Mixed irradiation studies with magnetic czochralski diodes

15th RD50 Workshop

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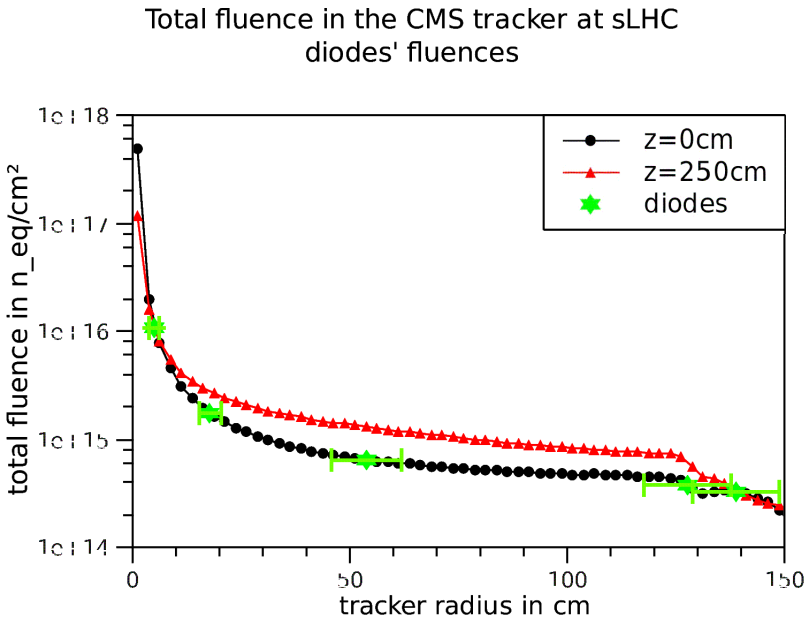
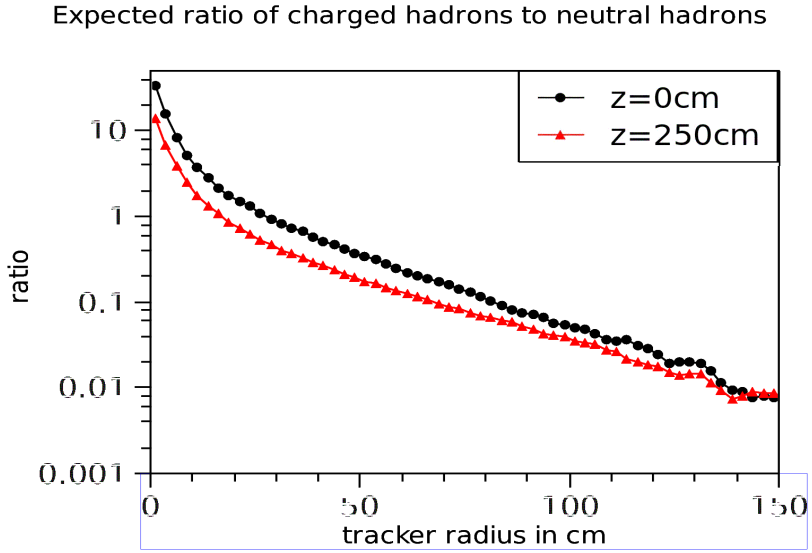
Experimental procedure

- Irradiation
  - Neutrons at Louvain-la-Neuve
  - Protons at Karlsruhe (25Mev, k=1.85)
- IV/CV measurements
  - Probestation Karlsruhe: before irradiation, after each irradiation step
- Annealing steps
  - Initial: 40h at room temperature
  - 4h – 14h at 40°C
- TCT
  - TCT-Setup at Karlsruhe: red Laser (678nm), max. voltage 1100V,
  - Cooling to -190°C
- Measurements: 0 – 1000V, -40°C – 0°C, 2°C steps
- Name of diodes indicates important parameters
- MCz-n_<fluence>-A/B MCz-p_<fluence>_spray/stop

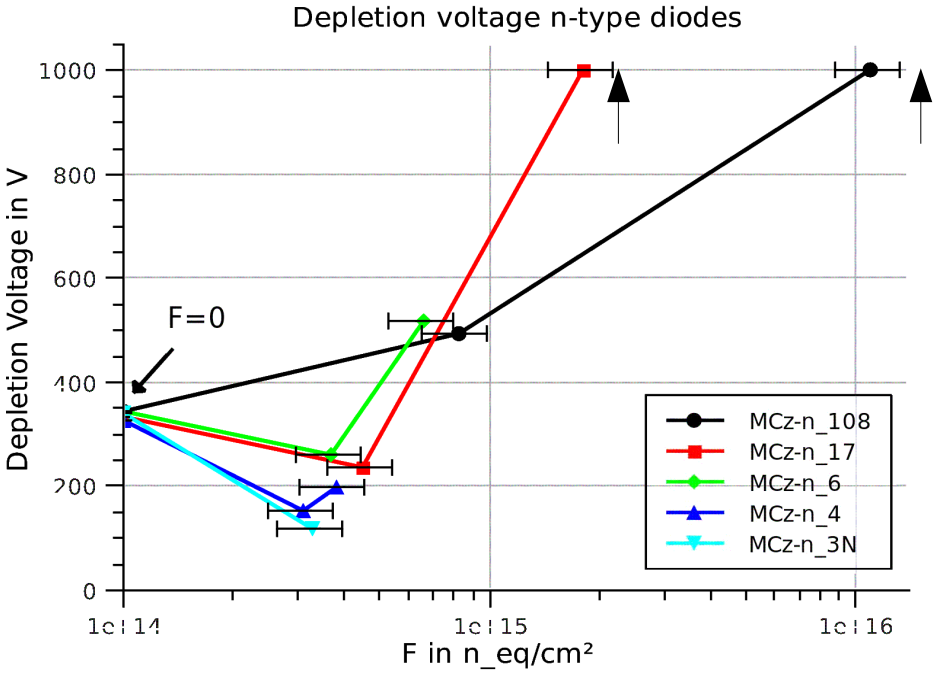
Irradiation

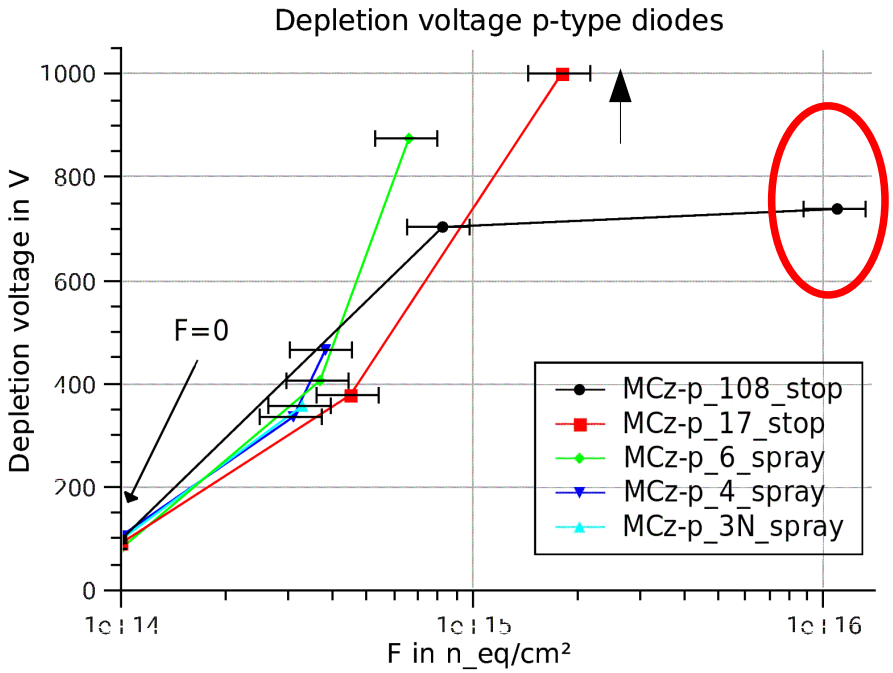
- Magentic Czochralski silicon diodes from HIP
- 300µm thick
- 10 n-type diodes
- 10 p-type diodes
- Mixed irradiation with
  - 1. neutrons
  - 2. protons
- Ratio of charged hadrons to neutral hadrons as expected in the CMS tracker at the sLHC





