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Charge Collection Efficiency of micro-strip Silicon Sensors designed for studying Charge Multiplication after Hadron irradiation

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Outline

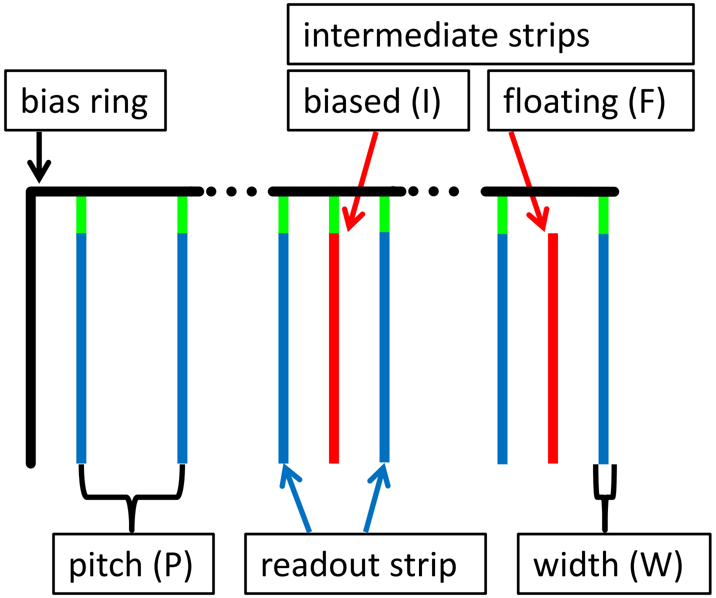
- Charge Multiplication Sensors
- ALiBaVa readout system
- Charge Collection measurement results
- Long term room temperature annealing
- TCT/eTCT system and results

Charge Multiplication

- At high fluences and bias voltages, charge multiplication of the signal in the detector has been observed
- Multiplication due to impact ionisation
  – Begins when electric field reaches 10-15 V/μm
- Charge multiplication can be beneficial for sensors, leading to higher signal
  – Particular for not fully depleted sensors after high irradiation doses
- Same process that is responsible for charge multiplication also leads to increased noise and lower breakdown voltage

Sensors

- Dedicated charge multiplication sensors, produced by Micron Semiconductor Ltd (UK)
  - Detectors aim to enhance the electric field near the readout strips
- 1cm x 1cm, n-in-p FZ strip detectors
- Various strip pitch (P) and width (W)
- Some sensors with floating (F) or biased (I) intermediate strips between readout strips



Serial No	Thickness [μm]	Resistivity [kΩ/cm]	Implant Details	Labelling
2912-(2,3)	300	10-13	Standard, double implant energy	2E imp
2935-10	305	13	Standard, double diffusion time	extra diff
2935-(2,4,5,6,7,8,9)	305	13	Standard	std
2488-(6,7)	675*	8	Thick	thick
2885-5	150	10	Thin	thin

*: sensors should be 675 μm thick, but are only 300μm thick

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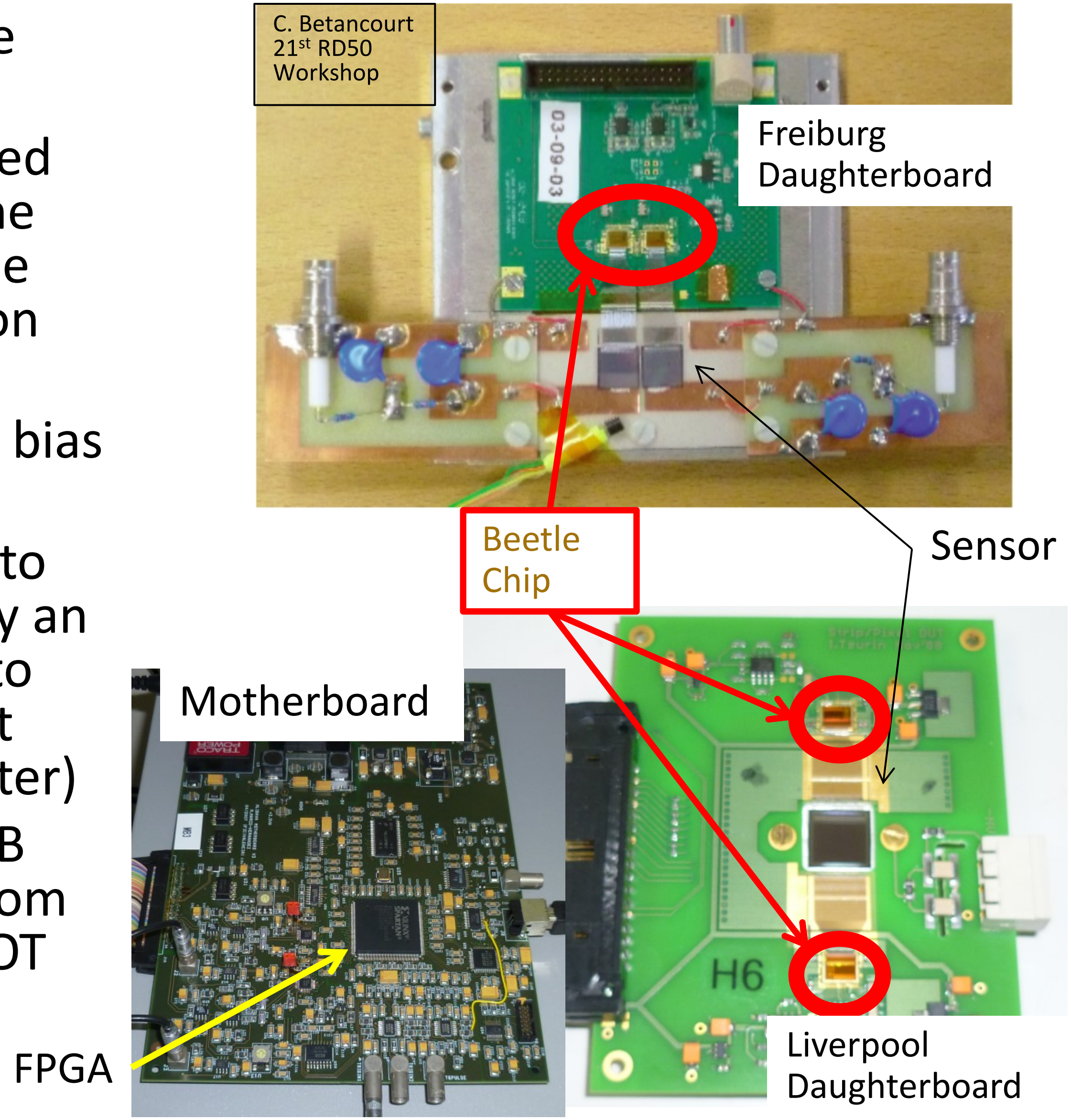
ALiBaVa Setup

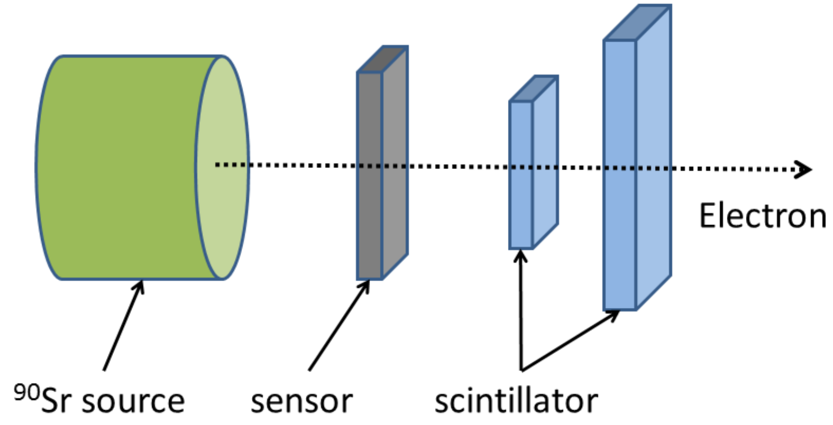
Use ALiBaVa system for charge collection measurements

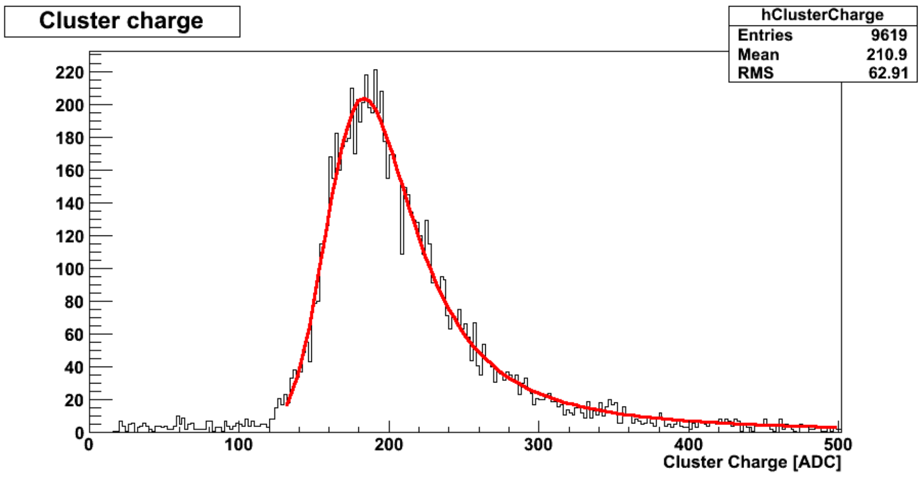
- Up to 2 sensors are attached to Beetle chips (ASIC) on the daughterboard for analogue readout (signal amplification and shaping)
- High voltage connection to bias ring on daughterboard
- Daughterboard connected to motherboard, controlled by an FPGA (signal conversion into digital counts using a 10-bit Analogue to Digital Converter)
- Raw data sent to PC via USB cable and analysed by custom software based off the ROOT framework



Beta Source Measurements

- MIP's from ^{90}Sr source to perform charge collection measurements
- Scintillators for triggering
- Resulting spectrum is fitted with a convolution of a Gaussian and Landau distribution to determine MPV
- With calibration value of daughterboard the collected charge is calculated from the MPV
- Irradiated sensors measured at temperatures between -20°C and -30°C in a freezer





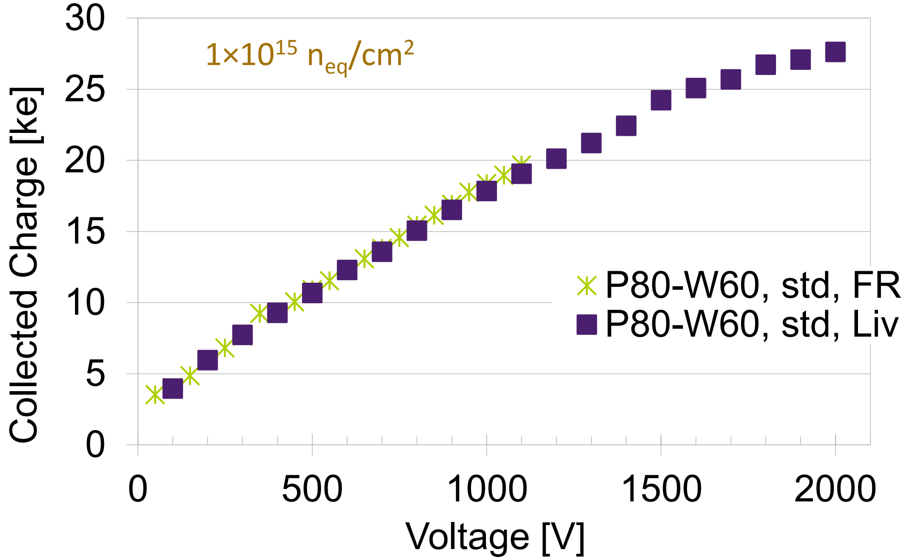
Irradiation

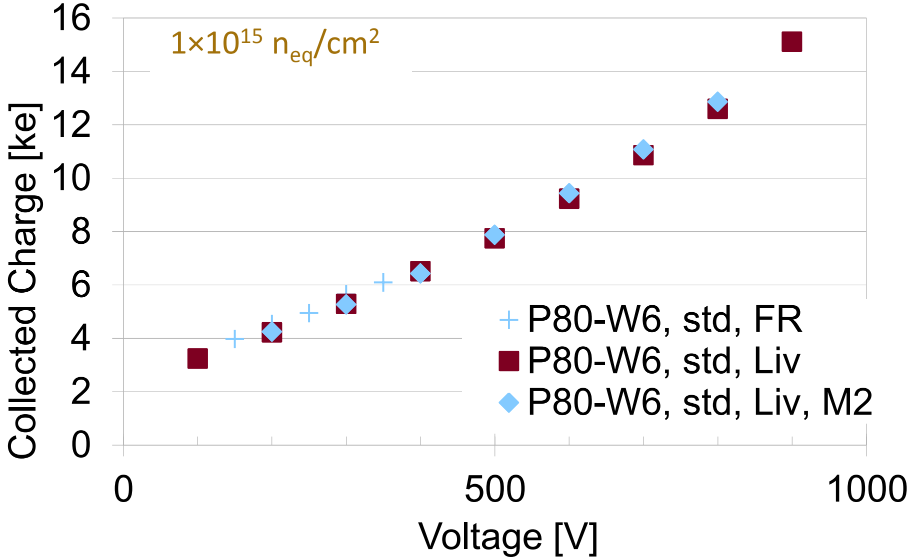
The sensors were irradiated with protons and neutrons to two fluences:

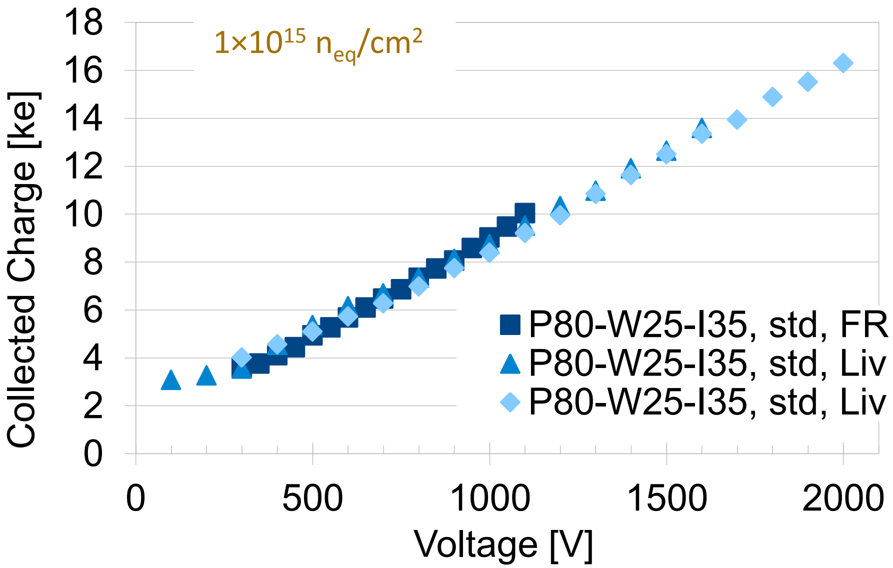
- Proton irradiation performed at Proton-Compact-Cyclotron at Karlsruhe (D) with 25MeV protons
  - Fluence of 1×10^{15} n_{eq}/cm^2
  - Only measured at Freiburg

- Neutron irradiation at Jozef Stefan Institute in Ljubljana (Sl) with reactor neutrons from TRIGA Mark II research reactor
  - Fluences of 1×10^{15} n_{eq}/cm^2 and 5×10^{15} n_{eq}/cm^2
  - Measured at Freiburg and Liverpool

Comparability



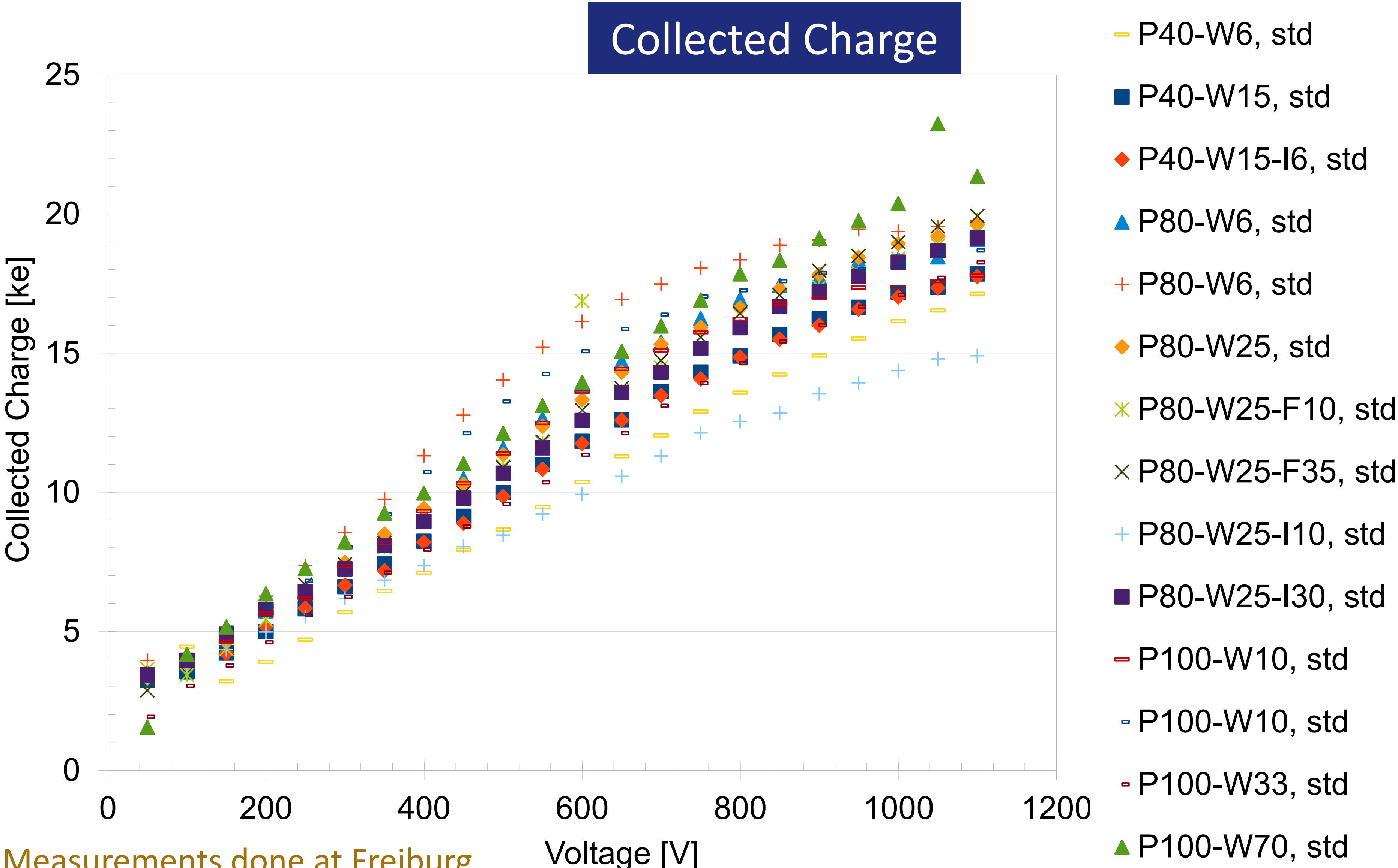




- Compare results of same sensor geometry and type
- Freiburg and Liverpool show good agreement

  => Results are comparable between different sites

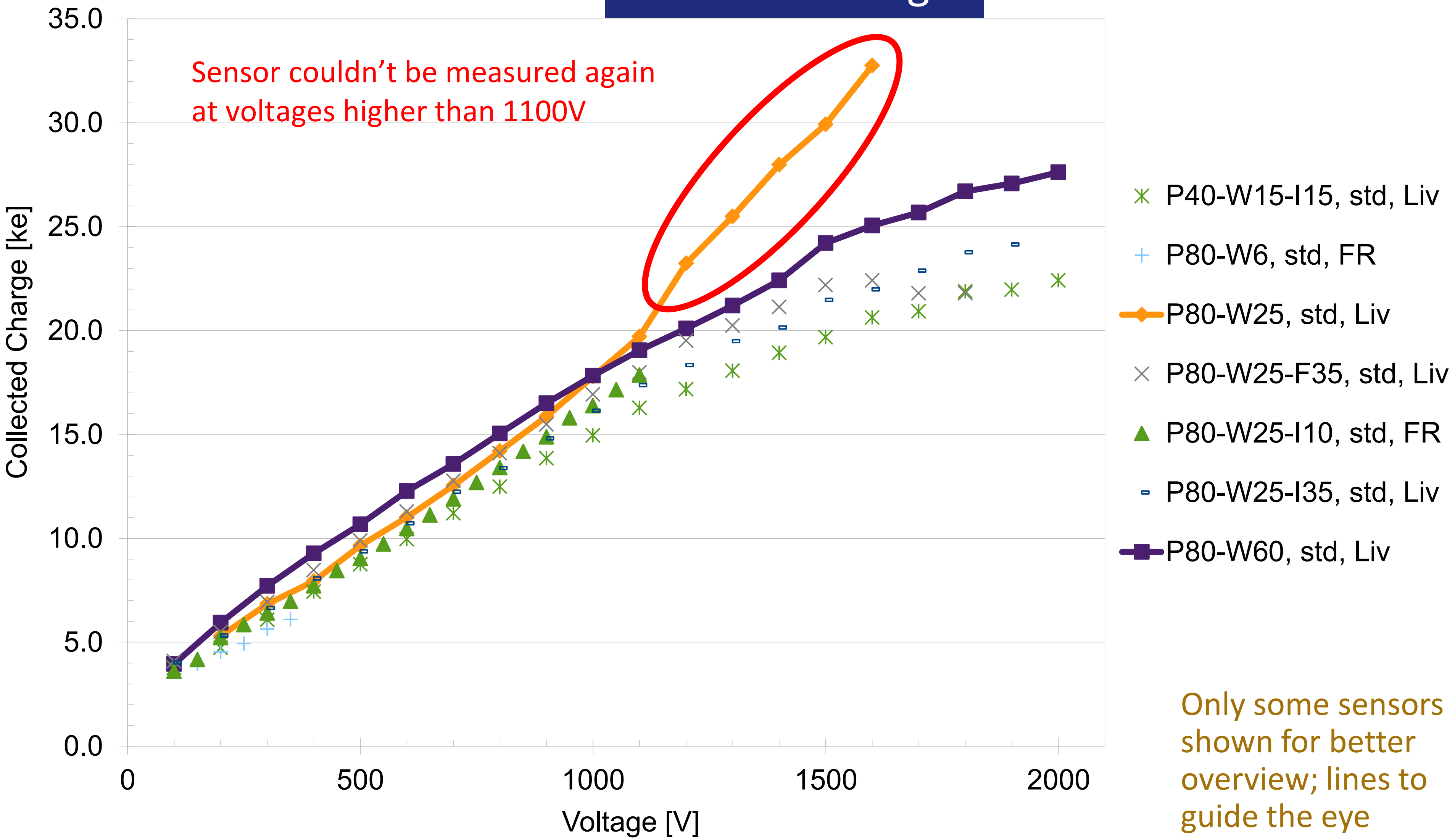
Proton Irradiation $1\times10^{15}\ n_{eq}/cm^2$



