Irradiations – Status and plans

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Motivation – Radiation damage at Belle II

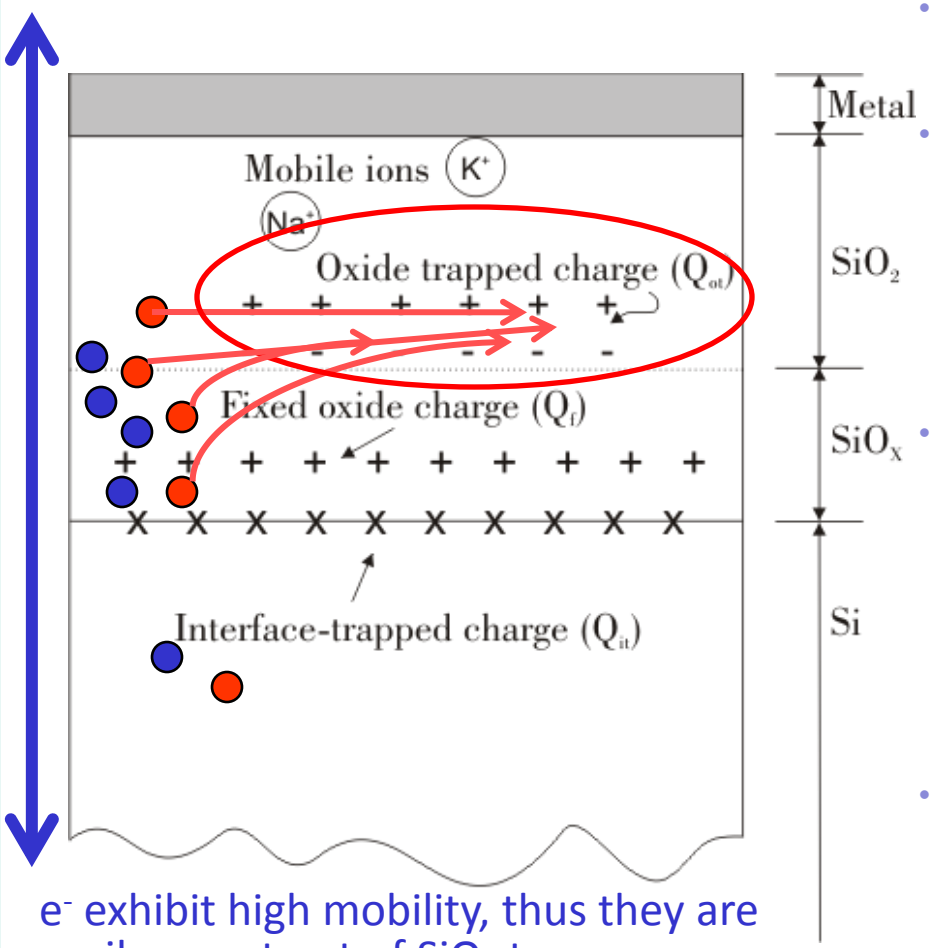
- Radiation dosage for DEPFET pixel detector in Belle II will be ~1 Mrad/year

  Radiation consists of:

  - synchrotron radiation (due to the Nano Beam option, synchrotron radiation should be less than in the High Current option)
  - Beam Gas Interaction (Vacuum in the Interaction Region could be 100x worse than in current KEK[1])
  - Intra Beam Scattering (Touschek Effect, 20x higher in the High Energy Ring(HER) than in current KEK[1])
- Exact Dose parameters and radiation profiles aren't available at present

  (Beam Gas and Beam Line simulations (for Single Beam) are under way from our japanese colleagues and should be presented this fall[1])

