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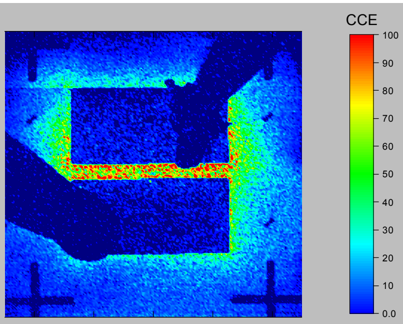

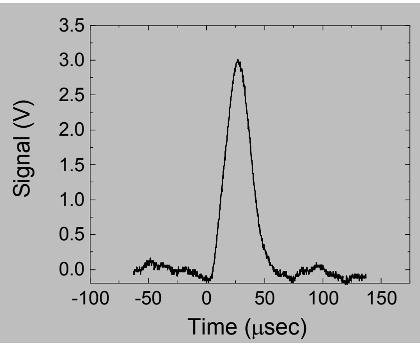

Single ion detection in diamond: A path for deterministic color center creation

J. Abraham, B. Aguirre, J. Pacheco, R. Camacho, E. Bielejec

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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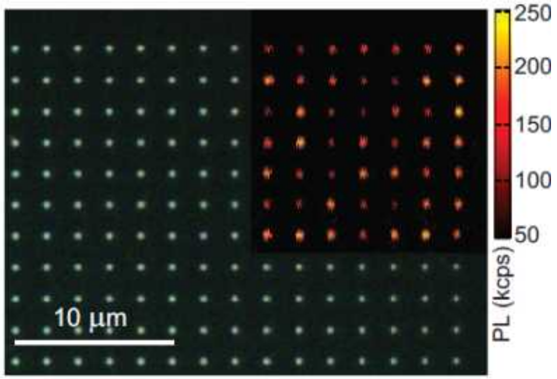
Deterministic Fabrication

Spatial localization Established → Masking - NV S. Sangtawesin et. Al. Appl. Phys. Lett. 105, 063107 (2014)

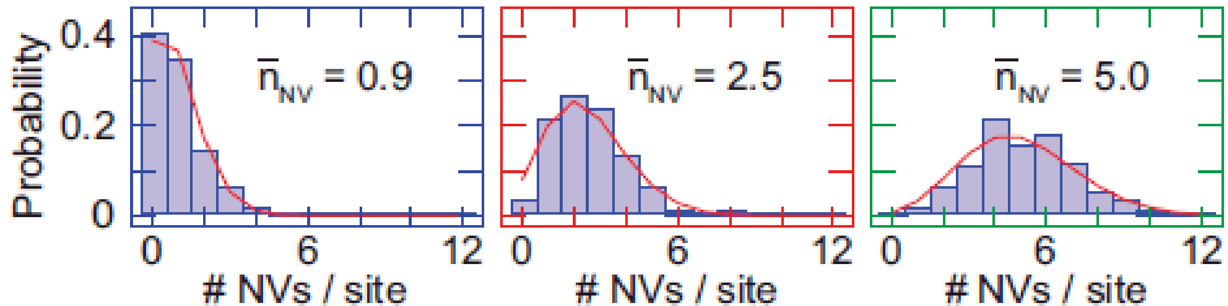
→ Focused Ion Beam - SiV S. Tamura et. al. Appl. Phys. Express 7, 115201 (2014)

Yield In progress

S. Sangtawesin et. Al. Appl. Phys. Lett. 105, 063107 (2014)

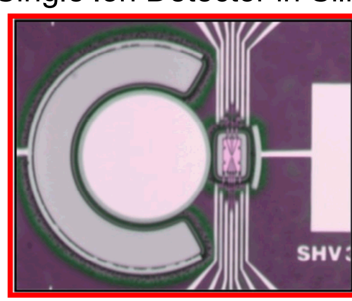


Poisson Statistics



In-situ single ion detection is a demonstrated path for yield control

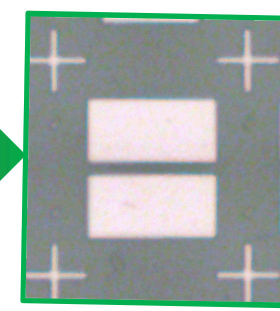
Single Ion Detector in Silicon



J.A. Seamons, et. al. Appl. Phys. Lett, 93, 043124 (2008)
E Bielejec, et. al. Nanotechnology 21, 085201 (2010)

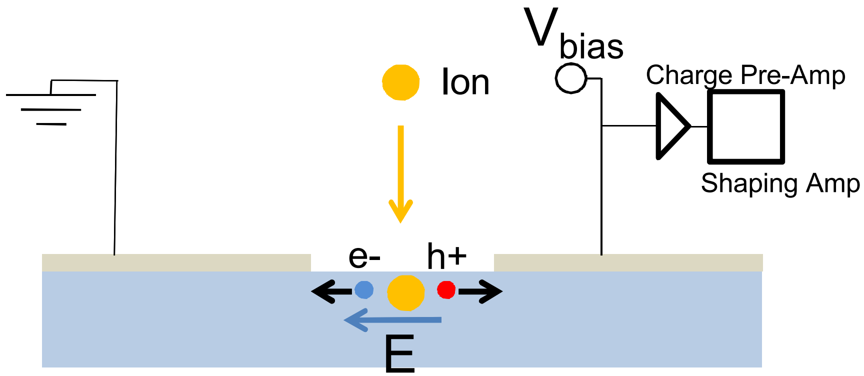
Our work: Translating single ion detection to diamond

