The University of Manchester

MANCHESTER 1824

27.11.17

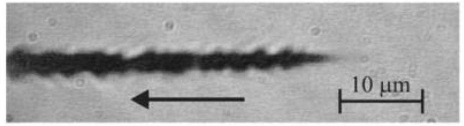
Updated on 3D Diamond developments

Alexander Oh
University of Manchester

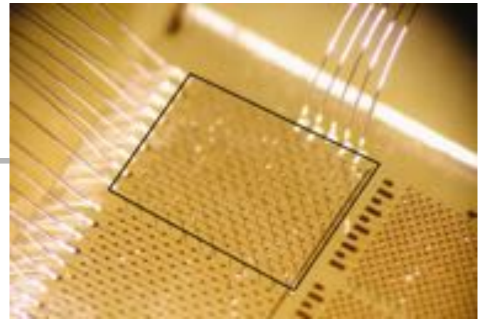
Thanks for material from the RD42 and ADAMAS collaborations!

3D Diamond Research - A relatively young field

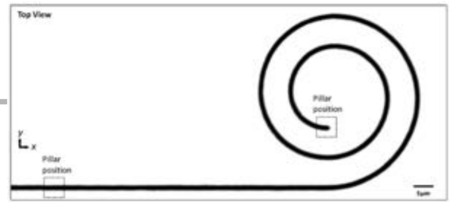
- Laser induced phase change in diamond.
  - E.g. T.V. Kononenko et al, Diamond & Related Materials 18 (**2009**) 196–199 "***Femtosecond laser microstructuring in the bulk of diamond*** "



- 3D "Pad" detector
  - E.g. S. Lagomarsino et al, Appl. Phys. Lett. 103, 233507 (**2013**), ***"Three-dimensional diamond detectors: Charge collection efficiency of graphitic electrodes"***



- 3D "strip array" detector with position resolution.
  - E.g. F. Bachmaier et al, NIM A, 786, (**2015**) 97-104, ***"A 3D diamond detector for particle tracking"***
- Radiation damage studies.
  - Eg. S. Lagomarsino et al, Applied Physics Letters **106**, 193509 (**2015**) "***Radiation hardness of three-dimensional polycrystalline diamond detectors"***
- Improvements in graphitization process.
  - Eg. B. Sun et al., Applied Physics Letters **105**, 231105 (**2014**), "**High conductivity micro-wires in diamond following arbitrary paths"**

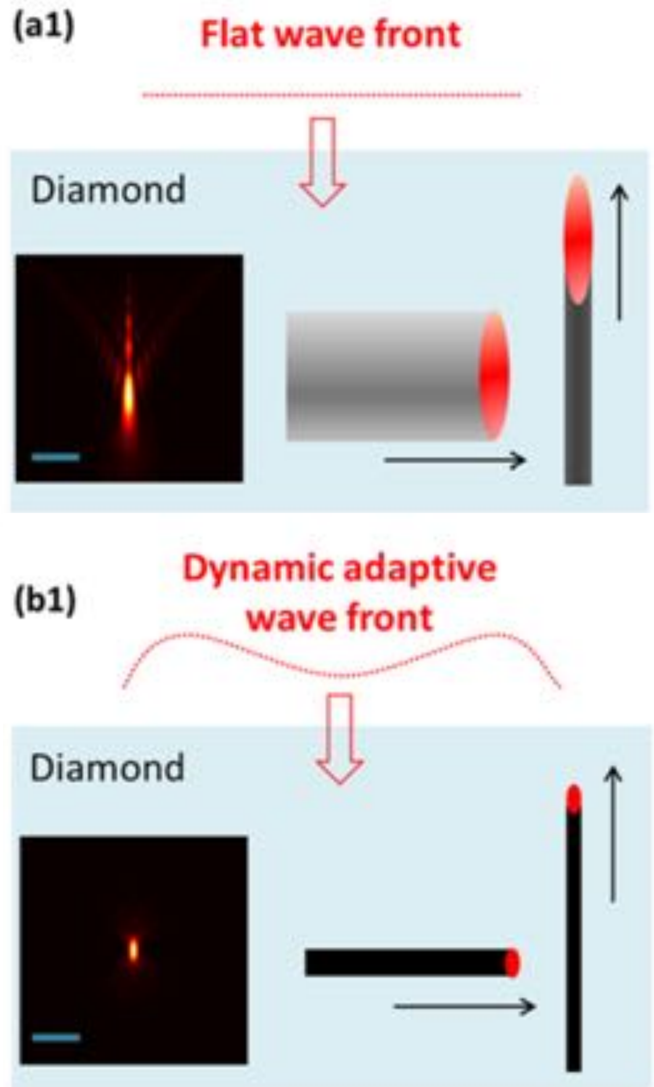


The University of Manchester

MANCHESTER 1824

Laser processing with Spatial Light Modulation

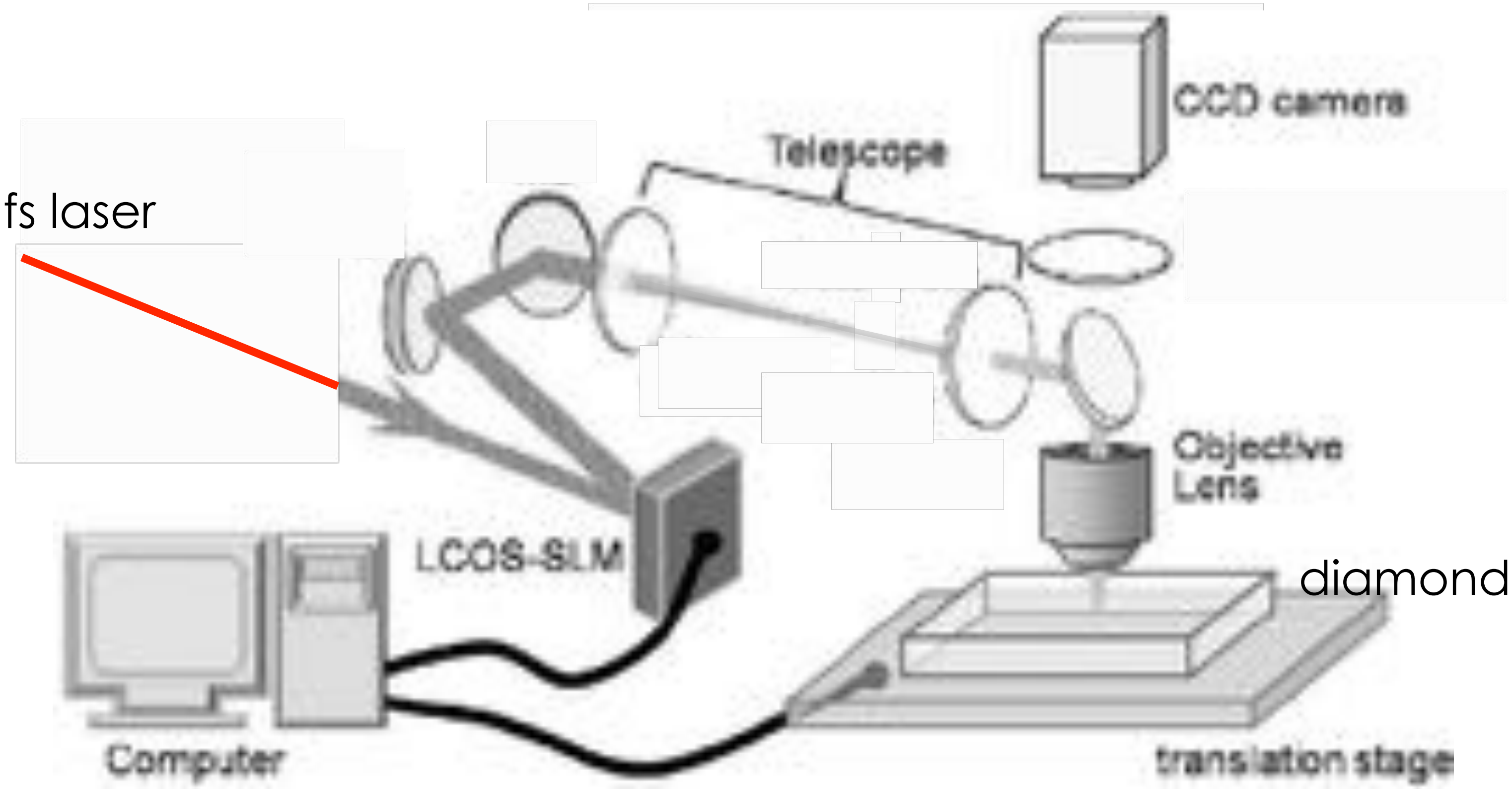
- "Dynamic adaptive wavefront" to compensate dispersion.
  - smaller focal spot.
  - reduced distortion.
  - technique used in various fields
    - holographic data storage
    - two photon absorption microscopy.



Bangshan Sun, Patrick S. Salter, and Martin J. Booth
Appl.Phys.Lett., 105, 231105 (2014)

SLM – Phase **S**patial **L**ight **M**odulation

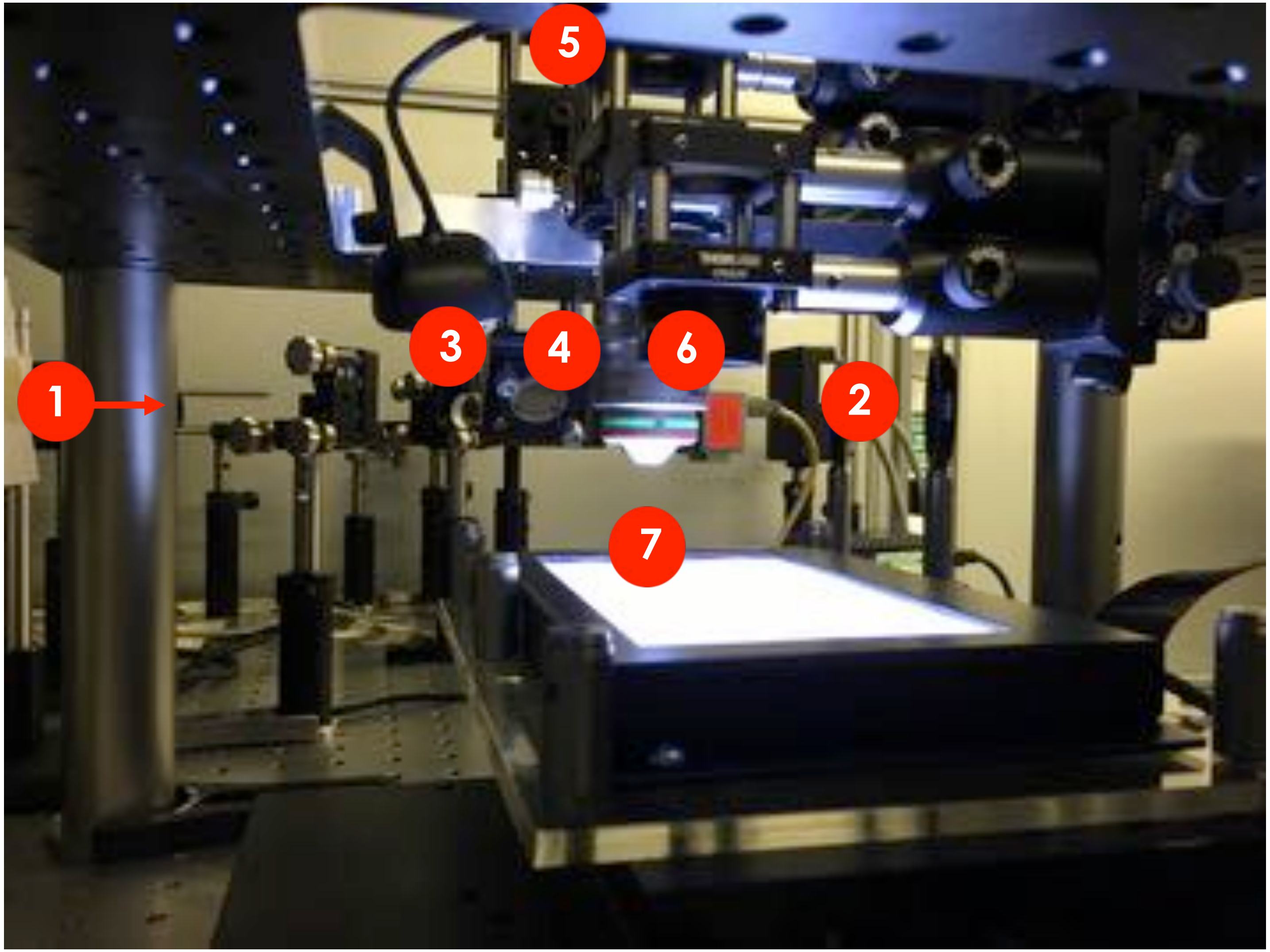
- Laser Setup with SLM



MANCHESTER 1824

The University of Manchester

Laser setup with SLM – Manchester



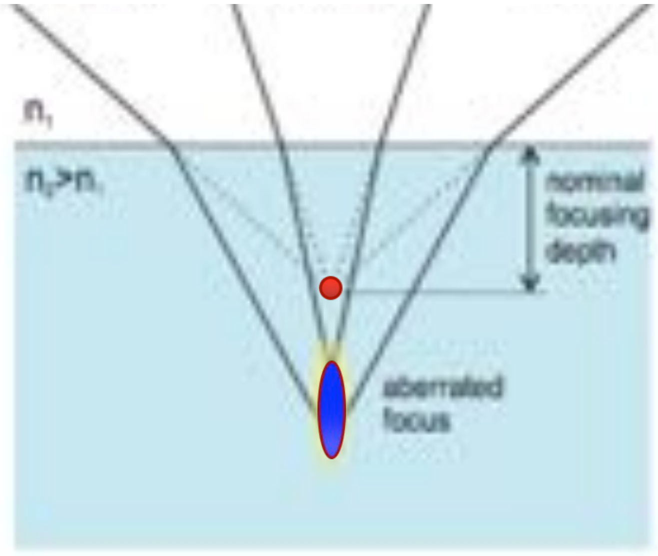
MANCHESTER 1824

The University of Manchester

SLM – Phase **S**patial **L**ight **M**odulation

- Comparison SLM vs standard process.

