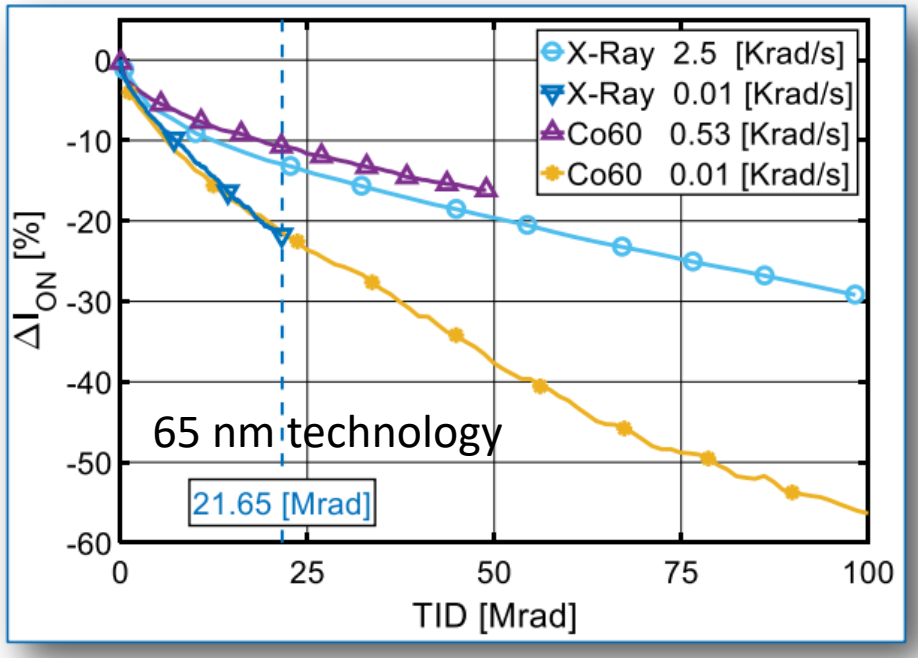
Investigation of LGAD performance dependence on neutron flux

Motivation

- LGADs will at HL-LHC exposed to fluxes of particles around 10^7-10^8 cm^2 s^{-1}
- Most of the irradiation studies done so far use fluxes which are much larger than that (typically ~10^{12} cm^2 s^{-1} at JSI reactor)
- Dose rate effects observed in electronics and present a major problem (depends on bias/temperature/annealing) – safety factors
- Question do we see that also in the bulk?
  - studies showed no flux effect on Neff/Ileak (D. Zontar et al.)
  - effects to removal of initial dopants was not studied to our knowledge
- Possible dependence of initial acceptor removal rate would have a large implication to operation of LGADs at HL-LHC
  - positive in case of smaller removal at low rates
  - negative in case of larger removal at low rates



F. Faccio, HSTD11, Okinawa, 2017

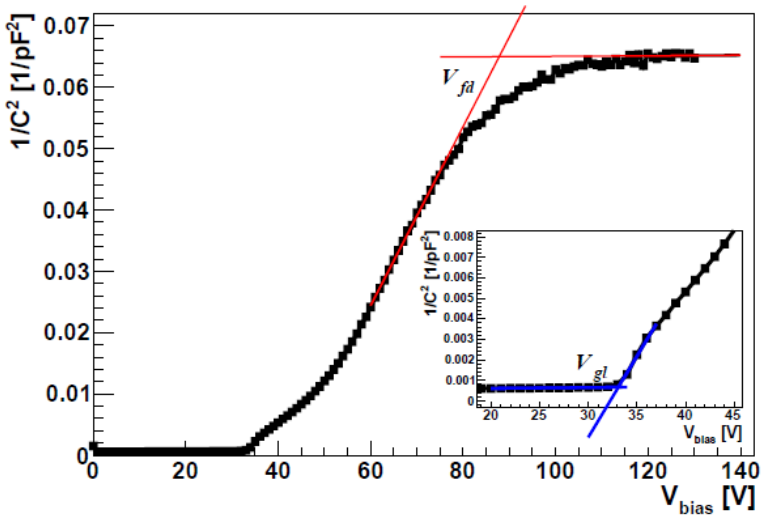
Reasons for possible flux effects

- The main channel for removal of initial acceptors is: Bs+I->Bi which is followed by reactions of Bi with other impurities and defects
- Different mobilities of Vacancies (V) and Interstitials (I) can lead to different recombination rate of V-I if more are created close in space and time and don't have time to react with other impurties
- Smaller recombination could effectively lead to larger removal at low fluxes ☹
- As the mechanisms are not fully know a check is required.

