ESRF X-ray Detector Workshop

Feb 13-14, 2003

(held in conjunction with the ESRF Annual Users' Meeting)

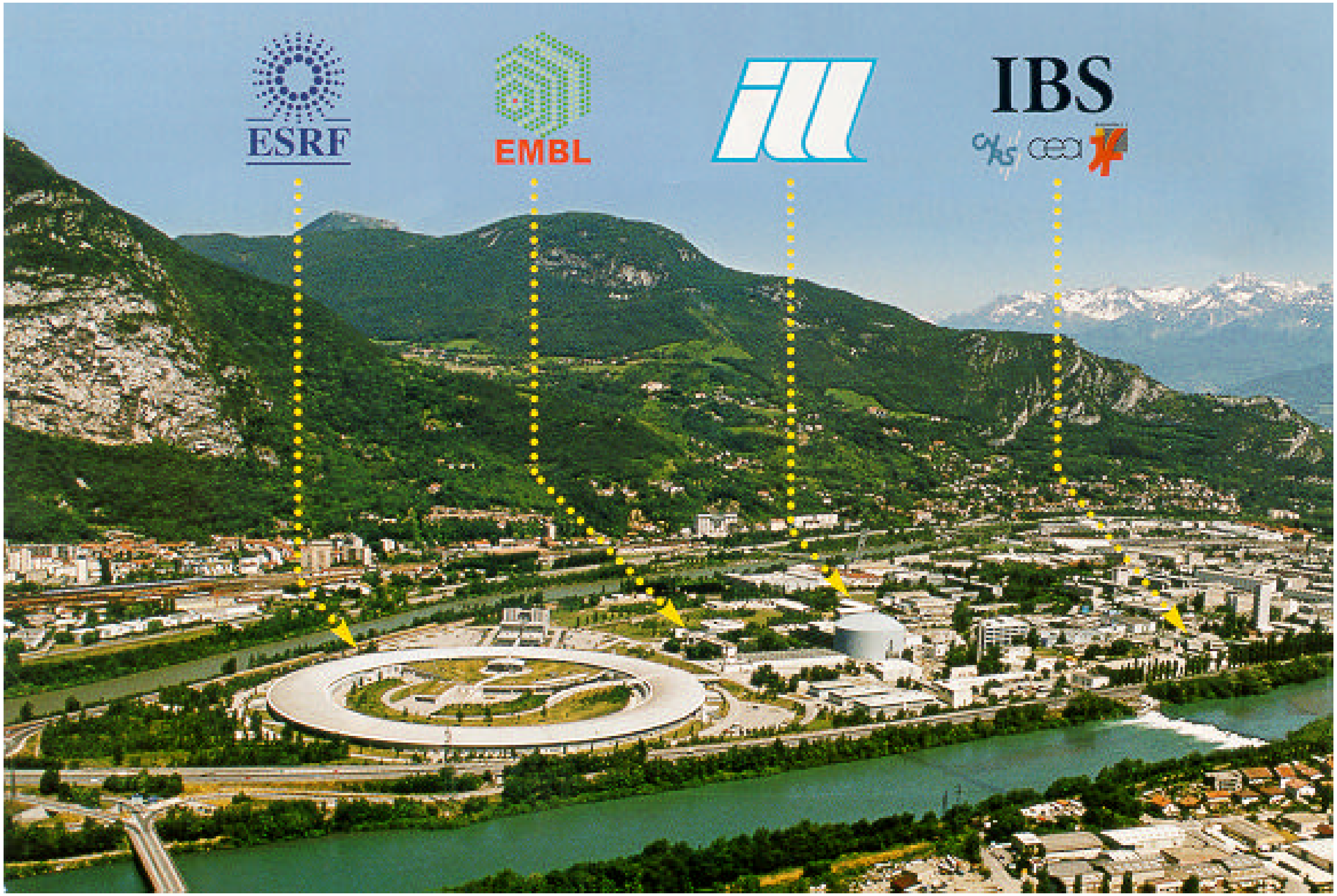
A Synopsis

Graham Smith

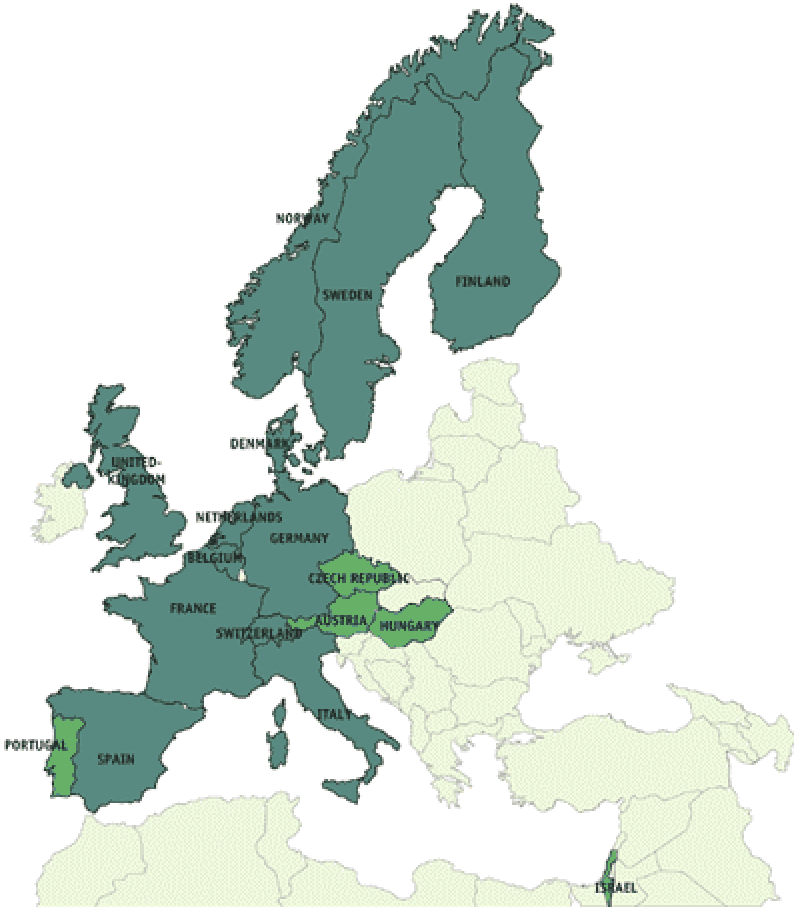
Instrumentation Division

(IO Seminar Series, February 26, 2003)

ESRF (European Synchrotron Radiation Facility) in Grenoble



ESRF Annual Budget ~ $60M



Members' share in contribution to the annual budget:

27.5% France
25.5% Germany
15% Italy
14% United Kingdom
4% Spain
4% Switzerland
6% Benesync (Belgium,Netherlands)
4% Nordsync (Denmark, Finland, Norway, Sweden)

Additional contributions
(percentages refer to Members' total contribution):

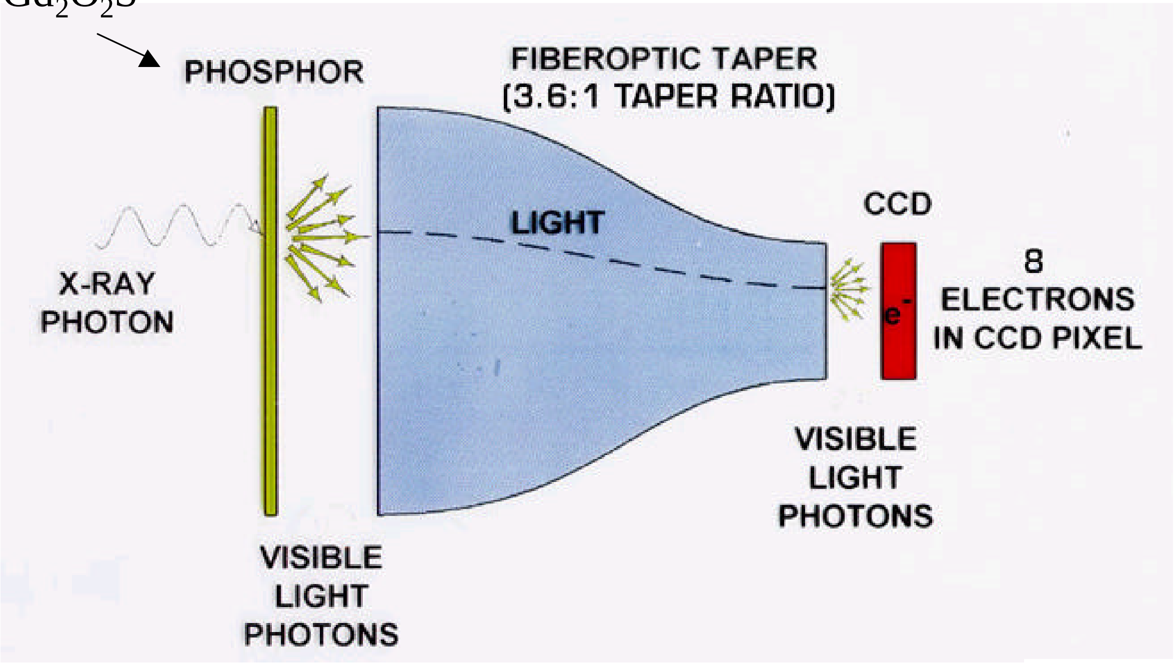
1% Portugal
1% Israel
1% Austria
0.38% Czech Republic
0.2% Hungary

Workshop Program: http://www.esrf.fr/

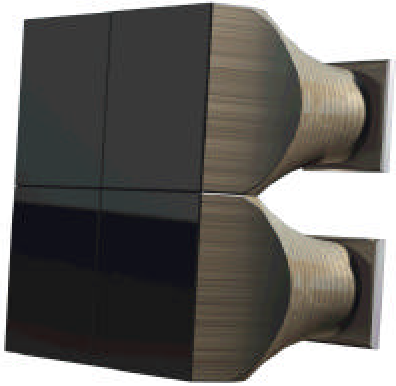
Imaging	Phosphor/CCD	Ron Hamlin, ADSC Sol Gruner, CHESS
	Solid State Pixels	Michael Campbell, CERN Sol Gruner, CHESS Jules Hendrix, MAR Research
	WAXS	MSGCs at ESRF
Spectroscopy	Energy Dispersive EXAFS	Jon Headspith, Rutherford Laboratory, UK
	Compound Semiconductors	Alan Owens, ESA/ESTEC, The Netherlands
	Cryogenic detectors	Stephan Friedrich, LLNL

