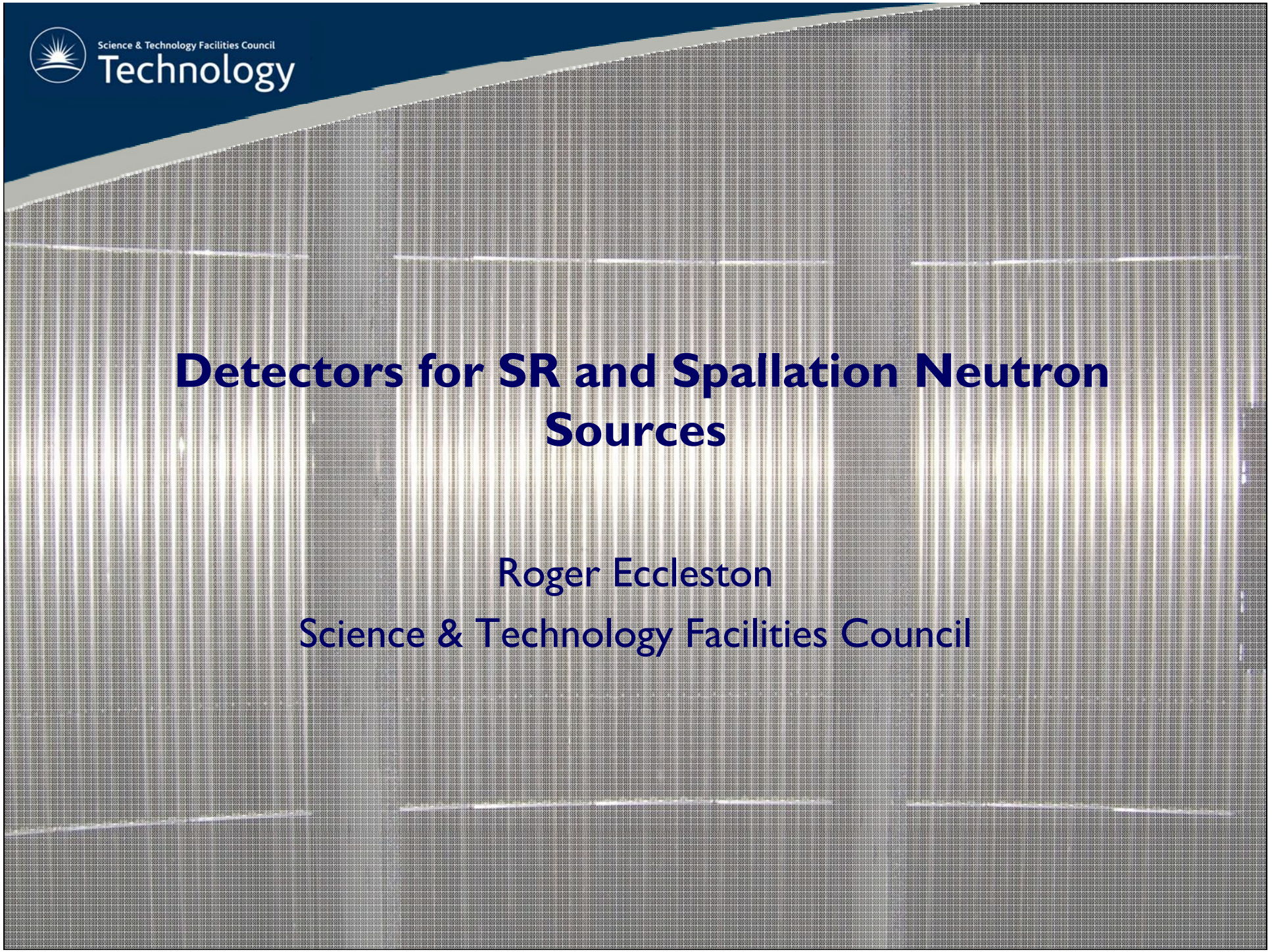


# Detectors for SR and Spallation Neutron Sources

Roger Eccleston
Science & Technology Facilities Council

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Technology
PETRA III

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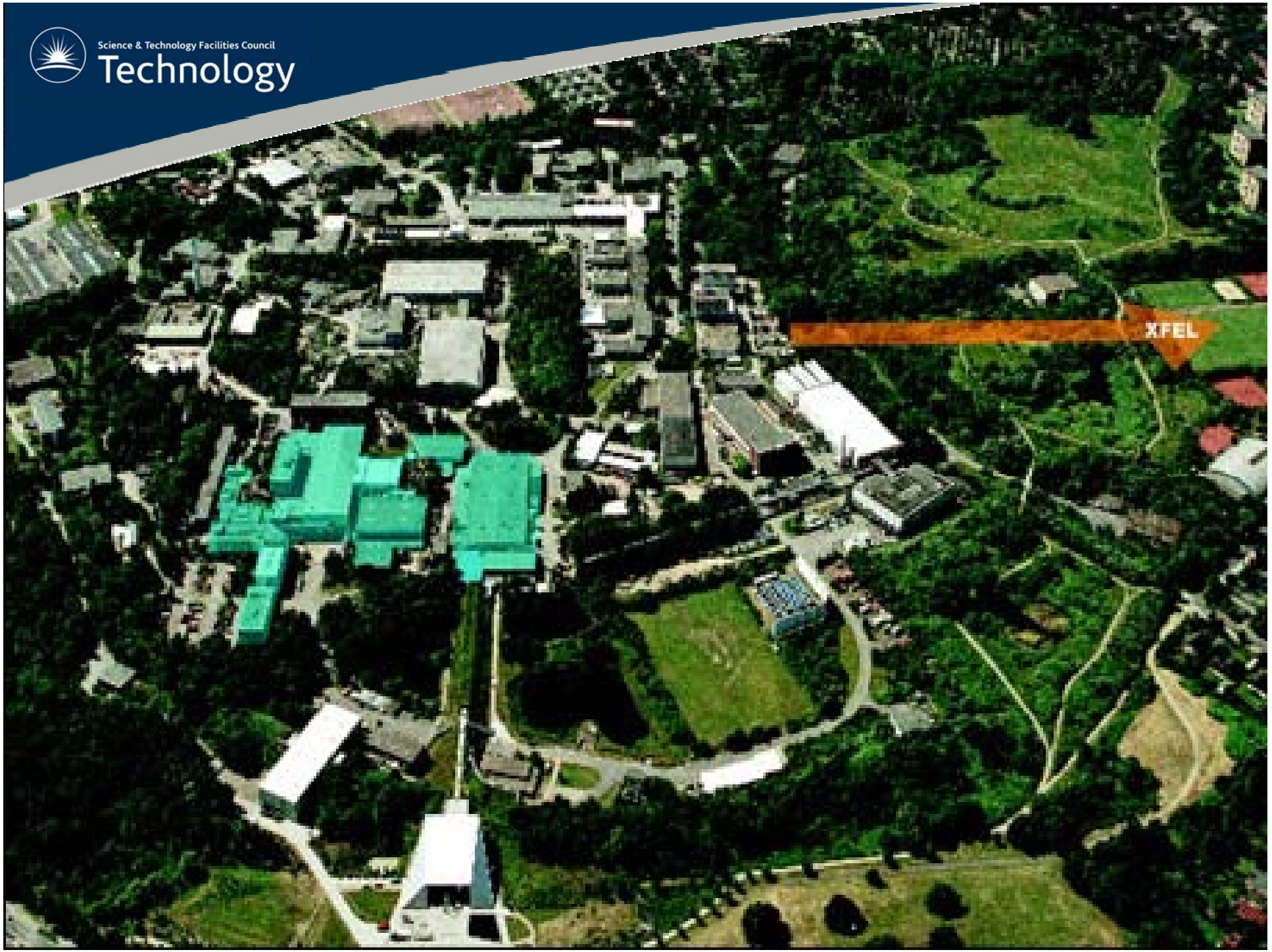
# Technology



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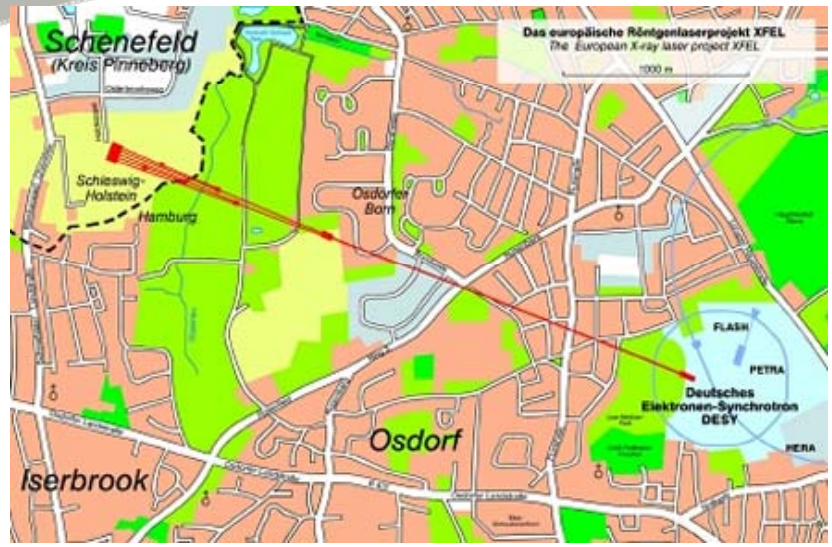



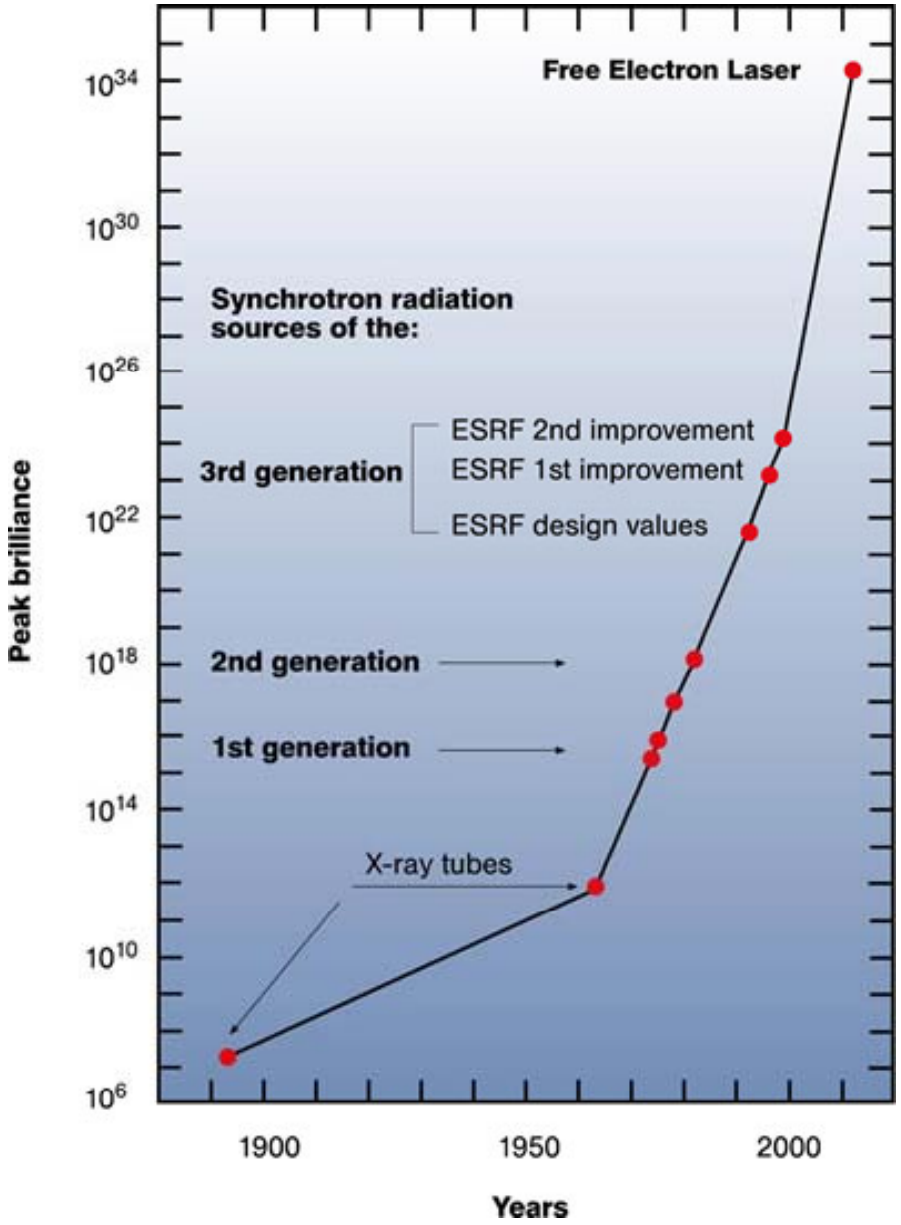

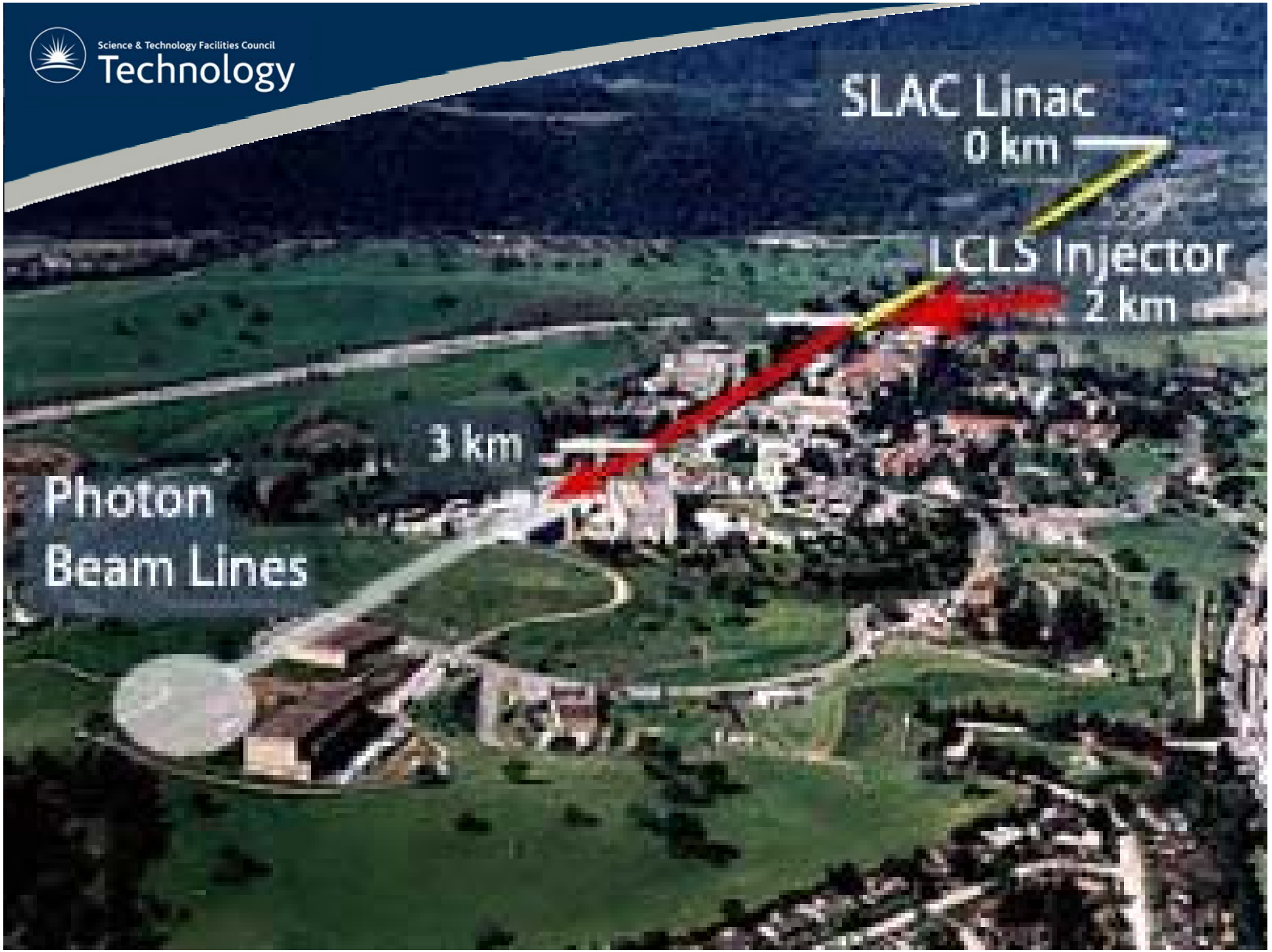
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Technology
SLAC Linac
0 km
LCLS Injector
2 km
3 km
Photon
Beam Lines


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# Technology


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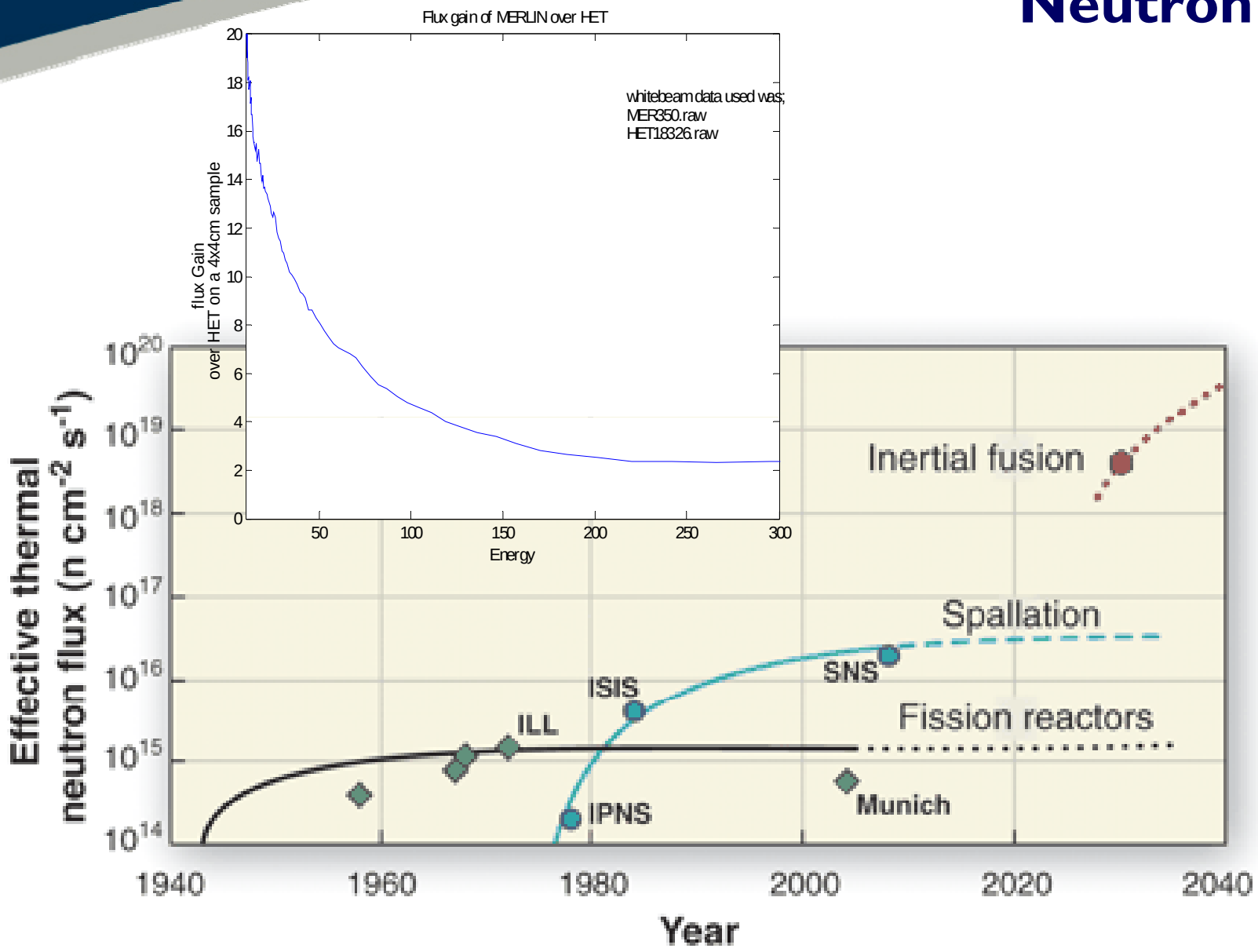
# Neutron Flux



