Avalanche Photodiodes at ESRF

Instrument Support Group,
Experiments Division

APD History:

At ESRF, ~50 NaI, YAP -PMT scintillation counters for diffraction, scattering and beam monitoring applications

These are limited to $<10^5 \ldots 10^6$ cps,

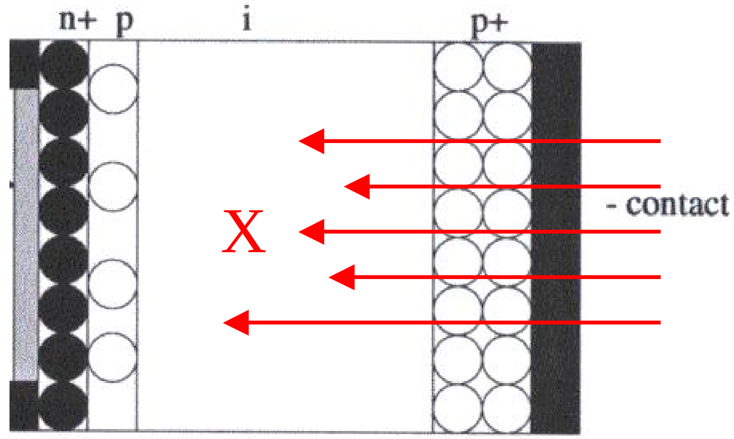
WIDESPREAD DEMAND FOR A FASTER COUNTER

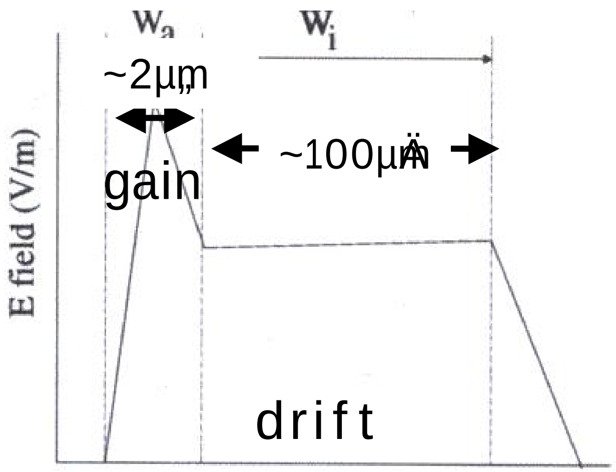
Silicon APDs used since ~1993 (A. Baron et al.) for Mossbauer experiments with <nanosec timing resolution

!! Could also be used as a fast counter ($> 10^7$ cps), but devices difficult/impossible to use for non-specialist users:

- array of NIM modules,
- need for fast oscilloscope
- sensitive manual adjustments (HT bias, etc...)

“Reach-through” avalanche photodiode*





Extremely robust devices

Thin , high field, ‘dead layer’ p+ entrance

Available commercially (infrared ranging market)

number of electron-hole pairs for a 5.9keV photon is = 5900/3.62 =1630

Charge collected in ~1ns, gives a current pulse ~260nA, or 13µV into a 50O‘ load !!

‘white’ amplifier noise too high for a fast counter (~500MHz bandwidth)

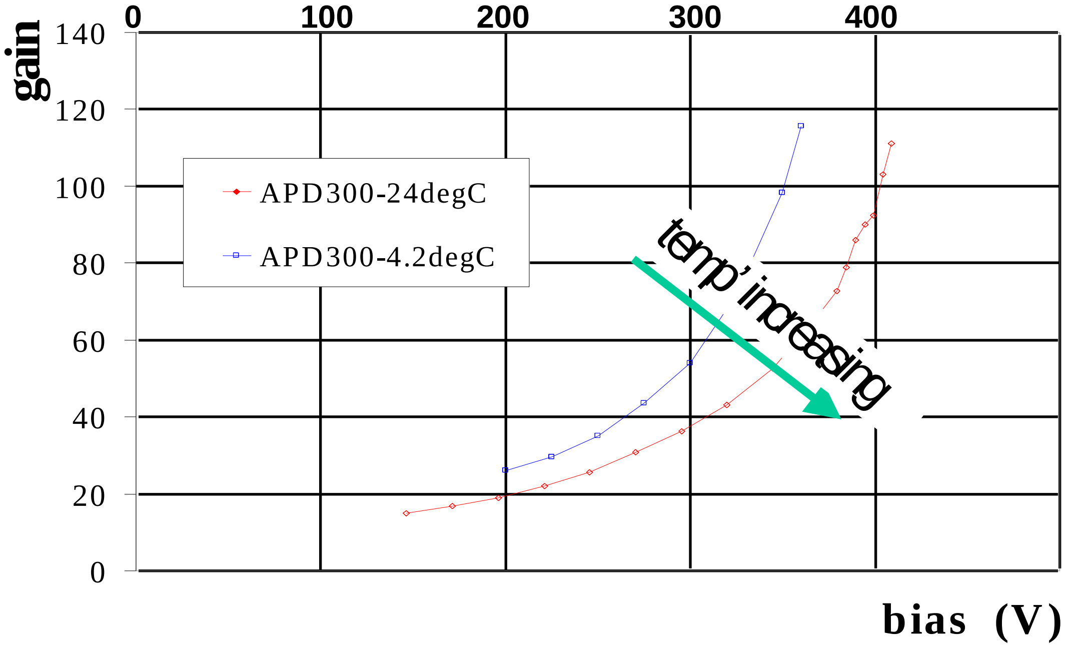
=> need detector ‘internal gain’

*see Webb, McIntyre, Conradi RCA Rev 35 1974

APD Gain...

