Avalanche Photodiodes (APDs) as Fast X-Ray Detectors

Alfred Q. R. Baron

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Advanced Detectors for Synchrotron Research.
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Any use of these slides or Information there-from should be appropriately referenced

Talk Contents

General Introduction

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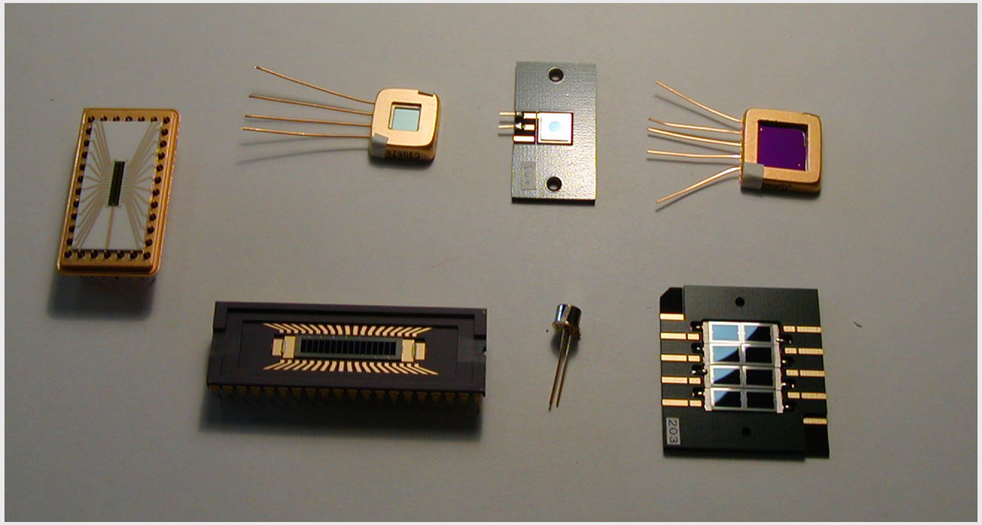
Data Acquisition System



X-Ray Detection History

Original x-ray focus was pulse height resolution
(PMT Alternative)

Fast X-Ray Detectors

First — 30 μm device, ϕ1 mm, 0.3 ns Resolution
Kishimoto, NIMA **309,** (1991) 603.

More Efficient — 50 μm device, ϕ16 mm, 0.7 ns Resolution
Baron and Ruby, NIMA **343,** (1993) 517.

Faster — 10 μm device, ϕ1 mm, 0.1 ns resolution
Kishimoto. NIM **A 351,** (1994) 554.

More Reliable — 100 μm device, 1x1 cm^2
Baron, NIM **A 352,** (1994) 665.

Better — Build your own amplifier - easy and *better.*
Baron, *et at*, NIMA **400,** (1997) 124.

Now: Development several places
DESY, ESRF, NSLS & …

Review: Baron, Hyp. Int. **125,** (2000) 29

APD Detector Overview

Fast Single Photon Detector
Si Diode + Internal Gain

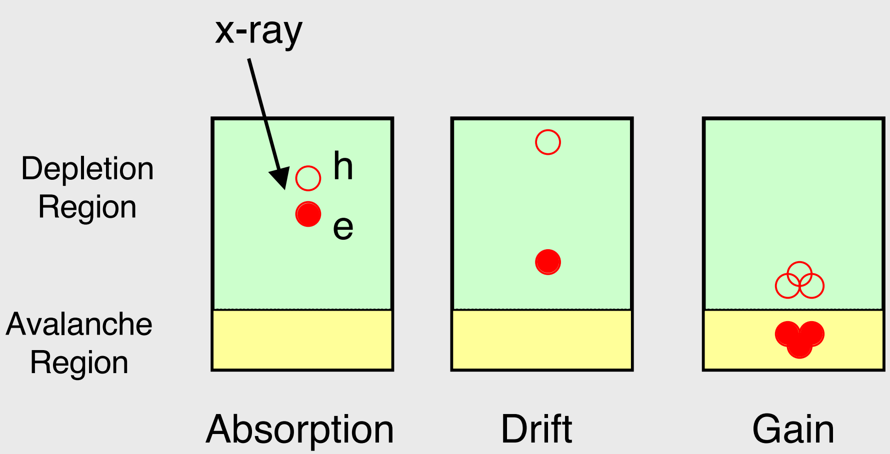
Good Points:

