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Status of 3D Diamond

ADAMAS

GSI meeting

19th Nov 2014

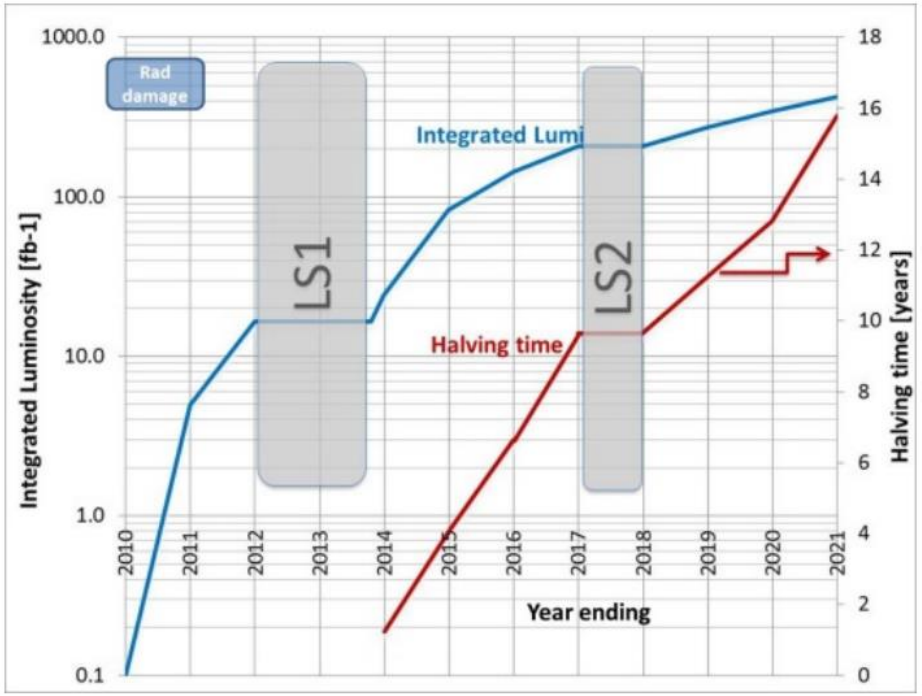
Alexander Oh

University of Manchester

3D Diamond Group / RD42

Challenges Ahead

- Luminosity upgrade of the LHC will increase the luminosity by O(2).



- Luminosity ~ Radiation damage
- Need new technologies in the innermost layers to survive the radiation levels.
- Candidates technologies:
  - 3D silicon
  - Diamond
- Why not: 3D diamond

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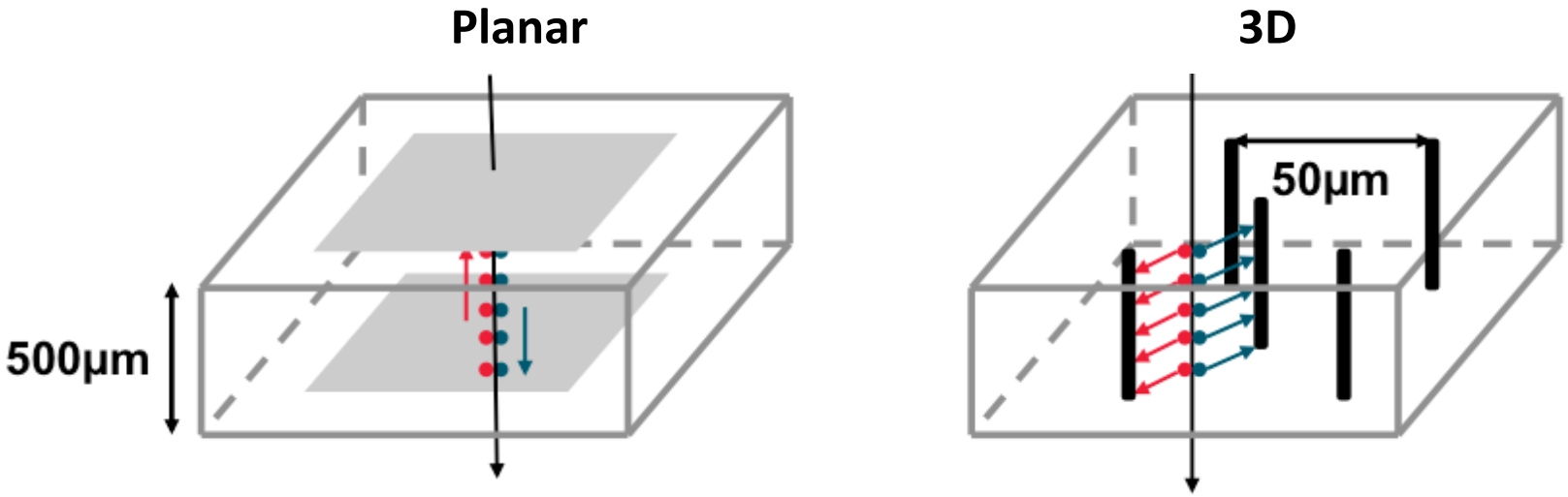
Motivation

Why 3D?