Perkin Elmer 5*5mm^2

C30626 APD



For hard X ray detection, APD is used in semi-proportional gain mode, NOT as an avalanche counter

=> energy resolution possible

Gain

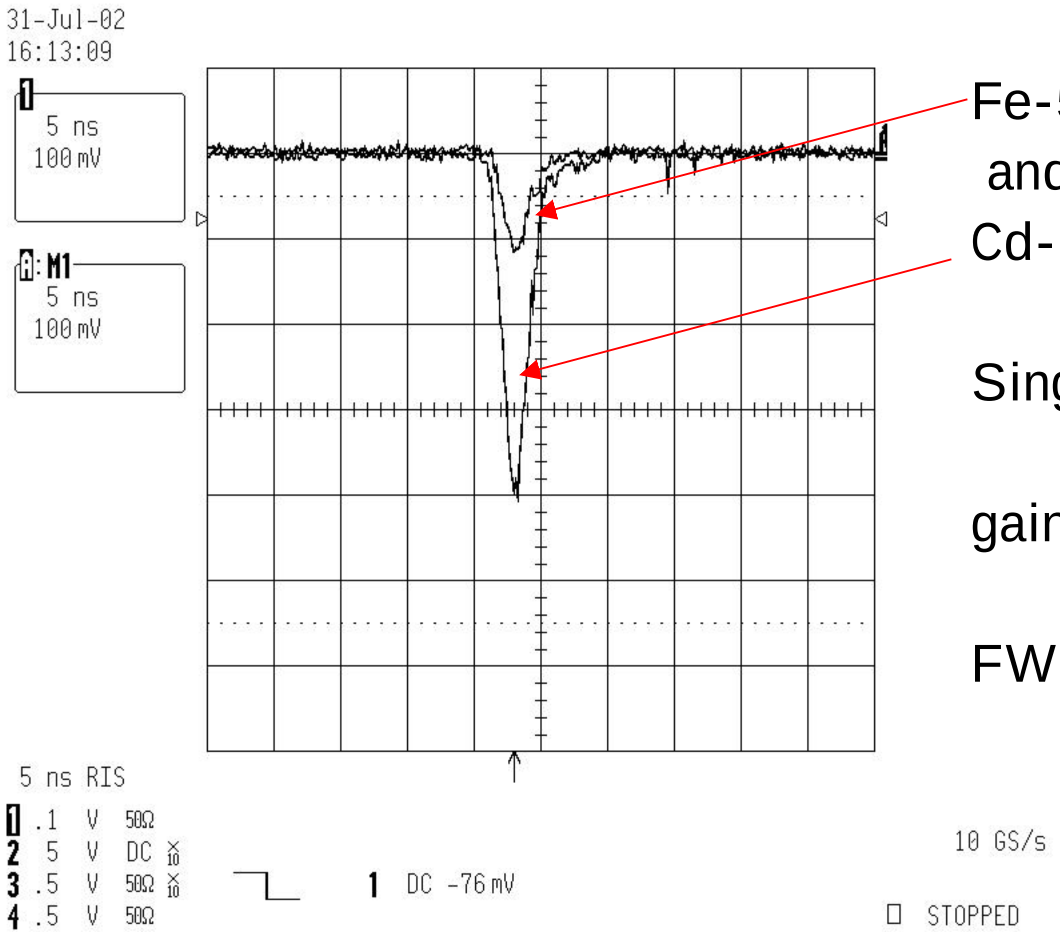
•increases logarithmically with voltage bias

•decreases with rising temperature

For constant gain, need compensation ΔV = 1.33% /°C (gain = 100)

ΔV = 0.65% /°C (gain = 20)

...and 'Speed'



preamp signal output

Fe-55 (5.9keV)
and
Cd-109 (22.4keV)

Single X-ray pulses

gain ratio ≈ 4 'correct'

FWHM of pulses ≈ 3 ns

Specifications for a fast Silicon Avalanche Photodiode counter:

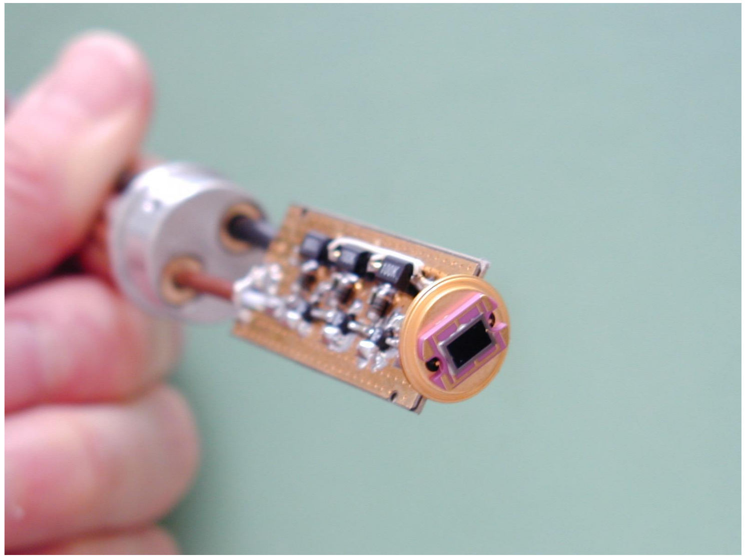
- Energy range < 3 keV (preamp noise threshold limit)
  up to Si absorption limit ~ 30keV √
- Counting rate > 10^7 cps √
- Time resolution < 1ns (silicon interaction depth-drift time limit) √
- Dark noise < 0.1 cps √
- Energy resolution ~ 20 %
  (separate of fluorescence and elastic scatter) [√]

- EASY TO USE, COMPLETE HARD- SOFTWARE SYSTEM √
- AVAILABLE TO ALL USERS AT AT ESRF AND BEYOND [√]

(36 APD heads and 26 ACE modules)

