Synchrotron applications of pixel and strip detectors at Diamond Light Source

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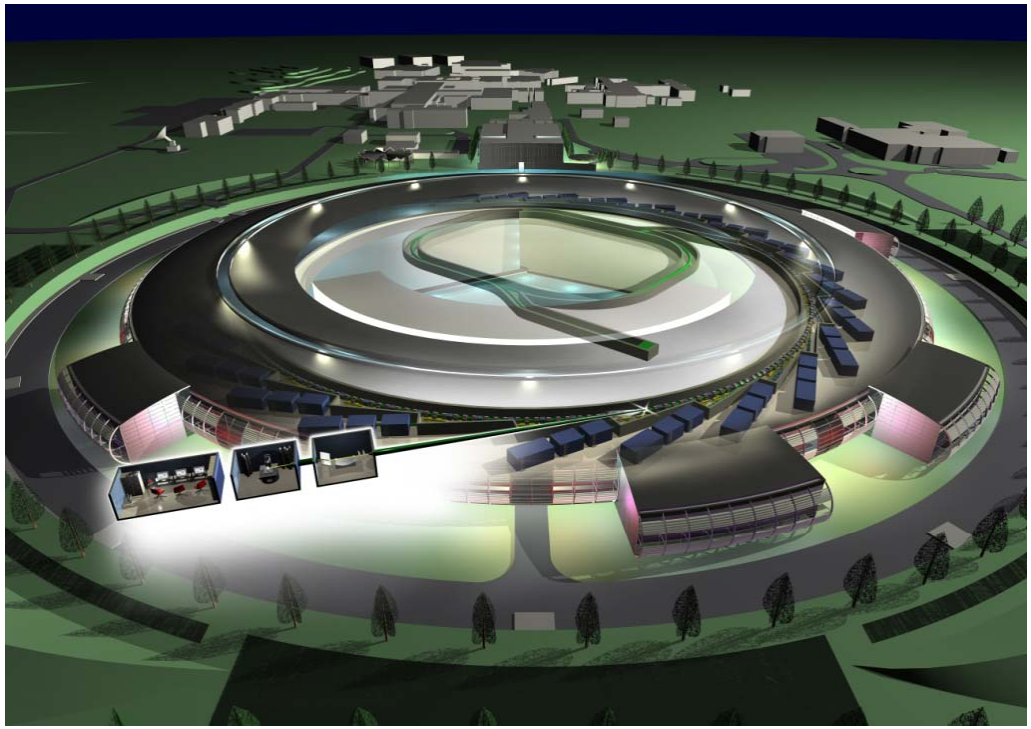
Outline

- Overview of position-sensitive X-ray detectors at Diamond Light Source
- Silicon pixel and strip detectors commissioning on beamlines
- Future pixel detector requirements

Diamond Light Source

- 3 GeV synchrotron machine
- 10 beamlines operational
- 12 more beamlines by 2011
- More beamlines by 2015



- **X-ray detectors on synchrotron beamlines:**
  - Diagnostic detectors
  - Spectroscopic detectors
  - Position-sensitive detectors

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Position-Sensitive Detectors

