Beam study of ATLAS-SCT module prototypes

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Due to the binary nature of ATLAS SCT readout electronics, statistical methods have to be applied to reconstruct the pulse shape of the front end shaper/amplifier from threshold scan data in a beam test. A formalism has been developed and applied to data obtained in a test beam at KEK. The results from 6 SCT module prototypes, two of which had previously been irradiated, will be compared to a simulation of the detector and the ABCD shaper/amplifier.

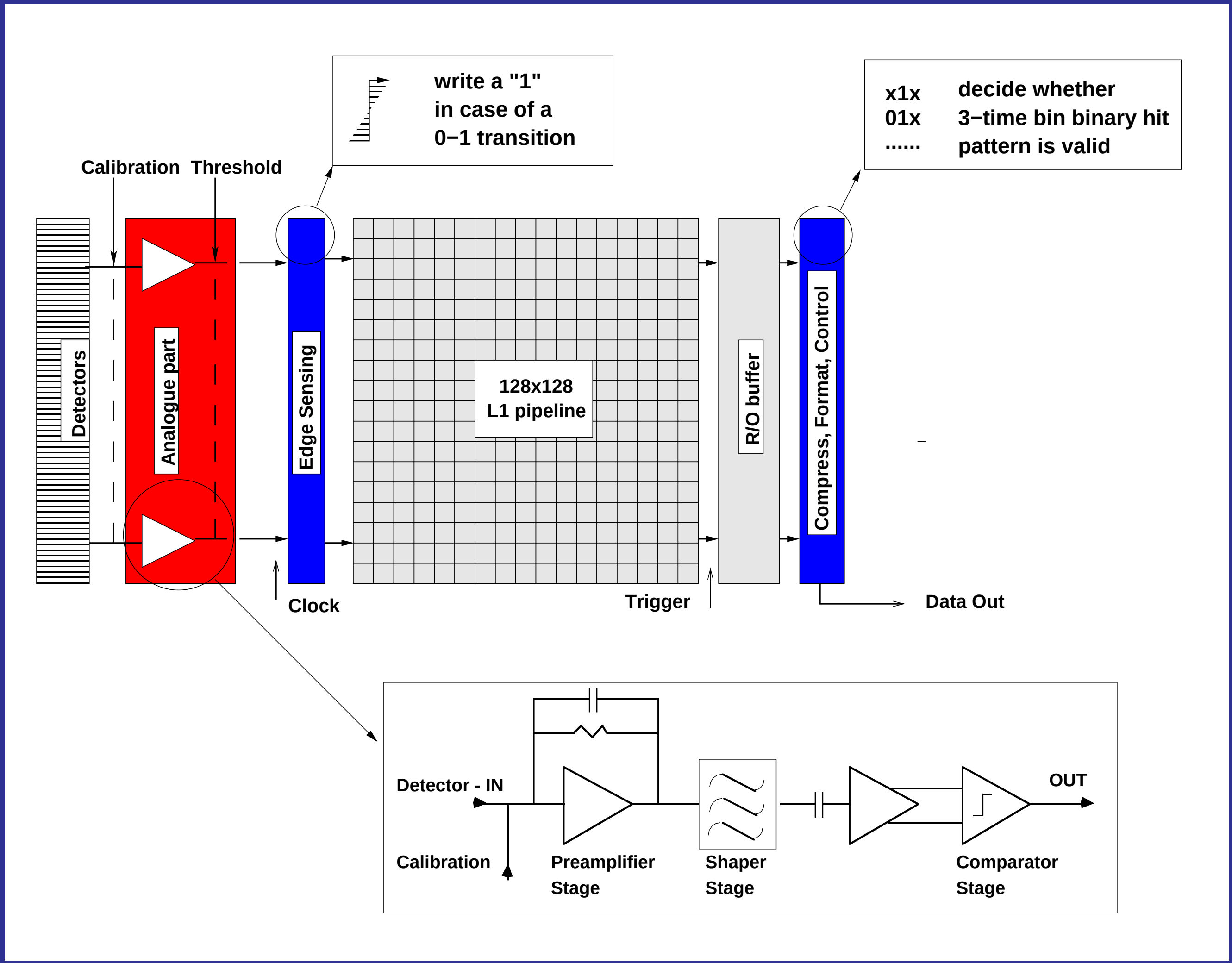
SCT binary electronics

- The baseline front end electronics for the ATLAS semiconductor tracker is the binary ABCD chip.
- After a fast ($< 23ns$) shaper-amplifier stage, the signal is discriminated. The (0/1) result is stored in a digital pipeline during the trigger latency.
- For each channel: at a LVL1 trigger write three bits - representing the comparator output for three beam crossings centred on the LVL1 trigger time - into the output buffer.

$$\boxed{... < 01 >< aaaa >< ccc, cccc >< 1 >< ddd > ...}$$

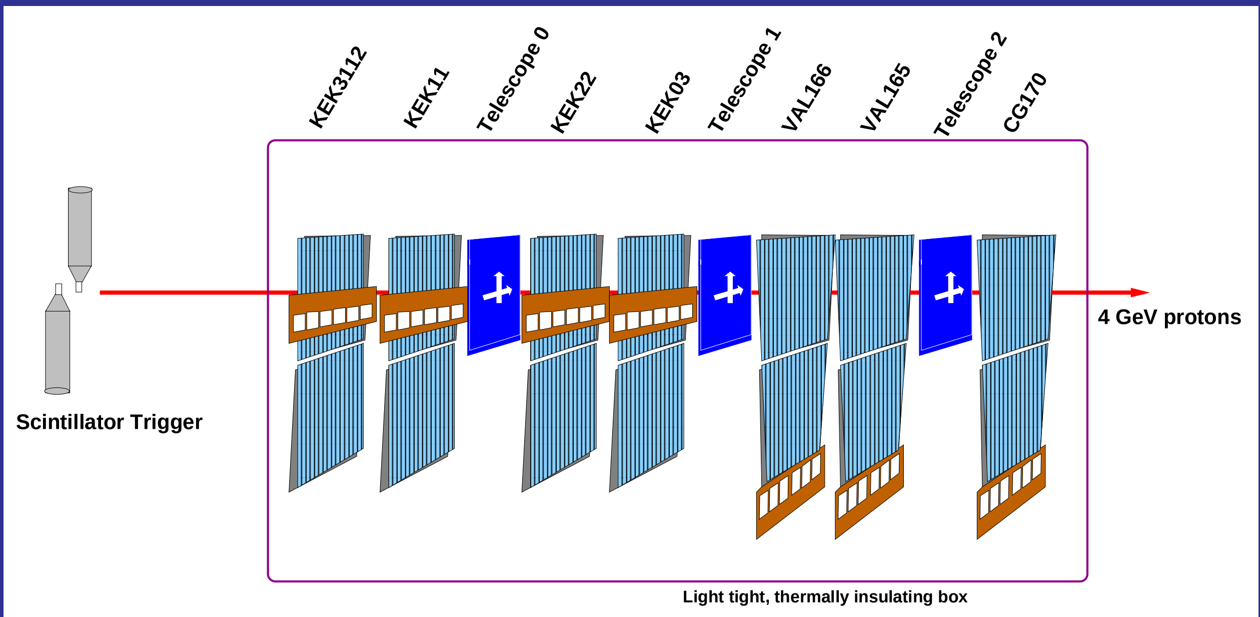
- The hit pattern of a channel is communicated to a VME unit if it satisfies the compression criterium (here: $1XX|X1X|XX1$)

