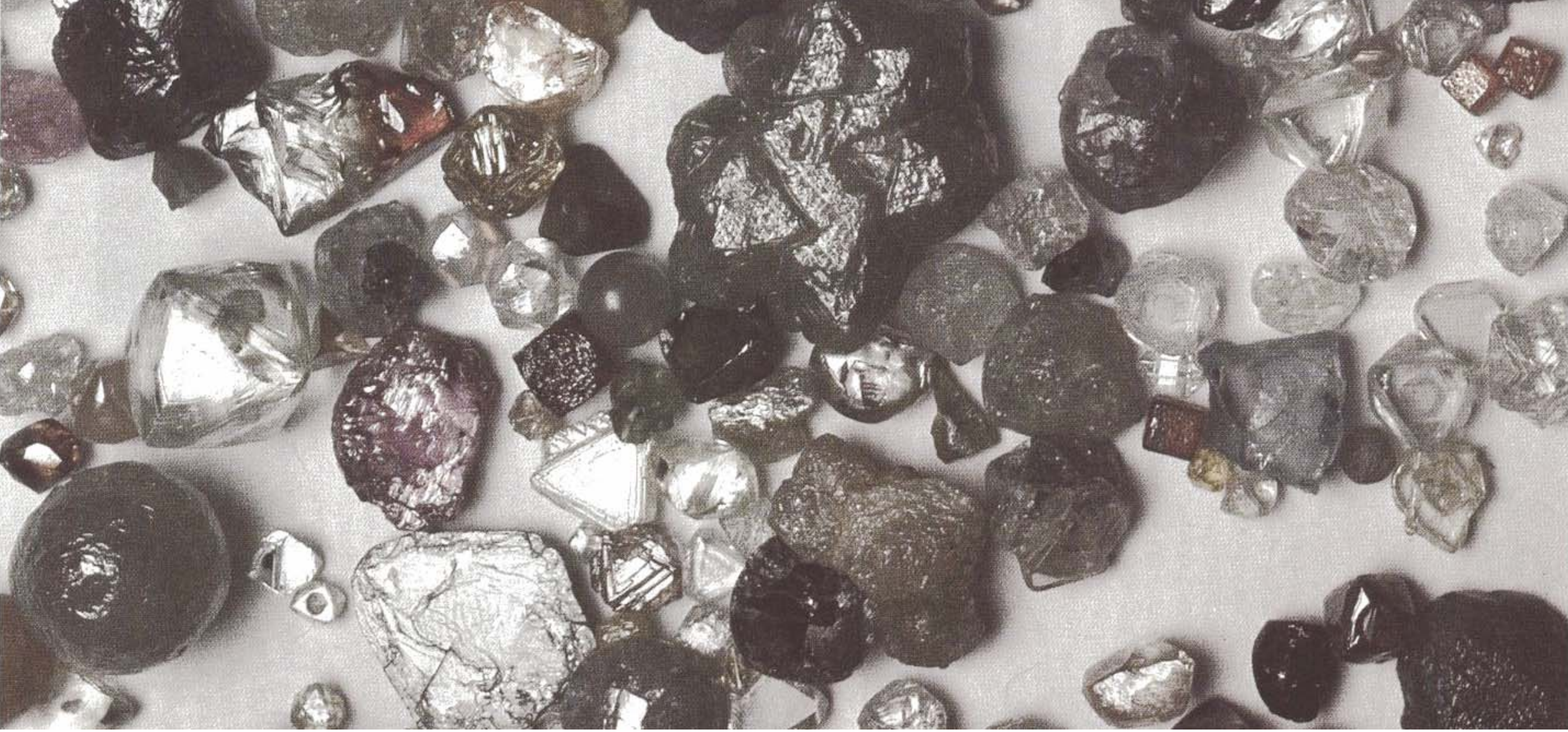


E. Berdermann, M. Ciobanu, M. Fischer, J. Frühauf, S. Gsell, M. Kiš,
W. Koenig, P. Moritz, MD. S. Rahman, M. Schreck, C. Stehl and M. Träger

CARAT RESULTS FROM DIAMOND-ON-IRIDIUM (DOI) SENSORS

OUTLINE

- INTRODUCTION - OBJECTIVES
- MATERIAL and SENSOR CHARACTERIZATION

  INTRINSIC Dia-On-Ir (DOI) SAMPLES: 2009, 2010, 2011

  - DEFECTS, DARK CONDUCTIVITY, CHARGE COLLECTION EFFICIENCY, ALPHA-TOF, BEAM-TESTS
- SUMMARY
- CONCLUSIONS and OUTLOOK

THE OBJECTIVES

- Engineering of CVD DOI plates for sensor applications
  - crystal growth and post processing; defect characterization
- Electronic properties and DOI- Detector performance
  - comparison of all three 'detector-grade' CVDD types
- FEE developments
  - Broadband amplifiers and discriminators – single-channel and ASICs - in particular, for fast MIP timing

Target: Large-area, advanced-diamond strip sensors of low material budget for tracking and ToF of HI + MIP

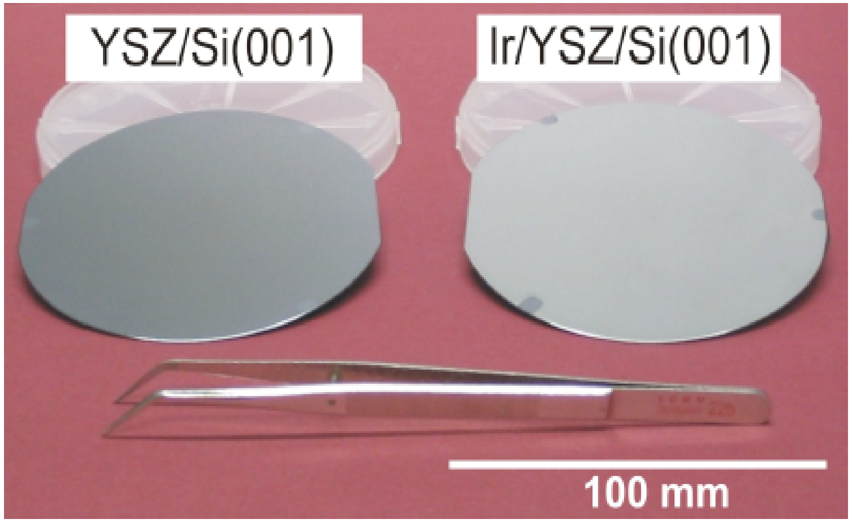
CVD DIAMOND-ON-IRIDIUM (DOI)

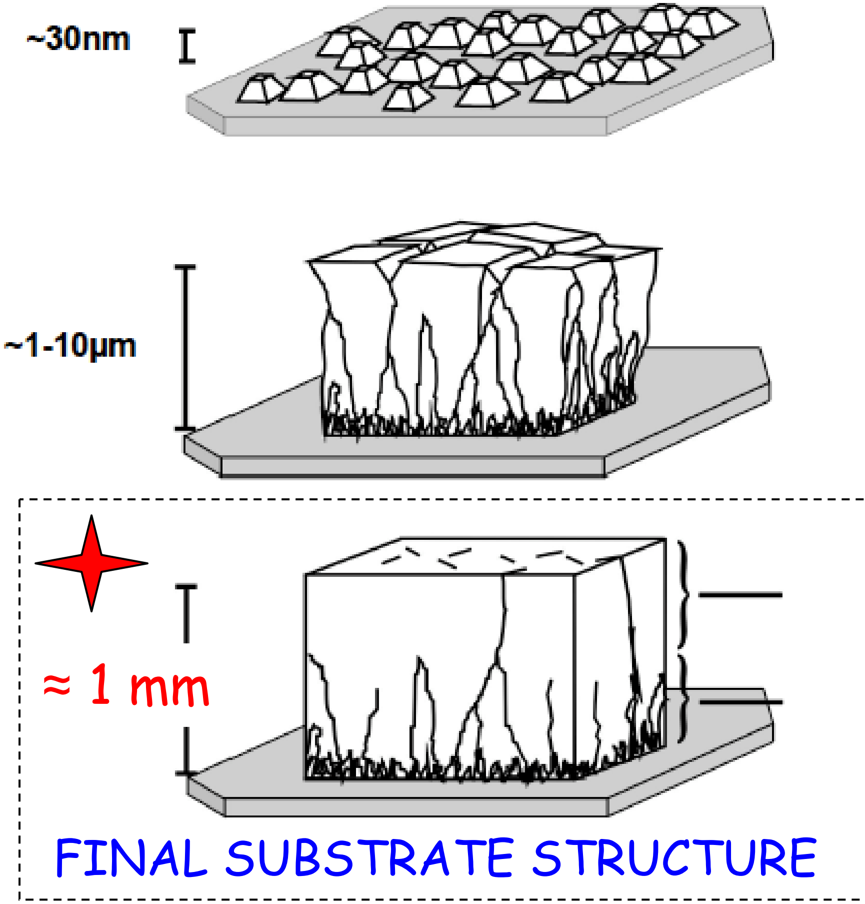
WAFER-SCALE SINGLE-CRYSTAL DIAMOND DETECTORS

UA: S. Gsell et al., Appl. Phys.Lett. 84 (2004)

BY HETEROEPITAXY

on large-area iridium substrates (CVD-DOI)