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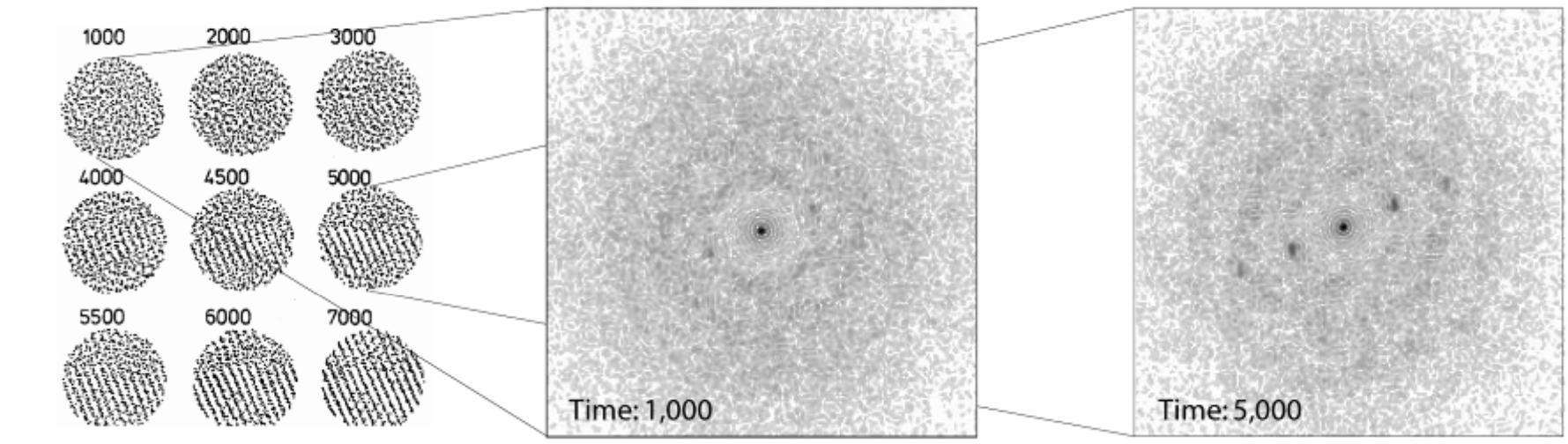
# Complex Experiments

- Weak signals
- Pump probe
  - Changes in spin states – fluorescence
  - Non-equilibrium dynamics
- Tomography
- Isotopic substitution



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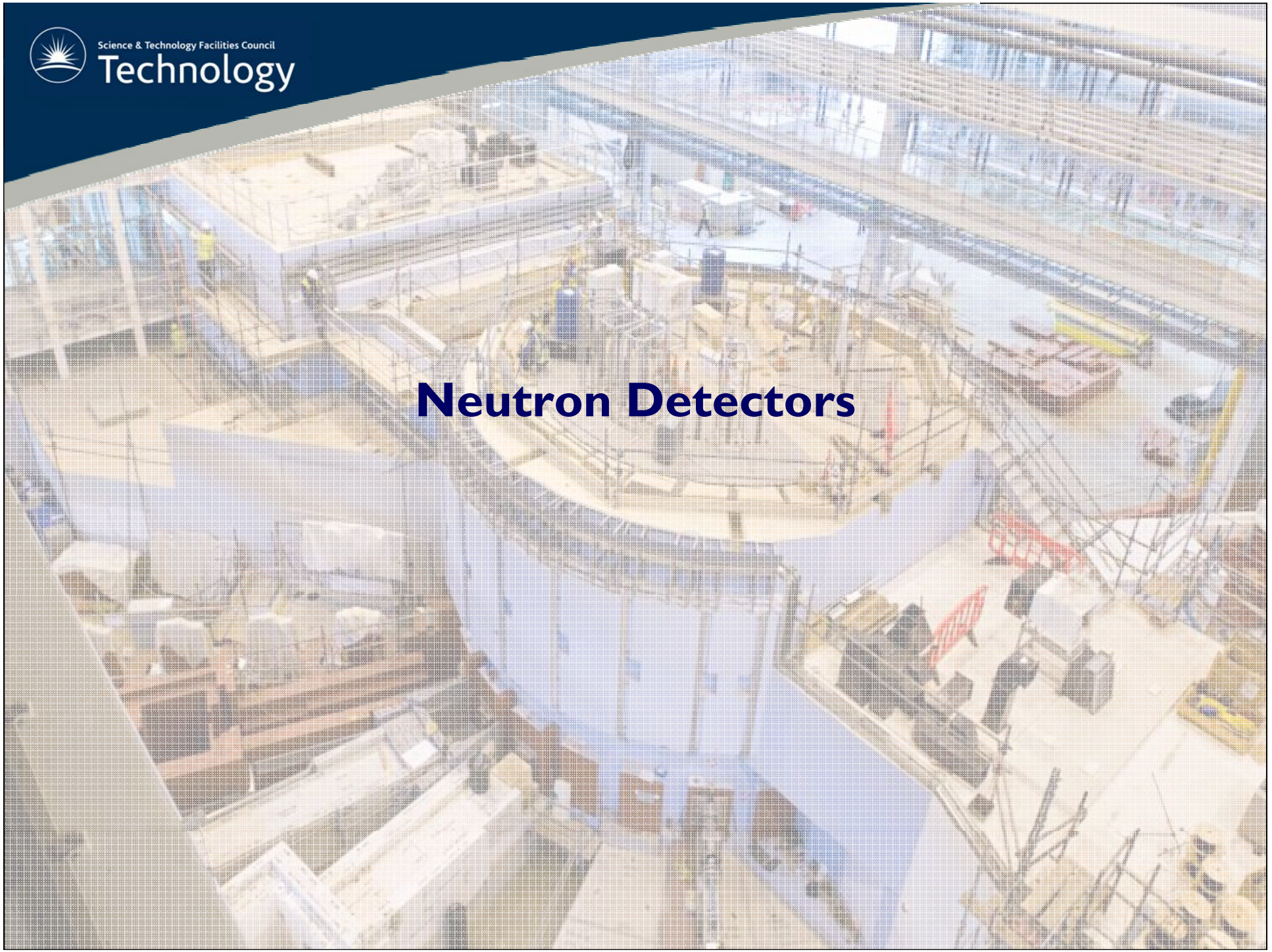
# New Facilities, increased demands

- New science, new experiments, new demands
  - Higher flux
  - Higher resolution
    - Time
    - Space
  - Dynamic range
  - Energy range
  - Efficiency
  - Stability
  - Low noise

| Type | Size | Pixel size | Count rate ($s^{-1}$) | Efficiency (at 1 Å) | γ Sensitivity | Stability (% $d^{-1}$) | Energy range (meV) | Candidate technology | Time scale |
|---|---|---|---|---|---|---|---|---|---|
| Reflectometers | $300 \times 100\,mm^2$ | $0.5 \times 100\,mm^2$ | $10^6$ | 80% | $<10^{-17}$ | <1 | 1–150 | Gas or scintillator | now |
| Reflectometers 2D | $300 \times 300\,mm^2$ | $0.5 \times 0.5\,mm^2$ | $10^6$ | 80% | $<10^{-7}$ | <1 | 1–150 | Gas | TS-2/now |
| SX low $L_2$ | $>200 \times 200\,mm^2$ | $3 \times 3\,mm^2$–$1 \times 1\,mm^2$ | $10^6$ | 80% | $<10^{-7}$ | <1 | 1–150 | Scintillator low parallax LiGdBO | TS-2/now |
| SX med, high $L_2$ | $>200 \times 200\,mm^2$ | $1 \times 1\,mm^2$ | $10^6$ | 80% | $<10^{-7}$ | <1 | 1–150 | Gas | Beyond TS-2 |
| Radiography, tomography | $20 \times 20\,mm^2$ | 0.02–0.2 $mm^2$ | $10^6$ | 80% | | <0.1 | 1–150 | Si active pixel | now |
| Monitors | $60 \times 60\,mm^2$ | $1 \times 1\,mm^2$ | $10^7$ | Low | | <0.1 | 1–1500 | Si or gas | now |
| High energy | $100 \times 100\,mm^2$ | $5 \times 5\,mm^2$ | $10^7$ | Epithermal | | <0.5 | 1–100,000 | YAP | now |
| SANS | $1 \times 1\,m^2$ | $5 \times 5\,mm^2$ | $10^6$ | | | <0.5 | 1–50 | Scintillator or gas | TS-2 |
| SANDALS/NIMROD | $200 \times 200\,mm^2$ | $200 \times 10\,mm^2$ | $10^7$ | Epithermal | $<10^{-6}$ | <0.1 | 1–30,000 | Scintillator or gas | TS-2 |
| Powder | $600 \times 200\,mm^2$ | $3 \times 200\,mm^2$ | $10^7$ | 80% | $<10^{-7}$ | <0.1 | 20–150 | Scintillator or gas | TS-2 |
| Inelastic | $1 \times 1\,m^2$ | $10 \times 25\,mm^2$ | $10^6$ | | $<10^{-7}$ | <0.1 | 1–1500 | Gas | TS-2 |
| Inelastic (BS) | $5 \times 100\,mm^2$ | $5 \times 100\,mm^2$ | $10^6$ | | $<10^{-7}$ | <0.1 | 1–50 | Gas | Beyond TS-2 |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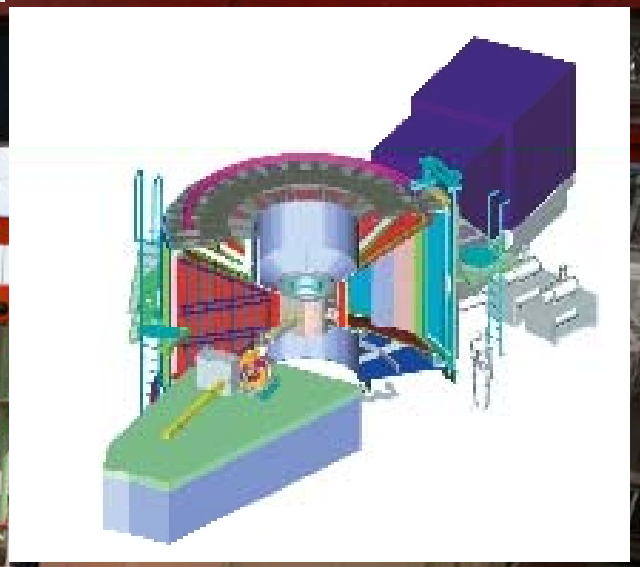
Technology
Neutron Detectors

Science & Technology Facilities Council

# Technology



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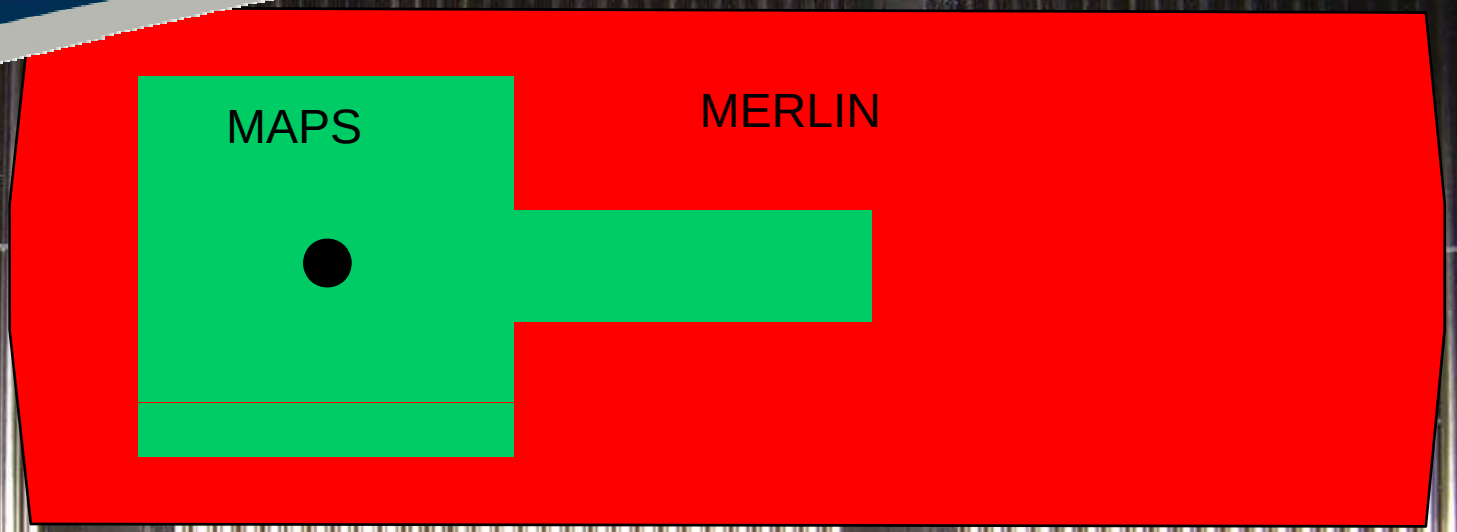


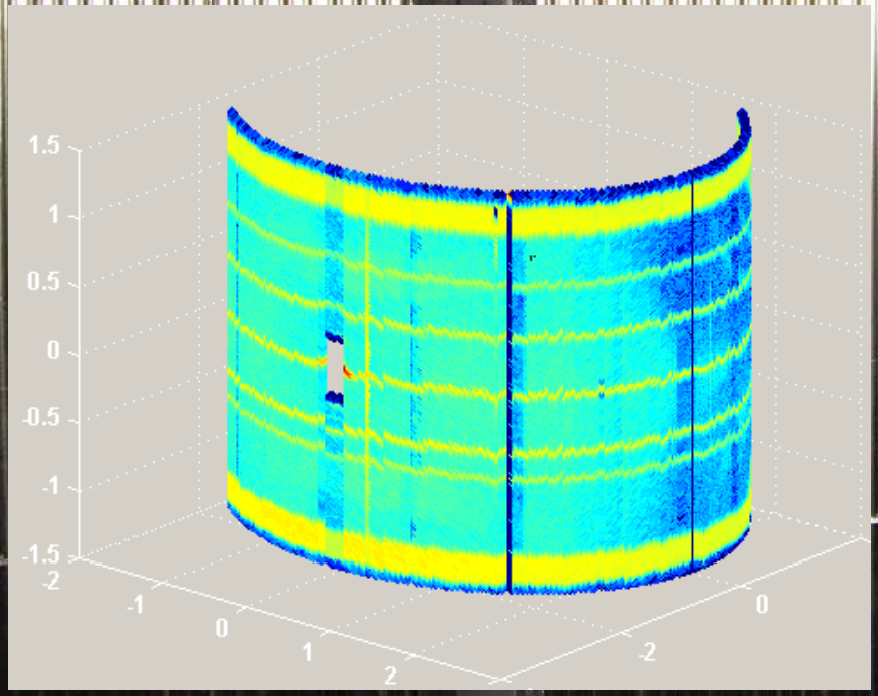

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T. G. Perring, R. Ewings

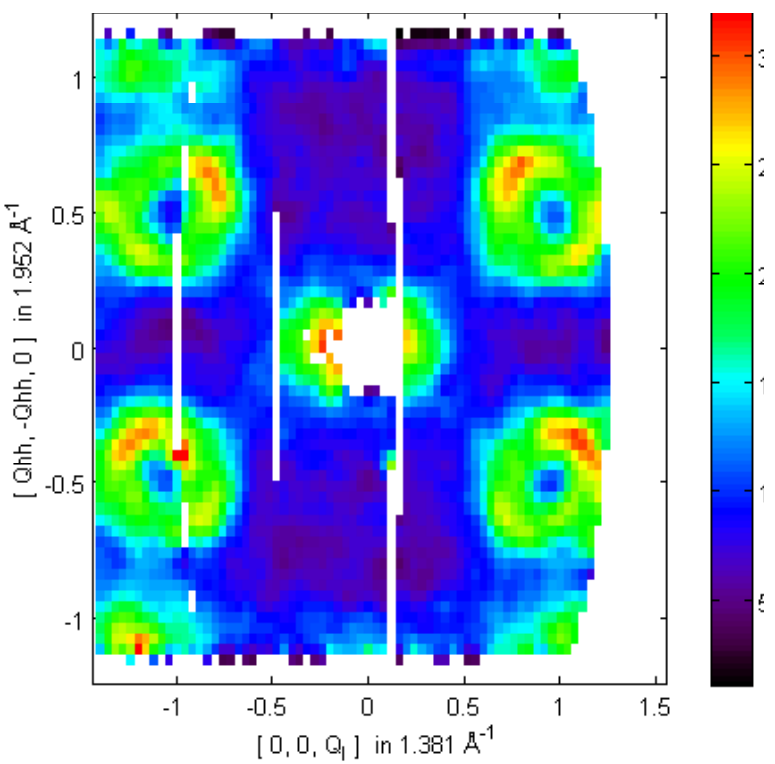
# MnSi single crystal

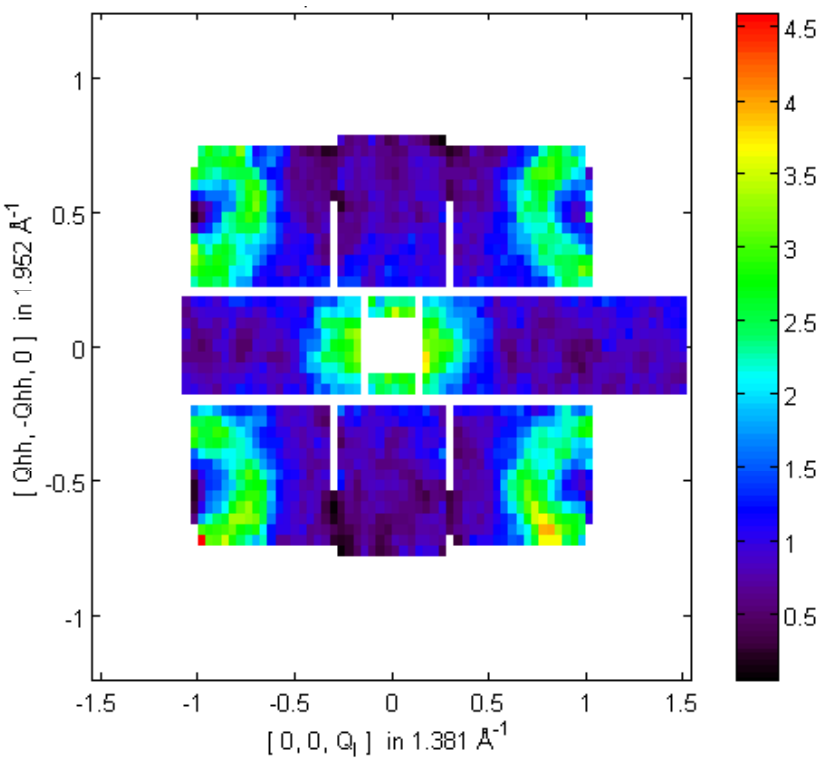
## MERLIN

Sample mass: 32 g
$E_i$ = 50 meV
Chopper speed = 300 Hz
778 μAhrs
T = 300 K, cut 10<E<13 meV

