Status of 3D Diamond

ADAMAS
GSI meeting
16-17th Dec 2013

Alexander Oh

University of Manchester
3D Diamond Group / RD42

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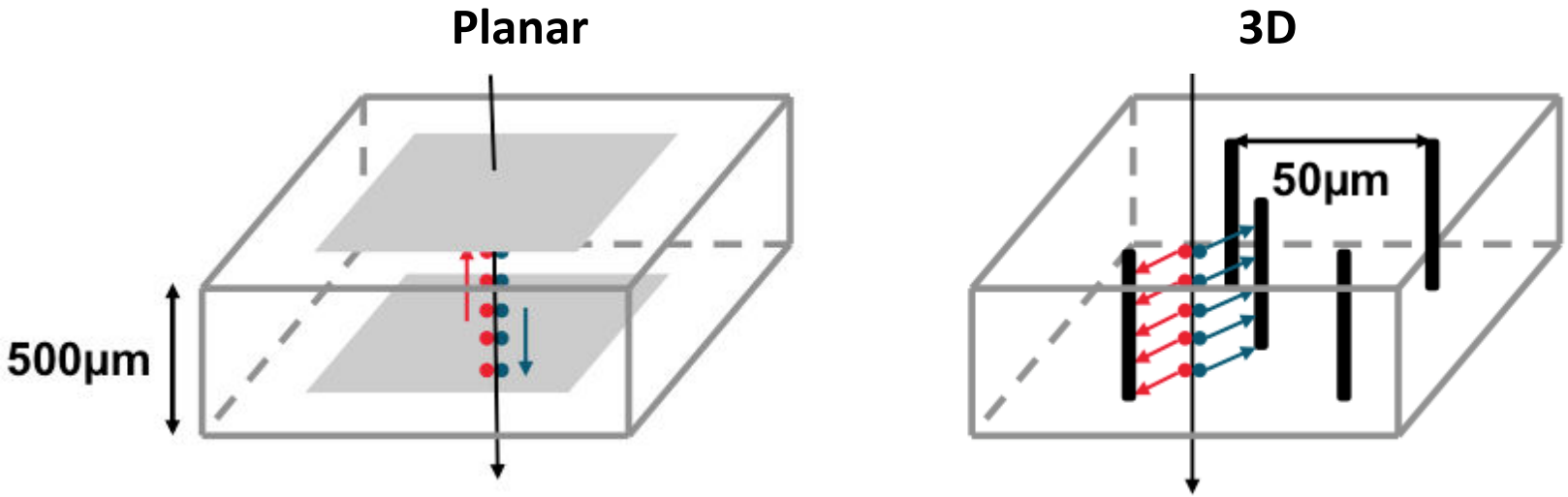
Motivation

Why 3D?

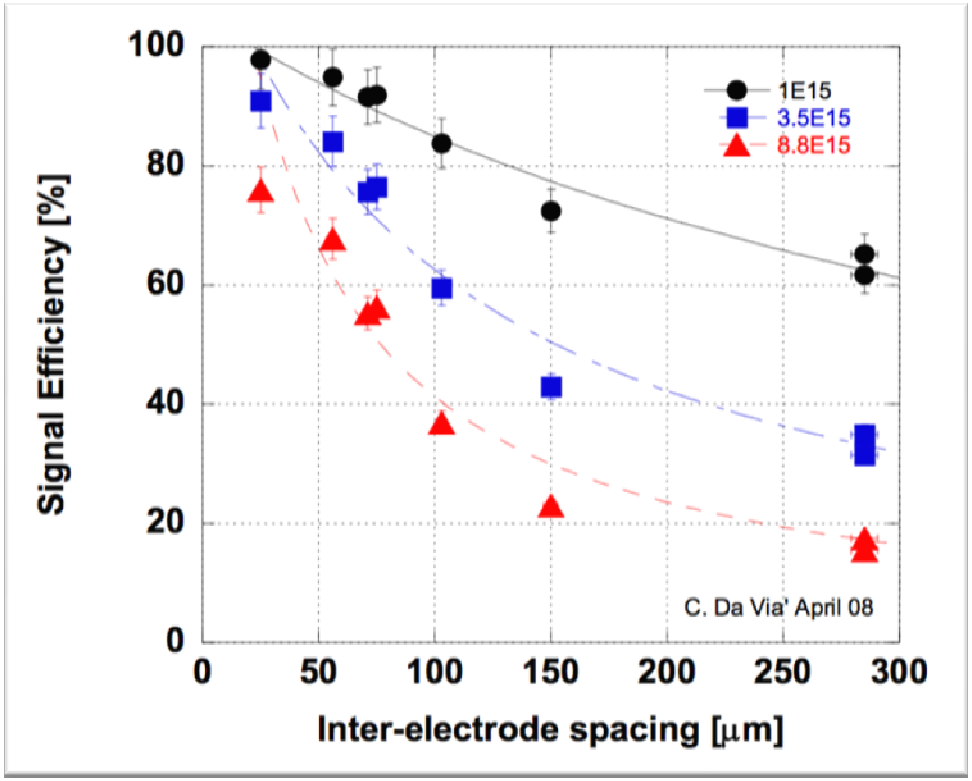


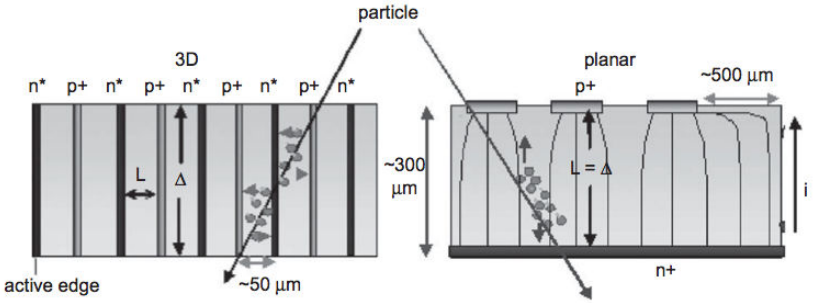
Drift distance comparable to mean free path of charge carriers in irradiated diamond.

Nuclear Instruments and Methods in Physics Research A 603 (2009) 319–324

Why 3D?

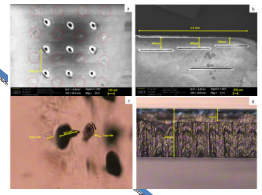
- Enhanced radiation hardness for **3D geometry** proven with Silicon.
- Since this is due to geometry the same should be applicable to **Diamond**.



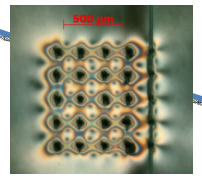


3D Diamond Research

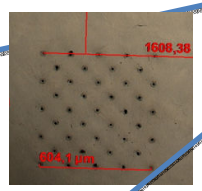
Lasered graphitic structures in pCVD (’10)



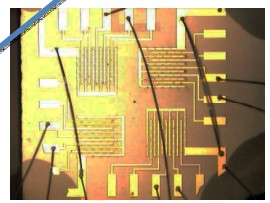
Single crystal with column structure (‘11)



Femto second laser for improved graphitic electrodes (‘12)



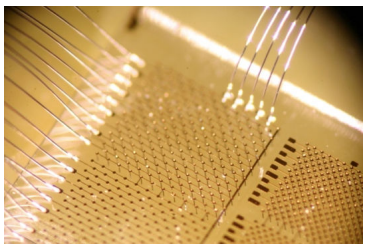
Improved laser processing and **TCAD simulation (‘13)**



3DD

University of Manchester,
CEA Saclay,
CERN,
ETH Zurich,
Ohio State University

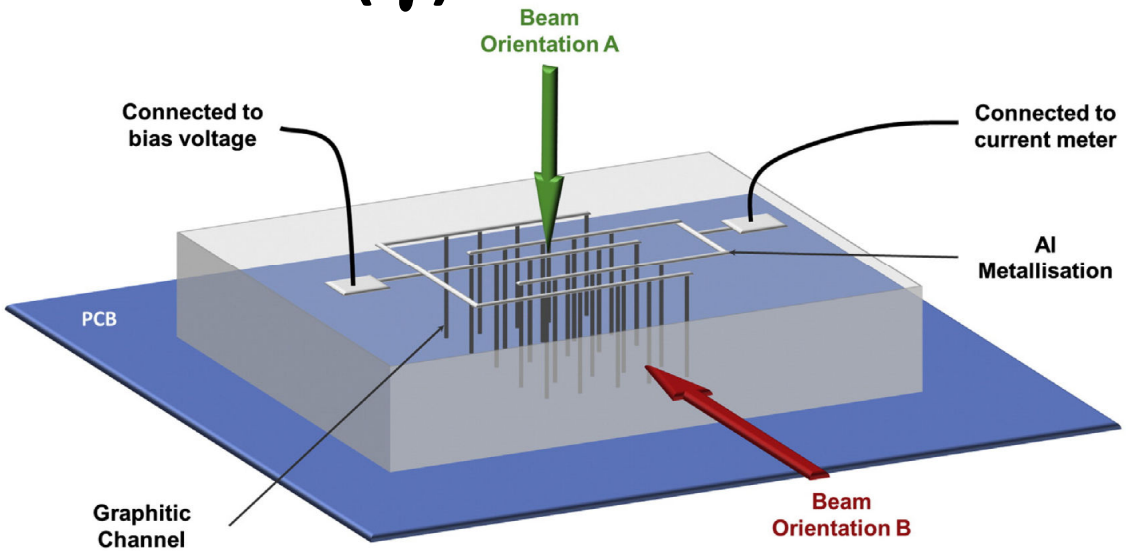
Several Prototypes tested at
Diamond Light Source (‘09,’10,’11, ‘13)
CERN test beam (’12)
RBI proton beam (‘13).

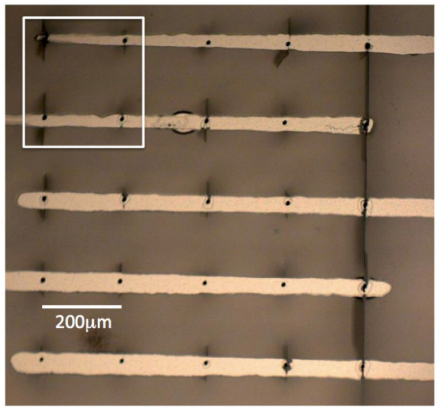


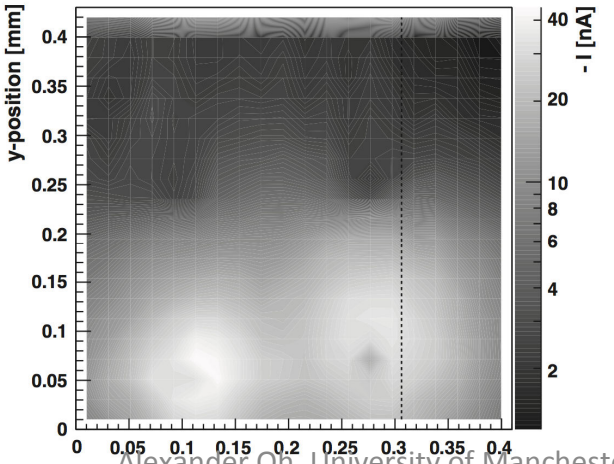
Diamond and Related Materials, Volume 38, September 2013, Pages 9-13

micro-beam results (γ)

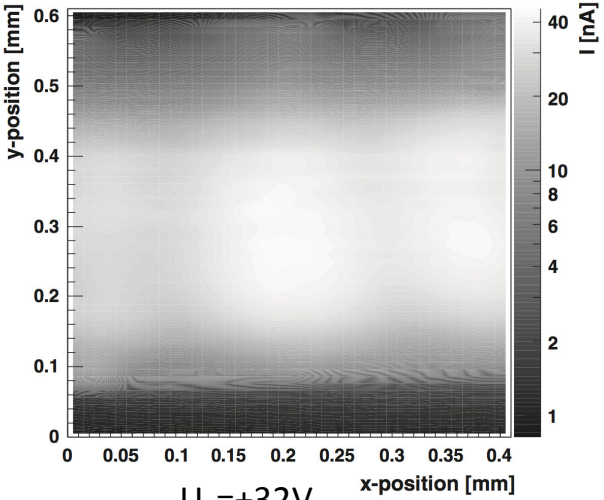
- Diamond 3D prototype
  - Single crystal
  - 200 x 200 µm colums
  - **15 keV photons Diamond light source.**
  - **First indication that 3D columns collect charge.**







