APD.Detectors Workshop
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Si-APD Detectors for Nuclear Excitation Experiments

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Outline

1. Nuclear excitation experiments using SR-X-rays and Si-APD

2. Hamamatsu Photonics's Si-APDs for NRS

3. Nuclear excitation by electron transition (NEET) and a Si-Avalanche Diode for electron detection

4. For Future

5. Conclusions

1. Nuclear excitation experiments using synchrotron X-rays

Ex..Nuclear resonance of ^{57}Fe: 14.4keV, $T_{1/2}$=98ns
We need an X-ray detector with a nanosecond time-resolution to record a time spectrum !

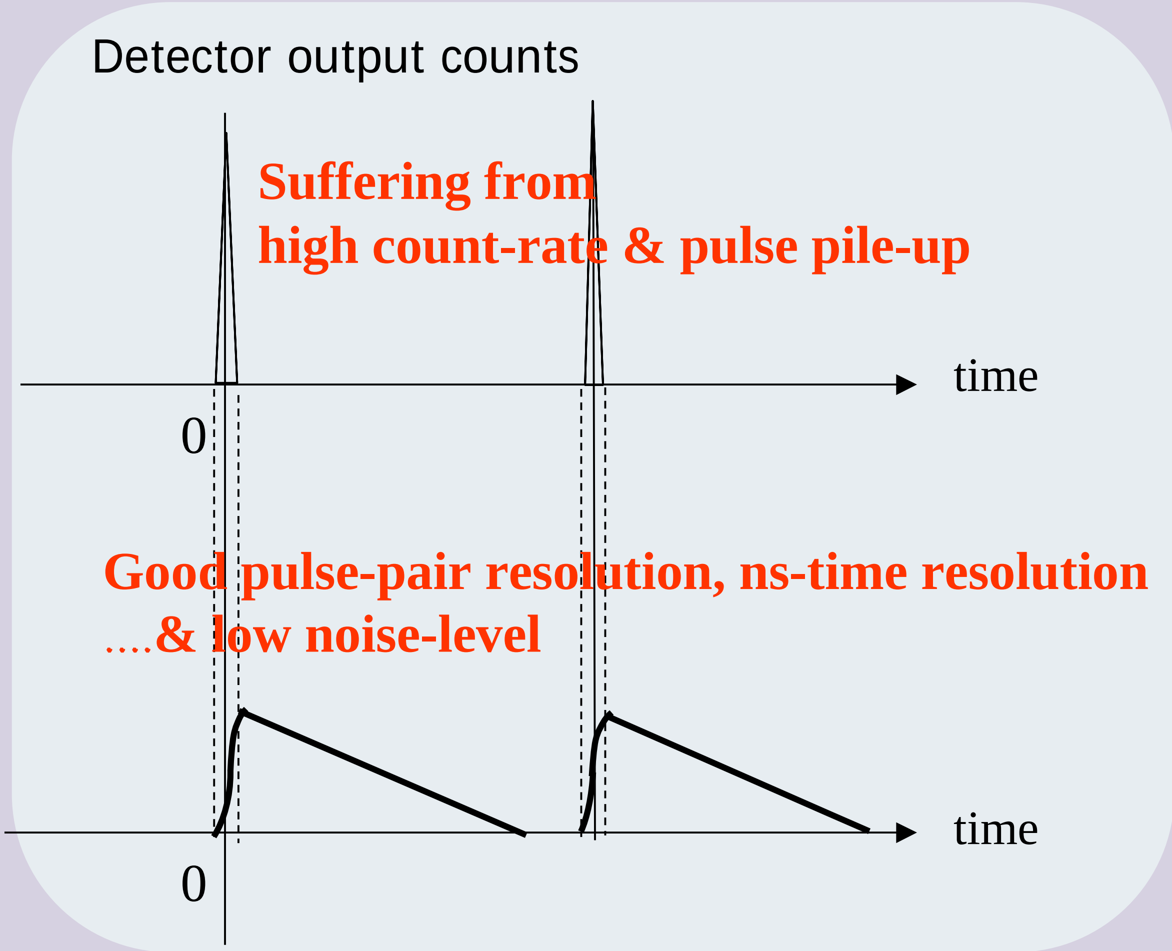
At a single or several-bunch mode operation,

Prompt radiation by electronic scattering ⇨

Intense!
: ≥ MHz

Radiation emitted from nuclei ⇨

Weak !
: ~1Hz

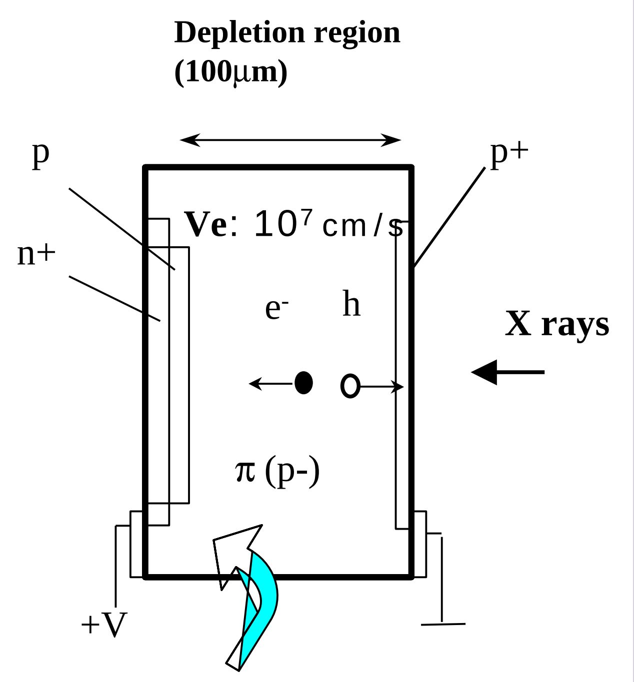


A silicon avalanche photodiode

Our detectors:

Detecting radiation Without a scintillator to obtain a faster response

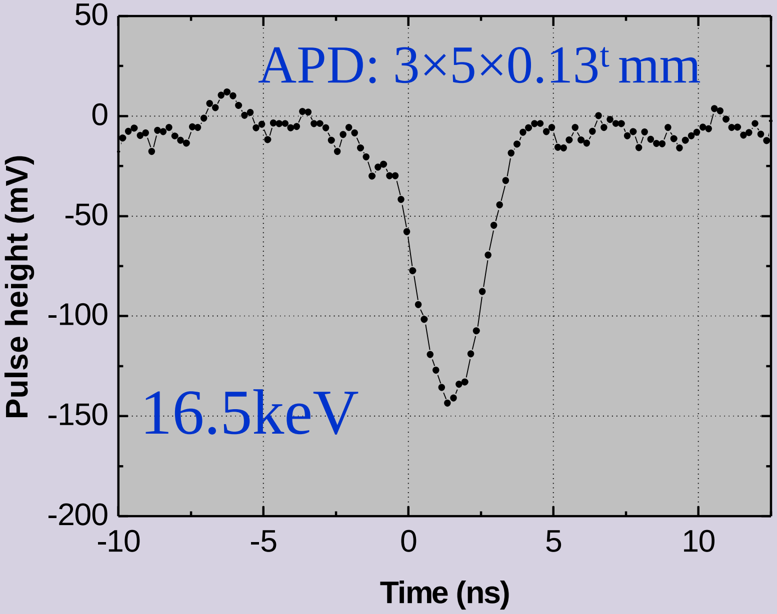
⇨ By processing signals With a wide-band amplifier (gain>100), a nanosecond-width pulse for one X-ray photon



Multiplication at a p-n⁺ junction

Ex. C30872E (EG&G Opt.)
Reach-through, bulk

high-rate capacity : up to 10^8 s^{-1}
time resolution : < 50ps – 1.5ns
Noise.level : 10^{-2} s^{-1} (one device)



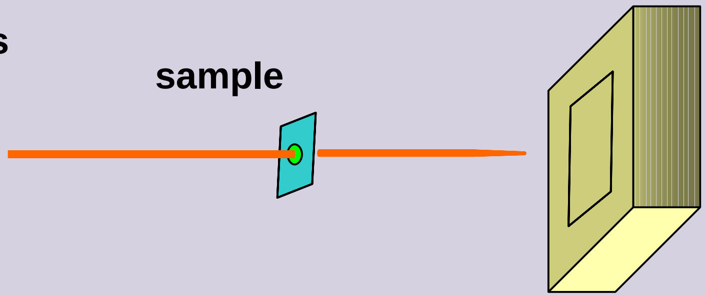
Si-APD detectors for Nuclear Resonant Scattering

*In Photon Factory **NE3A**, SPring-8 **BL09XU***

Mössbauer time spectroscopy using time structure by the interference of hyperfine transitions

X-rays

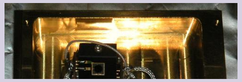
sample



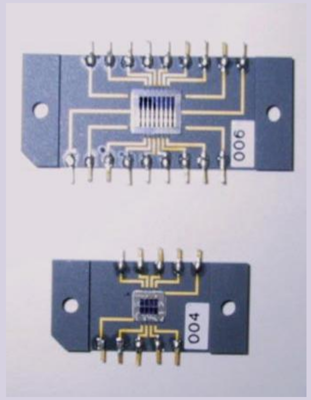
A stack of Si-APD plates

& An array detector

3mm in dia. 4ch,
150μm, ε≈80%.



