Characterization of SC CVD diamond detectors for heavy ions spectroscopy and MIPs timing

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SC CVD diamonds → producer e6

SC-E6-4 → 3.5 x 3.5 x 0.48 mm^3 ; Cr(50 nm) Au (100 nm)
BDS-5→ 5 x 5 x 0.325 mm^3 ; Cr(50 nm) Au (100 nm)
BDS 7→ 5 x 5 x 0.318 mm^3 ; Cr(50 nm) Au (100 nm)
BDS 9 → 5 x 5 x 0.32 mm^3 ; Al(100nm) guard ring
BDS 10 → 5 x 5 x 0.3 mm^3 ; Al(100nm) guard ring
BDS 14 → 5 x 5 x 0.49 mm^3 ; Al(100nm) guard ring

Cleaning and oxidation before metallisation:

If metallised before → Aqua Regia

H_2SO_4 + KNO_3 boiling ~30 min → rinse with ultra-pure water ultrasonic bath→dry with N_2

Metallisation sputtering or evaporation at Target Laboratory of GSI → Bettina Lommel talk

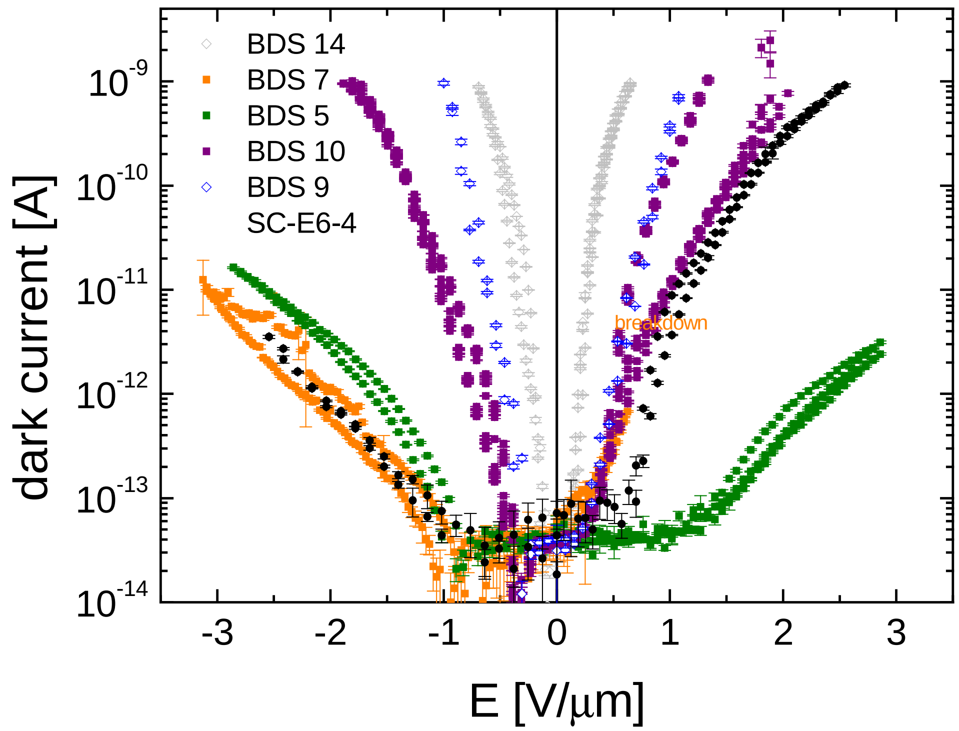
Cr(50nm)Au(100nm) ; Ti(30nm)Pt(50nm)Au(100nm); Al(100 nm) → **annealing 500C for 10min Ar**

OUTLINE

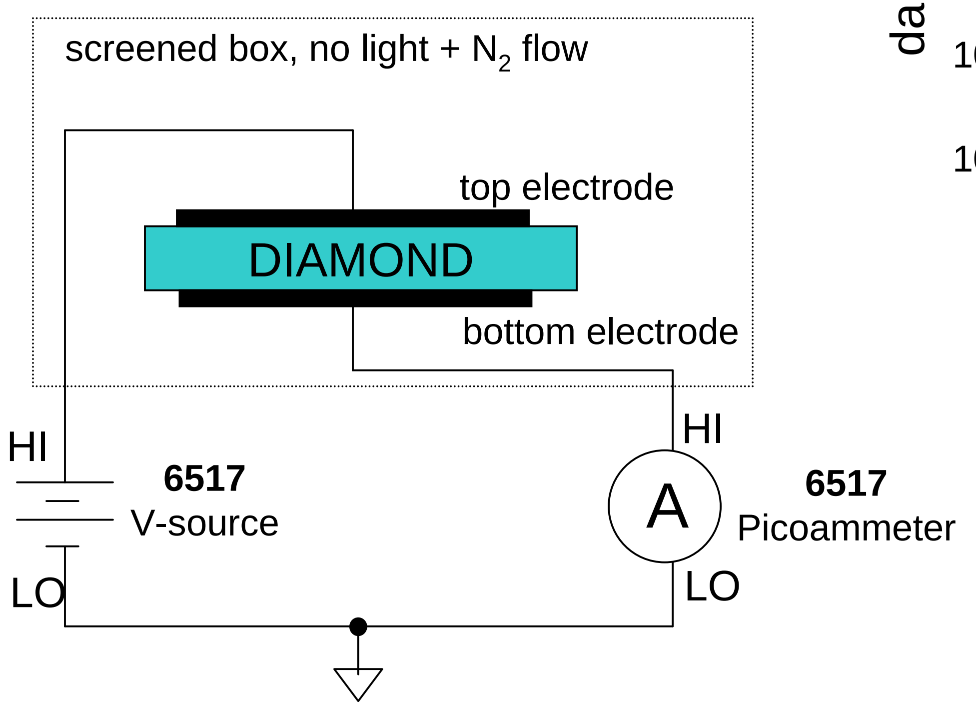
- Current-Voltage characteristics and surfaces influence
- Charge collection properties and stability
- Energy resolution
- Timing properties
- Summary

