MANCHESTER 1824

The University of Manchester

3D Diamond Development for tracking and dosimetry measurements

Dr. Iain Haughton
The University of Manchester
iain.haughton@cern.ch

ADAMAS workshop - 2016

Authors

[1] The University of Manchester – Manchester, UK

Alex Oh, Iain Haughton, Steve Murphy, Giulio Forcolin, Francisca Munoz Sanchez

Introduction - objectives

1. Build an ultra radiation tolerant particle detector.

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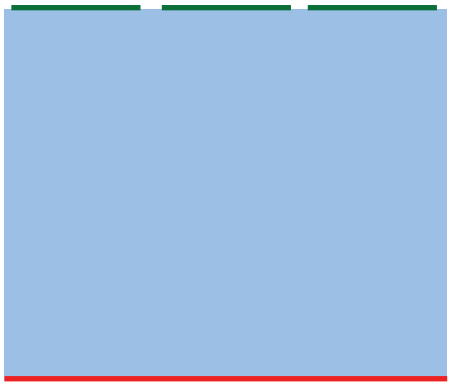

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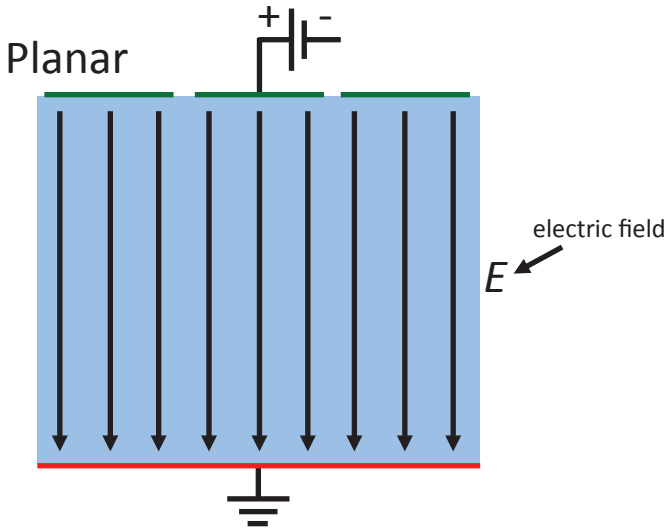

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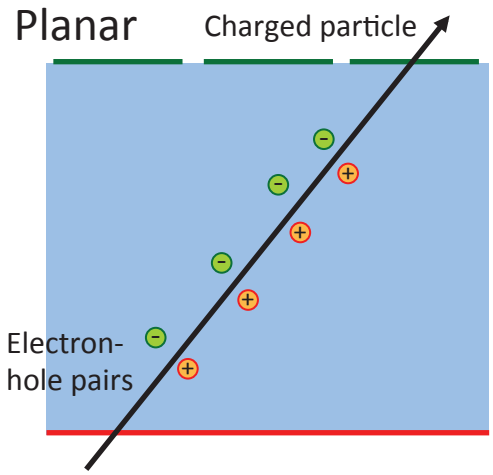

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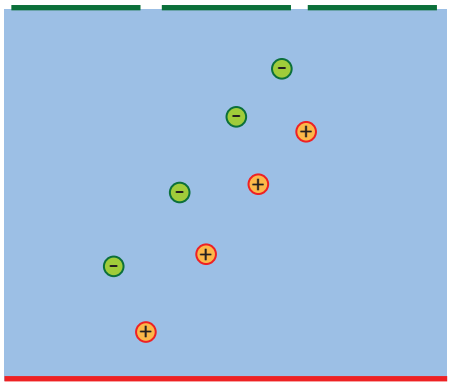

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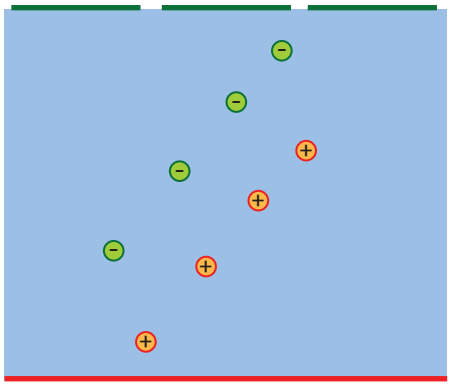

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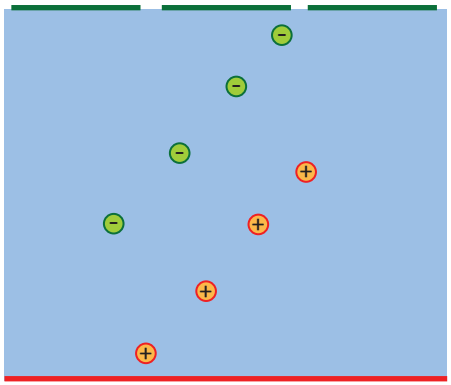

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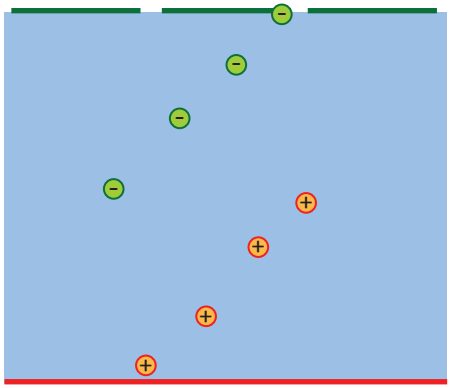

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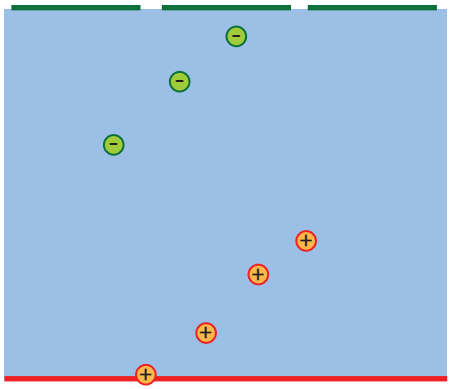

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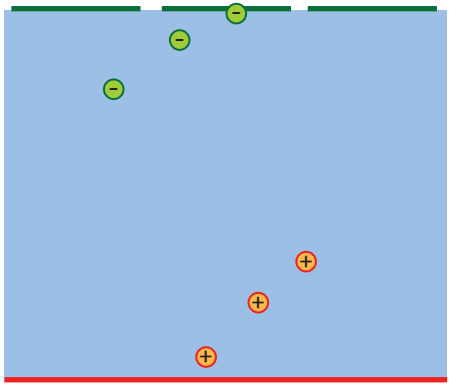

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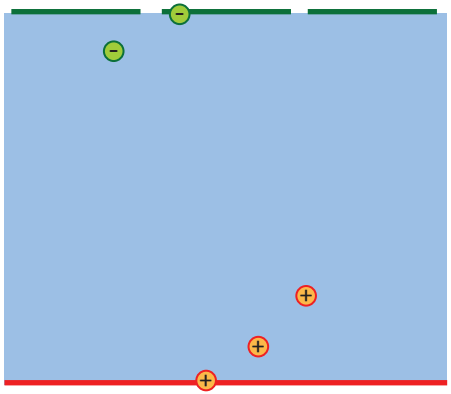

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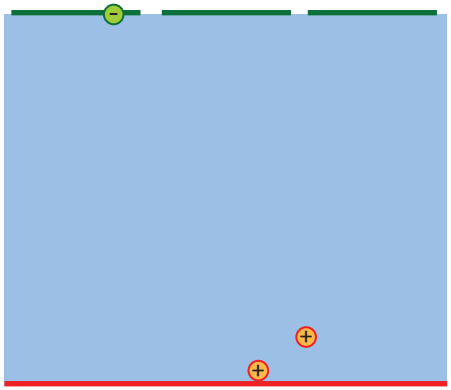

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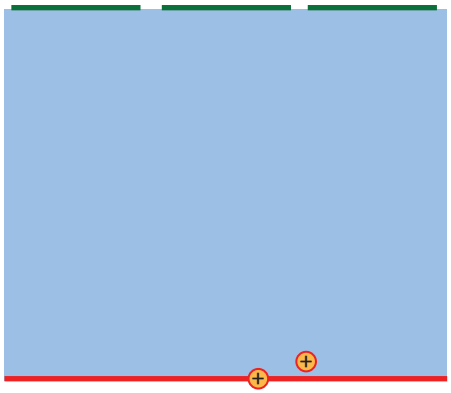

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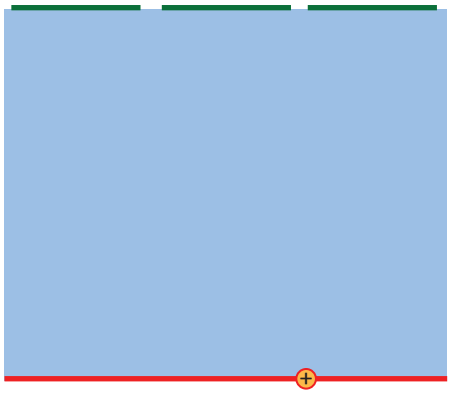

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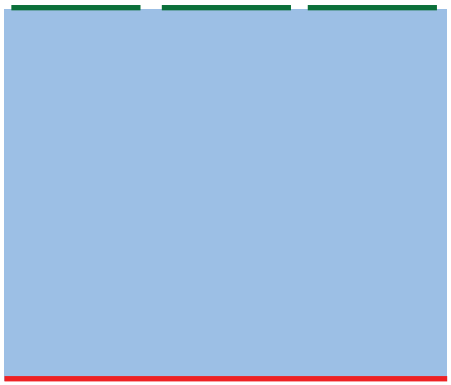

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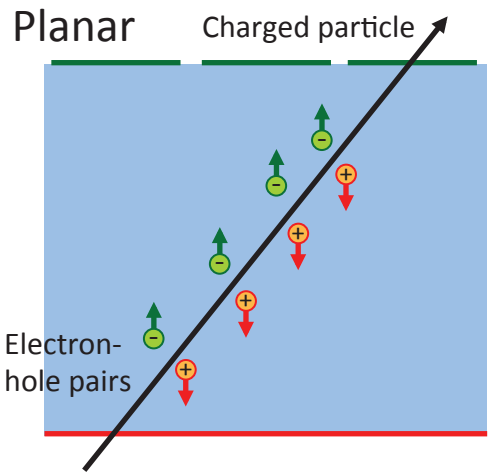

$$i = E_w q v$$

Instantaneous current — Carrier charge — Weighting field — Carrier velocity

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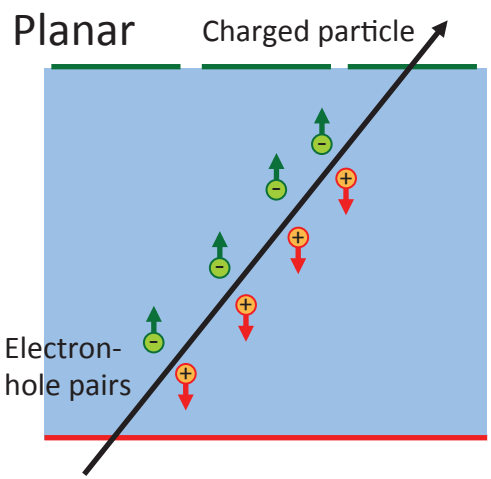

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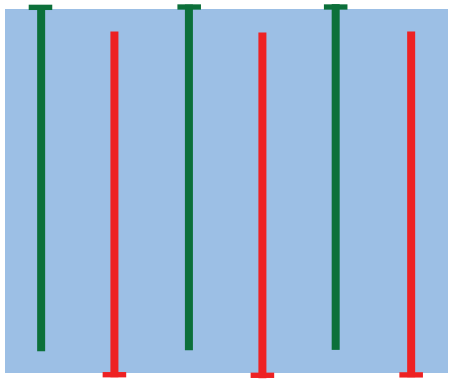

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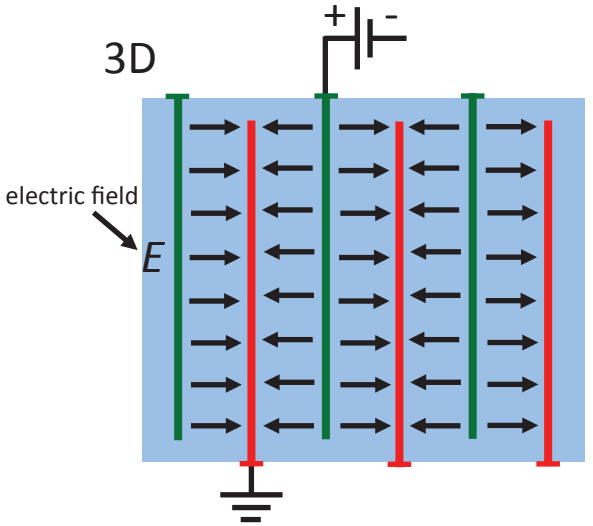

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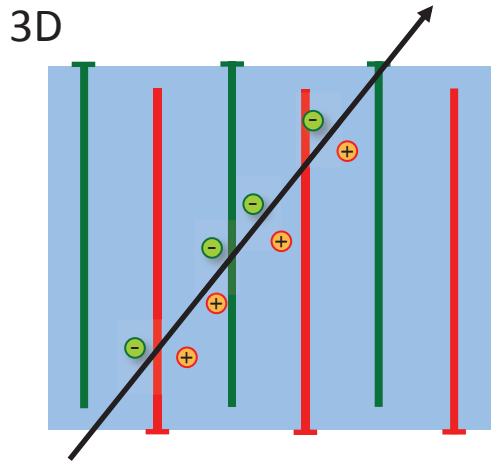

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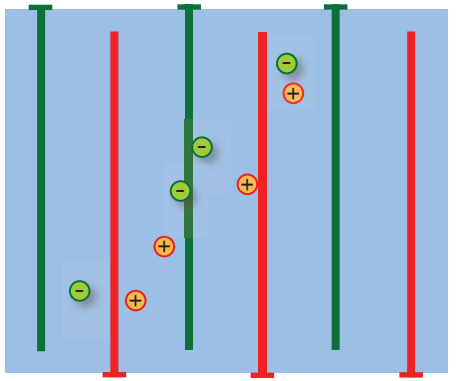

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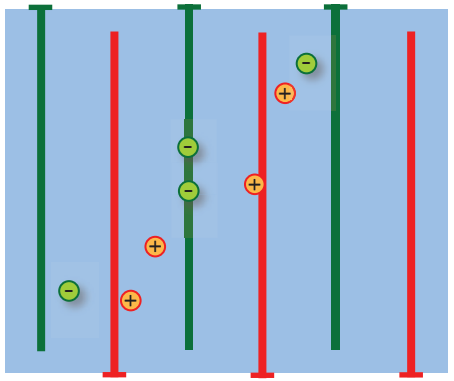

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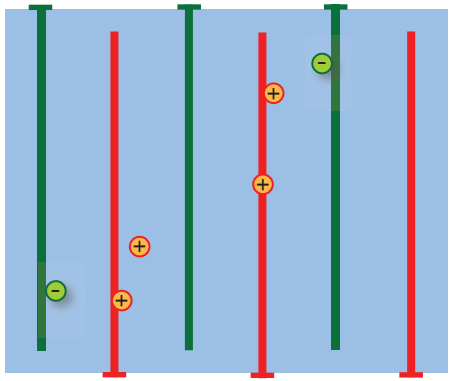

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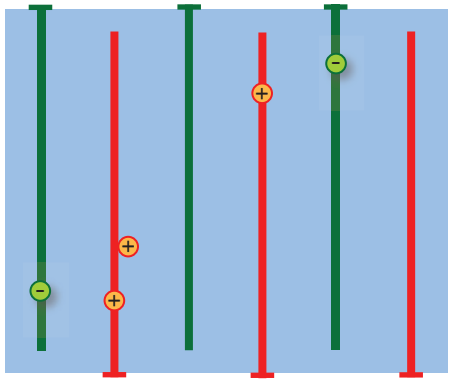

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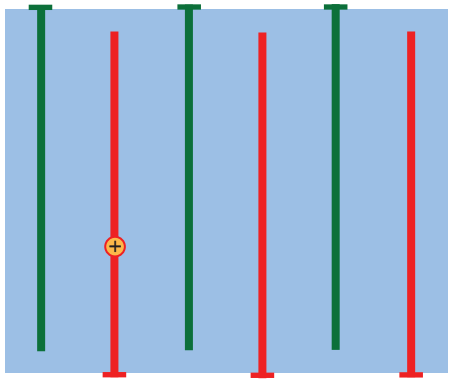

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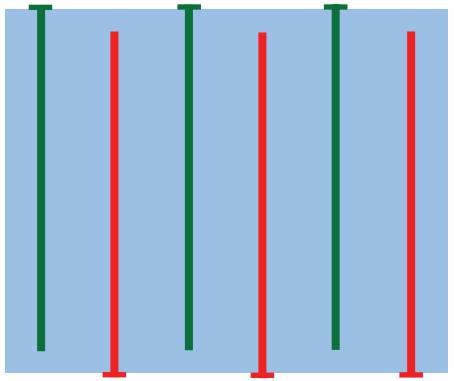

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Weighting field — Carrier velocity

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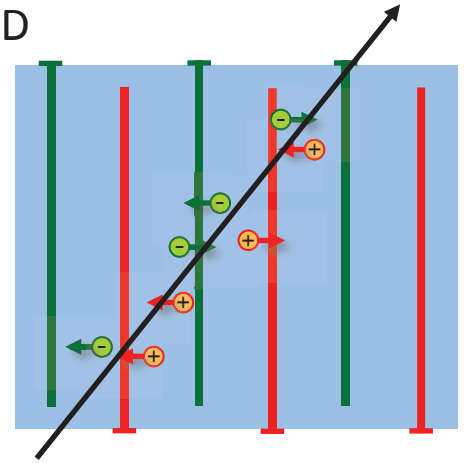

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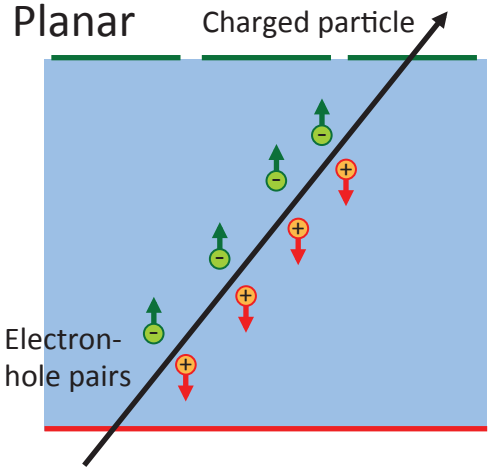

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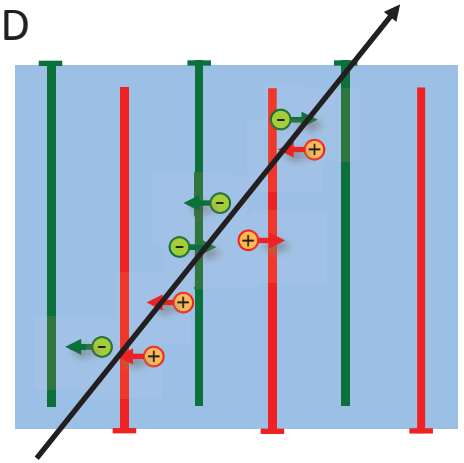

- Carriers have to travel a much shorter distance in 3D to get equivalent charge induced.

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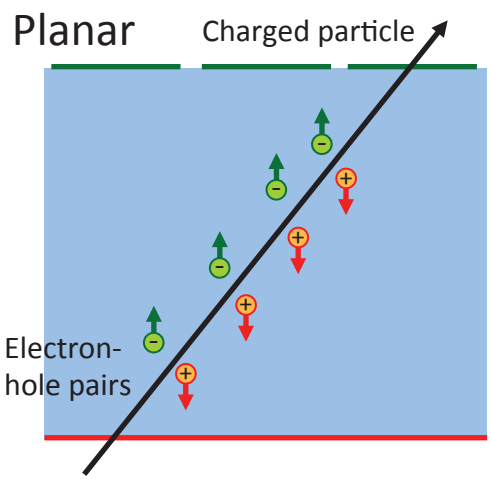

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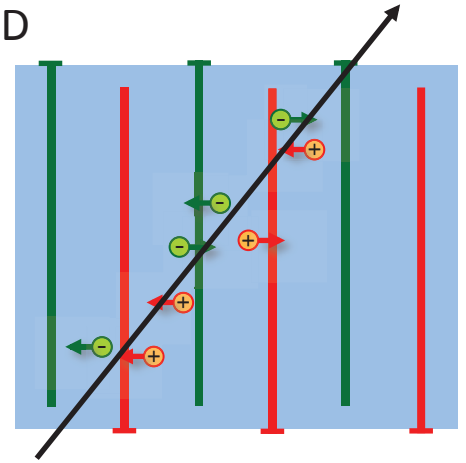

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Number of carriers

$$n(t) = n_0 e^{-t/\tau}$$

Carrier lifetime

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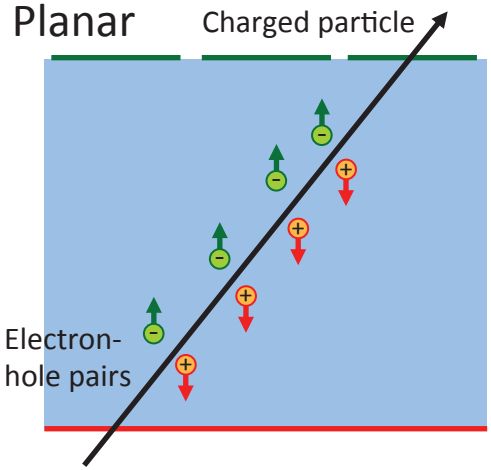

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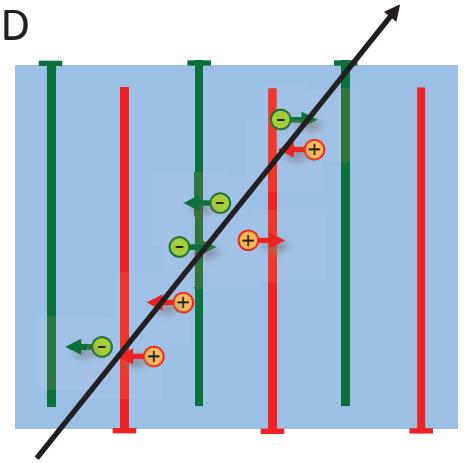

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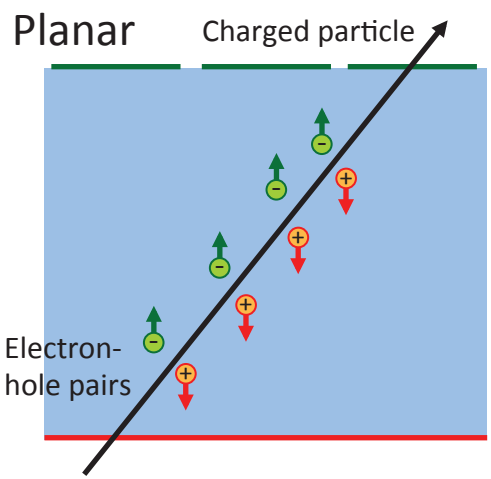

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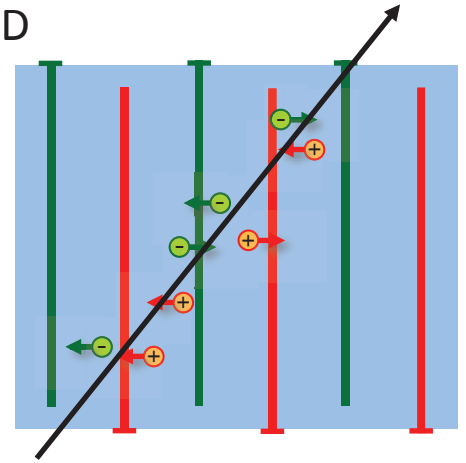


- Carriers have to travel a much shorter distance in 3D to get equivalent charge induced.