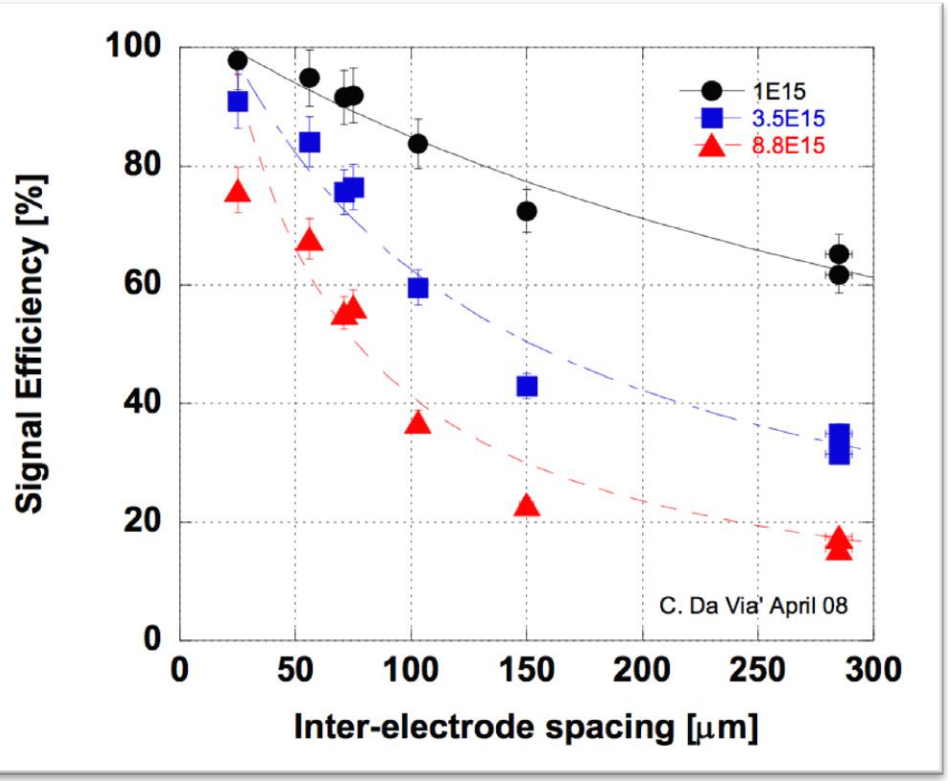


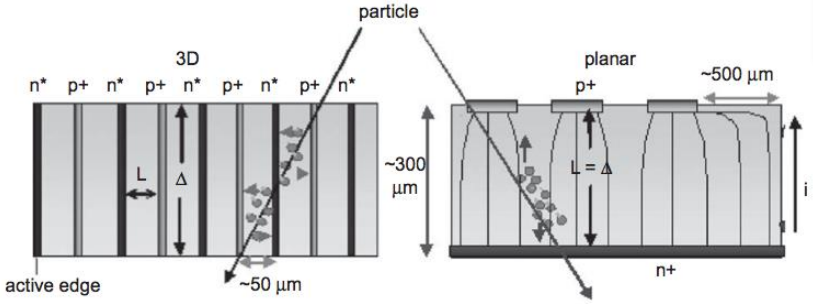
Drift distance comparable to mean free path of charge carriers in irradiated diamond.

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**.





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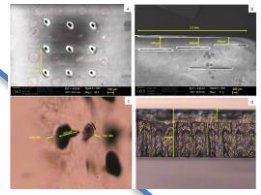
3D Diamond Research

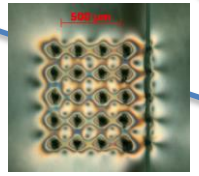
Lasered graphitic structures in pCVD ('10)

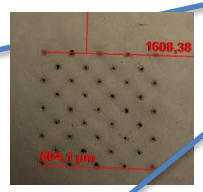
Single crystal with column structure ('11)

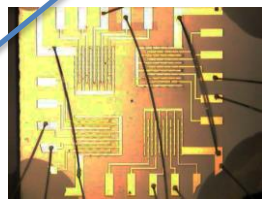
Femto second laser for improved graphitic electrodes ('12)

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





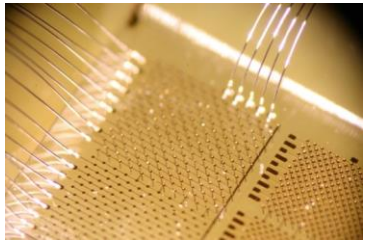




3DD

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).



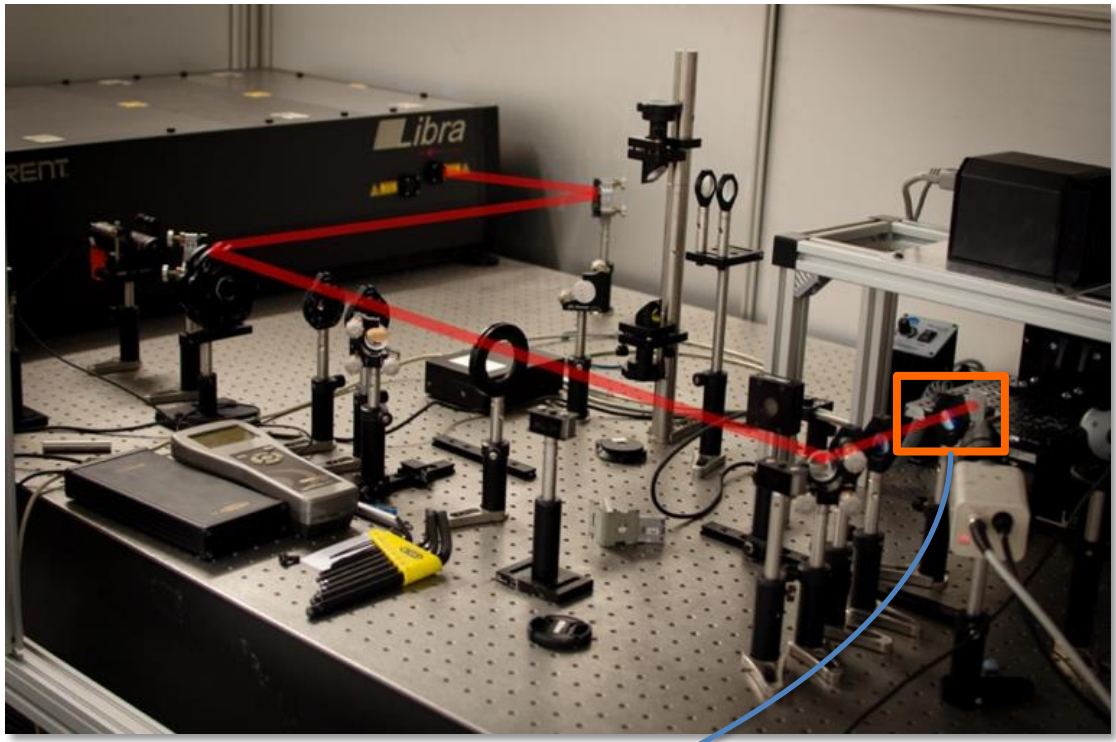
Developments in 2014

- **Laser**
  - After moving to another lab laser broke down.
  - Took a while to find the fault.
  - Power supply related.
  - Fix found as of two weeks ago.
  - Reproduce graphitisation process.
- **Analysis**
  - Finalised analysis of CERN test beam data, publication in final sign-off.
  - Synchrotron and RBI proton micro-beam data still in analysis.
- **Simulation**
  - Working on TCAD simulation validation.
  - Parameter optimisation to match experimental data.
  - Validation of test-beam results.

Laser

University of Manchester, Laser Processing Research Center.