CURRENT-VOLTAGE CHARACTERISTICS

„Zoo" of I-V characteristics



bulk + surface current

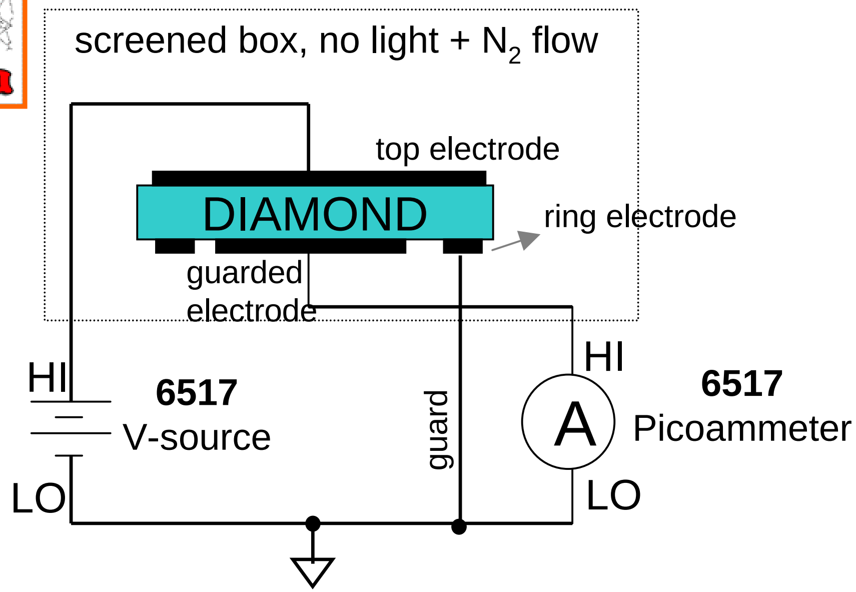


- not reproducible I-V for various samples

- asymmetry

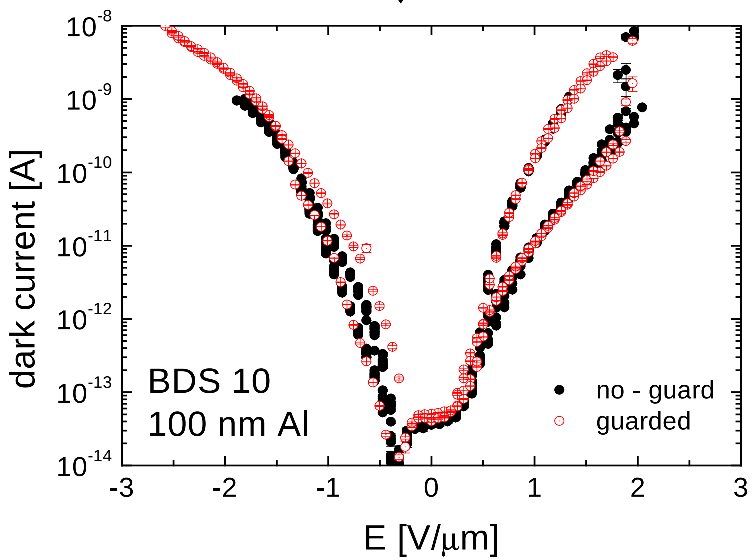
CURRENT-VOLTAGE CHARACTERISTICS

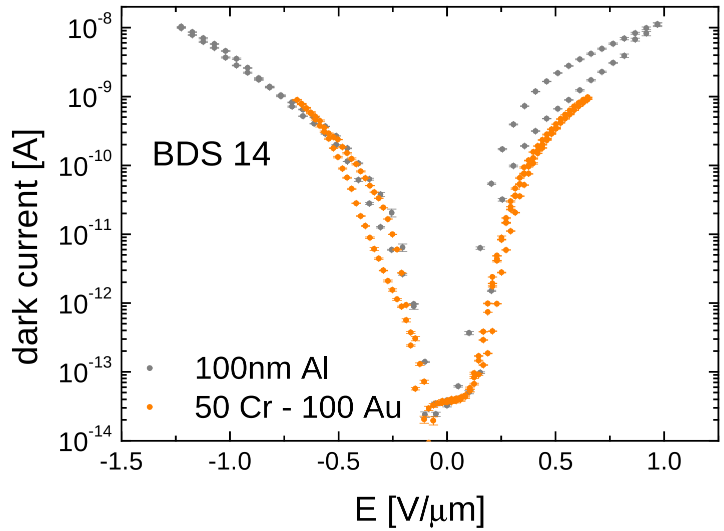
bulk current



no difference in I-V for:

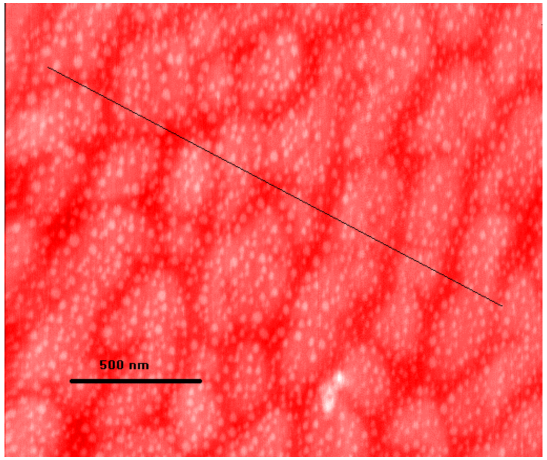
- various metallisation (Al,Cr,Ti) (2 samples tested)
- guarded electrode → mainly bulk leakage current (3 samples tested)

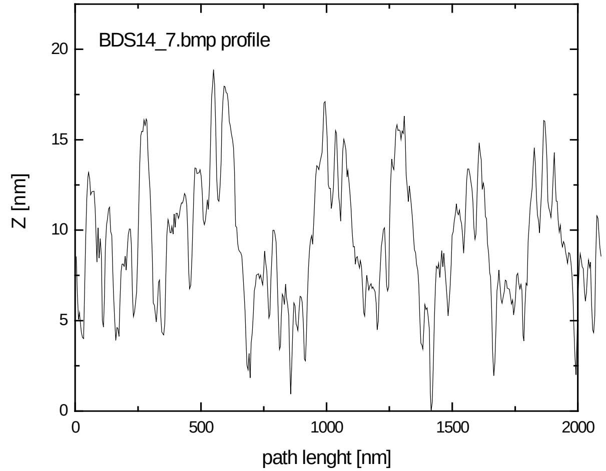




CURRENT-VOLTAGE CHARACTERISTICS

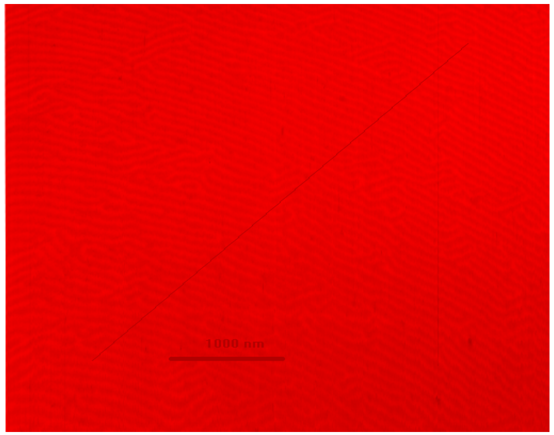
AFM pictures of both diamond (BDS14) surfaces

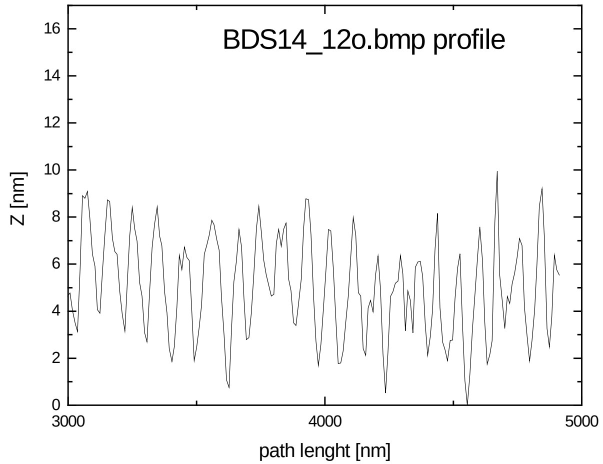




substrate side (?)

roughness
rms≅5.6 [nm]