	Std.	SLM
Resistivity	1 Ωcm	0.1 Ωcm
Diameter	~3μm	~1μm
Diamond to graphite ratio	~4	~0.2

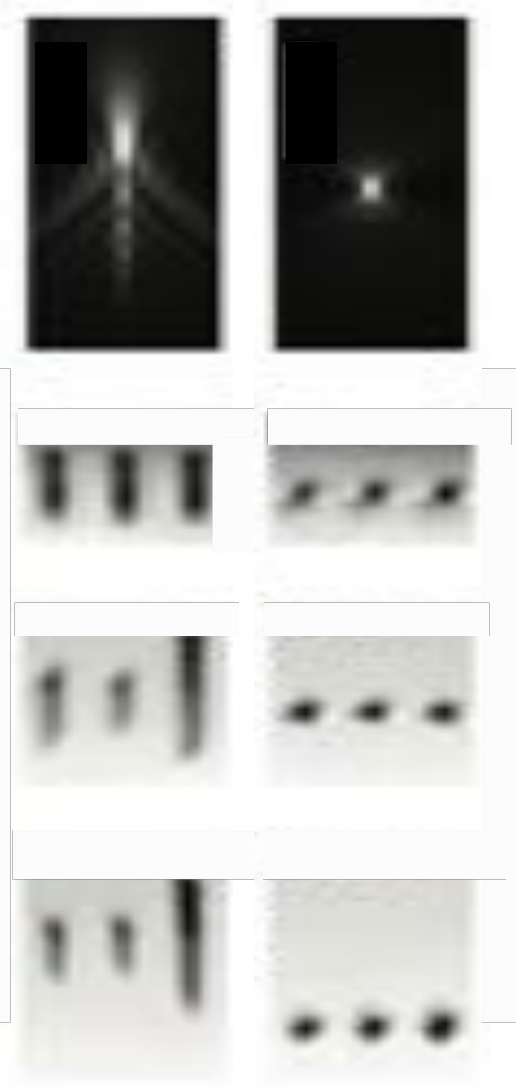


Simulated depth = 40 μm

Measured depth = 40 μm

depth = 80 μm

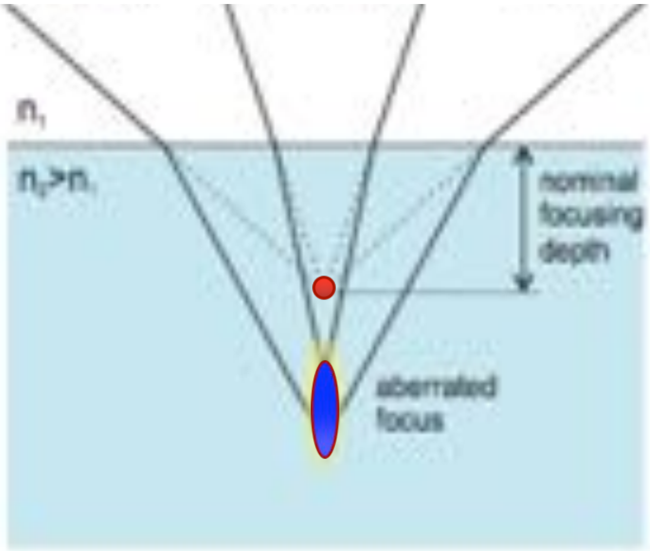
depth = 130 μm

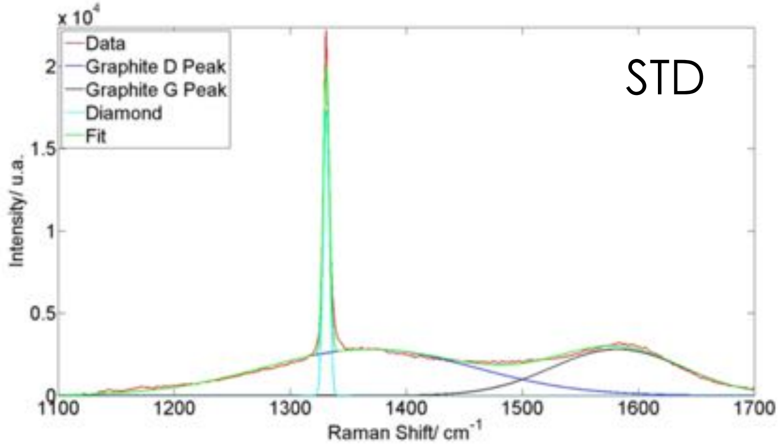


SLM – Phase **S**patial **L**ight **M**odulation

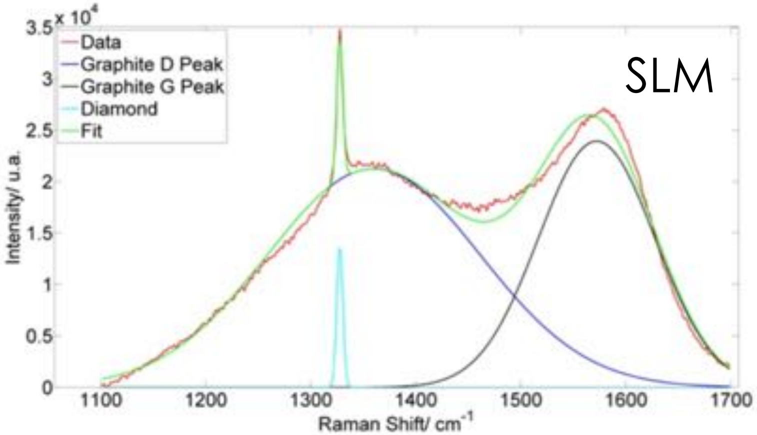
- Comparison SLM vs standard process.

	Std.	SLM
Resistivity	1 Ωcm	0.1 Ωcm
Diameter	~3μm	~1μm
Diamond to graphite ratio	~4	~0.2

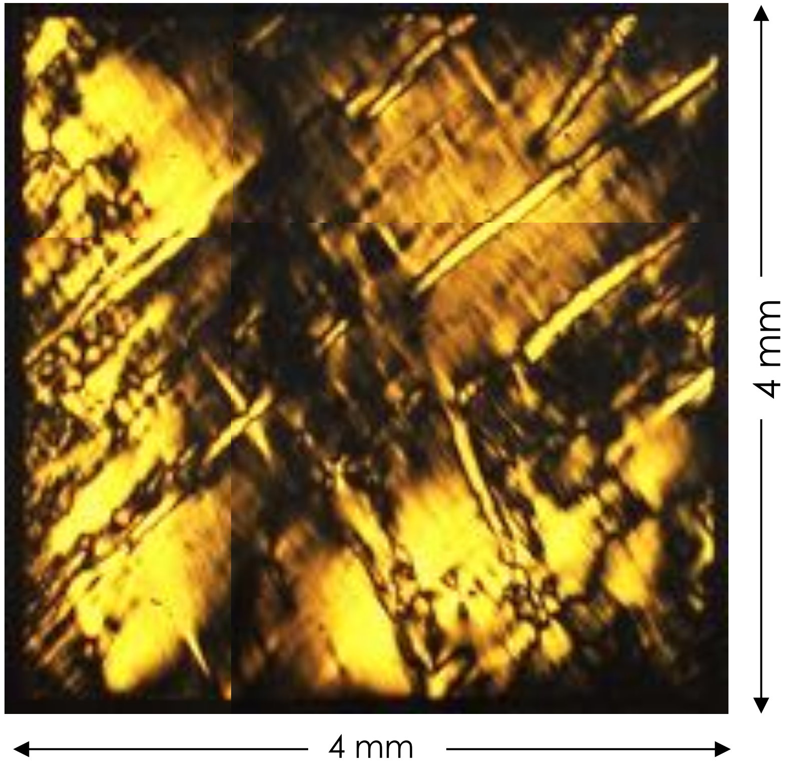


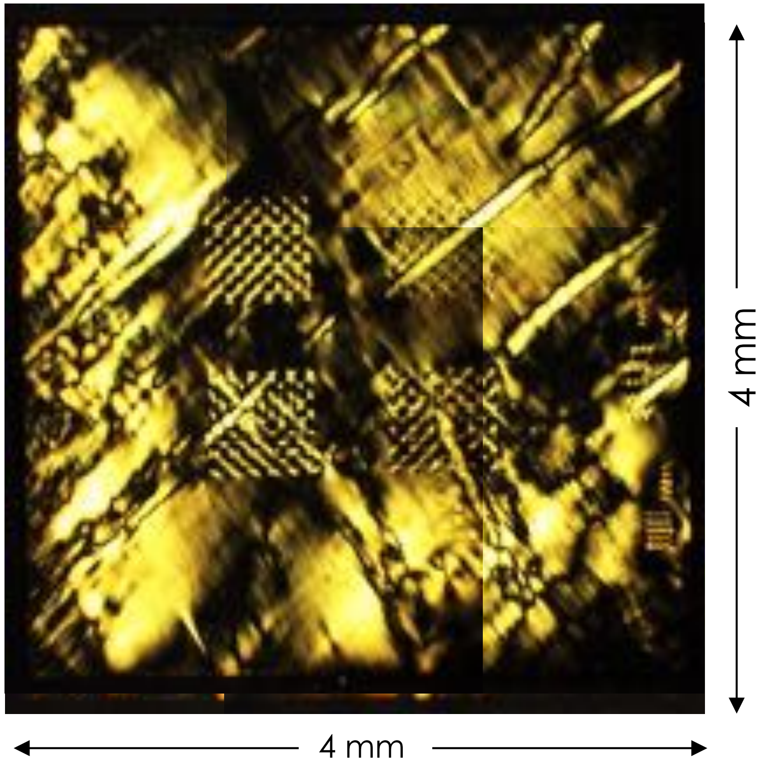


(a)



X-polariser image

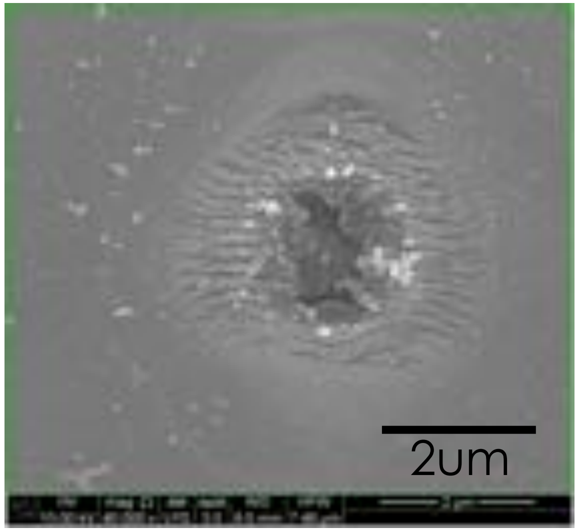


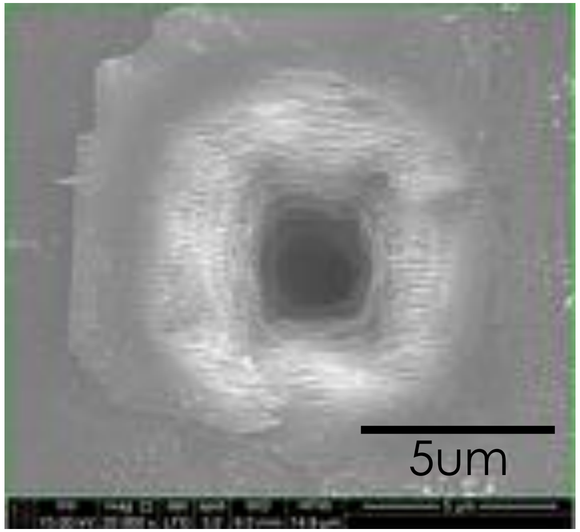


- Optical grade scCVD diamond.
- Post processing.