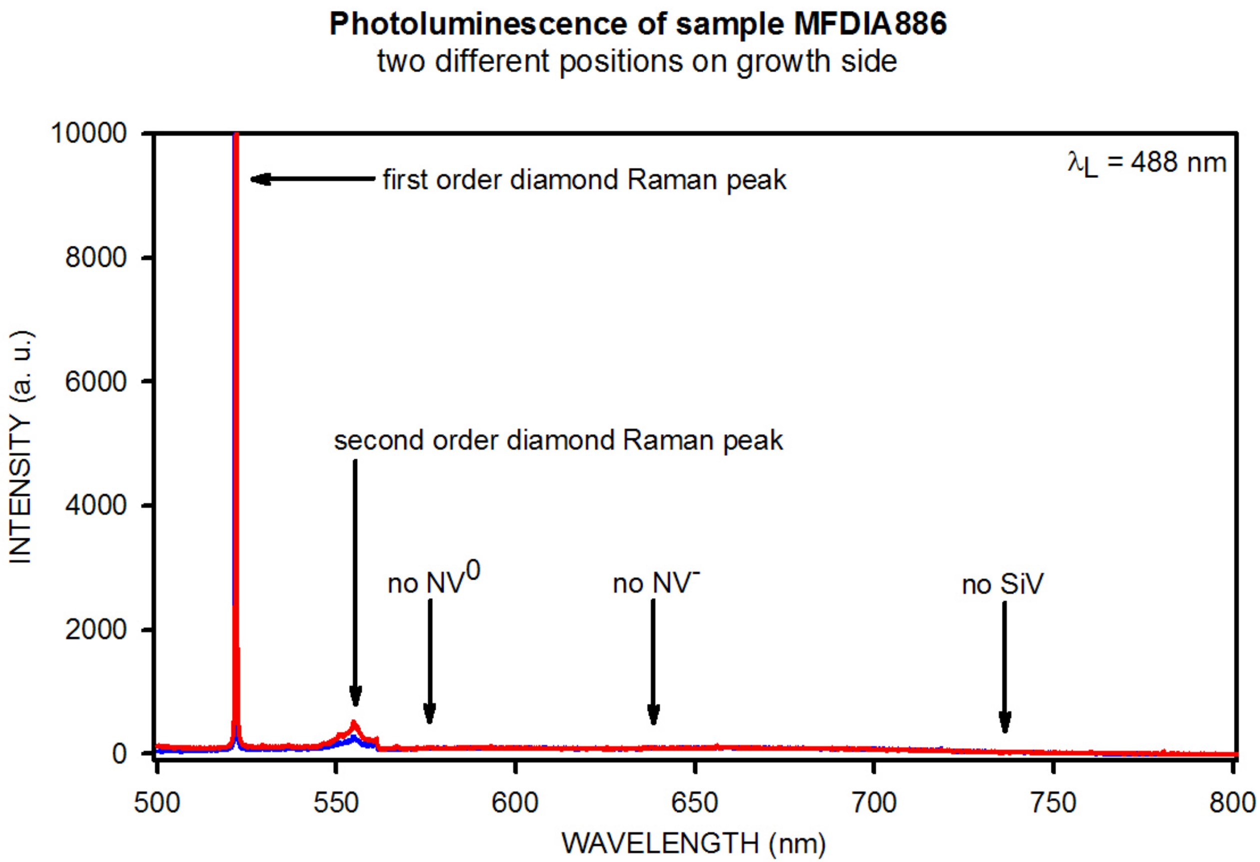


FINAL SUBSTRATE STRUCTURE

DEFECT SPECTROSCOPY

NITROGEN and SILICON IMPURITIES

UA: C. Stehl, M. Schreck, M. Fischer

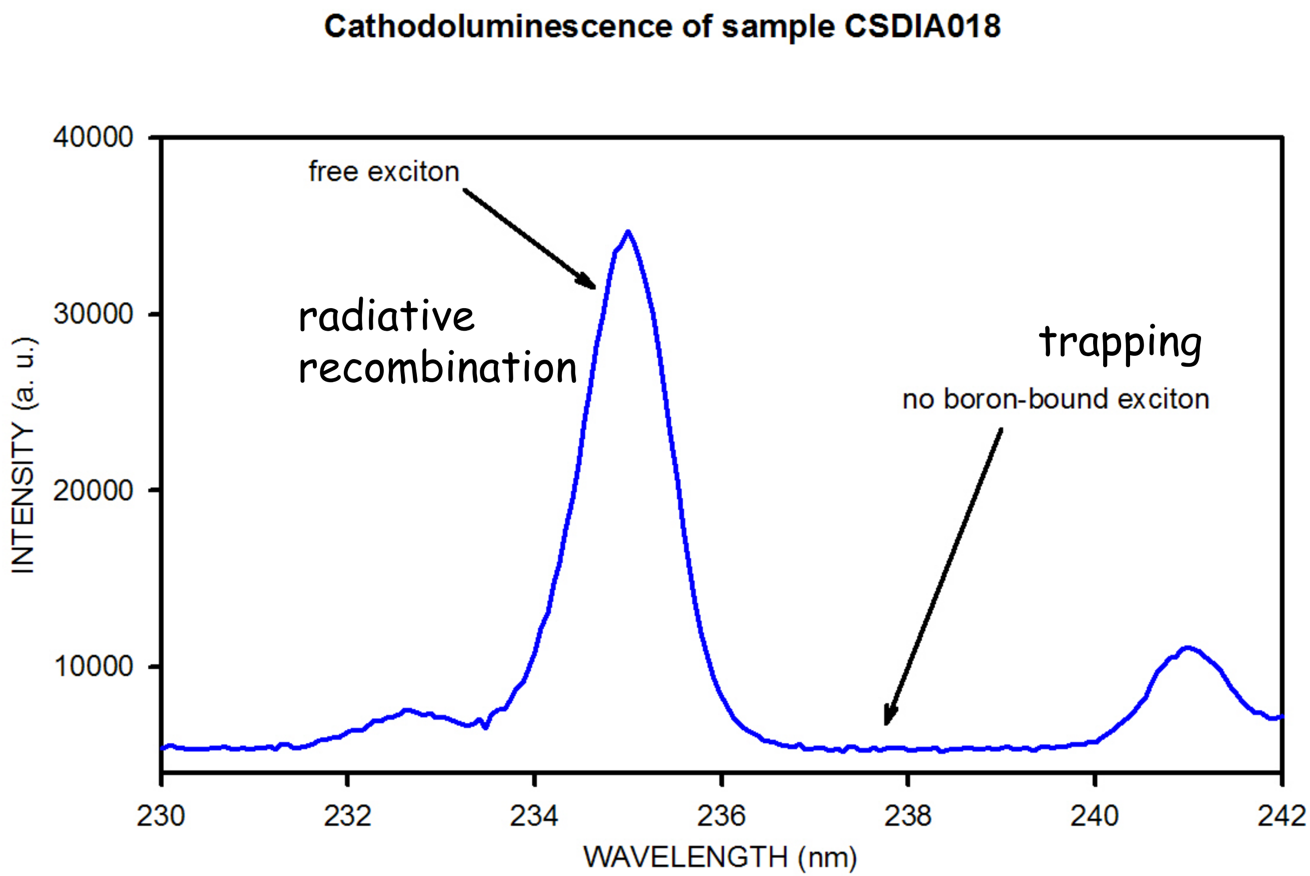


No SiV and NV peaks visible

DEFECT SPECTROSCOPY

BORON IMPURITIES

UA: C. Stehl, M. Schreck, M. Fischer



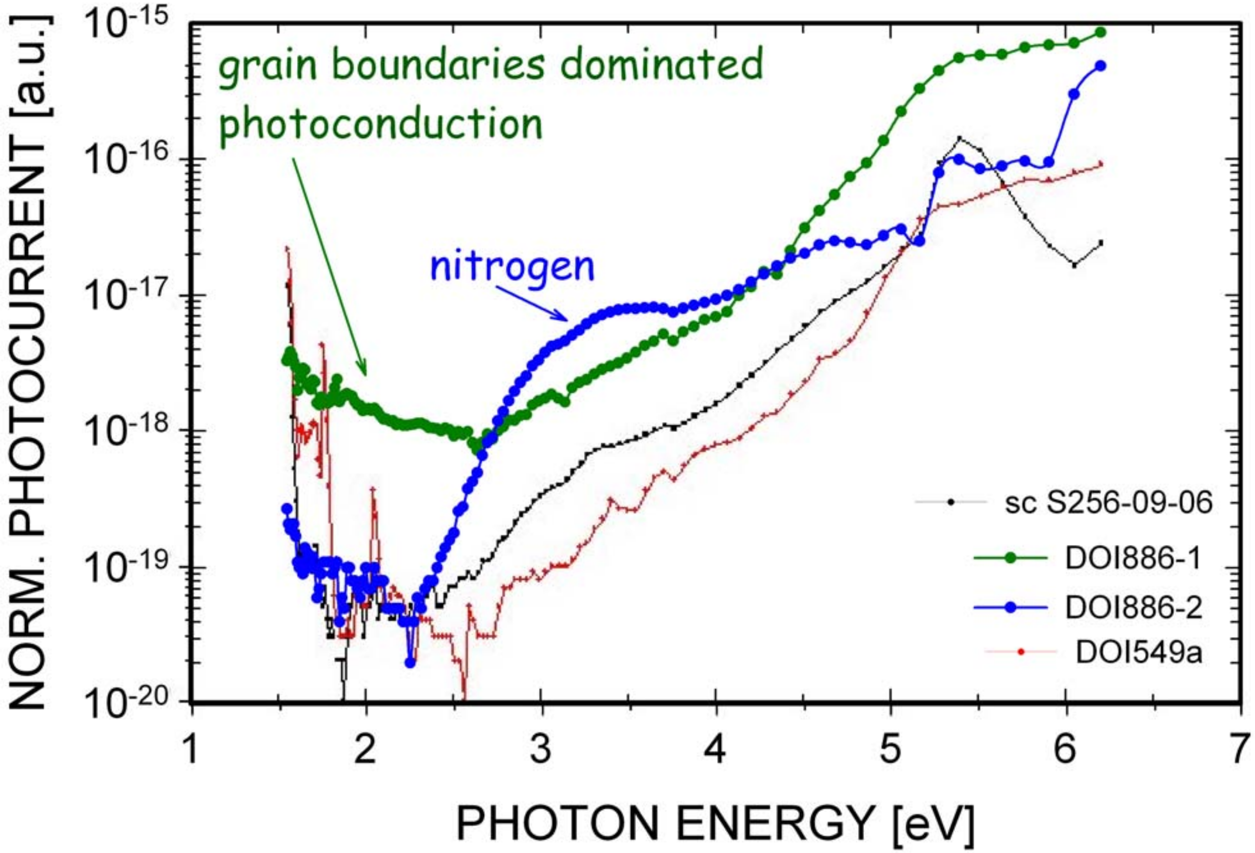
Boron concentration ≤ 1×10^{14} cm^{-3} (≈ measurement limit)