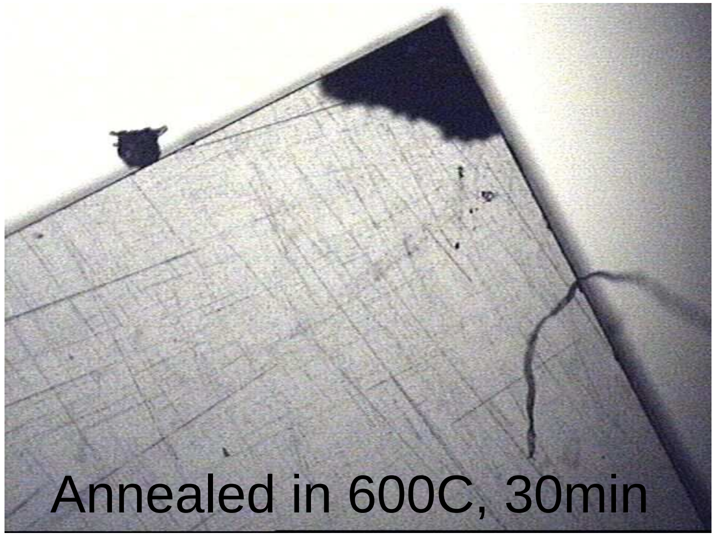


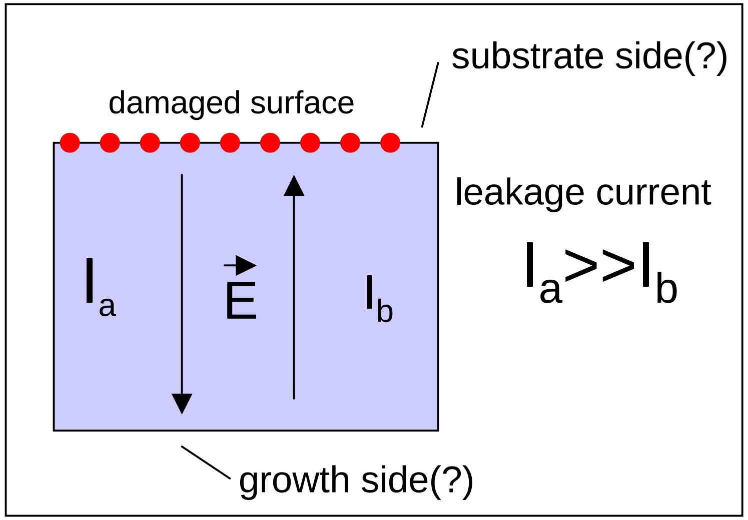


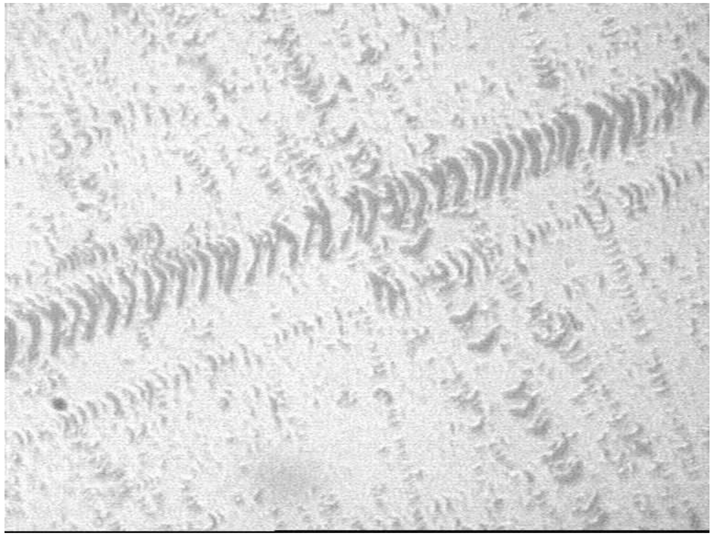
growth side (?)

roughness
rms≅1.4 [nm]

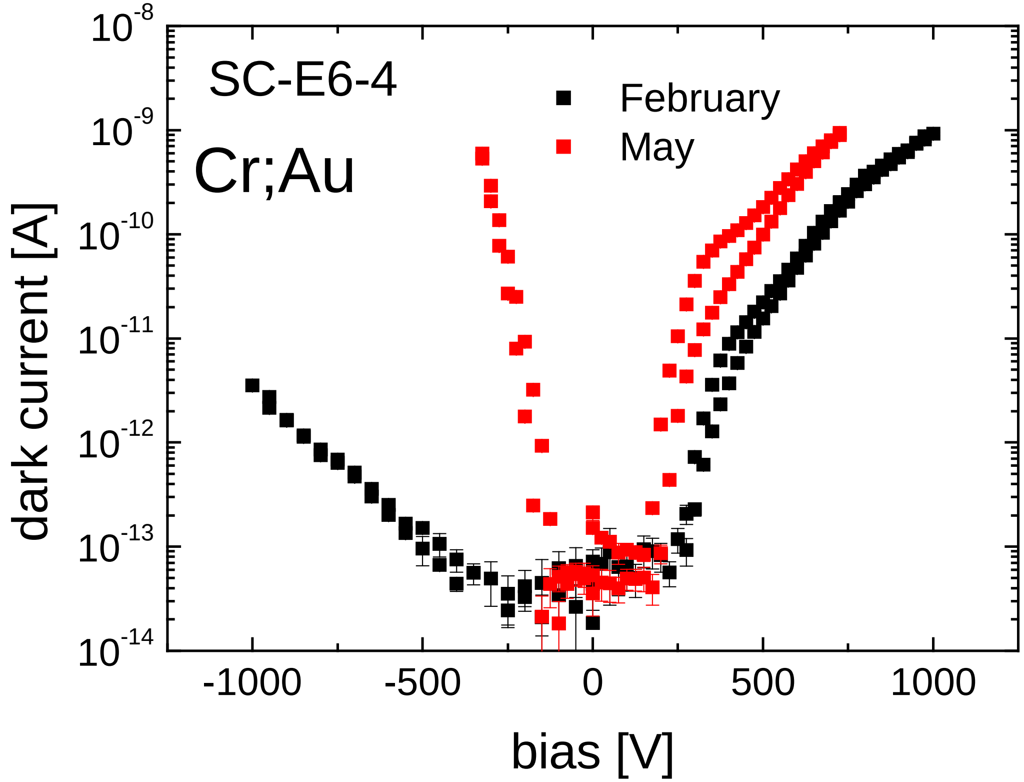
Asymmetry in I-V characteristic is present due to surface damage (polishing?) ... scratches „pop up" after samples annealing...







Long term stability



CHARGE COLLECTION

- Use of an **α-source ^{241}Am (5.486 MeV)** for charge injection

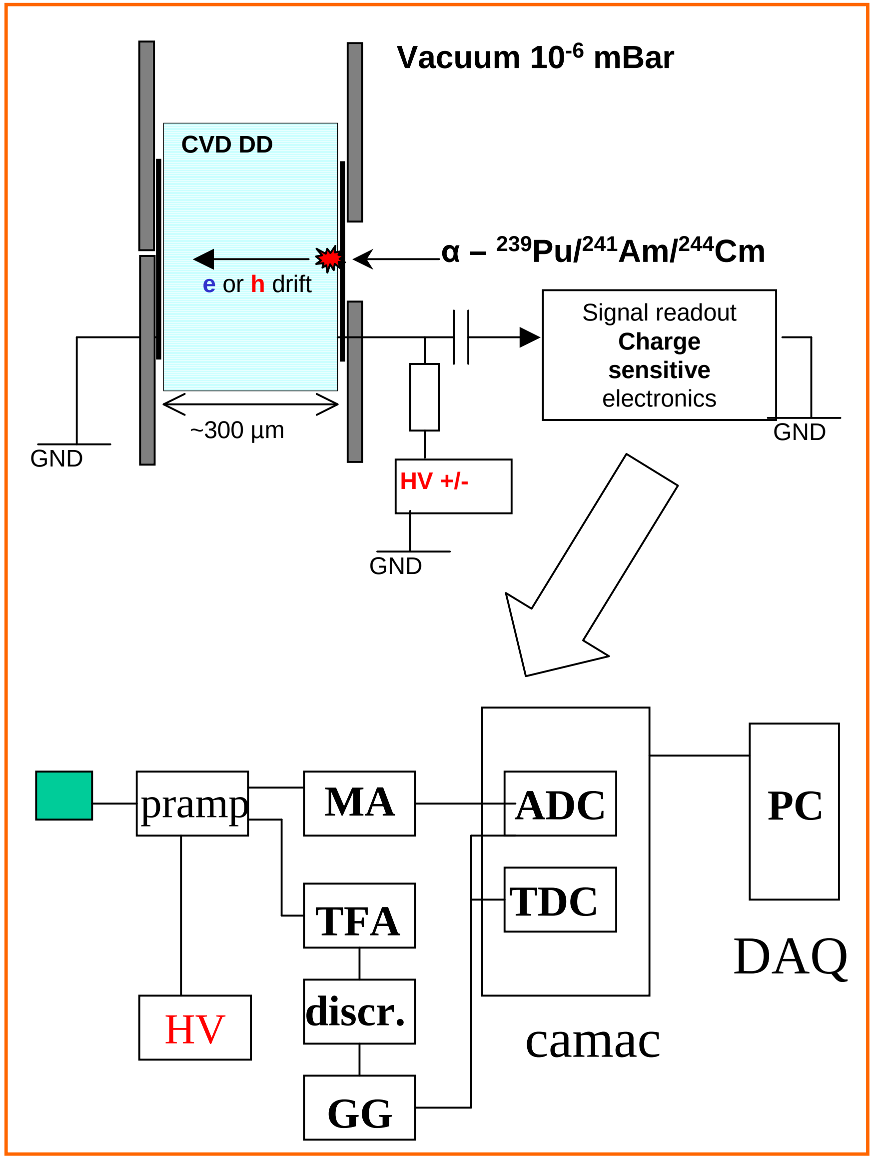
- α-particle range in diamond→~***12μm***

- detector thickness >***320μm***, induced charge → mainly motion of one type of carriers