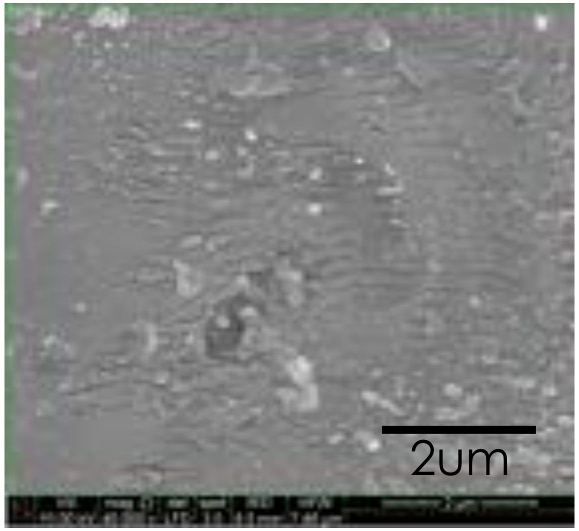
SEM surface image

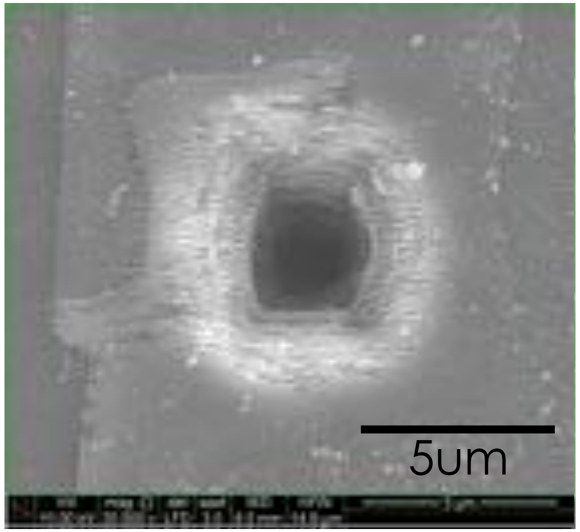
- Seed surface
- Exit surface





With SLM
10um/s
400nJ

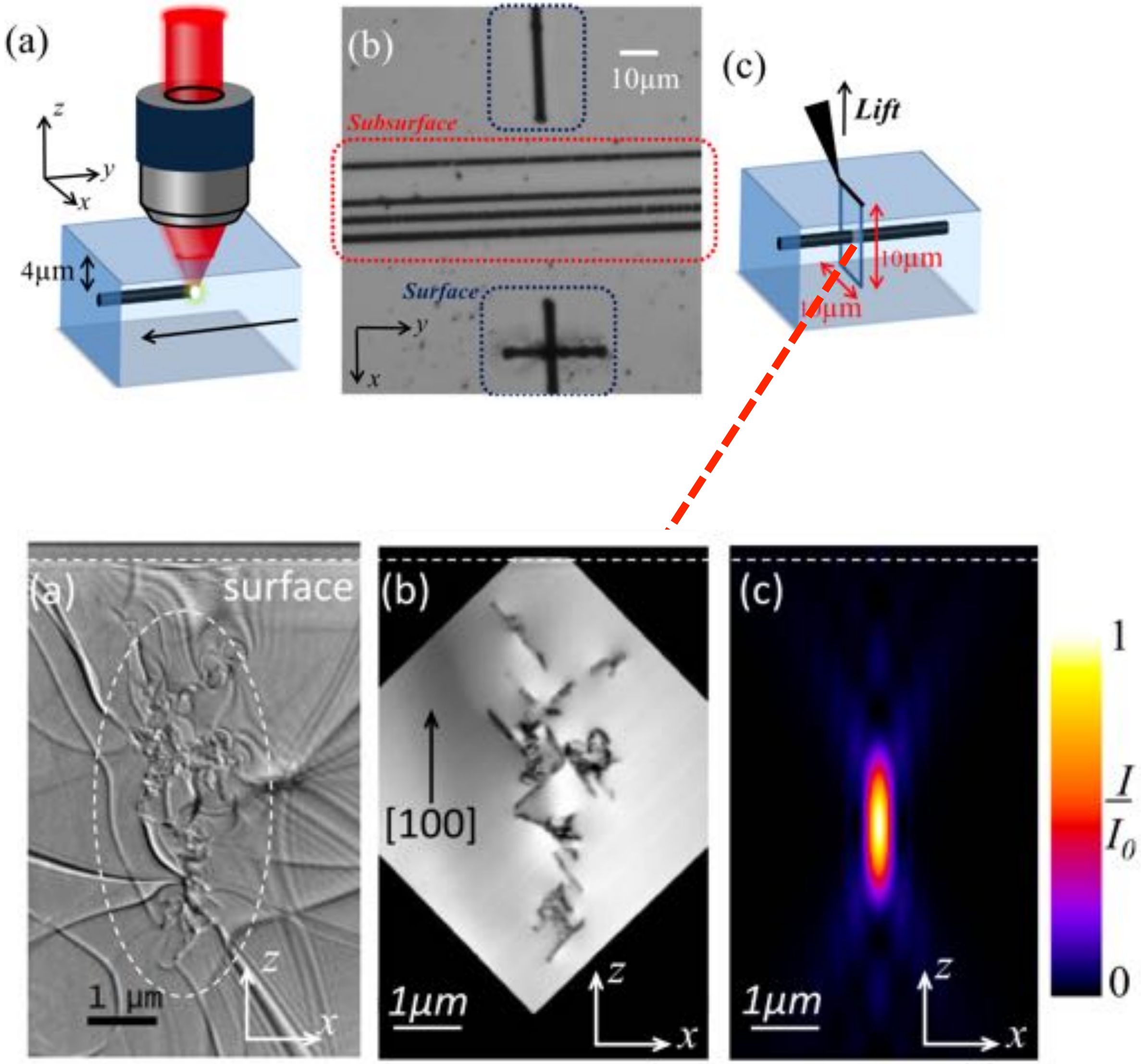




Without SLM
10um/s
400nJ

Internal structure

Patrick S. Salter et al., APPLIED PHYSICS LETTERS 111, 081103 (2017)



- Prepare sample with horizontal graphitic wires.
- STEM image of wire cross section.
- Optical and spectral data points to micro-cracks and nano-clusters of sp^2 bonded carbon.
- Micro wires are not macroscopic structures!

MANCHESTER 1824

The University of Manchester

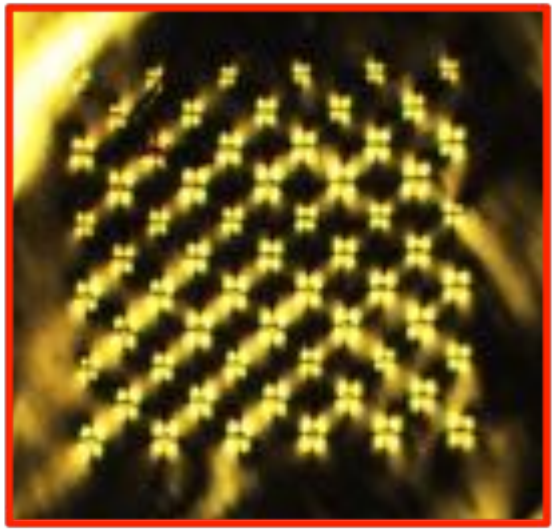
Parameter space scan

Patrick Salter, Oxford
Iain Haugton, AO, Manchester

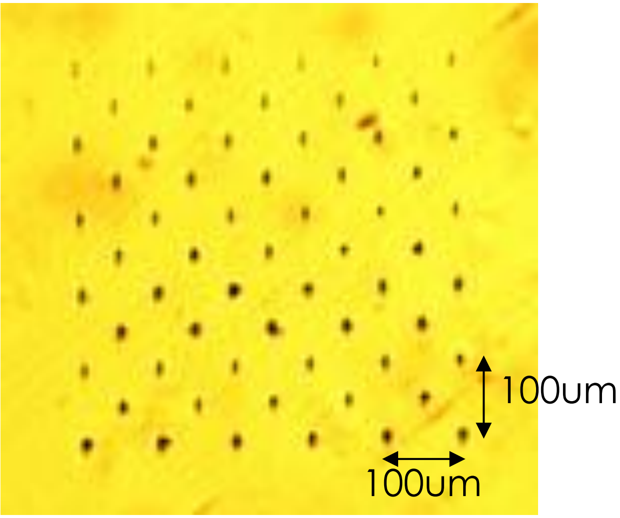
Laser beam energy		Laser translation speed			
		5um/s	10um/s	20um/s	30um/s
	100nJ	x	x		
	200nJ	x	x	x	
	300nJ		x	x	x
	400nJ		x	x	x
	500nJ			x	x
	600nJ				x

- Repeat **with** and **without** SLM correction.

Metallisation



X polarisers



Microscope

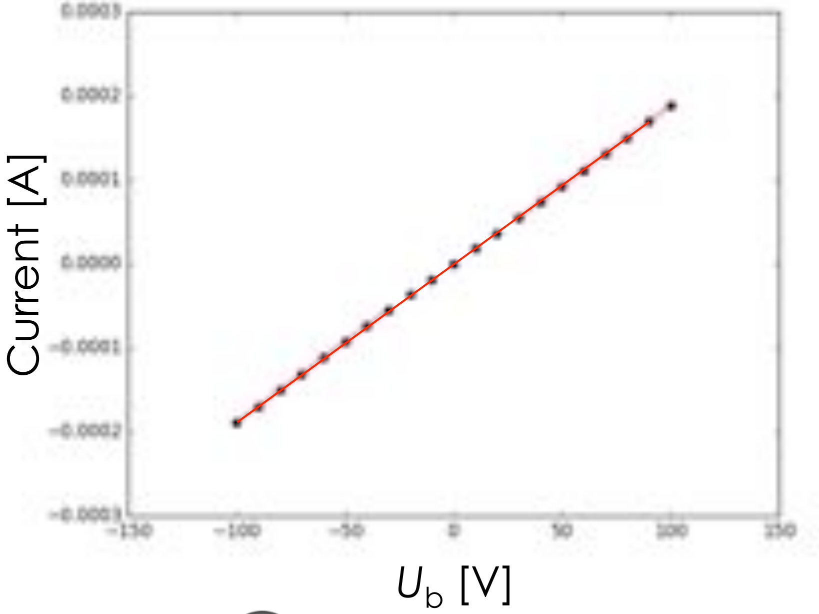
Metallisation mask
(Seed surface)

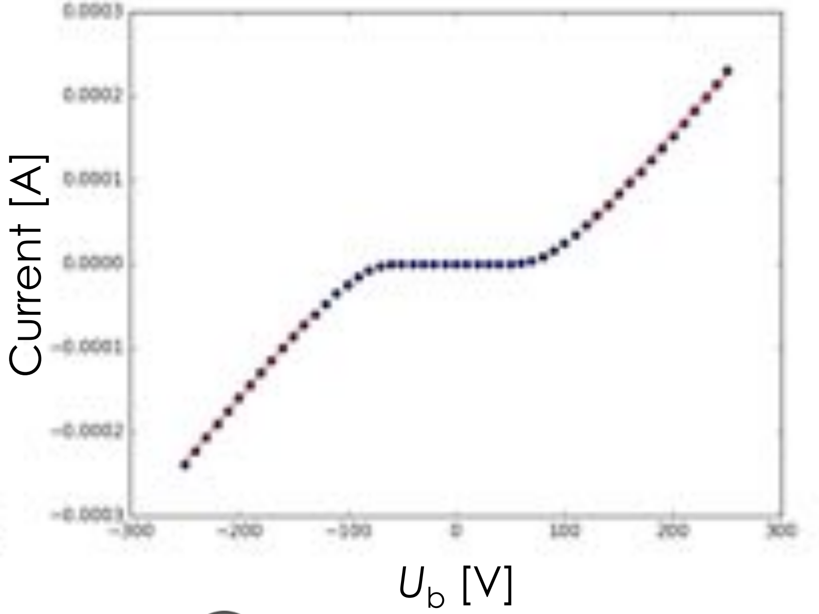
Metallisation:
- Chromium-Gold

Seed surface structured.
Exit surface pad.

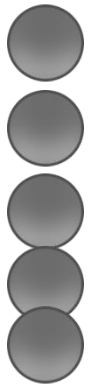
IV curves

- Ohmic and barrier potential curves observed.



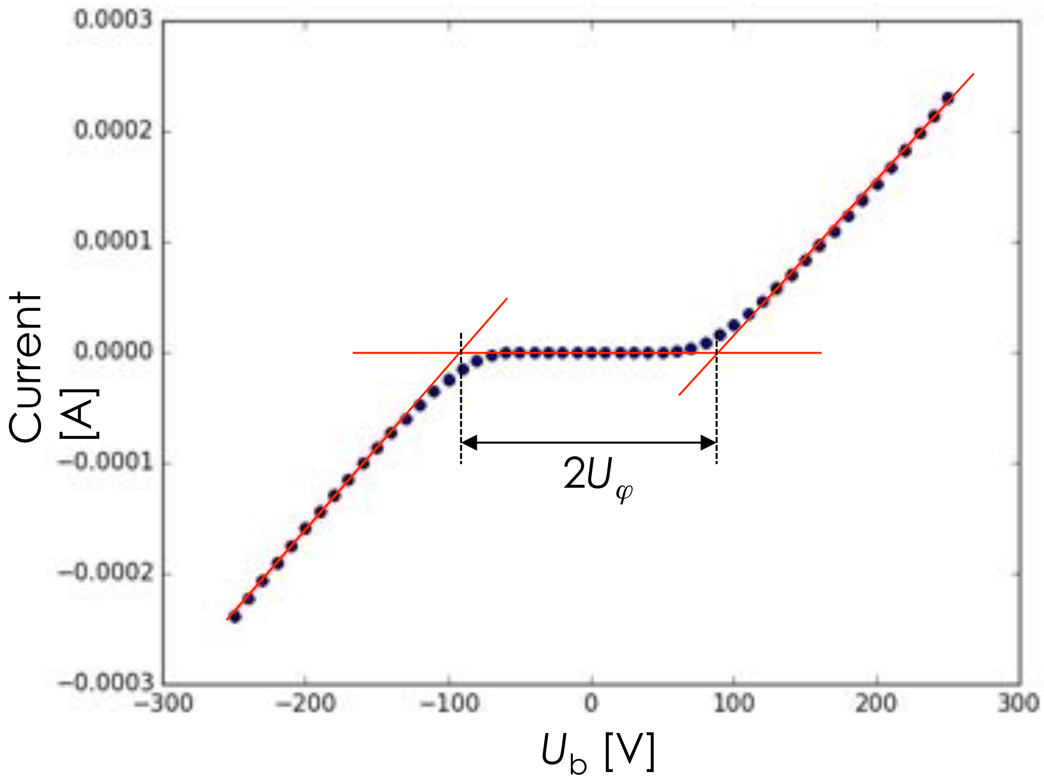


Continuous.