SCT binary electronics



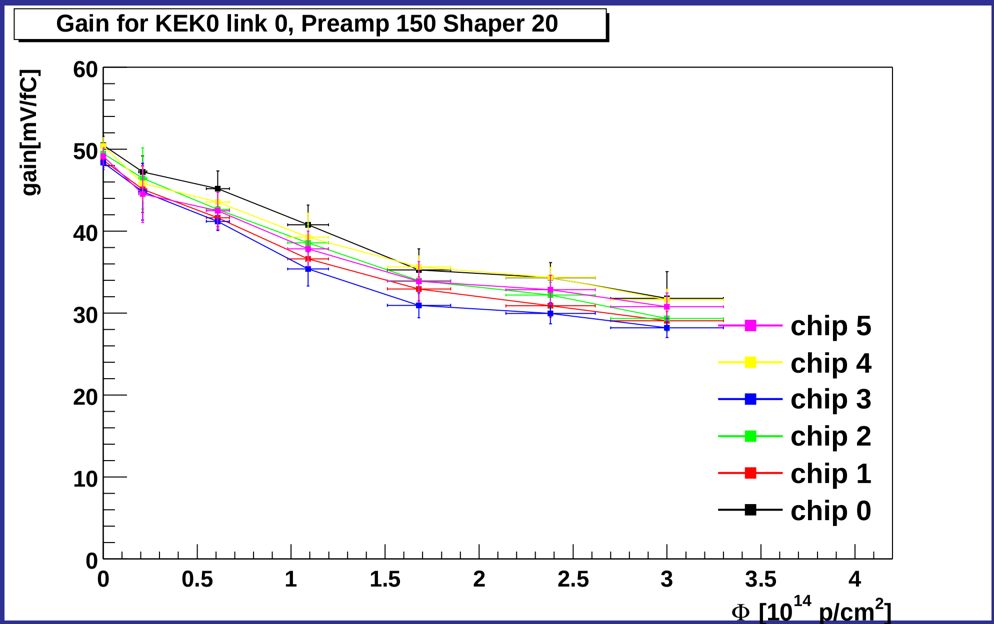
Test Beam Setup

- 4 GeV pions beam ($\pi 2$ at KEK-PS)
- Scintillator trigger $\rightarrow$ time measurement
- Beam telescope of 3 pairs of Silicon Strip Detectors with analog readout
- 3 barrel and 3 forward modules
- VAL166 and K03 irradiated to 3×10^{14} 24 GeV protons$/cm^2$ in the PS

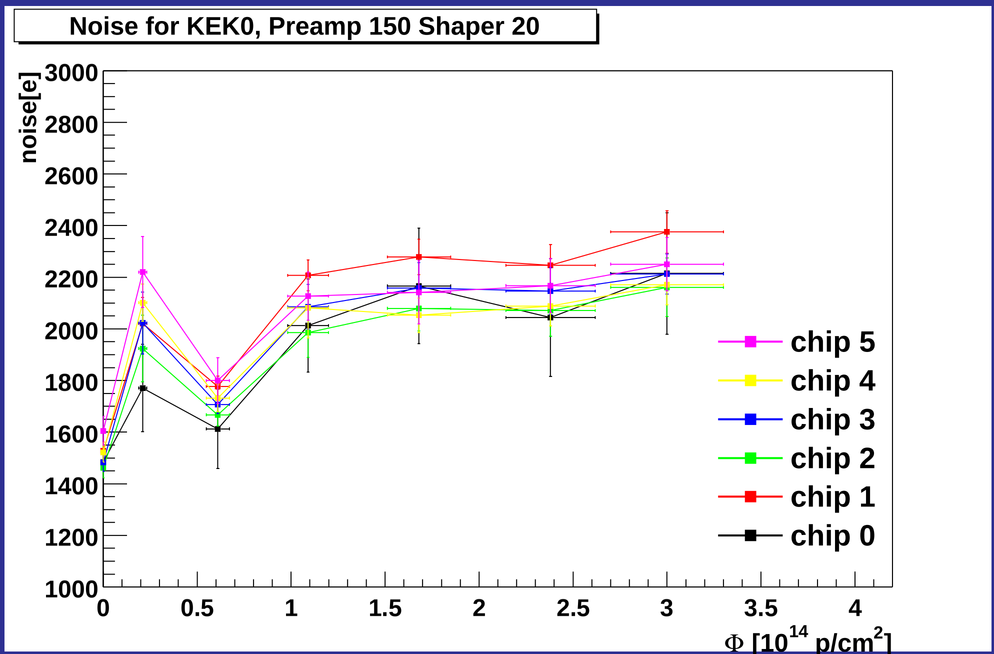


Schematic setup of the beam test at the KEK $\pi 2$ beam line in December 2000.

Irradiation: evolution of chip parameters

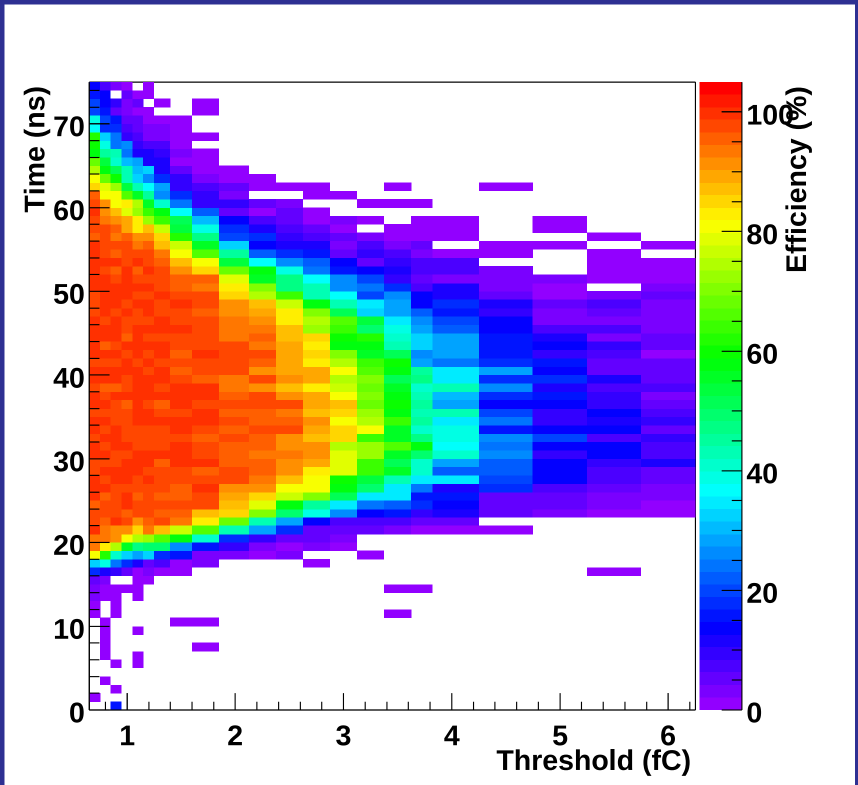


Amplifier gain.



Equivalent Noise Charge.

Pulse Shape Reconstruction



Efficiency as a function of threshold and time. Hit information from three time bins has been combined to form a 75 ns range.

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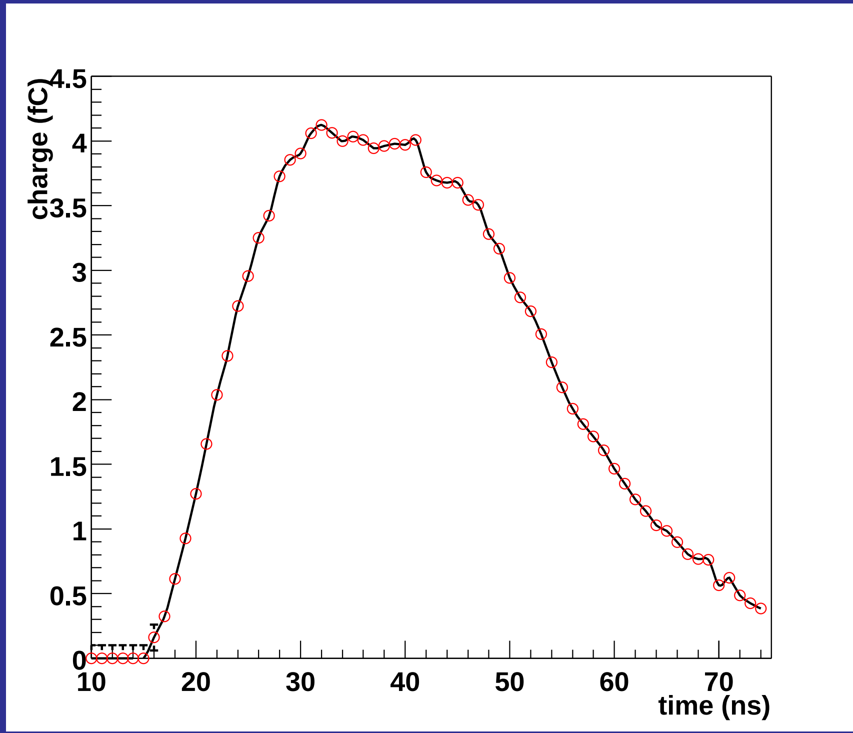


The median charge of each time slice is found by fitting the 50 % efficiency points.