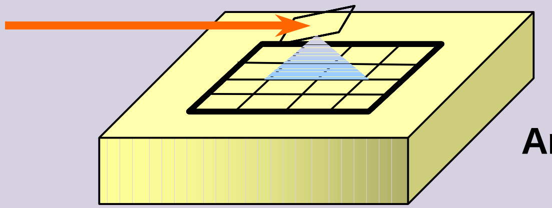
0.5x2mmx(8x2)ch,
0.5x1mmx(4x2)ch,
50μm.(monolithic)



Phonon energy spectroscopy using a neV resolution

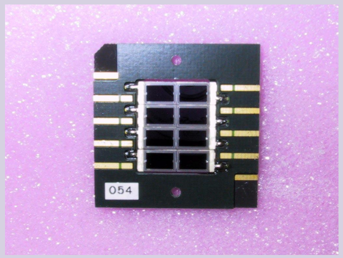
X-rays

sample



Array detector

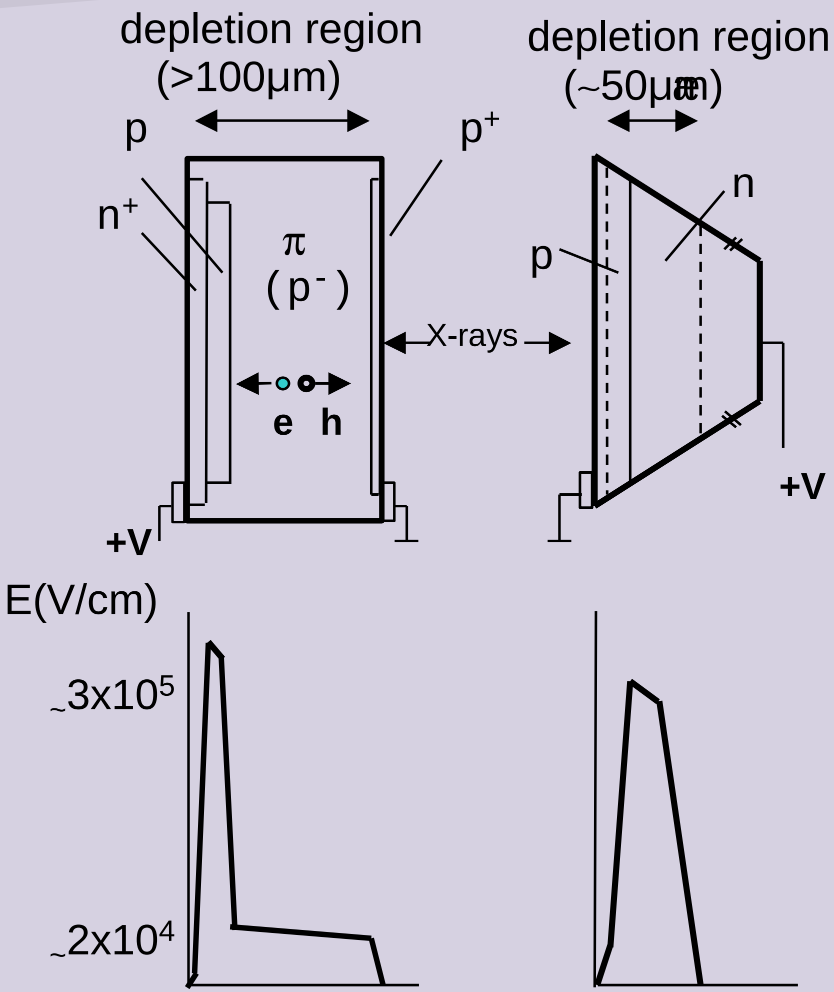
3x5mmx(4x2)ch,.150μm

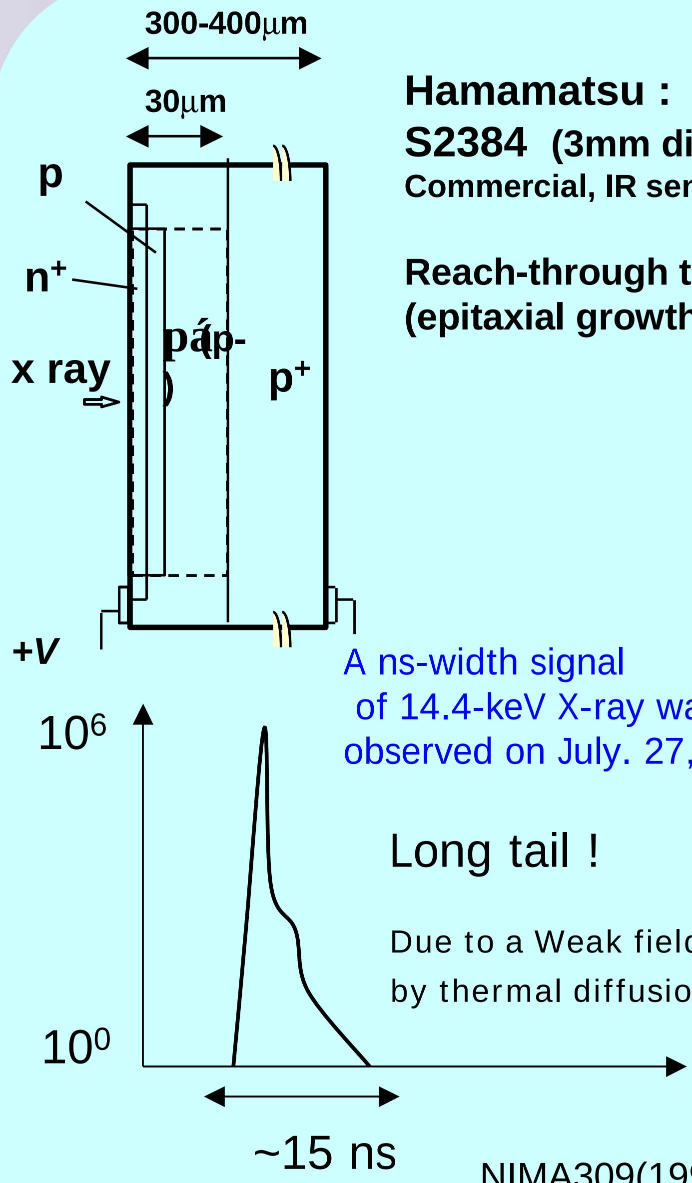


2. Hamamatsu's Si-APDs for NRS

Type of Si-APDs

(a) reach-through (b) beveled edge





Hamamatsu : S2384 (3mm dia.)
Commercial, IR sensor

Reach-through type (epitaxial growth)

A ns-width signal of 14.4-keV X-ray was first observed on July. 27, 1990

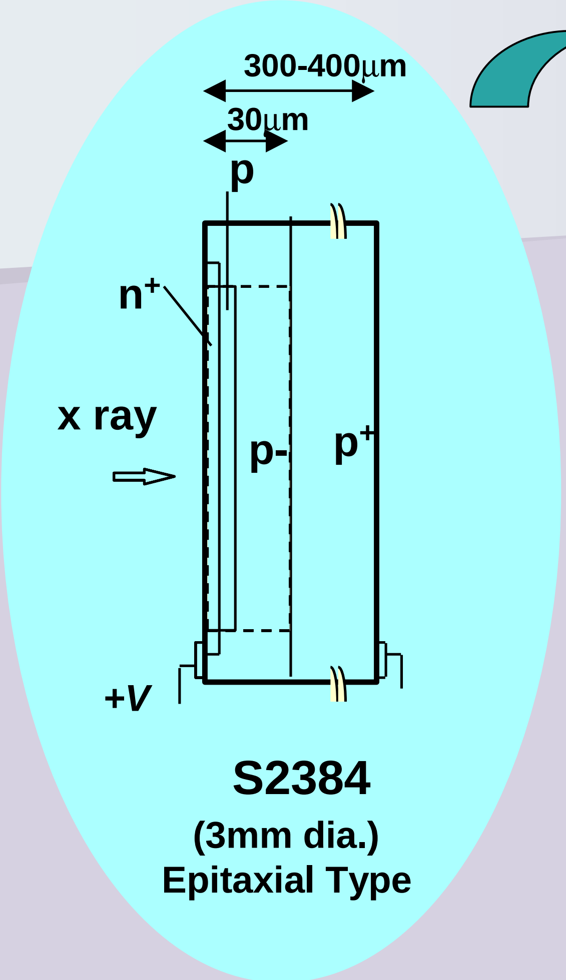
Long tail !

