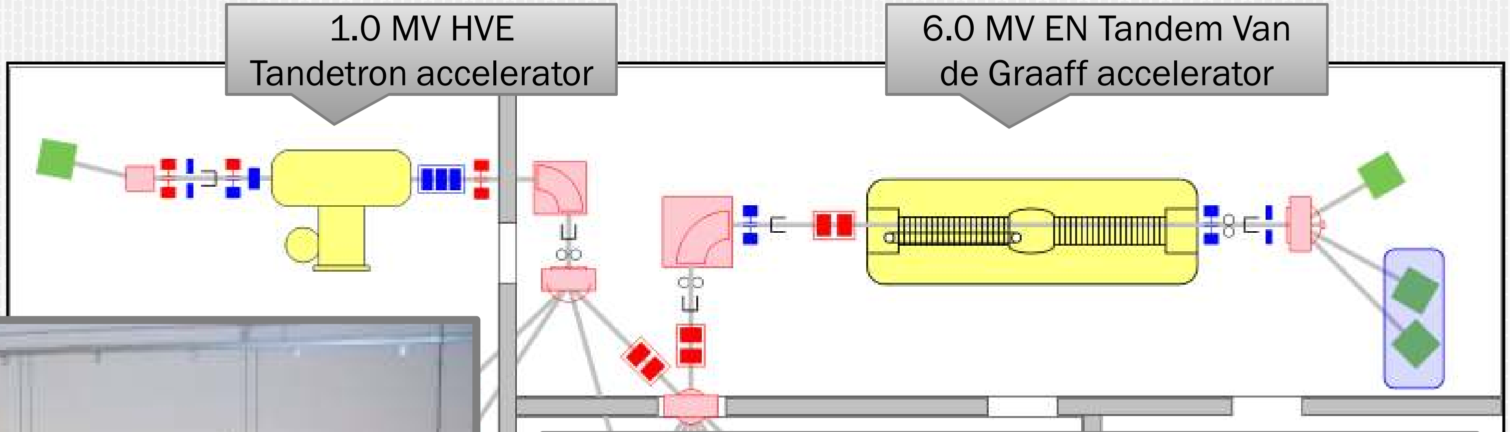
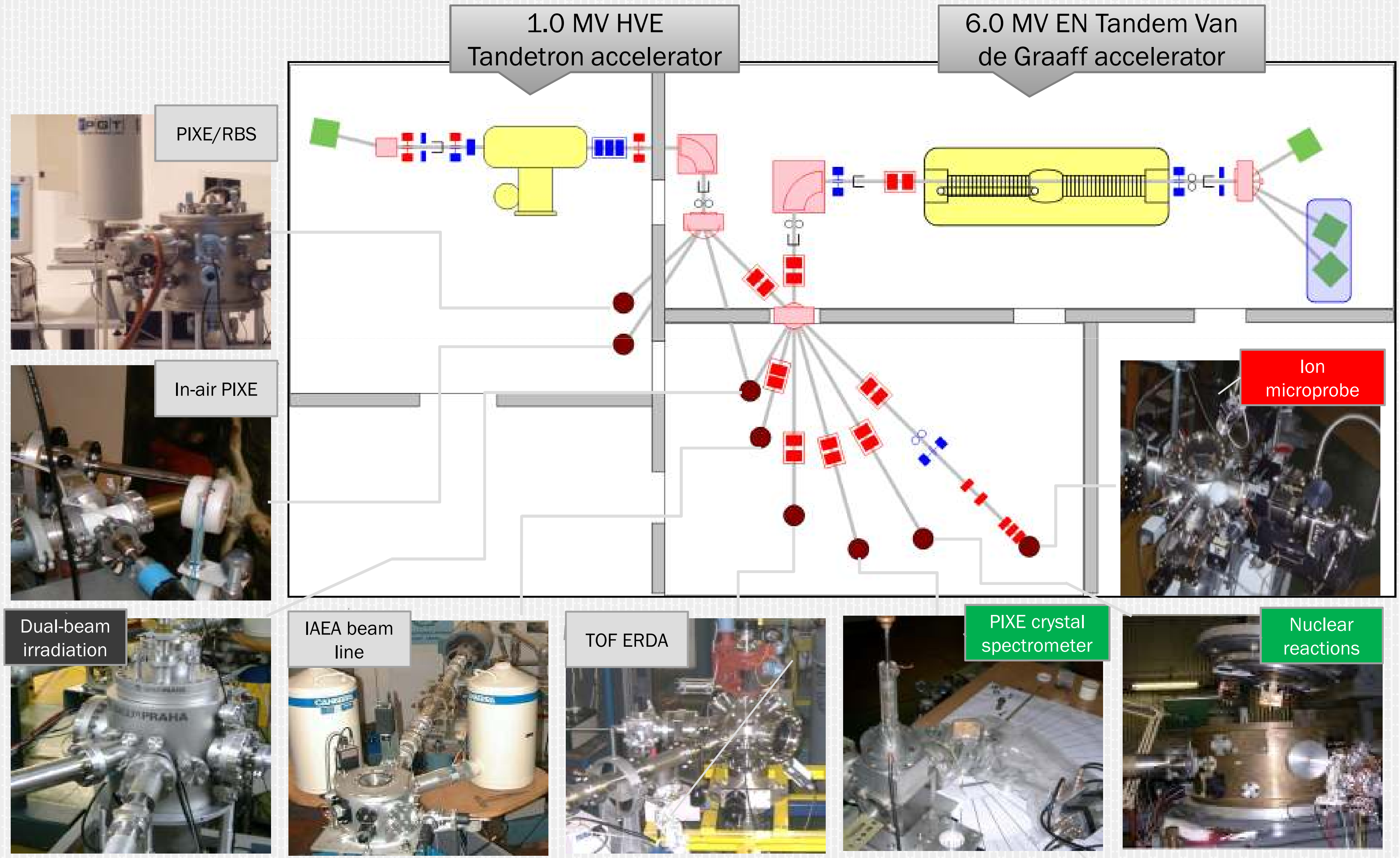
Milko Jakšić, Veljko Grilj, Natko Skukan, Ivana Zamboni
Željko Pastuović (ANSTO), Tomihiro Kamiya, Wataru Kada (JAERI)
Ruđer Bošković Institute, Zagreb, Croatia

RADIATION HARDNESS of scDIAMOND DETECTORS under IRRADIATION by MeV energy range CARBON ions (and protons)

1. RBI – FACILITIES - accelerators



1. RBI – FACILITIES – beam lines

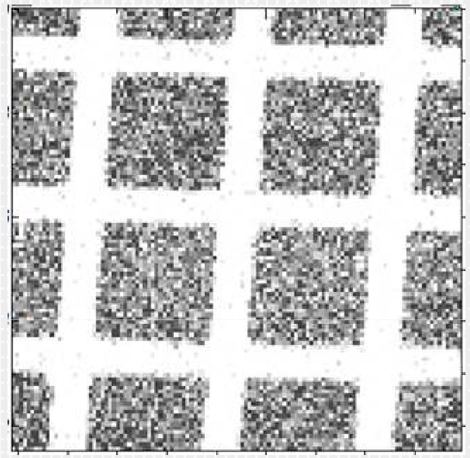


1. RBI - FACILITIES - Heavy ion microprobe

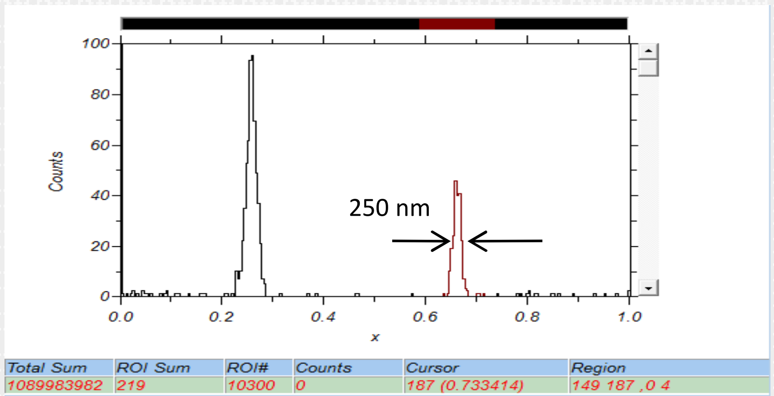
up to 15 MeV (ME/q2) magnetic rigidity.

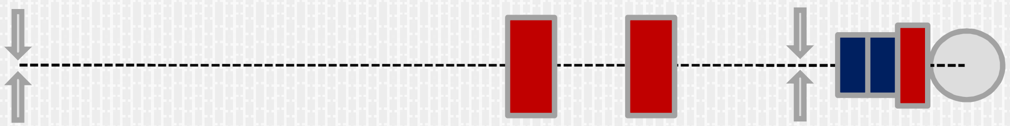
With short image distance (110 mm) of the new chamber, demagnifications of Dx=90 and Dy=110