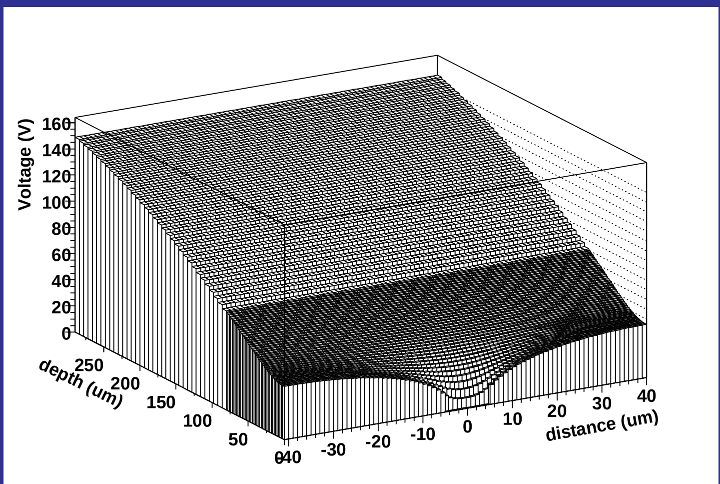
Simulation

An algorithm developed by Leslie, Seiden and Unno [*SCIPP 92/61*] is used to simulate the Signal in the silicon strip detector. Given the Silicon dimensions and the bias and depletion voltage, it determines the field strength on a two dimensional mesh solving Poisson's equation.

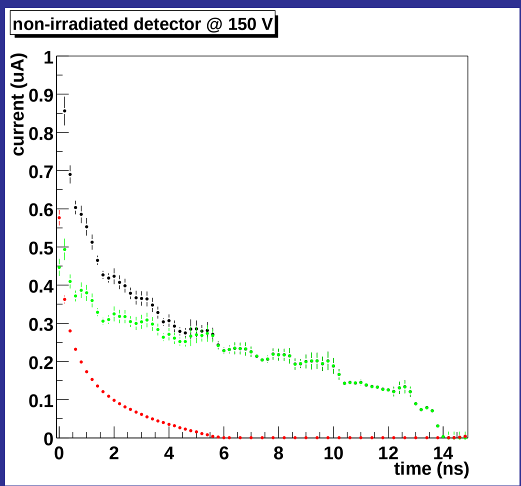
Free carriers are created according to [*G. Hall, Ionisation energy losses of highly relativistic charged particles in thin silicon layers. Nucl. Instr. Methods 220, 1984(pp. 356)*] and drifted through the field [*R. Muller and T. Kamins, Device Electronics for Integrated Circuits, Wiley, 1986(pp. 32-37)*]

Moving carriers of both types induce a current on the strip. Induction is simulated by means of a weighting field, found by solving the Laplace equation.

The signal on the strip is convoluted with the shaper/amplifier response function ($CR(RC)^3$ shaper with an extra differentiation step).

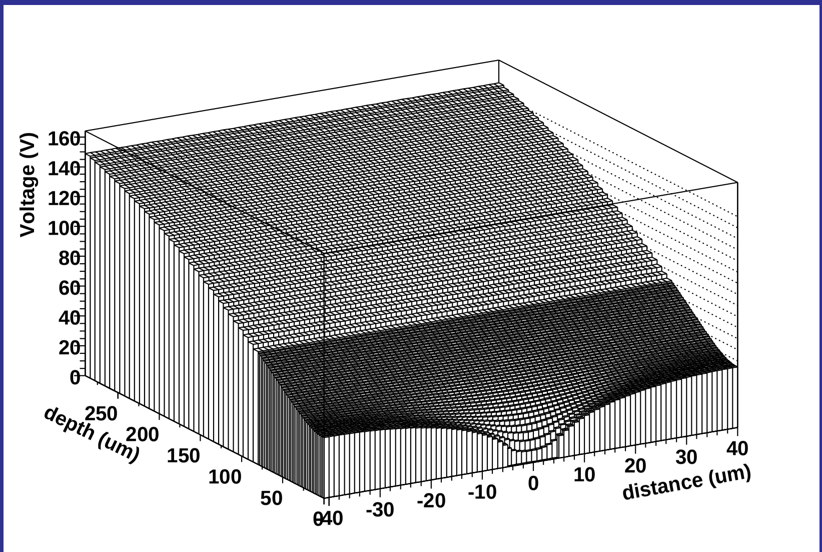


Voltage through the Silicon



Detector signal

Simulation: field maps

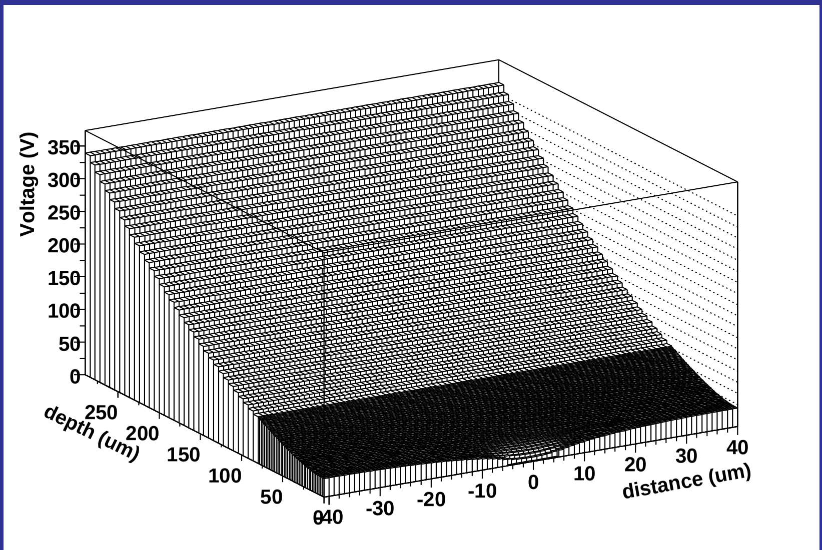


non-irradiated

detector

$V_{bias} = 150V$

$V_{dep} = 65V$



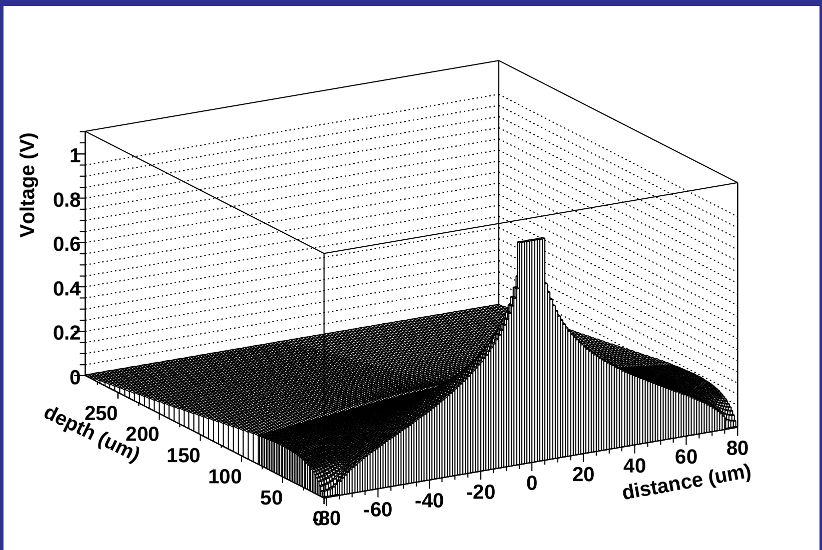
irradiated

(type-inverted)

