Detectors for Neutron Scattering and Synchrotron Radiation

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Neutron and Synchrotron Facilities Worldwide:

Synchrotron Radiation News:	**36 correspondents**
Neutron News:	**31 correspondents**
CERN Courier:	27 correspondents

Outline of Talk

Neutron Detectors:

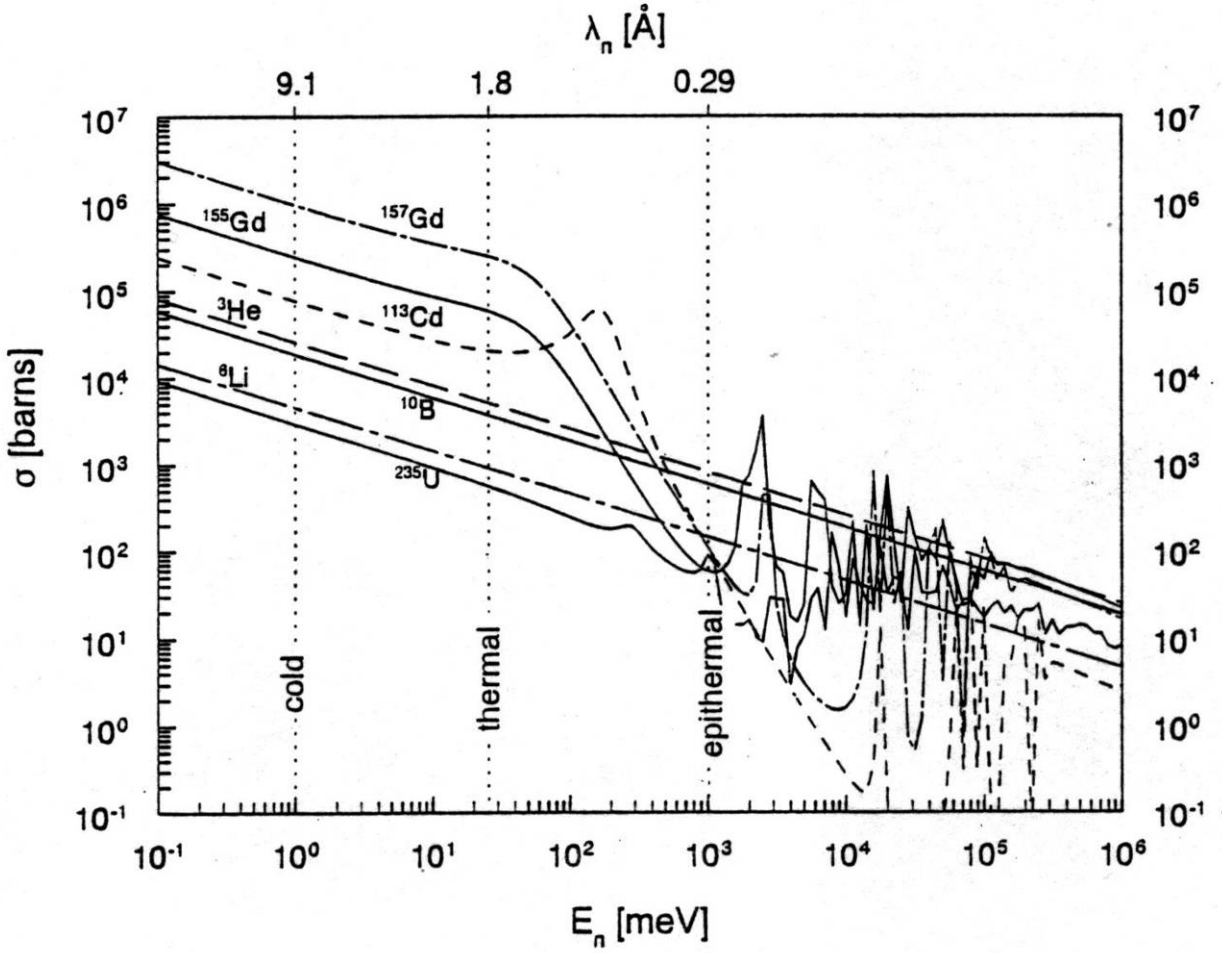
- Conversion Media
- Large Instrument Installations
- Position Sensing
- BNL Curved Detector
- Operation in Ionization Mode

X-ray Detectors:

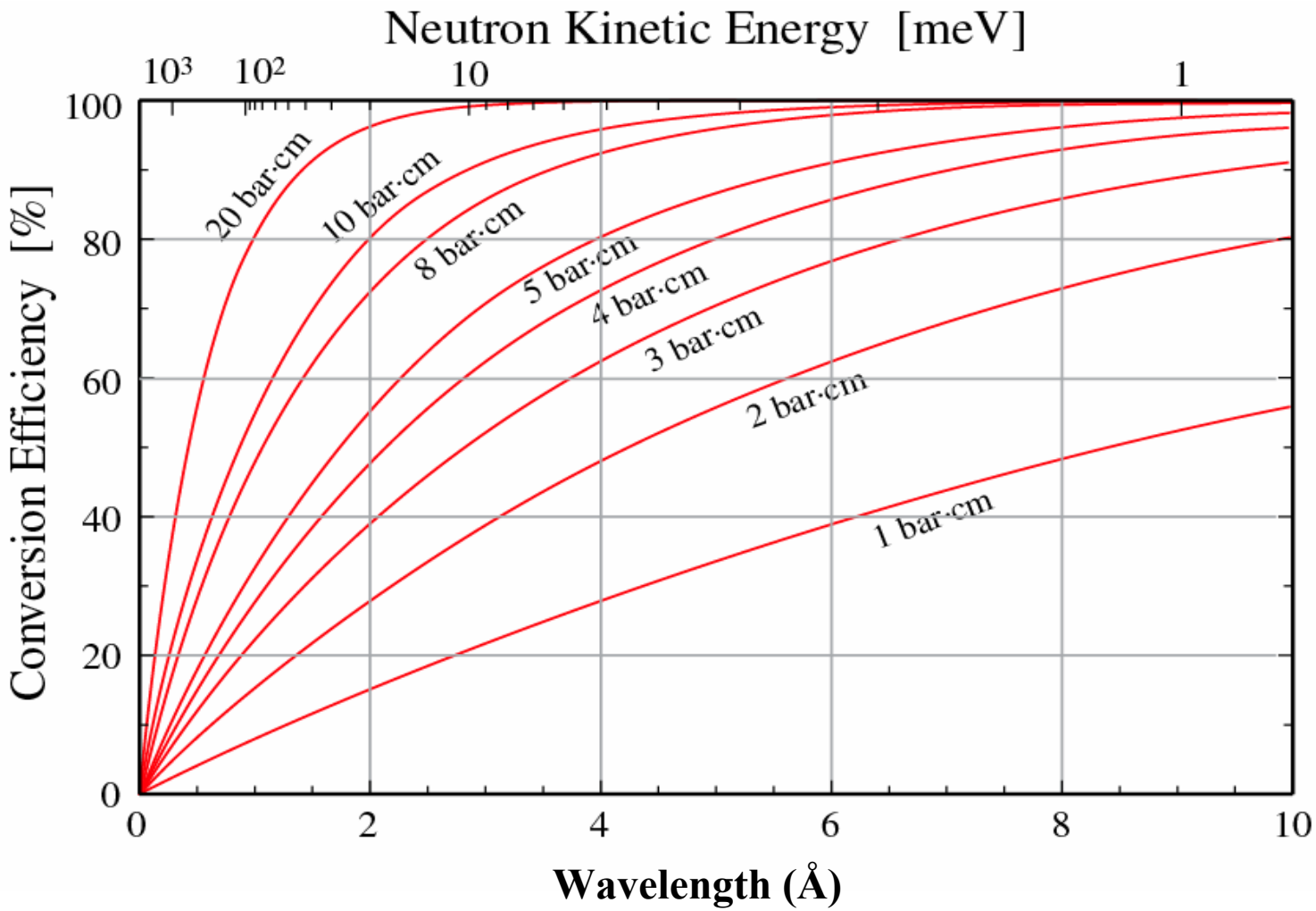
- Requirement for High Rate
- X-ray Microscopy
- Si pad Detectors – Fluorescence
- X-ray Protein Crystallography

Neutron Absorption Cross Sections

(1 barn = 10^{-24} cm^2)



Conversion Efficiency of ^{3}He Filled Detectors

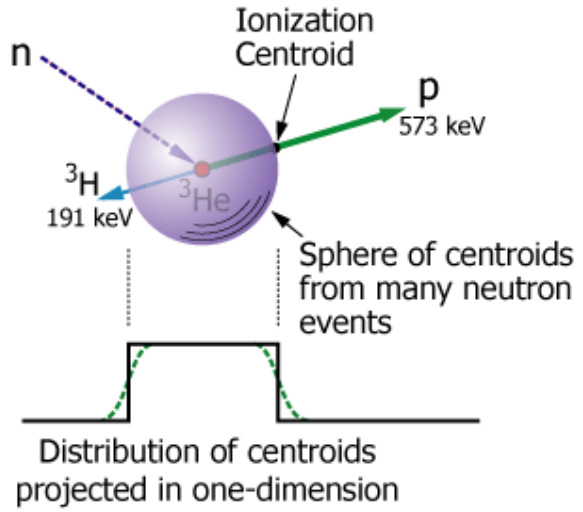


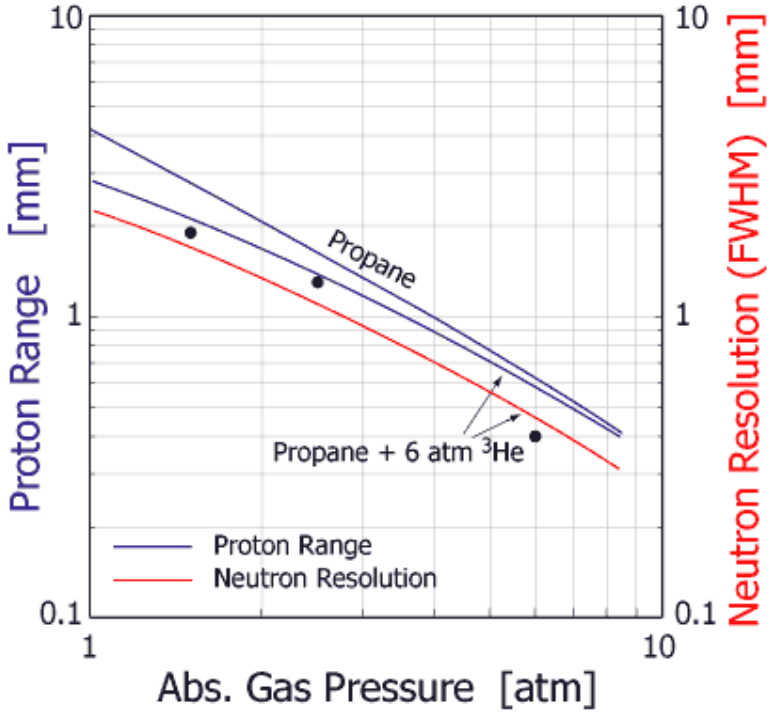
Thermal Neutron Detection in ^{3}He and Position Resolution

$$n + {}^3He \rightarrow p + {}^3H + 764\ keV$$

$$\downarrow$$

~25,000 electron-ion pairs

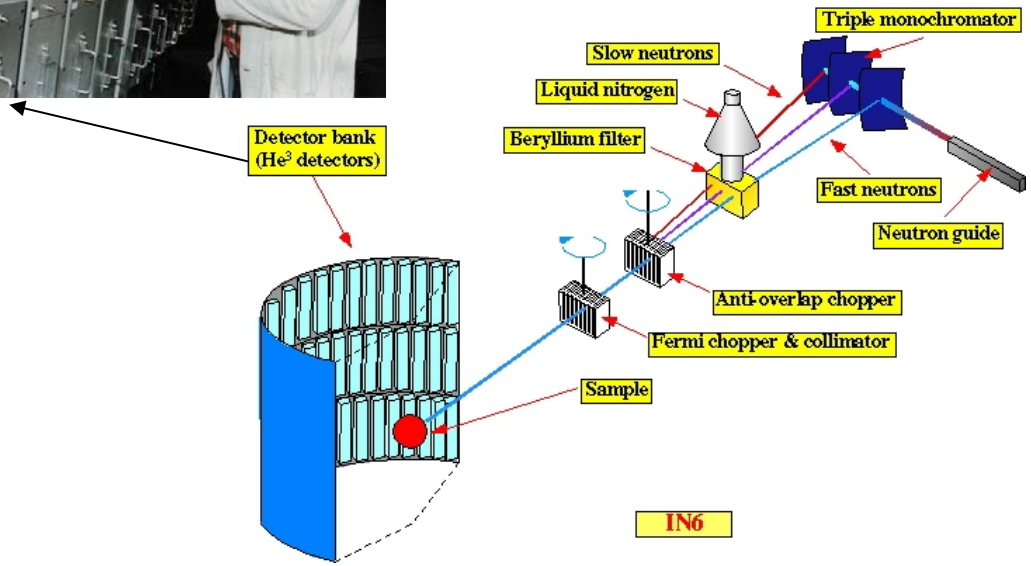




FWHM ~ 0.8 × proton range
(~4.2mm in 1 atm. propane)

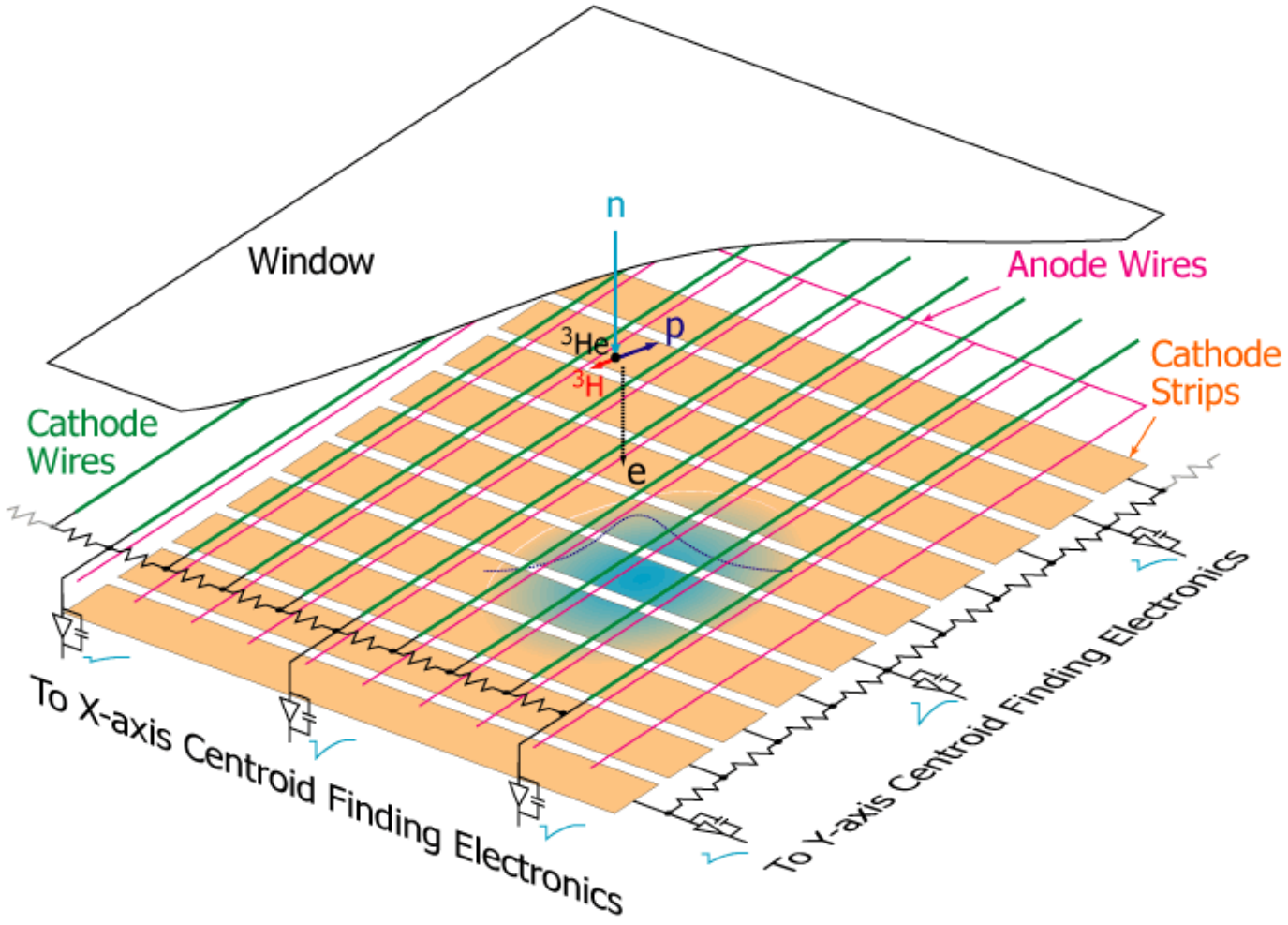
Examples of Position Sensitive Proportional Counters (Tubes) at Neutron User Facilities

Beam-line IN6 (ILL, Grenoble): a time-of-flight spectrometer for quasi-elastic and inelastic scattering.