Single Ion Detector in Diamond

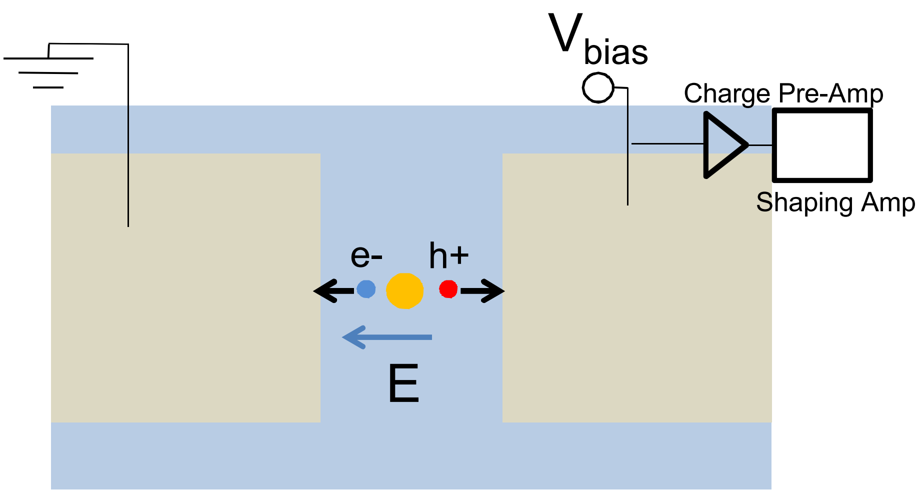


By counting in ions, we will remove a source of Poisson statistics

Physics of Ion Detection



Side View



Top View

Shockley-Ramo Theorem:

$$\boxed{i = q\vec{v} \cdot \vec{E}}$$

Moving charges in an electrical field will induce a current on the electrodes applying the bias

Charge Collection Efficiency (CCE):

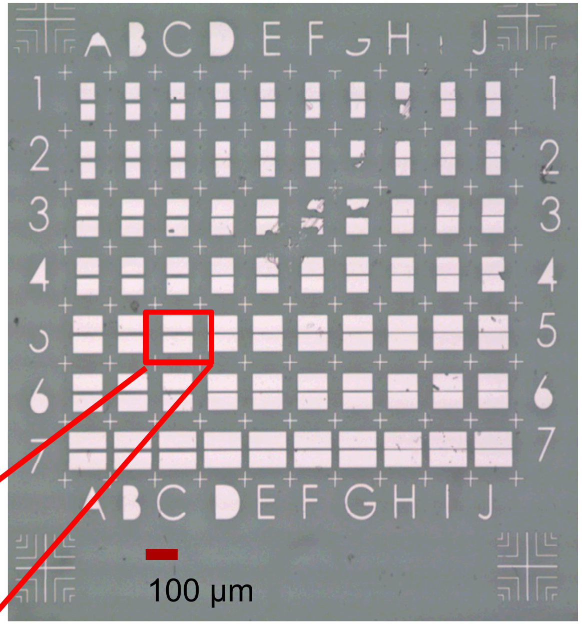
$$\boxed{\mathrm{CCE} = \frac{\mathit{Charge\ Collected}}{\mathit{Charge\ Depositied}}}$$

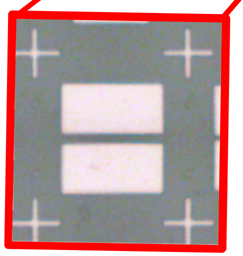
Ion Beam Induced Charge (IBIC):

Ion Beam is rastered across device to measure the Charge Collection Efficiency (CCE) as a function of position