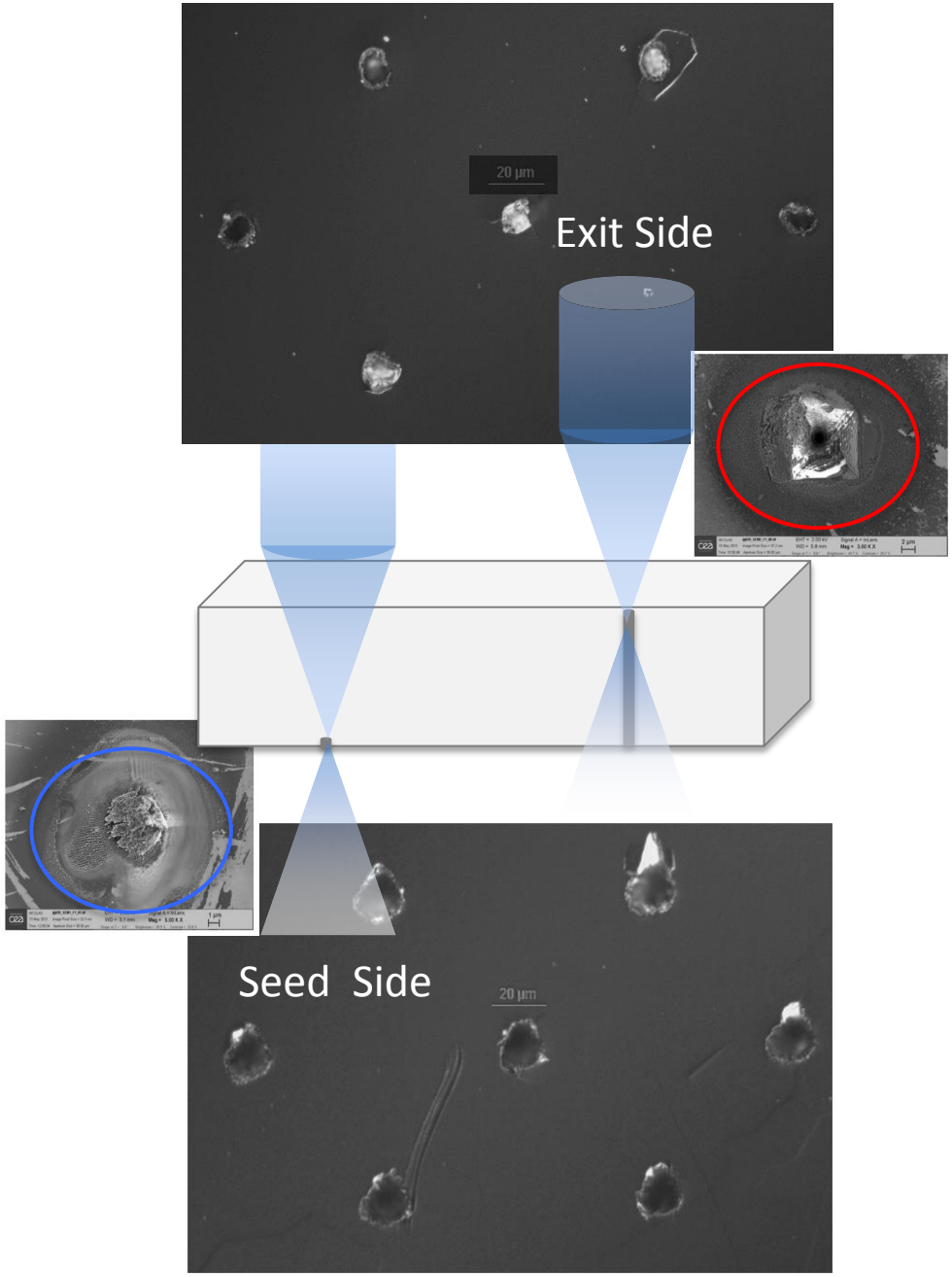
- Wavelength = 800 nm
- Repetition rate = 1 kHz
- Pulse duration = 100 fs
- Spot size = 10 µm
- Pulse Energy ~ 1 µJ



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.



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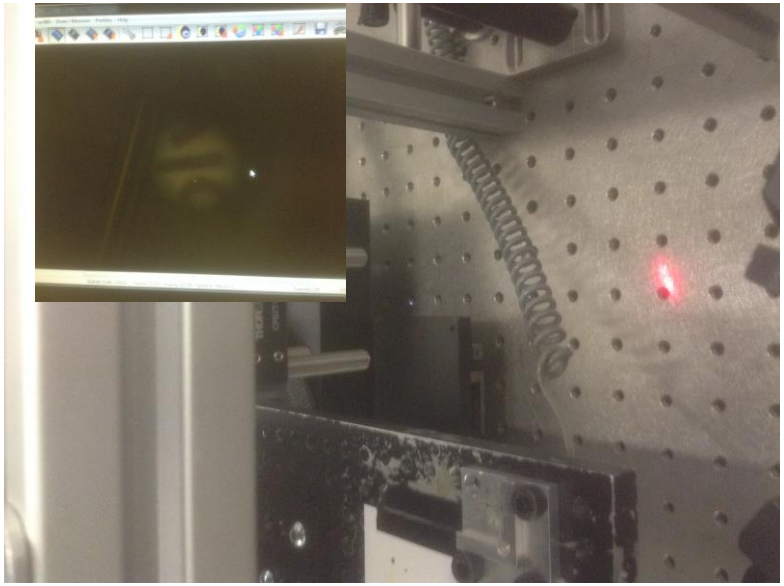
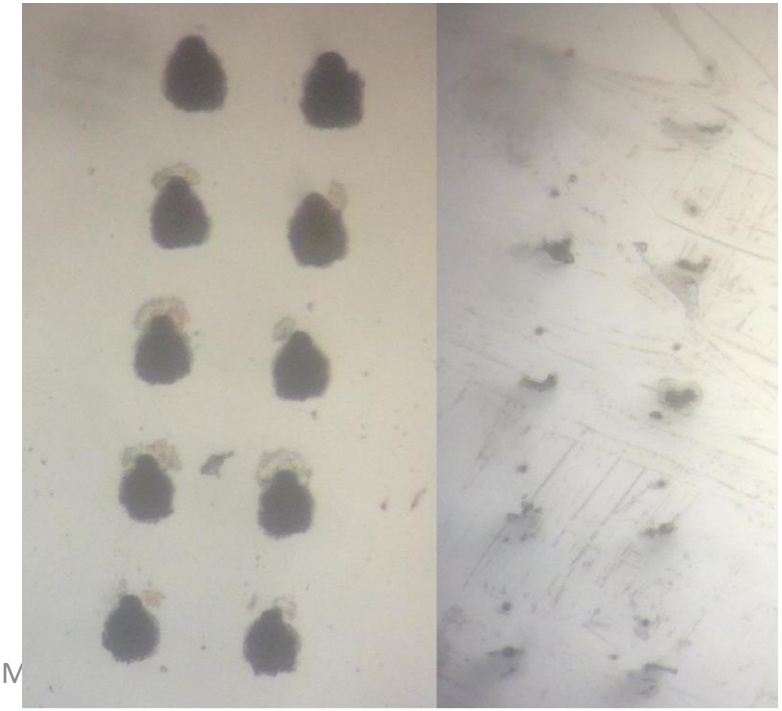
Laser

University of Manchester, Laser Processing Research Center.