Number of carriers

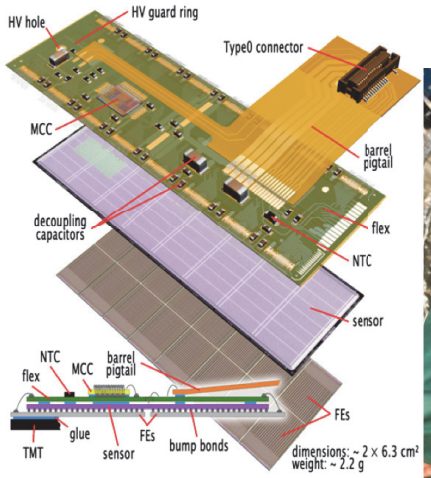
$$n(t) = n_0 e^{-t/\tau}$$

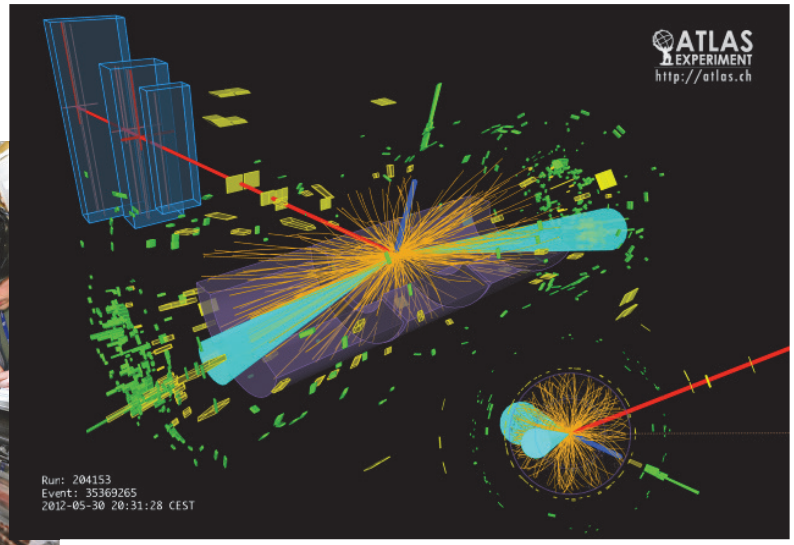
Carrier lifetime

- τ decreases with radiation exposure.
- τ is smaller in polycrystalline diamond than in single crystal diamond.

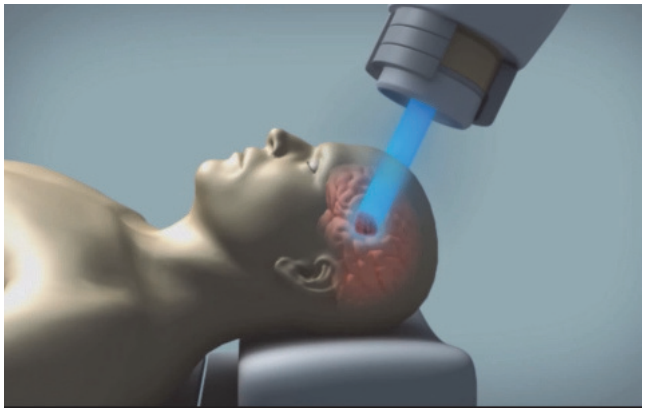
Introduction - applications

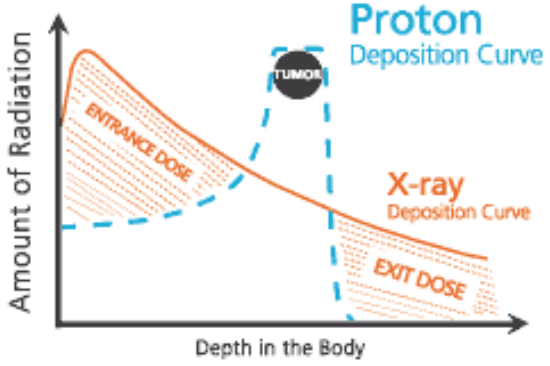
- High energy physics:





- Medical dosimetry (proton therapy):





MANCHESTER 1824

The University of Manchester

Fabrication

The University of Oxford – Oxford, UK

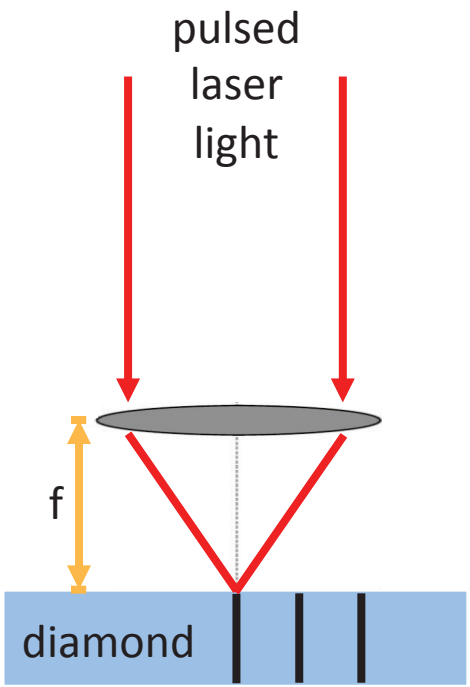
Martin Booth

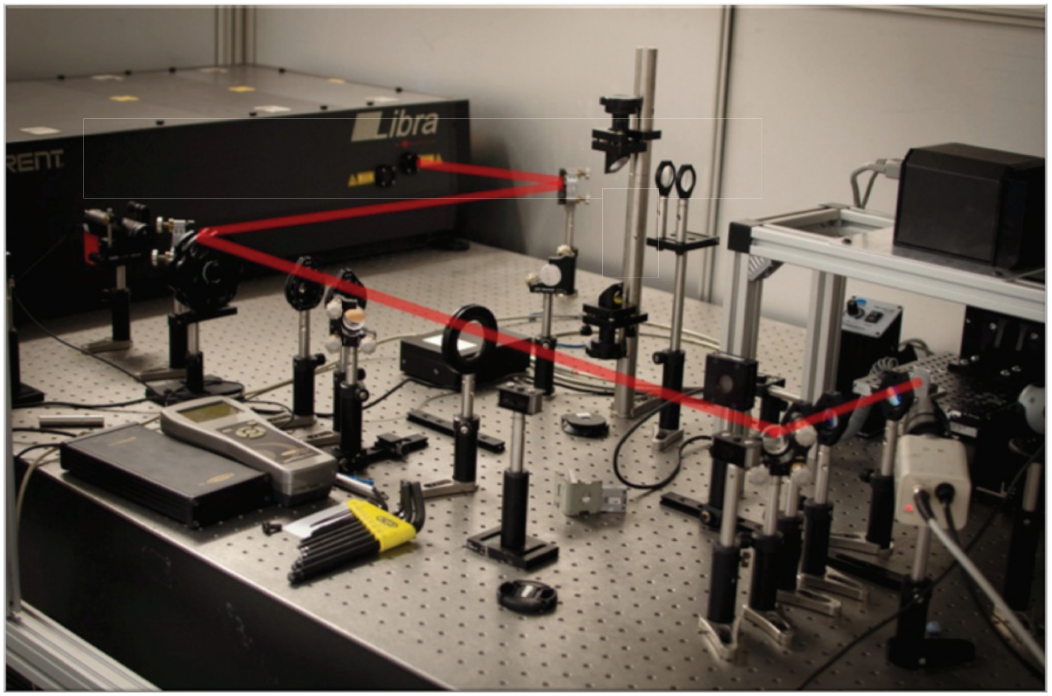
Patrick Salter

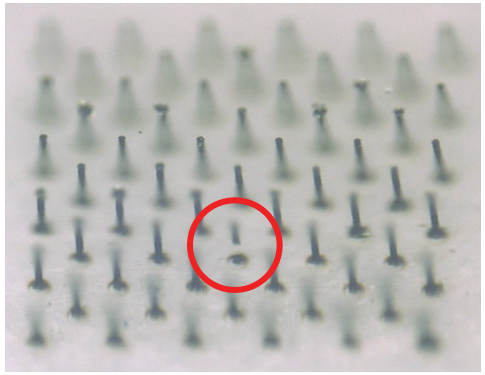
[4] M. Booth et al, "Three dimensional laser microfabrication in diamond a using dual adaptive optics system", Opt. Express (2011).

[5] M. Booth and A. Jesacher, "Parallel direct laser writing in three dimensions with spatially dependent aberration correction", Opt. Express (2010)

Laser processing

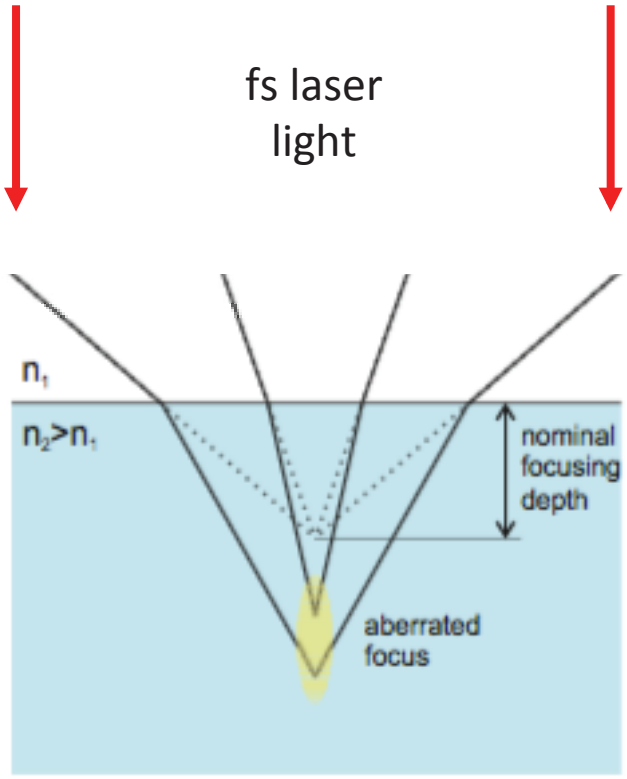






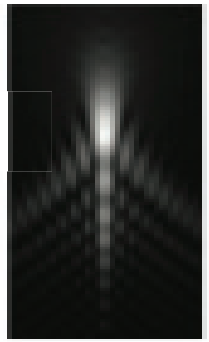
- Laser wavelength = 800nm.
- Laser pulse length = 120fs.
- Transform sp^3 diamond (non conductive material) into a combination of diamond-like carbon, amorphous carbon and graphite (conductive material).

Light aberration



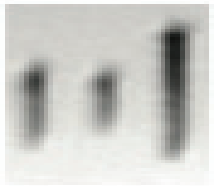
Drilling efficiency (best achieved)	~ 90 %
Resistivity	~ 1Ω cm
Diameter	~ 6 µm

Simulated
depth = 40 µm

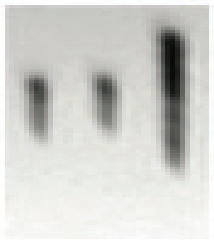


Measured
depth = 40 µm

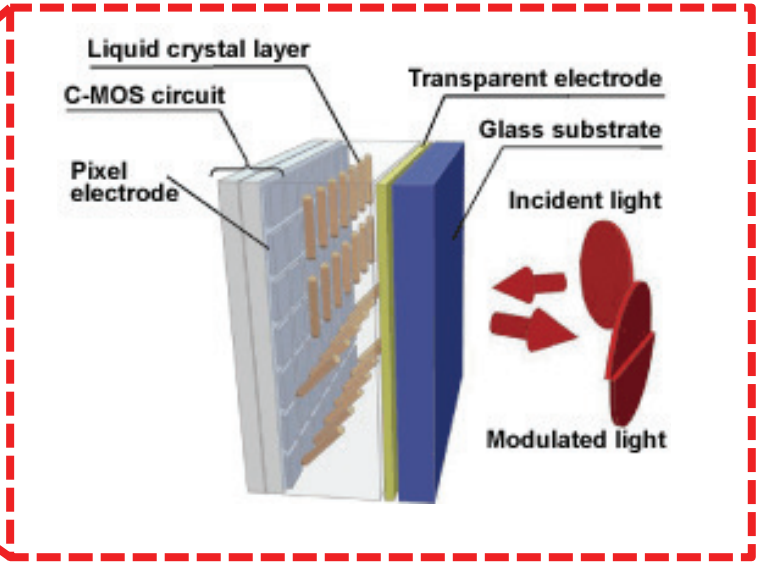
depth = 80 µm

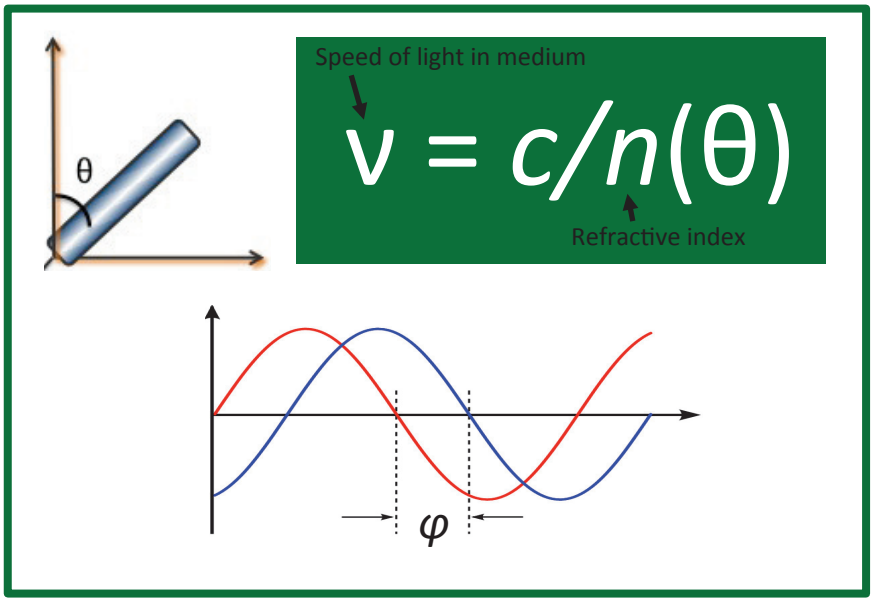


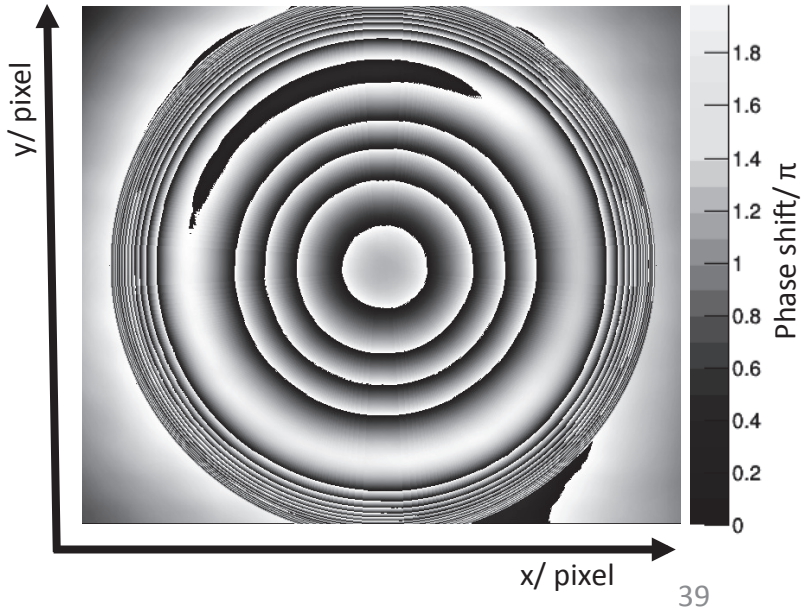
depth = 130 µm



Spatial Light Modulator (SLM) correction







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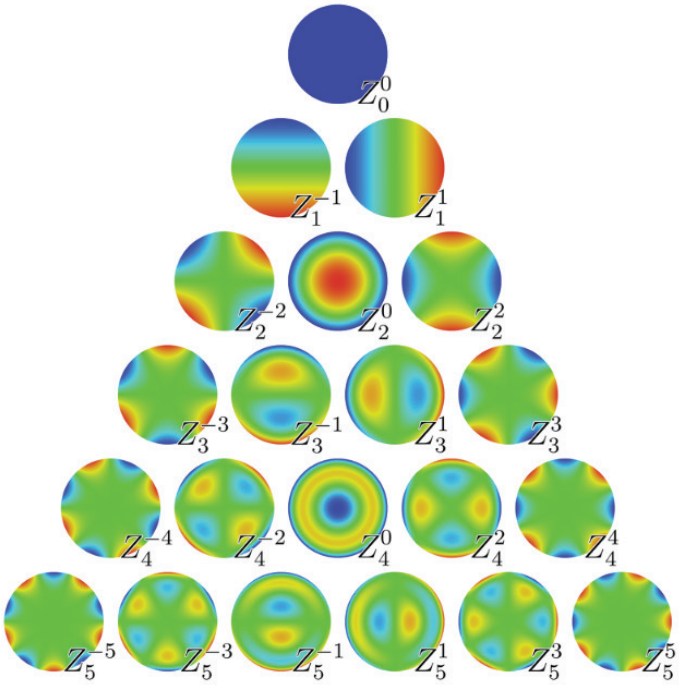
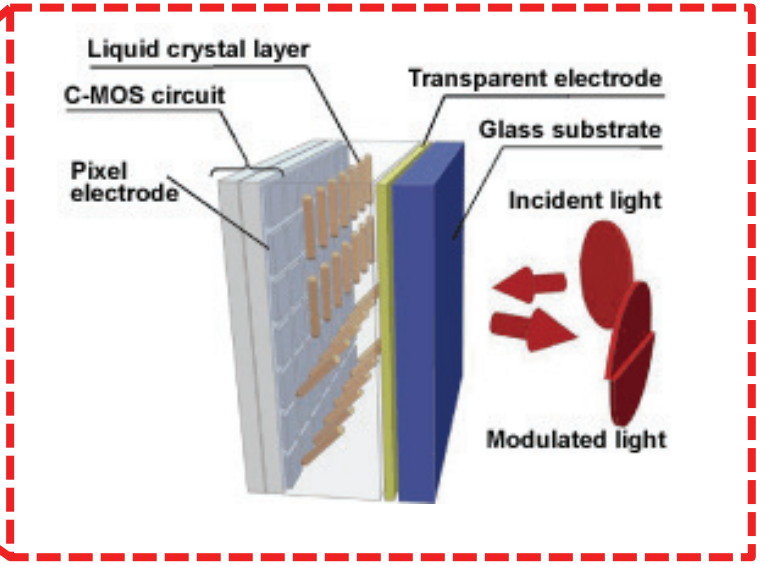
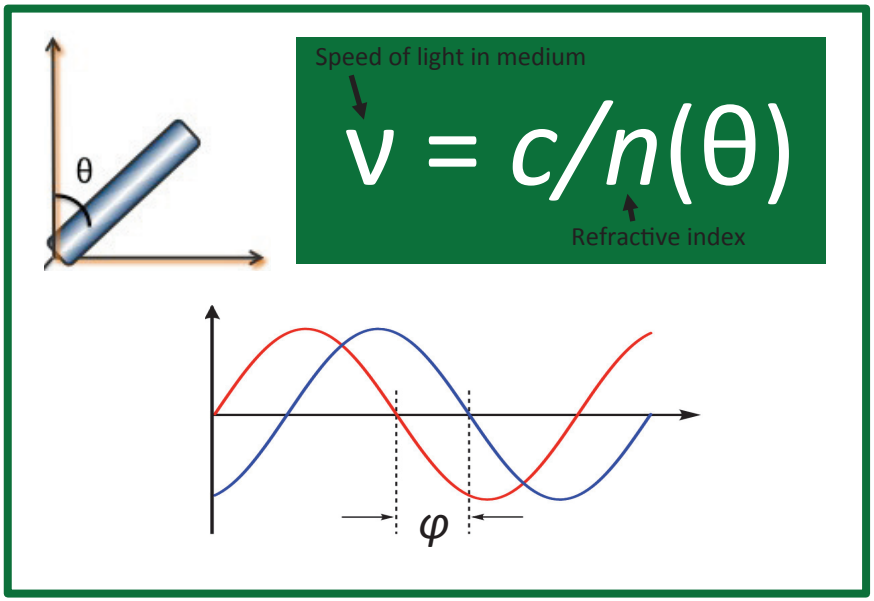
Zernike polynomials

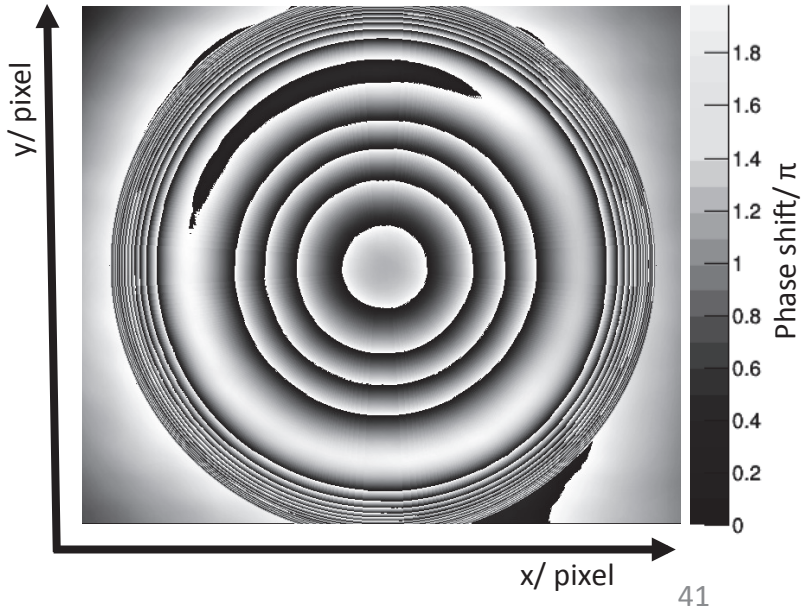
- Any sufficiently smooth real-valued phase field over a unit disk $g(x, y)$ can be represented in terms of its Zernike coefficients.