## MAPS

Sample mass: 50 g
$E_i$ = 50 meV
Chopper speed = …….
1887 μAhrs
T= 300 K, cut 10<E<13 meV



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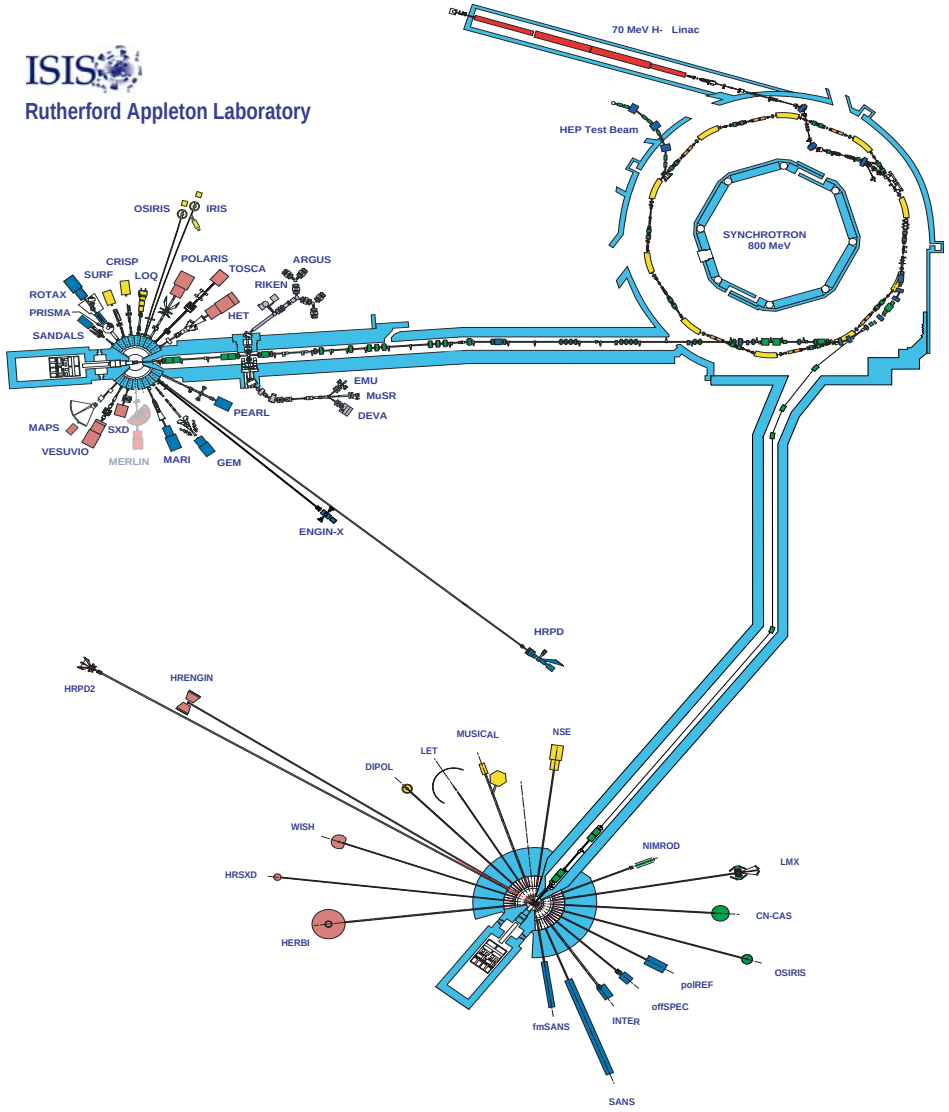
# ISIS TS2




TS2 ISIS
second target station project

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# LET:

# Low energy transfer spectrometer

**Detector array**

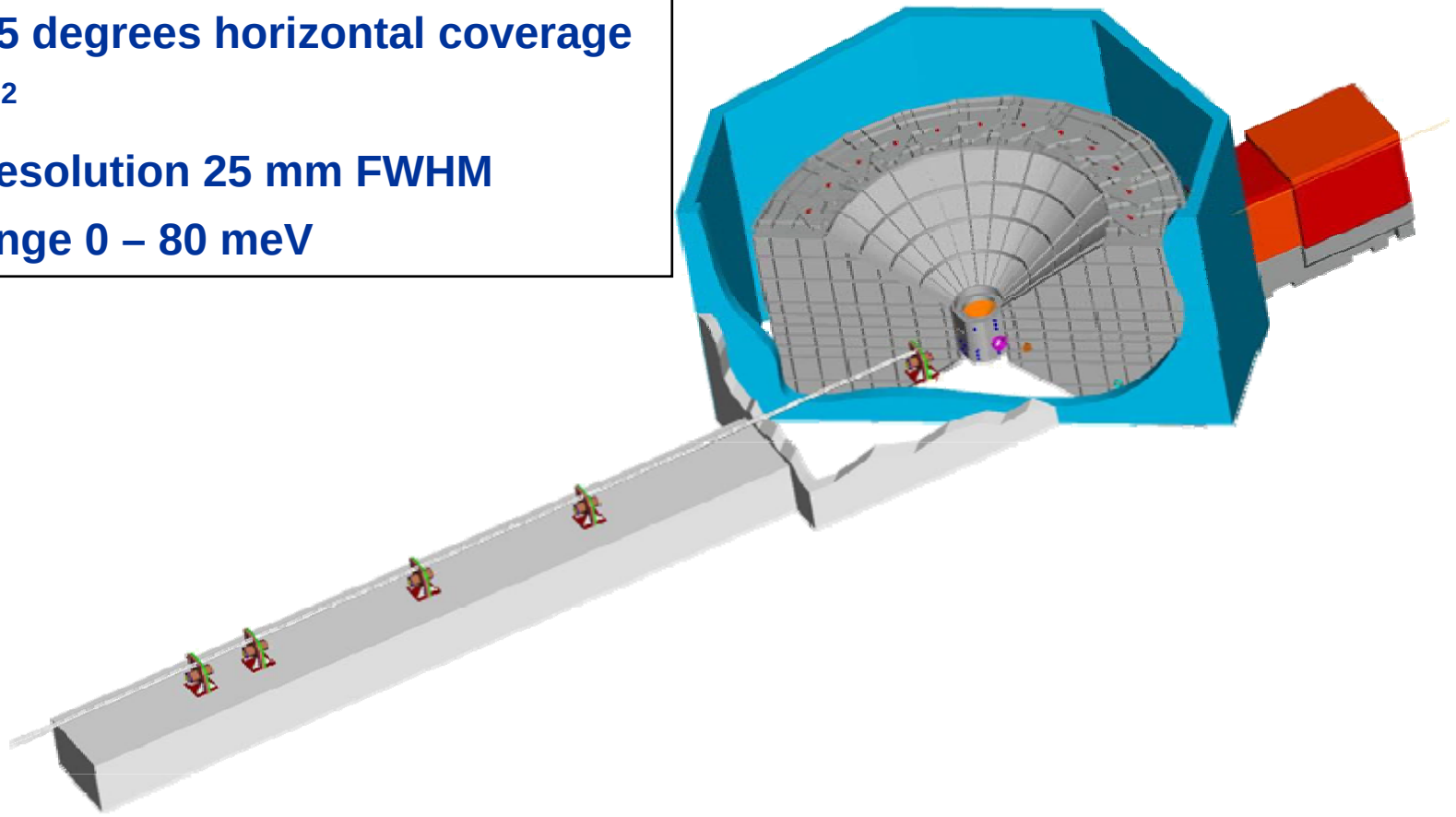
**4m high array at 3.5 m radius**

**-35 to +135 degrees horizontal coverage**

**Area 40 $m^2$**

**Position resolution 25 mm FWHM**

**Energy range 0 – 80 meV**



TS2 ISIS
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# LET

## detector assembly

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**25 mm diameter 4 m long resistive wire detectors**
**224 for day one**

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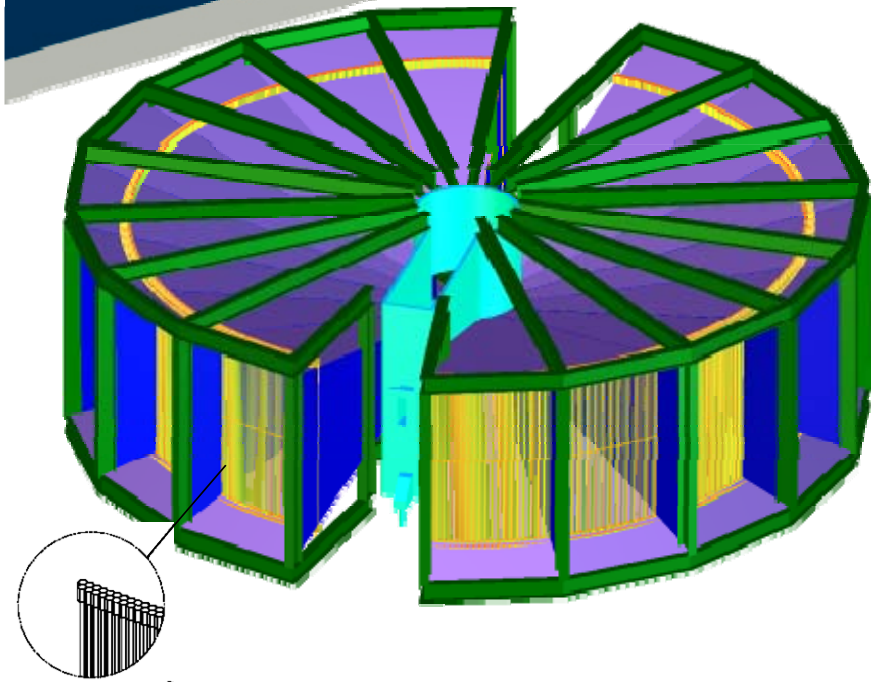
# WISH



**Detector array**

**~ 1m high array at 2.2 m radius**

**± 10 to ± 170 degrees horizontal coverage**

**Position resolution 8 x 8 mm pixels**

**Wavelength range 1.5 – 15 Å**

**Large area powder / single crystal diffractometer for the study of magnetic materials**

**Resistive wire technology**

**~1500 detectors**

**1 $mm^3$ crystal 100 kHz per detector**

**5 $mm^3$ crystal 12 MHz per detector**

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# WISH

**8 mm diameter 1 m long resistive wire detectors, like D22**
**760 for day one spanning 10 to170 degrees at 2.2 m radius**

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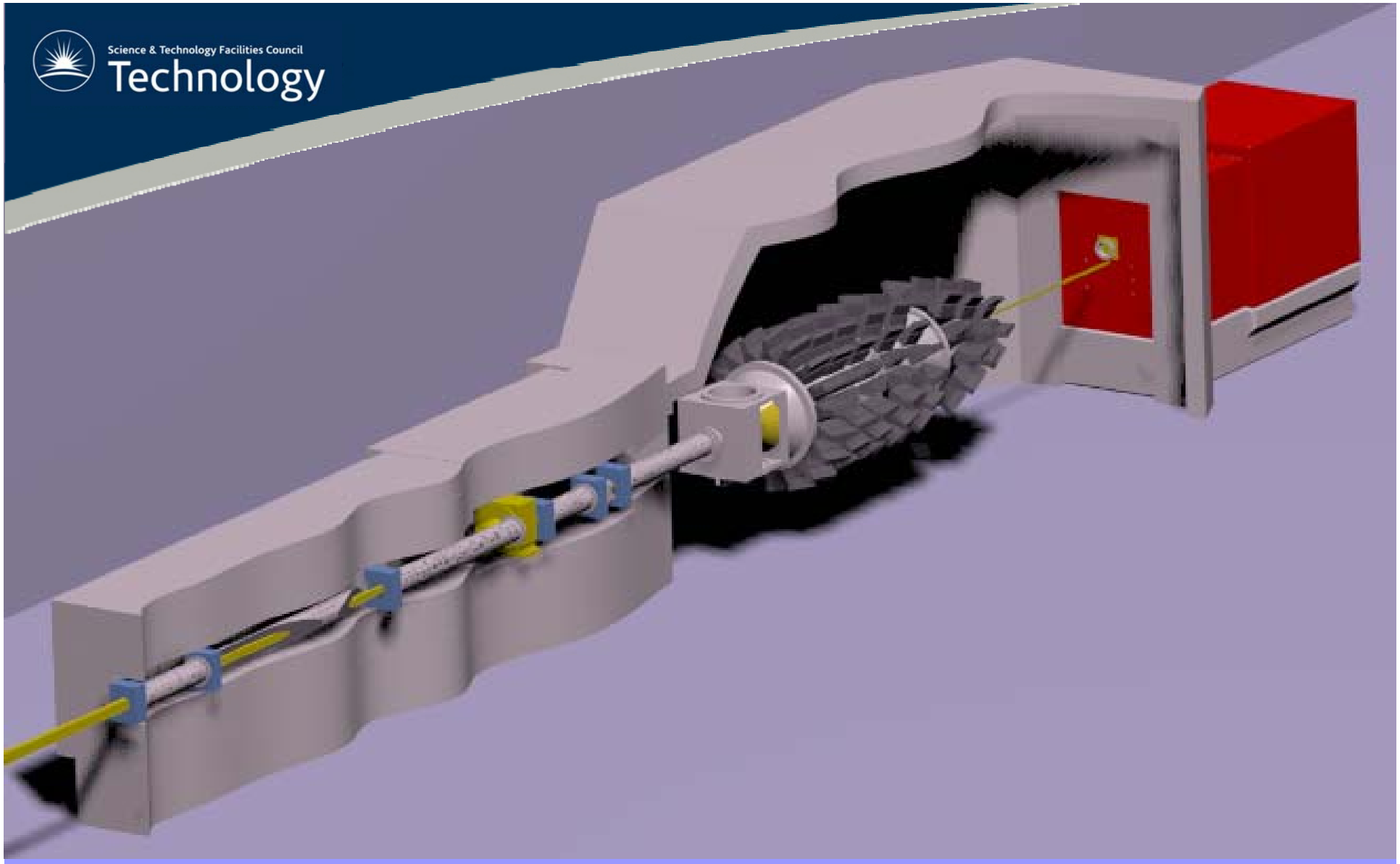


**High efficiency at 10 eV**

**High stability - 0.1% change in count rate per several days**

**2110 pixels ~10 mm x 200 mm Total area 4.2 m²**

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# NIMROD

## scintillation detector

18 detector elements

200 x 10 $mm^2$

60 modules for day 1

2.16 $m^2$ detector –

60 $m^2$ scintillator

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second target station project

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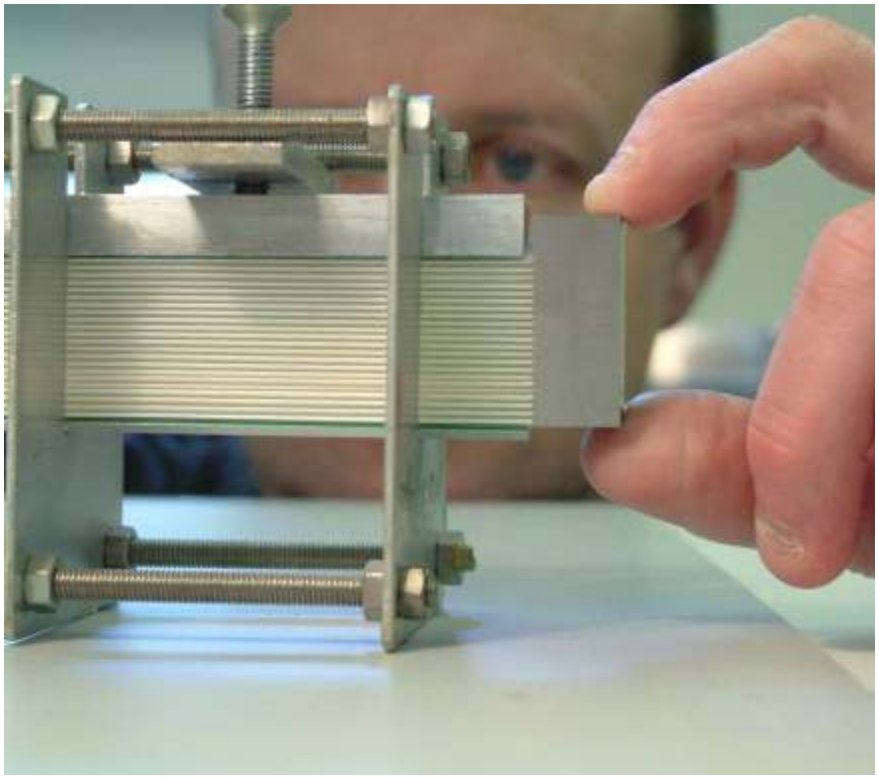
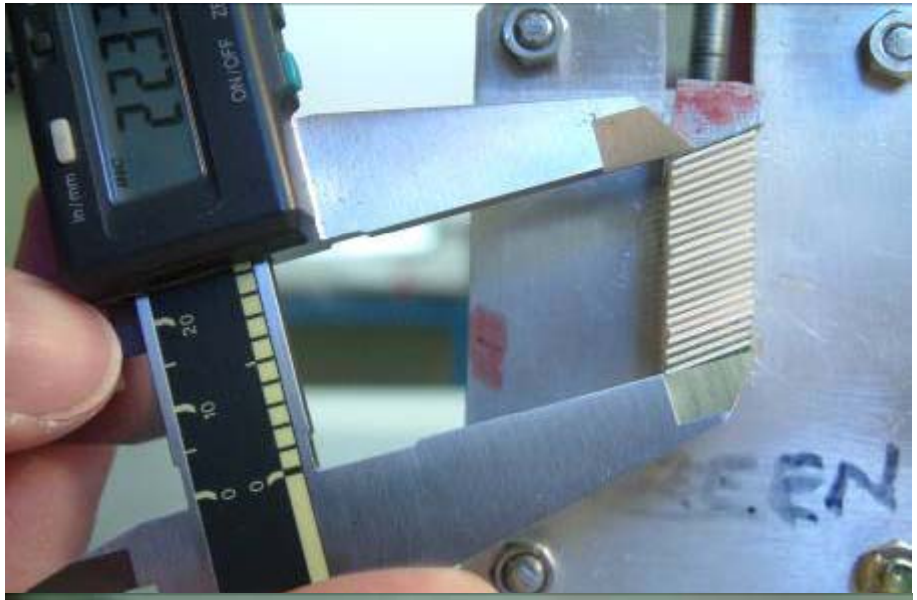
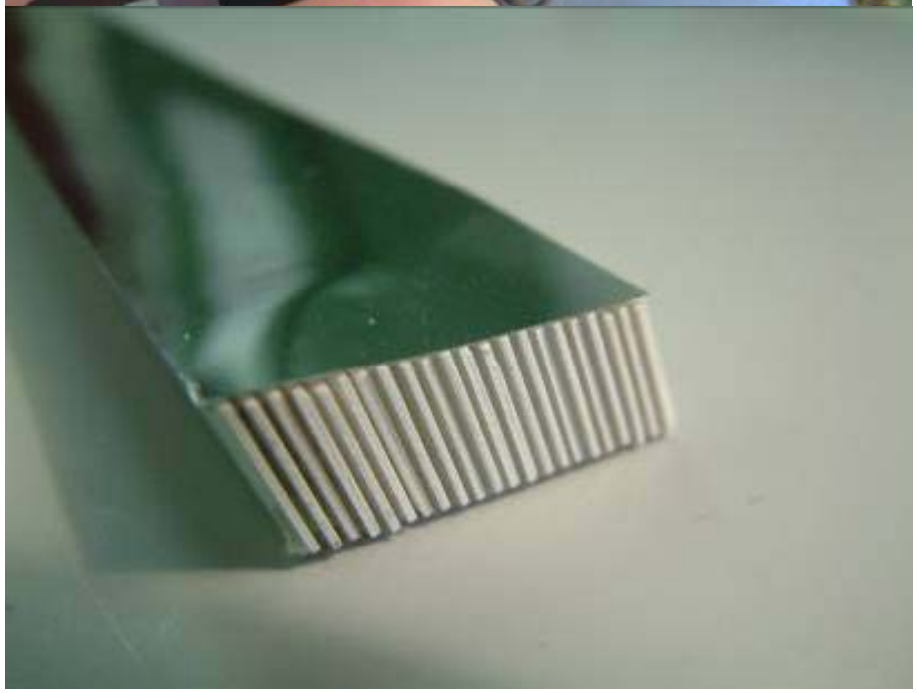
# NIMROD