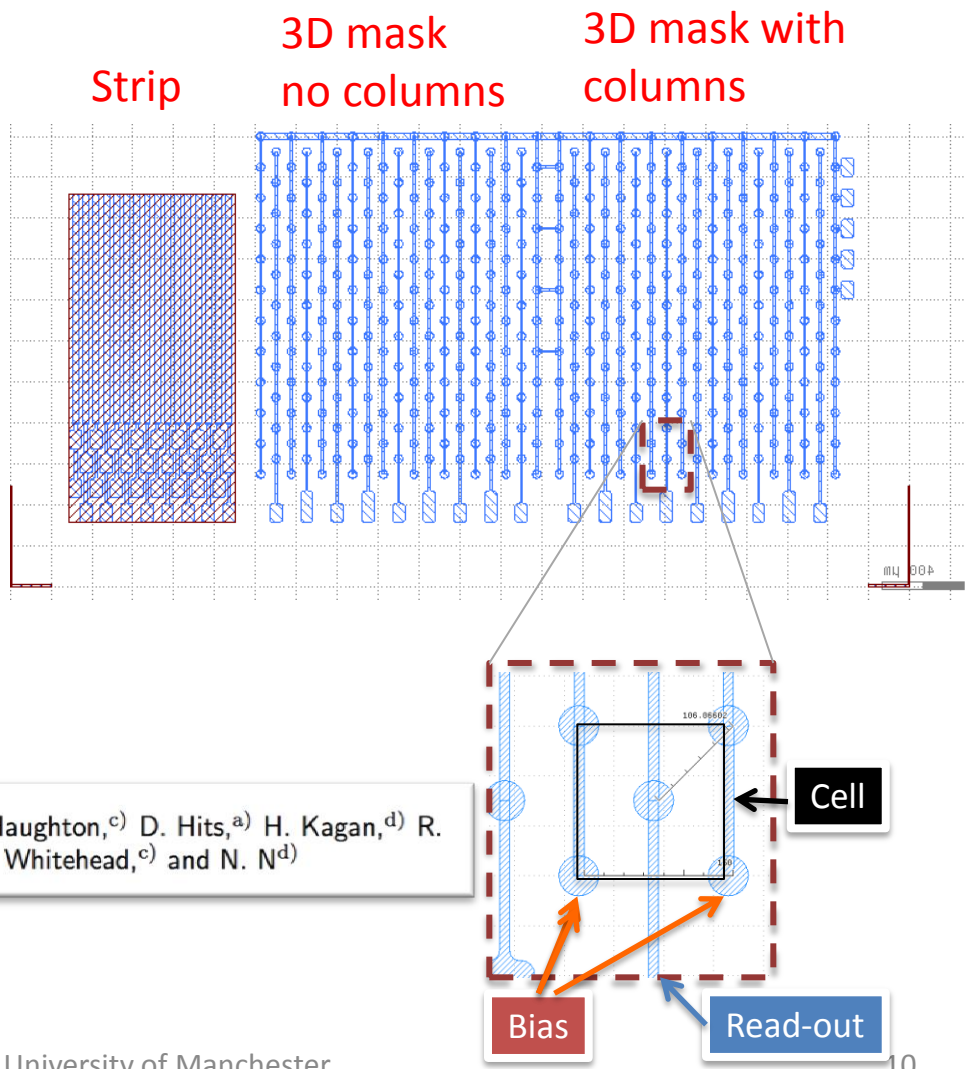
- **In repair most of 2014**
  - Faulty power supply after move to new location diagnosed.
- **Improvements to set-up:**
  - In-situ camera to track progress.
  - New bolometer.





CERN Test-beam

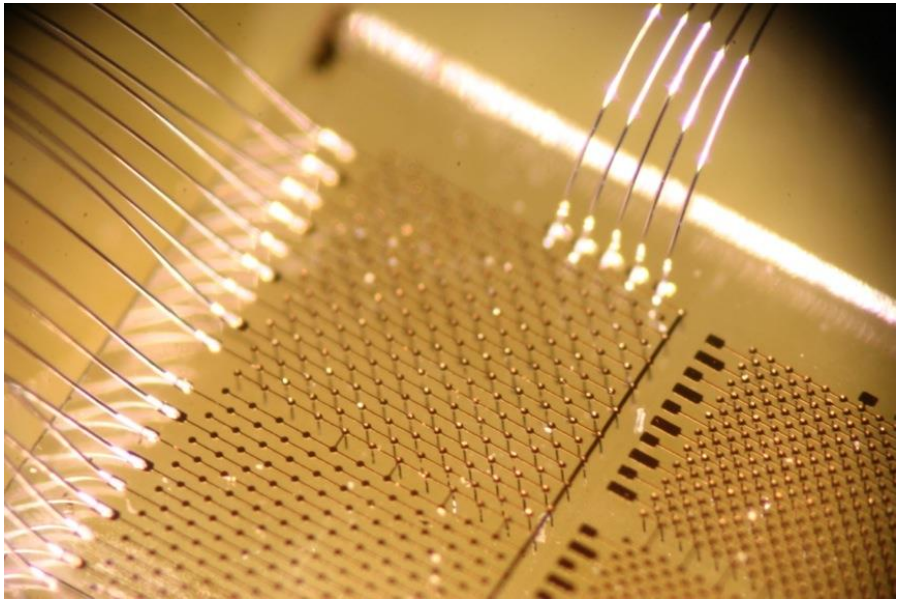
- **Proto-type**
  - Strip detector with back side contact
  - 3D metal only pattern
  - 3D metal + graphitic columns
  - Cubic cell base size 150μm
  - 99 cells
- Measure response with 200 GeV protons.
- Finalised analysis Nov 2014.
  - Paper draft in circulation.

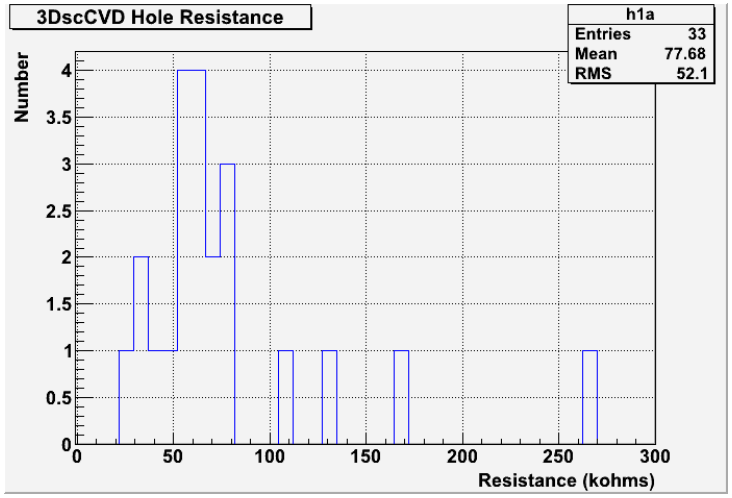


F. Bachmair,[a] L. Baeni,[a] P. Bergonzo,[b] B. Caylar,[b] G. Forcolin,[c] I. Haughton,[c] D. Hits,[a] H. Kagan,[d] R. Kass,[d] L. Li,[c] A. Oh,[c] M. Pomorski,[b] V. Tyzhnevyi,[c] R. Wallny,[a] D. Whitehead,[c] and N. N[d]

