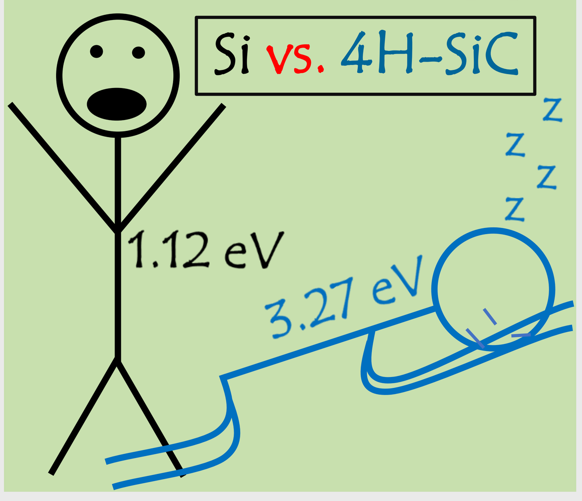
Performance of neutron-irradiated 4H-Silicon Carbide diodes subjected to proton beams and UV Laser pulses

P. Gaggl[1], A. Gsponer[1], R. Thalmeier[1], S. Waid[1] and T. Bergauer[1]

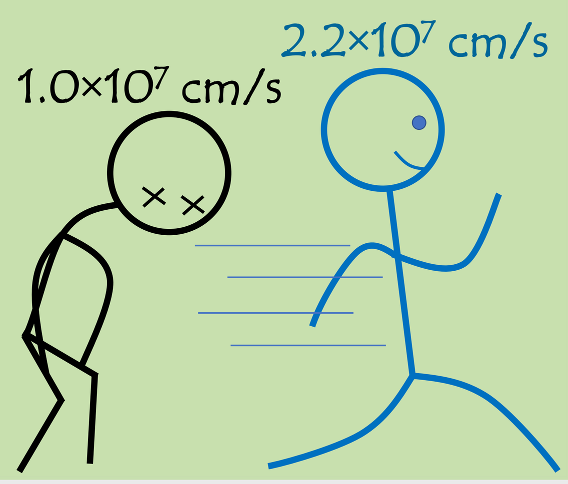
[1]Institute of High Energy Physics, Austrian Academy of Sciences

Why 4H-SiC?

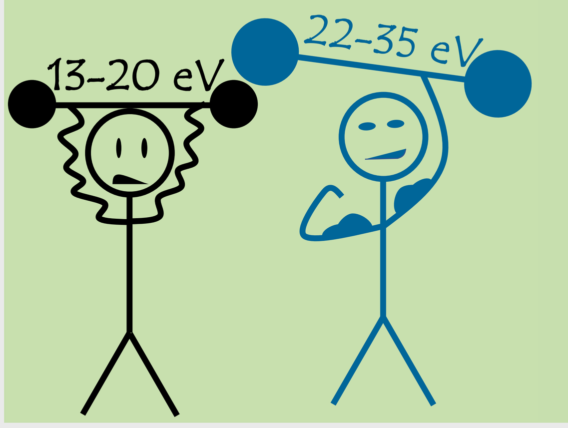
Quieter
larger bandgap
→ less dark current [1]



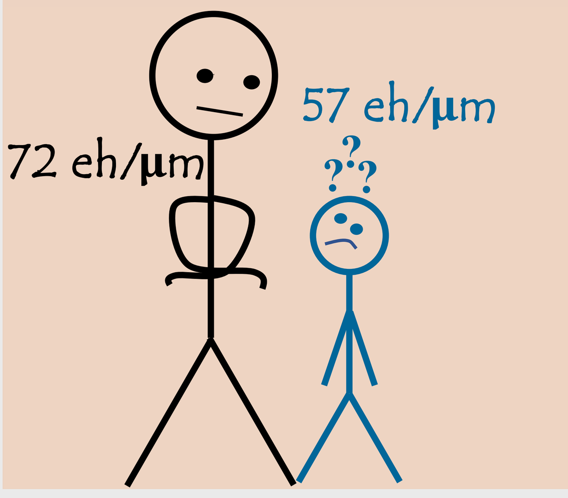
Faster
higher saturation vel.
→ faster signals [1]