Measurements done at Freiburg

Neutron Irradiation $1\times10^{15}\ n_{eq}/cm^2$

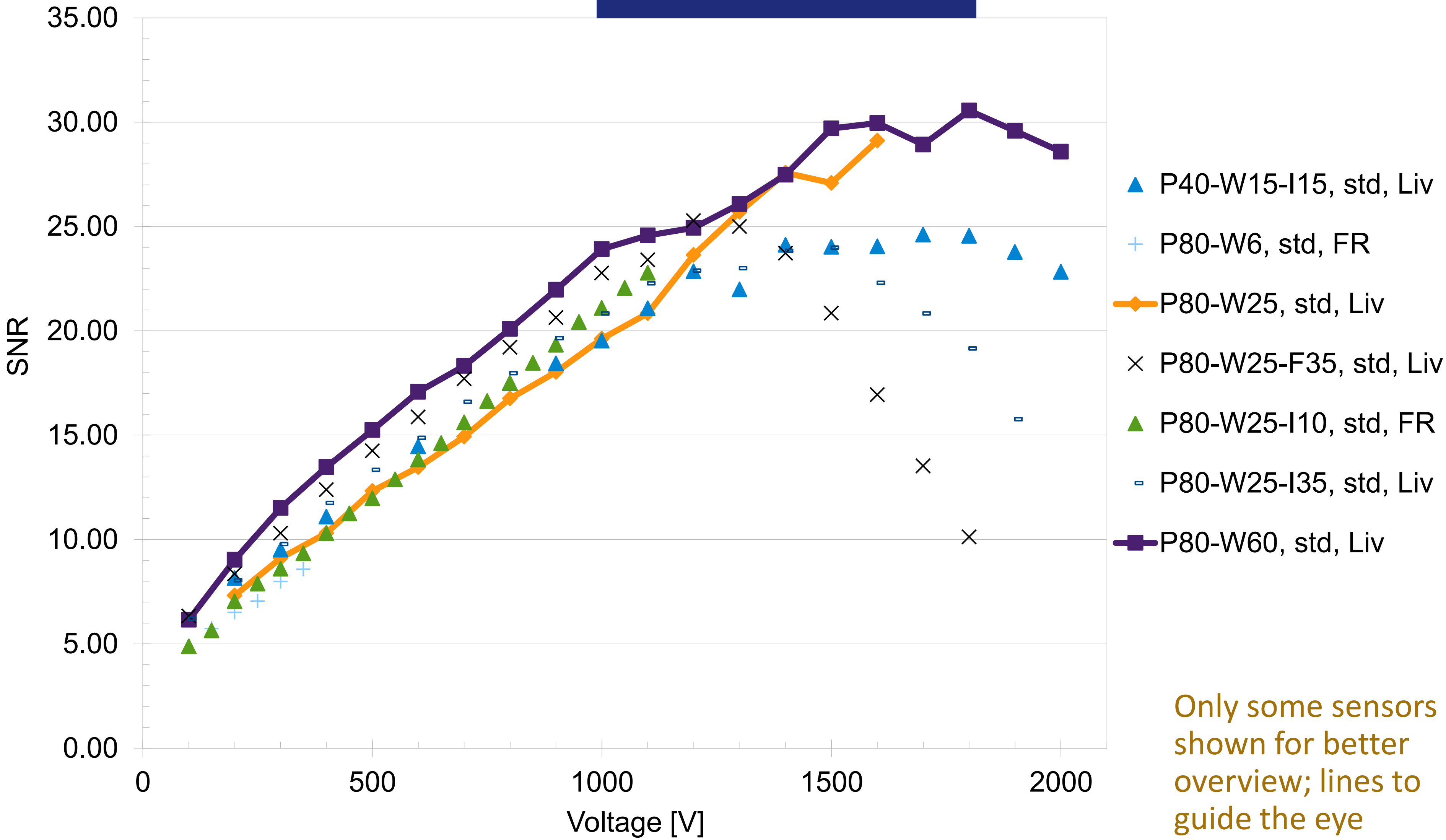
Collected Charge



Only some sensors shown for better overview; lines to guide the eye

Neutron Irradiation 1×10^{15} n_{eq}/cm^2

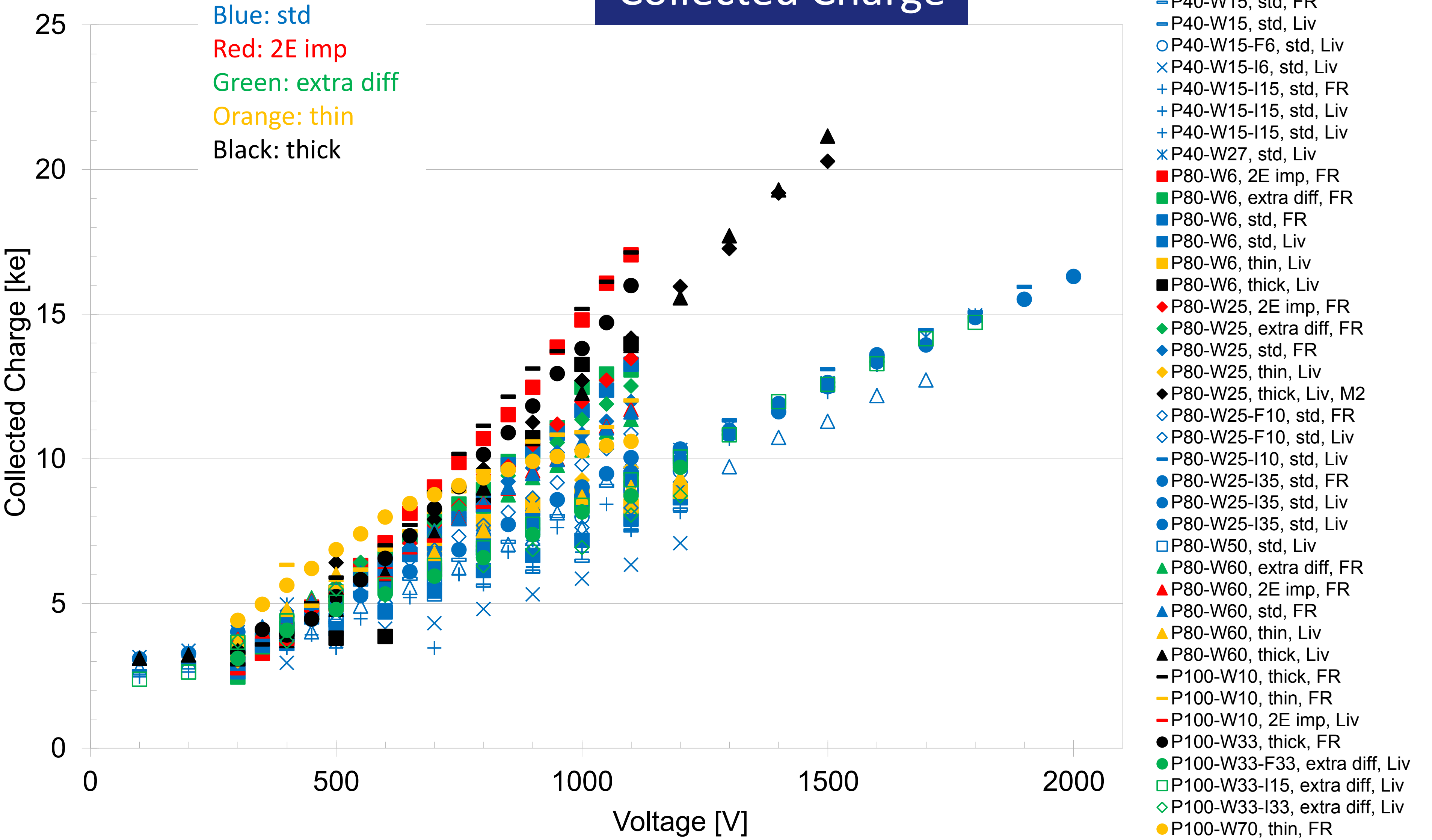
SNR



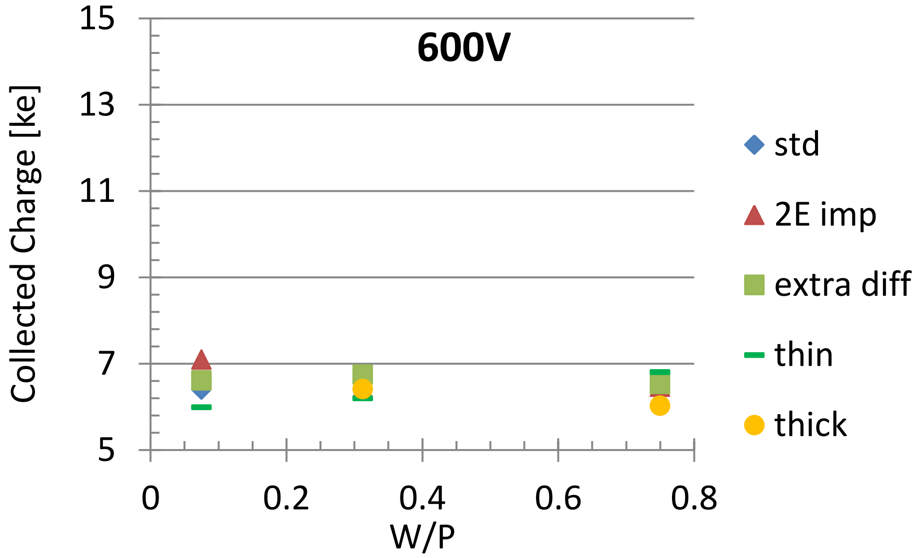
Only some sensors shown for better overview; lines to guide the eye

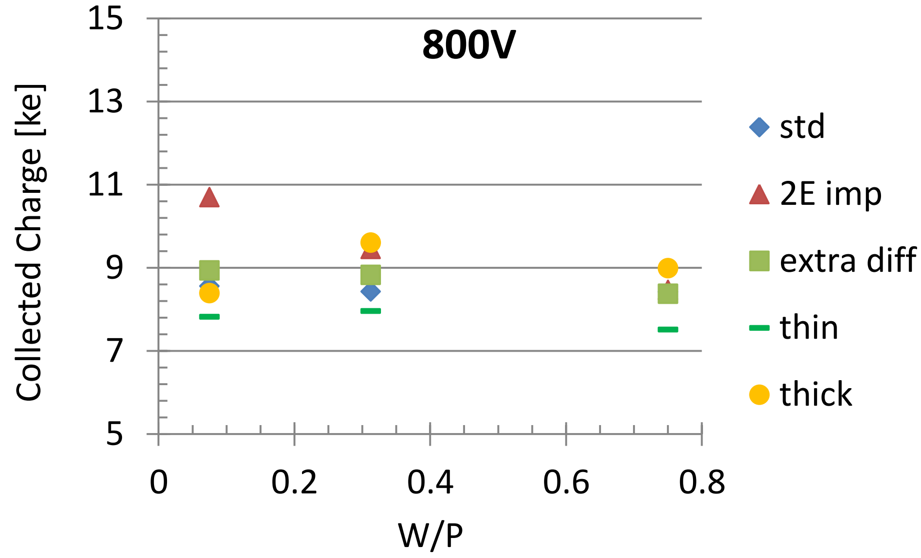
Neutron Irradiation 5×10^{15} n_{eq}/cm^2

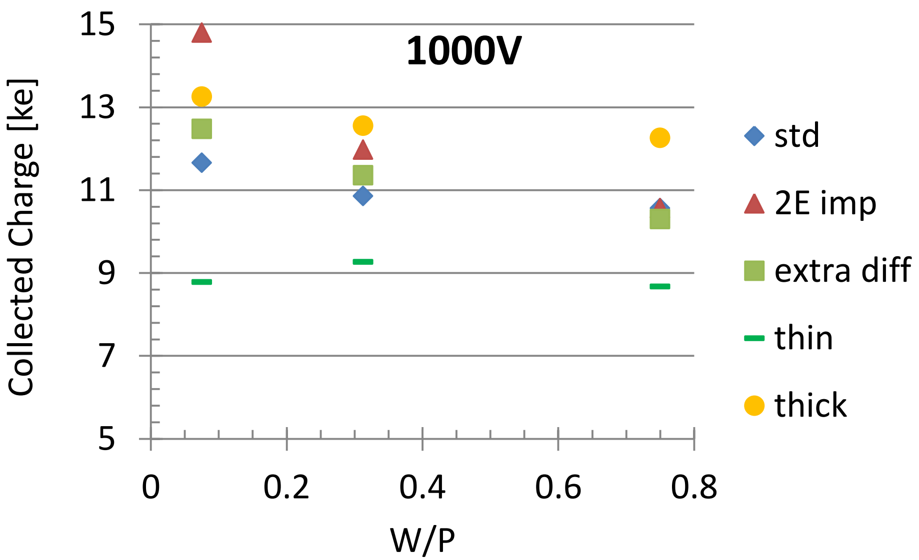
Collected Charge



Width/Pitch for $5\times10^{15}\ n_{eq}/cm^2$

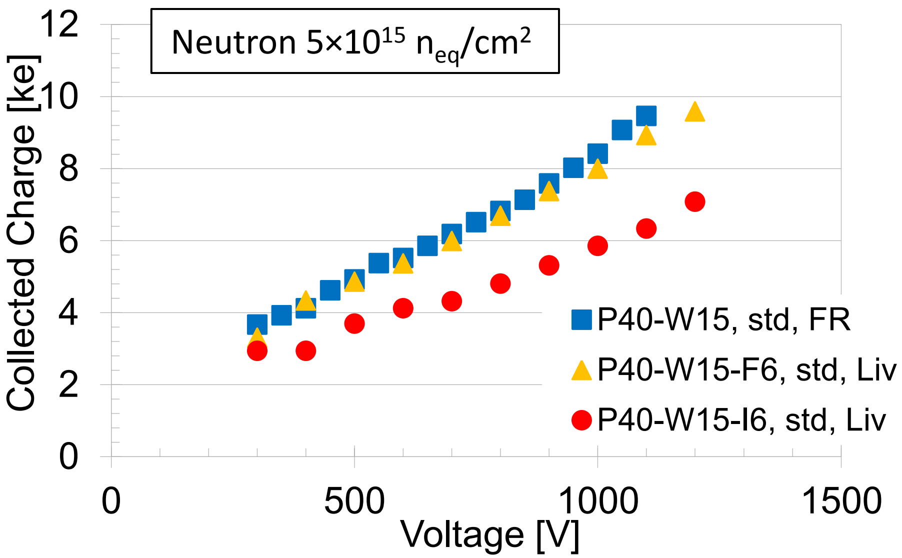


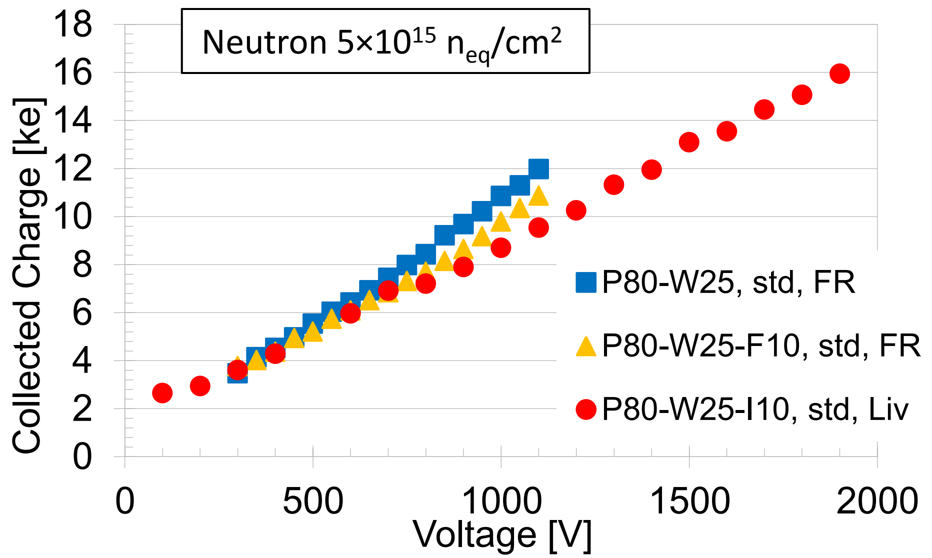


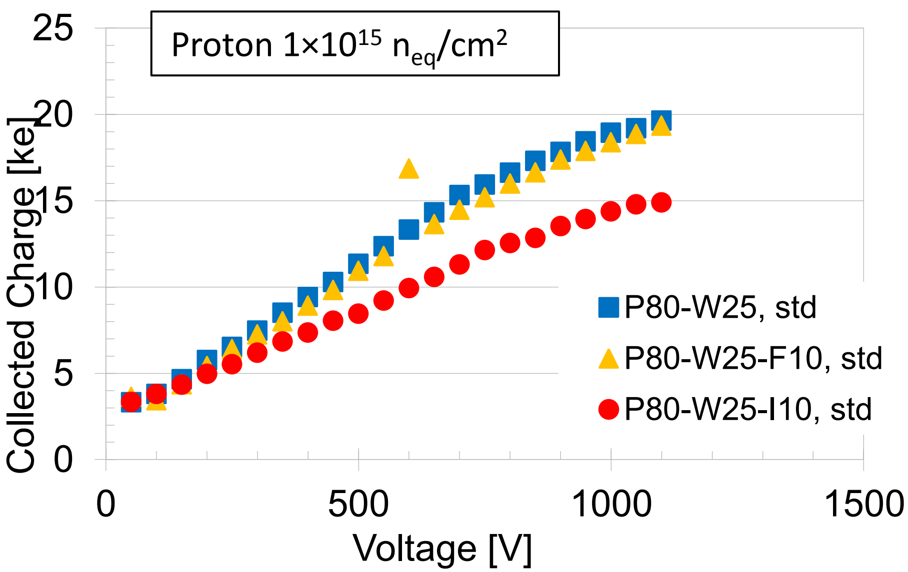


- Charge multiplication only observed at V_{bias}>600V
- Extra diff, 2E imp and thick show charge multiplication with respect to standard wafer
- Lower W/P ratio leads to more pronounced multiplication (as expected since fields are larger at strip edges)

