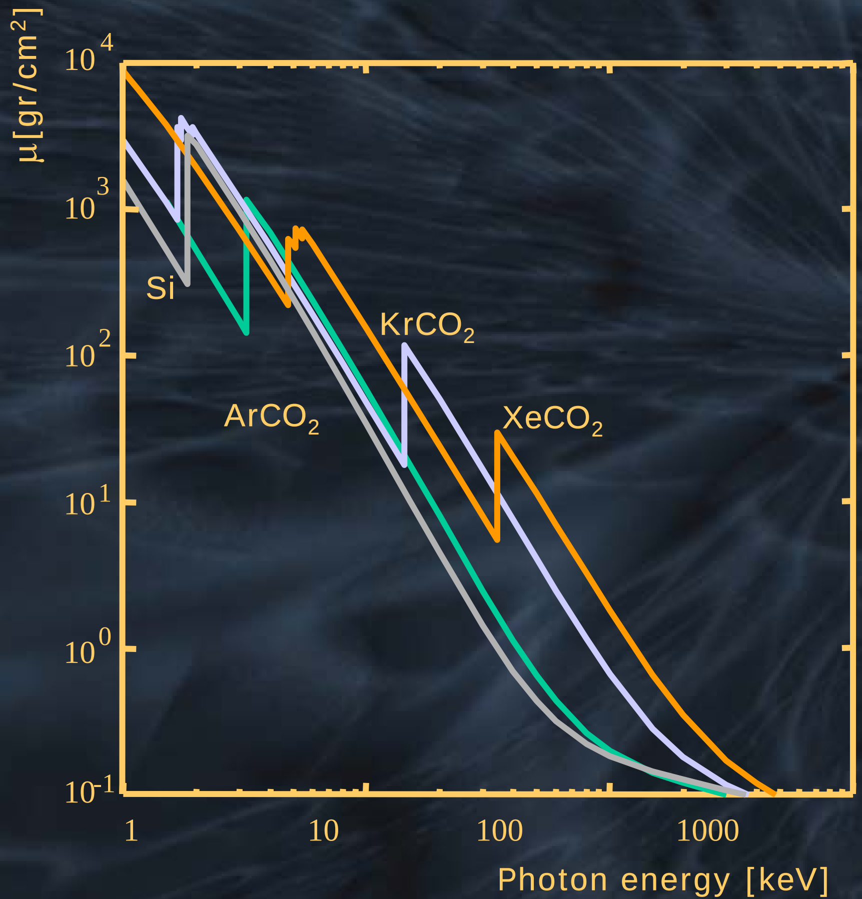
Gaseous detectors
Molo Audacio, Trieste

Inherent advantages of gaseous detectors

Why should we couple ancient design with new technologies?

Mass absorption coefficient for photoelectric effect



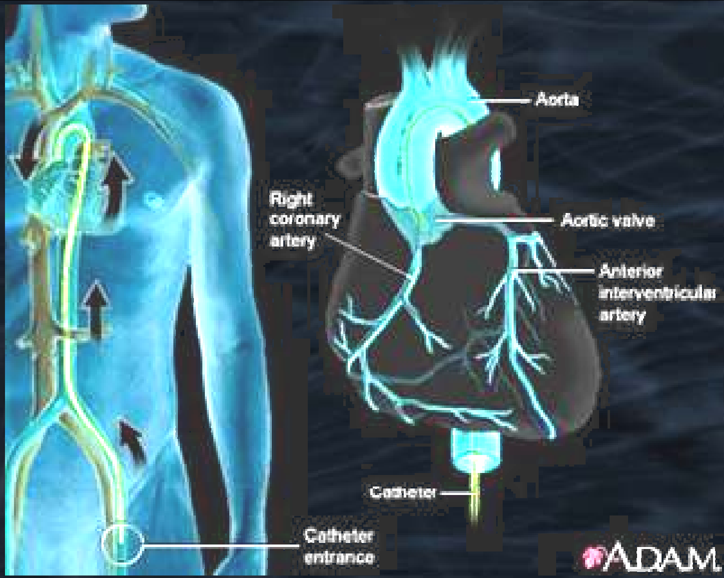
- Gas mixture can be adjusted
- Absorption properties can be adjusted
- great freedom in the choice of the geometry
- <p> ~ $e^{-(W_{ion}/kT)}$ W_{ion} ~ 20- 30 eV -> almost noise free @ room temp
- Adjustable gas gain
- high rate stability
- reasonable fast
- reasonable financial requirements on infrastructure
- robust

Direct Imaging

Castle Miramare, Trieste

Absorption contrast agents

$$D_{skin} = \frac{2 \cdot L \cdot e^{\mu \cdot L} \cdot SNR_{out}^2}{DQE(f) \cdot \mu^2 \cdot w^4 \cdot C_\mu^2} \cdot E_\gamma \cdot \left(\frac{\mu}{\rho}\right)$$



Increasing $C_\mu^{\,2}$ utilizing contrast agents

Proc. Natl. Acad. Sci. USA
Vol. 83, pp. 9724–9728, December 1986
Medical Sciences

Transvenous injection of contrast agent

Detection of 20 fold diluted contrast agent

Transvenous coronary angiography in humans using synchrotron radiation

(arteriography/coronary artery disease/imaging)

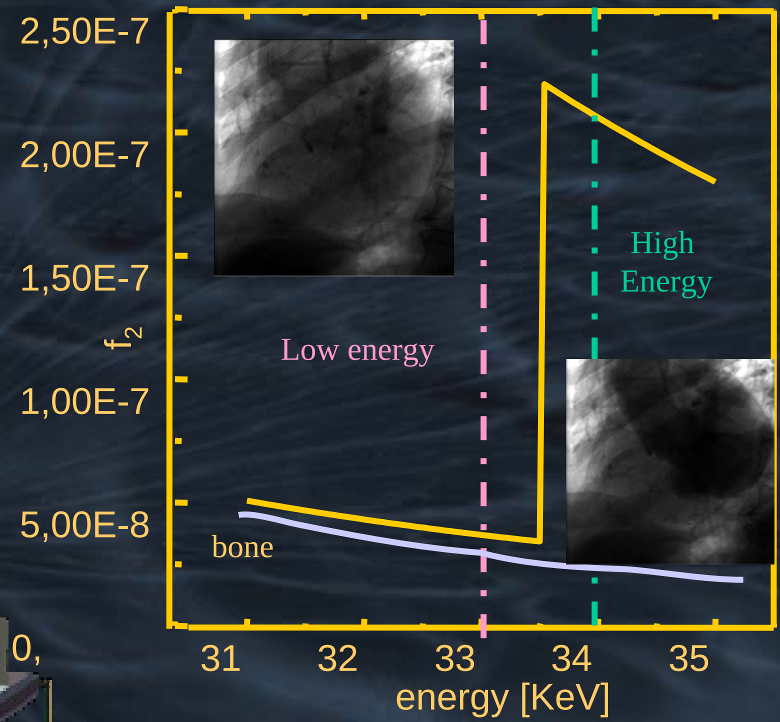
Edward Rubenstein*, Robert Hofstadter†, Herbert D. Zeman†, Albert C. Thompson‡, John N. Otis†, George S. Brown§, John C. Giacomini*, Helen J. Gordon*, Robert S. Kernoff*, Donald C. Harrison*, and William Thomlinson¶