Effects of Irradiation on MOS devices



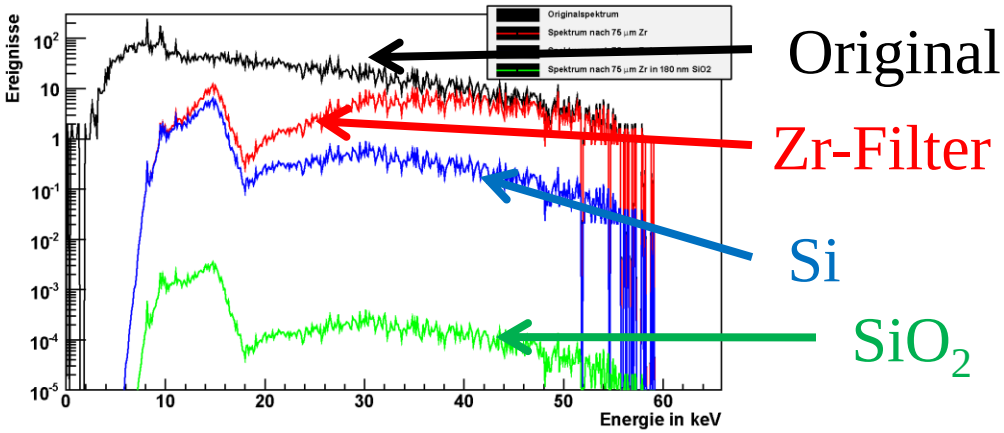
e⁻ exhibit high mobility, thus they are easily swept out of SiO_2 to an appropriate electrode

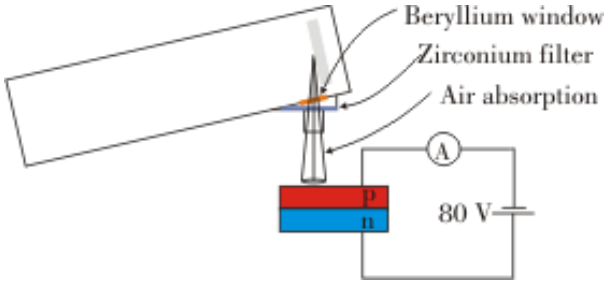
- Ionizing radiation creates electron/hole pairs in SiO_2
- Holes get trapped near the interface (Oxide trapped charge Q_{ot}), also defect generation at the interface, leading to an increase of interface states density D_{it}
- Trapped charge alters device characteristics, mainly:
  - Threshold voltage (Q_{ot})
  - External gain g_m and therefore also g_q (D_{it})
- In Si_3N_4 electron trapping is favored – compensate SiO_2

Final dosimetry at the x-ray facility in Karlsruhe - spectrum

Dosimetry was done via photo current in a depleted diode and a simulated spectrum of tungsten, bombarded with 60 keV electrons