12 MeV C



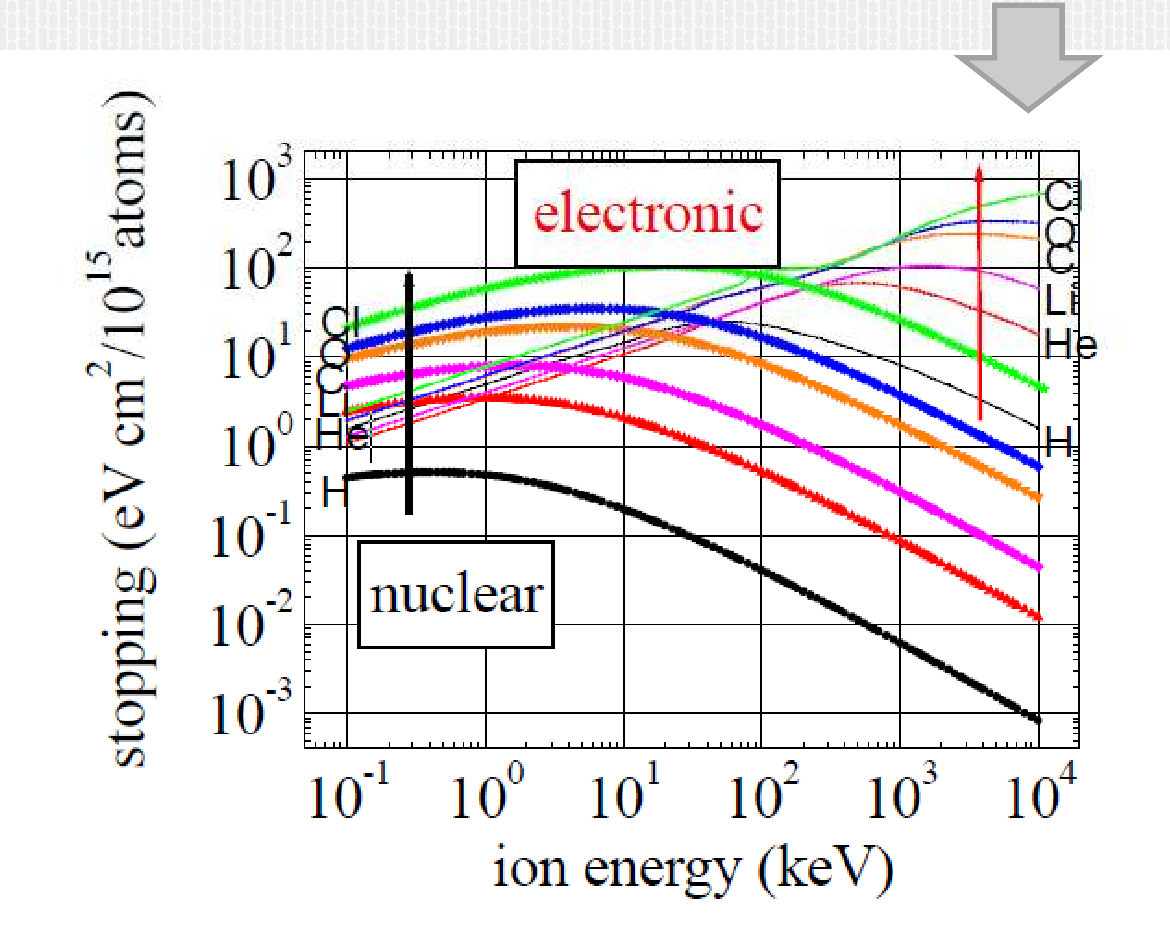
best resolution - 250 nm





1. HEAVY IONS - Unique properties

wide range of dE/dx

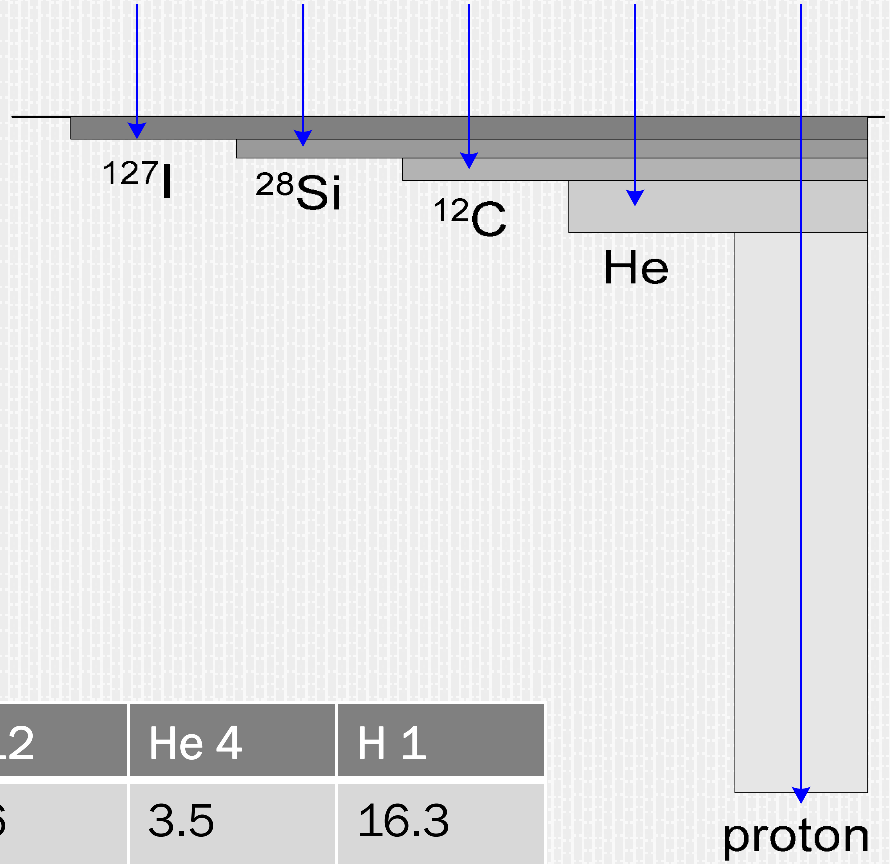


Electronic stopping power dominates for ions at MeV energies, Bragg peak!

Huge energy transfer (in particular for heavy ions at ~ 1MeV/amu)

1. HEAVY IONS - Unique properties

wide range of ranges



RBI accelerators:

Terminal voltages – 0.1 to 6 MV

Ion sources – sputtering,

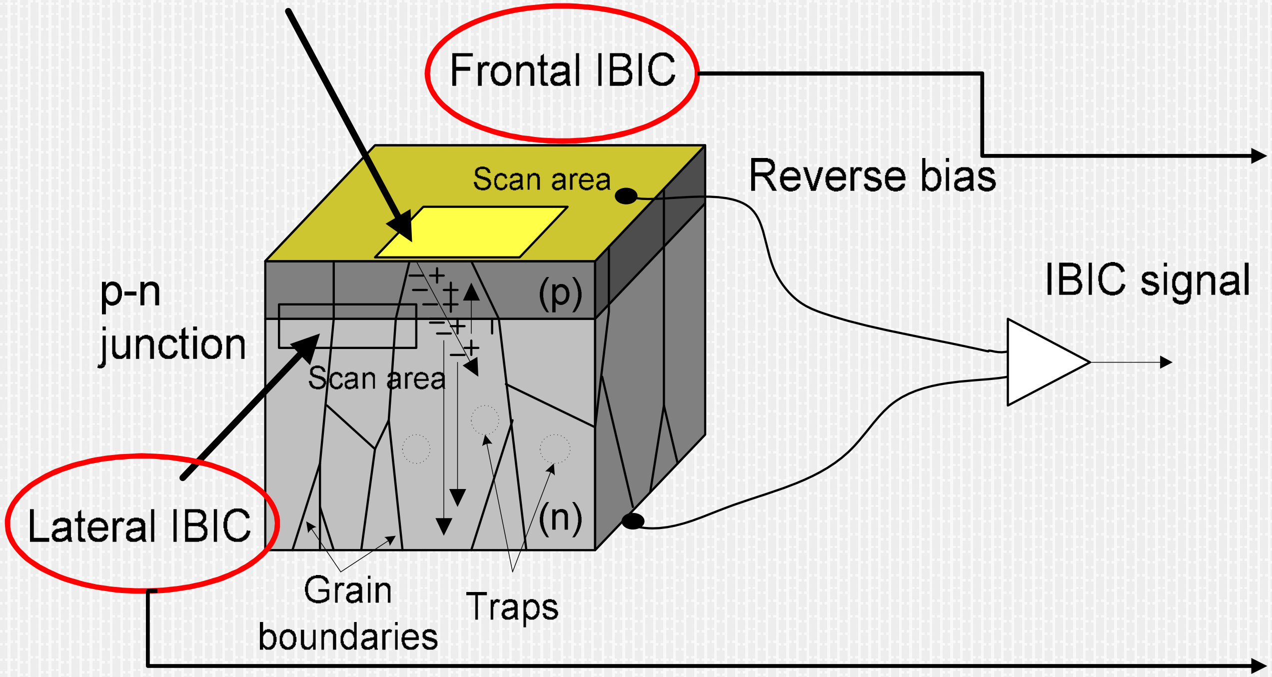
RF alphatross, duoplasmatron

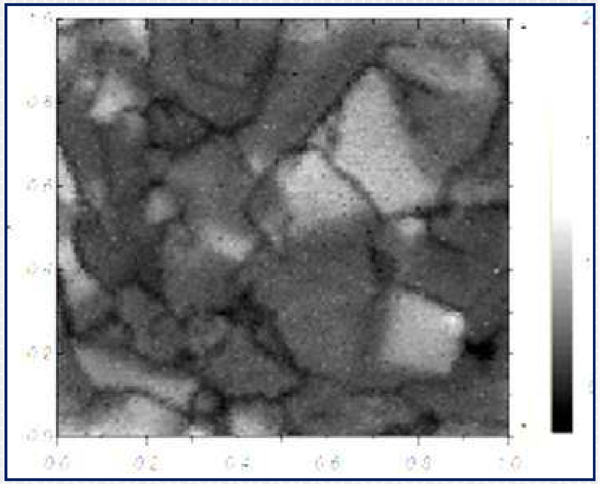
Good selection of ion ranges !!

Silicon	I 127-	Si 28	C 12	He 4	H 1
Range(μm) E=1 MeV	0.37	1.13	1.6	3.5	16.3
Range (μm) E=10 MeV	3.7	4.8	9.5	69.7	709

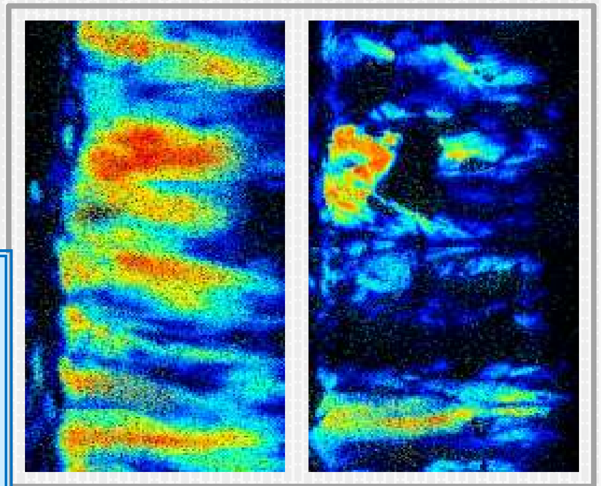
2. RADIATION INDUCED DEFECTS – IBIC

ION BEAM INDUCED CHARGE





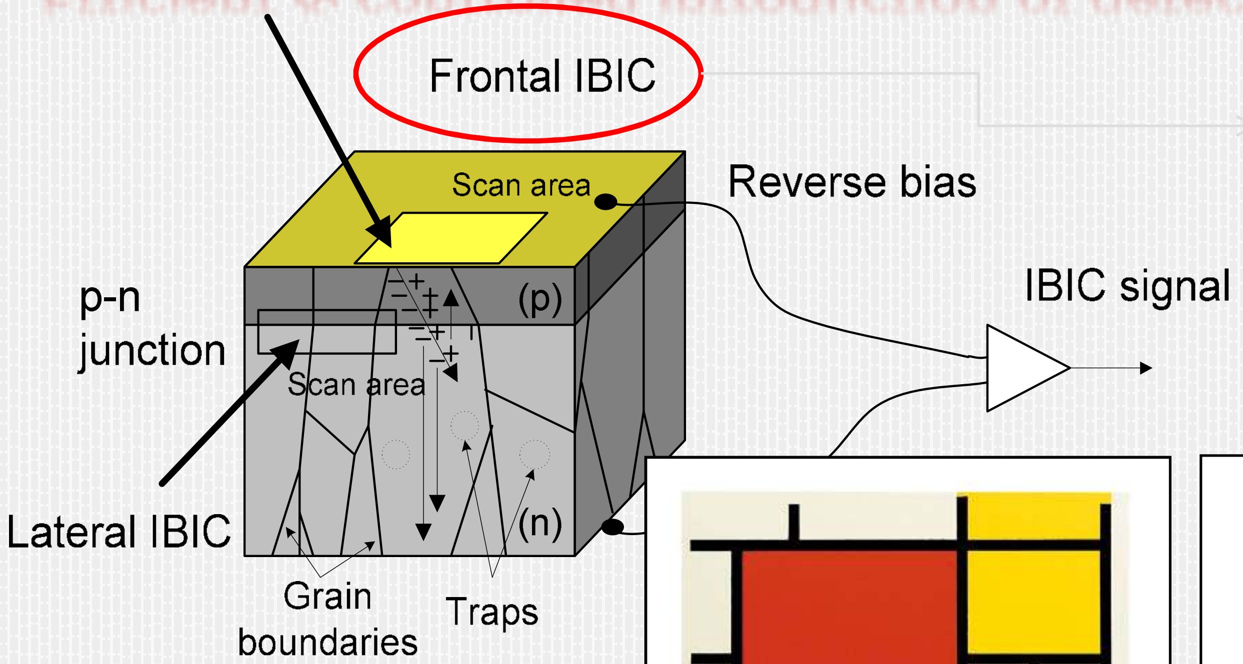
IBIC - single ion technique for imaging of microscopic distribution of charge transport properties !
- Imaging of grain boundaries, defects (such as dislocations), electric field (polarization),...

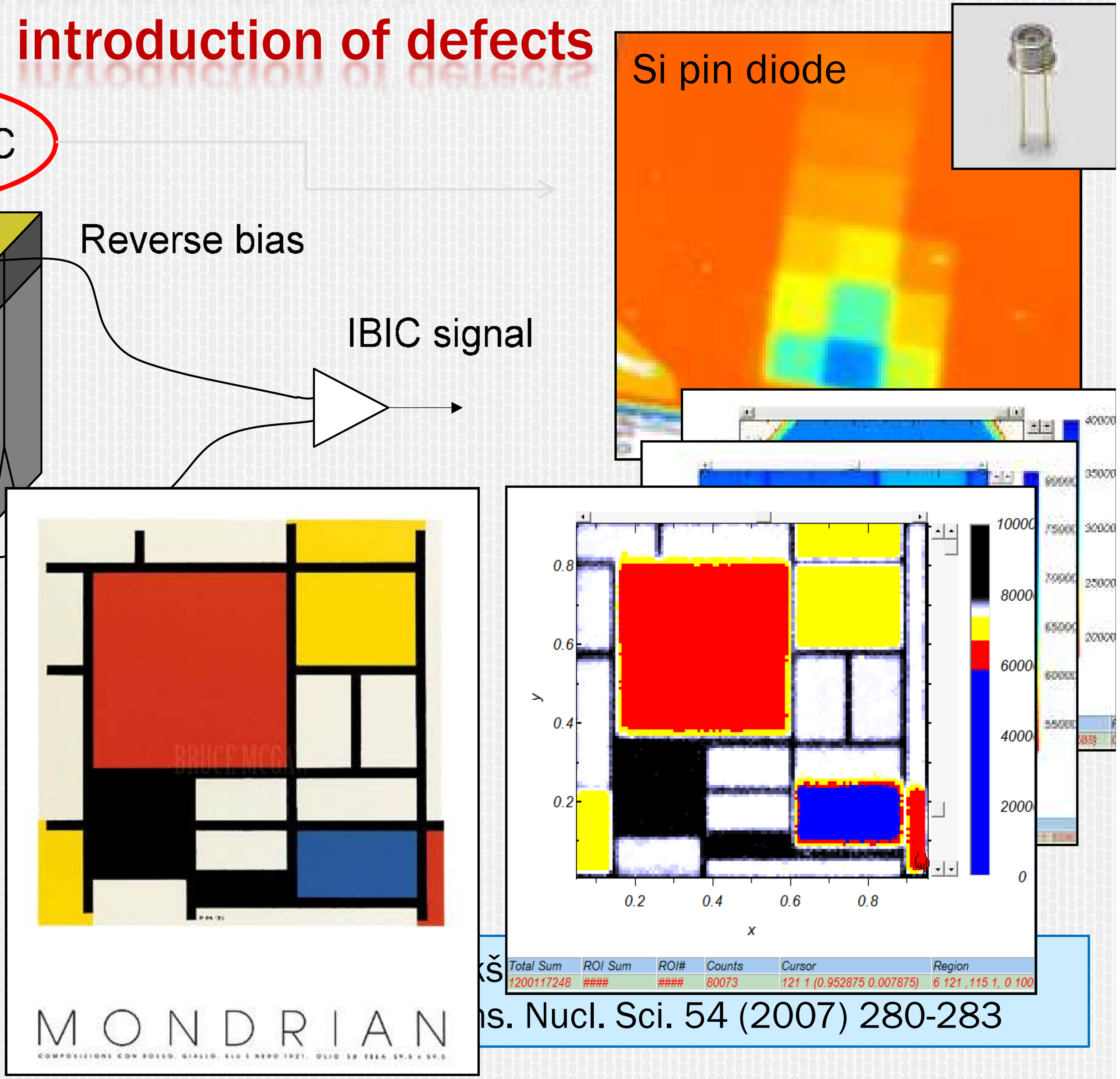


CVD diamond (1997)