Stronger
larger atomic displacement threshold
→ radiation resistant [1]



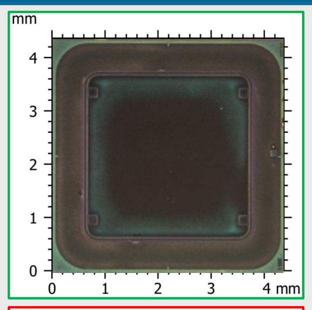
But…smaller
higher ionization energy
→ smaller signals [1, 2]

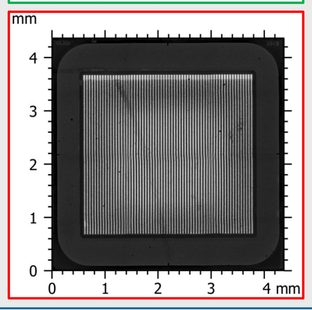


Samples, readout & analysis

Samples:

- 4H-SiC p on n diodes [3, 4]
- 3x3 mm^2 active area [3, 4]
- planar pad & 64 strip sensors
- 50 µm active epitaxial layer [3, 4]
- from IMB-CNM-CSIC Barcelona [5]
- V_{depl} = 300 V, $I_{leakage}$ < 10 pA [6]





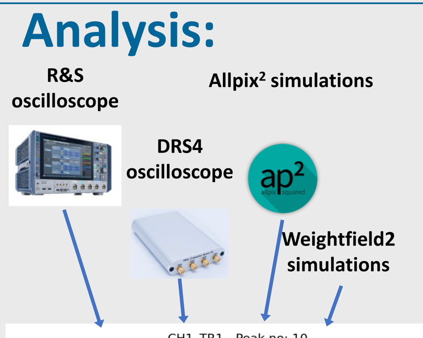
Readout:

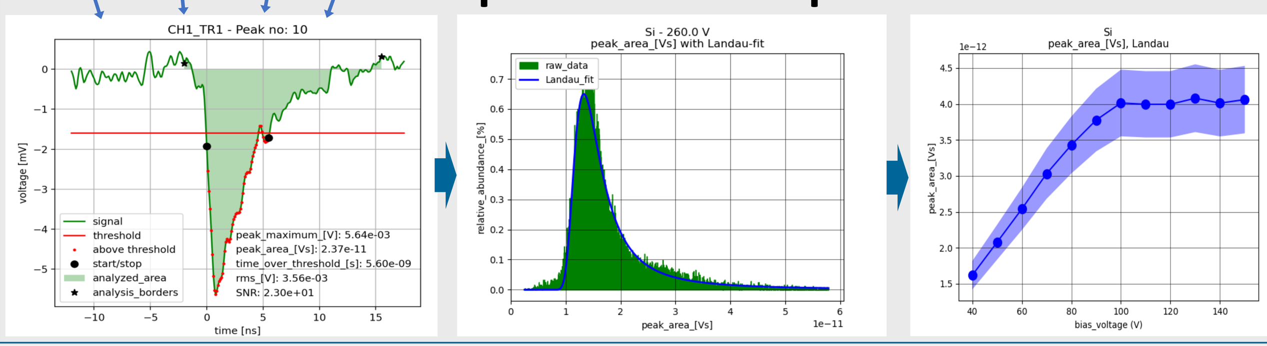
- single channel testboard
- UCSC - "LGAD" board
- widely validated & used
- data recording with osci

- multi channel
- APV25 chip (originally designed for CMS [7])
- analysis using ROOT & Corryvreckan

Analysis:

- developed an automated peak finding & analysis software
- openly available on GitLab [*]
- generation of signal statistics
- parameter ramp evaluation via fits