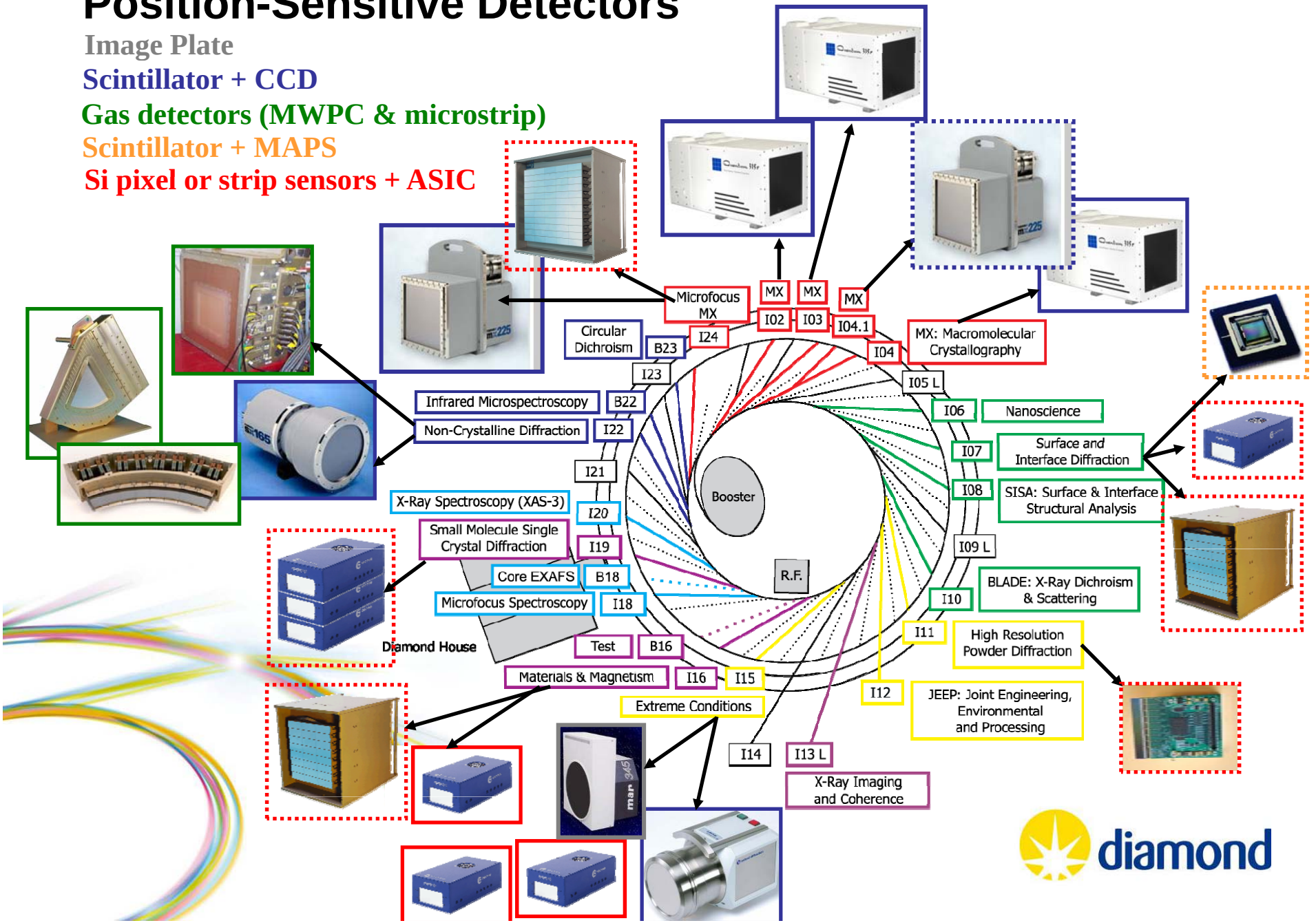
Image Plate

Scintillator + CCD

Gas detectors (MWPC & microstrip)