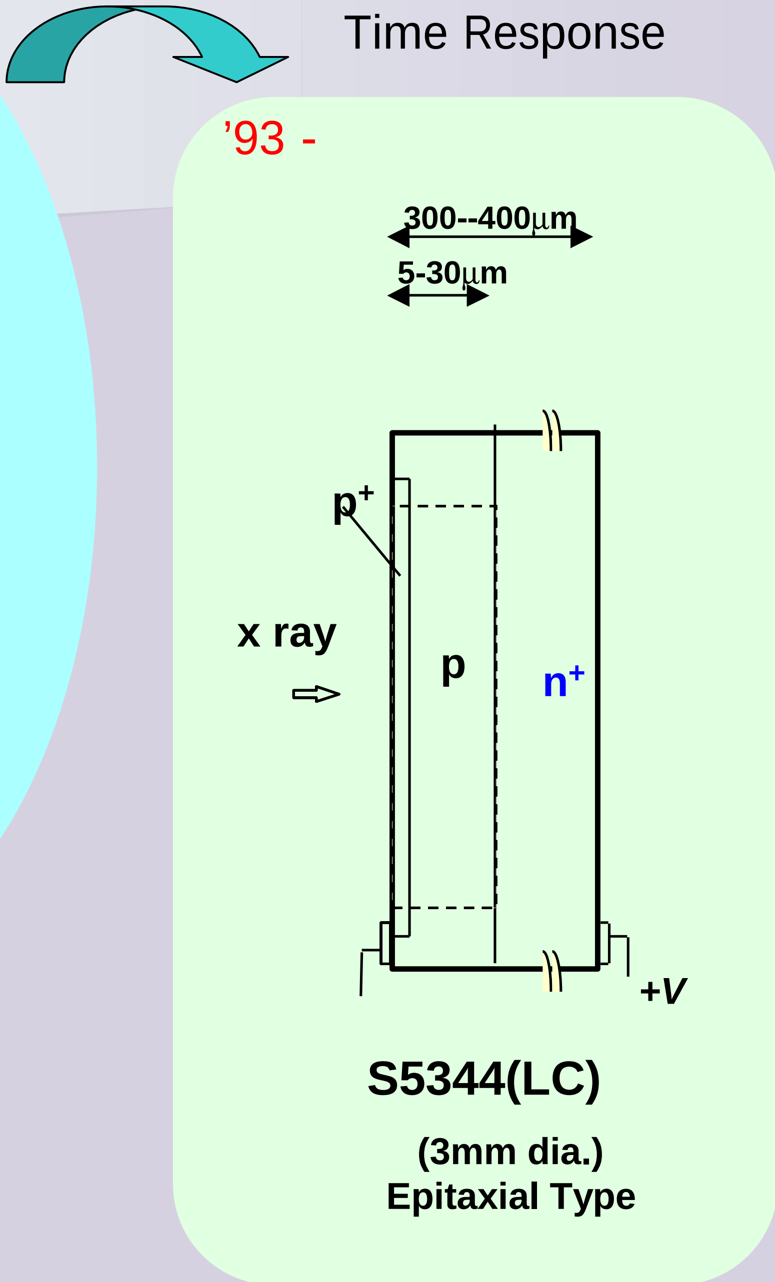
Due to a Weak field by thermal diffusion of p^+

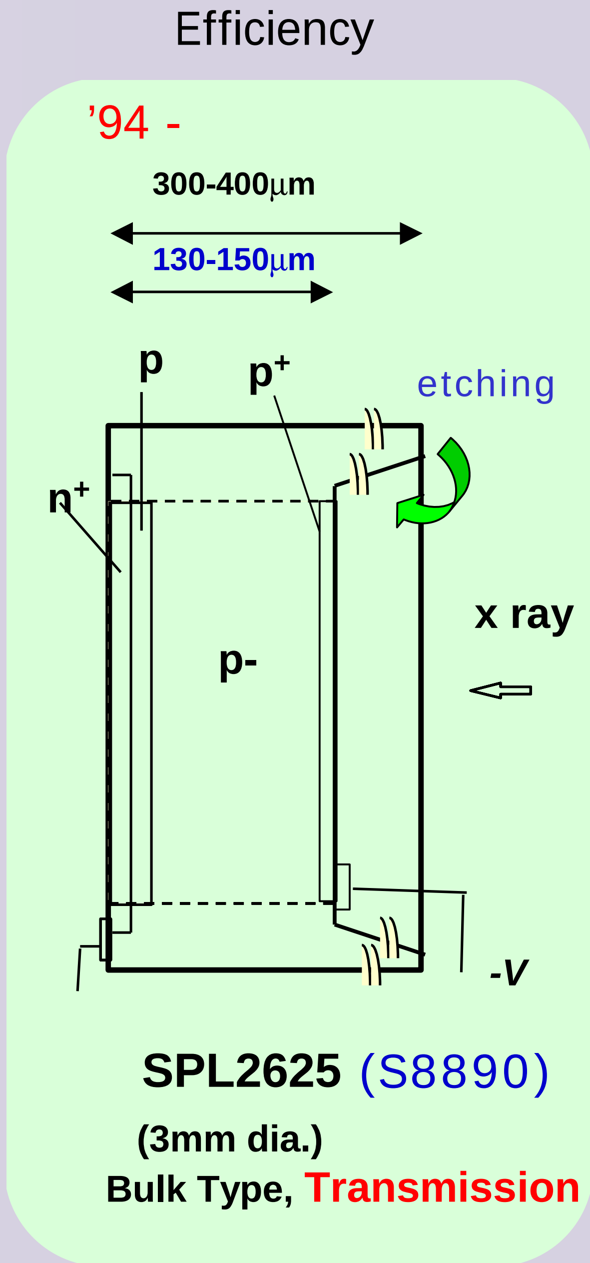
NIMA309(1991)603

We had to improve the device !

Improvements of HM's APDs



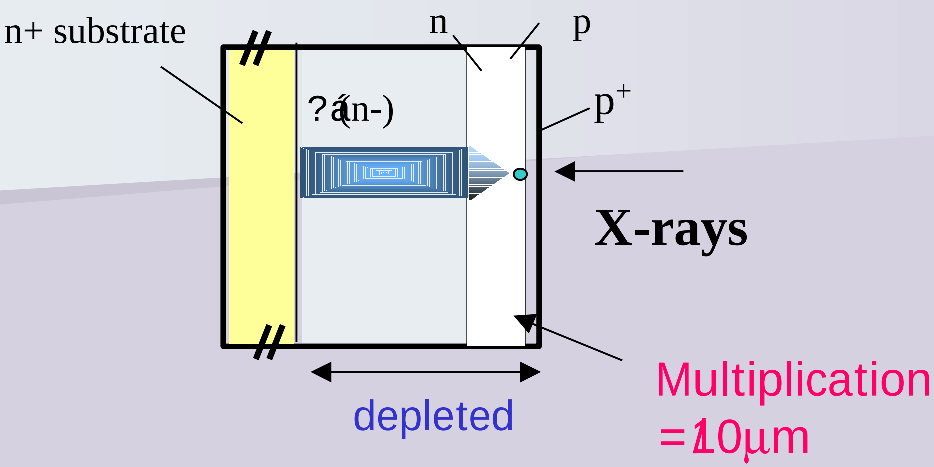




Hamamatsu Si-APDs for NRS (X & γ rays)

Model	Size (mm)	Thickness (μm)	Type
S238X	1-5 dia.	30	Epitaxial Injection: n^+ side
S534X (S534X LC)	3,5 dia. (0.5-5 dia.)	10 (20, 30)	Epitaxial Injection: p^+ side
S8890 (SPL2625)	0.2-3 dia. (3 dia., 3x5,5x5)	130-150	Injection: n^+ side (Injection: p^+ or n^+ side)
S8864	0.2-5 dia., 5x5, 10x10	7-10 (45)	Reverse structure (developed for High energy Phys. Exp.)