- Fast -> Good Time Resolution (0.1 to 1 ns) & High Rates (<~10^8/Channel)
- Good Pulse Height Resolution (~20%)
- Low Noise (~0.01 Hz)
- Good Efficiency at Lower X-Ray Energies
- Small, Rugged (relative to a PMT)

Less Good Points:

- Small (< ~1 cm^2, ~ mm^2 typical)
- Poor Efficiency for High X-Ray High Energy

X-Ray Detection with an APD



Important Points:

Lots of carriers to start - 1 eh pair/ 3.6 eV

Efficiency determined by "active thickness" of Si before the gain region

Drift to gain region takes time (~10 ps/μm)

Trade Off: Higher efficiency *(at normal incidence)* <-> Poorer time resolution

Electronics

Wide-Band (~GHz) Amplifier (near the diode)

~50 Ohm Input Impedance

(Minicircuits, Phillips, Ortec....)

Fast Discriminator (NIM levels) (Ortec, Phillips, ...)

Important Point: (Assuming sufficient amplifier bandwidth)

Leading edge shape (rise time) due to

Carrier Transport Time

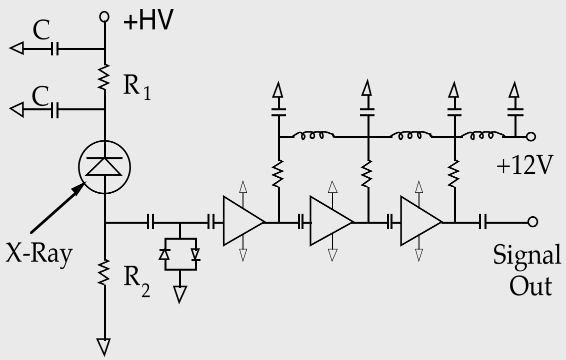
Trailing Edge (fall time) due to

Diode Capacitance & Amplifier *Input Impedance*

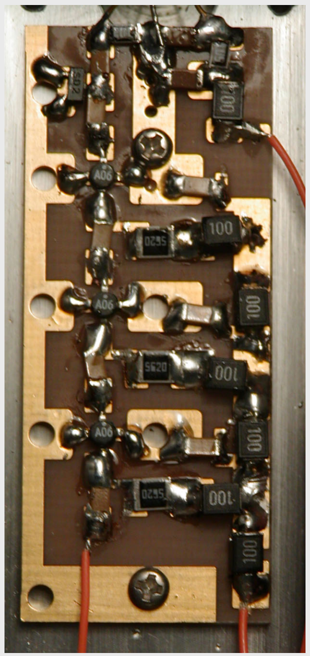
Generally: Smaller Capacitance Devices have Faster Signals