detector

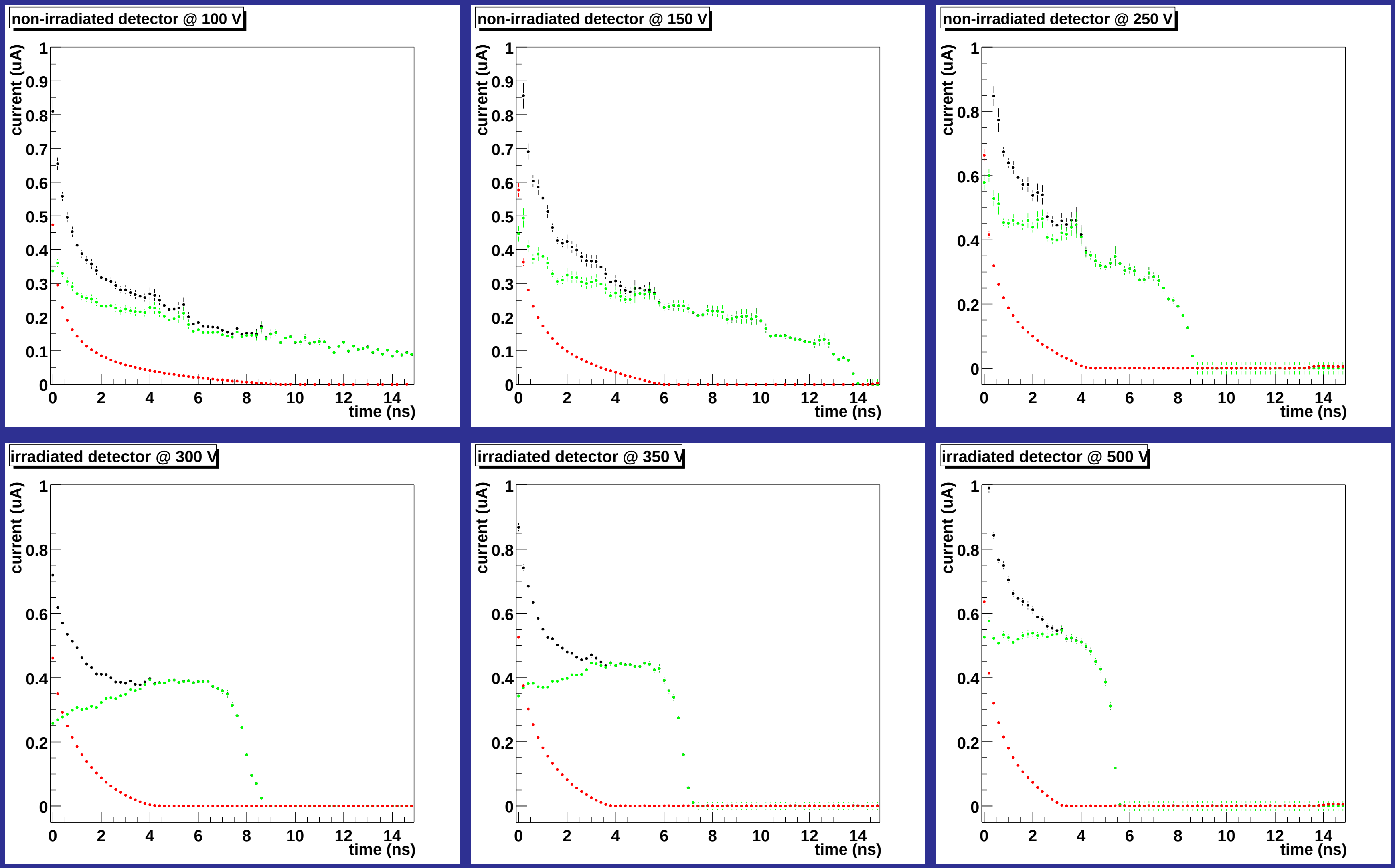
$V_{bias} = 350V$

$V_{dep} = 250V$

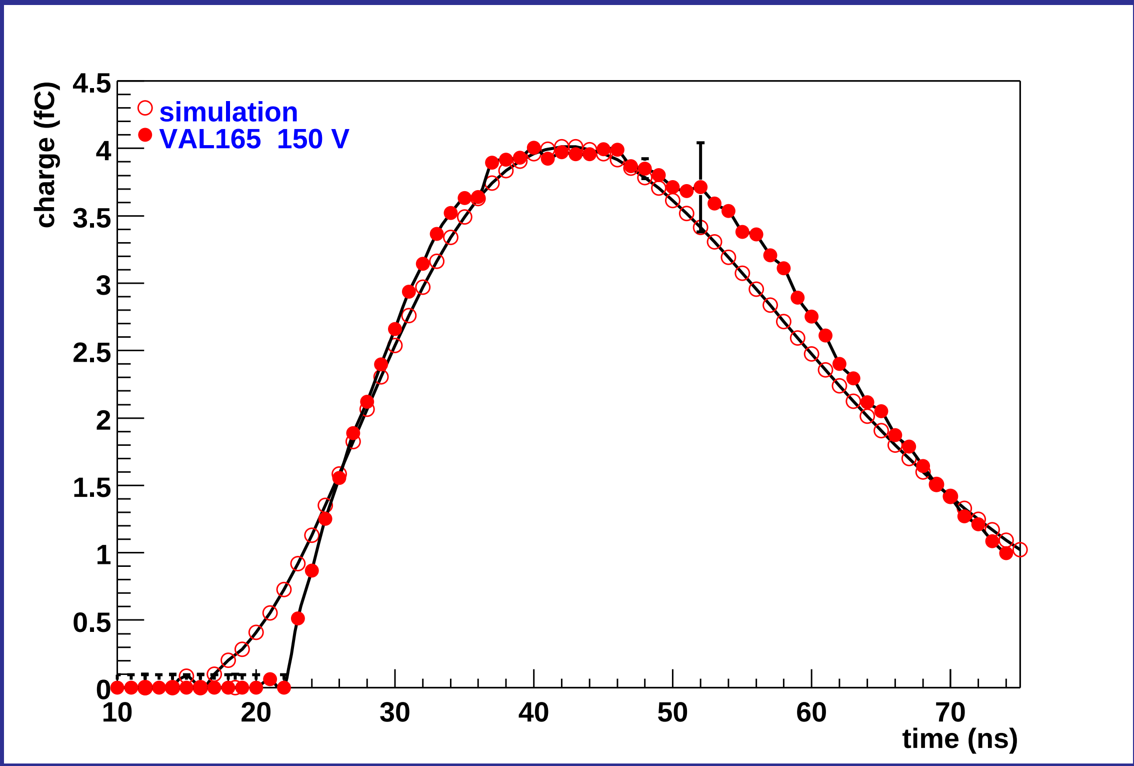


Weighting field

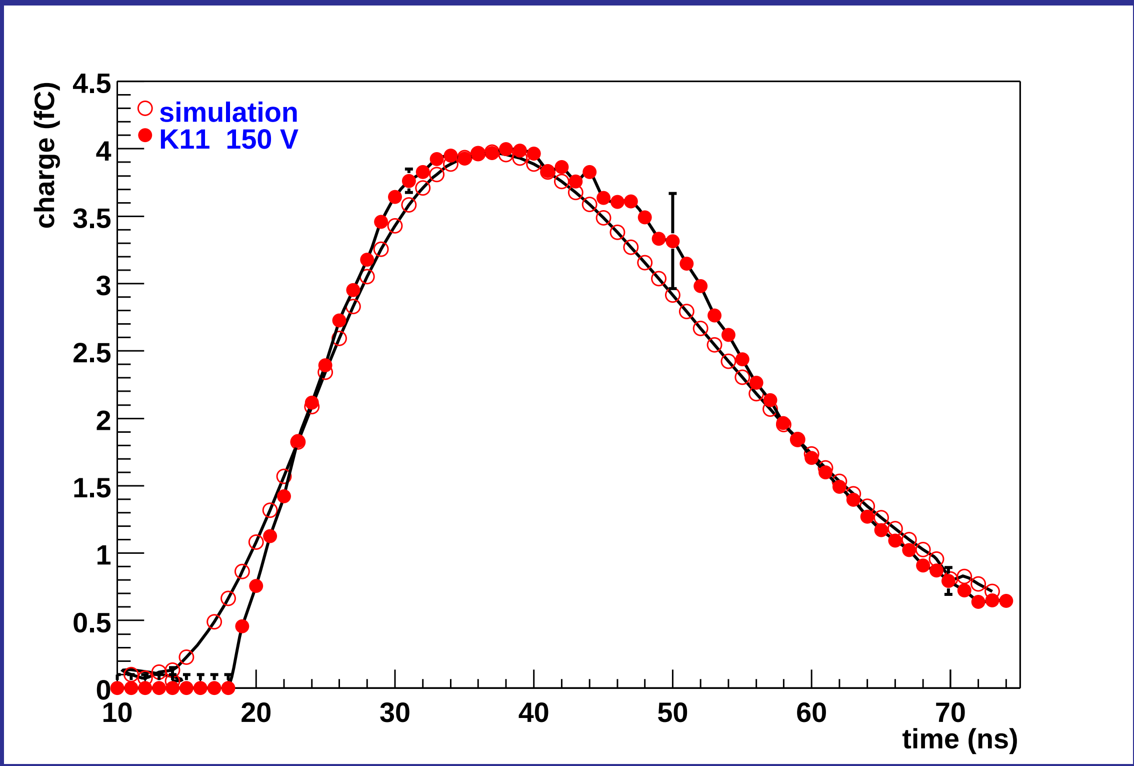
Simulation: detector signal



Results: non-irradiated modules

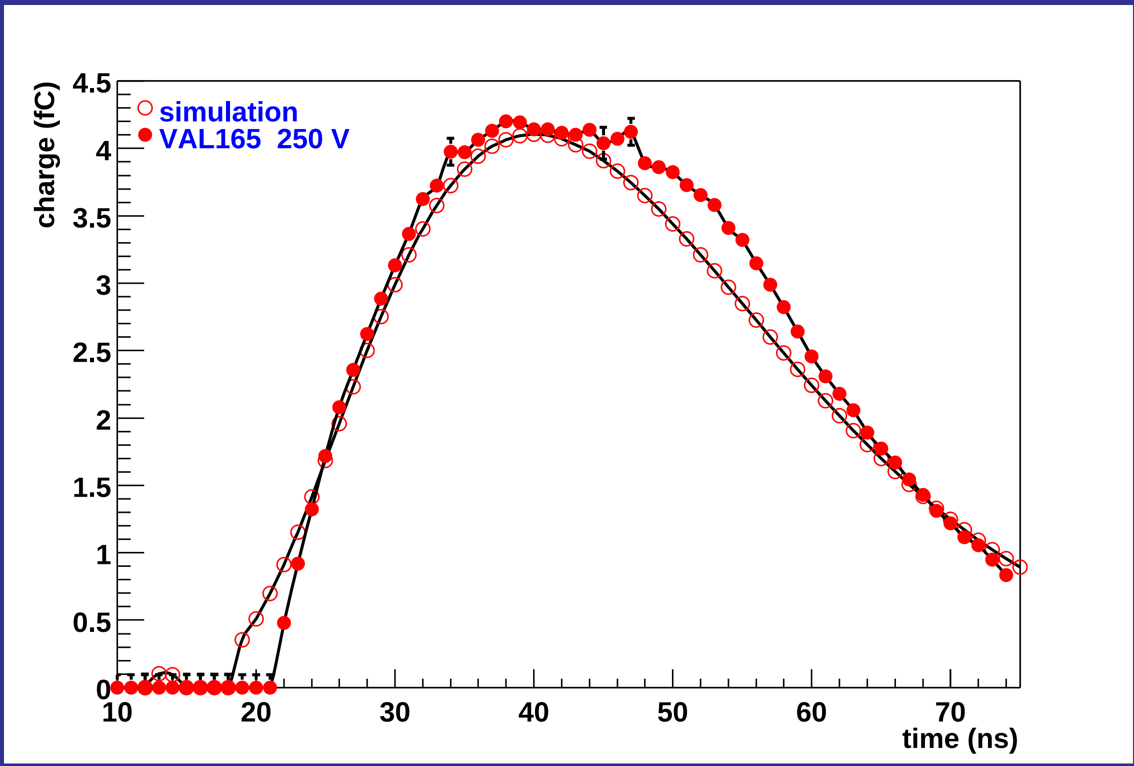