ESRF APD system

APD head /preamplifier

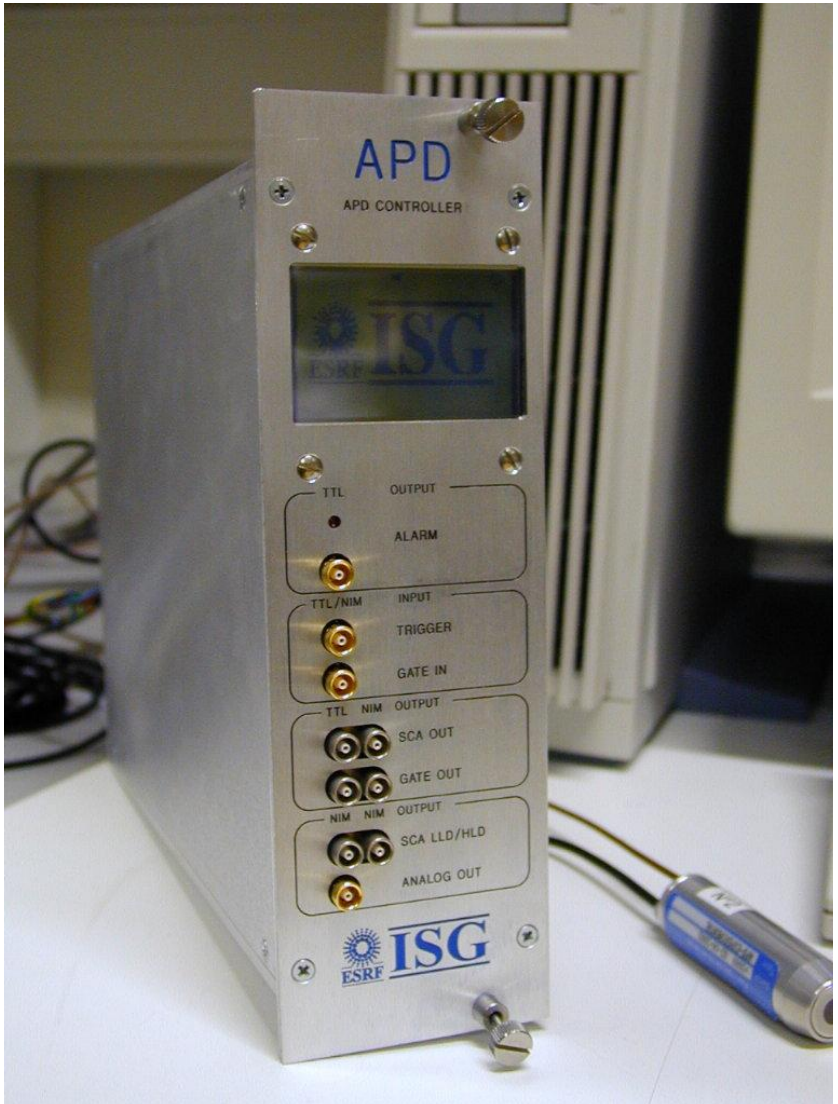


Hamamatsu 5*3mm^2
thickness 135µm
(absorption 45% at 12 keV)

or

Perkin-Elmer 5*5 and 10*10mm2
thickness 110µm (215µm)

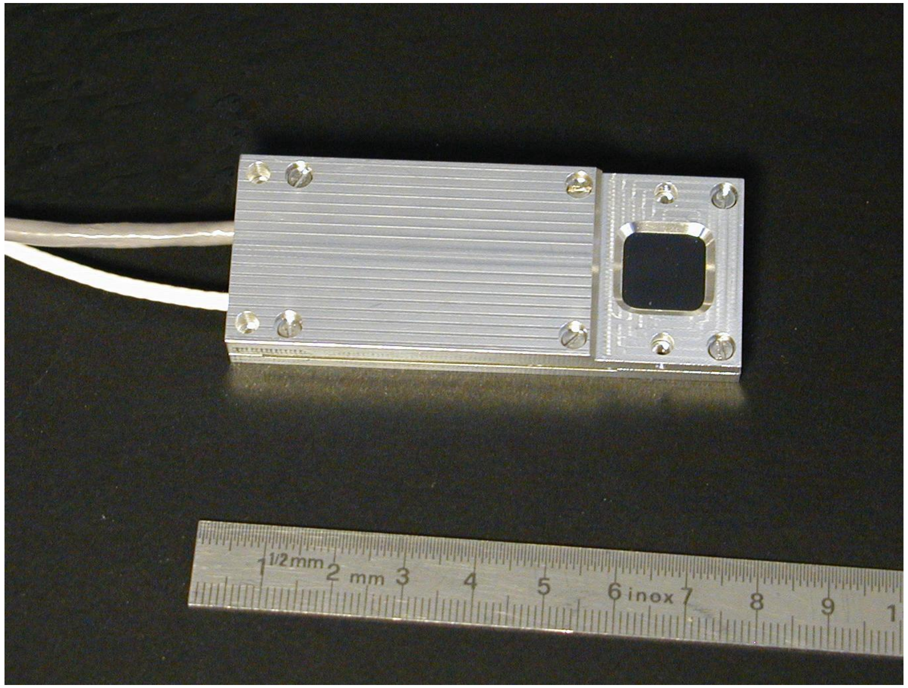
Controller, timer-scaler, power supply



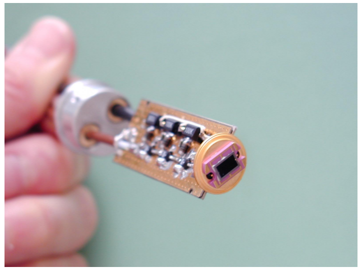
ESRF Heads

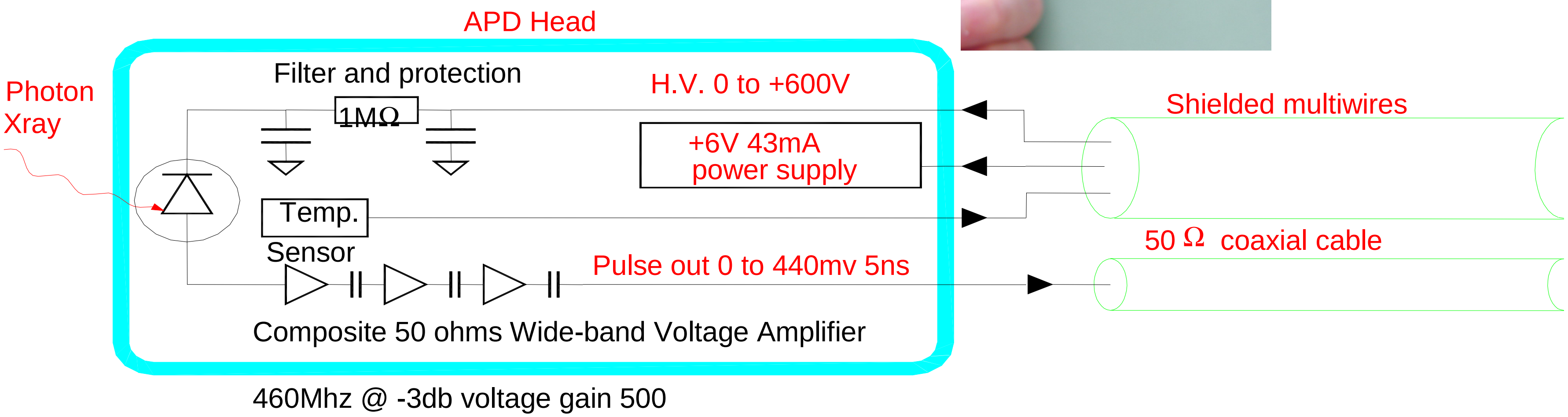
Pekin-Elmer 10*10mm2
thickness 110µm (215µm)
Transmission mode

Hamamatsu 5*3mm^2
thickness 135µm
(absorption 45% at 12 keV)
and Perkin-Elmer 5*5
thickness 110um



