Radiation hardness study of the Philips Digital Photon Counter with proton beam

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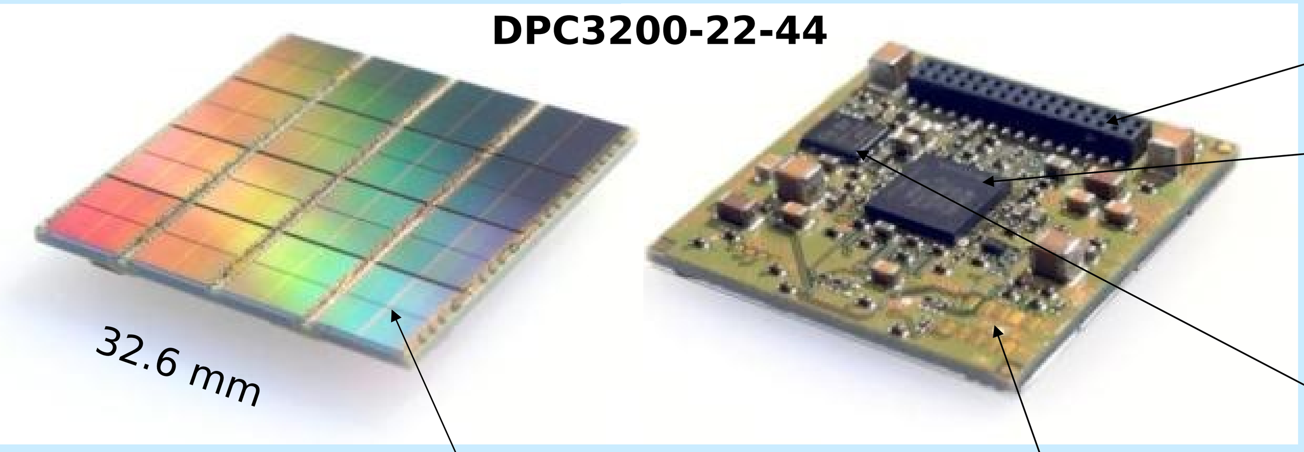
Philips Digital Photon Counter



Connector

FPGA
- Clock distribution
- Data collection/concentration
- TDC linearization
- Saturation correction
- Skew correction

SPI Flash
- FPGA firmware
- Configuration
- Inhibit memory maps

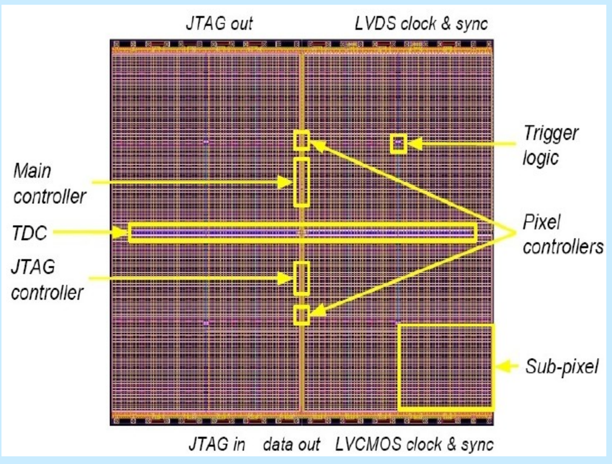
4x4 dies

Temp. sensors

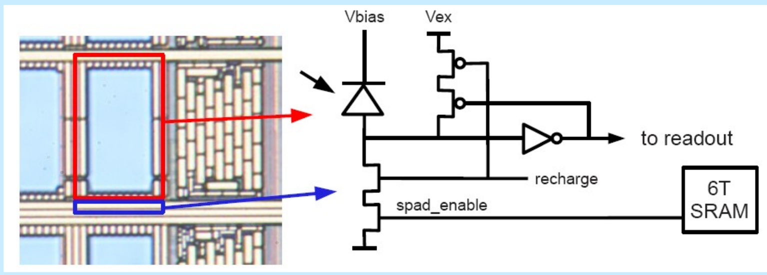
Single die

Die
- 2x2 pixels
- TDC (20 ps LSB)
- Logic

Pixel
- 2x2 subpixels
- 3200 cells (Geiger-mode APDs)
- Photon counter



Single cell



- Active quenching
- Digital output
- Cell can be disabled

Main advantages:
- integrated digitization and readout
- reduced dark counting rate due to inhibition of noisy cells
- time resolution ~50 ps for single detected photon