Phosphor coupled to CCD

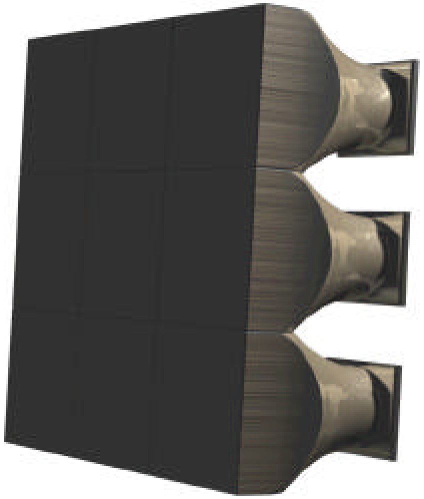
~ 10 mg cm^{-2} Gd_2O_2S



2 × 2 array



3 × 3 array



Single phosphor segment:
105mm × 105mm

	$600k	$1.25M	$1.7M

ADSC

Quantum

CCD X-Ray Detectors

	Quantum 4R	Quantum 210	Quantum 315
Detector Type:	Array (2x2); Active area: 188mm x 188mm	Array (2x2); Active area: 210mm x 210mm	Array (3x3); Active area: 315mm x 315mm
Number of Pixels:	2304 x 2304; 5.31 million	4096 x 4096; 16.8 million	6144x 6144; 37.75million
Pixel Size at Detector Surfaces:	81.6 x 81.6 microns	51 x 51 microns	51 x 51 microns
Phospher (optimized):	1 X-ray Angstrom	1 X-ray Angstrom	1 X-ray Angstrom
Spatial Resolution FWHM:	90 microns; 1.1 pixels	90 microns; 1.76 pixels	90 microns; 1.76 pixels
Taper Ratio:	3.7 to 1	3.7 to 1	3.7 to 1
Optical Coupling (CCD to Taper):	Direct bond	Direct bond	Direct bond
CCD Type:	EEV 05-30 AIMO	Thomson THX 7899 (2Kx2K)	Thomson THX 7899
CCD Pixel Size:	22.5 x 22.5 microns	14 x 14 microns	14 x 14 microns
Operating Temperature:	-50 degrees Celcius	-50 degrees Celcius	-50 degrees Celcius
Cooling Type:	Thermoelectric	Thermoelectric	Thermoelectric
Dark Current:	0.03 e/pixel/sec	0.015 e/pixel/sec	0.015 e/pixel/sec
Controller Electronics:	PI ST-138	ADSC Custom	ADSC Custom
Readout Times (Full Resolution): (2x2 binned):	9 and 3 seconds 1 second	1 second 330 milliseconds	1 second 330 milliseconds
Read Noise (Pixel Rate):	(150 kHz): 9 electrons typical	(1 MHz): 18 electrons typical	(1 MHz): 18 electrons estimated
Full Well Depth (Full Resolution):	440,000 electrons typical	270,000 electrons typical	270,000 electrons typical

??