Fabrication

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

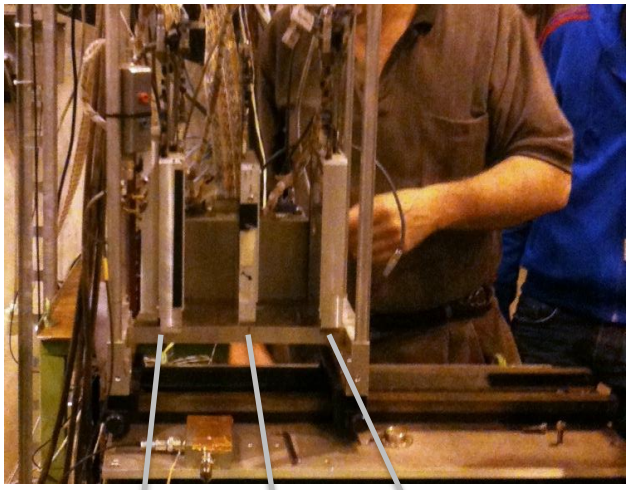


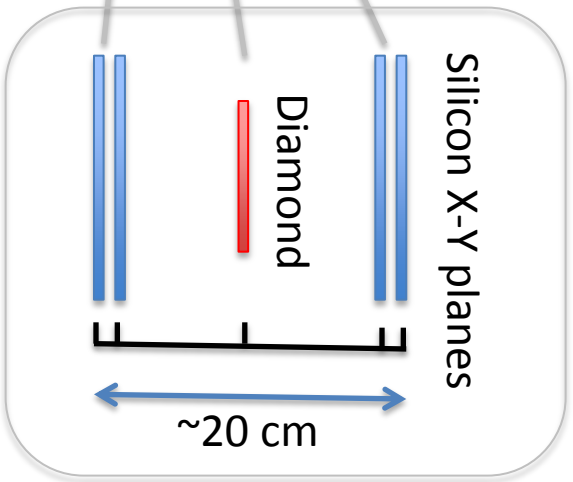


- Yield of working columns ~ 90%.
- Resistivity ~ 1 Ω cm.

Test-beam

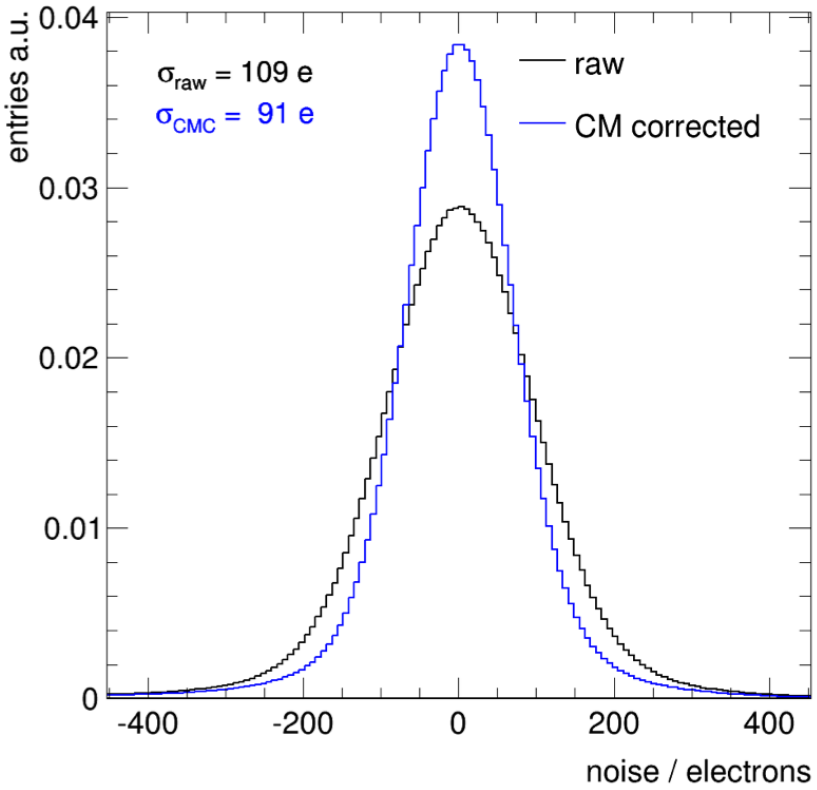
- **CERN Test-beam set-up**
  - SPS H6 beamline
    - Protons with p = 120 GeV/c.
    - spill every 40 sec
    - ~4k events per spill.
  - Silicon telescope for track reconstruction
    - 4 planes of X and Y strips.
    - Resolution few O(μm)
    - Two scintillator (~1 cm^2), trigger on coincidence.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