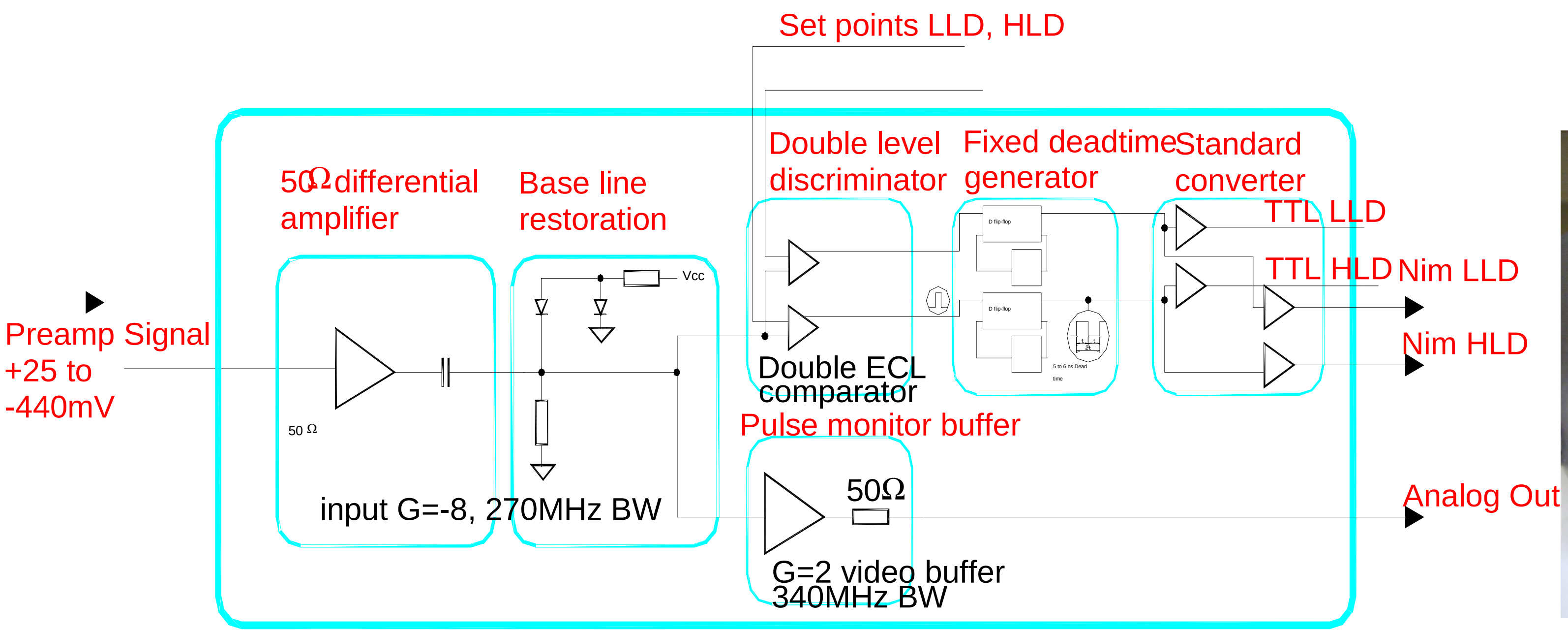
Head = APD + Pre-amplifier





- Low noise 3 stage amplifier mmic (Agilent) ~ 500MHz BW
- Thermally stable (temperature feedback stabilization possible)
- Compact (<300mW)
- Compatible with Perkin-Elmer and Hamamatsu APDs (15... 120pF)
- STABLE AGAINST OSCILLATON !!

APD Controller Electronics NIM unit: signal processing



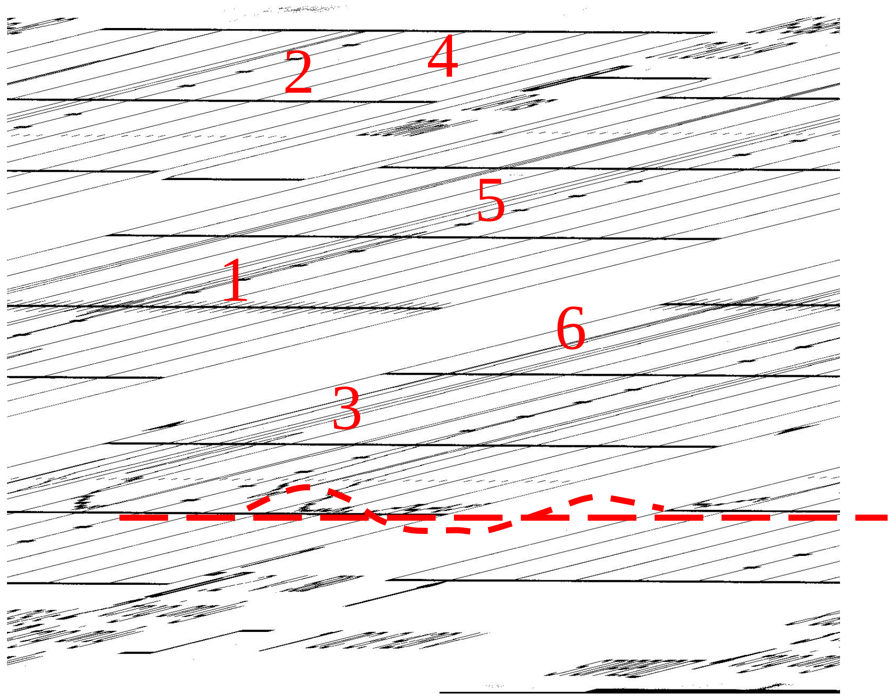
Base line restoration to remove AC coupling offsets.