2. RADIATION INDUCED DEFECTS – IBIC

Efficient & controlled introduction of defects



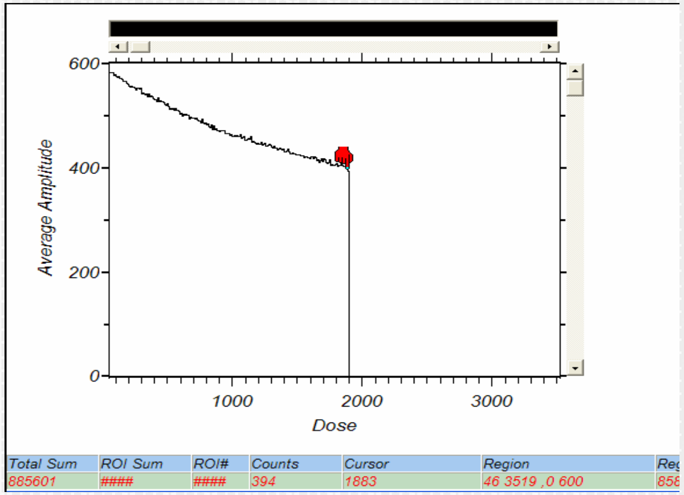


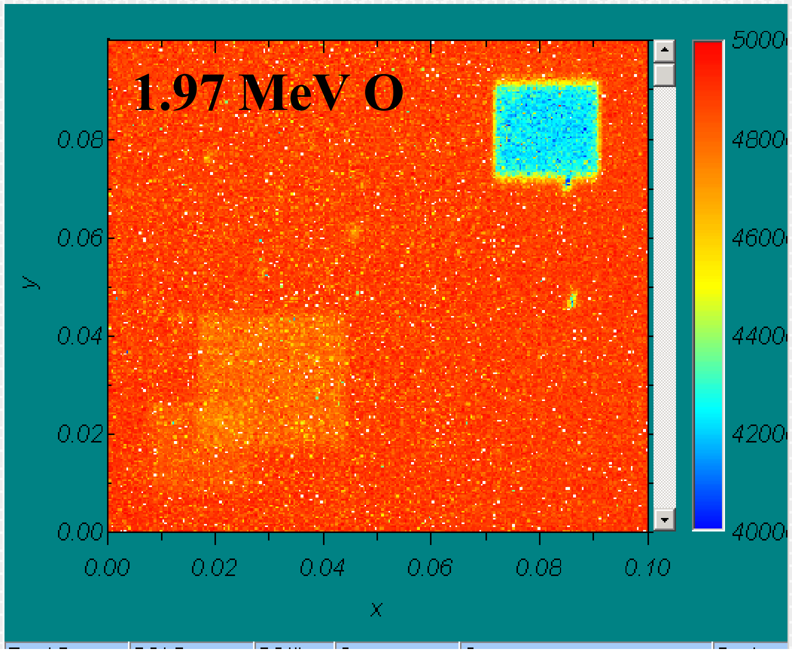
Irradiation of certain regions in test samples will increase defect concentration and decrease IBIC signal

kš

ns. Nucl. Sci. 54 (2007) 280-283

2. RADIATION INDUCED DEFECTS – IBIC





$$\frac{Q_0}{Q} = 1 + K_{ed} \cdot \Phi \cdot NIEL_{ave}$$

D_d

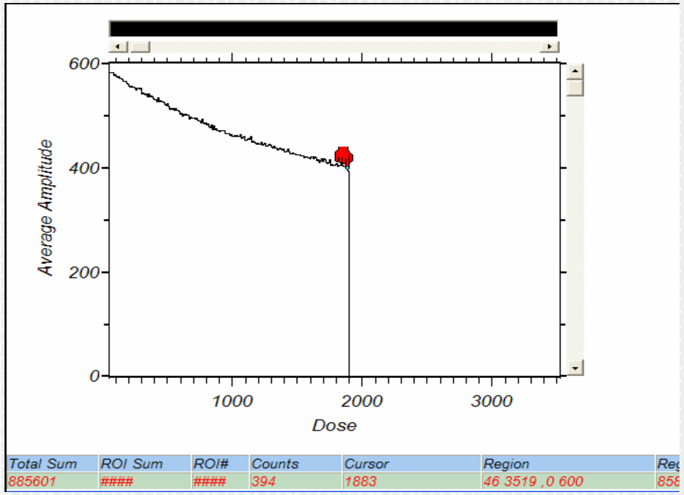
K_{ed} –equivalent damage factor (g/MeV) (property of the material + ?)

Φ - damaging ion fluence (cm^{-2})

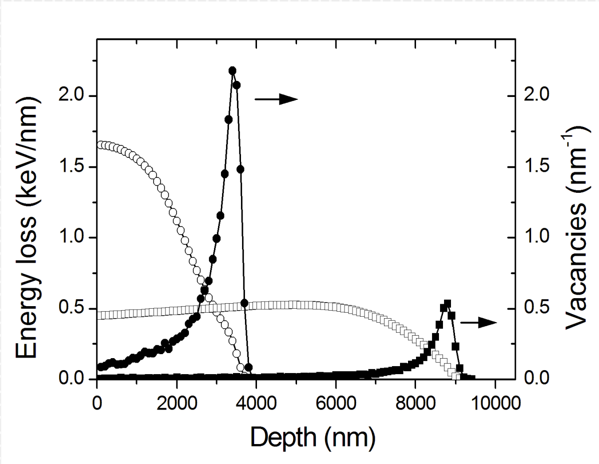
NIEL – non ionizing energy loss (MeVcm^{2}g^{-1})

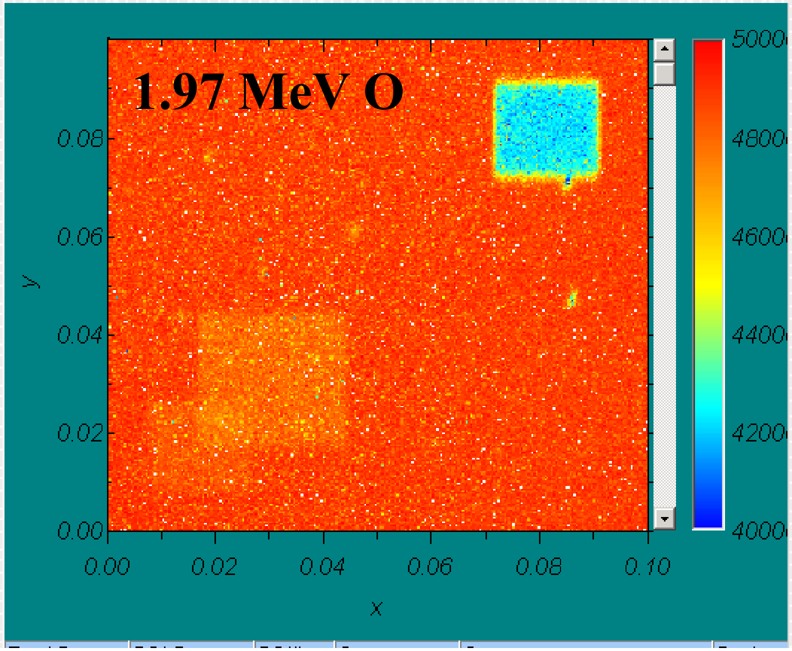
D_d - displacement damage dose (Φ*$NIEL_{ave.}$)

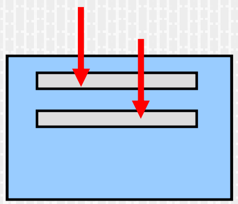
2. RADIATION INDUCED DEFECTS – IBIC

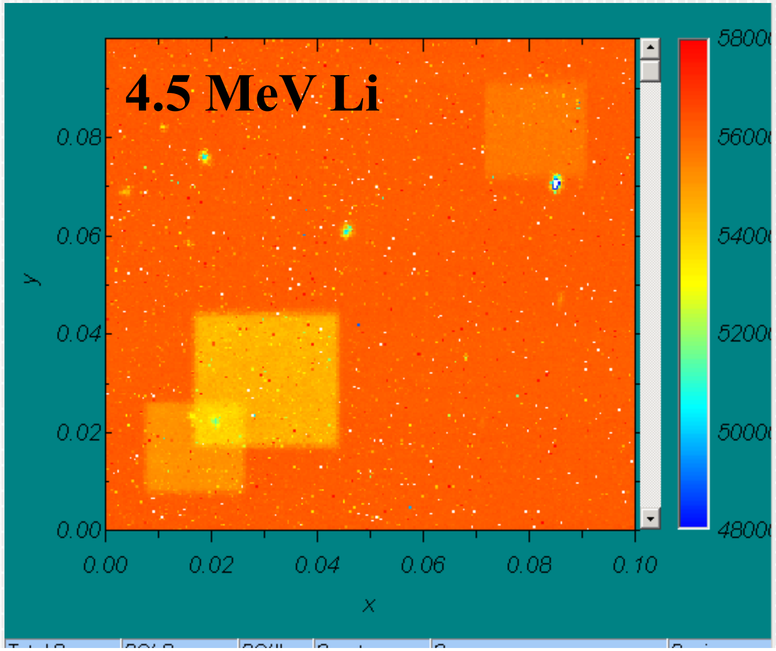


MeV ions produce inhomogeneous depth distribution:
- damaging profile – NIEL
- IBIC probe $(dE/dx)_{el.}$