Samples used in the study

- LGADs from ATLAS-HGTD prototype run with HPK were used – they different in implant dose and also in depth profile of the implant

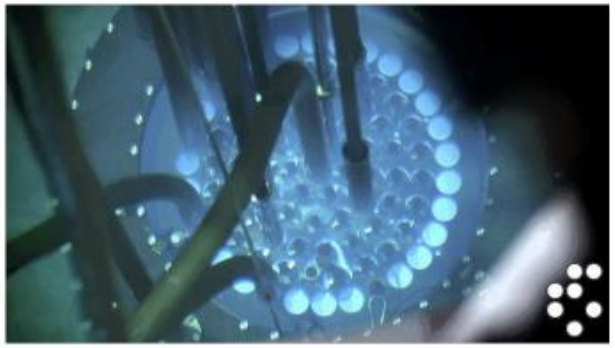
Sample name	Thickness	Vgl [V]	Vfd [V]
HPK-3.1-50	50 mm	42	49
HPK-3.2-50	50 mm	56	64



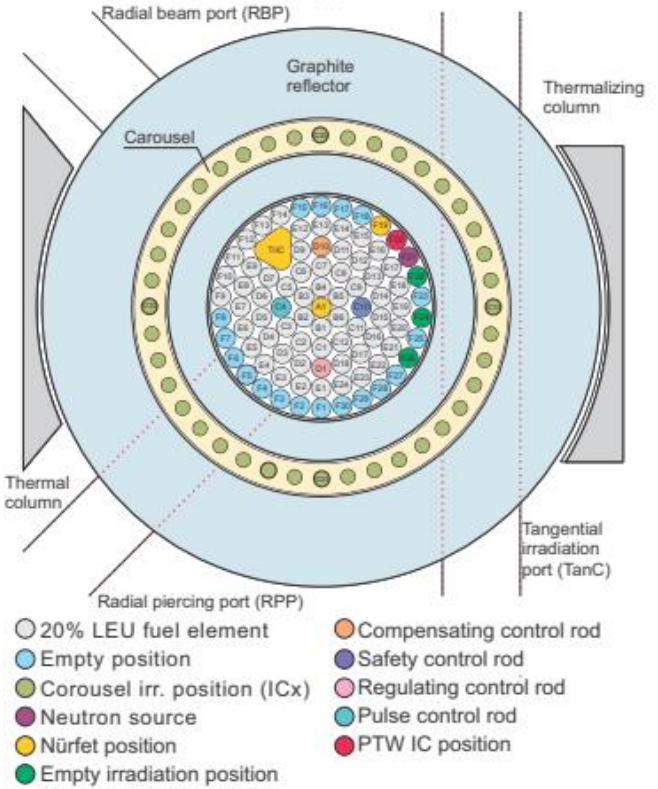
- Samples were studied
  - with CV/IV at 20oC and 10 kHz to determine Vgl, Vfd
  - Timing setup to verify that there is no impact to timing performance as well
- All samples were annealed for 80min @ 60oC after irradiation to wipe out different history during irradiations

Irradiations

- Samples were irradiated with reactor neutrons at three different fluxes
  - 1.55e12 cm-2 s-1 (250 kW, F19 channel – our standard irradiation flux)
  - 1.55e10 cm-2 s-1 (2.5 kW, F19 channel)
  - 7e12 cm-2 s-1 (250 kW, Central channel)
- All samples were irradiated to the same fluence of 4e14 cm-2
  - Effects on Vgl are clearly visible
  - Timing measurement can be accurately performed
  - A wide flux range can be practicaly studied
    - 26000 s for slow (F19)
    - 260 s for standard (F19)
    - 57 s for fast (CK)