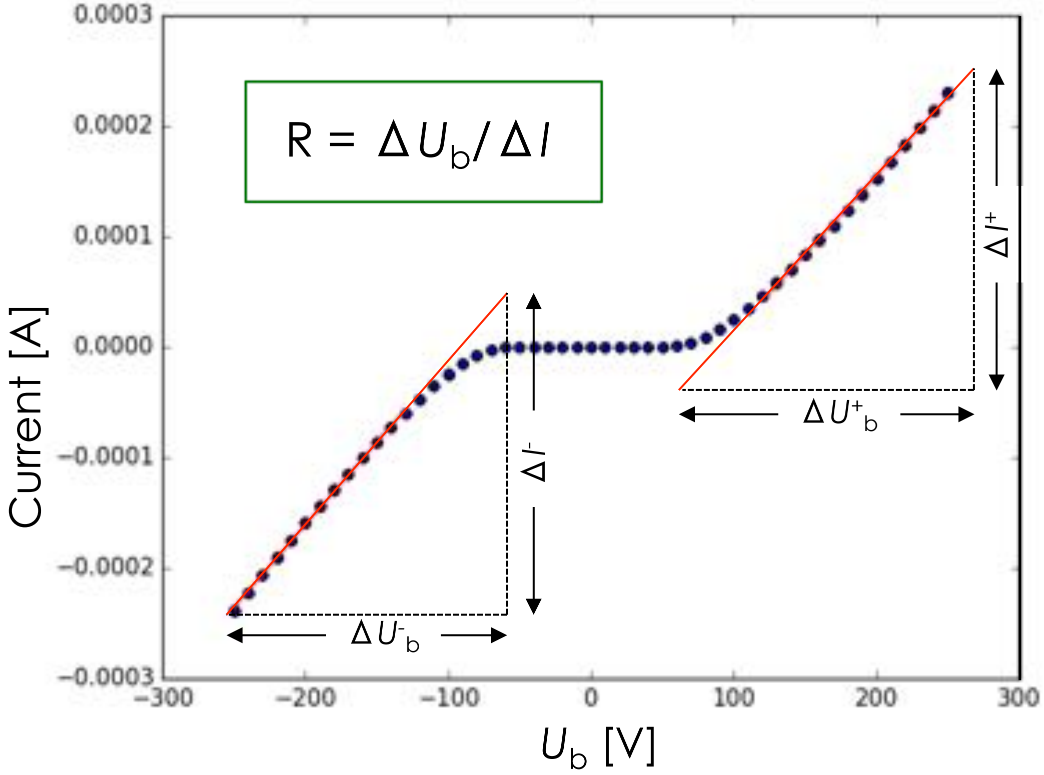


Bulk effect?
Micro gaps?