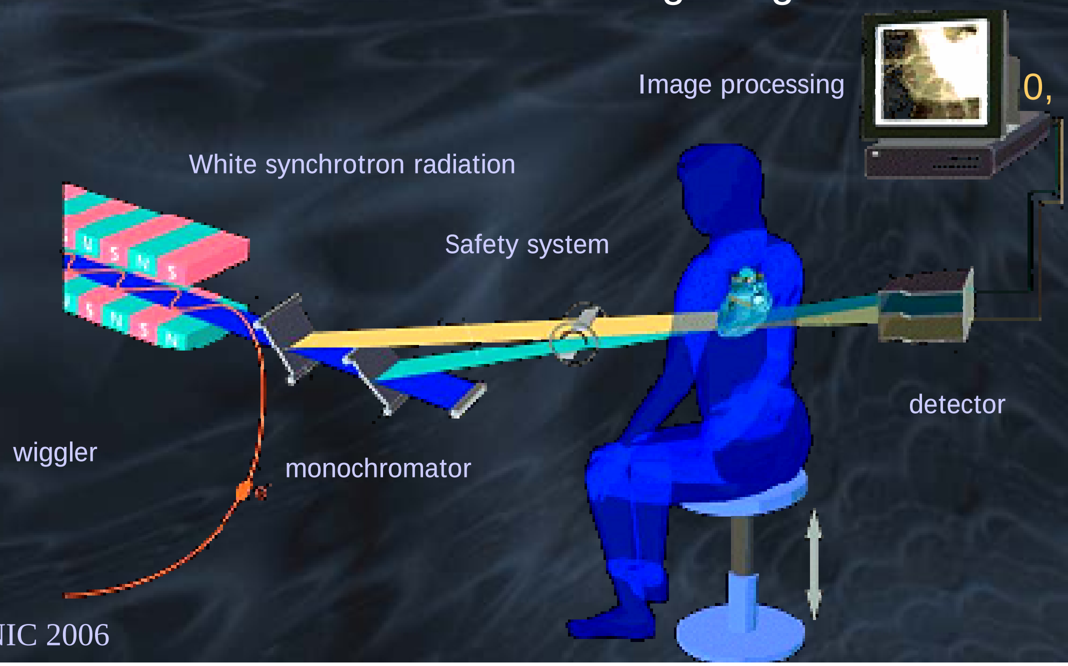
*Department of Medicine, School of Medicine, †Hansen Laboratories of Physics and Department of Physics, and §Stanford Synchrotron Radiation Laboratory, Stanford University, Stanford, CA 94305; ‡Lawrence Berkeley Laboratory, University of California, Berkeley, CA 94720; and ¶National Synchrotron Light Source, Brookhaven Laboratory, Long Island, NY 11973

Contributed by Robert Hofstadter, August 18, 1986

Absorption contrast agents

DQE	as high as possible for 33 keV photons as low as possible or 99 keV photons
Active area	5mm * 15 cm
Spatial resolution	0.3 – 0.5 mm
Time resolution τ	0.8 – 1 ms / line
Noise equivalent	< 10 photons / τ
Dynamic	>> 65000: 1
Max count rate	10^7 per pixel/ τ
	> Integrating detectors

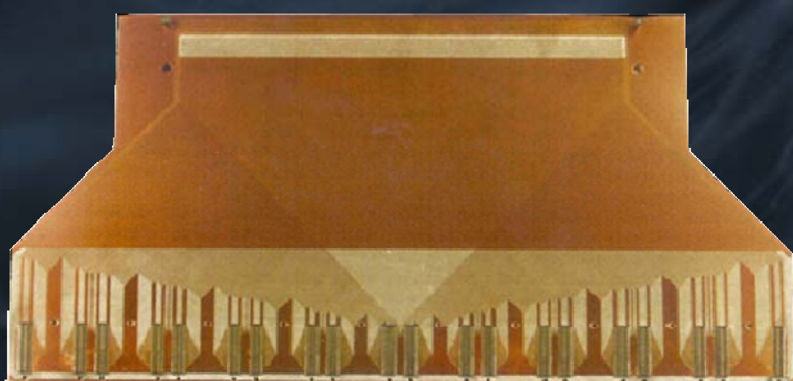




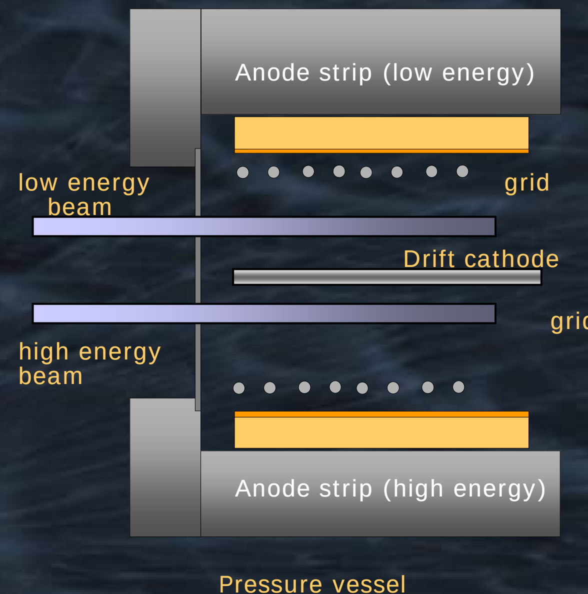
Transvenous coronary angiography

SF bay area NSLS	Li drifted Si detector (Al Thompson)
HASYLAB, DESY	Kr, Xe filled high pressure (10 bars) ionization chamber
ESRF, France	Ge detector (Eurosys)