Possible applications:
- Aerogel RICH detector for forward spectrometer of PANDA experiment at FAIR
- Aerogel RICH detector for experiment at Super Charm-Tau factory (BINP's project)

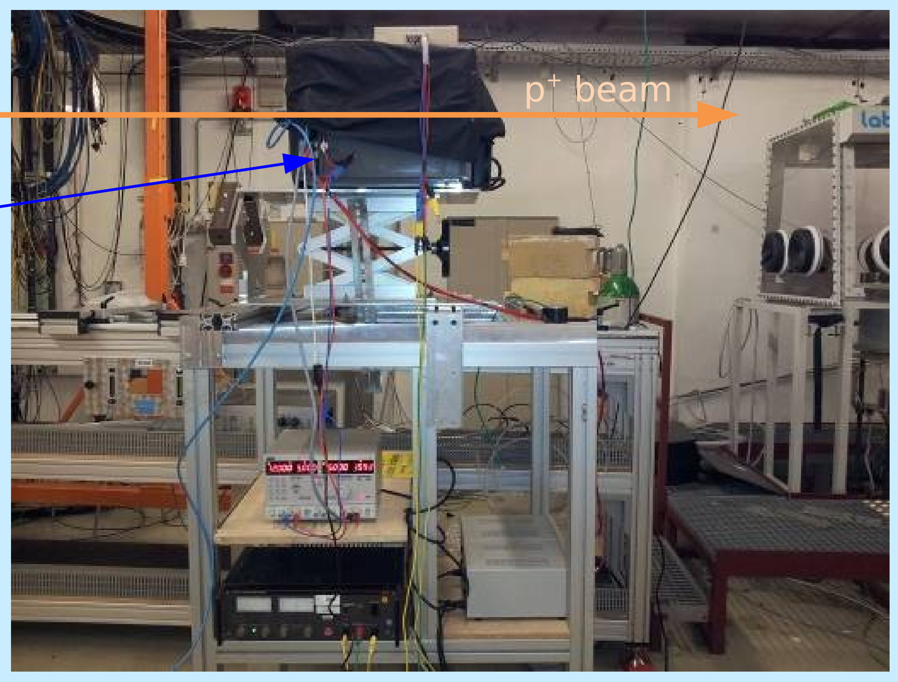
Test setup

Proton beam extracted from COSY
IKP, Forschungszentrum Jülich (Germany)

Proton beam
- P=800 MeV/c (T=295 MeV)
- Beam size ~15 mm
- Intensity up to $2\cdot10^7$ s^{-1}

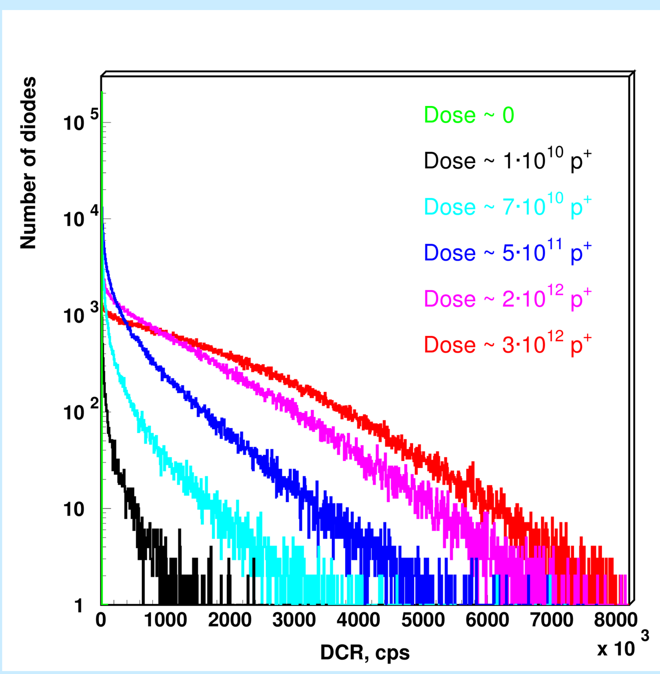
Test box
- Two DPC3200-22-44 tiles
- Philips Technology Evaluation Kit for readout
- Tiles were cooled down to -15..-20°C by Peltier elements