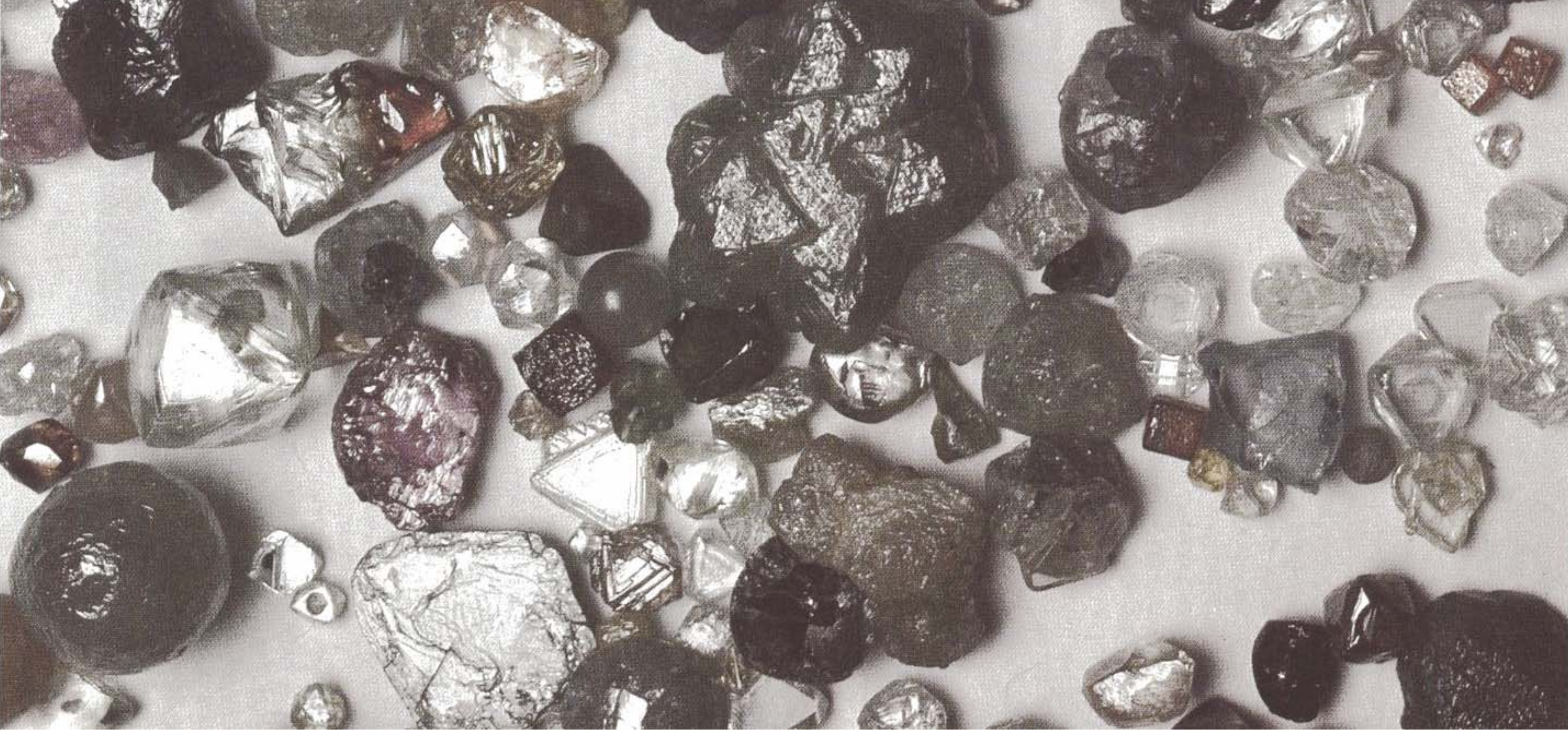
DEFECT SPECTROSCOPY

SPECTRALLY RESOLVED PHOTOCURRENTS

IAF: E. Layevski, C. Nebel

2010



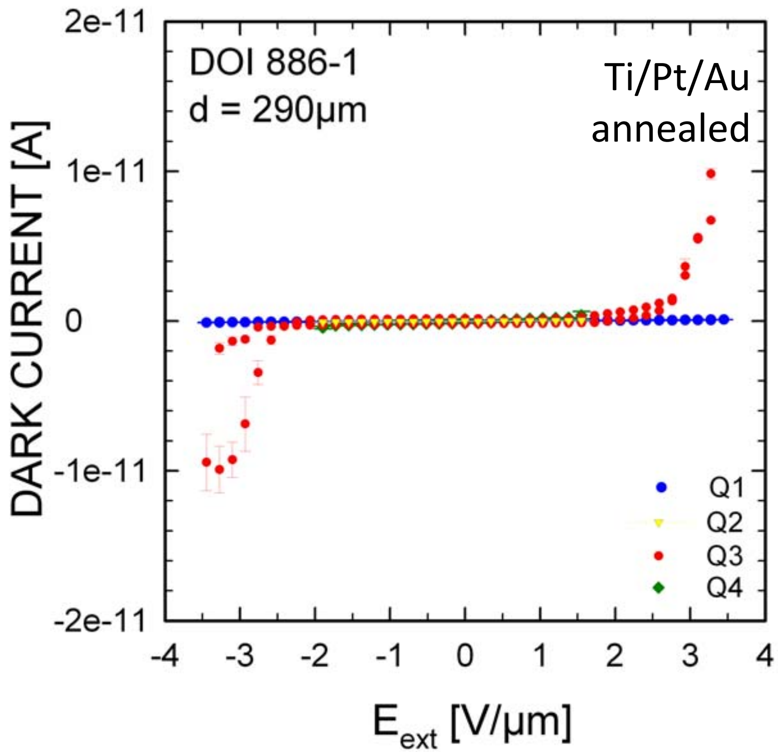


DETECTOR PROPERTIES

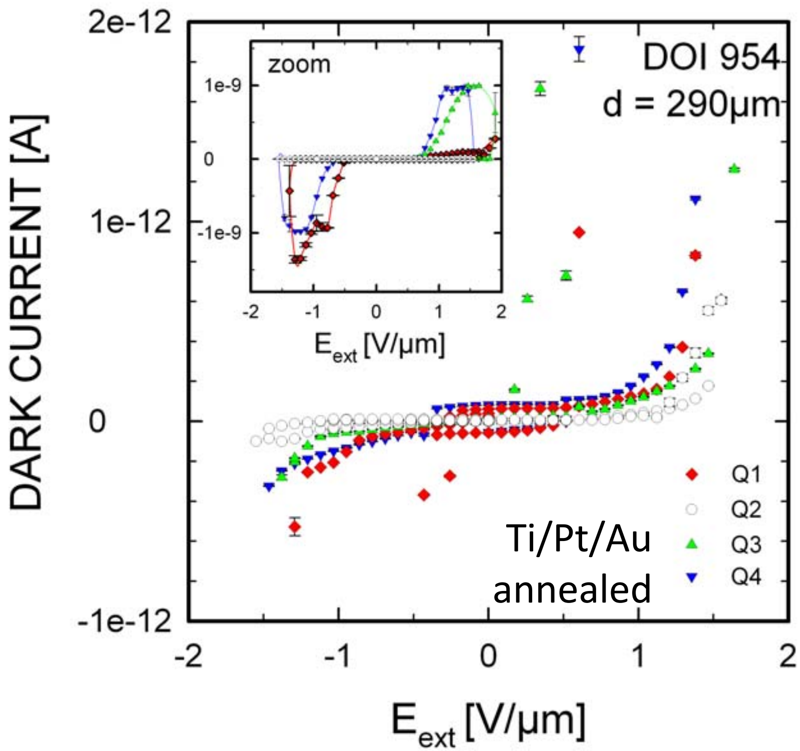
DARK CONDUCTIVITY

➤ LOW I_{Dark}: COMPENSATION OF TRAPS ➡ GSI: M. Träger, S. Rahman

QUADRANT- SENSOR
SPATIAL HOMOGENEITY

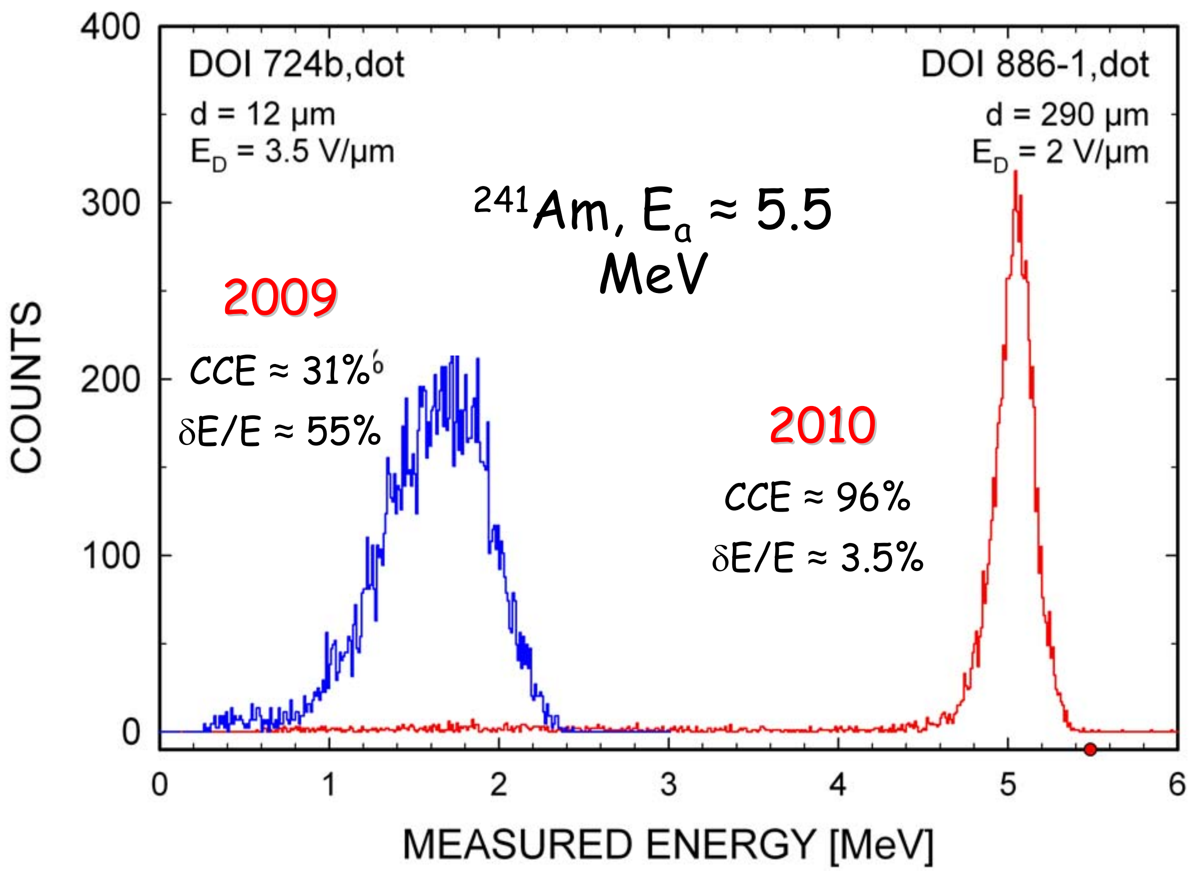


QUADRANT-SENSOR
SPATIAL HOMOGENEITY



Q-COLLECTION PROPERTIES

GSI: M. Träger, S. Rahman, EBe



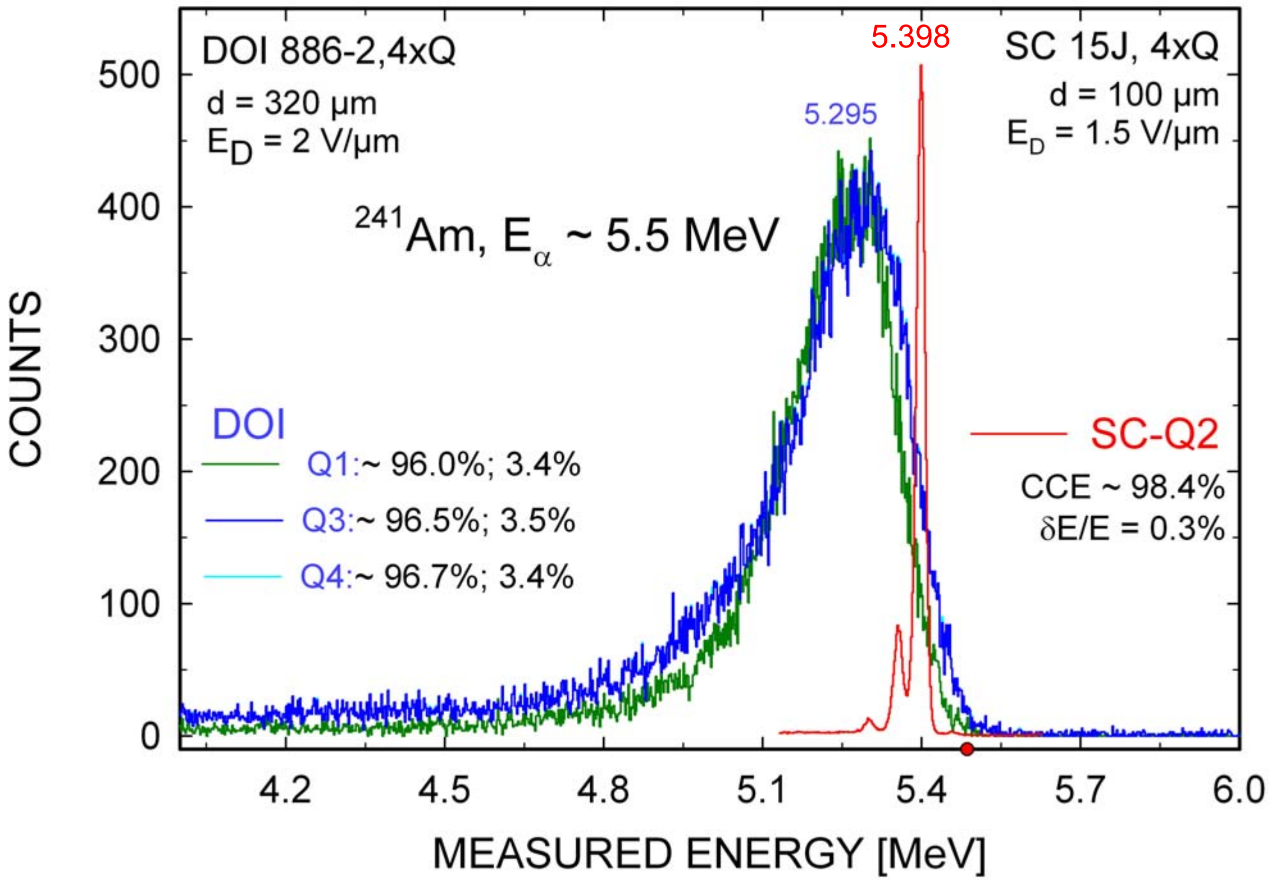
RAPID PROGRESS IN CCE

Q-COLLECTION PROPERTIES

- DOI STARTS TO BEHAVE as HSC-CVDD

➡ CCE : HSC - 2.5%
$\delta E/E$: HSC + 3%

2010



IMPROVING ENERGY RESOLUTION

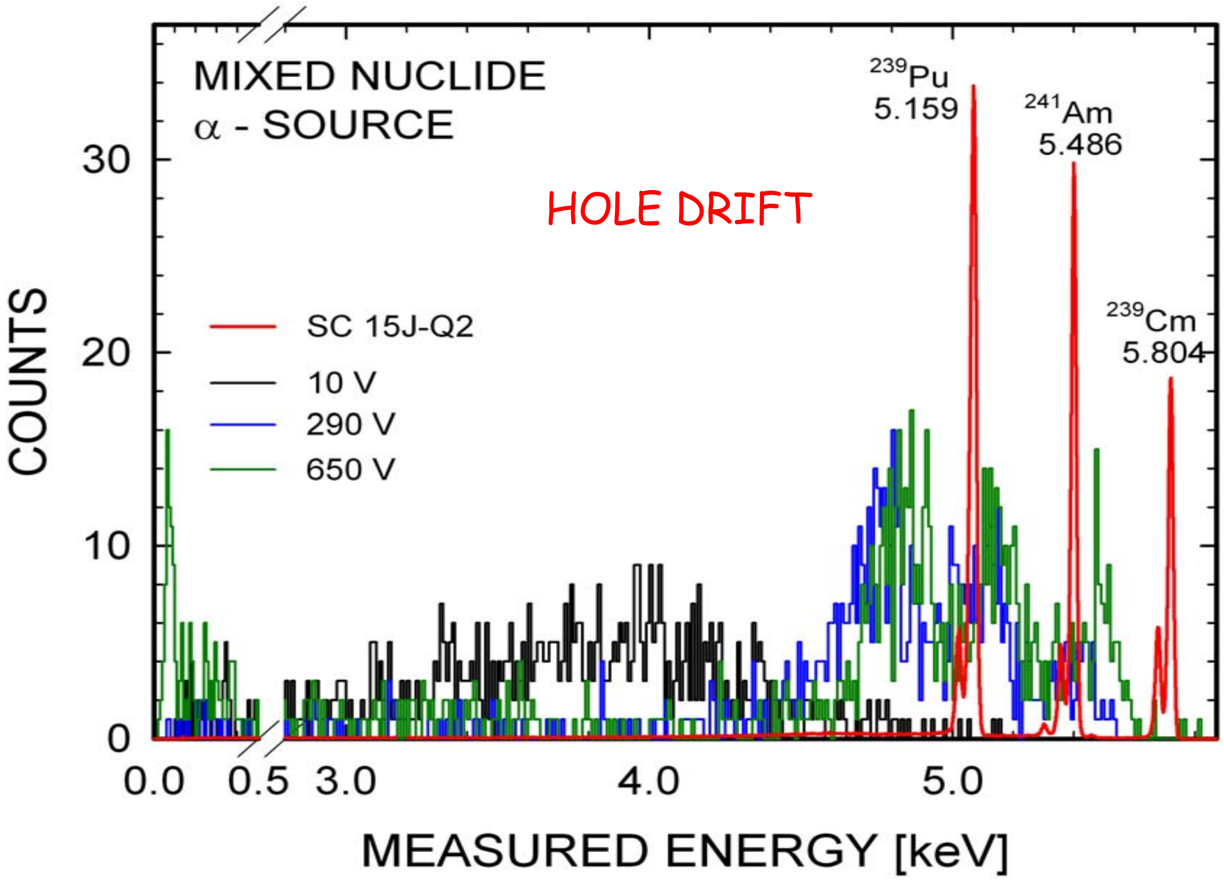
Q-COLLECTION PROPERTIES

- CCE + ENERGY RESOLUTION