- Choosing the HV +/- → drift of holes or electrons

- presented geometry **+HV – holes drift, -HV - electrons drift**

- detector coupled to classical spectroscopy front-end electronic



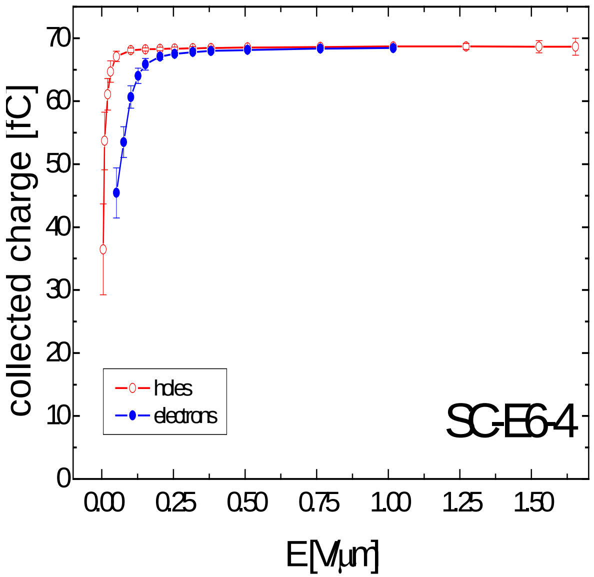
CHARGE COLLECTION

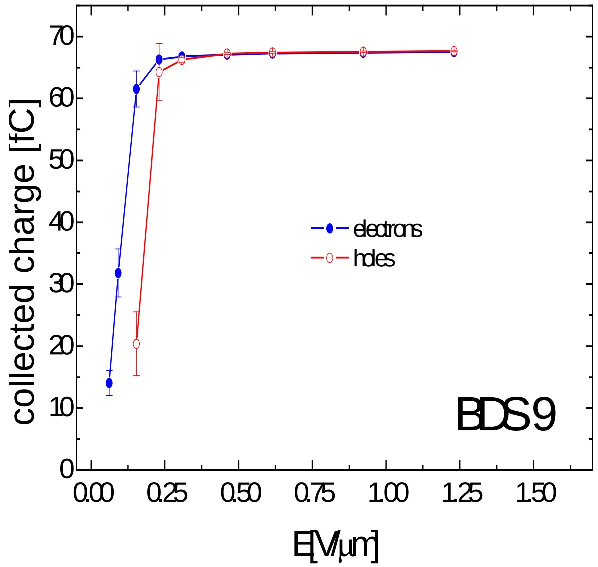
Saturation to ~ 68.6 [fC]
for both
electrons and holes drift.

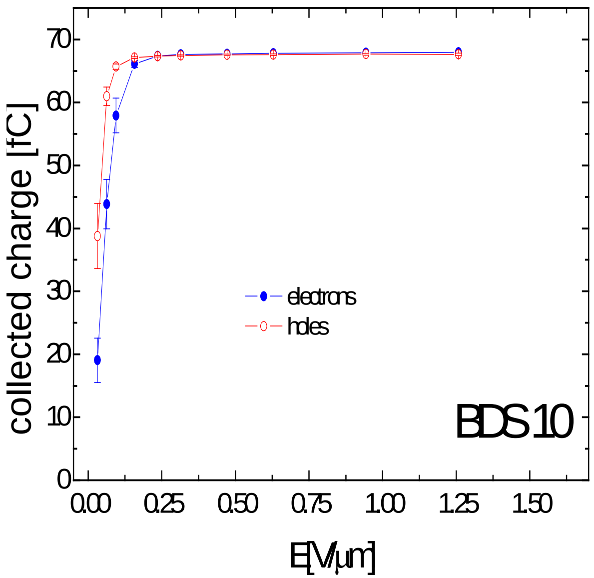
CCE=100% at low electric field < 0.3 V/mm