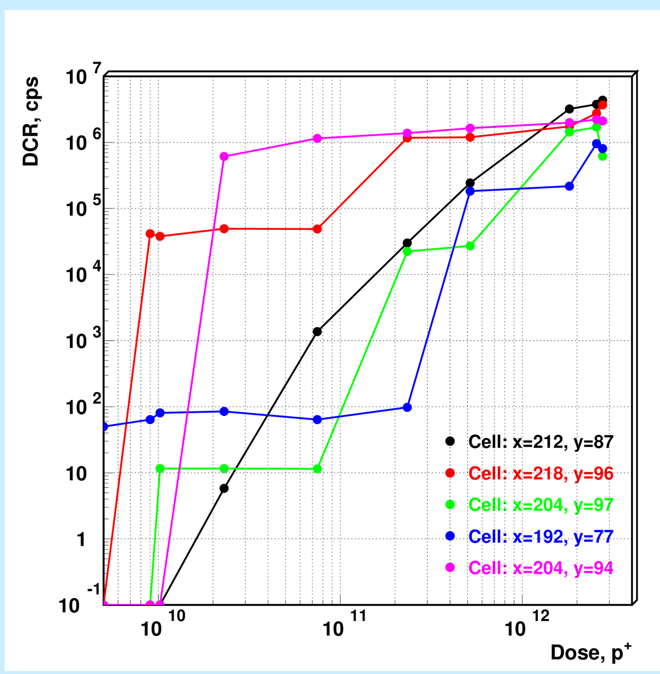
Beam diagnostics
- Ionization chambers for total dose measurement



