Studies on irradiated single-crystal diamond sensors

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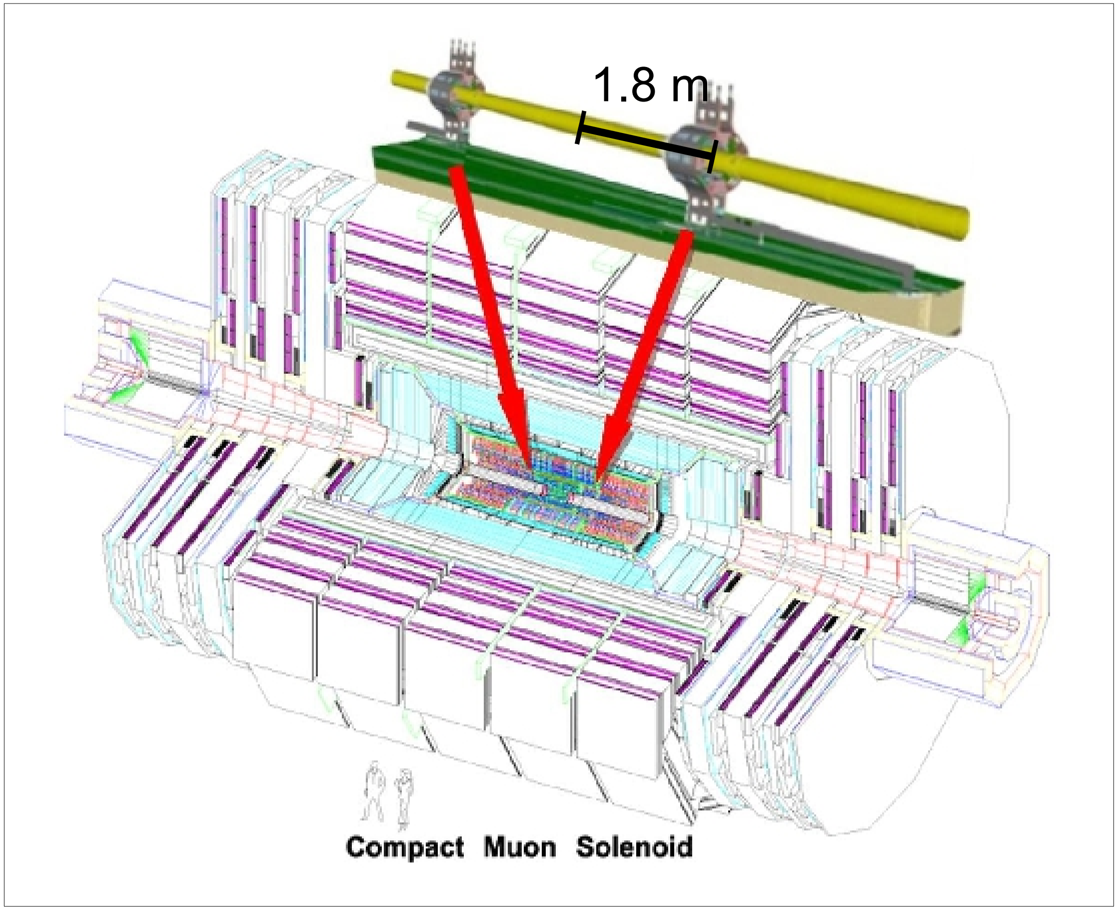
BRIL

Very high particle flux and energies at LHC.

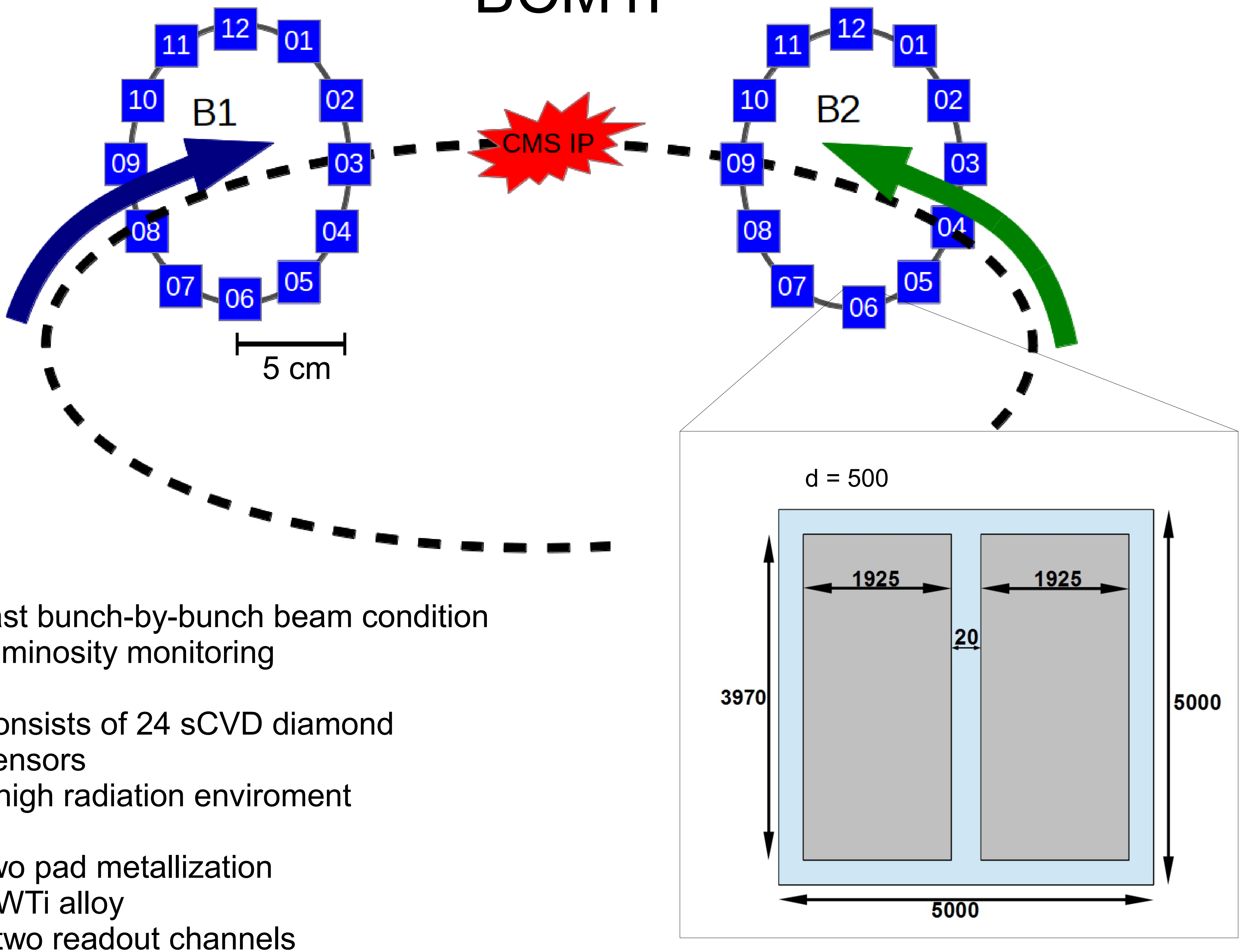
CMS installed several independent subdetectors for Beam and Radiation Instrumentation and Luminosity measurements (BRIL):