Fabrication/TCAD Modeling

Co-planar Surface Electrode Detector

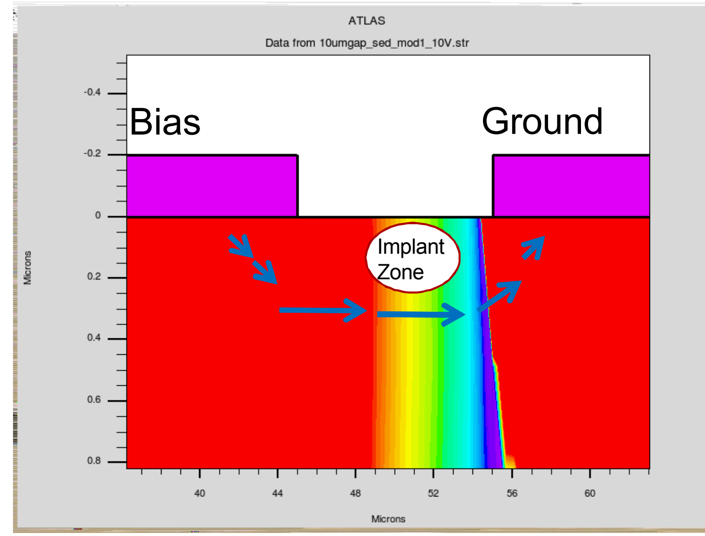




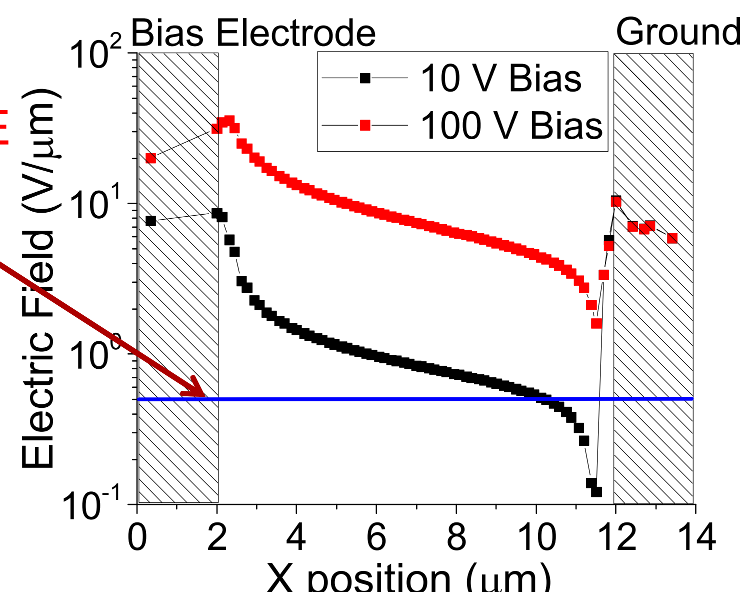
Fabrication

- Electronic grade single crystal diamond (Element 6)
- 200 nm Ti/Pt/Au Electrodes
- Varied width and gap spacing
    - 50-125 um width
    - 2 – 10 um gaps

(TCAD) Electric field simulation

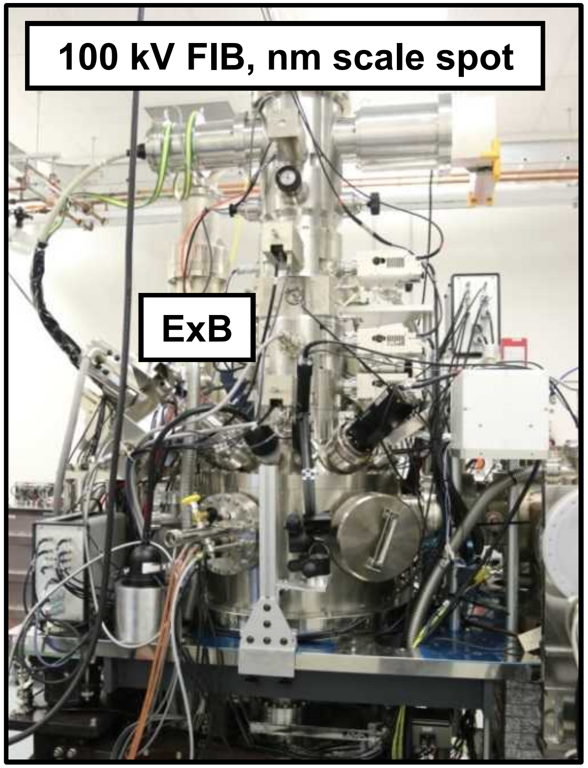


Confirm 95% CCE From E6



Detector Characterization

SNL NanoImplanter (nI)

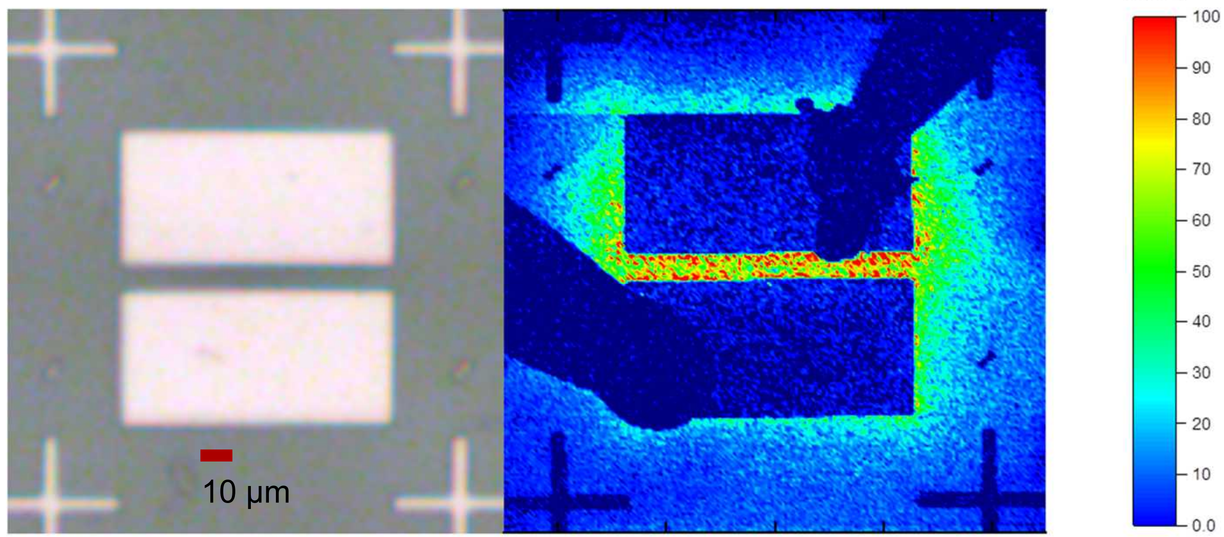


- Direct write lithography platform
  → nm targeting accuracy

Ion Beam Induced Current (IBIC)