Forward module (VAL165) at 150 V. Simulation: $\tau = 24$ ns.

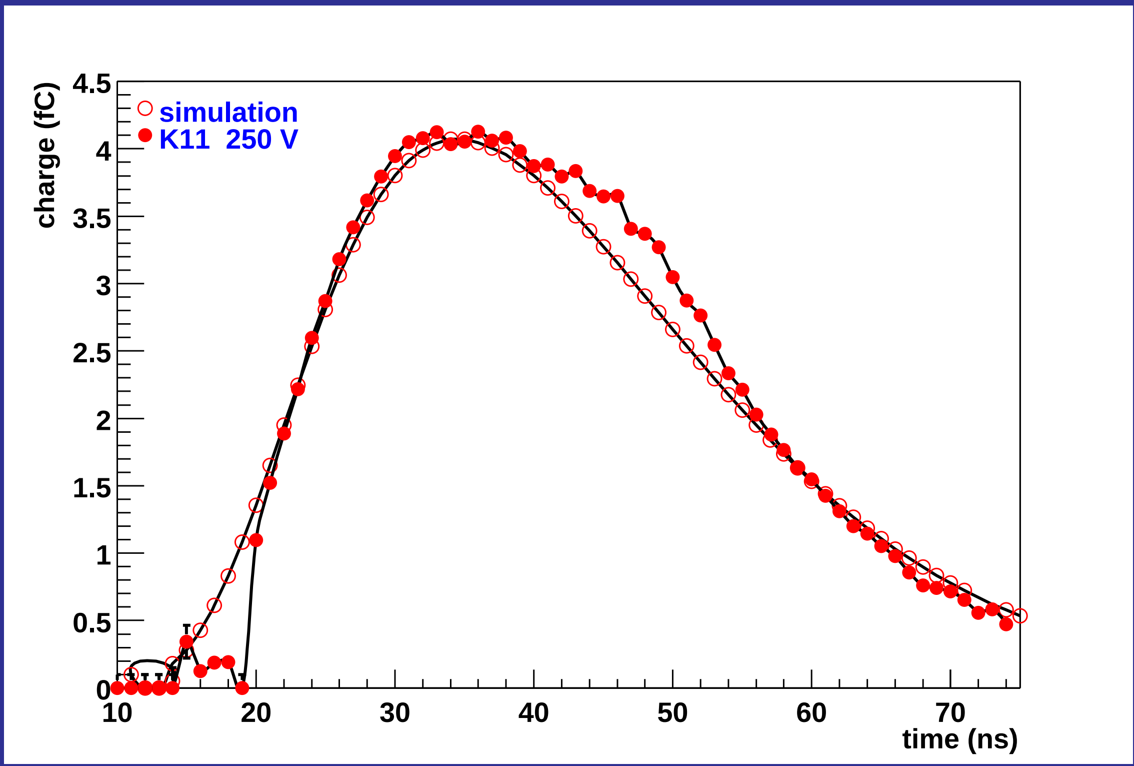


Barrel module (K11) at 150 V. Simulation: $\tau = 22$ ns.

Results: non-irradiated modules

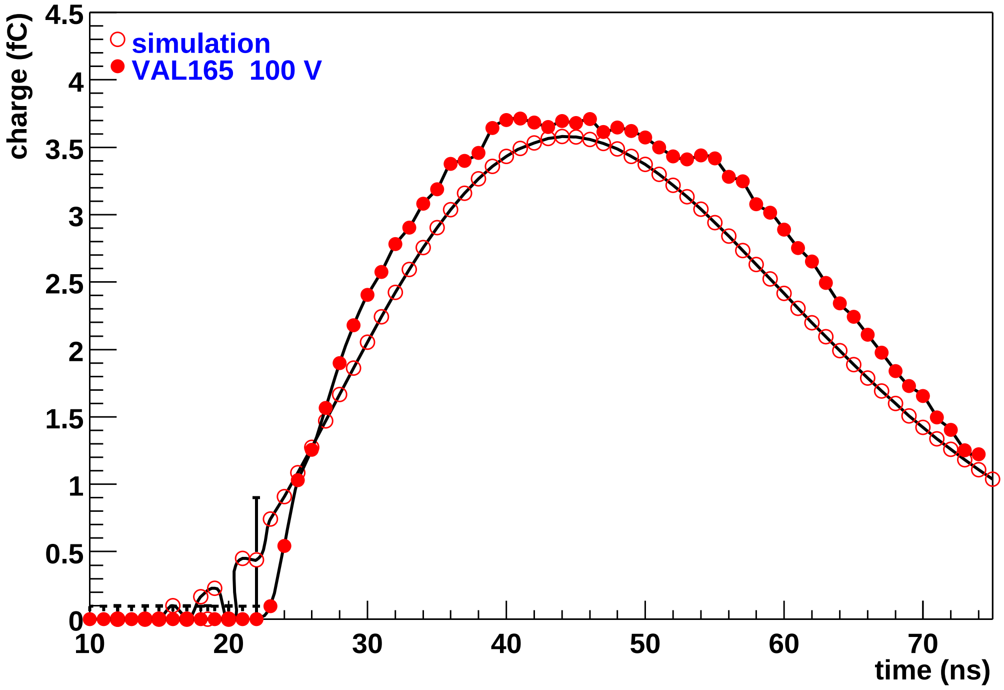


Forward module (VAL165) at 250 V. Simulation: τ = 24 ns.