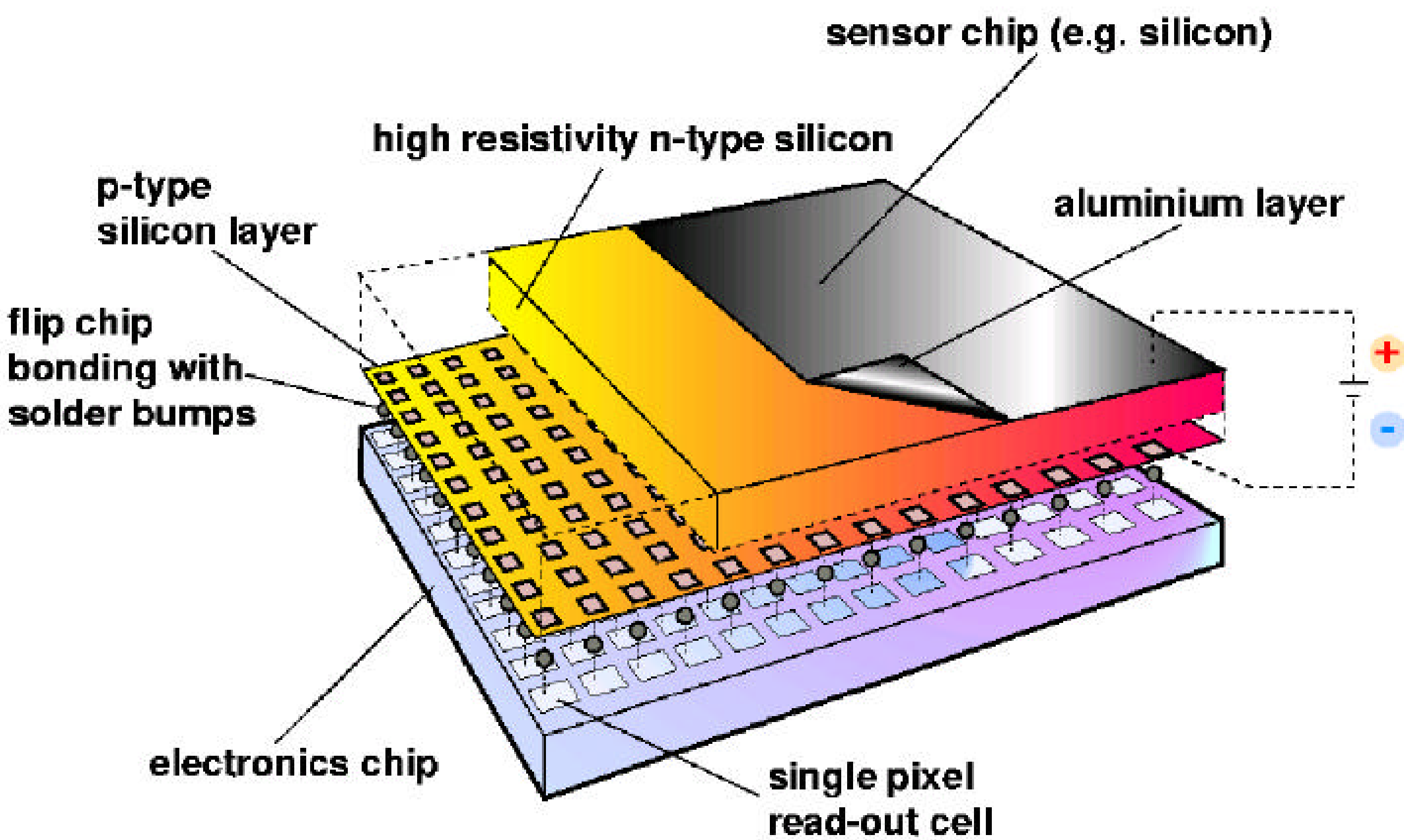
Quantum 420

3×3

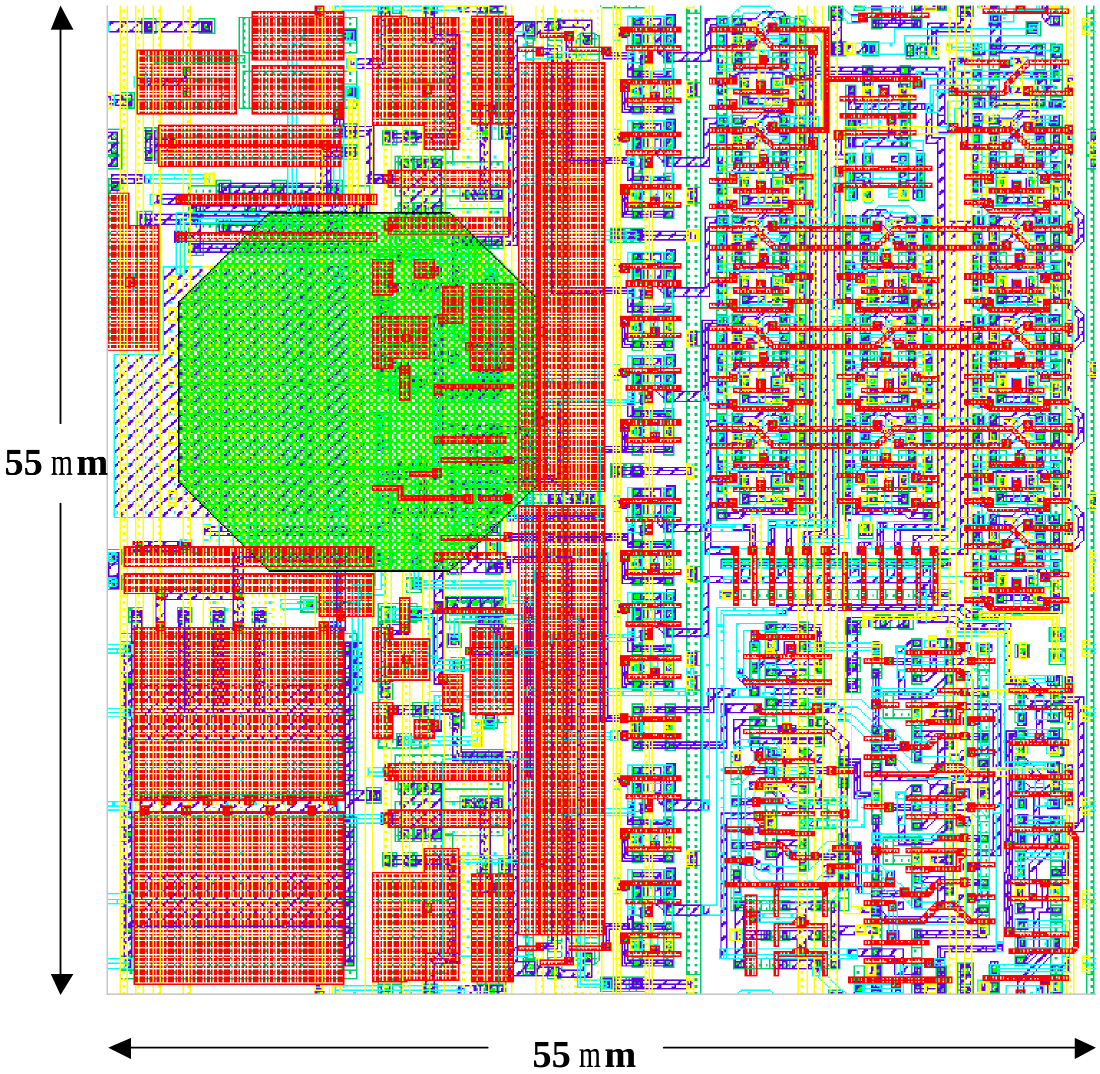
420 mm × 420mm

Hybrid Pixel Detector

Michael Campbell, CERN



Medipix2 Cell Layout

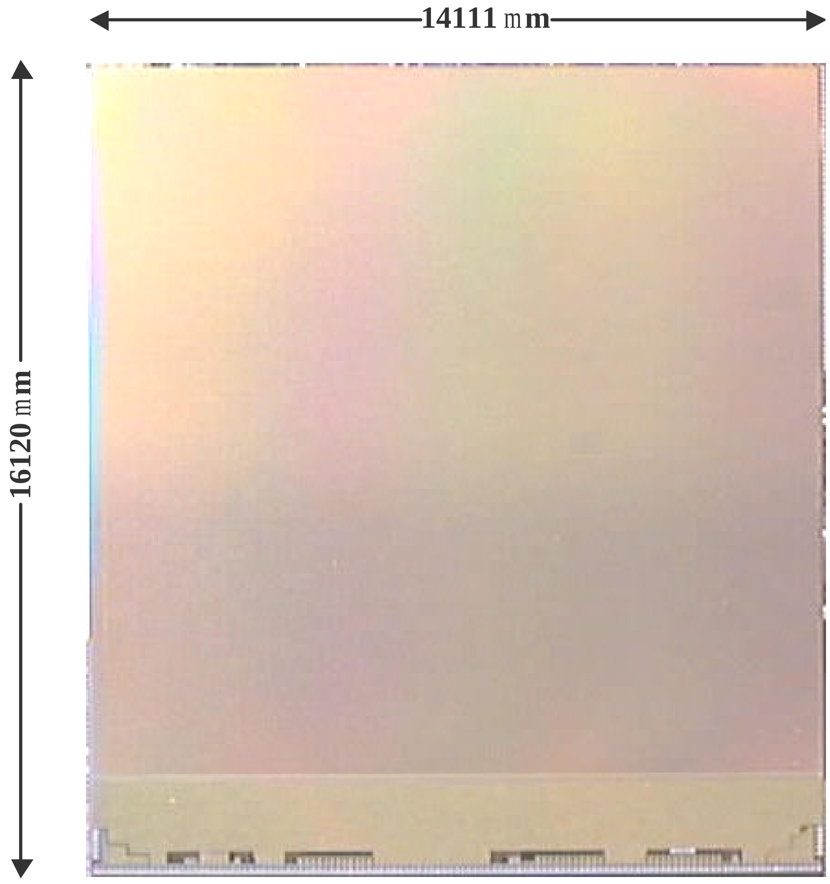


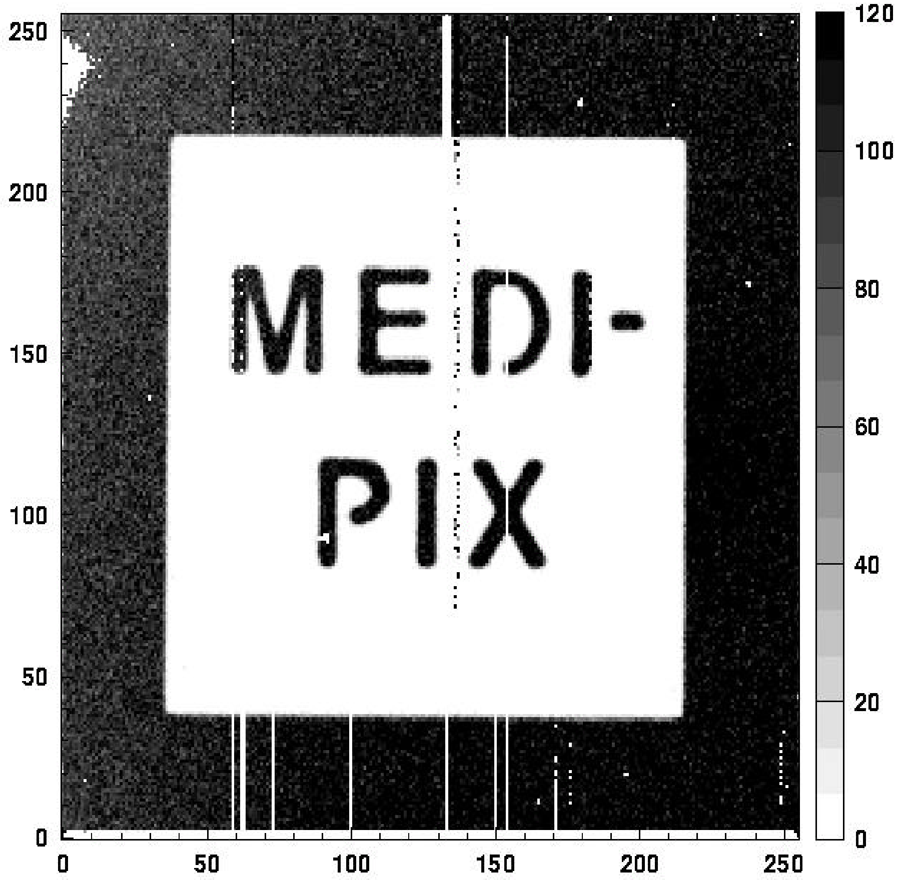
CERN: Medipix2 Chip Architecture &Performance

Single photon counting, in approximately 70,000 pixels

Limited instantaneous rate, very high dynamic range

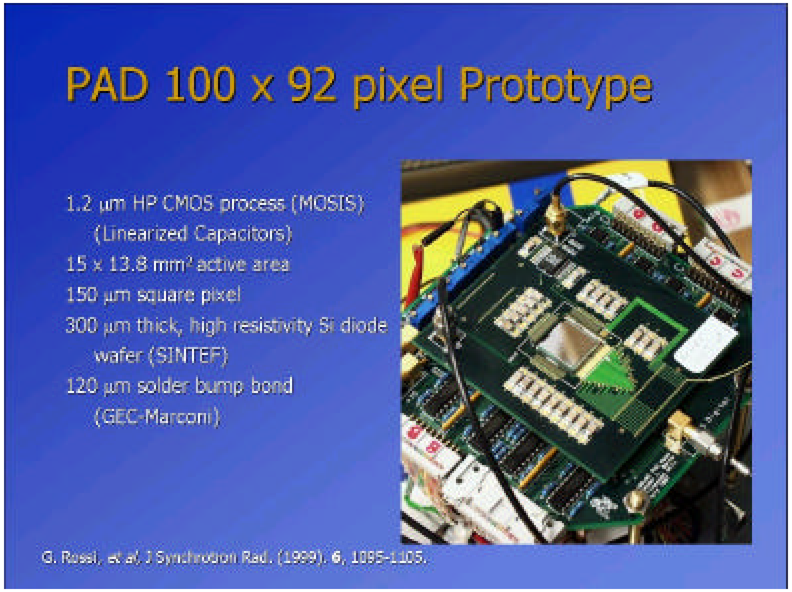
^{109}Cd irradiation

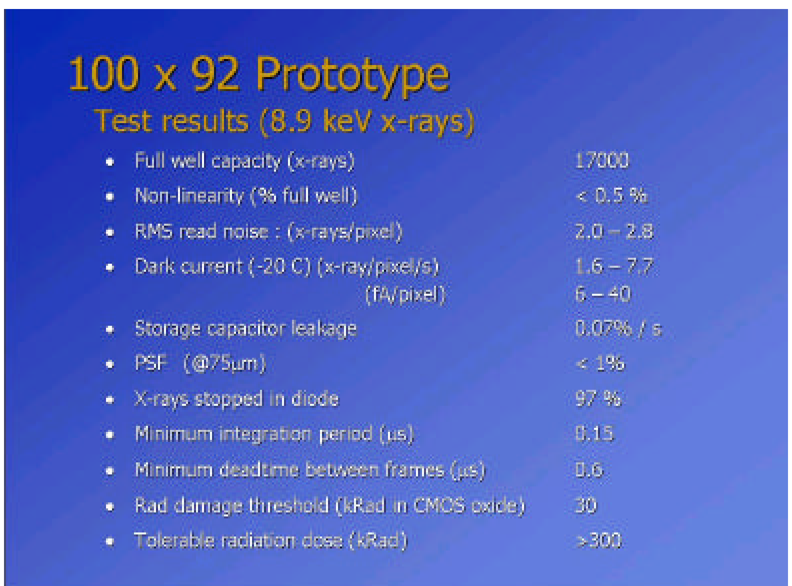




Charge integration in 9,200 pixels

High instantaneous rate, limited dynamic range





PADs – Pixel Array detectors

Sol Gruner, CHESS

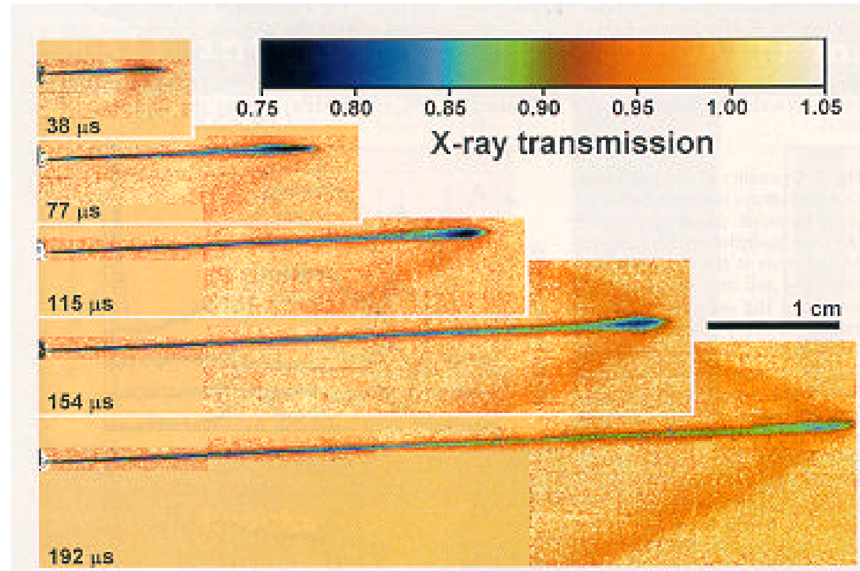
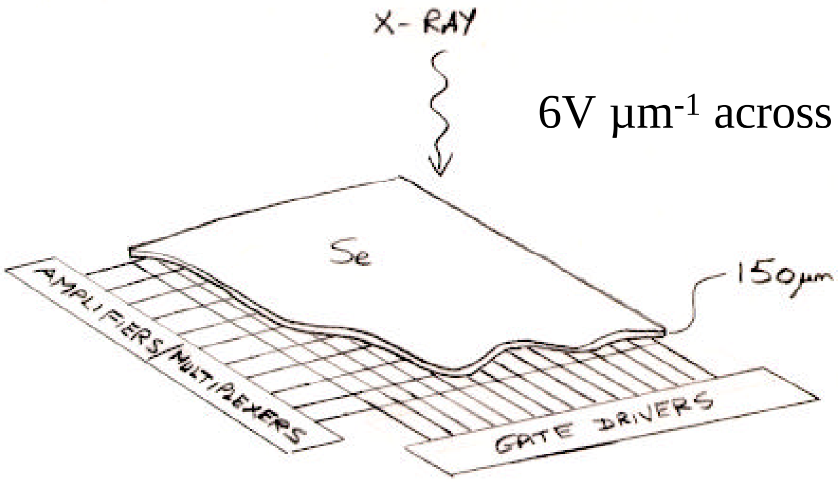