Strip Structure





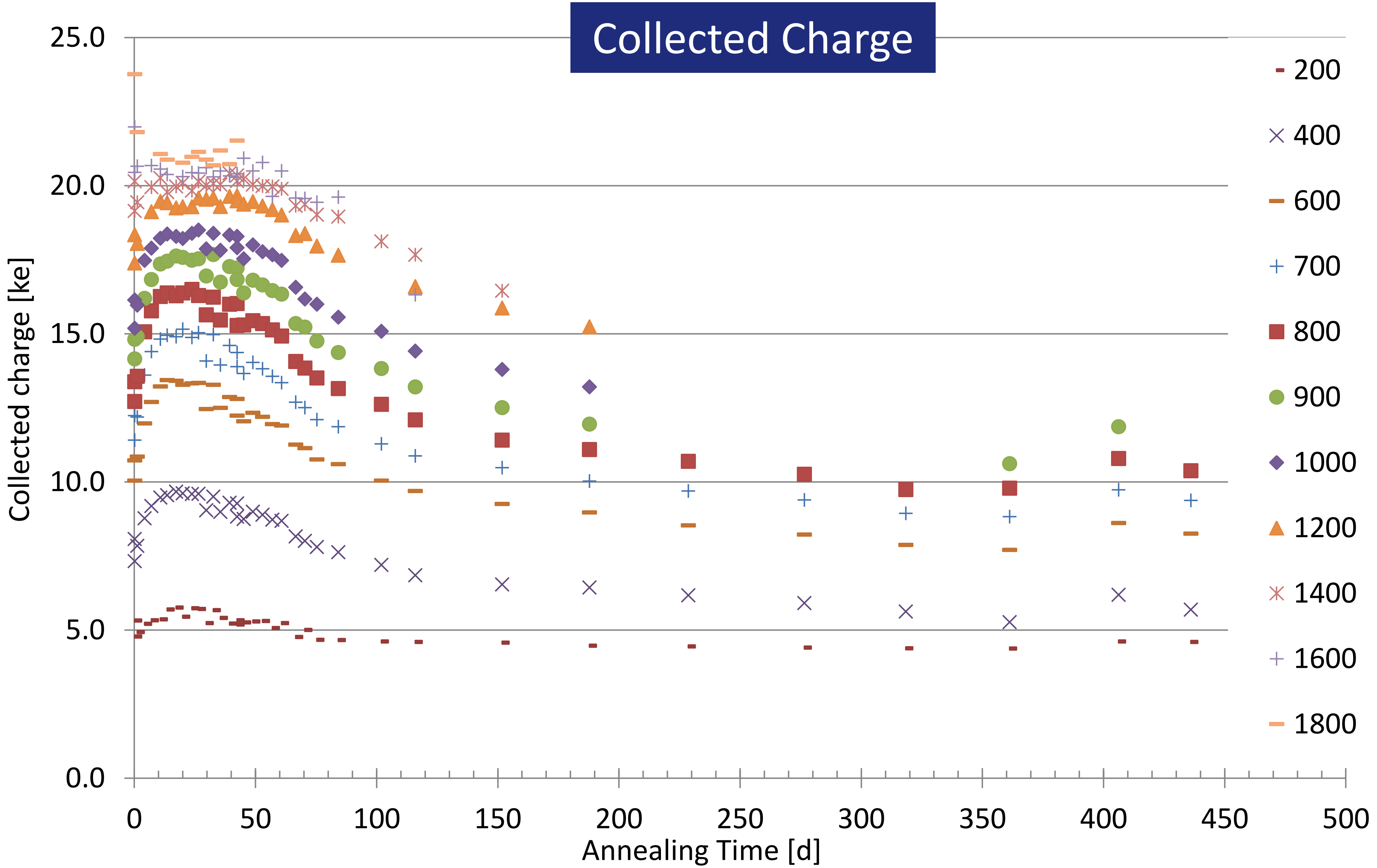


Detectors with biased intermediate strips (I) show a clear deficit of charge compared to no intermediate strip detectors or floating intermediate strip (F) detectors

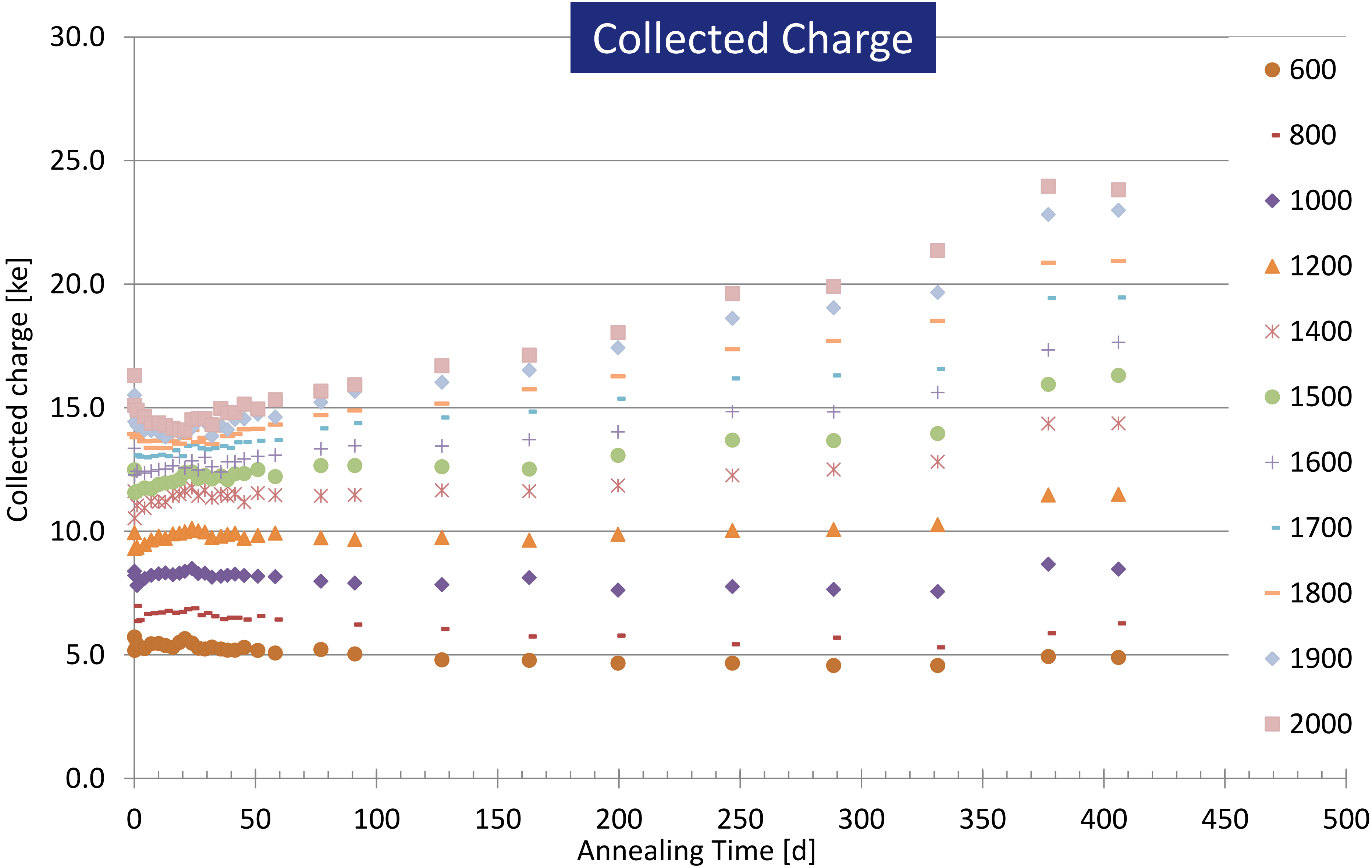
Annealing

- Room temperature (20°C) annealing in nitrogen cabinet
- Sensors:
  - P80-W25-I35, std, Liv; 1×10^{15} n_{eq}/cm^2
  - P80-W25-I35, std, Liv; 5×10^{15} n_{eq}/cm^2

P80-W25-I35, $1\times10^{15}\ n_{eq}/cm^2$



P80-W25-I35, $5\times10^{15}\ n_{eq}/cm^2$

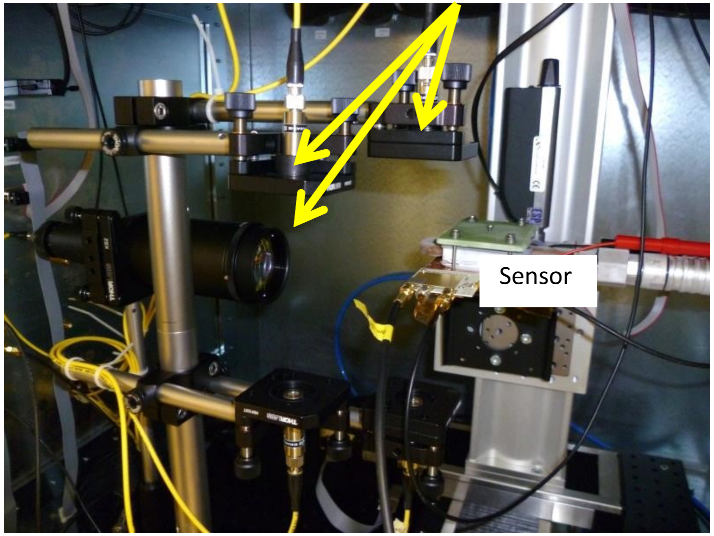


TCT/eTCT

- **T**ransient **C**urrent **T**echnique
- Pulsed ps red/infrared laser illumination (front/edge) generates electron-hole pairs
  - Drift in electric field (external bias voltage)
  - Measure induced current in 5th strip
    - Amplified signal measured with digital oscilloscope
- Measurements performed at the CERN SSD laboratory
  - Two setups: TCT+ (TCT and eTCT), eTCT
  - Sensors cooled to -20°C
- ROOT based analysis software (CERN SSD group)