Scintillator + MAPS

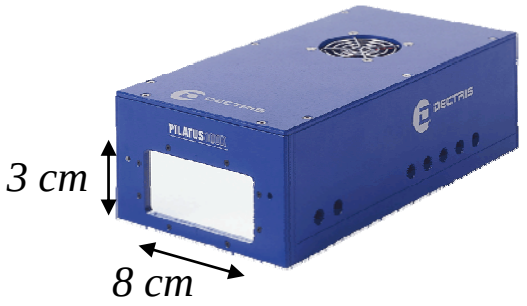
Si pixel or strip sensors + ASIC



Hybrid Pixel Detectors

Single-module Pilatus 100K

- P100K developed at PSI and **commercialized by Dectris**

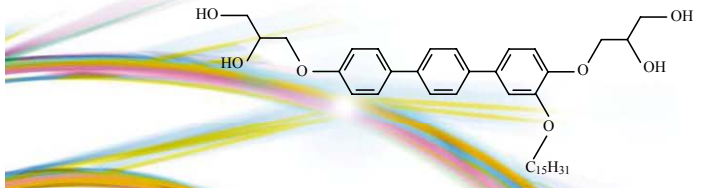


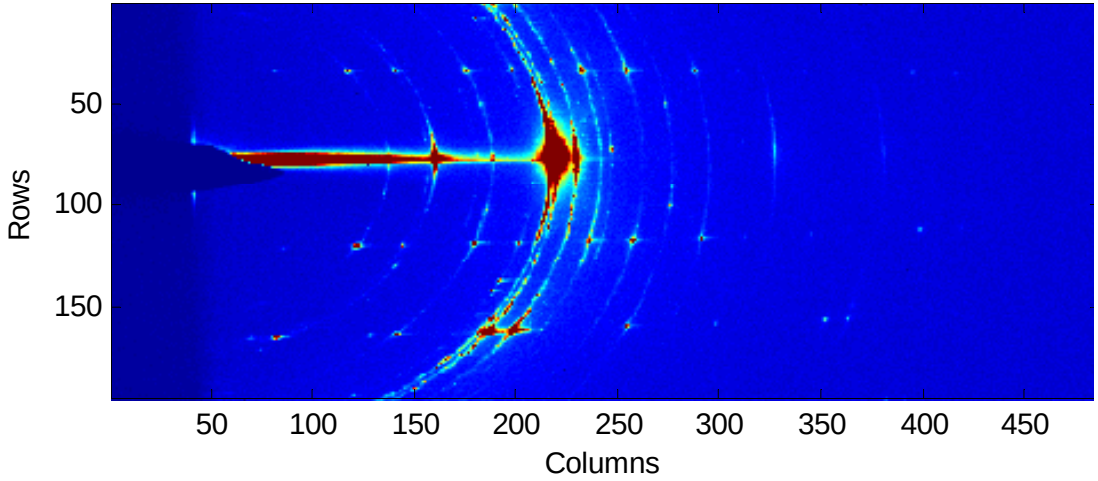
Dectris P100K
Hybrid Pixel Detector

- **Specifications:**

  Pixel size: 172 µm x 172 µm
  Sensor: 320 µm thick Si (QE=55% @ 15 keV)
  Frame rate: up to 200 Hz
  Read-out mode: Photon counting (energy threshold 3-20 keV)
  Pixel counter bit depth: 20 bit

Example of data recorded with P100K on I16:
GISAXS pattern of liquid-crystalline phase formed by self-assembly of T-shaped molecules:





Courtesy of Dr Steve Collins (I16) and Prof. G. Ungar (University of Sheffield)

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Hybrid Pixel Detectors

Multi-modules Pilatus detectors

❑ 1 Pilatus 2M **under commissioning** on material & magnetism beamline [I16]

❑ 1 Pilatus 2M **under fabrication** for surface and interface X-ray diffraction studies [I07]

❑ 1 Pilatus 6M **under fabrication** for microfocus macromolecular crystallography [I24]

Pilatus 2M Hybrid Pixel detector (produced by Dectris)

❑ **Pilatus 2M**
3 x 8 modules
Active area: 25 cm x 29 cm
Frame rate: 30 Hz
Image size: 2.4 MB

❑ **Pilatus 6M:**
5 x 12 modules
Active area: 43 cm x 45 cm
Frame rate: 12 Hz
Image size: 6.5 MB

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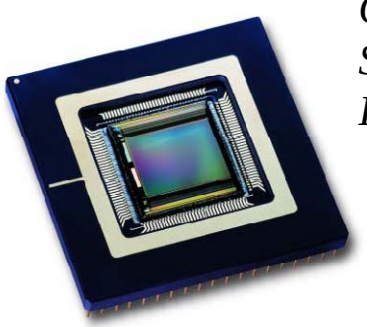
Monolithic Active Pixel Sensor (MAPS) + scintillator

SOLO detector

- **XPCS: X-ray photon correlation spectroscopy [I07]**
- Detector needs good **spatial/angular resolution** & good **time resolution**
- **SOLO project:** Collaboration with University of Sheffield
  Gadox scintillator + Fiber Optics Taper + Commercial CMOS MAPS
  1280 x 1024 pixels (12 microns pixel size)
  Integrating read-out
  500 Hz frame rate
  4000 Hz for a 1280 x 128 pixels ROI



CMOS Active Pixel Sensor from Micron Imaging

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Silicon Strip Detectors

Mythen2 strip detector

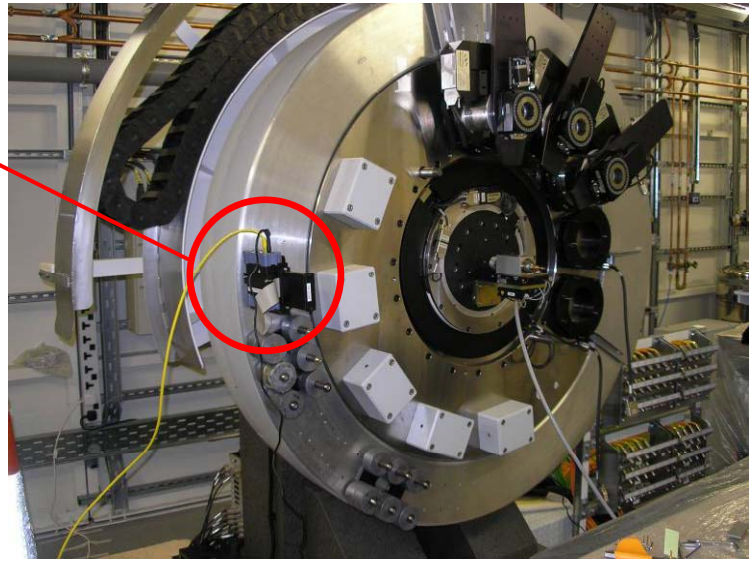
❑ Mythen2 developed by **PSI Detector Group** for the Powder Diffraction beamline @ **SLS**