Double (window) discriminators

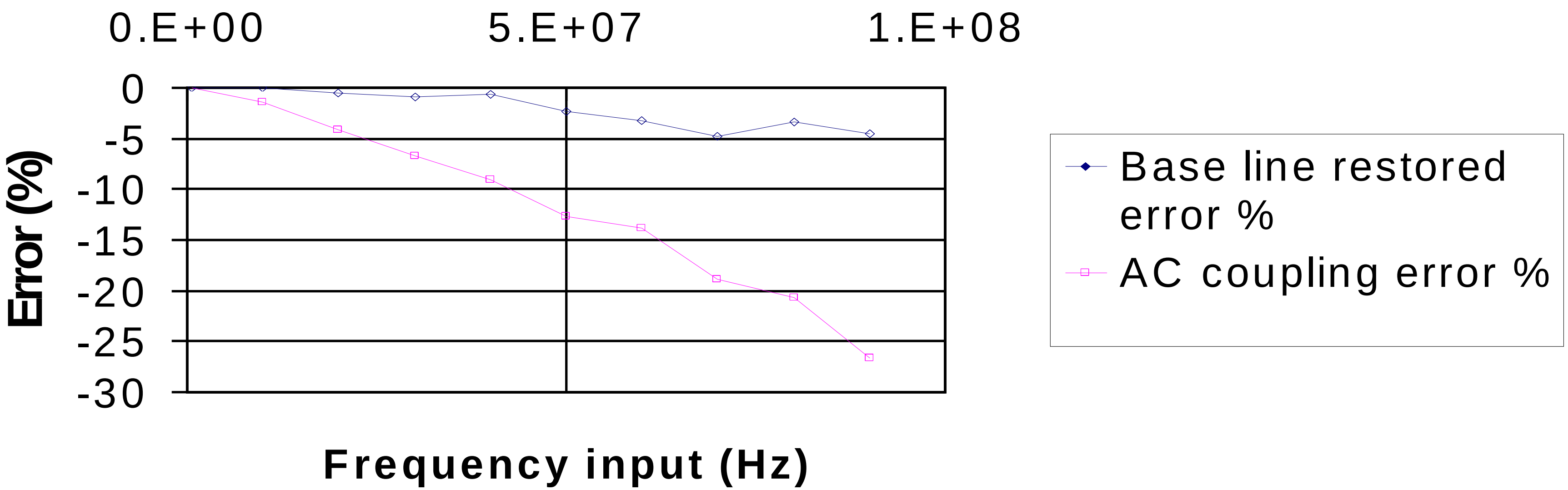
Fixed dead time generator.

Pulse Pile-up and base line restoration

RF preamp stages are a-c coupled, so 'average baseline' evolves with X-ray count rate



Schottky diode (non-linear) baseline restorer:

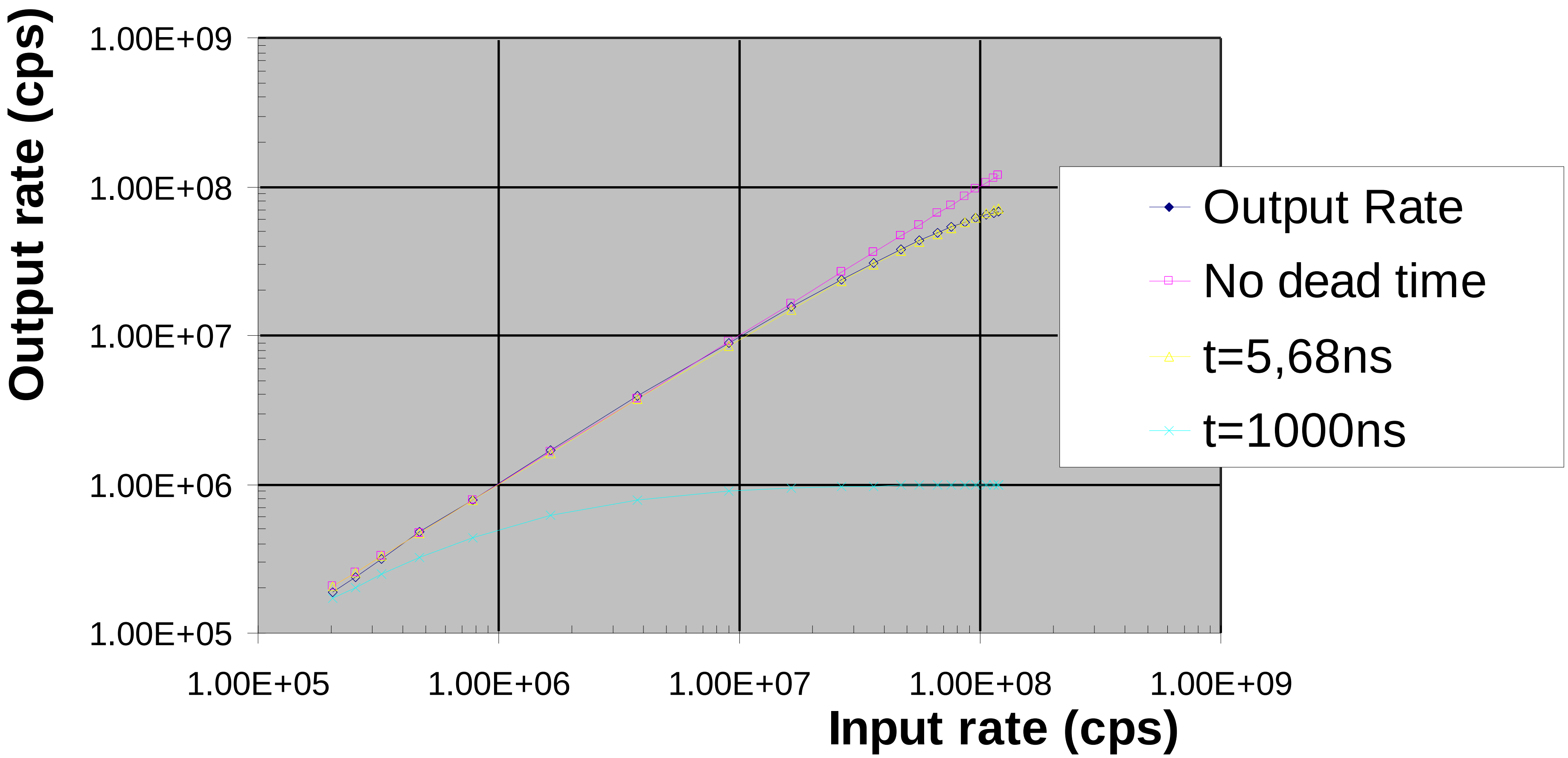


ACE (APD Controller Electronics) NIM unit

- Internal counter, 100MHz (180MHz / 10 pulse burst rate)
- External event synchronization : Trigger and gate input-output, direct SCA outputs (TTL and NIM)
- Energy Spectrum inspection by DAC controlled window discriminator scan
- bias current measurement for count saturation indicator and overload safety-- passive load plus HV feedback adjust
- Local control/display by graphic LCD with touch panel.
- Beamline remote control and data acquisition ('SPEC' software) via RS232/422 or GPIB.