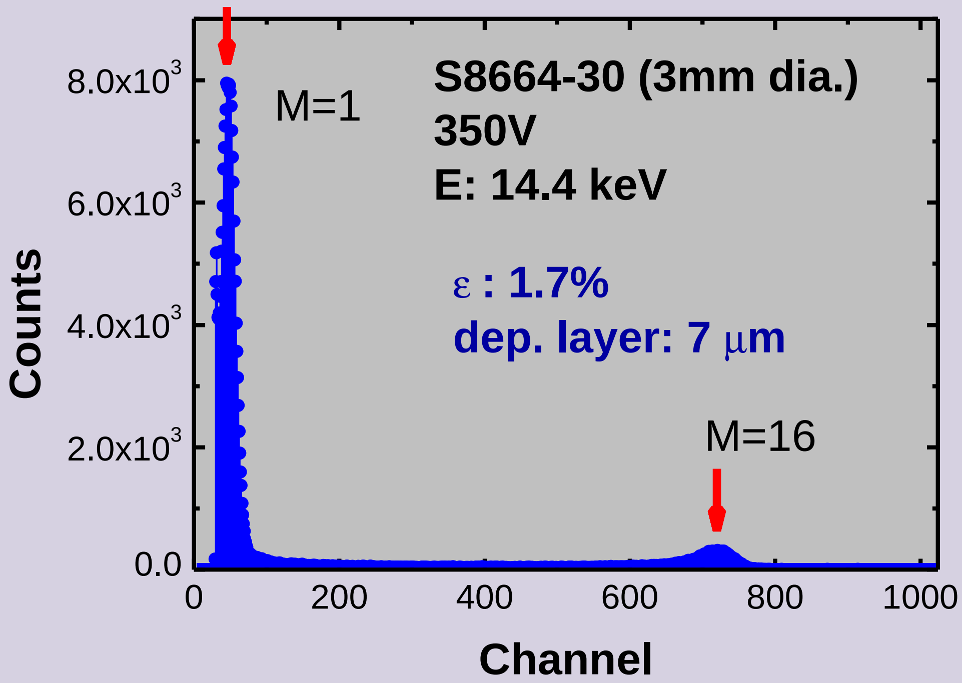
Reverse structure – “sensitive” only near the surface region



Energy spectrum

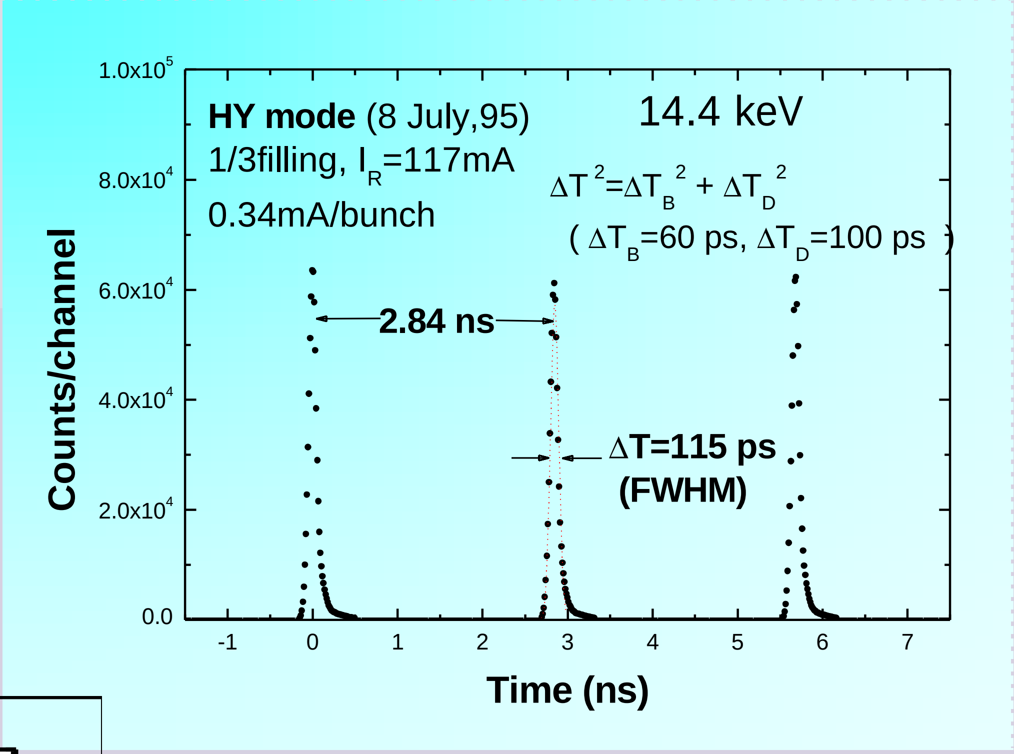
S8664 series

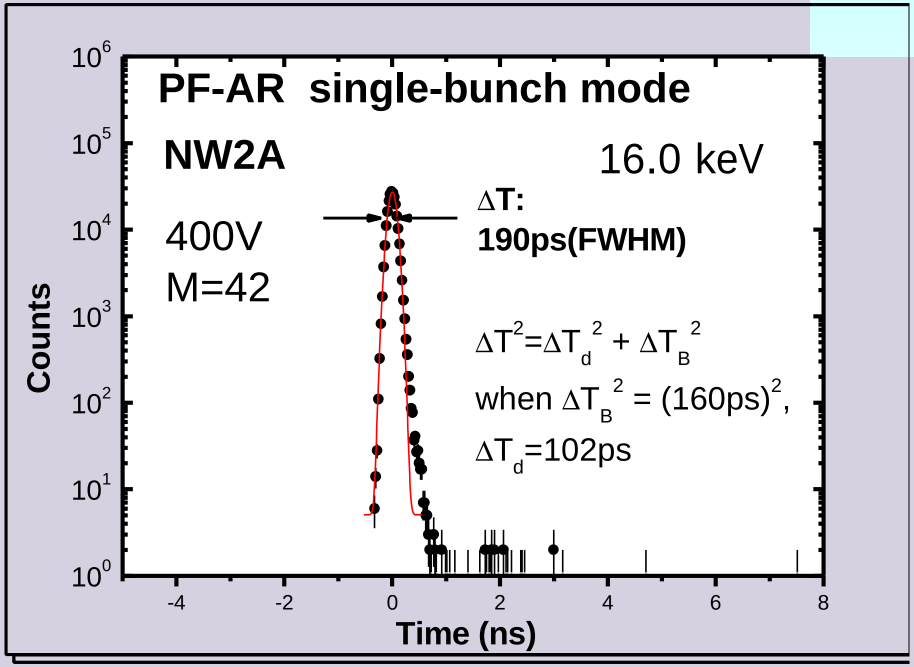
C_p~20pF (3mm dia.)



Timing

S5343
(1mm dia., 10μm)





S8664-30
(3mm dia., 7-10 μm)

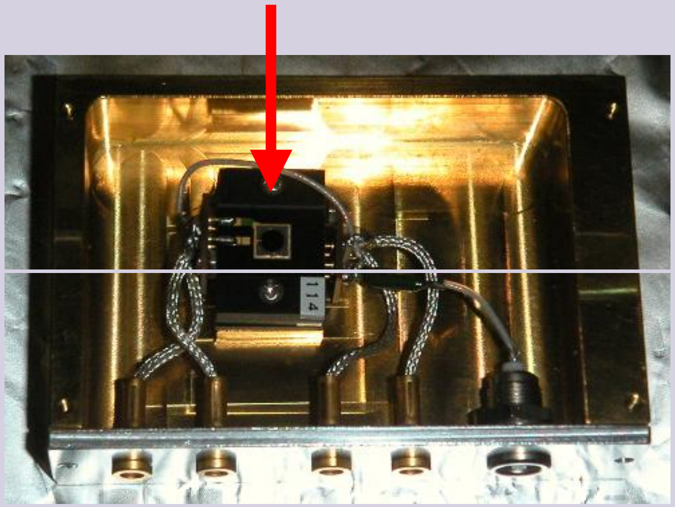
ΔT< 100ps is possible !