Smaller Area & Thicker Depletion Region

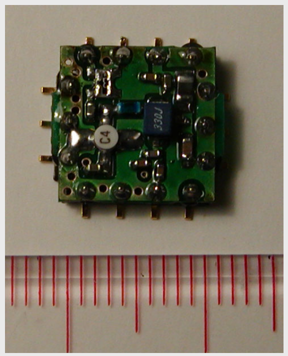
Fast Amplifier



50 Ohm
0.5 - 2 GHz
50 dB Gain
~3 to 5 dB NF
2-10 dBm output



Older: ~1 GHz, 2 dBm



New - for faster (array) devices
2 GHz, 10 dBm

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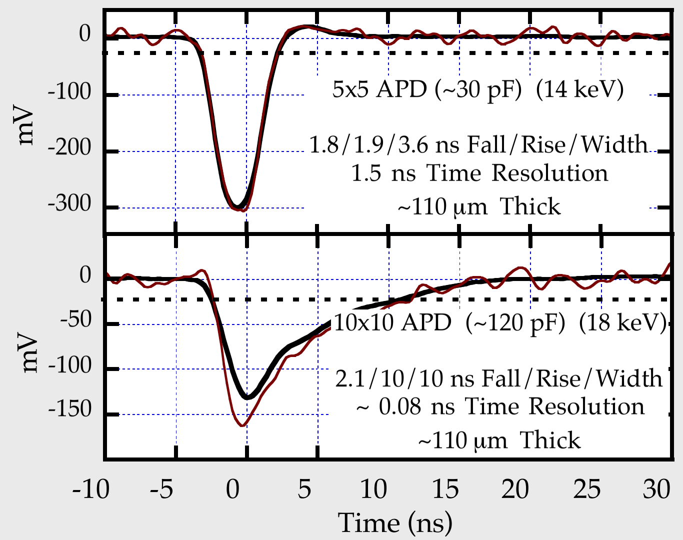
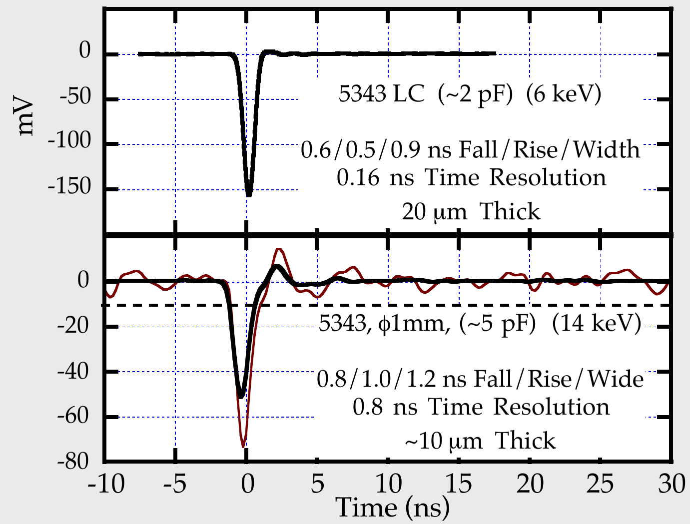
Scope Traces





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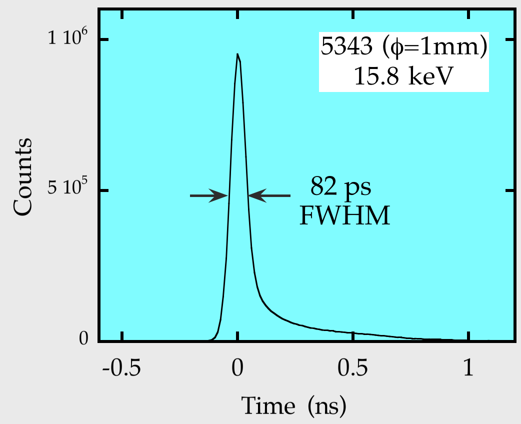
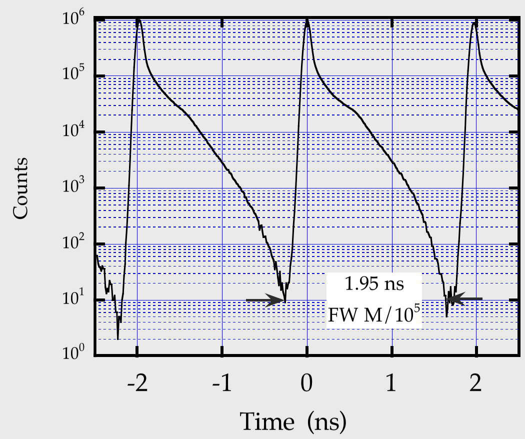
Some Single Element APDs

Company & Type	Area & Model#	Operating Voltage	Active Thickness	Time Resolution
API Beveled Edge	ϕ5, 10, 16 mm (also smaller)	2000-2500V	30-50 µm	~0.5 ns FWHM Tail to >5 ns
Radiation Monitoring Devices (RMD) Beveled Edge	8x8 mm^2 (also custom)	~1800 V	30-50 µm	~0.5 ns FWHM Tail to > 10 ns
PKI (EG&G) Reach Through	5x5 mm^2 (C30626)	300-400 V	~110 µm	~1.6 ns FWHM Tail to ~ 5ns
	10x10 mm^2 (C30703)	350-450 V	~110 µm	~0.7 ns FWHM Tail to ~ 4ns
	10x10 mm^2 (Prototype)	350-450V	~185 µm	~1.7 ns FWHM Tail to ~5 ns
Hamamatsu Photonics Reach Through	ϕ 1, 3, 5 mm (S238X)	100-250 V	~ 30 µm	~0.3 ns FWHM, Tail to >5 ns
	ϕ1 3, 5 mm (S534X)	~150 V	~ 10 µm	~0.08 ns FWHM Tail < 2 ns
	ϕ1, 3, 5 mm (S534X LC)	250-300 V	~ 25 µm	~0.2 ns FWHM Tail < 2 ns
	ϕ 3mm 3x5 mm^2	500~700 V	~ 130 µm	~1.3 ns FWHM