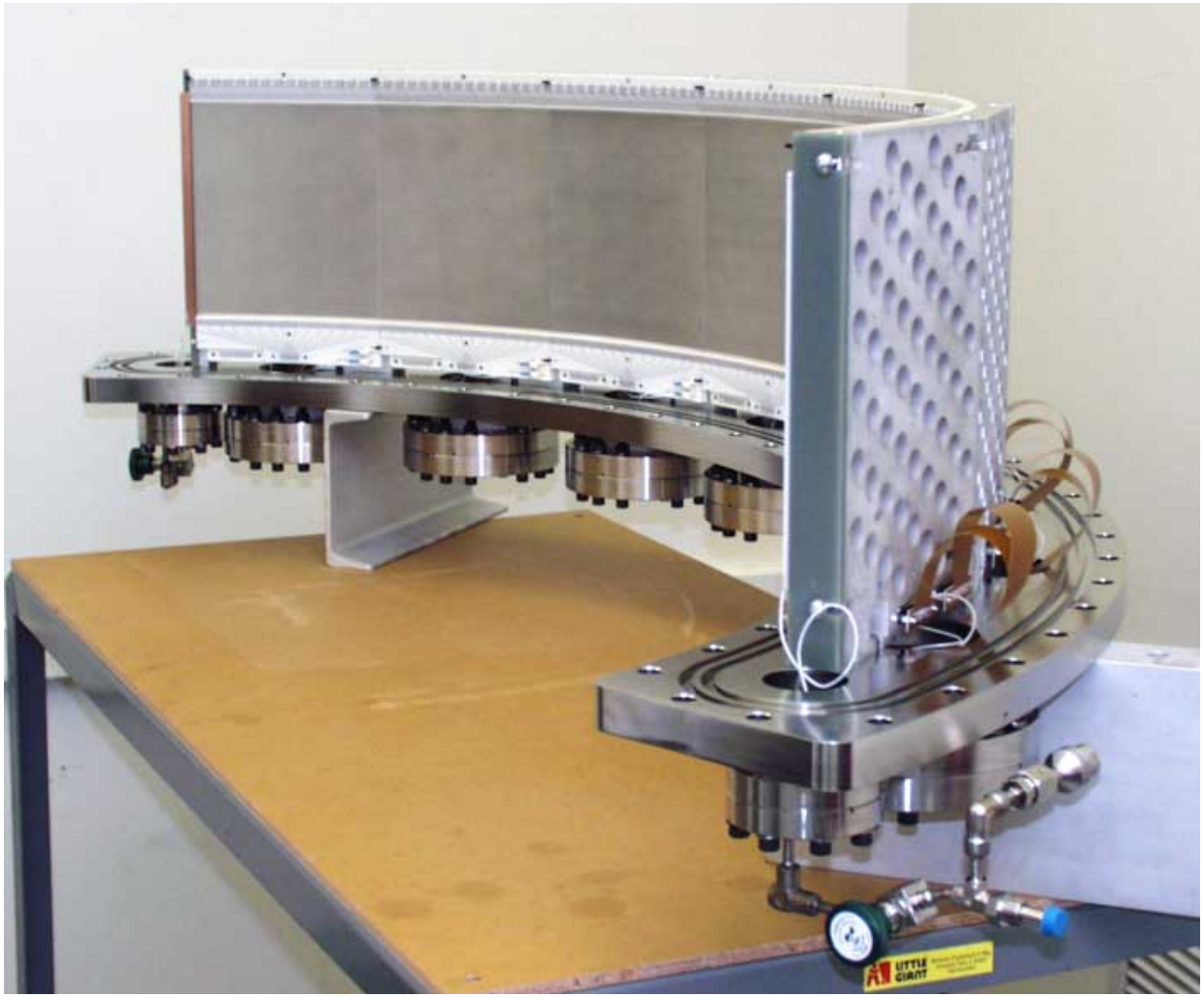
2m long, position-sensitive proportional counters for other time-of-flight experiments

Position Encoding with Interpolating Cathode Strips



120° Two-dimensional Neutron Detector

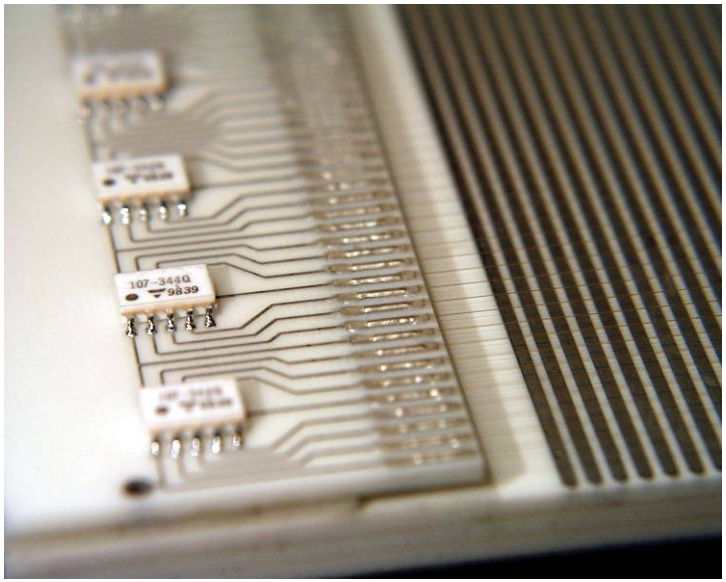
Eight wire segments mounted on flange



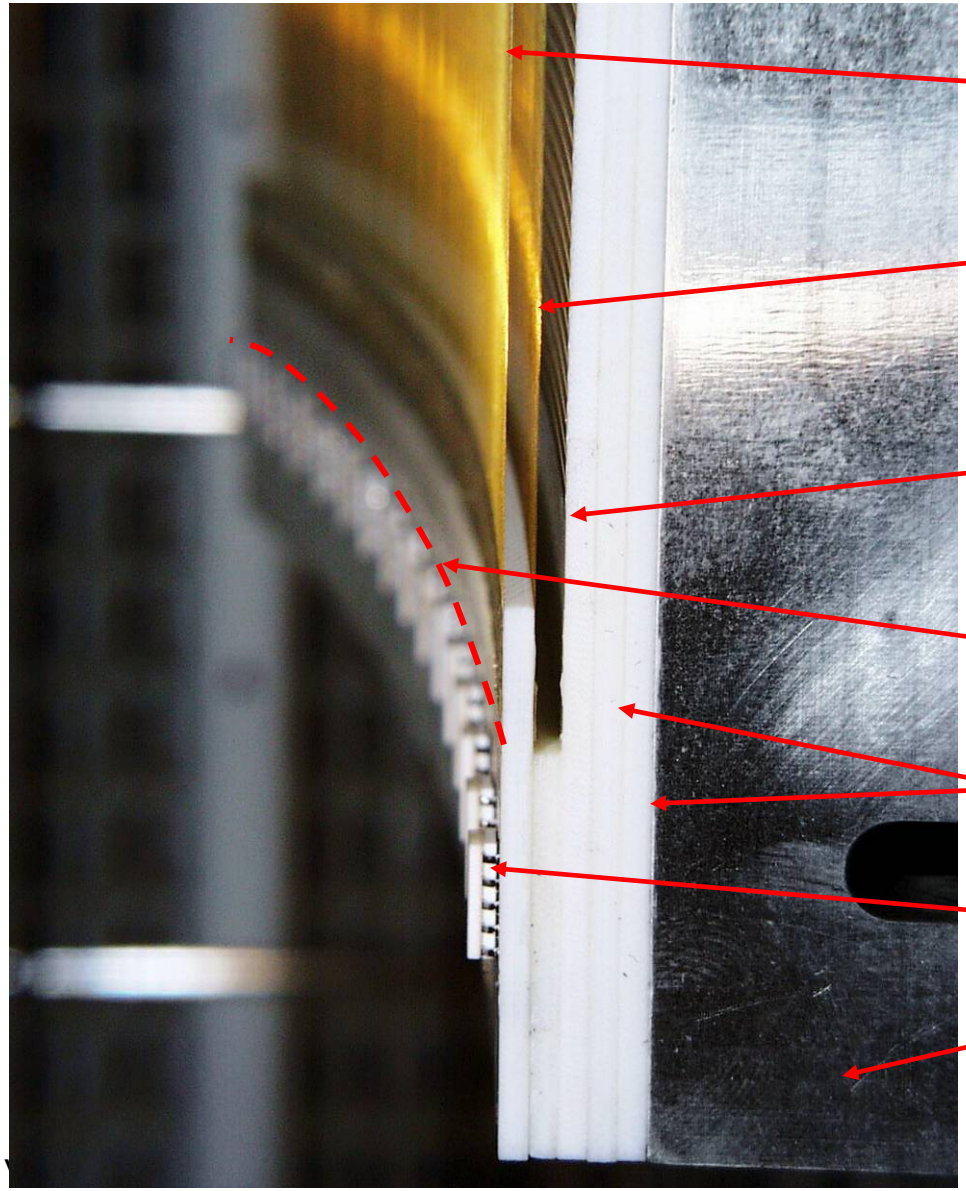
Wire Segment for Curved Detector

15 nodes in X, 17 nodes in Y

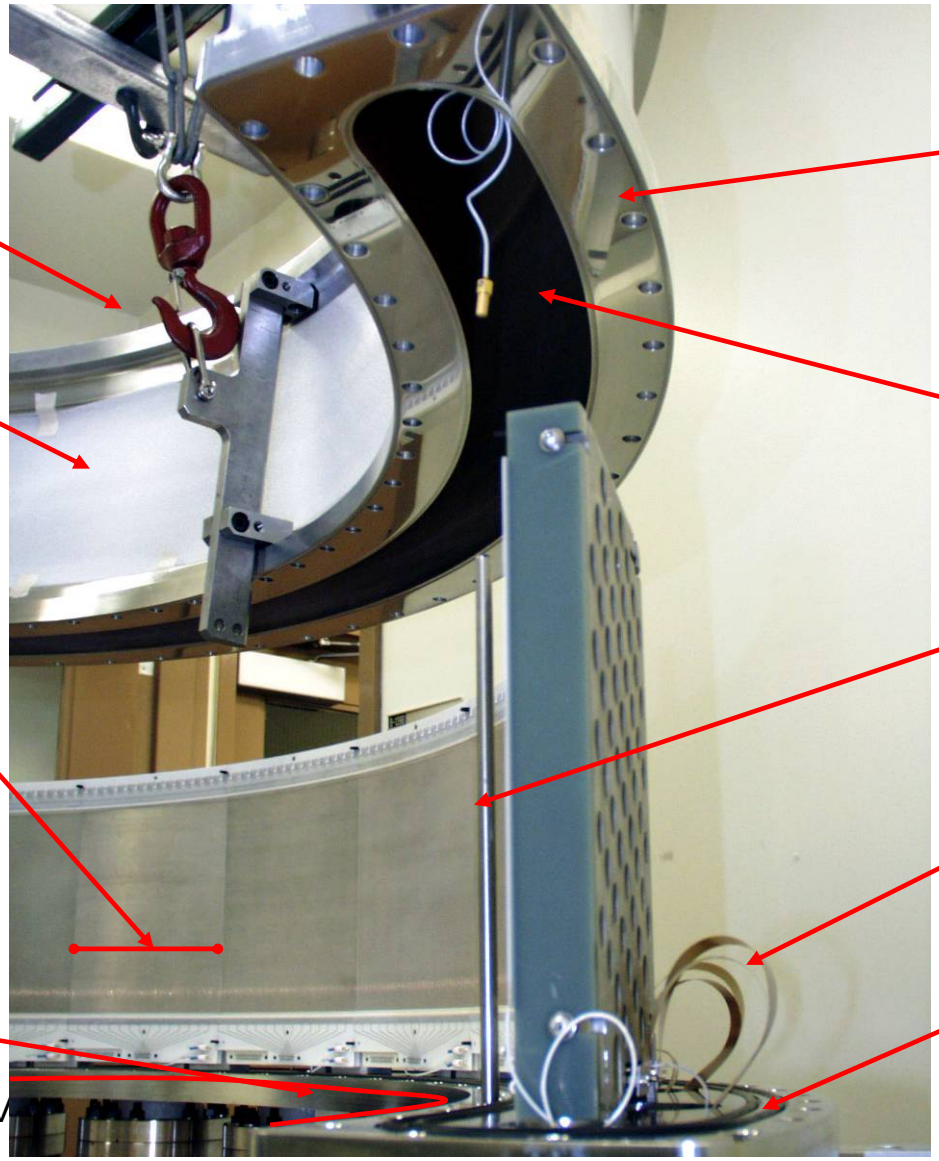
Close-up of one corner



One Segment – Edge View

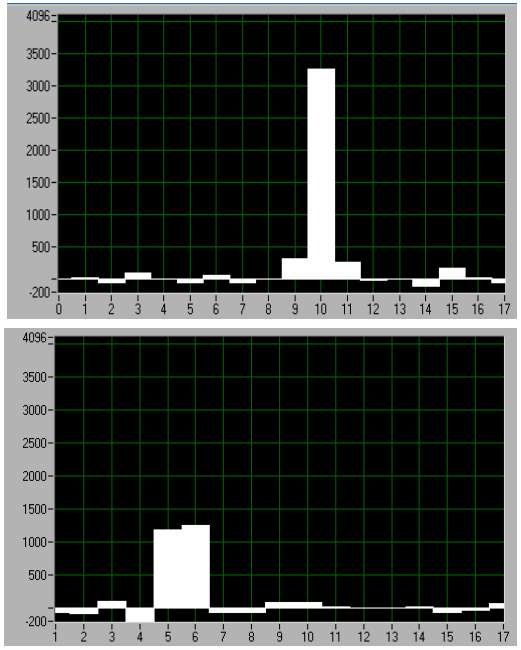


Final Assembly of 8 Segment Detector (120°)