$$\mathrm{CCE} = \frac{\textit{Charge Collected}}{\textit{Charge Depositied}}$$

optical IBIC



200 keV Si, <10 ions>/pulse,9 V/um bias

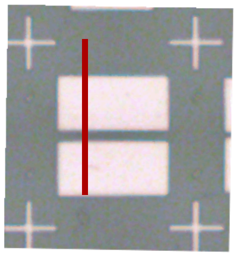
- Good detection in the fielded gap (drift)
- Fair detection in the periphery (diffusion)

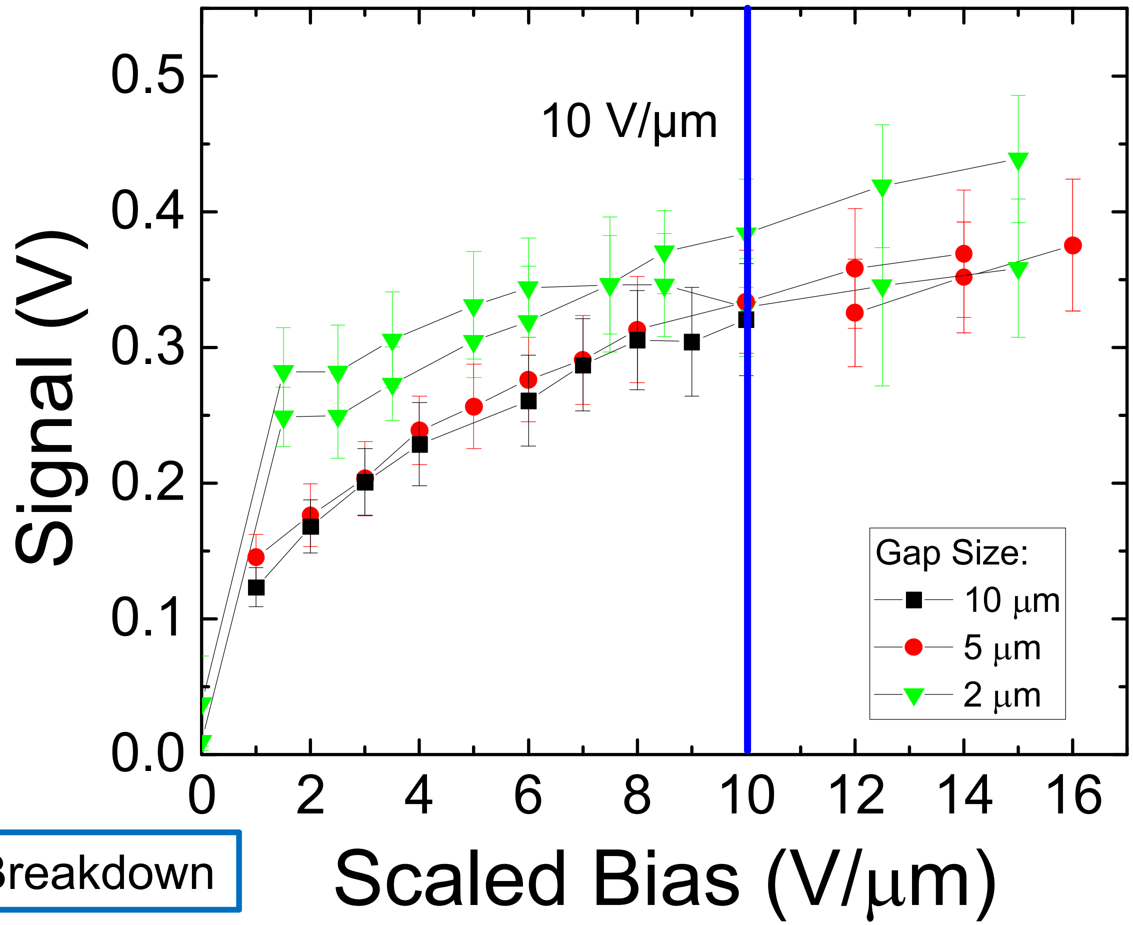
IBIC/Detection Demonstrated for low energy heavy ions