$CCE_{h\text{-}drift} \approx 93\%$

$\delta E/E \approx 1.5\%$

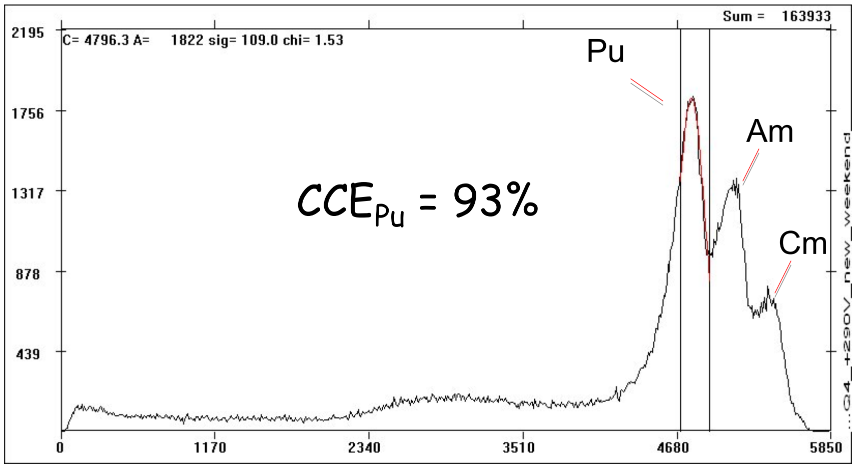
2011



TOWARDS SPECTROSCOPIC GRADE DIAMOND

Q-COLLECTION PROPERTIES

➤ DEVICE STABILITY OVER WEEKEND ➡ GSI

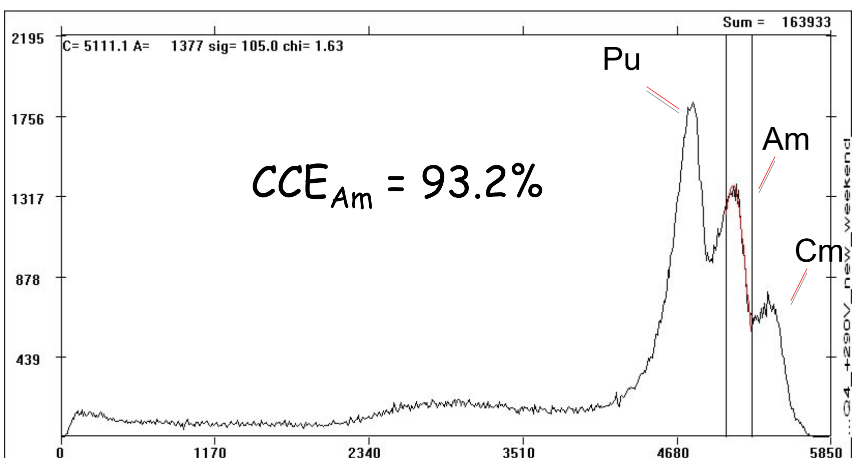


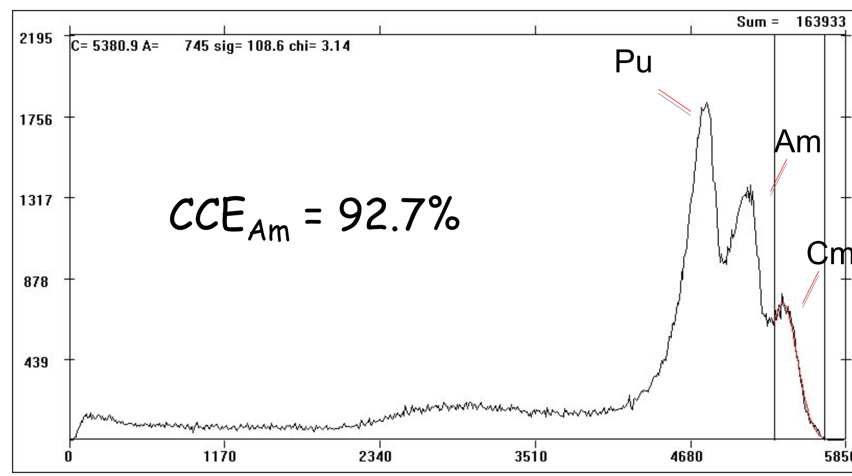
2011

HOLE DRIFT DATA

@ 400V

$CCE_{h\text{-}drift} \approx$ 93% (initially pumped)



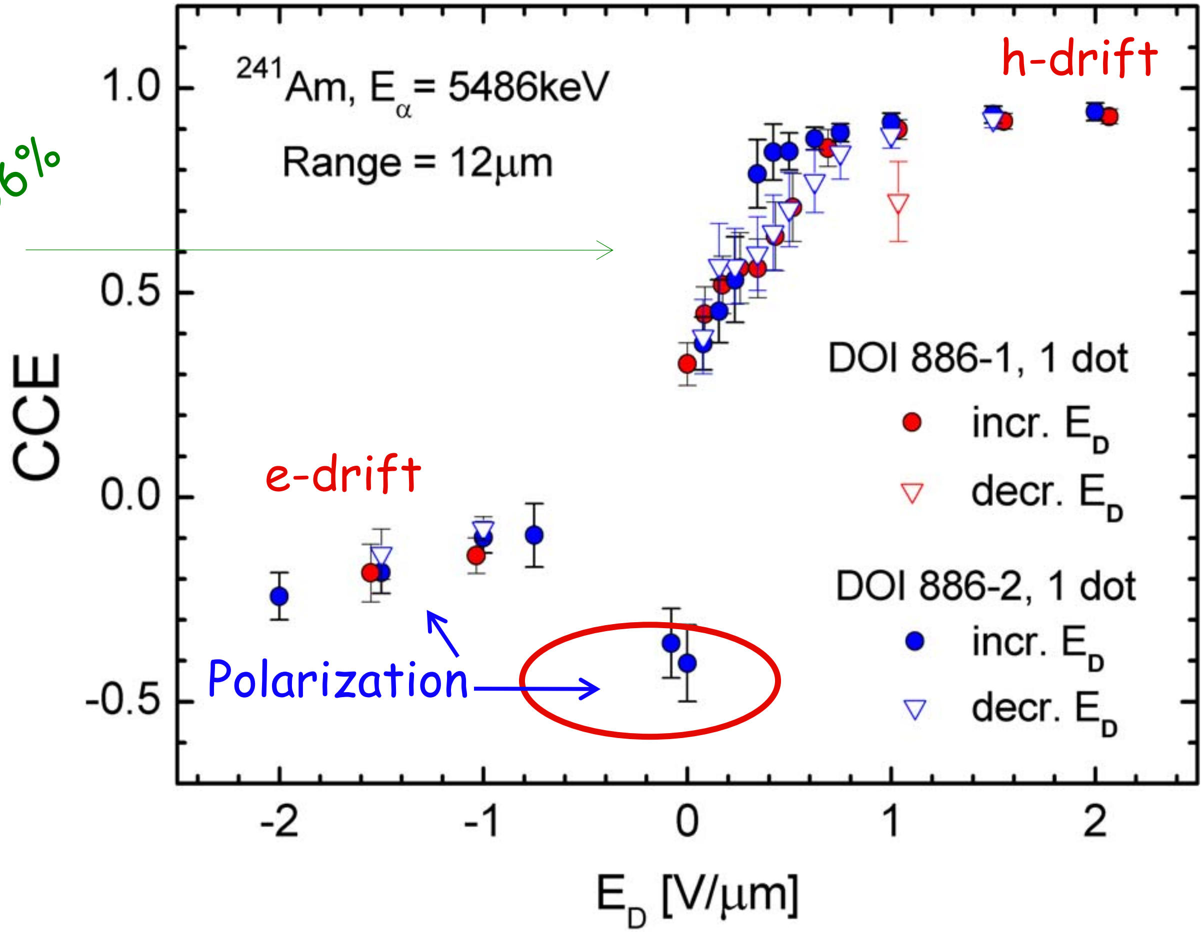


Q-COLLECTION PROPERTIES

➢ COLLECTION EFFICIENCY ➡ 2010

$CCE_{h\text{-}drift} \approx 96$
$CCE_{e\text{-}drift} < 30\%$

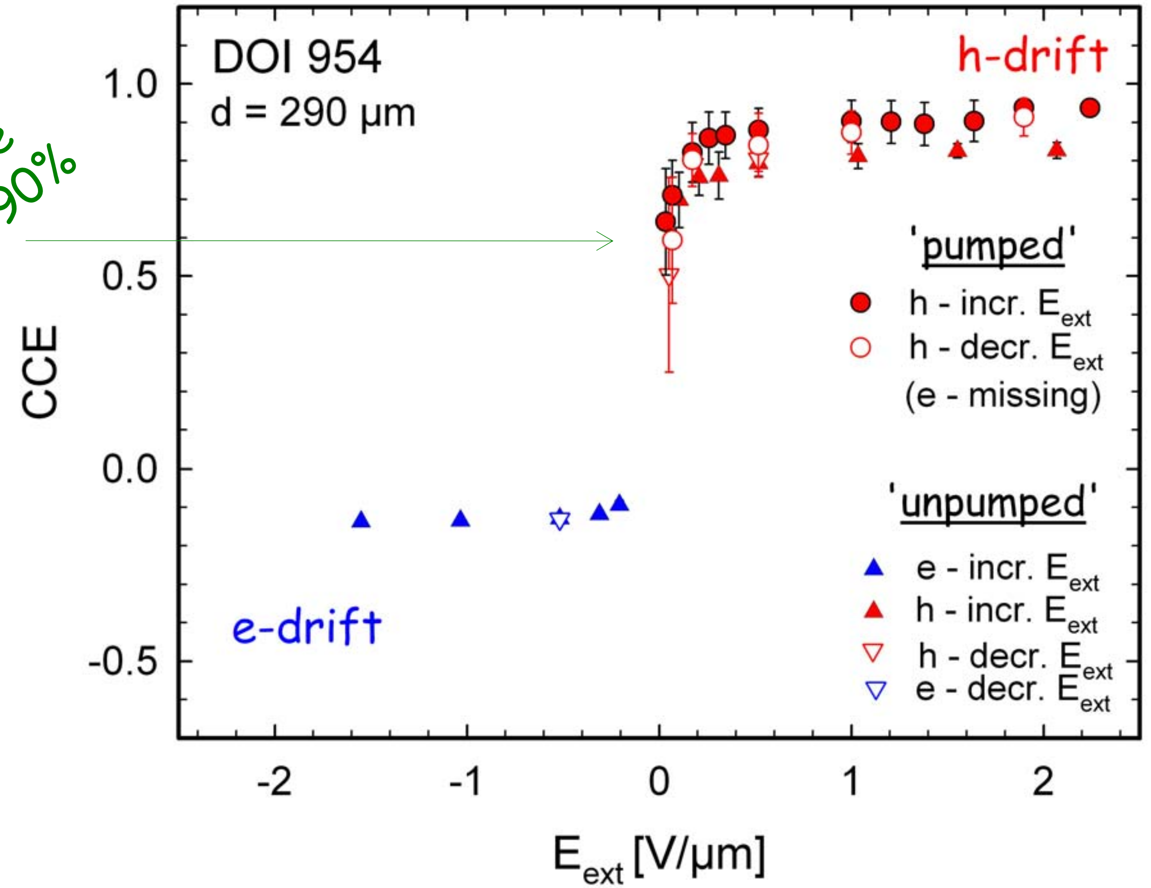
'flat' rise to CCE > 96%



Q-COLLECTION PROPERTIES

- COLLECTION EFFICIENCY ➡ 2011 GSI: $CCE_{h\text{-}drift} \approx 93\%$ (pumped)
  $CCE_{e\text{-}drift} \approx 13\%$ (unpump.)