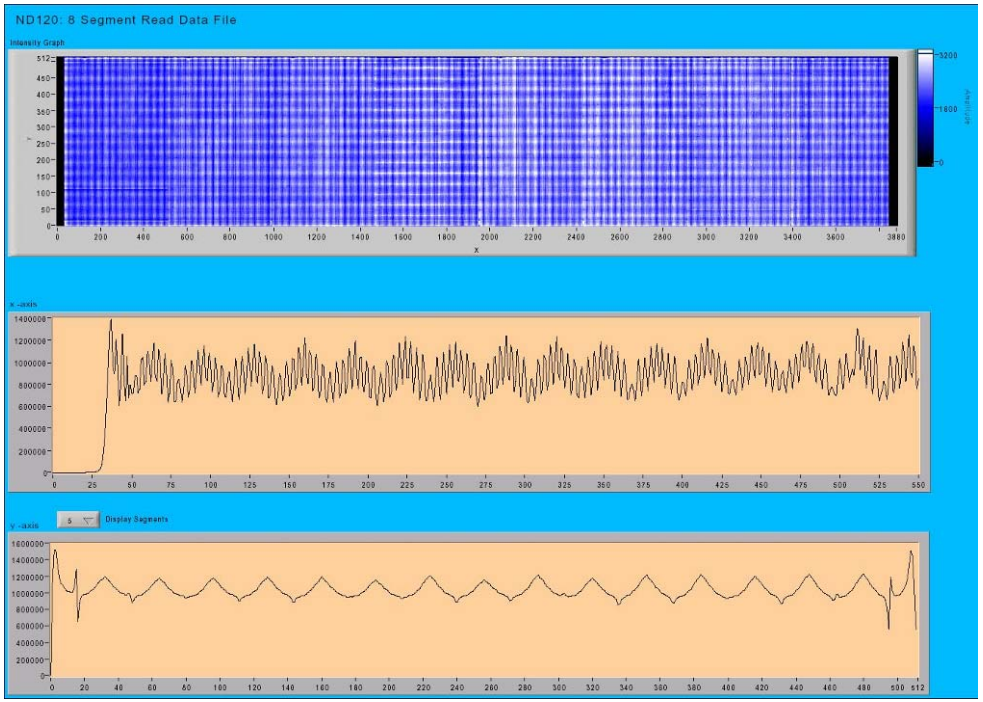


120° Neutron Detector for Protein Crystallography

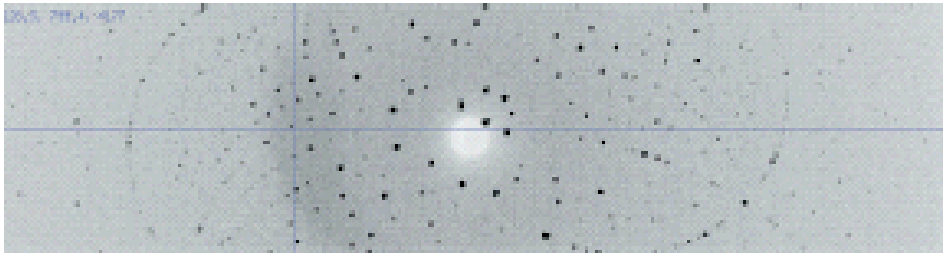
X and Y signals from one event in one segment



Eight Segment Uniform Irradiation Response



D-xylose isomerase



~ 2 million pixels, or ¼ million resolution elements

120° Neutron Detector:
Some recent press for Protein Crystallography

Physics Today, November 2003

Neutron Diffraction Overcomes Flux Limits to Resolve a Large Protein Structure

To demonstrate the effectiveness of neutron diffraction in biology, crystallographers bring neutrons to bear on an important industrial enzyme.

On paper, thermal neutrons seem ideal for probing the structure of crystalliz tenths of waveleng matches thermal enough w tural info to pass th Anothe mal neutr

same strength as potassium. Scattering strength also varies

third-generation synchrotrons flood samples with 10^{19} x-ray photons per second per square centimeter, a reactor source, such as the one at the Institut Laue–Langevin in Grenoble, rons per low in- it takes o collect than an ıd more be pres- e practi- ıve to be

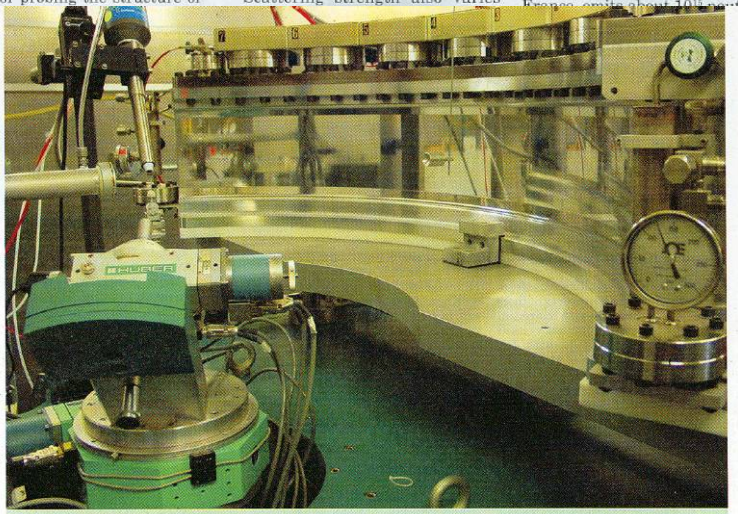
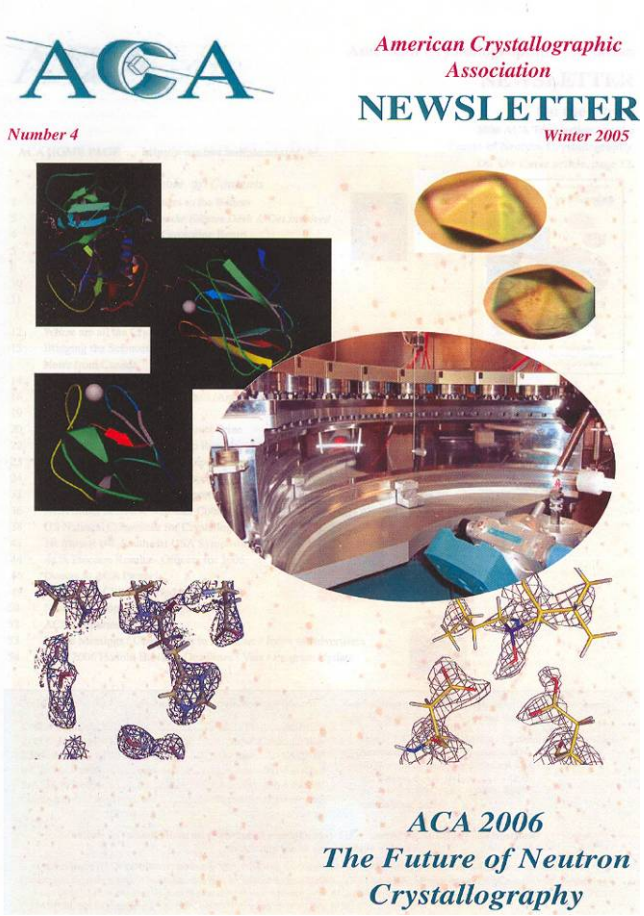


Figure 1. The Protein Crystallography Station at the Los Alamos Neutron Science Center. The sample is held by the rotating stage at the bottom left. Eight detectors are arrayed about 1 meter away from the sample to collect the scattered neutrons. (Courtesy of Gerry Bunick.)

ACA Newsletter, Winter 2005

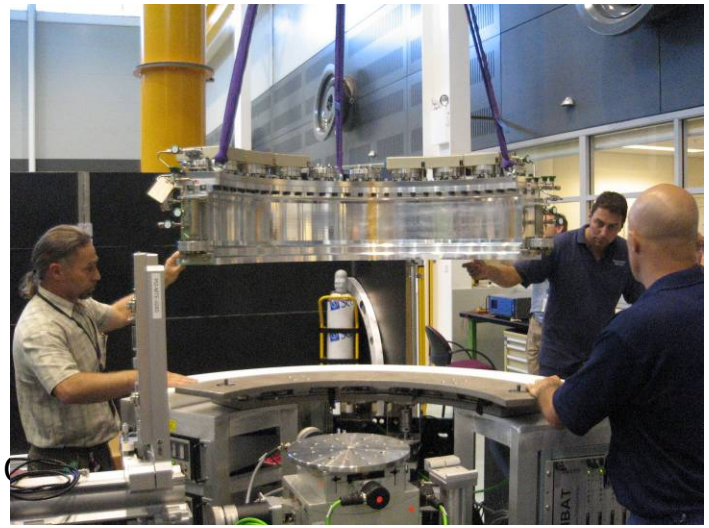


120° Neutron Detector: Installation at High Intensity Powder Diffractometer at new OPAL Reactor, Australia

Shipment arrives

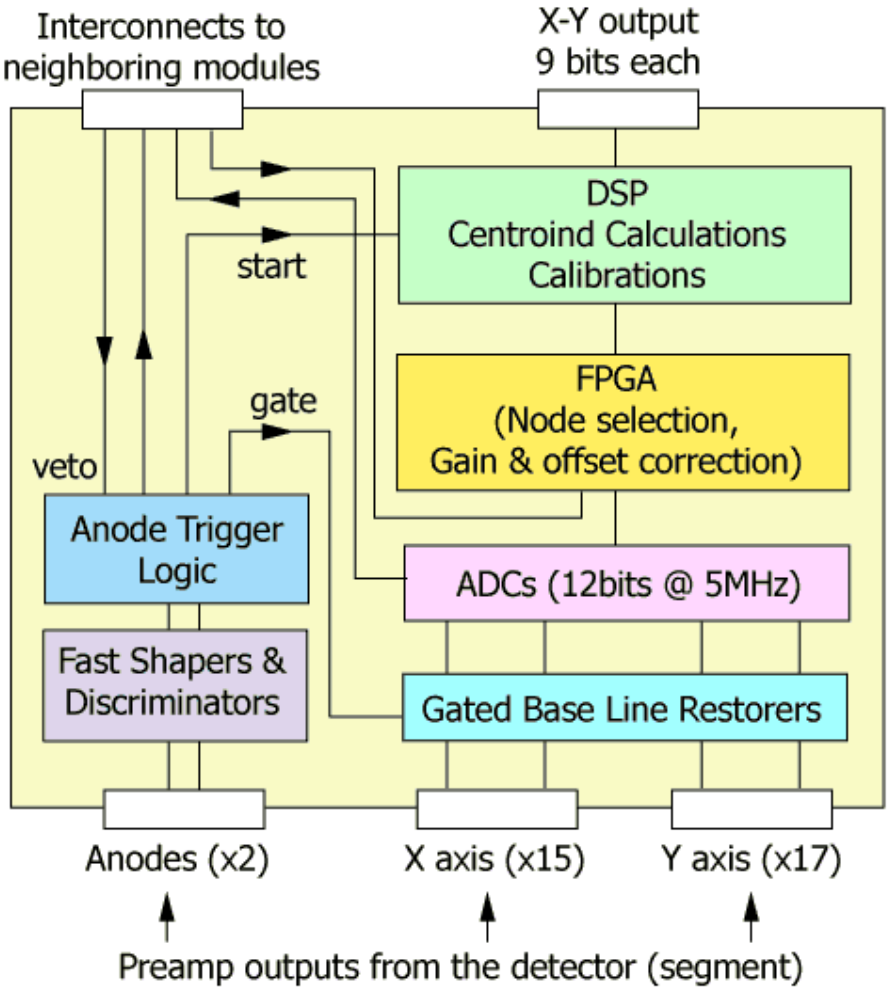
Moving detector to spectrometer

Lowering detector onto spectrometer

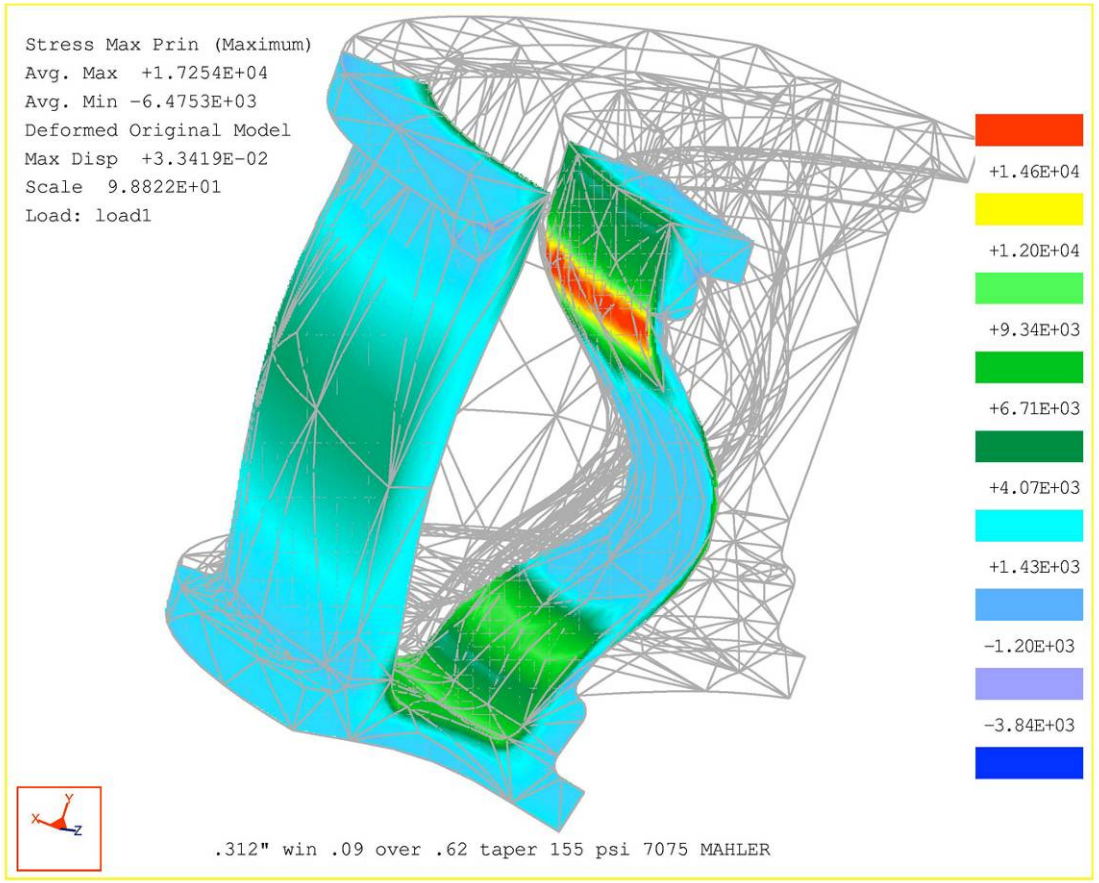


Completed instrument

Block Diagram of New Digital Encoding System

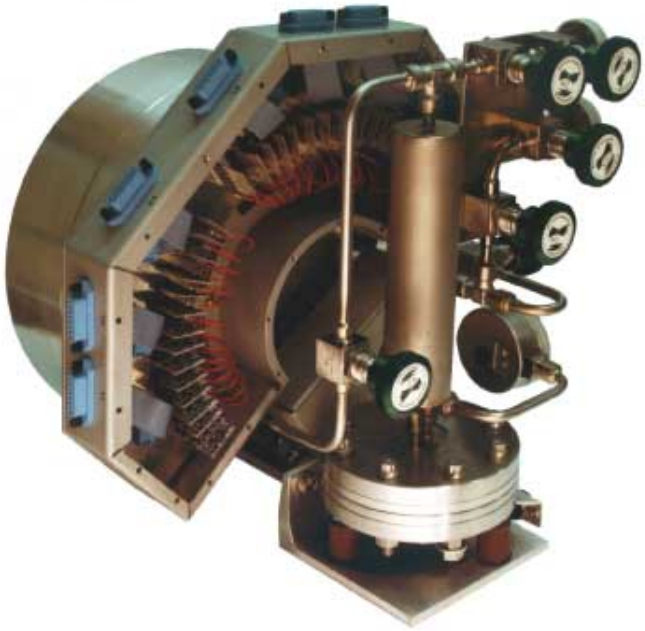


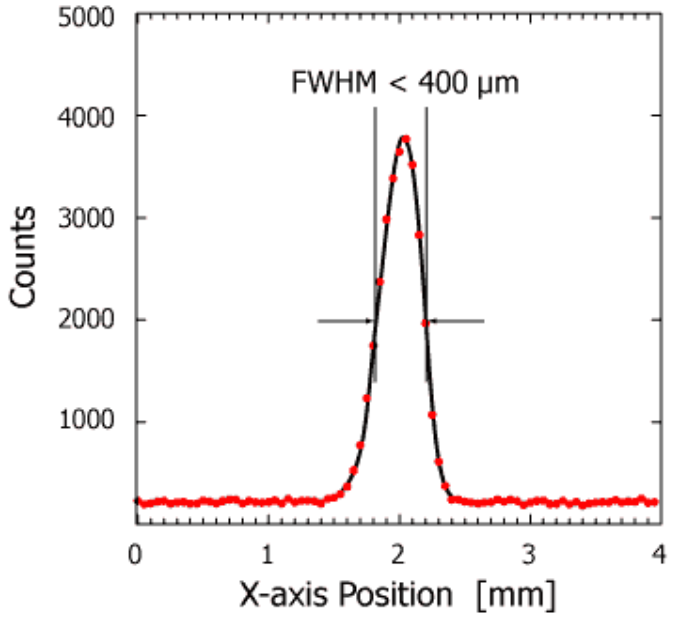
120° Neutron Detector:
Stress Analysis for Pressure Vessel