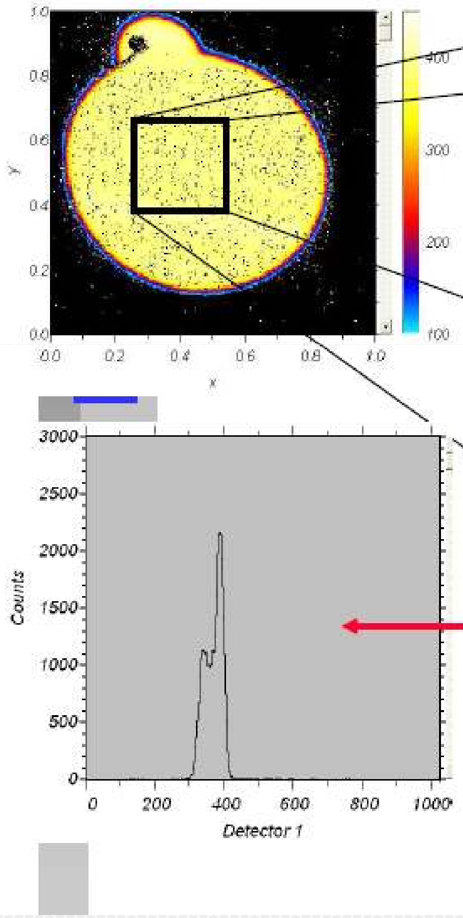


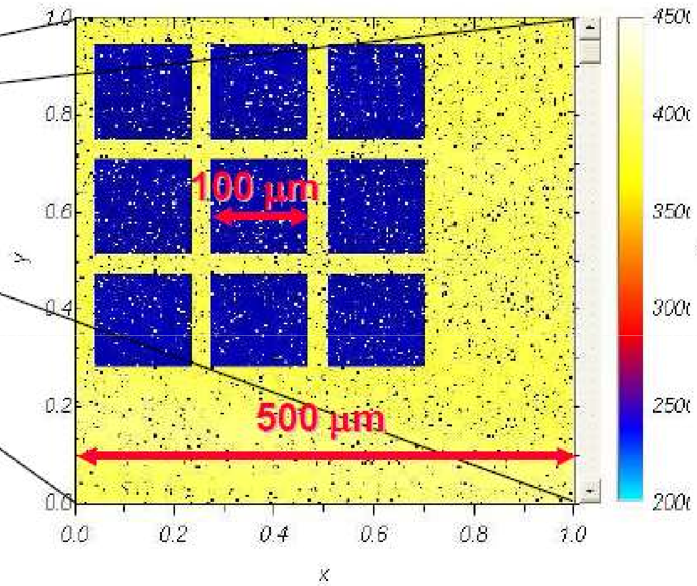


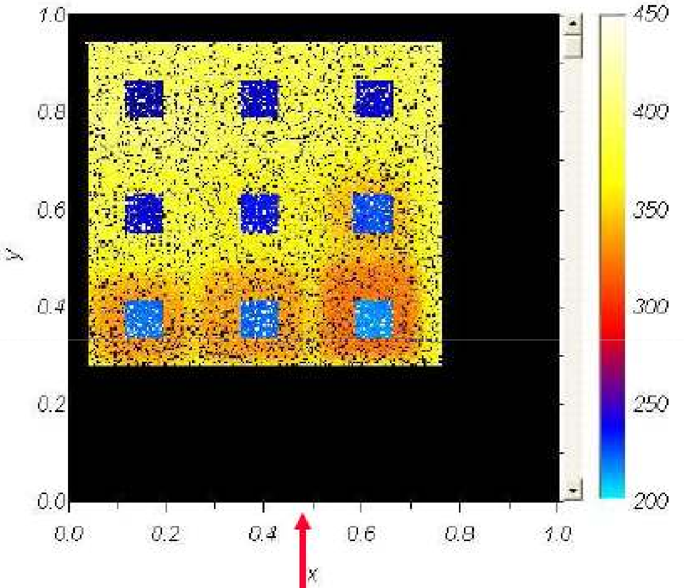


3. RADIATION HARDNESS of Si pin diode

Microbeam irradiation protocol







Irradiation pattern (3 x3 quadrants, 50 x 50 pixels, 100 x 100 µm^2 each, 20 µm gaps, t_{irrad} = 5 min. – 3 h)

Irrad. beam rate < 10000 cps (mostly 1kHz – 5kHz)

Measured IBIC response areal distribution of selectively irrad. areas

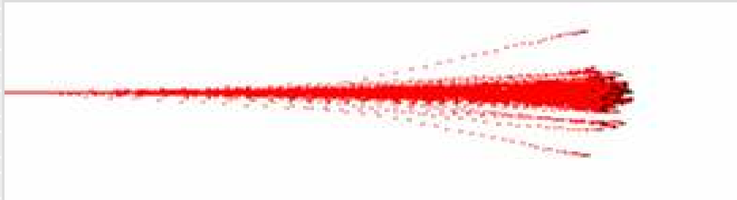
Probing beam rate < 500 cps

Željko Pastuović et al.
IEEE Trans. Nucl. Sci. 56 (2009) 2457-2464

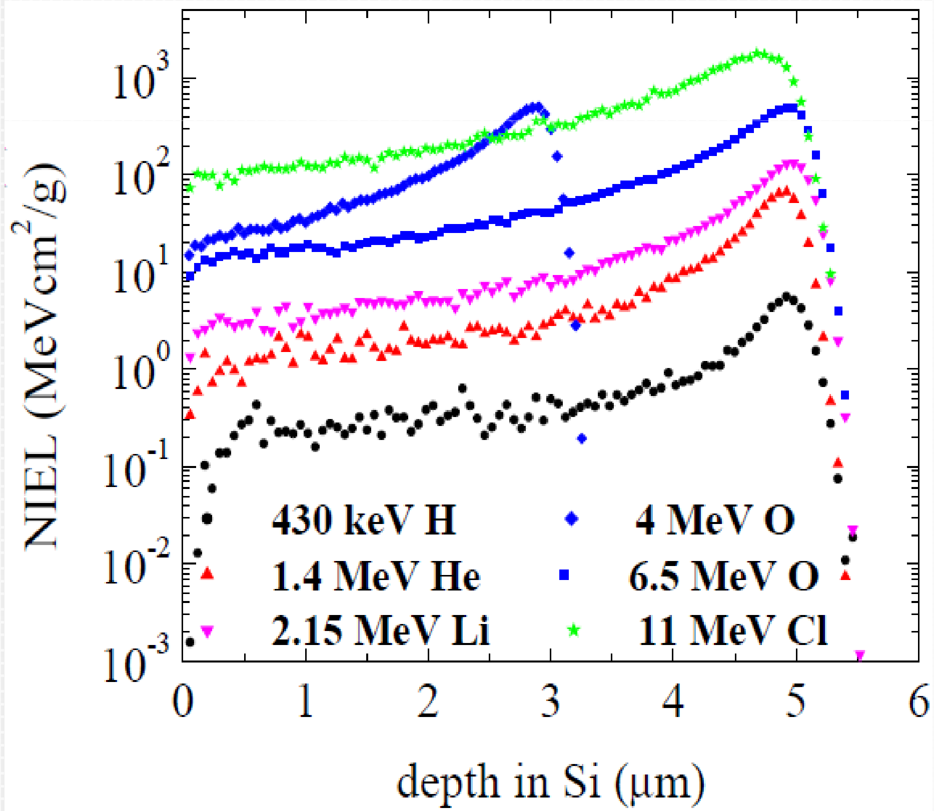
3. RADIATION HARDNESS of Si pin diode

MeV ions produce inhomogenoeus damage

In order to compare influence of ion mass/charge on the CCE, damege was produced by different ions of the same depth range in silicon (5 μm)



Ion	$NIEL_{ave}$
430 keV H	0.87
1.4 MeV He	9.13
2.15 MeV Li	21.91
4 MeV O	129.19
11 MeV Cl	450.38**



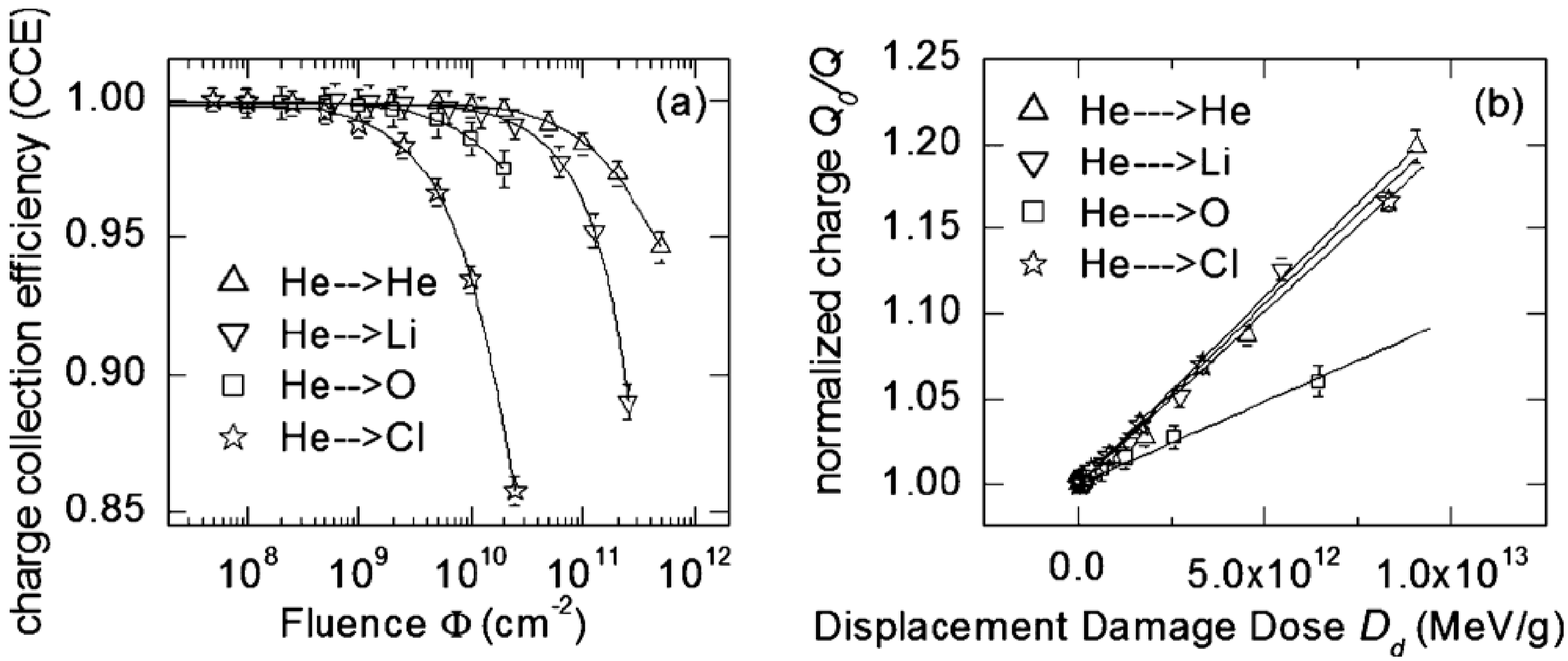
3. RADIATION HARDNESS of Si pin diode

He IBIC probe

1.4 MeV He ions for IBIC have homogeneous e-h pair creation depth profile !

$$\frac{Q_0}{Q} = 1 + K_{ed} \cdot \Phi \cdot NIEL_{ave}$$

K_{ed} is the equivalent damage factor- reflects properties of material !

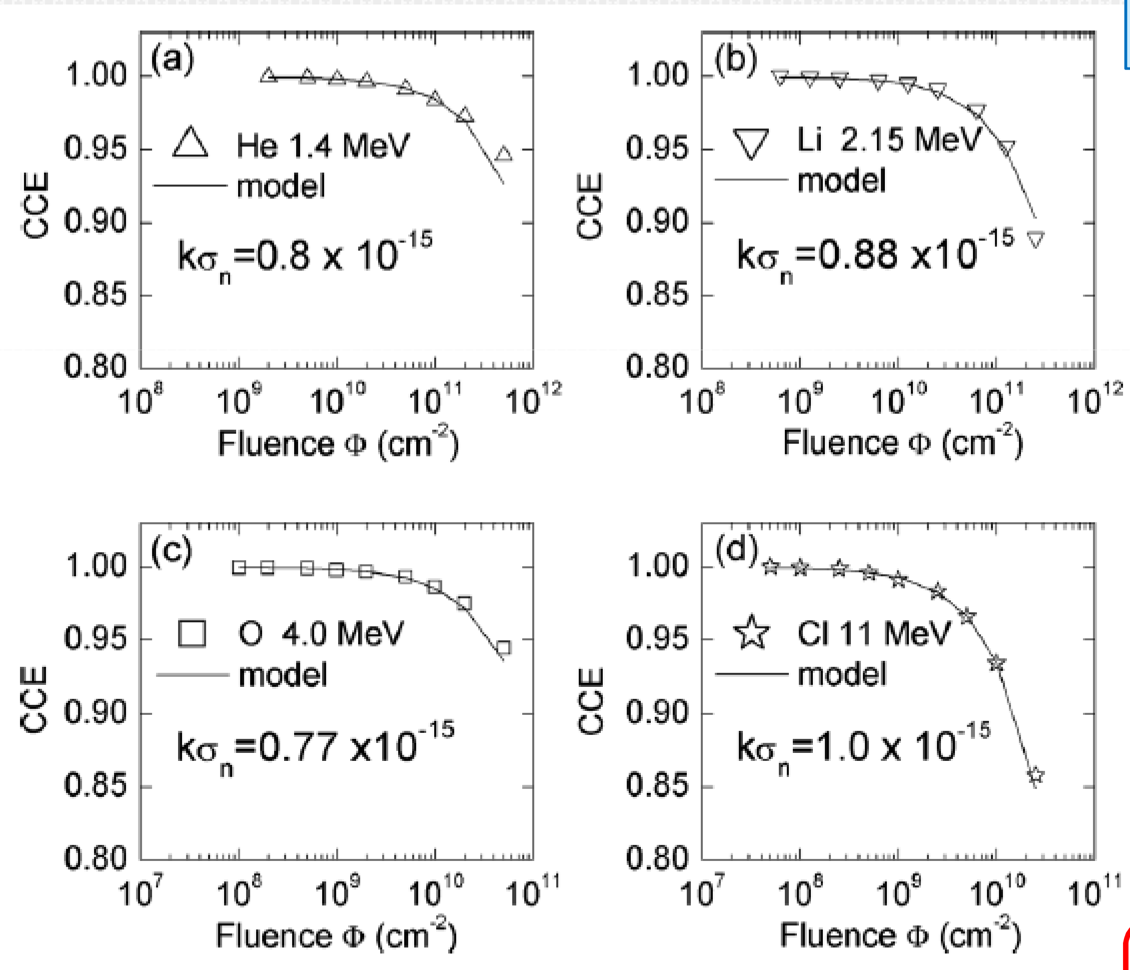


Probe → damage	He → He	He → Li	He → O	He → Cl
$K_{ed}(\times 10^{-14}$ g/MeV)	2.1 ± 0.1	2.2 ± 0.1	0.96 ± 0.04	2.02 ± 0.02

3. RADIATION HARDNESS of Si pin diode

MeV ions produce inhomogenoeus damage

Željko Pastuović et al.
Appl. Phys. Lett. 98, (2011) 092101



Modeling of CCE:

- doping profiles (incl. NIEL.)
- electric field profile (CV)
- only electron contribution
- only divacancies
- dE/dx from TRIM
- electron lifetime:

$$\frac{1}{\tau(z)} = \frac{1}{\tau_0} + V(z) \cdot k \cdot \sigma \cdot v_{th},$$

$k\,\sigma = 0.88 * 10^{-15}$

$k = 0.18$!!