Detector HASYLAB
Segmented double line ionization chamber



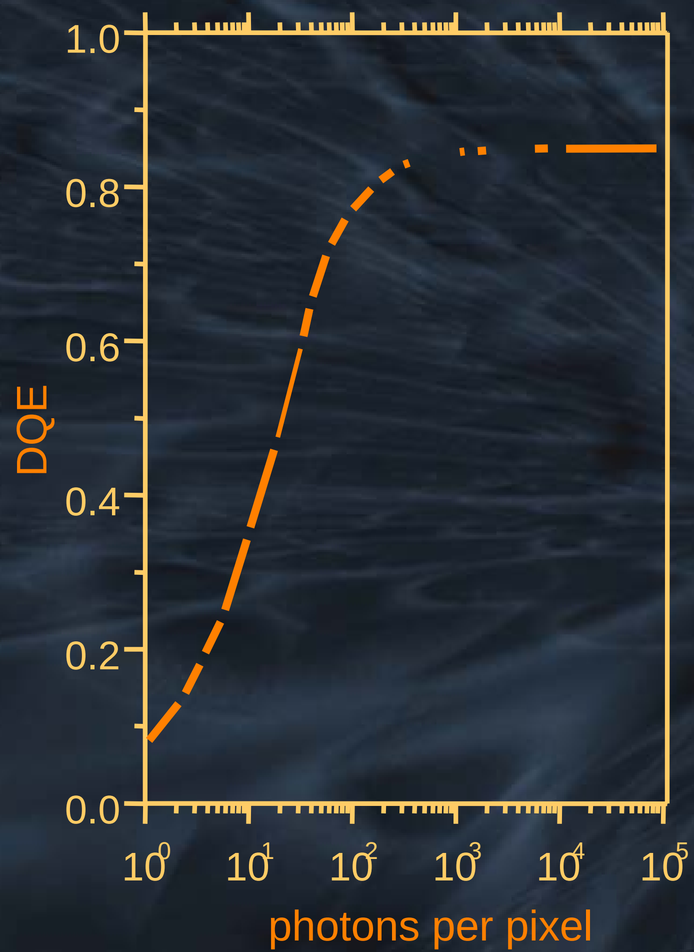
NIKOS IV

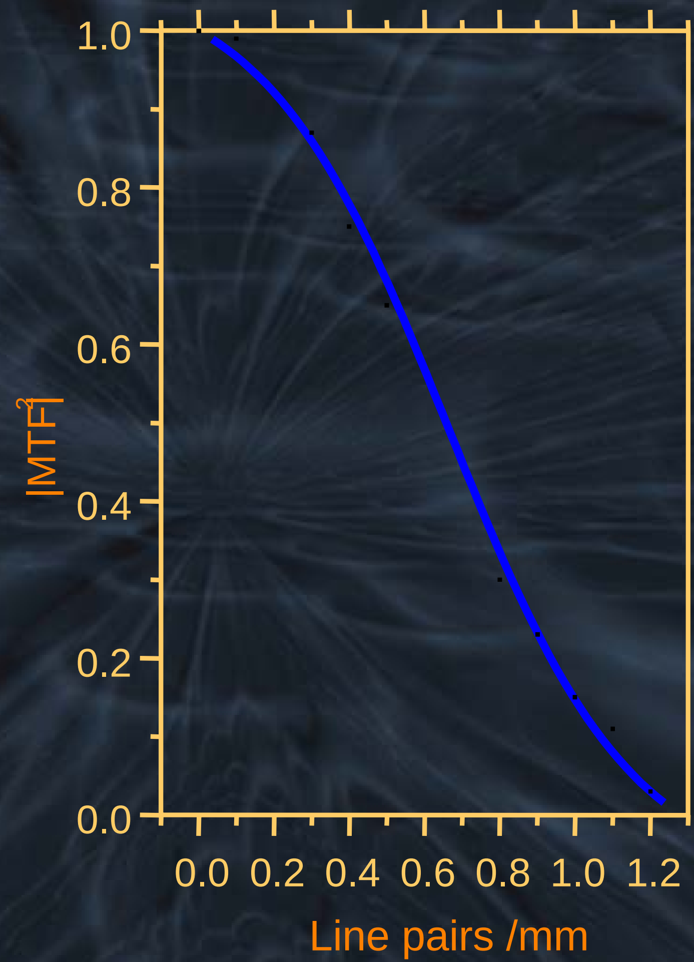


Frisch grid for fast e^{-} signal collection
length of the strips: 5 cm
distance drift cathode - anode: 3 mm

- two times 356 channels
- pitch 0.4mm
- integration time 0.8 ms
- 712 20 bit ADCs BB DDC 101
- optical fiber link

Detector performance

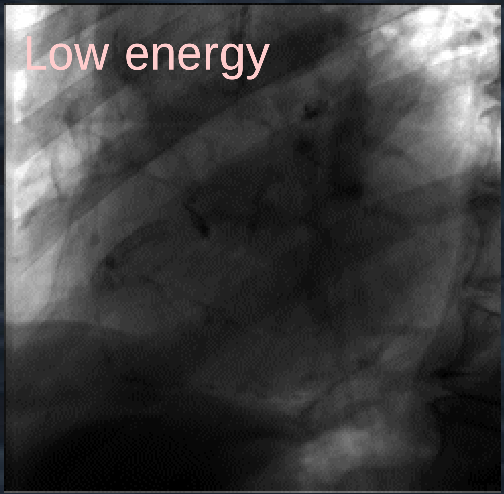


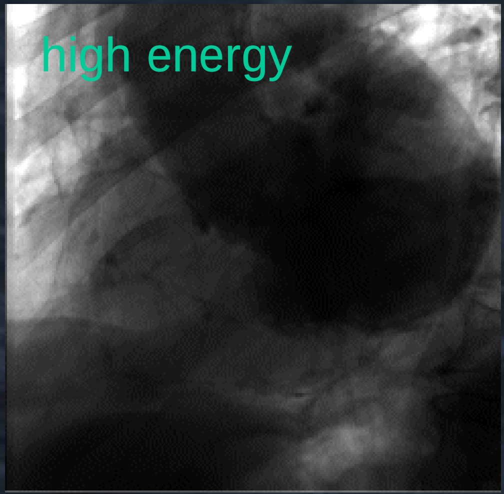


Dynamic 19 bit
DQE_{33} 0.83
Time res. 0.8 ms
Sp res 1 LP\mm
Noise 10 pho / t
No dead channels
With Kr suppression
of 3rd harmonics

1996 – 2001
376 patients
88% males
12% females

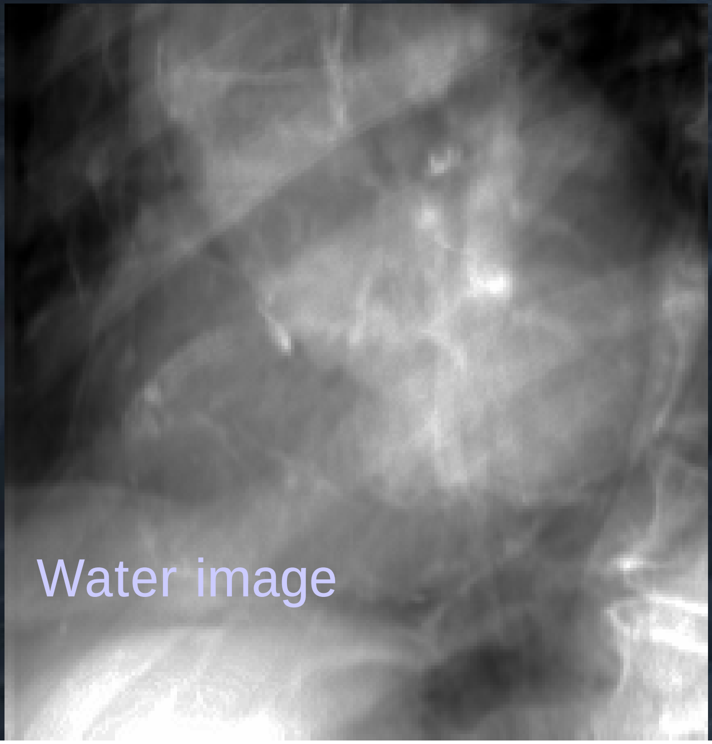
Non Invasive Coronary Angiography





$$\begin{pmatrix}\mu_w^{>} & \mu_i^{>} \\ \mu_w^{<} & \mu_i^{<}\end{pmatrix}^{-1}\begin{pmatrix}-\ln\left(\frac{\phi_1}{\phi_{01}}\right)\\ -\ln\left(\frac{\phi_2}{\phi_{02}}\right)\end{pmatrix} = \begin{pmatrix}\rho_w\cdot\Delta x_w\\ \rho_i\cdot\Delta x_i\end{pmatrix}$$

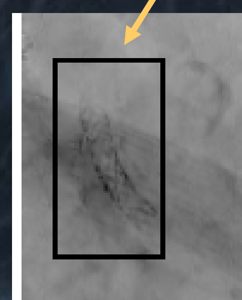
Works only for small contribution of 3rd harmonics