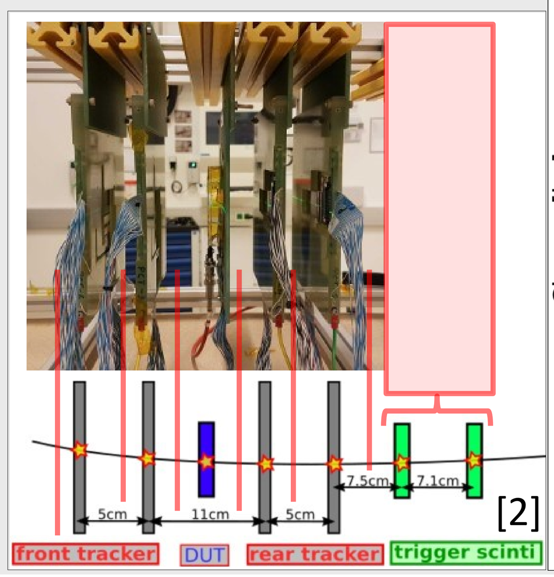


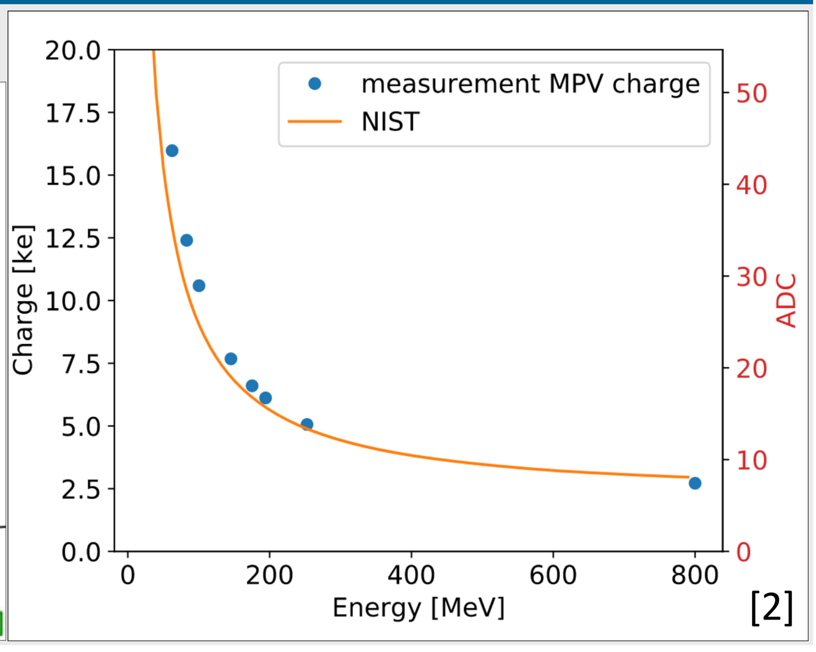


Proton beam energy scan using 4H-SiC strip detector [2]

- performed at an ion beam therapy centre [8]
- special low flux settings (≈ $5{\cdot}10^6$ p/s) [9]
- beam telescope setup + trigger scintillators
- two double sided Si strip detectors (∥ & ⊥) on each side [2]
- determined an ionization energy of 4H-SiC of 5.85 eV via calibration with Si detector [2]
- 57 ± 4 created e/h pairs per µm and MIP [2]

setup at MedAustron [2]

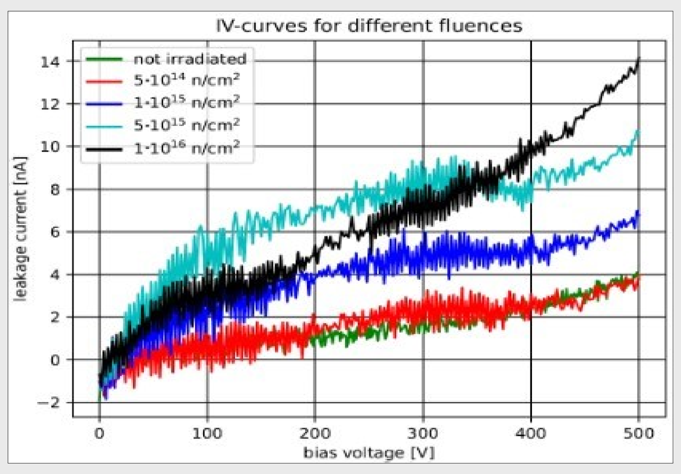




UV - TCT measurements of neutron irradiated 4H-SiC pad sensors [10]