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# NIMROD

**60 modules for day one**

**53 assembled to date**

**30 fully tested on neutron source and ready for installation**

**Low angle bank spanning 0.5 to 3 degree under development**

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# SANS 2d

- Active area : 1m x 1m
- Count rate: 2 x $10^5$ n/s at 10% deadtime
- Neutron efficiency: 50% at 2 Å
- Position resolution : 5 x 5 $mm^2$

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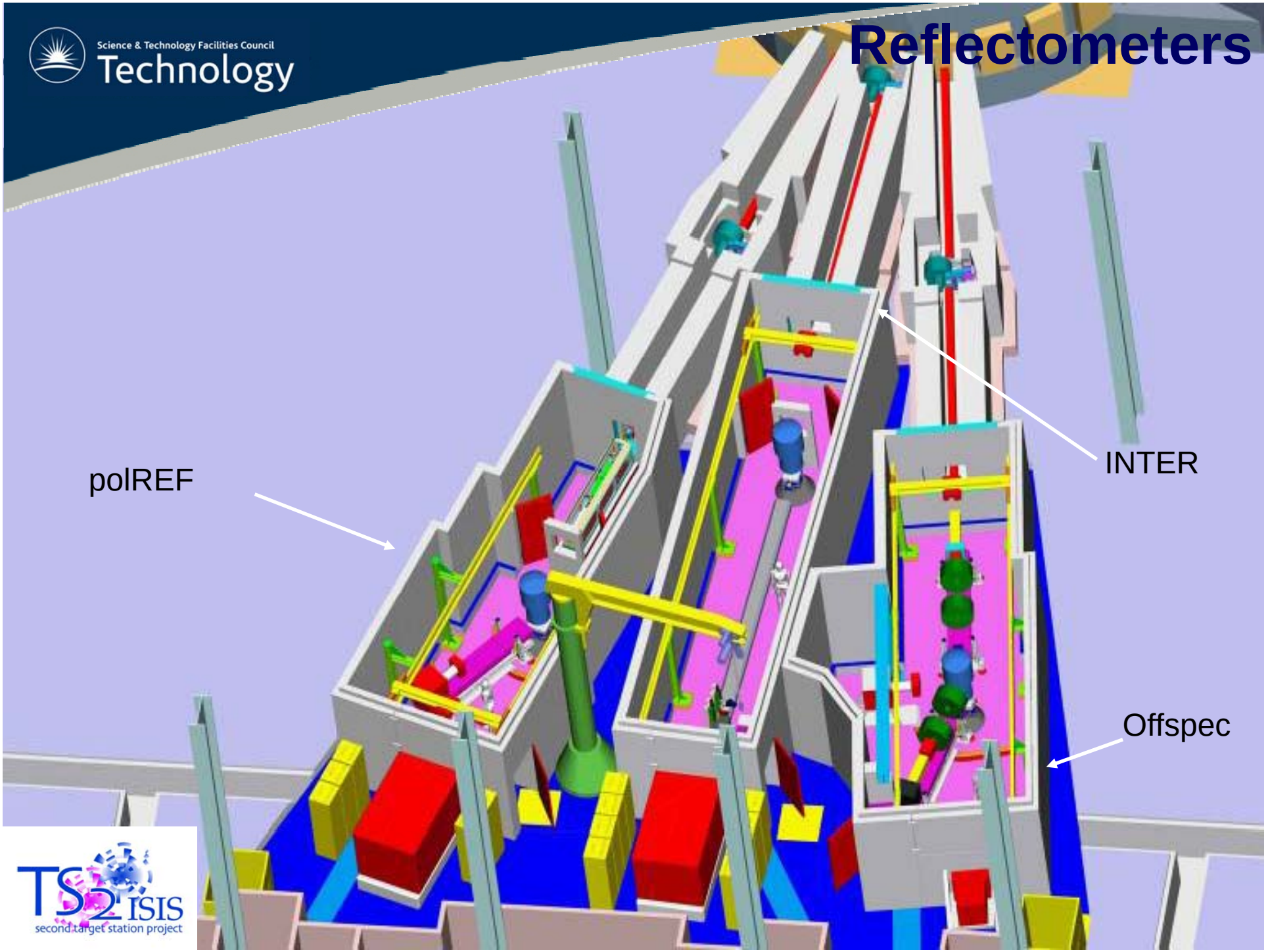
# Reflectometers

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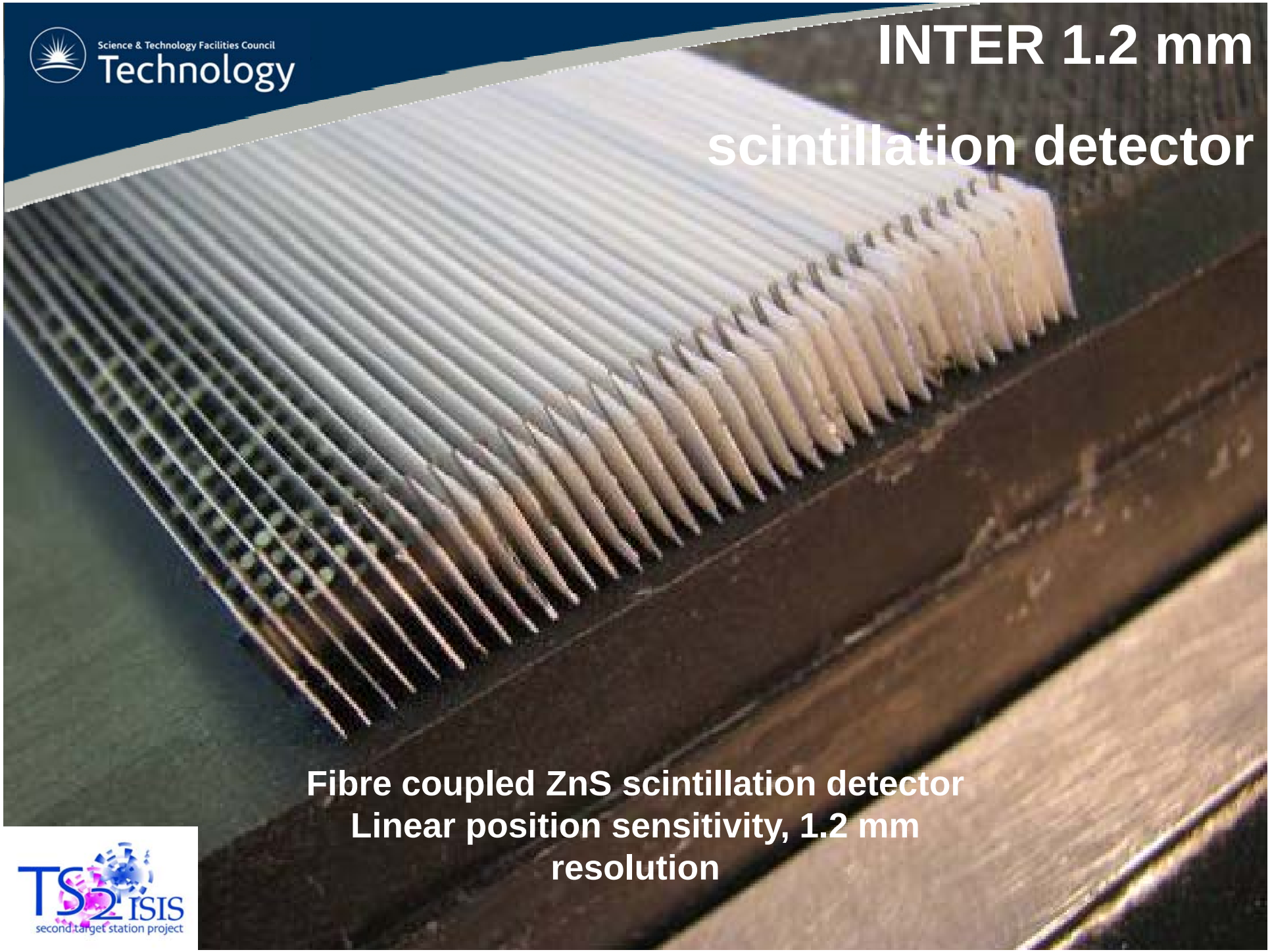
# INTER 1.2 mm scintillation detector



**Fibre coupled ZnS scintillation detector**
**Linear position sensitivity, 1.2 mm resolution**

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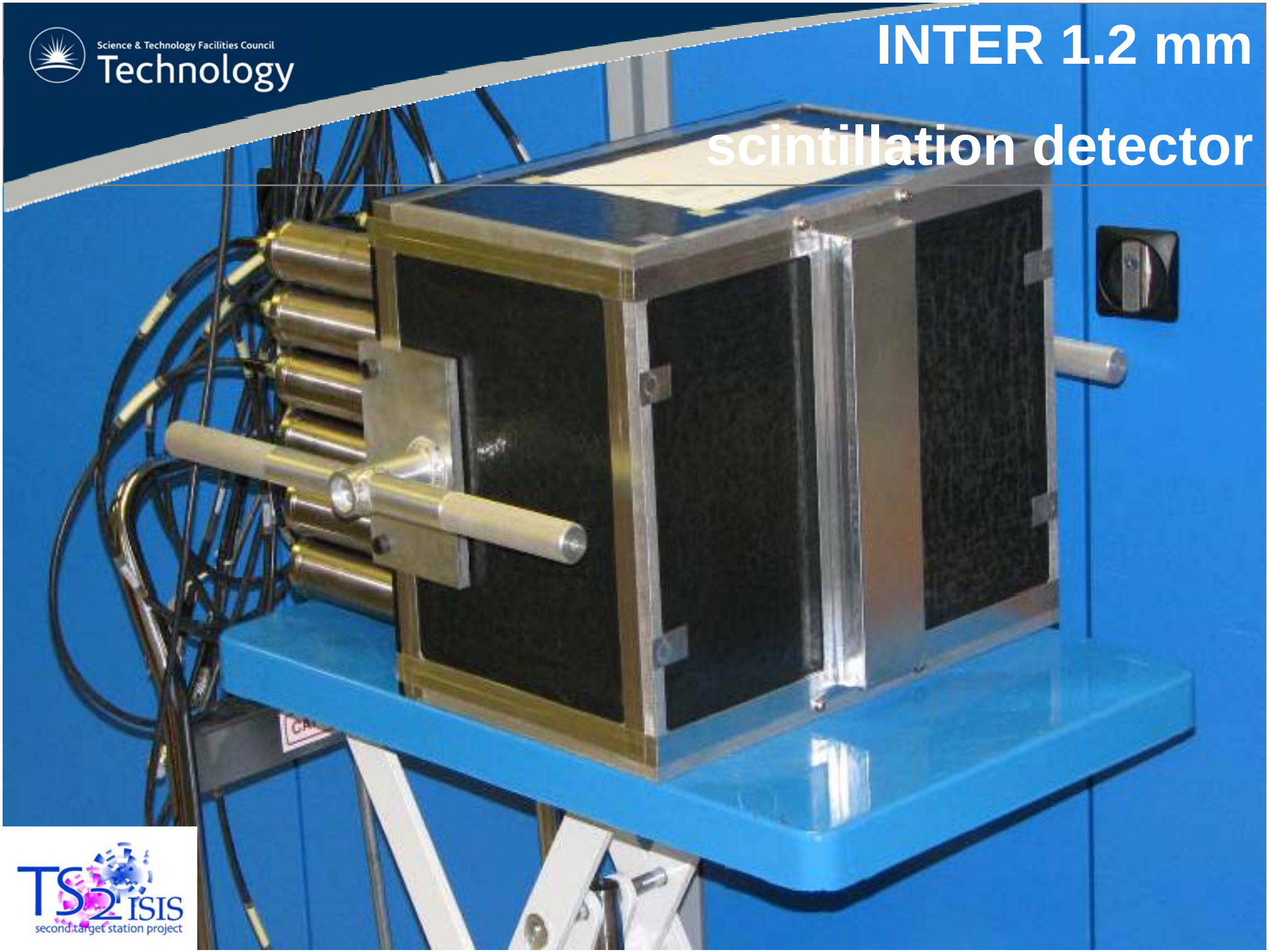
# INTER 1.2 mm scintillation detector



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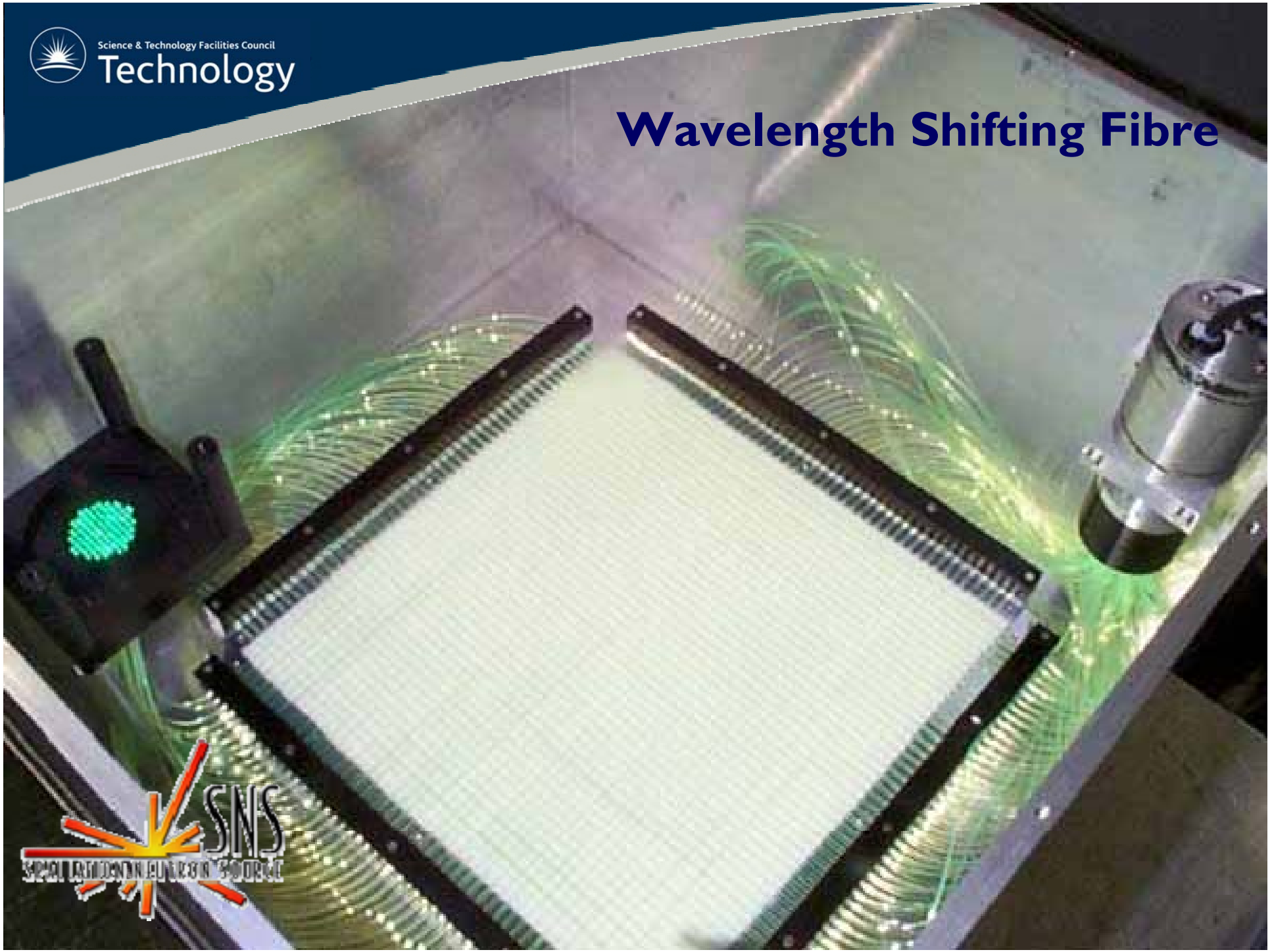
# Wavelength Shifting Fibre



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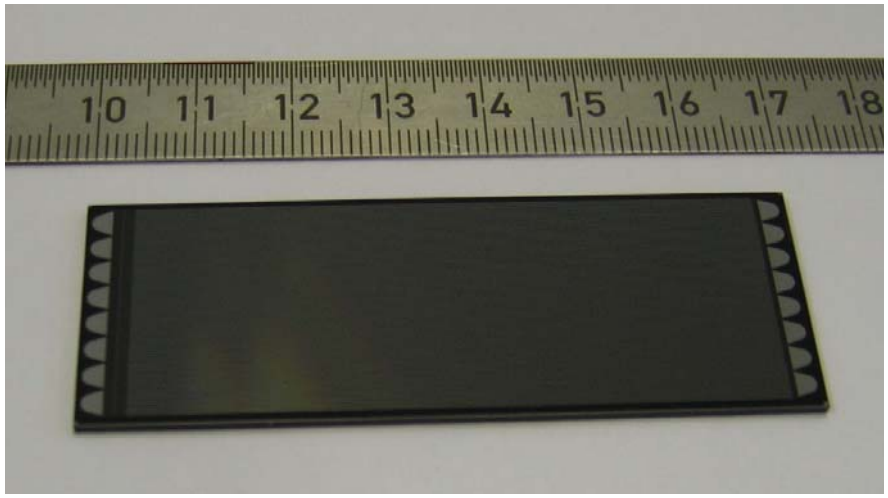
# Gas Detectors