1. Deposited (arbitrary) power of simulated spectrum (via GEANT 4, O. Brovchenko) in Si and SiO_2 were calculated

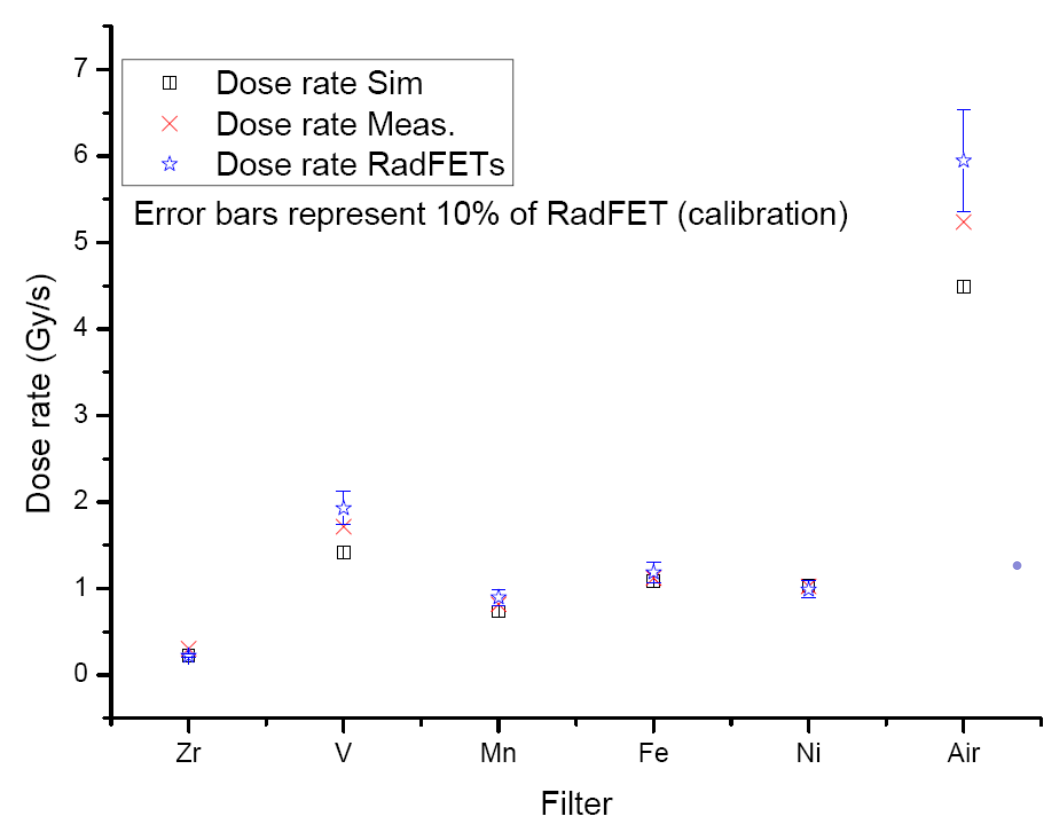




2. Deposited power can be measured in a depleted diode
3. Arbitrary power in the simulation can now be adjusted to the measurement
4. <u>New</u>: Spectrum has now been measured (M. Guthoff and myself) and the above calculation has been redone for the measured spectrum

   → Again: New set of dose rates determined (phew…)

Final dosimetry at the x-ray facility in Karlsruhe - RadFETs

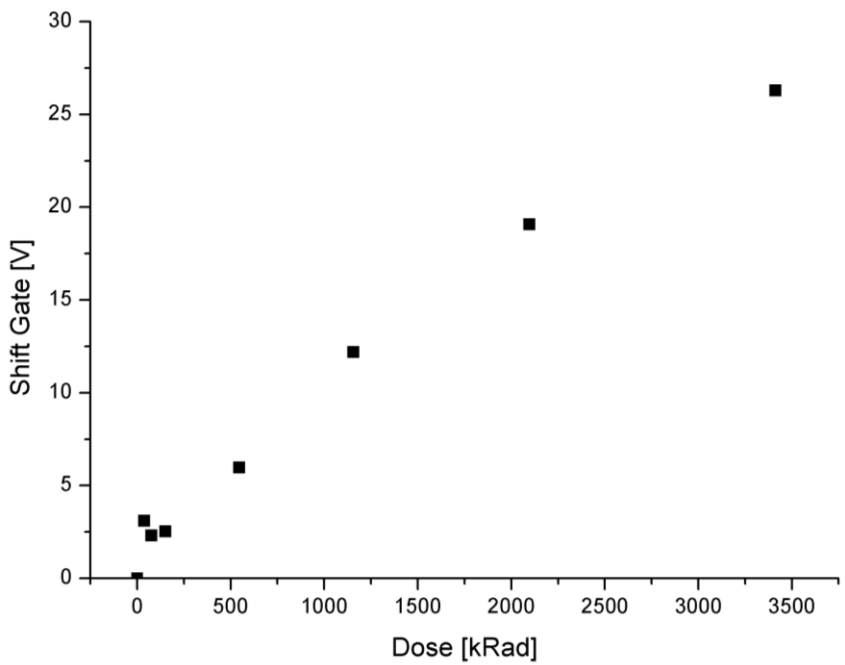


- RadFETs are calibrated MOSFETs. Threshold voltage shift has been calibrated to the delivered dose, using a Co-60 source (RadFET: d_{Ox} = 130 nm, calculation and check measuring with an aminogray dosimeter[2,3], by courtesy of T. Tsuboyama and S. Stanič)
- Different dose rates for different filters. Irradiations done with Zr-filter