Best Time Resolution ~ 75 ps

Measured at Spring-8,
~ 35 ps electron bunch length





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Array Devices

API &RMD -> Cut grooves in larger devices
- Pixels ~ 1 x1 mm^2
- Array of, say, 4x4 or 8x8 pixels

Hamamatsu -> Close packing of small devices
- Linear arrays of f1 mm devices
- 2x2 Arrays of f1 mm devices
- 16x2 Array of 3x5mm^2 Devices (Kishimoto)
- 4x2 Array of 3x5mm^2
- Monolithic Linear Array

PKI/EG&G(RCA) -> Special Structures
- Linear arrays with 300 or 150 mm pitch
- 25 to 128 elements

Pacific Silicon Sensor
- Monolithic arrays similar to Hamamatsu
- Not tested…

Fast Array (Hamamatsu)

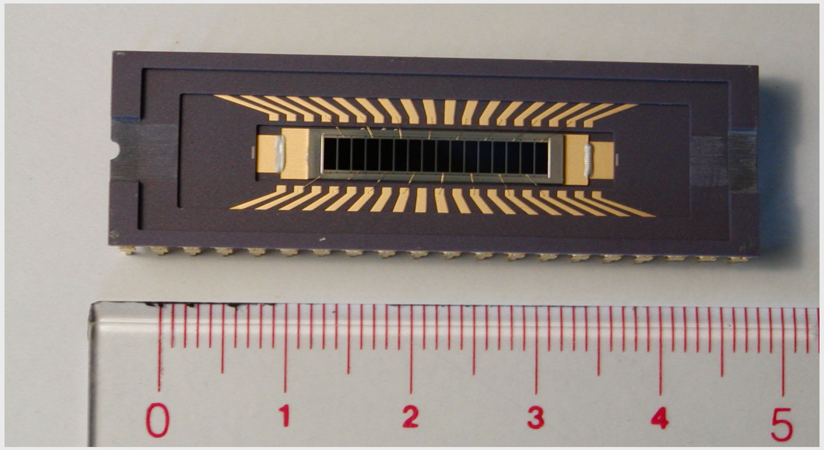
Element size: 2.0 x 1 mm^2 x 20 μm thick

16 Elements, 1.1 mm Pitch

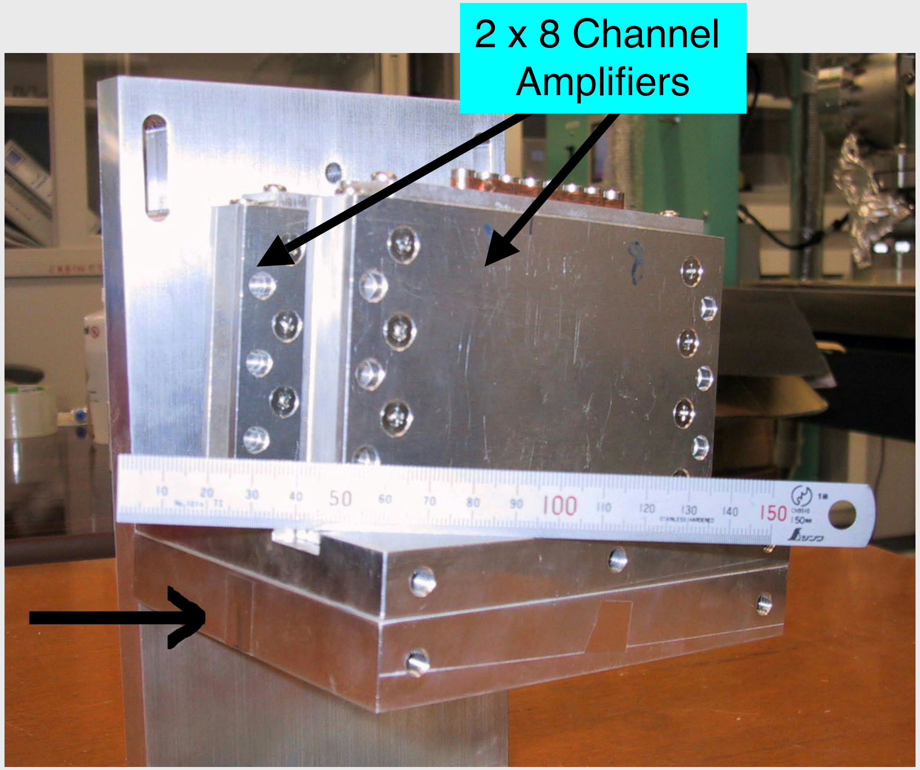
Designed for good time resolution (~180 ps), high rates (16 chan) and high efficiency