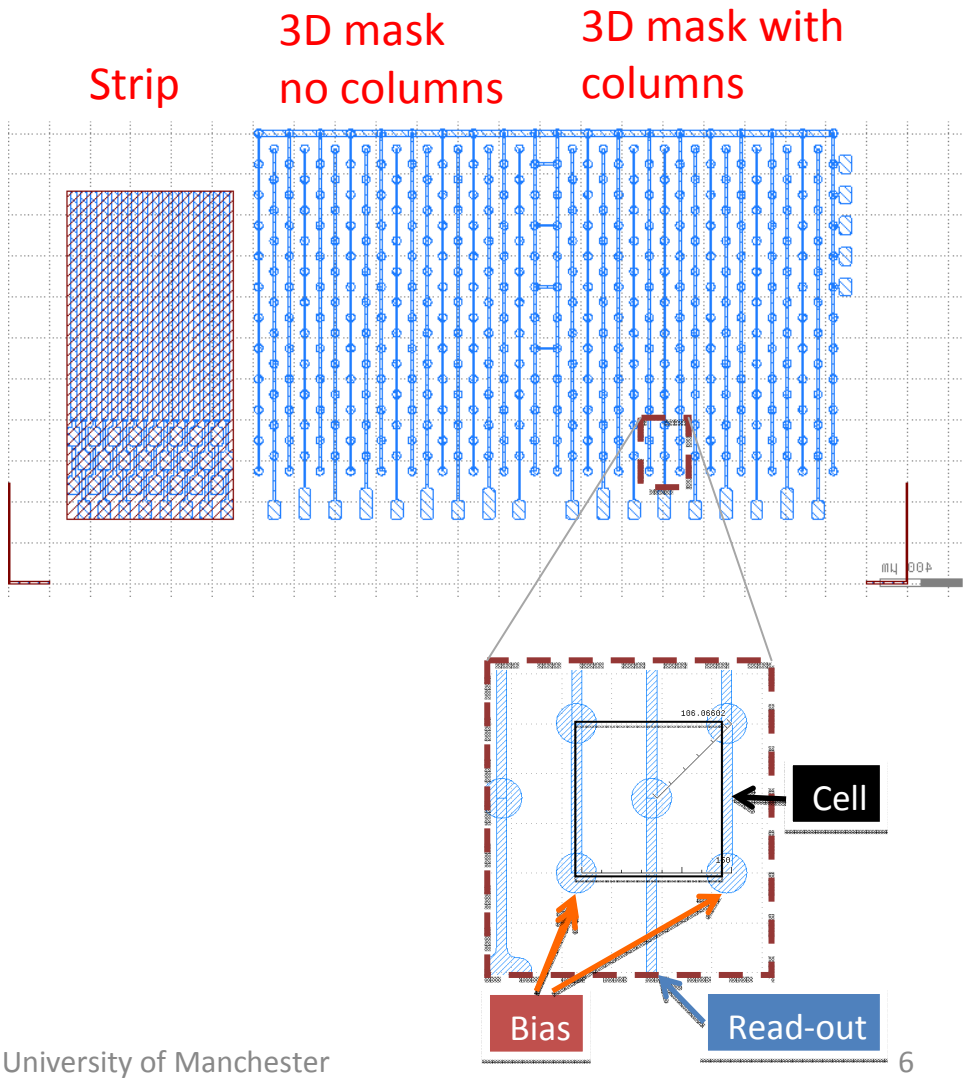
U_b=+32V



U_b=+32V

CERN Test-beam

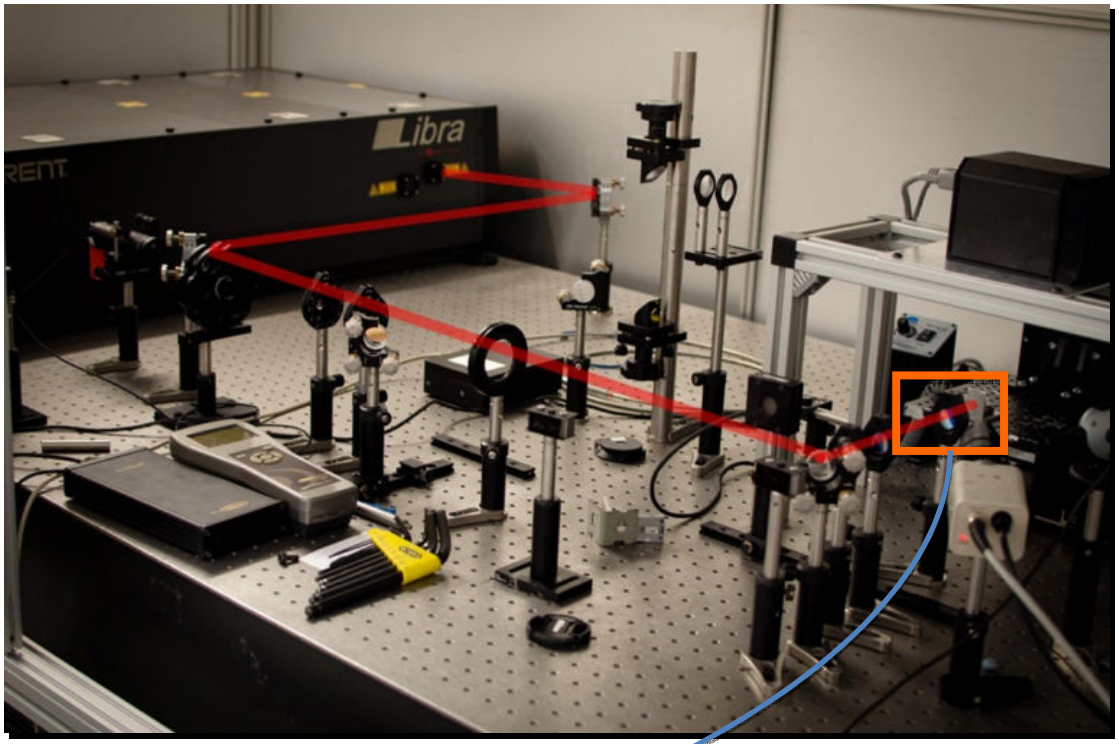
- **Proto-type**
  - Strip detector with back side contact
  - 3D metal only pattern
  - 3D metal + graphitic columns
  - Cubic cell base size 150µm
  - 99 cells



Fabrication

University of Manchester, Laser Processing Research Center.

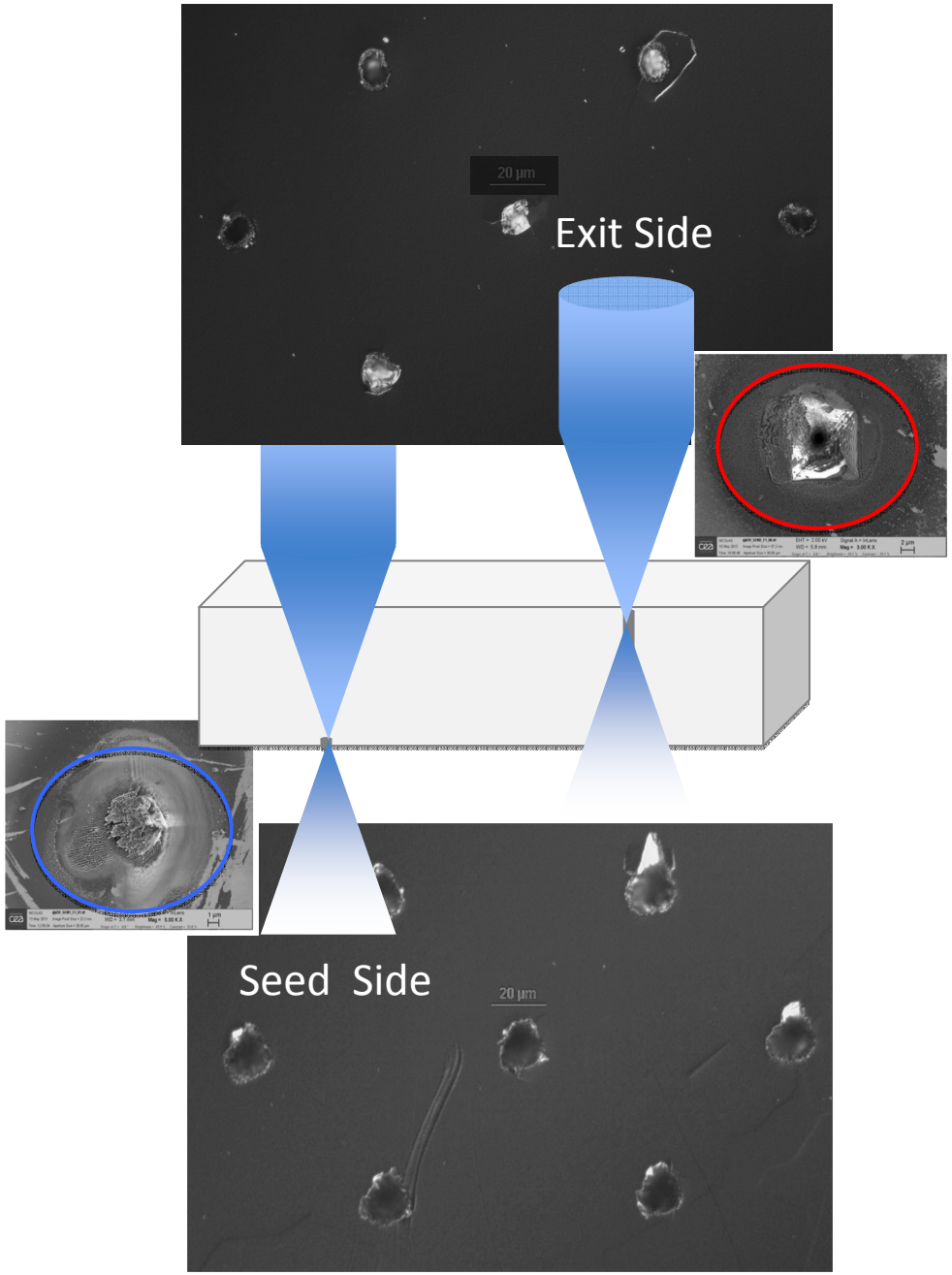
- Wavelength = 800 nm
- Repetition rate = 1 kHz
- Pulse duration = 100 fs
- Spot size = 10 µm
- Pulse Energy ~ 1 µJ



Fabrication

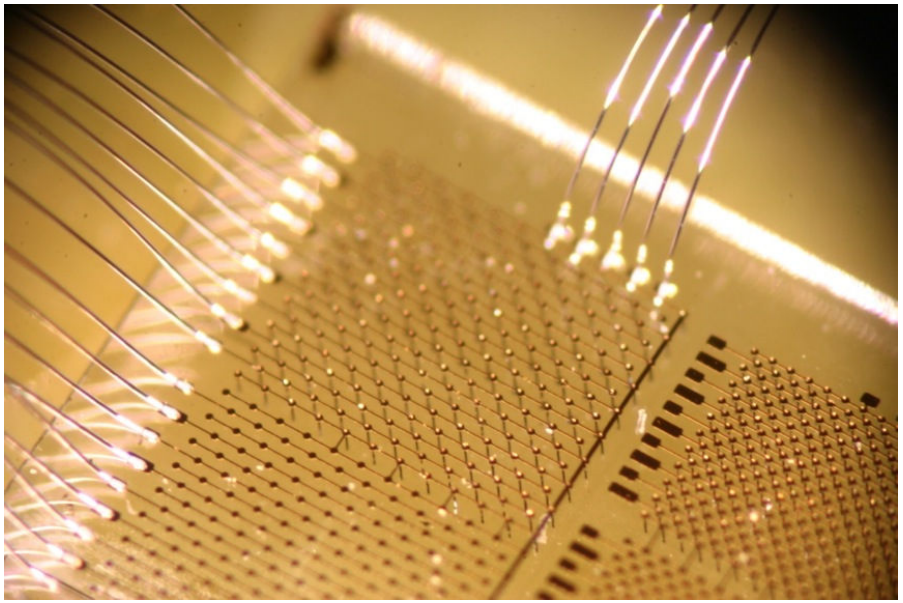
University of Manchester, Laser Processing Research Center.

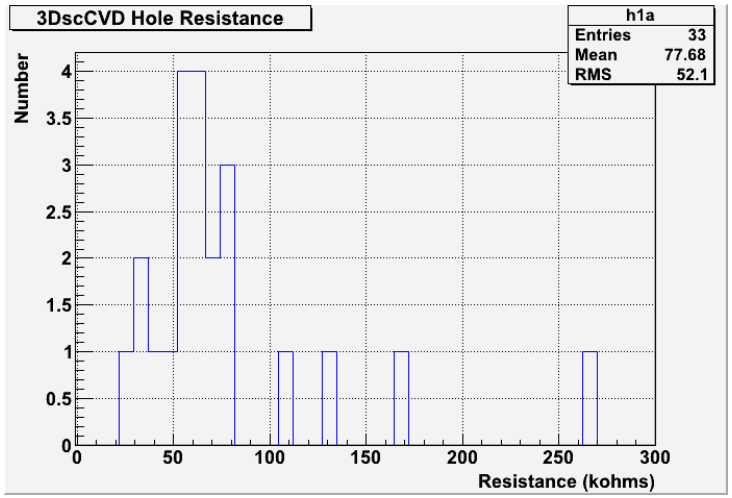
- Column formation starts at the bottom.
- **"Pulp"** formation at the seed side.
- Small **"craters"** observed on the exit side due to lower density of column material.



Fabrication

- **Metallisation**
  - Photo-lithography, lift-off.
  - Ti-Pt-Au sputter.
  - Annealing + Oxygen plasma treatment.

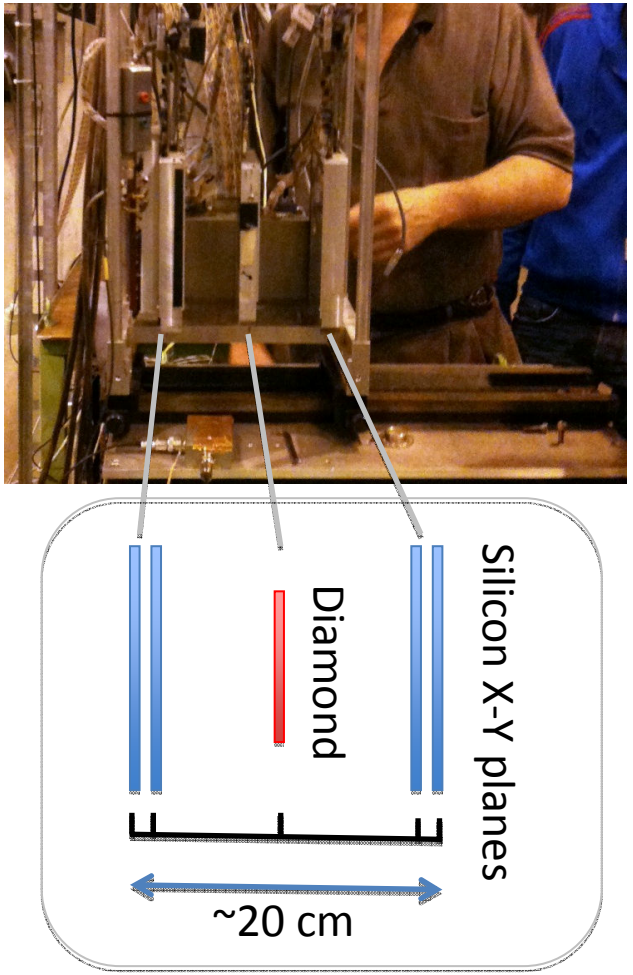




- Yield of working columns ~ 90%.
- Resistivity ~ 1 Ω cm.

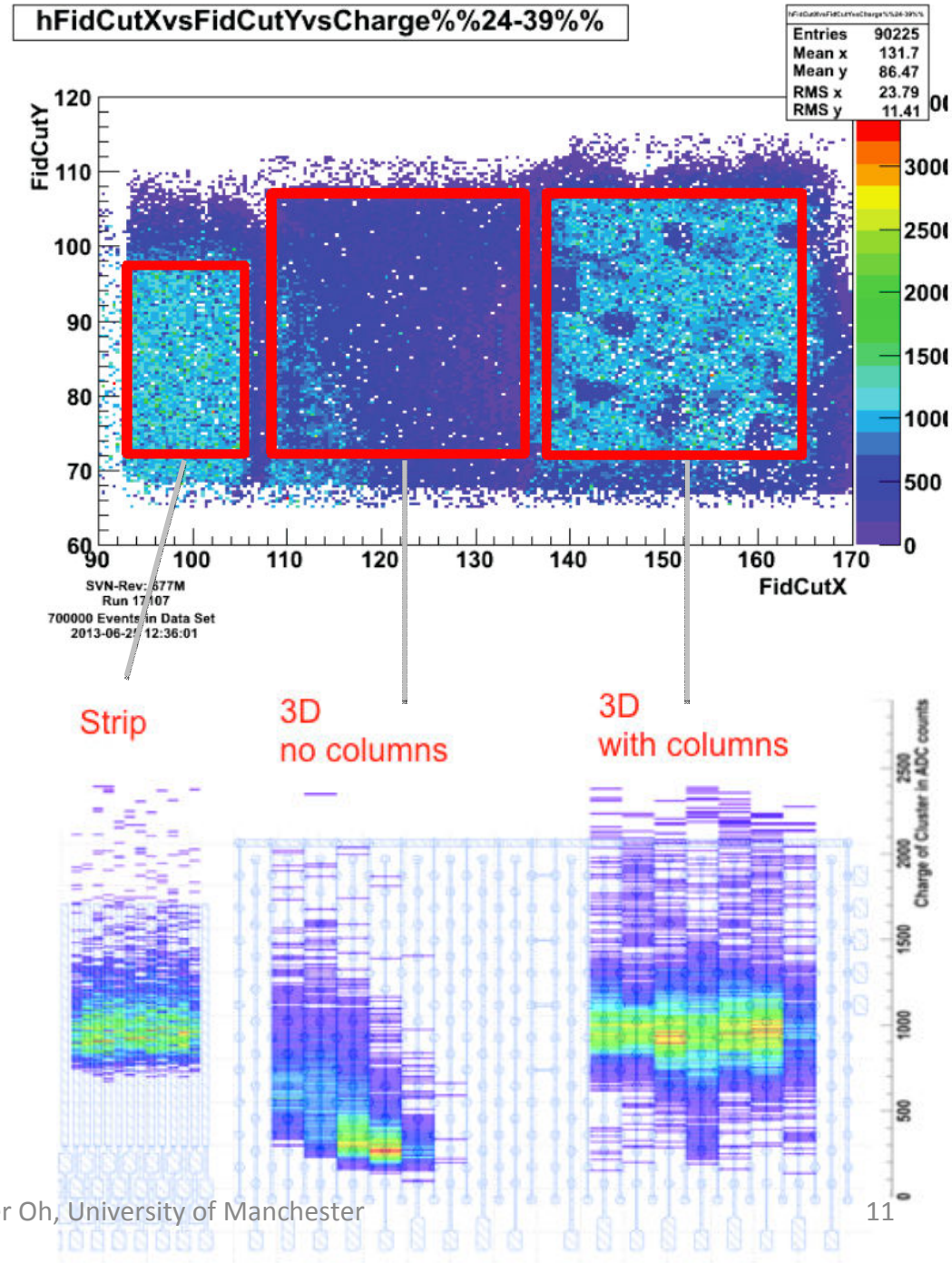
Test-beam

- **CERN Test-beam set-up**
  - SPS H6 beamline
    - Protons with p = 120 GeV/c.
    - spill every 40 sec
    - ~4k events per spill.
  - Silicon telescope for track reconstruction
    - 4 planes of X and Y strips.
    - Resolution few O(μm)
    - Two scintillator (~1 cm^2), trigger on coincidence.
  - DUT primed with β from Sr^{90} before measurement.