High Precision 5cm×5cm Detector

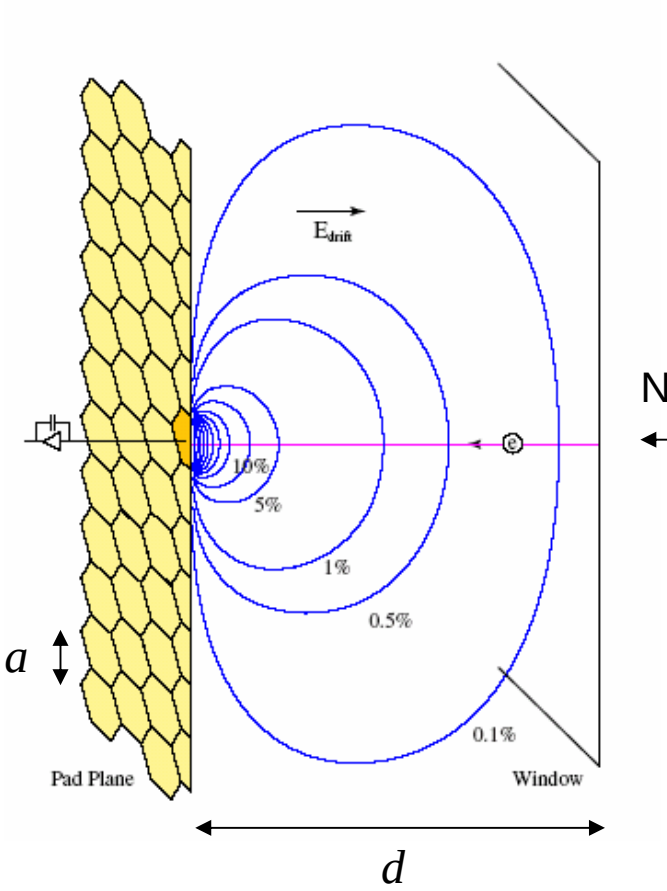
- Developed for fluid dynamics, radiography
- 8 atm. ^{3}He + 6 atm. Propane
- Best neutron position resolution to date in a ^{3}He gas detector





Two-dimensional, Neutron Pad Detector: Operation in Ionization Mode

Weighting field of a single pad in a parallel plate geometry



Neutrons ←

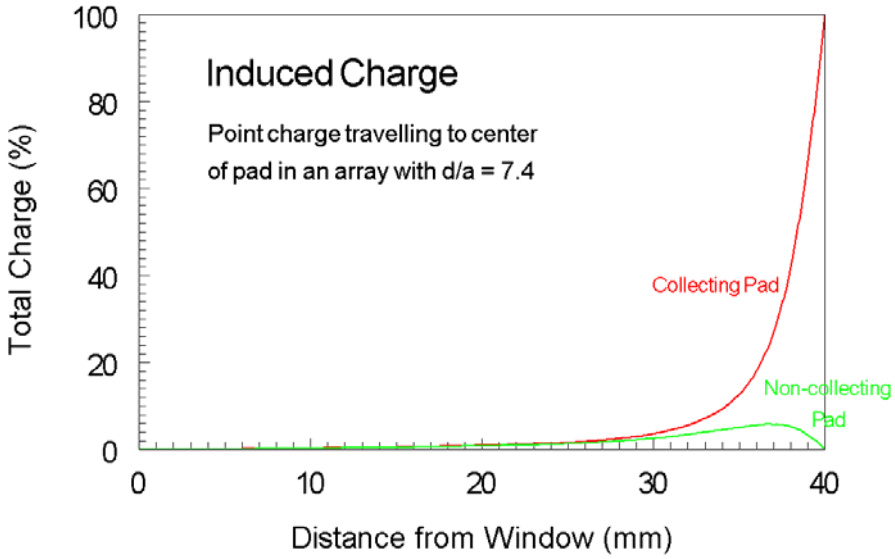
In test detector:

Area of each pad = 25mm^2

a = 5.4mm

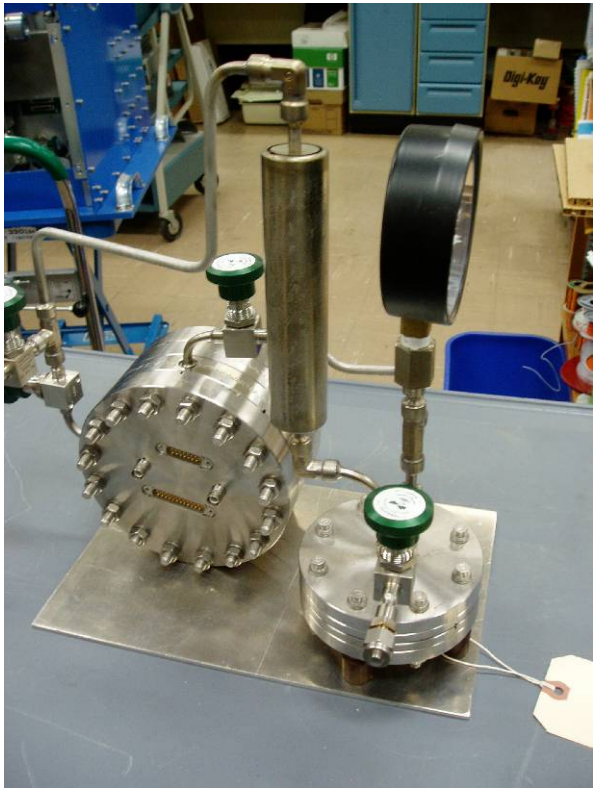
d = 40mm

d/a = 7.4

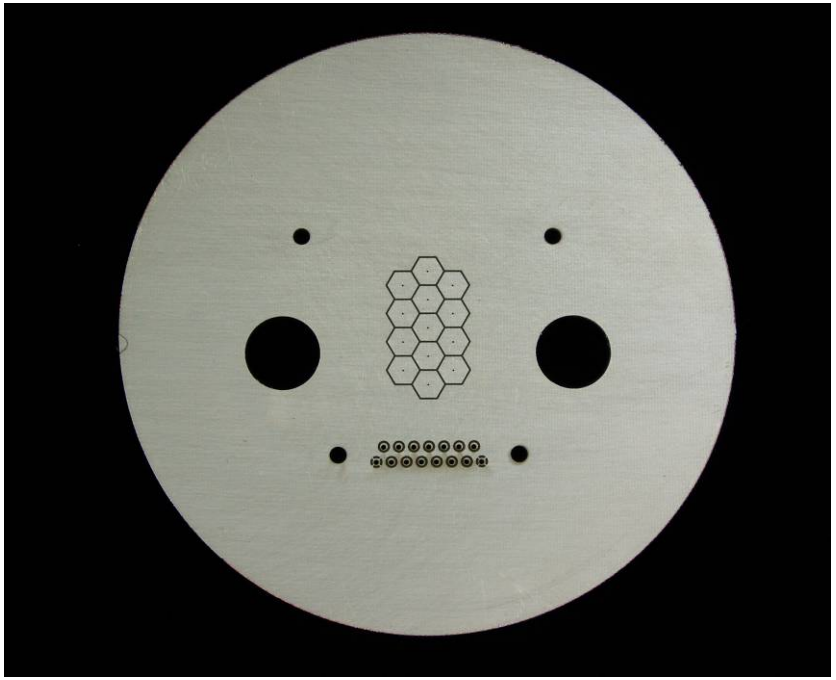


Pressure Vessel and Gas Cell with Pad Plane

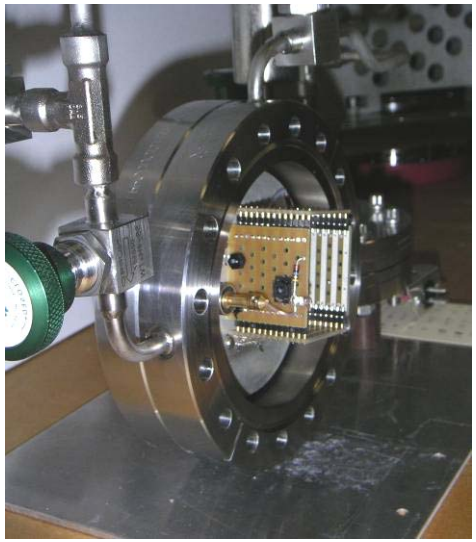
Detector housing and gas pump/purifier

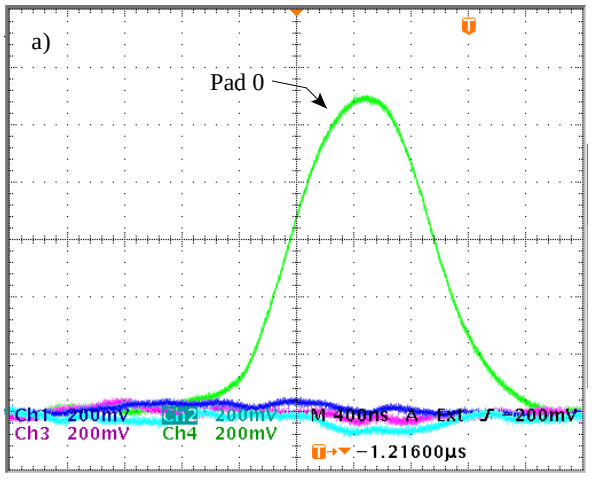


13 pad anode designed and fabricated as double layer board

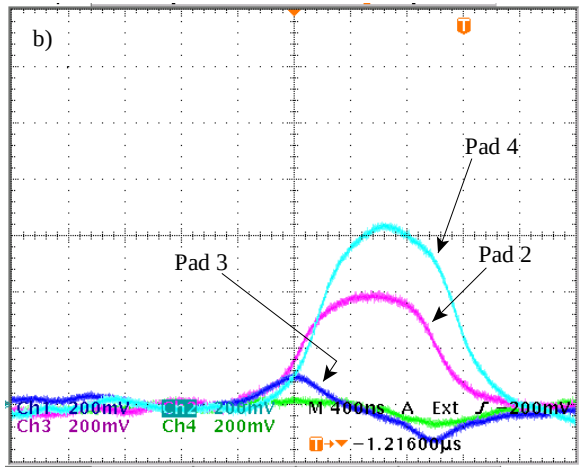


Neutron Pad Detector: Charge Collection on Pads

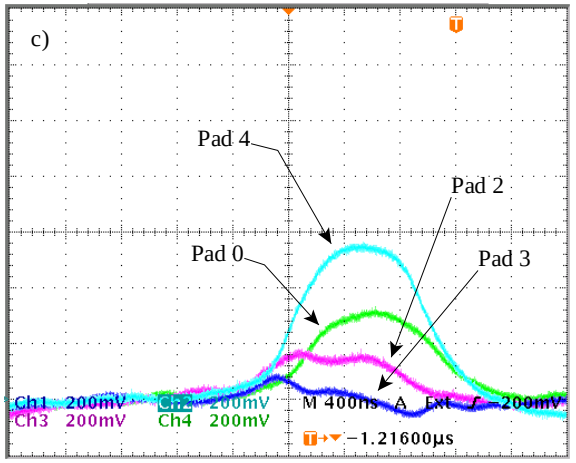




Charge collected by ONE pad



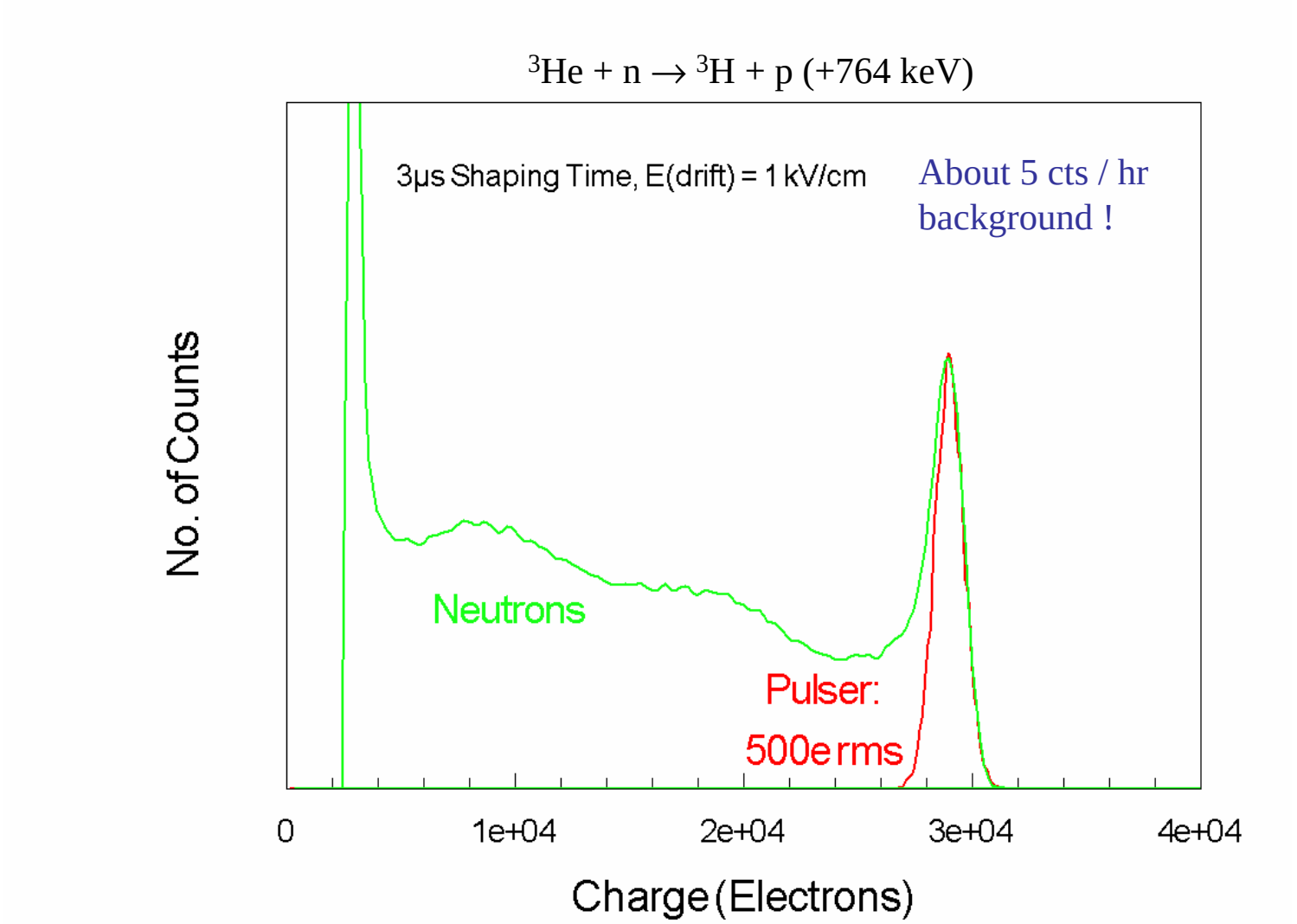
Charge collected by TWO pads



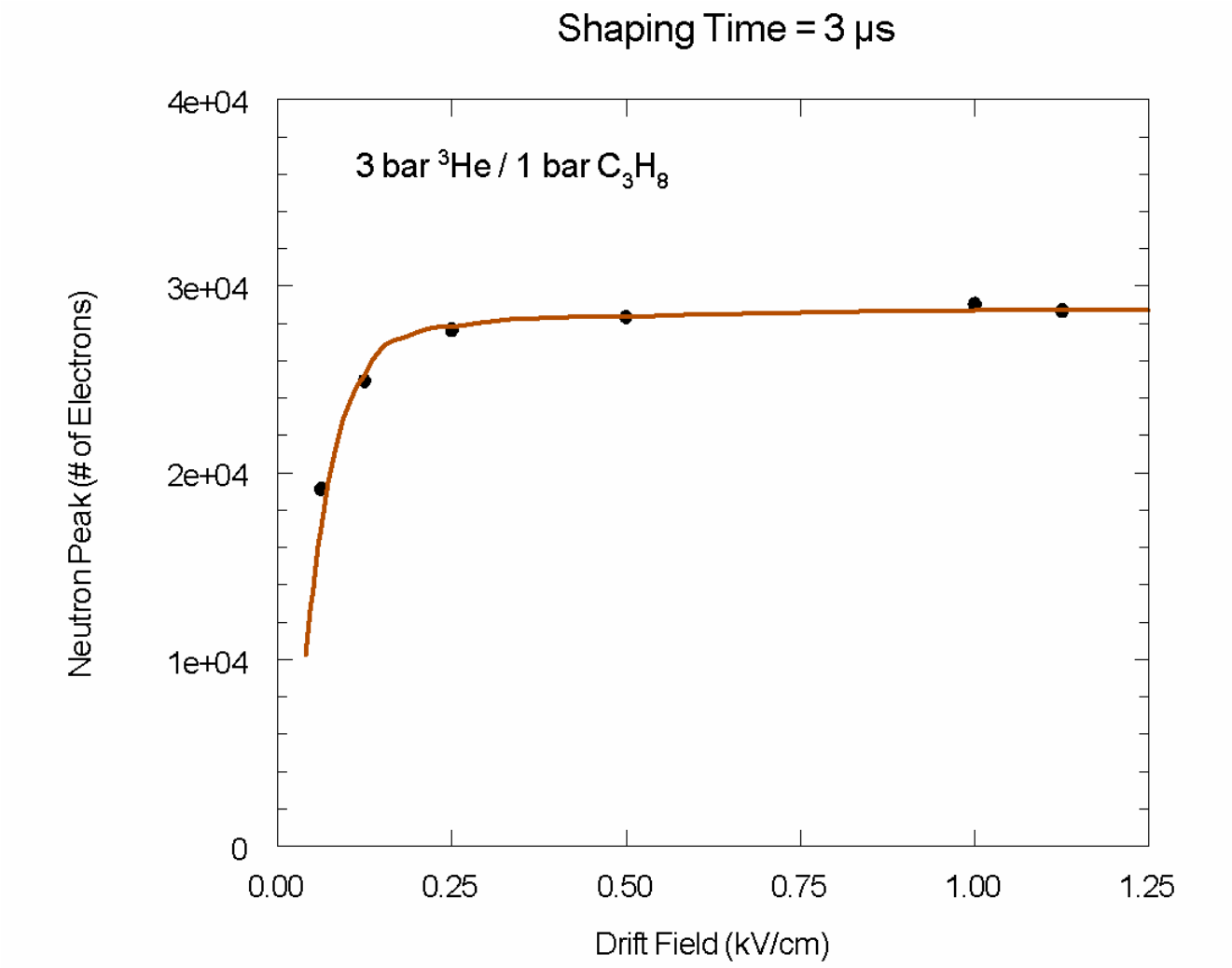
Charge collected by THREE pads

Neutron Pad Detector: Pulse Height Spectra

Single pad, 3 bar ^3He + 1 bar C_3H_8 and electronic noise contribution

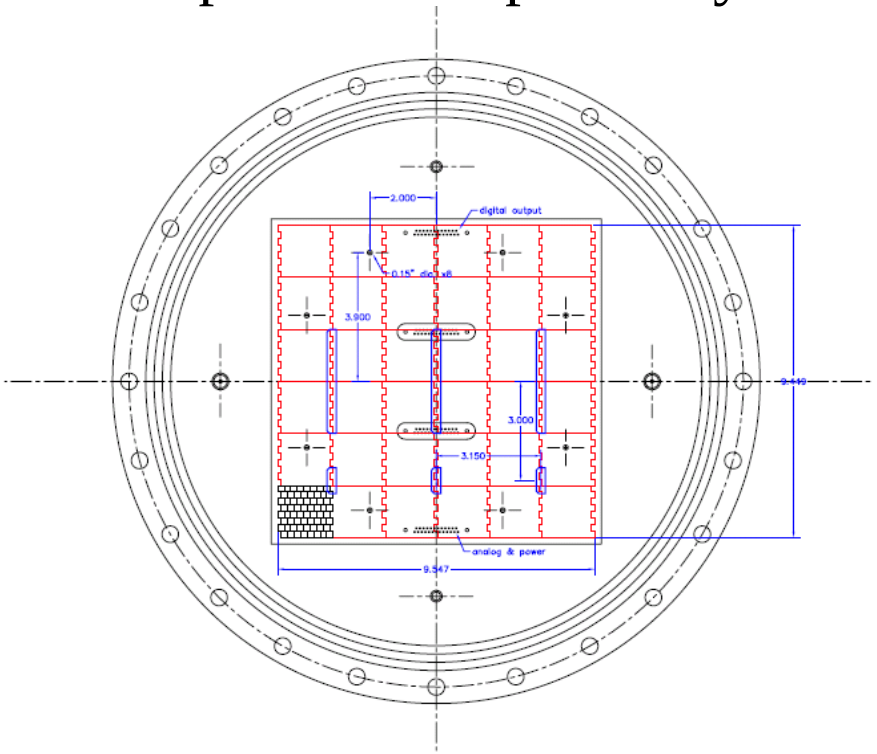


Single Pad: Pulse Height vs Drift Field

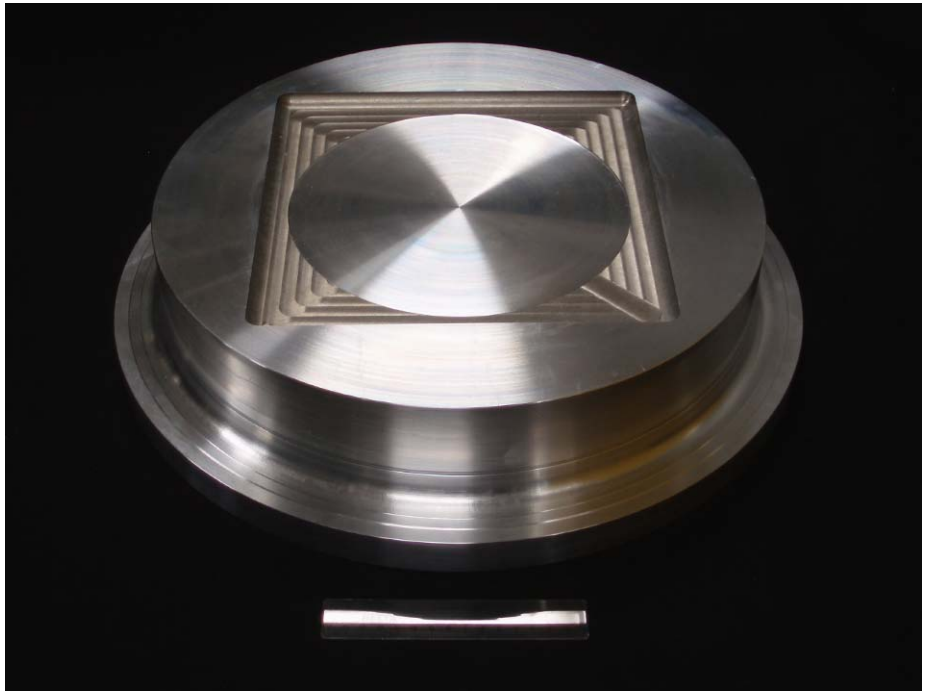


Development of a 48 × 48 Pad Detector: 1/16 of a full-size SANS device

Base plate of pressure vessel, with anode plane showing repeat of 8×8 pad array

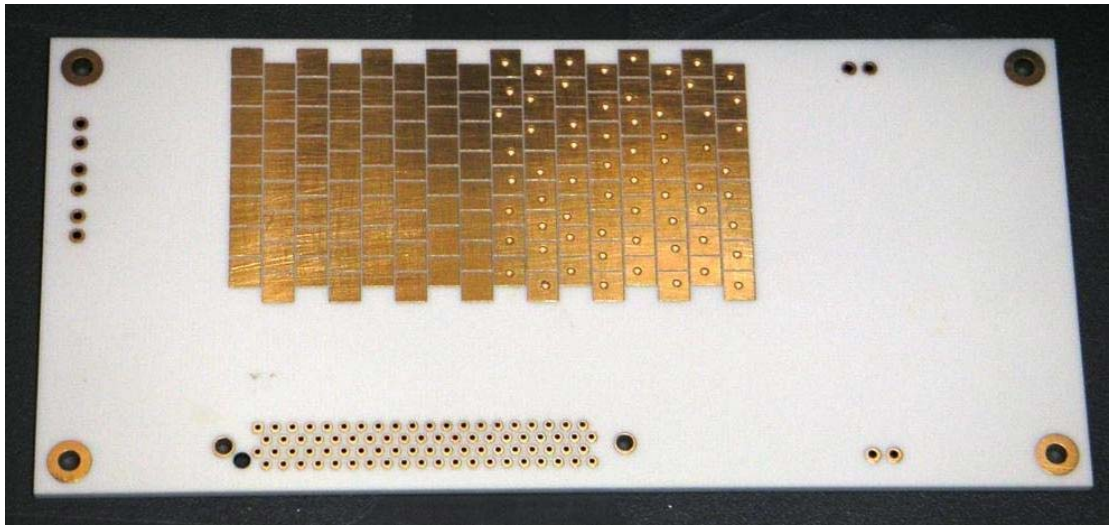


Pressure plate for gas enclosure – rough machined

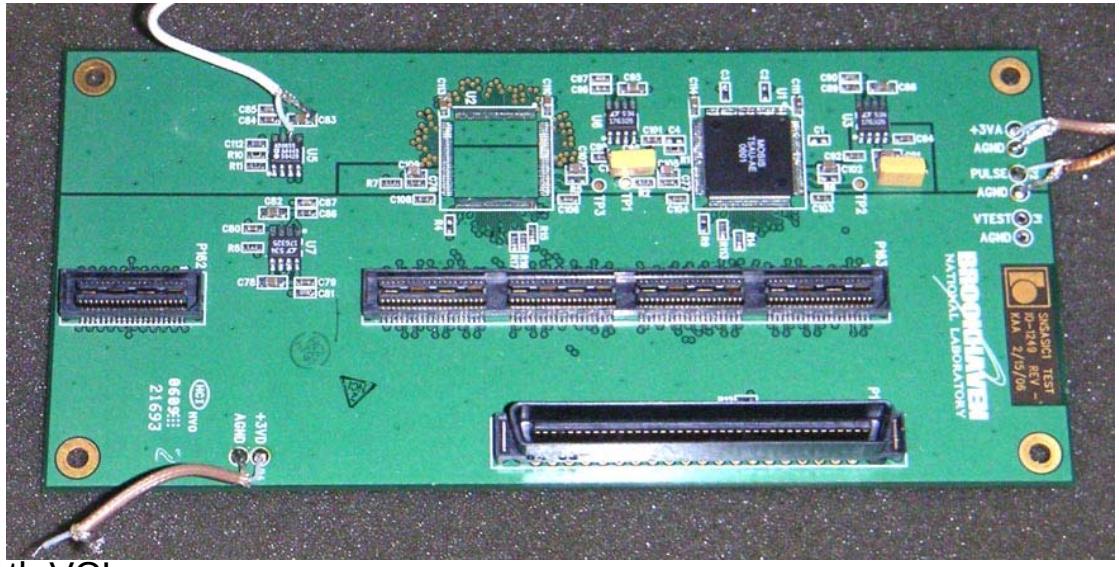


Test Board for Two 8 × 8 Pad Arrays

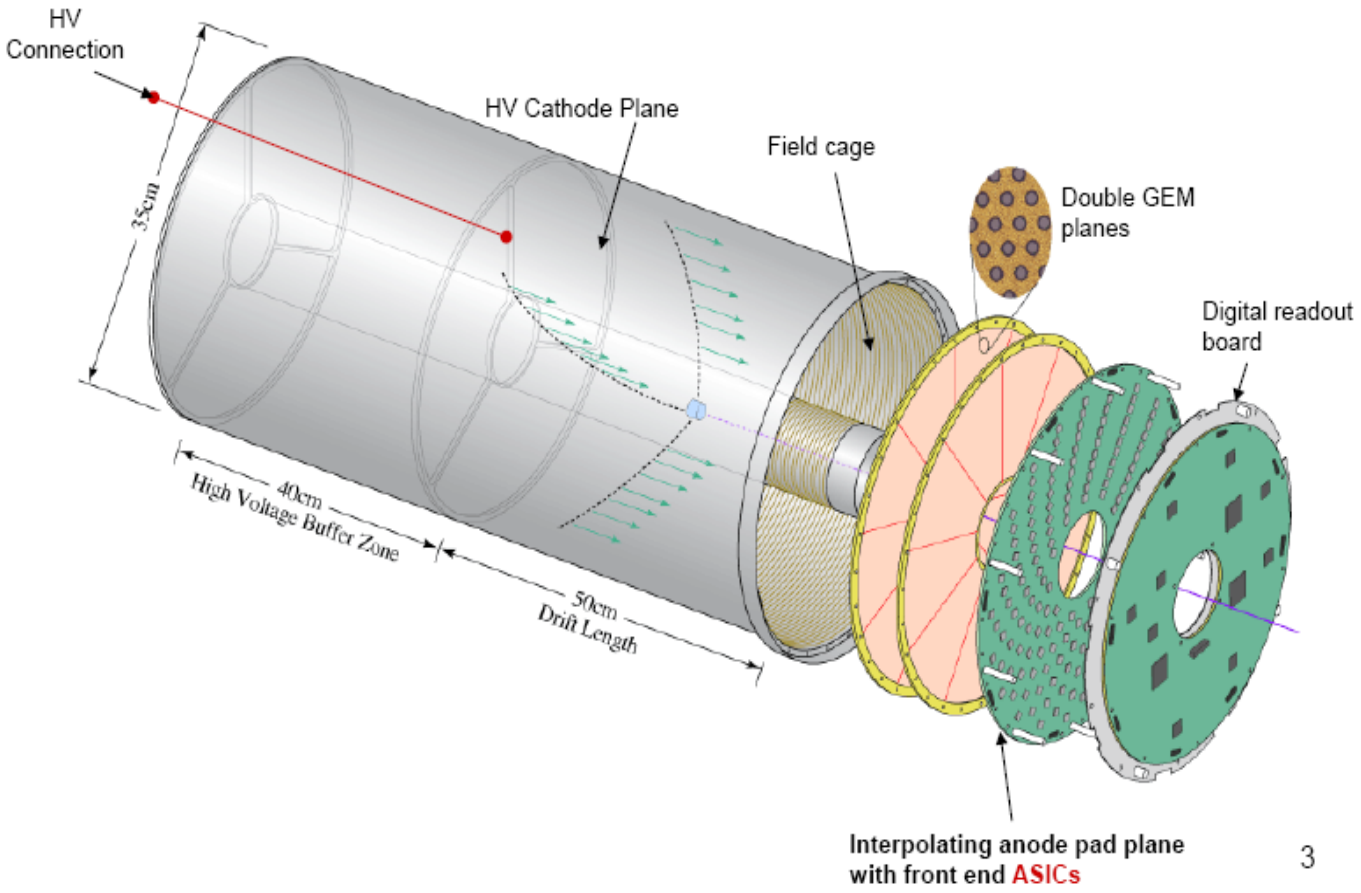
Top side



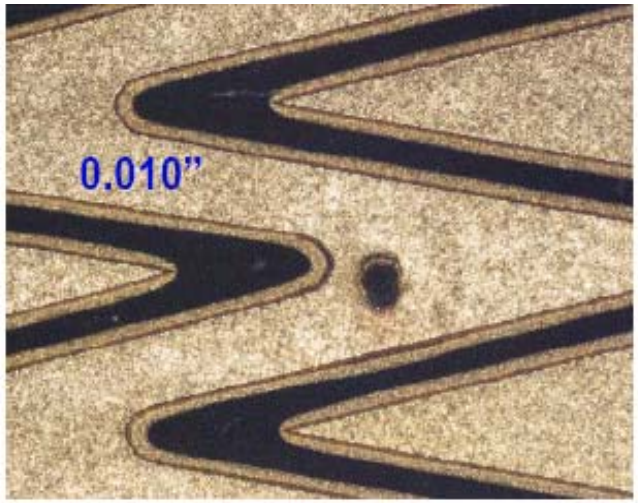
Bottom side



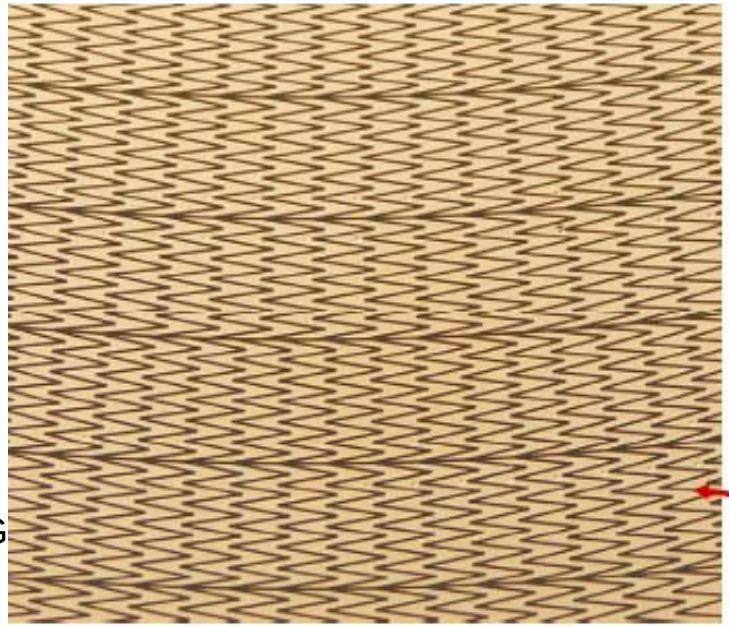
TPC – multi-layer anode board with 7296 channels: 228 ASICs (32 channels/ASIC)