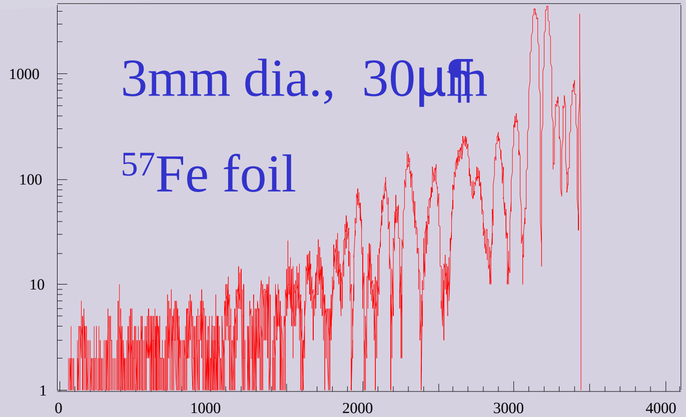
Efficiency and Solid-angle

Stack of Transmission-type APDs ⇨ **more efficiency without deficit of a time resolution**

Stacking of 4 plates (SPL2625 type)

3mm dia. : 30, 150µm
3x5 mm : 150µm



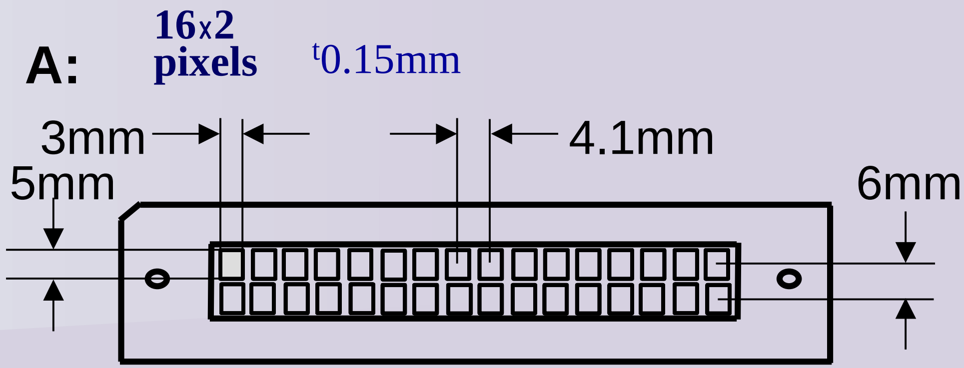


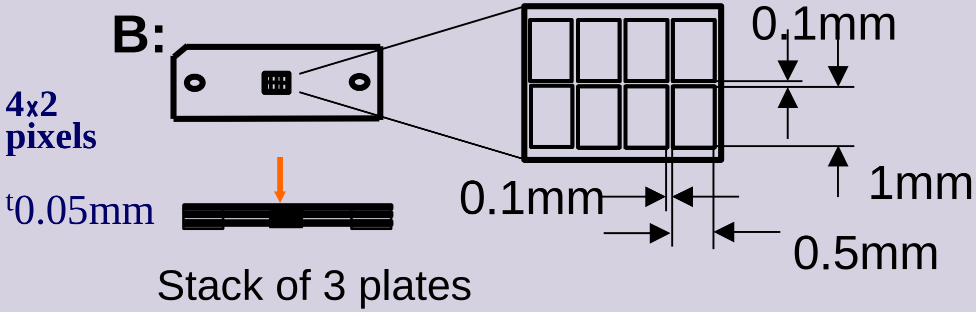
200ns ⇦ 0

4-ch	
efficiency(14.4keV)	
3mm dia. /30µm	26%
3mm dia. /150µm	78%

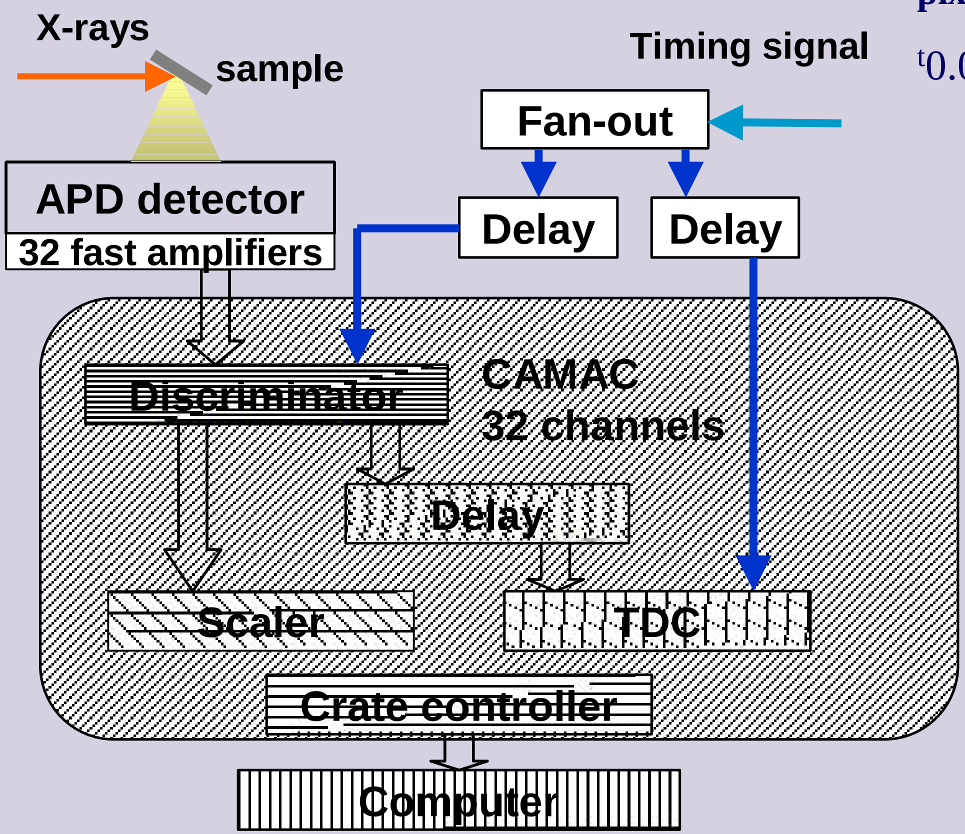
Si-APD Array

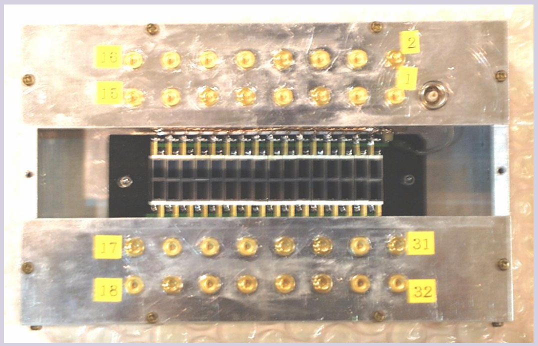
'97~ : tested some prototypes

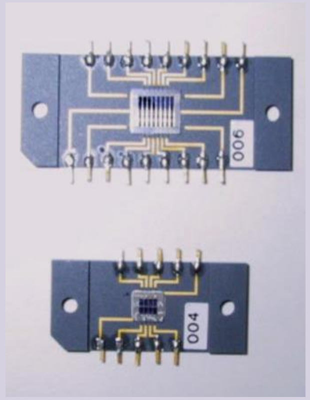


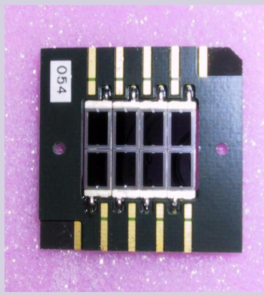


The detector system for the APD array (32 ch)