- safety: beam losses → damage to the experiments sub detectors
- performance: more luminosity → less pressure on DAQ → better data



- **Fast Beam Condition Monitor BCM1F**
- Low Beam Condition Monitor BCM1L
- Pixel Luminosity Telescope PLT
- Beam Condition Monitor BCM2

BCM1F

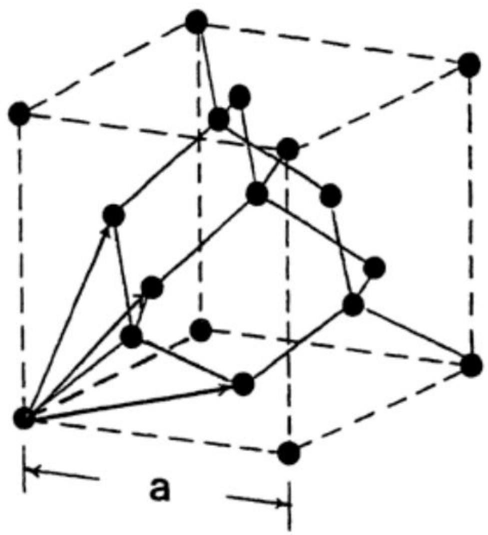


- fast bunch-by-bunch beam condition
- luminosity monitoring

- consists of 24 sCVD diamond sensors
  - high radiation enviroment

- two pad metallization
  - WTi alloy
  - two readout channels

sCVD Diamond

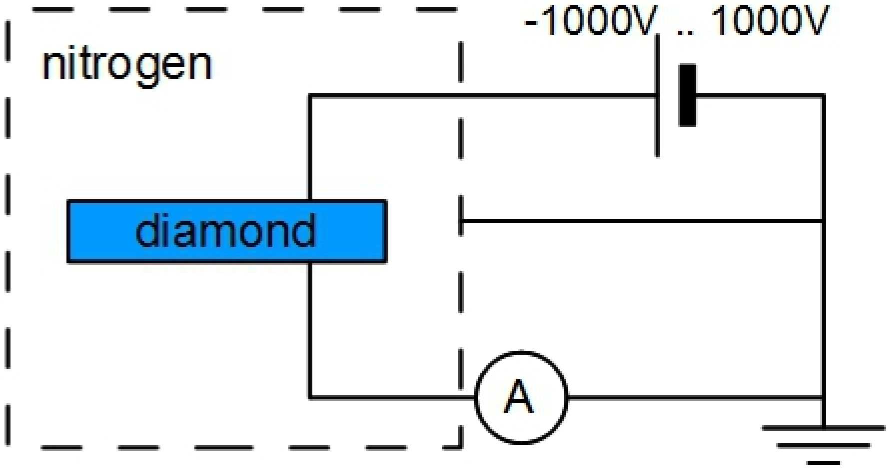


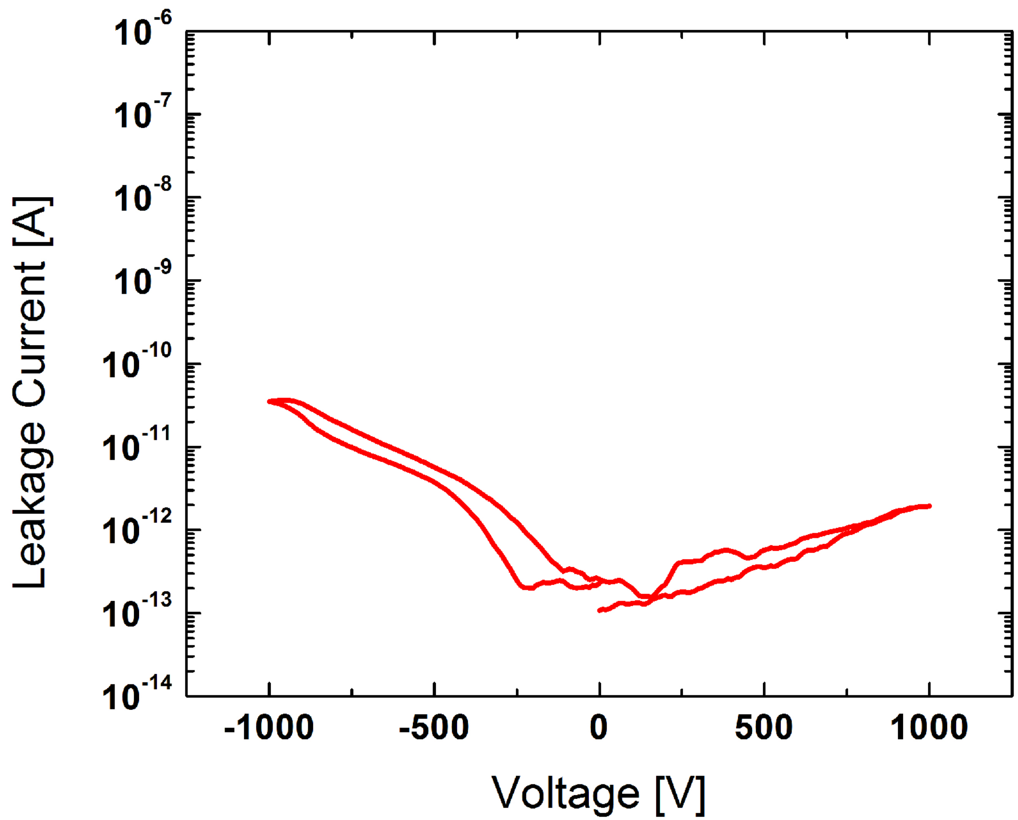
- low leakage current and radiation hard
  → used as solid state ionization chamber for particle detection in high radiation enviroment

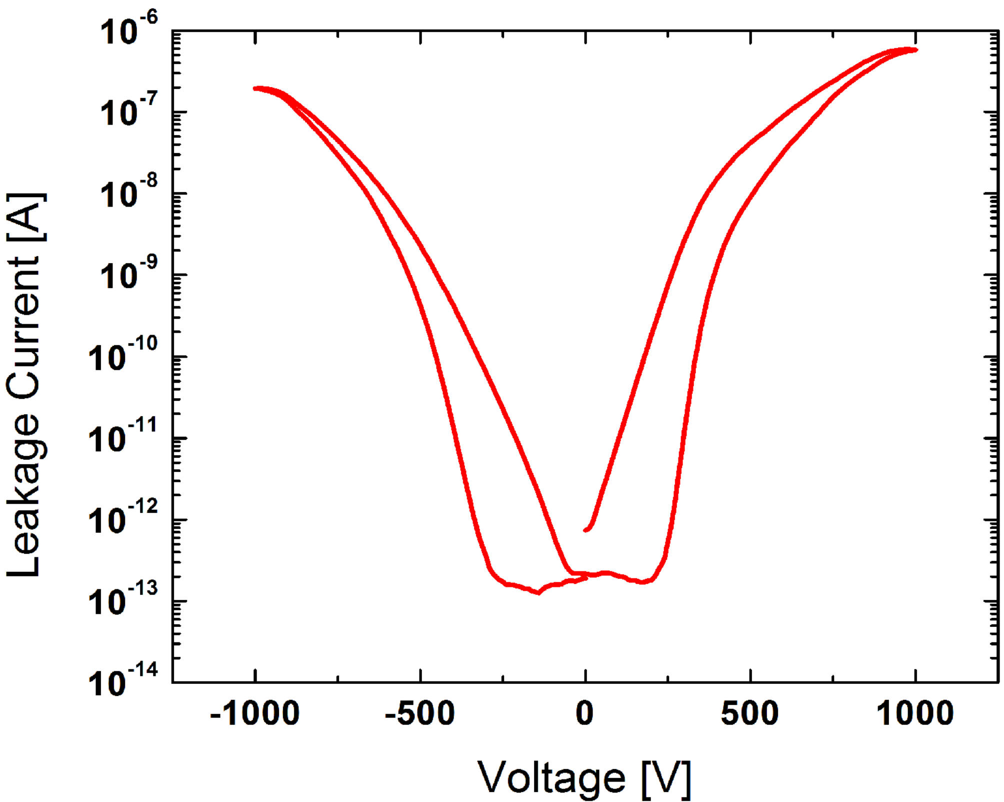
Property	Diamond	Silicon	Units	Results for diamond
Band gap	5.5	1.12	eV	insulator
Specific resistance	$> 10^{11}$	$6.4 \cdot 10^2$	Ωcm	low leakage current
Breakdown field	20	0.3	MV/cm	high bias voltage possible
Electron mobility	4500	1450	cm^2/Vs	fast signal
Hole mobility	3800	480	cm^2/Vs	
Displacement energy	43	< 20	eV per atom	radiation hard
Thermal conductivity	2000	150	W$m^{-1}K^{-1}$	heat spreader
Energy to create e-h pair	13	3.61	eV	low signal
Aver. signal created	3602	8892	e_0 per 100 µm	