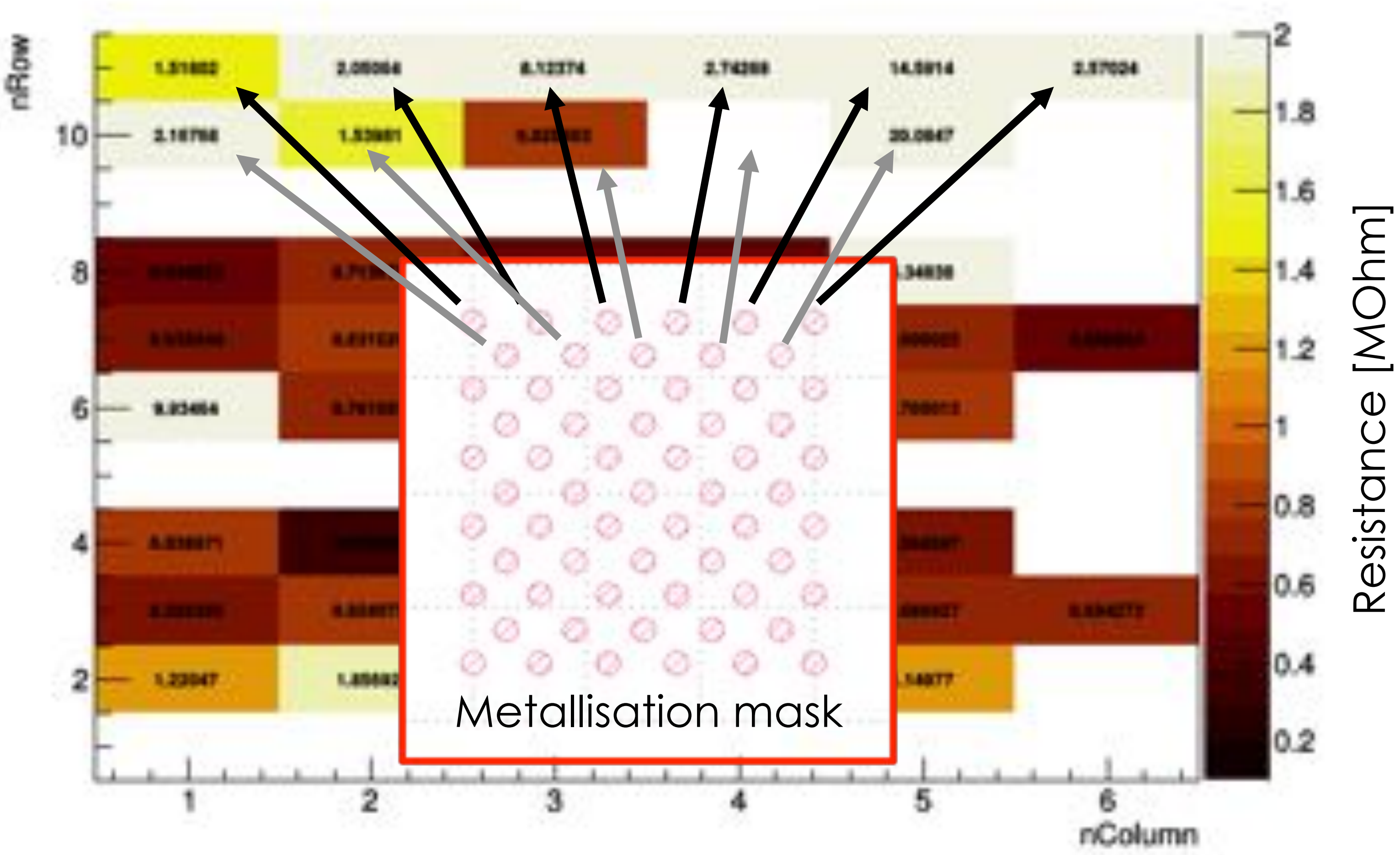
Barrier potential



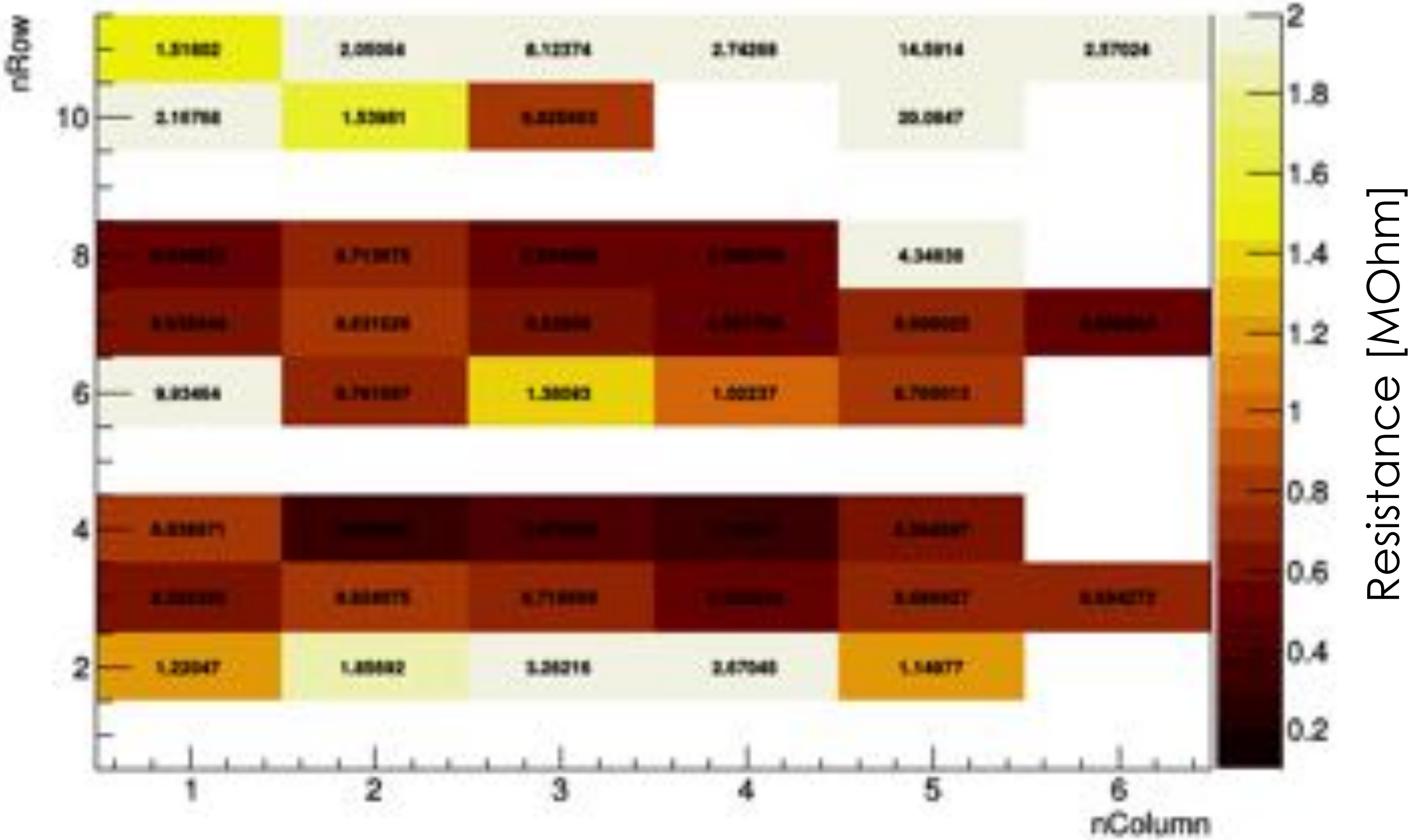
Resistance measurement



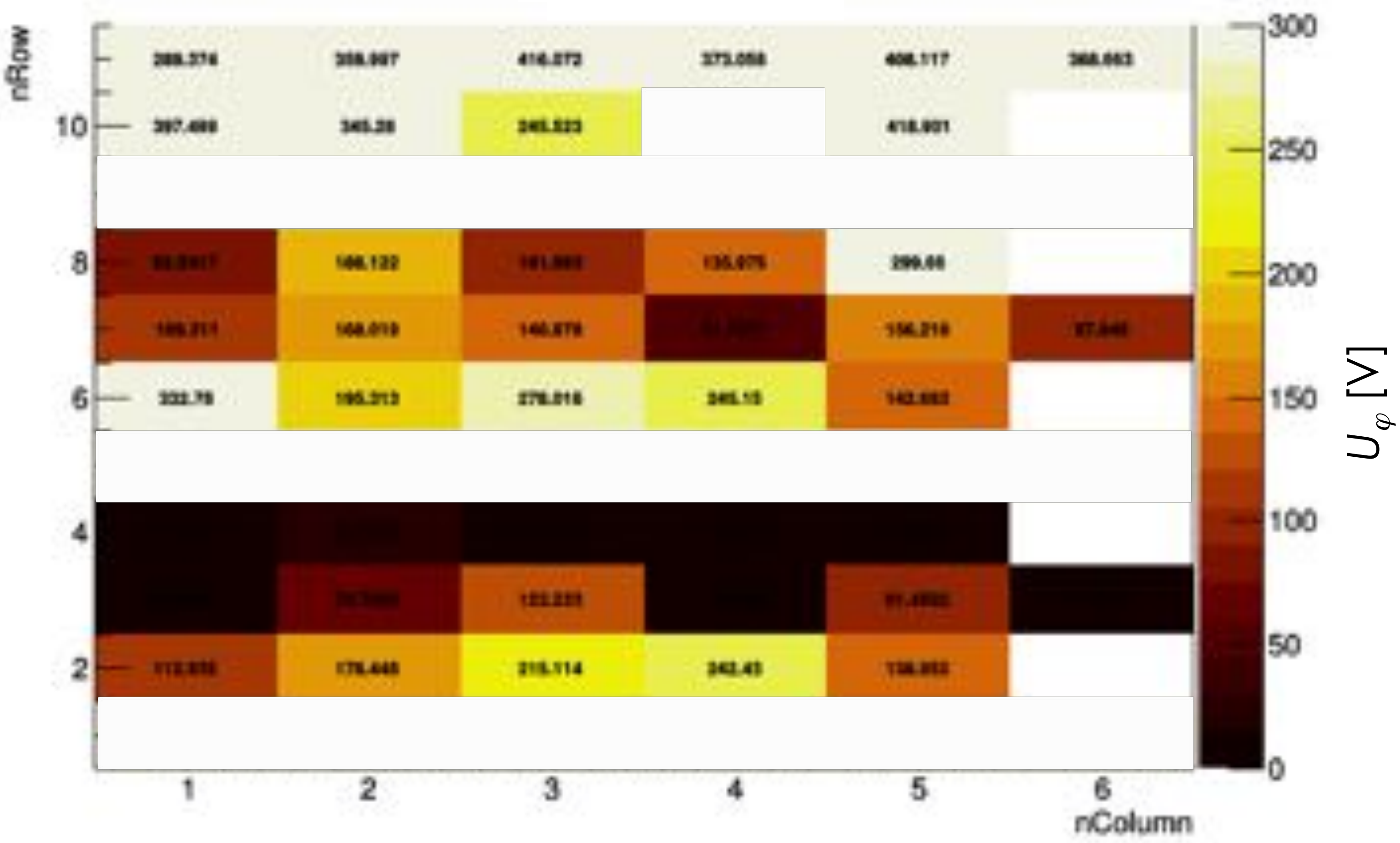
With SLM



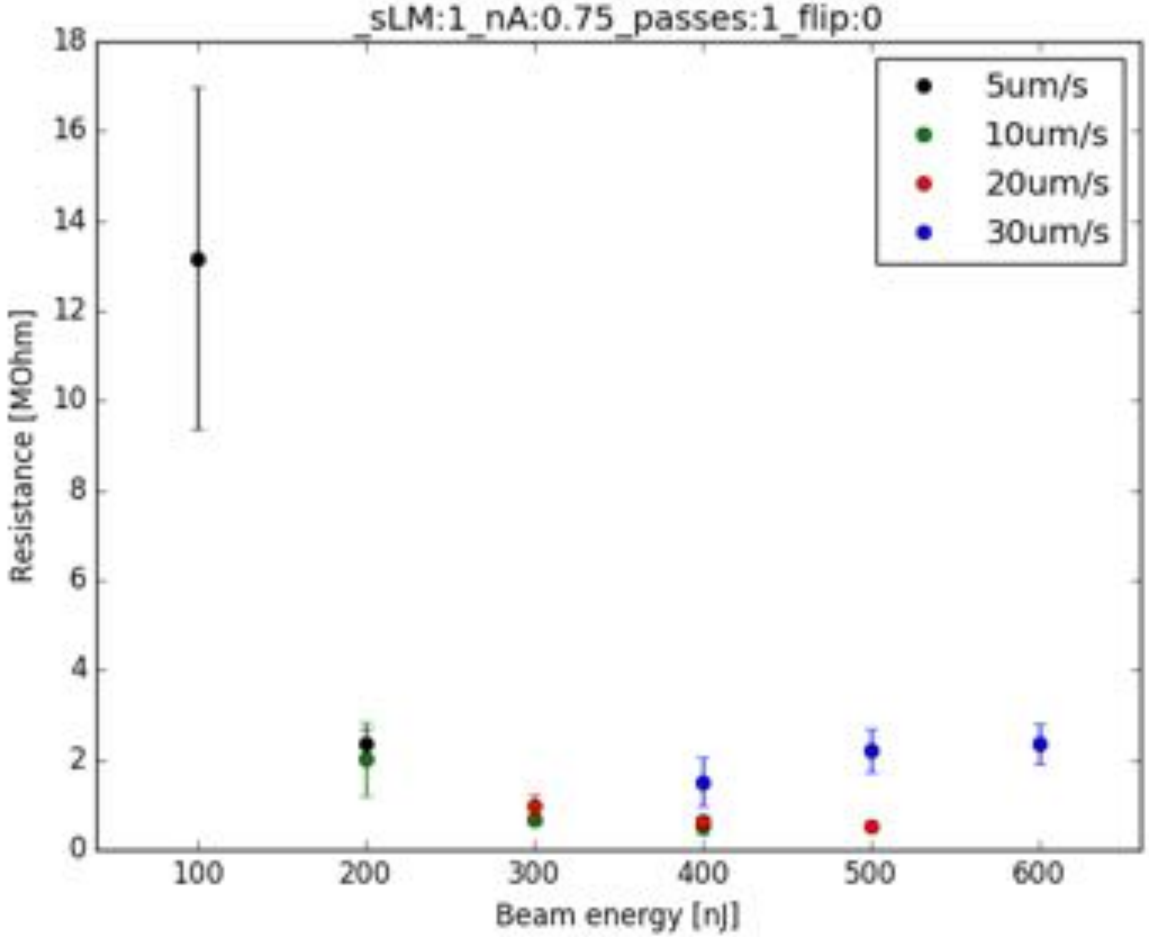
With SLM


nRow
10
8
6
4
2
1
2
3
4
5
6
nColumn
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
Resistance [MOhm]
20.0847
4.34838
1.00237
3.26216

With SLM

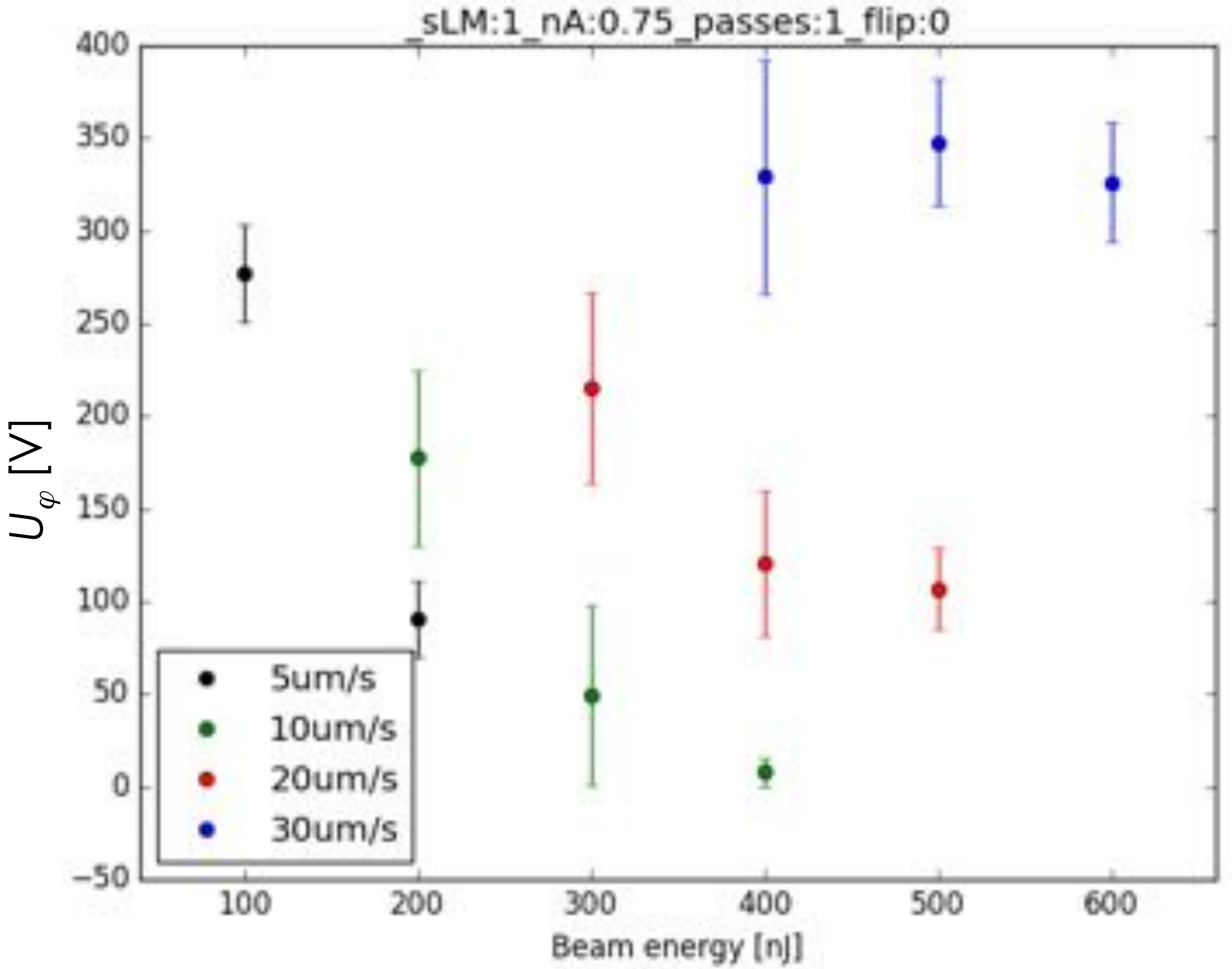


Resistance



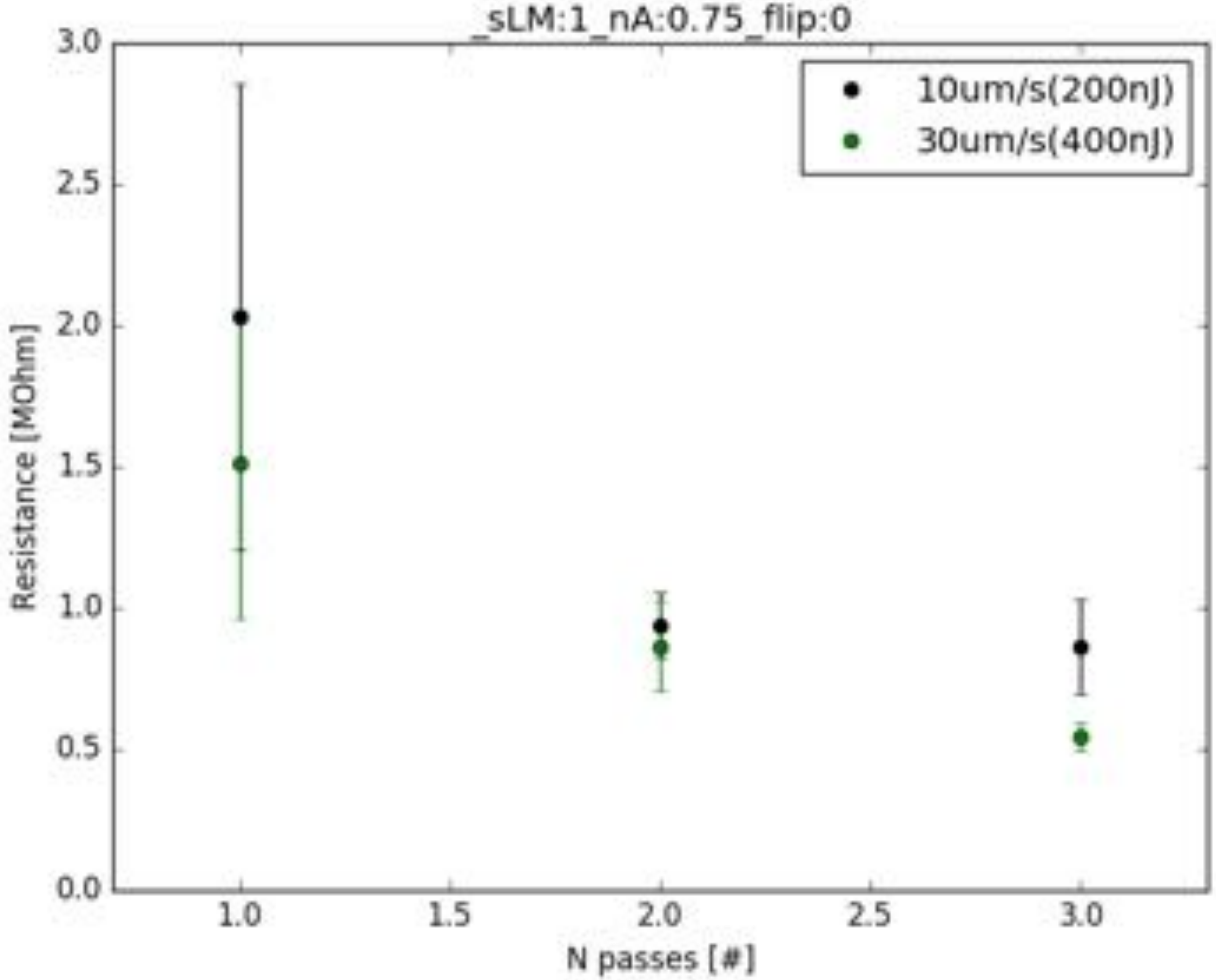
- Resistance increase as power law
  → multi-photon process.
- Clear discrepancy at 30um/s.

Barrier energy



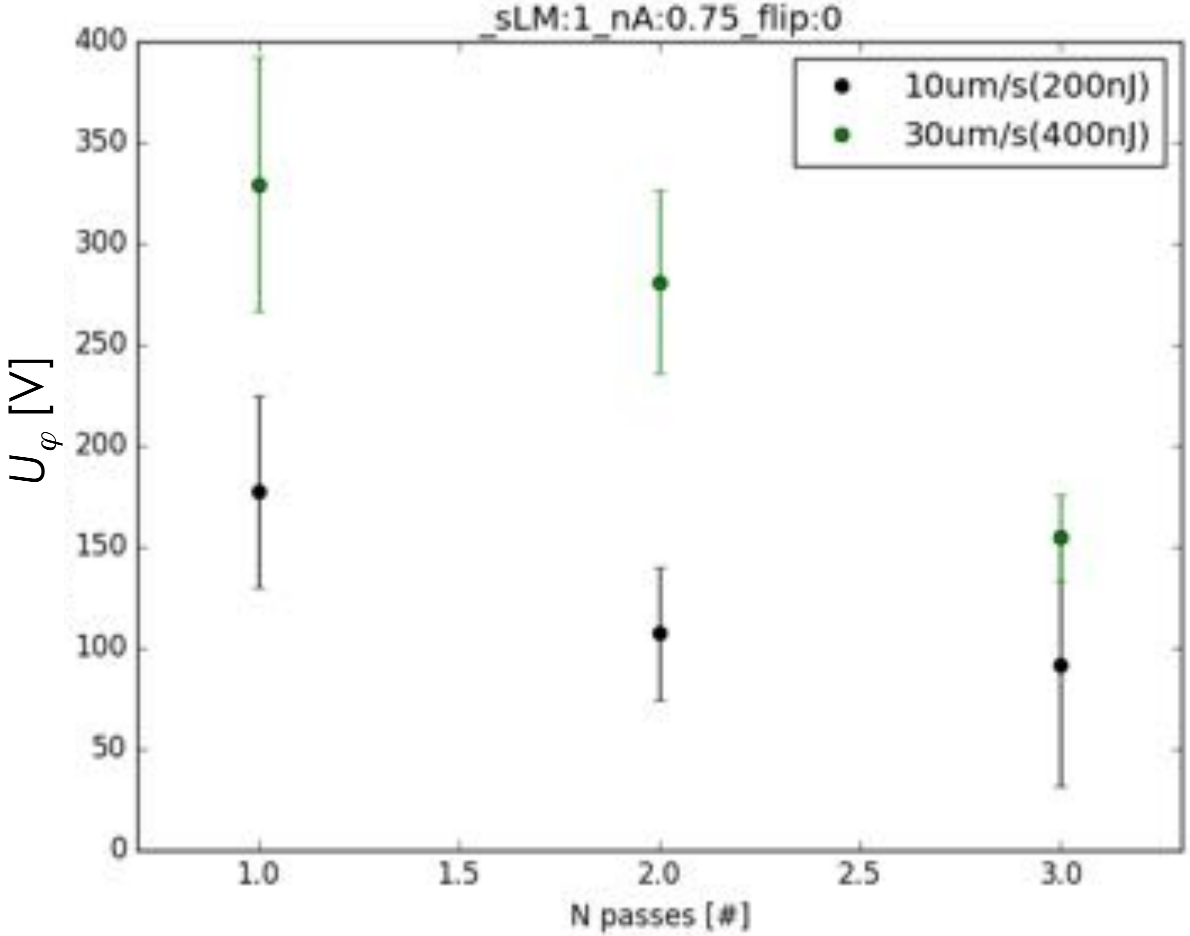
- Reduction in barrier with increased energy.
- Discrepancy at 30um/s.