Setups

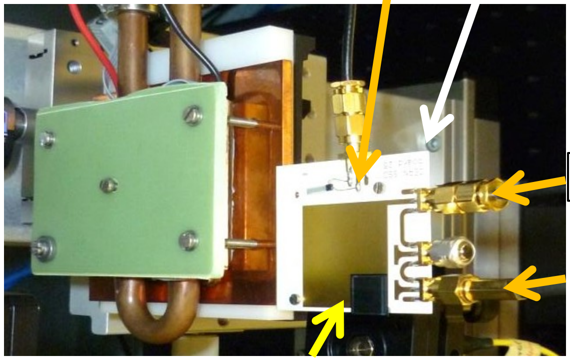
Laser



Cold block with chiller connection and peltier for cooling

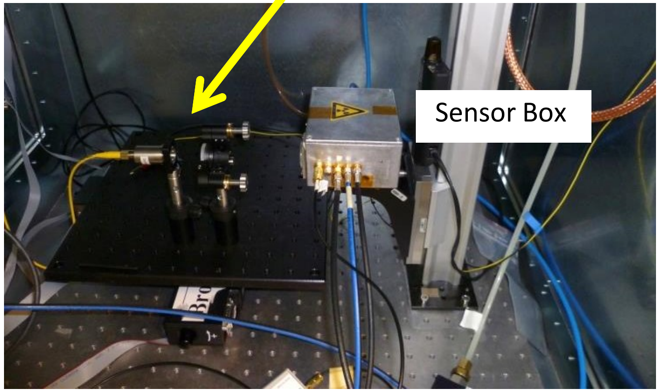
PT1000 temperature sensor

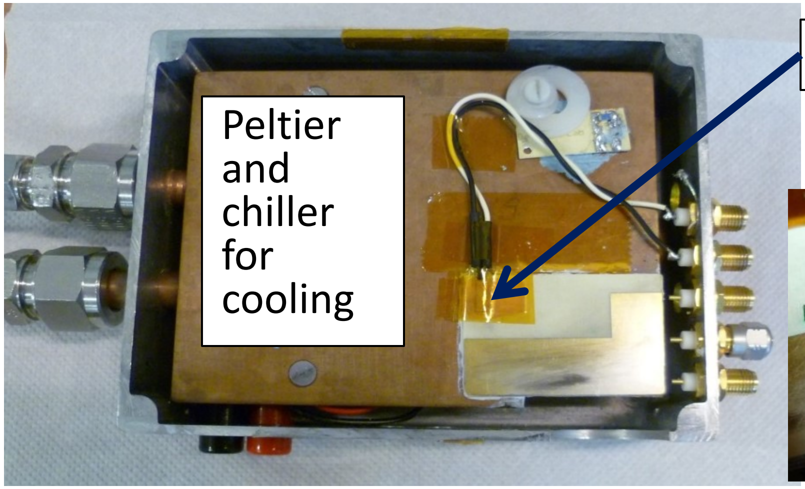
PCB



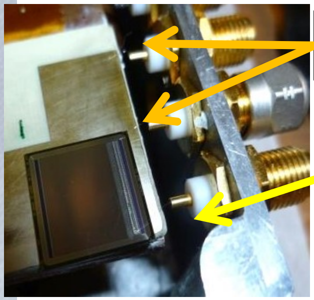
TCT+

Laser



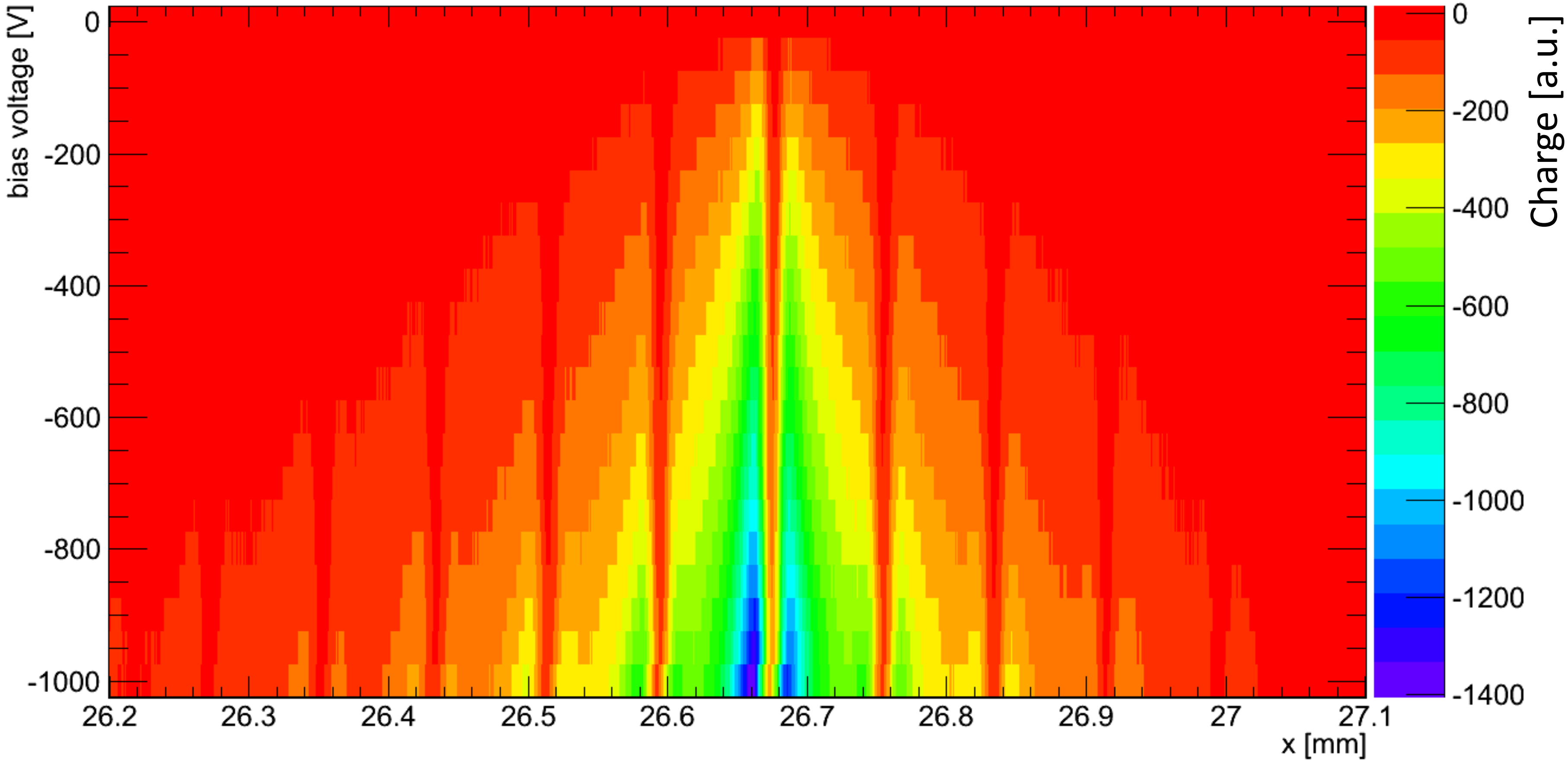


eTCT



P80-W6, $1\times10^{15}\ n_{eq}/cm^2$

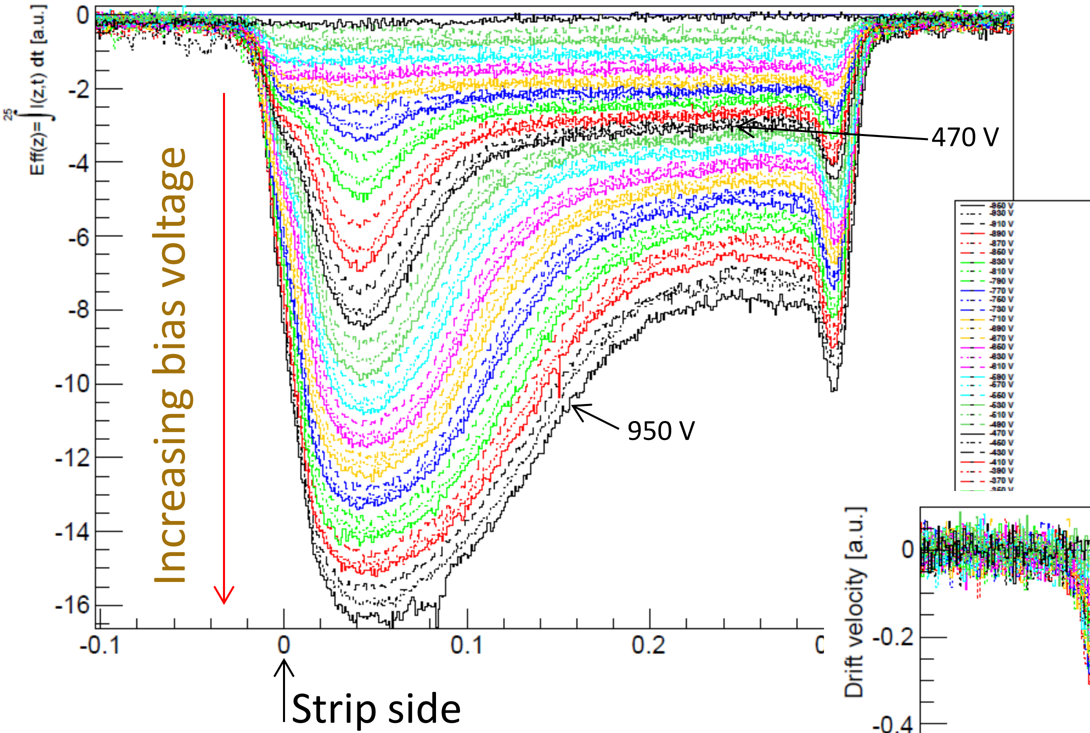
IR top



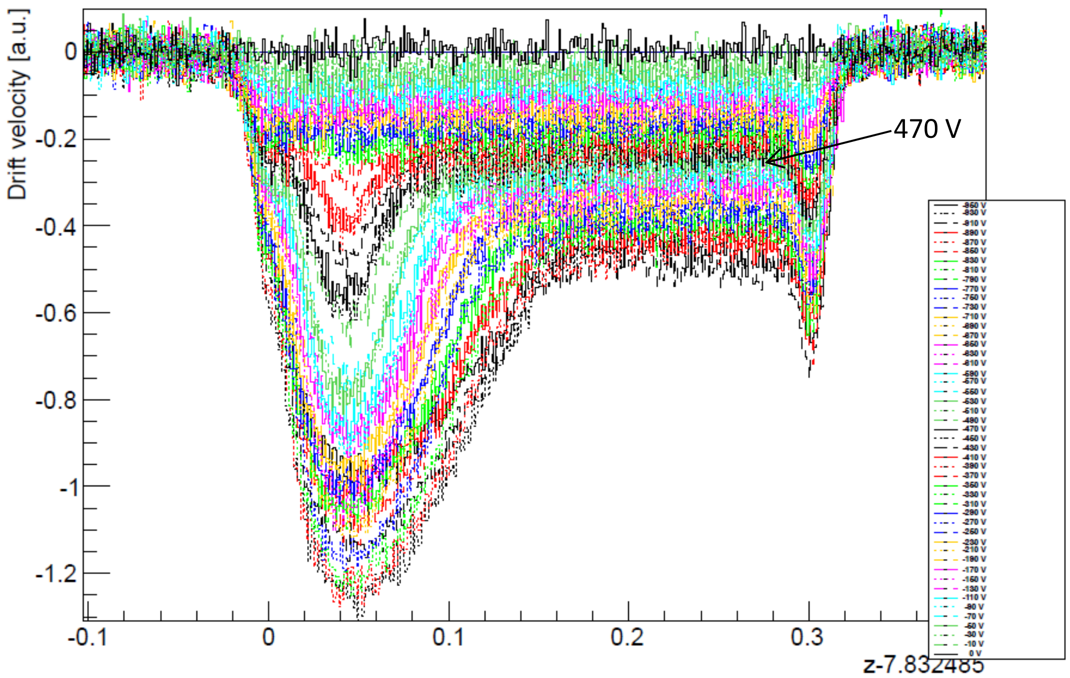
- With increasing bias voltage the collected charge at the 5th strip increase
- Sensitive distance from readout strip increase as well

P80-W6, $5\times10^{15}\ n_{eq}/cm^2$

edge



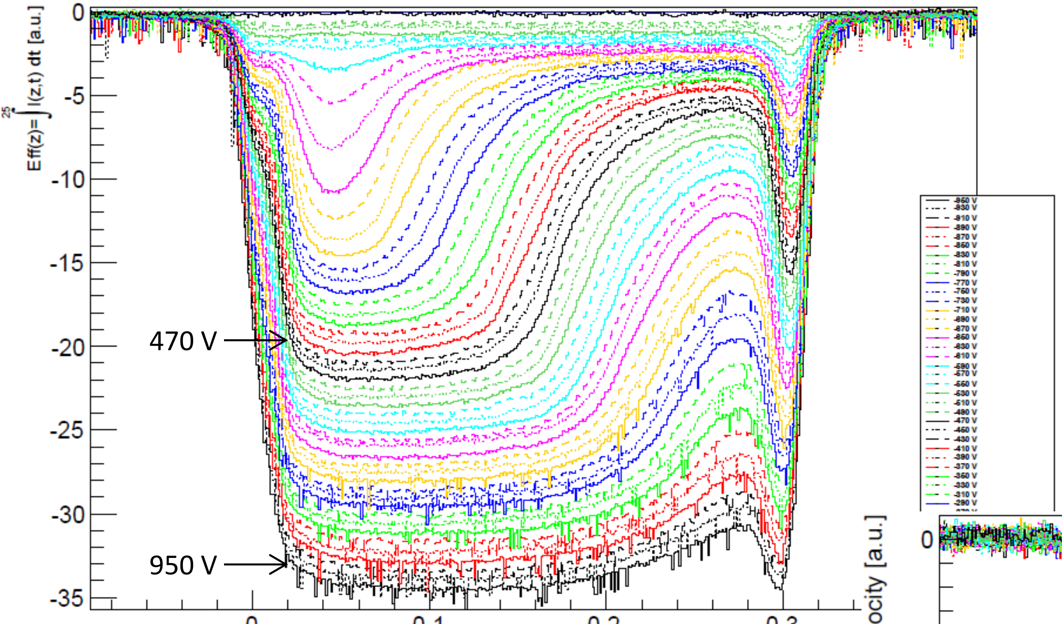
Efficiency correlated to charge, drift velocity correlated to electric field

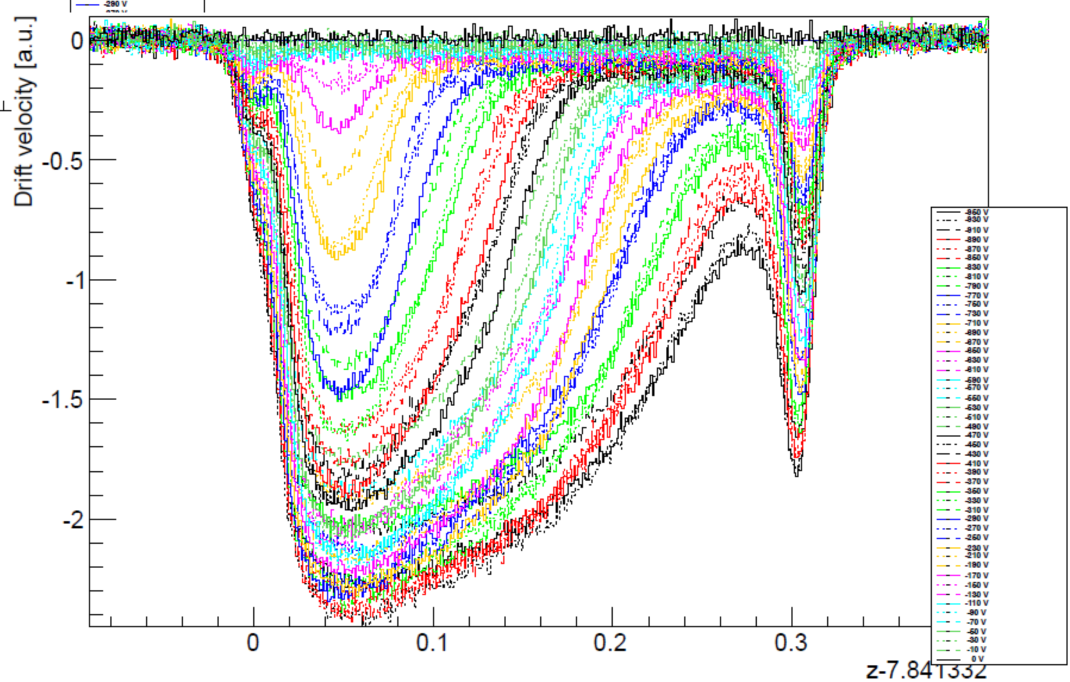


- Highest efficiency at p-n junction
- With increasing bias voltage, high efficiency region "grows"
- Peak on backside most likely because of doping concentration difference between bulk (p) and backside contact (p+)

P40-W15-I15, 1×10^{15} n_{eq}/cm^2

edge





- Sensor almost complete depleted at 950V

Summary/Conclusion

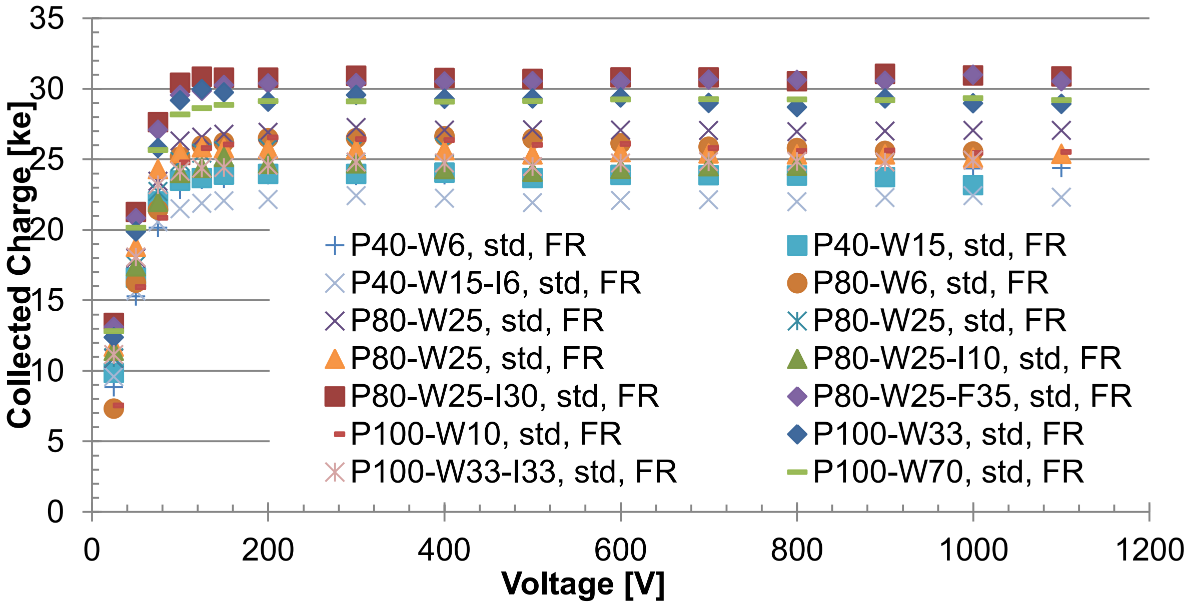
- No charge multiplication observed in unirradiated sensors
- No sign of charge multiplication after proton irradiation with 1×10^{15} n_{eq}/cm^2; measured noise is nearly constant in full voltage range
- Neutron Irradiation with 1×10^{15} n_{eq}/cm^2
  - P80-W25 and P80-W60 (both std) show signs of charge multiplication
- Neutron Irradiation with 5×10^{15} n_{eq}/cm^2
  - Three wafer types (2E imp, extra diff, thick) show signs of charge multiplication for voltages higher than 600V with no decrease in the signal-to-noise ratio
  - Enhancement of charge is small, but consistent among wafer types relative to std for various sensor geometries
  - Low Width/Pitch ratio leads to more multiplication, as expected since fields are larger at strip edge
- Detectors with intermediate strips show less collected charge than sensors without
  - Detectors with floating intermediate strips show only a small deficit
  - Detectors with biased intermediate strips show clearly a charge deficit
- Annealing:
  - The collected charge of P80-W25-I35 (std), irradiated to 1×10^{15} n_{eq}/cm^2, increase in the first few days and than decrease
  - For P80-W25-I35 (std), irradiated to 5×10^{15} n_{eq}/cm^2, the collected charge is increasing with annealing time for voltages above 1200V, which is caused by charge multiplication
- TCT/eTCT
  - First measurements of sensors performed
  - Increase of depleted region with increasing bias voltage clearly visible
  - Measurements of further sensors will follow