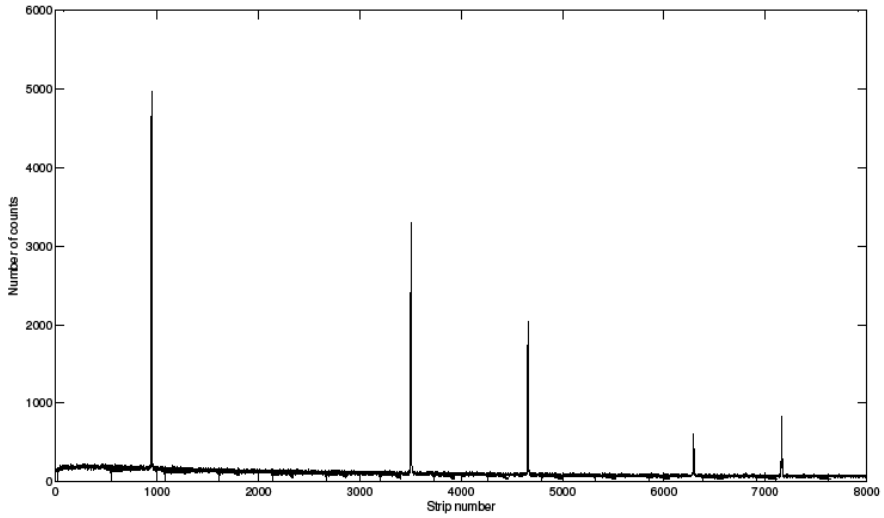
❑ Mythen2 technology will also be used for time-resolved powder diffraction beamline at DLS [I11]

Mythen2 module specifications:

- **Number of Si strips:** 1028
- **Si thickness:** 300 microns
- **Strip pitch:** 50 microns
- **Read-out:** Photon-counting (energy threshold)
- **Threshold adjustment:** 6 bit
- **Threshold dispersion:** 140 eV FWHM after equalization

Mythen2 module





Si powder diffraction pattern recorded with a single module on I11

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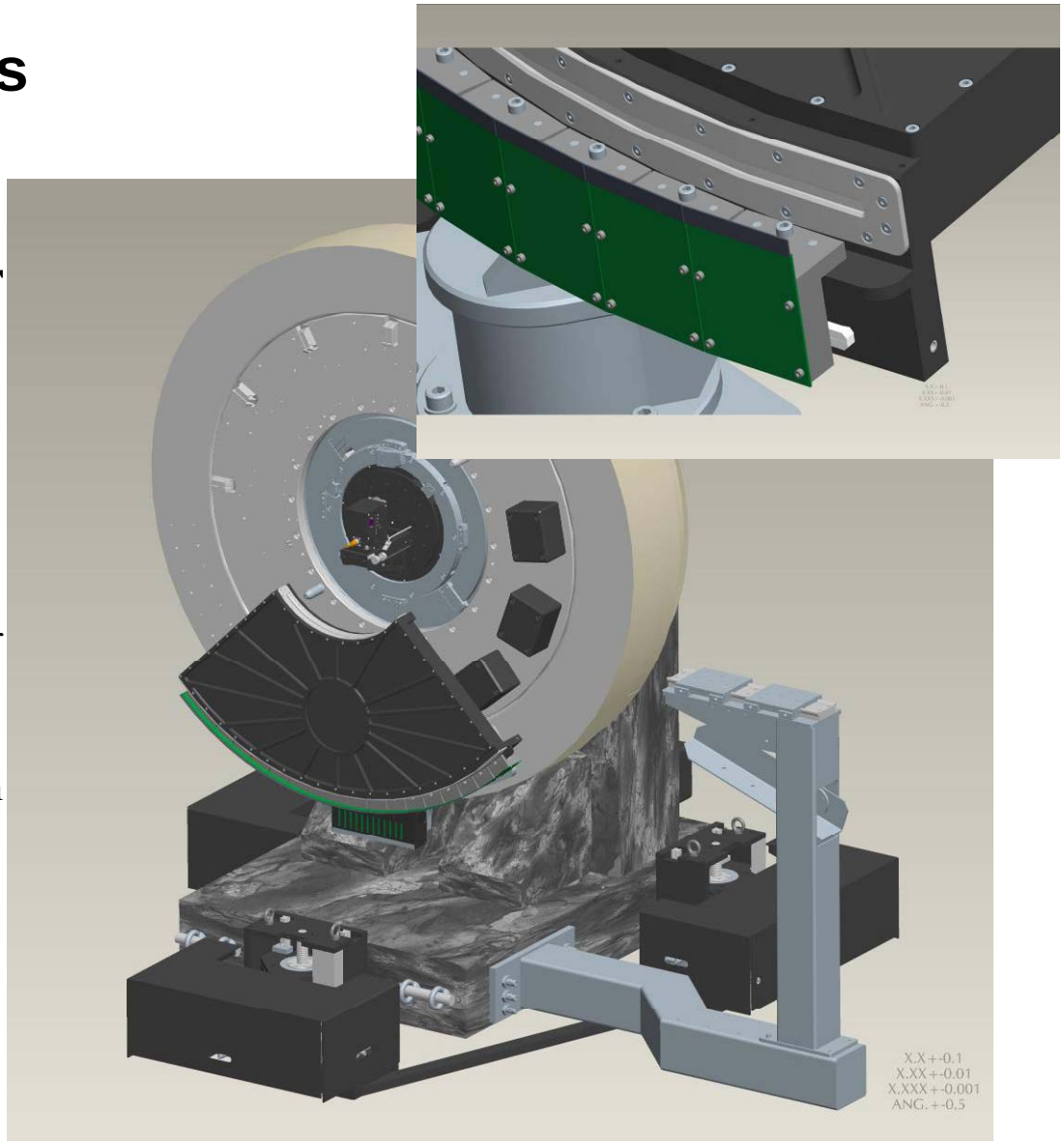
Silicon Strip Detectors