Multiple passes



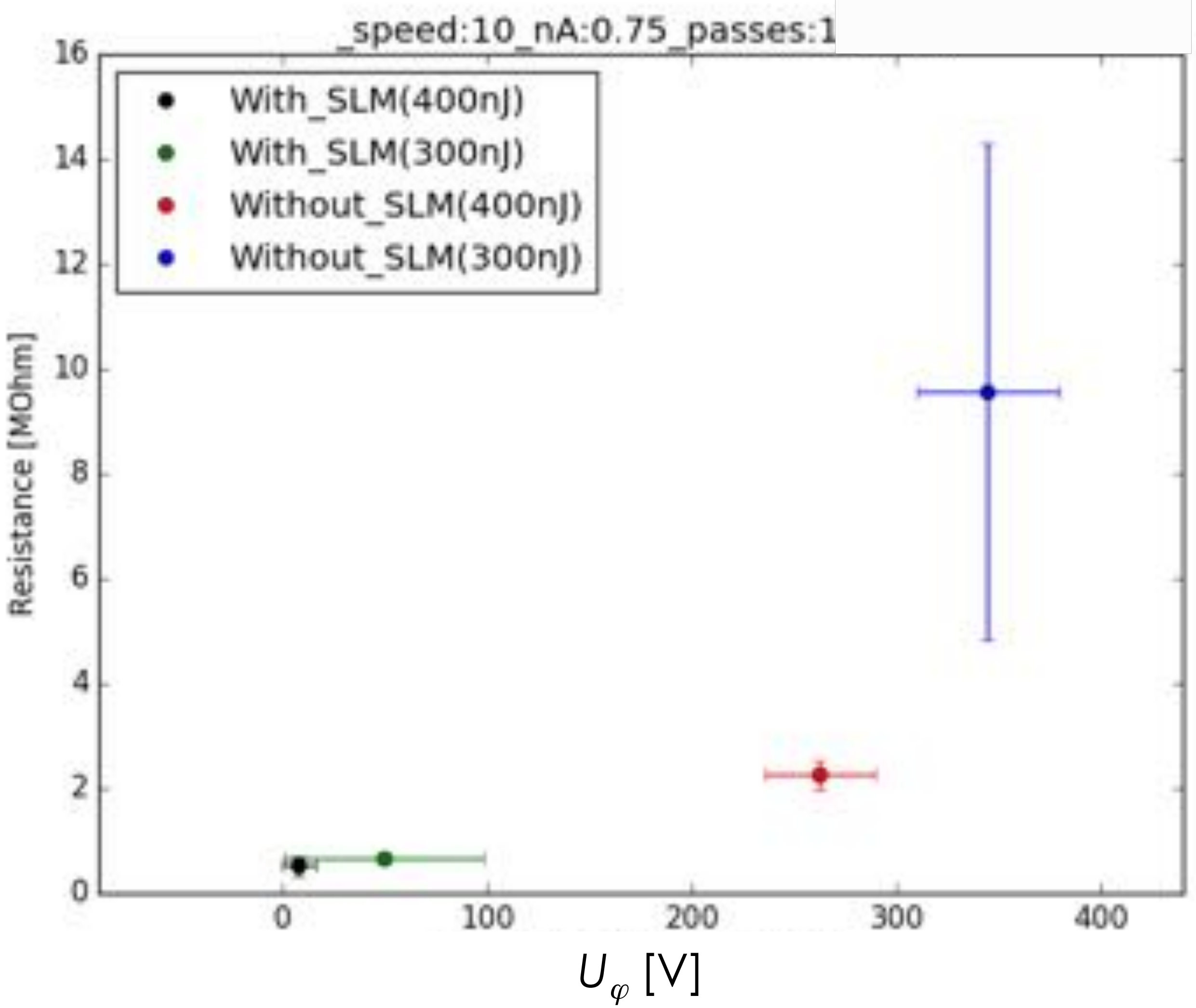
- Multiple passes reduces resistance and increases uniformity of the columns.

Multiple passes



- Multiple passes also reduces U_φ.

With and without SLM

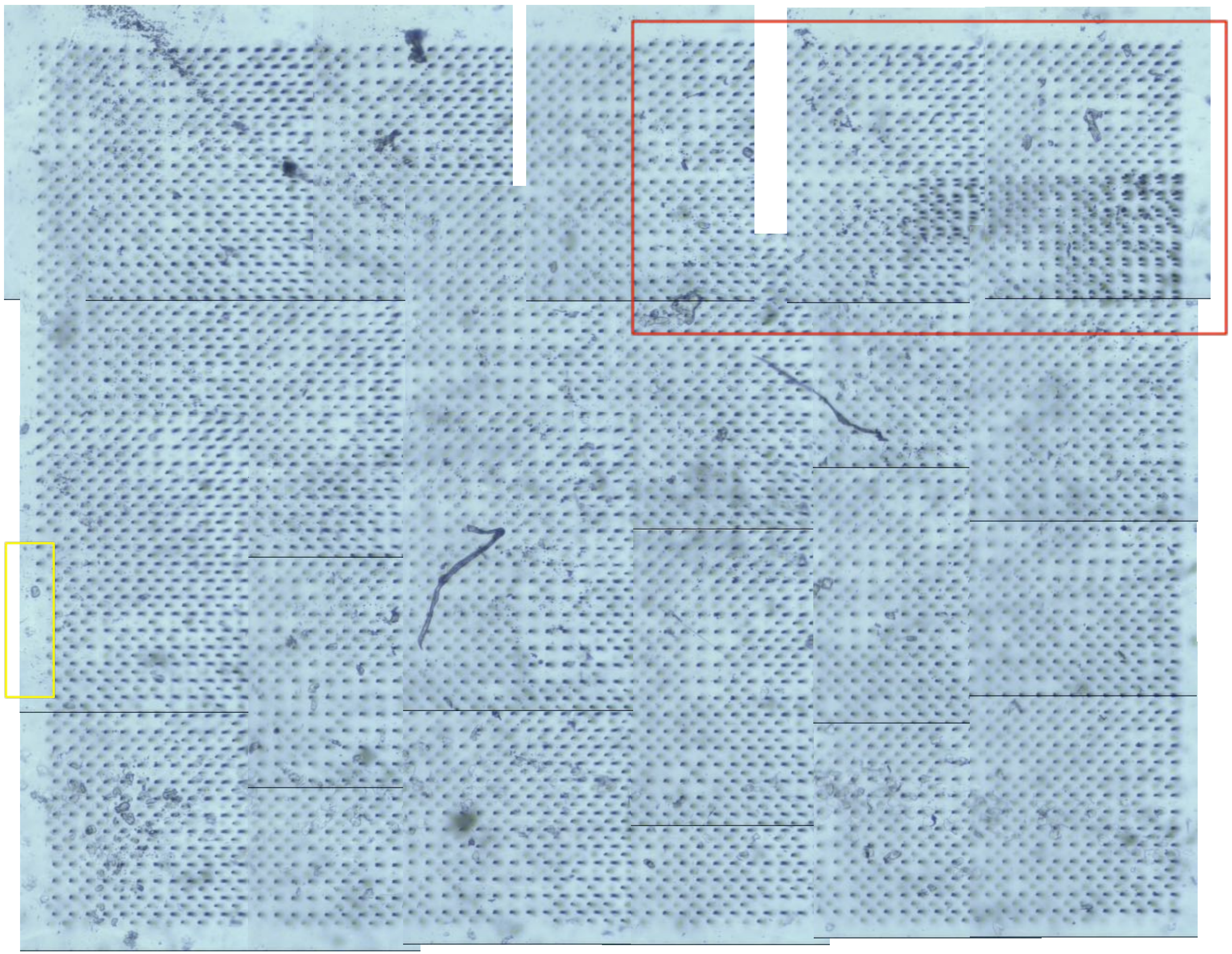


Latest Processing

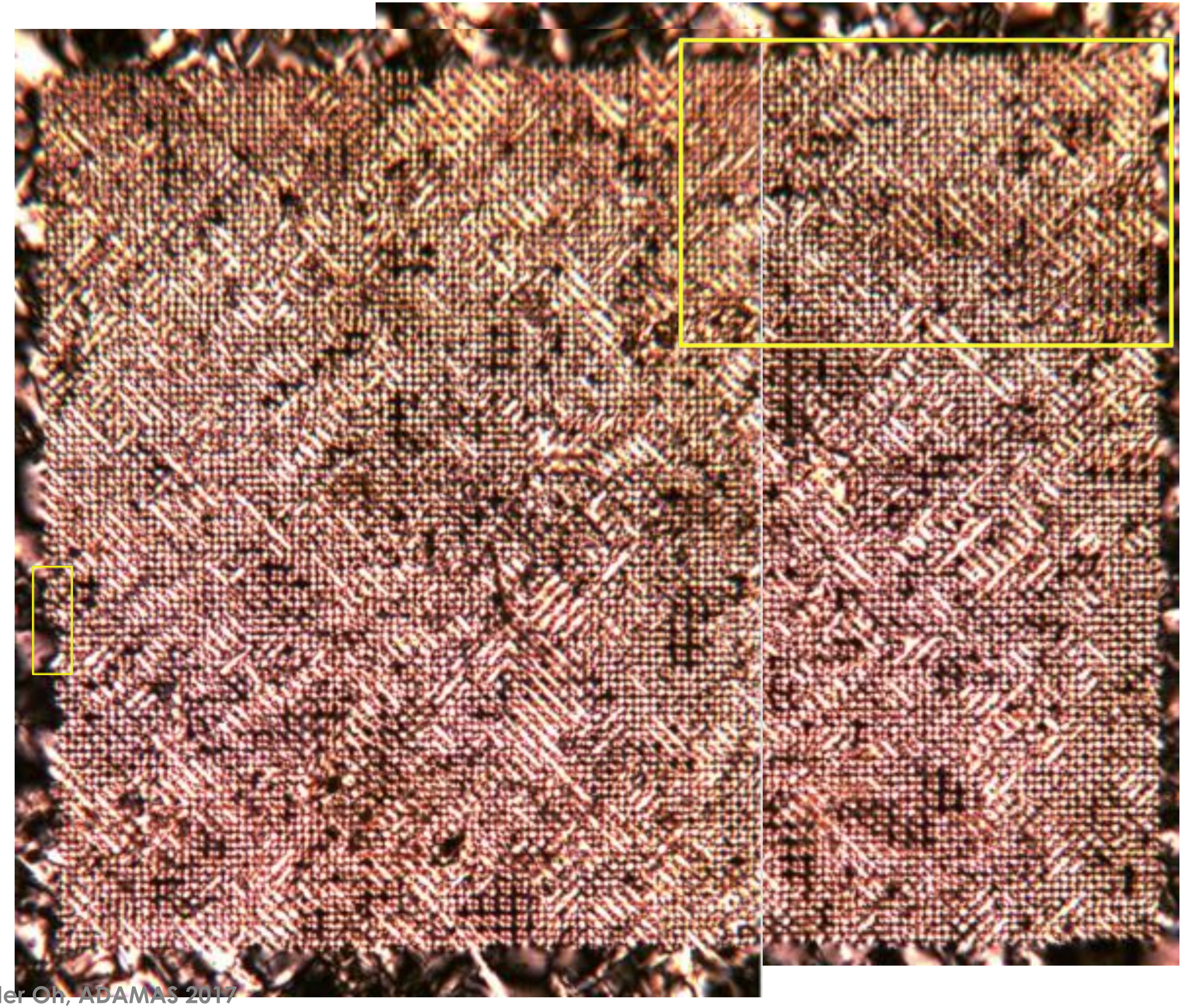
- LHC Phase-2 study sample for ATLAS/CMS with
  - 50x50um cell size
  - ~3500 cells
- Processing parameters:
  - 10um/s, 680uW
  - first 85um 3 pass, full column 1 pass.
  - No flipping.
- Processing started 1st October.
- 2nd October: interrupted due to PC failure.
- Restarted processing, slight misalignment.

- Finished processing 11th October
- Columns reaching the bottom surface:
  - Success rate ~100%
- Columns reaching the top surface:
  - Success rate ~70-80%.
  - Not all start at the same height.