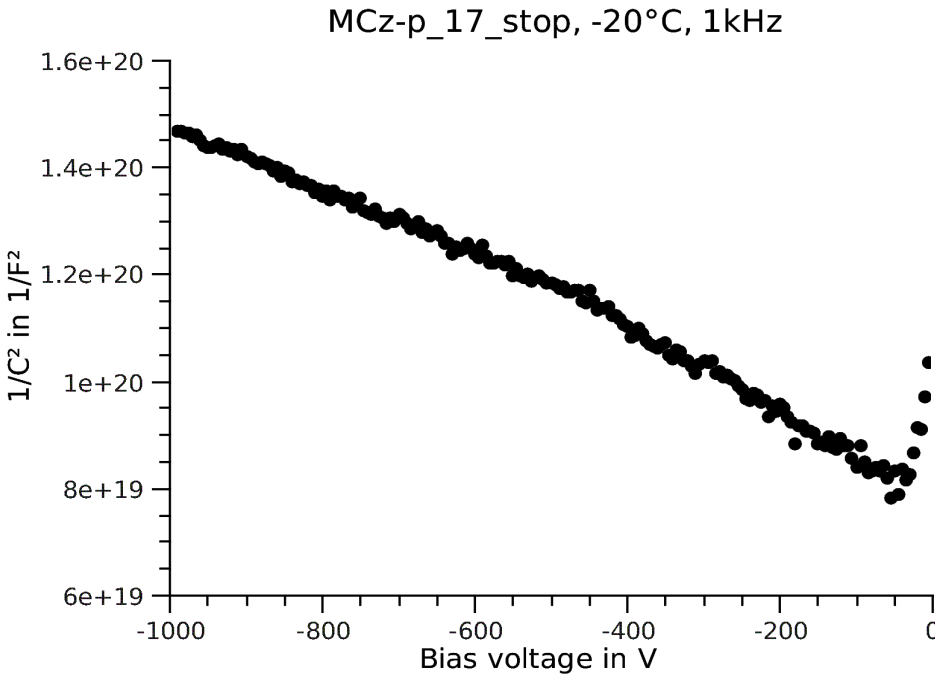
Depletion voltage

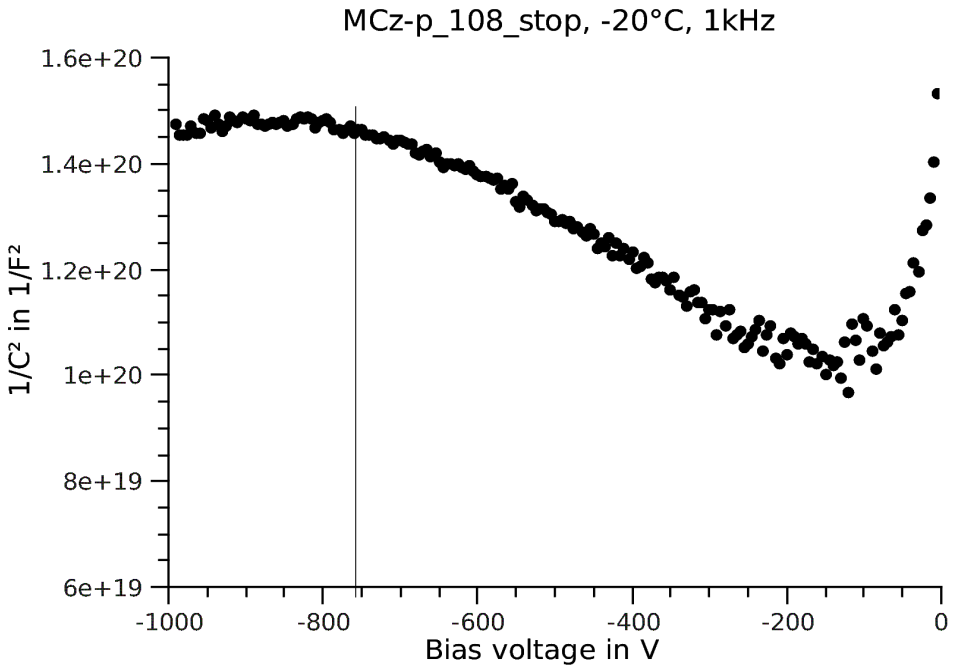




- Depletion voltage extracted from CV curves
- CV measurements at T= -20°C, frequency 1kHz
- Only n-type diodes show type inversion
- Annealing time: 40h at room temperature

CV-Curves





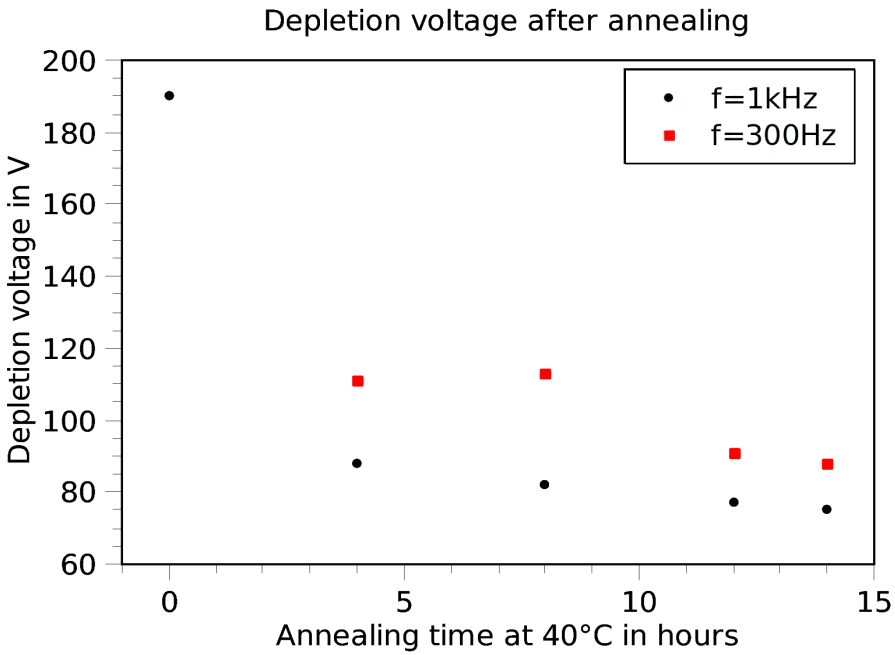
F=1,7*10¹⁵ n/cm2
V_{dep} > 1000V

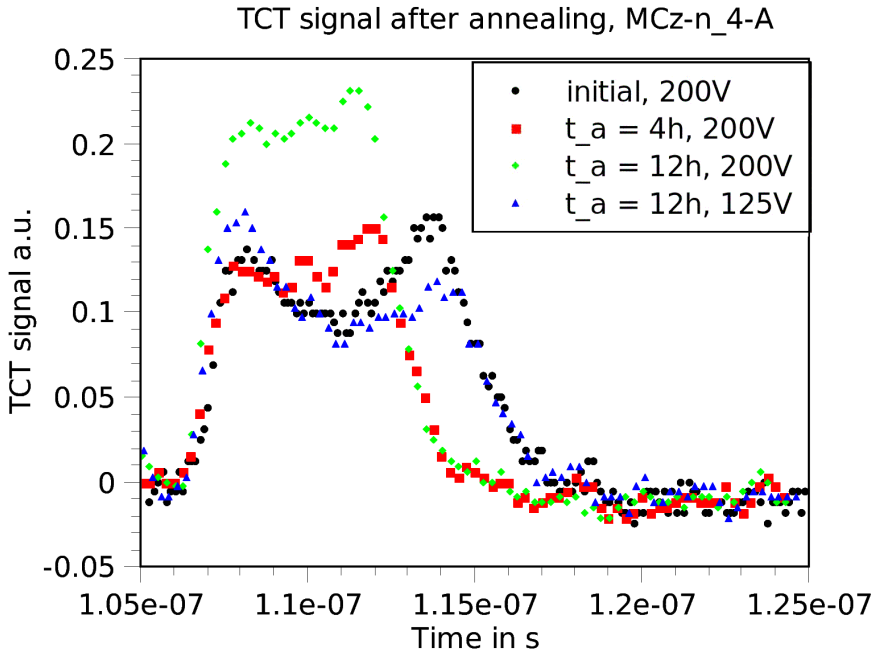
F=1,08*10¹⁶ n/cm2
V_{dep} ~ 750V

TCT: no depletion till 1000V

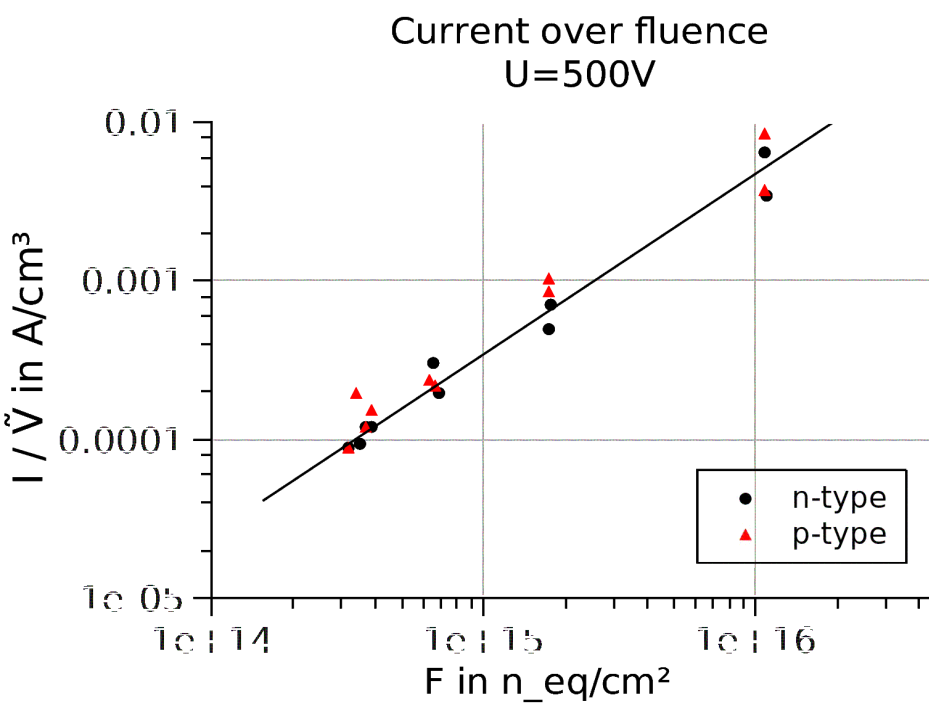
Depletion voltage after annealing

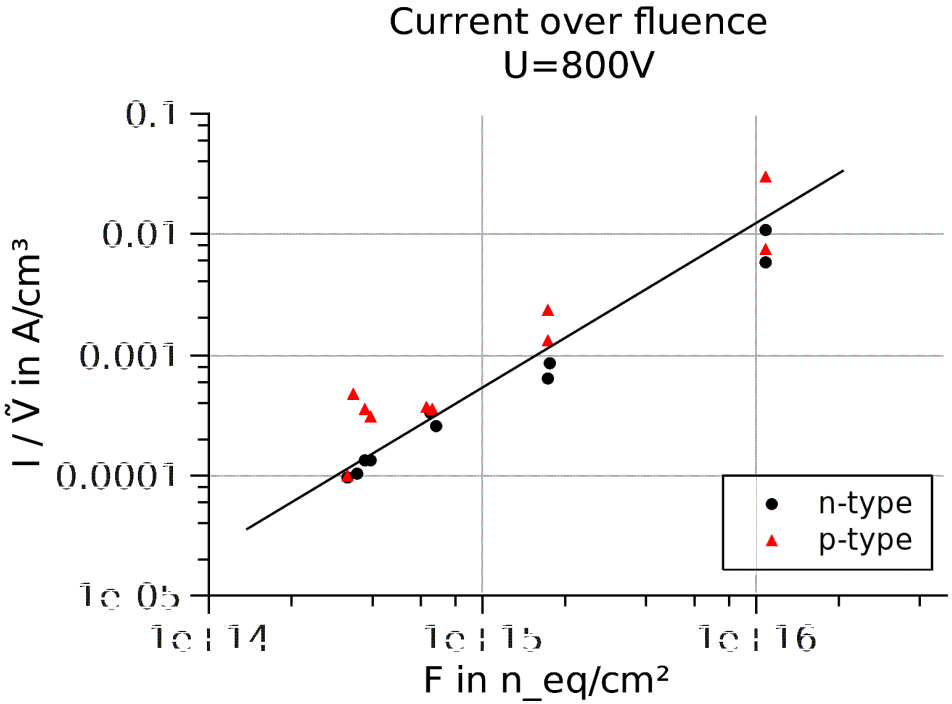
- Annealing at 40°C
- Depletion voltage obtained from CV measurements