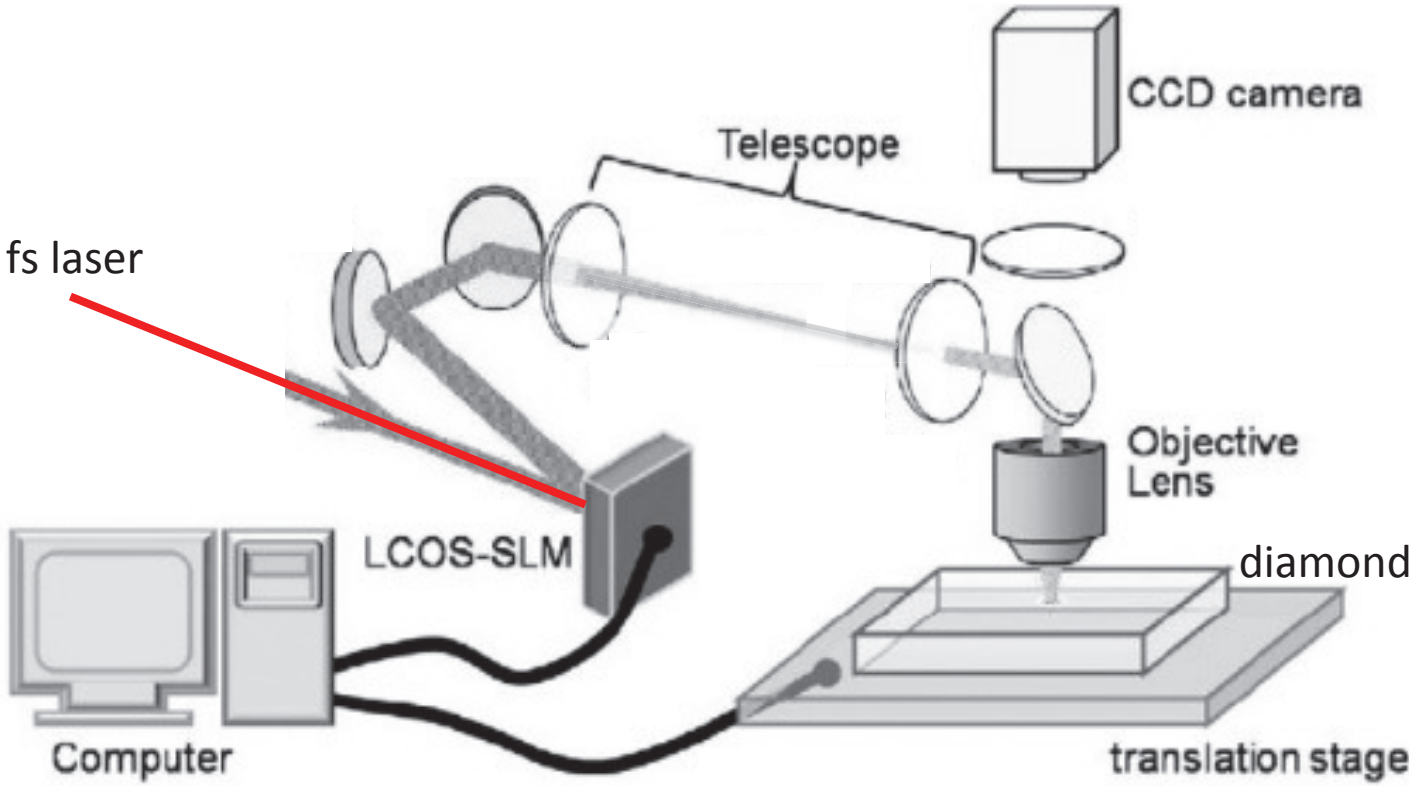
Spatial Light Modulator (SLM) correction







Laser setup


CCD camera
Telescope
fs laser
Objective
Lens
LCOS-SLM
diamond
Computer
translation stage

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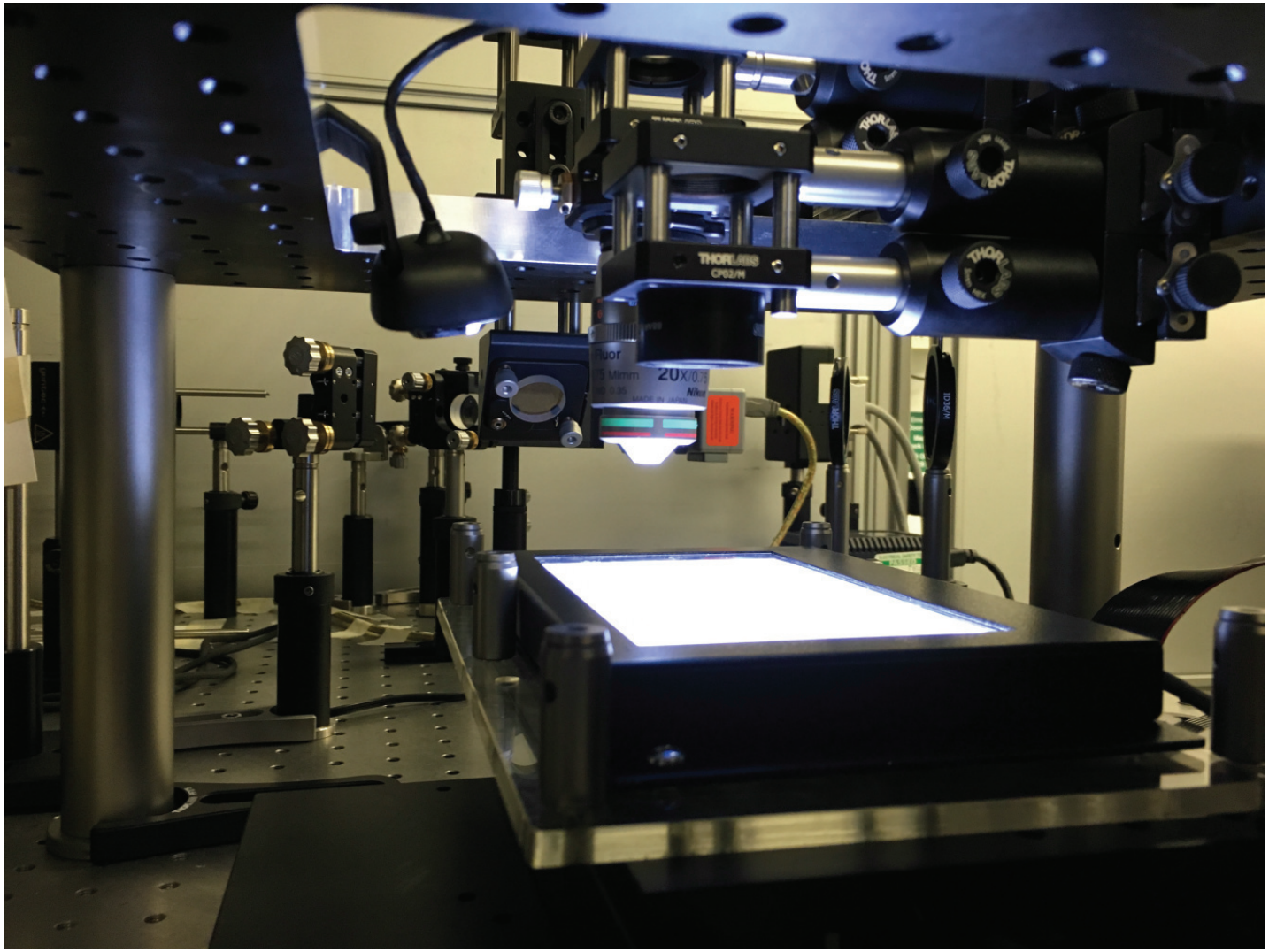
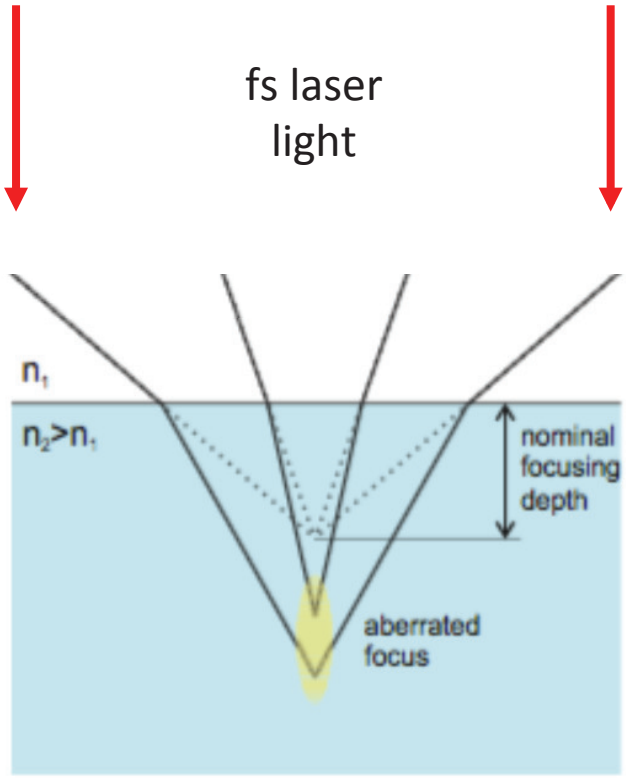
Laser setup – Manchester (PSI)



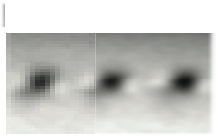
Light aberration – SLM corrected



Drilling efficiency (consistent)	~ 100 %
Resistivity	~ 0.1 Ωcm
Diameter	~ 1 µm

Simulated
depth = 40 µm

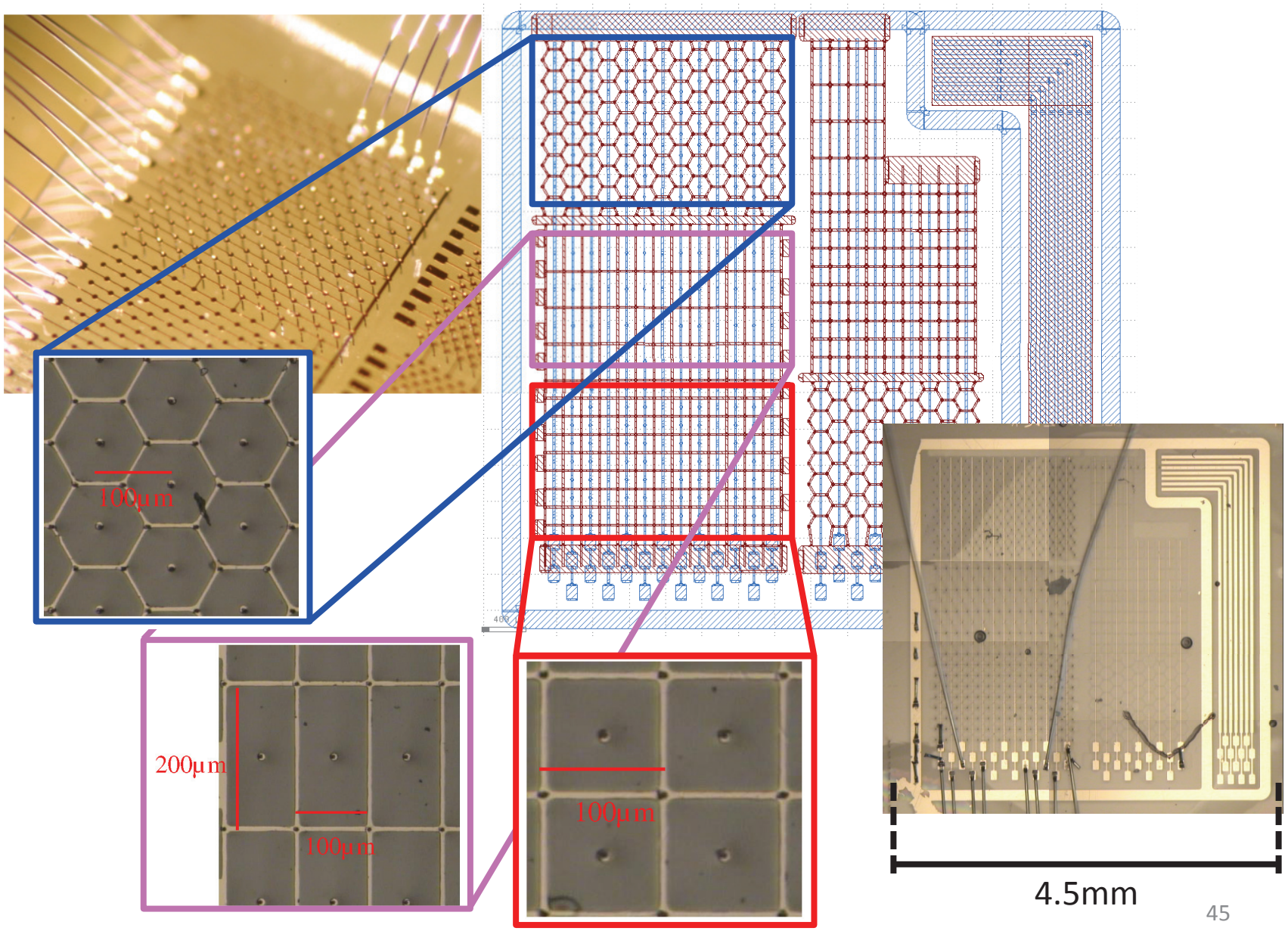
Measured
depth = 40 µm



depth = 80 µm

depth = 130 µm

Metallisation



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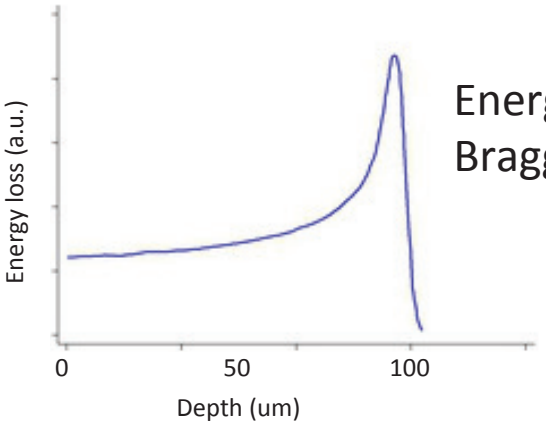
Proton beam test

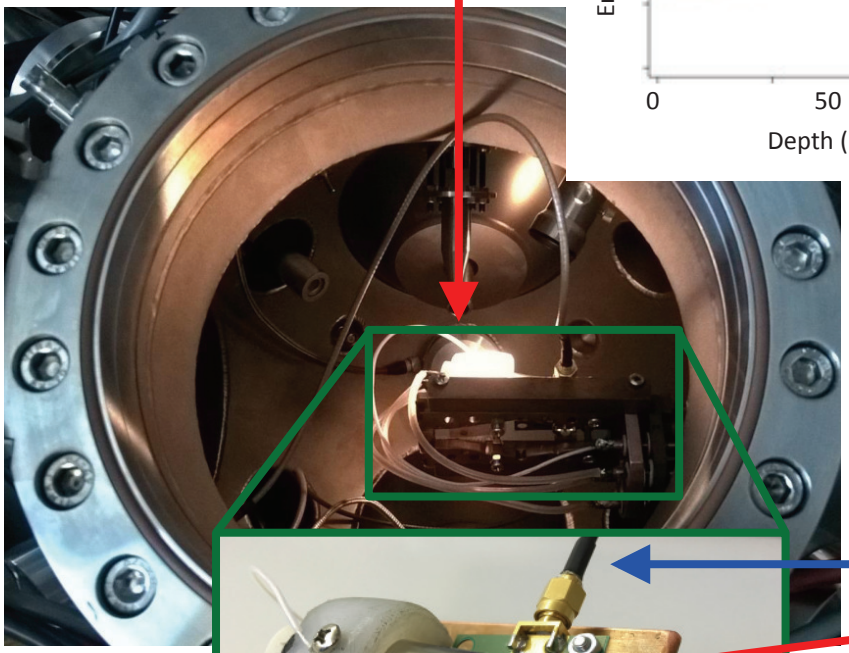
Ruder Boskovic Institute – Zagreb, Croatia
Milko Jaksic
Natko Skukan
Ivan Sudic

Proton beam test

4.5 MeV protons

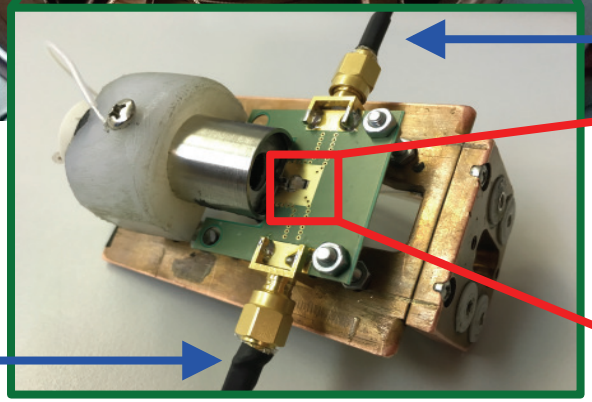


Energy deposition - Bragg peak

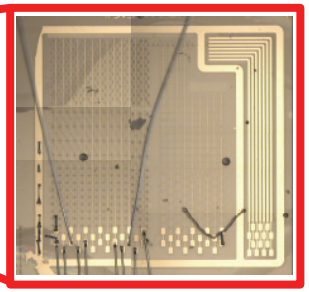


- Single particle beam.
- Rate ~ 1kHz.
- Beam position resolution < 2µm.

Read-out channel 1



Read-out channel 2



3D diamond detector

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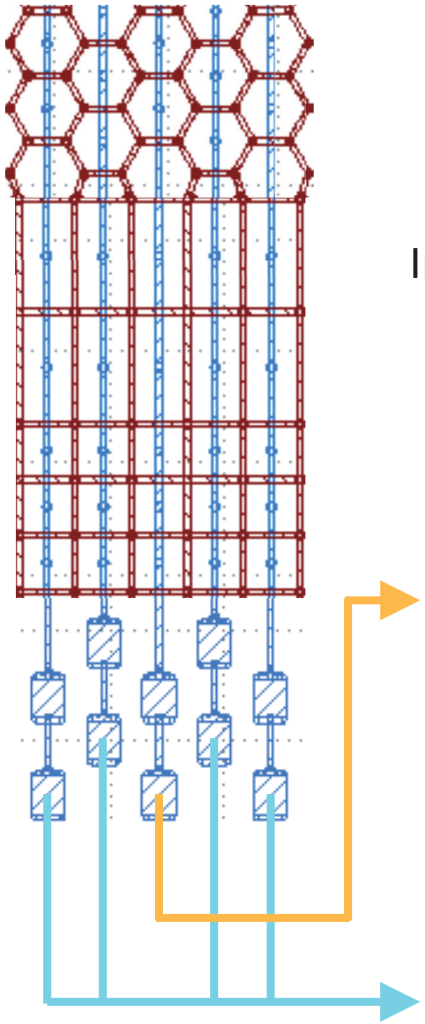
Ion Beam Induced Charge (IBIC)

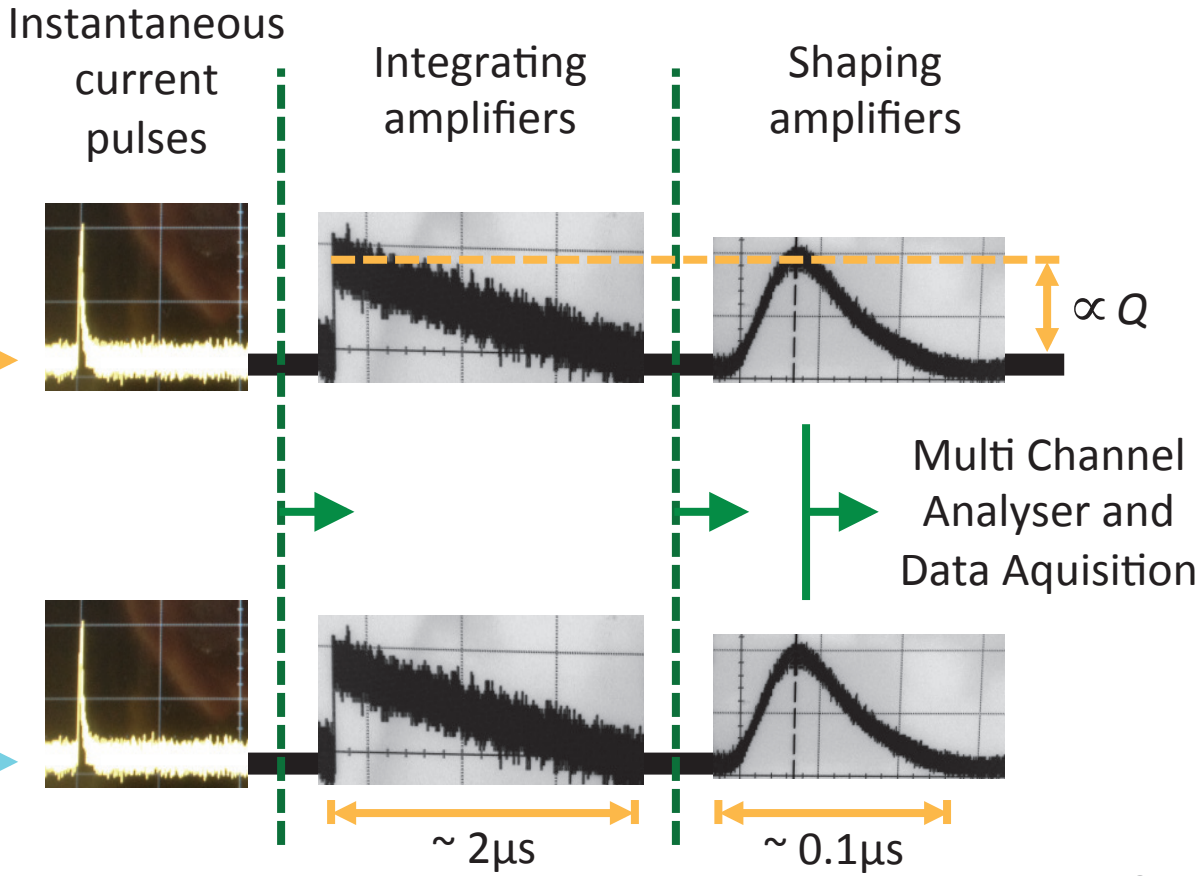
$$Q = \int i \, dt$$

Induced charge

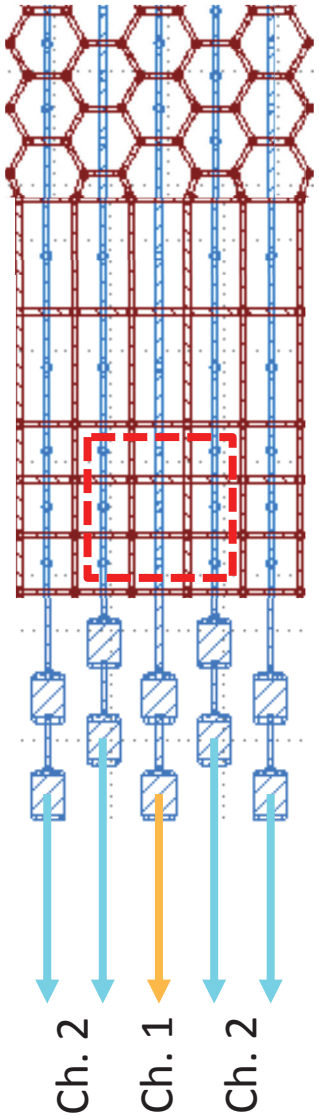
IBIC - setup



- Two read-out channels and amplification chains.