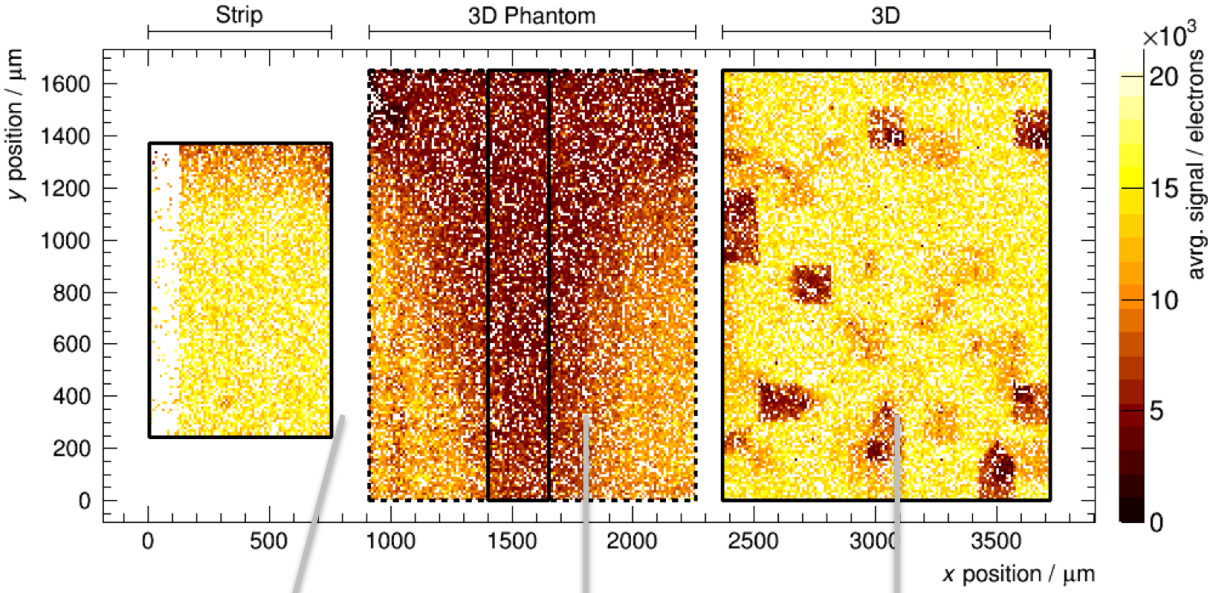
Test-beam

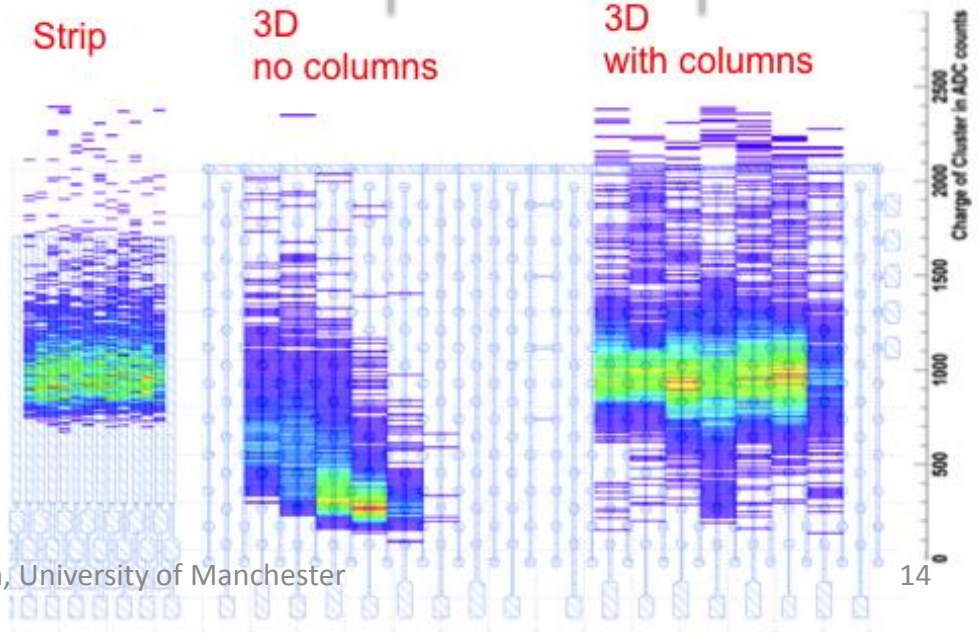
- **CERN Test-beam set-up**
  - Raw signals pedestal subtracted.
  - Common mode correction.
  - Noise after corrections 91e.



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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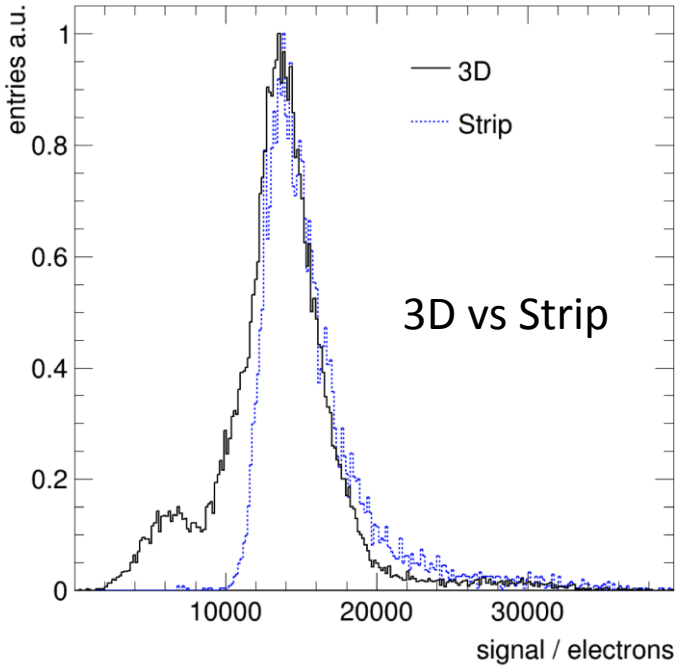
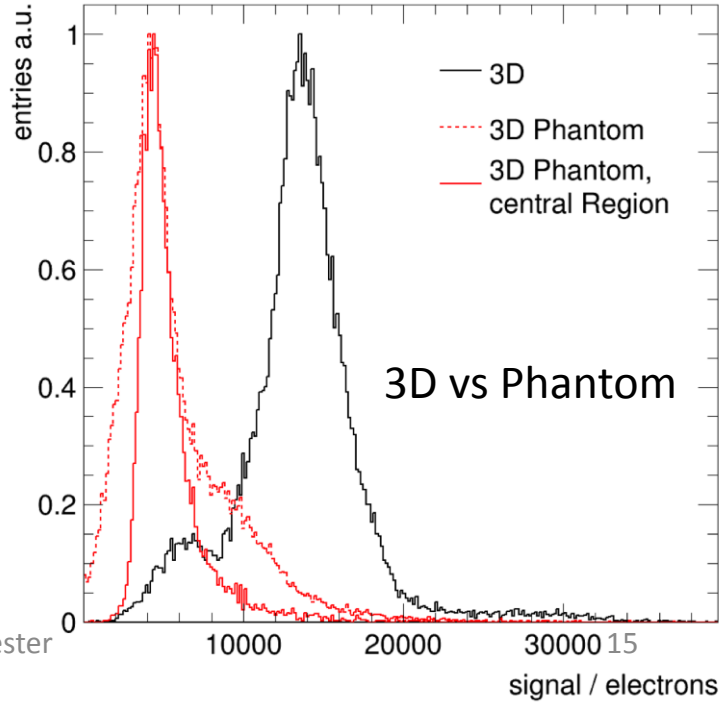
Test-beam Analysis

- **Reconstruction:**
  - Require a single Silicon track.
  - Take cluster charge of **three strips**.
  - Require a hit in the diamond (clustered analysis)
  - Build cluster charge at track position on the diamond (transparent analysis).
- 3D vs Strip show similar MP
  - lower shoulder at 3D due to imperfect cells.
- 3D vs Phantom
  - ~1/3 signal in phantom
  - lower should coincides -> missing read-out columns in 3D.