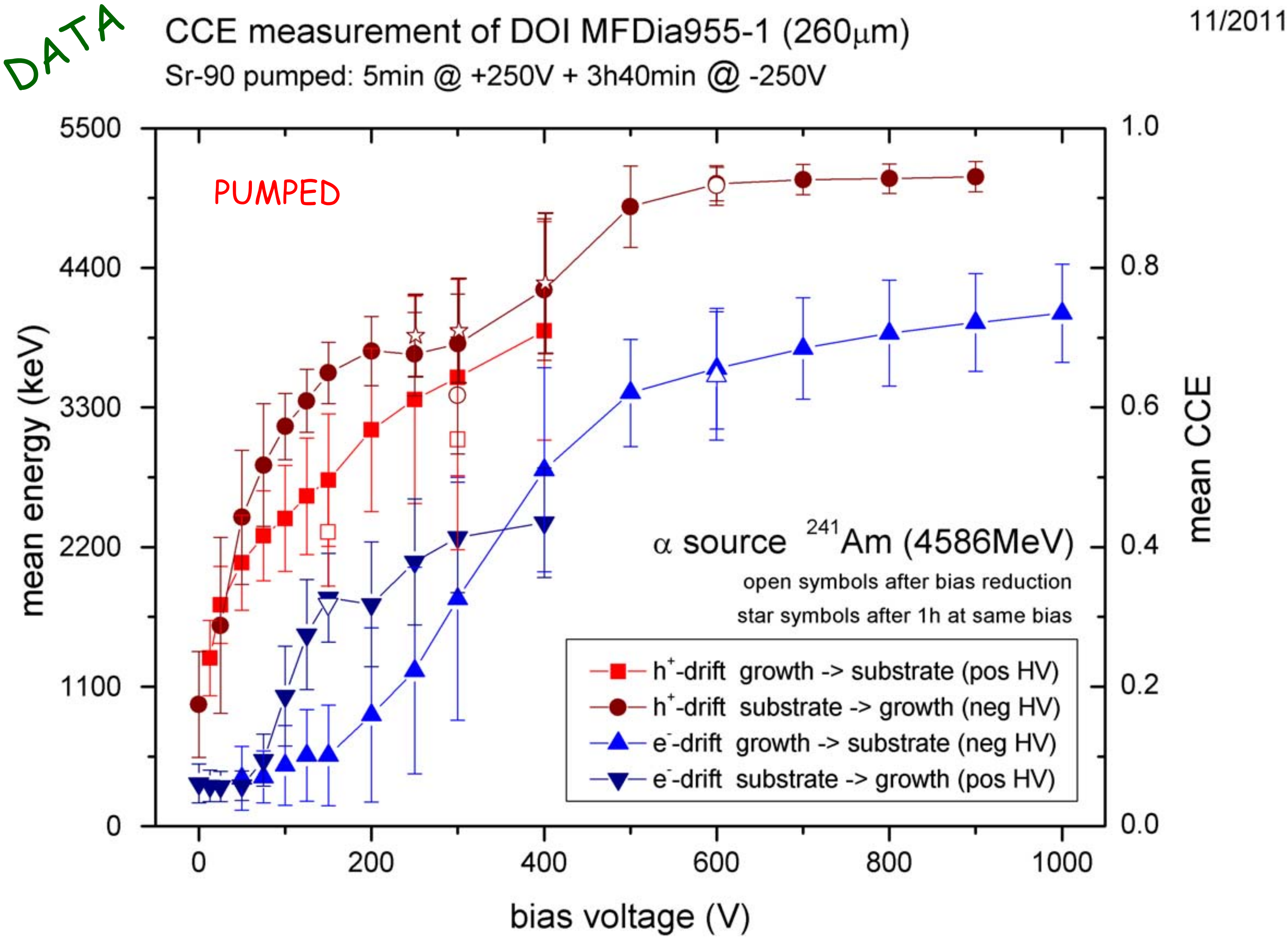
steep rise to CCE > 90%



Q-COLLECTION PROPERTIES

2nd DOI DELIVERY 2011 ➡ M. Träger, GSI

VERY RECENT DATA

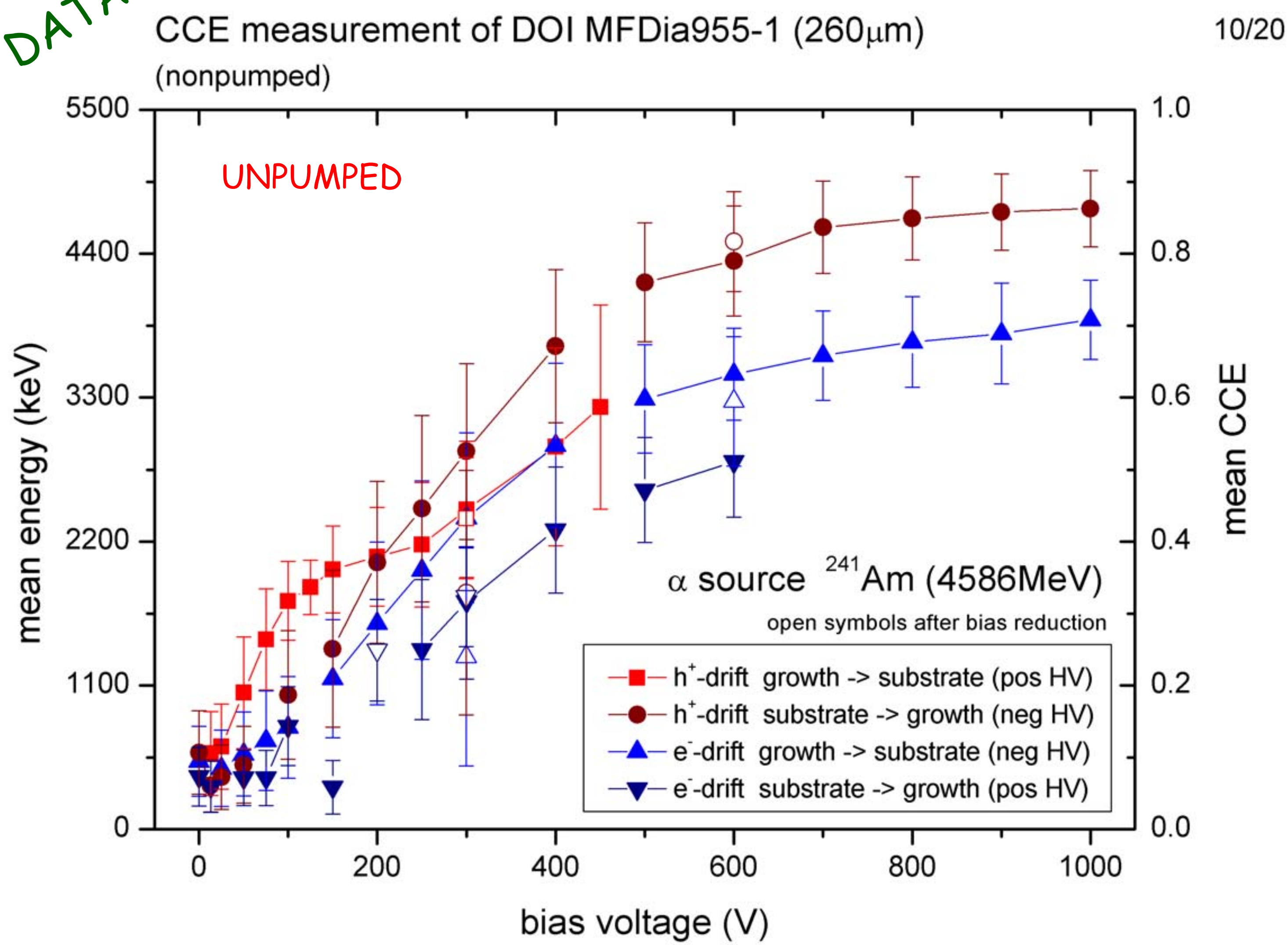


Q-COLLECTION PROPERTIES

2nd DOI DELIVERY 2011

→ M. Träger, GSI

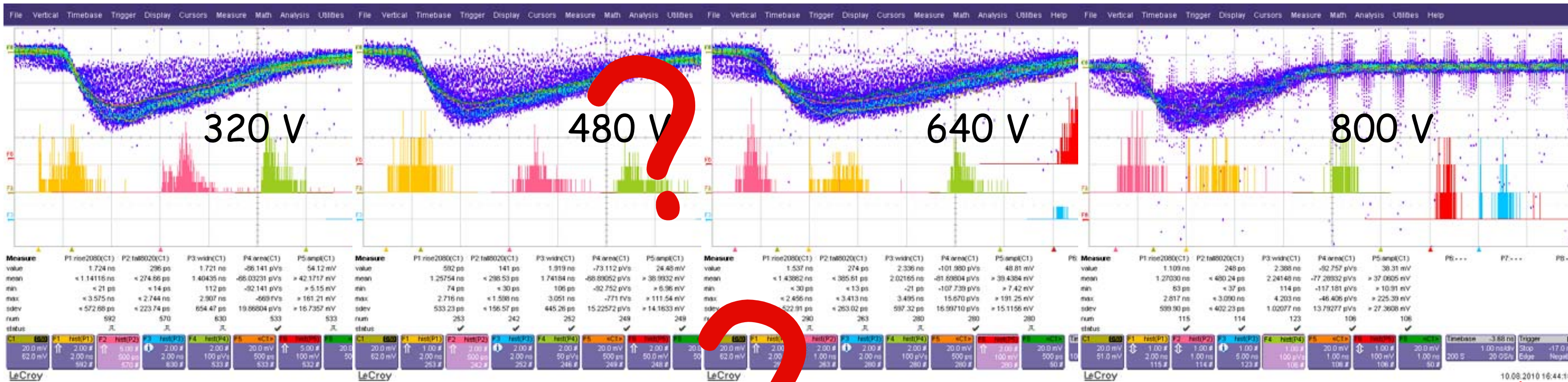
VERY RECENT DATA



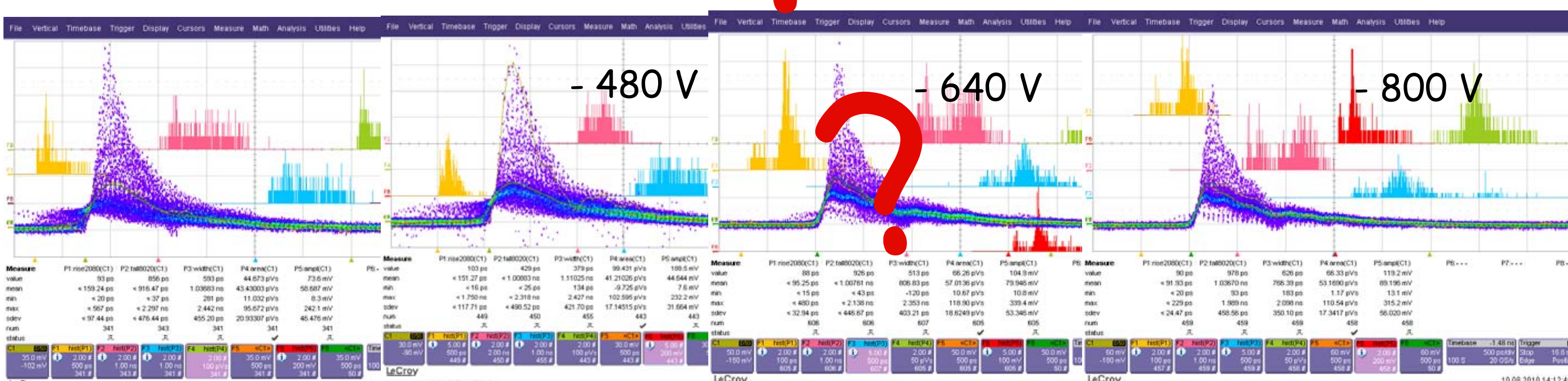
INTERNAL FIELD PROFILE - TCT

TRANSPORT PARAMETERS ➡ 2010

GSI: M. Traeger, S. Rahman, EBe



1.071 ± 0.473 | 1.322 ± 0.447 | 2.021 ± 0.597 | 2.241± 1.021 | FWHM [ns]



1.037 ± 0.321 | 1.110 ± 0.421 | 0.877 ± 0.415 | 0.780 ± 0.319 | FWHM [ns]

TRAPPING and RELEASE ?