Mythen2 strip detectors

I11 Position-Sensitive-Detector specifications:

- 18 modules covering 90°
- Angular resolution: 0.004 °
- Frame rate 15 Hz (whole detector @ 24 bit/pixel)
- Higher frame rates achievable with less modules and 16 or 8 bit/pixel



3D view of I11 PSD mechanical housing

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Future pixel detector requirements

Priority 1: Smaller pixel size (~50 microns)

- **Large area detector with small pixels**
  Sharp diffracted features (from small highly perfect crystals) in crystallography
  Sharp speckles in photon-correlation spectroscopy [I10, I07]

- **Curved area detector with small pixels**
  Parallax error reduction for powder diffraction [I07] and long λ MX [I04.1]

- **Annular detector with small pixels**
  For combined WAXS and SAXS

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Future pixel detector requirements

Priority 2: More efficient with hard X-rays

- **Quantum Efficiency of 300 µm thick Si:** 27% @ 20 keV

- **2 beamlines at DLS operate at X-ray energies above 25 keV**
  - Extreme conditions high-energy X-ray diffraction beamline [I15]
    Energy range: 20 keV to 80 keV
  - Multipurpose high energy beamline [I12] (under construction)
    Energy range: 50 keV to 150 keV

- **Current technology:** Flat panels (CsI+TFT) → limited dynamic range
  → image lag

- Large-area hybrid pixel detectors based on **high-Z materials** are required

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Future pixel detector requirements

Priority 3: High frame rate

- **Pilatus frame rate:** 200 Hz for P100K
  30 Hz for P2M
  10 Hz for P6M

- **Frame rate > 1 kHz required for time-resolved experiments**
  - liquid crystals switching
  - x-ray photon correlation measurements
  - material and magnetism experiments
  - powder diffraction…

- **At high frame rate, the read-out dead time of photon-counting detectors becomes a limitation → Simultaneous Read-Write operation required**

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Future pixel detector requirements

Priority 4: High count rate/dynamic range

- Strong **and** weak diffracted features to be imaged at the same time in many diffraction experiments.
  - → I**ntegrating** detectors require **high dynamic range**
  - → **Counting** detectors require **high count rate**

- Max count rate for photon counting detectors ~ 2.10^6 X-rays/sec/pixel

- Possible solution: **mixed mode detectors** switching from photon counting to integrating (High DQE not required for high intensities)

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Summary

- DLS beamlines are equipped with:
  - Mature position-sensitive detector technology

  Image Plates, CCDs, MWPC, Microstrip gas detectors
  - New promising semiconductor pixel and strip detector technology

  Commercial Hybrid Pixel Detectors, developmental strip detectors, MAPS

- Requirements of future pixel detectors have been identified through a survey among DLS beamline scientists:
  Smaller Pixel size, Higher efficiency, Higher frame rate, Higher count rate/dynamic range

- A strong development program with commercial & academic detector developers is necessary

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