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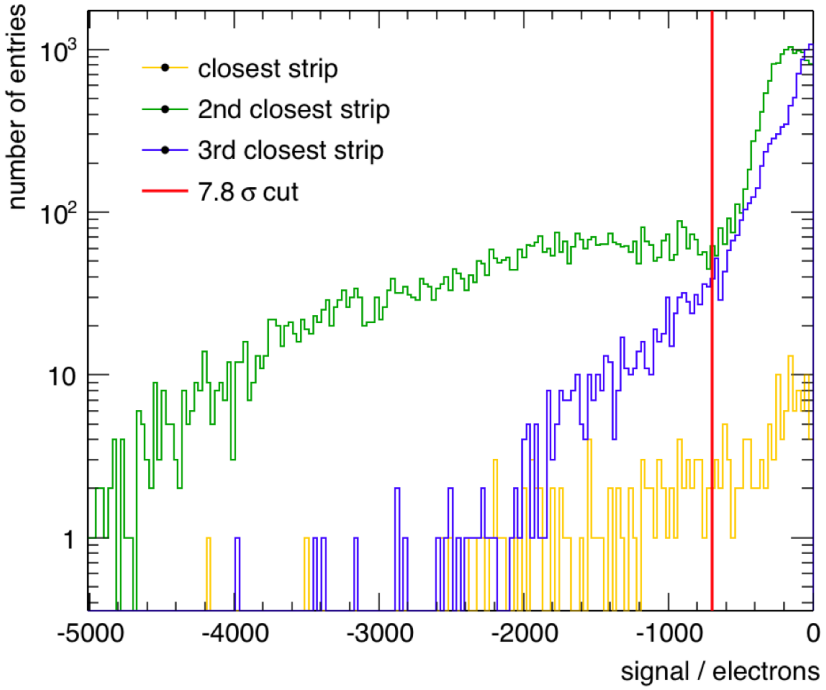
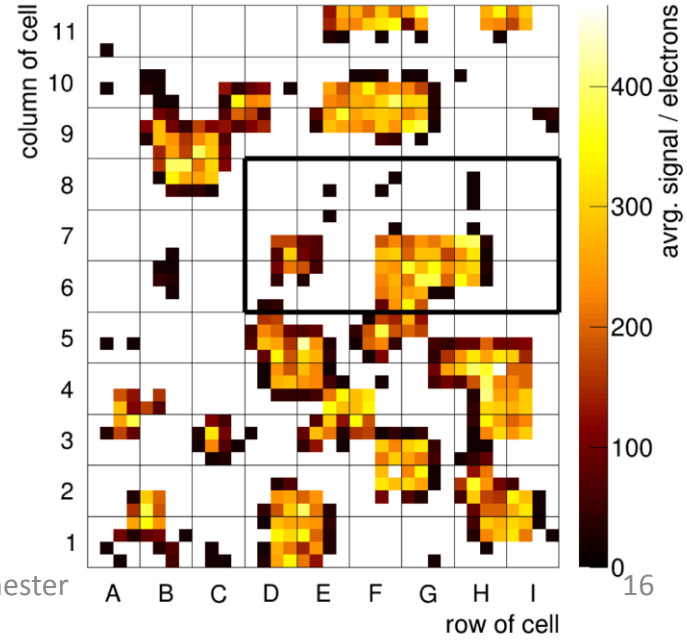
Test-beam Analysis

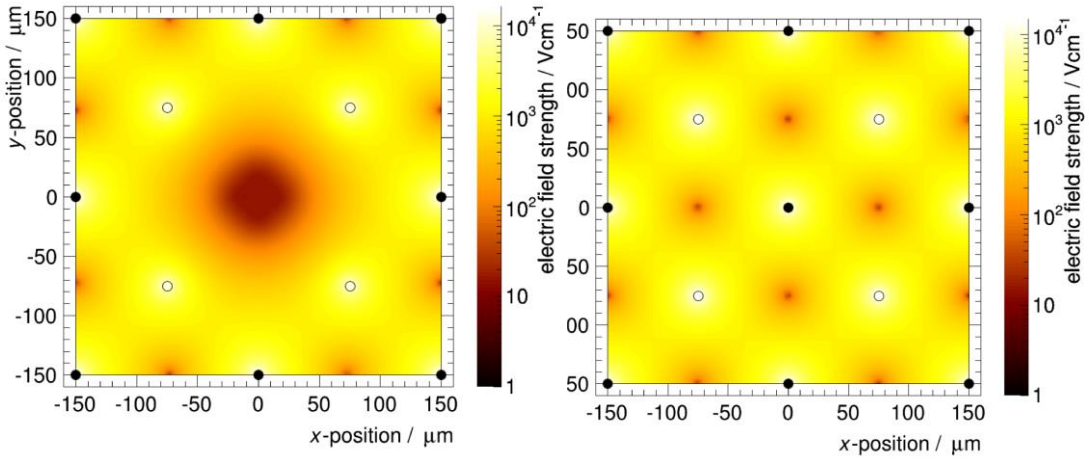
- Observed negative signals near some “bias columns”.
- Strongest negative signal on 2nd closest strip to track.
- Probably due to missing bias columns?

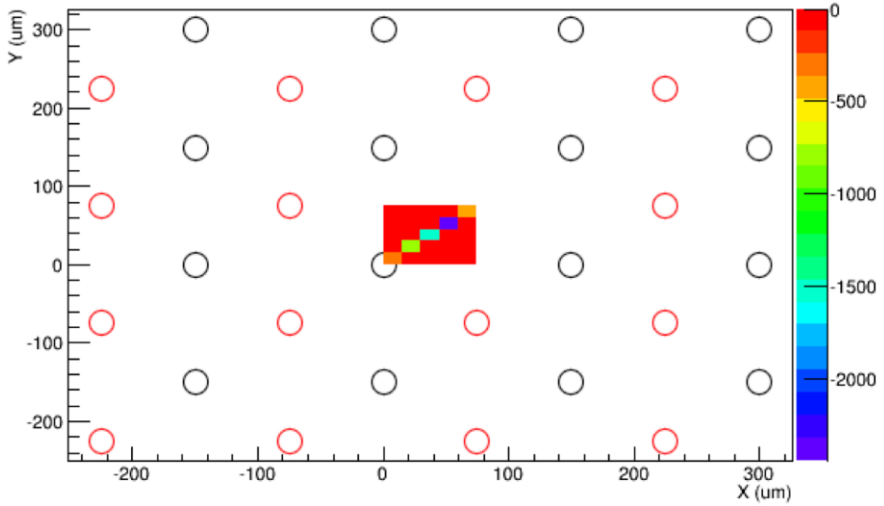




Test-beam Analysis

- **TCAD simulation**
  - 3D simulation of defect cells including metallization pattern.
  - trap free
  - look at signal of X ns to aproximate traps.
  - Computing intensive (O(10)h on 10 cores).
- **Results**
  - Qualitative agreement of negative signal observation.
  - Due to weighting field shape.
  - Similar behaviour observed in 3D silicon.