## FastGas

10 bars $^3$He, 4bars $CF_4$

>90% efficiency for 1Å neutrons

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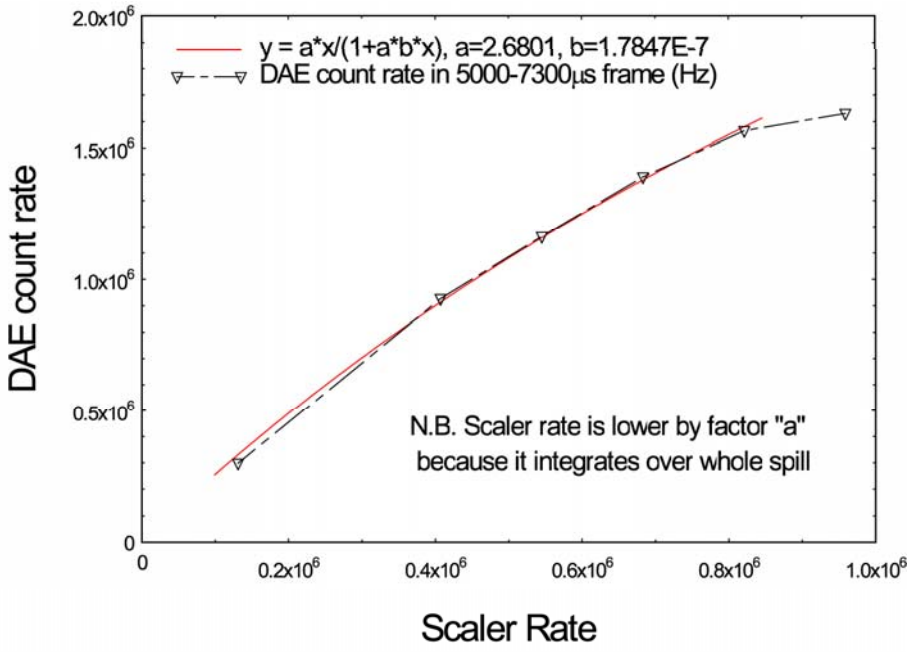
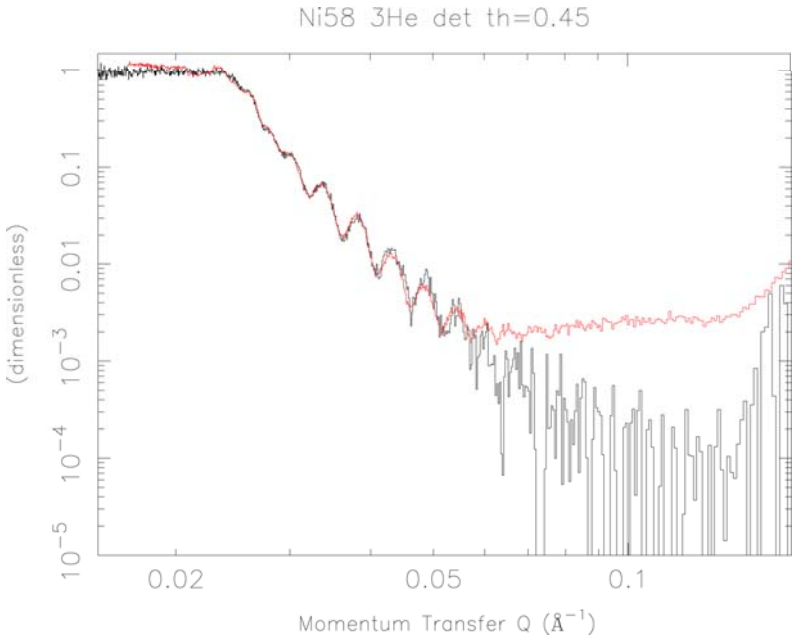
# Data from CRISP instrument on ISIS

100 times greater rate performance than existing $^{3}$He tubes, with no noticeable degradation in performance




Neutron reflection from $^{58}$Ni sample. Black curve $^{3}$He tube, red curve FastGas



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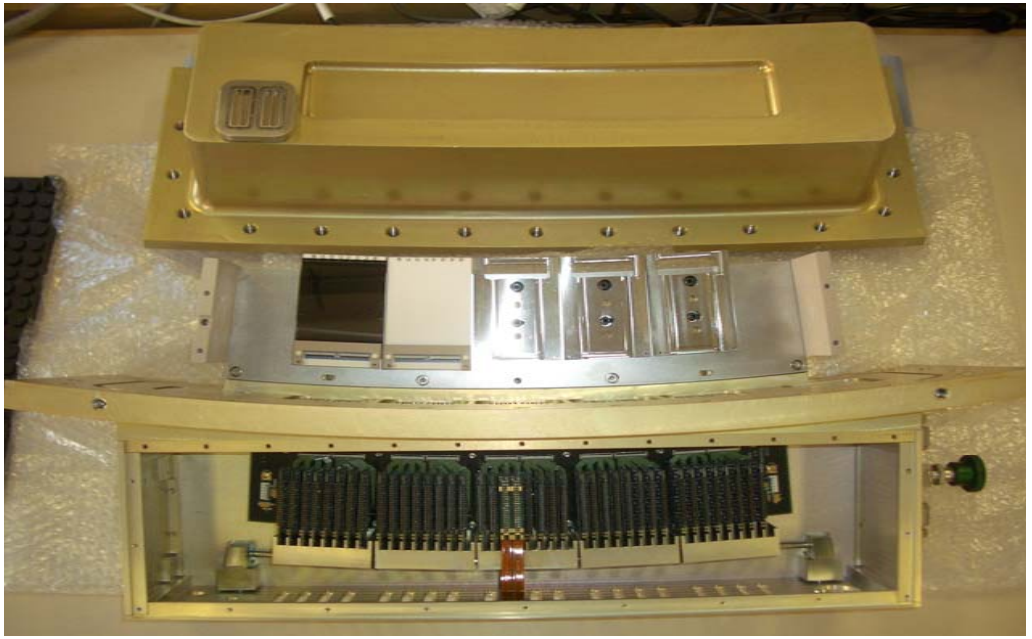
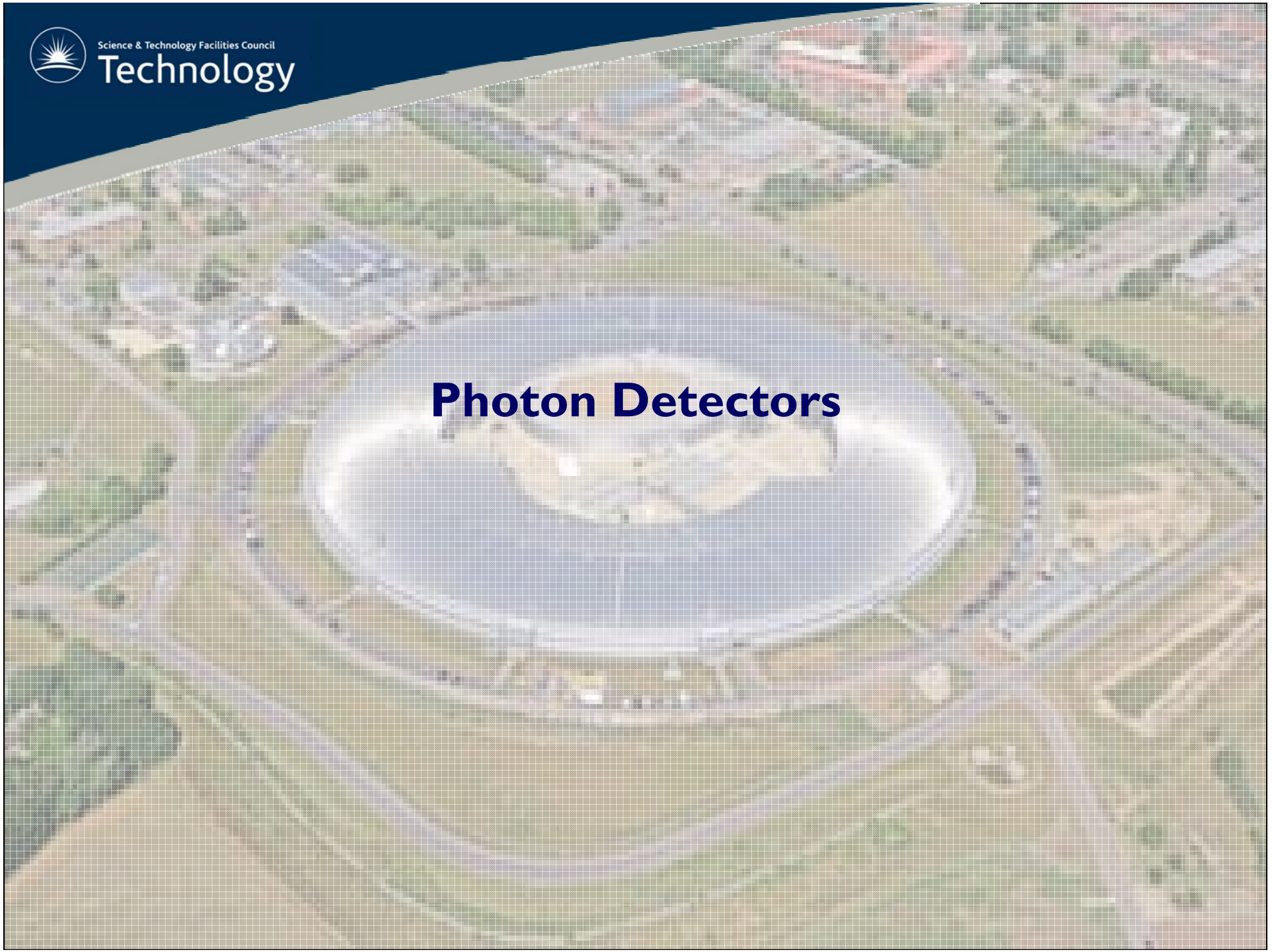
# OSMOND

- Position sensitive, parallax free neutron detector
- Position resolution of 0.5mm or better (FWHM)
- Neutron detection efficiency ≥ 50% @ 1 Å
- A local count rate performance of at least $10^5$counts per second
- A dynamic range of 6 orders of magnitude
- A gamma sensitivity of $10^{-8}$ at 1.3MeV

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Photon Detectors

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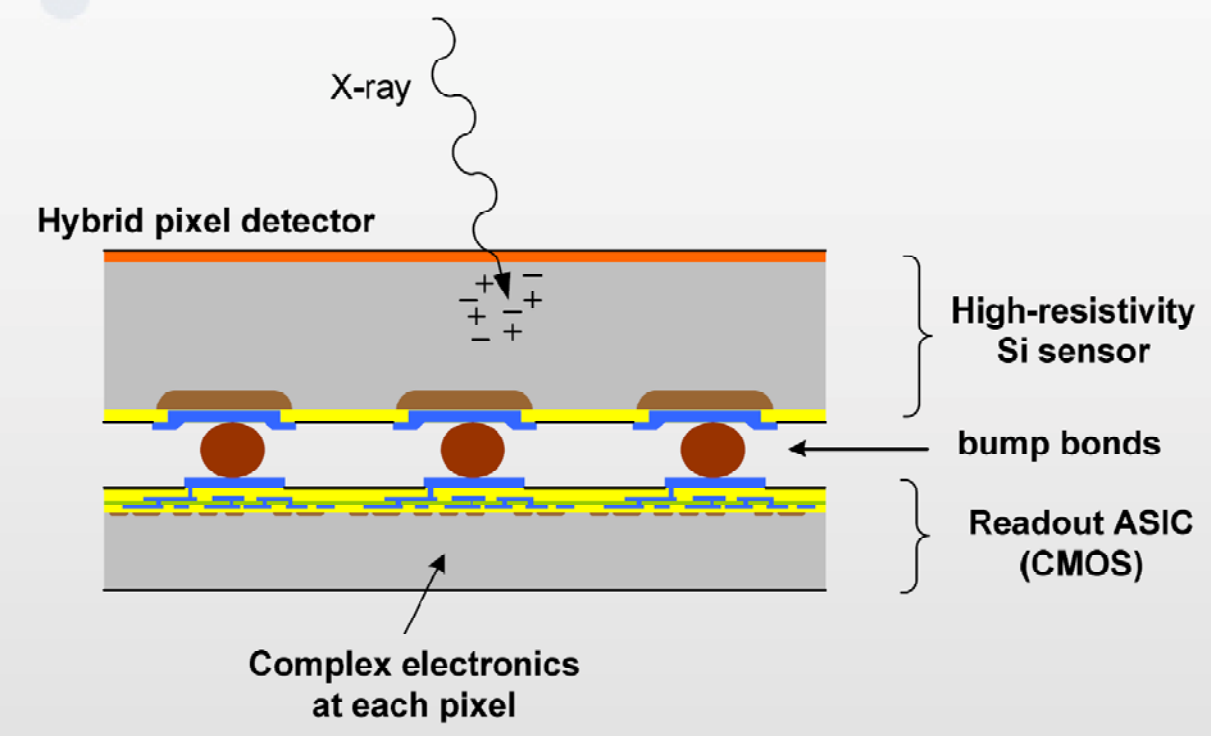
# Hybrid Pixel Detectors

- Hybrid pixel, photon counting
  - No dark current
  - Excellent point spread function
  - High quantum efficiency
  - Short readout time



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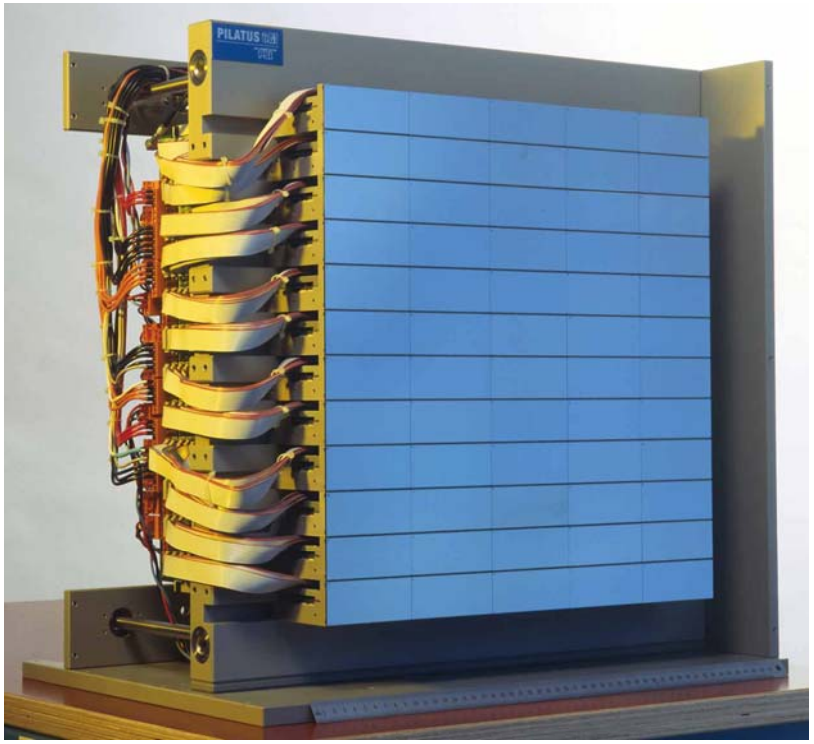
# PILATUS

- 6M
  - 5 x 12 modules
  - 2463 x 2527 pixels
  - 424 x 435 $mm^2$ active area




SWISS LIGHT SOURCE SLS

PAUL SCHERRER INSTITUT PSI

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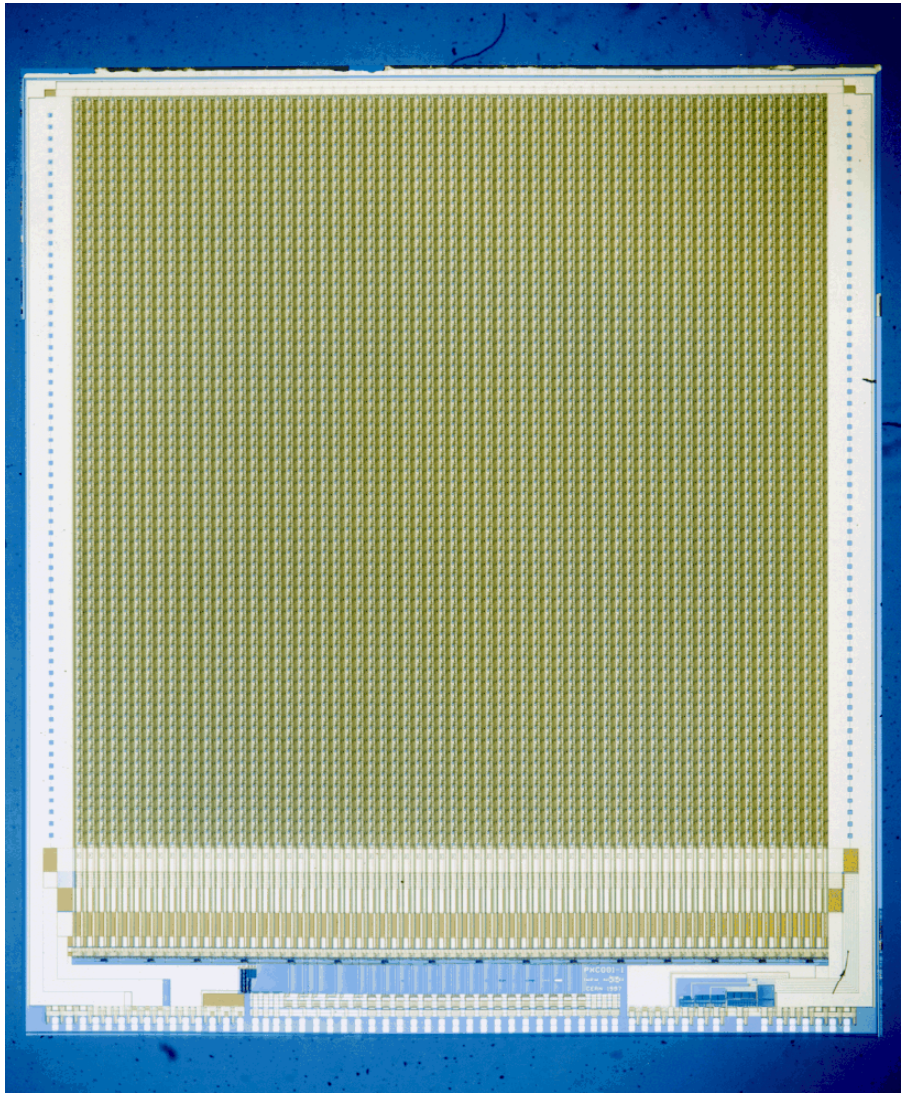
# Medipix

- Medipix 1
  - 170 μm pixels
  - 64 x 64 pixels per chip
- Medipix 2
  - 55 μm pixels
  - 256 x 256 pixels per chip
  - 3 sides buttable
- Medipix 3
  - Mitigates charge diffusion