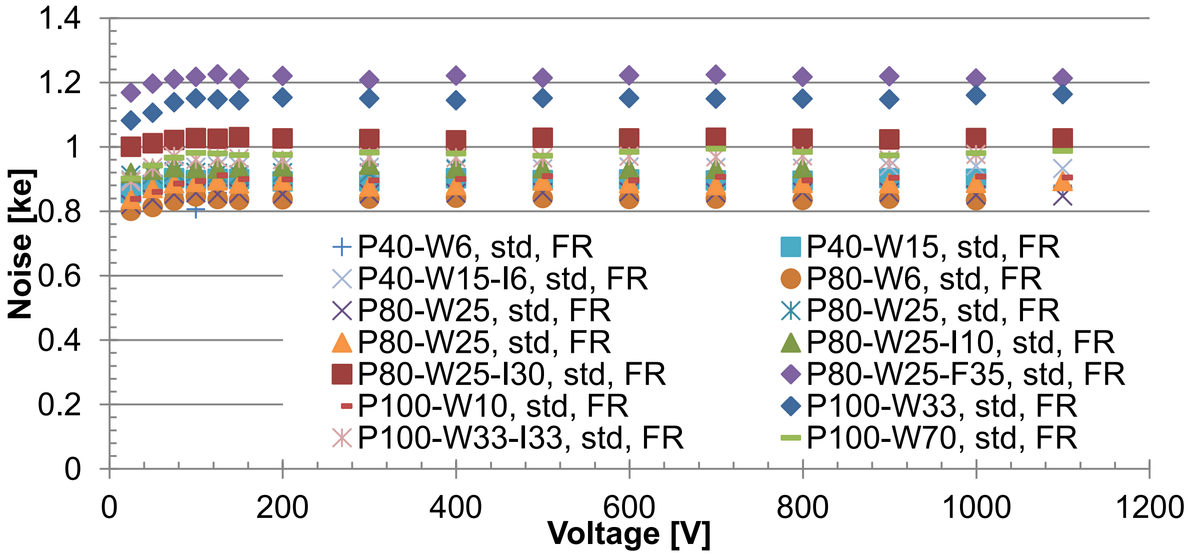
Acknowledgements

- Irradiations supported by the Initiative and Networking Fund of the Helmholtz Association, contract HA-101 ("Physics at the Terascale")
- The research leading to these results has received funding from the European Commission under the FP7 Research Infrastructures project AIDA, grant agreement no. 262025
- We would like to thank the irradiation teams at Ljubljana and Karlsruhe
- We would like to thank Christian, Marcos , Hannes and Michael at CERN for the help wit the TCT measurements and sharing their setups.

BACKUP

Unirradiated Results



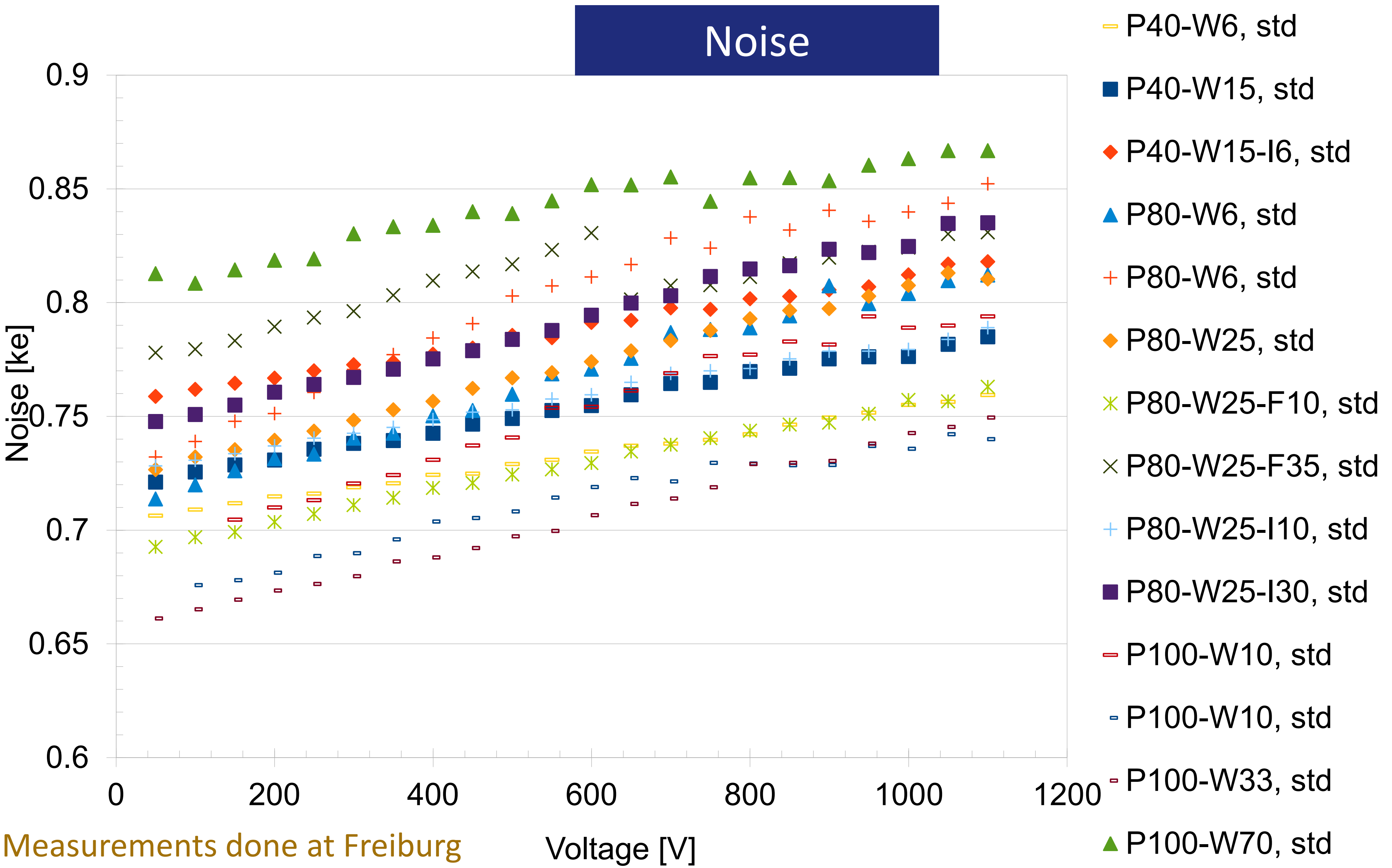


- Full depletion reached at 100-125V
- No charge multiplication observed up to 1100V
- Most sensors show no breakdown up to 1100V
- Large spread of collected charge -> see C. Betancourt, 21st RD50 Workshop