Leakage Current





- P-type diodes at 3-4*10^{14}n/cm2 have seen more fluence than expected
- Fluence varying with position at irradiation
- $\alpha = (5.7 +/- 1.1)*10^{-17}$ A/cm
- Expect $\alpha \sim 6 *10^{-17}$ A/cm for 48h at 21°C

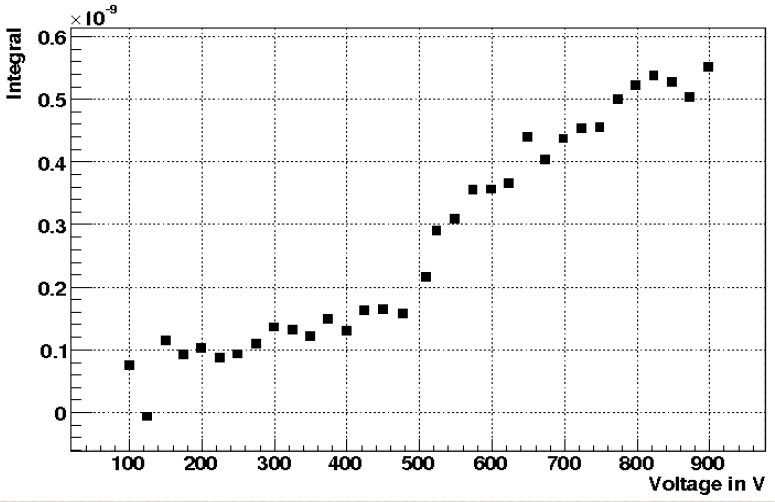
Method to determine trapping times

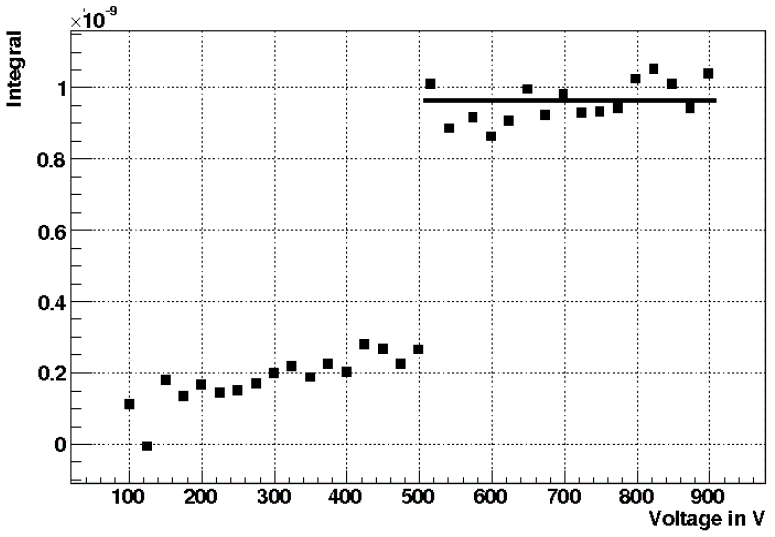
- Correct measured signal with varying trapping times

$$I = I_{meas} * e^{t/t_{trap}}$$

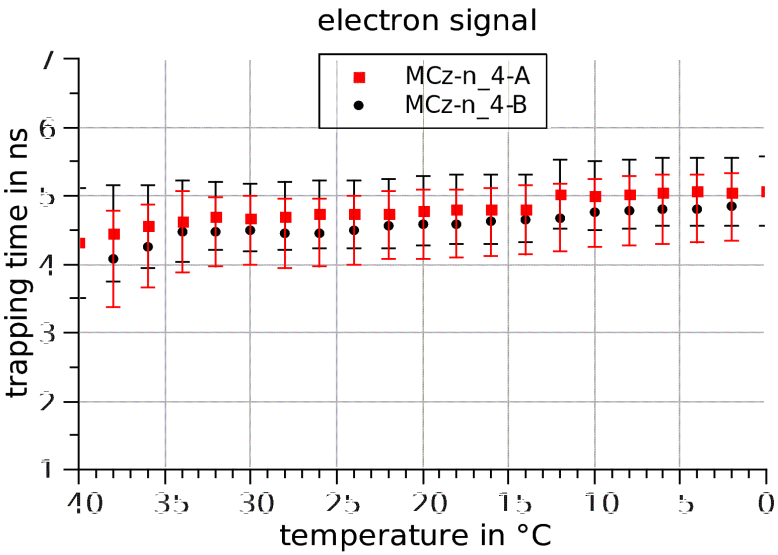
- Above depletion voltage, CCE is constant
- Need datapoints above V_{dep} !
- Fit linear slope
- Find trapping time when slope=0
- Errors:
  - Depletion voltage not exactly known
  - Fit linear slope with