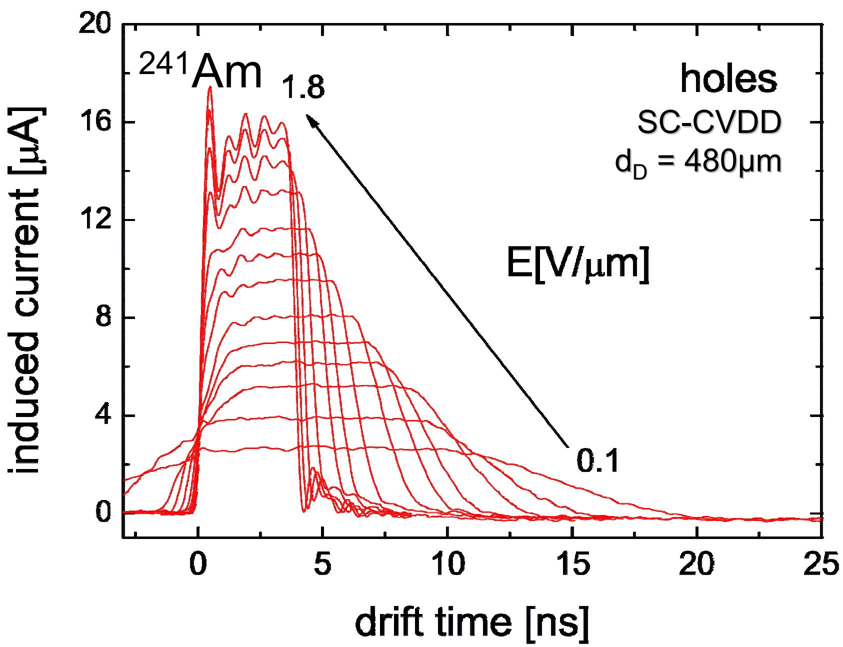
trapping ≈ nanoseconds (BB-FEE);
release and collection ≈ order of microseconds
(shaping constant of shaping amplifier)

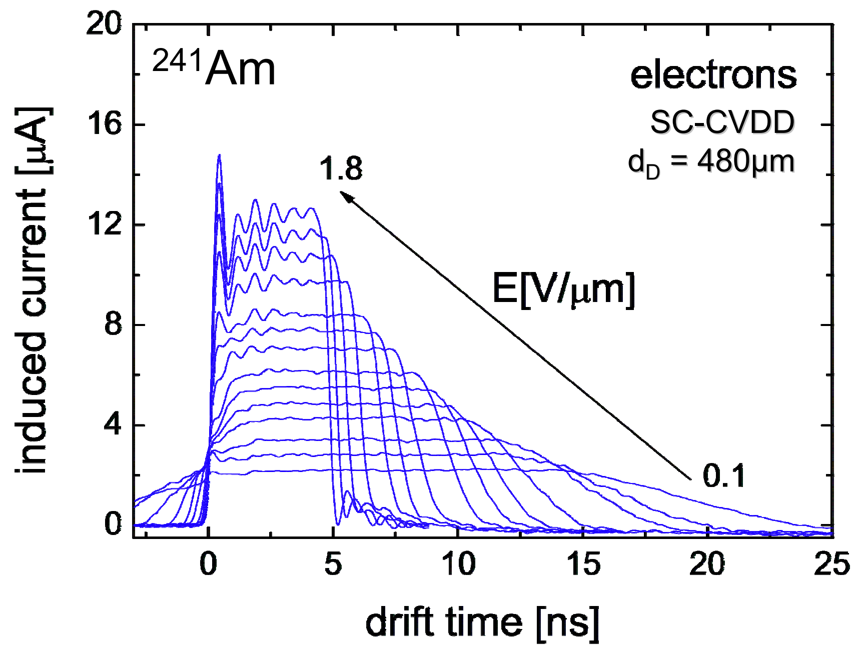
INTERNAL FIELD PROFILE - TCT

TRANSPORT PARAMETERS ➡ Michal Pomorski, PhD thesis, Univ. of Frankfurt (2008) :

REMINDER!

DEFECT-FREE HOMOEPITAXIAL SC-CVDD





$v_{Drift} \geq 120\ \mu m/ns$

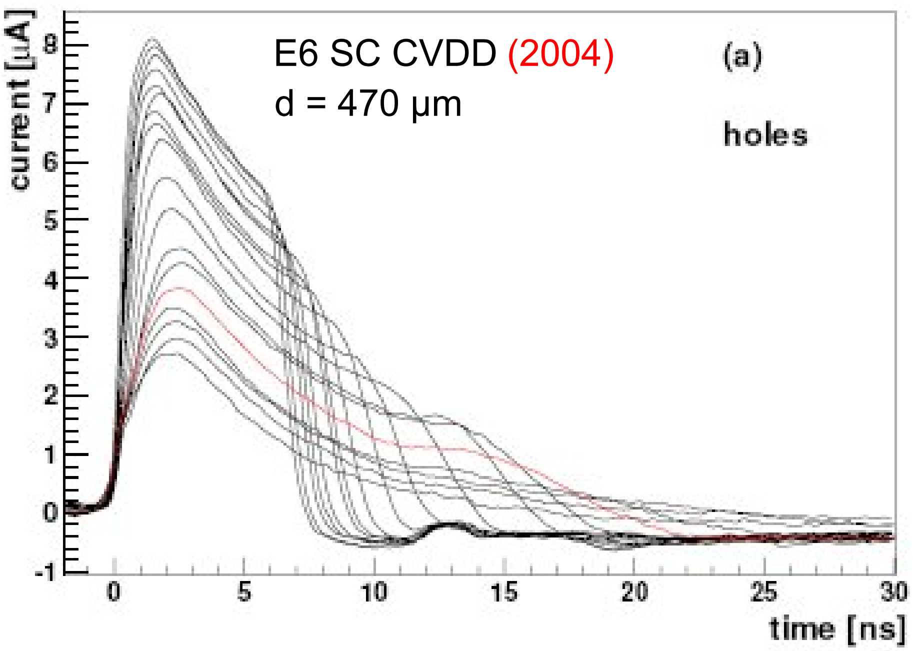
$v_{Drift} \geq 100\ \mu m/ns$

INTERNAL FIELD PROFILE - TCT

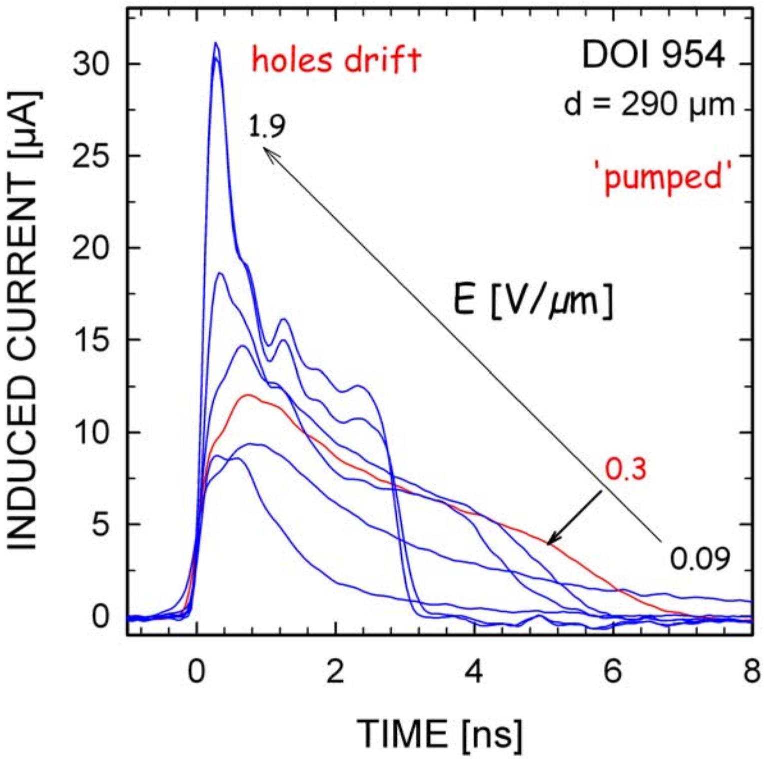
TRANSPORT PARAMETERS COMPARED

'EARLY' HOMOEPITAXIAL SC-CVDD

DOI 2011



H. Pernegger, J. Appl. Phys. 97 073704 (2005)



TIMING PROPERTIES – TCT

TRANSPORT PARAMETERS COMPARED

(HOLE DRIFT)

PRELIMINARY

DRIFT VELOCITY

DIAM -TYPE	E_D [V/µm]	v_{DRIFT} [cm/s]
CVD DOI	1.0	7.5×10^6
,,	2.0	1.0×10^7
HSC CVDD	2.0	1.6×10^7

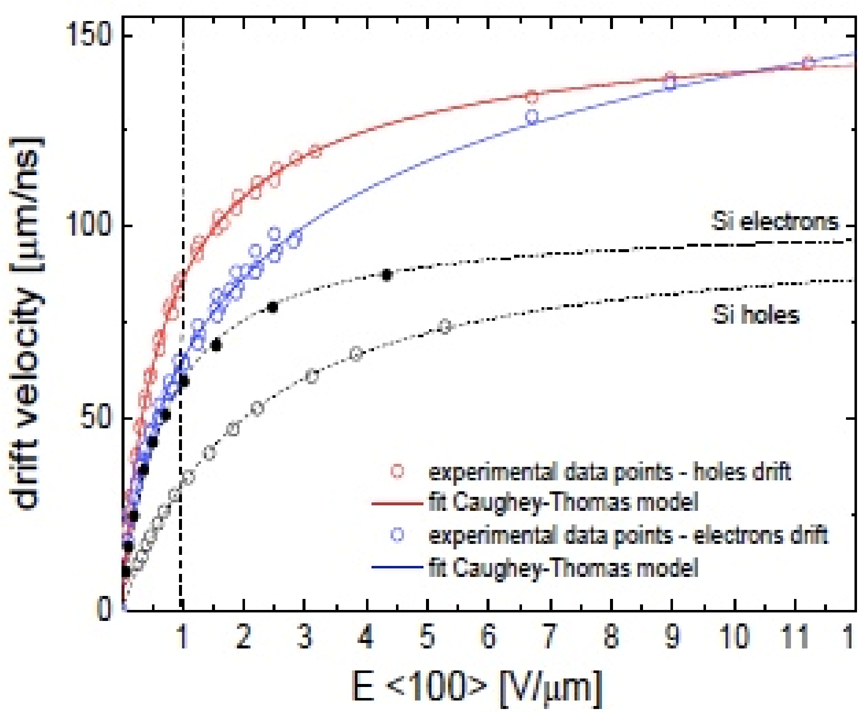
$$v_{DRIFT} = d_D/t_{Tr}$$

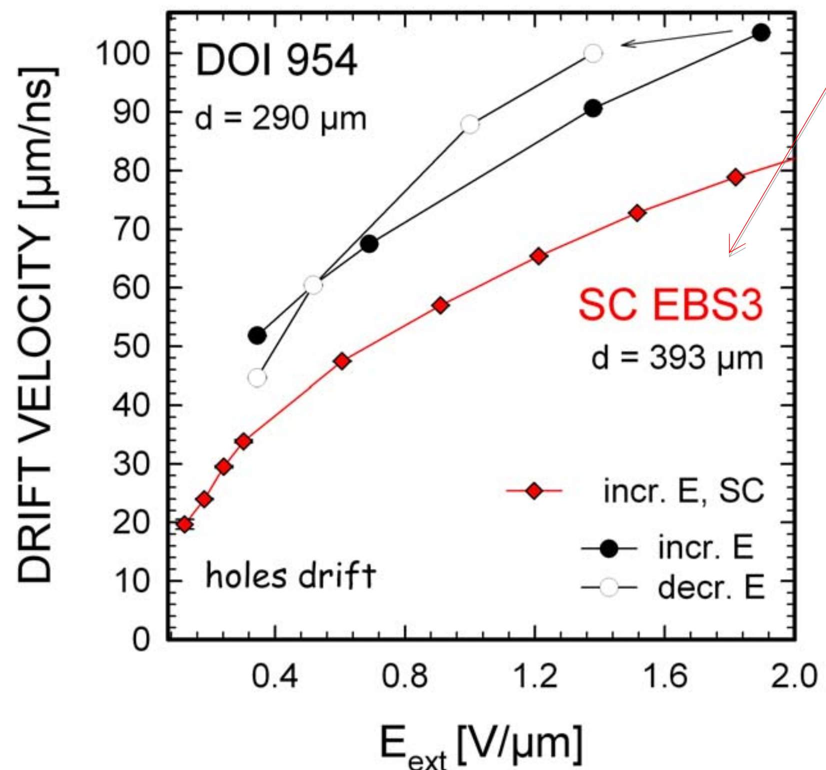
DRIFT VELOCITY – HOLES

TRANSPORT PARAMETERS COMPARED

DOI HOLE DRIFT DATA (P R E L I M I N A R Y !)

damaged !