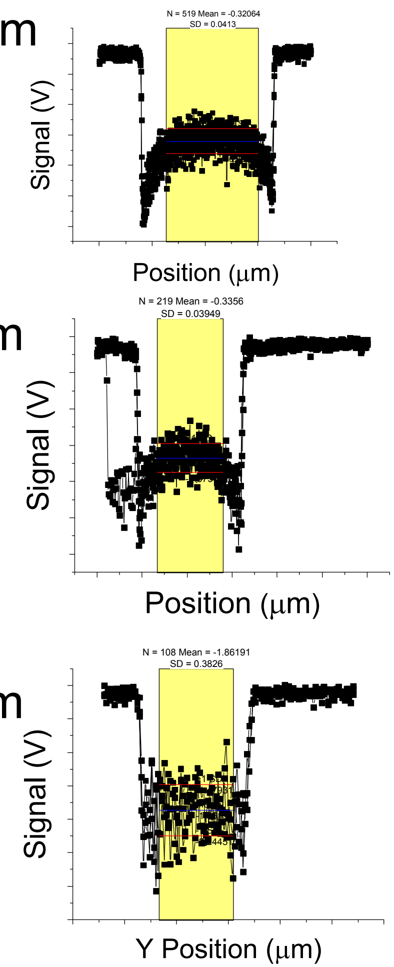
Detector Operation I

<100> ions/pulse = 100 +/- 10 ions/pulse

Y line cuts







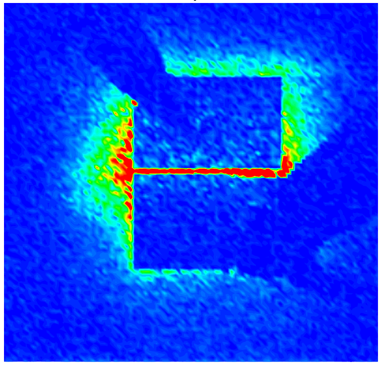
10^3 V/µm: Breakdown

Smaller Gap has a more uniform response and requires less bias for saturation

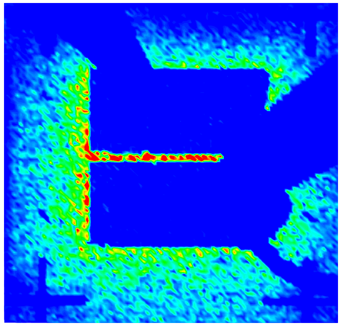
Detector Operation II

<10> ions/pulse = 10 +/- 3 ions/pulse

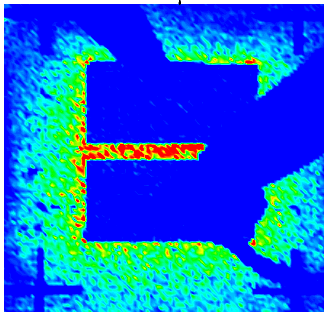
2 μm

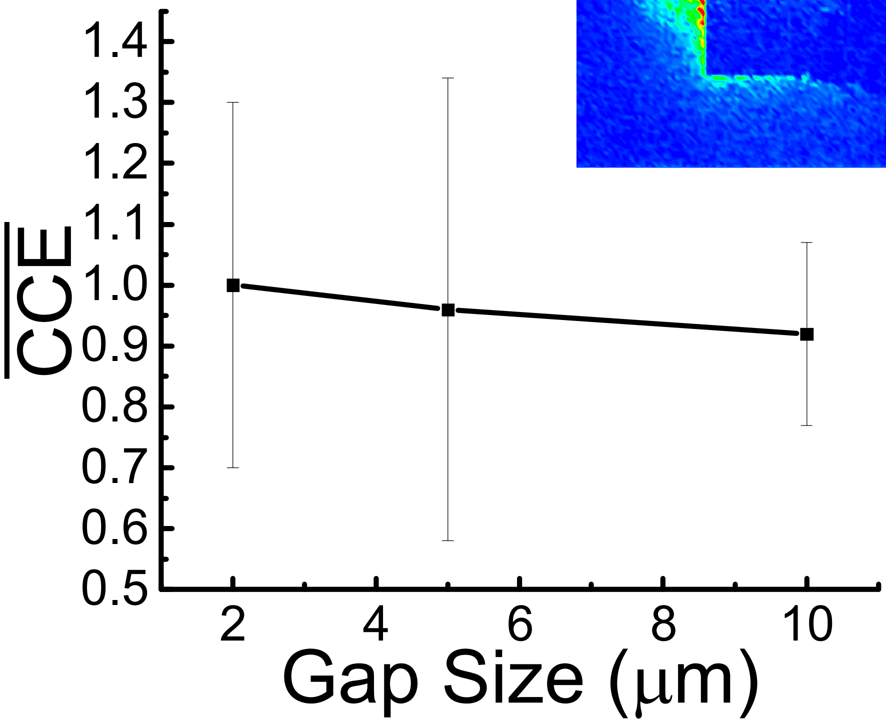


5 μm



10 μm

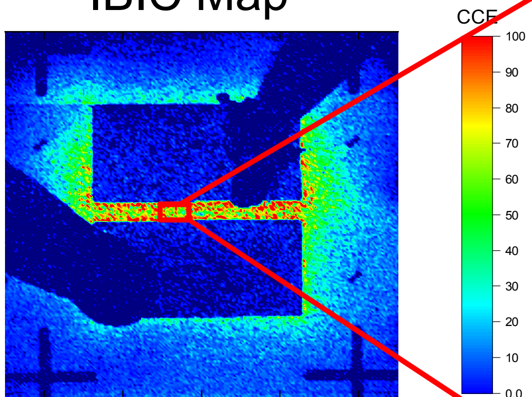




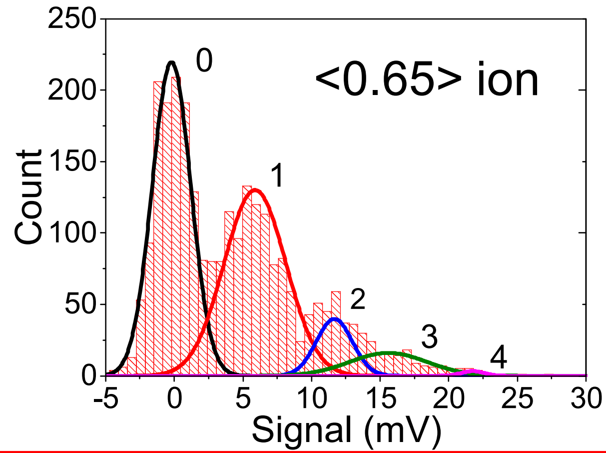
Smaller gap size improves detector performance