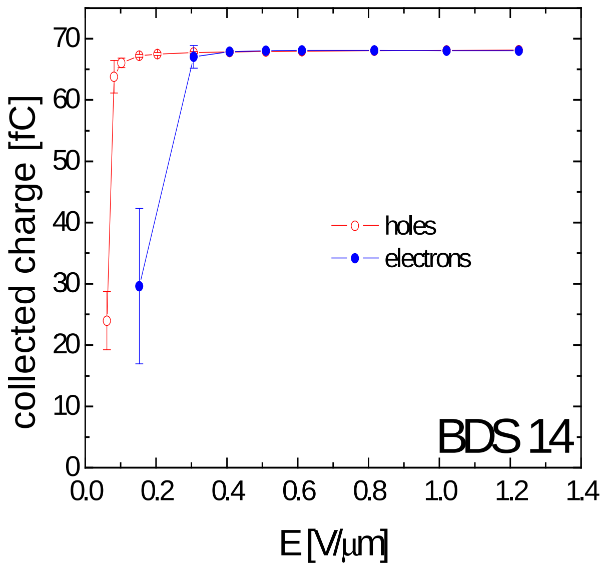
68.6 [fC] → 429 372 e-h

Average energy
for e-h pair creation
→ 12.8 eV/e-h





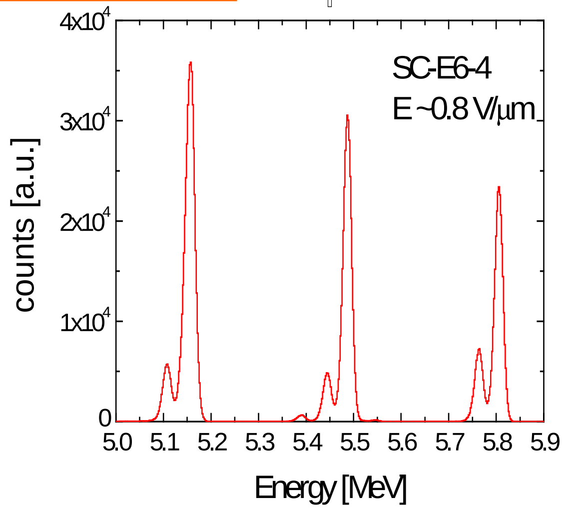


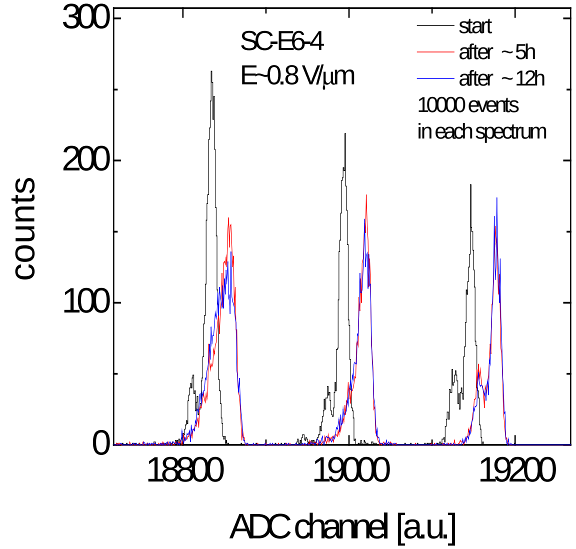


DETECTION STABILITY

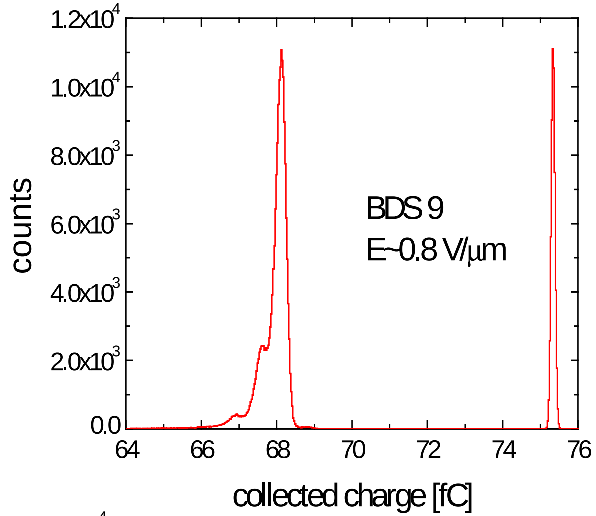
Time of spectrum collecting > 12h

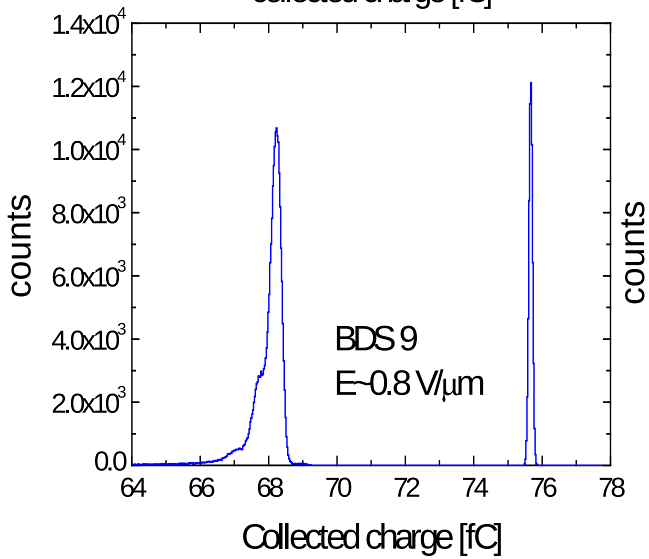
SC-E6-4



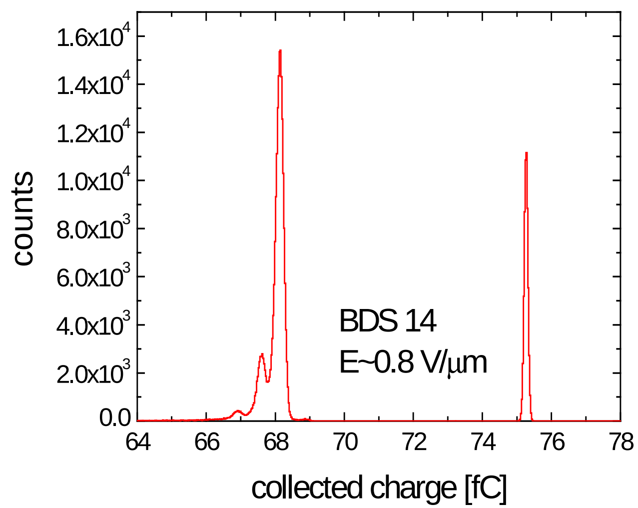


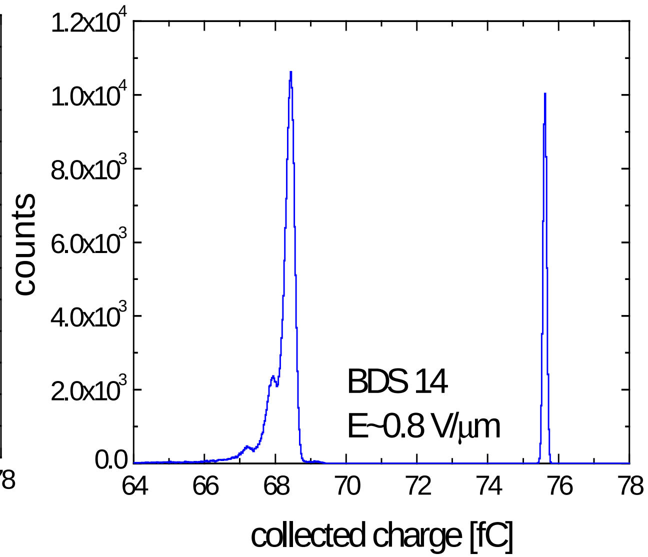
BDS 9





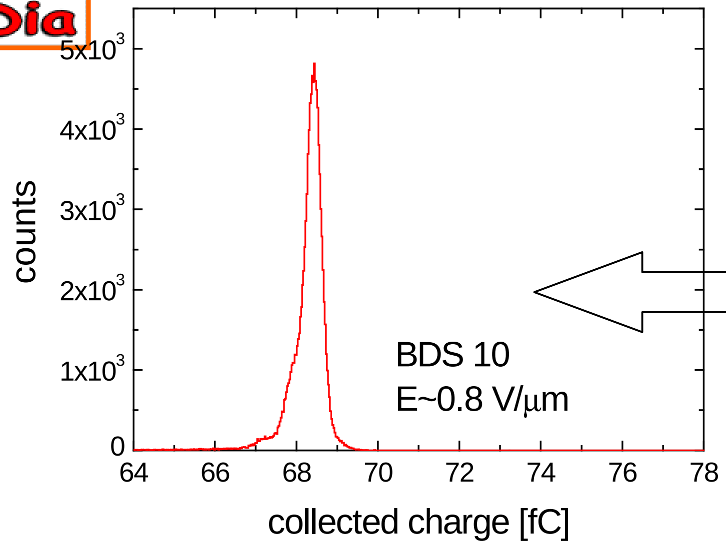
BDS 14

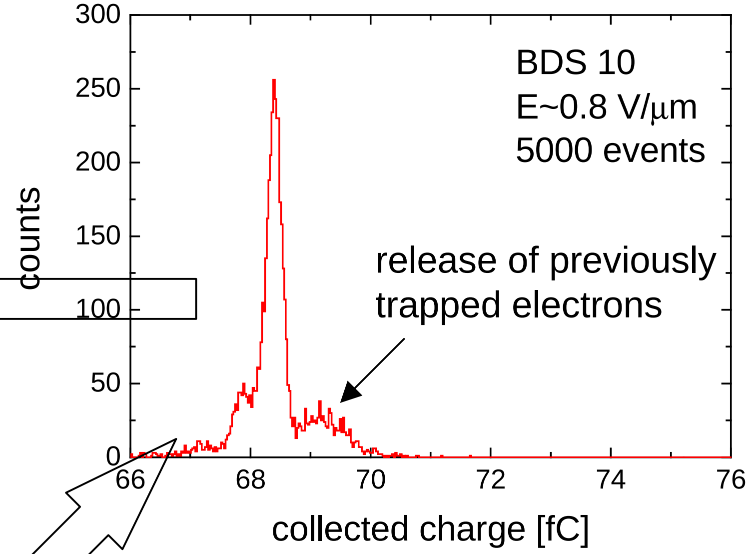


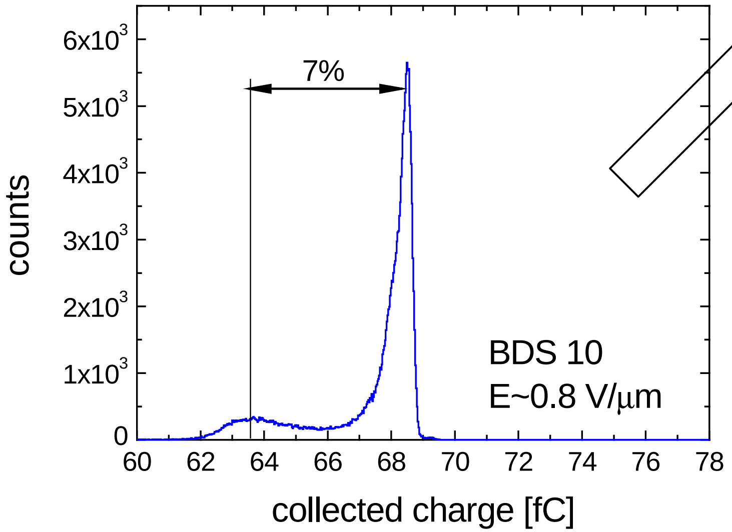


DETECTION STABILITY

BDS 10







Indication of presence for electrons:

regions with 100% efficiency → main peak

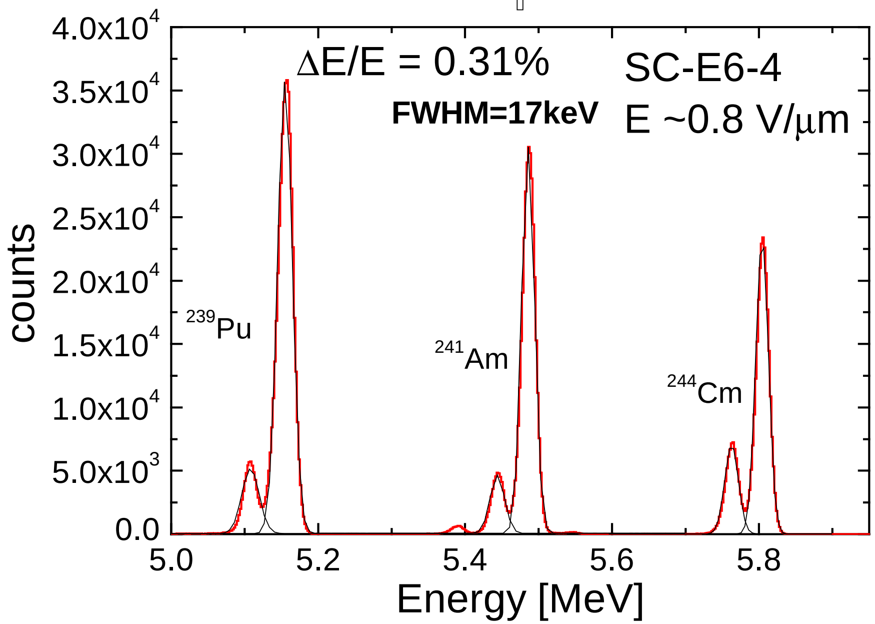
region with lower efficiency 93%, quite uniform density of trapping centres → shifted peak