18% of radiation induced defects leads to stable divacancies !

3. RADIATION HARDNESS of Si pin diode

Conclusions of importance to diamond

- Weak correlation between $k\sigma$ values and Z of ion
- NIEL scaling works well

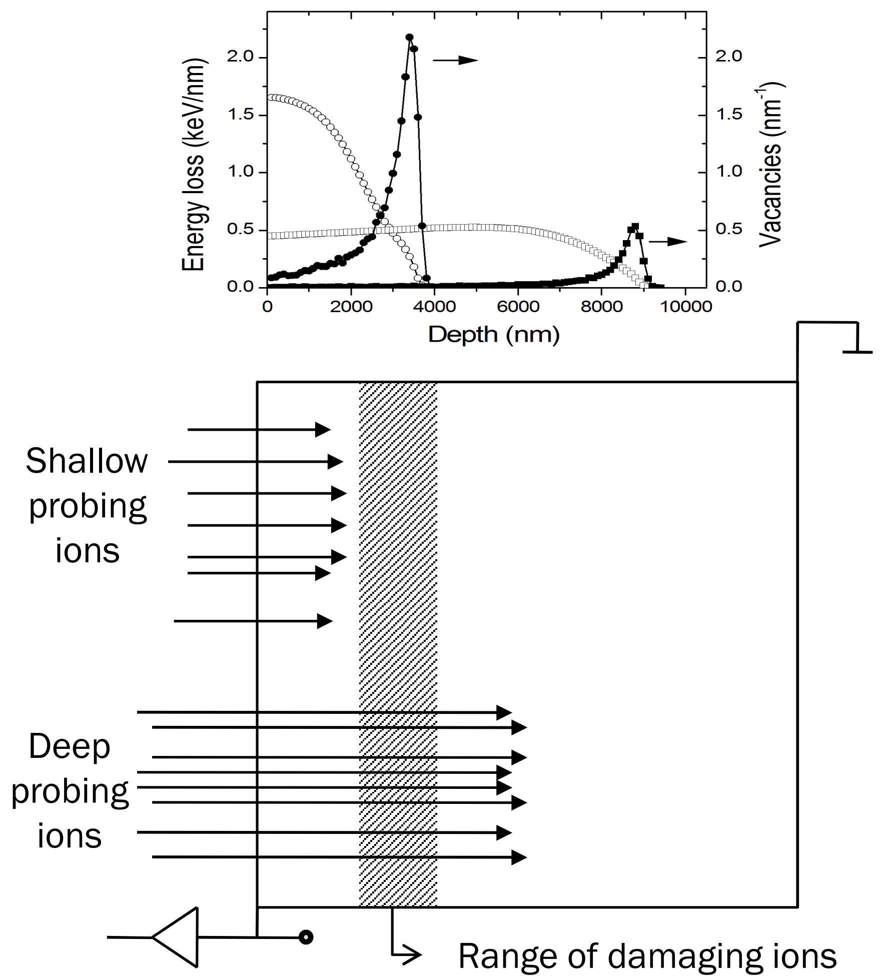
Direct comparisson of Si pin diode with scDiamond detector using same range of ions in Si and diamond!

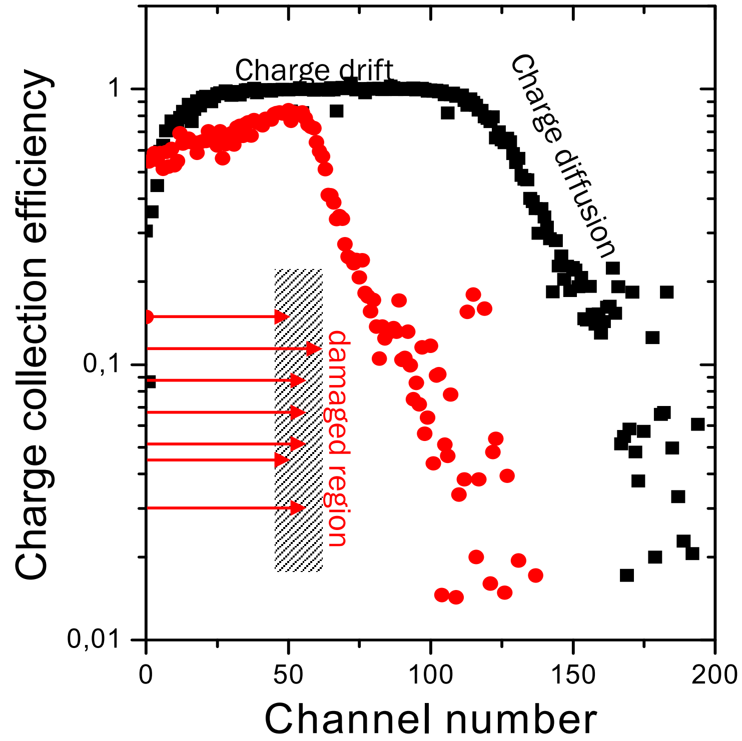
- 1 mm^2; 500 μm thickness – Diamond Detectors Ltd.
- 10 mm2; 50 μm thickness – Diamond Detectors Ltd.

	Si	Diamond	SiC	Range
Damaging C ions	2.6 MeV	6.5 MeV	4.5 MeV	3 μm
Shallow probe	600 keV He ions	430 keV p	1 MeV He ions	2.25 μm
Deep probe	1.3 MeV p	2 MeV p	1.7 MeV p	25 μm

4. RADIATION HARDNESS OF DIAMOND

Radiation hardness - experiment and modeling

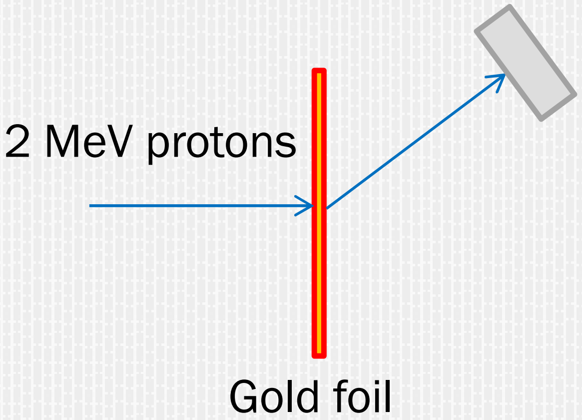


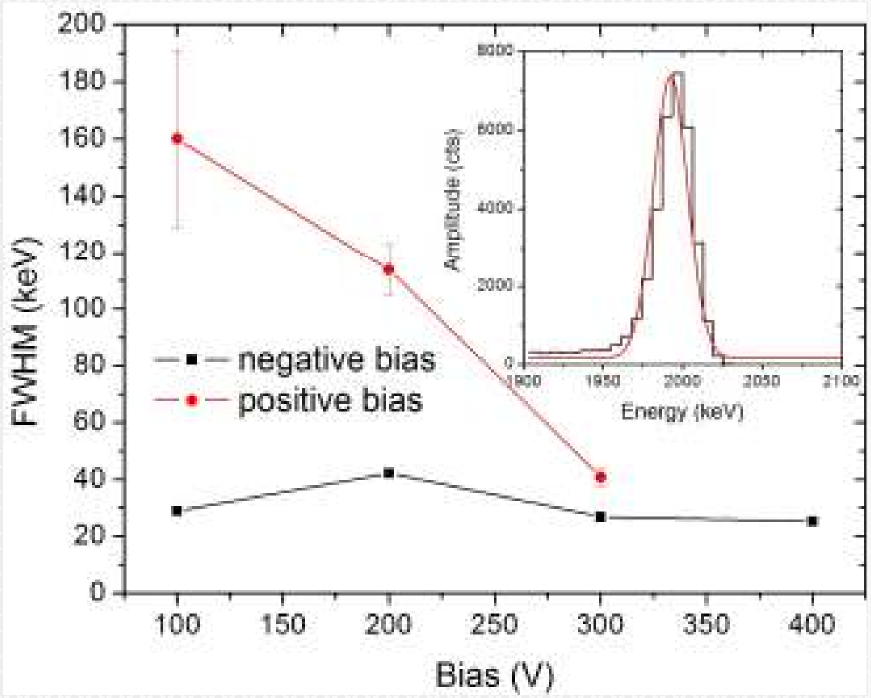


Problem: increased sesitivity for Si pin diode due to changes in electric field profile