Single Ion Detection

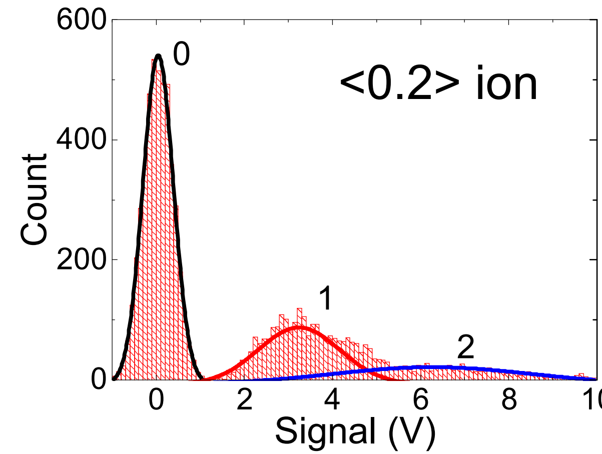
IBIC Map



Quantized Detection → Single Ion Counting

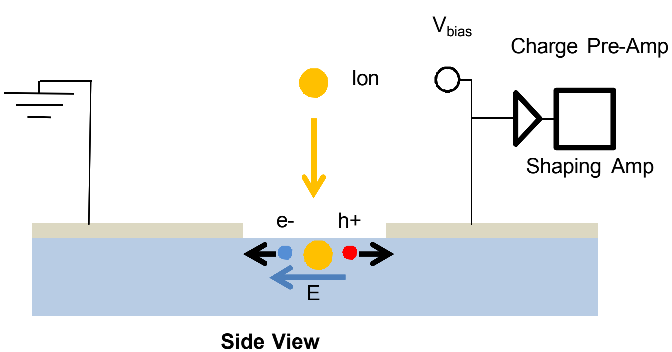


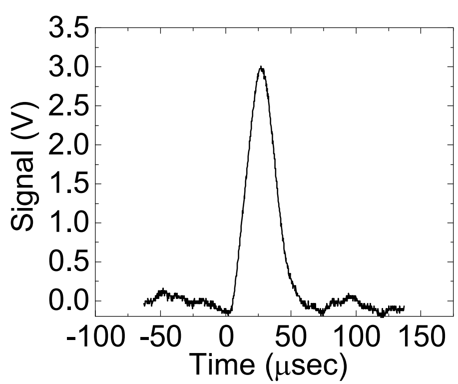
SNR = 1.7



SNR = 3.7

Signal amplitudes match Poisson statistics to 4%

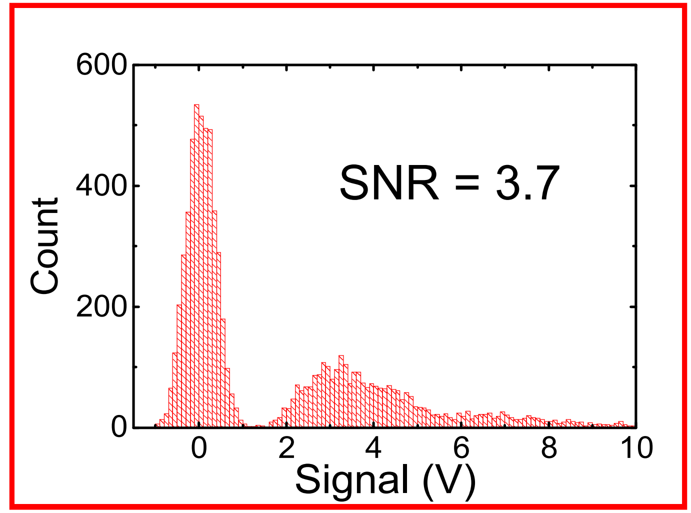




Gate signal for ion beam

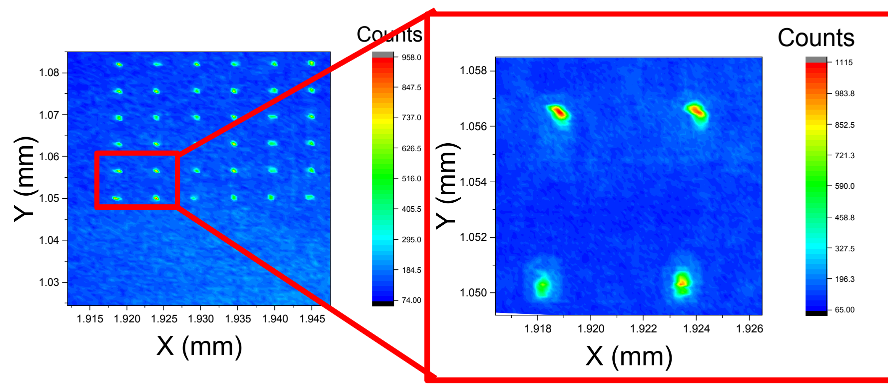
Conclusion/Outlook

- Conclusion:
  - Goal: Counted implantation to minimize Poisson statistics of SiV yield
  - Status: In-situ single ion detection is demonstrated in diamond



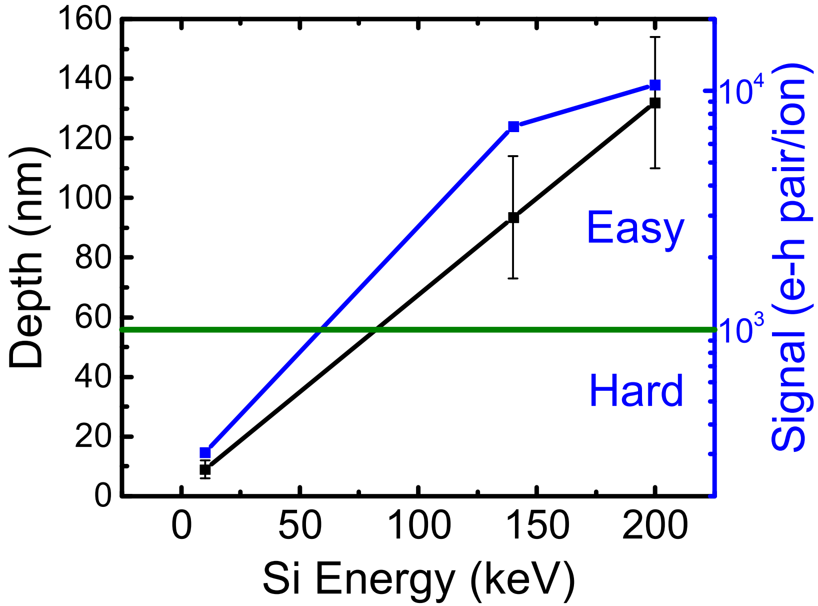
- Follow on work:
  - Measure the yield of a counted implantation.
  - We are in the process of setting up the measurements for yield – PL and g2

738 nm photoluminescence (PL) of timed SiV

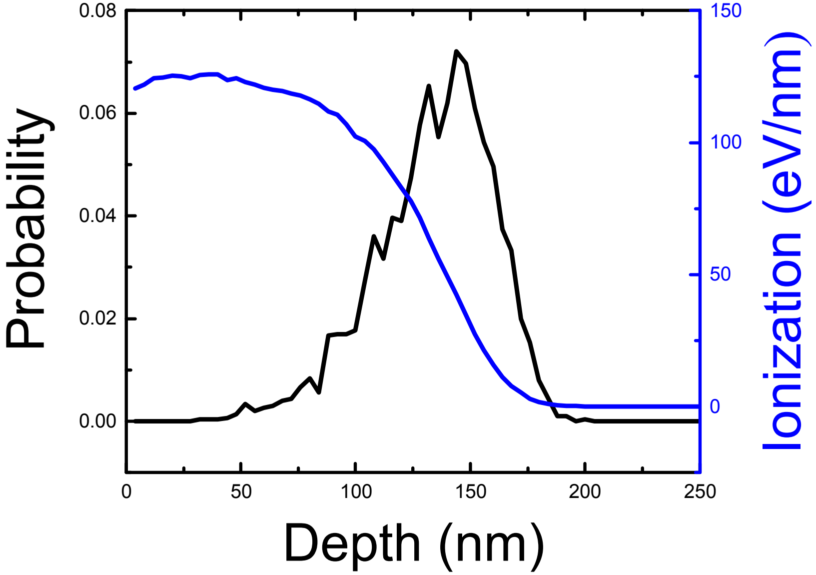


Monte Carlo Simulation (SRIM)