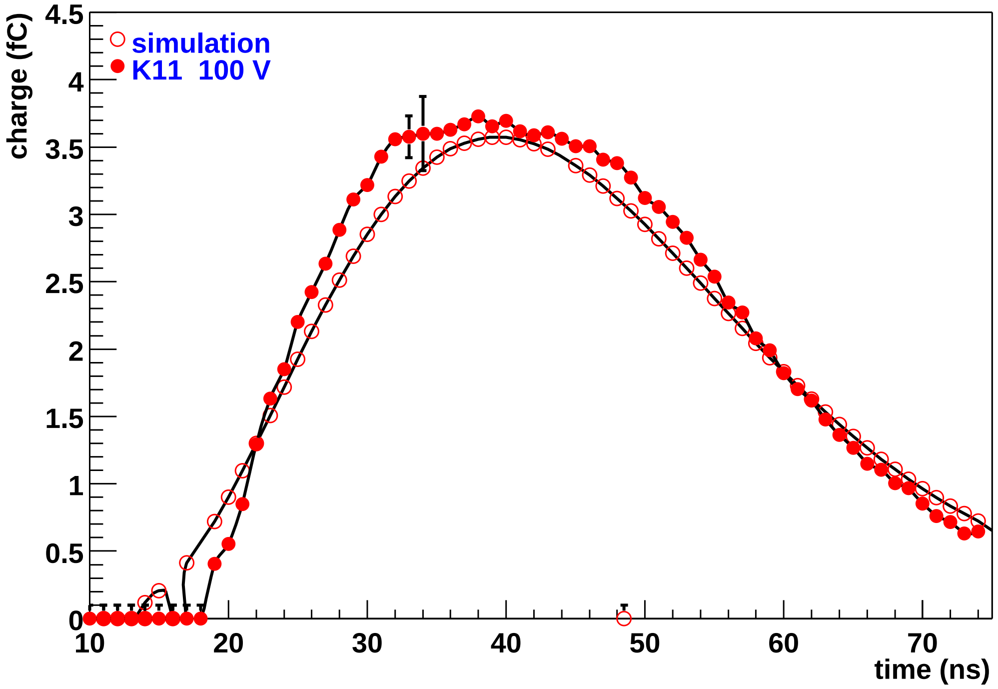


Barrel module (K11) at 250 V. Simulation: τ = 22 ns.

Results: non-irradiated modules

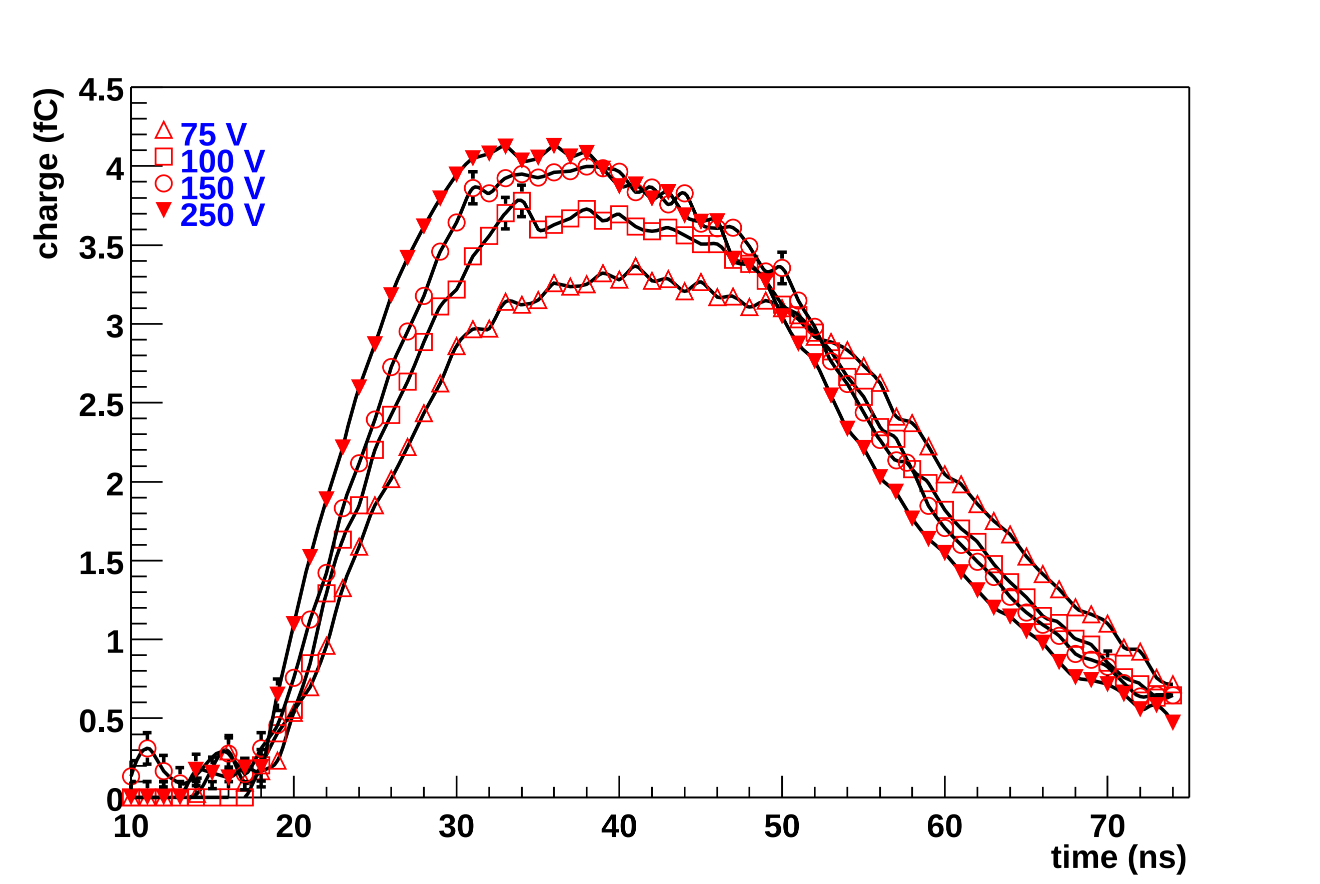


Forward module (VAL165) at 100 V. Simulation: $\tau = 24$ ns.