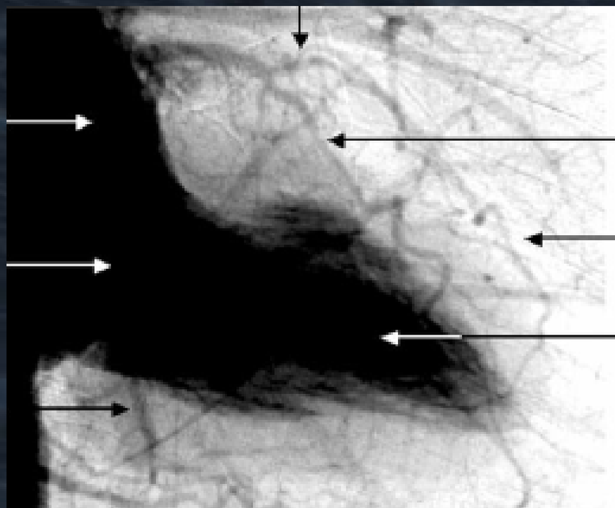
Non Invasive Coronary Angiography

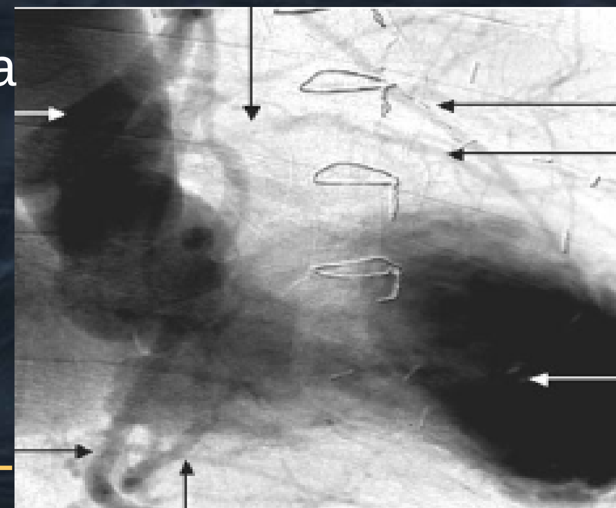
Clinical angiography

SR iodine image



Water image of stent



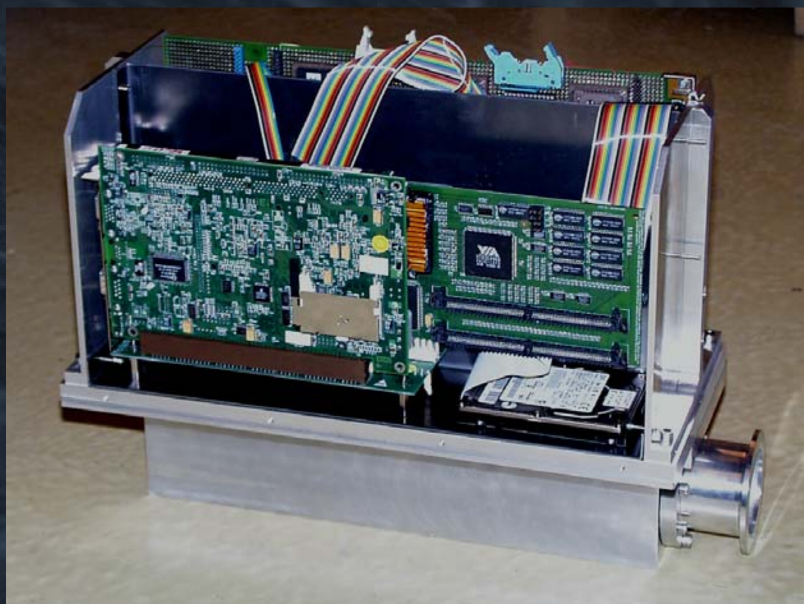


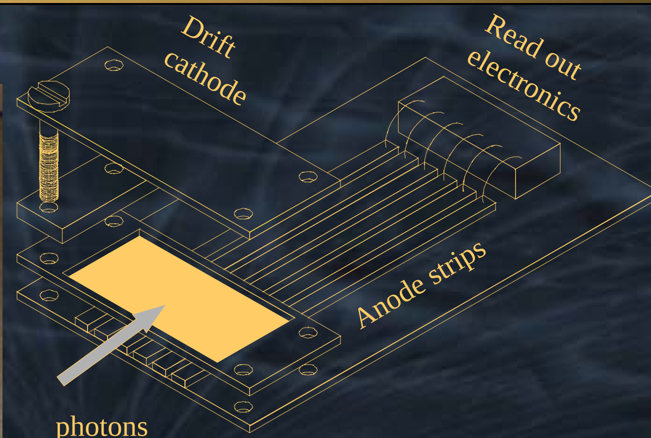
- 79% sensitivity (true positives) and 92% specificity (true negatives) for the RCA
- 45% sensitivity and 98% specificity for the LAD (superposition problem).

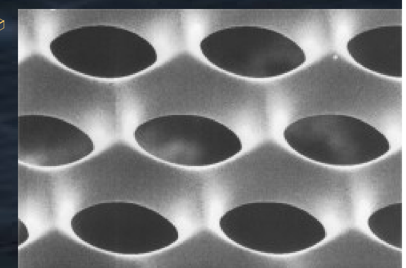
No further patients after 2002 (detector used as expensive thermometer)

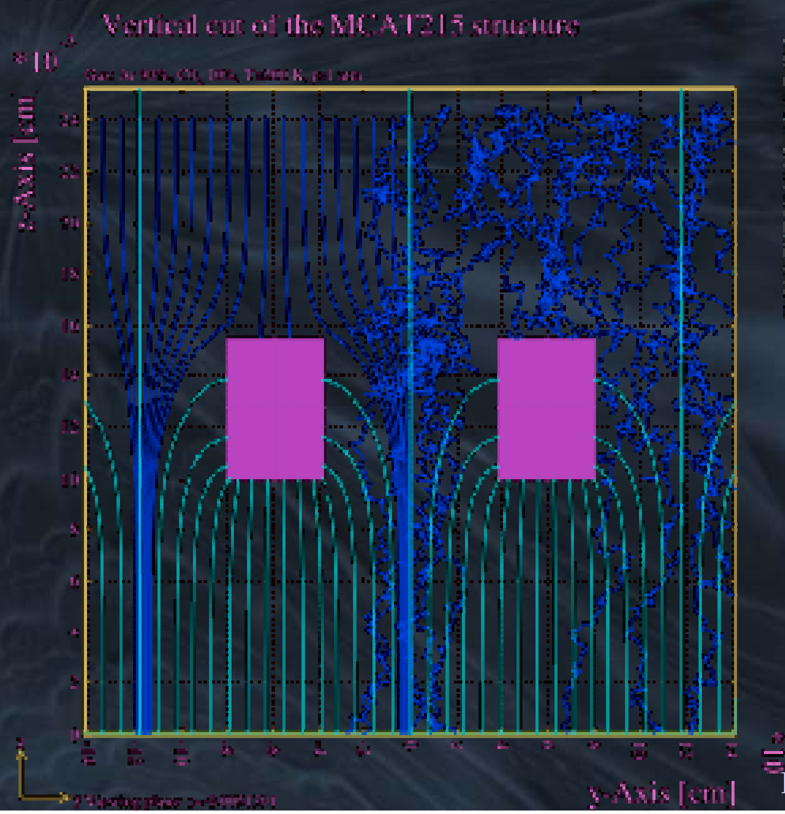
May be resurrection for a dedicated SR medical center in Germany
SR angiography and functional heart imaging with Gd based contrast agents

1-d integrating detector DQE shifter









- Xe-CO_2 @ 4 bar
- 1500 strips/ channels
- adjustable gas gain (DQE shifter)
- precision < 0.1%
- frame rate 10 kHz
- spatial resolution < 100 micron

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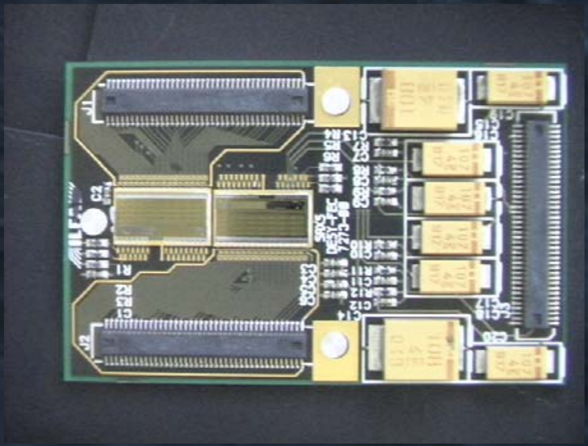
1-d SAXS detector integrating detector DQE shifter

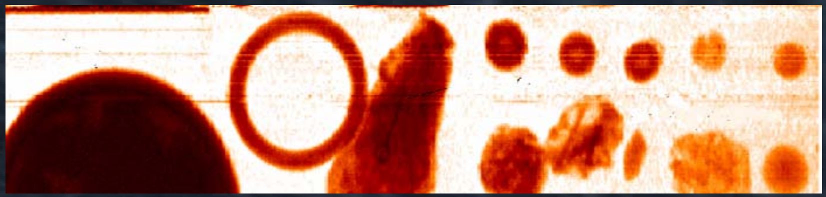


64 channel analog integrator (W Buttler)
8 gain settings
Correlated oversampling
Serial analog output
400 e^- noise (1 photon @ 8keV / integration time)