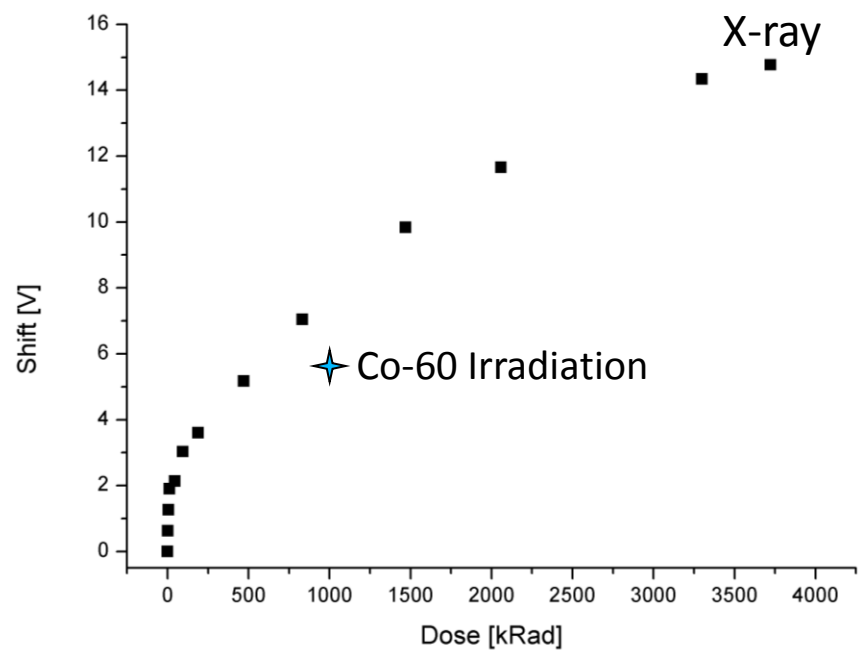
→ adjust data by factor of 0.47 (~ 1/2 , because RadFETs themselves have approx. 10% accuracy)

Status

Irradiations of DEPFET matrices and single pixels are now done to 4 Mrad. For the lifetime of Belle II, radiation hardness should be done up to 10 Mrad.