Analysis steps

- **1.1M** events recorded U_b(Strip) = 500V U_b(3D) = 25V
  - Require **single cluster** in each Si-plane and a good track fit.
  - Plot **average charge** of primary cluster charge in diamond at predicted position.
  - Define **fiducial regions** for strip and 3D regions.



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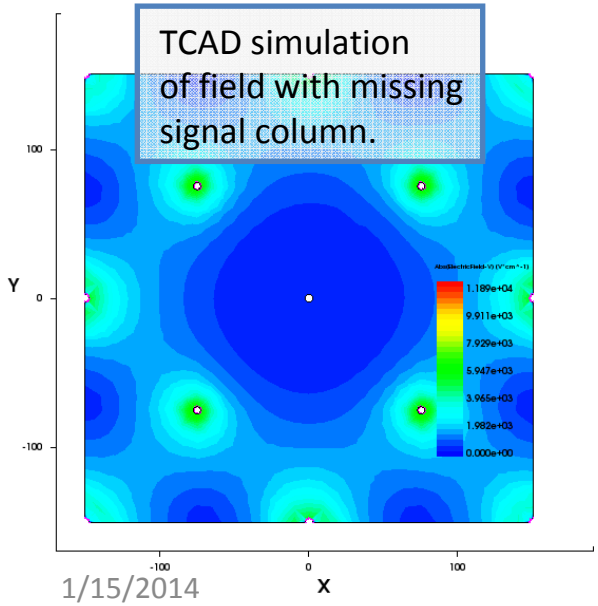
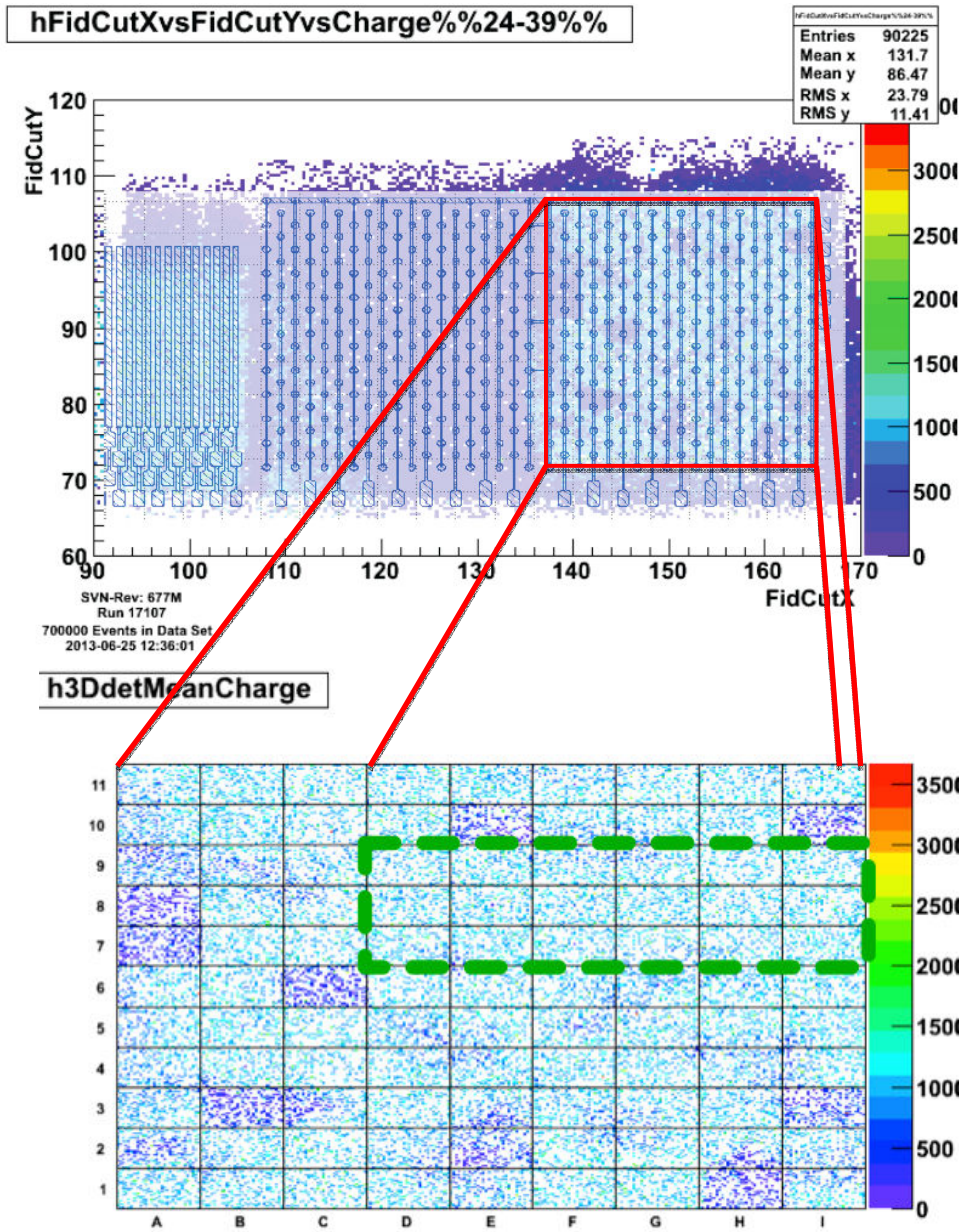
Analysis steps

- Observe varying response due **missing columns**.
- Missing Read-out / HV columns attenuate and spread the signal.
- Identify **continuous region** of intact cells for analysis.





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Test-beam Analysis

- Require a single Silicon track.
- Take cluster charge of **three strips**.

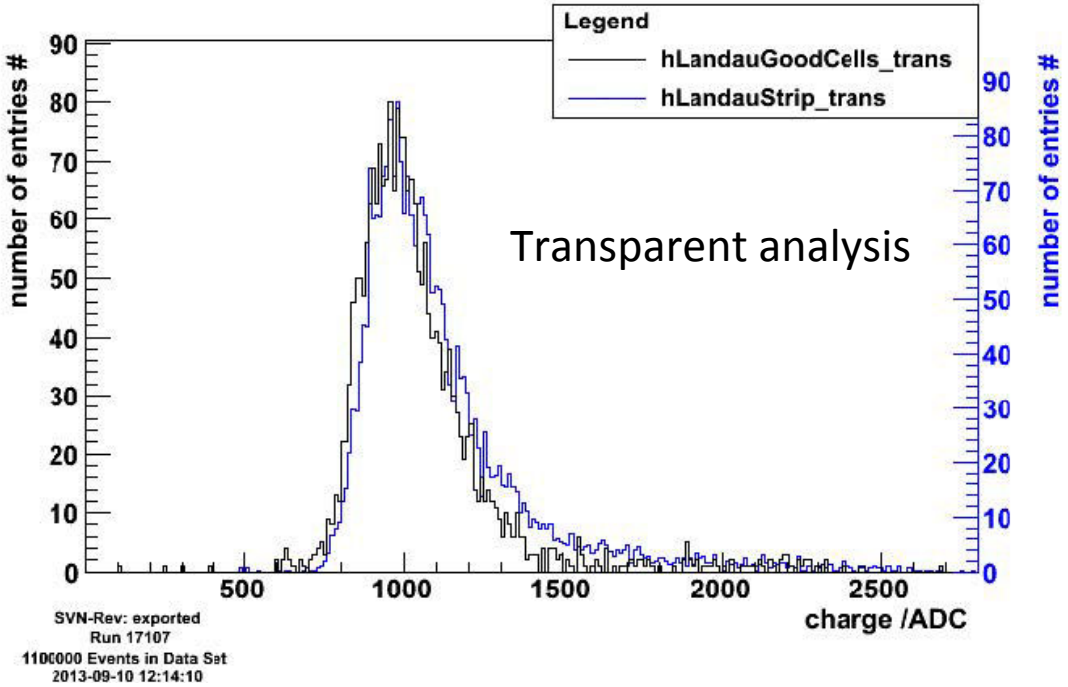
Transparent analysis

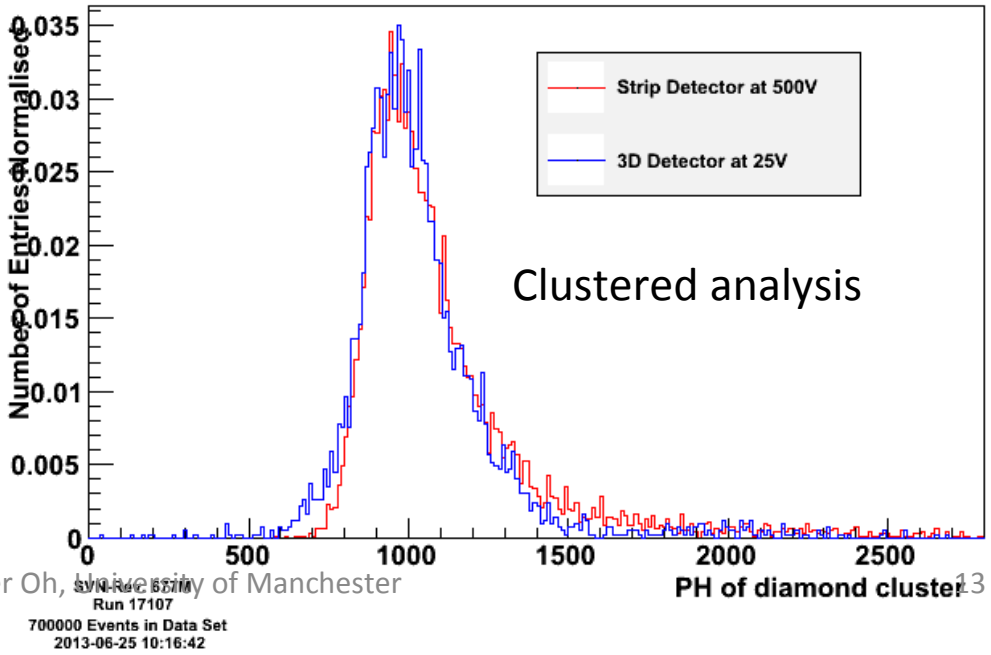
- **Build cluster charge at track position on the diamond.**

Clustered analysis

- **Require a hit in the diamond**

Transparent analysis shows slightly lower signal.

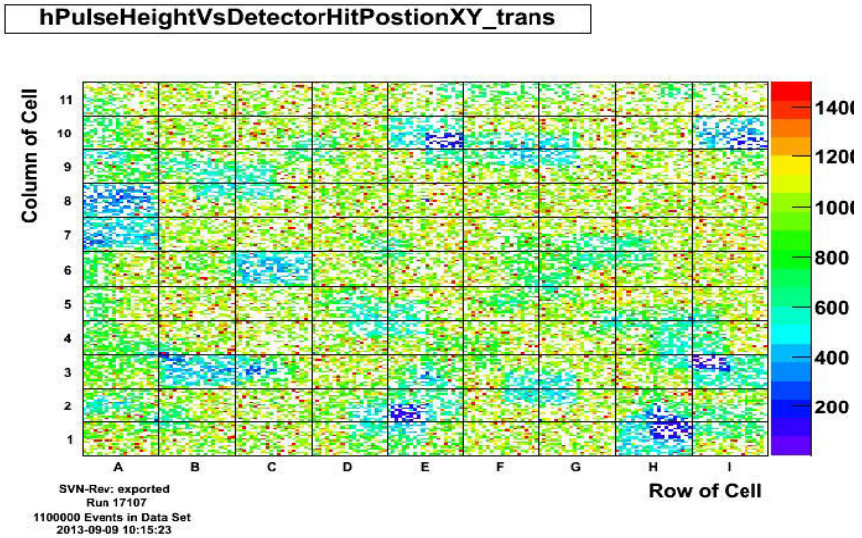


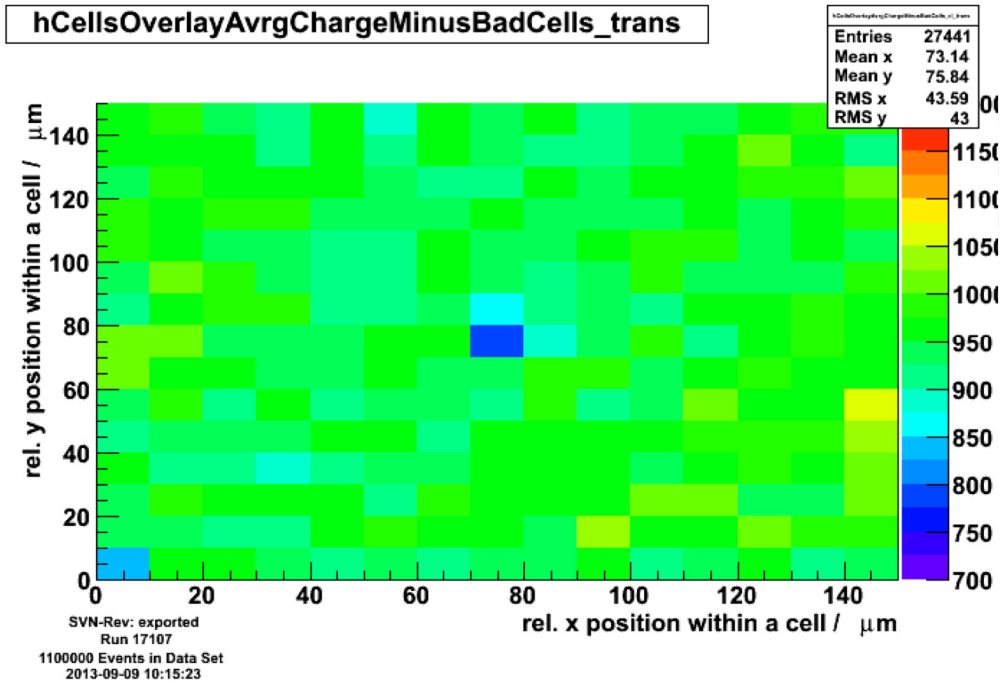


Test-beam

Overlay

- Working cells are projected onto each other.
- Expect to see electrodes.
- Charge deficit consistent with ~6µm column.