CERN

MEDPIX collaboration

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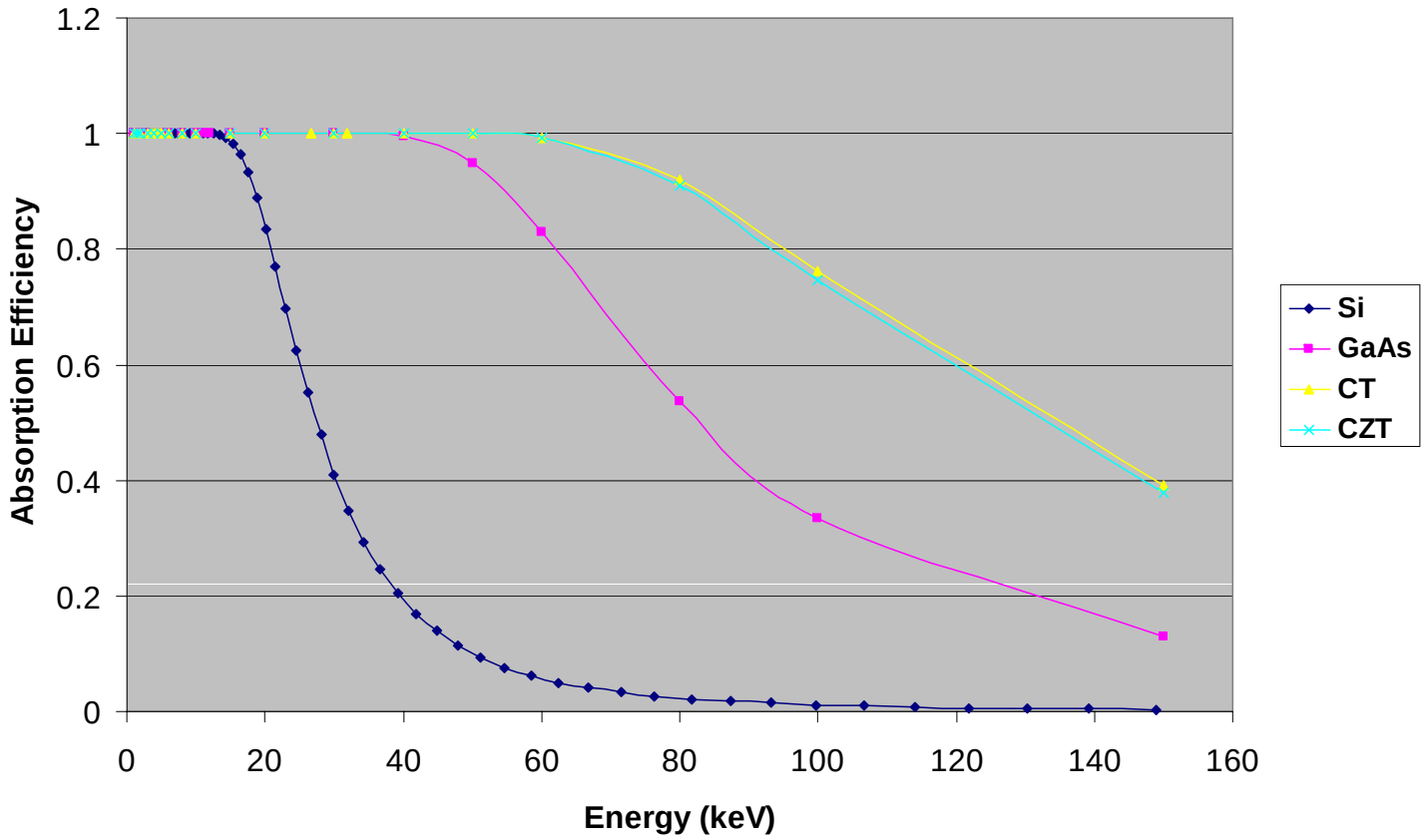
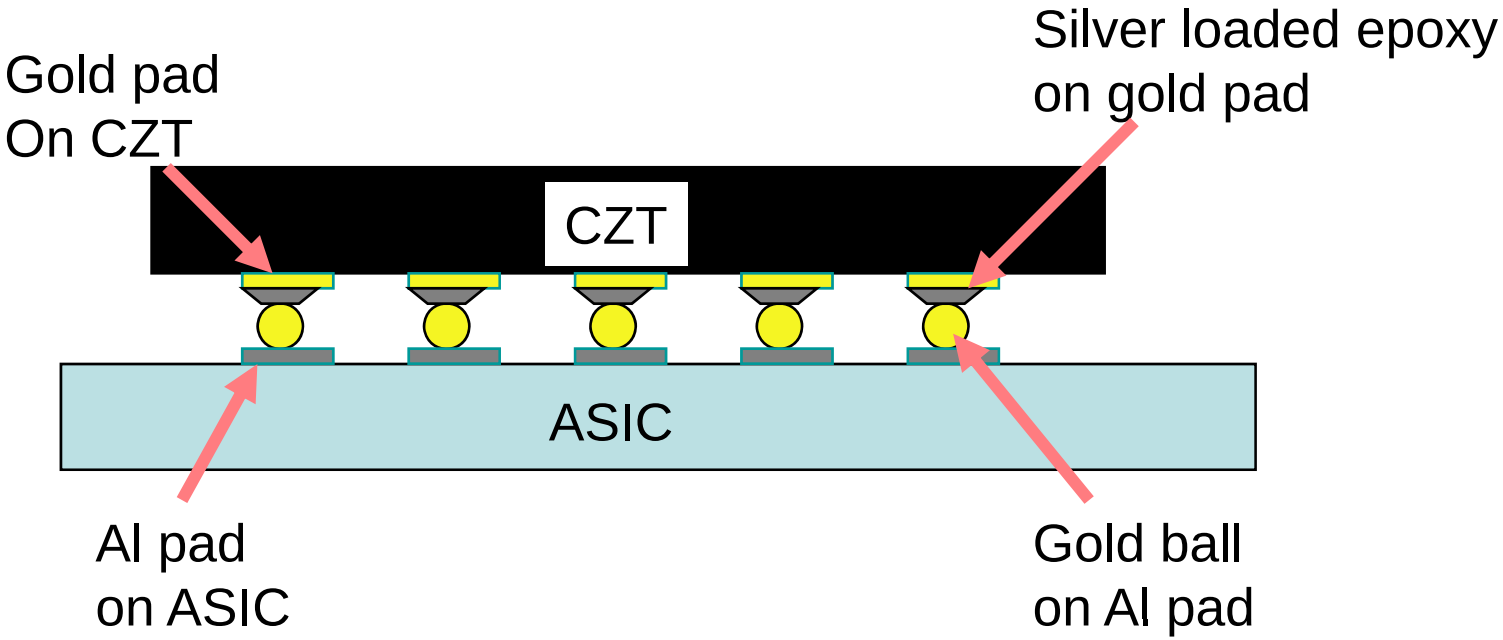
# CZT- HEXITEC

- CZT has a good stopping power for high energy X-rays in many applications (synchrotrons, space, HEP, nuclear, medical)
- Gives radiation-hard detectors in proton environments (HEP and space)






Low temperature, low stress bump bonding for CZT

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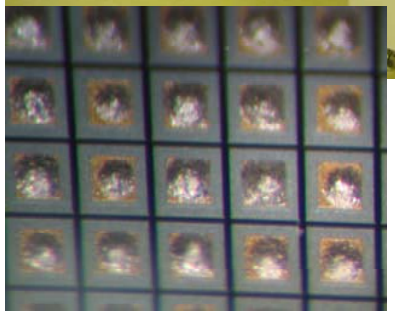

Silver loaded epoxy
dispense 120um dots




Questar Gold-Stud bond

Low temperature stud bonding process

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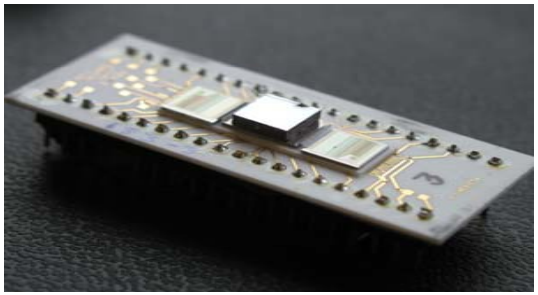
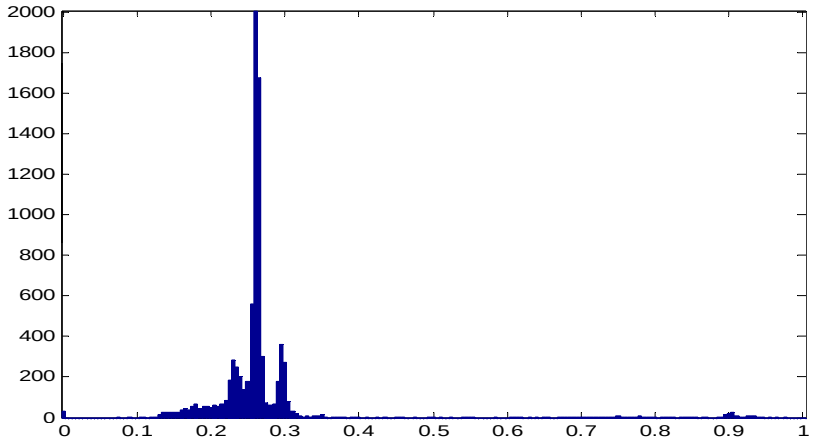
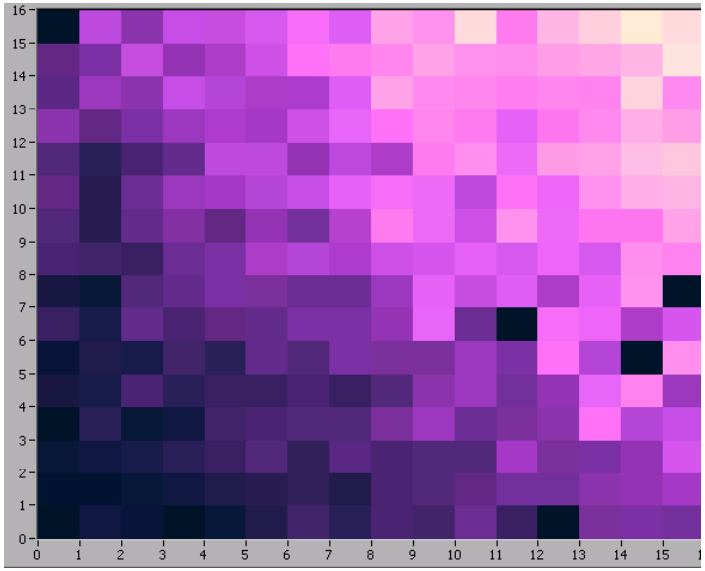
# Gold Stud Bonding



*ERD2004 module with 2mm thick CZT detector*




*X-ray image and spectrum taken with ERD2004 and Mo X-rays at 17keV bonded at RAL to 500um silicon detector.*

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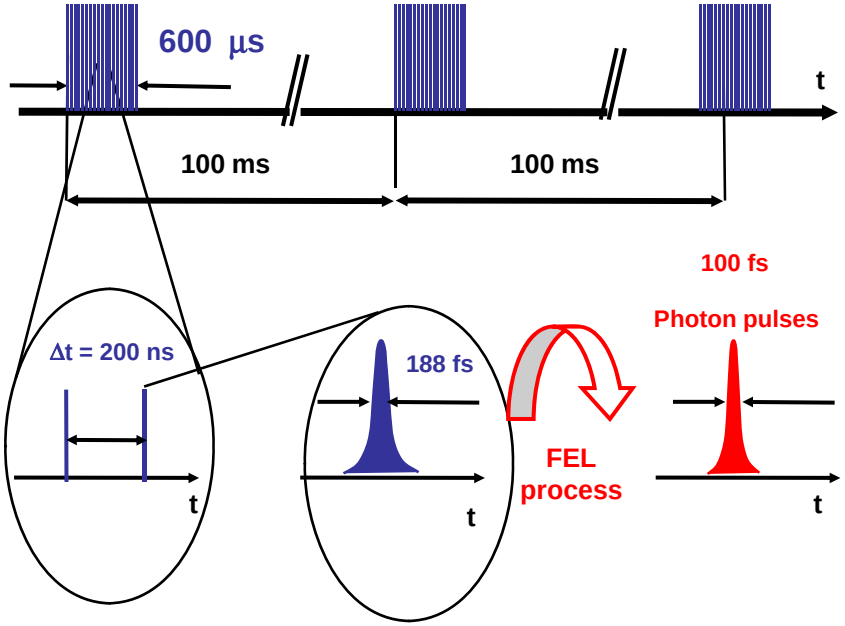
# Pixels for XFEL

- FEL sources deliver bright short pulses of radiation
- Requires high performance pixel systems





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# XFEL LPAD

## European XFEL, LPAD Sensor requirements and timescales

- Silicon sensors to convert high flux images of coherent 12keV X-rays, bump bonded to ASICs. Use 500um thick DC coupled Si detector
- X-rays arrive in 100 femto second pulses every 200 nano seconds. Charge completely cleared for next pulse.
- 250 detectors (= 80 wafers) per Mega-pixel area
- First sensors ready end 2008

  First system ready mid 2009

  1Mega-pixel system ready end 2010

  Multi-megapixel systems (16-32 total) ready end 2012.

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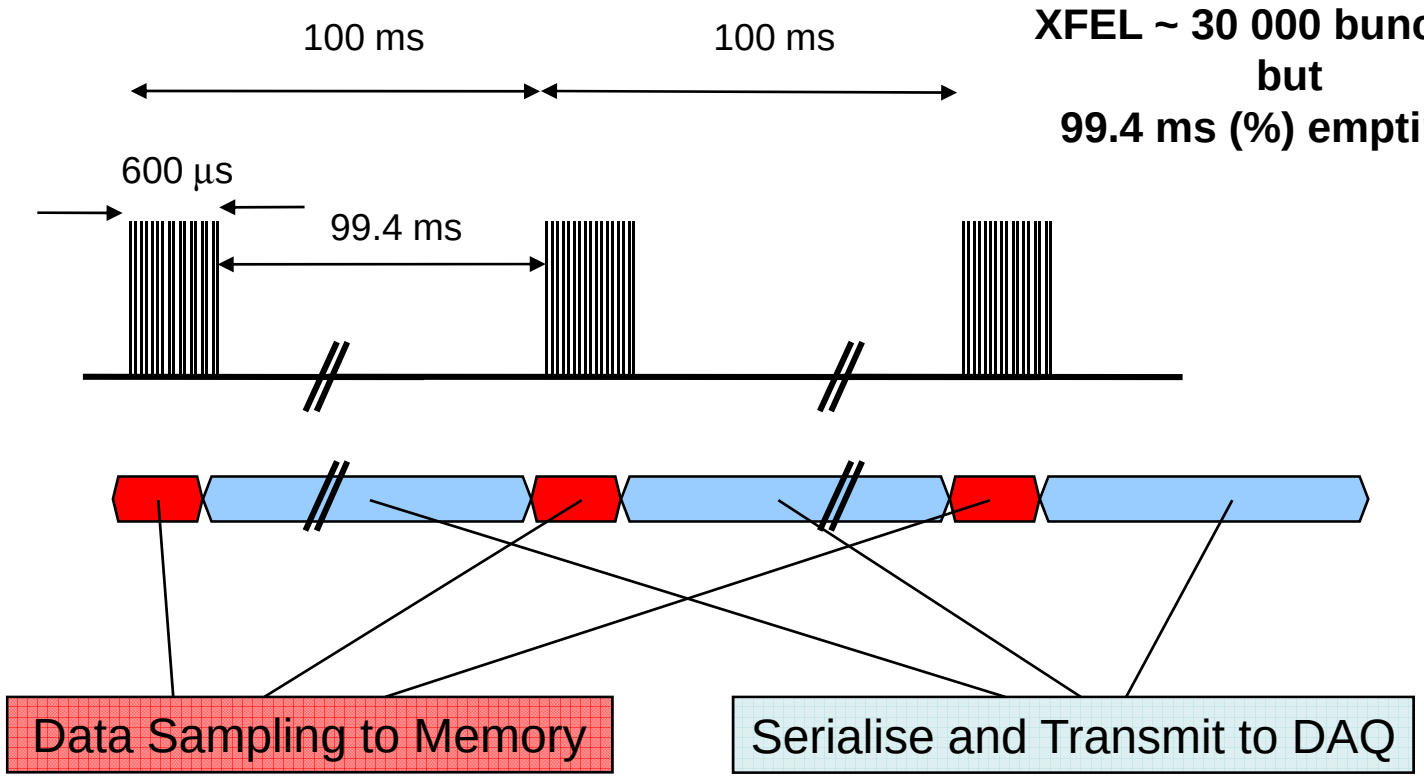
# XFEL LPAD

Electron bunch trains; up to 3000 bunches in 600 µsec, repeated 10 times per second.
Producing 100 fsec X-ray pulses (up to 30 000 bunches per second).