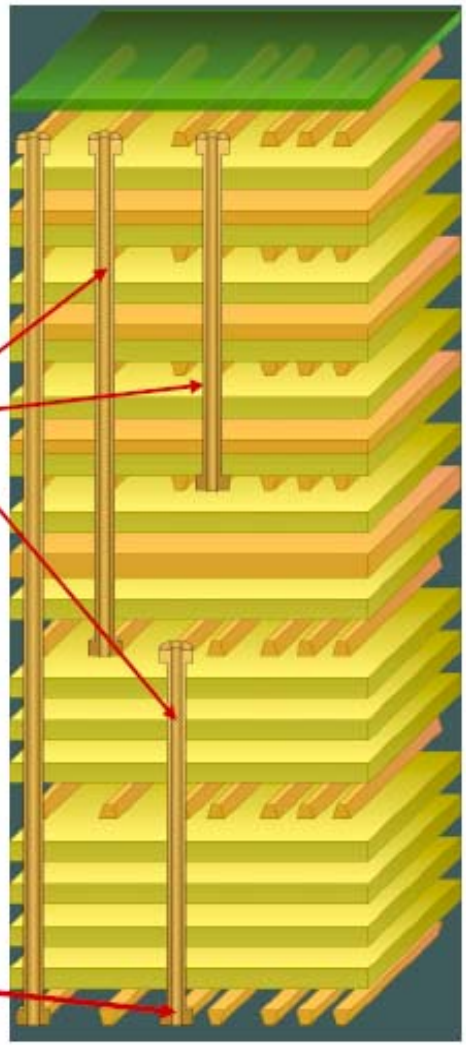
TPC: Anode Pad Plane – ASIC board



0.004”

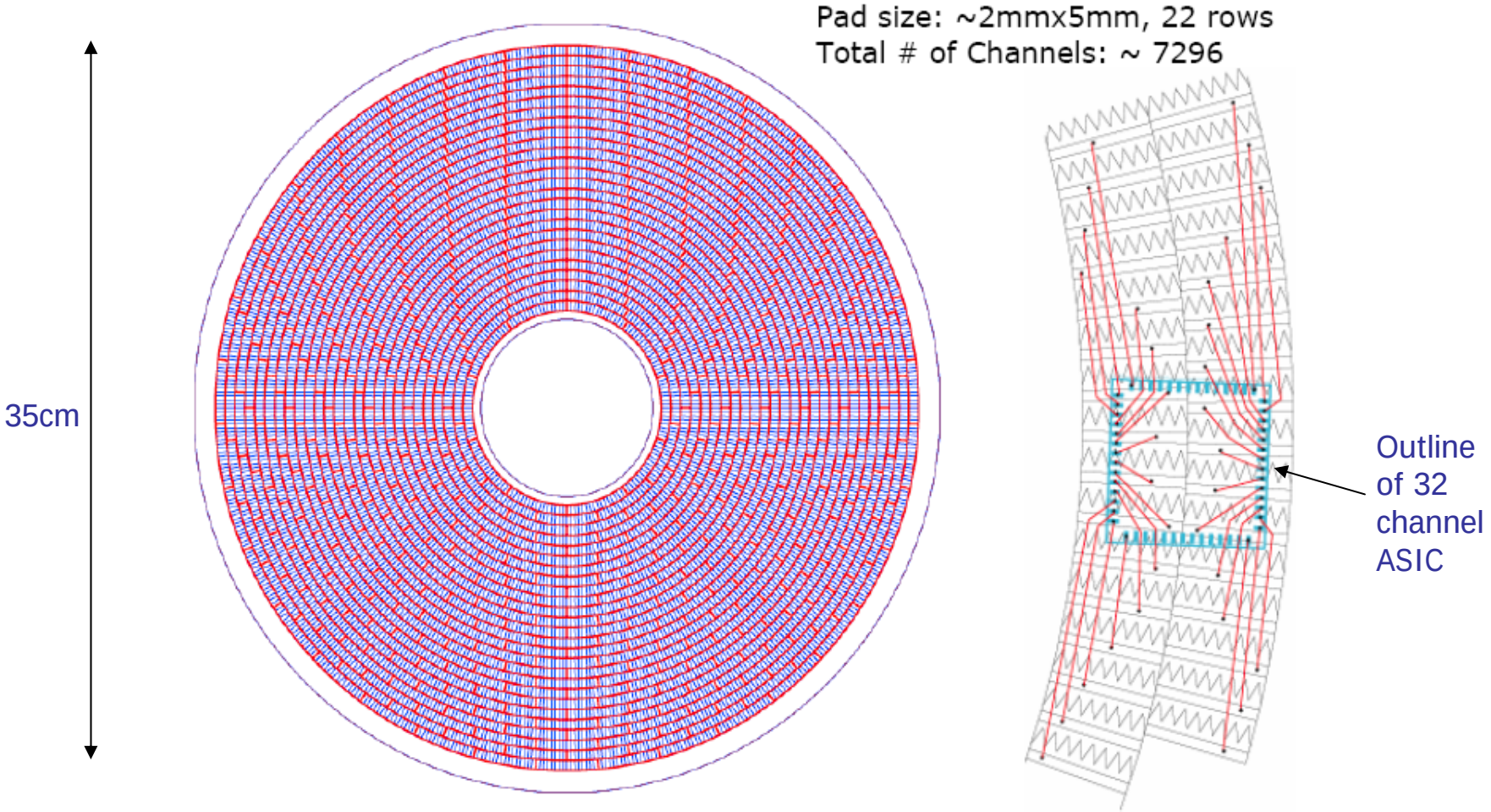


“Blind Vias”!



TPC -Layout of Anode Pad Plane:

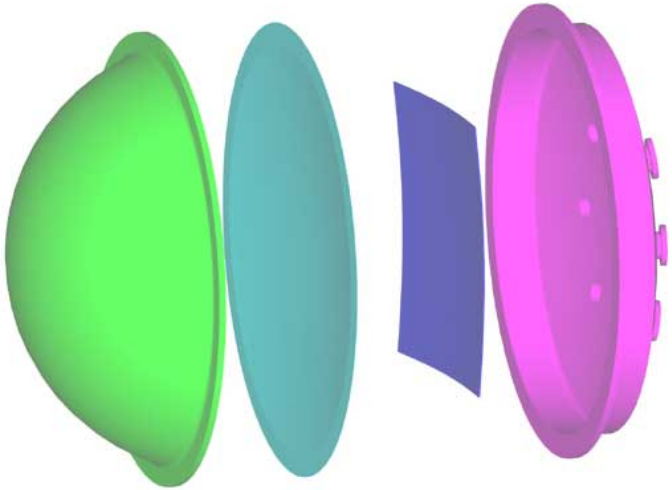
Topology of the Readout Board



Ultimate Neutron Pad Detector for SANS

- Ultra high count rate capability: ~10^5 /s per pixel, >10^8 /s per detector
- No gas amplification: No aging effects → stability and reliability
- Flexible geometry: Pixel: ~ 1 – 5mm, Reduced parallax, Large area
- Reliant on development of low noise ASICs

Detector suitable for Small Angle Neutron Scattering (SANS):



Area : ~ 1m × 1m

Pixel size : ~ 5mm × 5mm

Total channel count : 36,864

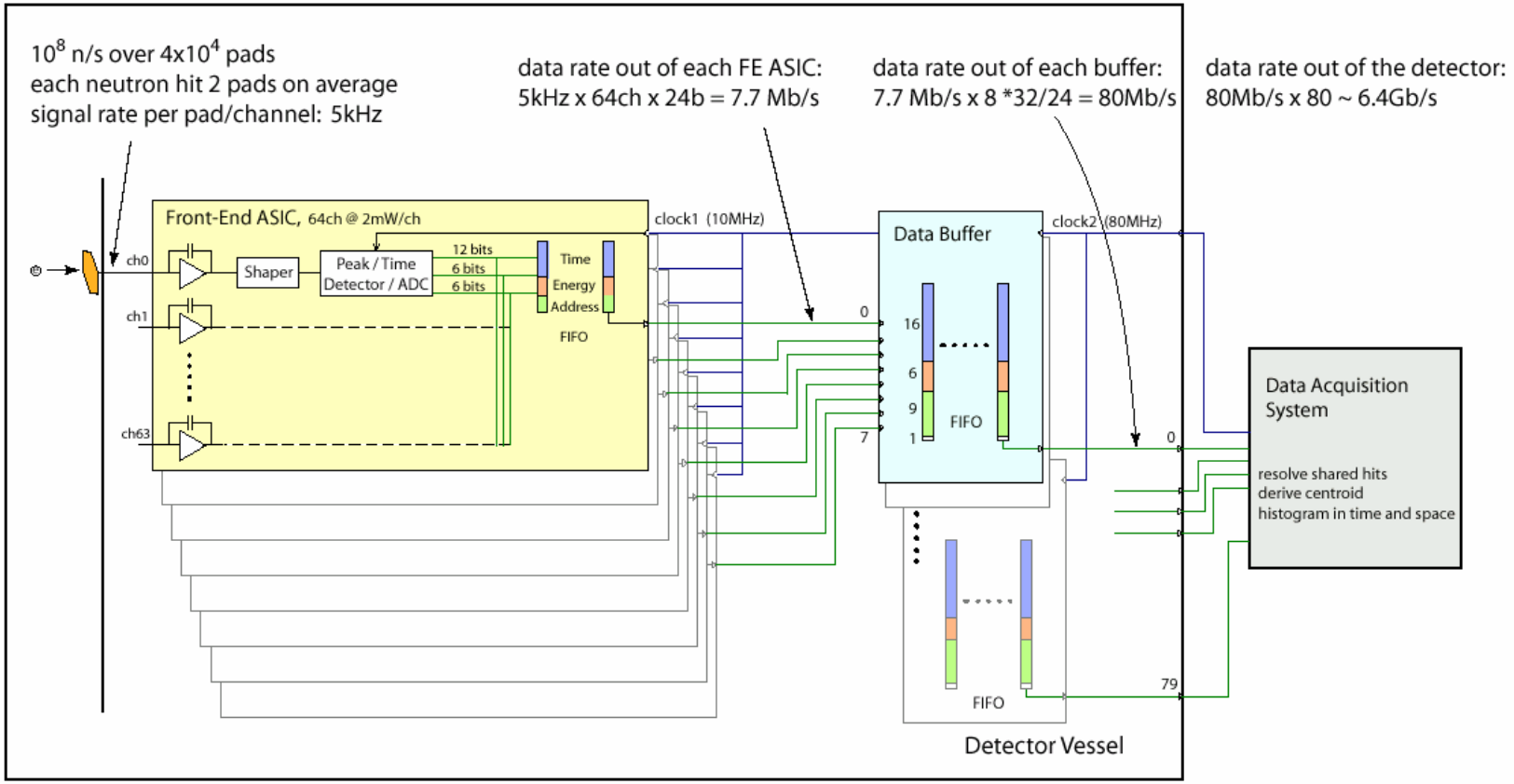
1st level: 64 channels per chip, 576 chips

2nd level digital analysis → ~ 100 feed-throughs

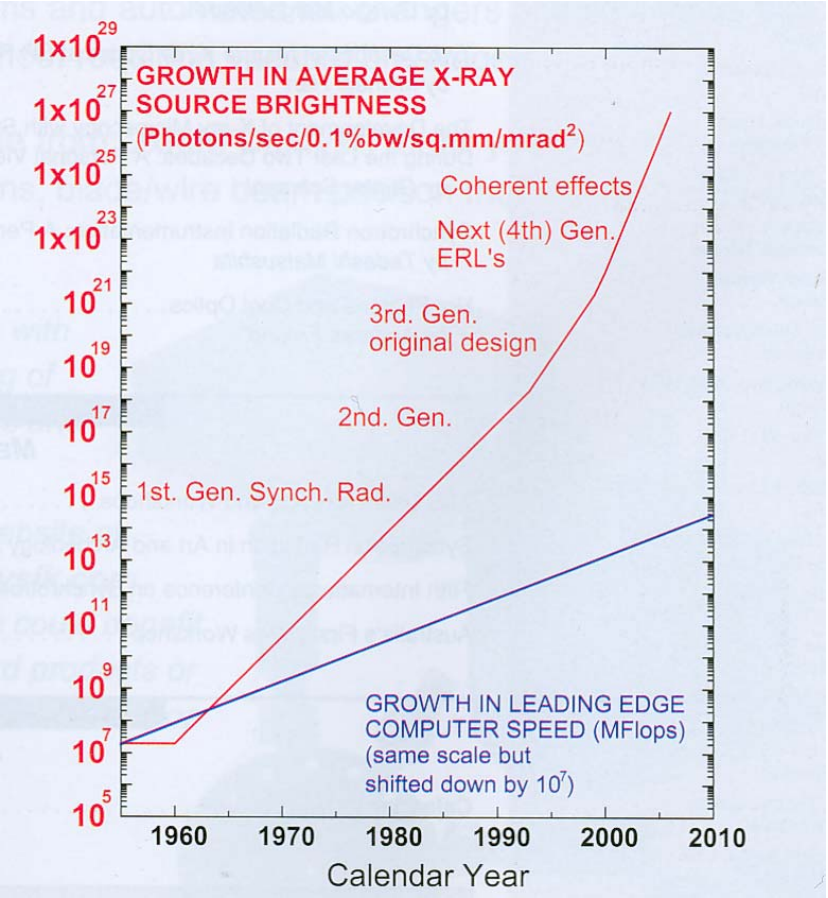
Total power: < 100W inside detector

Neutron Pad Detector: Data Flow Diagram

Full-size detector for SANS (1m × 1m , 40,000 pads)