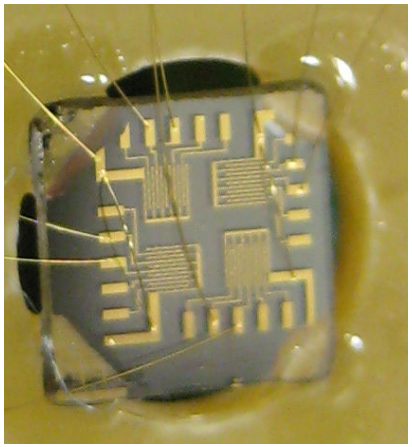


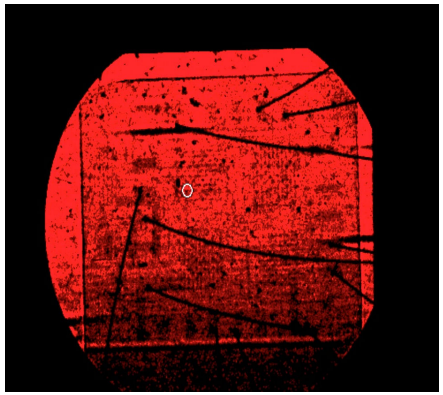


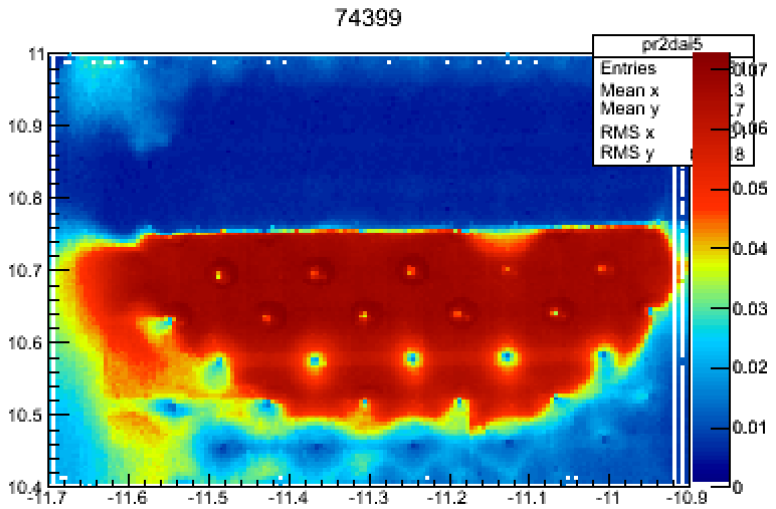
2013 Diamond photon test-beam

Beam time

- **Diamond light source, 15 keV**
  - 28Nov – 3Dev 2013
  - 4 diamond samples
  - First "**all manchester**" 3D diamond detector tested.
    - Graphitic wires (Laser Processing Centre)
    - Structured metallisation and bonding (School of Electrical and Electronic Engineering)
    - Assembly and test (School of Physics and Astronomy)
  - Collected data with multi-strip read-out.
  - Analysis in progress.



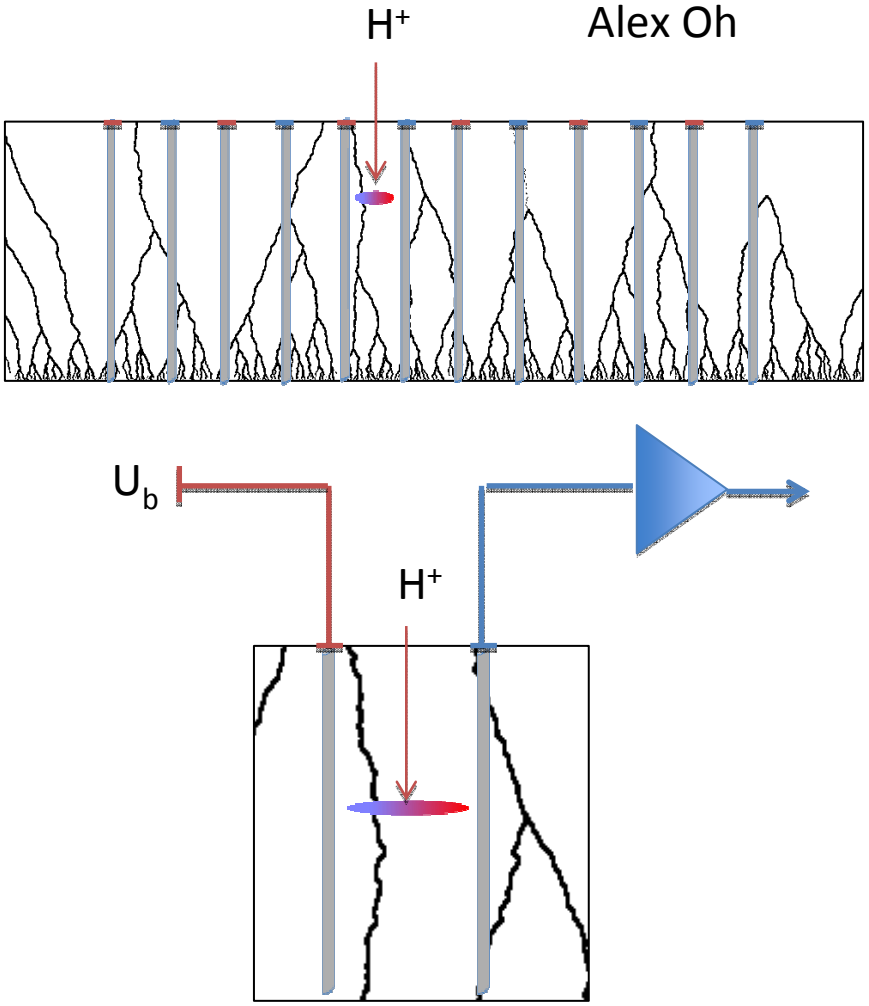




IBIC @RBI

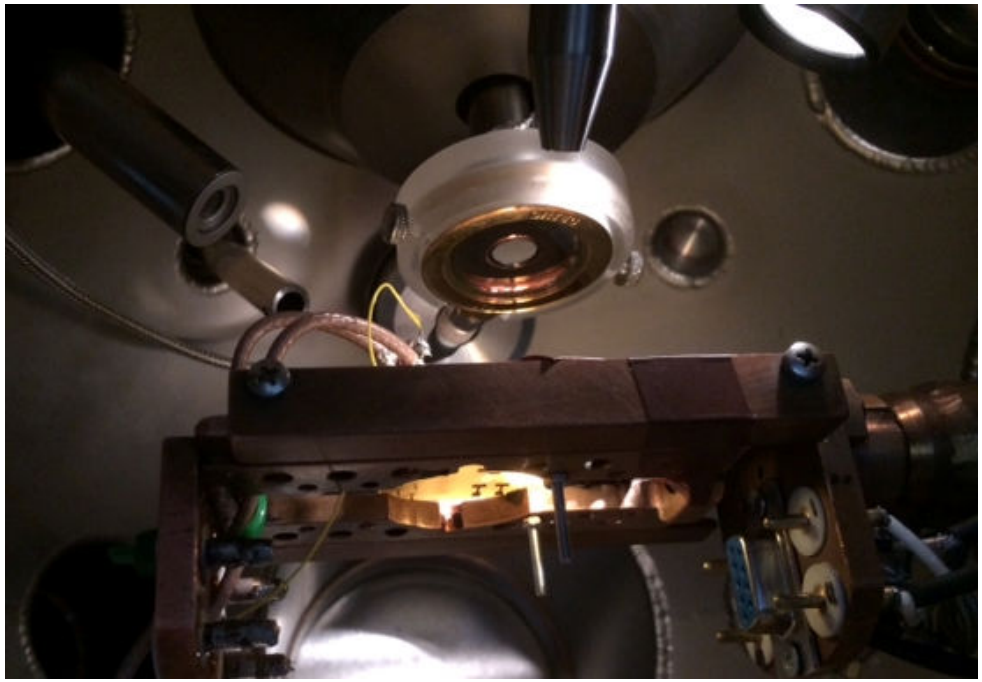
Natko Skukan
Milko Jaksic
Benoit Caylar
Iain Haughton
Alex Oh

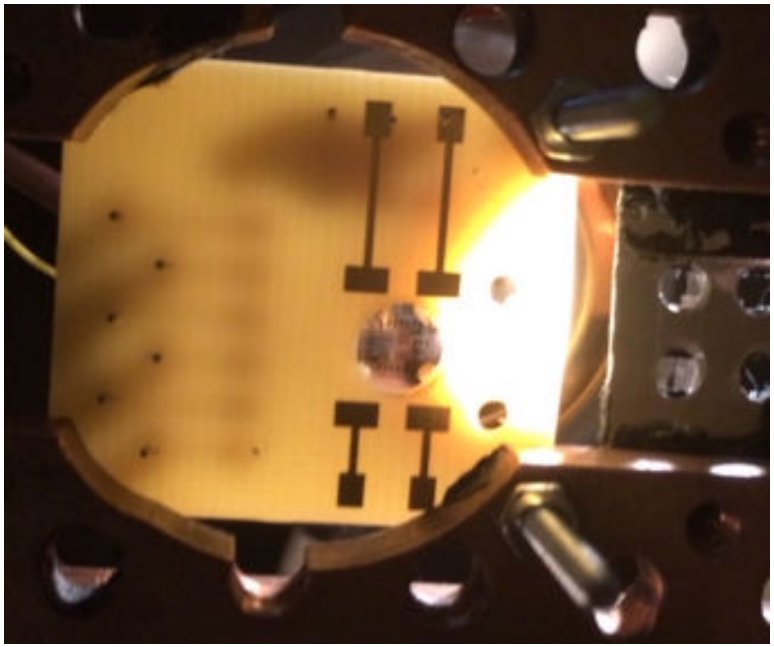
- 4.5 MeV protons
- 2mum resolution
- Single proton counting / irradiation possible
- Tested batch 1 SC and batch 2 pCVD 3D prototypes.
- Objective:
  - Map response with 4.5 and 4 MeV protons (~100 / 80 um penetration).
  - Lateral charge collection in 3D-> no polarisation!



IBIC @RBI

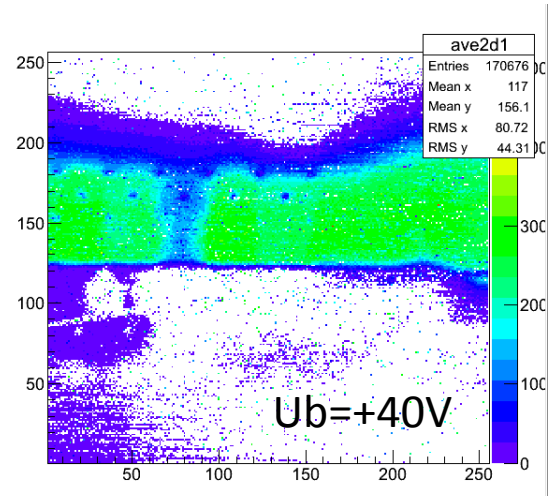
- Sample Holder, **SC-CVD "all Manchester"**

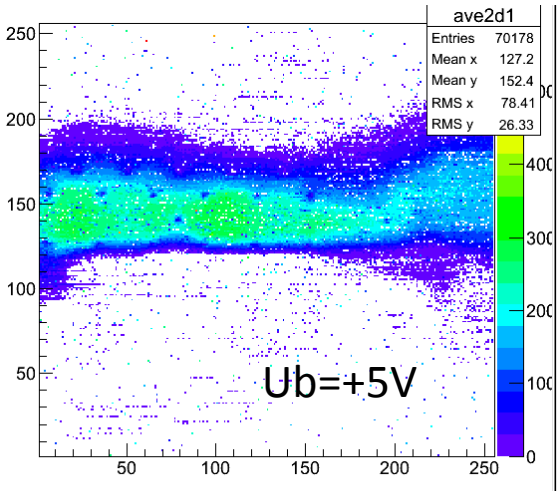


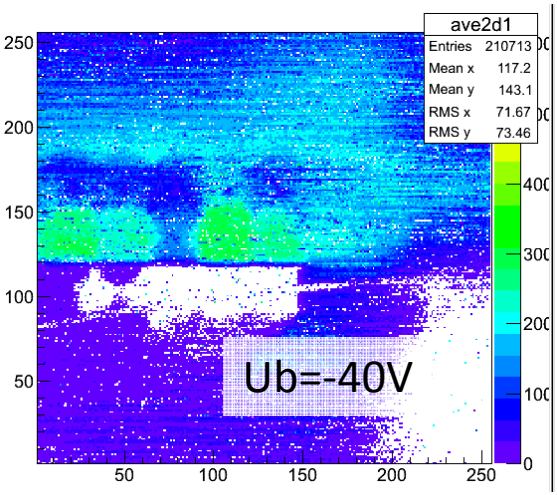


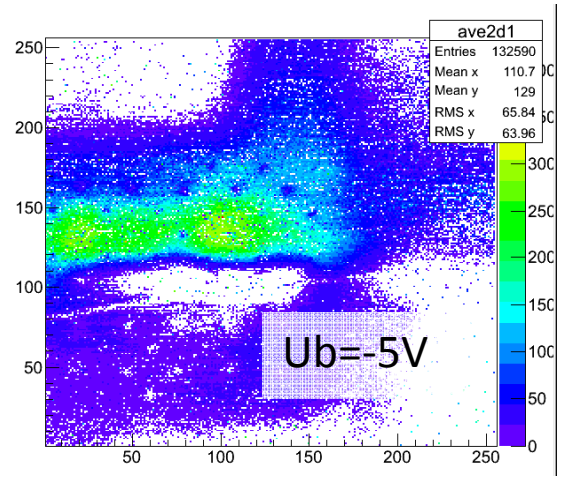
- Setup:
  - Two adjacent strips connected to separate channels.
- Response to 4 MeV protons.
- Areal response (~800x800 um):

- Response contained in basic cell.
- No charge sharing observed.
- Pos and neg polarity different response, one carrier type dominates at low fields?









Preliminary,
Data is 3 days old.

Transient Current

TCAD simulations to understand the time structure

- 3D electric field in 3D detectors is wire chamber like, not plate capacitor like.
- Expect that the time structure of the signal depends on position.
- Simulation work with TCAD and diamond 3D detector has started.

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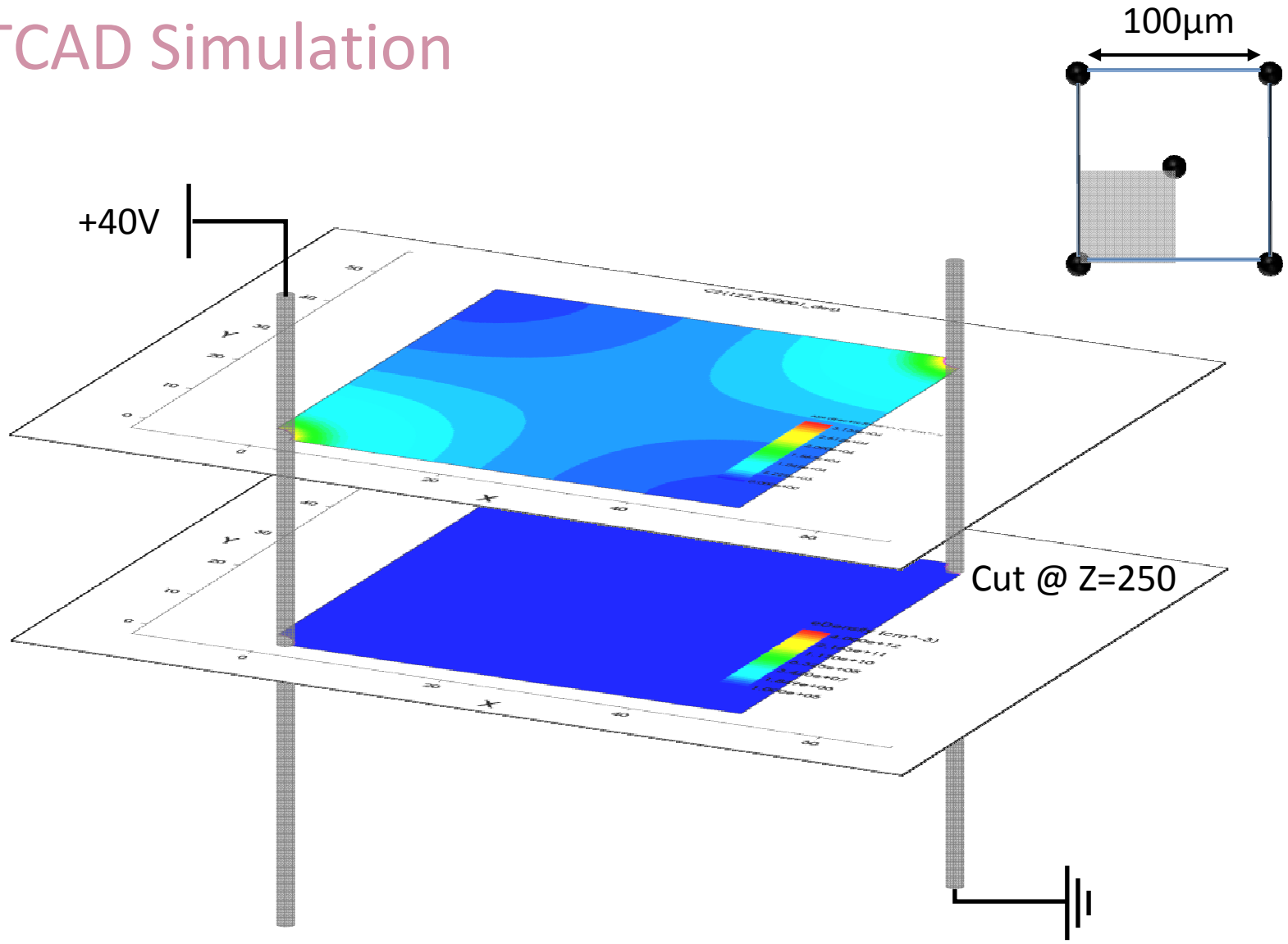
Motivation