4. RADIATION HARDNESS OF DIAMOND

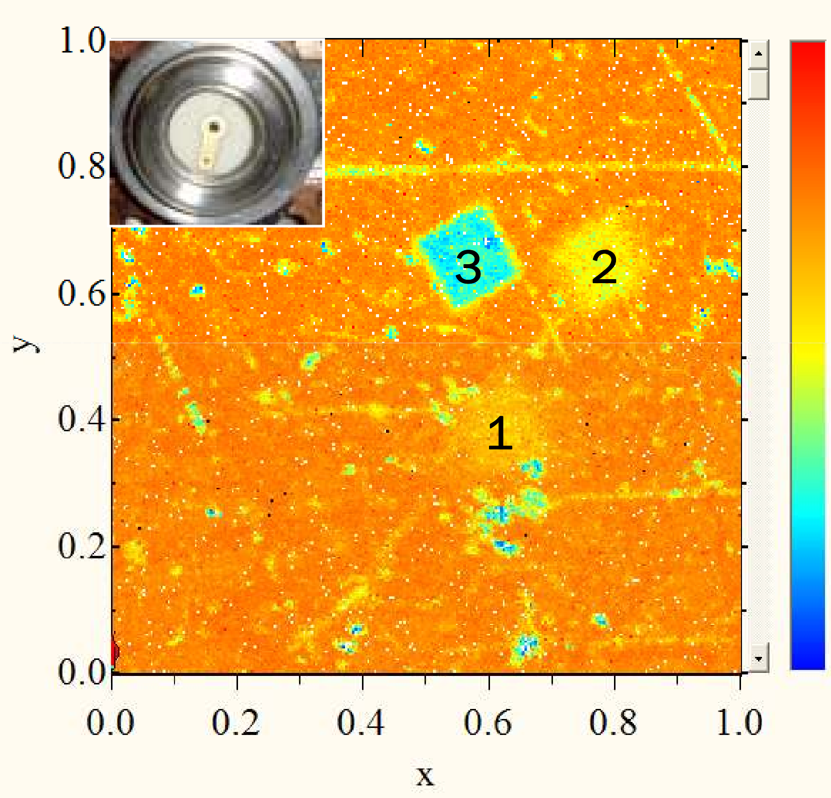
Spectroscopic properties

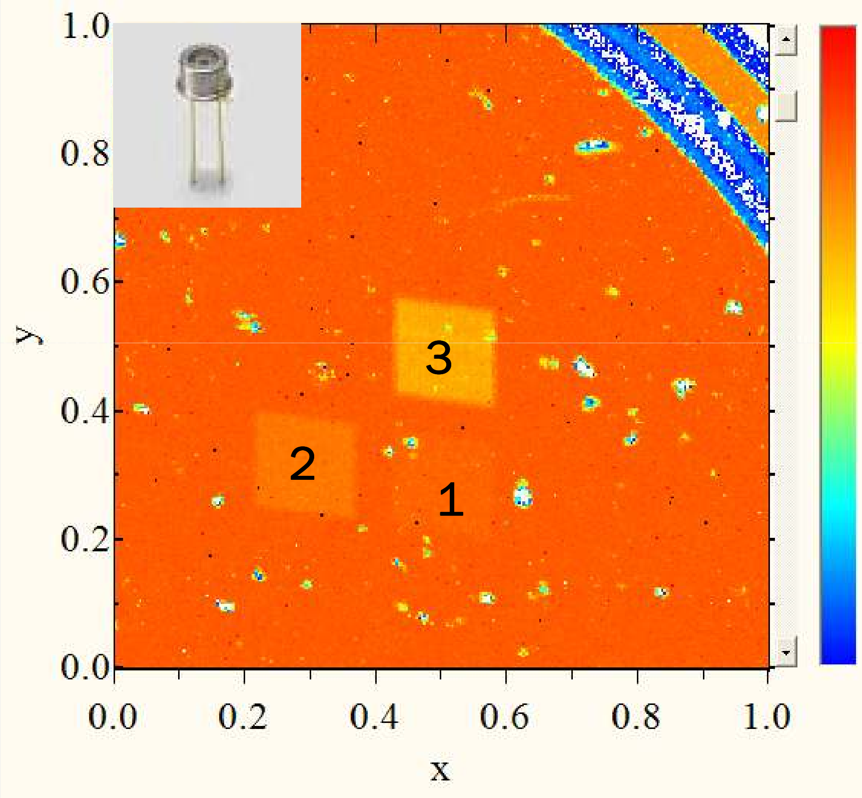




4. RADIATION HARDNESS OF DIAMOND

Radiation hardness - Si vs. Diamond

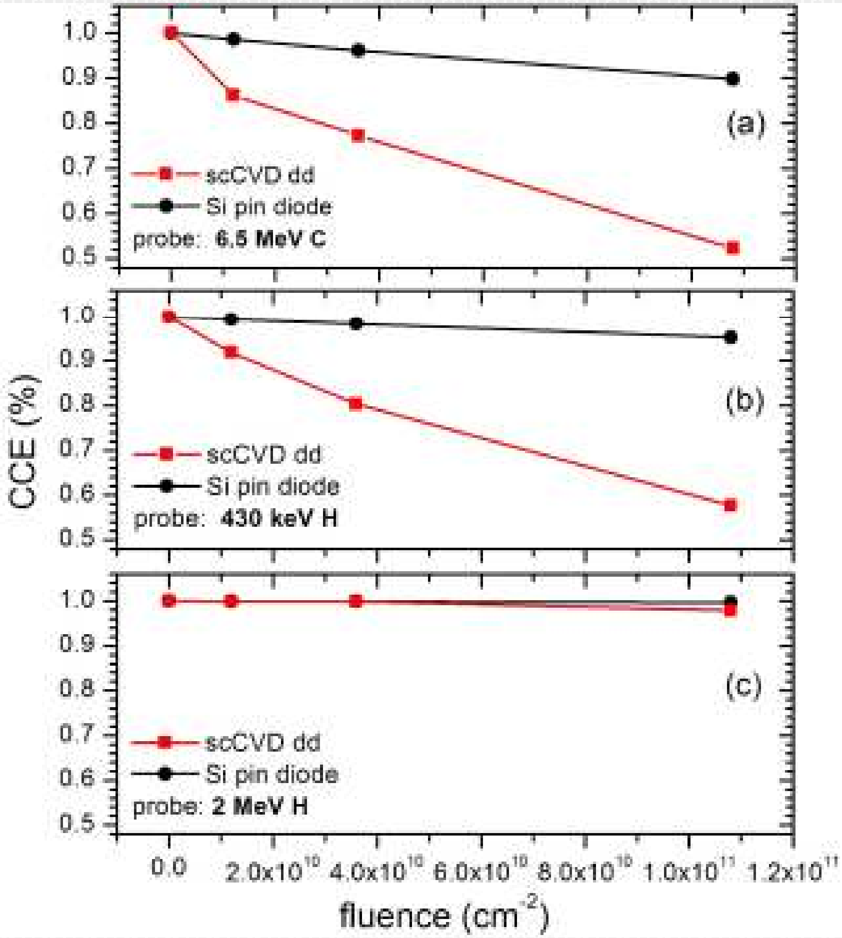




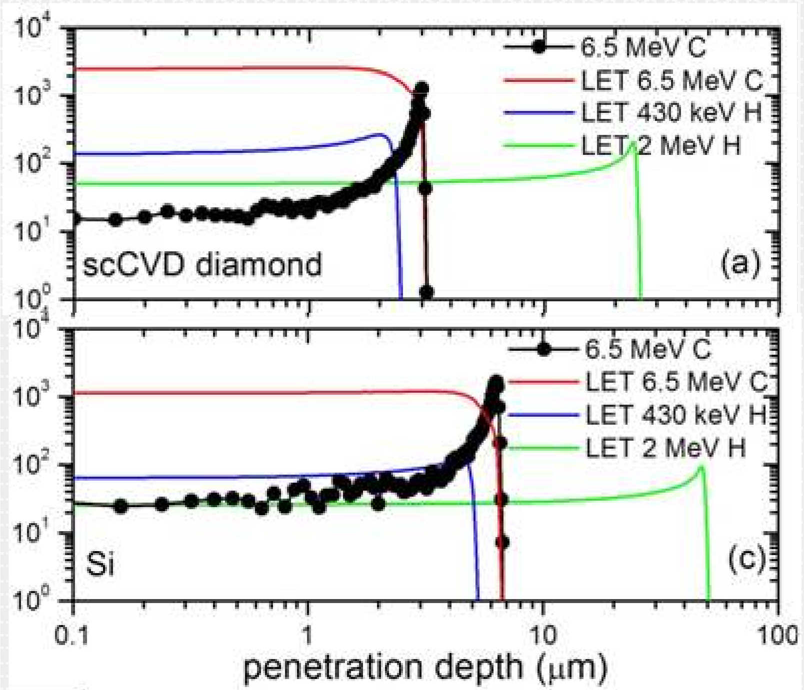
- scCVD (1x1x0.5 mm) and Si pin diode (1 x 0.1 mm)
- 50x50 μm^2 areas irradiated with 6.5 MeV C^{3+}
- IBIC images done with 430 keV protons