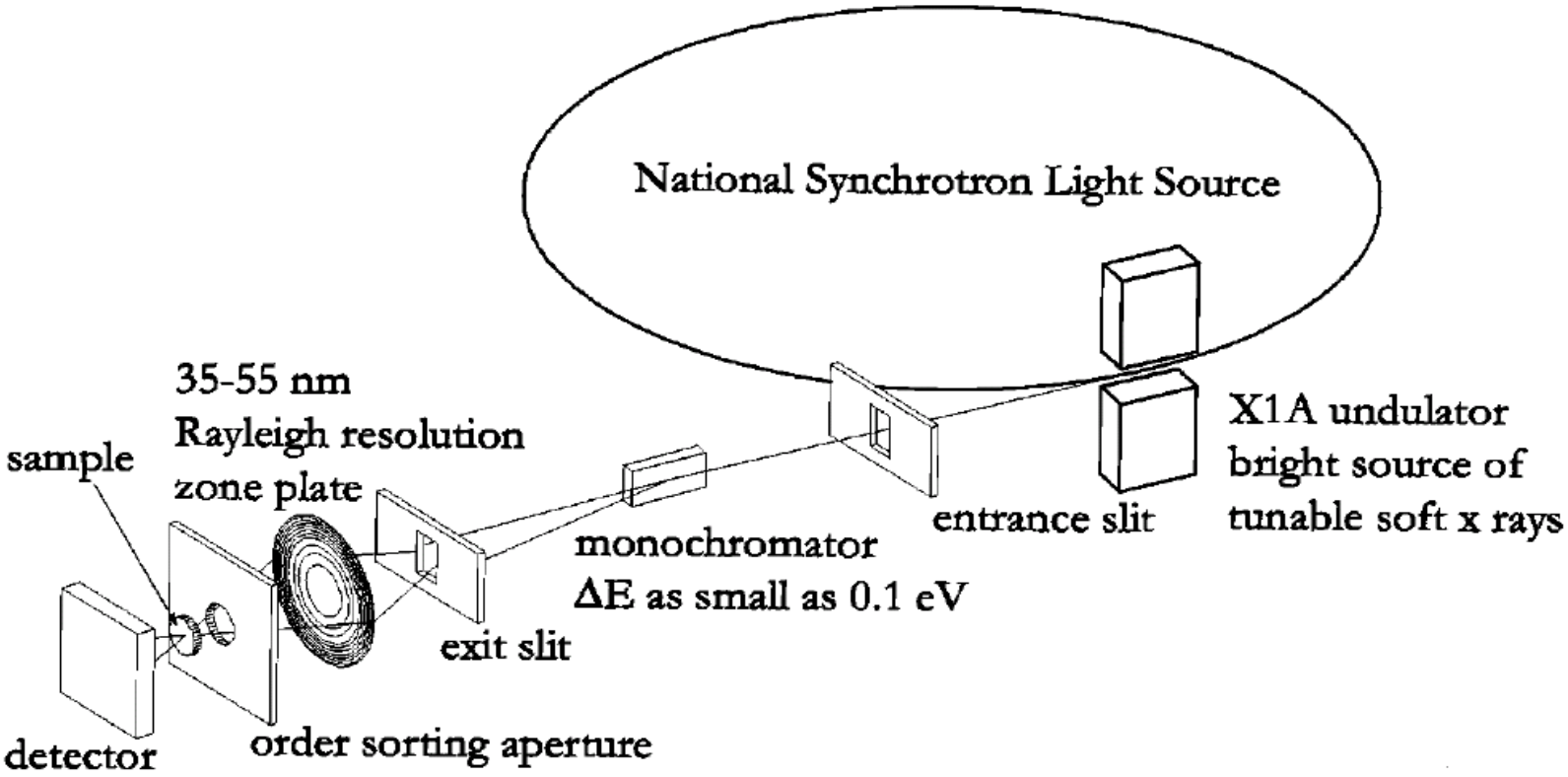


Growth in Average X-ray Brightness at Synchrotron Sources over Last 40 Years



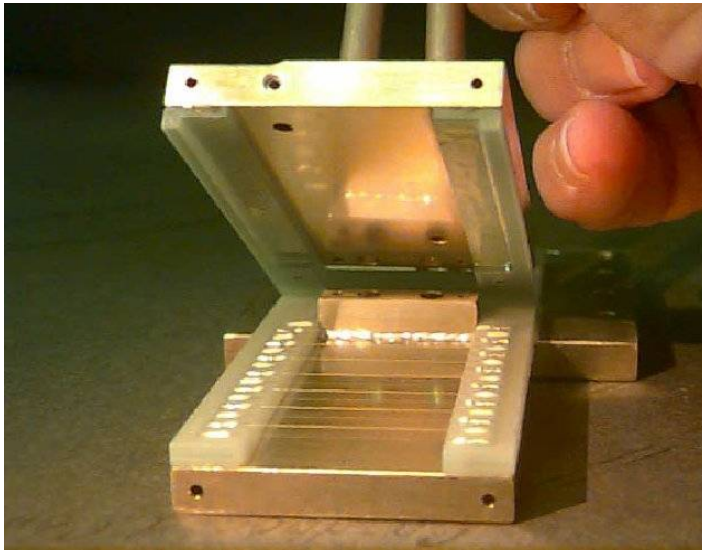
From Editorial page of latest *Synchrotron Radiation News* (Jan/Feb 2007,Vol. 20, no. 1)

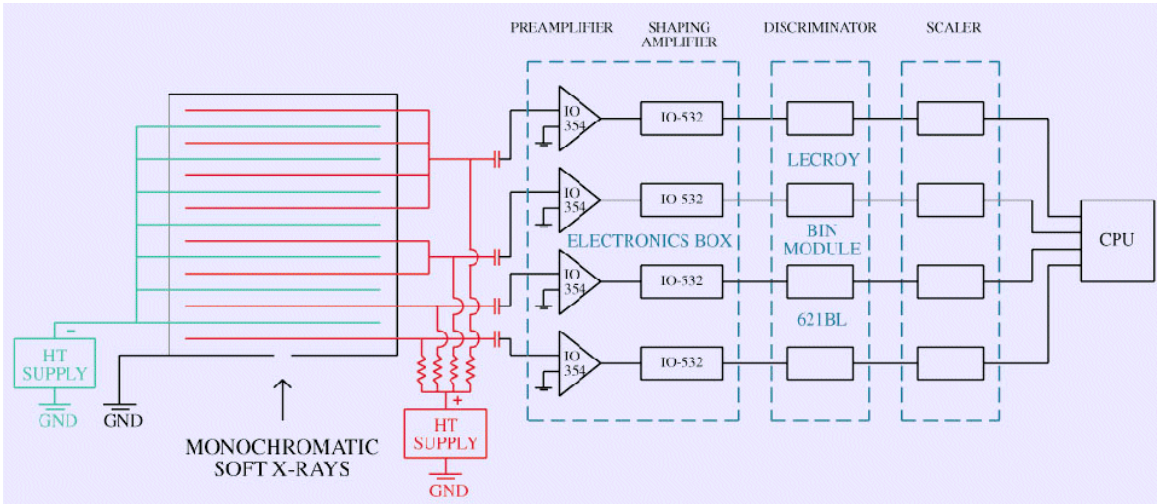
Synchrotron Applications: Soft X-ray Microscopy



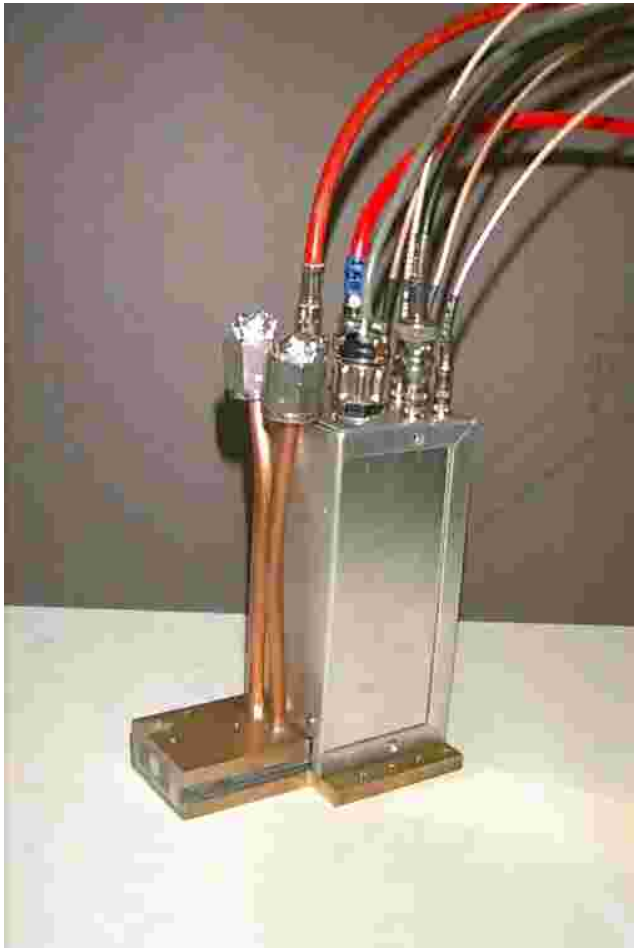
Soft X-ray Microscopy with a Gas-based Photon Counter

Detector and Electronics



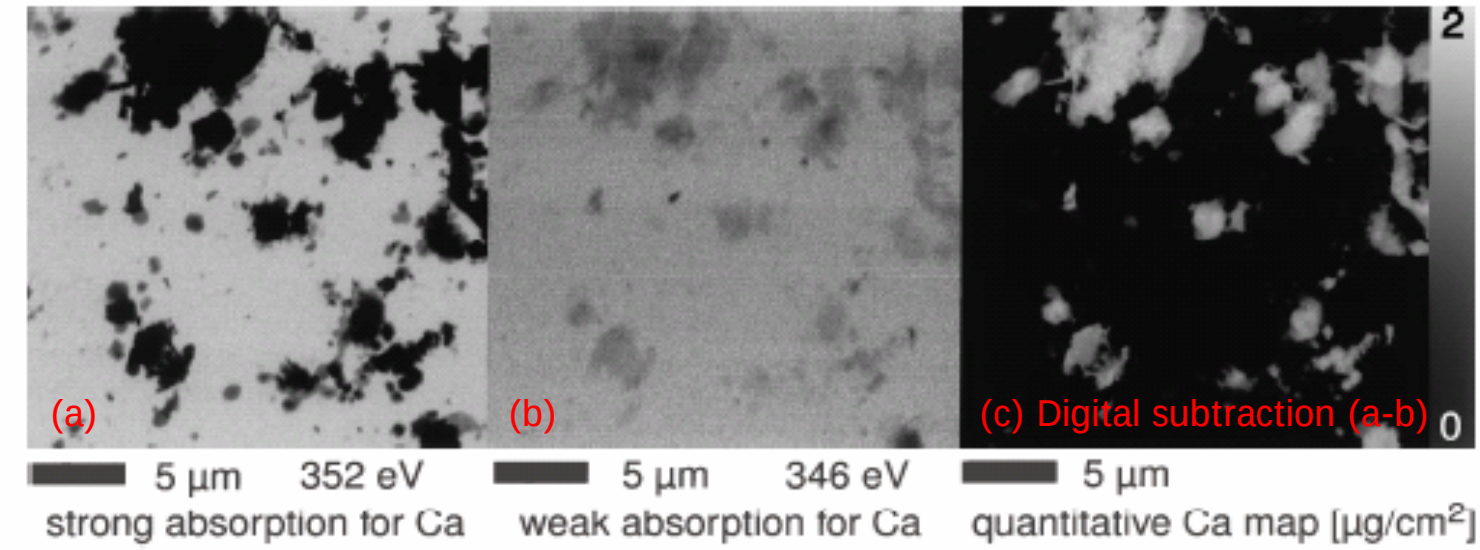


Complete Detector System



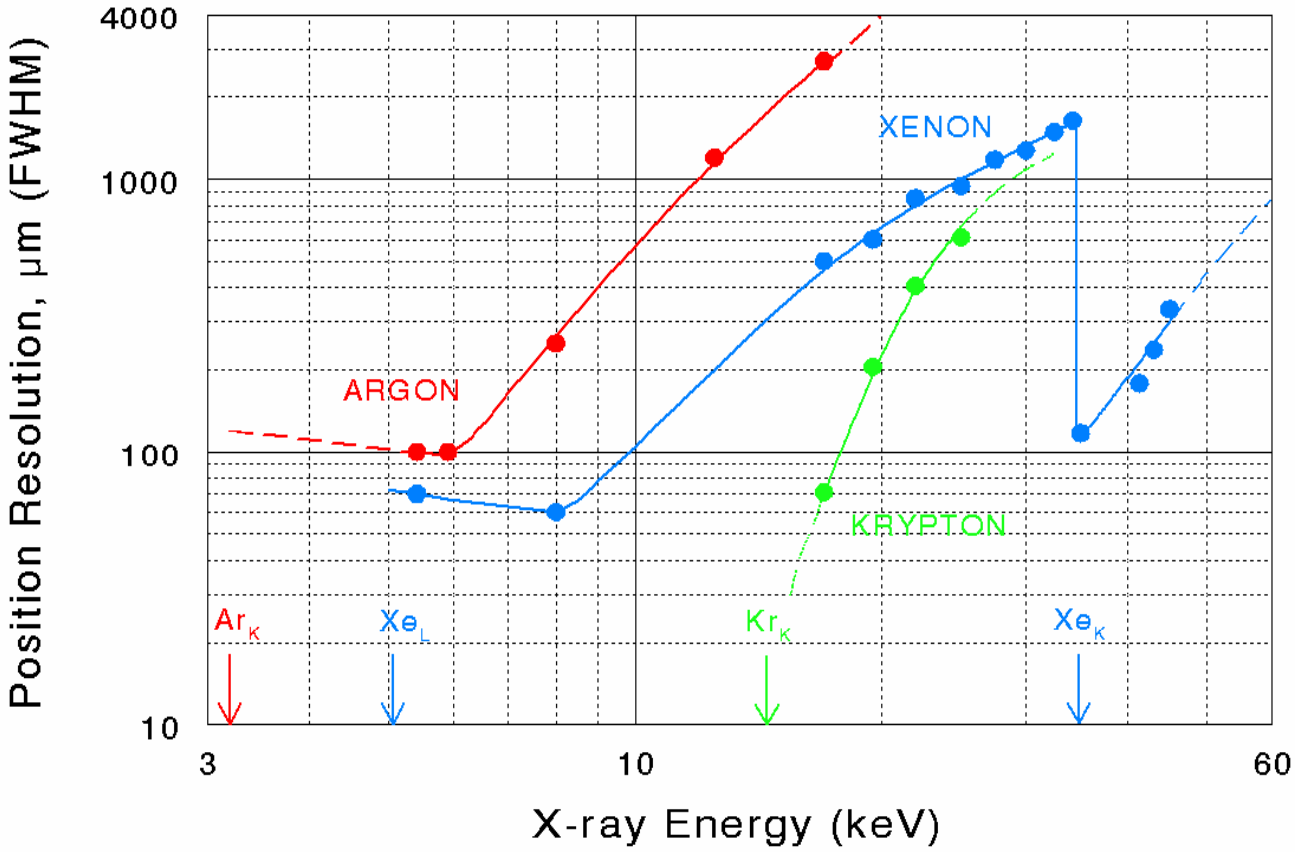
Soft X-ray Microscopy with a Gas-based Photon Counter

Example of location of Ca in thin material sample, using two X-ray energies that bound the Ca_L edge (about 350 eV)