TCAD Simulation



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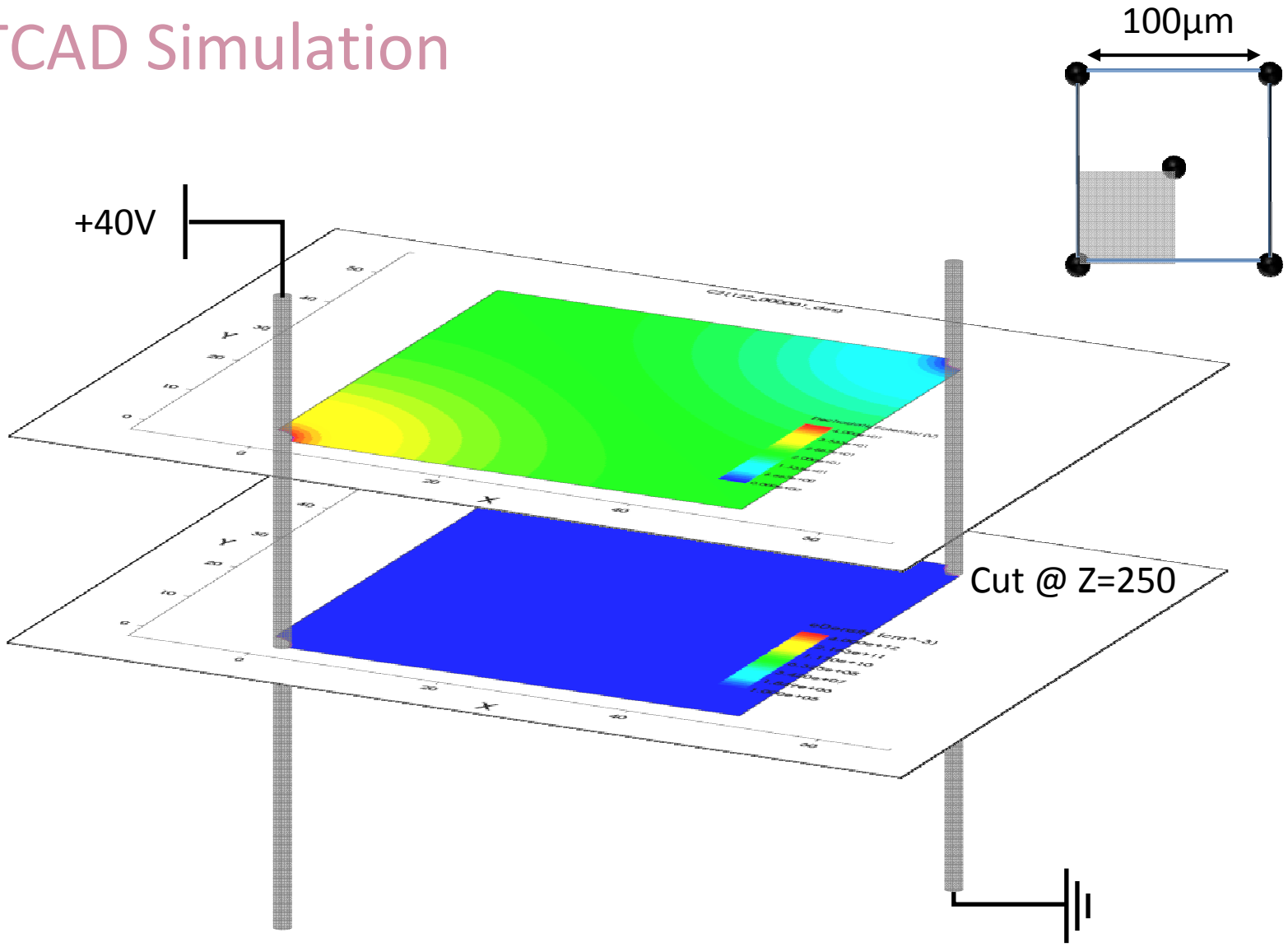
TCAD Simulation



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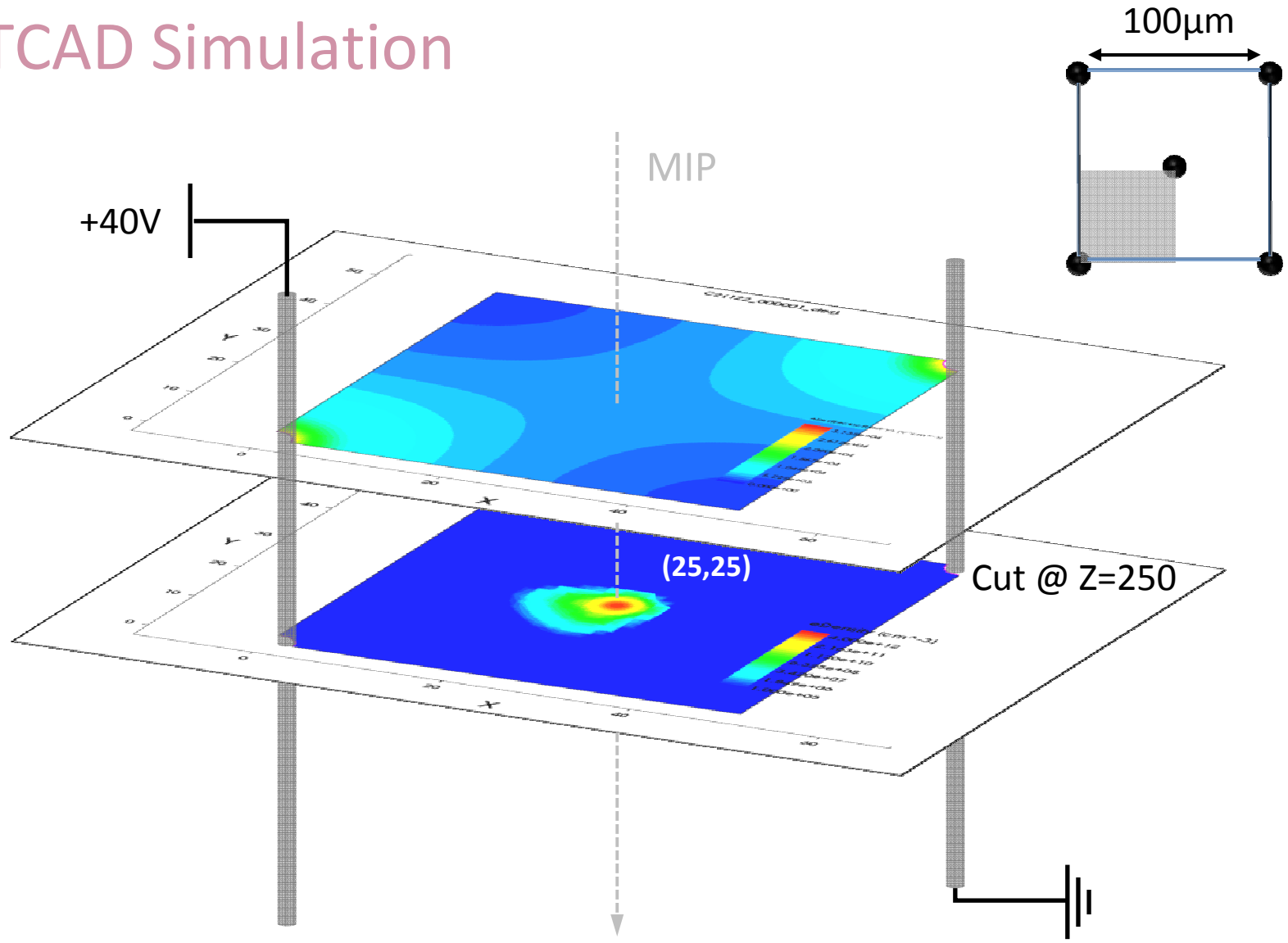
Motivation

TCAD Simulation



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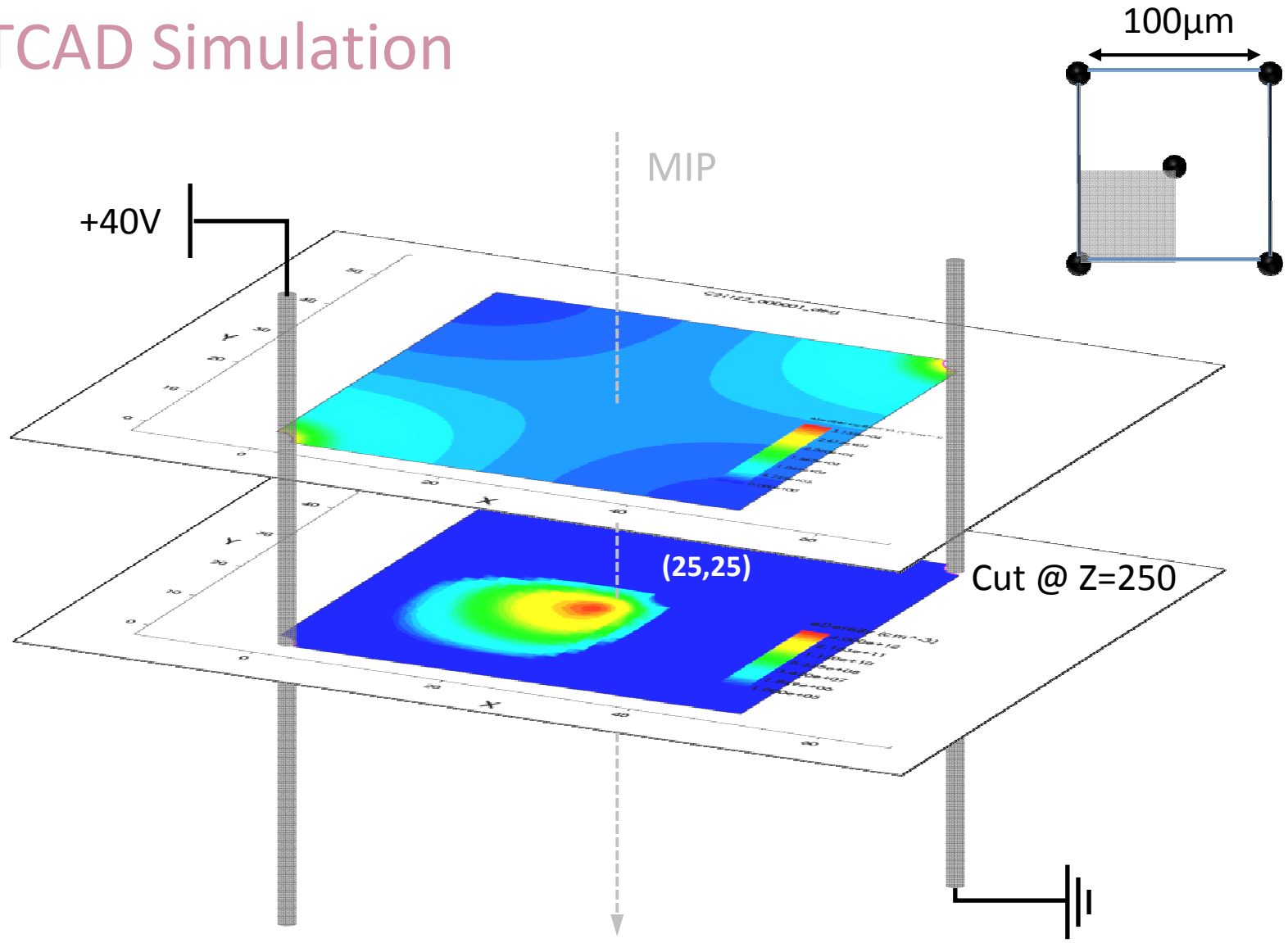
Motivation