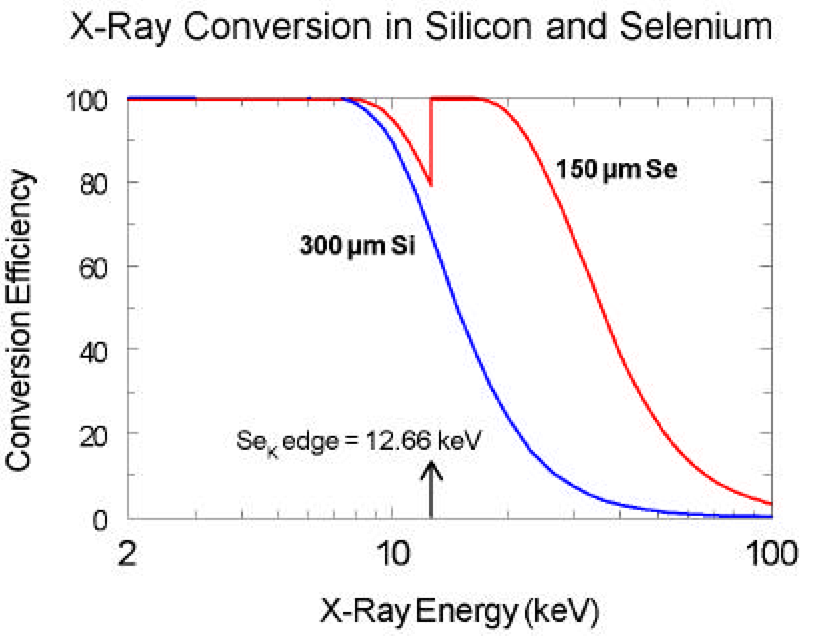
Fig. 3. Time-resolved radiographic images of fuel sprays and the shock waves generated by the sprays for time instances of 38, 77, 115, 154, and 192 μs after the start of the injection (selected from the total of 168 frames taken). The imaged area shown in the largest panel is 61.7 mm (H) by 17.5 mm (V) with data corrected for the divergence of the x-ray beam. Because the x-ray beam size in the experiment was 13.5 mm (H) by 2.5 mm (V), the imaged area was built up by shifting the position of the injector relative to the beam and the PAD and repeating the injection cycle. Boundaries between these areas can be seen upon close inspection. The exposure time per frame was set to 5.13 μs (twice the CHESS synchrotron period) with subsequent images taken after an additional 2.56-μs delay. Each position shown is the average of images from 20 fuel injection cycles. The detector was not positioned over all possible areas of the image, so specific images show missing areas. To optimize the conditions for the direct visualization of the shock waves, we chose the injection pressure to be 135 MPa. The contrast of the shock wave was low, corresponding to only an average of about 15% increase in gas density near the shock front. Therefore, the false-color levels of the images have been set to accentuate small differences in the x-ray intensity arising from the slightly increased x-ray absorption in the compressed SF_6 gas. The progression of the shock wave can be seen much more clearly in the "movie" of successive frames (26).

Movie at: http://bigbro.biophys.cornell.edu/

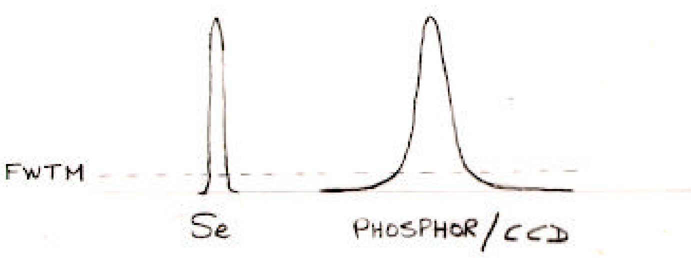
X-ray Conversion in Selenium



6V μm^{-1} across Se



Position response to point beam:



Selenium Flat Panel Detector

420 mm x 350 mm solid state detector

marresearch

Flat Panel Detector

- Fully solid-state technology
- No phosphor involved : The system is based on the direct conversion of X-rays into charges.
- Result: an unprecedented spatial resolution
- No tiling of the active area of 420 mm x 350 mm
- No geometric distortion
- Fast read-out and data storage: one second
- Negligible dark current: No cooling system required

This new fully solid-state detector is based on the direct conversion of the absorbed x-rays into charges. The charges follow electric field lines in the Selenium photoconductor. This direct conversion makes the use of phosphors and optical elements (e.g. optic tapers) obsolete. Consequently, the spatial resolution is extremely high. The point-spread function is well within one pixel. Measurements have shown that the reflection spot sizes and separation depend mainly on the source size, beam size, crystal size and beam divergence. Due to the high spatial resolution, reflections occupy a low number of pixels. The signal-to-noise ratio improves because a lower number of pixels contribute to the background- and read out noise.

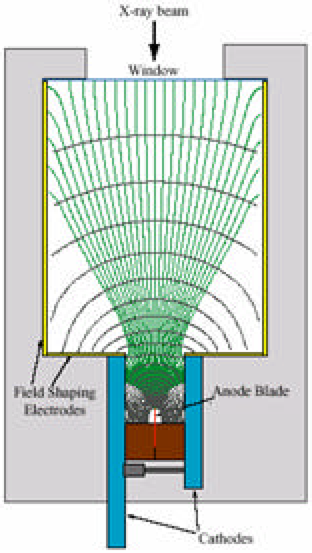
Technical Specifications:

• Size	Untiled active area of 420 mm x 350 mm
• Pixel size	140 µm x 140 µm
• Number of pixels	7.800.000
• Spatial resolution	point spread function less than 1 pixel
• Dynamic range	full 16 bit
• Sensitivity	1 to 1.5 X-rays per ADC-unit, depending on energy
• Read noise	4 X-rays @ 12 keV
• Read-out time	≅ one second

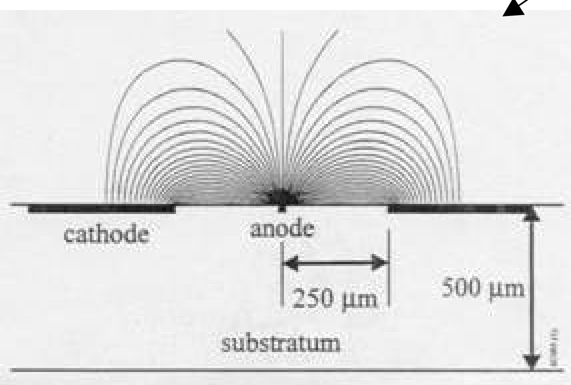
X-ray Research G.m.b.H.
Segeberger Chaussee 34
22850 Norderstedt, Germany

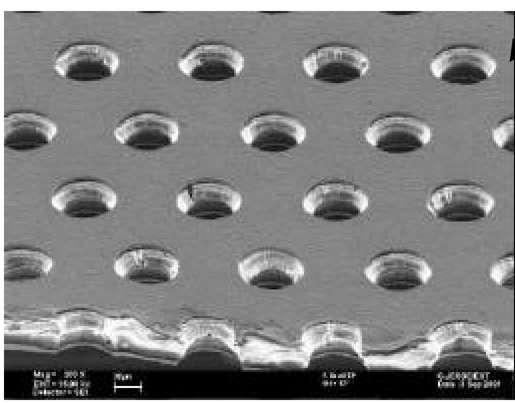
Mar USA, Inc.
1880, Oak Avenue
Evanston, IL 60201, USA

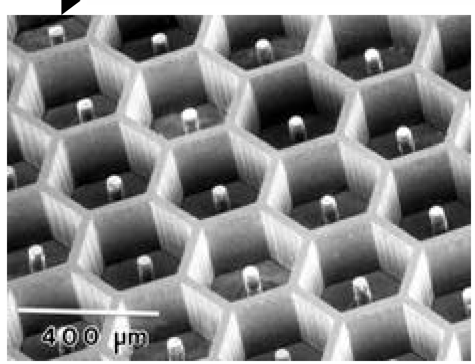
Micropattern Gaseous Detectors



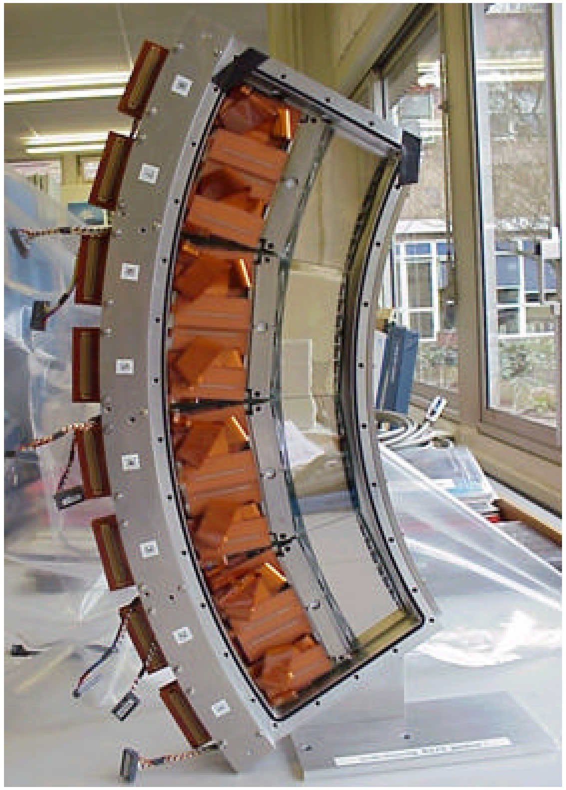
Acronym	*Translation*	*Origination*
Blade	Blade	1980's
MSGC	Micro-Strip Gas Chamber	A. Oed, Grenoble, 1988
MGC	Micro-Gap	R. Bellazzini, Italy, 1995
CAT	Compteur A Trou	F. Bartol et al France 1995
GEM	Gas Electron Multiplier	F. Sauli, CERN 1996
Micromegas	MICRO-Mesh Gaseous Structure	Y. Giomataris, France 1996
MIPA	Micro-Pin Array	P. Rehak, BNL, 1999







ESFR Beam Line X26



WAXS MSGC Detector	
Count Rate	4×10^5 / s / channel
Time Resolution	1.5 ms / frame
Energy Range	5-25 keV
Opening Angle	60°
Angular Resn	0.03 °
Radius of curvature	360 mm (from anodes)

A Fast Position Sensitive Microstrip-Gas-Chamber Detector at High Count Rate Operation

I.P. Dolbnya, H. Alberda, F.G. Hartes, F. Udo, R.E. Bakker, M. Konijnenburg, E. Homan, I. Cerjak,, P. Goedtkindt and W. Bras

Rev. Sci Instrum. 73 (2002) 3754- 3758

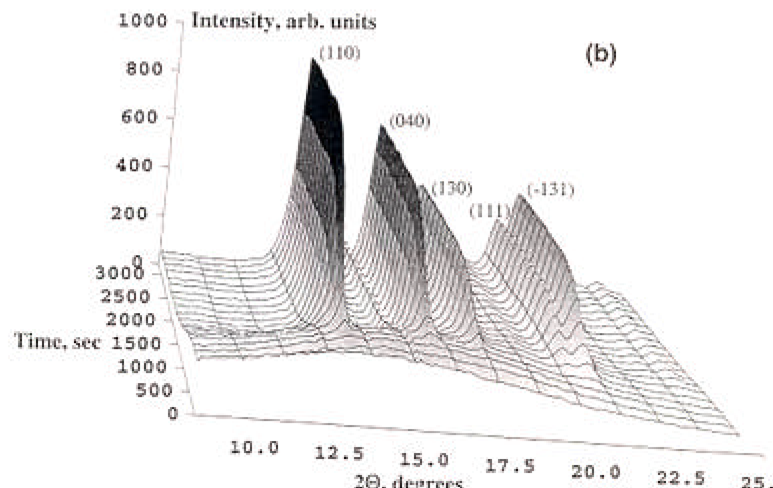


FIG. 6

Time development of WAXS patterns of isothermally crystallizing iPP at 130° demonstrate different stages of the crystallization process (10 keV)