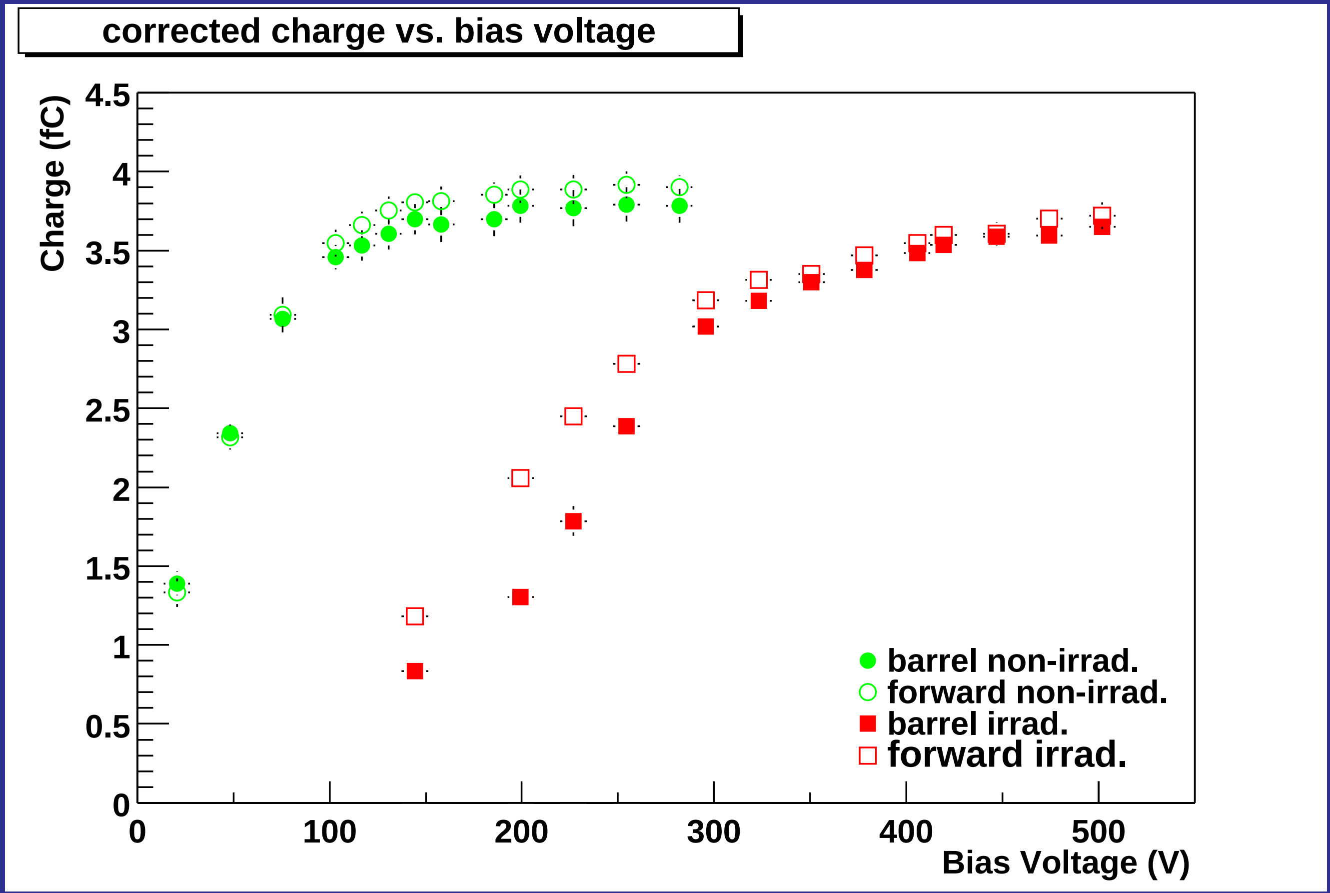
Barrel module (K11) at 100 V. Simulation: $\tau = 22$ ns.

Results: non-irradiated modules



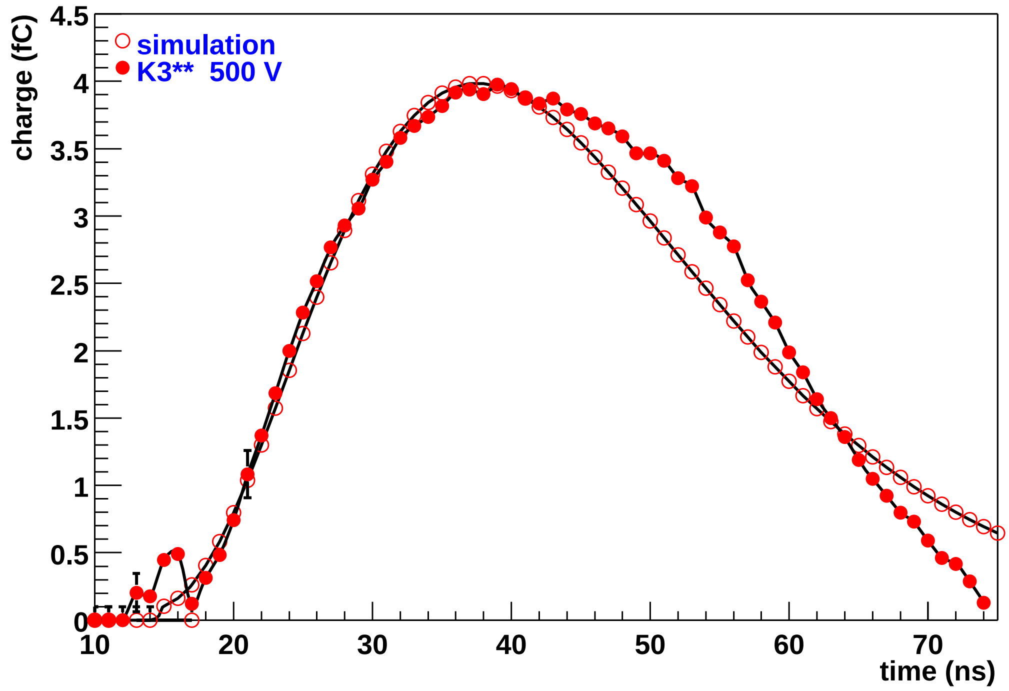
Non-irradiated barrel module (K11)