4. RADIATION HARDNESS OF DIAMOND

Radiation hardness - Si vs. Diamond

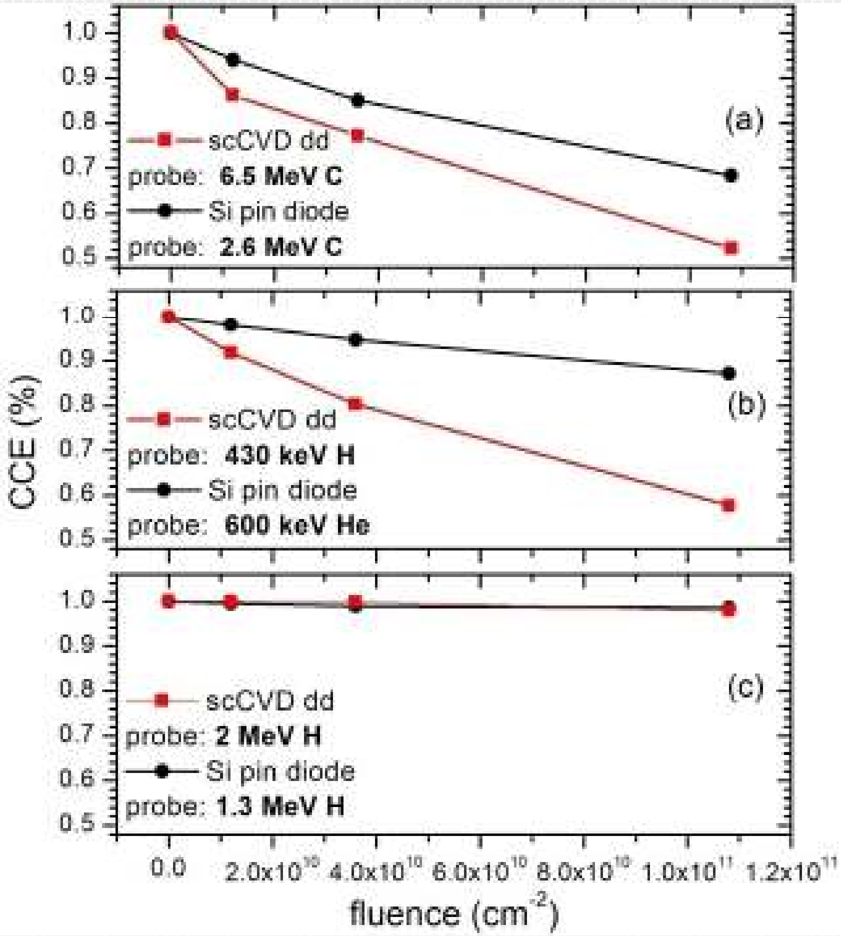


Si & diamond irradiated by 6.5 MeV C ions

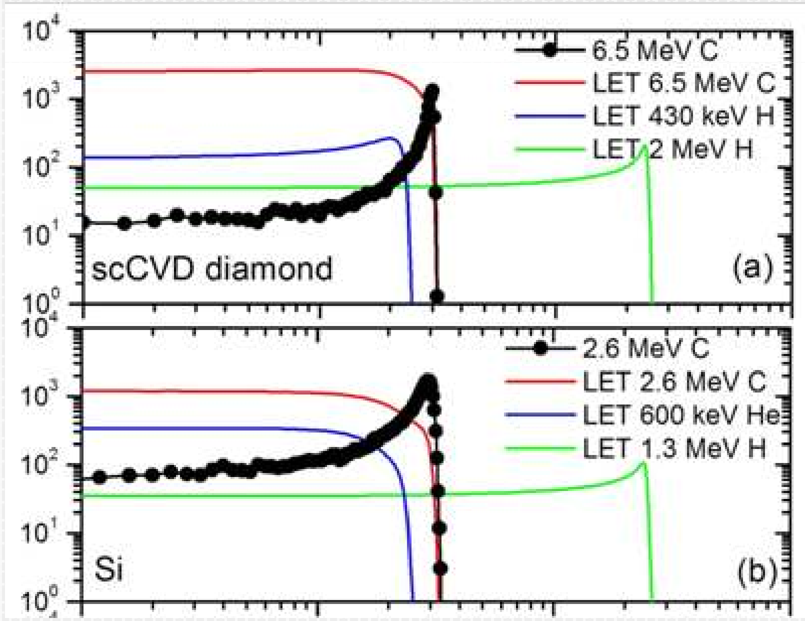


4. RADIATION HARDNESS OF DIAMOND

Radiation hardness - Si vs. Diamond

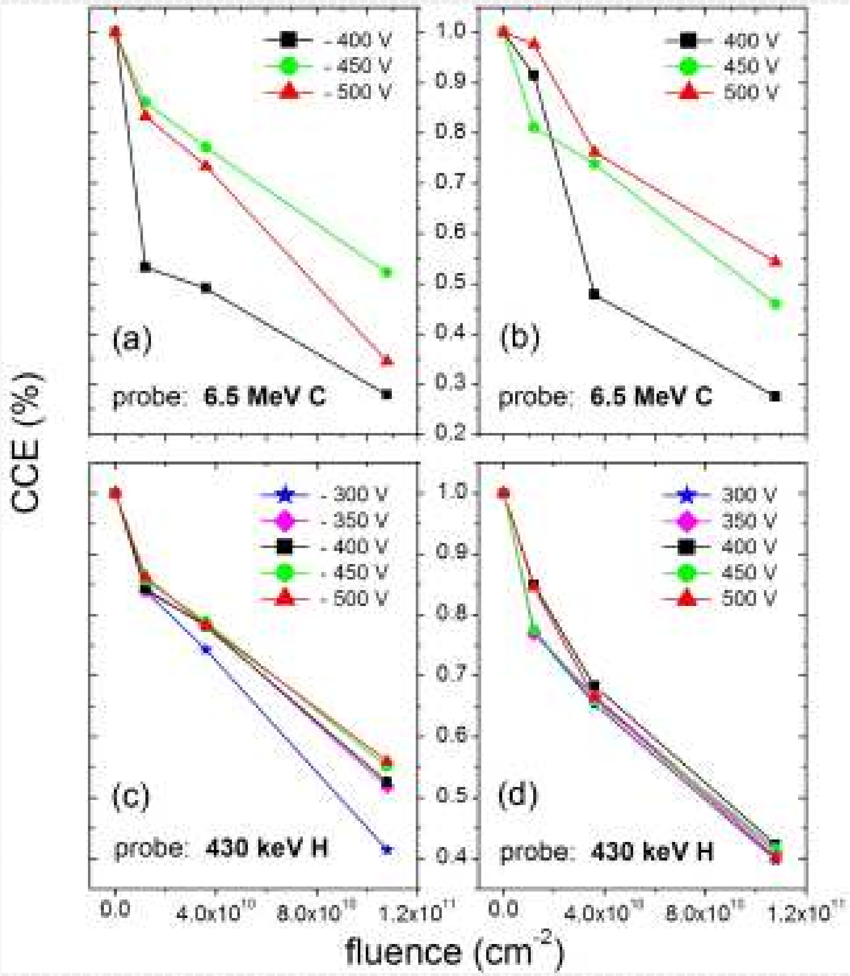


Si irradiated by 2.6 MeV C ions
Diamond irradiated by 6.5 MeV C ions



4. RADIATION HARDNESS OF DIAMOND

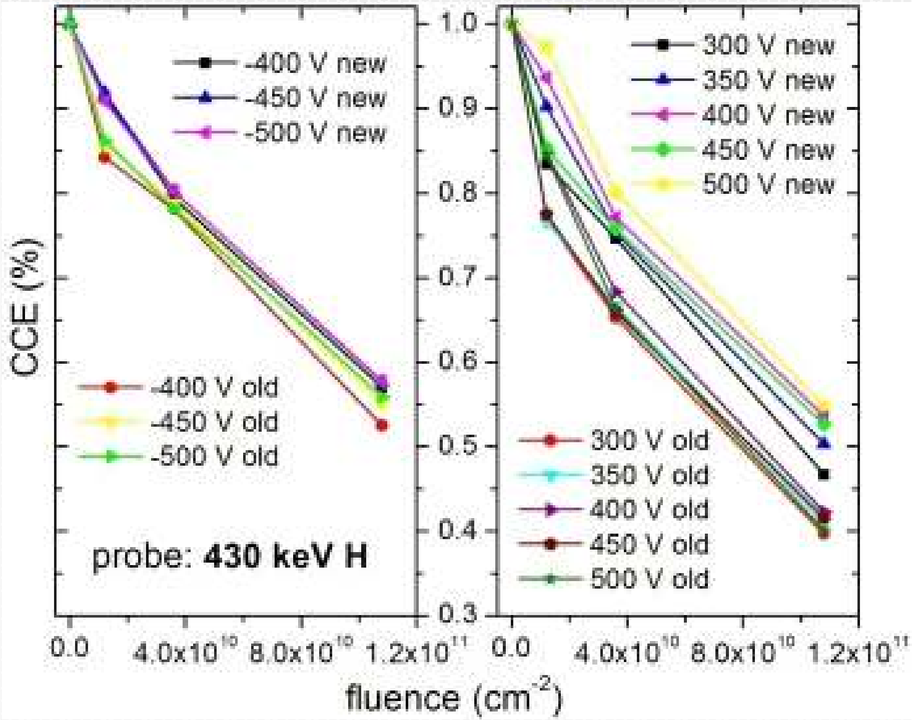
Radiation hardness - Si vs. Diamond



6.5 MeV C probe introduce 15 times more charge than 430 keV protons in the same volume – **possible polarisation, but not significant!**

4. RADIATION HARDNESS OF DIAMOND

Radiation hardness - Si vs. Diamond



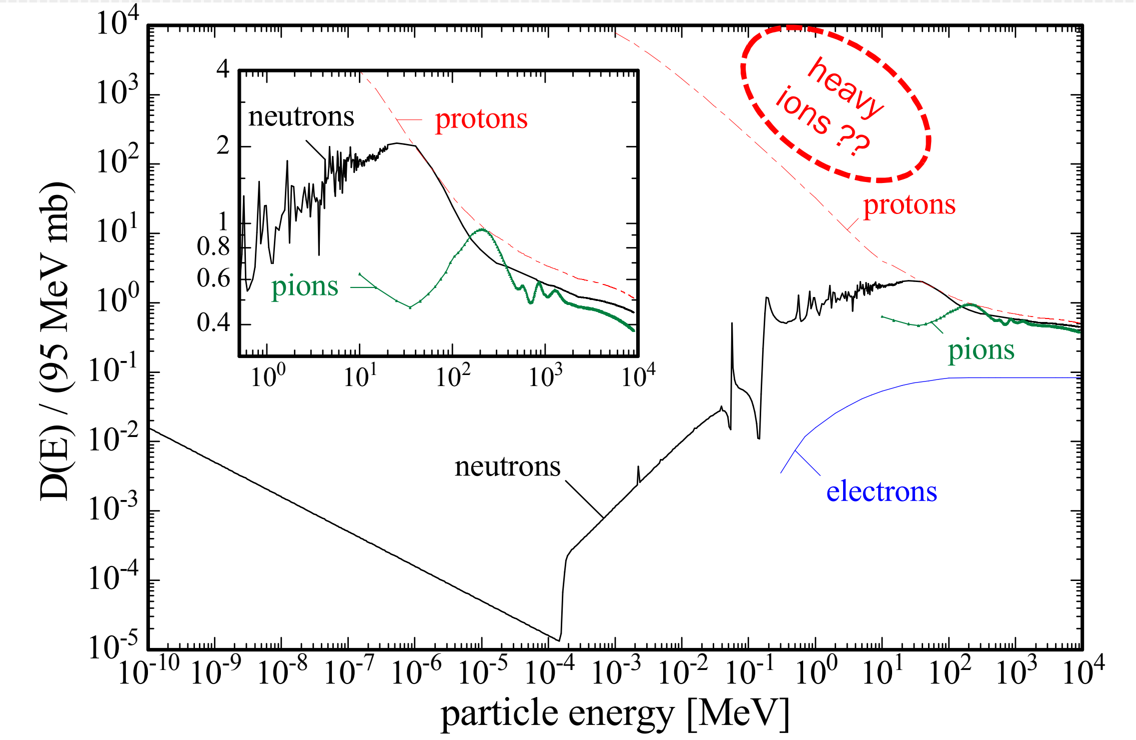
'new' measurements performed one year after 'old'

There is no significant difference due to long term anealing or polarisation

4. RADIATION HARDNESS OF DIAMOND

Conclusions

In the case of irradiation by 6.5 MeV C ions, induced defects in diamond are affecting CCE more than in Si pin diode!
Higher defect recombination probability (room temperature anealing) in silicon may be one of the main reasons for that.

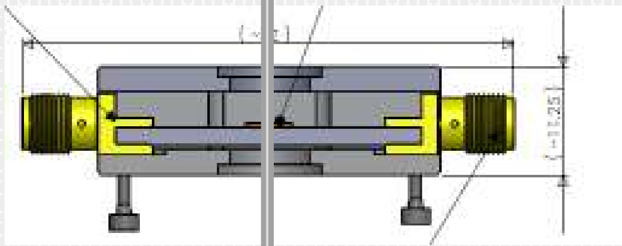


Other issues:
- Polarization ?
- Priming ?
- short ion range – strong influence of contact and surface imperfections

4. RADIATION HARDNESS OF DIAMOND

Proton irradiation, 50 µm thick scDIAMOND

4.5 MeV protons, $(dE/dx)_{nucl.} = 4.04\ 10^{-5}$ MeV/mg cm^{-2}

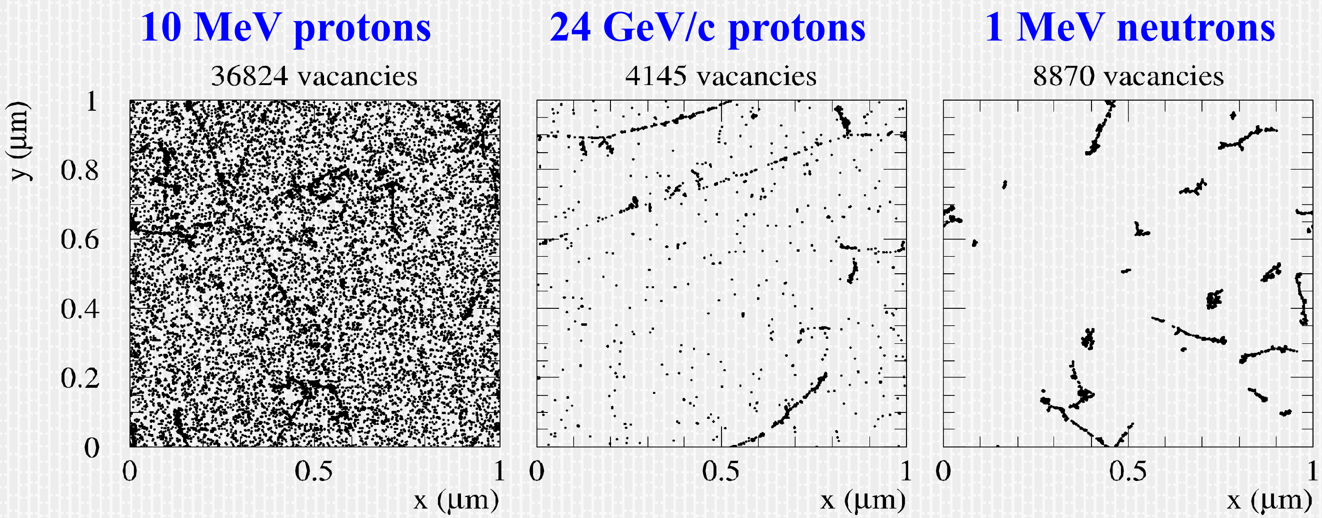


3 MeV protons, $(dE/dx)_{nucl.} = 5.9\ 10^{-5}$ MeV/mg cm^{-2}

Simulation:

Initial distribution of vacancies in $(1\mu m)^3$ after 10^{14} particles/cm^2

[Mika Huhtinen NIMA 491(2002) 194]



4. RADIATION HARDNESS OF DIAMOND

Proton irradiation, 50 µm thick scDIAMOND

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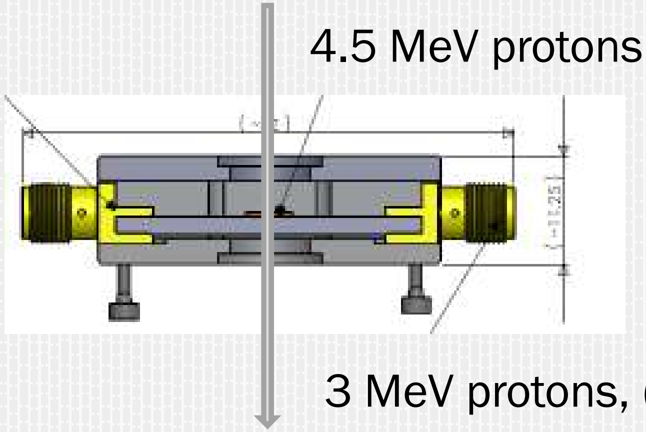
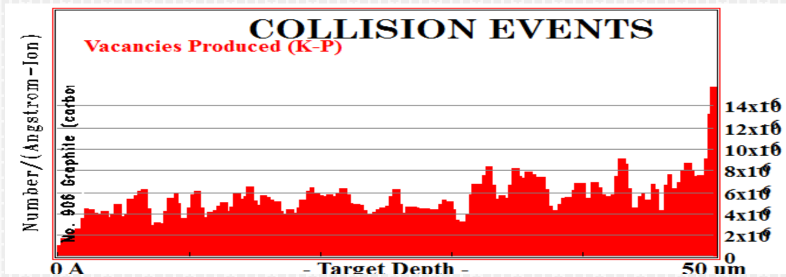
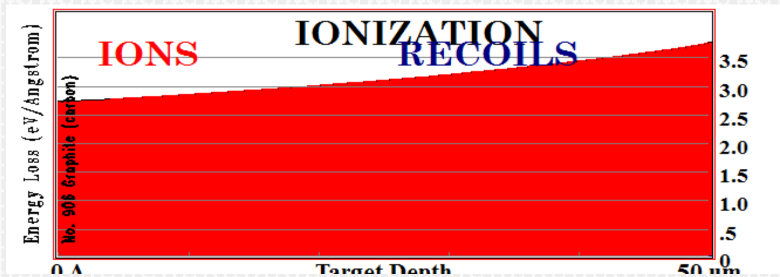