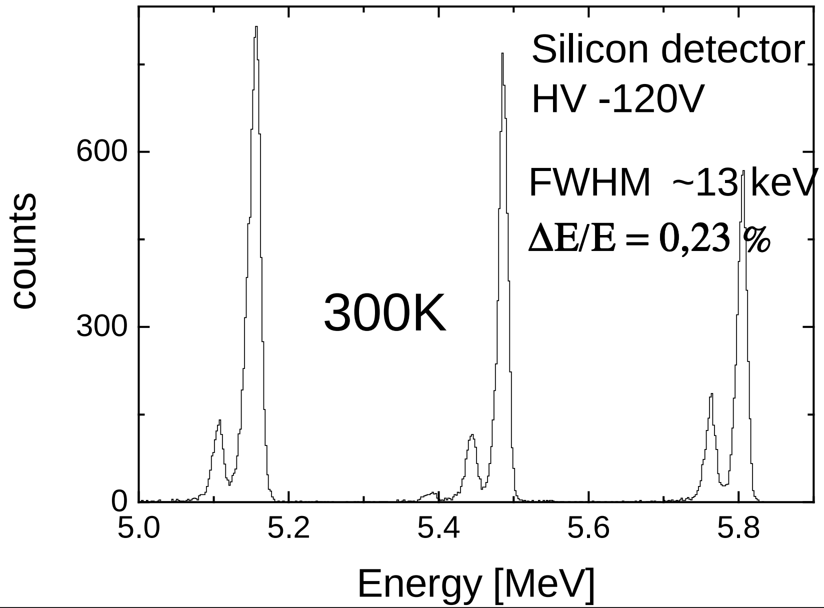
ENERGY RESOLUTION

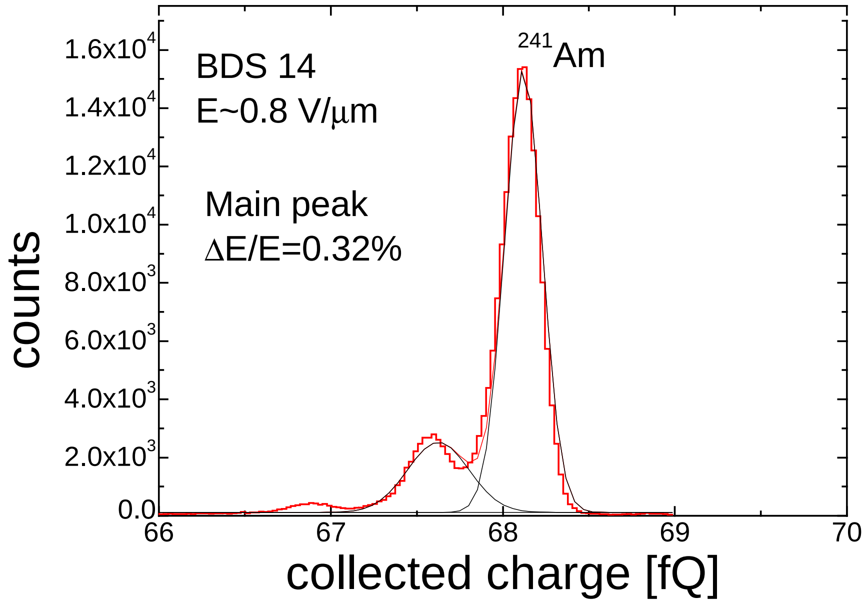
Diamond resolution close to silicon detectors:

FWHM = 17 keV (5.486 MeV) (sc-e6-4 holes)
measured with not dedicated CS electronics

silicon → e~3.6 eV/e-h; diamond →e~12.8 eV/e-h
We are close to statistical limits (Fano factor?)



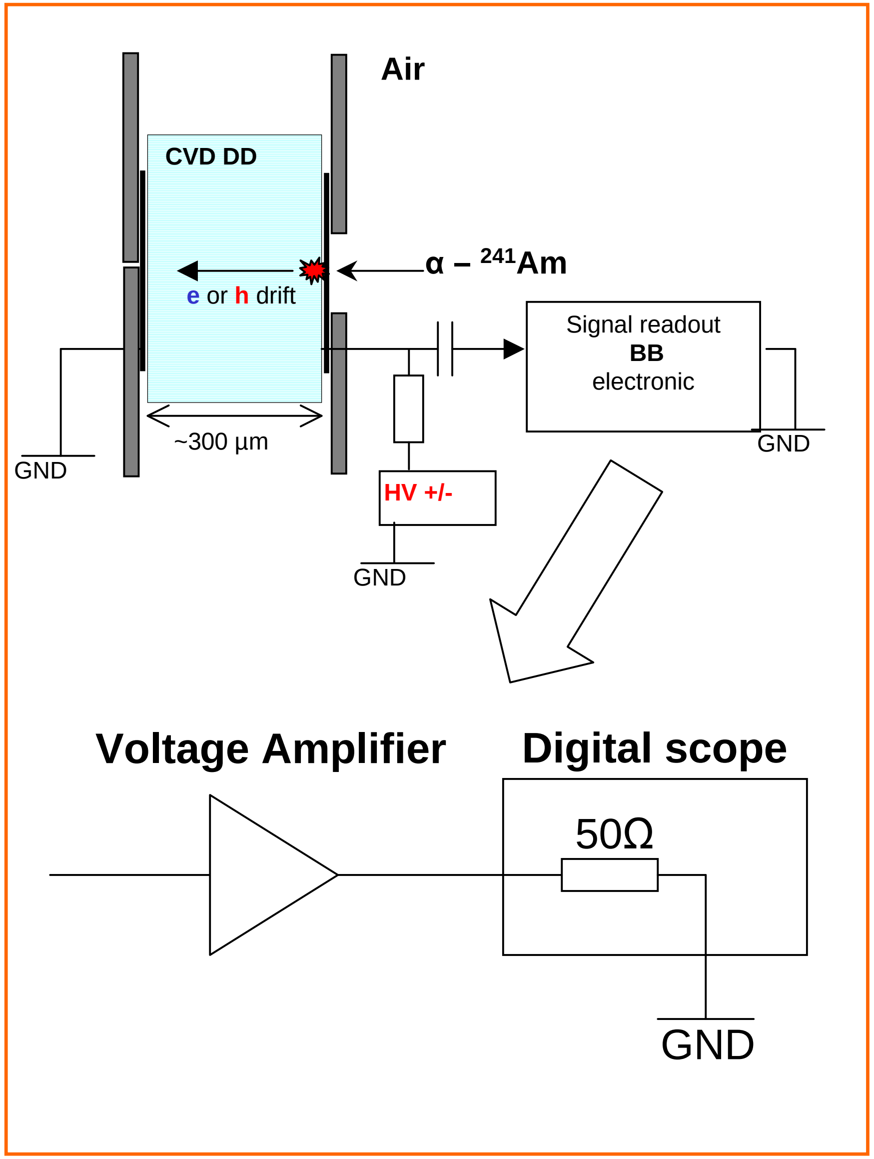




Time of Flight Technique

Low impedance of 50 Ω voltage amplifier
DBA – II, bandwidth **2.3 GHz** (3dB), gain 44dB