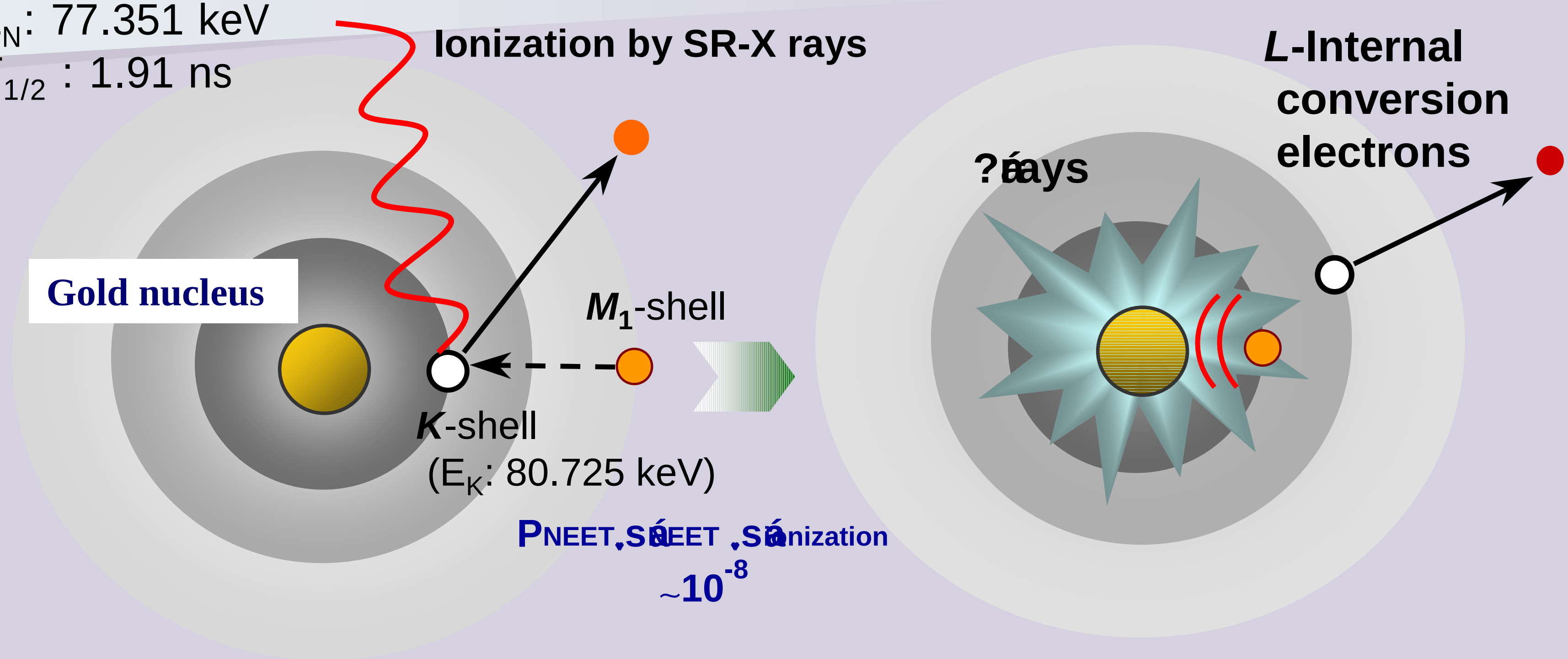


Device's design is depending on requests of an experiment !

3. Nuclear Excitation by Electron Transition (NEET) and Si-AD

Ex. ^{197}Au, Phys.Rev.Lett. 85,1831(2000)

E_N: 77.351 keV
$T_{1/2}$: 1.91 ns

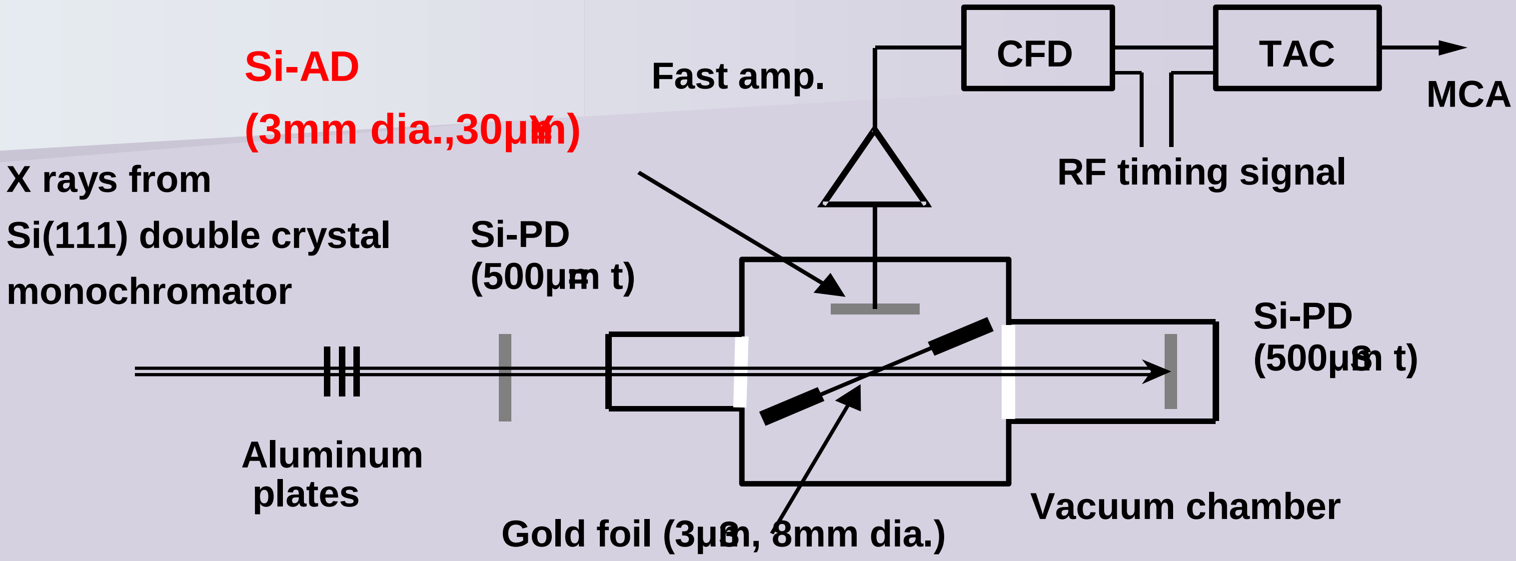


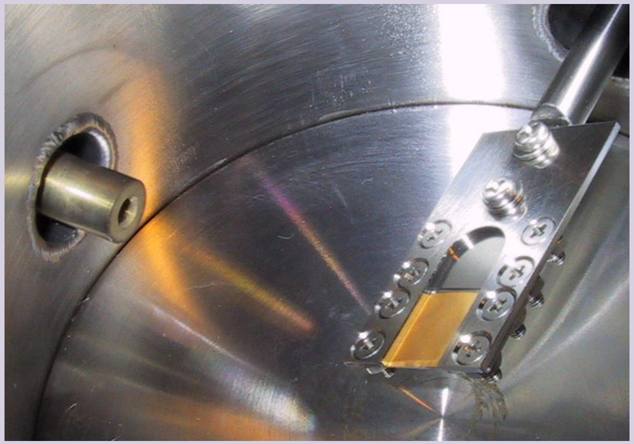
***K*-holes are made by ionization, and filled by an atomic transition from an outer orbit (M_1).**

The nucleus is excited, followed by emitting radiation with a lifetime of the excited level.

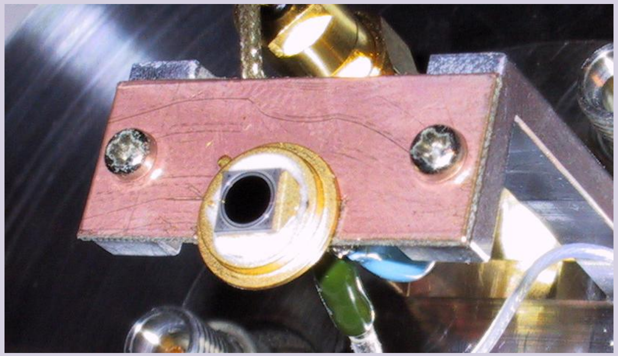
NEET experiment at SPring-8 BL09XU

A Si avalanche diode was used to detect *L*-Internal conversion electrons.





Detecting Internal conversion electrons

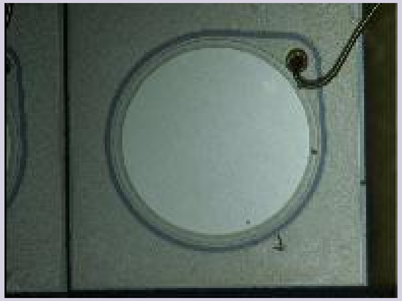


Detection of electrons by Silicon Avalanche Diode

Si-AD : S5344LC, 30μm thick (*L_1* conv. E=63keV, λe ~24μm)

⇨ a thin SiO_2 layer : 15-20nm (cf. std.: 130nm)

SPL3940(Oct.1994) SPL3941(Nov.1995)



1mm dia. 10μm^t

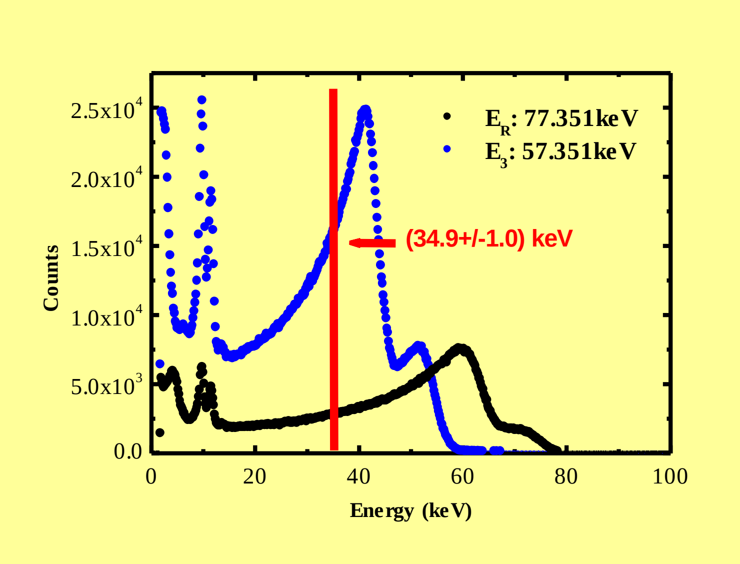
1mm dia. 30μm^t

Charge-up in the insulator & discharge !