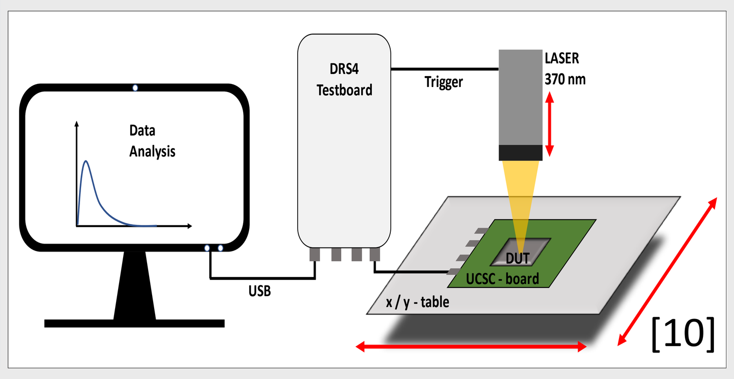
Irradiation

- at TRIGA Mark II reactor [11]
- fluences up to 10^{16} n_{eq}/cm^2
- leakage currents remain low, no cooling necessary [10]



UV -TCT

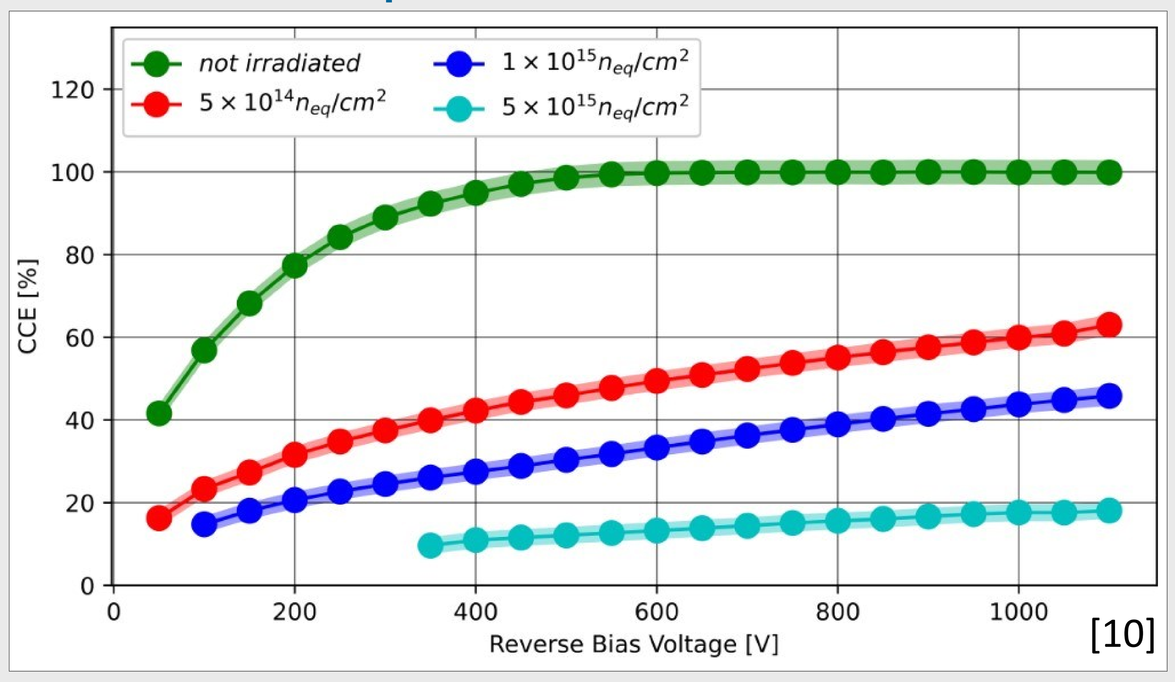
- Transient Current Technique
- UV laser with λ = 370 nm [11]
- large energy deposition
- consistent signals
- external triggering