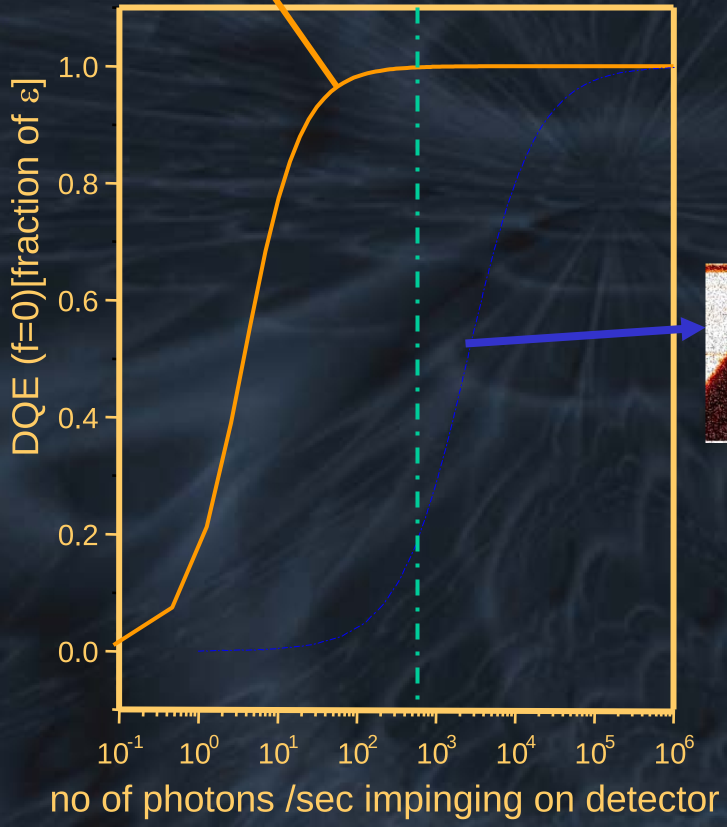
Mode of operation
- ionization chamber mode (I_0 calibration)
- with gas gain single photon detection

1-d integrating detector DQE shifter

Mammographic phantom
E_γ = 17 keV, entrance dose xx mGy



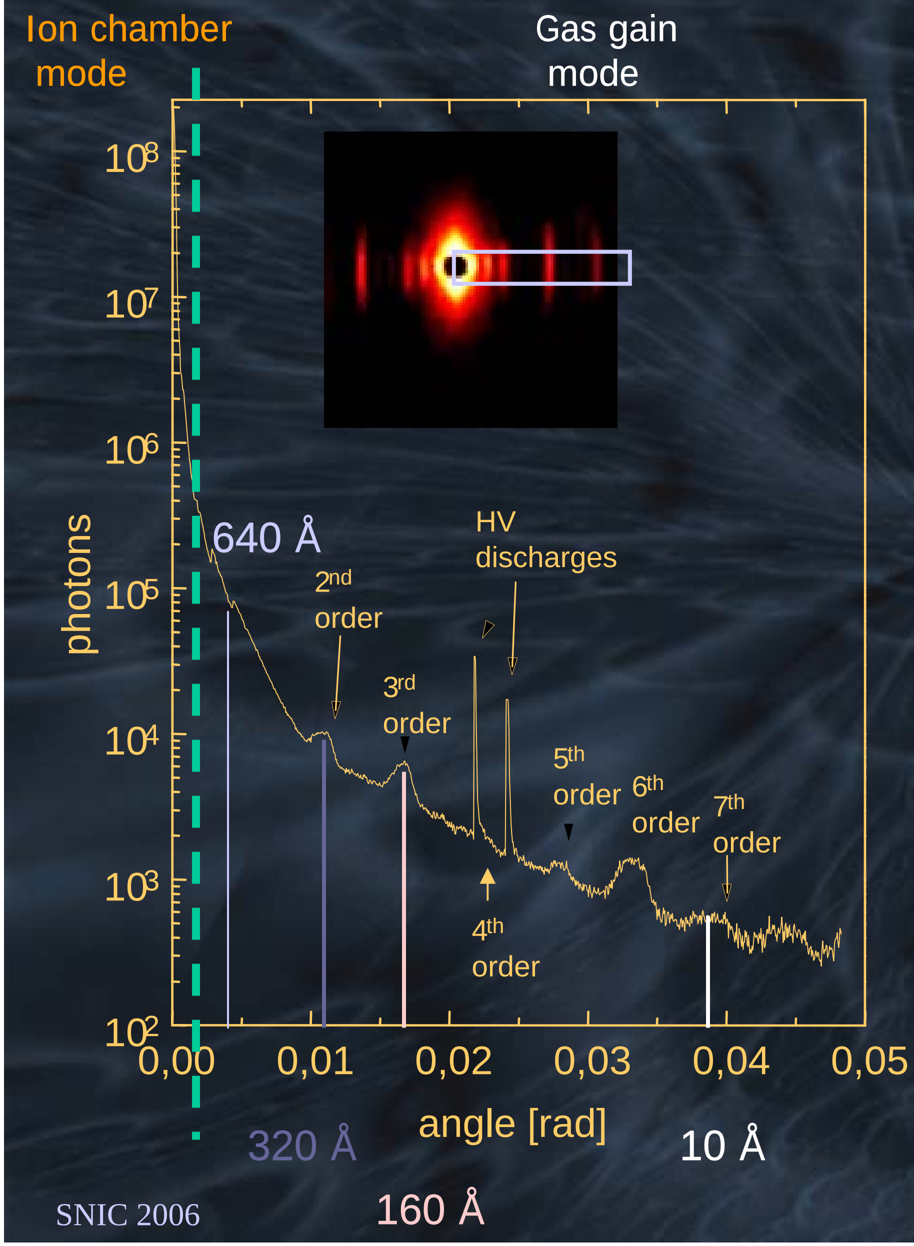
Integrating with gas gain
Single photon resolution