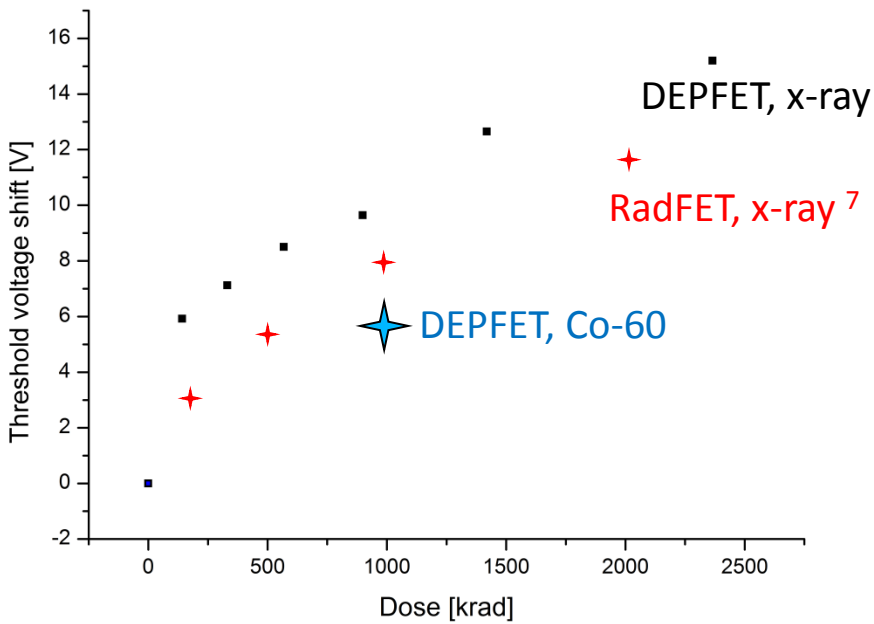


Threshold voltage shift with adaptive biasing (S. Rummel[5])



Threshold voltage shift with fixed biasing (S. Rummel[5])

X-ray tube vs. Co-60



Measurement of threshold voltage shift with positive Gate voltage at the beginning of the irradiation, after ~600 krad Gate voltage was adopted

RadFETs were zero biased during irradiation

Why is there such a difference between irradiation with the x-ray tube and Co-60?

- Irradiation with Co-60 took place with a low dose rate

  0.0548 Gy/s = 19,73 krad/h [6]

  → RT annealing during irradiation

- Irradiation is strongly Gate bias dependent
  - Settings at Co-60 irradiation
    - U_{DS} = -5V
    - Source = GND
    - U_{Bulk} = +12 V
    - U_{Gate} = +5V (not adopted)

Plans

- Measure threshold shift (=shit in flat band voltage) for DEPFET mini matrices up to 10 Mrad (Design PXD 5, ILC – New diploma student: Peter Müller)

- Measure flat band voltage shift in MOS Diodes (SiO_2 thickness 85 nm and 105 nm, both with Si_3N_4 thickness of 10 nm) up to 10 Mrad, Structures already exists from Q. Wei[4])