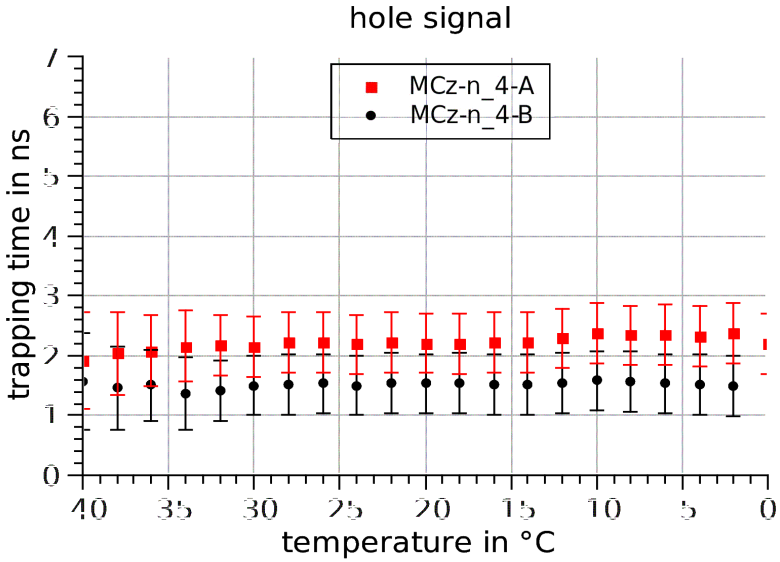
    V_{dep} +/- 25V





Trapping times n-type diodes

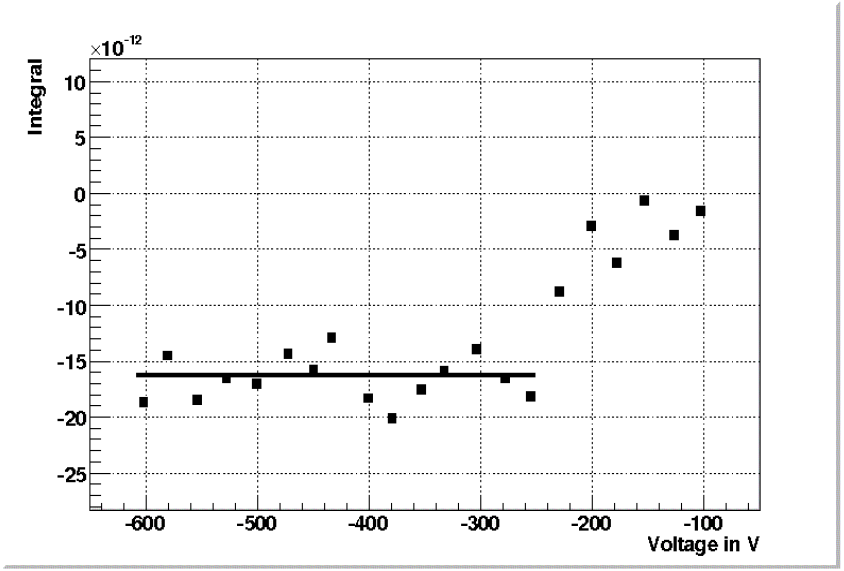




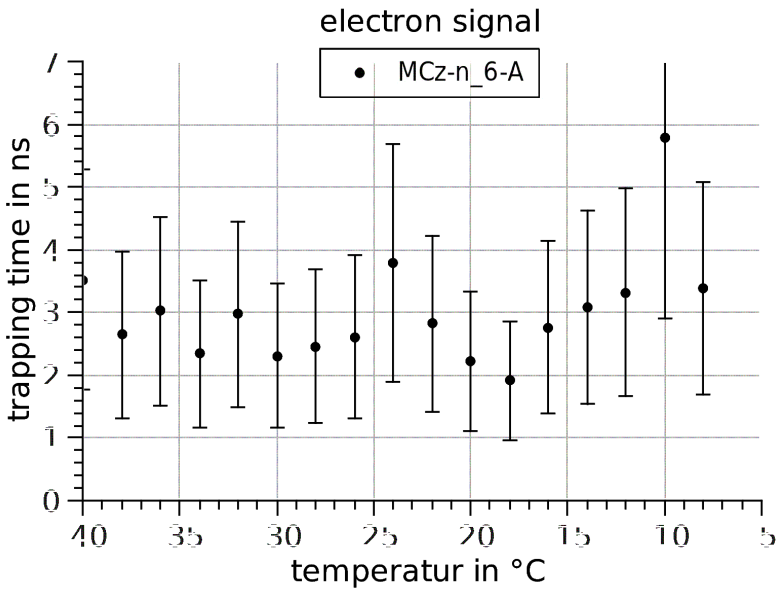
A:F=3.7*10¹⁴n/cm2

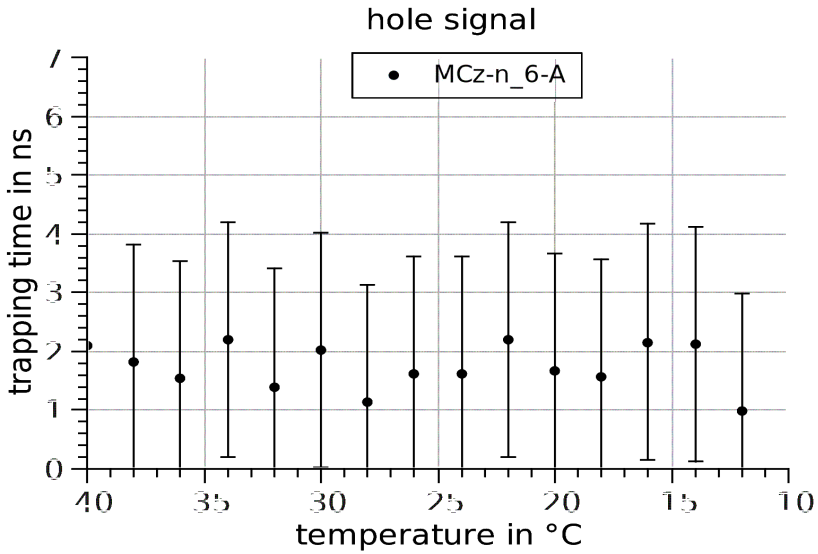
B:F=3.9*10¹⁴n/cm2

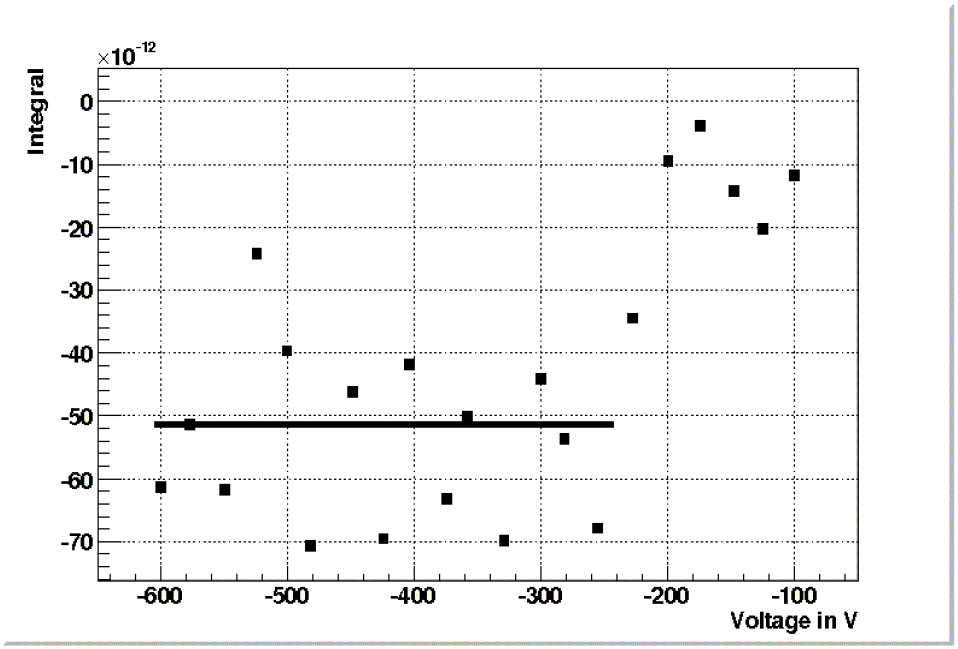
Protons and neutrons



Trapping times n-type F=6.5*10¹⁴ n/cm2

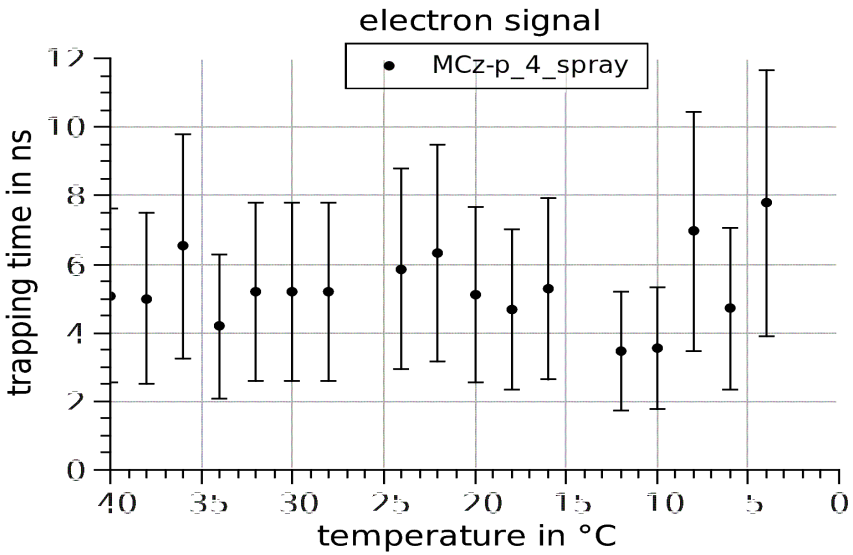




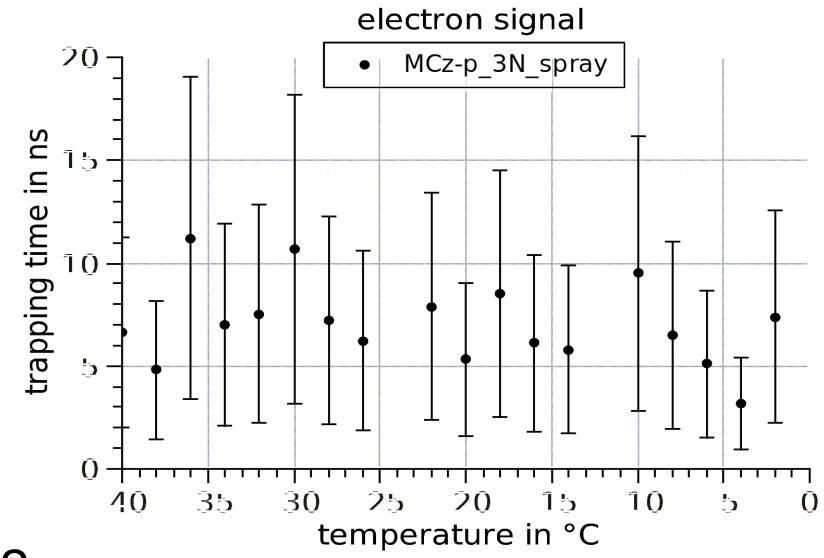


Trapping times p-type diodes

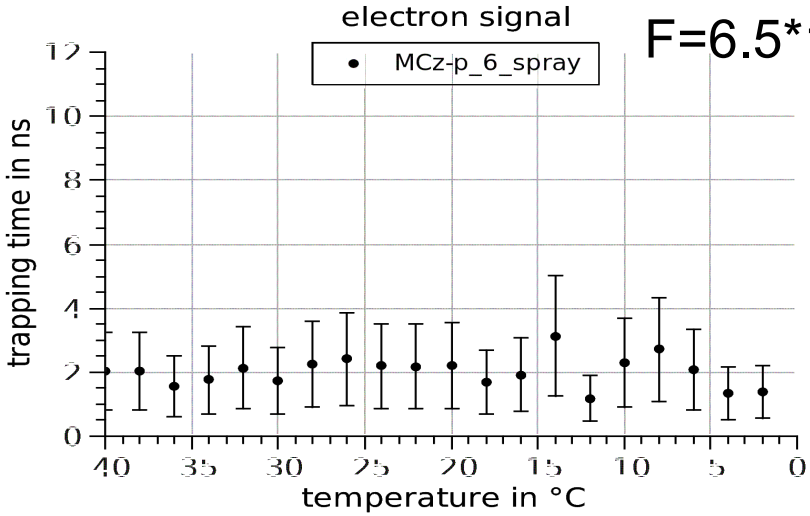
F=3.7*10¹⁴n/cm2

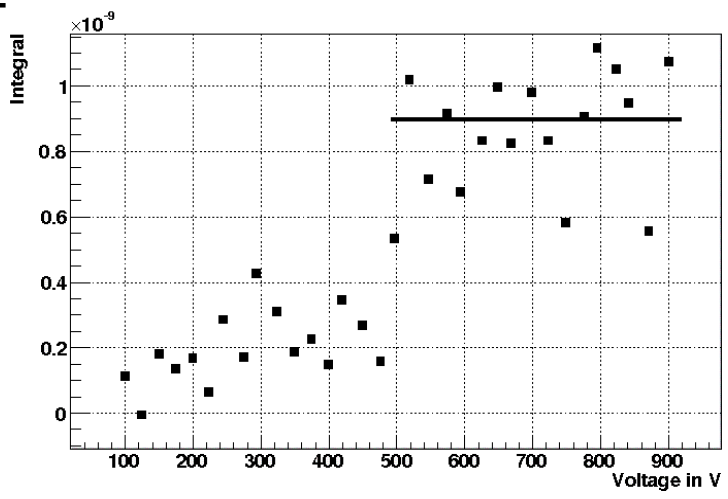


F=3.2*10¹⁴n/cm2



F=6.5*10¹⁴ n/cm2





Trapping times

Overview:

Diode	$F_{eq}(n)\left[\frac{n_{eq}}{cm^2}\right]$	$F_{eq}(p)\left[\frac{n_{eq}}{cm^2}\right]$	τ_e[ns]	τ_h[ns]	$\beta'_e\left[\frac{cm^2}{ns}\right]$	$\beta'_h\left[\frac{cm^2}{ns}\right]$
MCz-n_3N-A	$3,2 \cdot 10^{14}$	-	$5,96 \pm 0,7$	$2,87 \pm 0,8$	$5,2 \cdot 10^{-16}$	$10,8 \cdot 10^{-16}$
MCz-n_3N-B	$3,5 \cdot 10^{14}$	-	$5,40 \pm 0,6$	$1,21 \pm 1,0$	$5,3 \cdot 10^{-16}$	$23,6 \cdot 10^{-16}$
MCz-n_4-A	$3,3 \cdot 10^{14}$	$6,8 \cdot 10^{13}$	$4,92 \pm 0,5$	$2,2 \pm 0,5$	$5,2 \cdot 10^{-16}$	$11,6 \cdot 10^{-16}$
MCz-n_4-B	$3,0 \cdot 10^{14}$	$6,8 \cdot 10^{13}$	$4,44 \pm 0,5$	$1,51 \pm 0,6$	$6,1 \cdot 10^{-16}$	$17,9 \cdot 10^{-16}$
MCz-n_6-A	$3,6 \cdot 10^{14}$	$2,9 \cdot 10^{14}$	$3,00 \pm 1,5$	$1,74 \pm 2,0$	$5,1 \cdot 10^{-16}$	$8,84 \cdot 10^{-16}$
MCz-n_17-A	$4,4 \cdot 10^{14}$	$1,3 \cdot 10^{15}$				
MCz-n_108-A	$8,1 \cdot 10^{14}$	$1,0 \cdot 10^{16}$				

Diode	$F_{eq}(n)\left[\frac{n_{eq}}{cm^2}\right]$	$F_{eq}(p)\left[\frac{n_{eq}}{cm^2}\right]$	τ_e[ns]	τ_h[ns]	$\beta'_e\left[\frac{cm^2}{ns}\right]$	$\beta'_h\left[\frac{cm^2}{ns}\right]$
MCz-p_3N_spray	$3,2 \cdot 10^{14}$	-	$6,7 \pm 2,6$	$1,8 \pm 1,9$	$4,7 \cdot 10^{-16}$	$17,4 \cdot 10^{-16}$
MCz-p_4_spray	$3,1 \cdot 10^{14}$	$6,8 \cdot 10^{13}$	$5,3 \pm 4,9$	$5,7 \pm 4,0$	$5,1 \cdot 10^{-16}$	$4,7 \cdot 10^{-16}$
MCz-p_6_spray	$3,7 \cdot 10^{14}$	$2,9 \cdot 10^{14}$	$2,3 \pm 1,2$	$2,2 \pm 2,2$	$6,6 \cdot 10^{-16}$	$6,9 \cdot 10^{-16}$
MCz-p_17_stop	$4,5 \cdot 10^{14}$	$1,3 \cdot 10^{15}$	-	-		
MCz-p_108_stop	$7,4 \cdot 10^{14}$	$1,0 \cdot 10^{16}$	-	-		

Comparison for β:

$\beta_e = 4,1 - 5,7 * 10^{-16}$ cm≤/ns

$\beta_h = 6,0 - 7,7 * 10^{-16}$ cm≤/ns

$$1/tau = \beta * F$$

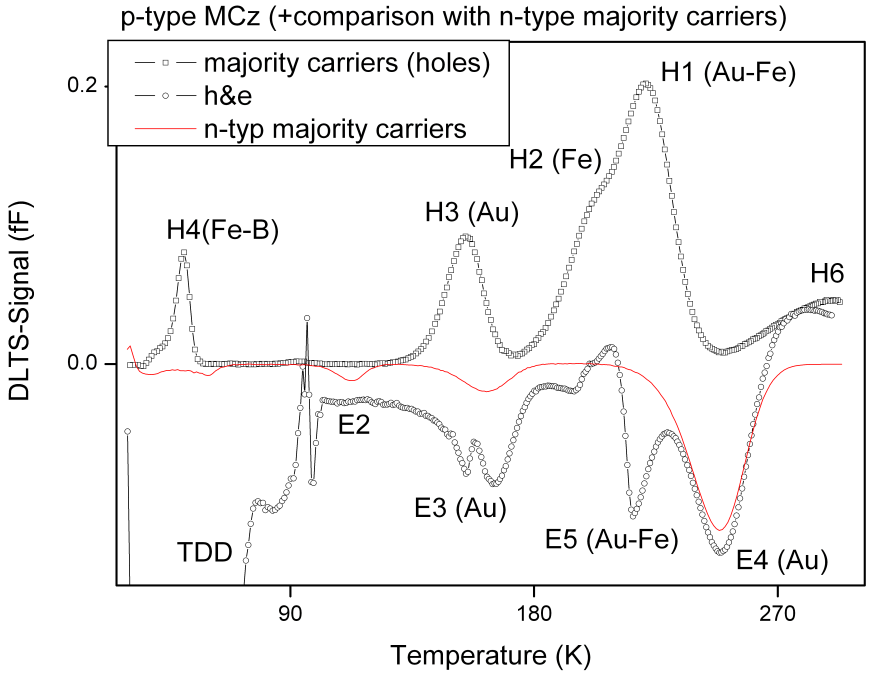
Diodes F>10^{15} n/cm≤

- Depletion voltage > 1000V
- Trapping times could not be extracted

DLTS

- DLTS with unirradiated diodes in Hamburg (A. Junkes)
- Impurities in silicon lead to recombination of charge carriers - trapping
- Impurities come from metal
- Diverse possible impurities – assignment difficult

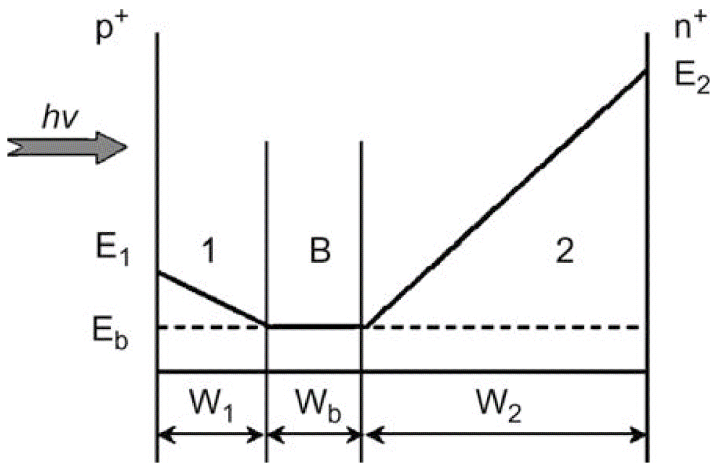
- Gold is a good candidate
- Some defects are introduced during the production of MCz silicon (traps E1 – E4, n-type and p-type)
- E5 only visible in p-type silicon, defects introduced while processing of diodes



Simulation and reconstruction of the electric field

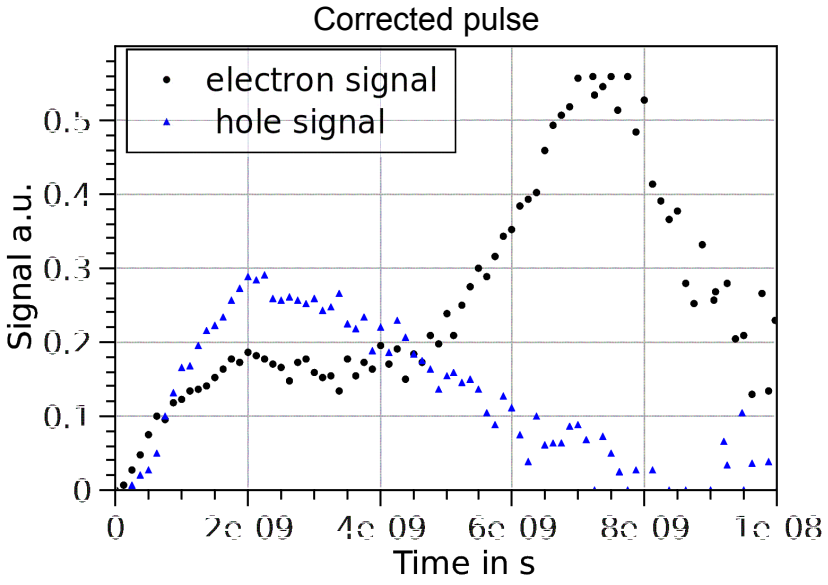
- Simulated transient current through diode
- Electric field as input parameter
- Other parameters:
  - saturation drift velocity
  - charge generation depth
  - Diode thickness
- Methode from Verbitskaya et al.
- Fit simulated signal to measured signal
- ➔ Reconstruction of electric field in the diode possible

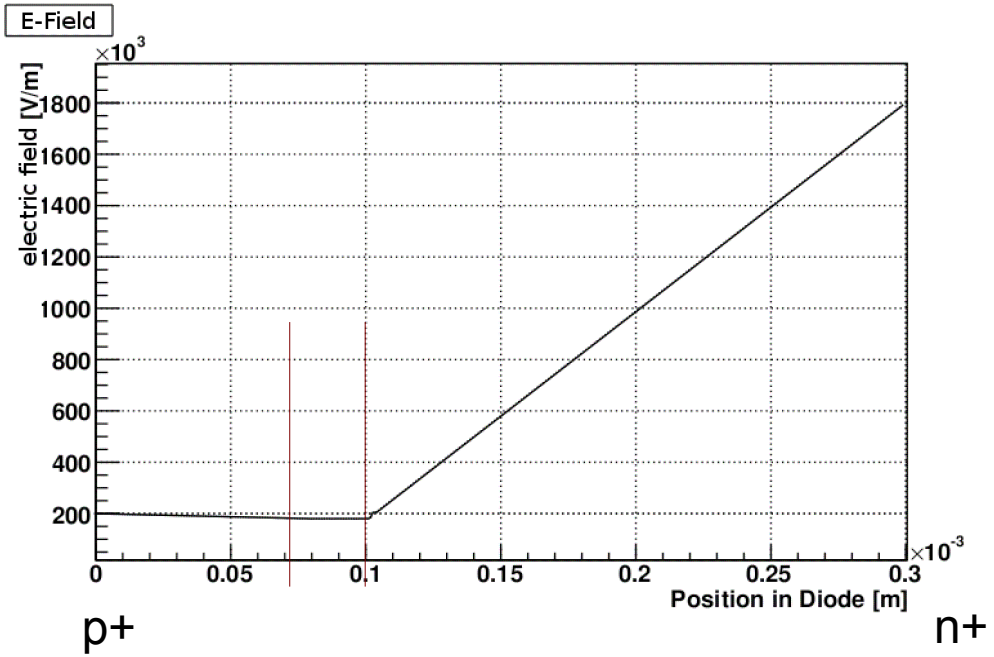
- Used signals at -20°C
- Diode MCz-n_4-A at 200V / 400V