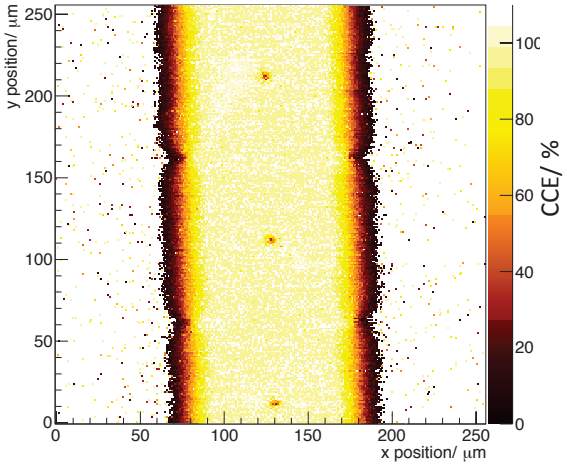


Charge collection efficiency at +20V

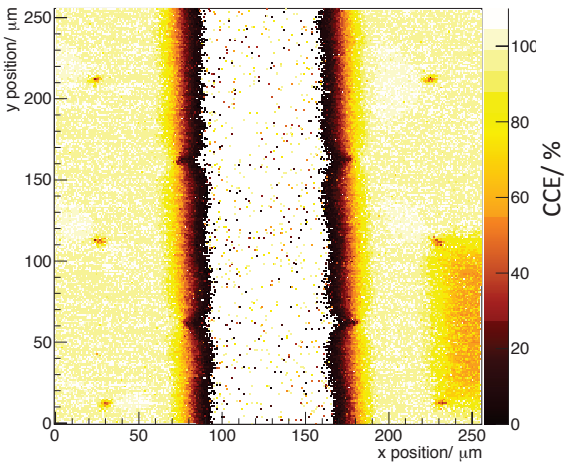


- Charge Collection Efficiency (CCE) calculated by comparison to a standard planar silicon detector assumed to collect full charge.

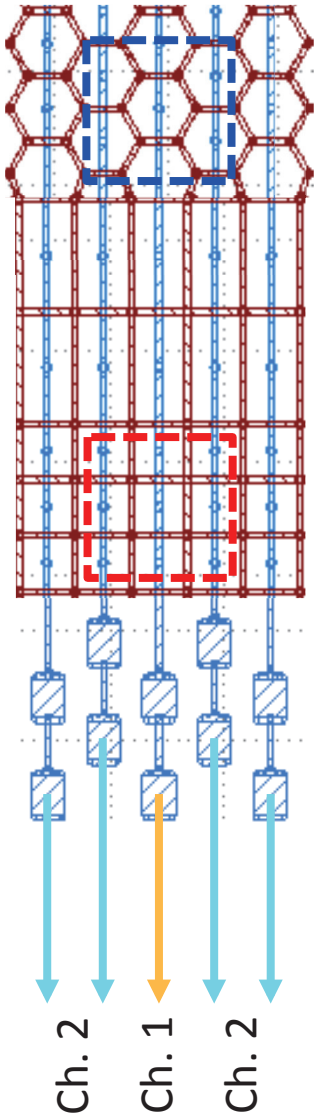
Channel 1



Channel 2



Charge sharing



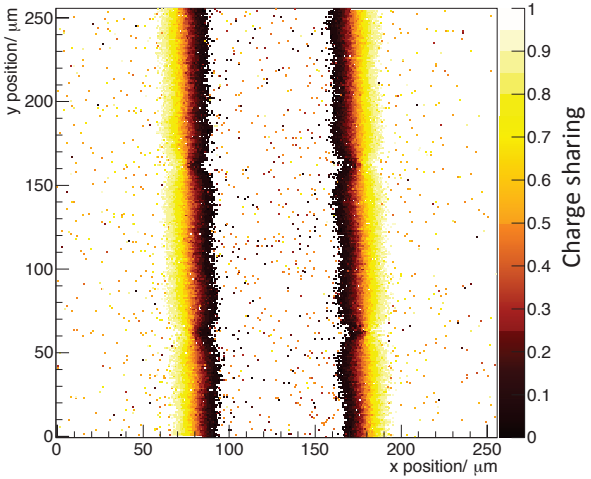
Charge Sharing (CS)