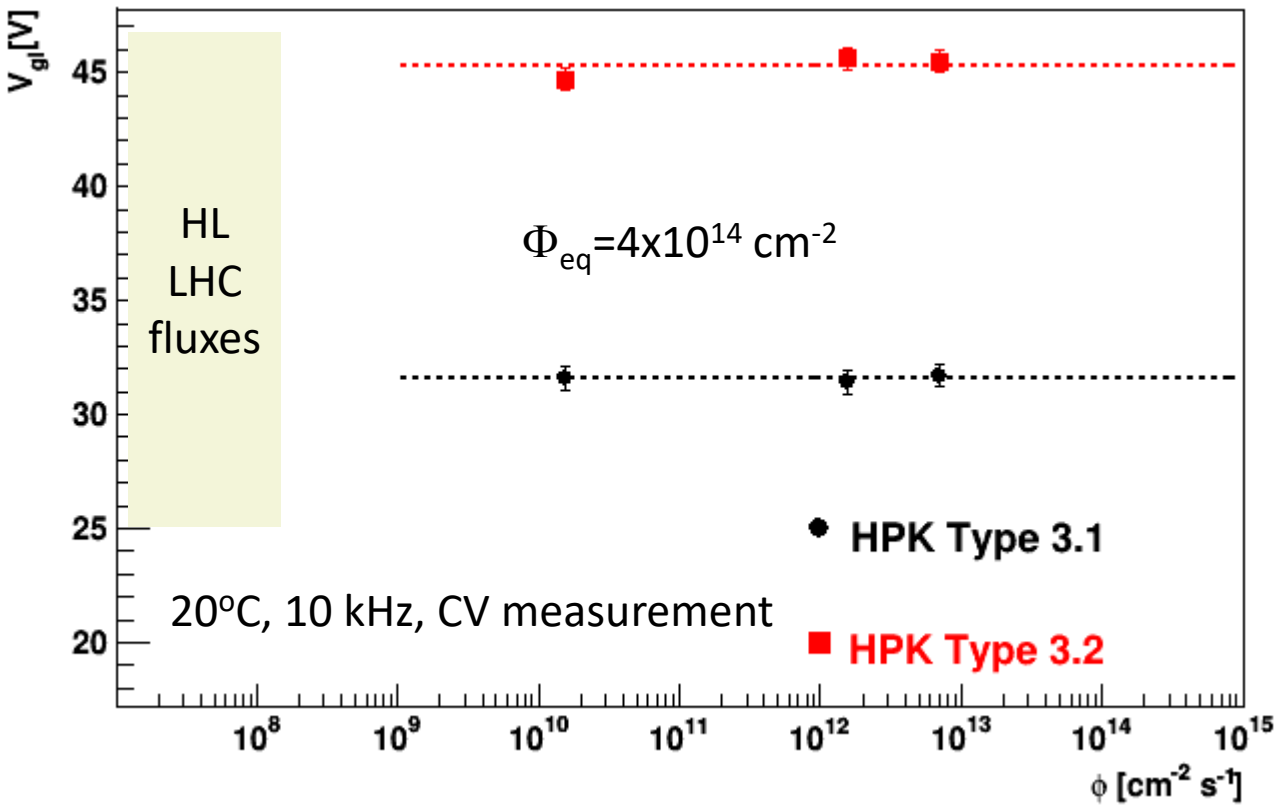


(a)