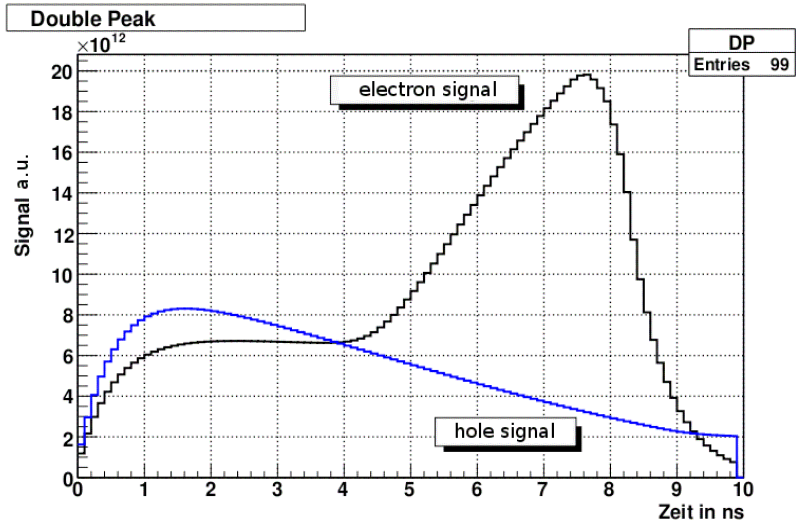


Verbitskaya et al.

Adjustment of electric field



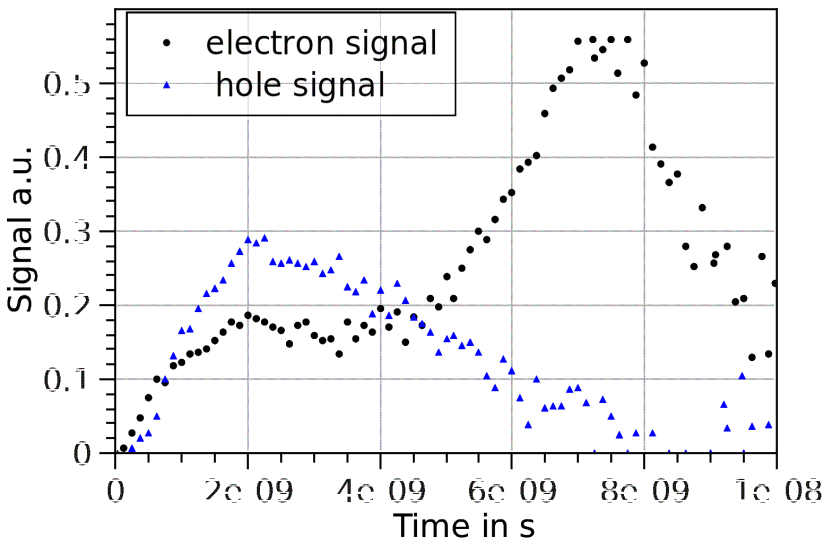




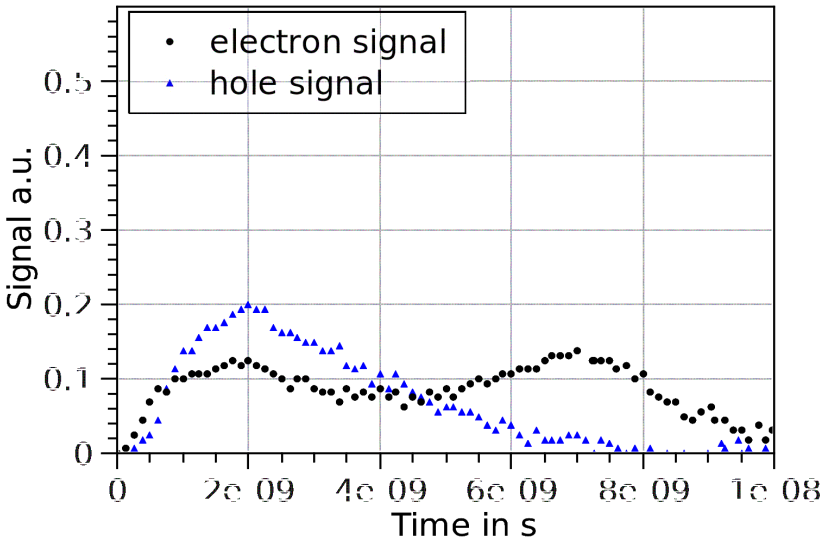
- Use information from both type of charge carriers
- Correct measured signal with trapping time
- V=200V, Vdep ~ 150V