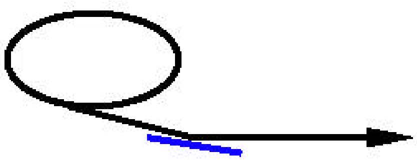
X-ray Absorption Spectroscopy

Synchrotron beam

Intense, monochromatic, tunable

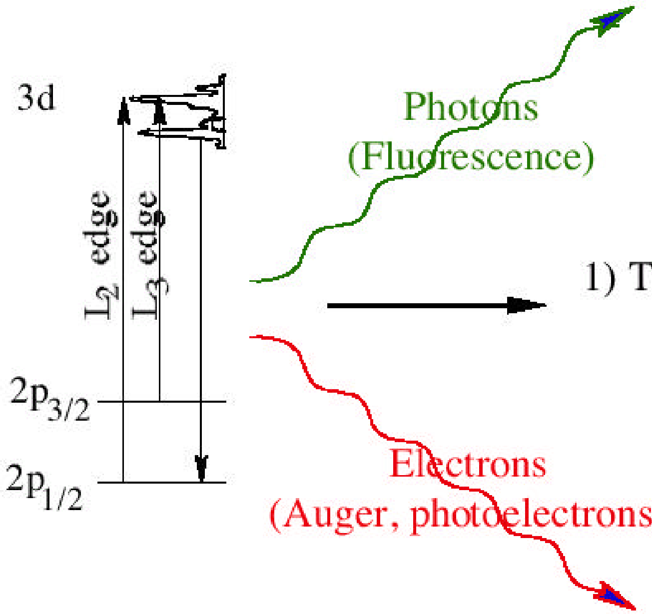
$I_0 \approx 10^{12}$ photons/s

$\Delta E = 0.1$ eV



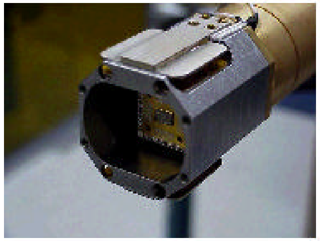
Sample x

Absorption $\mu_x(E)$



Detection

3) Fluorescence $\propto I_0 \cdot \mu_x$ (E)



1) Transmission $\propto I_0 (1 - \mu_x - \mu_{bgnd})$

Thin samples

High background

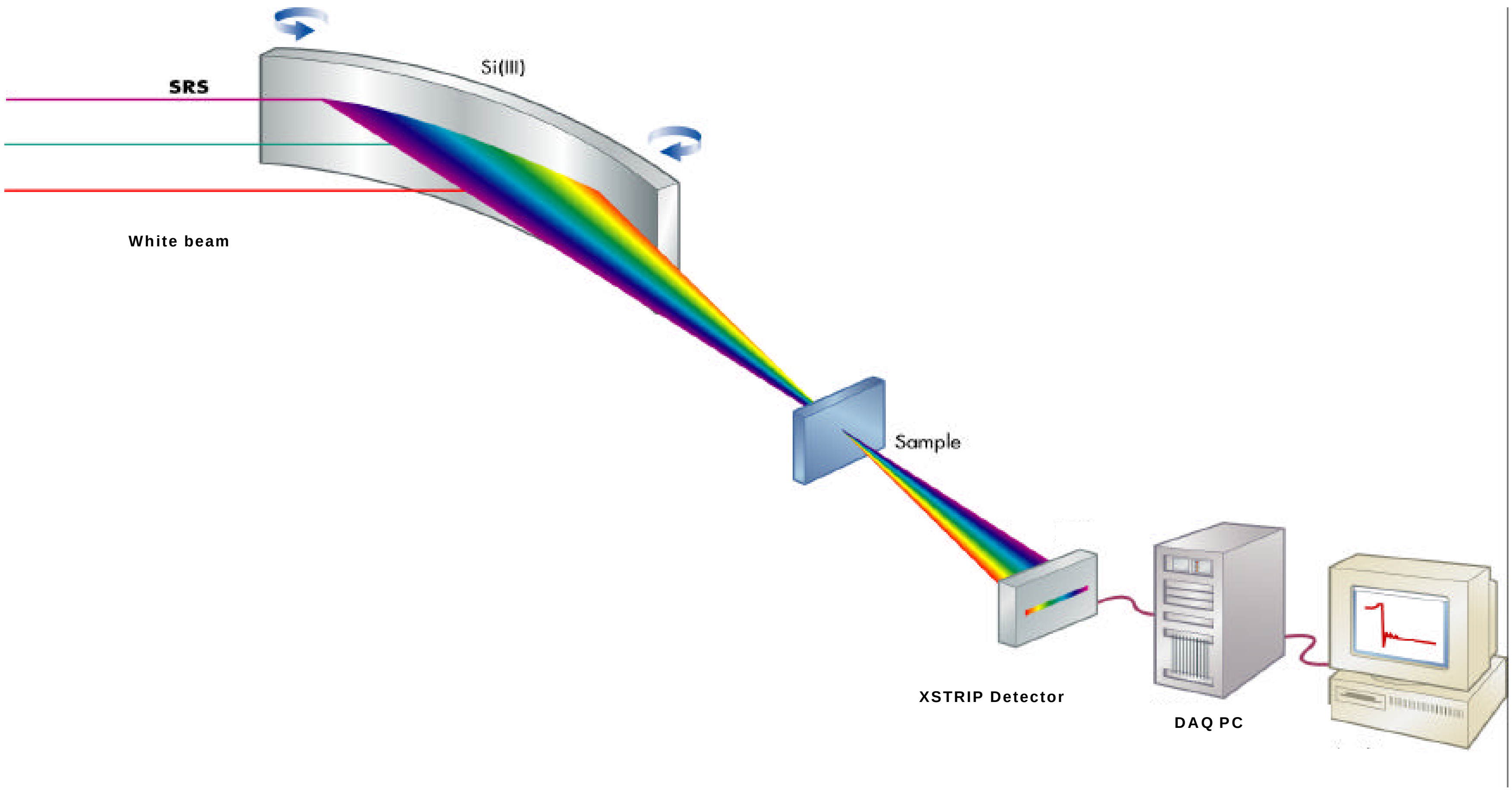
2) Electron signal $\propto I_0 \cdot \mu_x$ (E)

Surface sensitive

Moderate background

Energy Dispersive EXAFS (EDE)- Technique

Jon Headspith, Darebury Laboratory, UK

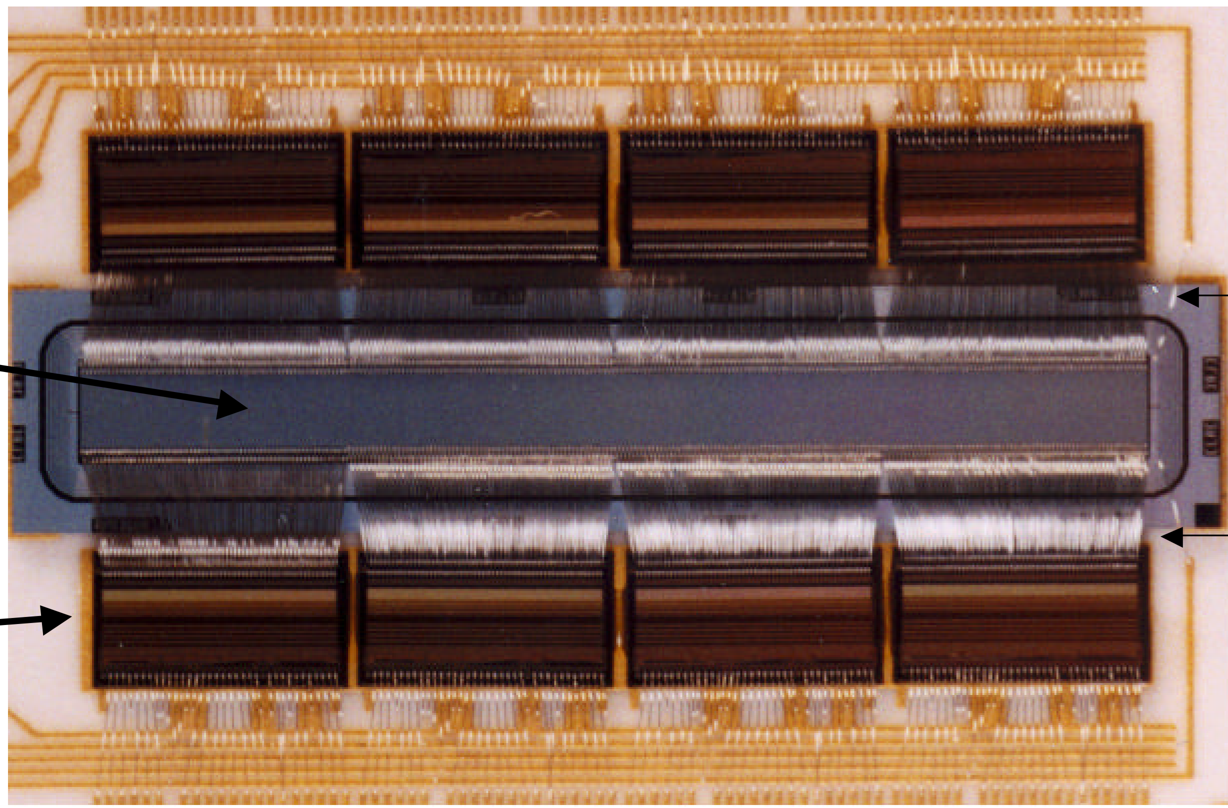


CCLRC Silicon microstrip based system (XSTRIP)