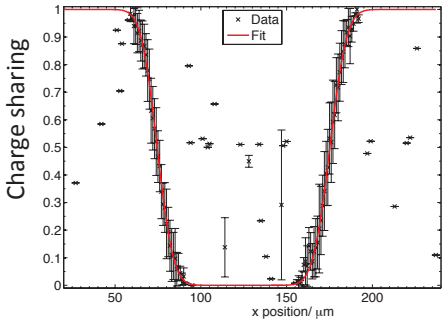
$$CS = Q_2/(Q_1+Q_2)$$

Induced charge on Ch. 2

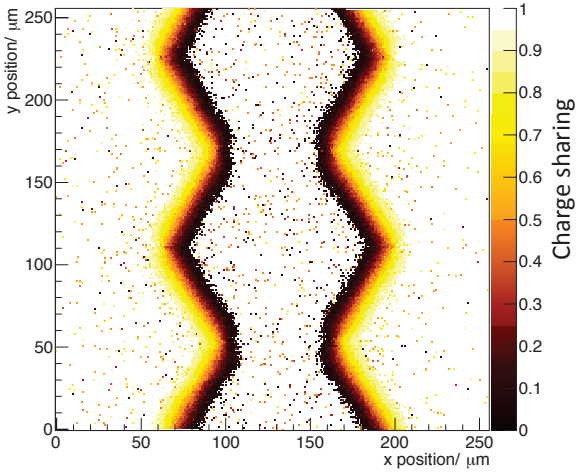
Induced charge on Ch. 1

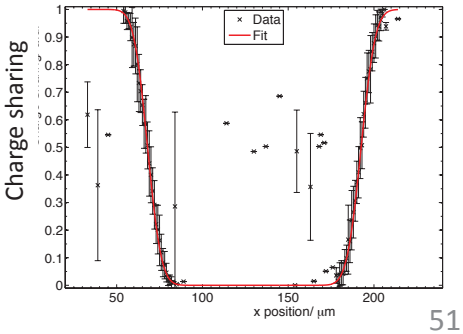
Square



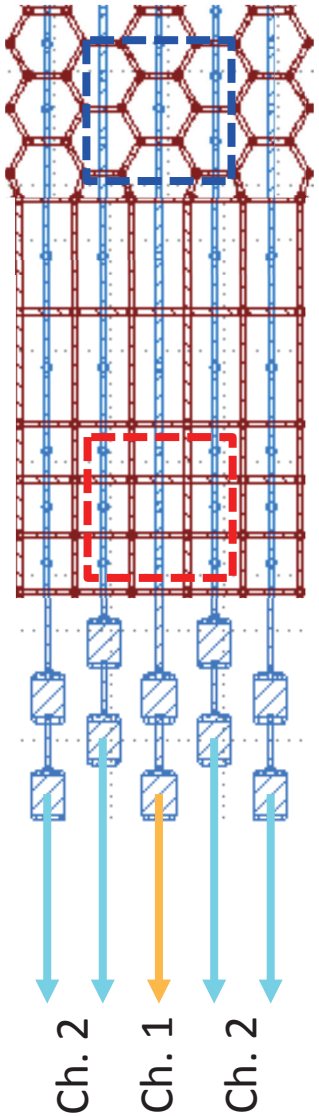


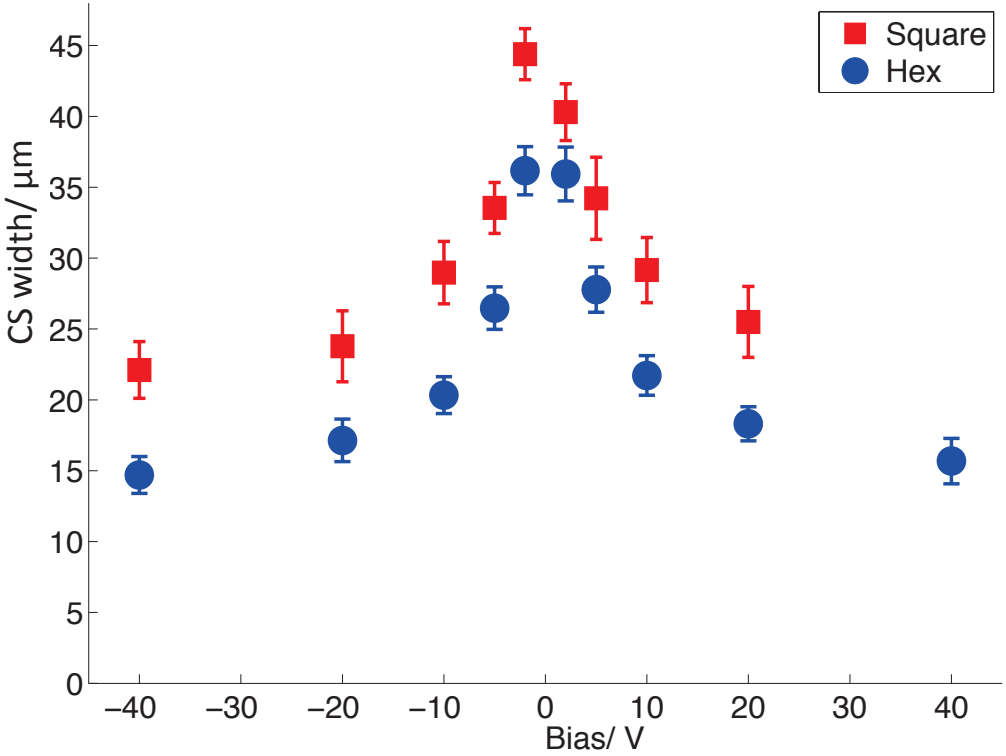
Hexagonal



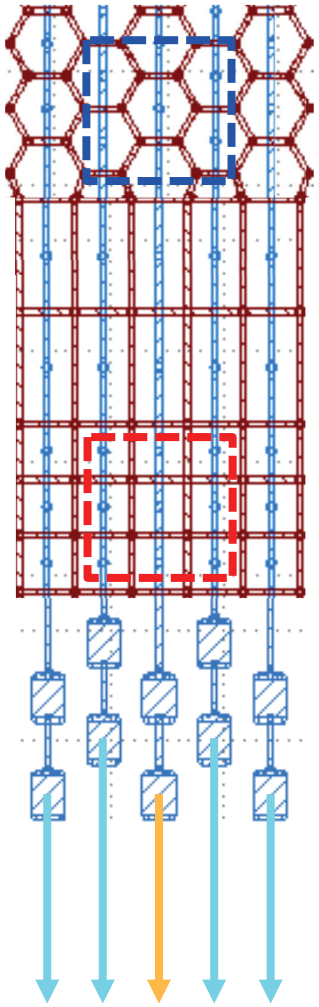


Charge sharing comparison



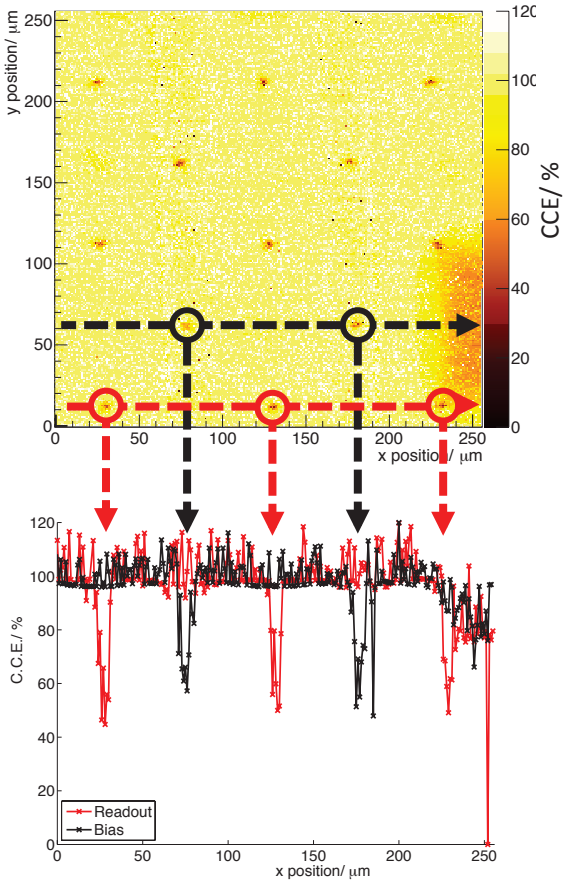


Combined Ch. 1 and Ch. 2 at +20V

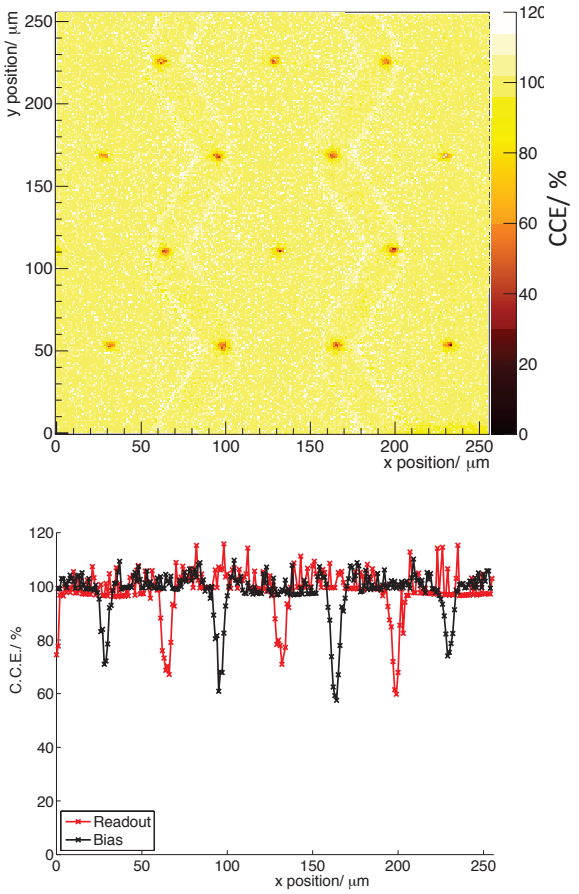


Combine

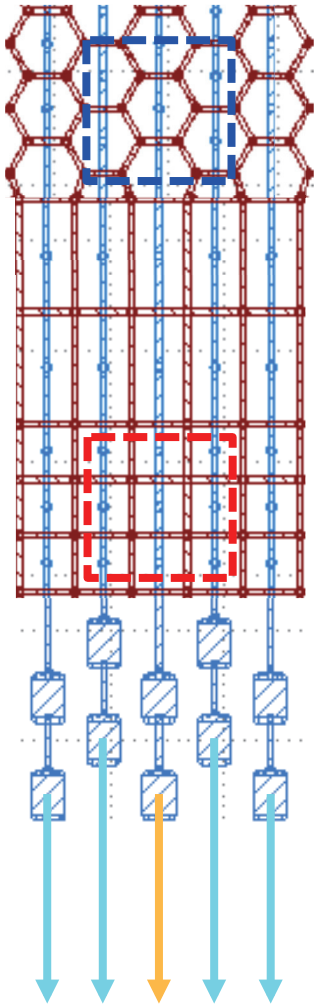
Square



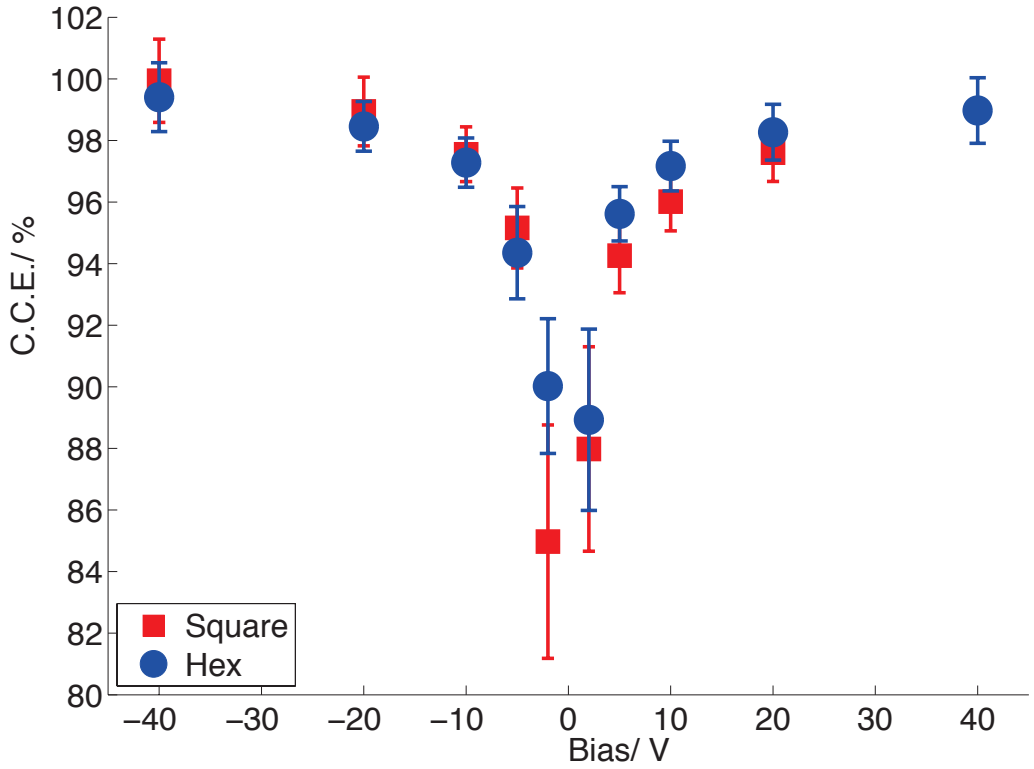
Hexagonal



Charge collection efficiency comparison



Combine



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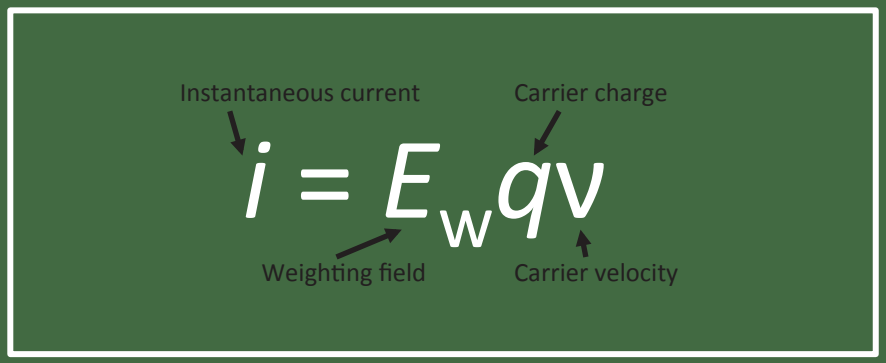
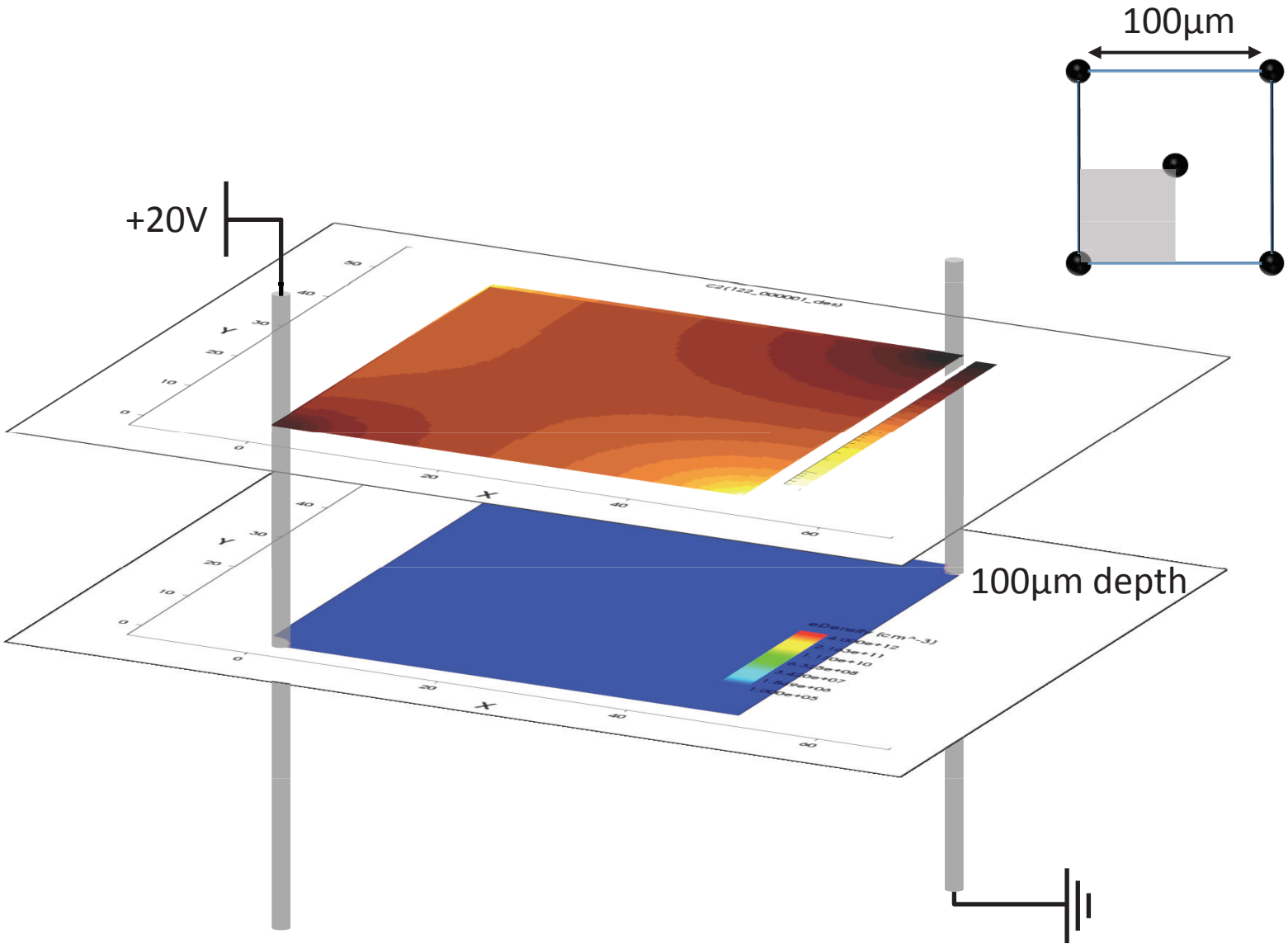
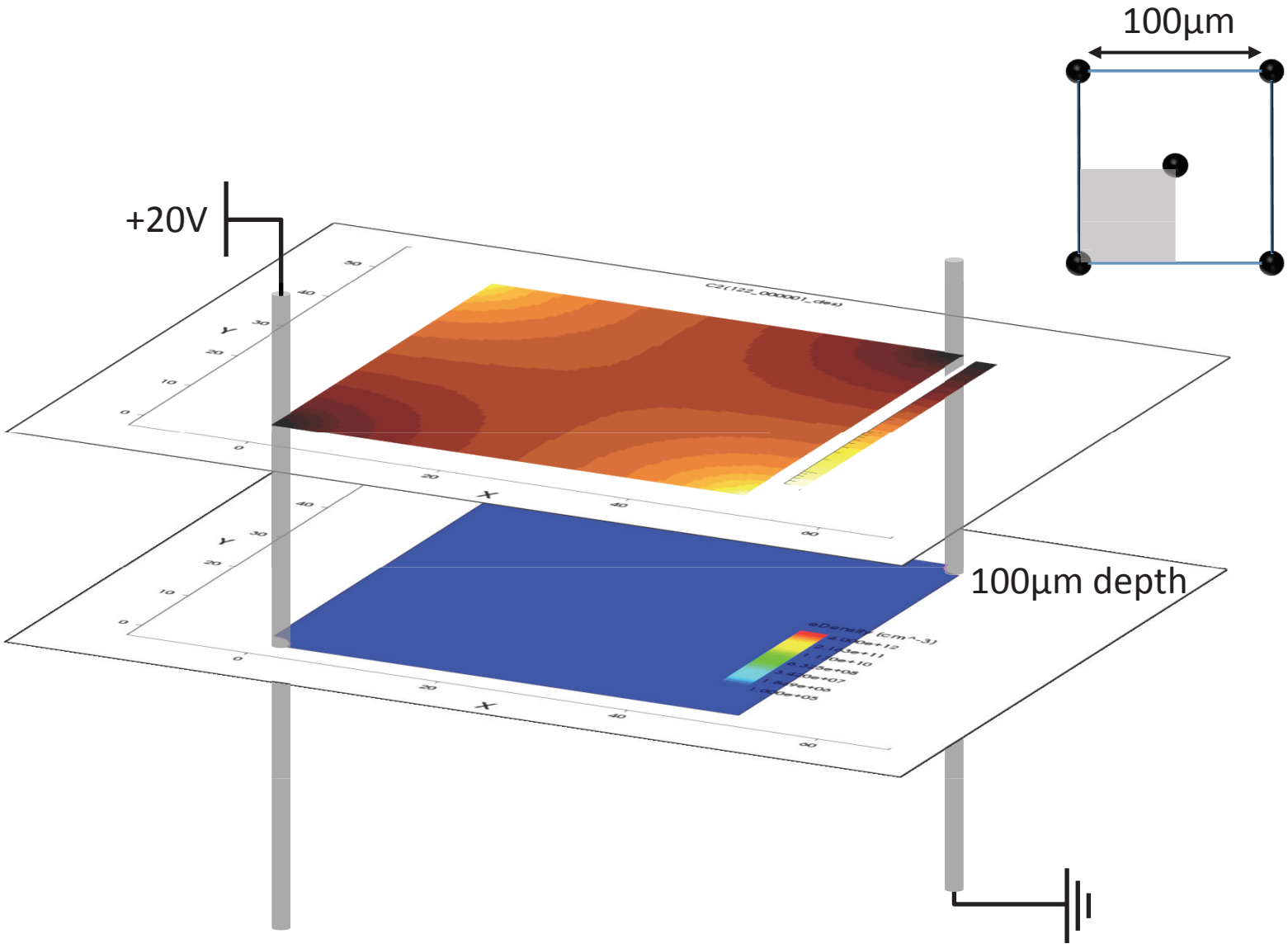
Time Resolved IBIC (TRIBIC)