(Single chan = 160 ps)

Grazing Incidence Acceptance: 2.0 x 0.7 mm^2
Effective Thickness: ~ 0.5 mm



16 Channel Array



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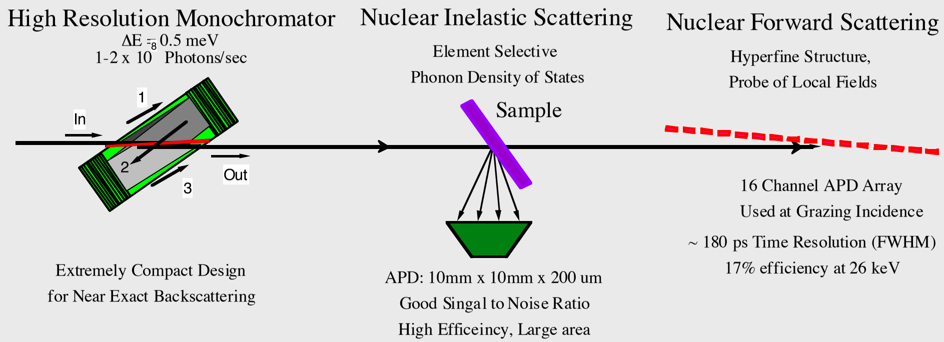
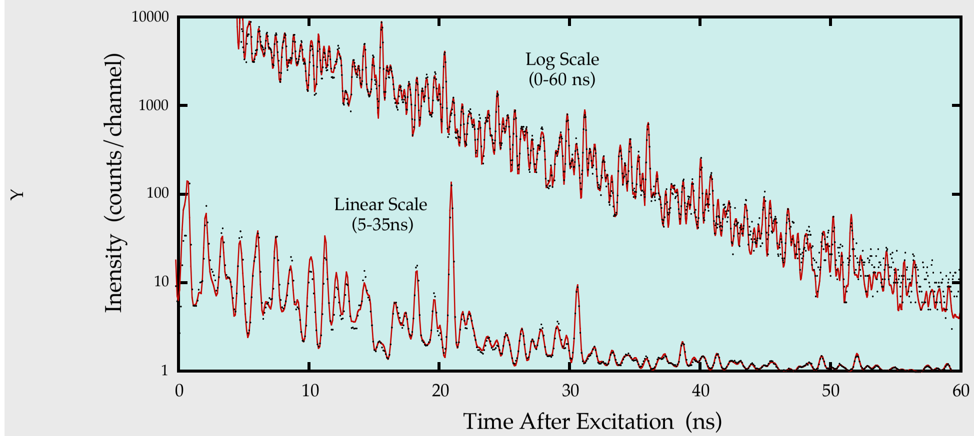
NFS From ^{161}Dy

Normal Incidence: < 1% DQE
Grazing Incidence: ~ 17% DQE

Time Resolution: 180 ps (fwhm) Achieved





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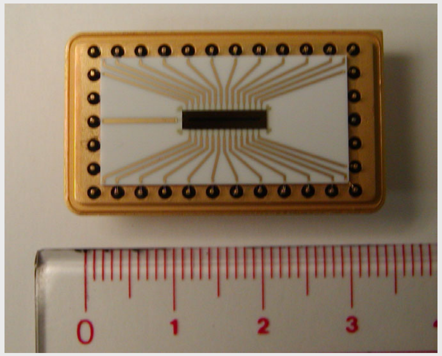
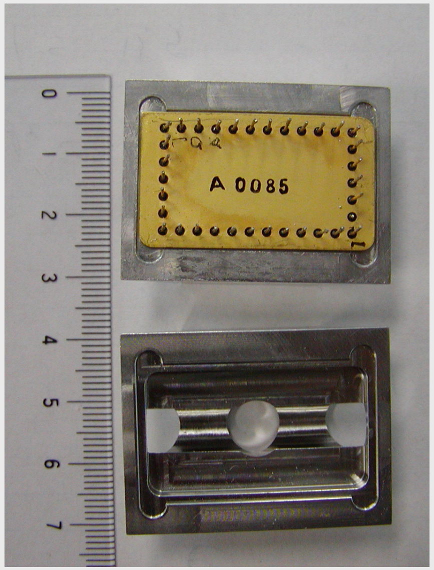
25 Element Linear Array