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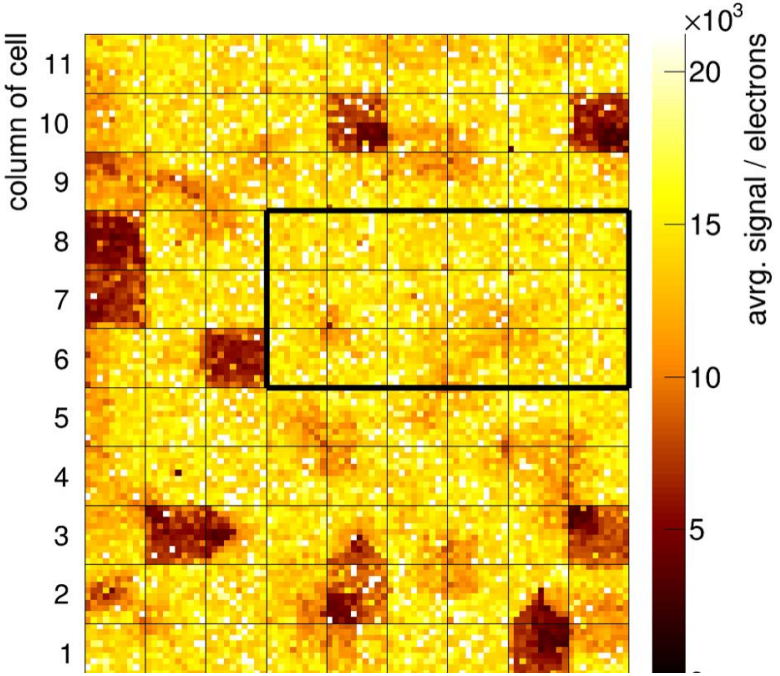
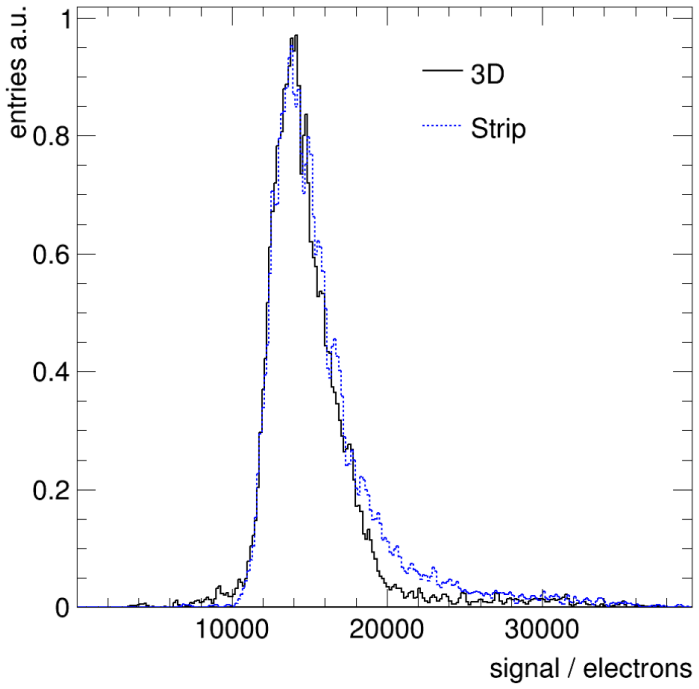
Analysis steps

- Identify **continuous region** of intact cells for analysis.
- Exclude contribution of negative signals.
- **Average charge**
  Strip: 16.8ke
  3D: 15.9ke
- **MP:**
  Strip: 14.7ke
  3D: 15ke





3D and Strip show comparable response.
Conclusion -> 3D works!

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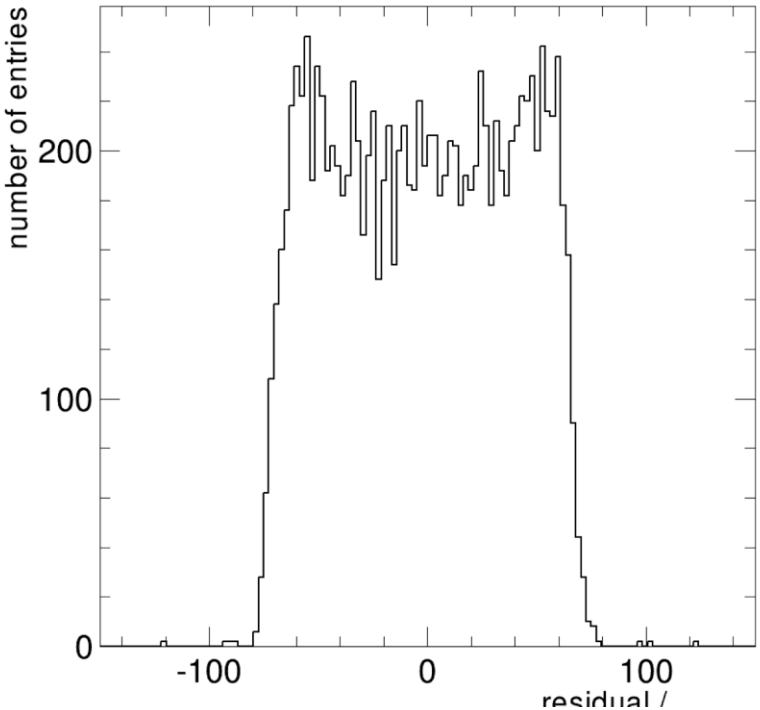
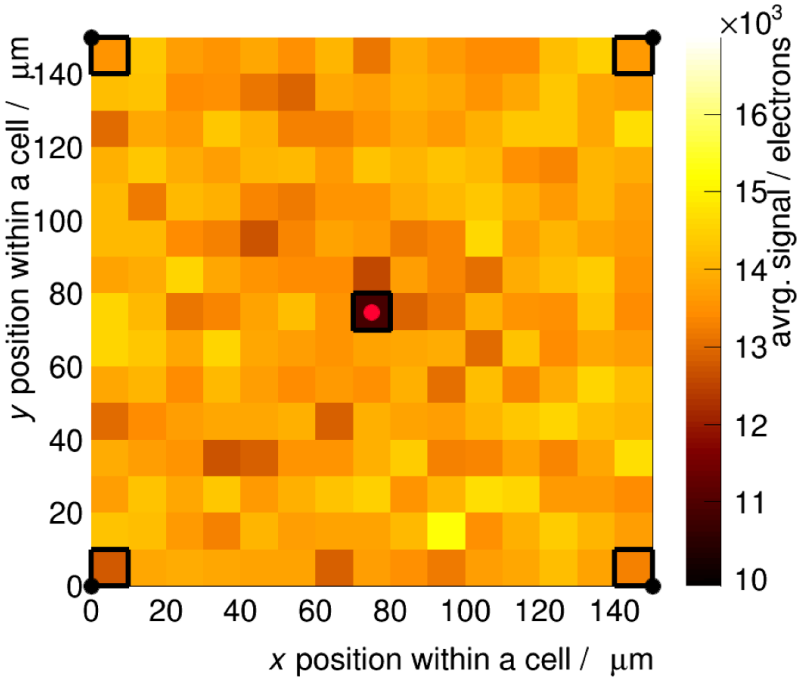
Results

- Residual distribution $r=x_{3D}-x_{rec}$
  - RMS ~40μm
  - expect digital = 43um
- Overlay of cells
  - See degradation of signal in column areas.
  - Consistent with 6μm column width and metallization signal pick-up.





Summary

- **Laser operational again (hopefully!).**
- **Analysis of 3D single crystal finished and close to publication.**
  - **More test-beam data is waiting for analysis!**
- **The next steps are :**
  - **Further improvement of the laser process.**
  - **Study of the radiation hardness.**