**XFEL ~ 30 000 bunches/s**
**but**
**99.4 ms (%) emptiness**

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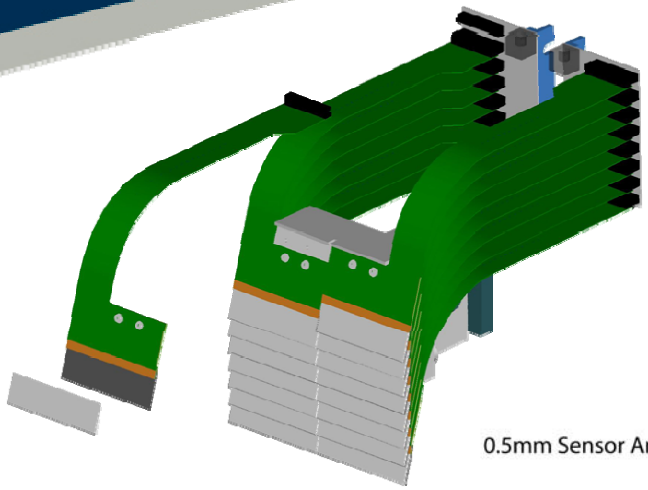
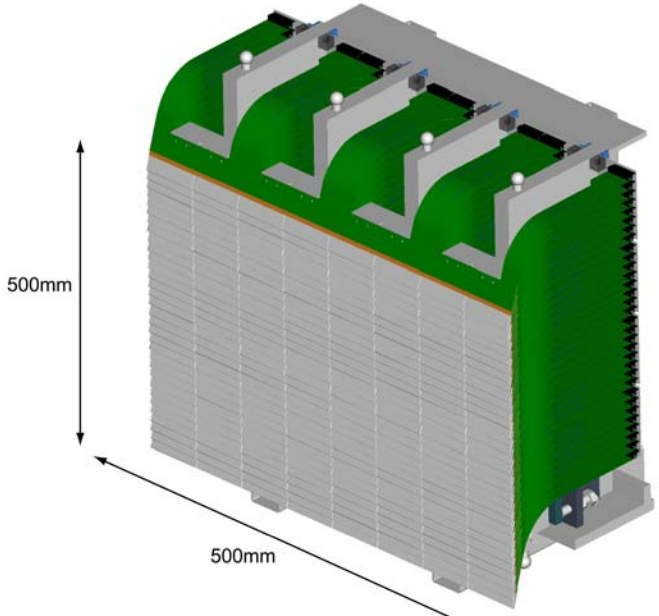
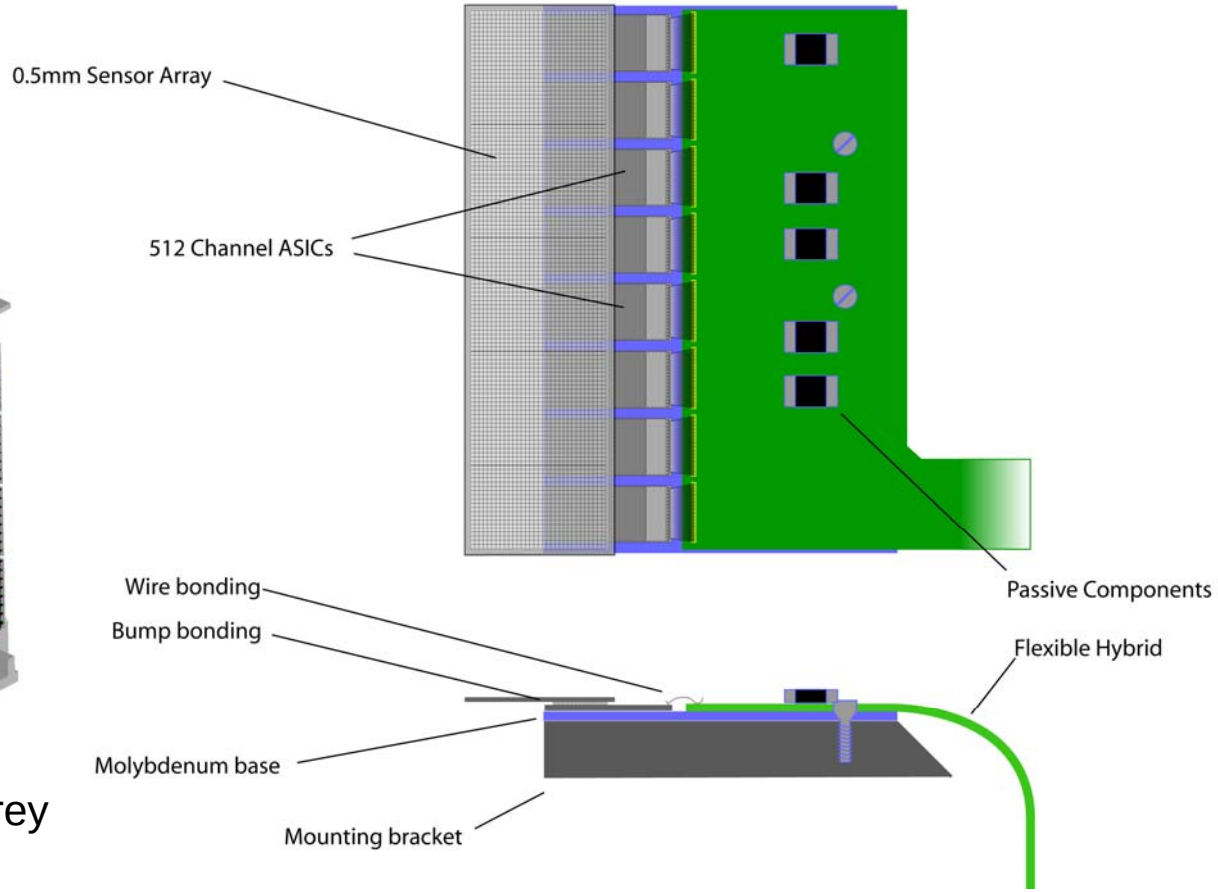
# XFEL LPAD






- Working with Glasgow and Surrey

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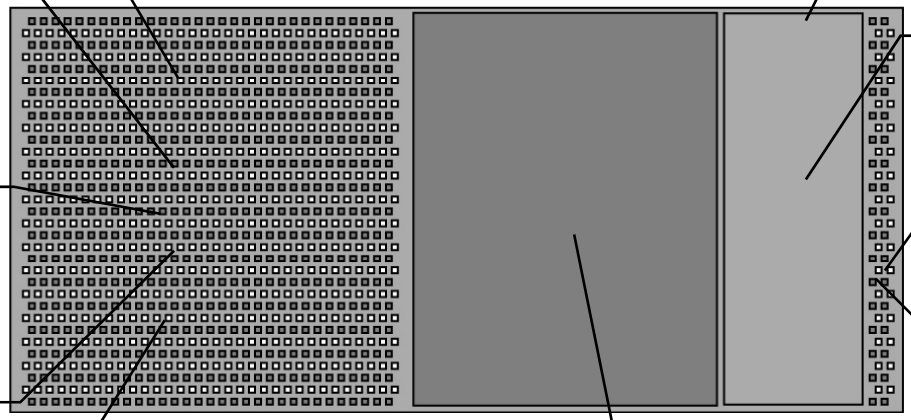
# LPAD ASIC




- Preamplifiers
- Dynamic range stages
- Overload Control
- Pixel Resetting
- Power supply Conditioning
- Sequencing and control
- ADC Stages
- IO to DAQ
- Power supplies
- Deep pipeline memory (786,432 samples)

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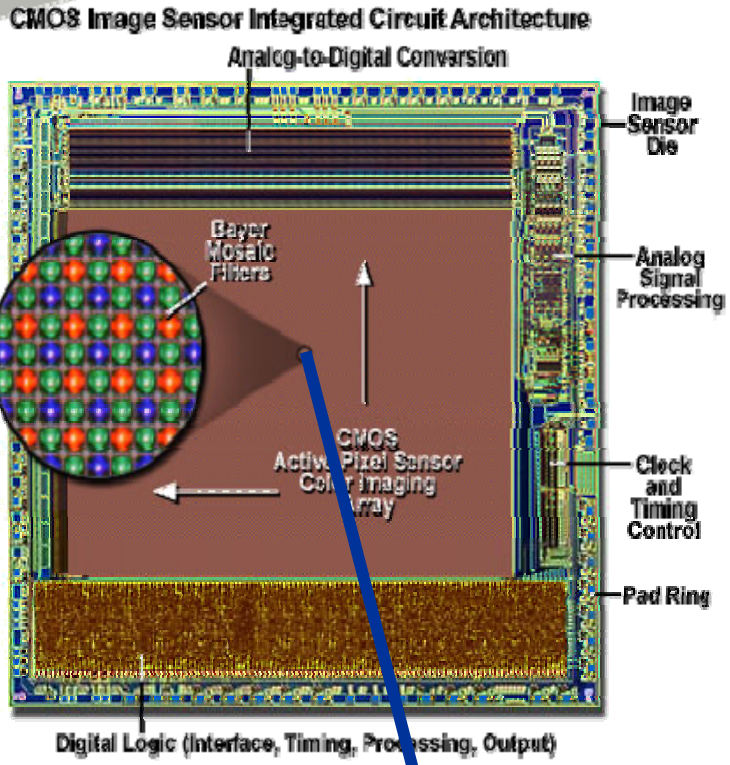
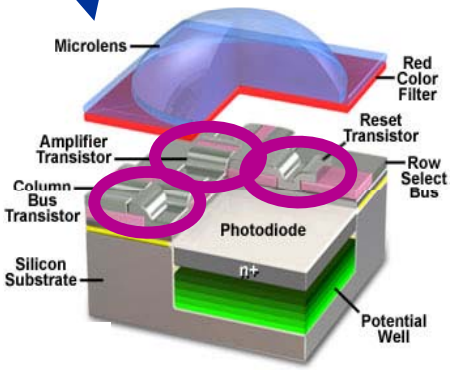
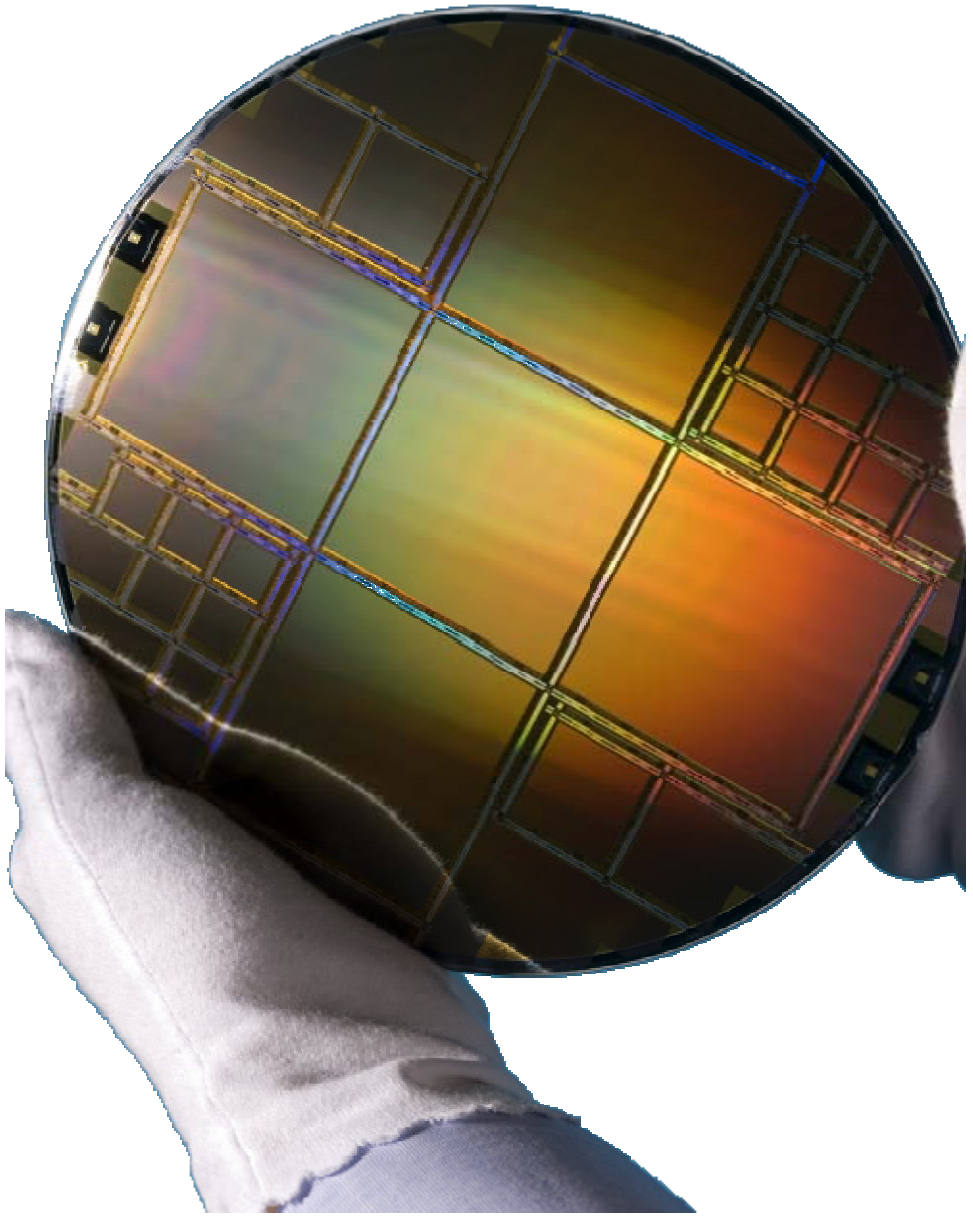
# MAPS



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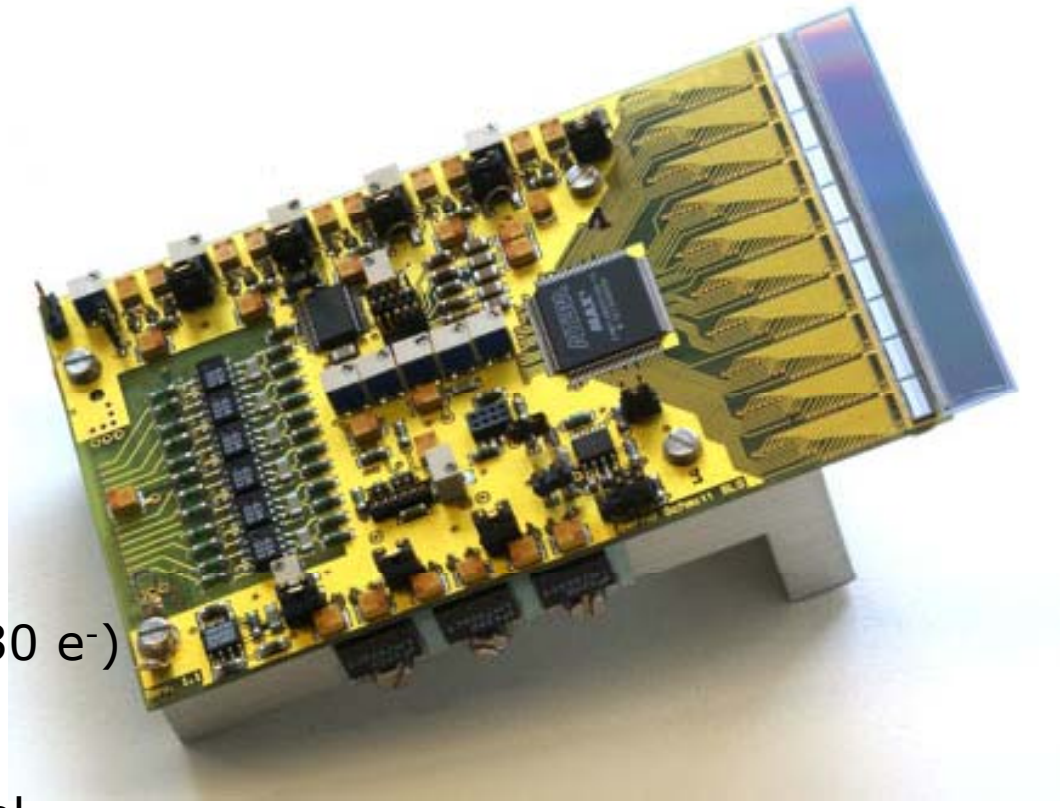
# MYTHEN

**Silicon sensor**:

- 1280 strips
- 8 mm long
- 50 μm pitch
- 300 μm thick.



**Read out chip**:

- 128 channels
- low noise preamp (noise ≈ 230 $e^-$)
- 18 bit counter
- Read-out time: 250 μs
- Count rate: 1 MHz per channel

SWISS LIGHT SOURCE SLS

PAUL SCHERRER INSTITUT PSI

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# MYTHEN

- Angular coverage: 60°
- Number of channels: 15000
- Angular resolution: 0.004°
- Read-out time: 250 μs

SWISS LIGHT SOURCE SLS

PAUL SCHERRER INSTITUT PSI

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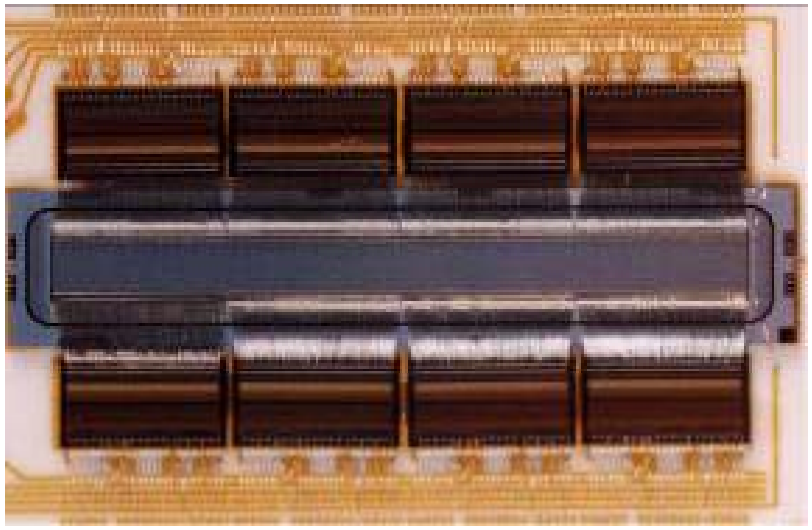
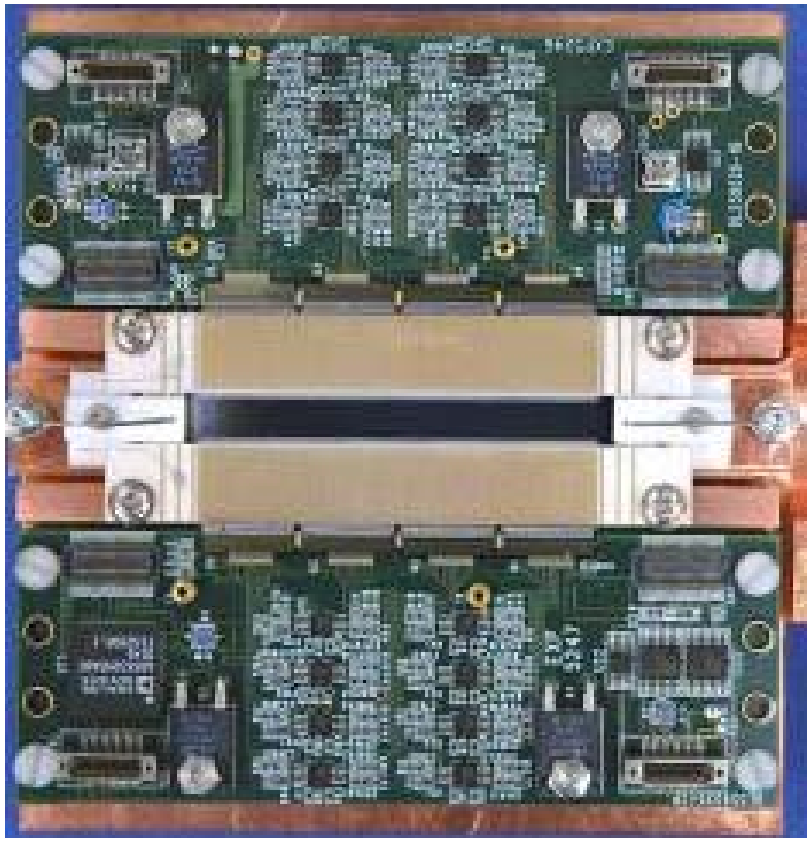
# micro-strip Si and Ge