Element size: ~250 x 400 μm^2 x 110 μm thick
on 300 μm pitch

Goal: Very high rates and good efficiency
Modest (~ns) time resolution

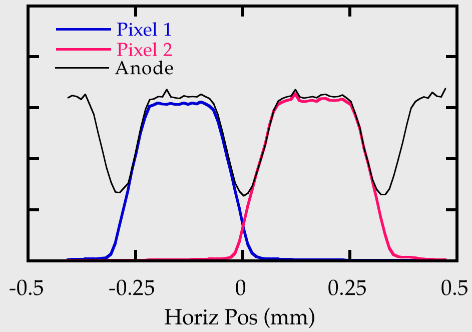
New: Be Cover (Normal and Grazing Incidence)

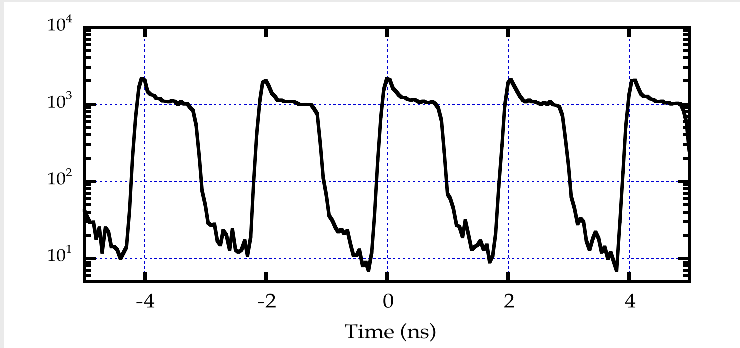




Webb & McIntyre
IEEE Trans. Electron Dev. ED31 (1984) 1206

C30985 Response





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Multi-Parameter, Multi-Channel Data Acquisition System

H. Thiess, A.Q.R. Baron & T. Ishikawa,
manuscript in preparation.

Adapt a nuclear-physics, event-based, data acquisition system to NRS experiments.

NRS is usually a low count-rate experiment, so this is relatively easy.

CAMAC based system (1 μs/instruction) with a Discriminator & an ADC

For each event, record
- Detector channel (Discriminator)
- TAC output (ADC)
- Drive velocity (ADC)

Present system: 2 Parameters and up to 30 detectors.
Easy to interface with existing fast (NIM) electronics.

Data rates up to a few kHz (10% dead-time at ~2 kHz)

Camac System Logic Diagram

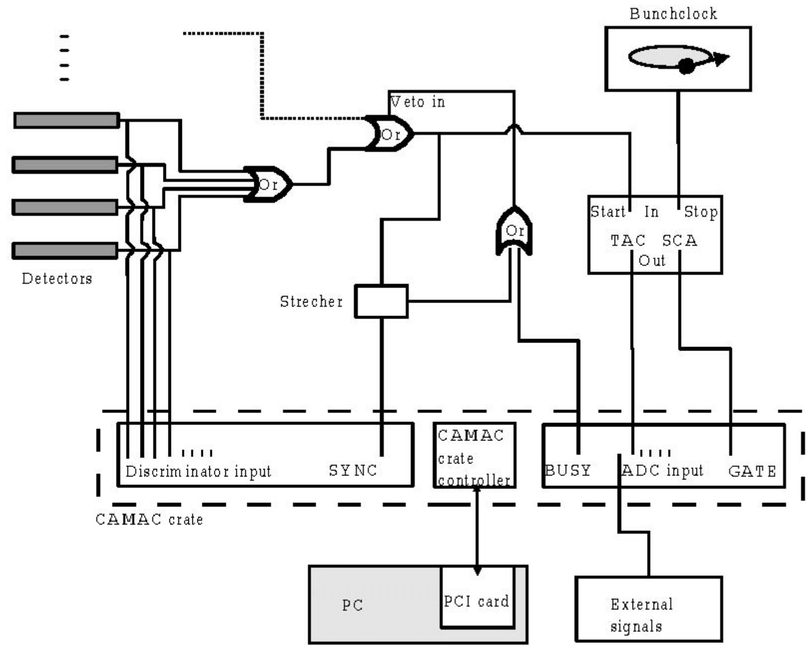
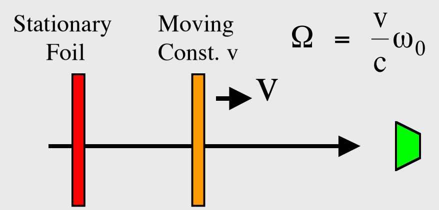