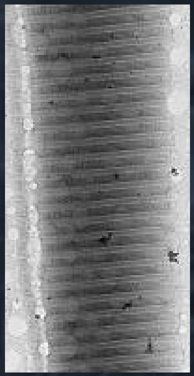


Ionization chamber mode

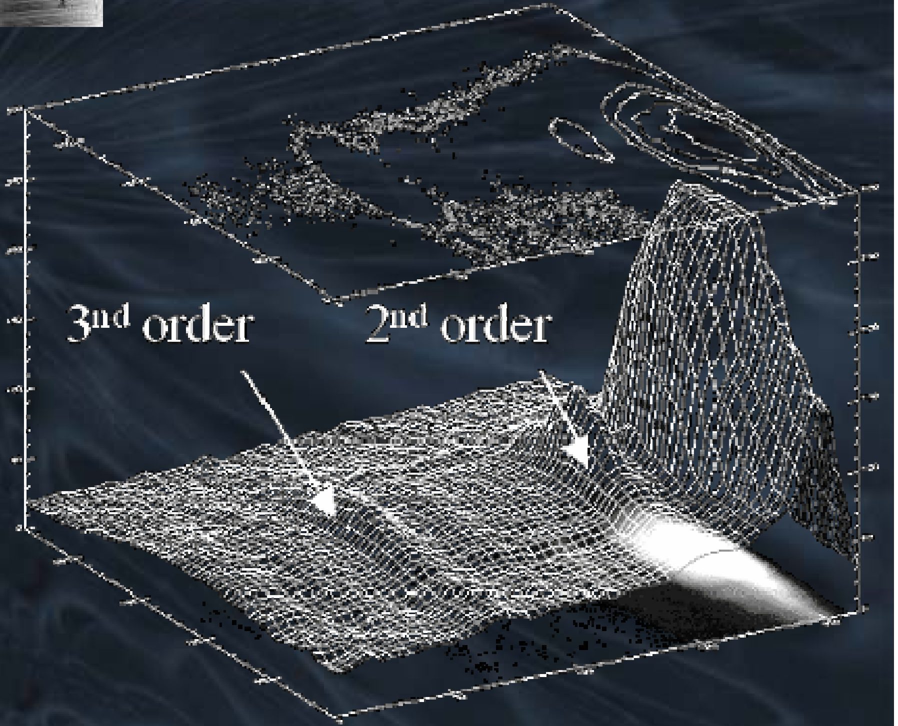

Indirect imaging
Roman theatre Trieste

DQE shifter in SAXS

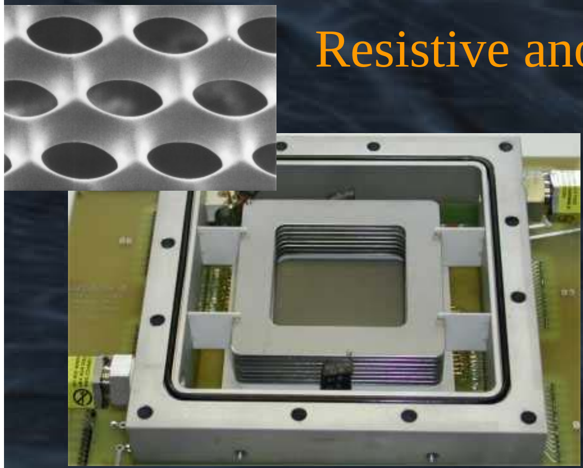




Rat tail collagen
Calibration standard

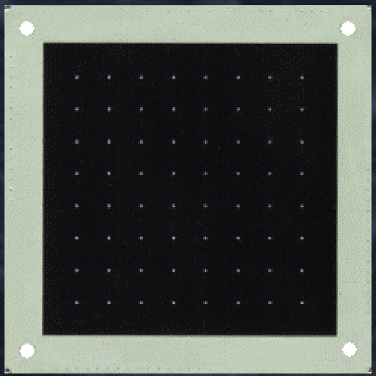


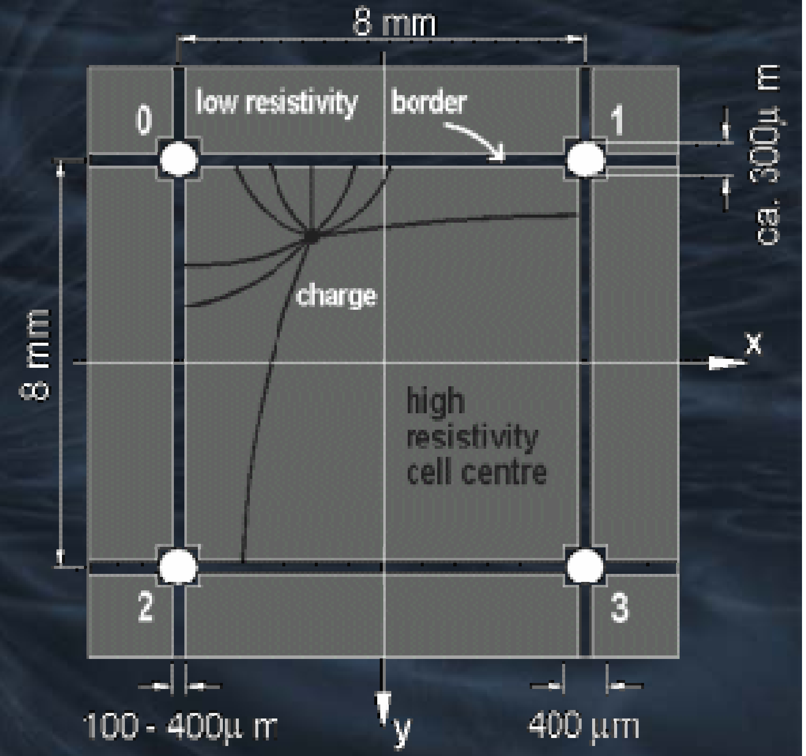
2-d virtual pixel detector SPC



Resistive anode 2-d SAXS detector

M Lampton C.W. Carlson, Rev. Sci. Instr. 50, (1979), 1093





Position encoding through measurement of current differences of single event

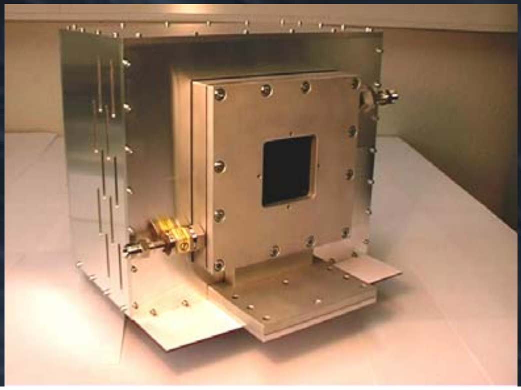
Time stamp for each photon

$$x = \frac{I_1 + I_3}{I_0 + I_1 + I_2 + I_3} \quad \text{and} \quad y = \frac{I_0 + I_1}{I_0 + I_1 + I_2 + I_3}$$