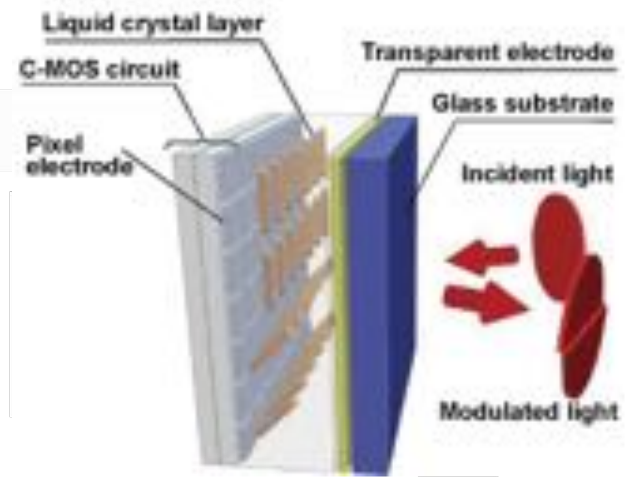
Latest processings

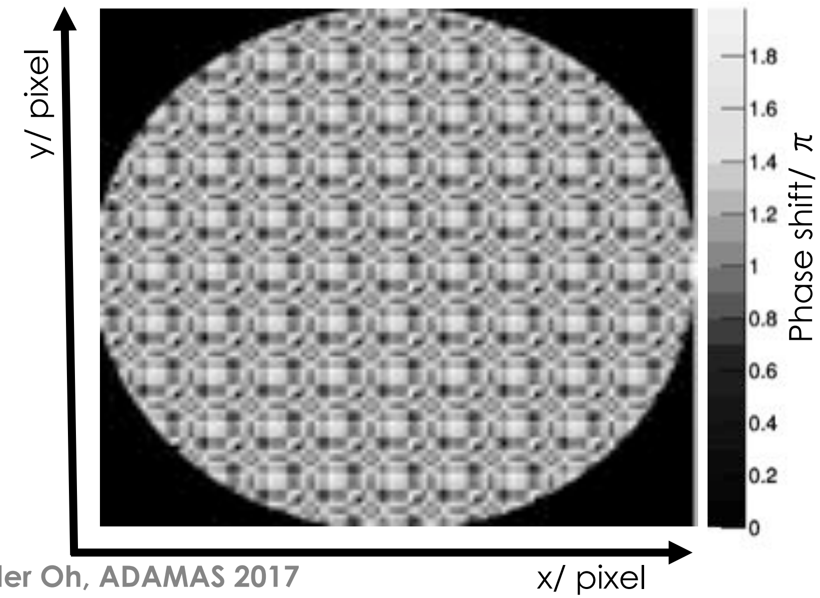


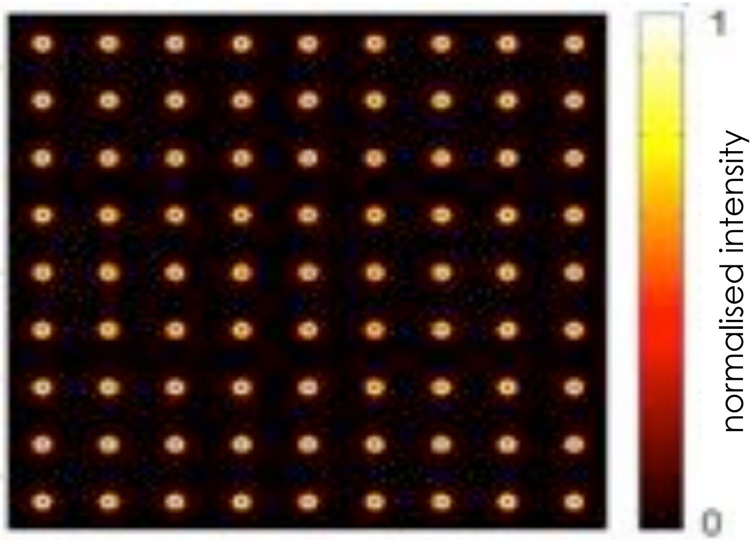
x-polariser



SLM parallel processing?







3D Diamond detector tests with relativistic charged particles

- Types
  - 100x100um cell size ganged to form strips
  - 100x100um cell size, bonded to pixel read-out
  - 50x50um cell size, bonded to pixel read-out
- All detectors made from polycrystalline diamond.
- Beam tests
  - CERN beam line H6 : protons ~ 120 GeV/c
  - PSI : pions ~ 250 MeV/c

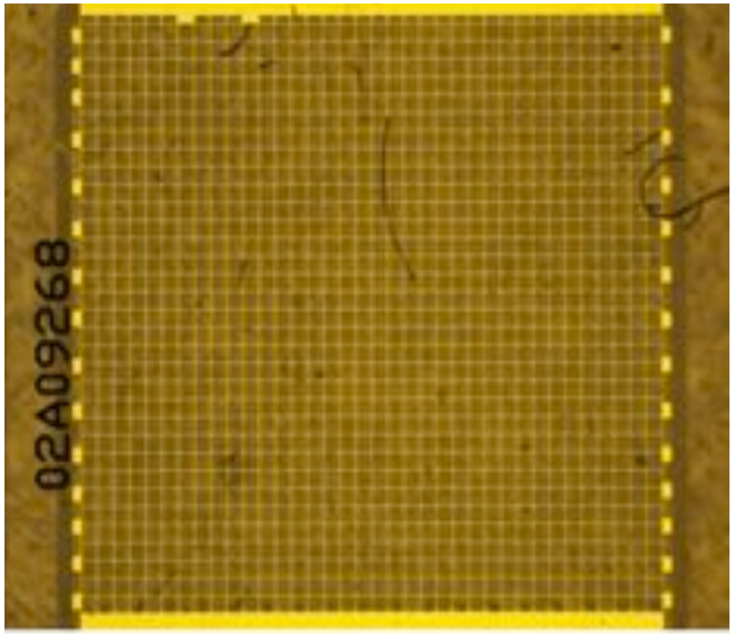
Thanks for material from the RD42 collaboration!

Large area 3D, pCVD, 100x100

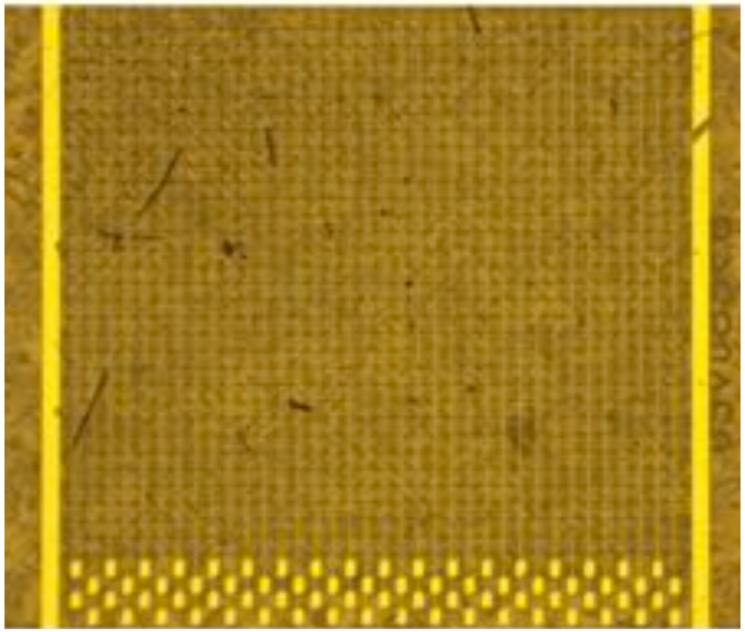
In May/Sept 2016 tested the first full 3D device fabricated in pcCVD with three dramatic improvements:

1. An order of magnitude more cells (1188 vs 99).
2. Smaller cell size (100um vs 150um).
3. Higher column production efficiency (>99% vs ~90%).

HV side



Readout side

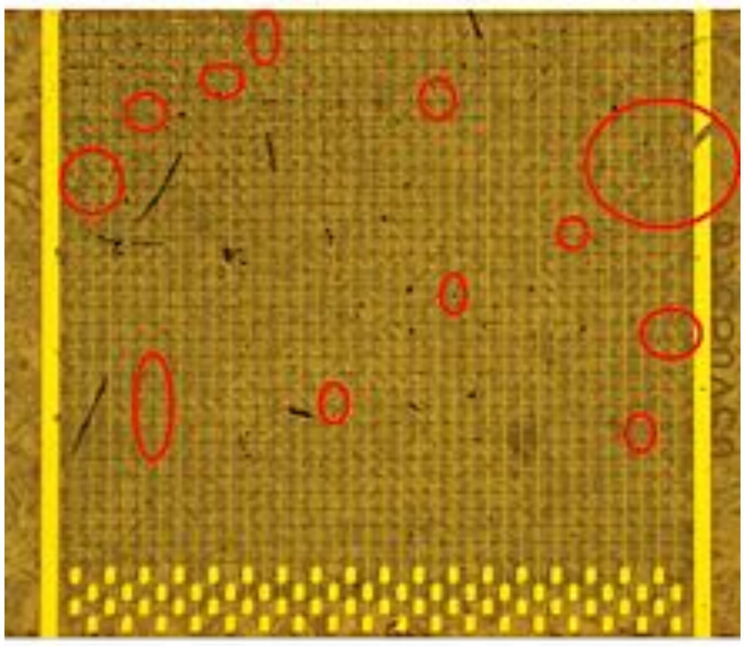


Large area 3D, pCVD, 100x100

In May/Sept 2016 tested the first full 3D device fabricated in pcCVD with three dramatic improvements:

1. An order of magnitude more cells (1188 vs 99).
2. Smaller cell size (100um vs 150um).
3. Higher column production efficiency (>99% vs ~90%).

Readout side



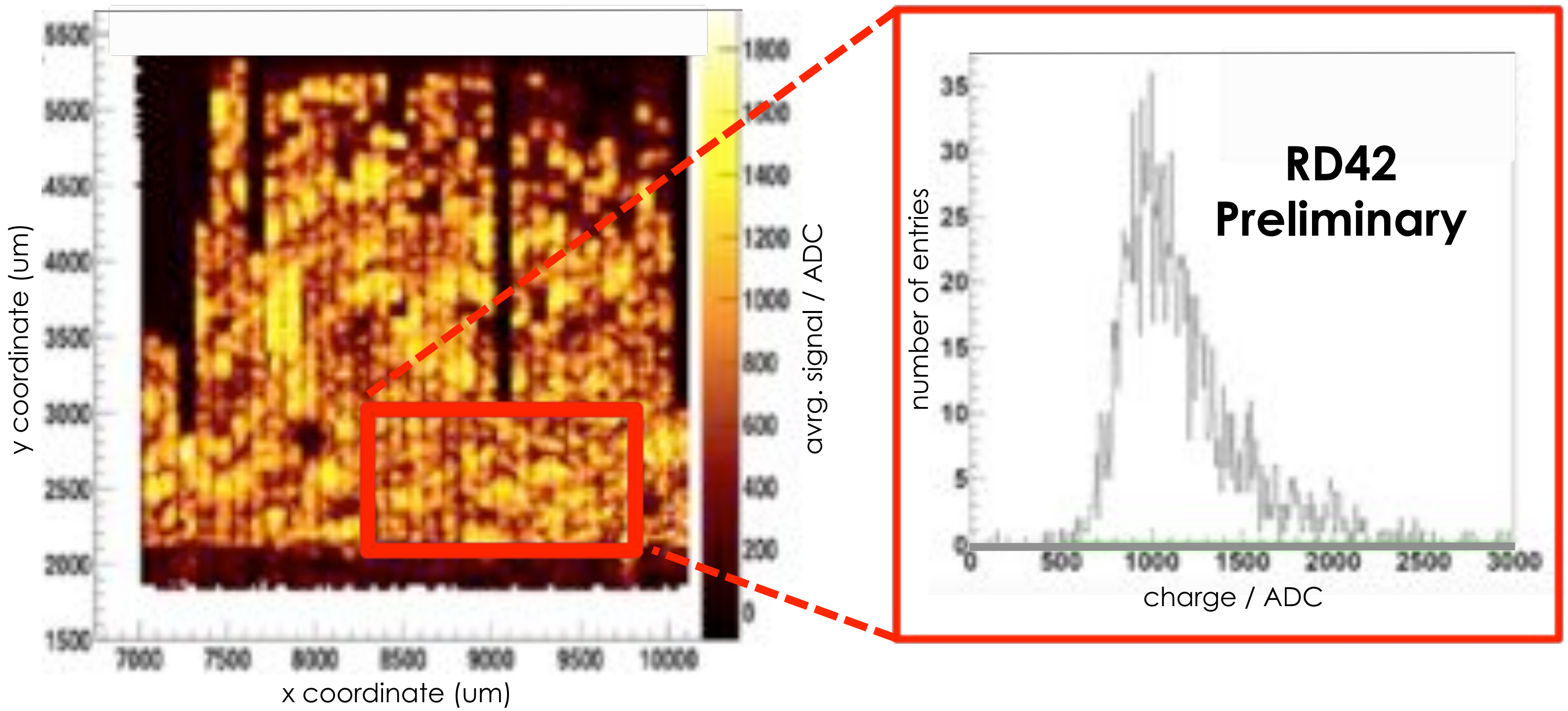
Some issues with handling procedures led to:

- Surface contamination.
- Some breaks in surface metallisation.

→ All fixable!

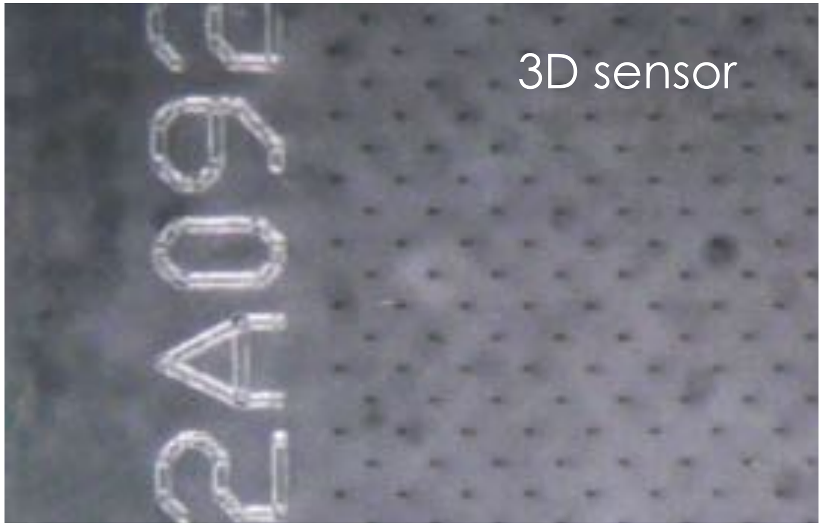
Large area 3D, pCVD, 100x100

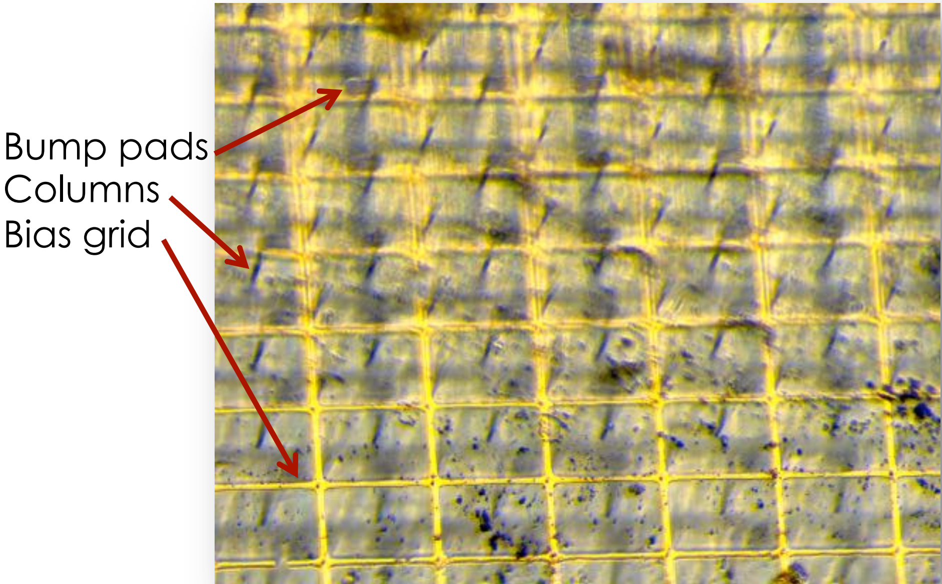
- Largest charge collection to date in pcCVD diamond!
    - >85 % of charge collected in continuous region.
- Analysis in progress on full detector.