Dark counting rate vs. total dose

DCR spectra after different total doses accumulation



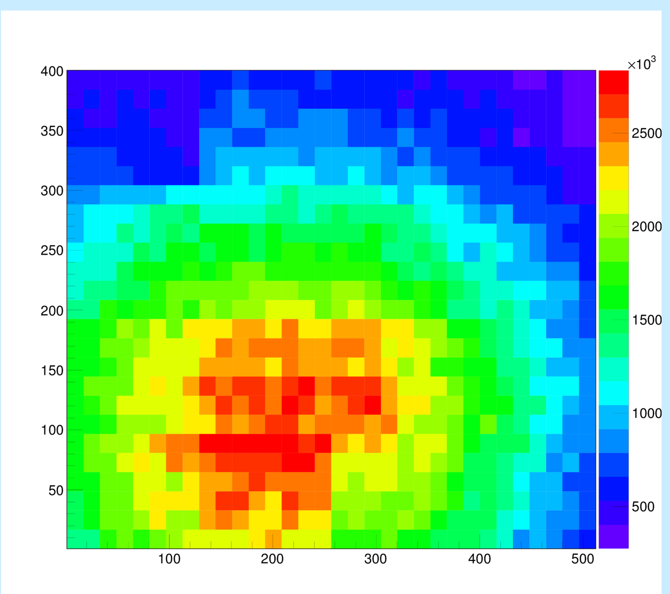


DCR of single cells from one subpixel as a function of total dose

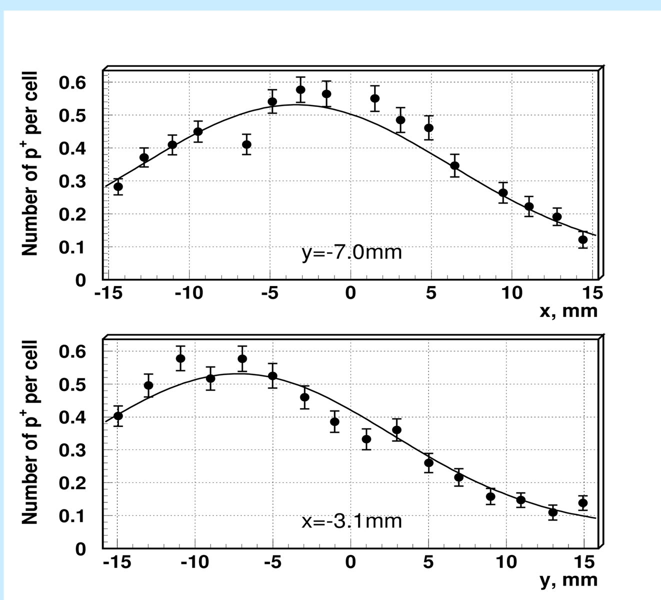
With the dose accumulation the number of noisy cells increases rather than DCR of each cell. ⇒ Cell damage caused by single interaction of p^+ with Si lattice.

Beam profile

evaluated from the fraction of damaged cells per subpixel (32x25 cells)

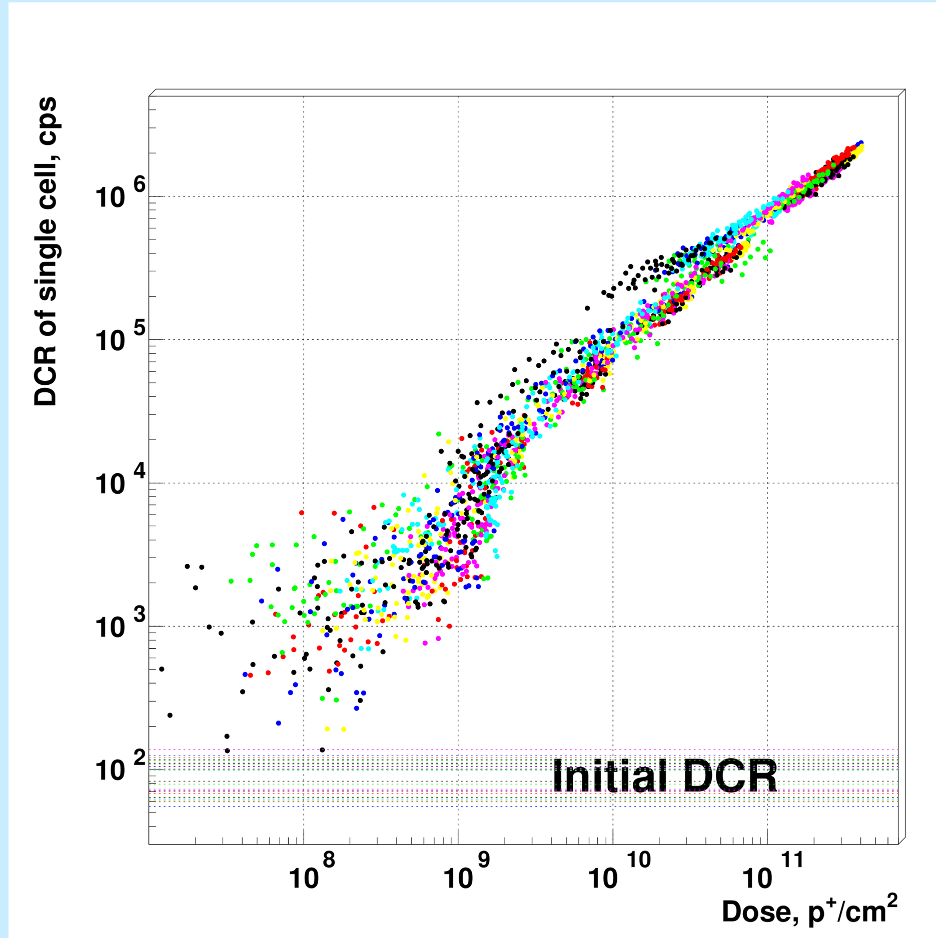


Map of dark counting rate (DCR) after full dose accumulation



Gaussian fit of beam profile

Dark counting rate vs. fluence



Each point indicates single cell DCR averaged over one subpixel (32x25 cells). Different colors for different dies.