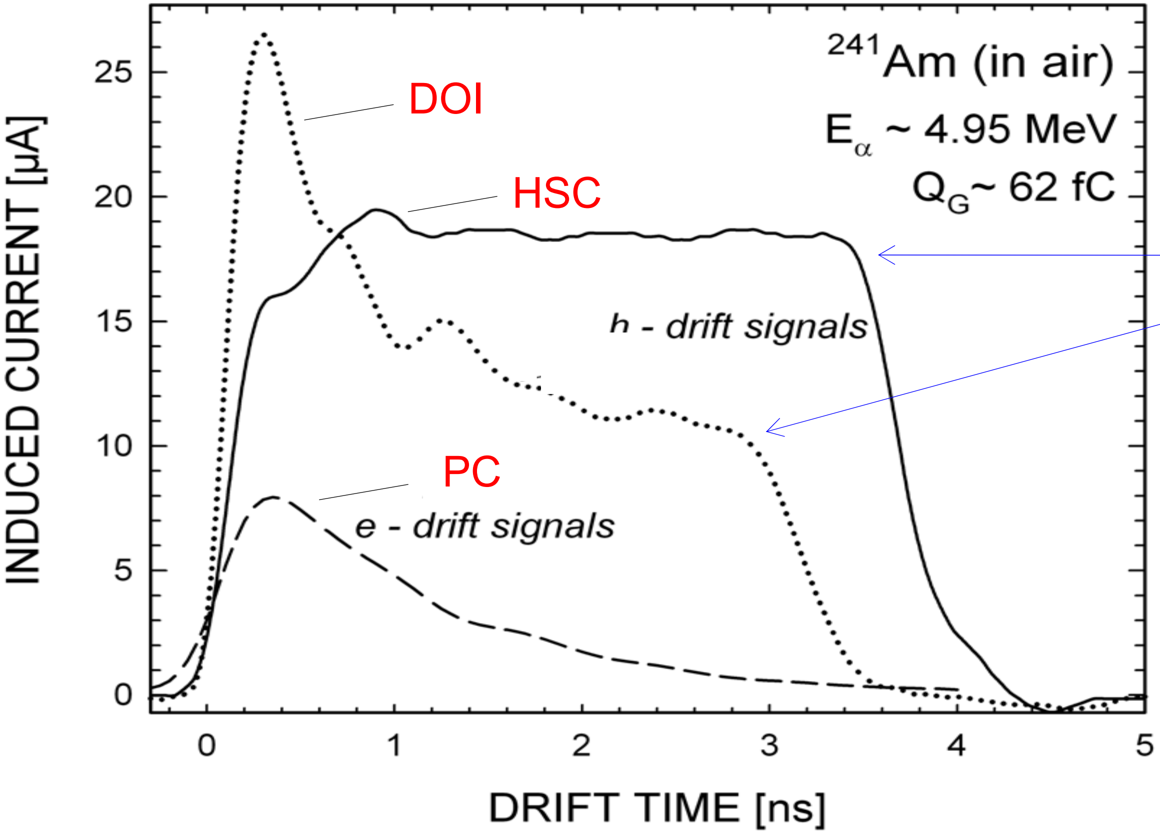


Michal Pomorski PhD thesis (2008)