Results

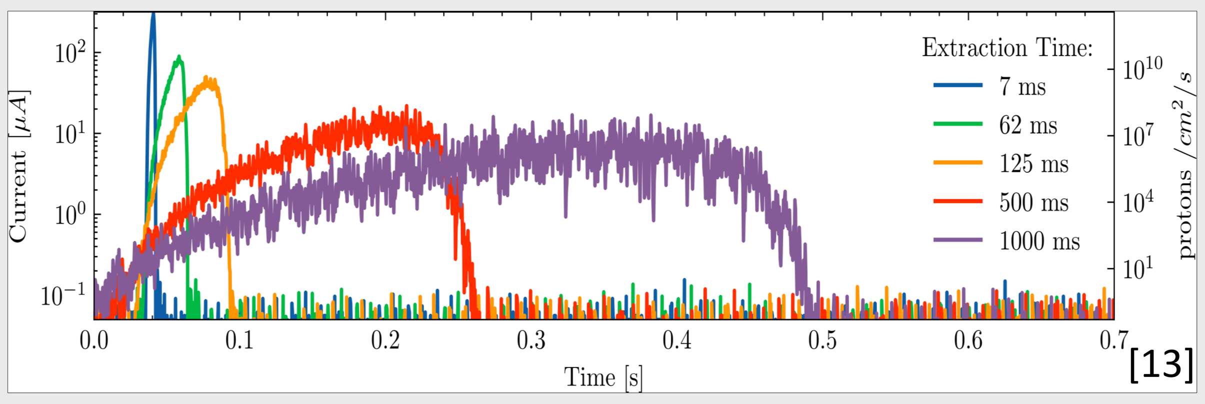
- collected charge of non-irradiated sample saturates at about 500 V
- irradiated samples do not saturate up to 1100 V reverse bias voltage
- charge collection efficiency (CCE) decreases with irradiation level
- decent CCE for fluences up to $5{\cdot}10^{15}$ cm^{-2} (63% & 46%)
- no data acquisition for highest irradiated sample possible

charge collection efficiency (CCE) of neutron irradiated planar 4H-SiC diodes



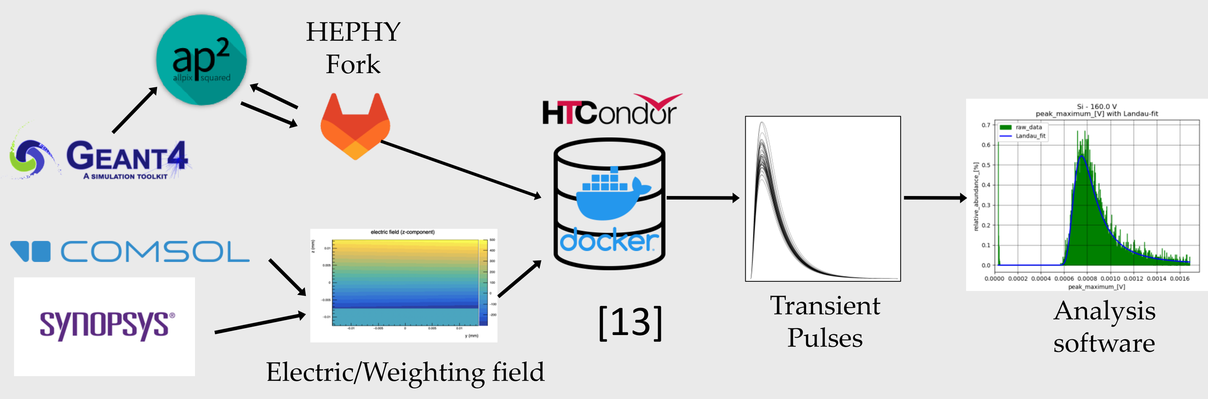
Monitoring ion beam therapy

- need to characterize proton rates up to several GHz
- even higher for potential *FLASH* therapy
- measured current at various proton rates via different extraction times of beam "spills"
- promising results for rates ≈ $2{\cdot}10^{12}$ p/(s·cm^{-2})



Computational approach

- reliable simulations of 4H-SiC devices are crucial
- however, material parameters and models are often unknown or not/badly implemented
- combination of different frameworks to construct reliable models of future 4H-SiC prototypes



Outlook and further work

- larger pads; strip and pixel detectors
- thicker epi-layer to produce larger signals
- add gain layer to implement LGAD charge multiplication concept in SiC (larger signals)
- develop and verify simulation parameters to improve quality of SiC-models in TCAD, GEANT4 and Allpix²
- in-house development of an ASIC capable to switch between single particle detection and integrating mode to achieve a high dynamic range

References

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