Maximum fluence of 295 MeV protons is ~4×10^{11} cm^{-2}.

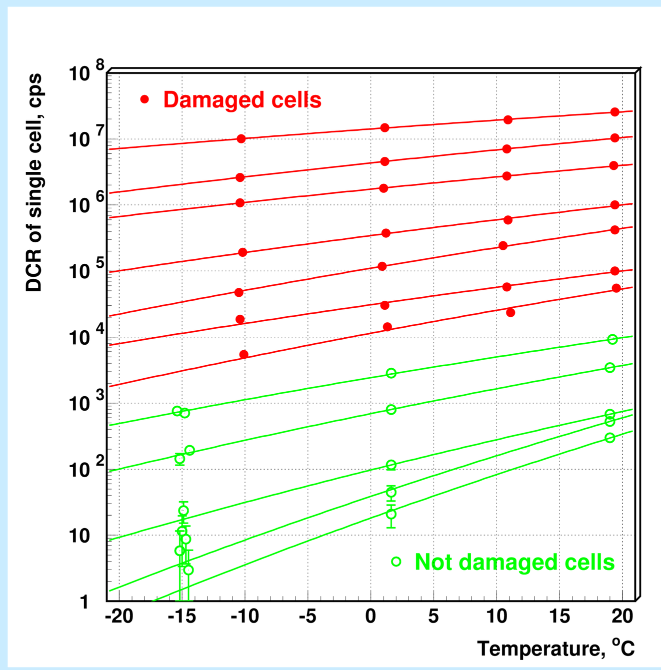
Equivalent fluence of 1 MeV neutrons scaled by NIEL in silicon is ~3×10^{11} cm^{-2}.

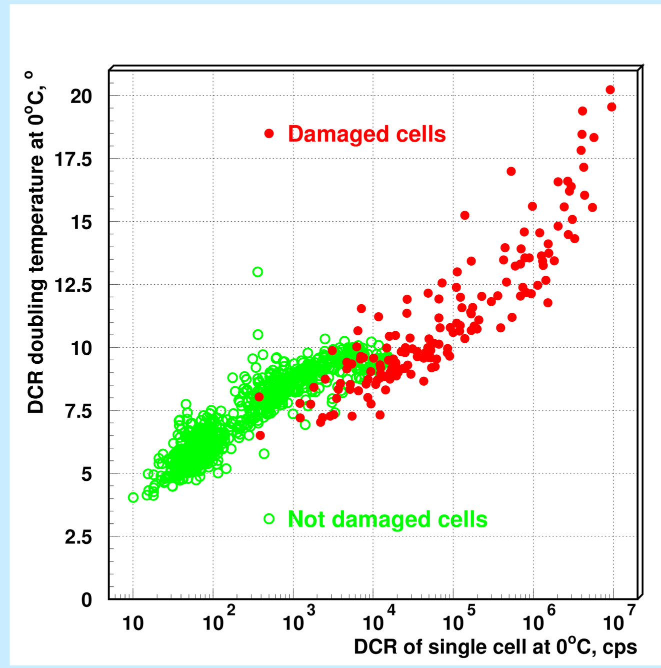
Attempt of annealing after full dose accumulation:
7.5 hours at +45°C ⇒ 1.7 times DCR decrease

Dark counting rate vs. temperature

DCR as a function of temperature.