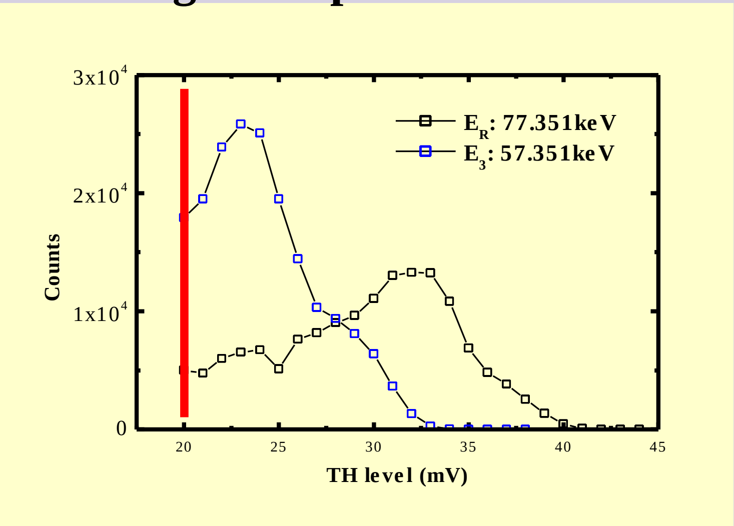
⇨ To suppress Discharge :

a groove

(a) Energy spectra

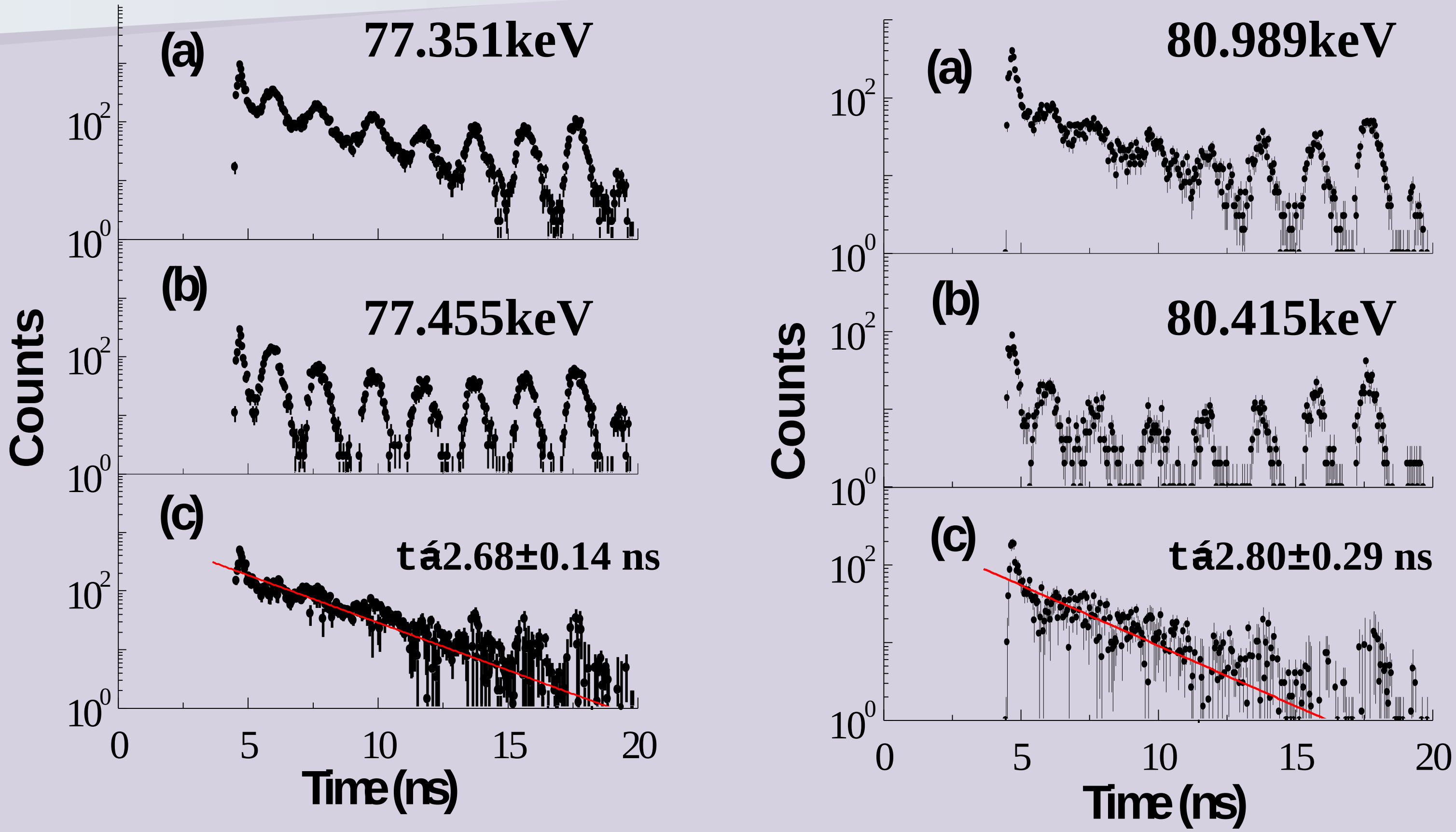


(b) Pulse-height distribution of fast pulses in measuring time spectra



Results in Au-197 Exp.

Time spectra of Nuclear resonant (left) & NEET.right.

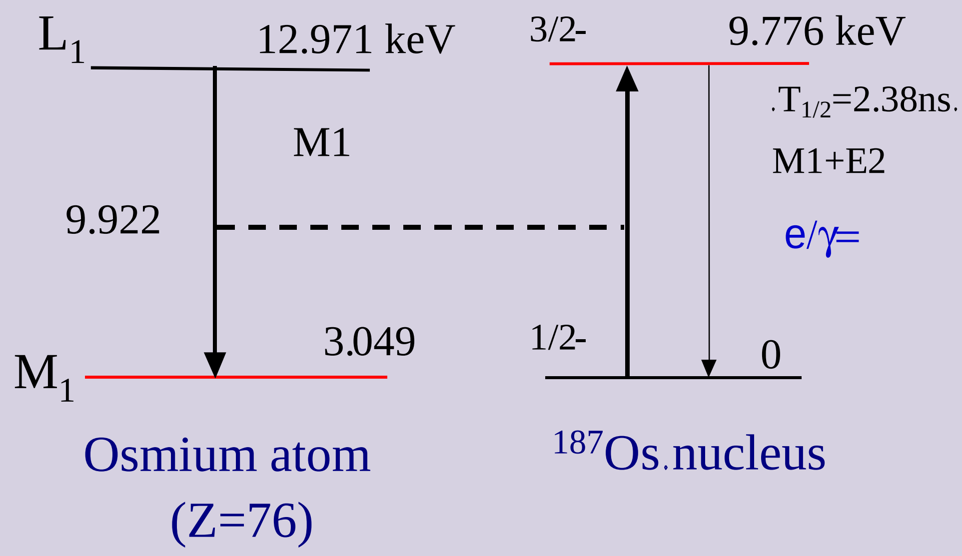


$T_{1/2}$=1.91ns?çç 2.76ns

$P_{NEET} = (5.0 \pm 0.6) \times 10^{-8}$

	E_{ion} (keV)	E_M(keV)	E_N (keV)	$T_{1/2}$(ns)	?E(keV)	P_{NEET} (cal)
^{197}Au(Z=79) 100%	80.725 (K)	3.425(M_1)	77.351	1.91	-0.051	3.8×10^{-8}
^{193}Ir(Z=77) 62.7%	76.111 (K)	3.174(M_1)	73.044	6.09	-0.107	2.0×10^{-9}
^{189}Os(Z=76) 16.1%	73.856 (K)	3.049(M_1)	69.537	1.62	1.270	1.1×10^{-10}
^{187}Os(Z=76) 1.6%	12.971(L_1)	3.049(M_1)	*9.776 (9.746)	2.38	0.146	$1\text{x}10^{-8}$?