TCAD Simulation



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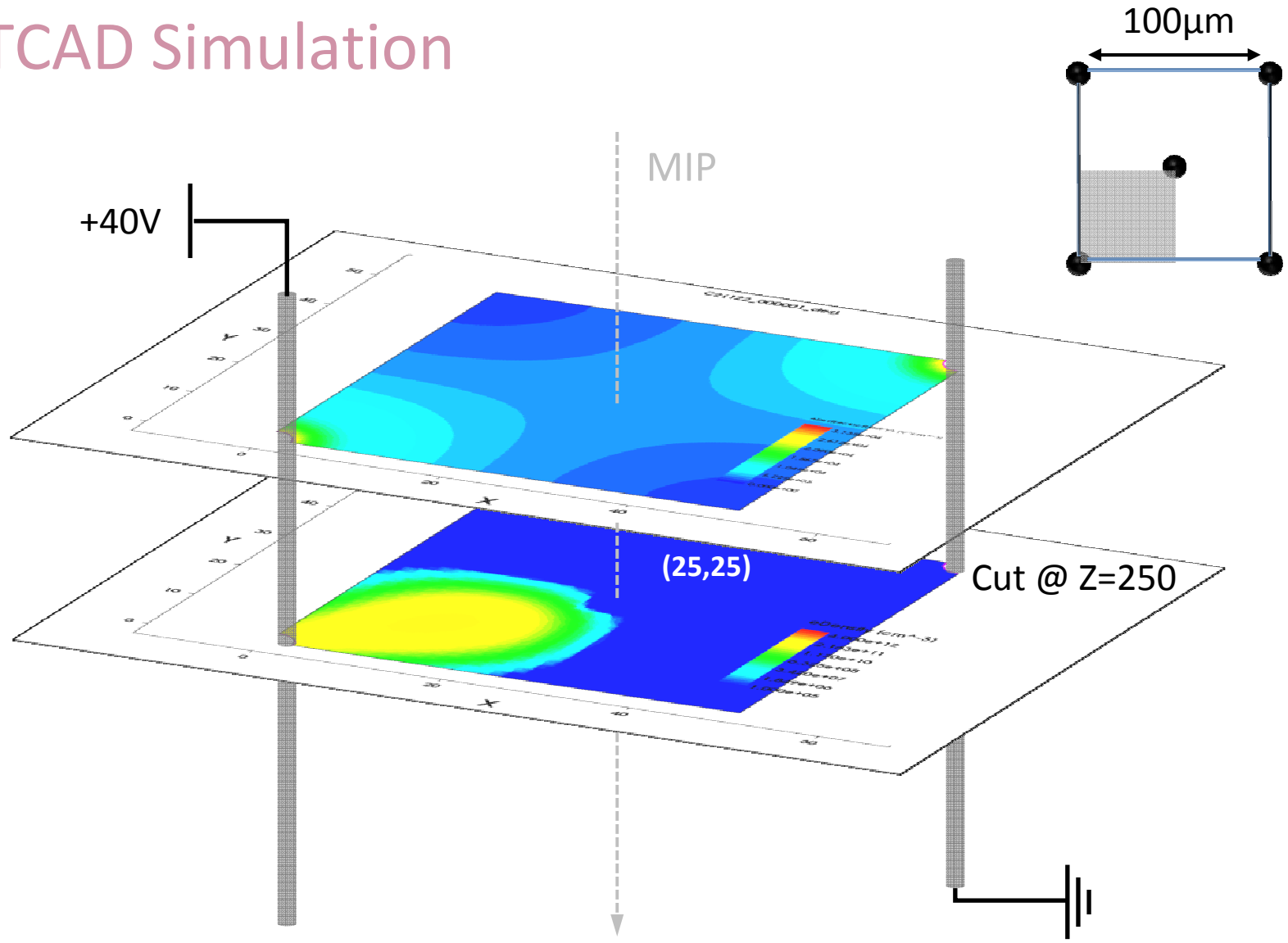
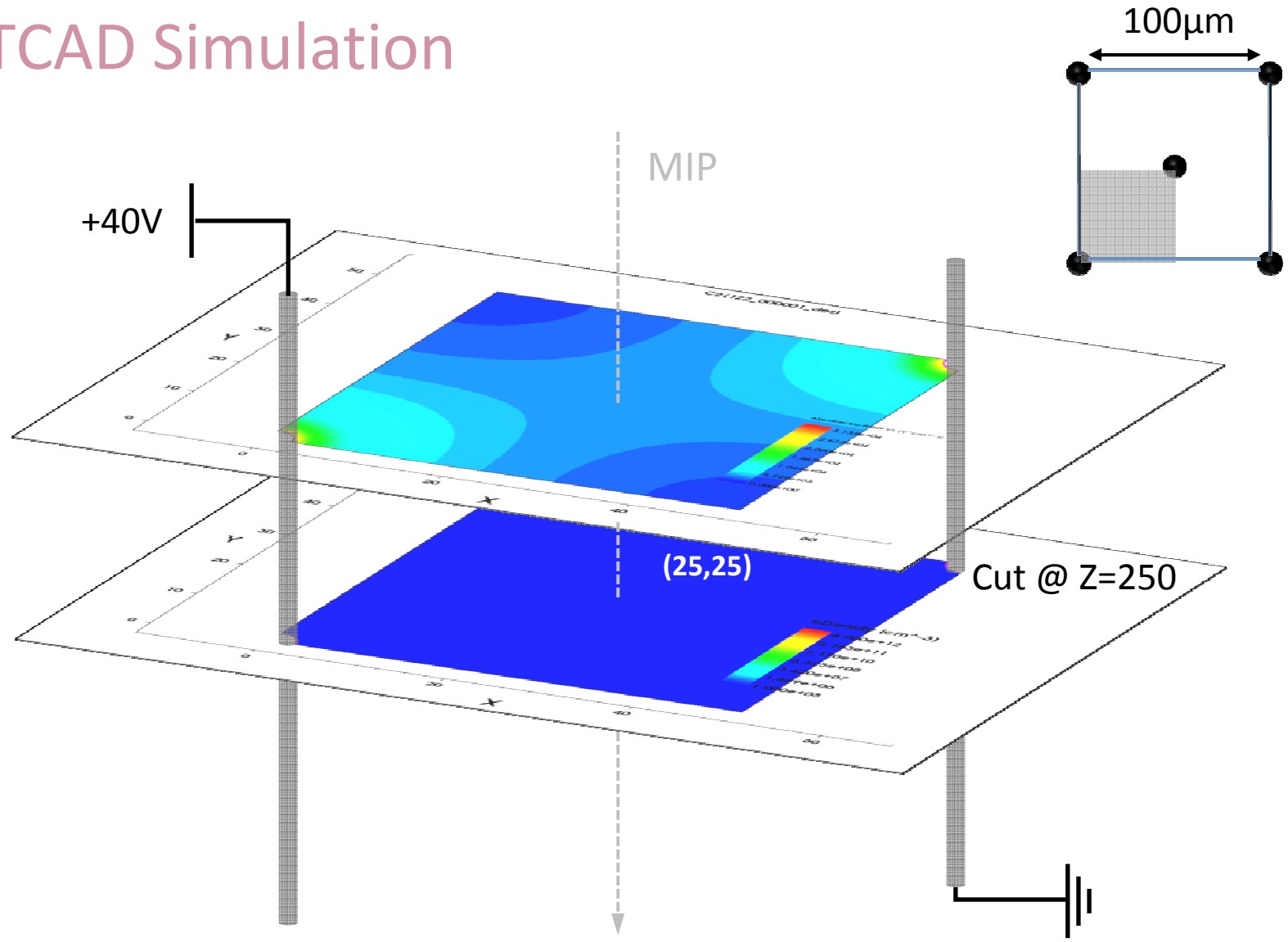
Motivation

TCAD Simulation



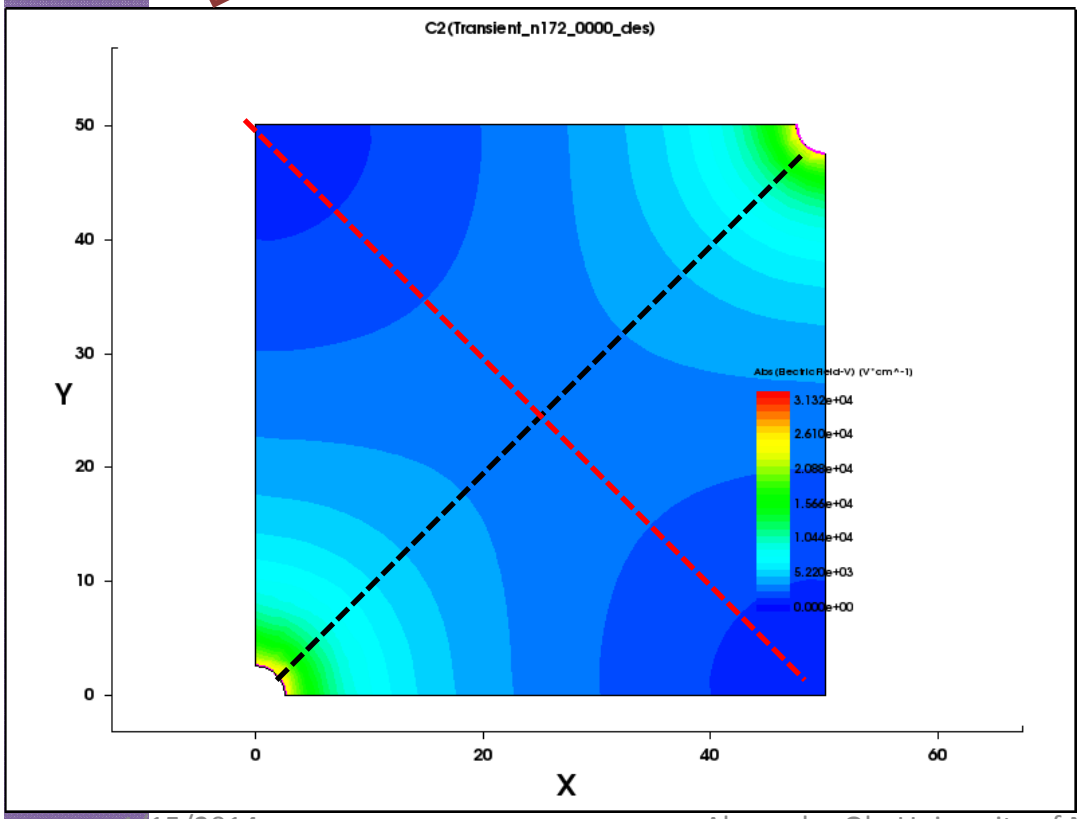
Motivation

TCAD Simulation

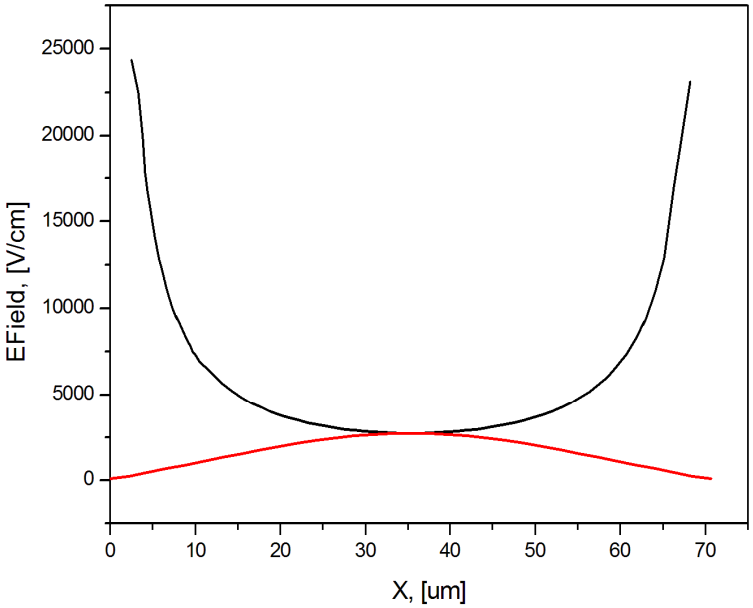


Electric Field (HV = 40V)

PRELIMINARY



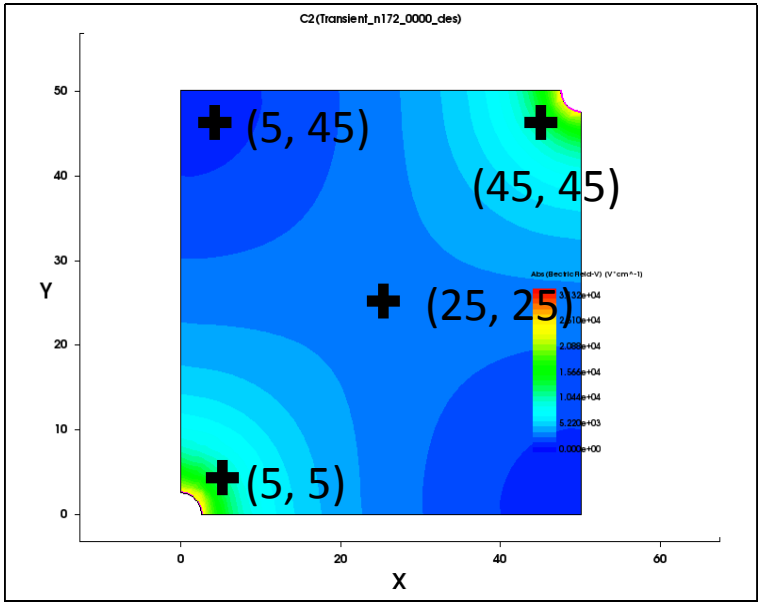
EField, Diagonal cuts

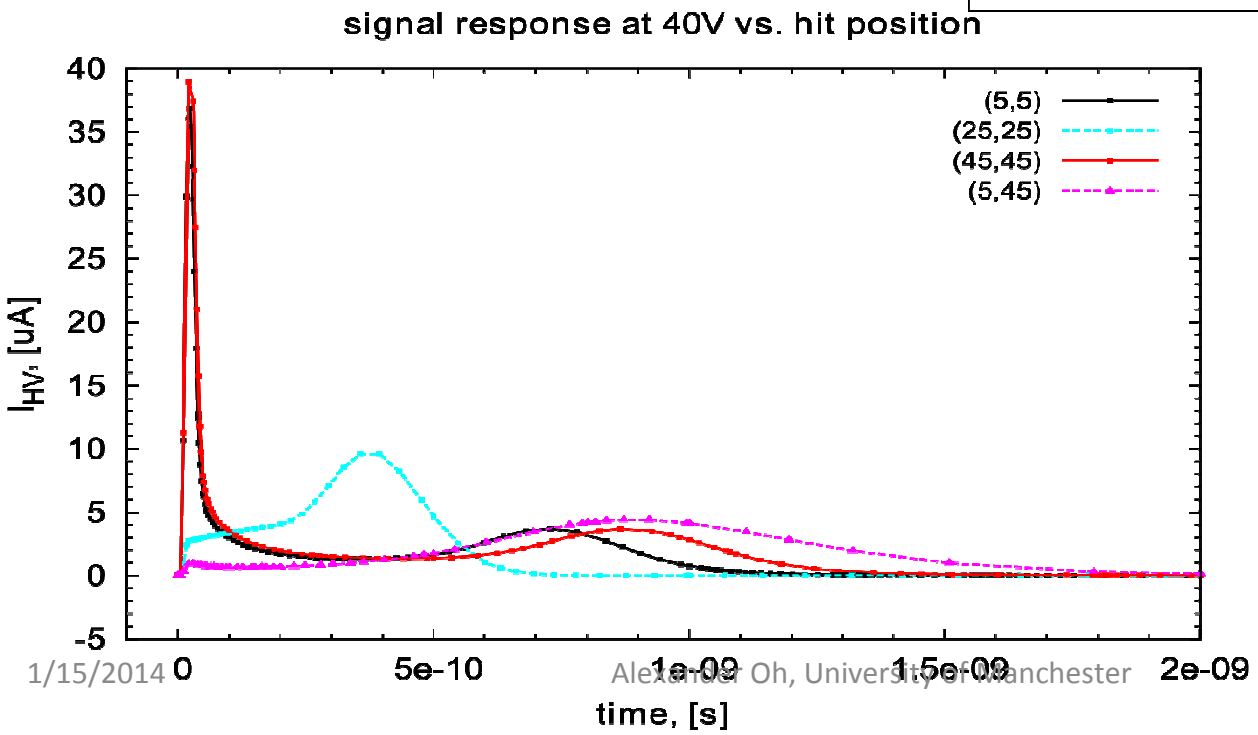


Signal response

PRELIMINARY

$\mu_{0,e}$=1714 cm2 /V s
$\mu_{0,h}$=2064 cm2 /V s





Transient Currents Technique

To understand the timing behaviour look at TCT.

- Use Proton micro beam in RBI, Zagreb, Croatia to study time structure of signal
  - See talk by Milko
- First proof-of-principle measurements done in May 2013 on a single crystal 3D Diamond.
- Second set of measurements planned for later this week.