*XSTRIP*



*XH – Ge μstrip*

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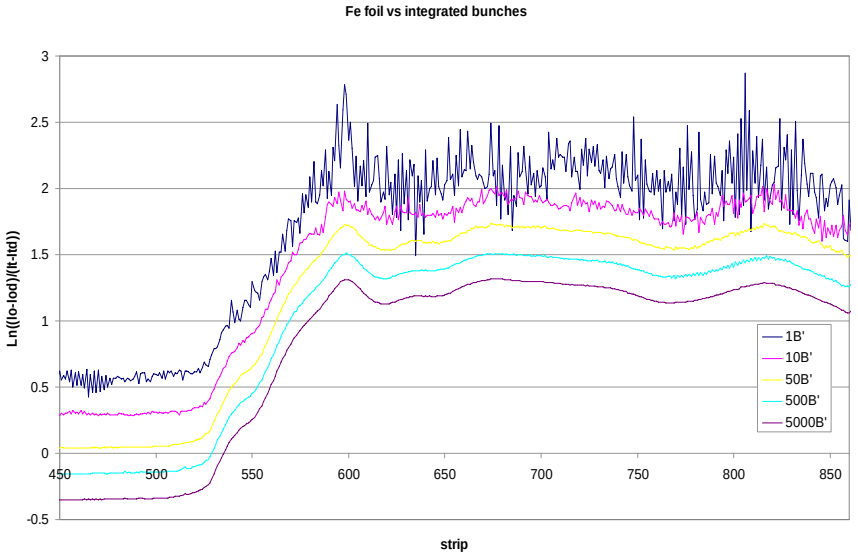
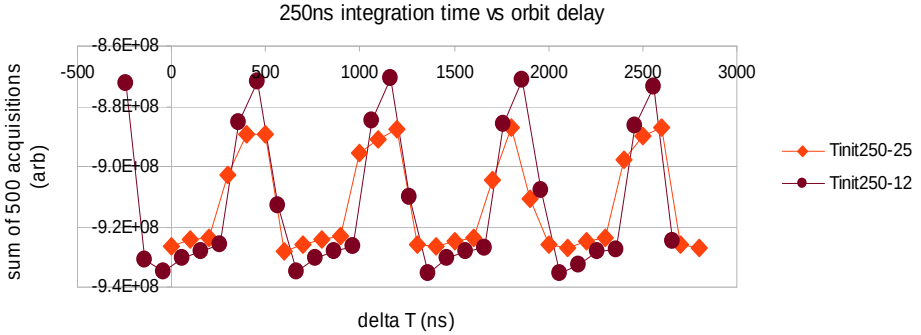
# micro-strip Si and Ge

*XH System on ESRF*



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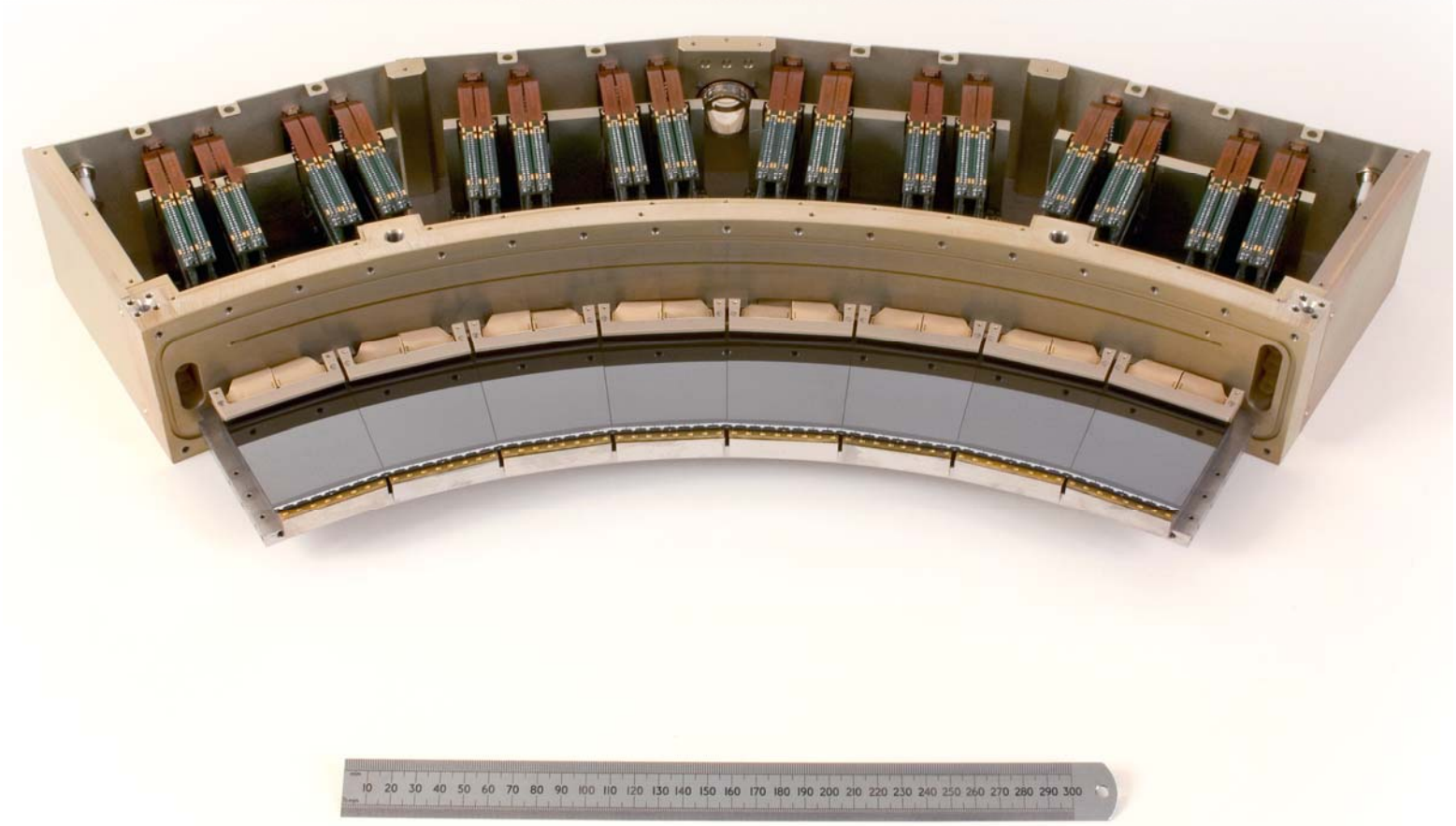
# HOTWAXS

## 8 precision mounted MSGC modules
## see NIM A580 (2007) p1526



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# HOTWAXS

- Position sensitive, parallax free, MSGC based, photon counting detector for combined SAXS/WAXS, XAS/XRD experiments
- 512 independent channels of preamplifier, scaler and discriminator (scalers and discriminators remotely located)
- Channel count rate of 1 MHz, Global count rate 500 MHz
- Position resolution of 0.16° for 8keV x-rays
- 60° angular coverage, 400mm sample to detector distance
- 50mm active gas depth

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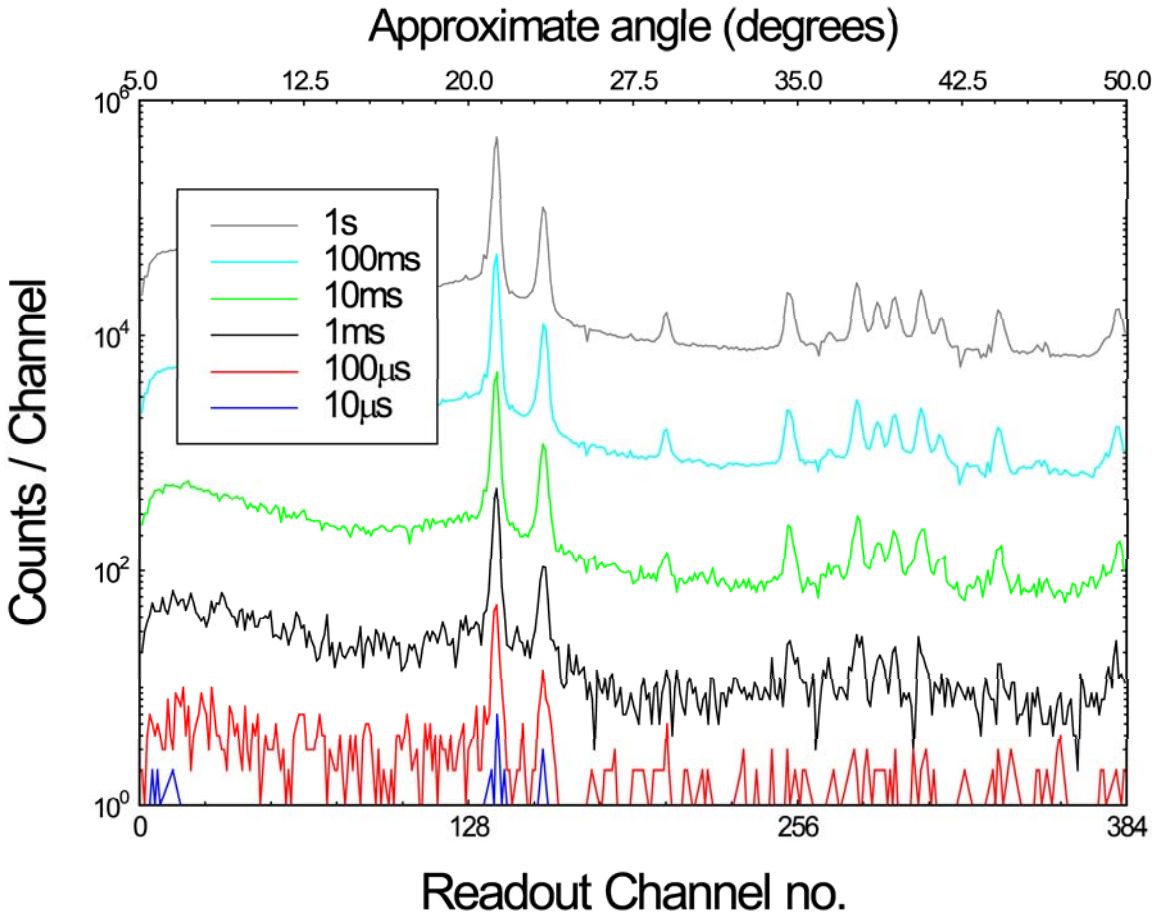
# Time framing capability of HOTWAXS system (16.1)



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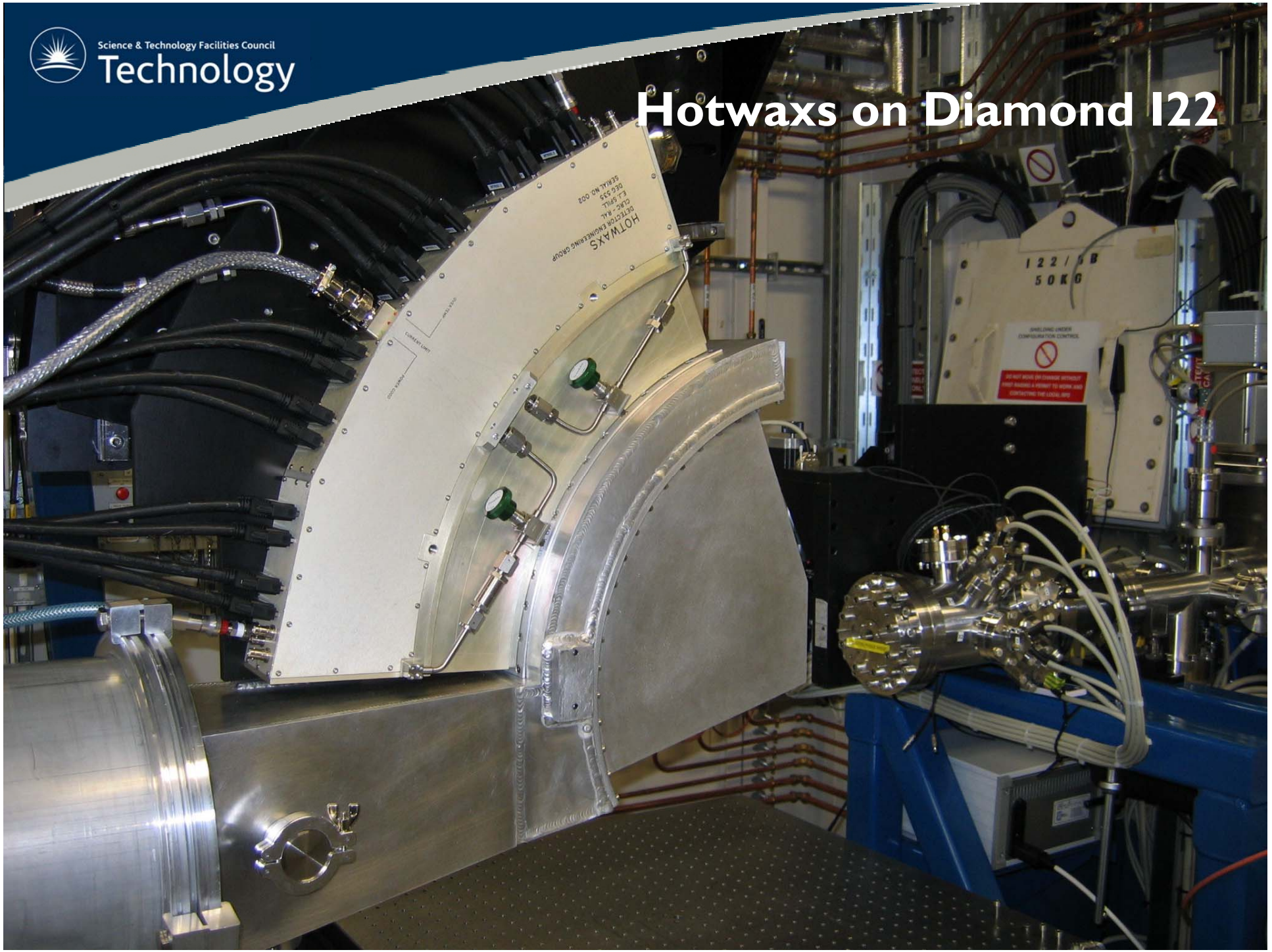
# Hotwaxs on Diamond I22



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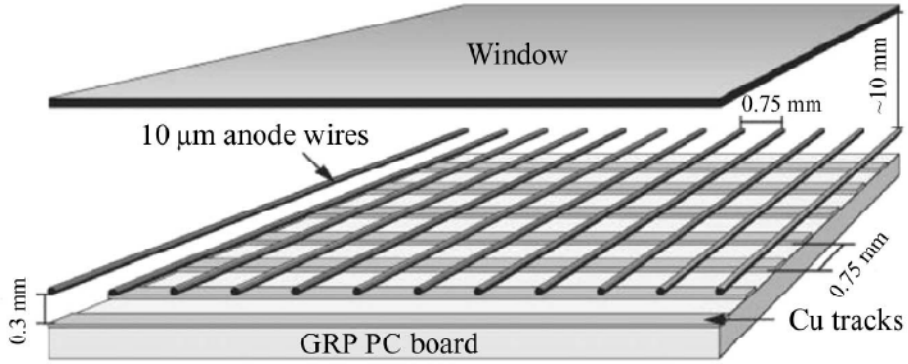
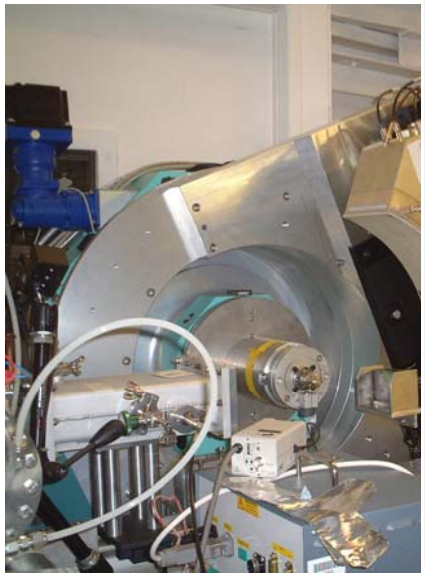
# RAPID2

- Amplifier per wire MWPC
- Micro-gap technology
- Radial Field development
- Interpolation



| | SAXS | WAXS |
|---|---|---|
| **Parameter** | **Value** | **Value** |
| Detector Style | 60° Quadrant | Linear |
| Energy Range | 4-12 keV | 4-12 keV |
| Sample - Detector spacing | 1200-4000 mm | 366mm |
| Angular range: | 3 - 9 degrees | 60 degrees |
| Angular Resolution: | 0.03-0.09 degrees | 0.06 degrees |
| Detector Length: | 200 mm | 384 mm |
| Spatial Resolution: | 0.375 mm | 0.375 mm |
| Pixel size: | 0.094 mm | 0.094 mm |
| Count Rate (Global): | 20 MHz | 20 MHz |
| Count Rate (Local): | 1 MHz /mm | 1 MHz /mm |
| Differential non-linearity: | 5% | 5% |

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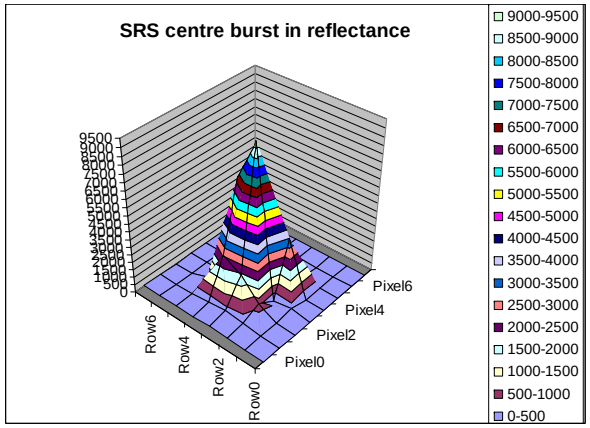
# HgCdTe (Mid-IR) Arrays

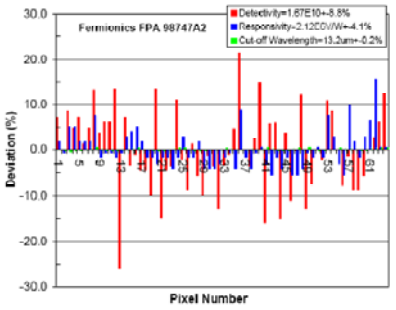



*DAIRS data*

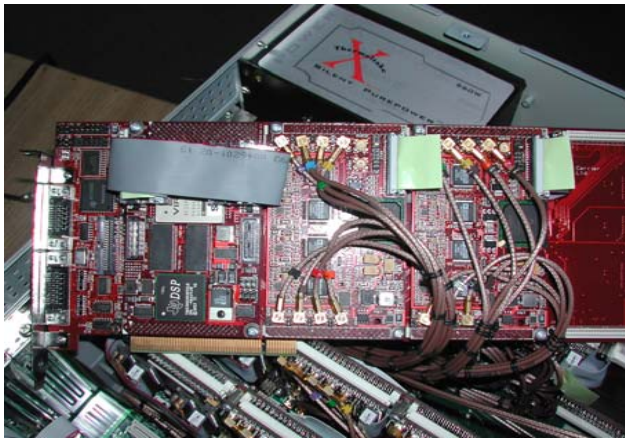
DAIRS detectors and pre-amp

FPA-98747A2 PIXELS

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
| 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
| 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 |
| 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 |
| 41 | 42 | 43 | 44 | 45 | 46 | 47 | 48 |
| 49 | 50 | 51 | 52 | 53 | 54 | 55 | 56 |
| 57 | 58 | 59 | 60 | 61 | 62 | 63 | 64 |




Pixel map and performance



DAIRS Readout

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# Neutron omissions

- Novel Scintilators
  - LiGdB?
  - Nano-particulate scintillators
  - YAP
- Gas
  - GEM
  - Micromegas
  - Brookhaven?
- Solid State
  - Si APS

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# Photon omissions

- CCDs
- Structured scintillators
- High purity Ge, GaAs
- Si drift, DEPFET
- APD
- Gas
  - GEMS, Micro-pin arrays

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