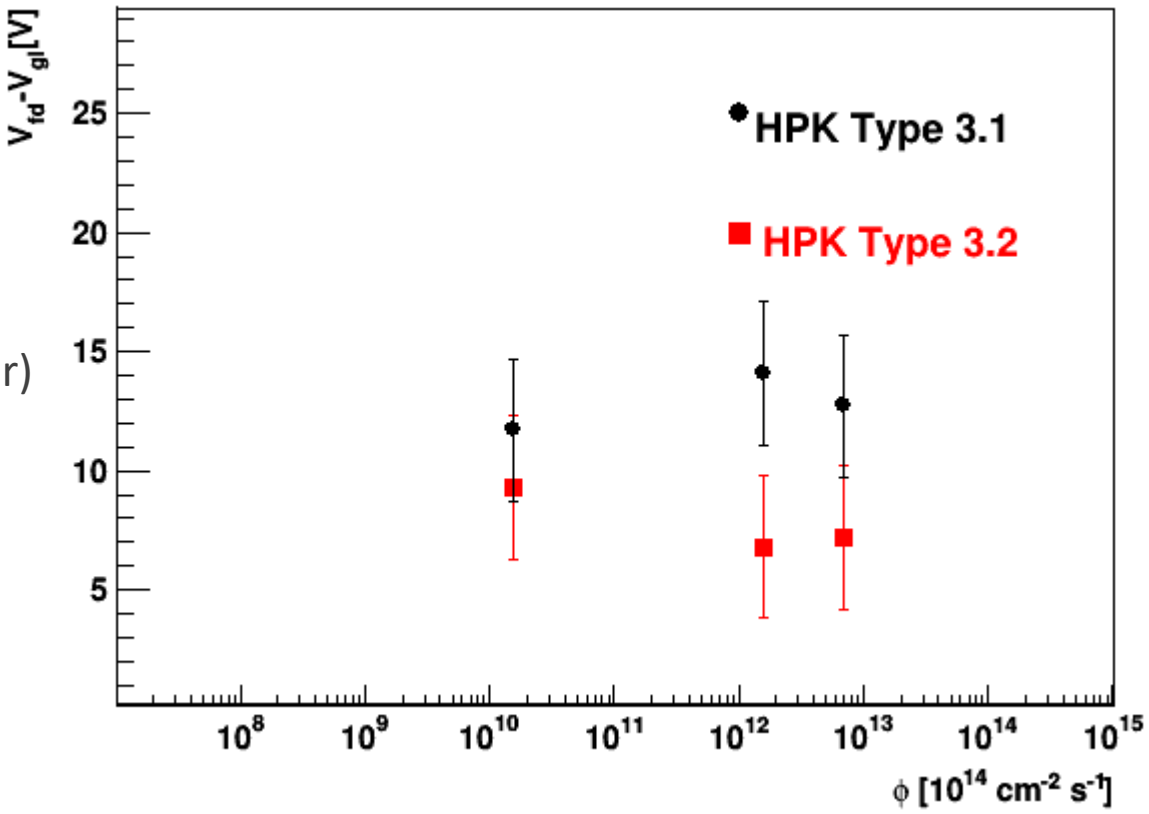
Measurements of gain layer depletion

- There is no flux impact on Vgl for both investigated samples with different implant profiles
- We are still two orders of magnitude away from HL-LHC fluxes, but the flux rate seem not to play a role on effective acceptor removal