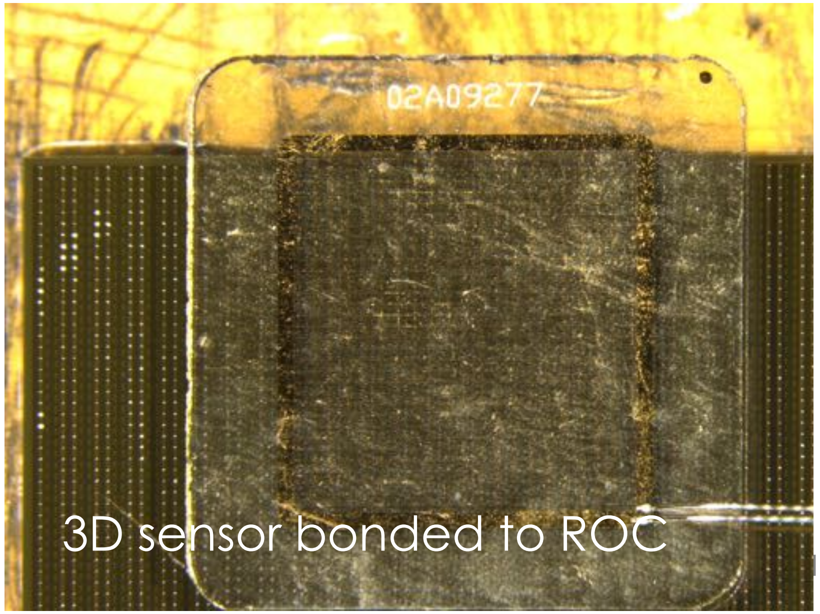


Pixel 3D, pCVD, 100x100

- First assembly with ROC chip produced.
  - Bump bonded in Princeton.
  - Cr-Au on bias side.
  - Ti-W under-bump metal.
  - Indium bumps on sensor.

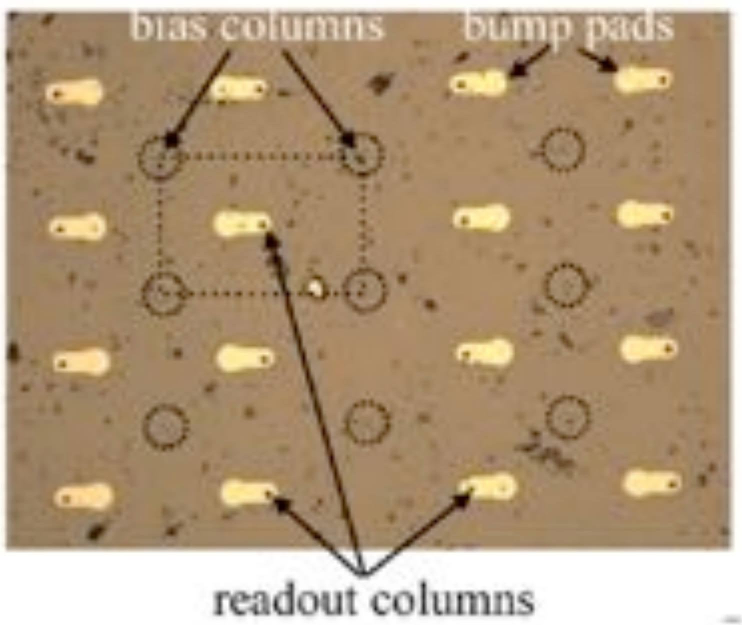


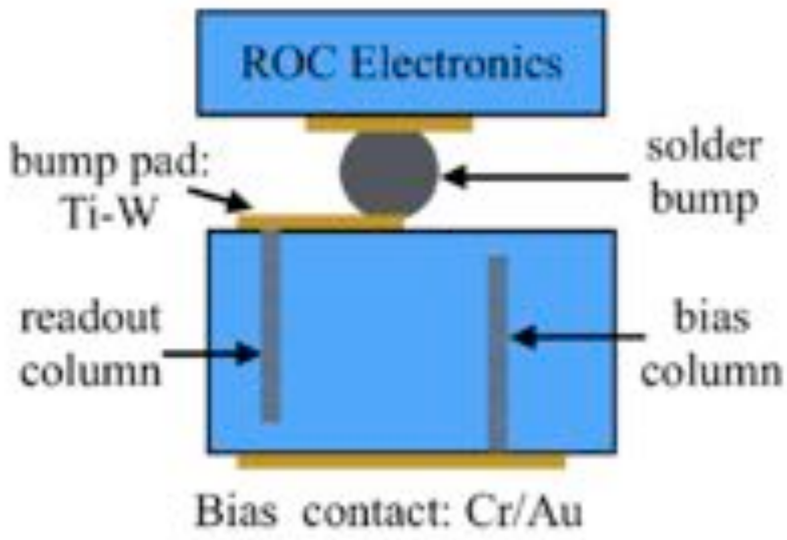




Pixel 3D, pCVD, 100x100

- Production of first pixel device using CMS readout electronics.

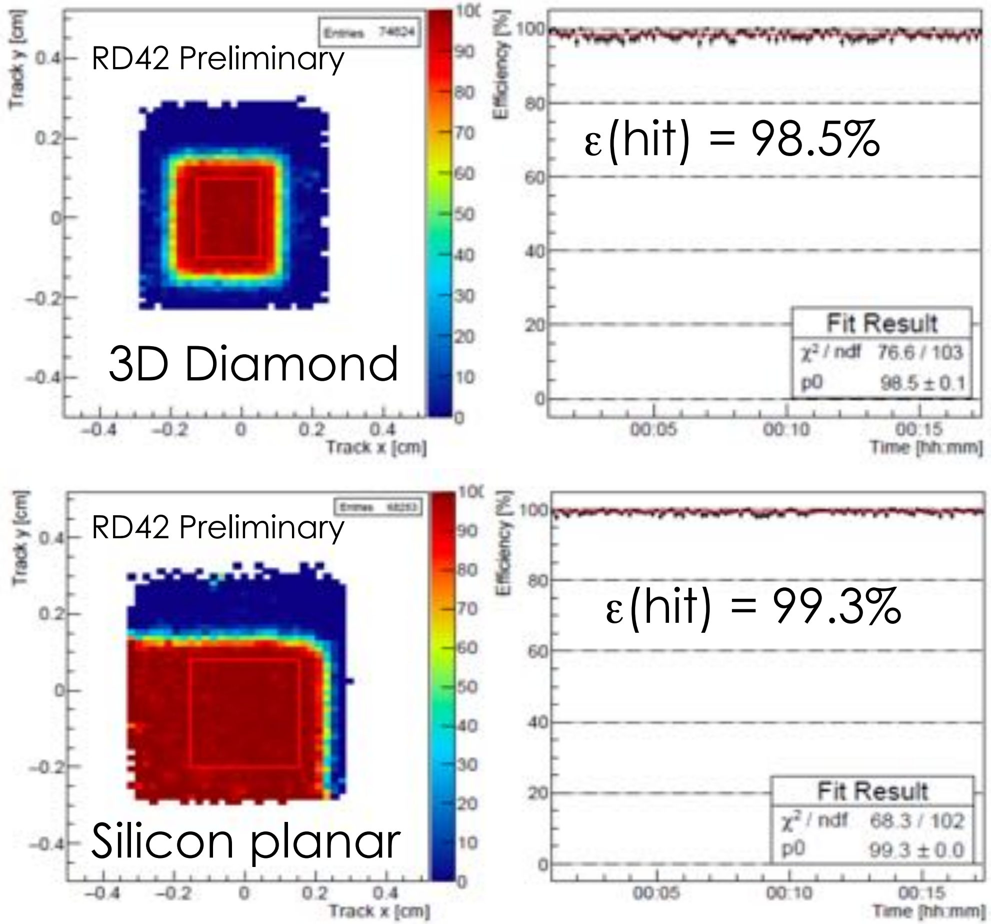




- Active region 3x3 mm with cell size ~100x100 um.

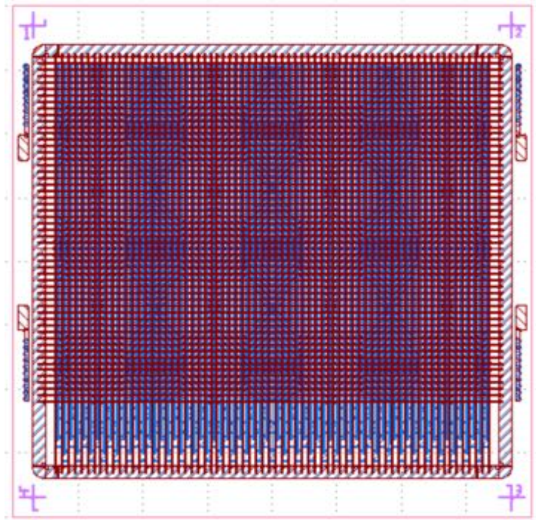
Pixel 3D, pCVD, 100x100

- Tested at PSI testbeam.
  - 3D diamond device and Silicon reference planar device.
  - Pixel threshold 1500e.
  - Check hit efficiency over time.
  - Device works!



Next generation 3D Diamond

- Produced 3500 Cell pixel protoype, 50x50um cell size.
- Sample production:
    - Oxford (2x cubic cells)
    - Manchester set-up in progress (expected production date end of month.)
    - Bump bonding
        - For ROC (CMS) Princeton.
        - For FE-I4 (ATLAS) IFAE.
- Data taking in August 2017 at PSI.

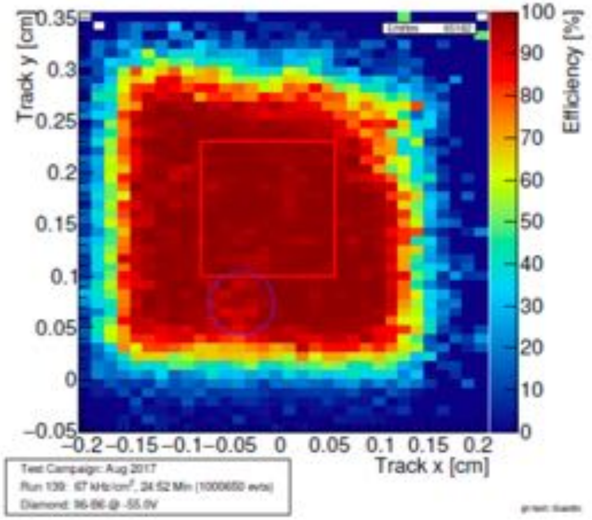


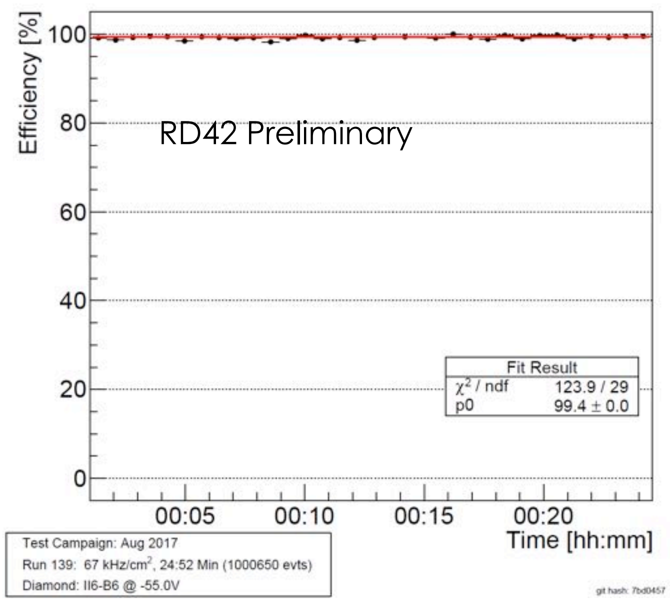
50x50 μm cell 3D Diamond

Preliminary Results (50μmx50μm pixels)

- Readout with CMS pixel readout.
- Bump bonding issue in upper right edge (Indium bump deposition machine not working properly)
- 6 columns (3x2) ganged together.
- Preliminary hit efficiency 99.2%
- Preliminary:
  Collect >90% of charge!
- Rate dependence tested with 10 kHz/cm^{-2} and 10 MHz/cm^{-2} ->
  no dependence observed.

RD42 Preliminary





Conclusion and Outlook

- Good progress in 3D detector devices made!
  - First bump bonded pixel devices.
  - 50x50um devices for ATLAS and CMS.
  - Two sites for laser processing (Oxford, Manchester).
- Aim to propose 3D diamond technology for phase-2 upgrade of ATLAS/CMS
  - Beam conditions monitor.
  - Luminosity measurements.

Research Assistant position

- 2 years position at University of Manchester.
- Working on 3D diamond detectors.
  - Development of laser process.
  - Prototyping detectors for HEP and Medical Applications.
  - Multi-Photon absorption for characterization.
- Ad to come out soon.
- Drop me an email if interested:
  alexander.oh@manchester.ac.uk

BACKUP