Si implantation

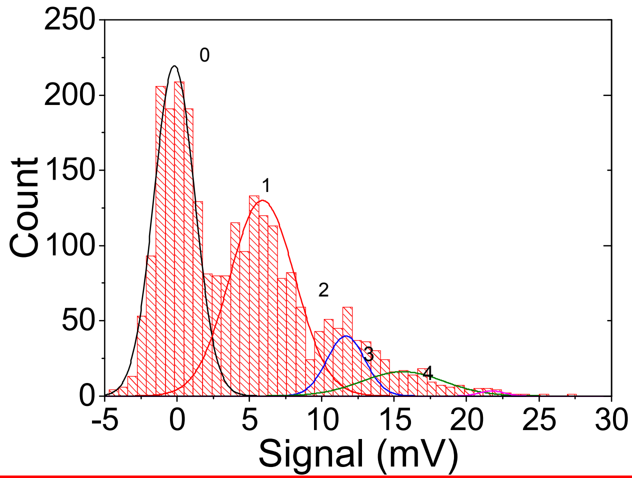


200 keV Si implantation

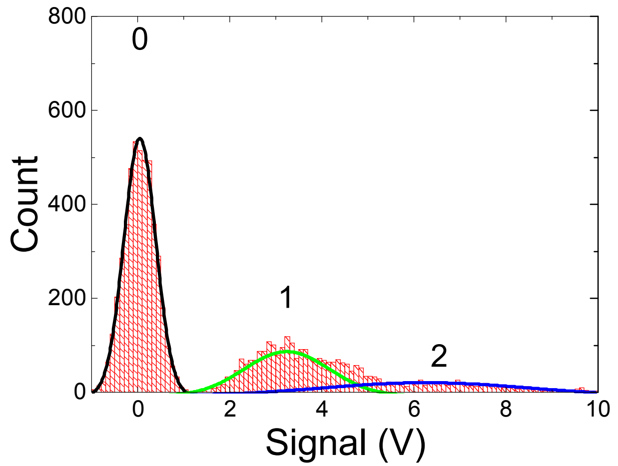


- 200 keV Si into diamond
  - 132+/-22 nm depth
  - 10^4 e/h pairs deposited in 75 nm depth

Poisson Statistics of Detection



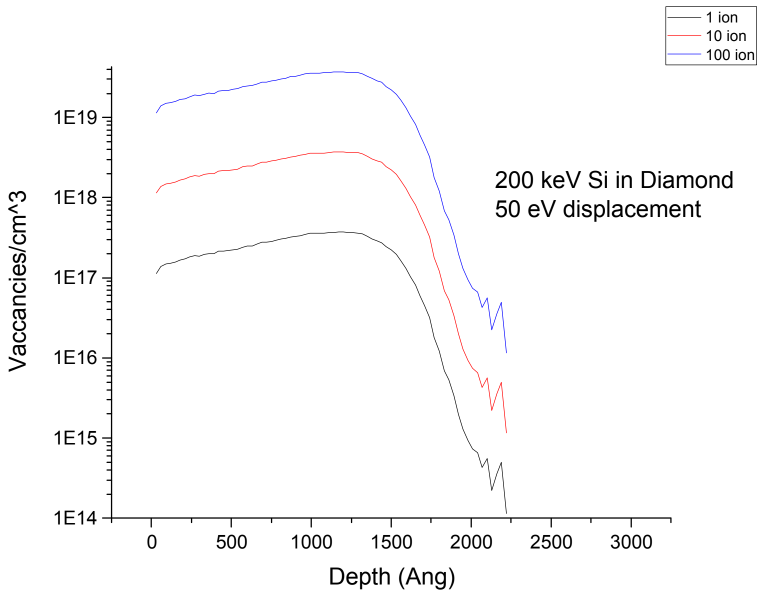
	Experiment	<0.65>
A_0	0.537	.522
A_1	0.319	.339
A_2	.099	.11
A_3	.039	.02
A_4	.007	.009



	Experiment	<0.2>
A_0	.816	.819
A_1	.141	.164
A_2	.052	.016

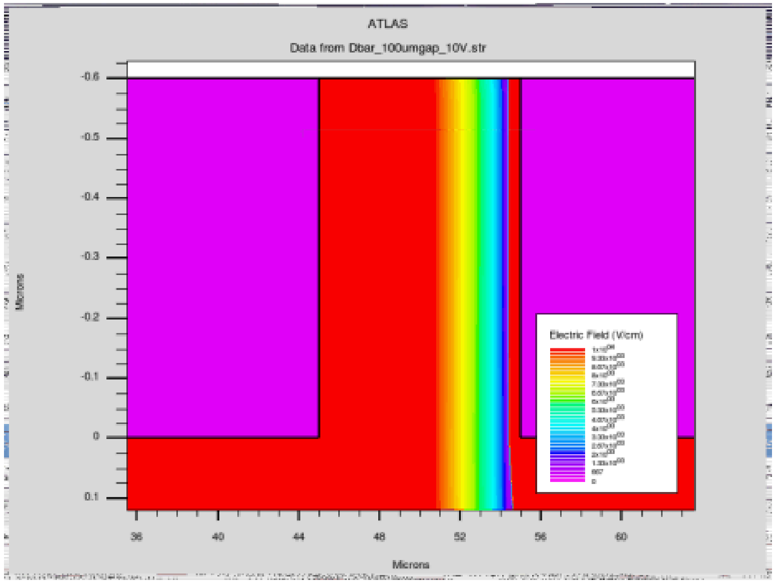
Remaining Detector Questions

- Linearity of response
  - CCE seems to drop off above 10 ions/pulse…



Need to generate a plot of CCE versus Dose for existing data.

How to improve



Paulos stuff with corrugated thing