3 MeV protons, $(dE/dx)_{nucl.}$ = 5.9 10^{-5} MeV/mg cm^{-2}

4.5 MeV protons are producing homogeneous distribution of damage

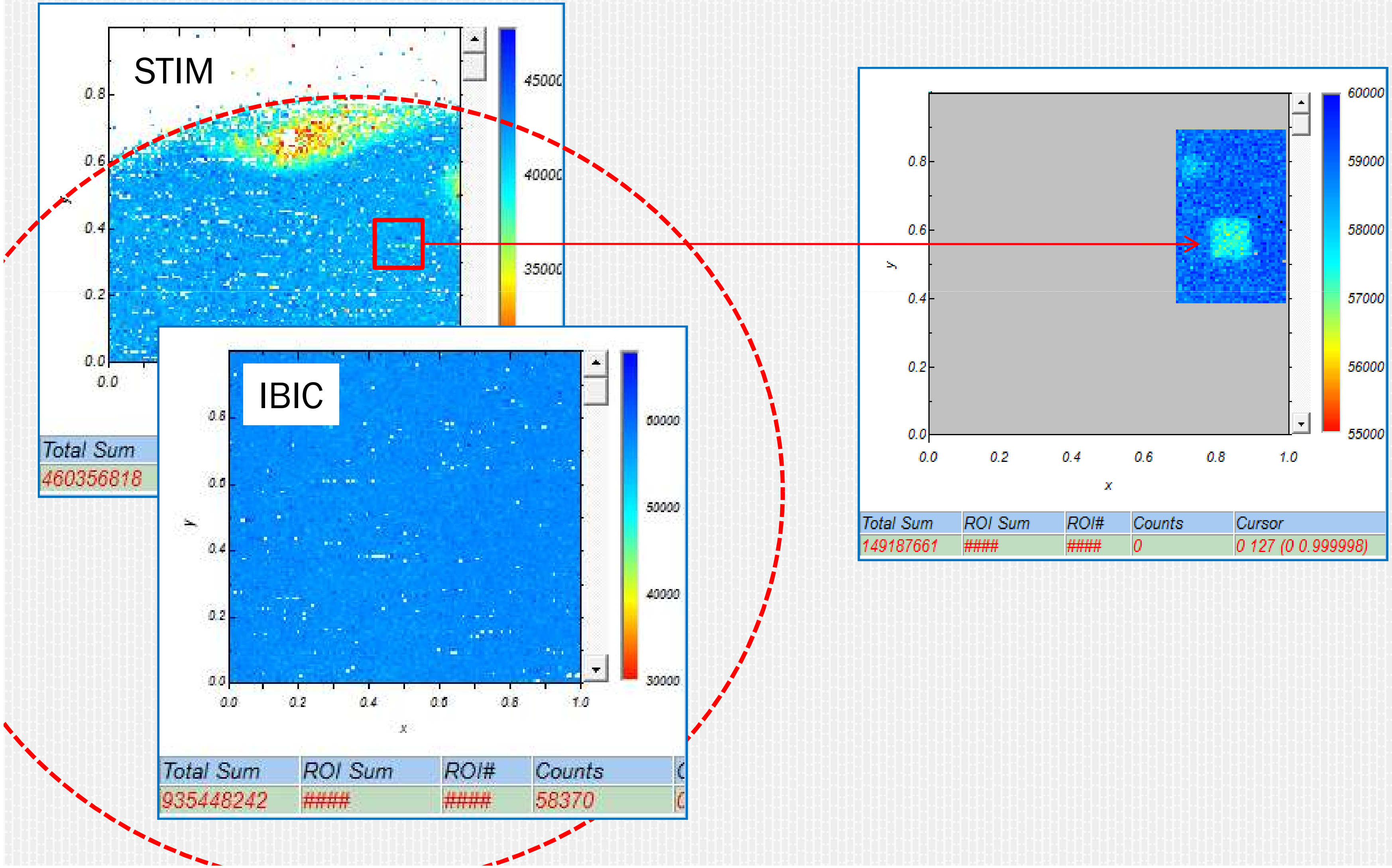


Spectroscopic performance; 2 MeV protons:
< 1% energy resolution
Can cope with 10000 cps in 50 x 50 μm^2 !



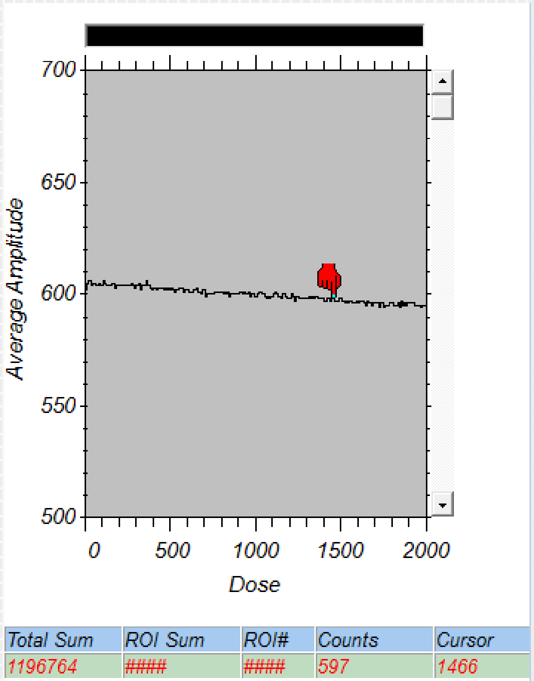
4. RADIATION HARDNESS OF DIAMOND

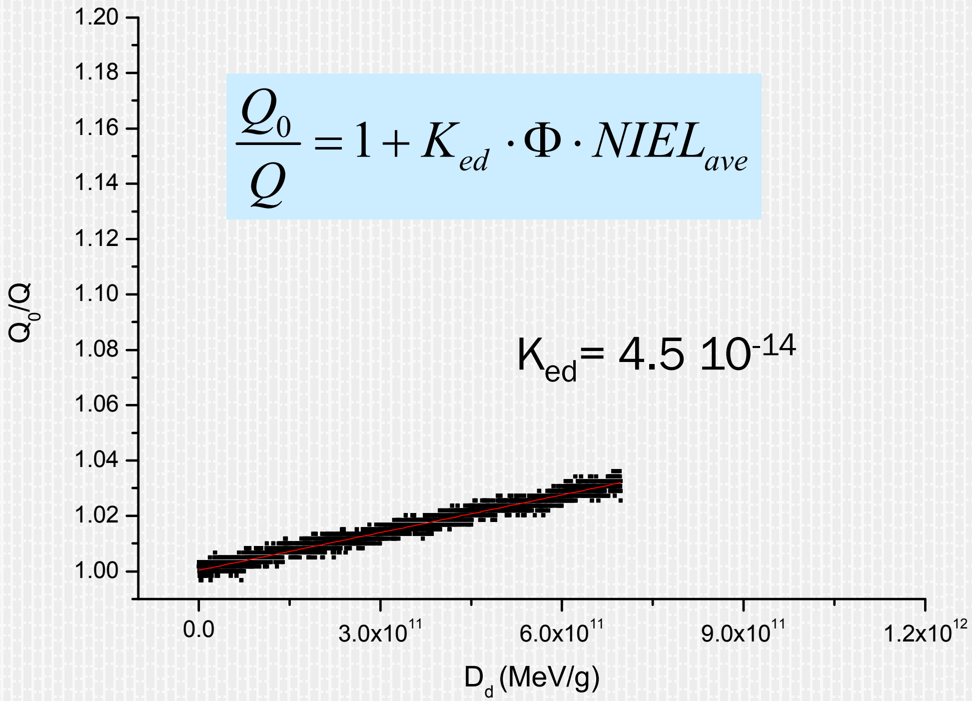
Proton irradiation, 50 µm thick scDIAMOND



4. RADIATION HARDNESS OF DIAMOND

Proton irradiation, 50 μm thick scDIAMOND





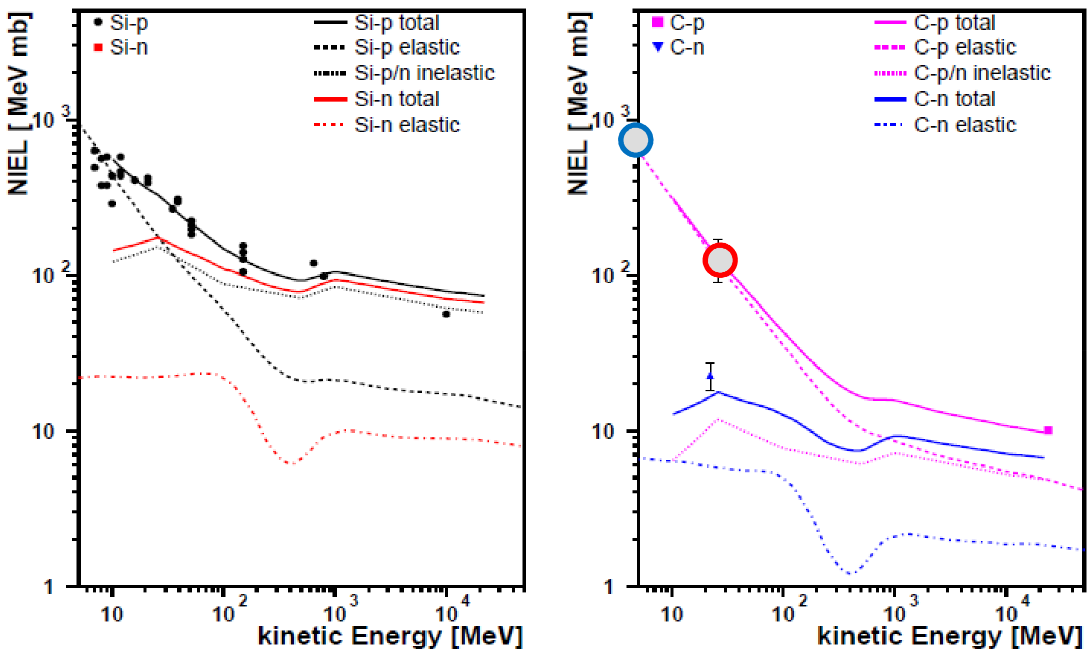
Total fluence 2 10^7 protons

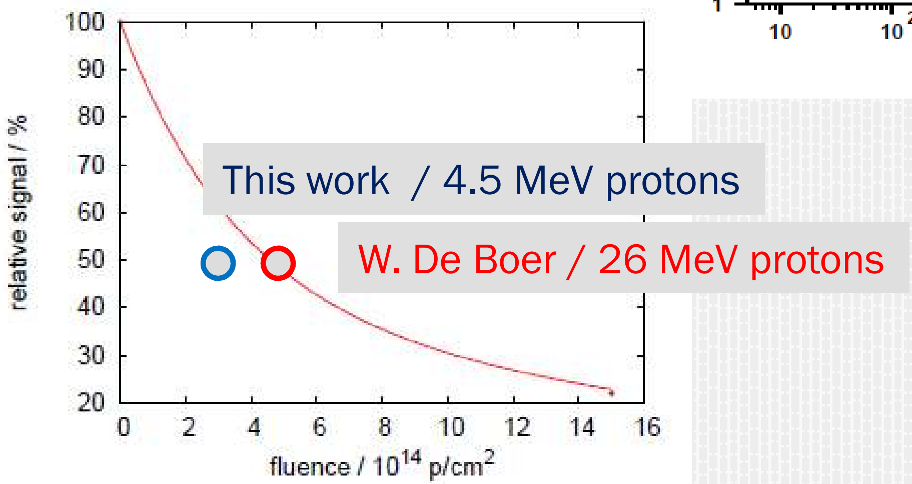
Area 50 x 50 μm^2

4. RADIATION HARDNESS OF DIAMOND

Proton irradiation, 50 µm thick scDIAMOND

Excvellent properties !
Comparisson with silicon underway !





Particle Detectors FP7 project

SEVENTH FRAMEWORK PROGRAMME

New vacancies for four experts

Four postdoctoral positions at the Division of Experimental Physics at the Rudjer Boskovic Institute in Croatia as part of the 3-year long 1.32M Euro FP7 project Particle Detectors , and that should be filled at latest by the last quarter of this year/1st quarter of 2011. The expertise sought of the experienced researches is in:

- **silicon detectors**
- **diamond detectors**
- **vacuum chambers/detector testing**
- **DAQ/process control**

The contracts will be one year long, with the possibility to extend them for the duration of the project. Brutto pay is about 3000 Euro, depending on experience. Detailed job descriptions for each of the four positions are provided here .

Diamond Detectors -
Development and Applications,
2nd RBI Detector Workshop, 7-10 May 2012,
Plitvice Lakes National Park, Croatia

Supported by:

- Strategic Japanese-Croatian Cooperative Program on Materials Science
- EU FP7 projects: PARTICLE DETECTORS, SPIRIT, ENSAR