Fig. 1. Simplified circuit diagram of the aquisition system. Four detectors are drawn, the extension to more detectors is straight forward. For a setup with more than 16 detector additional discriminators can be implemented. Besides the timing signal from the TAC another 15 external signals can be applied to the ADC. For the functional description see the text in the hardware section.

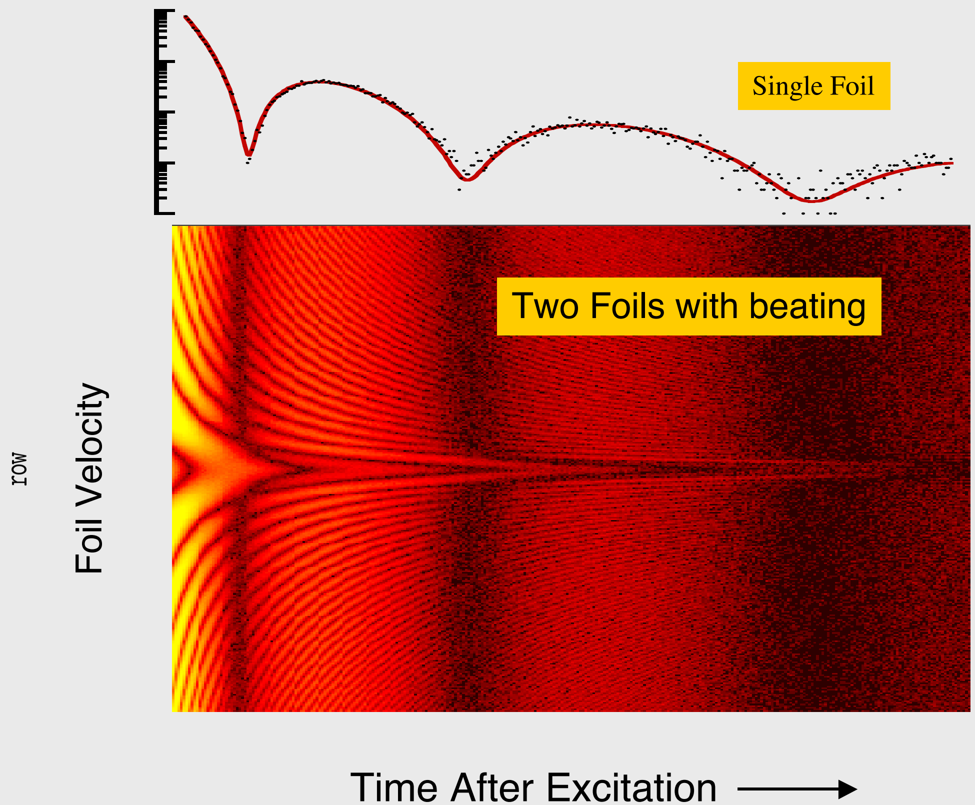
Simultaneous Two Parameter Measurement

Nuclear Forward Scattering (NFS) from two foils



$$\Omega = \frac{v}{c}\omega_0$$

$$I(t) \propto e^{-t/\tau}\left[\frac{J_1\left(2\sqrt{\beta t/4\tau_0}\right)}{\sqrt{\beta t/4\tau_0}}\right]^2 \left[1 + \cos(\Omega t)\right]$$



Comments

0. Device Stability - Still an issue.
   PKI Sealed 5x5 device is stable.
   Others: device dependent - some care needed.

1. Arrays of small elements interesting
   for high efficiency, high rates,
   and good time resolution

2. Closest Packing so far ~ 70μm dead space.

3. The amplifiers are getting smaller.
   ASIC would be nice.

4. Downstream Electronics = ?
   Integration = ?

5. Best Possible time resolution = ?

Collaborators

H Thiess (SPring-8) (Multichannel Electronics)

T. Ishikawa (SPring-8)