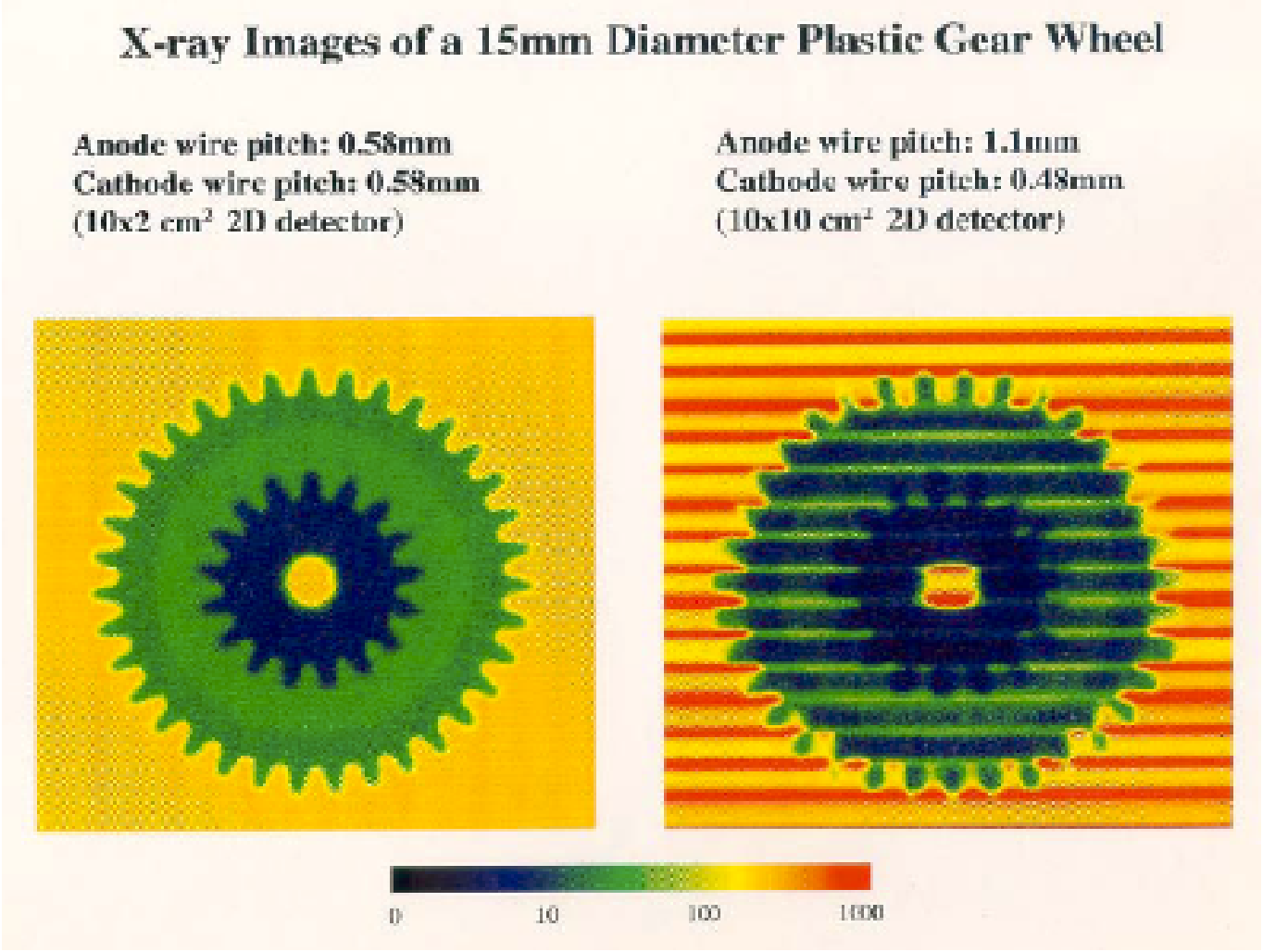


X-ray Position Resolution in Gas Detectors:

Limit determined by Electron Range (1 bar)



X-ray Images from 2D Delay Line Detectors

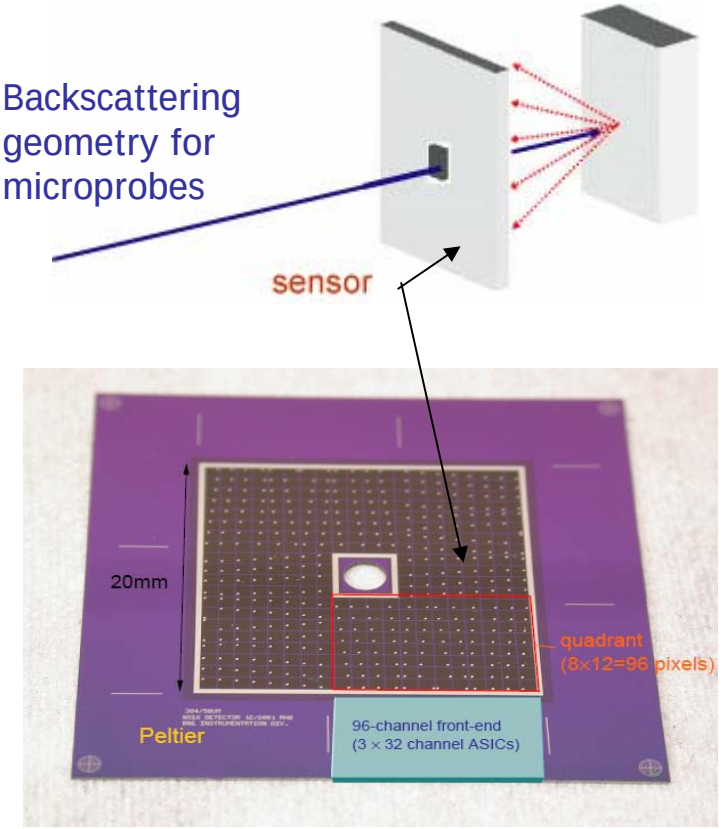


Multi-Element Silicon Detectors for Fluorescence

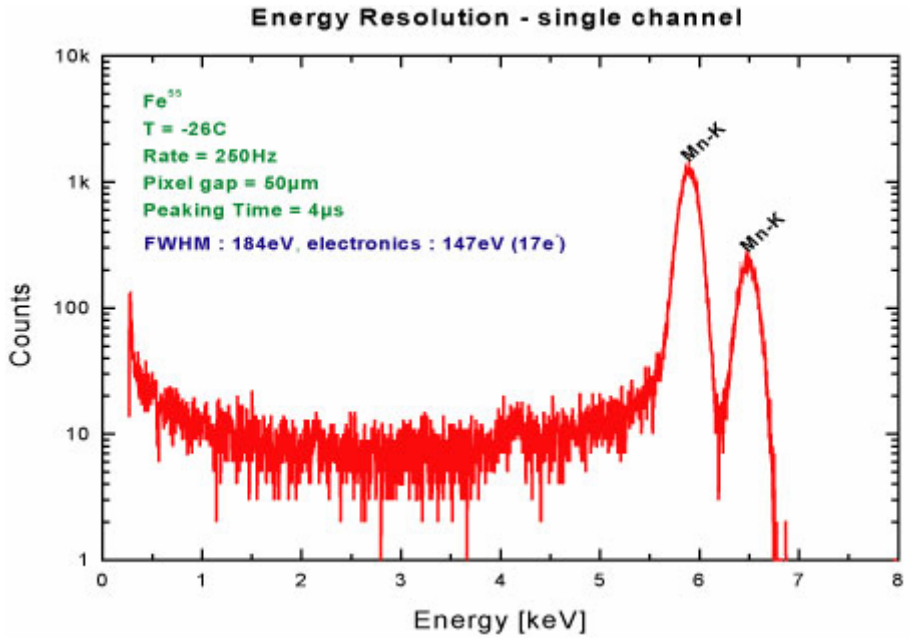
High-rate multi-element detector for fluorescence measurements

- 384-element silicon pad array for absorption spectroscopy and x-ray microprobes
- Central hole for incident pump beam to allow close approach to sample
- Uses twelve 32-channel ASICs
- Peltier cooled to -35 deg. C

Backscattering geometry for microprobes



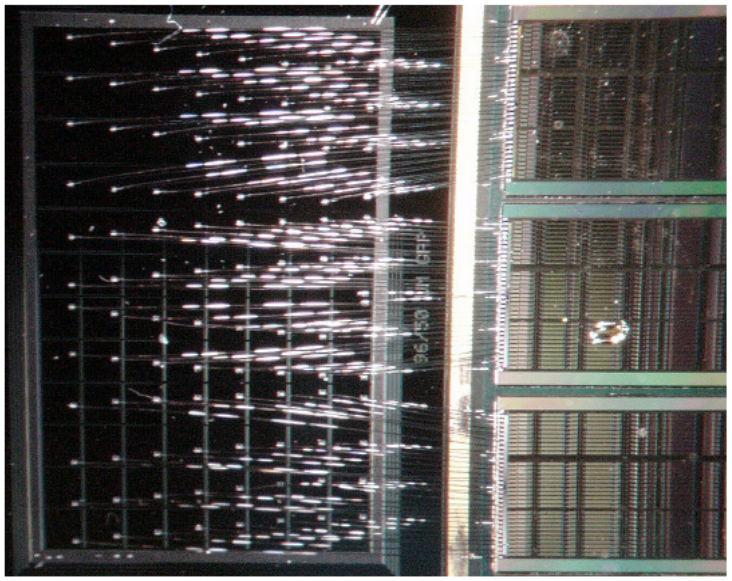
Si n-type high resistivity wafer 250µm thick,
N = 384 p^+ ≈1mm×1mm pixels,
gaps 10µm, 30µm, 50µm



Multi-Element Silicon Detectors:

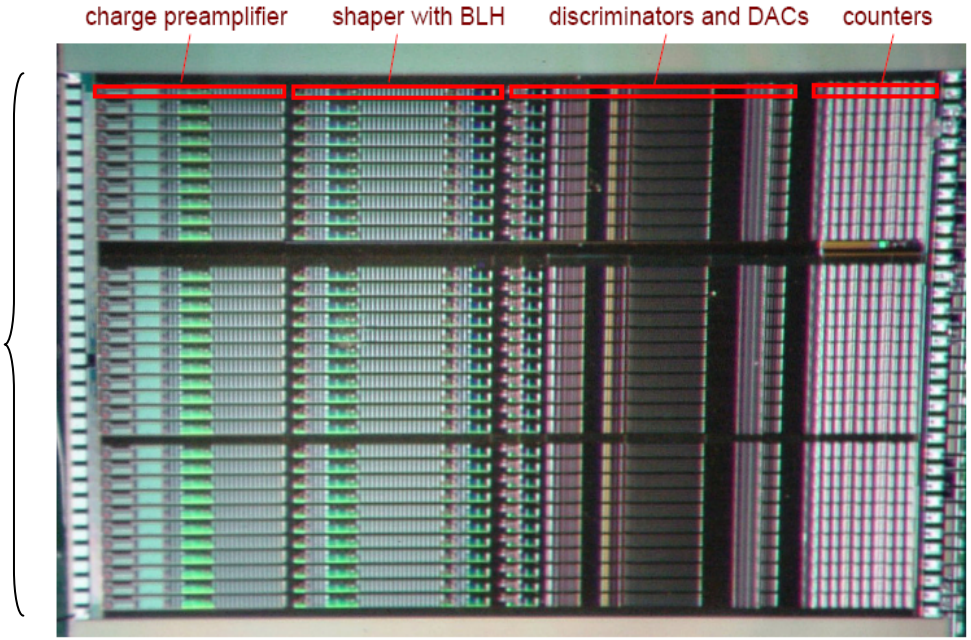
Detector / ASIC connection

Wire bonds between one quadrant
(96 pixels) and 3×32 channel ASICs



quadrant

Photo of 32 channel ASIC



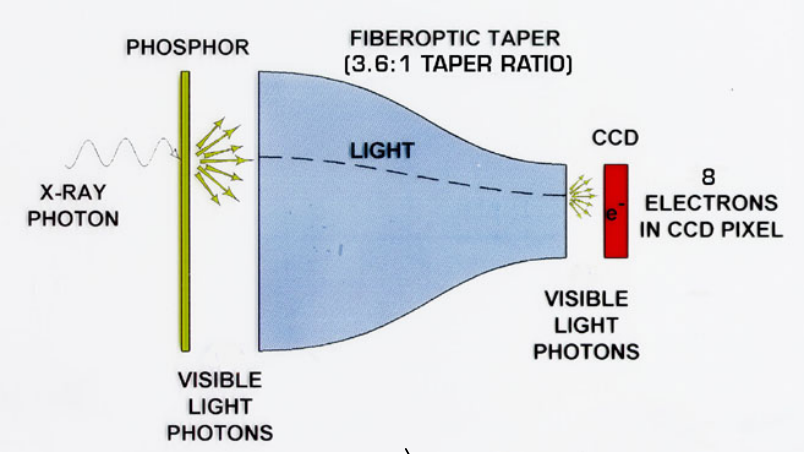
32 channels, 3.6 × 6.3 mm²

Detectors for Protein Crystallography:

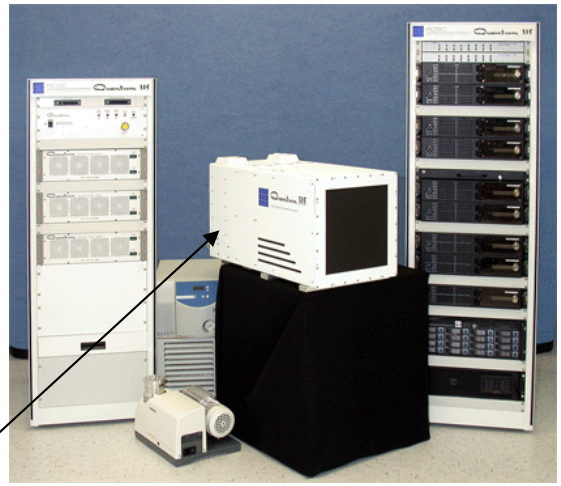
Scintillator coupled to CCD

Principle of Operation of One Module

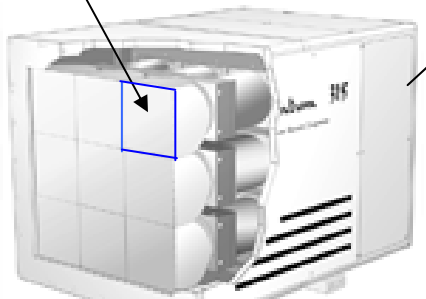
105mm × 105mm, 2048 × 2048 pixels



Full commercial system of 3×3 array

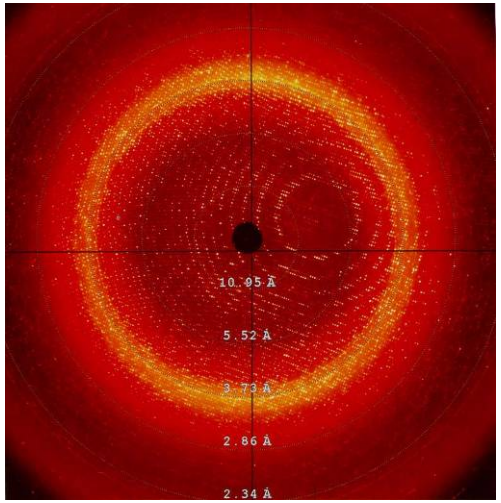


Cut-away view of 3×3 array



315mm × 315mm, 6144 × 6144 pixels

Typical diffraction image from 2×2 array



Detectors for Protein Crystallography:

PILATUS 1M detector

Ch. Broennimann et al., J. Synchrotron Rad. (2006) 13 120-130

Array of 18 hybrid-pixel detectors

0.3mm thick pn-diode array

Total area: 243mm $\times$ 210mm

Pixel size: 0.217 $\times$ 0.217 mm (~1.1 M pixels)

DQE@12 keV: 75%

Readout time: 6.7 ms

Energy range: > 4keV

18 modules, 3 modules per row constituting one bank. Detector consists of 6 banks, each tilted at 6° to overlap modules vertically.

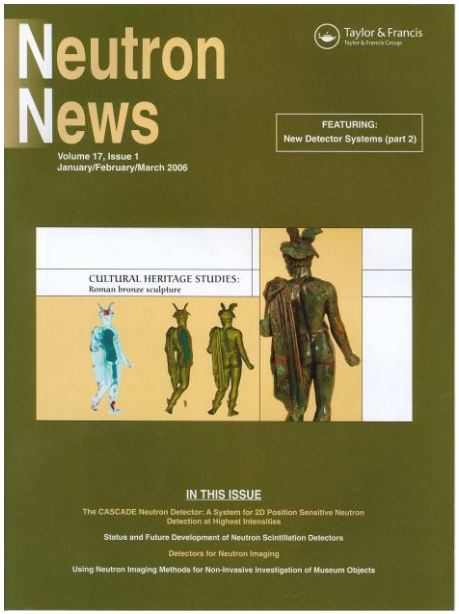
This is the first large-area pixel detector at a synchrotron source (Swiss Light Source).

Recent Articles on Neutron and X-ray Detectors

Neutron News

Vol. 16, #4, Oct/Nov/Dec 2005

Vol. 17, #1, Jan/Feb/Mar 2006



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