(APD temperature measurement for gain compensation and device safety)

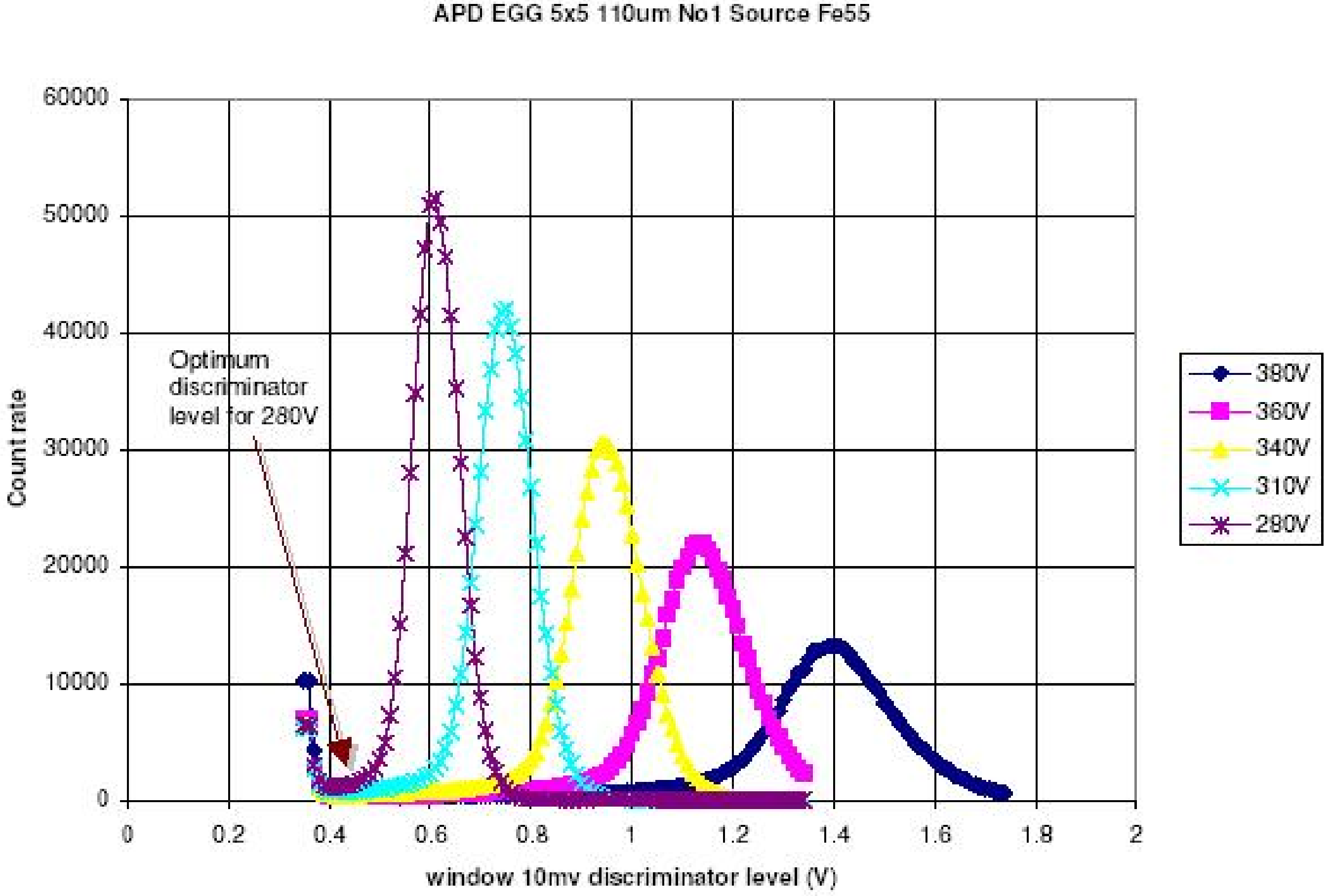
ESRF APD System: Count rate performance



ESRF uniform fill mode ID2 beamline tests at 12.5 keV

Hamamatsu 5x3mm^2 APD, nonparalyzable model fit

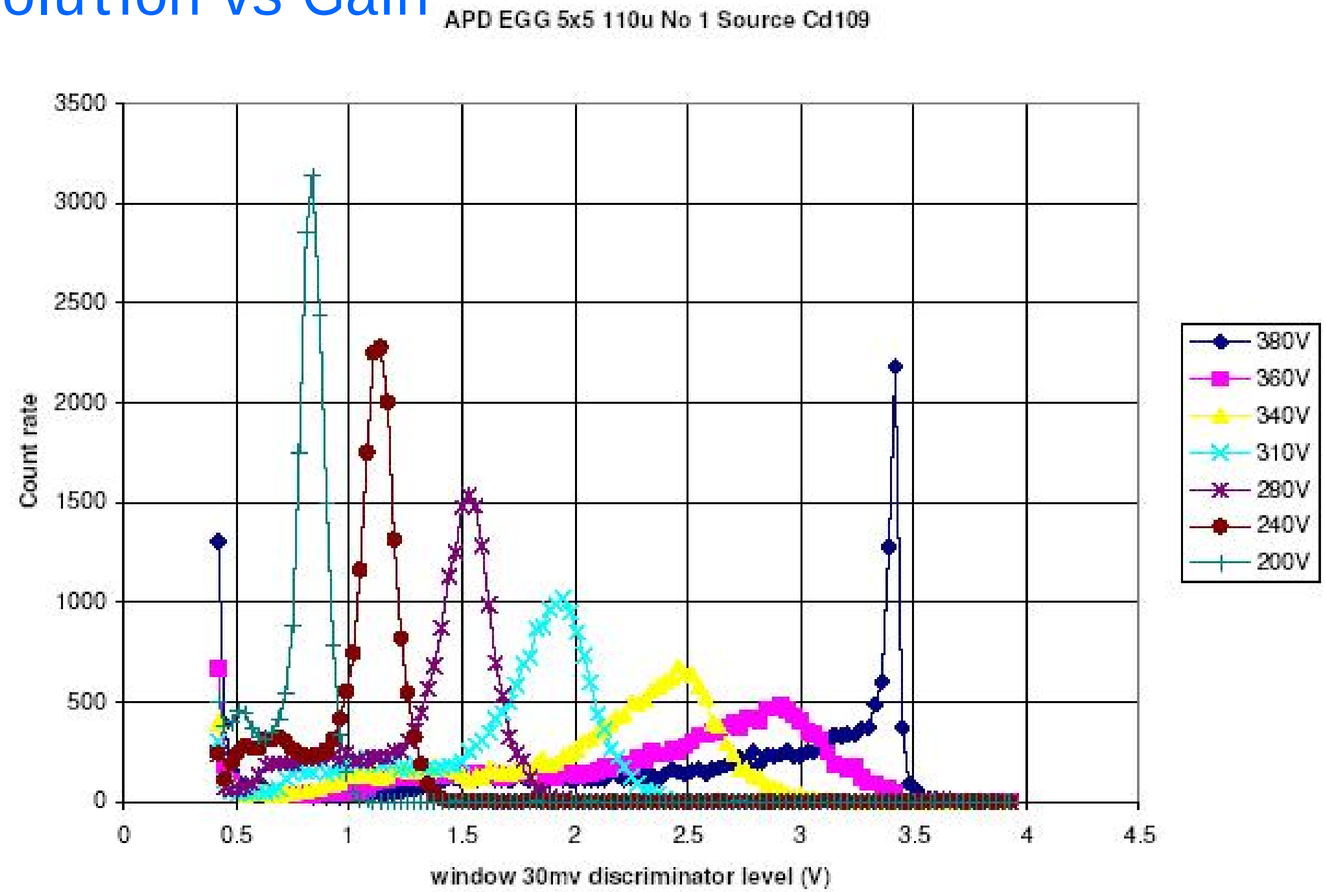
Energy resolution vs Gain



Fe-

The energy resolution (FWHM) versus bias voltage is:
Bias = 380V Energy resolution = 21% (optimal value for 6Kev)
Bias = 360V Energy resolution = 21.5%
Bias = 340V Energy resolution = 21.6%
Bias = 310V Energy resolution = 22.7%
Bias = 280V Energy resolution = 27%

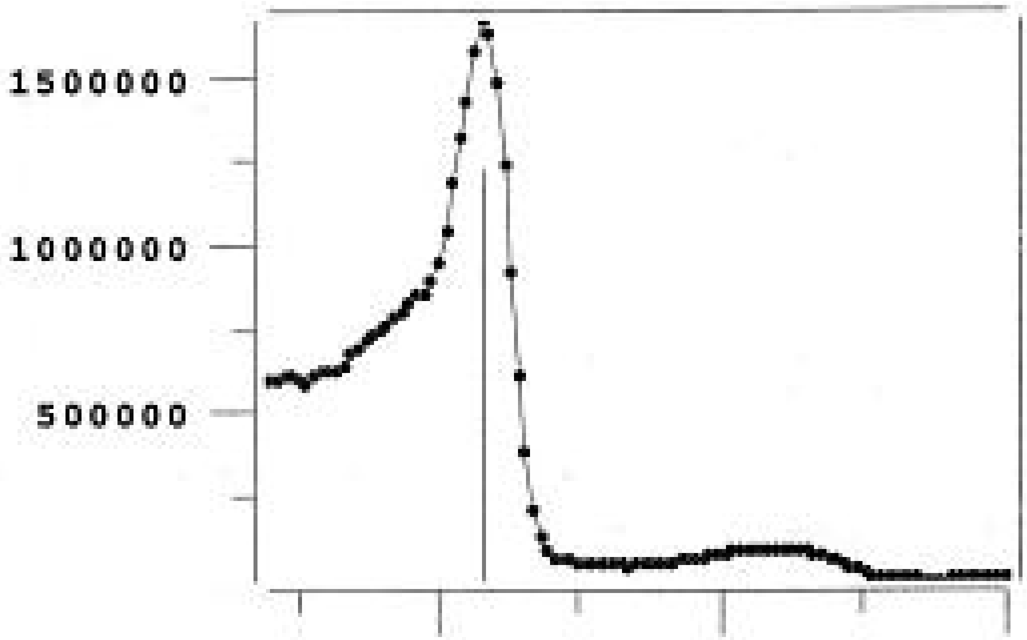
Energy resolution vs Gain (bis)



Cd-109 22/25keV