1024 strips on a 25 µm pitch

Si microstrips

Readout ASICs

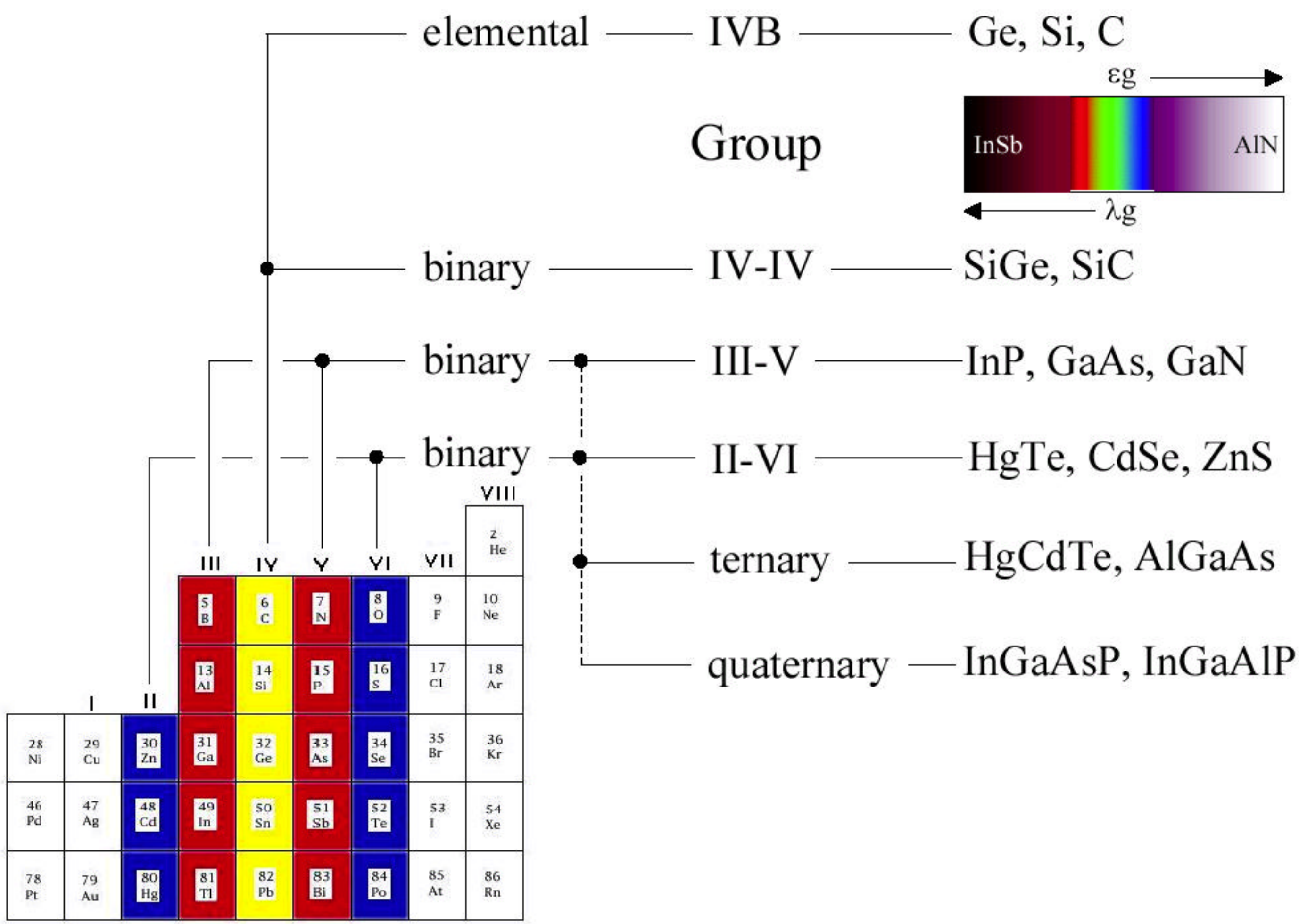


50 µm pitch

50 µm pitch

Alan Owens, ESA/ESTEC, The Netherlands

What are compound semiconductors?



Advantages of compound semiconductors

- Wide variety of compounds available
- Compounds can be selected for specific environments
- Materials can be engineered for specific applications
- Ability to match response and energy resolution to an application
- Wide range of stopping powers

  mass and cost benefits for planetary spacecraft, surgical probes

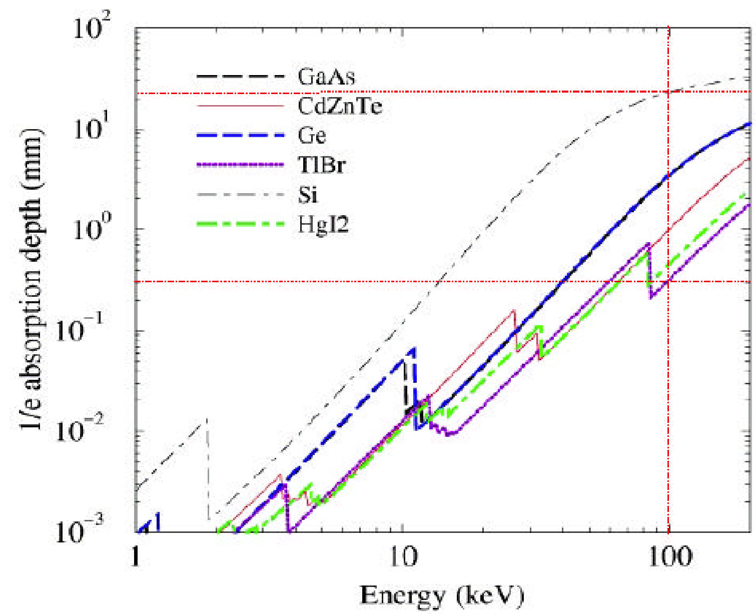
Material Properties

Summary of some material properties:

	Z	E_G (eV)	ω (eV/ehp)	r_i at RT (Ω)
Diamond	6	5	13	>10^{13}
SiC	6/10	3.3	8.4	10^{13}
Si	14	1.12	3.6	~10^{4}
Ge	32	0.66	2.0	50
GaAs	31/33	1.4	4.3	10^{8}
InP	49/15	1.4	4.2	10^{7}
CdTe	48/52	1.4	4.4	10^{9}
CdZnTe	48/52	1.6	4.7	10^{11}
HgI_2	80/53	2.1	4.2	10^{13}
TlBr	81/35	2.7	5.9	10^{11}

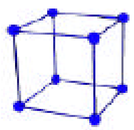
NB, wide range of stopping powers available with similar energy resolutions

40µm of GaAs is equivalent to 500 µm Si - same resolution



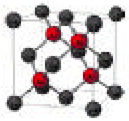
Pros and Cons of Current Detector Material

Si



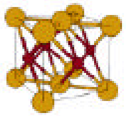
- ✓ well developed technology
- ✓ heritage
- ✓ well matched to optics
- ✗ limited X-ray response
- ✗ not rad hard
- ✗ cooling issues

GaAs



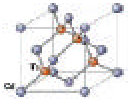
- ✓ near Fano
- ✓ RT operation possible
- ✓ well matched to optics
- ✓ hard X-ray response
- ✓ rad hard
- ✗ development issues

HgI_2



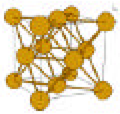
- ✓ near Fano
- ✓ RT operation
- ✓ hard X-ray response
- ✓ very rad hard
- ✗ difficult to work with
- ✗ soft

CdZnTe



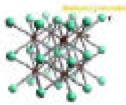
- ✓ sub-keV energy resolution
- ✓ hard X-ray response
- ✓ seems rad hard
- ✓ RT operation
- ✗ expensive (HPB)

Ge



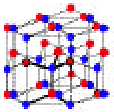
- ✓ Fano limited
- ✓ hard X-ray response
- ✗ not rad hard
- ✗ cryogenics
- ✗ fabrication problems

TlBr



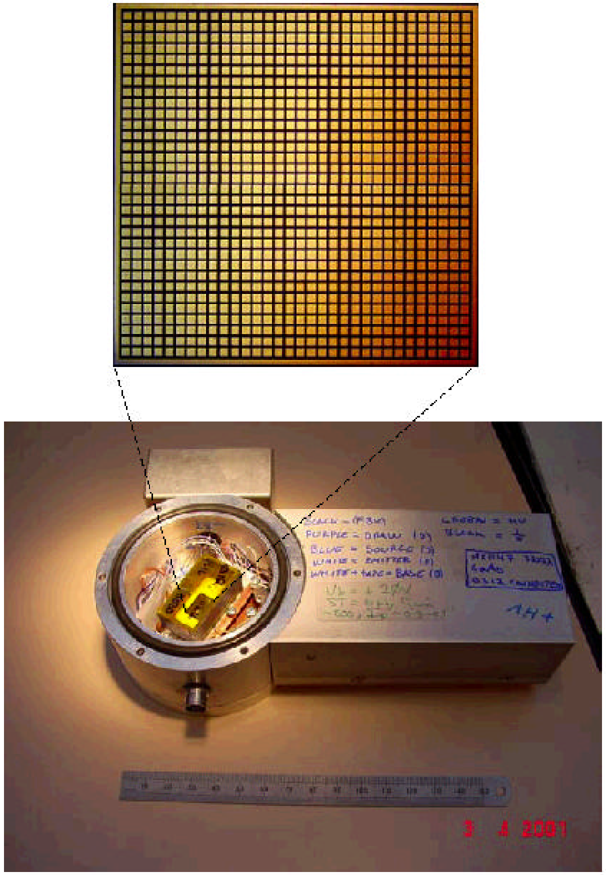
- ✓ sub-keV energy resolution
- ✓ hard X-ray response
- ✓ rad hard
- ✗ polarization effects
- ✗ difficult to work with
- ✗ toxic (genetic modifier)

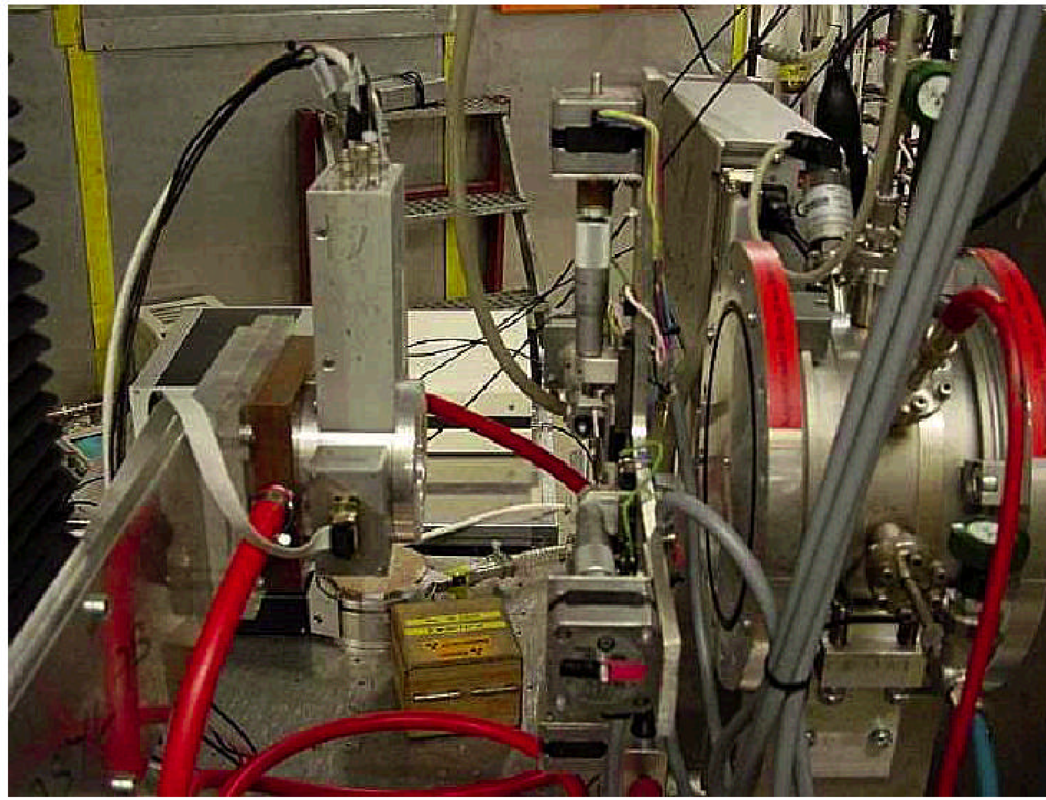
SiC



- ✓ kev energy resolution
- ✓ stable, chemically inert
- ✓ very rad hard
- ✗ poor transport properties