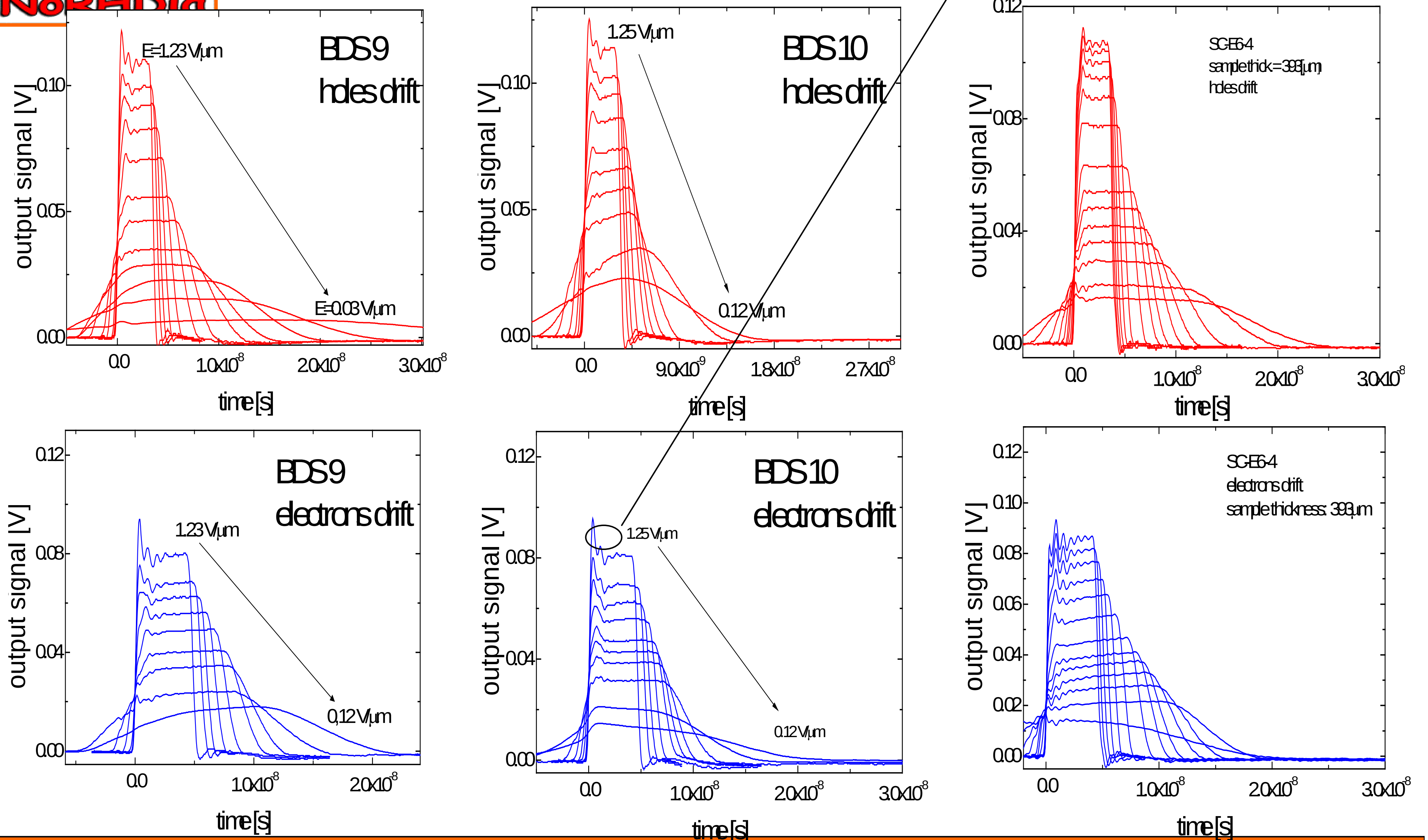
Digital Scope
bandwidth **3GHz**, 20GS/s