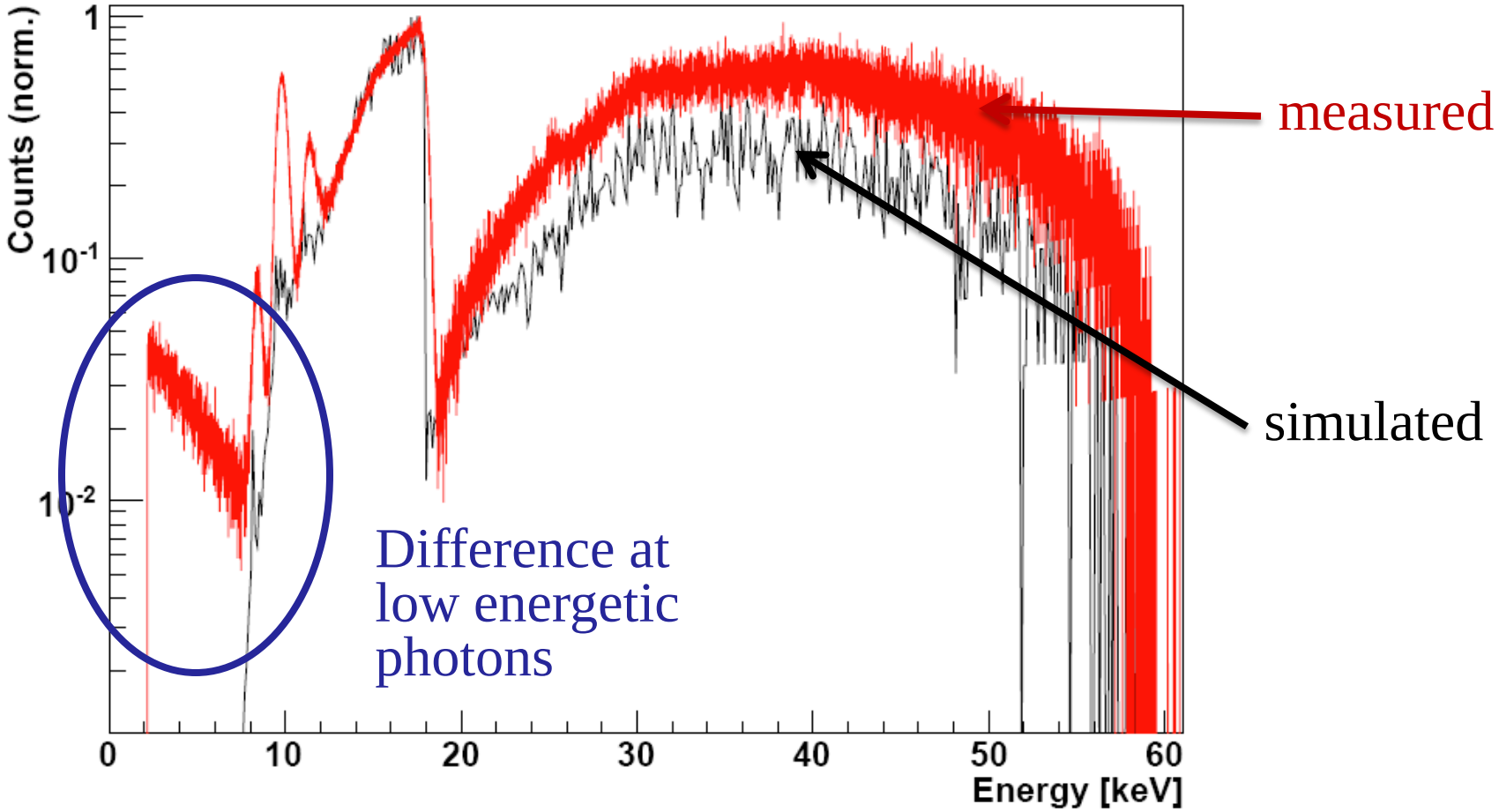
- Study the effect of various SiO_2/Si_3N_4 combinations with MOS diodes
  - Measure flat band voltage shift in MOS Diodes (thin oxides, various Si_3N_4 combinations, structures have yet to be produced)
  - From the best Combination construct MOSFETs, measure device characteristics and behavior up to 10 Mrad