Results: irradiated modules

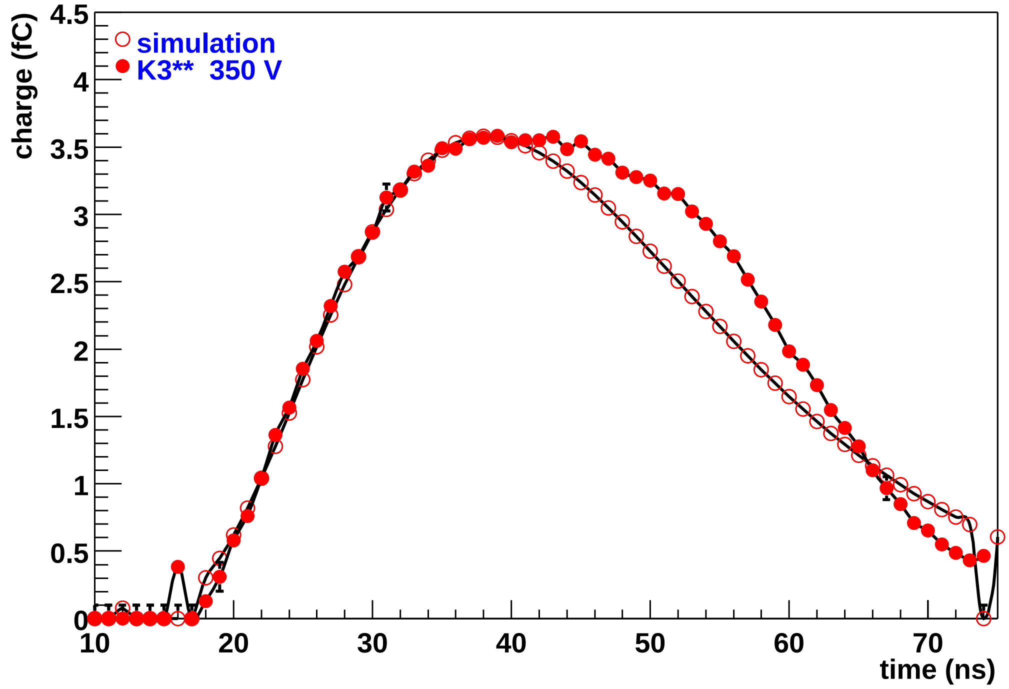


PRELIMINARY Median charge dependence on detector bias voltage

Results: irradiated modules

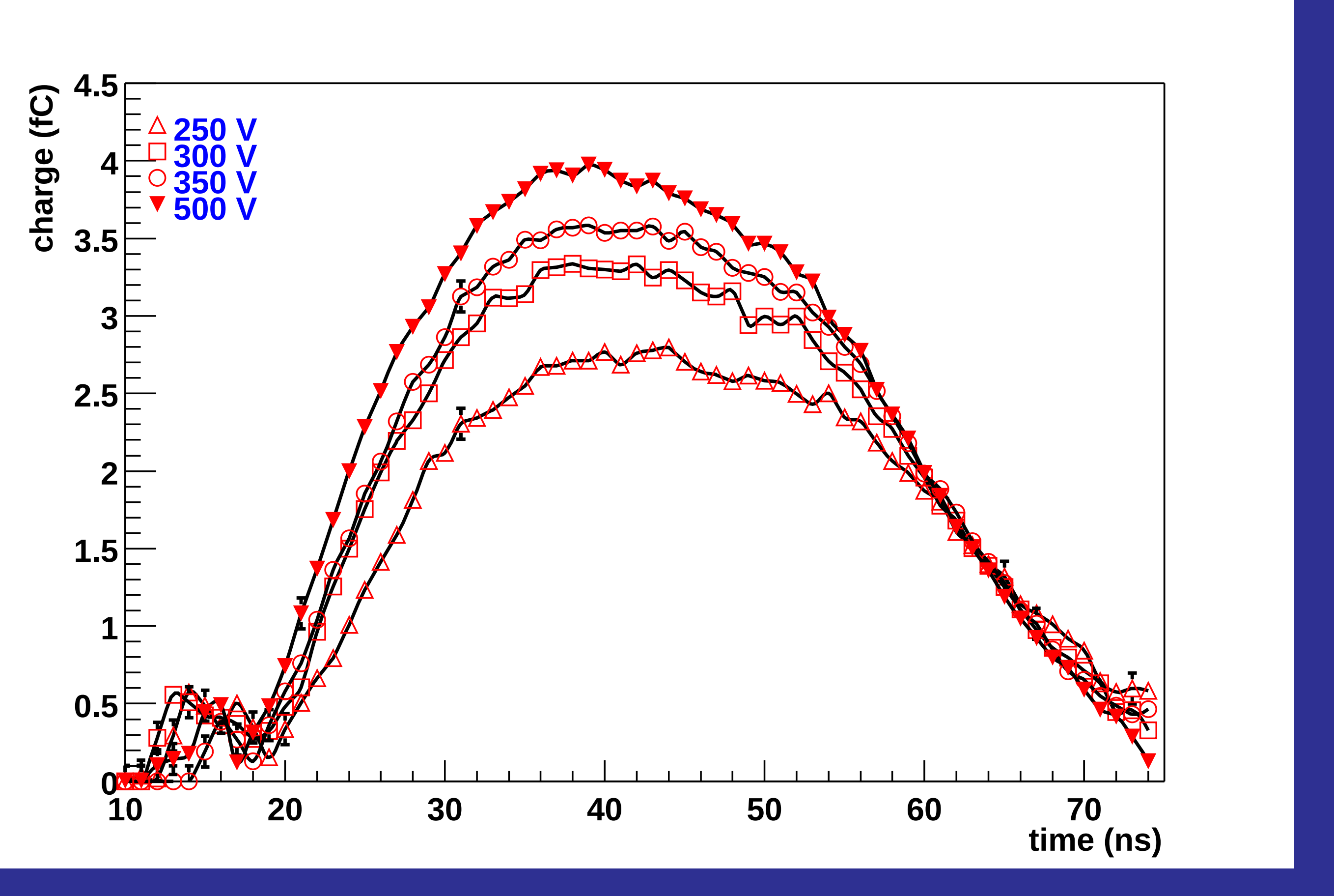


Irradiated barrel (K3) at 500 V. Simulation: $\tau = 24$ ns.



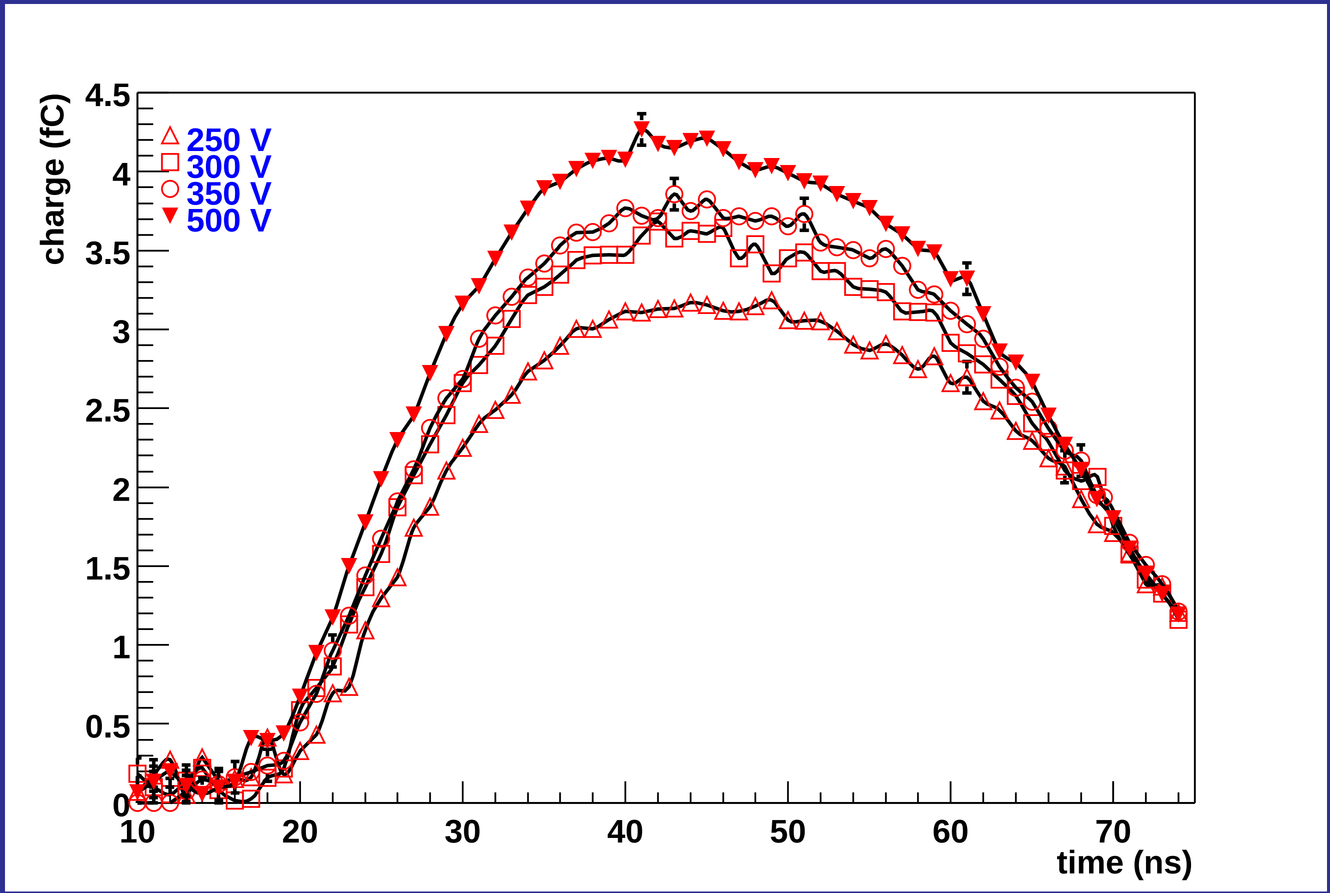
Irradiated barrel module (K3) at 350 V. Simulation: $\tau = 24$ ns.

Results: irradiated modules



Irradiated barrel module (K3)

Results: irradiated modules



Irradiated forward module (VAL166)

Conclusions

- The dependence of the pulse height and shape on detector bias voltage in non-irradiated modules is described reasonably well by simulation throughout the measured bias voltage range (25 to 275 Volts)
- Non-irradiated modules of the same type have very similar pulses. Forward modules are consistently slower ($\tau_{BAR} \sim 22ns$, $\tau_{FWD} \sim 24ns$).
- The shaper pulse in non-irradiated modules hardly changes between 150 and 275 Volts. At still lower voltages the pulse is stretched due to ballistic deficit of the shaper.
- The pulse shape in non-irradiated modules varies smoothly with bias voltage down to $\sim$ 300 Volts.
- In the irradiated modules the overall pulse length has increased, even though the rising edge is quite similar to the non-irradiated modules. The simulation does not reproduce this effect.
- The increase in pulse length is much more severe in VAL166 than in K3.