Approximated by $AT^2\exp(-\alpha/T)$





Temperature corresponding to DCR doubling versus DCR at T=0°C

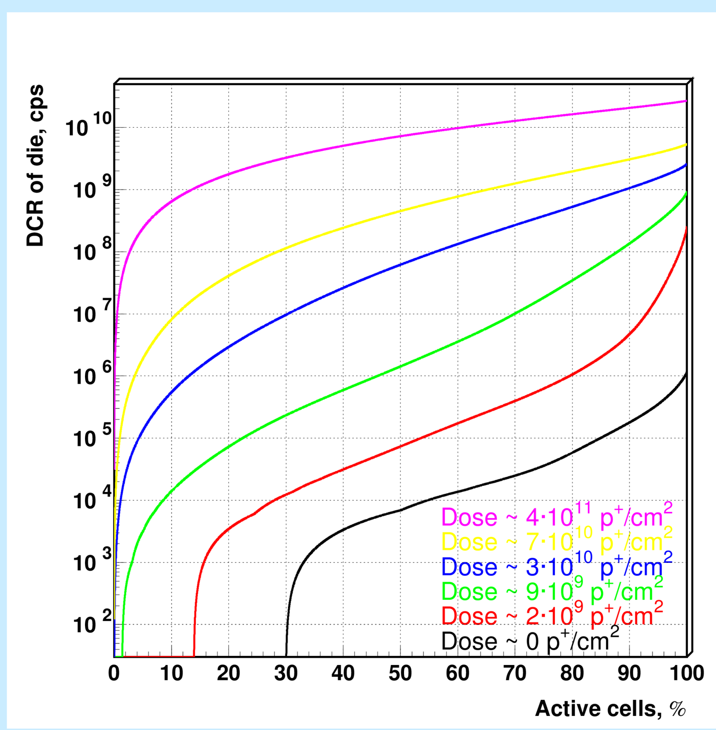
Temperature coefficient depends on the level of dark counting rate.
The higher DCR the less sensetive it to the temperature variation.
⇒ Reduction of DCR by cooling down is less efficient after irradiation.

Single event effect probability

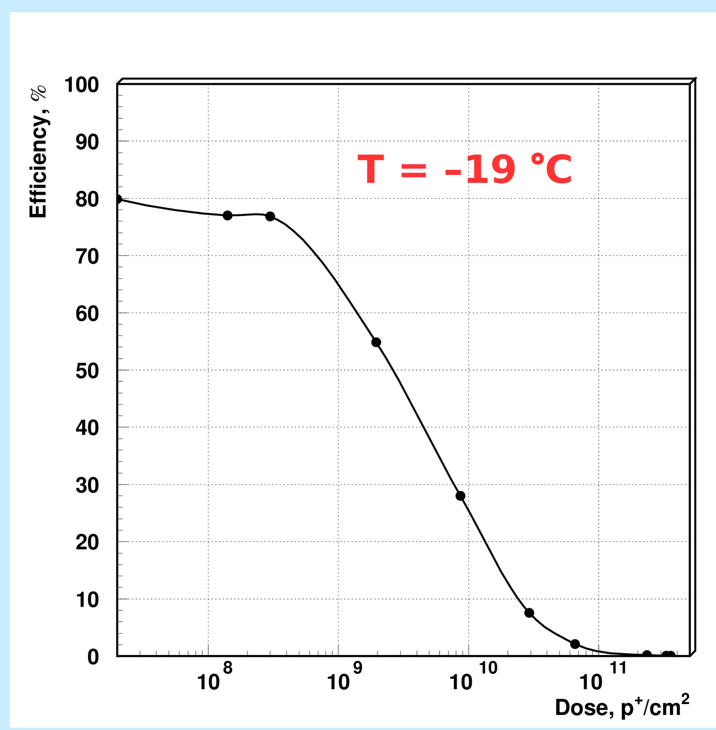
- Flash memory fault: content change was not observed.
- Cell inhibit memory fault: one bit-flipping per die after proton fluence of ~1×10^{10} cm^{-2} (equivalent to **460 rad**)
  – can be restored by inhibit map rewriting.
- FPGA failure: average proton fluence between two FPGA failures is ~3×10^{9} cm^{-2} (equivalent to **140 rad**)
  – can be restored by firmware reload.

Estimation of efficiency degradation

Optimal efficiency is a tradeoff between number of active cells and dead time due to dark conting rate. Minimum dead time for current chip design is 720 ns.



DCR of a die as a function of active cells fraction for different proton fluences.



Optimal efficiency of *single photons* detection as a function of proton fluence.