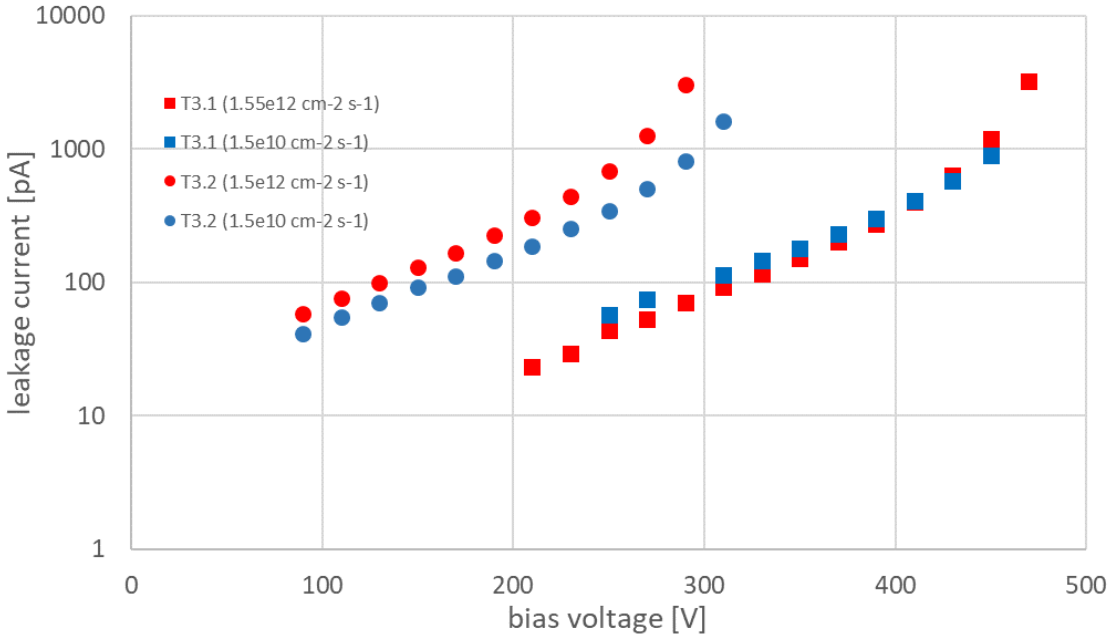
Depletion of the bulk

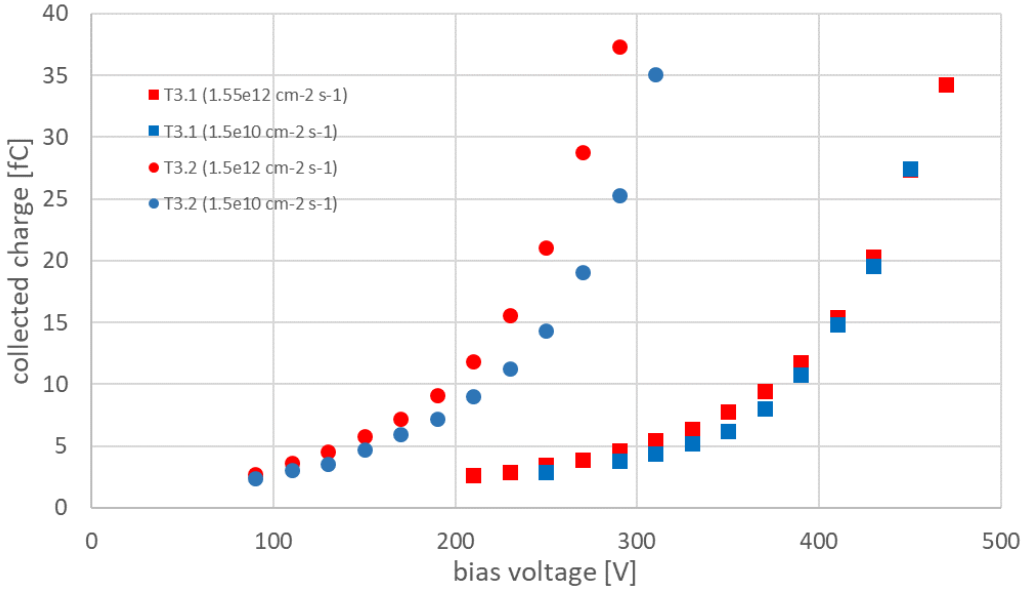
- There is no flux impact on bulk depletion voltage for both investigated samples with different implant profiles
- The result is in agreement with previous observations
  - More difficult to determine the Vfd (larger systematic error)
  - if full initial acceptor removal is assumed the gc=0.01-0.016 cm-1 which is compatible with standard introduction rate in FZ



Charge and Timing measurements

- At high voltages there may be effects not revealed by Vfd and Vgl measurements and may impact timing resolution and charge collection
- CC and timing measurements are the ultimate benchmark, therefore all detectors were tested with Sr90 setup to very high bias voltages for performance





Conclusions and future work

- In the investigated flux range of 10^{10} – 10^{13} cm^{-2} s^{-1} no flux dependence on the damage was found – gain layer and bulk
- The gain and timing performance of all the sensors at high operation voltages was similar – no effects of different flux observed
- This is still 2 orders of magnitude larger than rates at HL-LHC, but it is very probable that the flux effects are not present
- Plans:
  - we can't irradiate for months, so it is not possible to go to much lower fluxes
  - We will go to high fluxes 10^{15}-10^{16} cm^{-2} s^{-1} with reactor operating in pulse mode (above critical for very short amount of time) in the following months