electrical measurements

Leakage Current as a function of Voltage





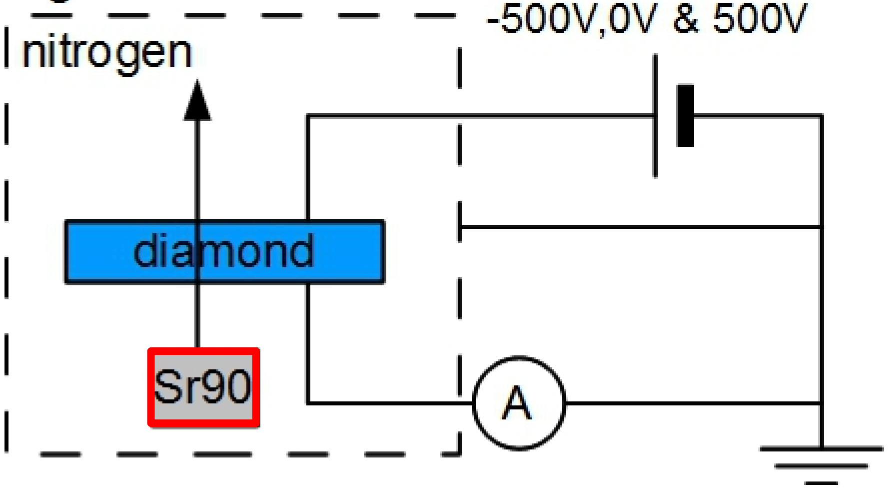


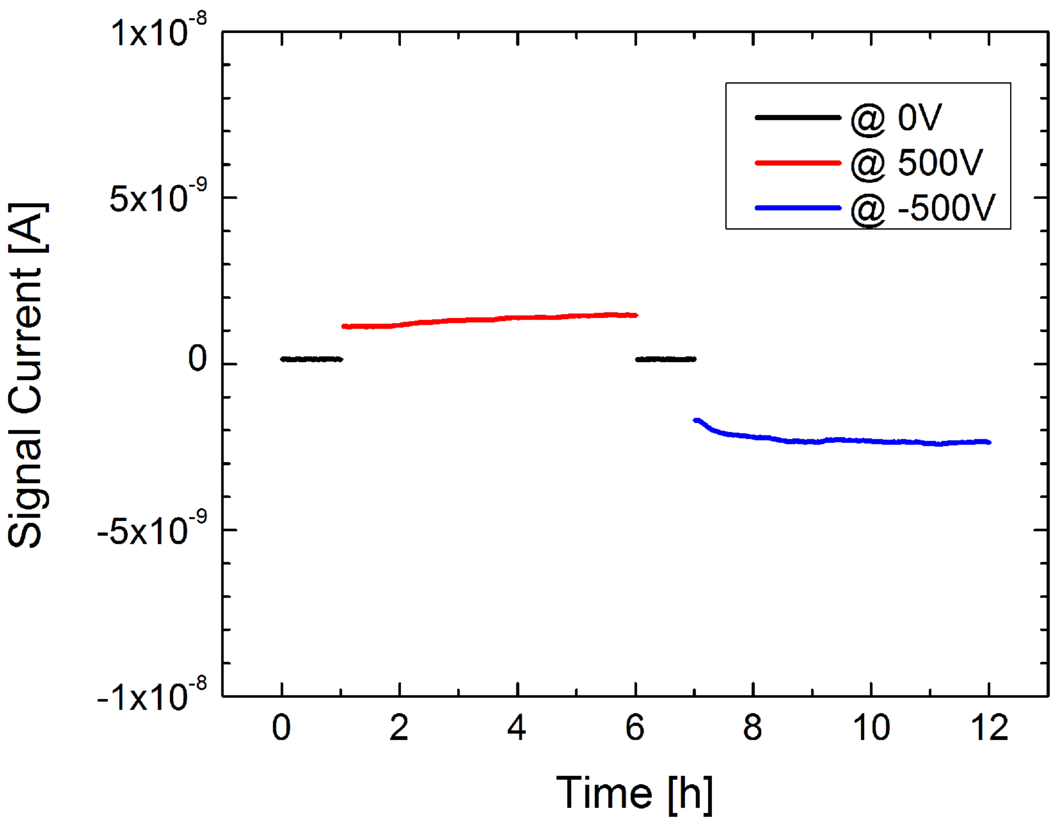
done to observe the leakage current of a diamond sensor