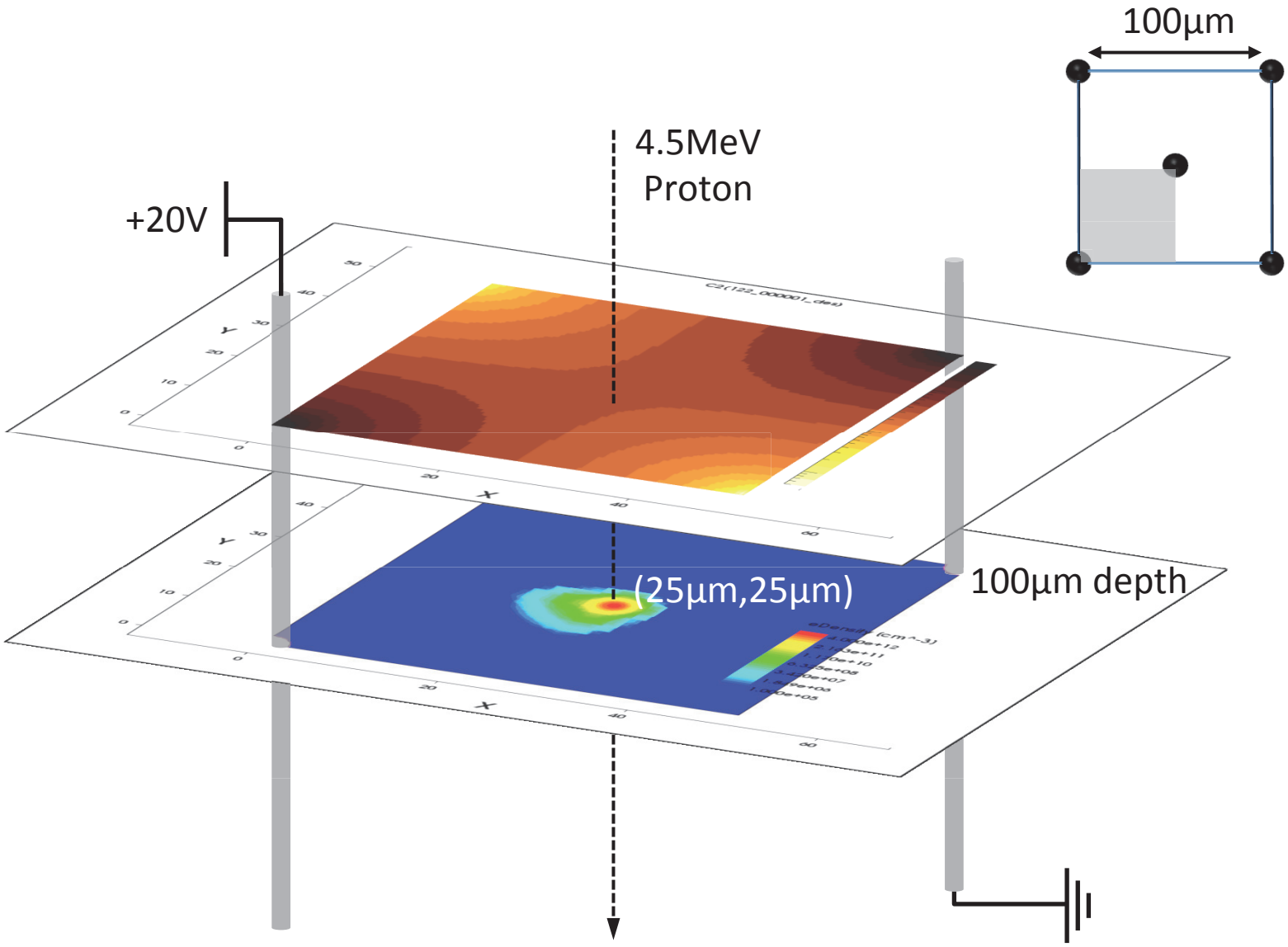
TCAD simulation



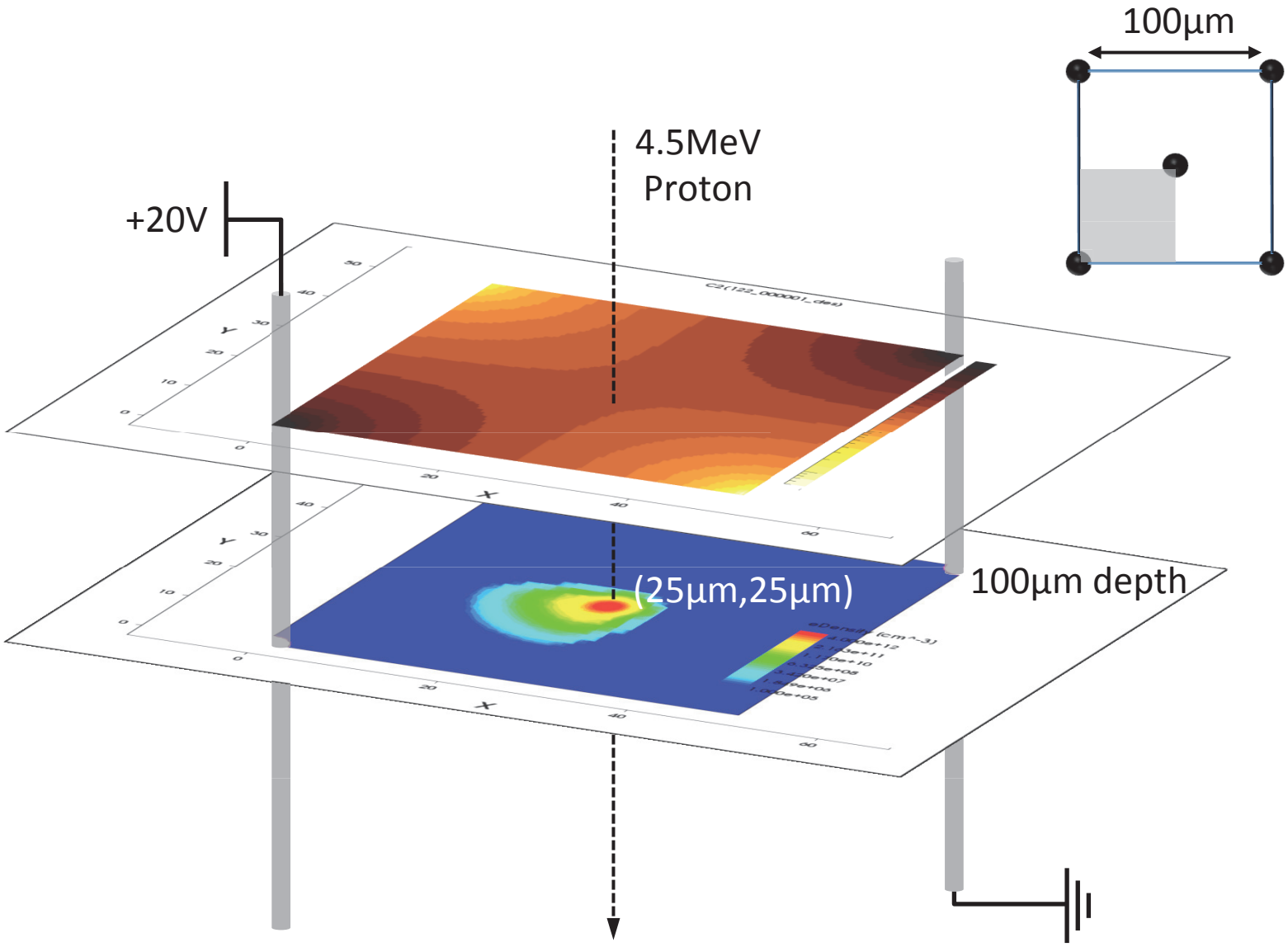
TCAD simulation



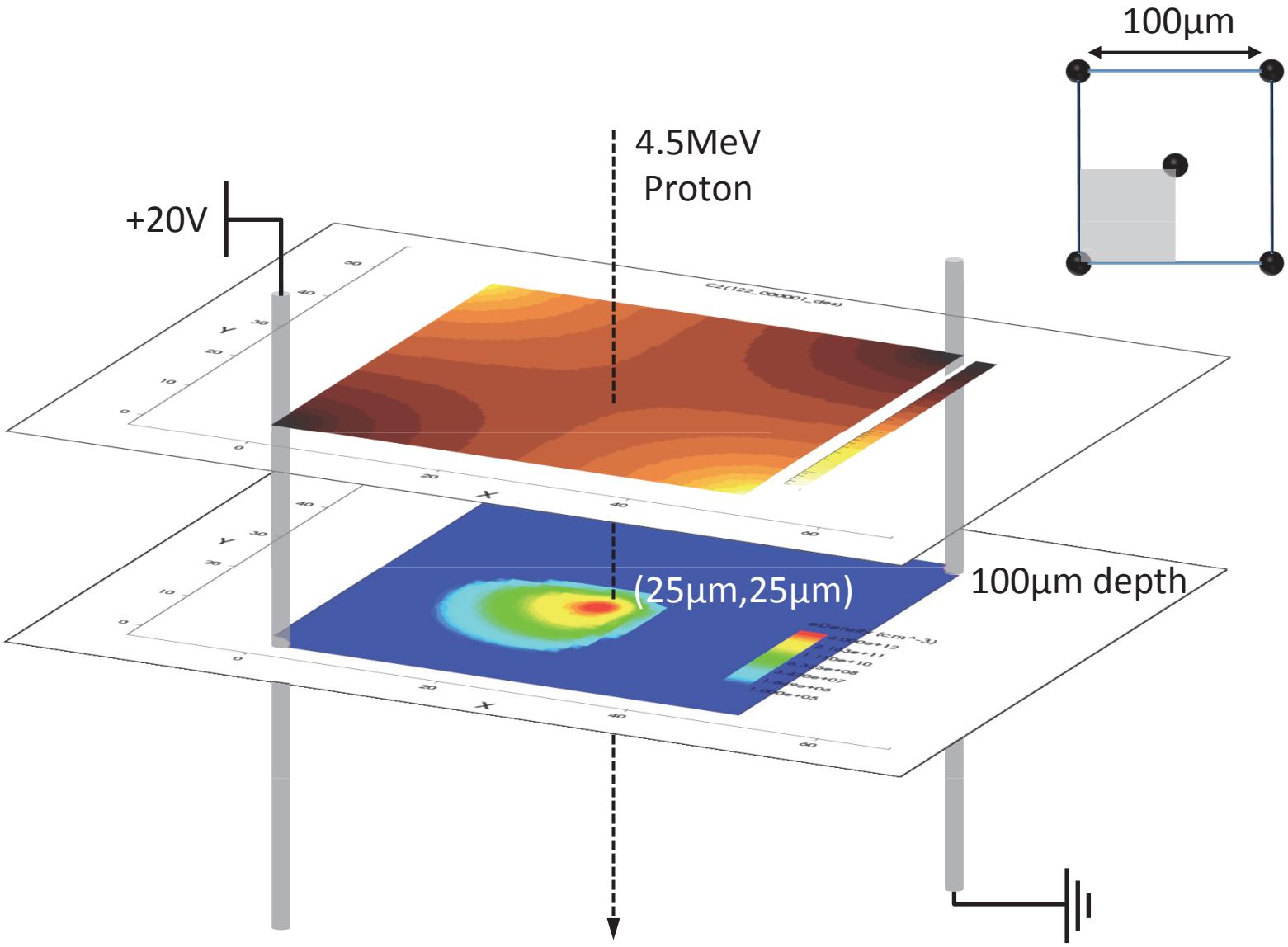
TCAD simulation



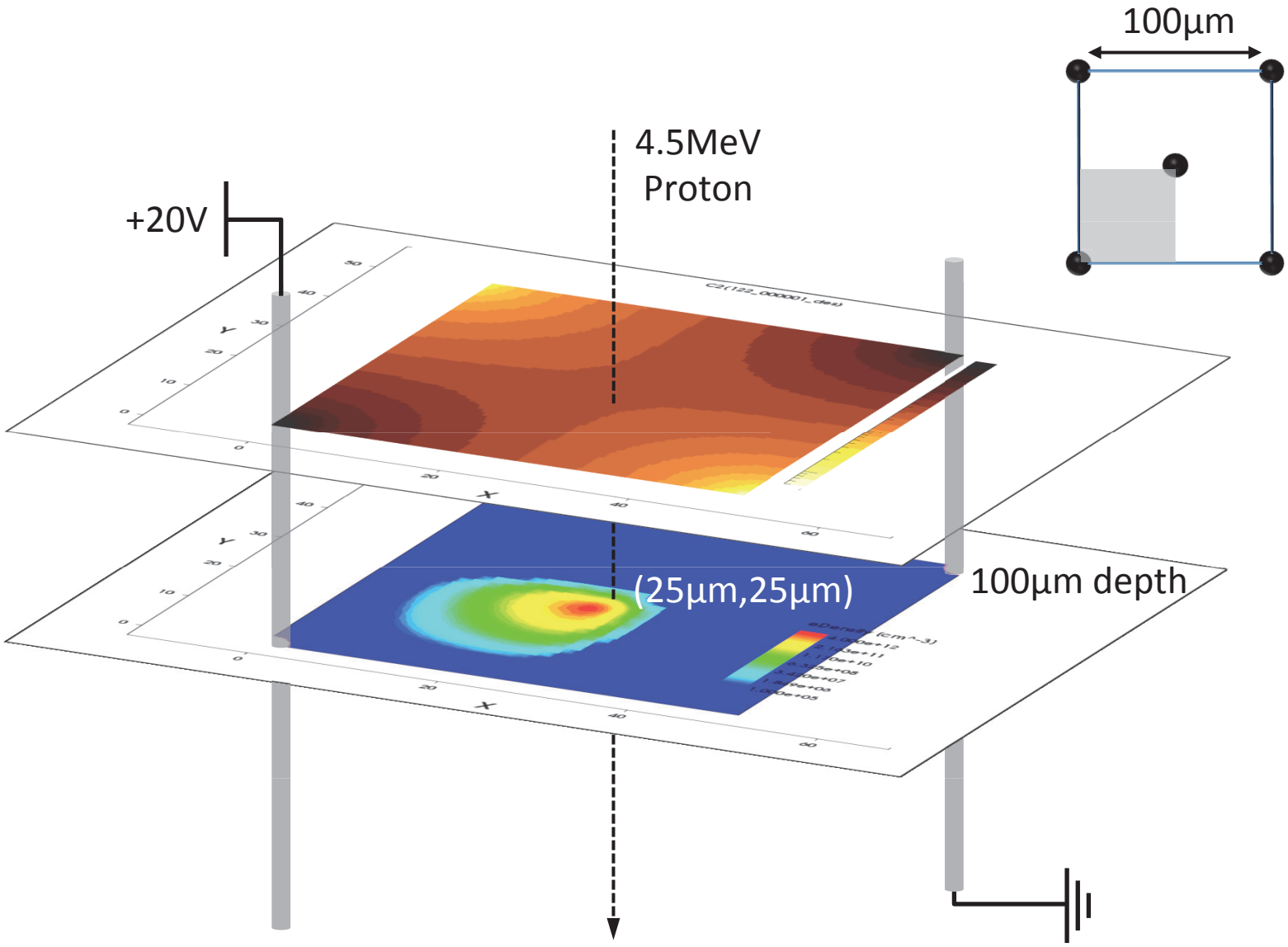
TCAD simulation



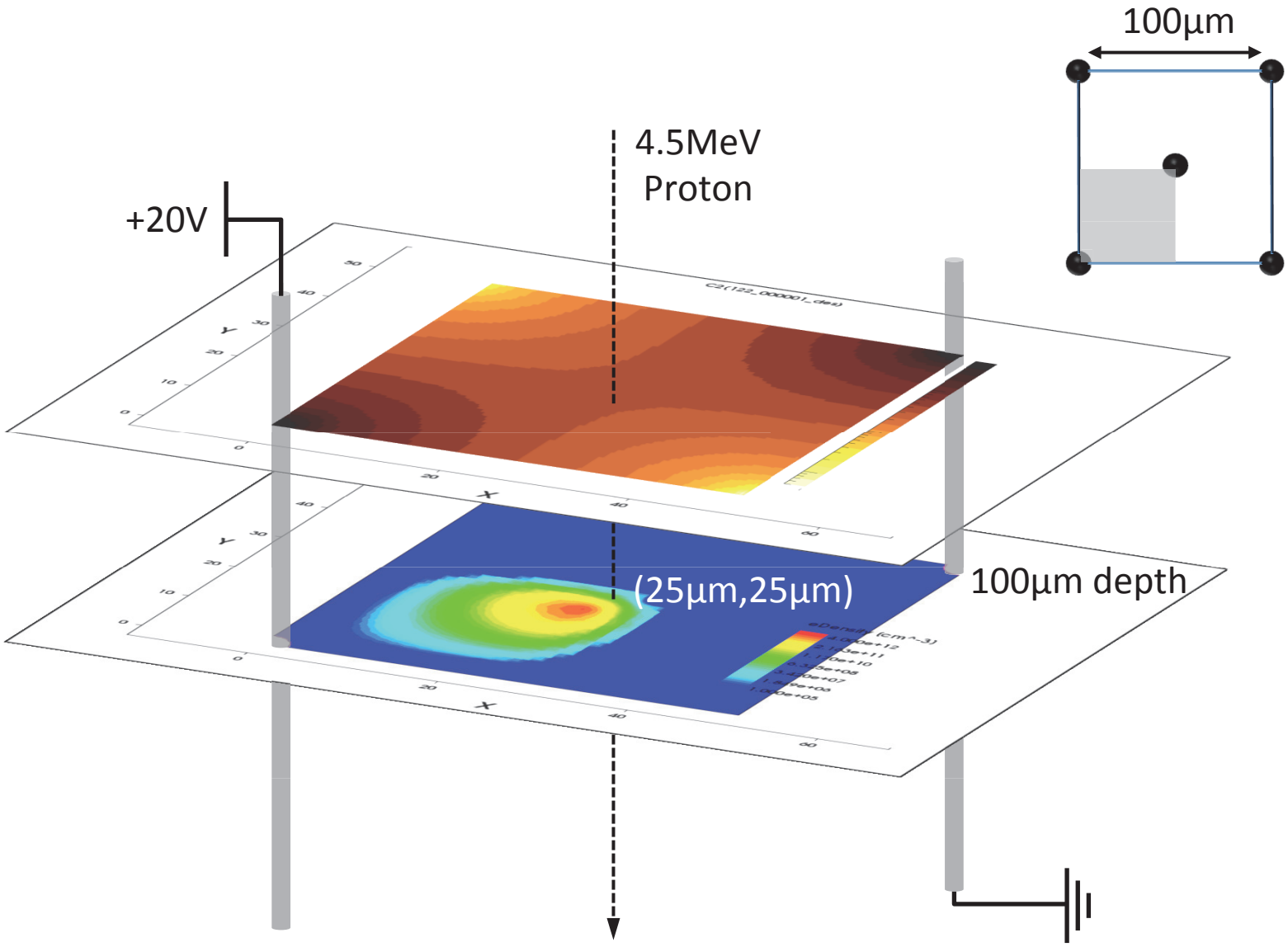
TCAD simulation



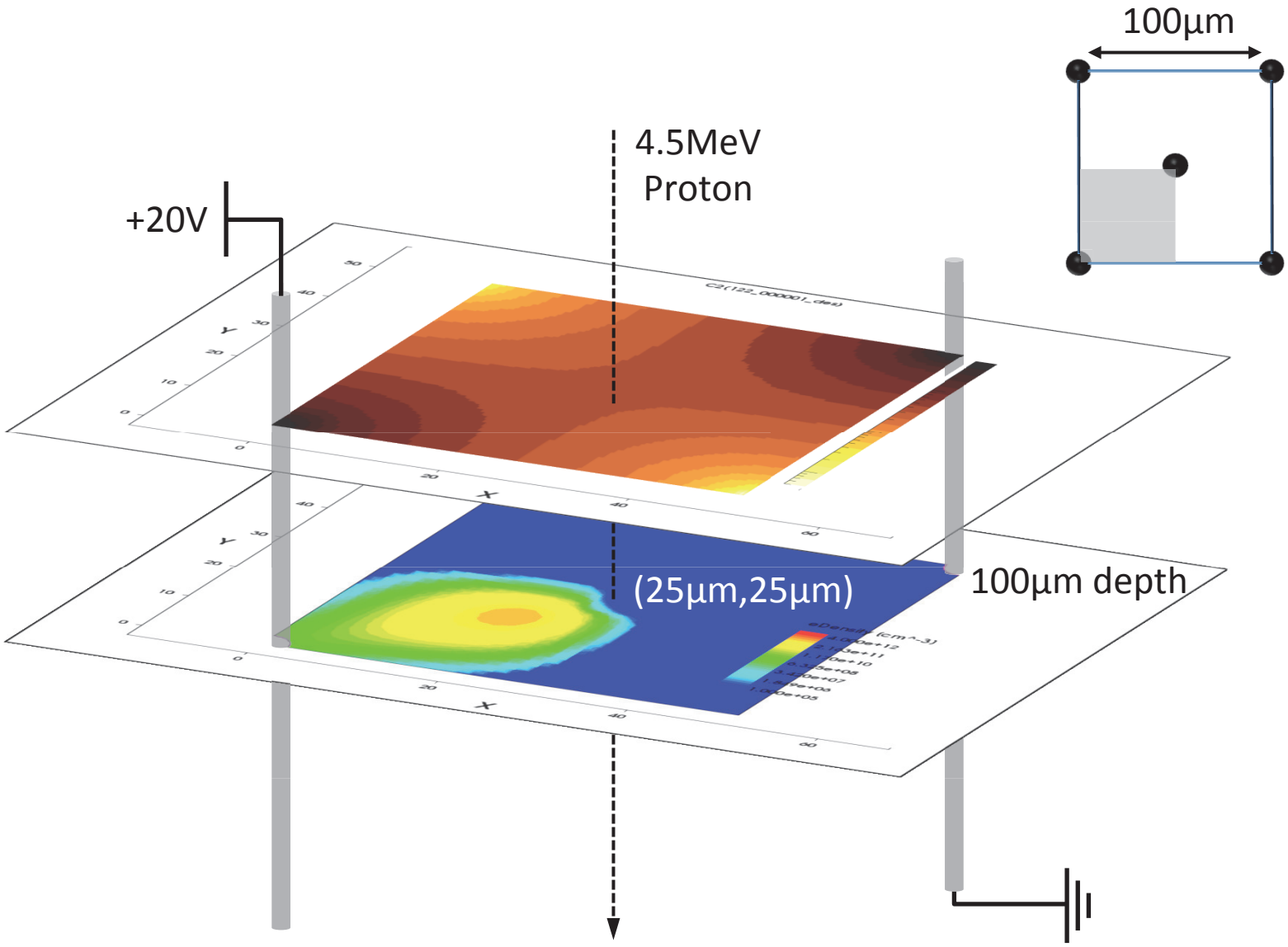
TCAD simulation



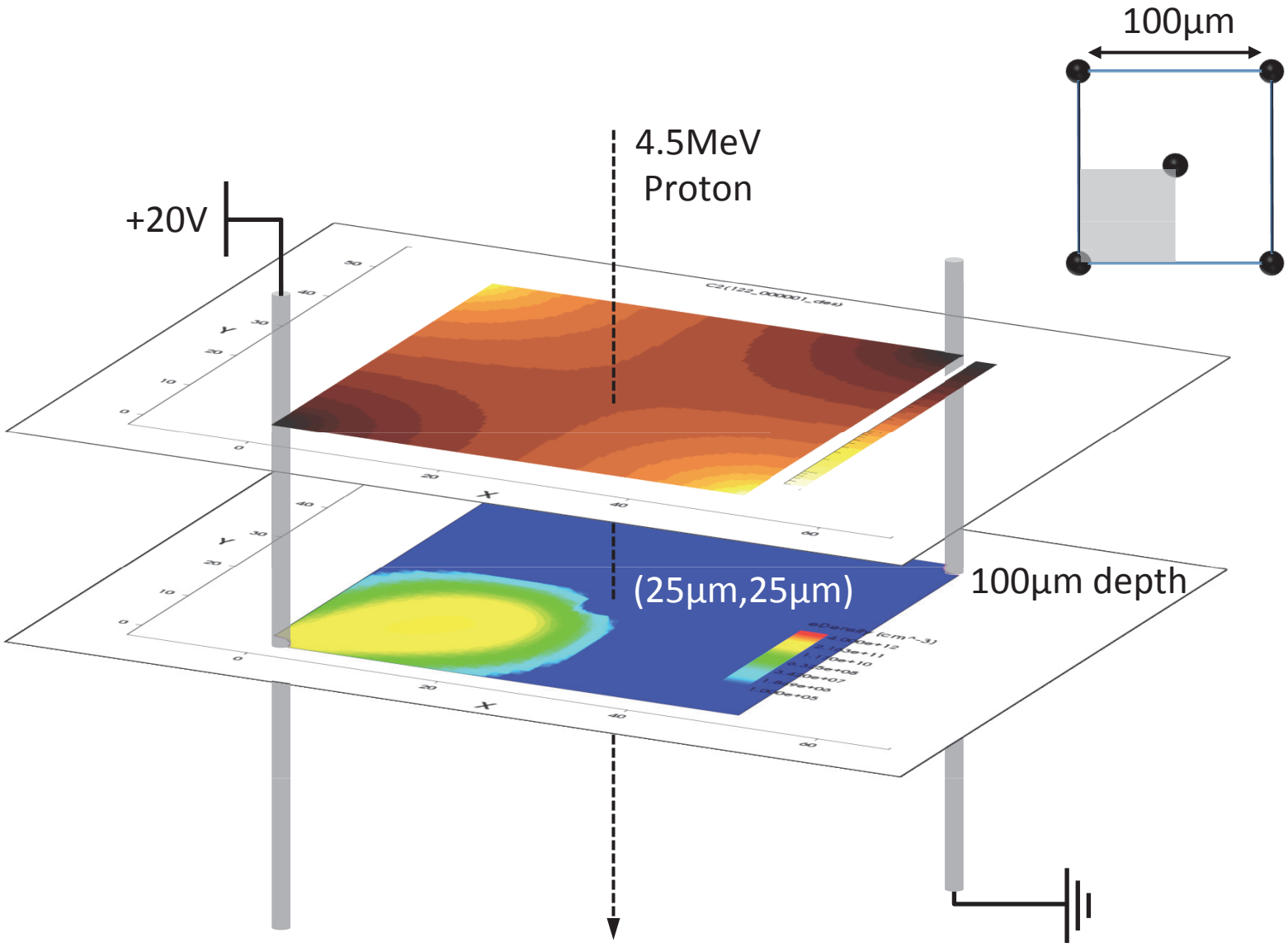
TCAD simulation



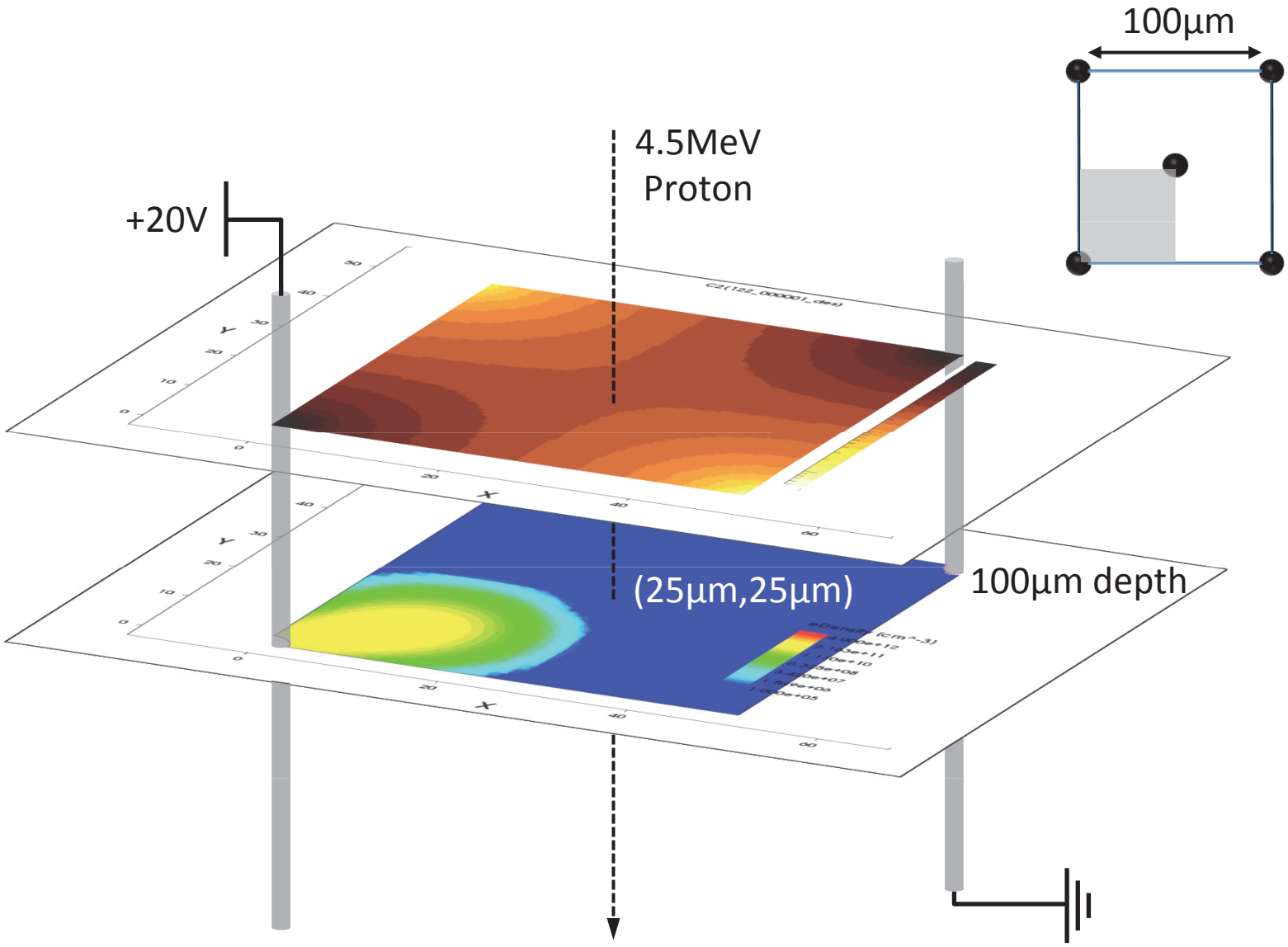
TCAD simulation



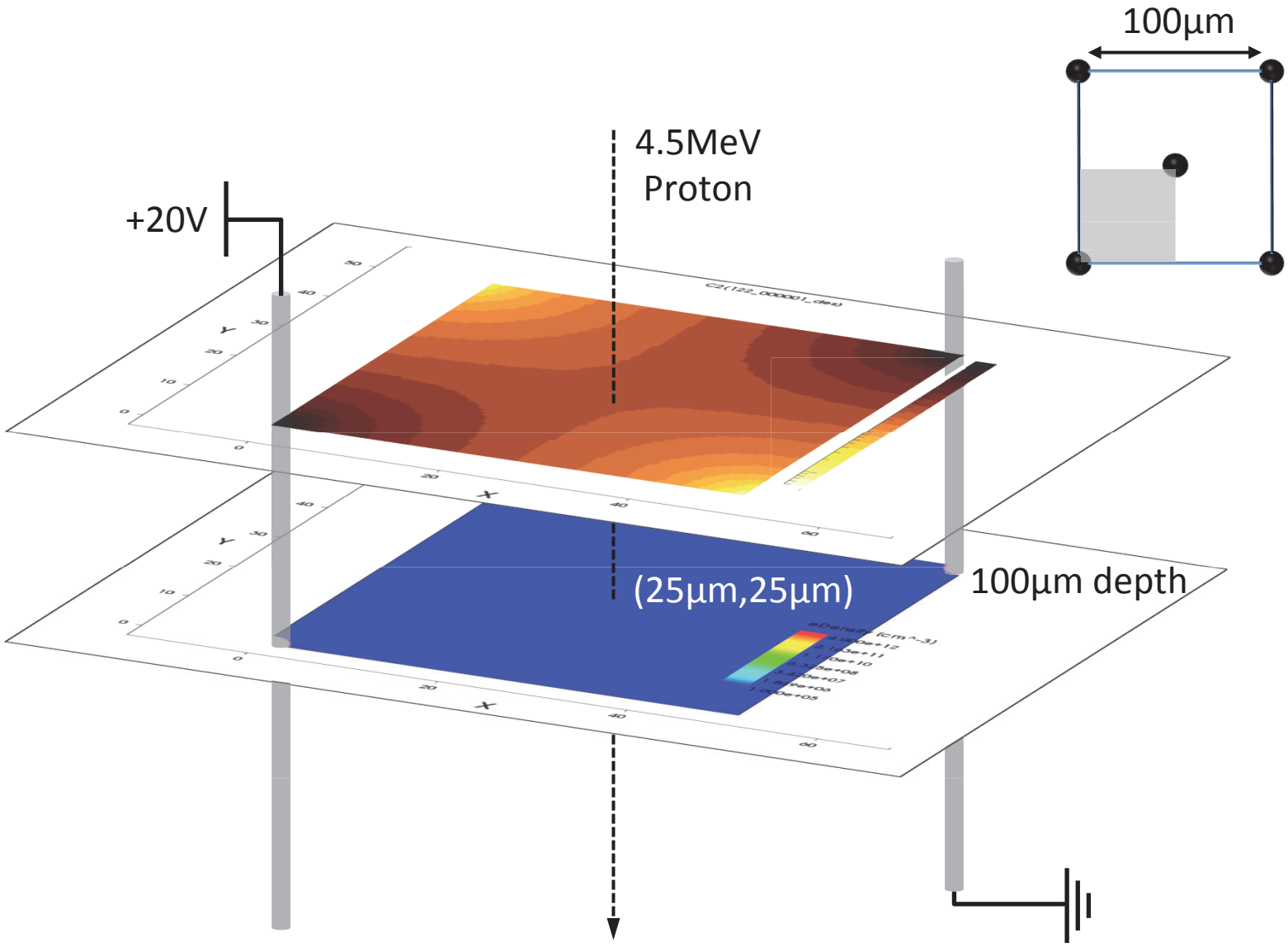
TCAD simulation



TCAD simulation

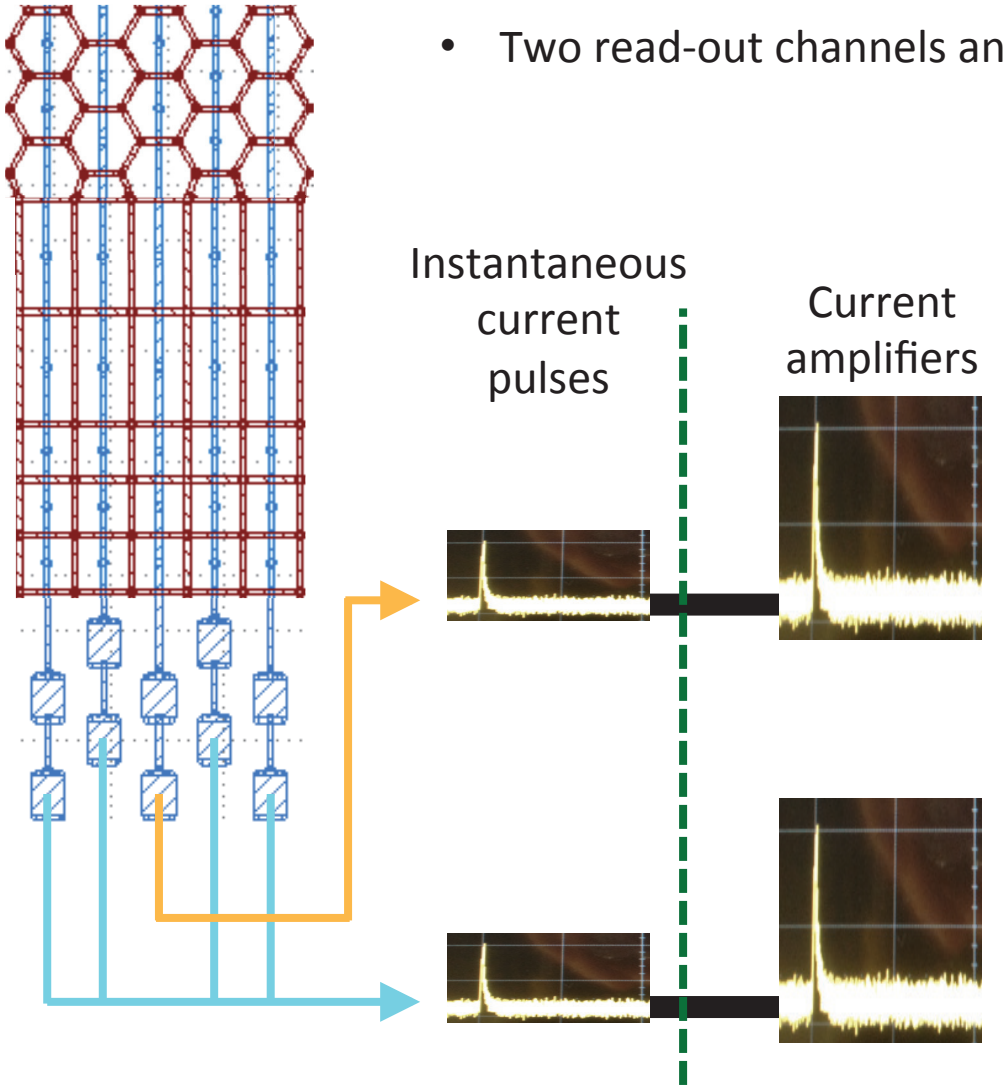


TCAD simulation

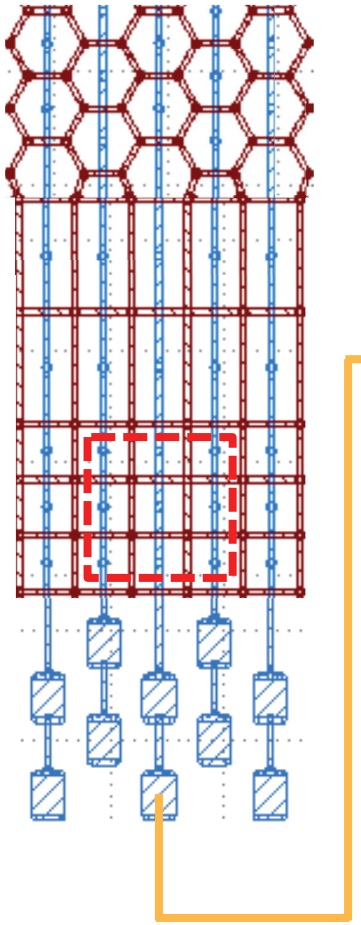


TRIBIC - setup

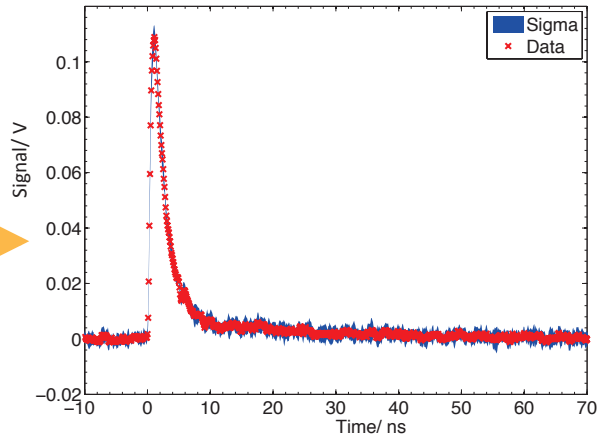
- Two read-out channels and amplification chains.