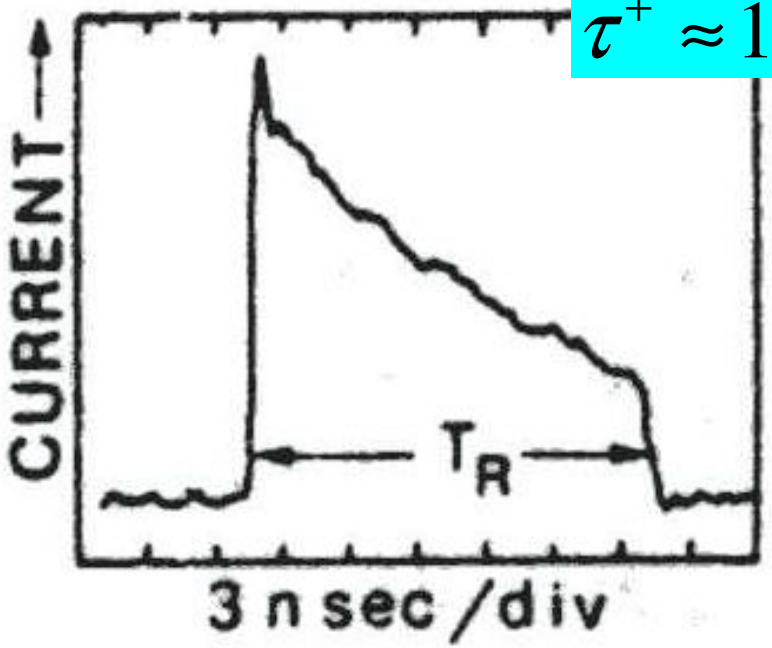
5. Time resolved IBIC - tribic

(transient current technique, TCT)

- use of current sensitive amplifier instead of charge sensitive
- high frequency oscilloscope (2GHz)
- novel technique

400 µm thick natural diamond

$\tau^{+} \approx 15ns$



$$I = q \cdot \frac{v}{d} \cdot \exp\left[-\frac{t}{\tau}\right]$$

C. Canali, E. Gatti, S.F. Koslov, P.F. Manfredi, C. Manfredotti, F. Nava, A. Quirini
Nucl. Instr. Meth. 160 (1979) 73-77

Slide from Veljko Grilj, RBI

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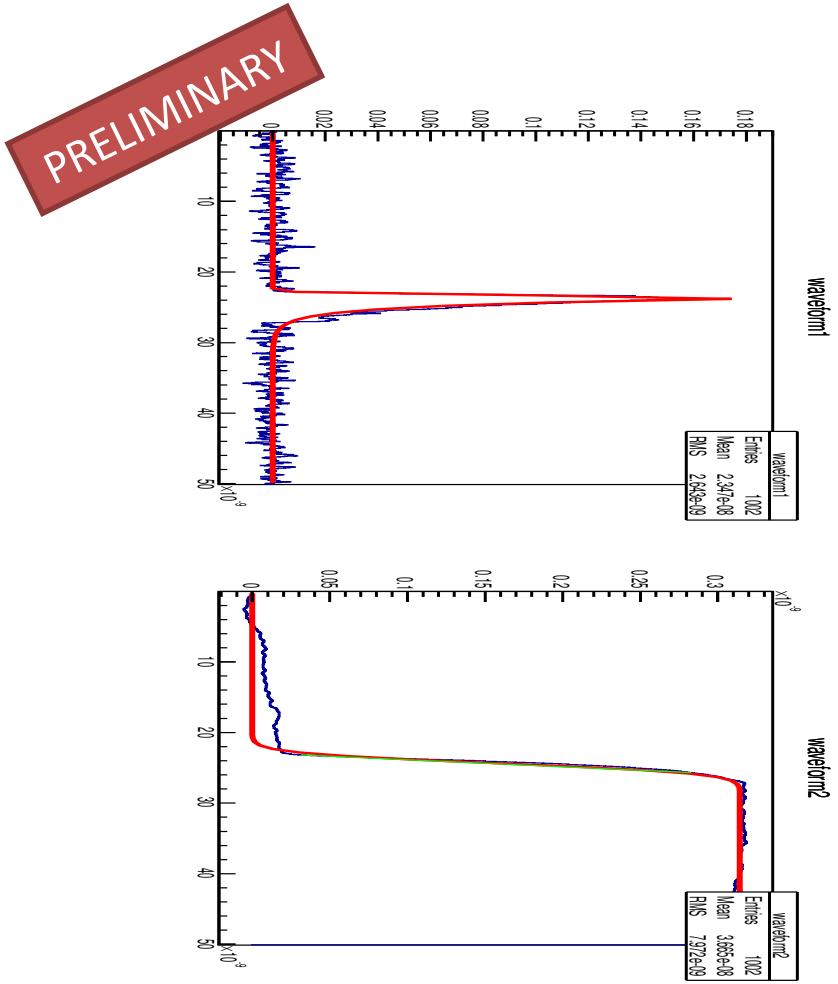
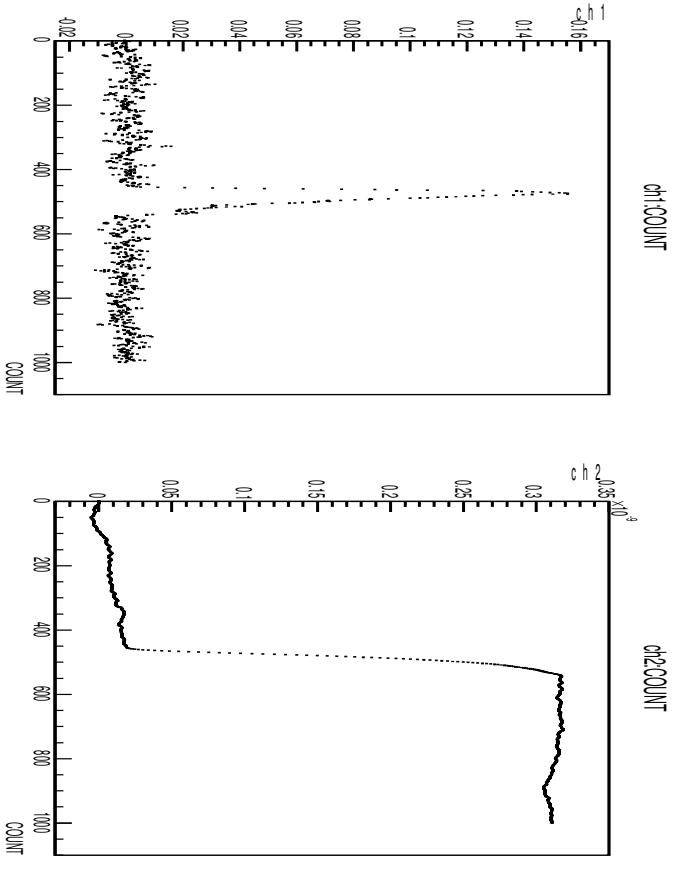
TRIBIC measurements

PRELIMINARY

A biased selection of a single signal

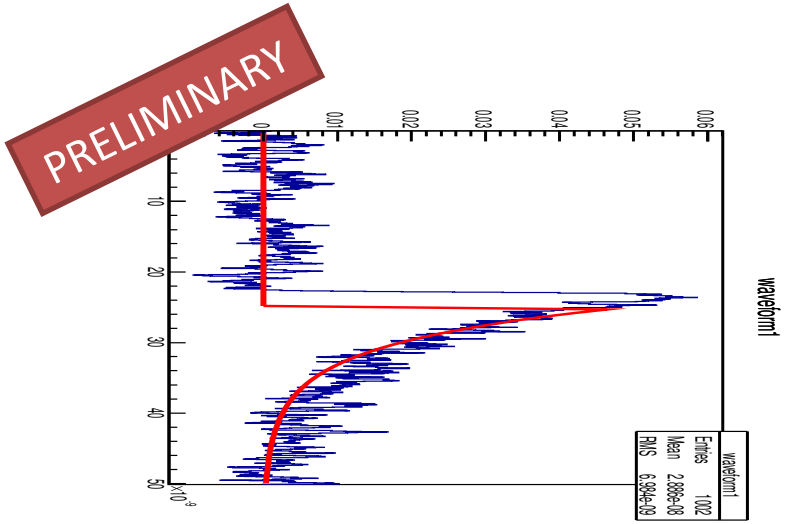


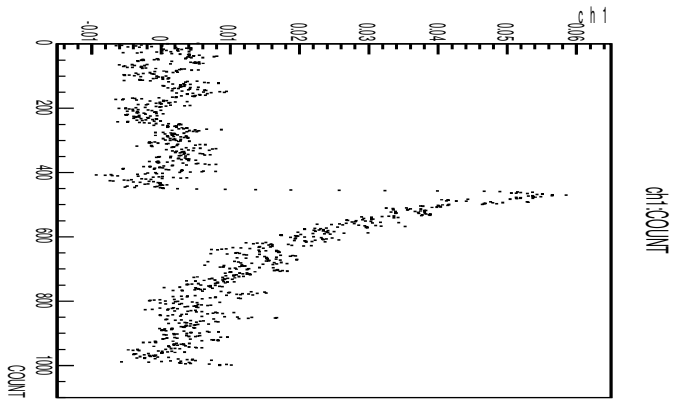


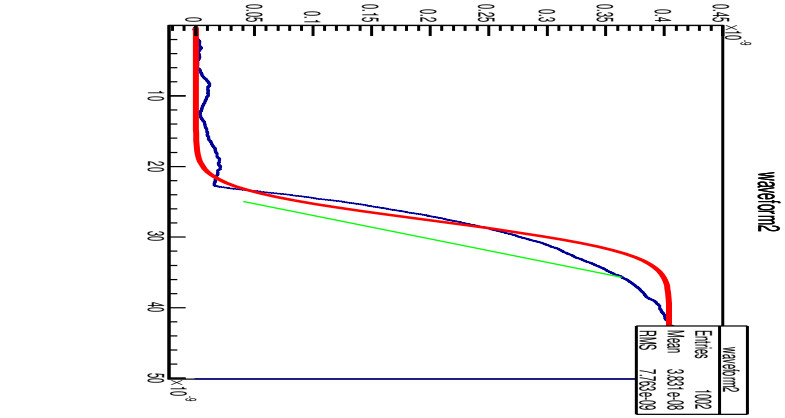
TRIBIC measurements

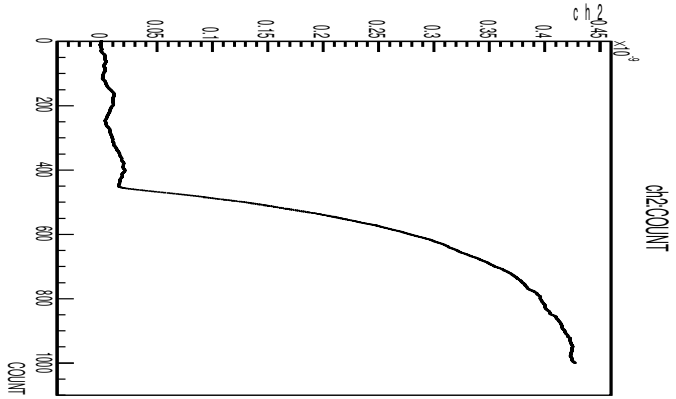
PRELIMINARY

A biased selection of a single signal



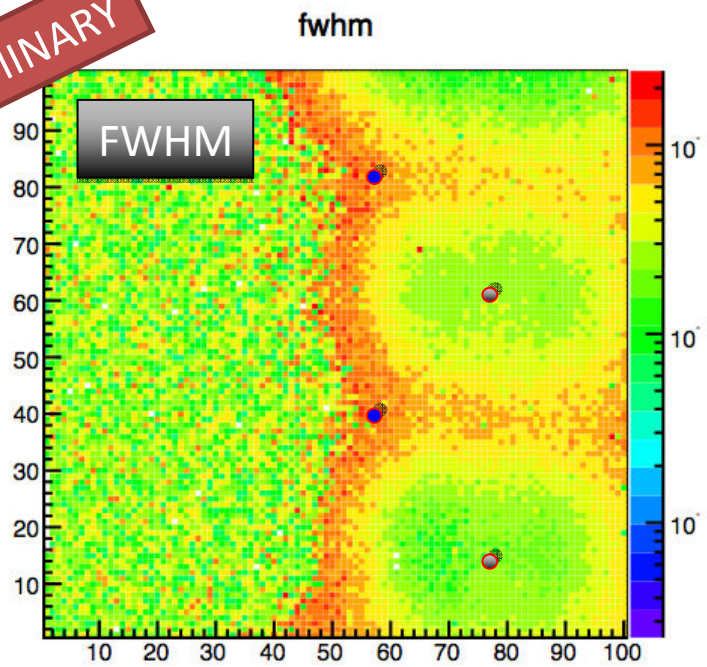




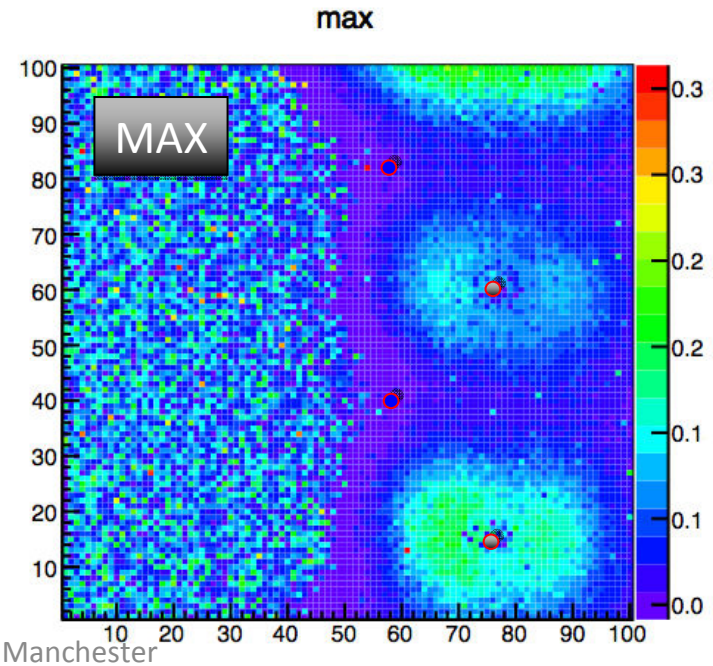


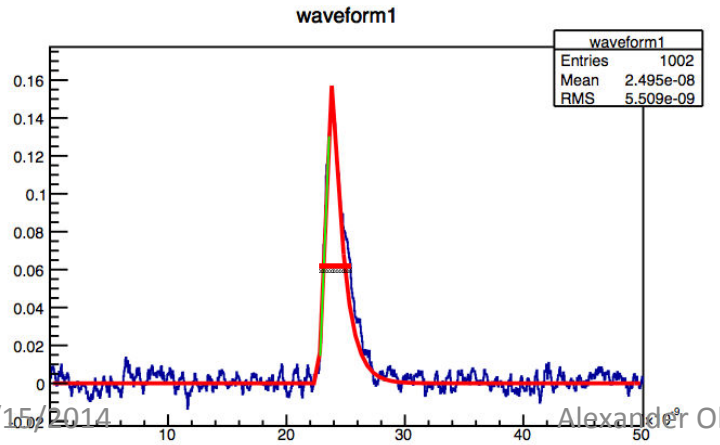
TRIBIC measurements

PRELIMINARY



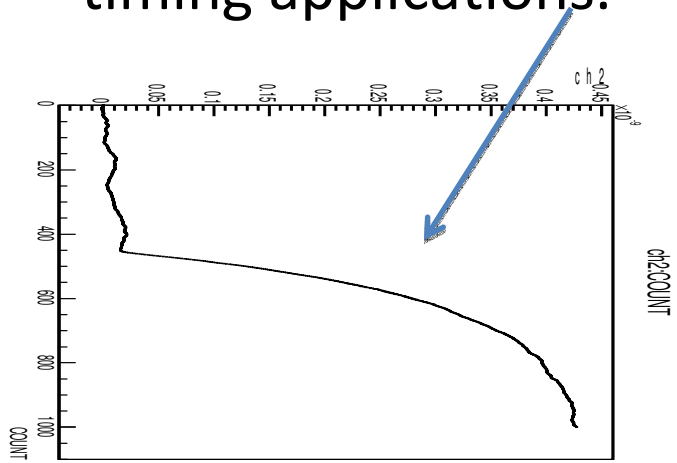
- Spatially resolved, each dot represents a measurement.
- Measurement is self triggered, noise is seen on the left side.
- Three cells are visible.
- FWHM varies from ~3ns in the center to ~10ns on the fringe.





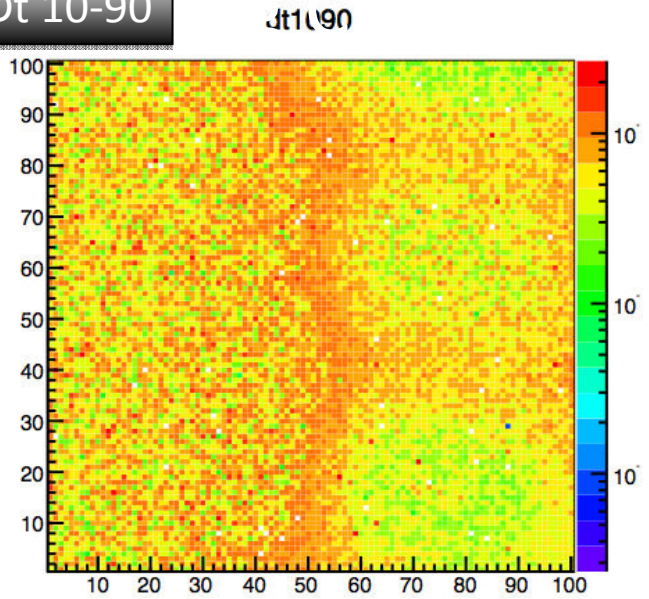
TRIBIC measurements

- Determine time of 10%-90% transition of integral of current signal.
- RMS ~ 2.8ns
- Looks challenging to use integrated charge signal for timing applications.