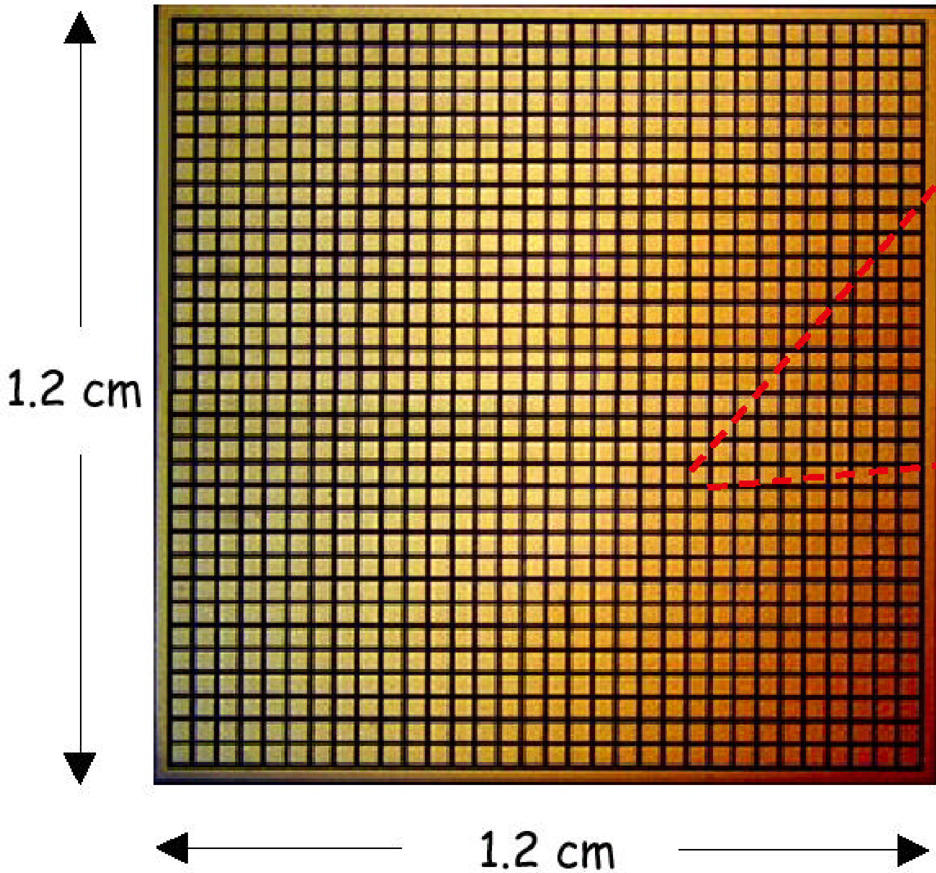
GaAs prototype 32 x 32 array - HASYLAB tests

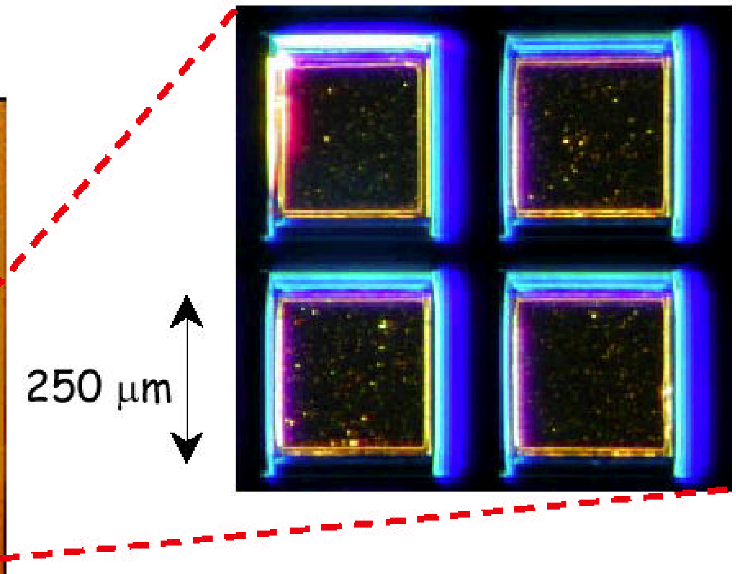




Beamline X-1

GaAs 32 x 32 array

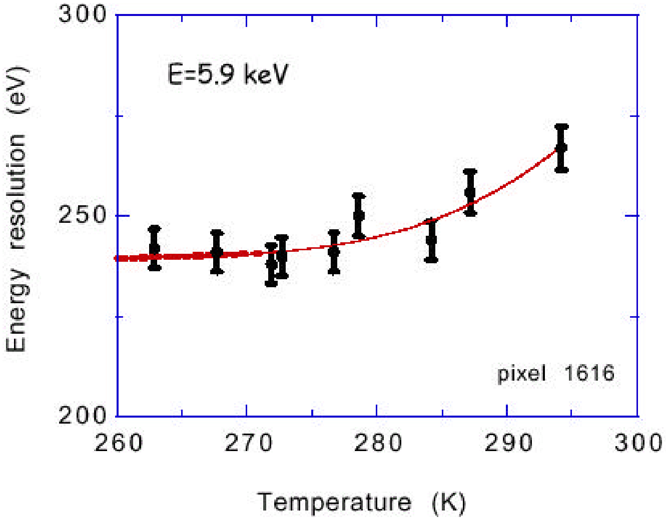


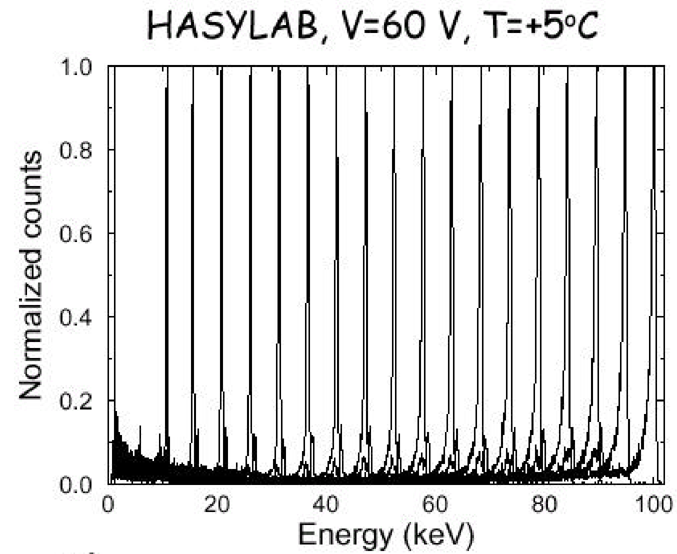


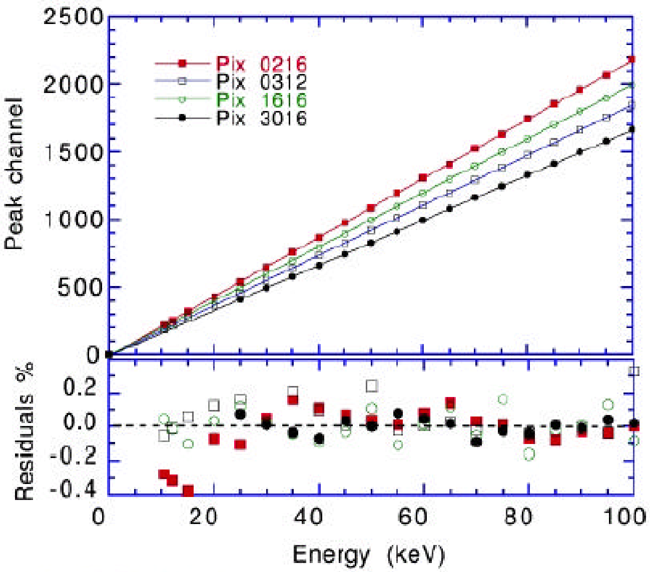
Design goal ΔE=180 eV @ 5.9 keV

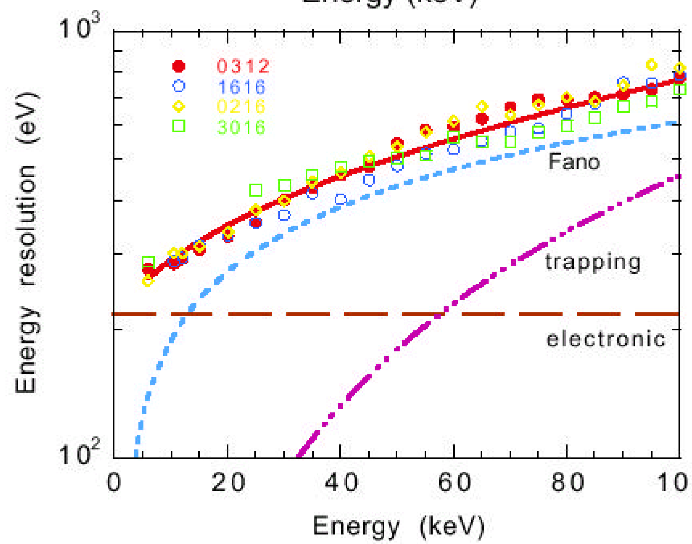
Pitch 300 µm, pixel size 250µm
Thickness 40 µm, 4 µm p^+, <1 µm n^+
Inter-pixel resistivity > $10^{10}\Omega$

GaAs prototype 32 x 32 array - first results









Erd *et al.*, Nucl. Instr. and Meth **A487** (2002) 78.

Outline: Why Cryogenic Detectors?

- Why low T? → Low thermal noise / Small excitation energies → High energy resolution

- Which technologies?

	Tunnel Junctions	Microcalorimeters
Operating Principle	$E \rightarrow \Delta Q$	$E \rightarrow \Delta T$
Resolution (0.1 to 6 keV)	2 - 12 eV FWHM	2 - 5 eV FWHM
Max. count rate	~10,000 cts/s	~500 cts/s

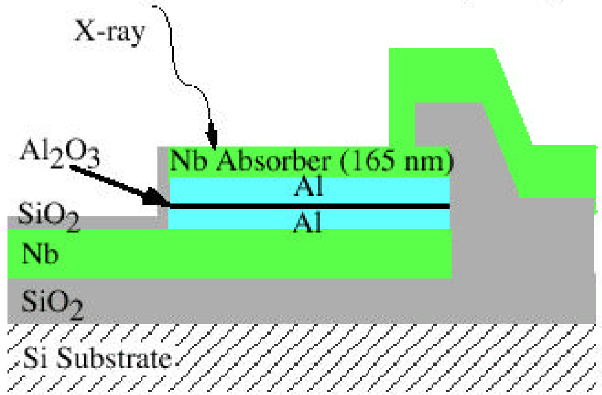
Both detectors have small pixel sizes $(\sim 0.2\ mm)^2$ and are operated around 0.1 K.

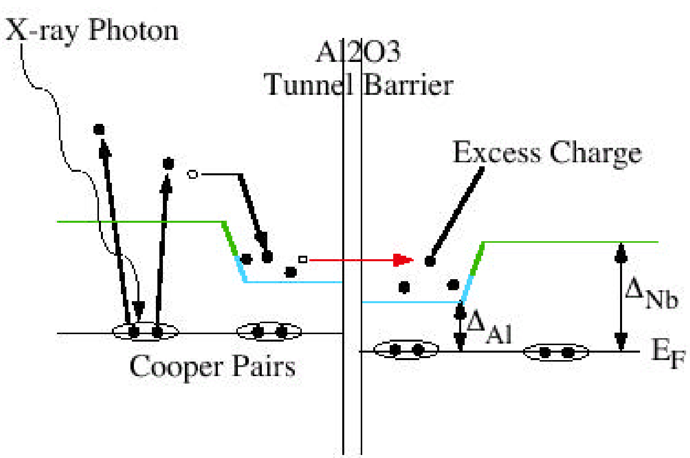
- What for?