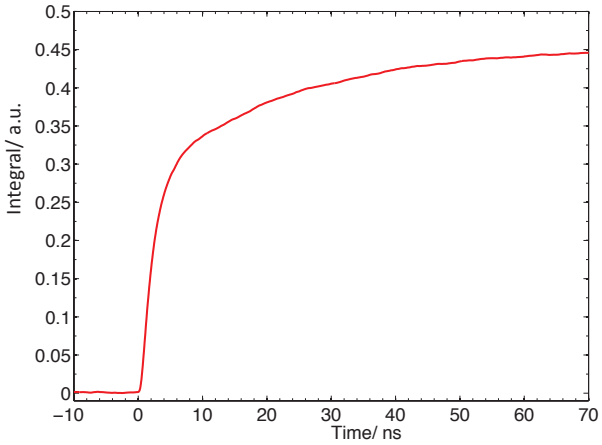
TRIBIC signals

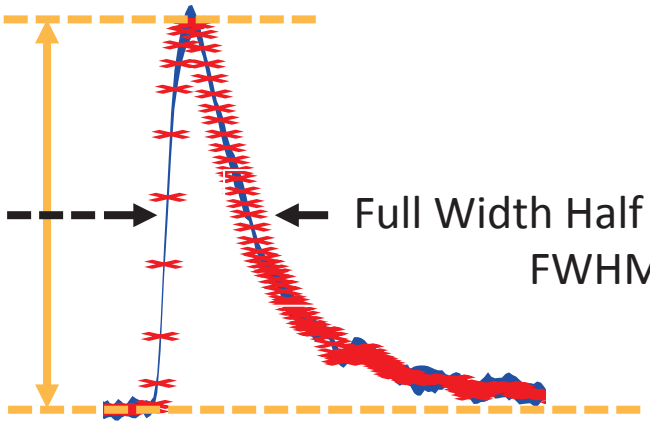


Instantaneous current pulse



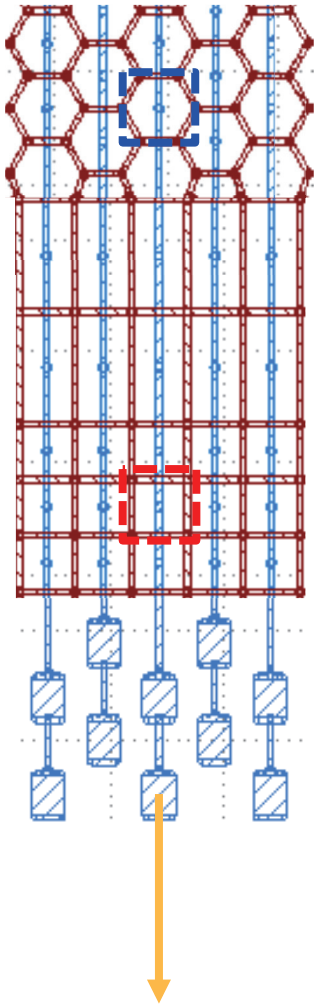
Integral





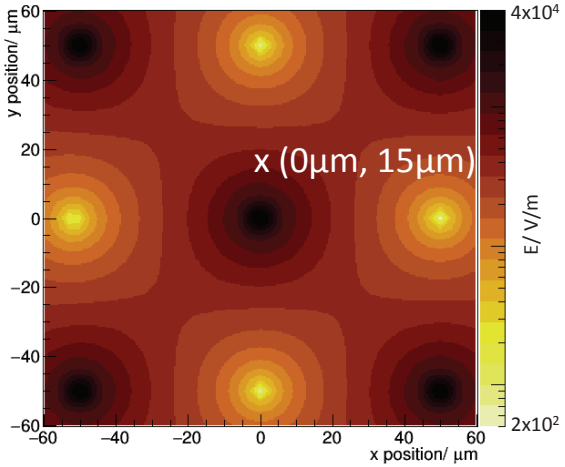
Full Width Half Maximum FWHM.

Position dependence – near electrode

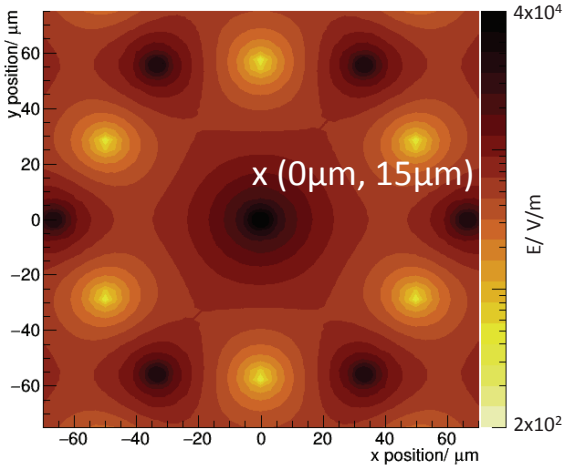


Simulated electric field at 20V

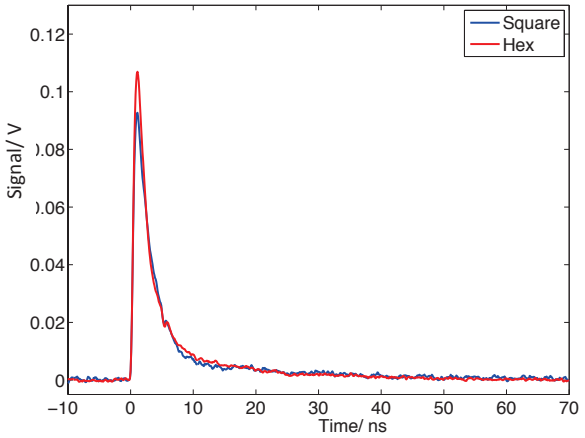
Square

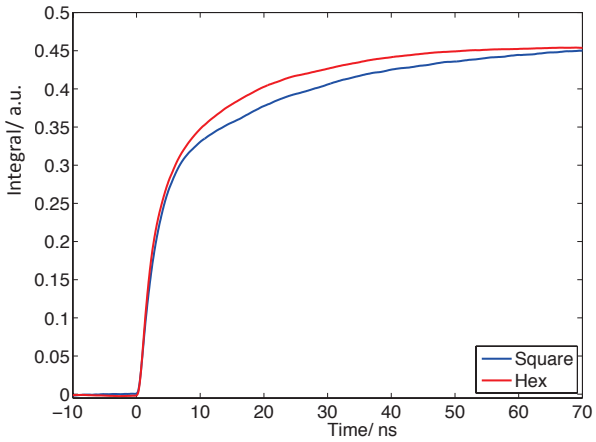


Hexagonal

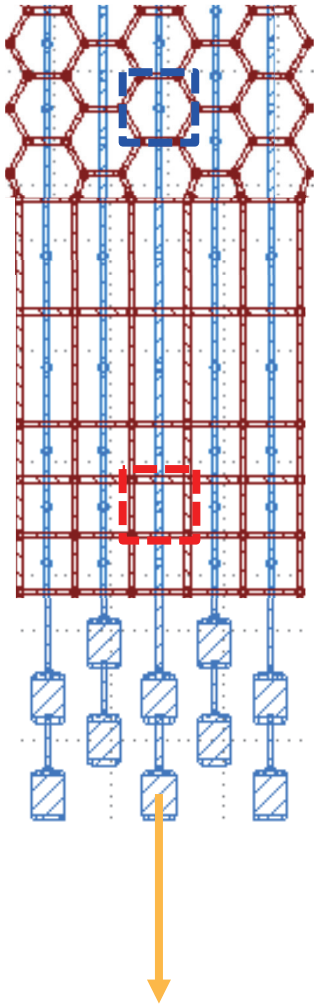


Measured current pulse at 20V



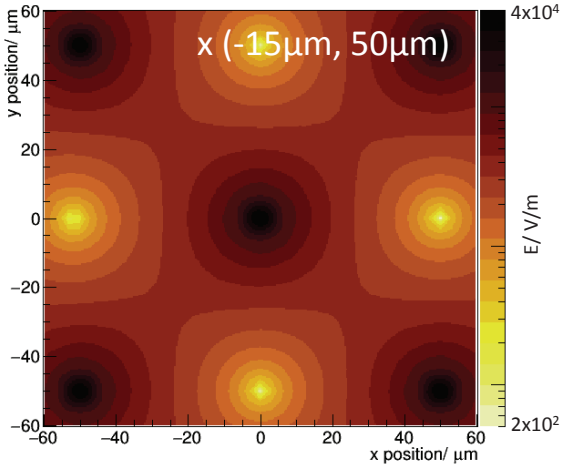


Position dependence – far from electrode

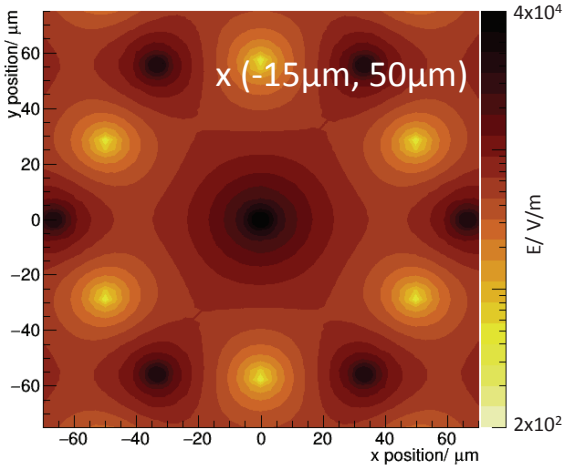


Simulated electric field at 20V

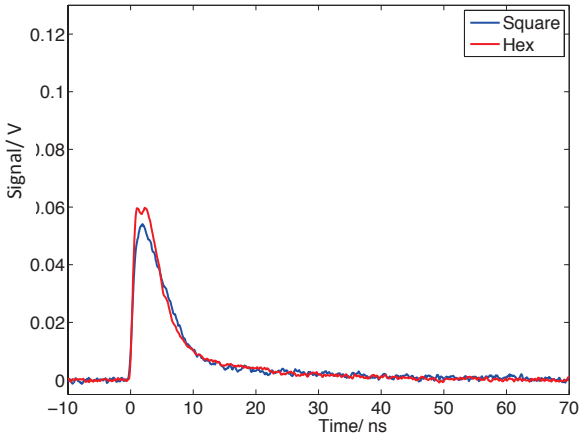
Square

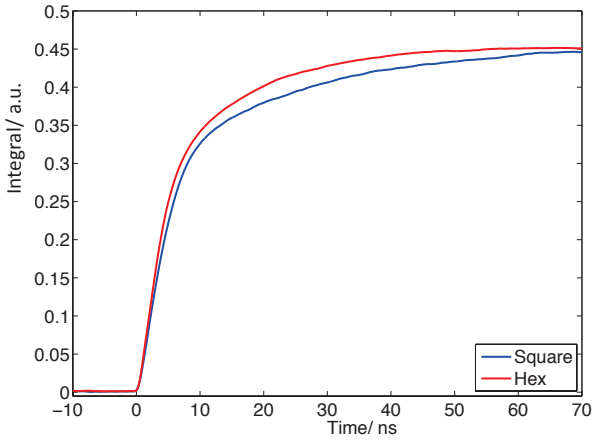


Hexagonal

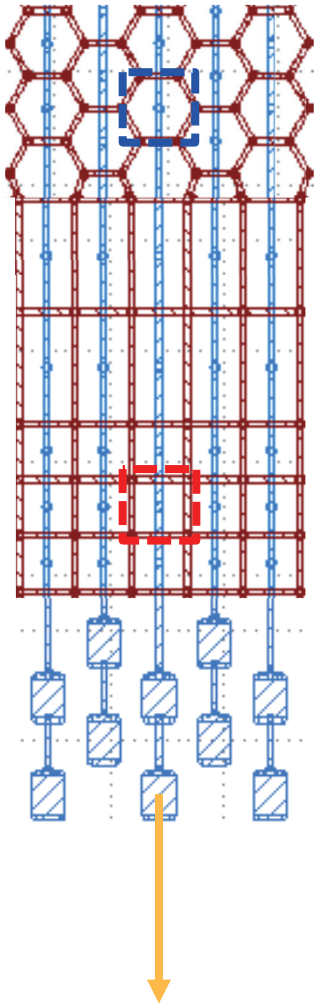


Measured current pulse at 20V



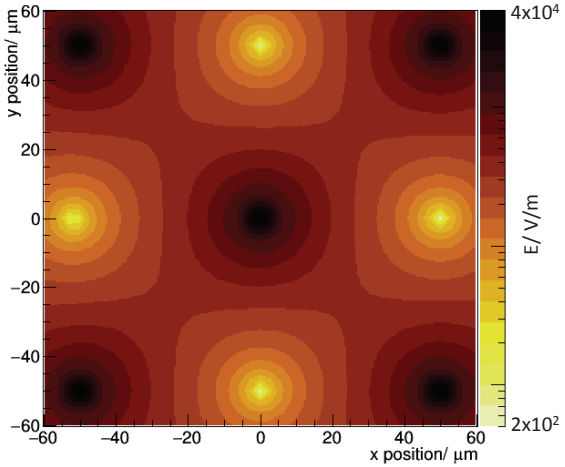


Position dependence - cell

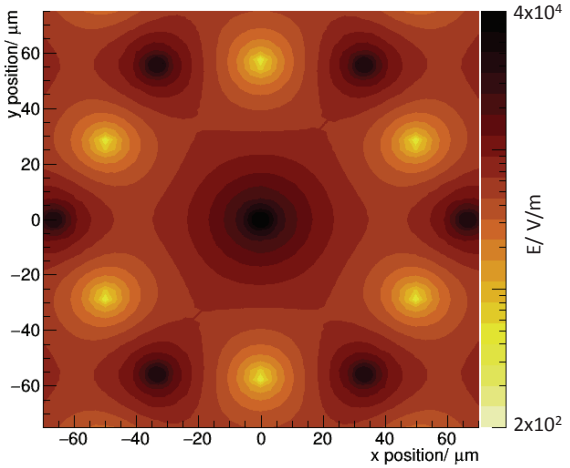


Simulated electric field at 20V

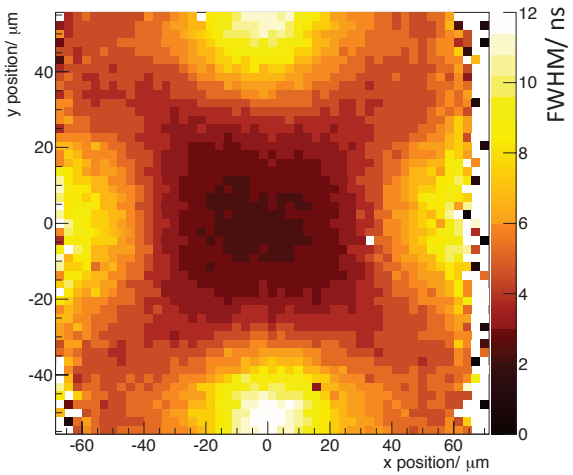
Square

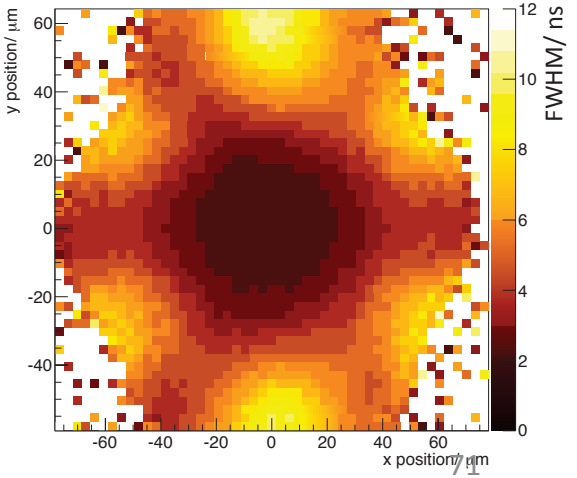


Hexagonal



Measured FWHM of pulse at 20V





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Dosimetry measurements

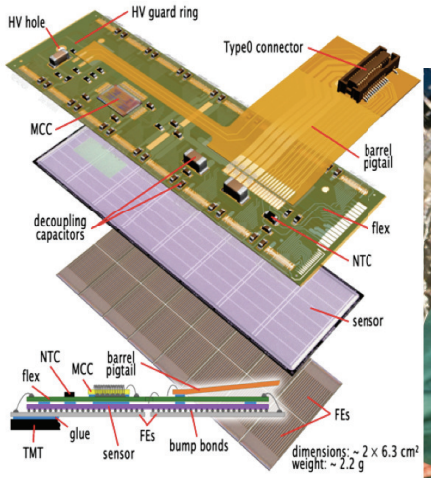
[6] Christie Hospital – Manchester, UK

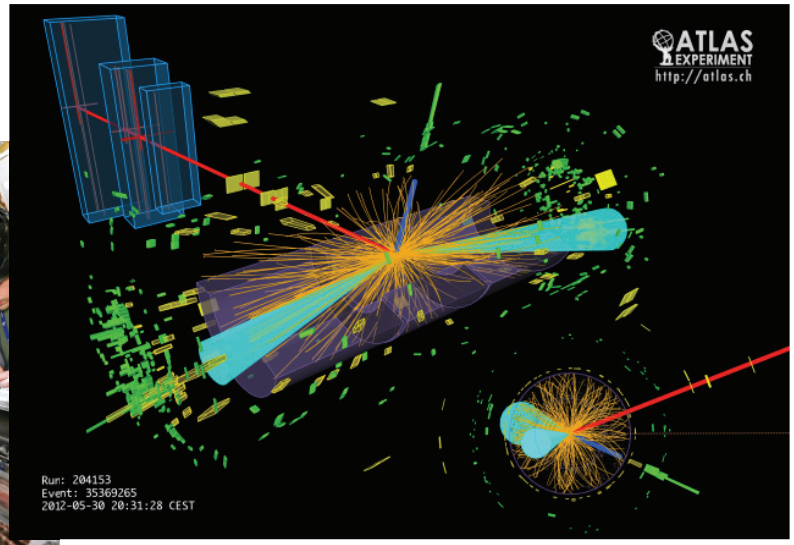
[7] University of Florence – Florence, Italy

Silvio Sciortino, Stefano Lagomarsino

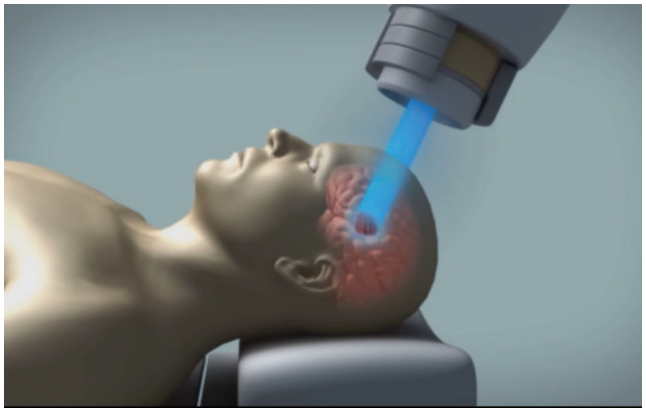
Introduction - applications

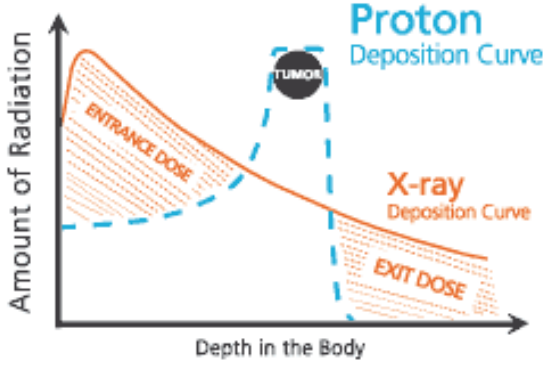
- High energy physics:





- Medical dosimetry (proton therapy):