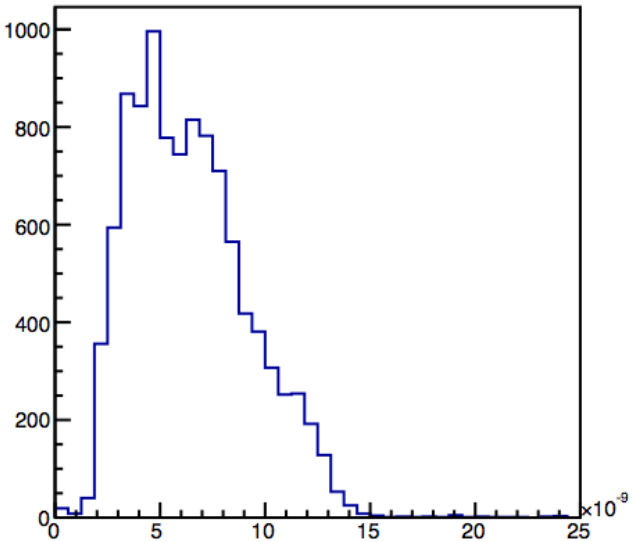


PRELIMINARY

Dt 10-90



Dt 10-90



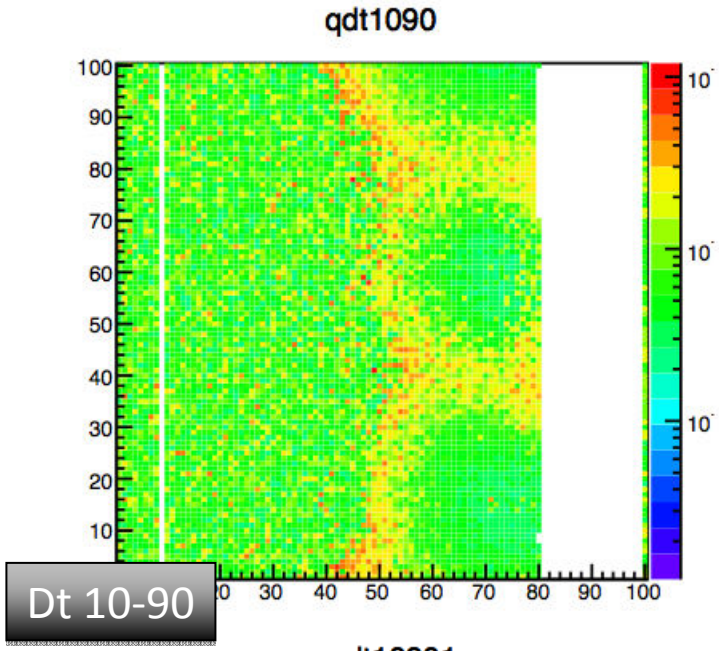
MANCHESTER 1824

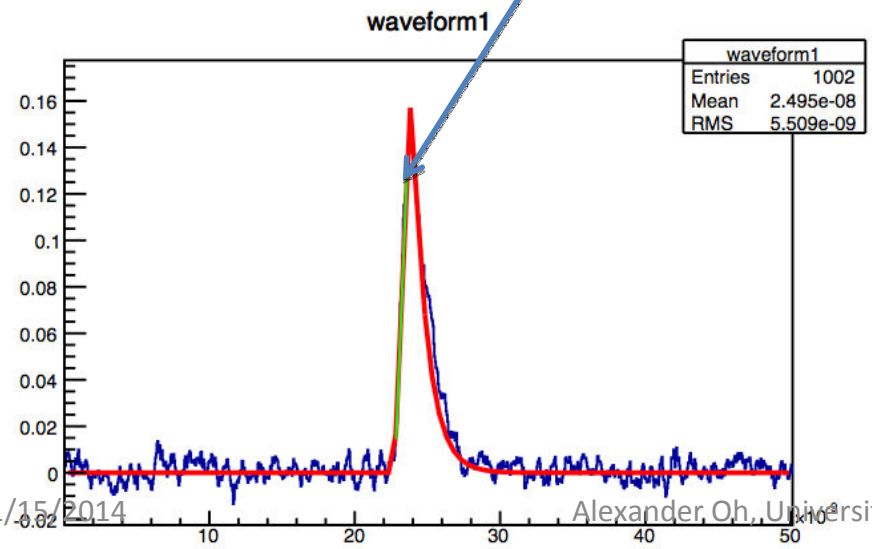
The University of Manchester

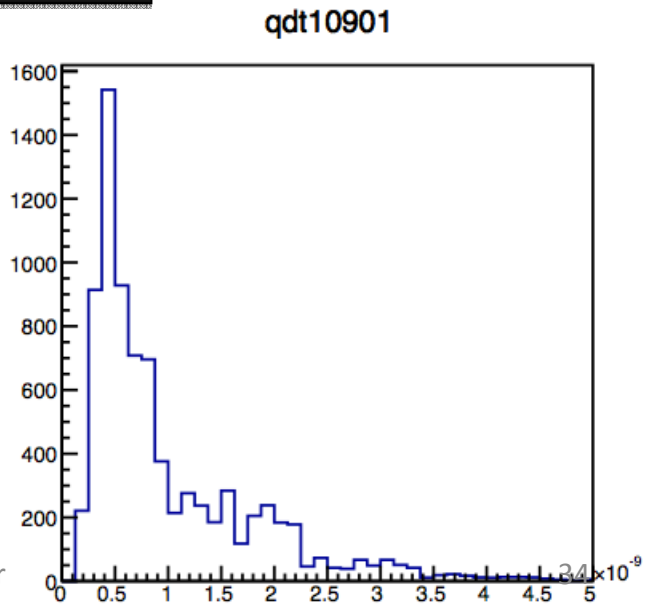
PRELIMINARY

TRIBIC measurements

- Determine time of 10%-90% transition of current signal.
- RMS << 1ns
- Looks promising if noise can be controlled.

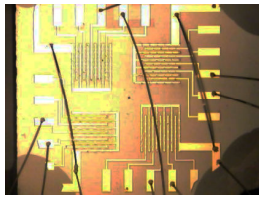


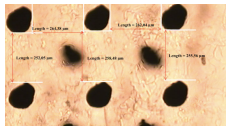


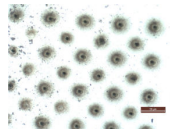


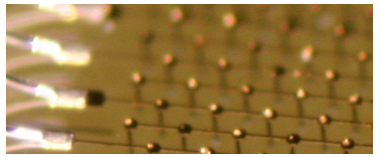
Summary

- **Good progress made in the last years towards 3D diamond detectors.**
- CVD diamond samples with graphitic bulk electrodes were investigated with a **micro-focused photon beam, proton micro beam** and **CERN test beam**.
- 3D diamond configuration works for **pCVD and single crystal diamond.**
- **Studies demonstrate the feasibility of 3D electrode structures in diamond.**
- **The next steps are :**
  - **Further improvement of the laser process.**
  - **Study of the radiation hardness.**



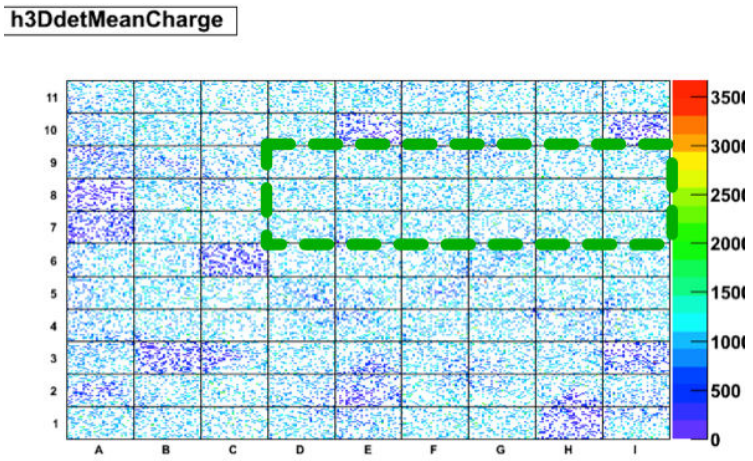






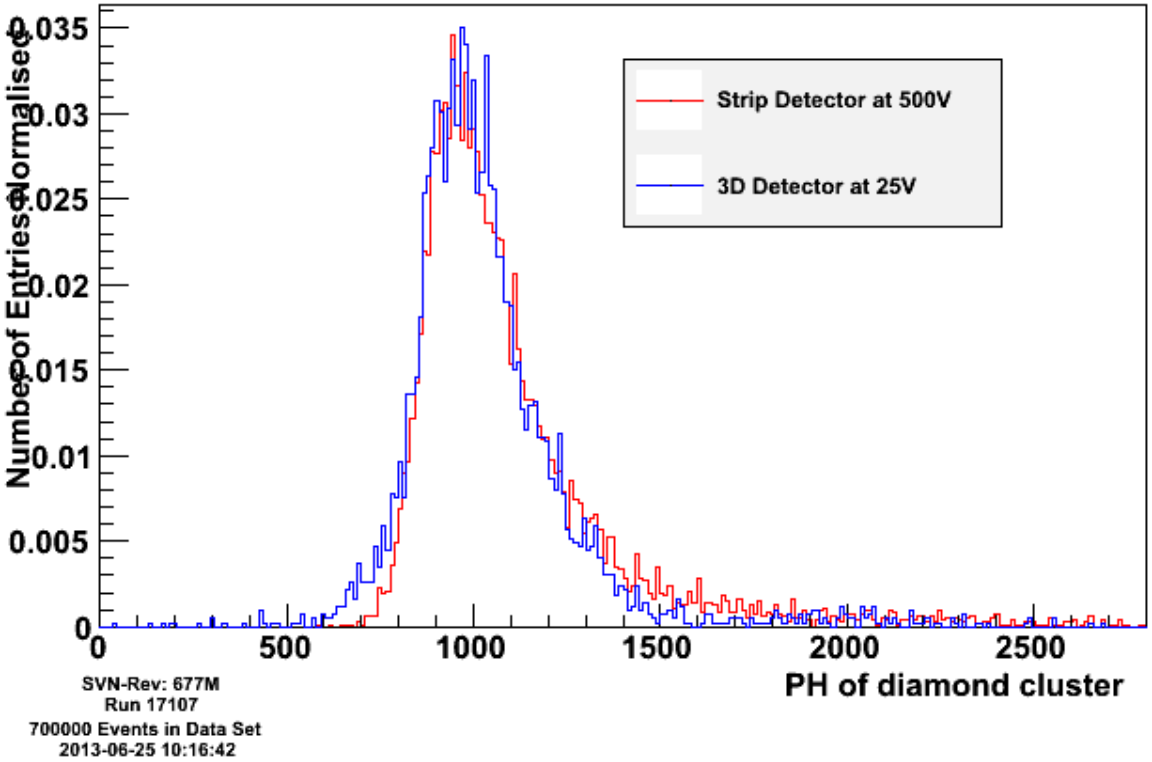
BACKUP

Test-beam



Clustered analysis

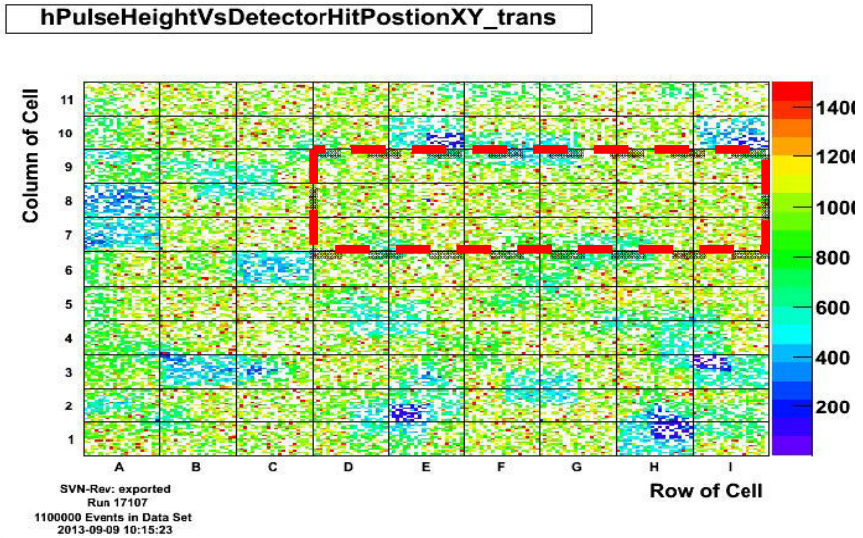
- Require a single Silicon track.
- **Require a hit in the diamond**
- Take cluster charge of **three strips**.
- **Most probable value of strip and 3D similar.**

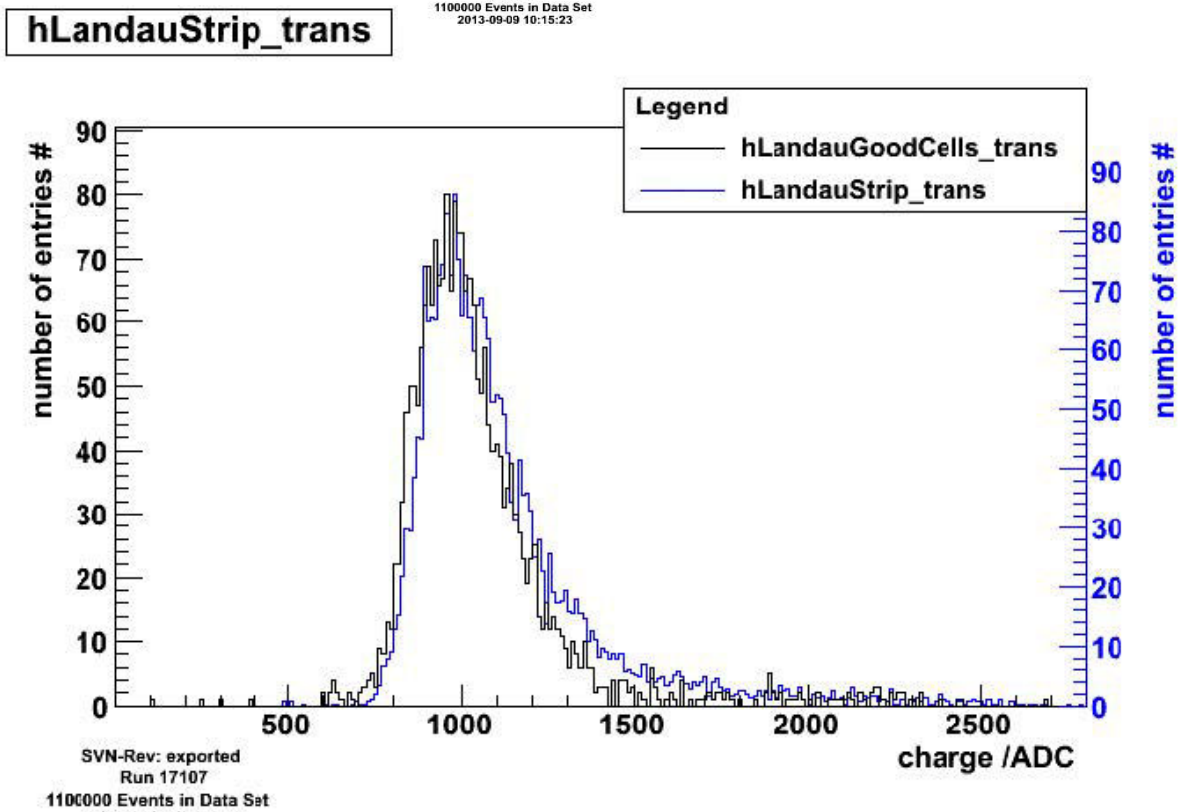


Test-beam

Transparent analysis

- Require a single Silicon track.
- **Build cluster charge at track position the diamond.**
- Take cluster charge of **three strips**.
- **Most probable value of 3D slightly below strip.**





Test-beam

Overlay

- Working cells are projected onto each other.
- Expect to see electrodes.
- Charge deficit consistent with ~6μm column.