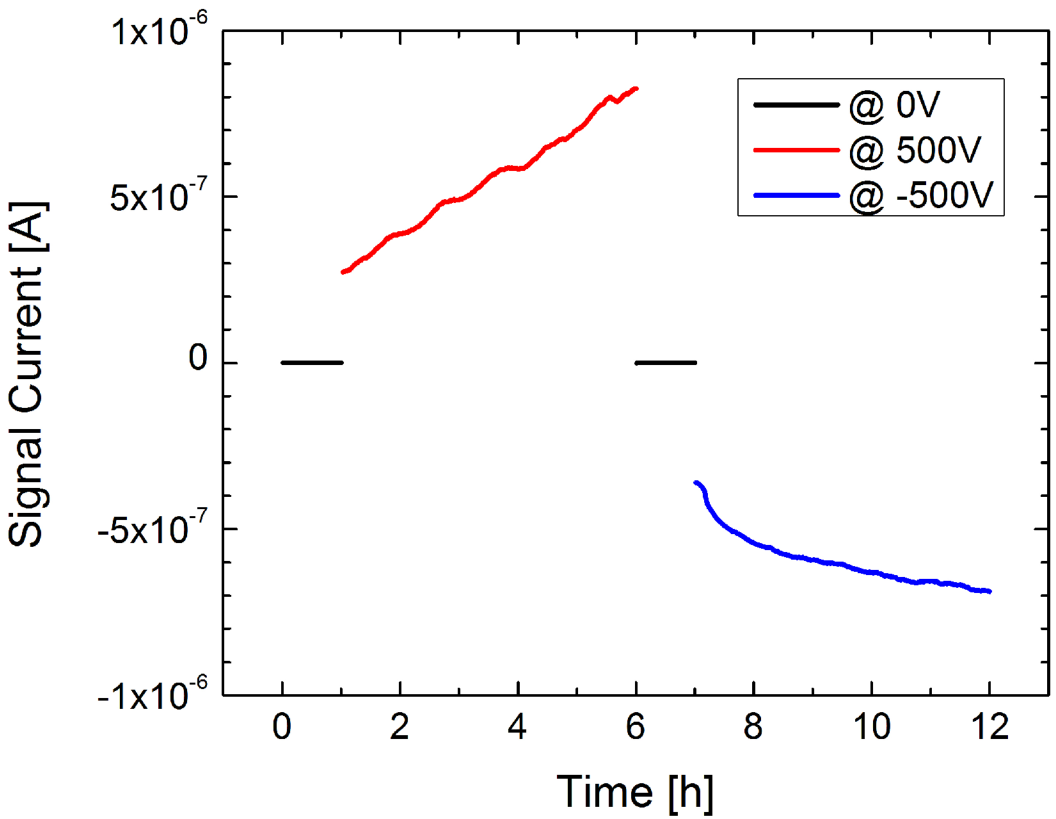
- lower leakage current
  better signal to noise ratio

electrical measurements

Signal Current as a function of Time

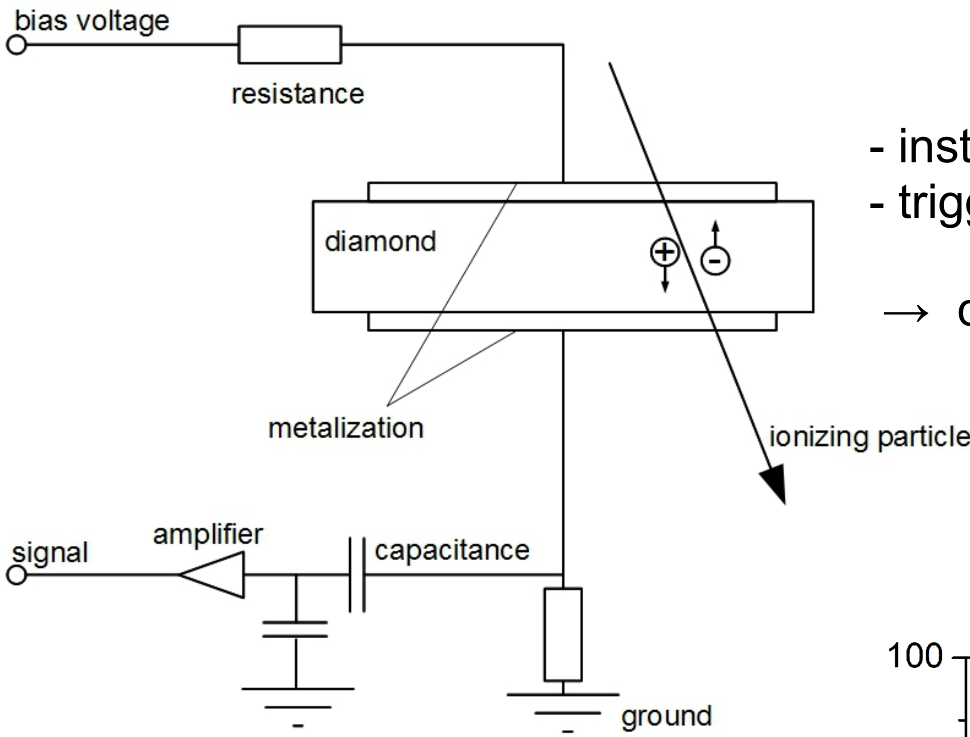






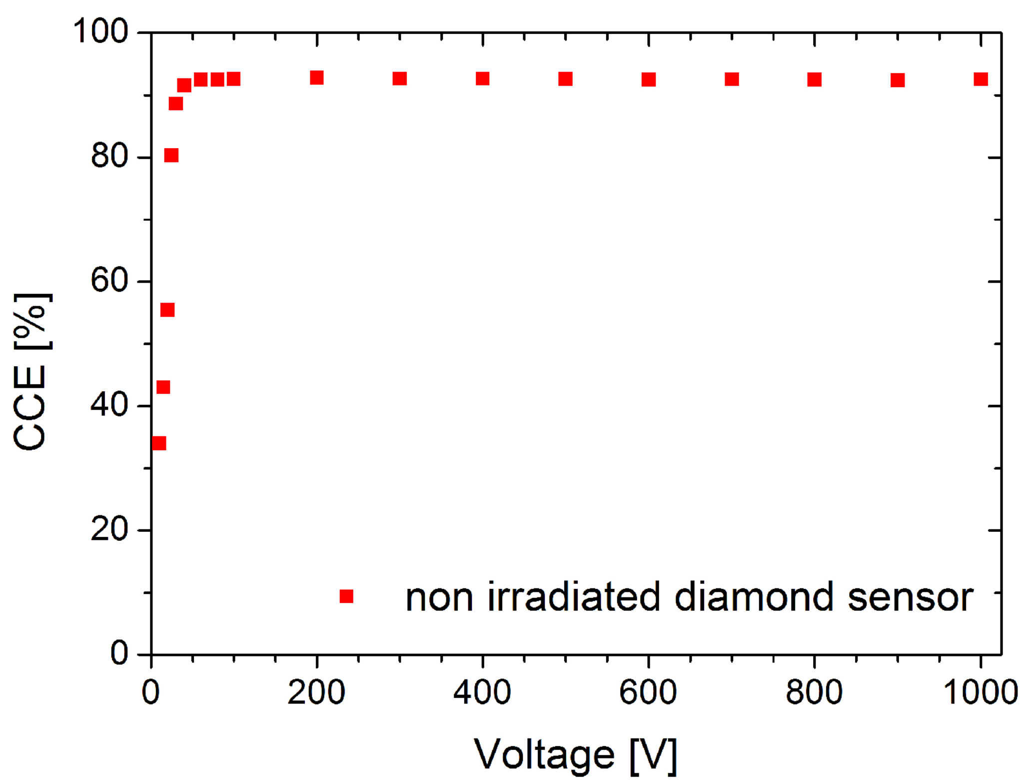
oberserve the stability of the signal current of a diamond sensor under irradiation

Charge Collelction Efficiency CCE



- installed as solid state ionisation chamber
- triggered on minimum ionizing particles from ^{90}Sr