The energy resolution (FWHM) versus bias voltage is:
Bias = 380V Energy resolution = no measurement (saturation of input)
Bias = 360V Energy resolution = 26.6%
Bias = 340V Energy resolution = 24%
Bias = 310V Energy resolution = 22%
Bias = 280V Energy resolution = 18.5%
Bias = 240V Energy resolution = 17% (optimal value for 22Kev)
Bias = 200V Energy resolution = 20%

Energy resolution vs. (Output) Count Rate



ACE window mode SCA scan, 52Mcps OCR

energy resolution (E= 12.5keV): $\Delta E/E$ = 39%

(Peak energy shift $\Delta V/V$ = -8%)

Commercialisation

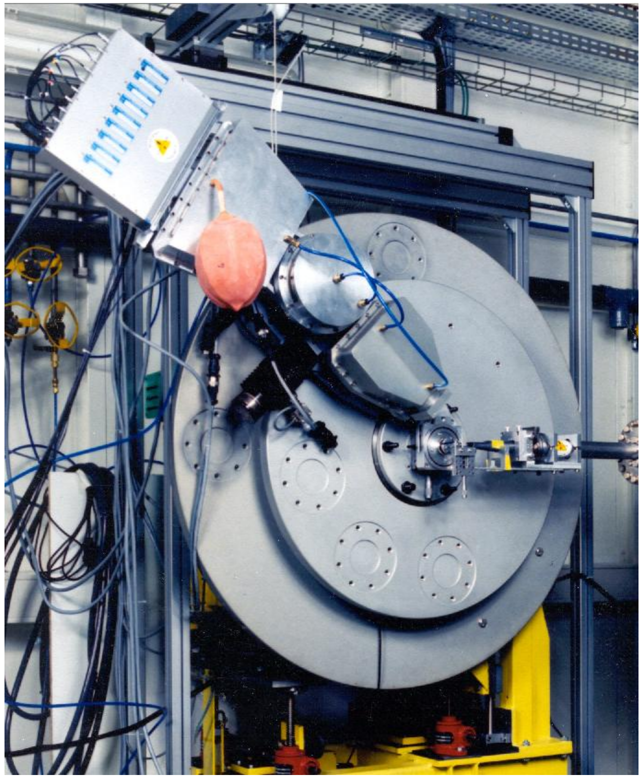
-Licensing agreement between ESRF and Cyberstar (Oxford Danfysik catalogue distribution)