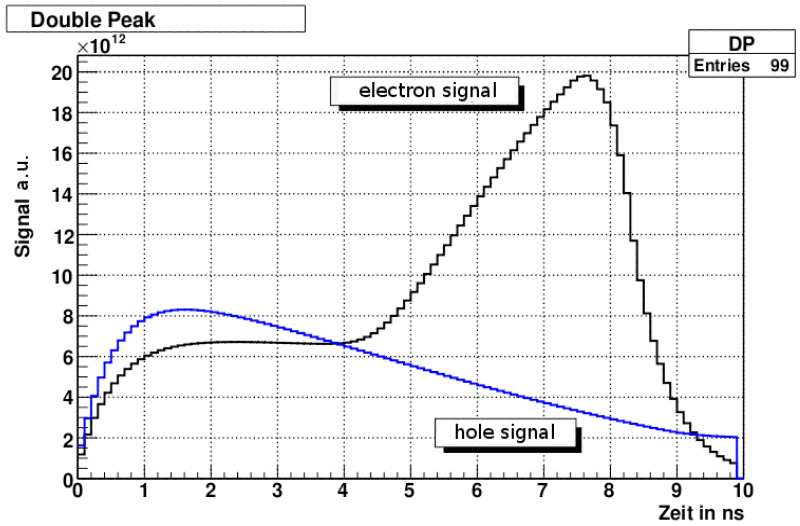
Electric field in the diode, 200V

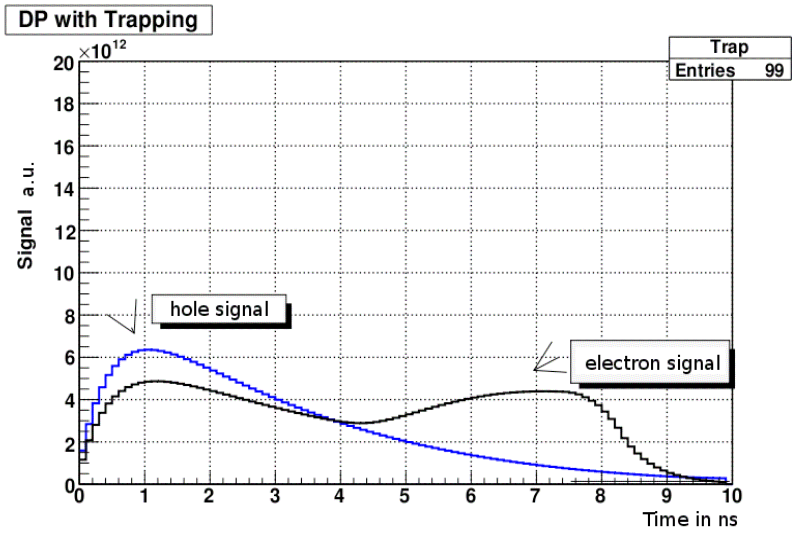
corrected puls



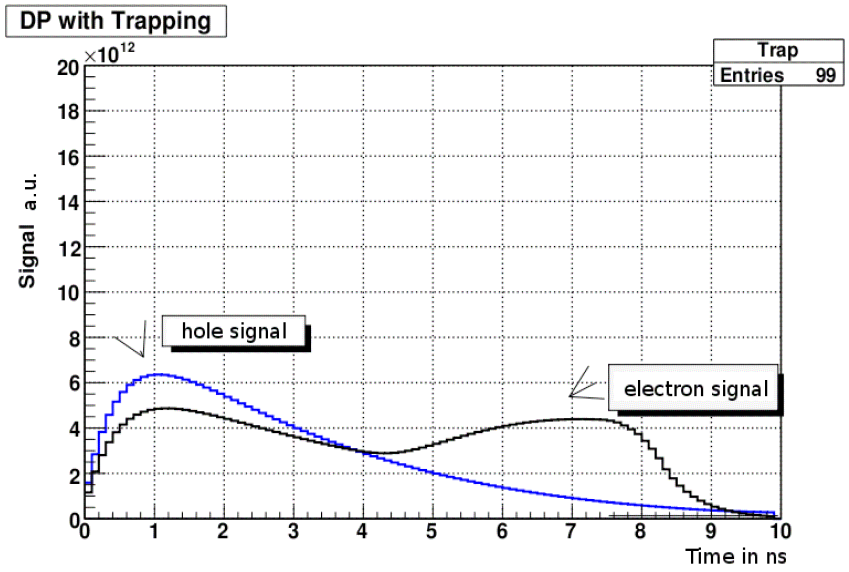
measured puls

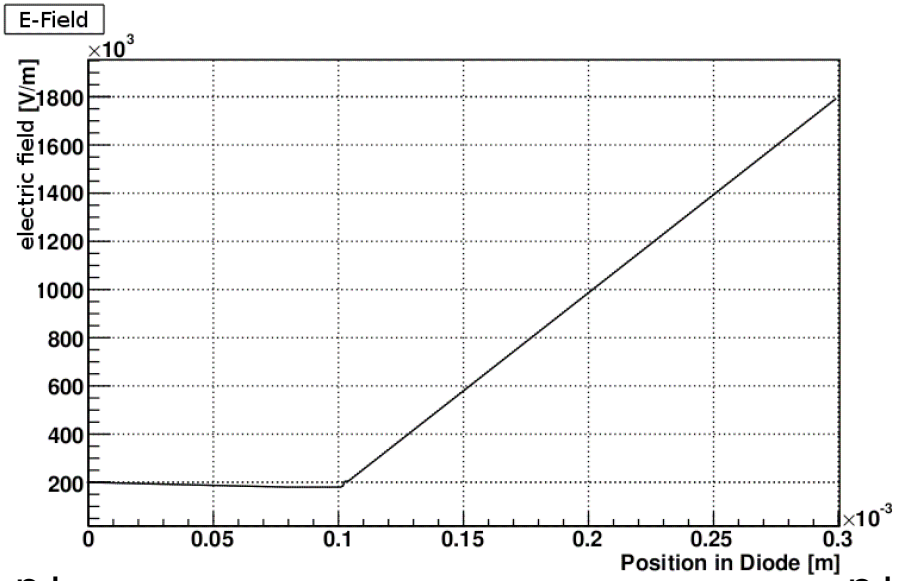


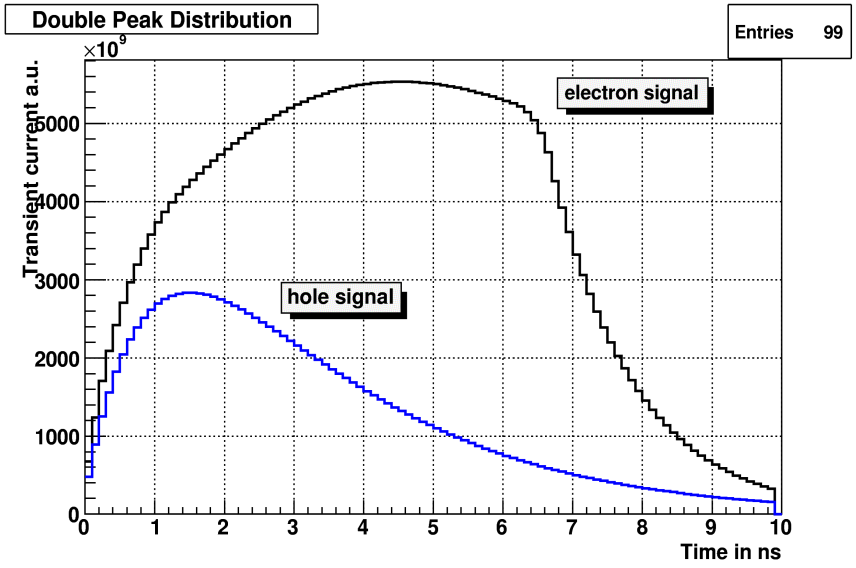


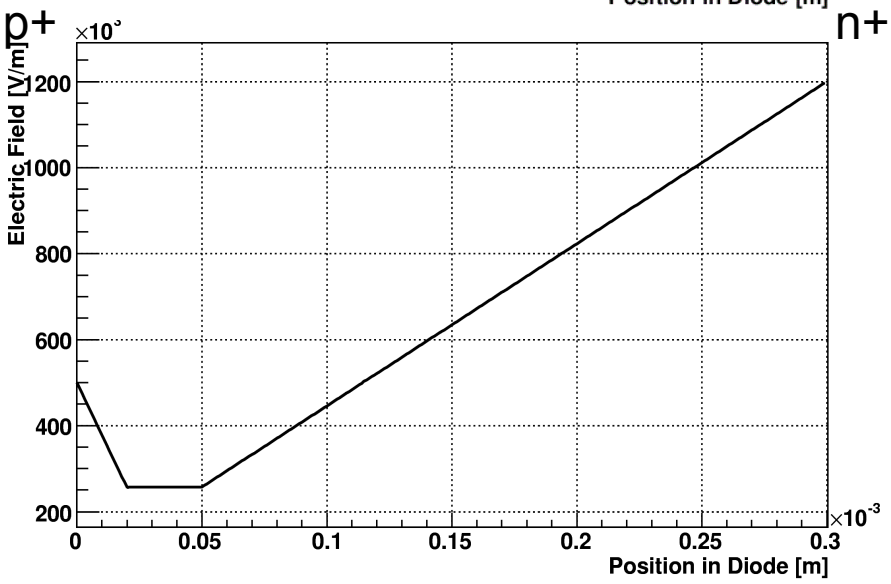


Changing the electric field, 200V

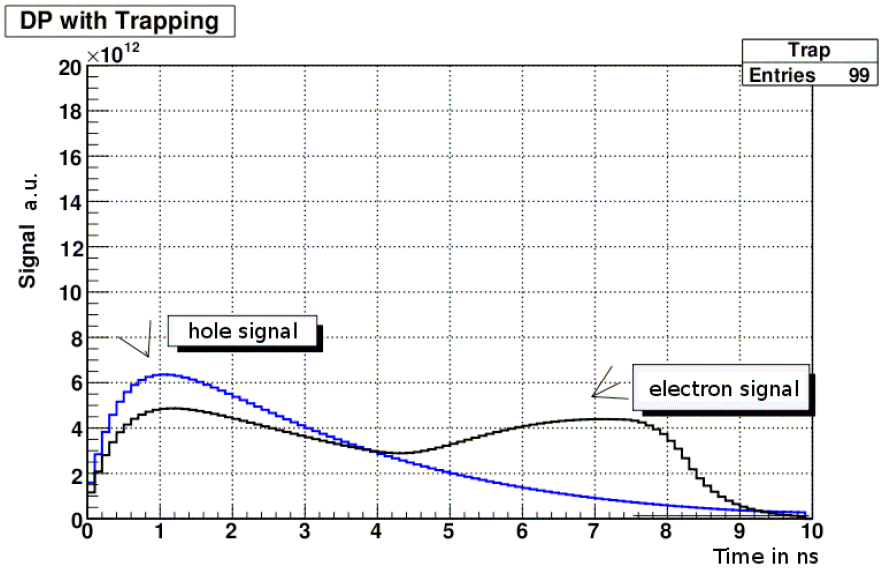


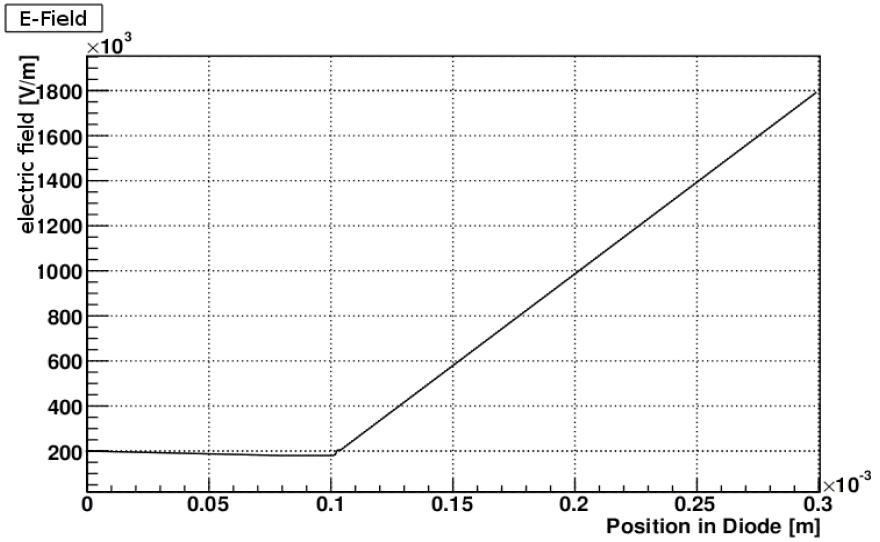


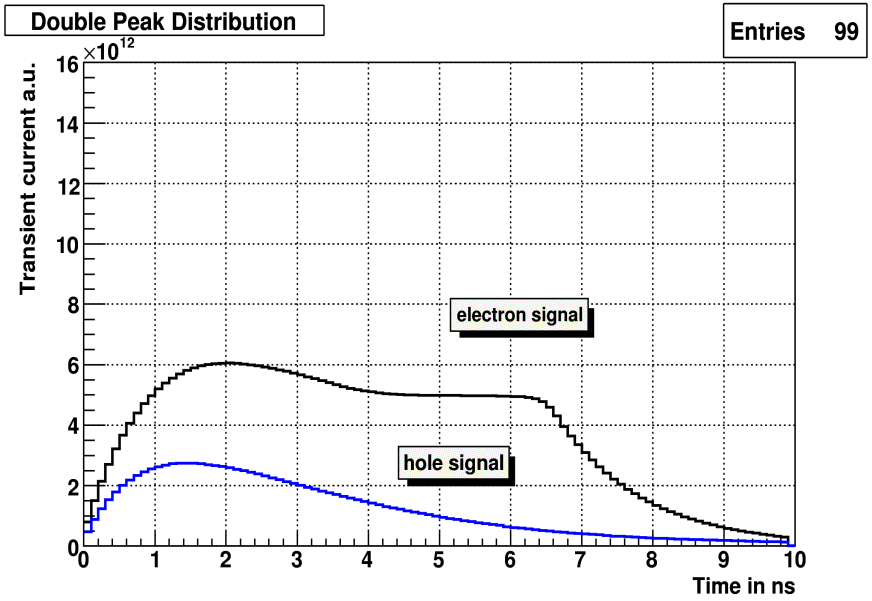


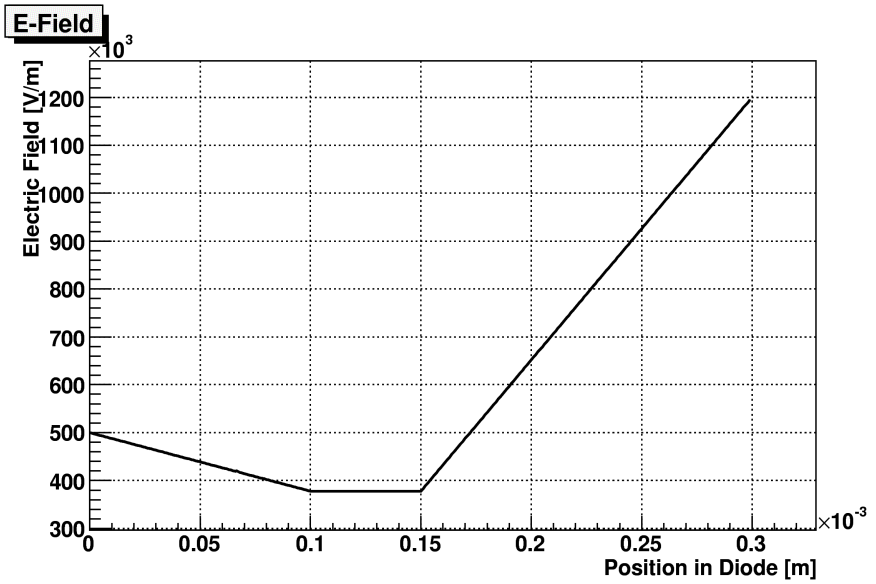


Changing the electric field, 200V

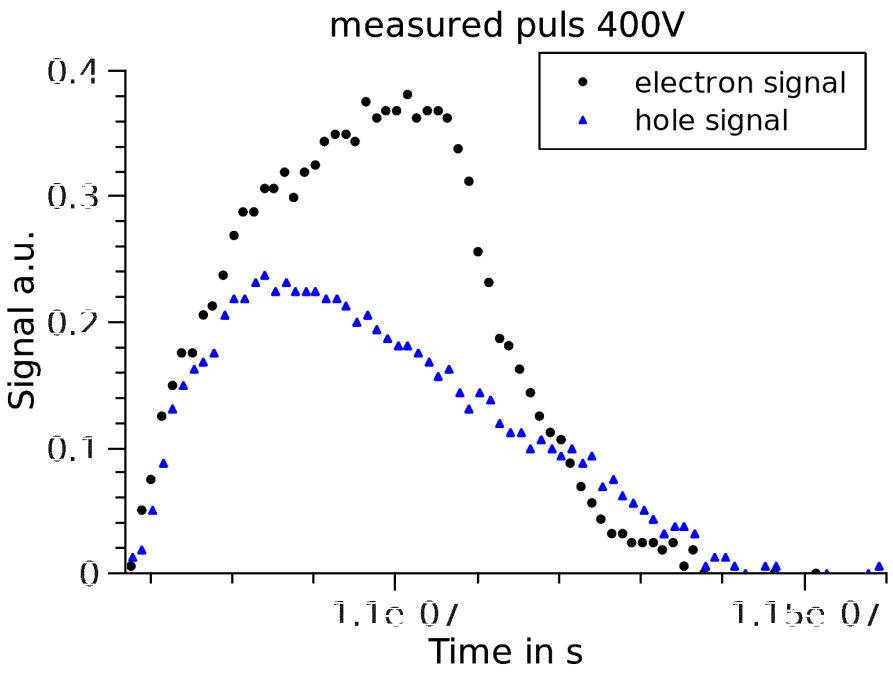


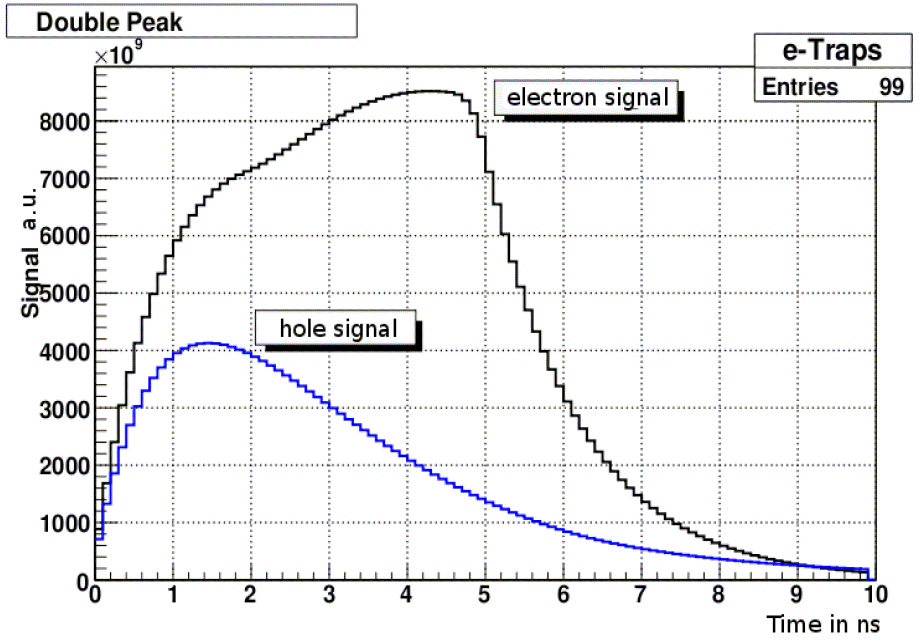




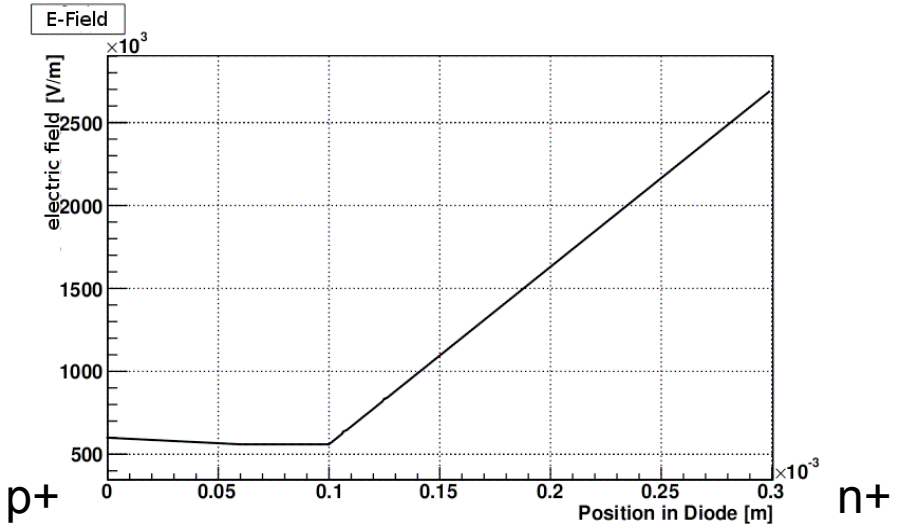