→ quantity of generated e-h pairs is known



$$CCE = Q_m / Q_c$$

Q_m the measured charges and
Q_c the created charges

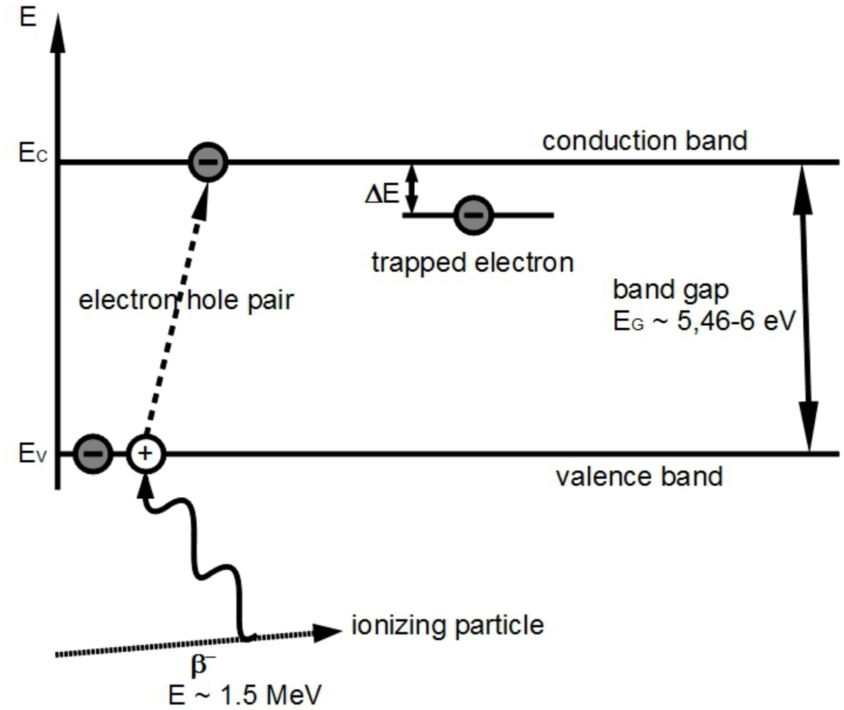
radiation damage

- radiation damage consists of lattice defects like vacancies and dislocations
  - creates an intermediate band gap state