Fluorescence-detected absorption spectroscopy of dilute samples

Superconducting Detector Technologies

Tunnel Junctions (STJ)

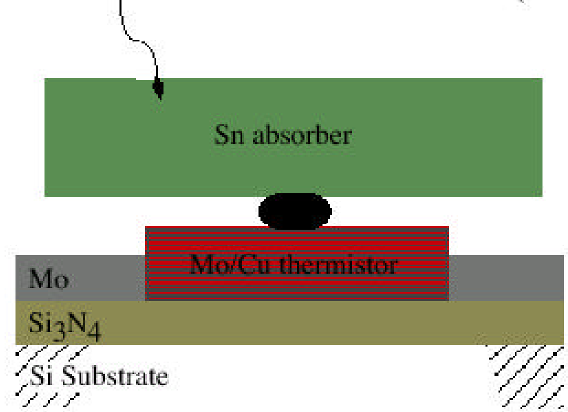


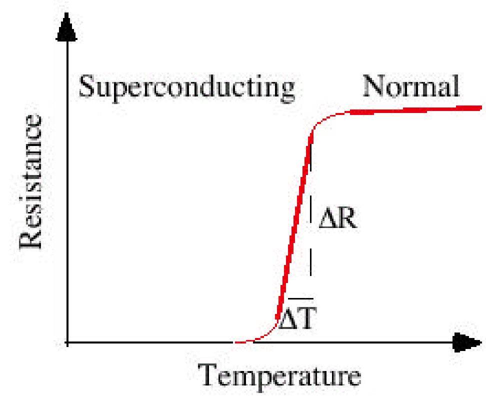


Signal = Current Pulse

High resolution, faster

Microcalorimeters (TES)



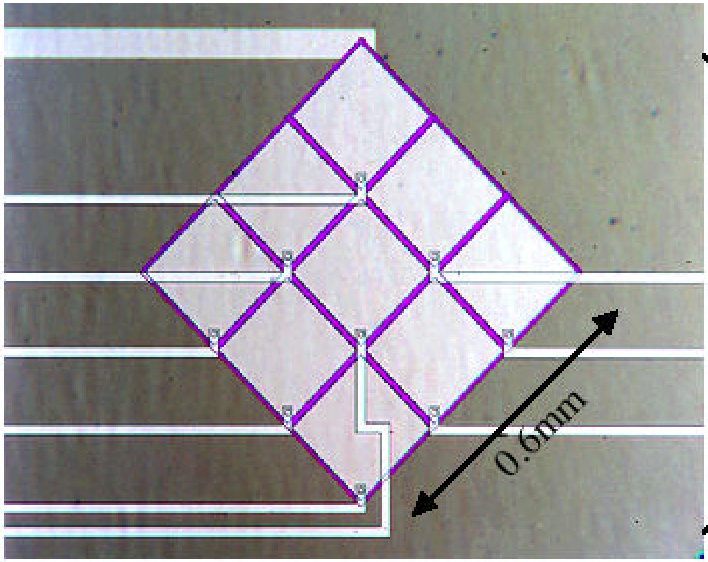


Signal = Resistance Change

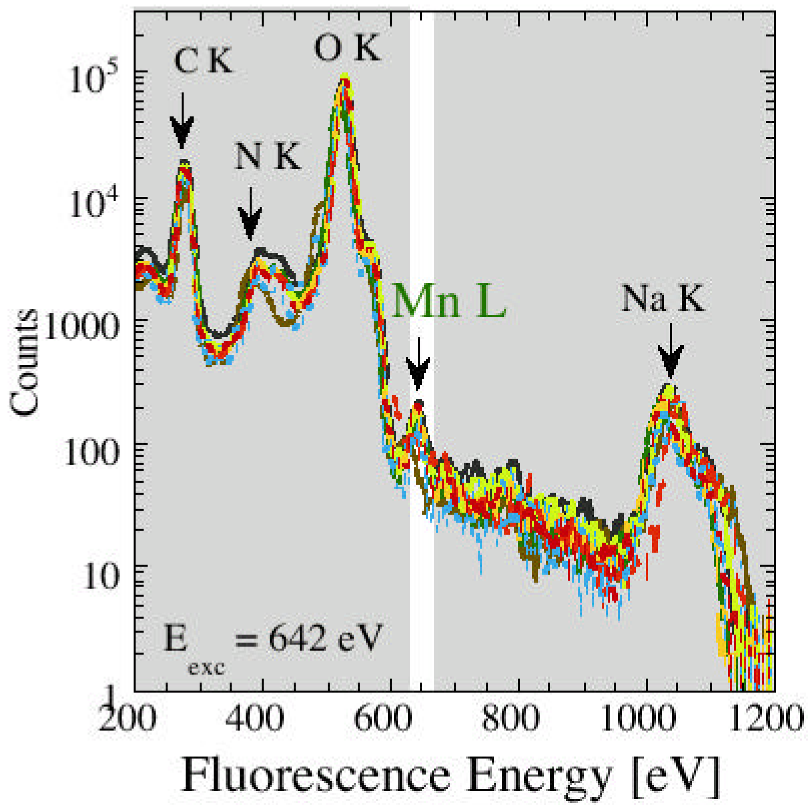
Highest resolution, slower

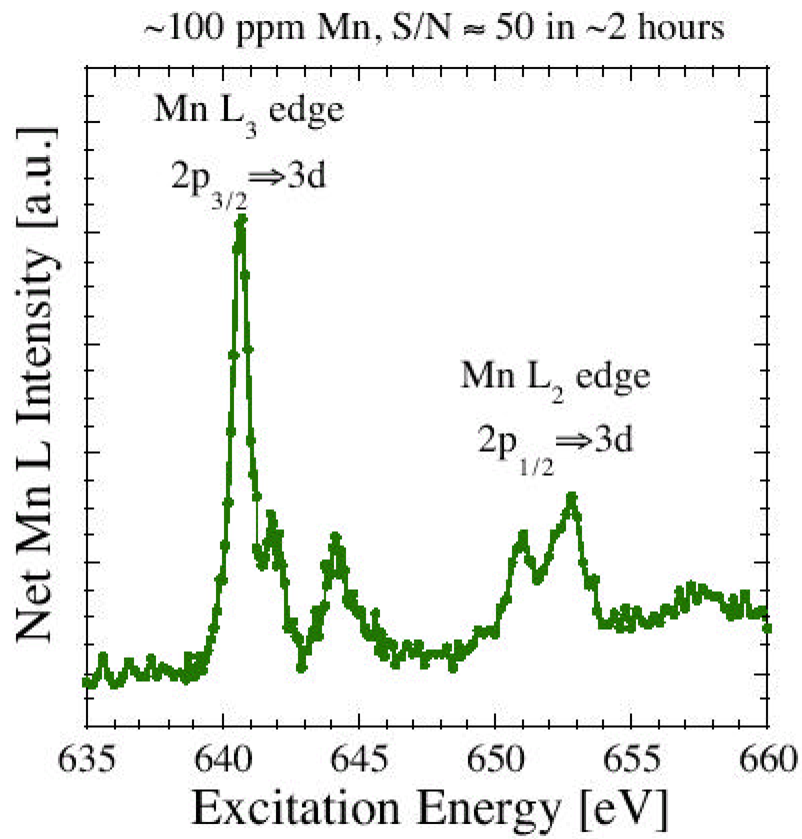
Two-Stage ADR with Cold Finger

- 70 mK base T, 20h below 0.4K
- 3×3 array at ≈15mm $\Rightarrow \Omega/4\pi \approx 10^{-4}$
- ≈15eV FWHM, >100,000 cts/s max



X-Ray Absorption Spectroscopy on Proteins

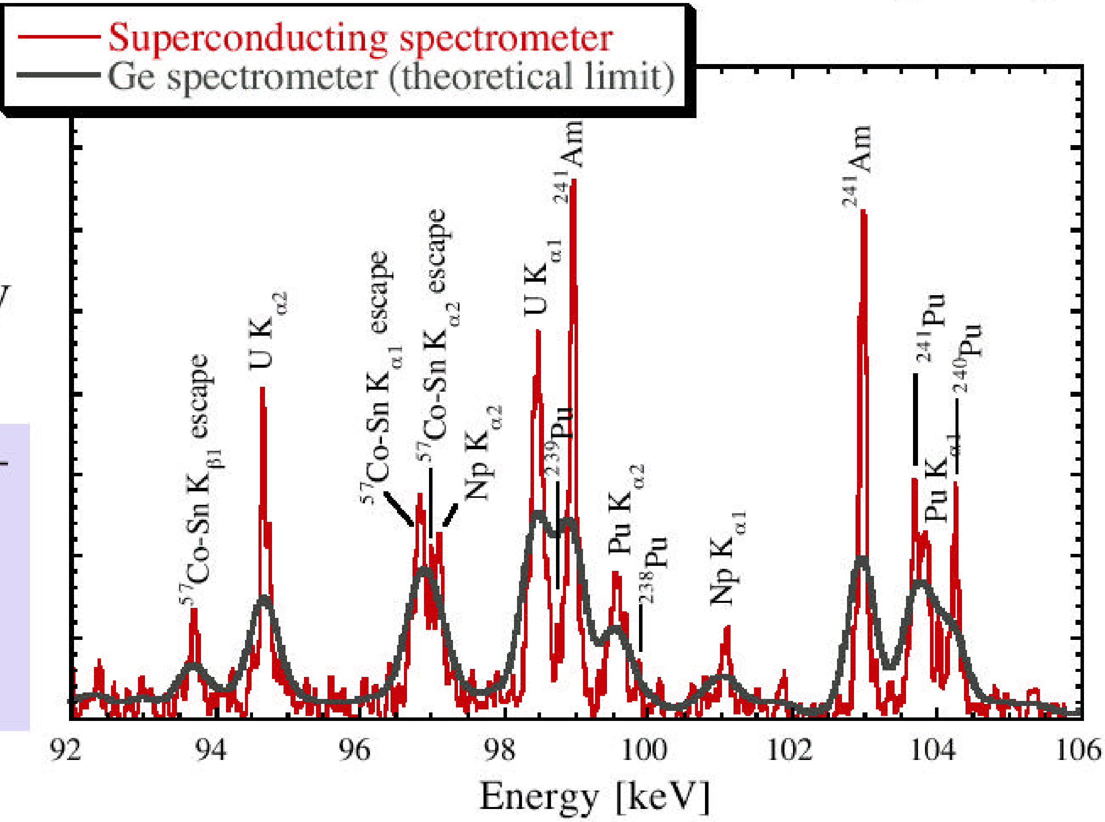




Spectrometer sensitivity is sufficient for ~100 ppm samples

Gamma Ray Spectrometry

First measurements of SNM: Pu mixed isotope sample



$\Delta E_{FWHM} \approx$ 60-90eV at 100keV

Superconducting γ-ray spectrometers enable high-resolution spectroscopy in cases where Ge detectors fundamentally limited by device physics.

Some observations:

- Strip/pixel arrays (imaging, spectroscopy…) becoming increasingly popular. ASIC revolution is essential.

- Gas-based detectors continue (and will continue) in niche activities, representing less expensive solutions.

- Significantly more detector R&D support and effort in Europe than in US.