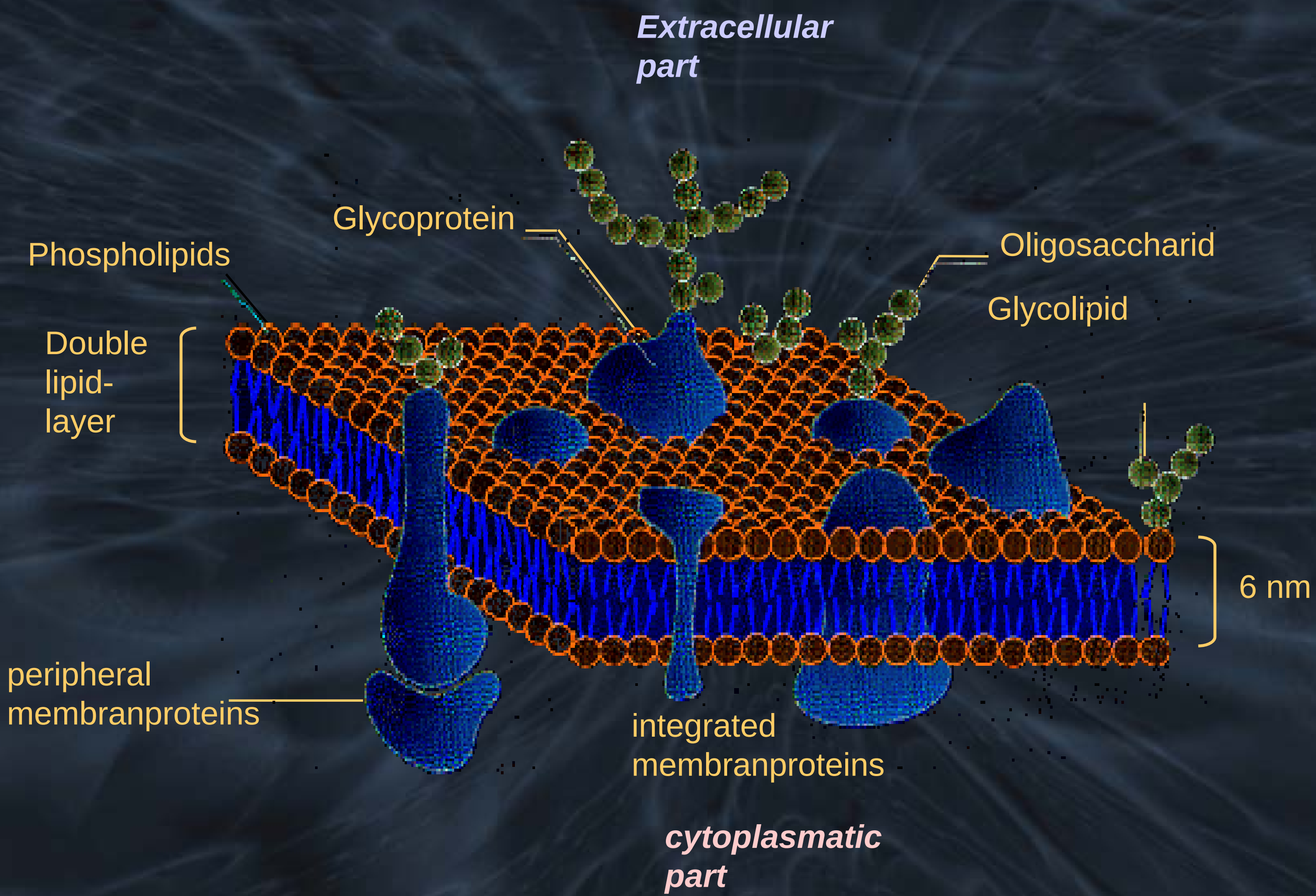
requires 4 channels per pad

local count rate ~ 1 Mhz per pad

64 pads tiled up- global count rate 64 Mhz

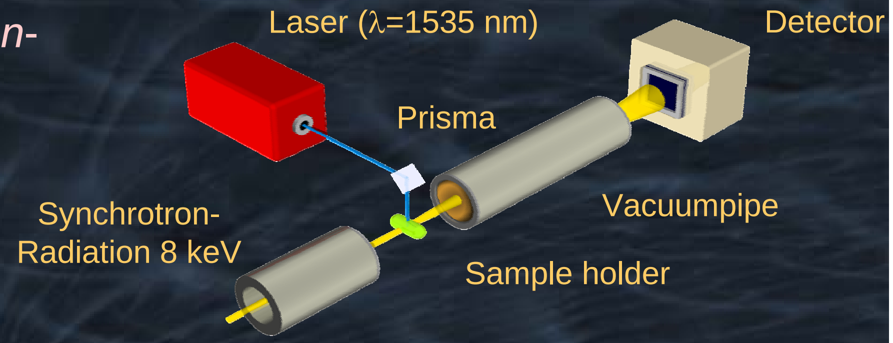


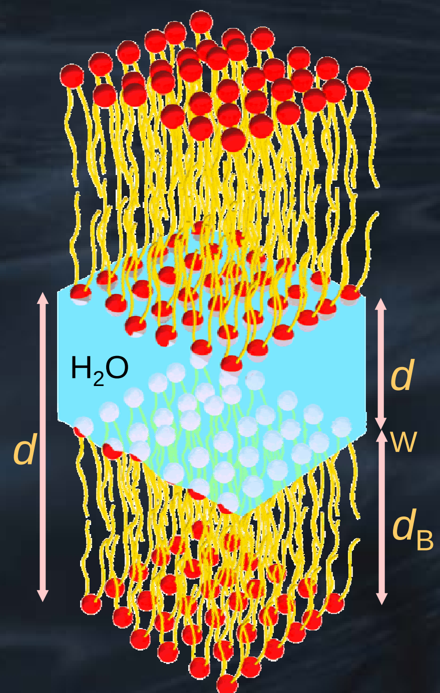
Phosphor Lipids

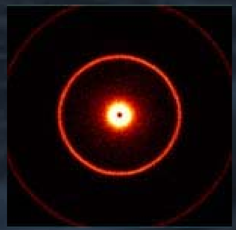


POPE

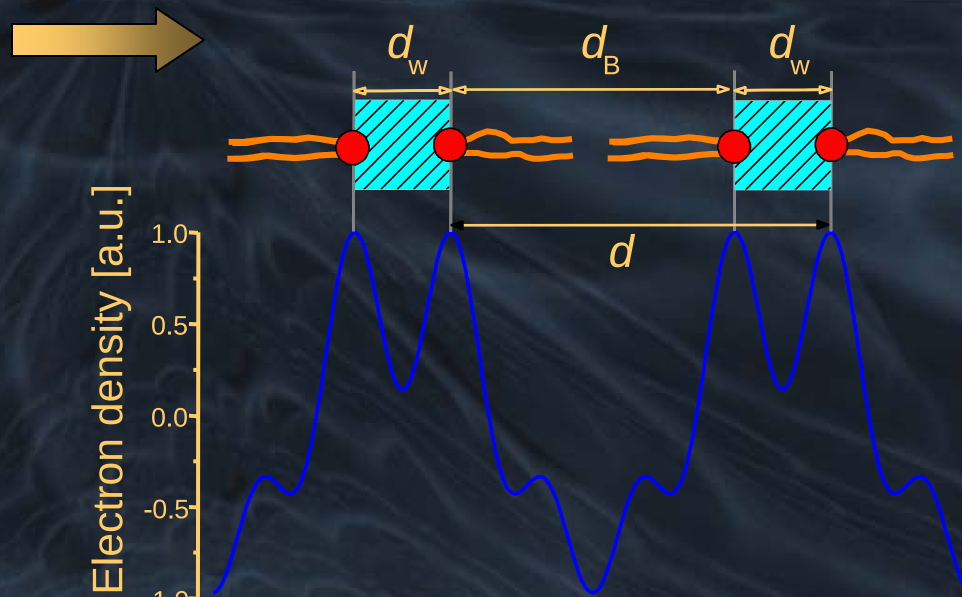
Determination of the *d*-value in 1-Palmitoyl-2-Oleoyl-*sn*-Phosphatidylethanolamin (POPE), after fast temperature rise induced by 3ms long laser pulses