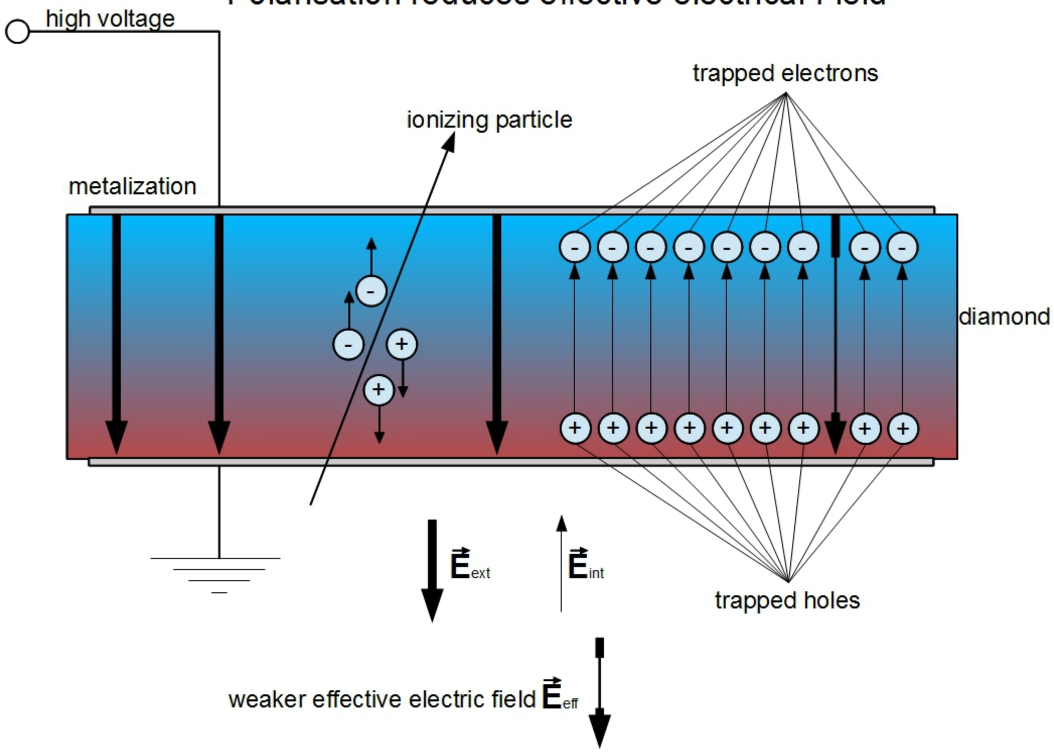
Trapping

- trapped charges are released by intrinsic effects or by recombination

→ equilibrium between filled and free traps



Polarisation reduces effective electrical Field



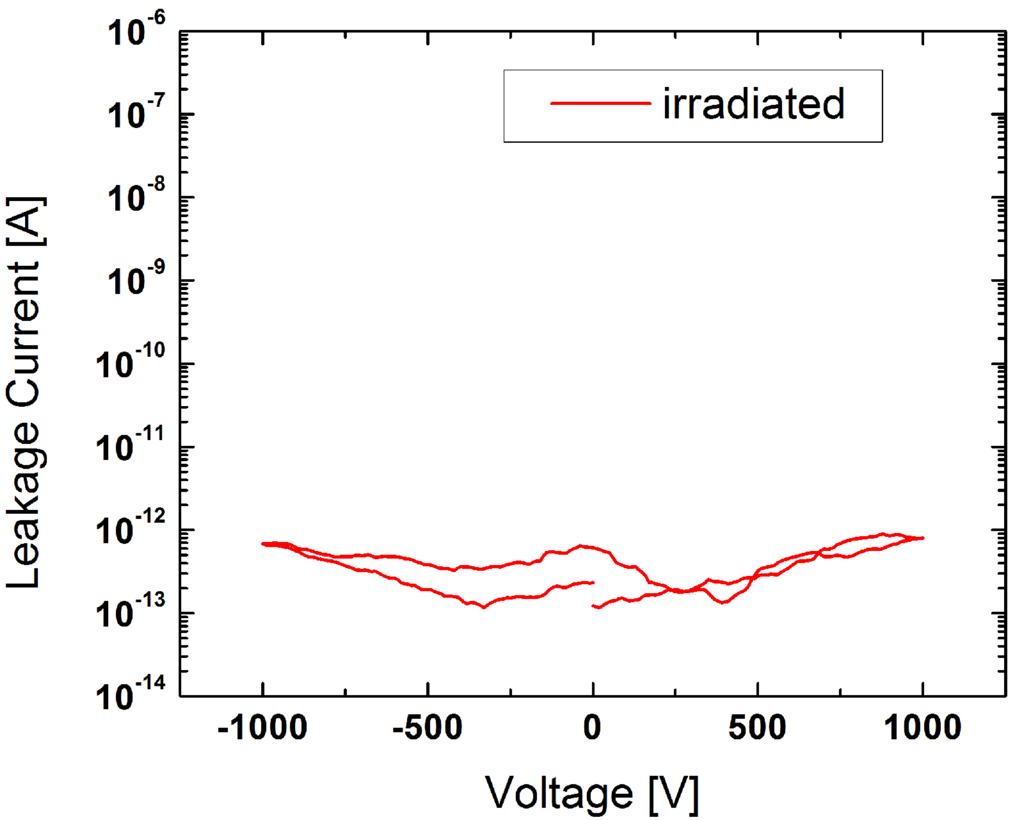
Polarization

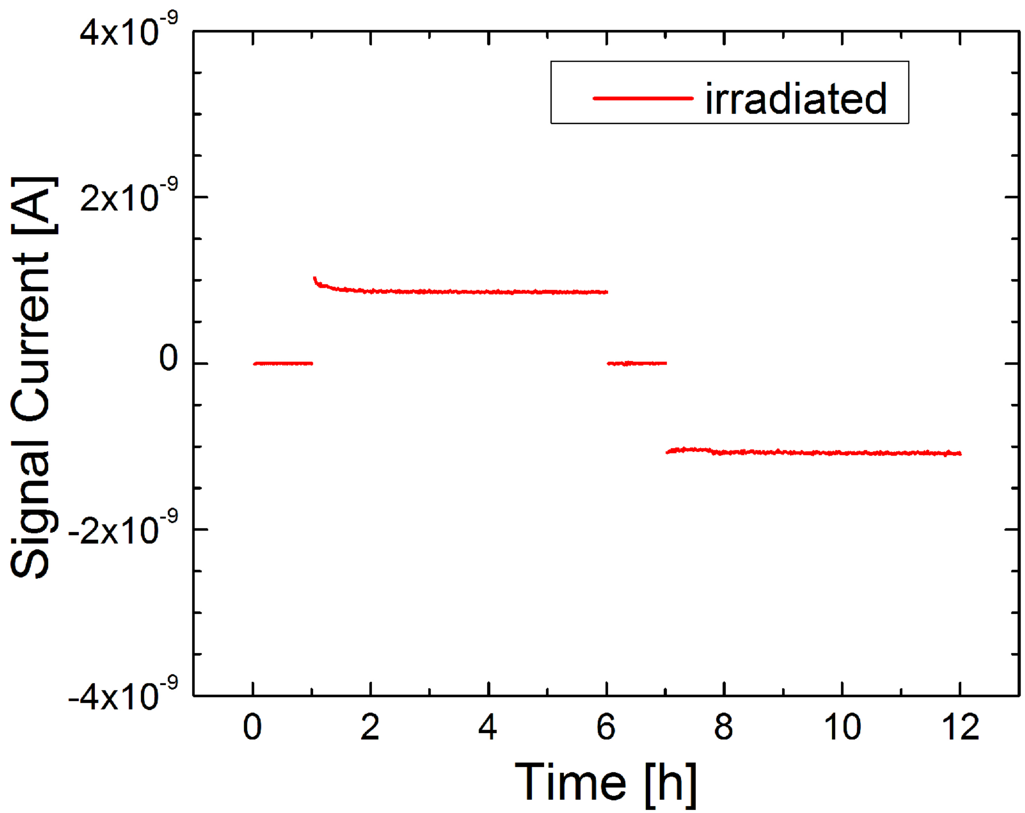
- generated electron-hole pairs are seperated by an external electrical field
- unevenly distributed free charges were trapped

→ unevenly distributed fixed charges
  → internal electrical field

(Sergej Schuwalow 15.12.2009, GSI)

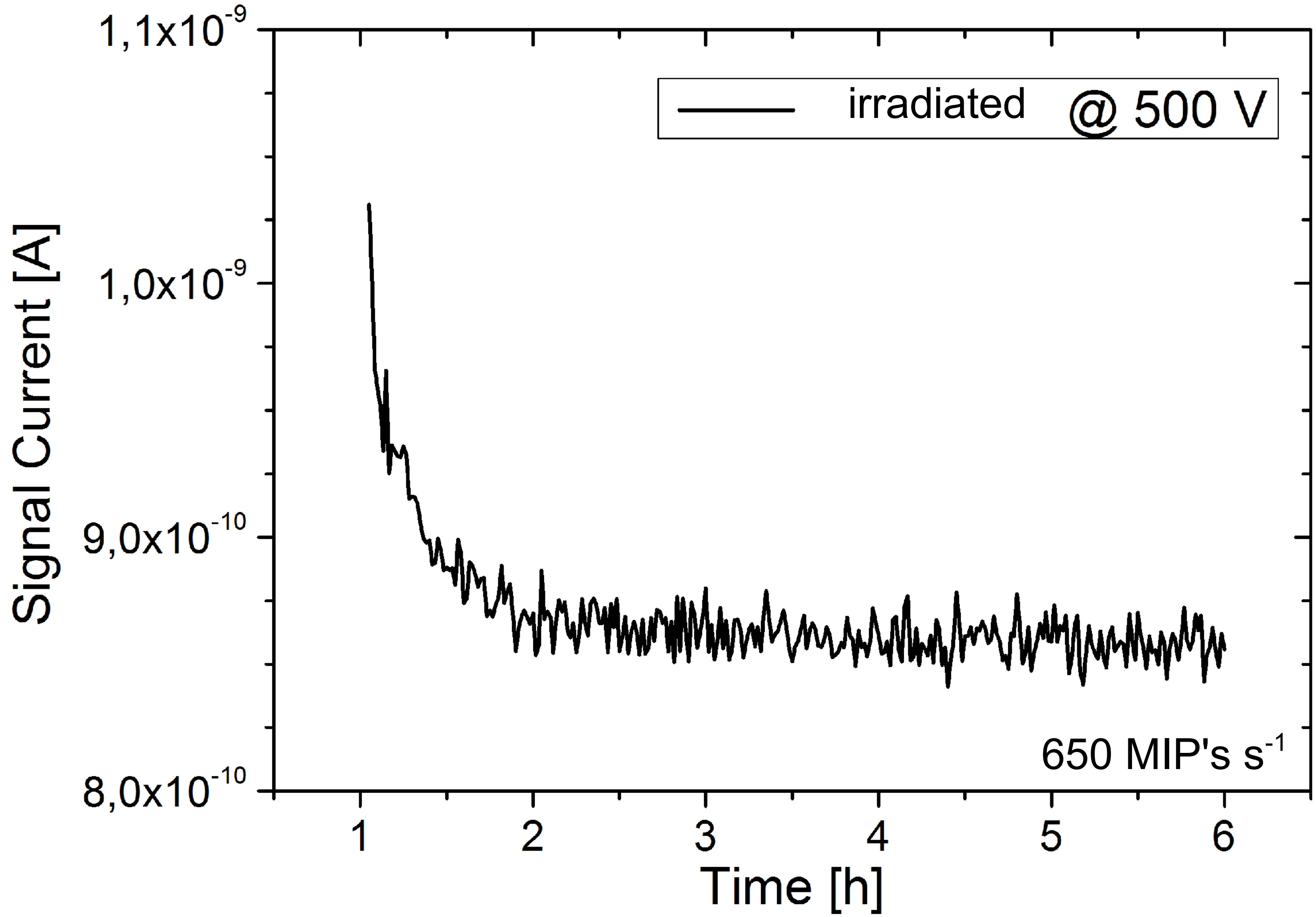
electrical measurements after irradiation