TIMING PROPERTIES

Average signals from 500 single shots

electronics oscillation 2GHz
due to 50ohm mismatching



TIMING PROPERTIES

Assuming uniform internal electric field (flat top of BB signals) and CCE=100%

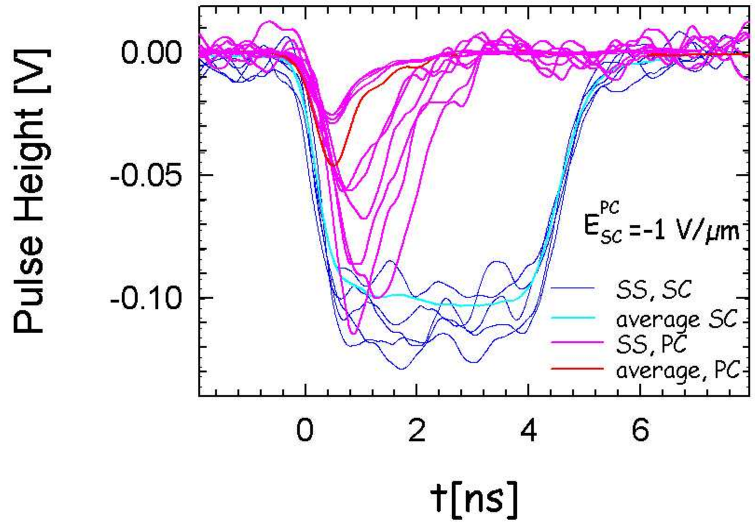
$$v_{dr}(E) = \frac{d}{t_{tr}}$$

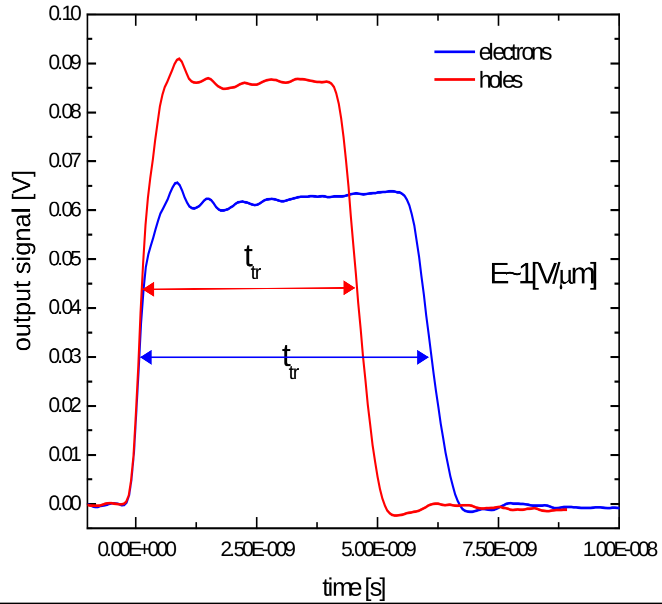
d – detector thickness

t_{tr} – transition time → FWHM of BB signals

error → standard deviation of signals at FWHM

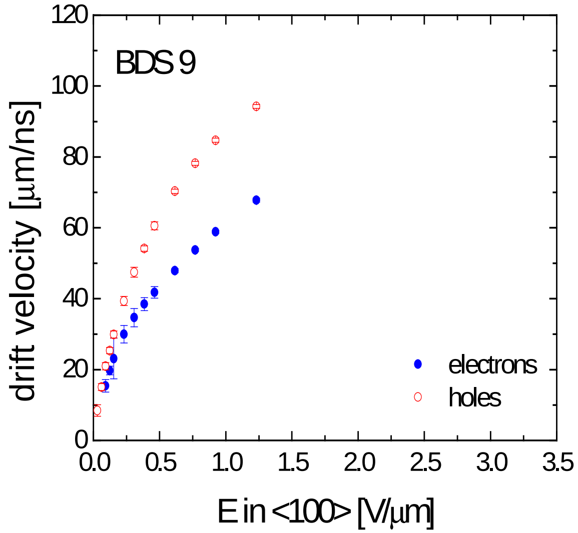
electron drift signals

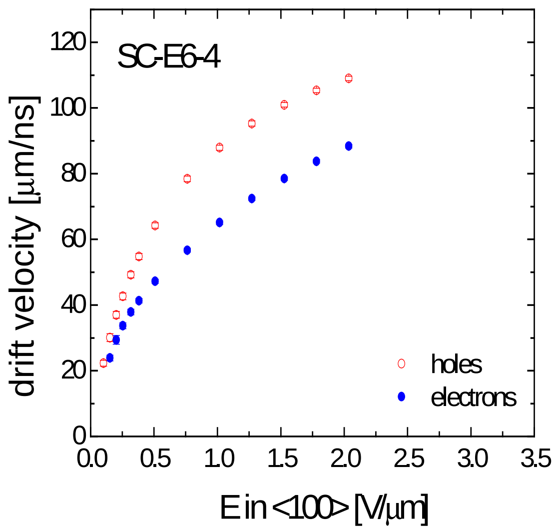


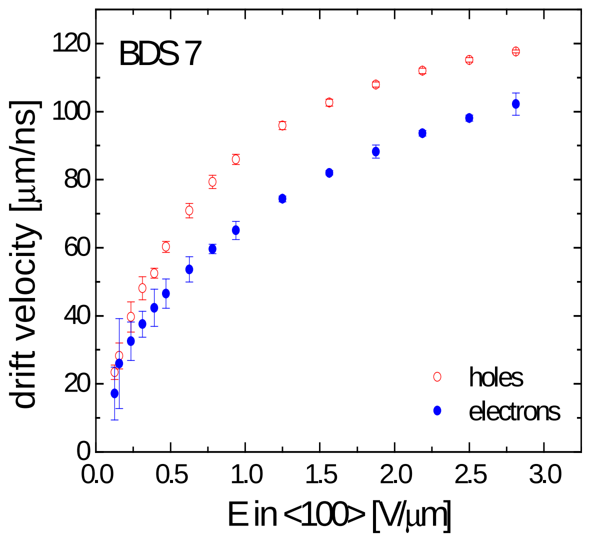


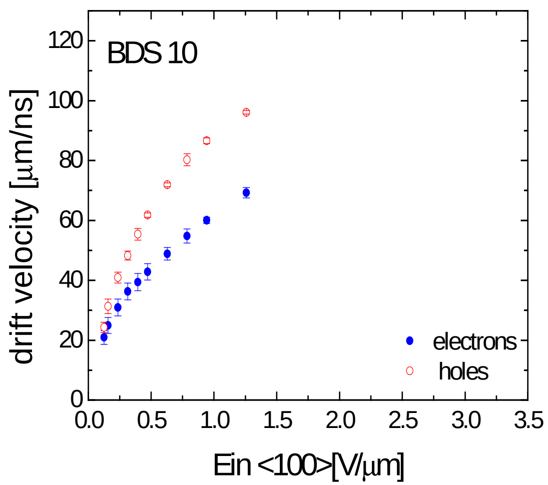
TIMING PROPERTIES

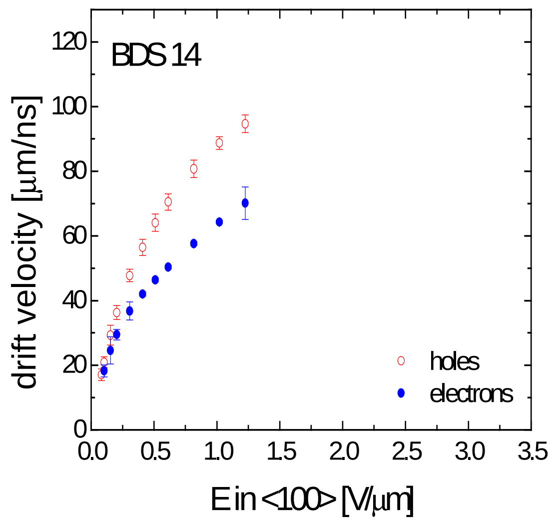
Drift velocities for electrons and holes

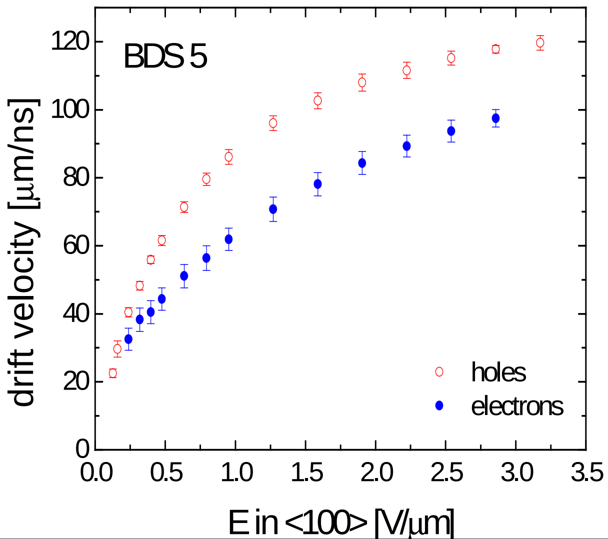












TIMING PROPERTIES

Novel Radiation Hard CVD Diamond Detectors for Hadron Physics — NoRHDia

$$V_{dr} = \frac{\mu_0 \cdot E}{\left[1+\left(\frac{v_{sat}}{\mu_0}\cdot E\right)^{\beta}\right]^{1/\beta}}$$

holes, $\beta \approx 1$ →

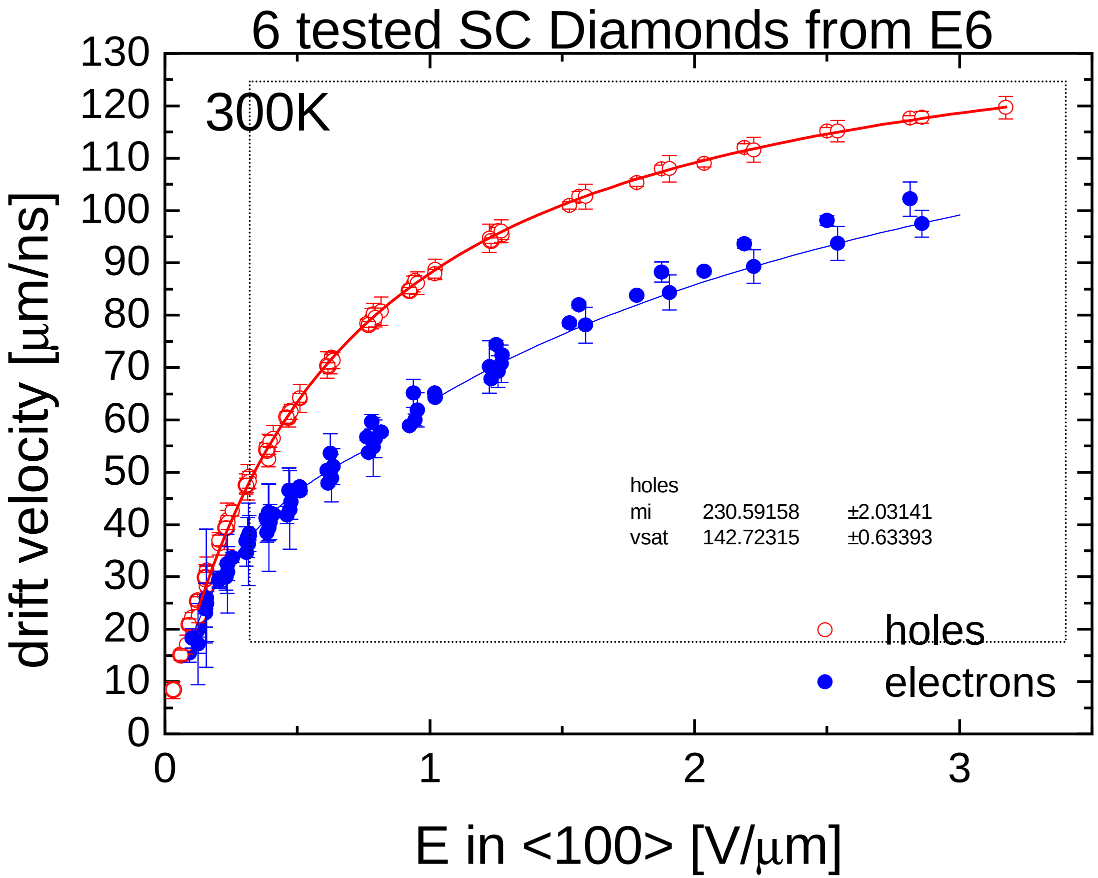
$$V_{dr} = \frac{\mu_0 \cdot E}{1+\frac{v_{sat}}{\mu}\cdot E}$$

electrons →

2 fits:

0.3 – 1 V/µm → μ_0

1 – 3 V/µm → v_{sat}



Holes

$\mu_0 \cong$ **2332 [cm²/Vs]**

$V_{sat} \cong$ **140 [µm/ns]**

electrons

$\mu_0 \cong$ **1400 - 3100[cm²/Vs]**

$V_{sat} \cong$ **190 [µm/ns]**

Current voltage characteristics

- huge difference in leakage current for various samples
- no difference for guarded samples→mainly bulk leakage
- Asymmetry in I-V probably due to damaged surface as a result of samples polishing → requires overgrowth after polishing
- No difference for various metallisation → proposal to use light elements e.g. Al

charge collection, stability, and ΔE

- CCE ~ 100% at low E < 0.3V/µ for holes and electrons – most of tested samples
- all samples → "spectroscopic grade" some of them resolution close to silicon detectors
- perfect behavior for holes drift – no trapping (or negligible)
- most of them stable as well for electrons drift

Novel Radiation Hard CVD Diamond Detectors for Hadron Physics

NoRHDia

SUMMARY

GSI

Timing properties

- flat top of BB signals for all tested samples – uniform internal electric field – no internal space charge

-common behavior -->

holes drift velocity **>** electrons drift velocity in <100>

- intrinsic limit for timing application with CSA electronic

drift of electrons 1ns / 100 µm (optimistic E=2.8V/µm)

- uniform rise time of ~160 ps (limited by electronics) jitter - 26 ps for BB electronic