References

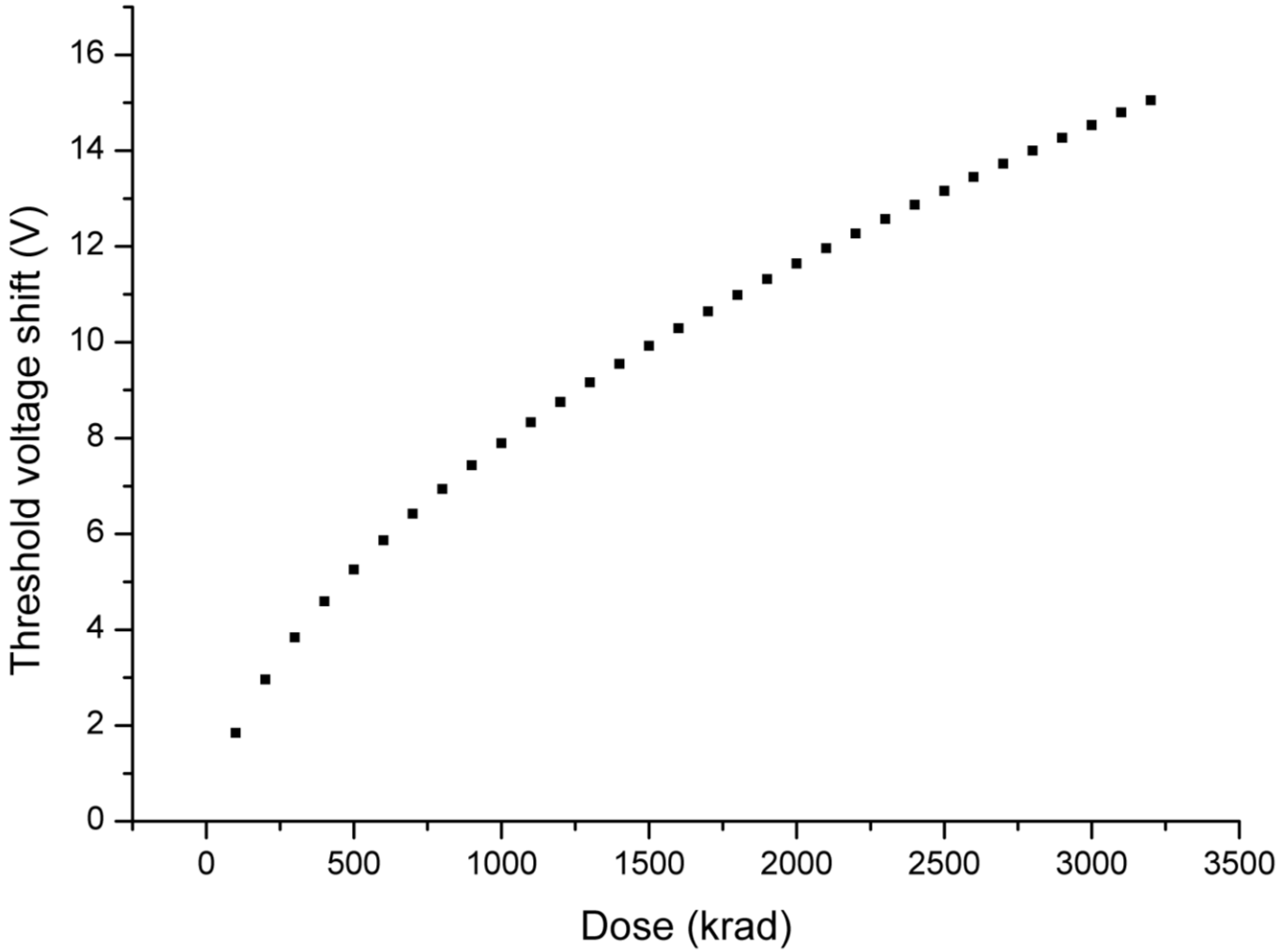
1. Masako Iwasaki; Status of the SuperKEKB Machine Studies; Belle II PXD EVO meeting; 22. September 2009
2. L. Ruckman, G. Varner, S. Stanič, A. Koga, and T. Tsuboyama; Development and implementation of a readout module for radiation-sensing field-effect transistors; Nuclear Science, IEEE Transactions on; Volume: 53, Issue: 4, Part 2; On page(s): 2452-2455
3. S. Stanič,Y. Asano, H. Ishino, A. Igarashi, S. Iwaida, Y. Nakano, H. Terazaki, T. Tsuboyama, I. Yoda and D. Žontar; Radiation monitoring in Mrad range using radiation-sensing field-effect transistors; Nuclear Instruments and Methods in Physics Research A; Volume 545, Issues 1-2, Pages 252-260; 11. June 2005
4. Q. Wei; Studies of radiation hardness of MOS devices for application in a linear collider vertex detector; PhD thesis Munich, Techn. Univ.; 2008
5. S. Rummel; plots from various. Talks, corrected to new dose rates
6. Ladislav Andricek; Co-60 Irradiation setup; Kalibrierung des ELDORADO für MPI Halbleiterlabor am 22. Feb. 2005
7. Calculated values (No measuring points) according to equation $D = 32\ U_{Th} + 12\ U_{Th}^2$ from Ref. [3]

Backup Slides

Compare: Simulated and measured spectrum (Zr-filter)



Characteristics of threshold voltage shift for RadFETs



Calculated according to equation:

$D = 32\ U_{Th} + 12\ U_{Th}^2$ from Ref. [3]