Reconstruction of the electric field, 400V





- Simulated Signal longer than measured
- Diode might be thinner



Summary & Outlook

- MCz diodes irradiated
- IV and CV measurements were made
- Trapping times determined for F < 10^15 n/cm2
- Continue measurements with annealing for more diodes
- Electric field simulated and reconstructed

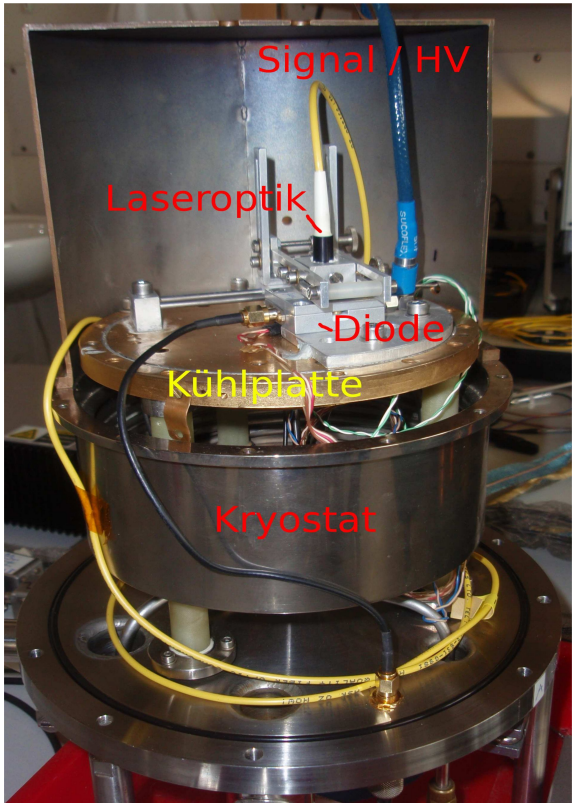
- MCz and FZ mini sensors irradiated like the diodes
- Mini sensors going to be tested in ALIBAVA

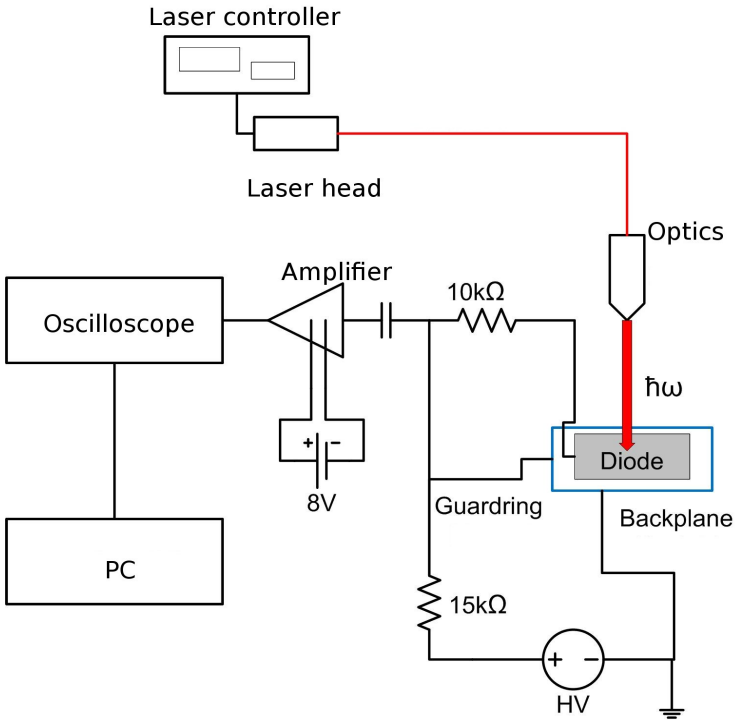
Thank You for Your Attention!

Any Questions?

Backup slides

Karlsruhe TCT Setup





- Laser: 678nm
- Temperature: -190°C to RT
- Voltage: 0V – +/-1100V