Measurements done at Freiburg

Proton Irradiation 1×10^{15} n_{eq}/cm^2

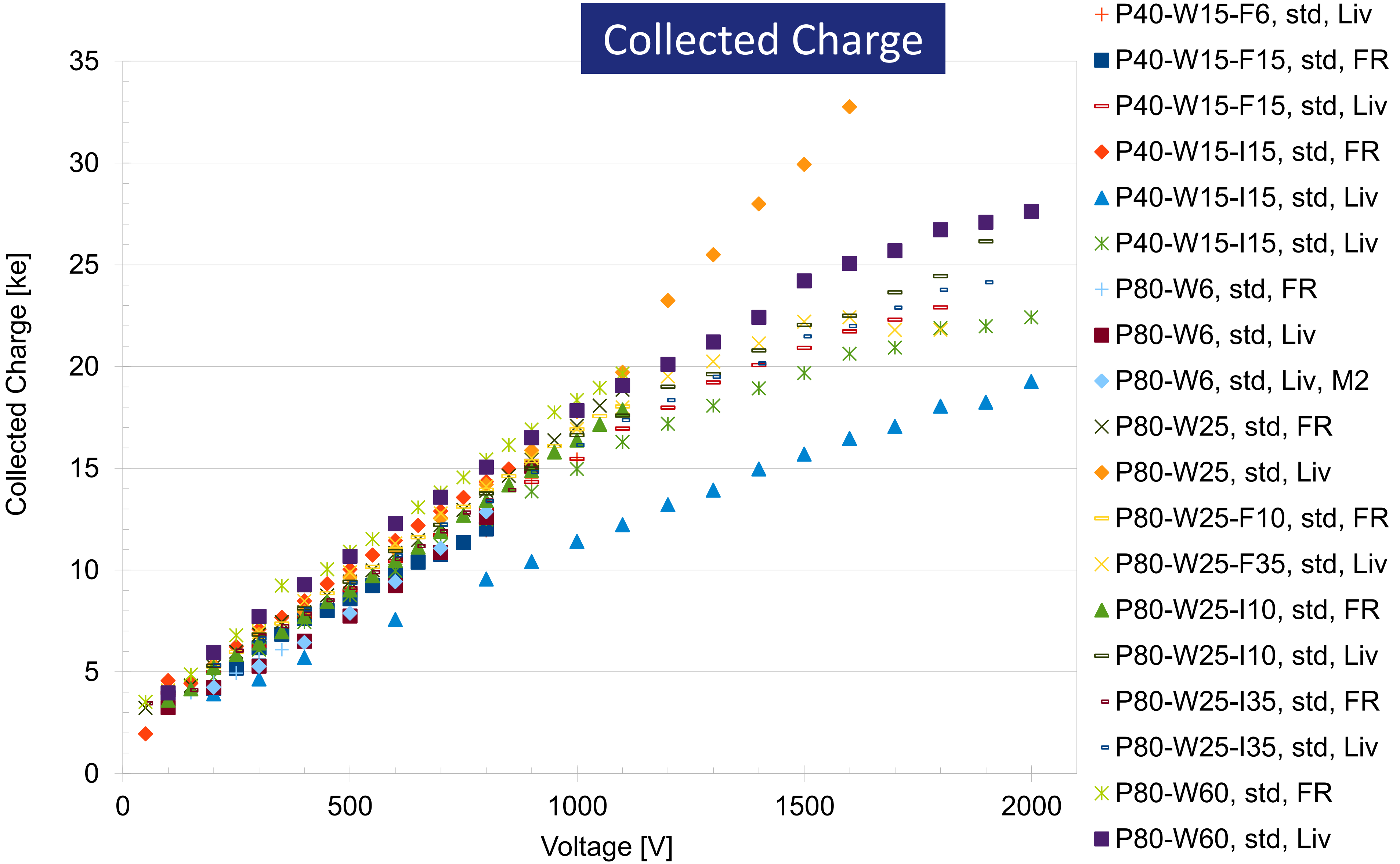
Noise



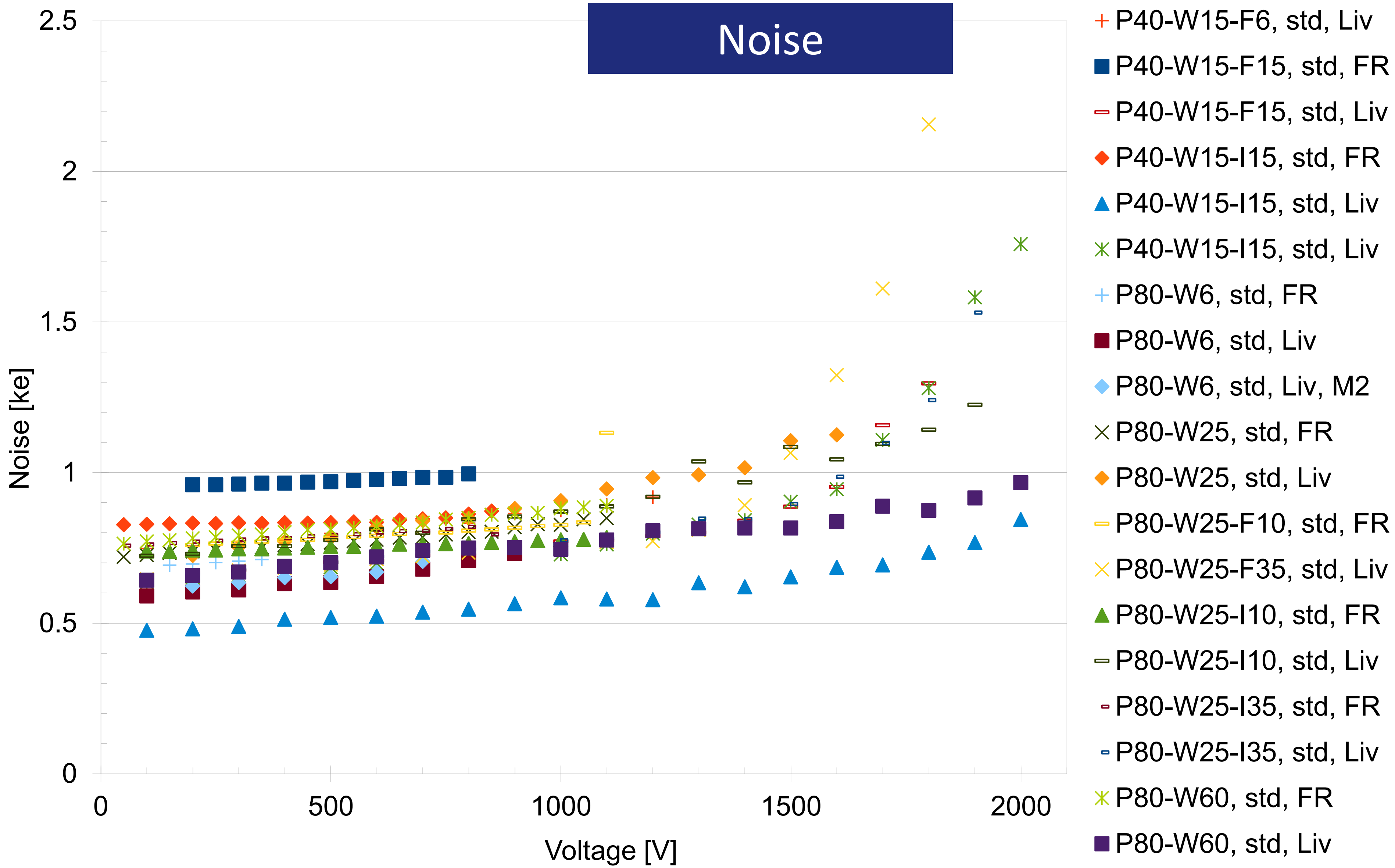
Measurements done at Freiburg

Neutron Irradiation $1\times10^{15}\ n_{eq}/cm^2$

Collected Charge

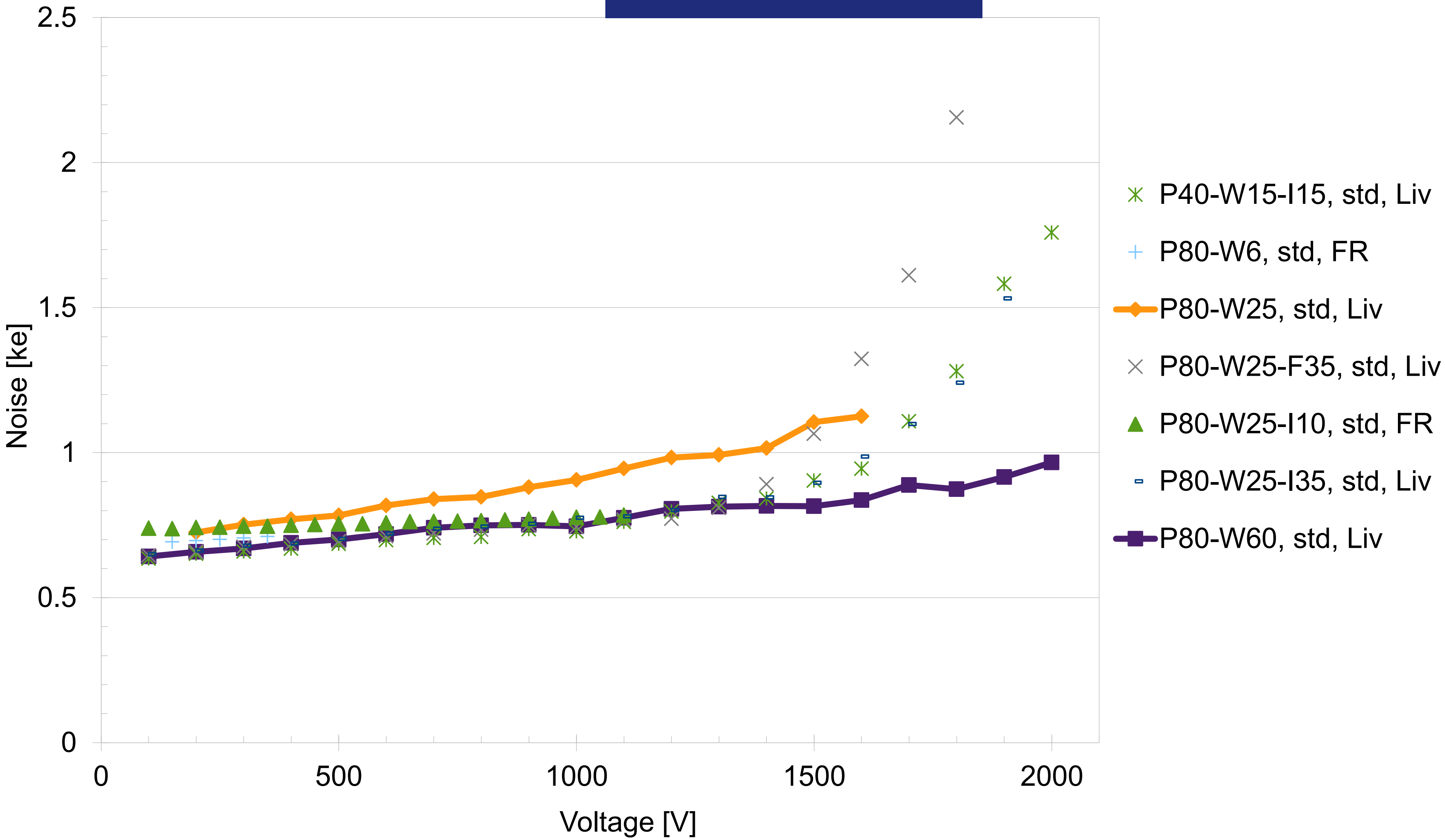


Neutron Irradiation 1×10^{15} n_{eq}/cm^2

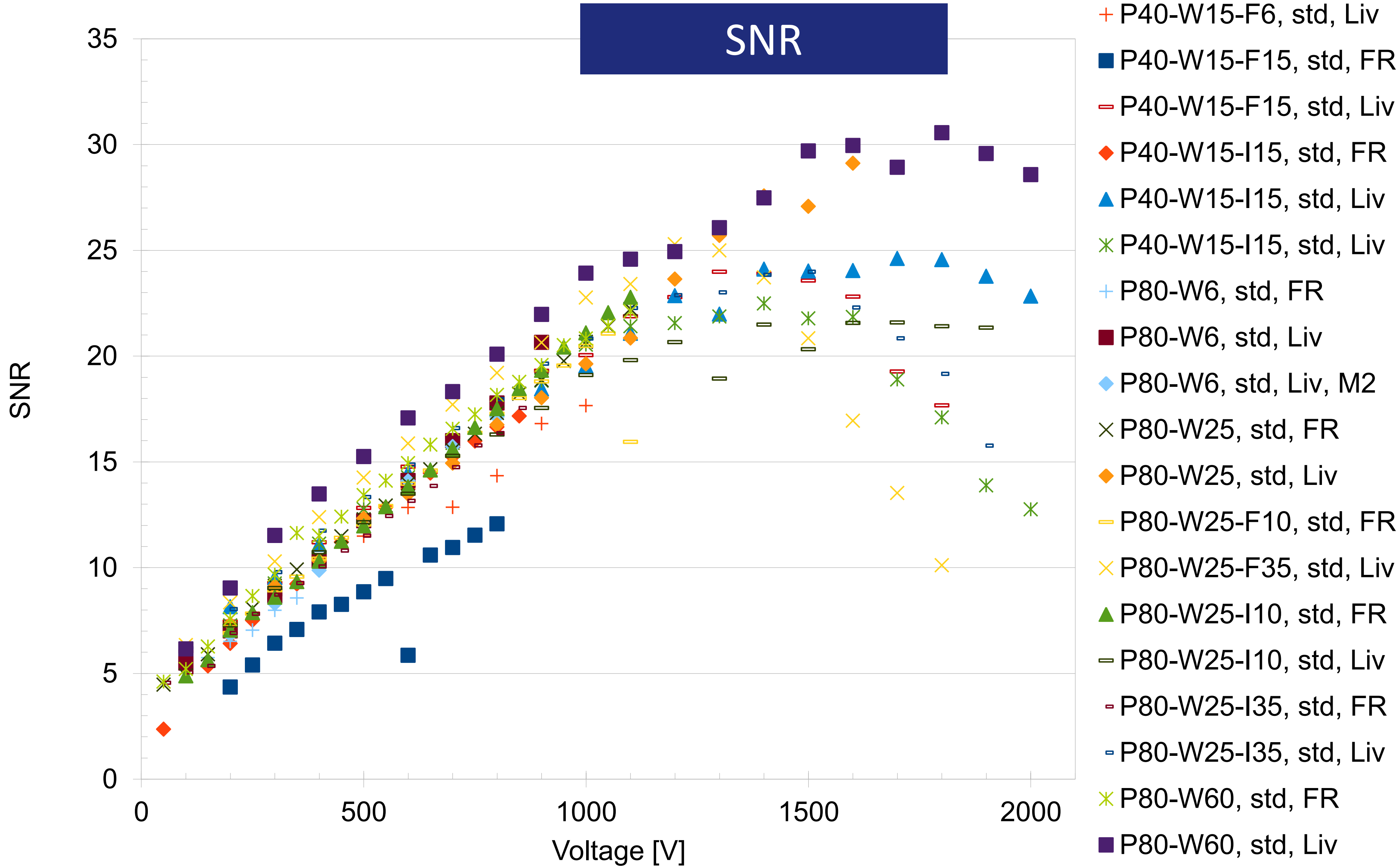


Neutron Irradiation $1\times10^{15}\ n_{eq}/cm^2$

Noise

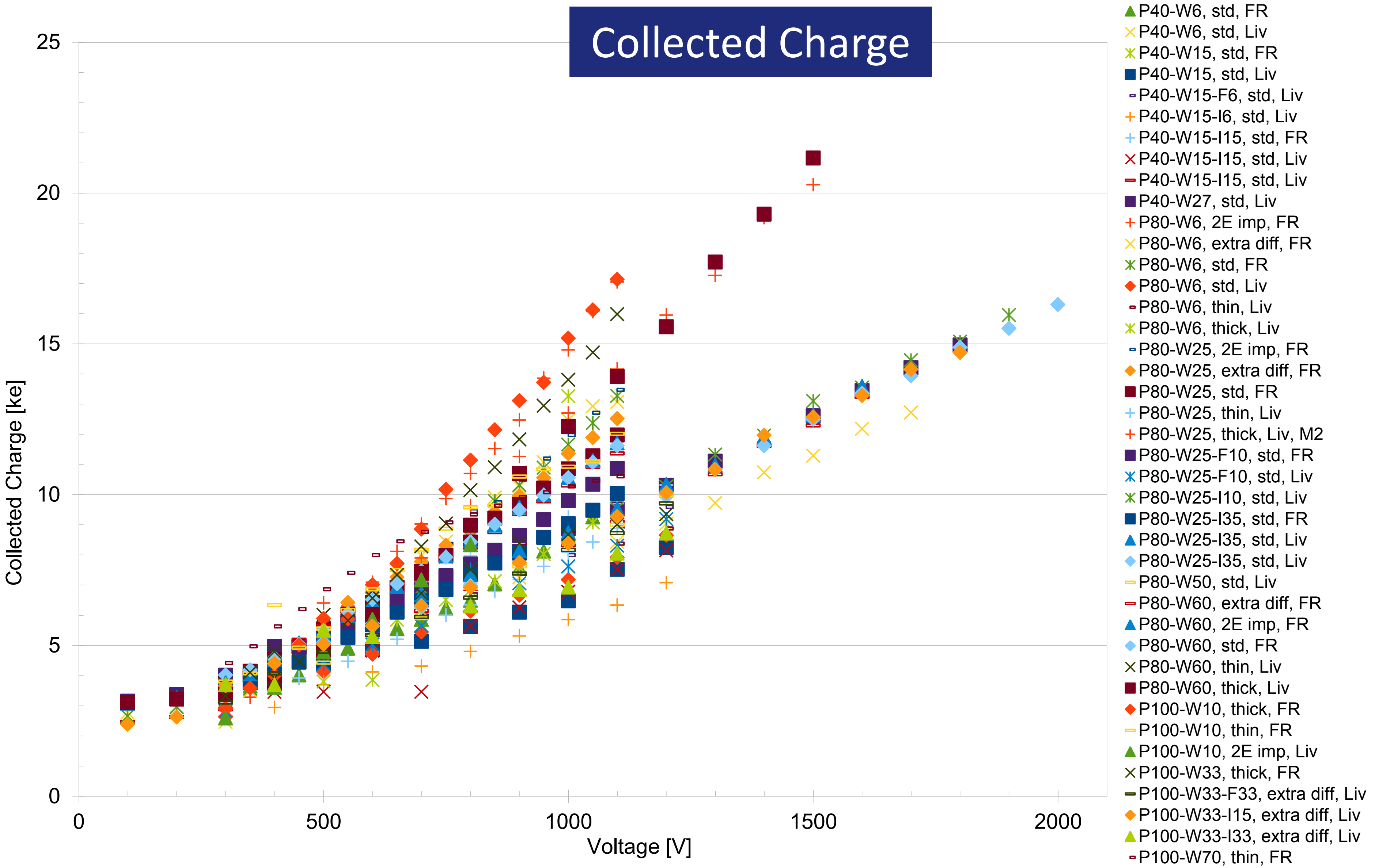


Neutron Irradiation $1\times10^{15}\ n_{eq}/cm^2$



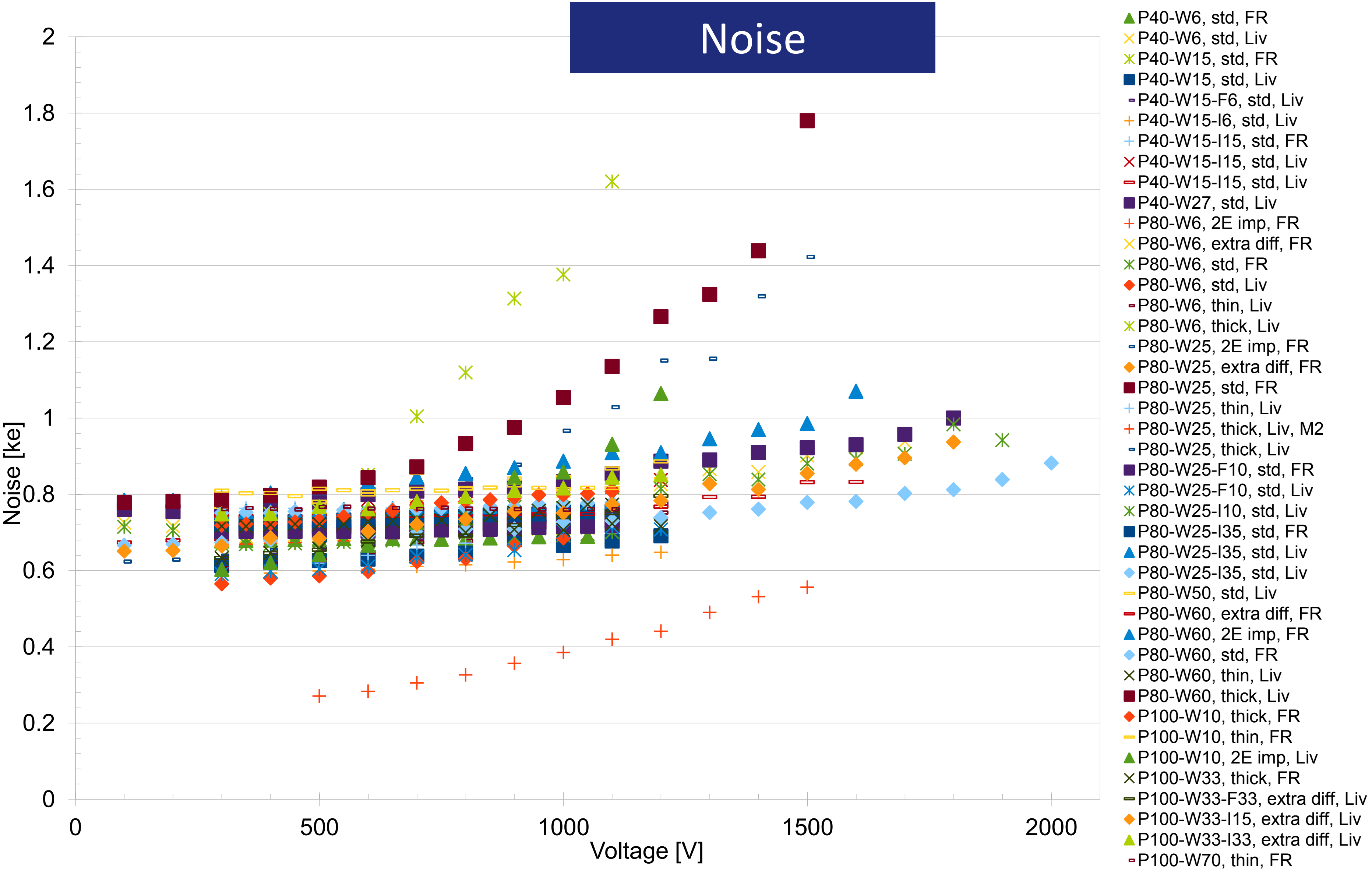
Neutron Irradiation $5\times10^{15}\ n_{eq}/cm^2$