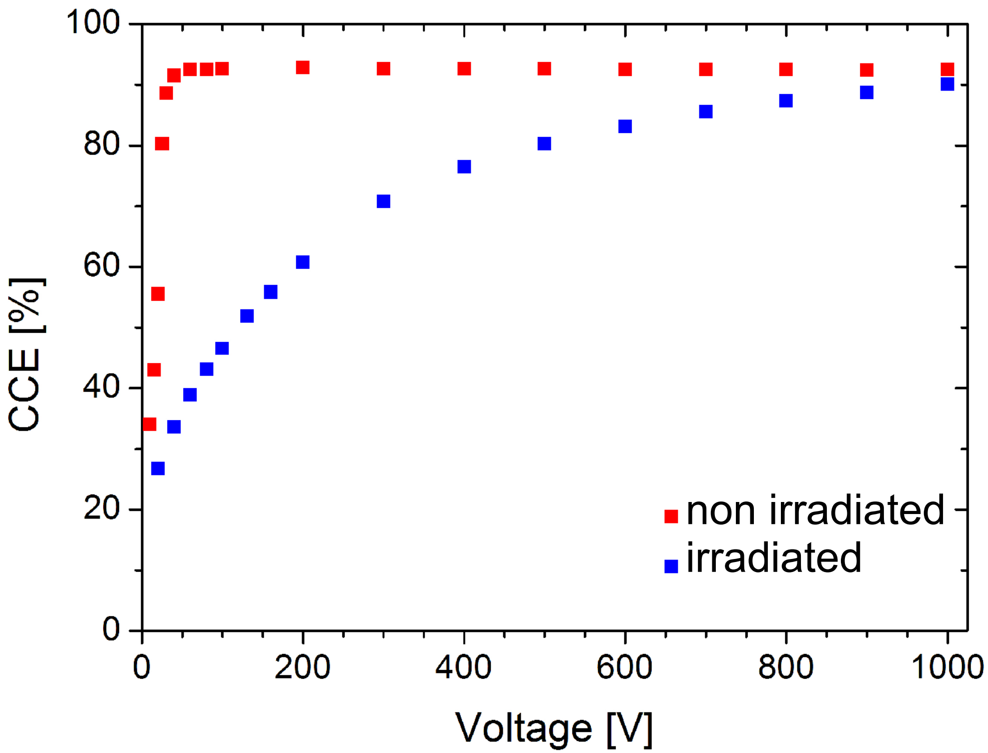
Irradiated diamond sensors from BCM1F installed from 2008 to 2014
show still low leakage currents and stable signal currents.

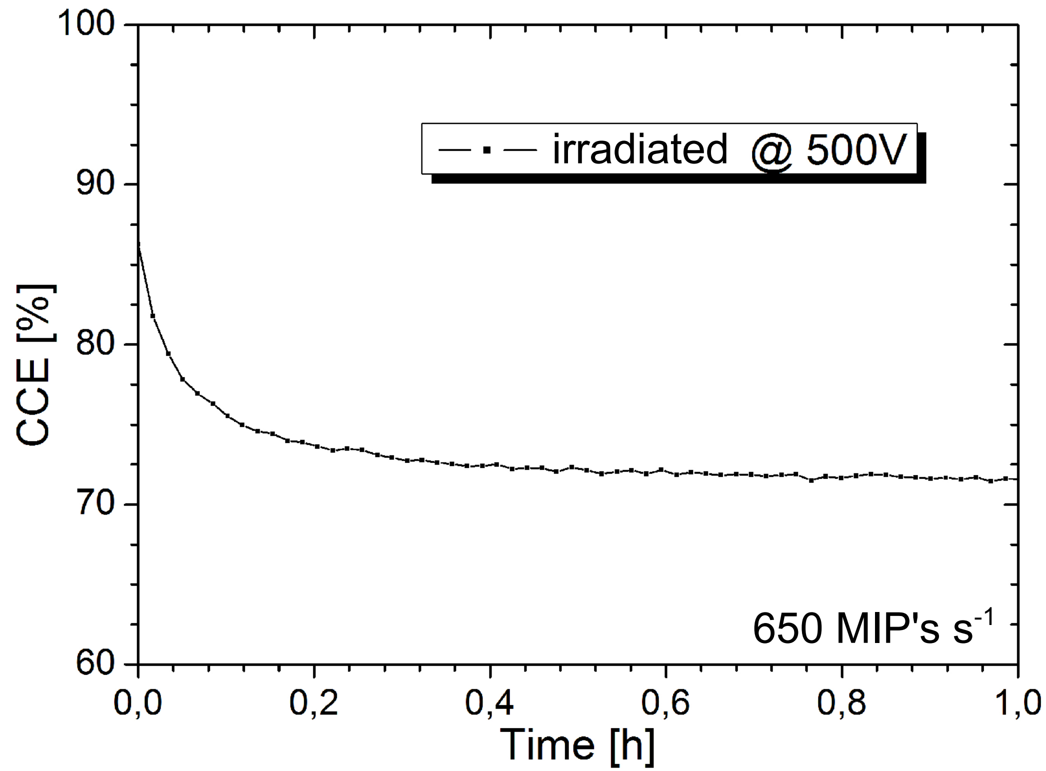
signal current after irradiation



After ramping from 0V to 500V polarization builds up about over several hours.