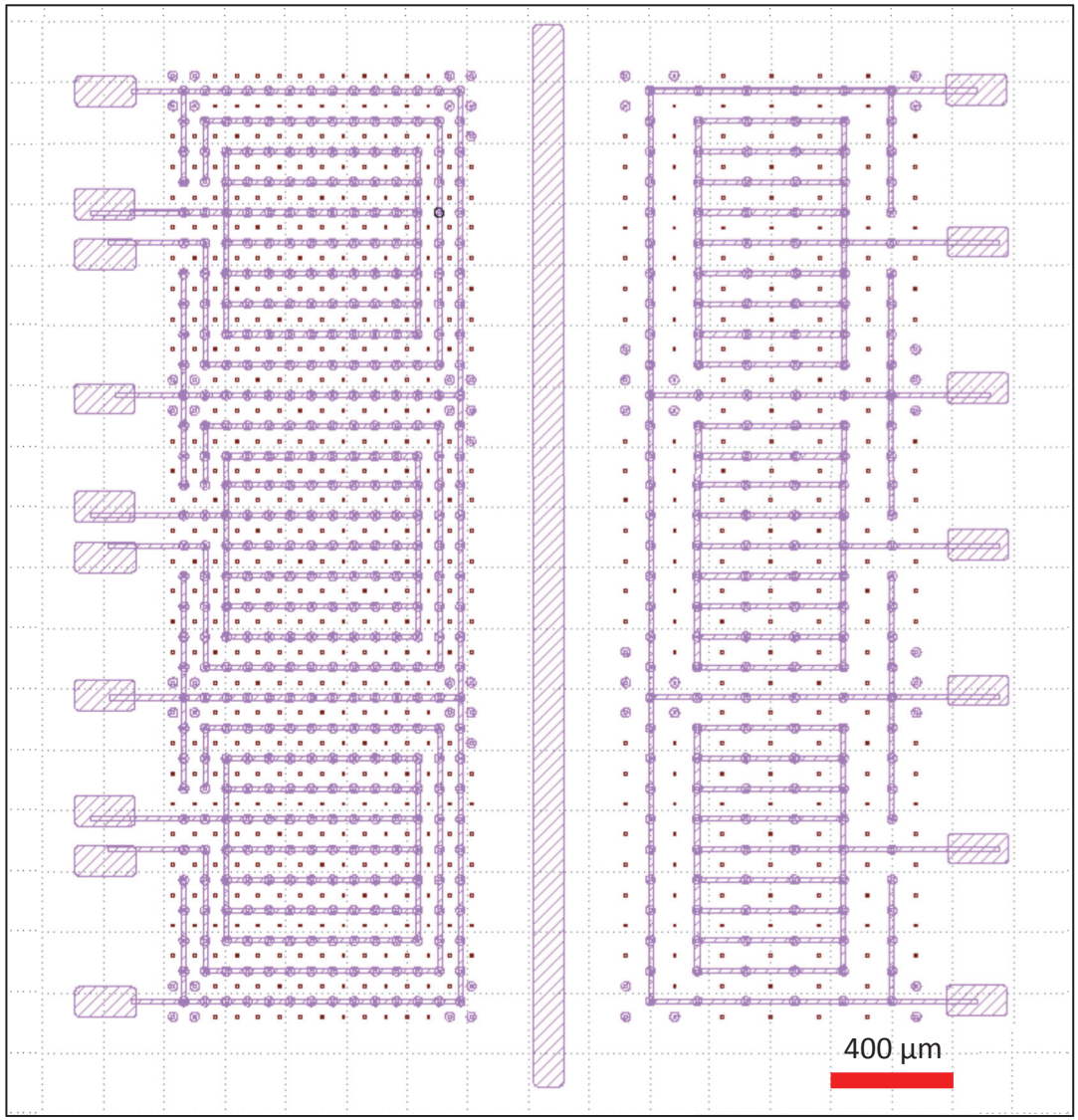


radiotherapy

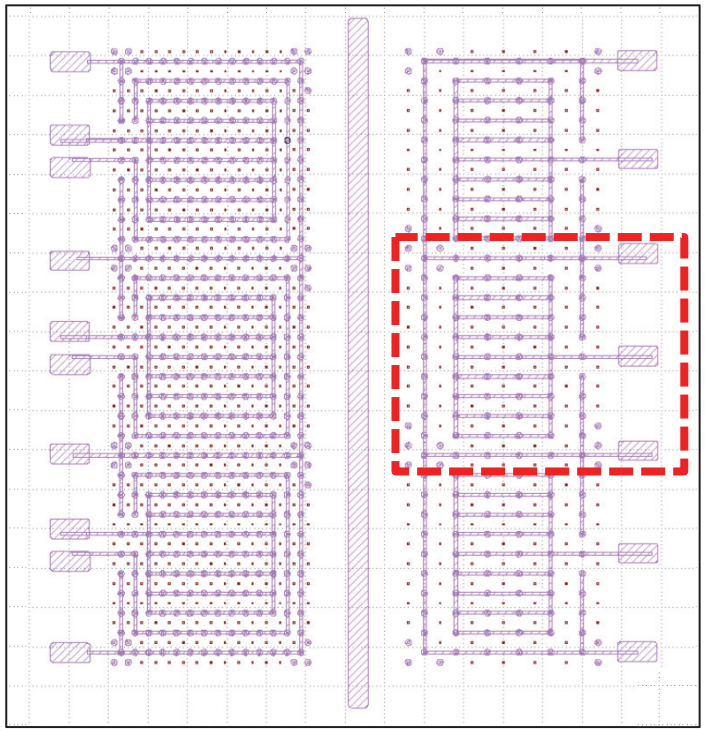
objectives

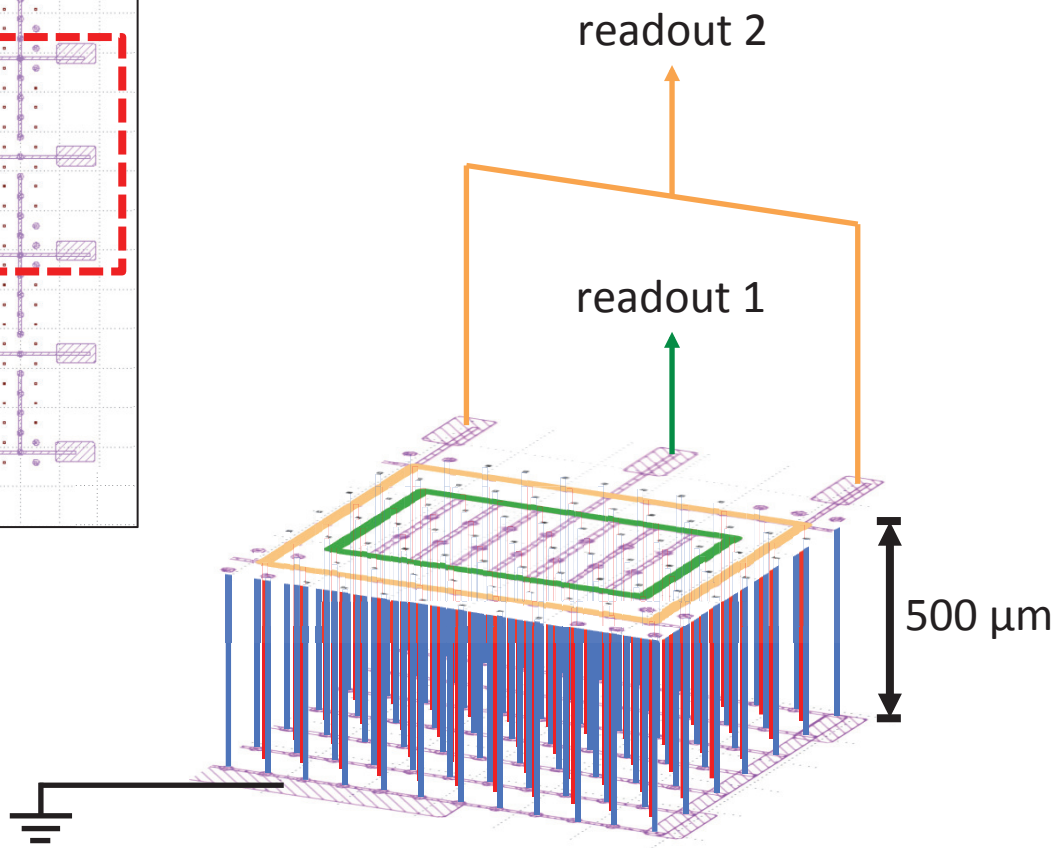
1. Test 3D diamond detector performance for real-time dosimetry measurements.

Introduction – 3D detector

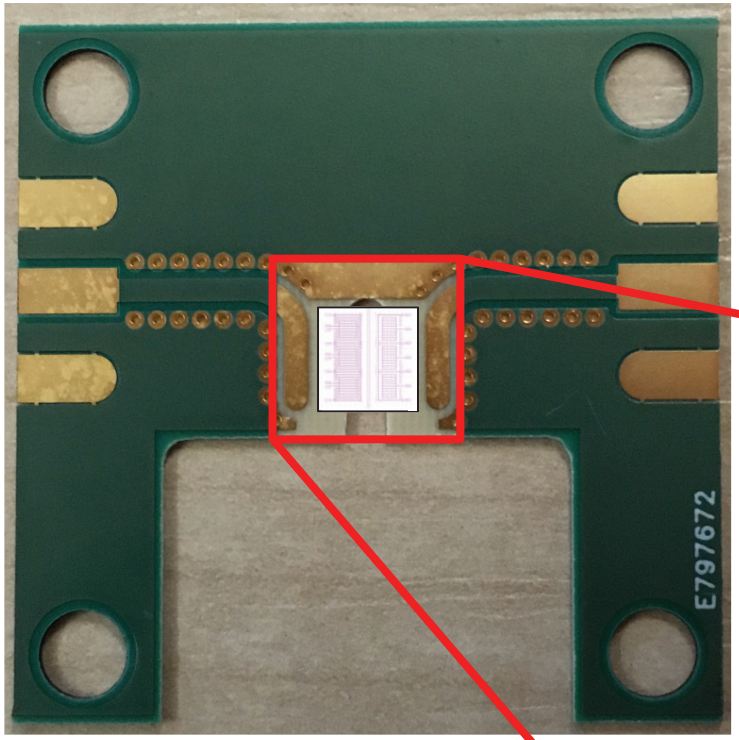


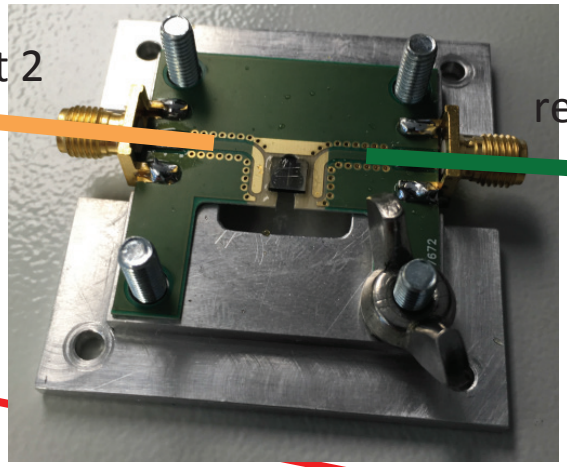
Setup – detector

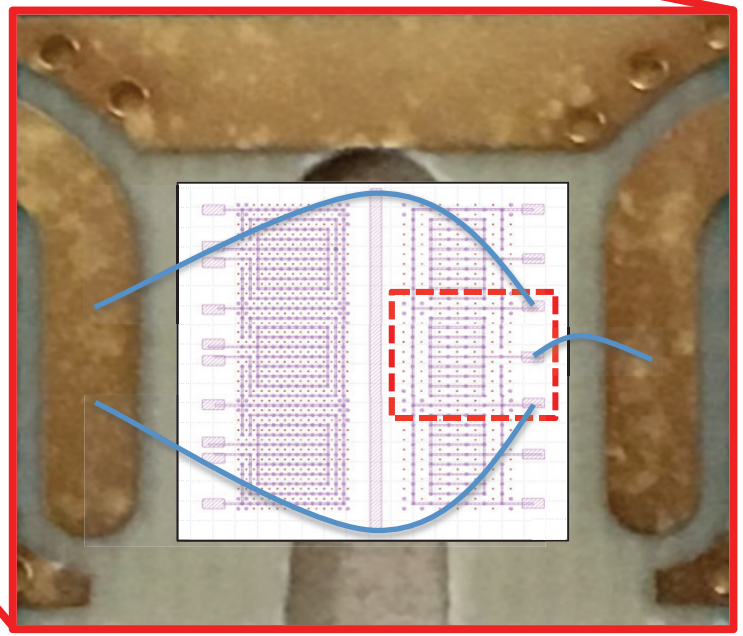




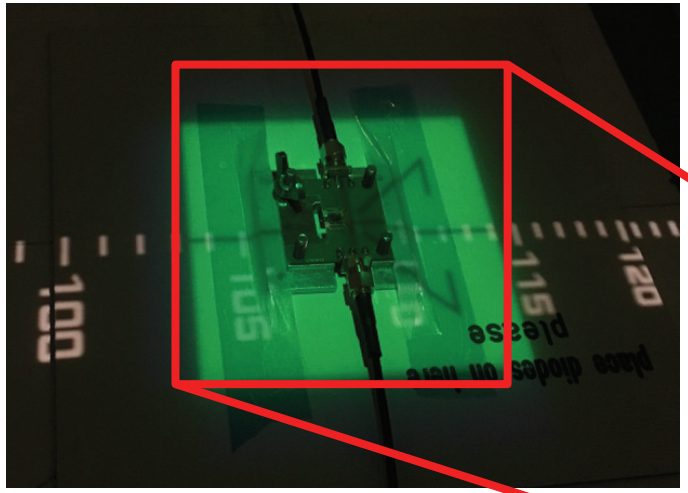
Setup - readout







Setup – measurement



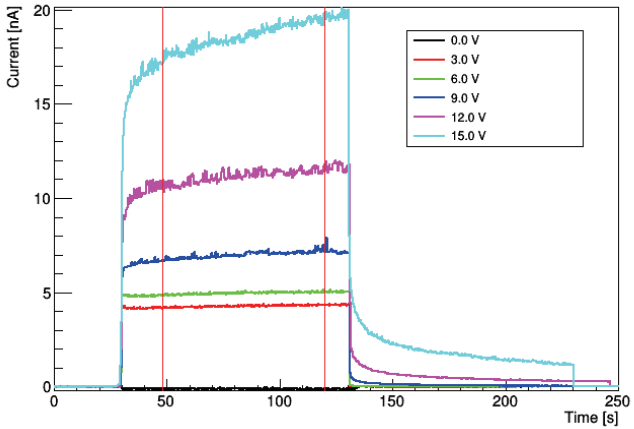
readout synchronisation

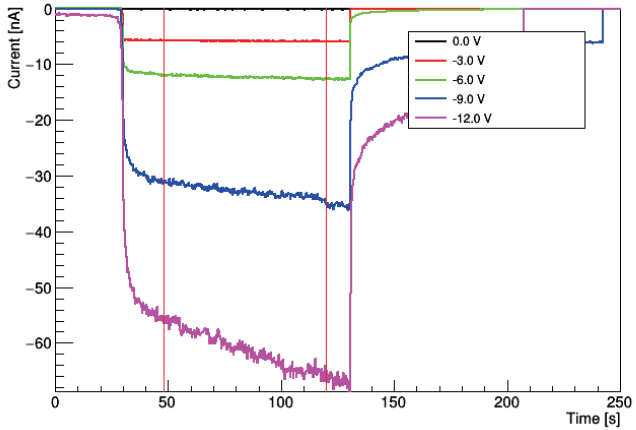
readout 2

readout 1

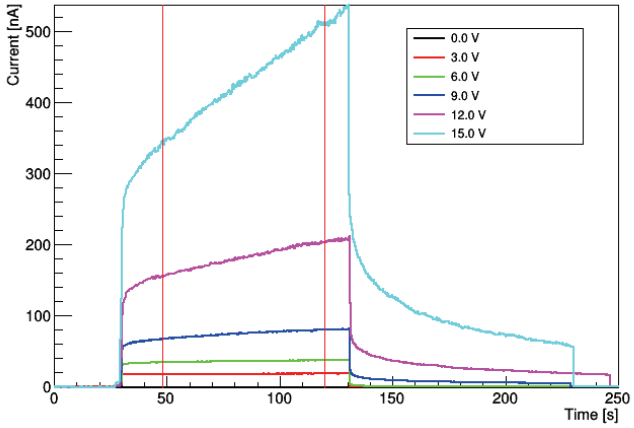
Results – bias scan

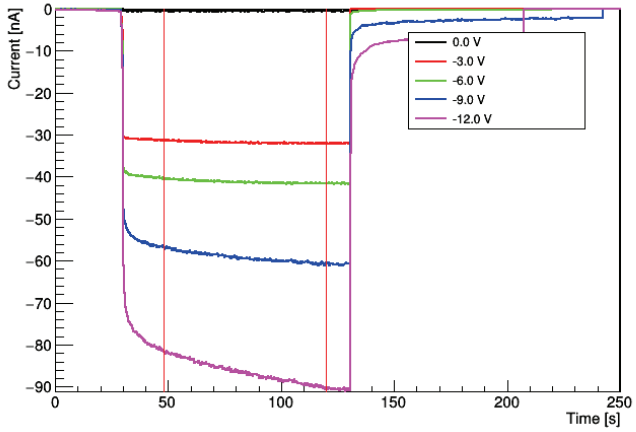
readout 1



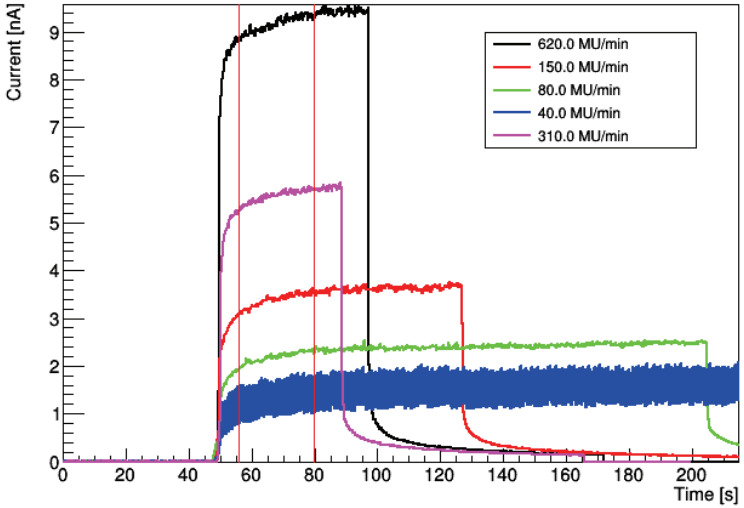


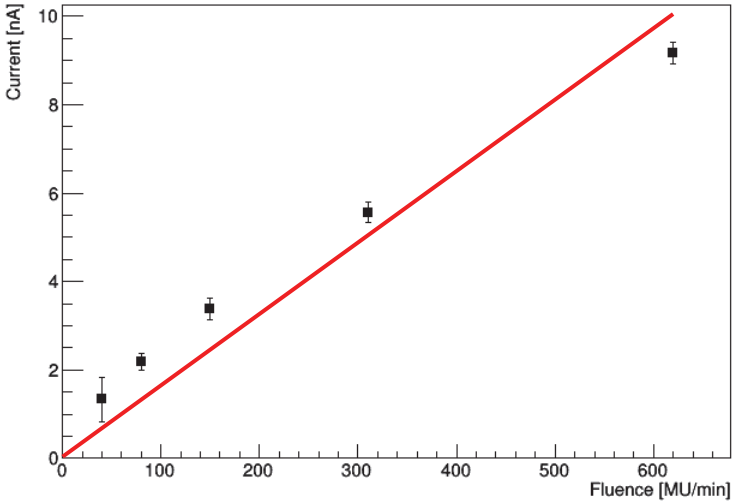
readout 2





Results – fluence scan at +12 V





Summary

- Increased fabrication reliability → Laser processing allows for rapid, low cost prototyping.
- 3D detector in single crystal diamond with ~100% charge collection efficiency.
- Made high quality transient current measurements using a proton micro-beam.
- Observed the behavior of two different cell geometries → develop for specific applications.
- Preliminary dosimetry measurements using a radiotherapy machine.

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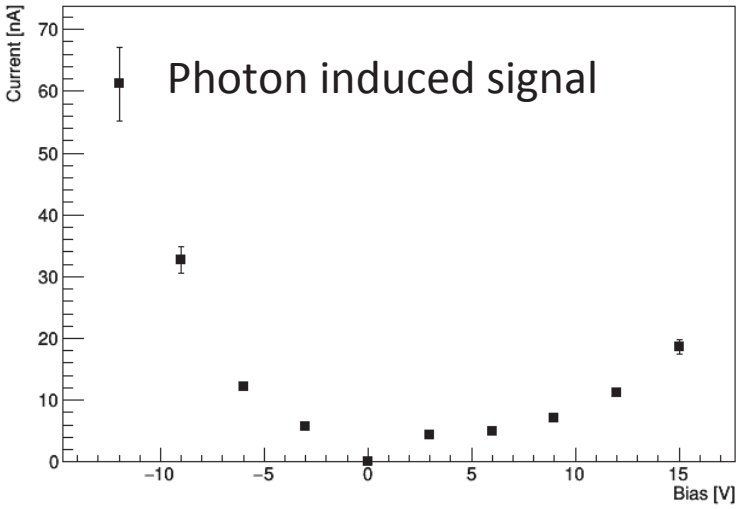
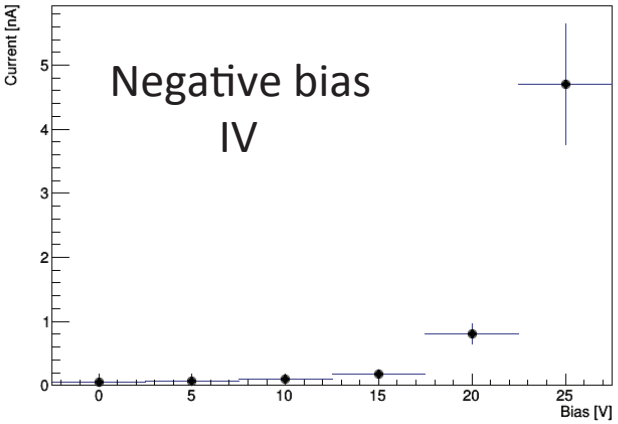
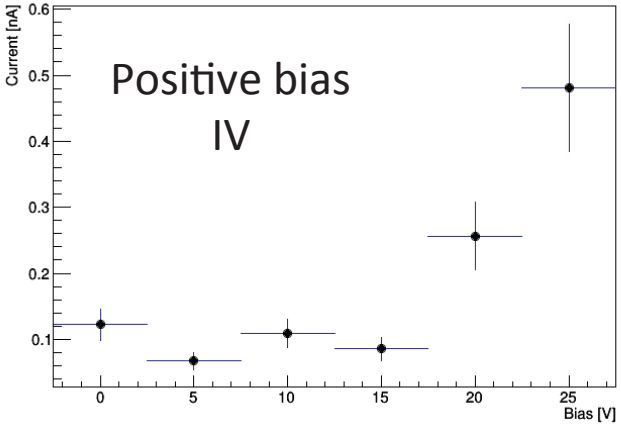
Thank you

Results – bias scan

readout 1

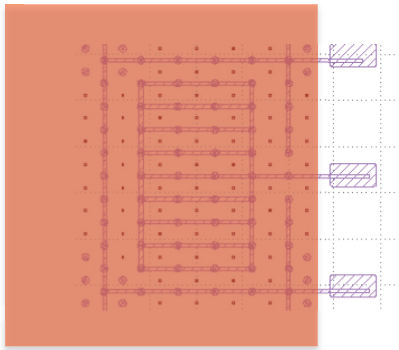




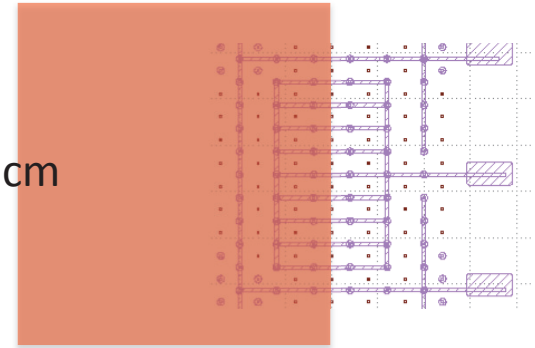


Results – beam-edge scan at +12 V

X1 = 8 cm



X1 = 10 cm



X1 = 12 cm