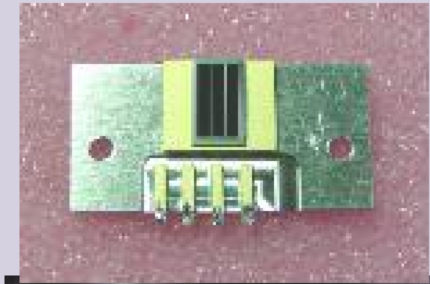
PF-AR NW2
& SPring-8 BL09XU



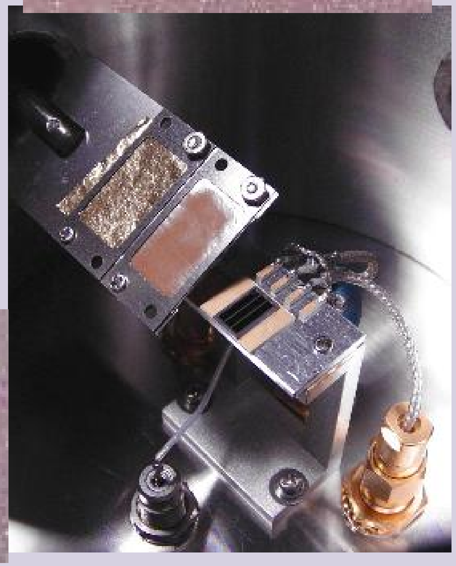
New devices for electron detection

Array : SPL2764

1x6 mm, 3 pixels (1.1-mm pitch), 30-μm depletion layer



To increase efficiency of electrons
Ω~10% (by double-sides setup) cf. 2% for 3mm dia.



Reverse structure : SPL3479 (under development)

A thin (< 5-μm) junction
to reduce the efficiency for elastic X-rays
at detection of low-energy electrons.

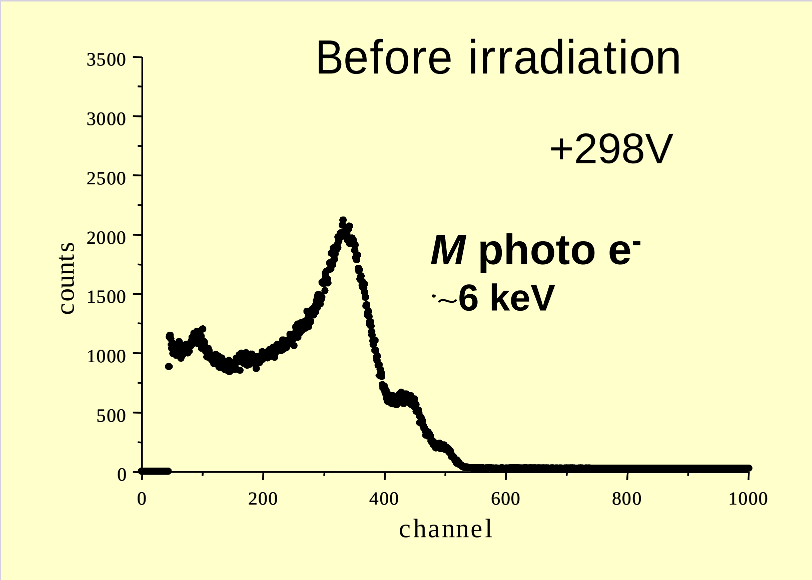
TO-8 mount

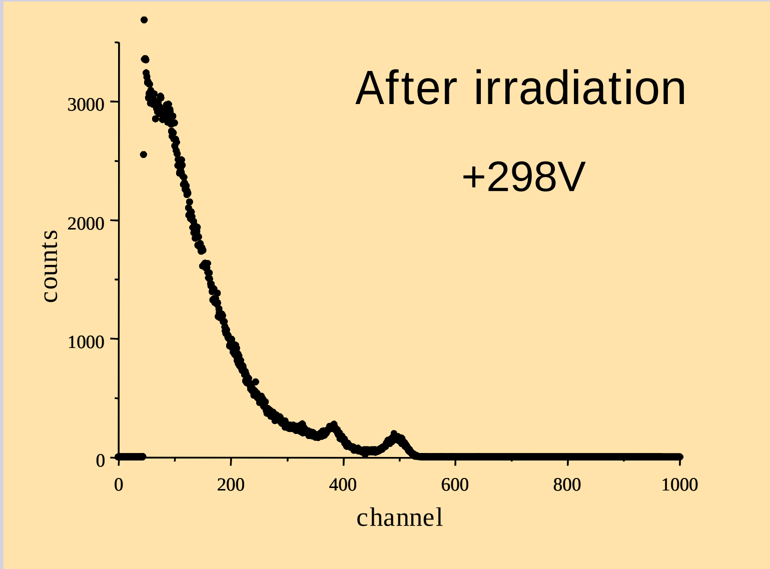
For Os-187 exp.,
7-keV Electron: λe~0.6 μm

In a 5-μm layer,
12-keV X-rays: ε ~2%
Cf. 30-μm dep. ε~12%

A dead layer is induced under a surface coating by intense irradiation of electrons. In detection of low-energy electrons (<10keV), this is a serious damage.

ex. 8.41-keV x-rays, Tm film(0.2μm) evaporated on Mylar, at injection of >10^{12} electrons (photo-e^-),





Due to Passivation of p^+ layer by hydrogen migration (under investigation)

To decrease the damage : a Si_3N_4 layer (15-25nm) is effective ?

4. For Future

In Nuclear excitation experiments by using SR-X rays,

Present

Width of X-ray pulses:.50-200ps.(FWHM)

Half-life of excited levels ($T_{1/2}$).order of nanosecond

...Res.-.^{40}K..4ns ..29.8keV.

...

. **Shorter Width of X-ray pulses** ..100fs-1ps

...$T_{1/2}$..extended to picosecond region

....ex. Res.-.^{155}Gd..193ps..60.0keV.

Wider energy region : >30keV

What should we do to improve the detectors ?

To improve the time response,

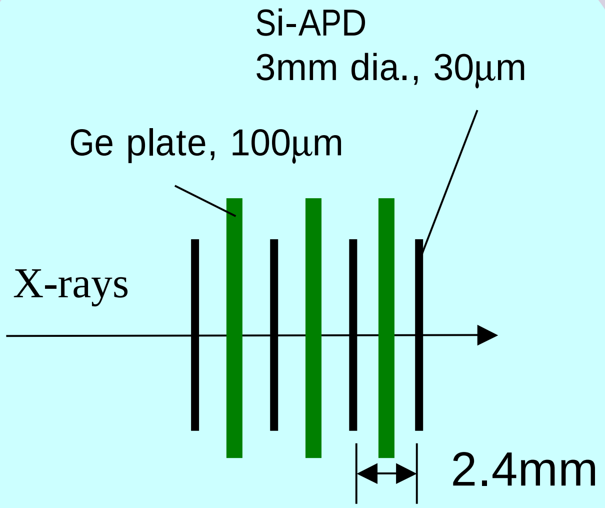
a thin Si-APD is useful

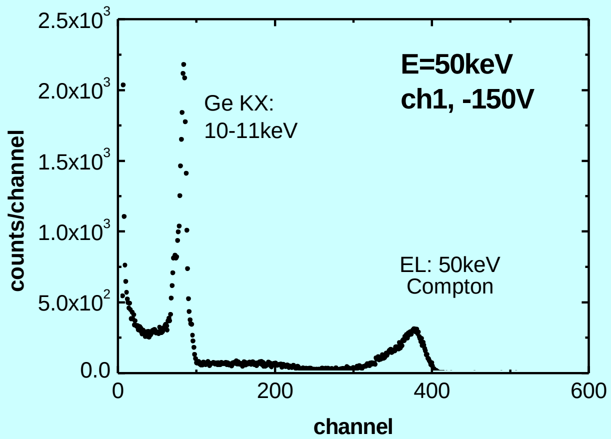
ΔT of several 0-ps will be possible with S8660 or S534X type
But, ΔT=šps is not possible by APD.

To improve the intrinsic efficiency for a high-energy photon (>30 keV),

1. Effective Use of Si-APD

Stack or grazing incidence
Detection of Secondary X-rays





eá4.8% at 50 keV
cf. ‹ Sum of four Si-APDs: ε=1.2%

2. A heavier-element APD or PD

APD: GaAs, InGaAs, Ge ?   PD: CdTe ?

3. Use of a fast Scintillator

ex. ps-decay emission of free-exciton recombination
in a direct bandgap semiconductor

5. Conclusions

1. Si-APD for NRS

Si-APD devices have been improved for NRS experiments.
Time response: cutting a long “tail” by changing the device structure
Efficiency: transmission-type APDs

2. In NRS or other nuclear excitation experiments,
Si-APDs will still be playing an important role.
faster response : several 10-ps time resolution is possible.
more efficiency at higher energies: stack or grazing incidence
Array devices: tile-arrangement or monolithic device
electron detection: high count-rate with a sub-ns ΔT

Si-APD has a flexibility in size and in structure to be designed.
but expensive ! : a new batch costs $ 20K-100K.

3. To step up for future, a break-through may be needed
in a detector.

An APD detector of Not silicon?
A detector of Not APD?

We need more efforts and more researchers for detector development !