Collected Charge



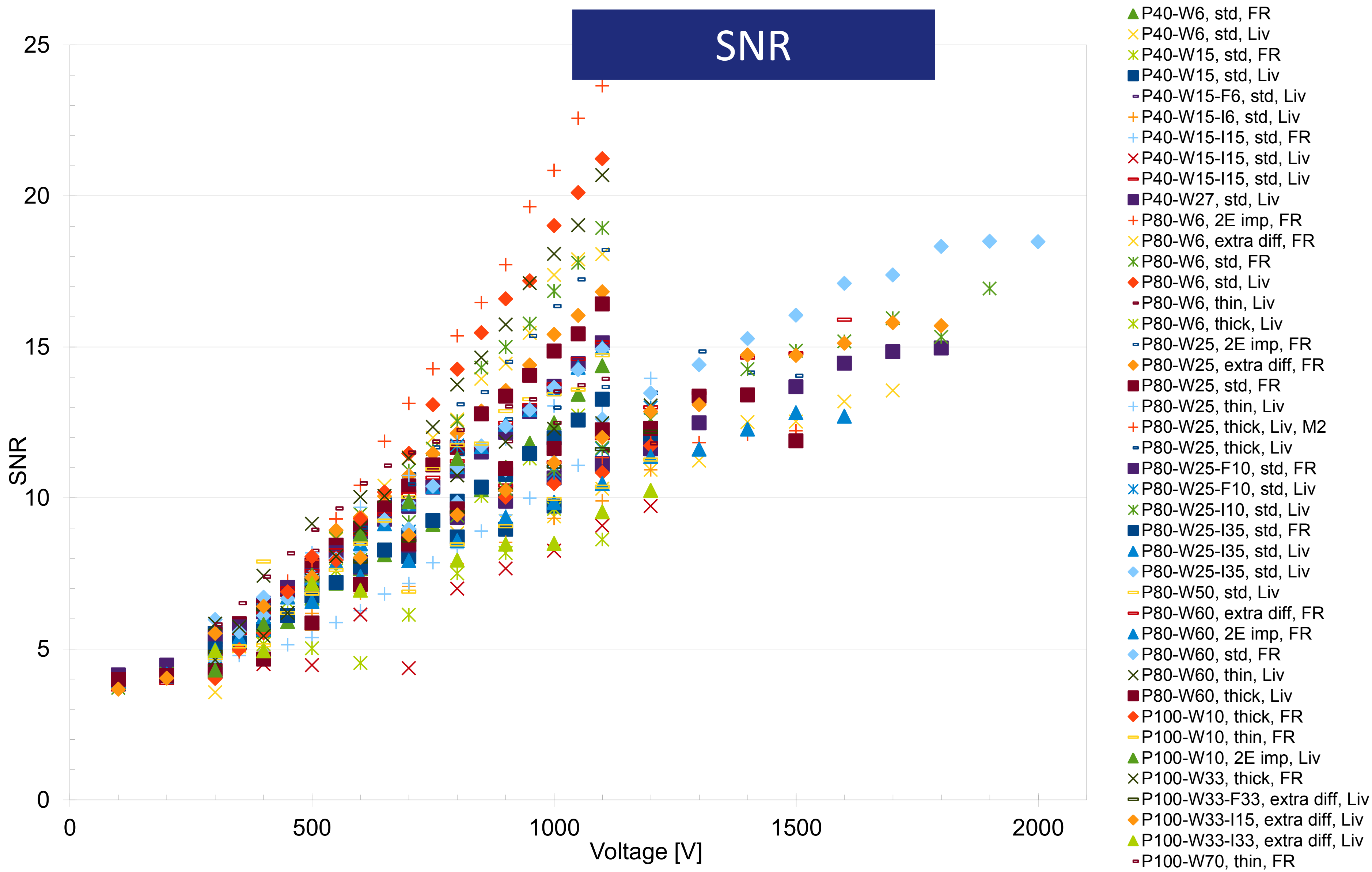
Neutron Irradiation $5\times10^{15}\ n_{eq}/cm^2$

Noise

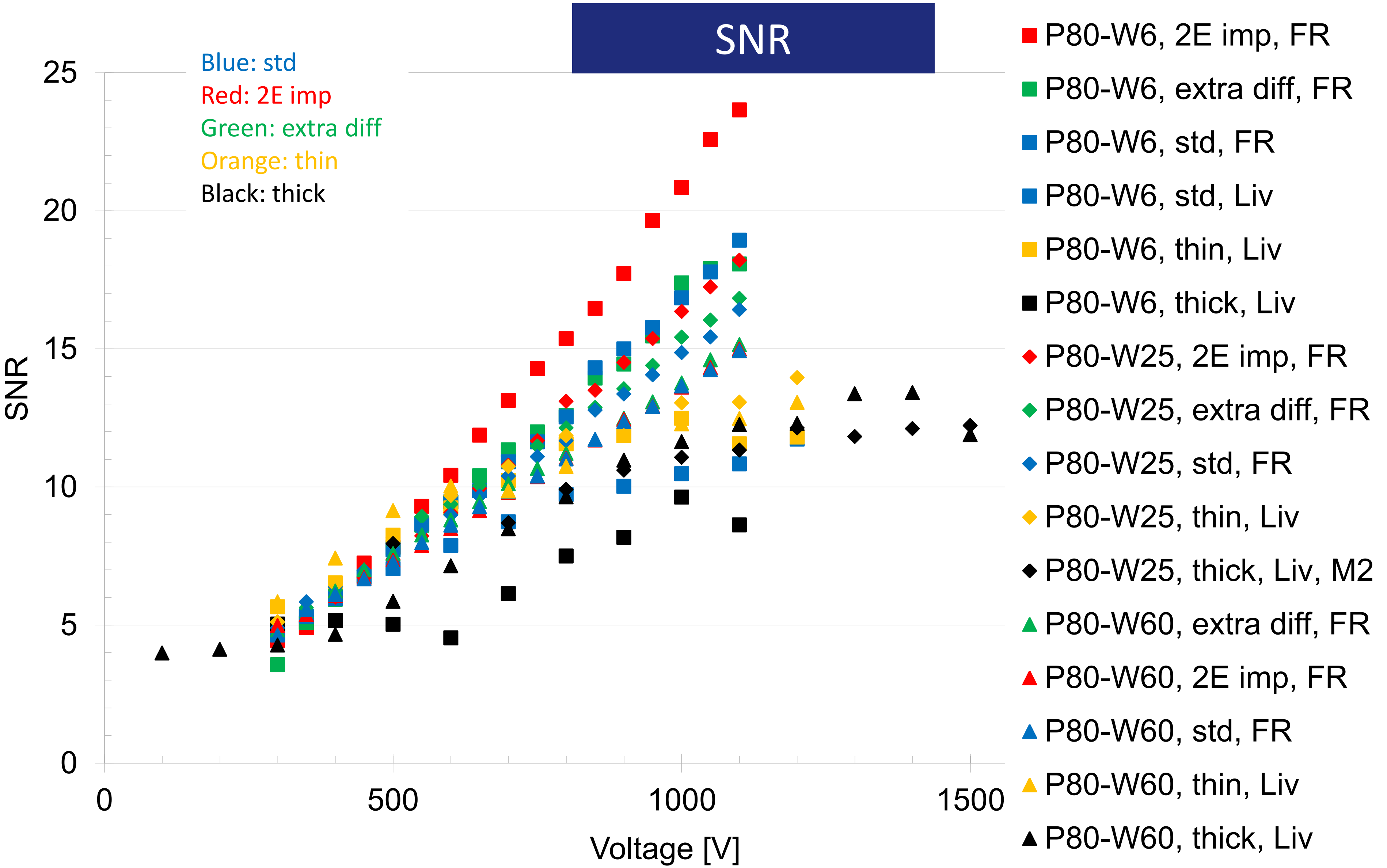


Neutron Irradiation $5\times10^{15}\ n_{eq}/cm^2$

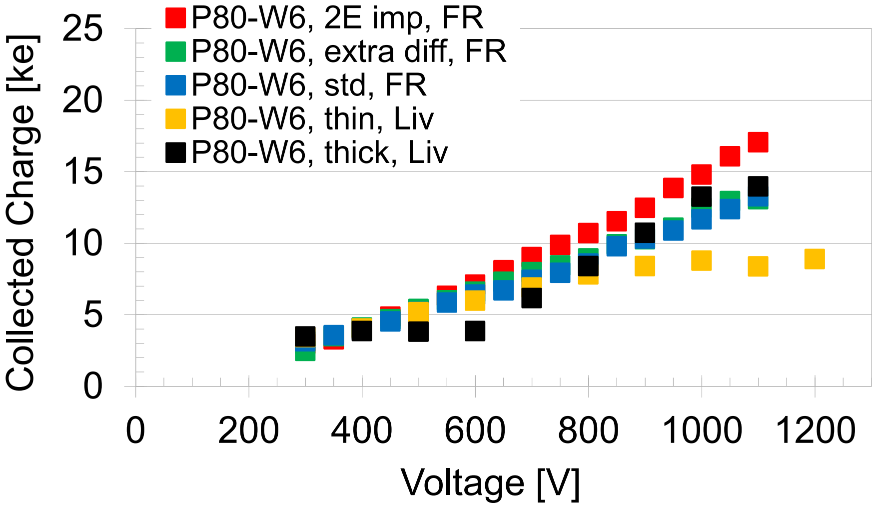
SNR

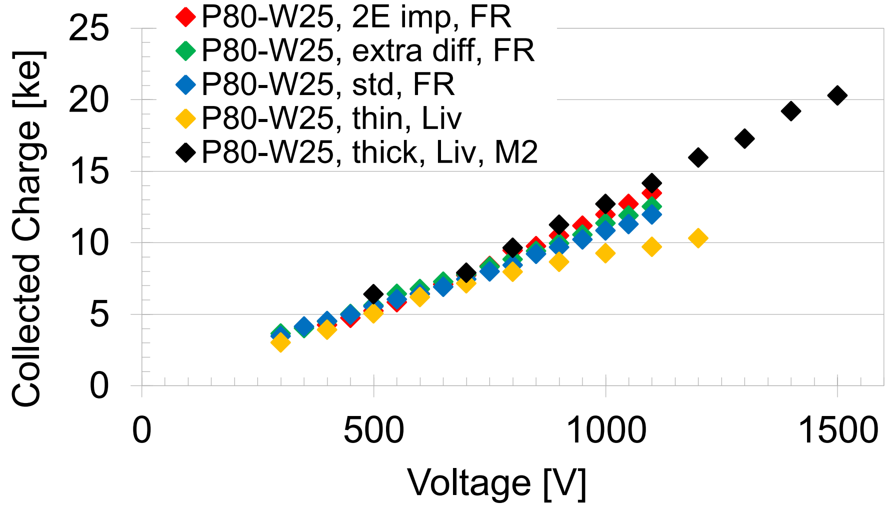


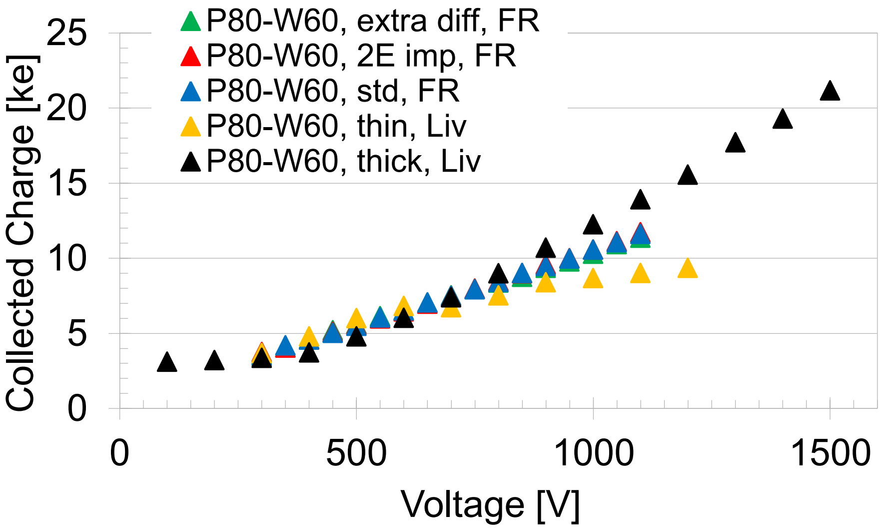
Neutron Irradiation 5×10^{15} n_{eq}/cm^2



Neutron Irradiation $5\times10^{15}\ n_{eq}/cm^2$







Double implant energy (2E imp) and thick sensors show in general more collected charge