CCE after irradiation



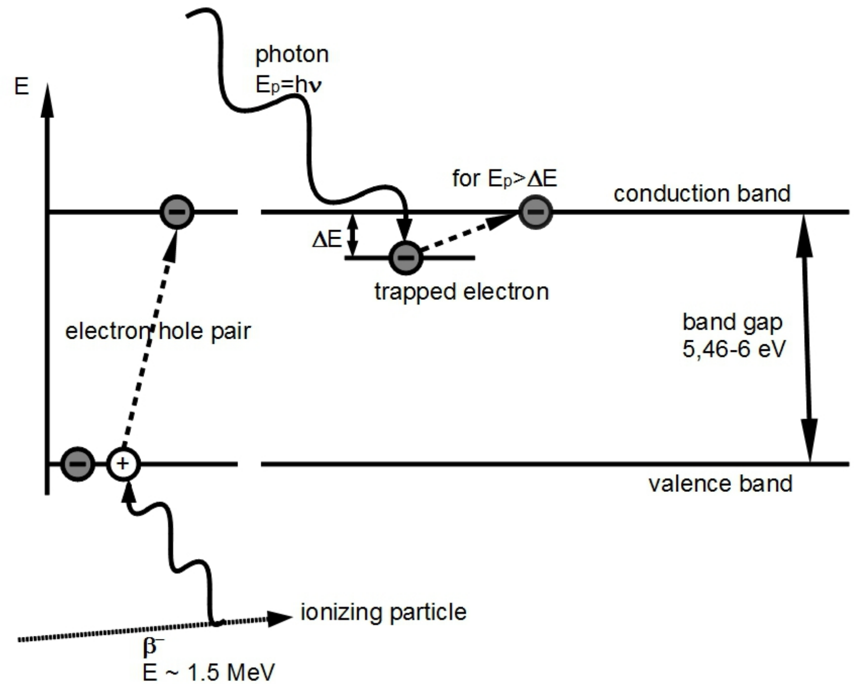


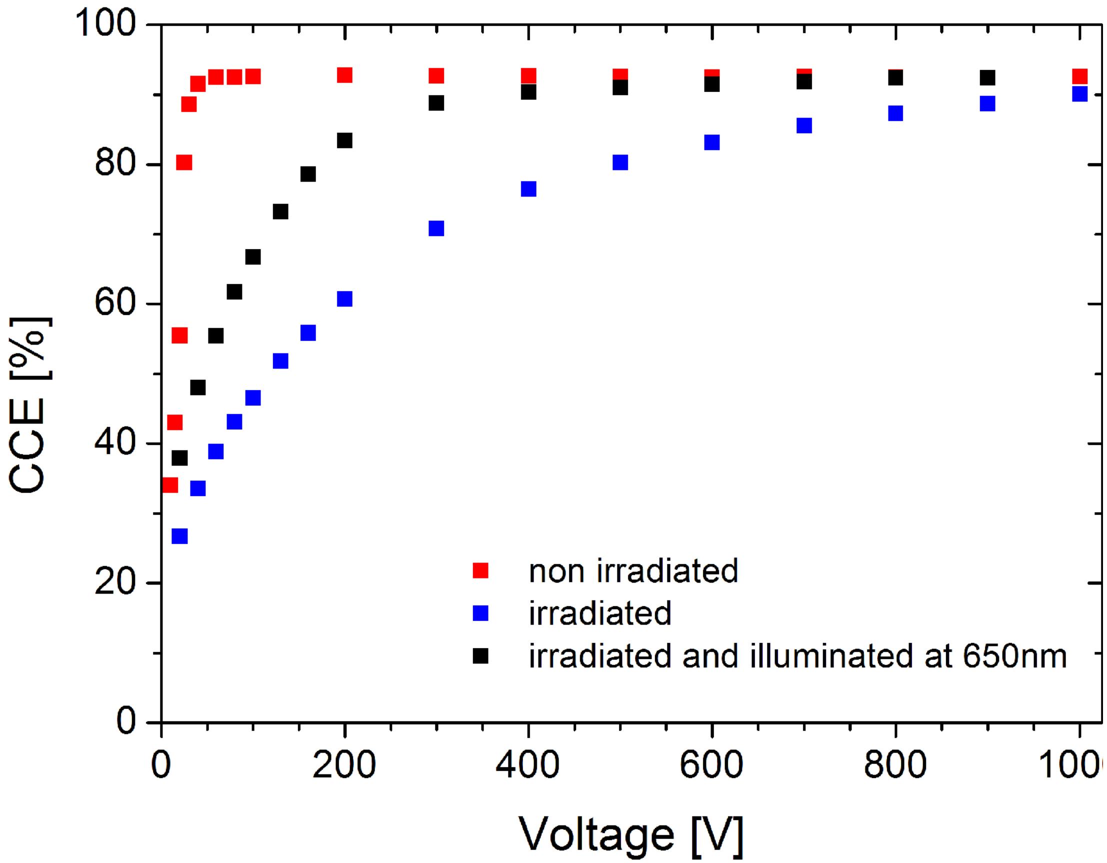
CCE is decreased by trapping and polarization after irradiation.

further investigation on radiation damage

- assumption intermediate band gaps states near the conduction band
- a photon lifts a trapped charge to conduction band if:
    - 650nm → 1.91eV

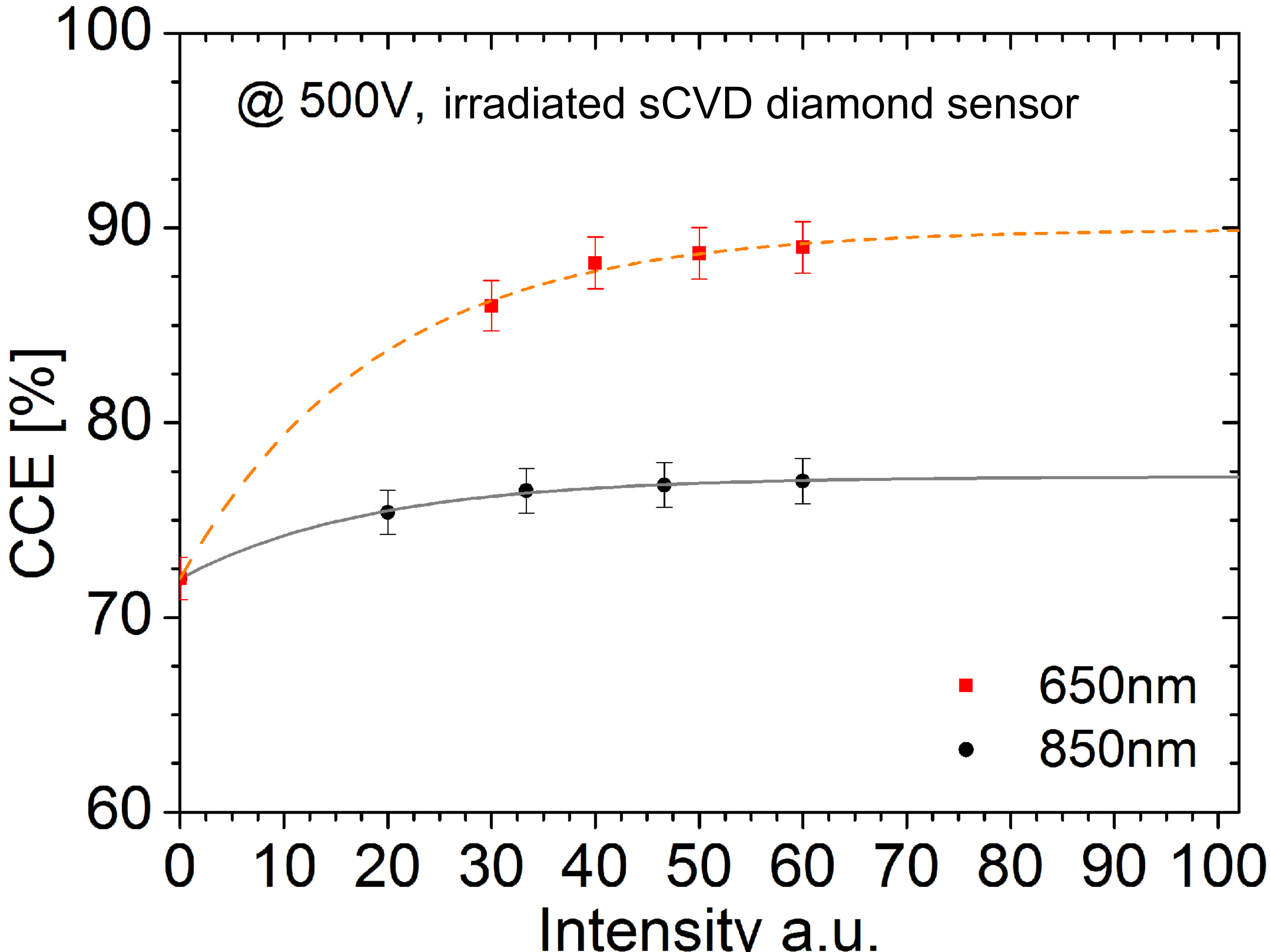
$$E_p > \Delta E$$
$$E_p = h \cdot \frac{c}{\lambda}$$
$$\Delta E = E_c - E_t$$





- equilibrium between filled and free traps shifted to more free trapps
→ polarization decreased

CCE dependence on intensity and energy of Light



zero intensity – no light
higher intensities – more trapped charges released, less polarization effects
lower wavelength – higher photon energy, more trapped charges released

Conclusion

- diamonds were successfully used at LHC to measure beam conditions and luminosity
- properties of such diamonds before and after irradiation:
  - leakage current stays low and signal current stays stable over time after irradiation
- signal current and CCE is reduced by irradiation effects
  - trapping and polarization

- method using light to mitigate irradiation based effects
  → polarization is reduced
  → CCE increas depends on wavelength and intensity of light

→ diamond sensors signal yield can be enhanced by illuminating