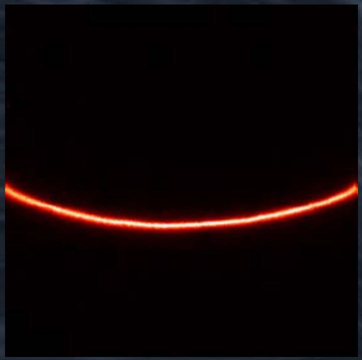


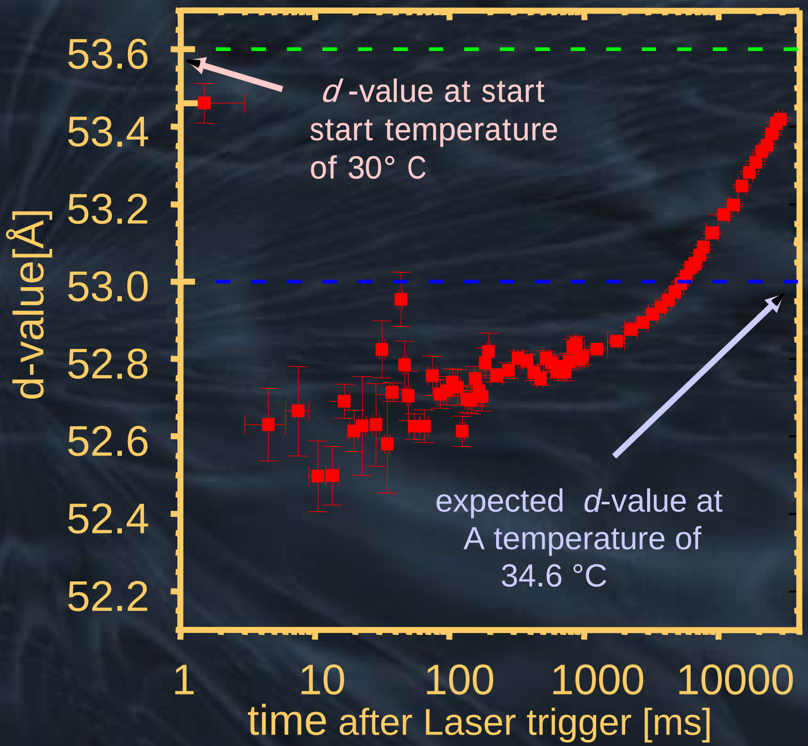


Inverse FFT



POPE





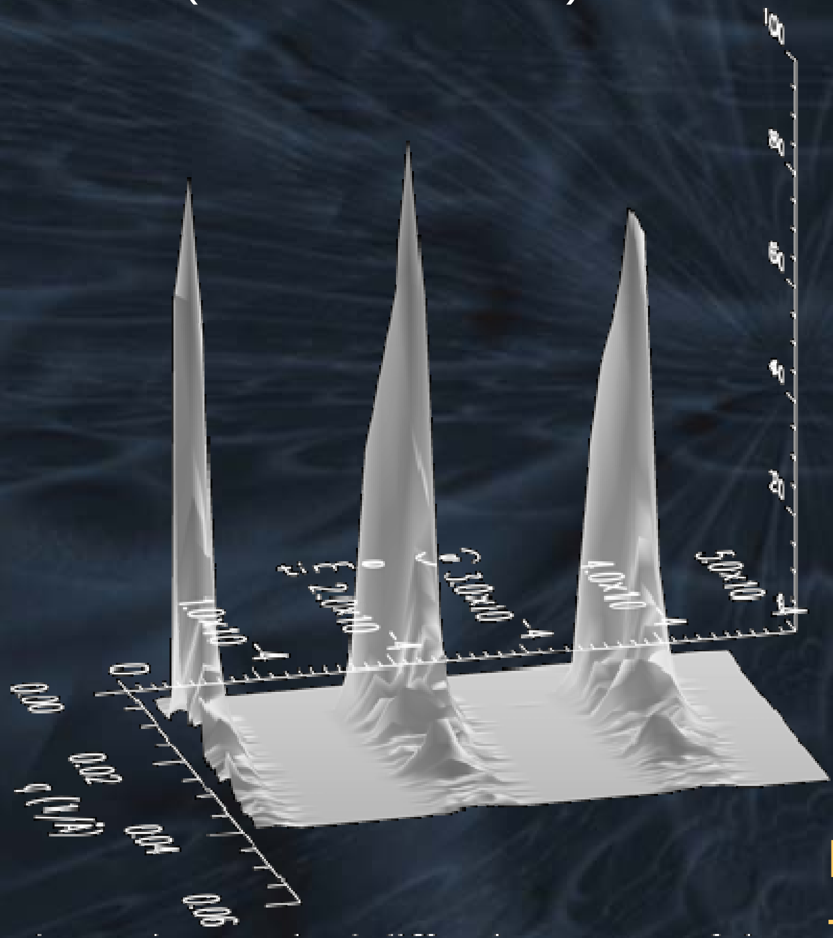
observation:

• increase of temperature leads to a snap off of carbon hydrate chains
→ decrease of *d*-value

• decrease of *d*-value is more pronounced than under steady state conditions

Explanation: formation of an anormalous thin waterlayer in between double lipid layers due to excitation in the out of equilibrium state

1-Dimensional MikroGap delay line Detector – VÅNTEC-1 (Yacouba Diawara)



Local = global count rate > 1Mhz

Time framing 11μs

Conclusion

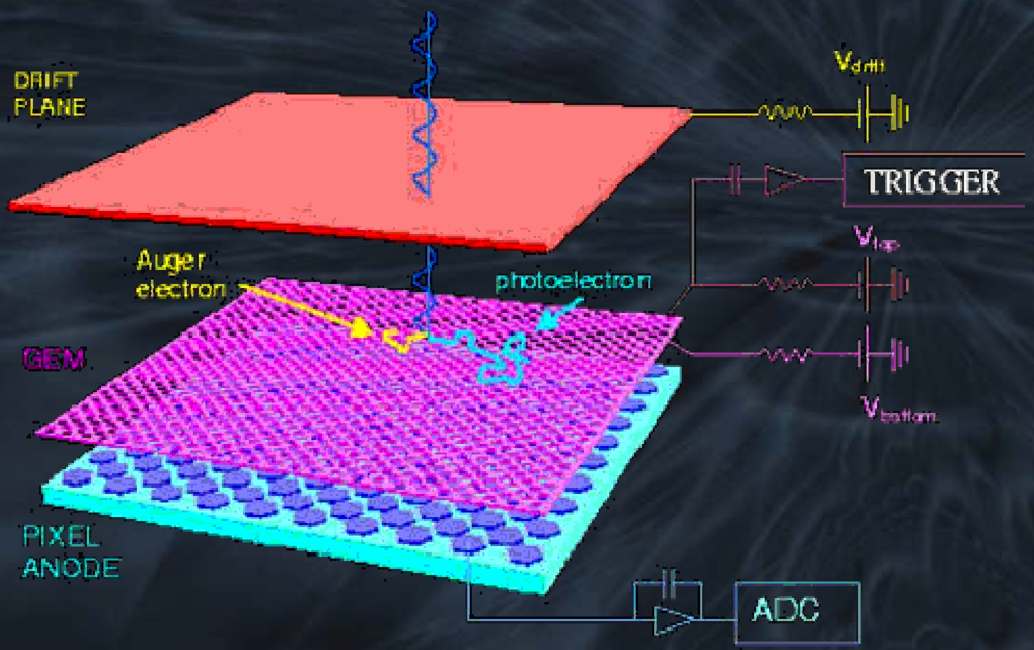
Gaseous detectors are

- reliable & robust detectors for SR
- Well suited for medium fast dynamic measurements
- Well suited for high dynamic range applications
- Well suited for medium high spatial resolution applications
- Have good chance to remain working horses in the SR business

Gaseous detectors are rather classical performers than old fashion devices

The way to go ....

Gas – Si hybrids ....



E.Costa, P.Soffitta, R.Bellazzini, A.Brez, N.Lumb, G.Spandre, ”An efficient photo-electric X-ray polarimeter for the sudy of black holes and neutron stars”, Nature, vol. 411, 2001, 662-664.

Angiography

H. J. Besch (UniSI), W. Bleifeld (UKE; deceased), O. Duenger (HASYLAB), K. Engelke (UniHH), C.-C. Gluer (UniHH), W. Graeff (HASYLAB), U. Groûmann (UniSI), G. Heintze (HASYLAB), J. Heuer (HASYLAB), K. H. HoÈ hne (UKE), C. P. Hoeppner (UniHH), H. Hultschig (HASYLAB), S. Iksal (UniSI), G. Illing (HASYLAB), H. Jabs (UniHH), D. Jowanowich (UniSI), M. Jung (HASYLAB), B. Kaempf (UniHH), J. Knabe (HASYLAB), H. Krieger (UniSI), R. Langer (UniSI), I. Makin (Fachhochschule Hamburg-Bergedorf), T. Meinertz (UKE), M. Mishima (UKE), T. Moechel (UniHH), W. Neef (UniSI), R. Reumann (HASYLAB), C. Rust (UKE), H. W. Schenk (UniSI), L. Schildwa Èchter (HASYLAB), L. Schlueter (UKE), S. Schroeder (UKE), G. Seiffert (UKE), P. Steiner (UKE), K.-H. Stellmaschek (HASYLAB), U. Tafelmeier (HASYLAB/UniSI), M. Wagener (UniSI), A. H. Walenta (UniSI), T. Wroblewski (HASYLAB) and H. C. Xu (UniSI).

Diffraction detector

H.Amentisch, (OeAW), F.Arfelli (UniTrs), H. J. Besch (UniSI), S.Bernsdorff, (Elettra), W.Buttler, C. Hall (SRS), K.Hansen (DESY), S. Martoiu, (UniSI), A.Orthen (UniSI), M.Rappolt (OeAW), A. H. Walenta (UniSI), H.Wagner, (UniSI), H.Walliser (UniSI)