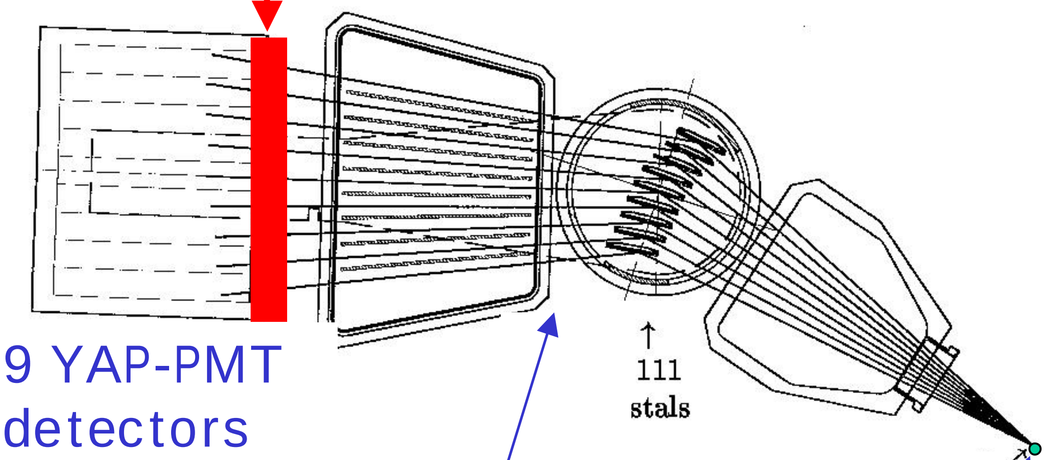
- NSLS (Brookhaven) basic NIM module, also produced by Cyberstar for Oxford Danfysik

Comparison of APD to YAP and NaI scintillator.

	NaI(Tl)	**YAP:Ce**	**APD**
Active area	$5cm^2$	$5cm^2$	0.15 -$1cm^2$
Energy range	5keV…	5…60keV	3…30keV
Energy resolution @ 22keV	28%	56%	20-30%
Dynamic with dead time correction	400Khz	3Mhz	50Mhz
Dead time	1μs	0.11μs	0.006 μs
Linearity @ 1% dead time	10K	100khz	2Mhz
Linearity @ 5% dead time	50K	450khz	9Mhz

beamline ID31

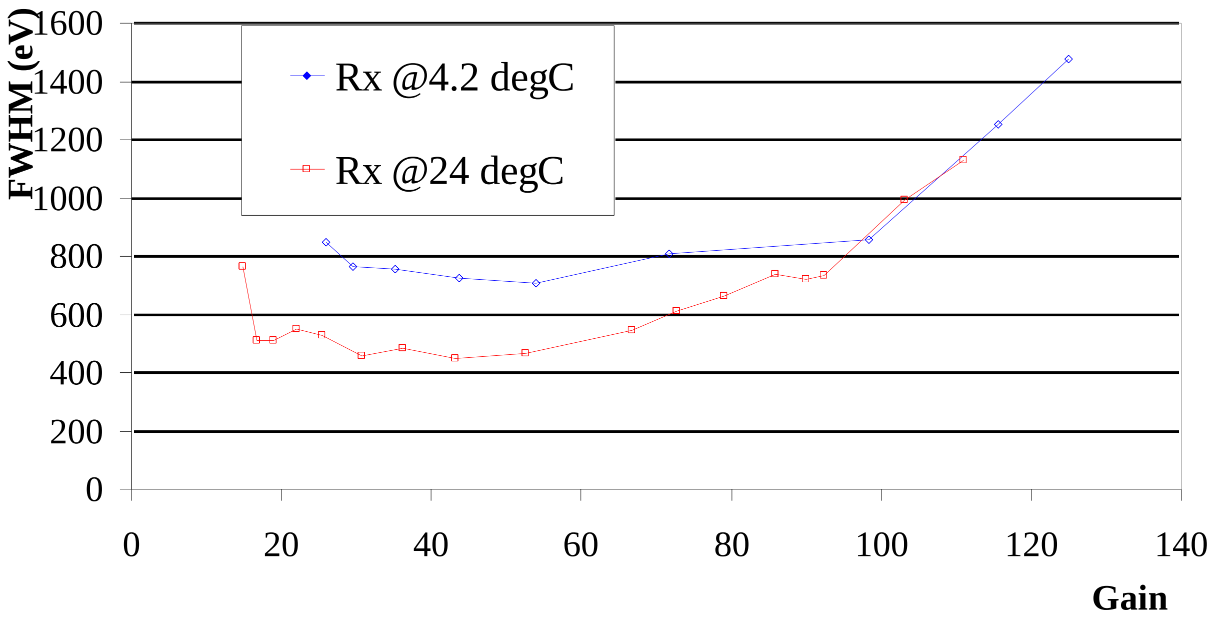




ESRF beamline ID31 (A Fitch)
Nine-channel multianalyser stage: J.-L. Hodeau, M. Anne, P. Bordet, A. Prat, CNRS-Grenoble.

...Resolution...

C30626 , Fe-55 source (Mn $K_{\alpha,}$ at 5.9, 6.4keV)

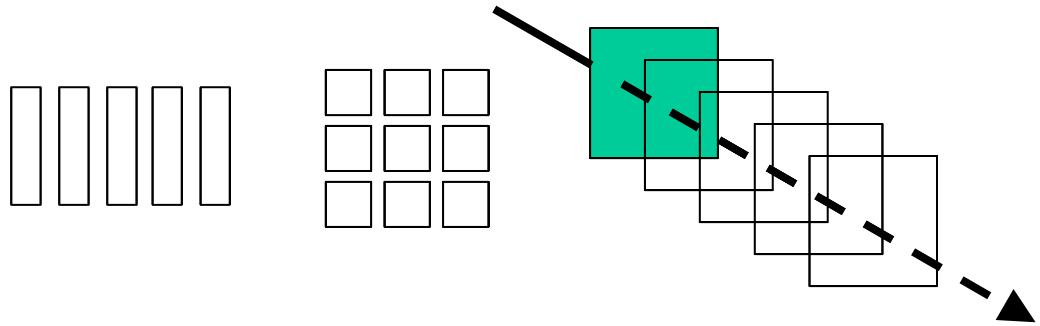


Resolution is dependent upon

- Fano statistics of photon absorption (~photon energy$^{1/2}$)
- Multiplication noise (~APD internal gain^{2})
- preamplifier noise (~bandwidth$^{1/2}$)

Future?

- APD arrays and telescopes



- custom head packaging (vacuum, cryogenic...?)

- faster counting --> 350 MHz ‘ESRF machine limit’