INTERNAL FIELD PROFILE - TCT

TRANSPORT PARAMETERS COMPARED

ALL THREE DETECTOR-GRADE CVDD TYPES

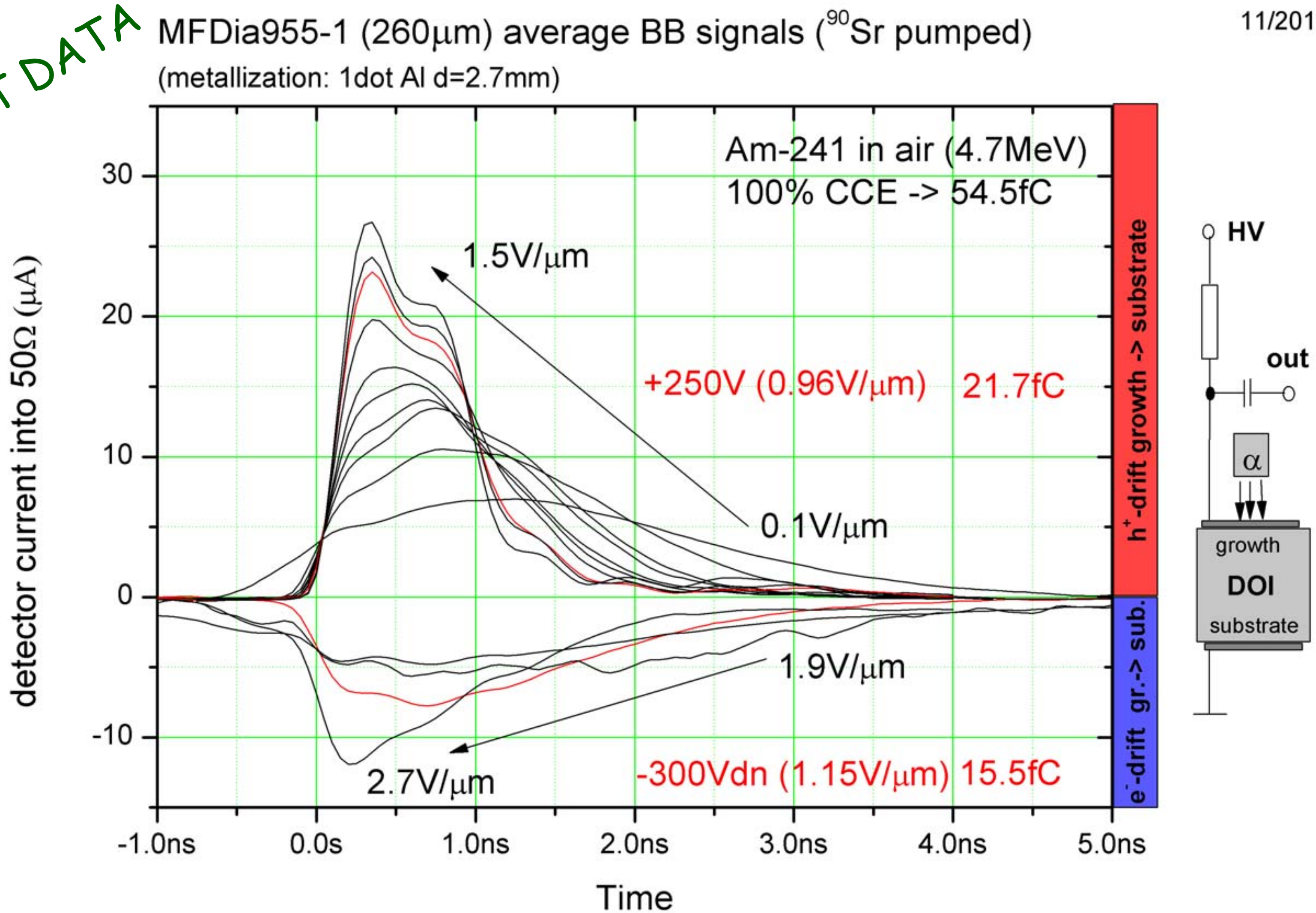


- FULL CHARGE DRIFT
- INCREASING DRIFT VELOCITY with E-FIELD

INTERNAL FIELD PROFILE - TCT

2nd DOI DELIVERY 2011 → M. Träger, GSI

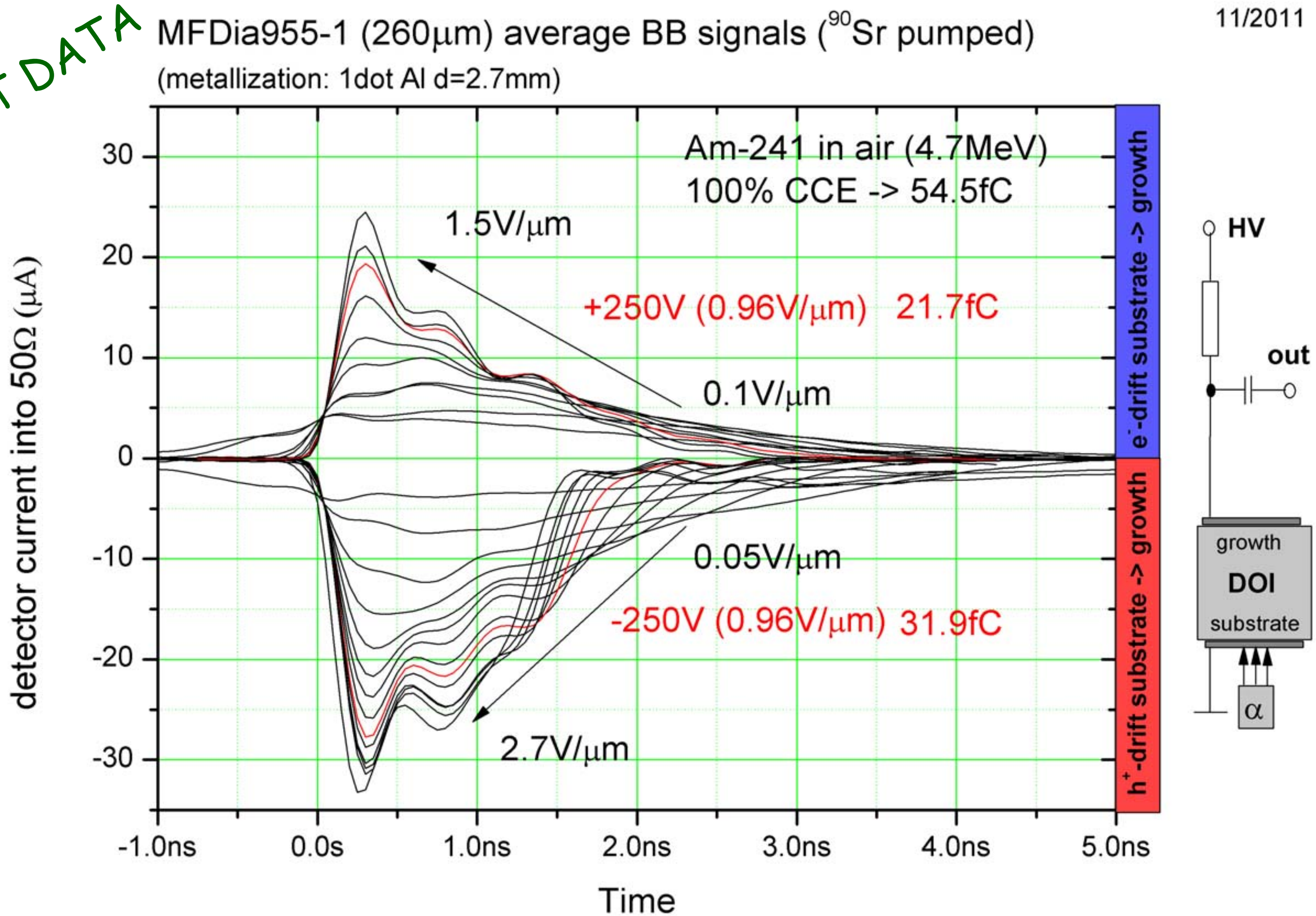
VERY RECENT DATA



INTERNAL FIELD PROFILE - TCT

2nd DOI DELIVERY 2011 ➡ M. Träger, GSI

VERY RECENT DATA

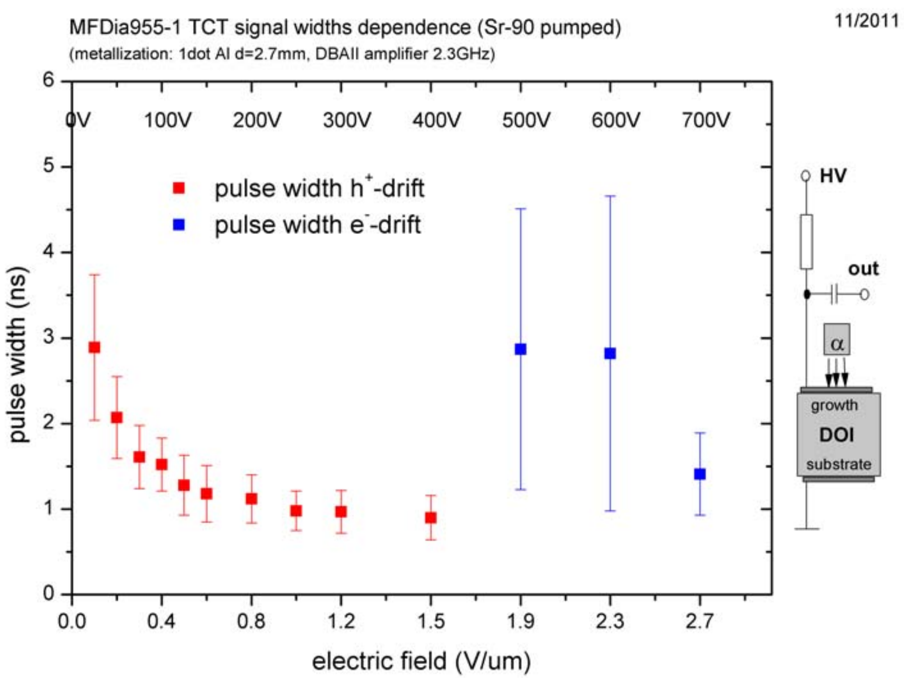


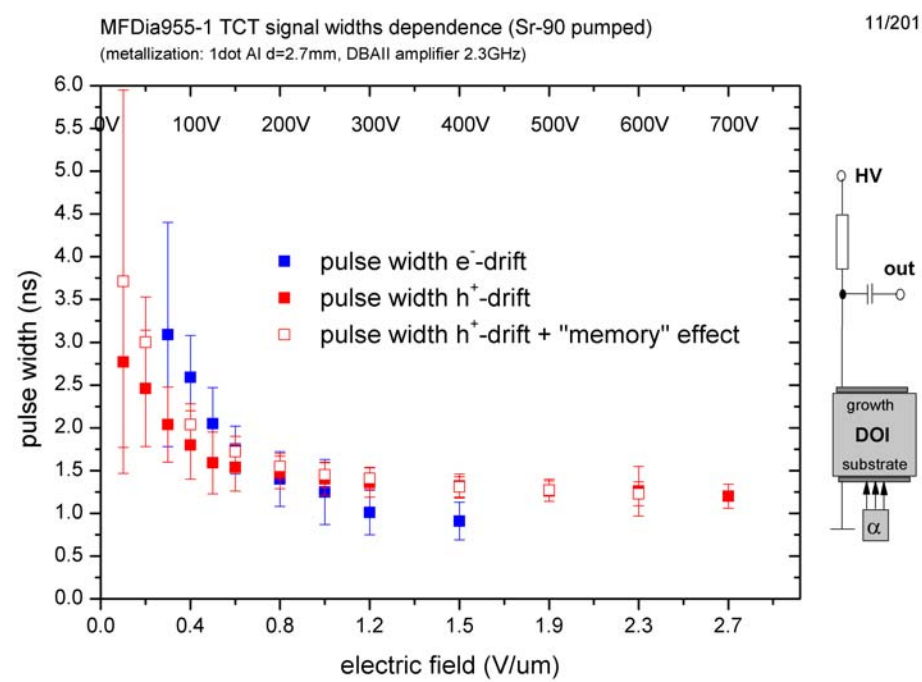
INTERNAL FIELD PROFILE - TCT

2nd DOI DELIVERY 2011

M. Träger, GSI

VERY RECENT DATA





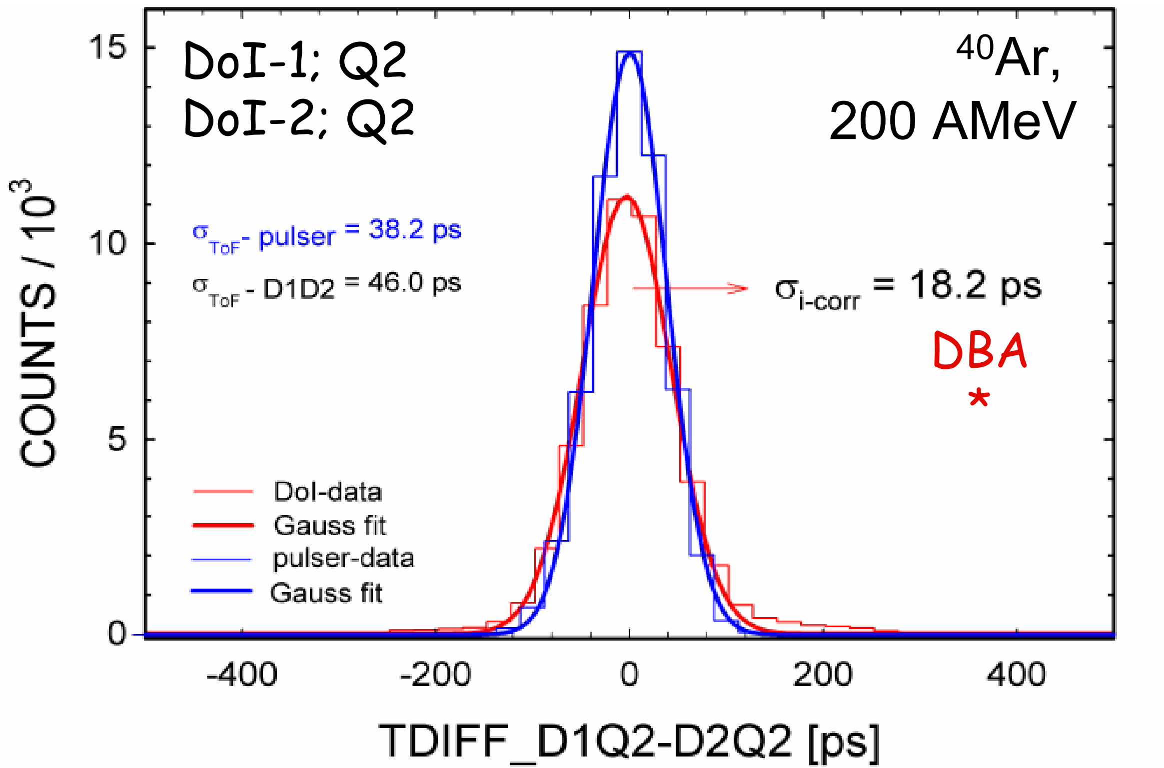
? better substrate side

BB ELECTRONICS

➢ TOF RESOLUTION

CONFIRMED ➡ SIMILAR TO PC and HSC

CVDD



extended calculations and simulations

M. Ciobanu et al., IEEE TNS 58 no. 4, 2073 (2011)

GSI: P. Moritz, M. Ciobanu, W. Koenig
M. Träger, S. Rahman, C. Stehl, EBe

SUMMARY

- CHARGE COLLECTION SIGNIFICANTLY IMPROVED
  - CCE: 90%-96%
  - $\delta E/E(\alpha's)$: 1.5%
- TIME RESOLUTION CONFIRMED
  - 20-25 ps
- FEE (BB) BETTER UNDERSTOOD
  - low-noise, low-capacitance setups
- NOT YET TESTED (ALTHOUGH POSSIBLE)
  - Larger area samples
  - Micro-strip sensors with PADI

CONCLUSIONS and OUTLOOK

- DOI is ALREADY a (DEFECTIVE) SINGLE CRYSTAL DIAMOND MATER.
  - BUT ONLY REGARDING THE HOLES
  - ELECTRON BEHAVIOR: NOT UNDERSTOOD

- NEXT STEPS TO DO
  - TO UNDERSTAND BETTER THE OBTAINED RESULTS
  - TO MINIMIZE THE DISLOCATION DENSITY
  - TO ENLARGE THE TEST SAMPLE AREA
  - TO USE PULSED UV-LASER FOR THE CHARACTERIZATION

LARGE-AREA DOI: EXAMPLE

Replacement of established neutron monochromator materials by diamond:

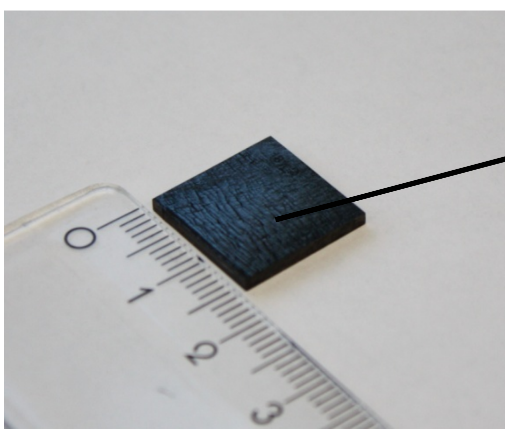
Established materials:

Graphite (HOPG), plastically deformed
Ge, Cu, Si

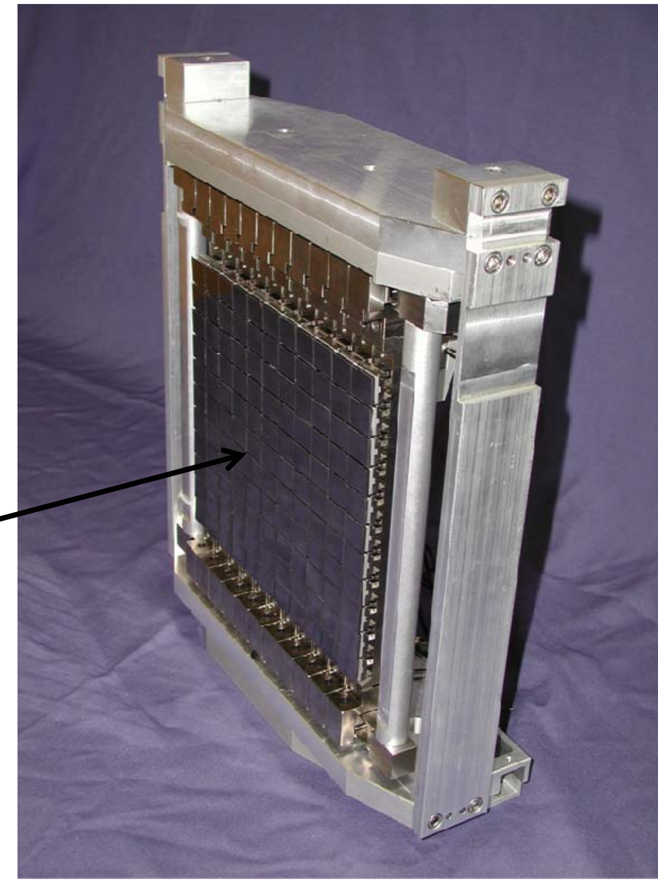
New material:

DOI mosaic crystals with well defined mosaic spread of 0.2° to 0.5°

➡ UA: M. Schreck, M. Fischer



DOI sample to replace standard HOPG element (1.5 x 1.5 x 0.15 cm^3, 6 ct)



The HOPG-monochromator of PANDA with 121 individual ajustable elements (2 x 2 x 0.2 cm^3) (priv. comm. G. Borchert, FRM II)

CARAT CONCLUSION

UNEXPECTED RAPID PROGRESS

OF SAMPLE QUALITY

⬇

DOI DIAMOND TOWARDS
LARGE-AREA
'SPECTROSCOPIC-GRADE' CVD DOI !