3D DETECTORS CONSTRUCTED WITH POLY-CRYSTALLINE CVD DIAMOND

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The 2021 RD42 Collaboration

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31 Institutes

DIAMOND PARTICLE DETECTORS

- Diamond is a radiation tolerant sensor material.
- Diamond detectors operate as **solid state ionisation chambers**
- Use synthetic **CVD diamond** either single or **polycrystalline CVD (pCVD)**
- Polycrystalline material can be grown to larger wafer size than single crystal

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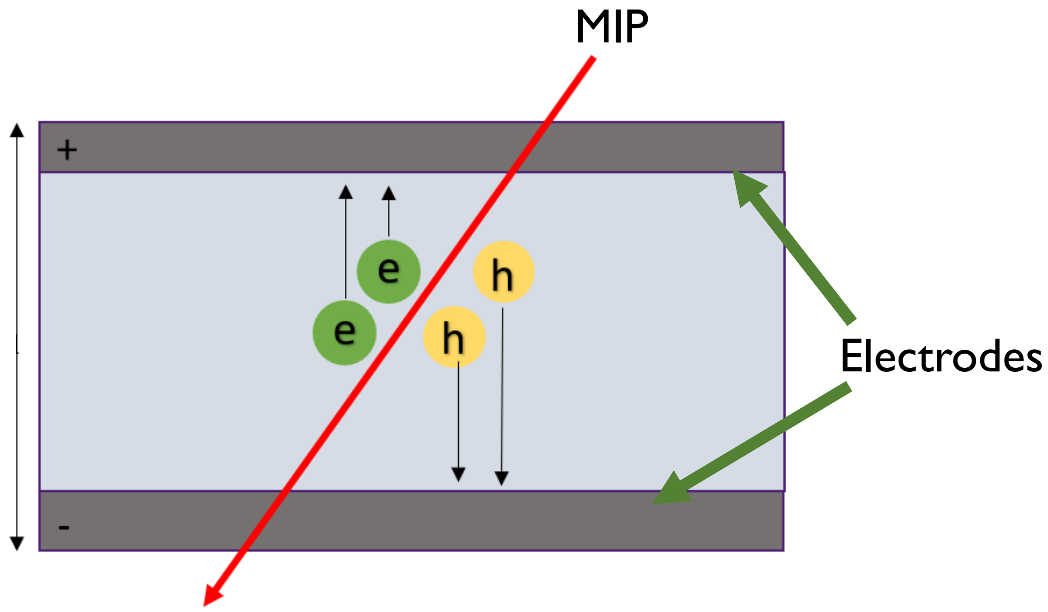
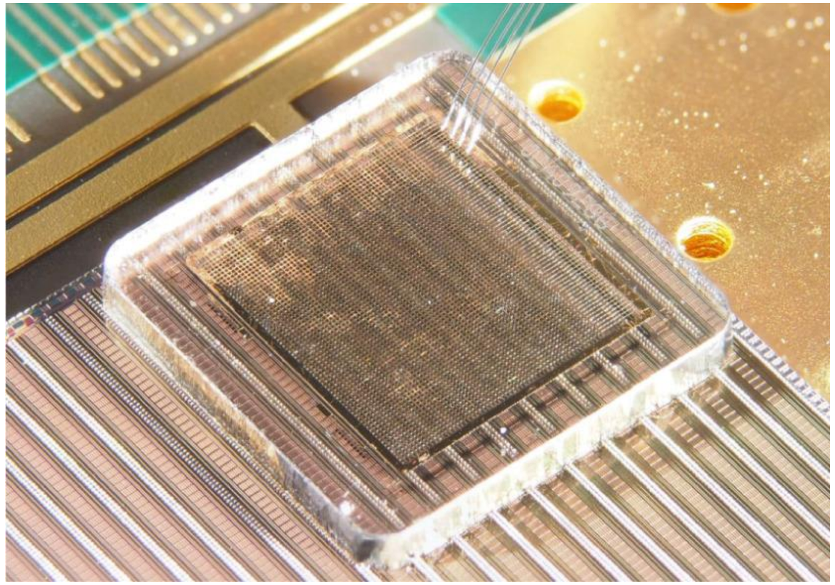


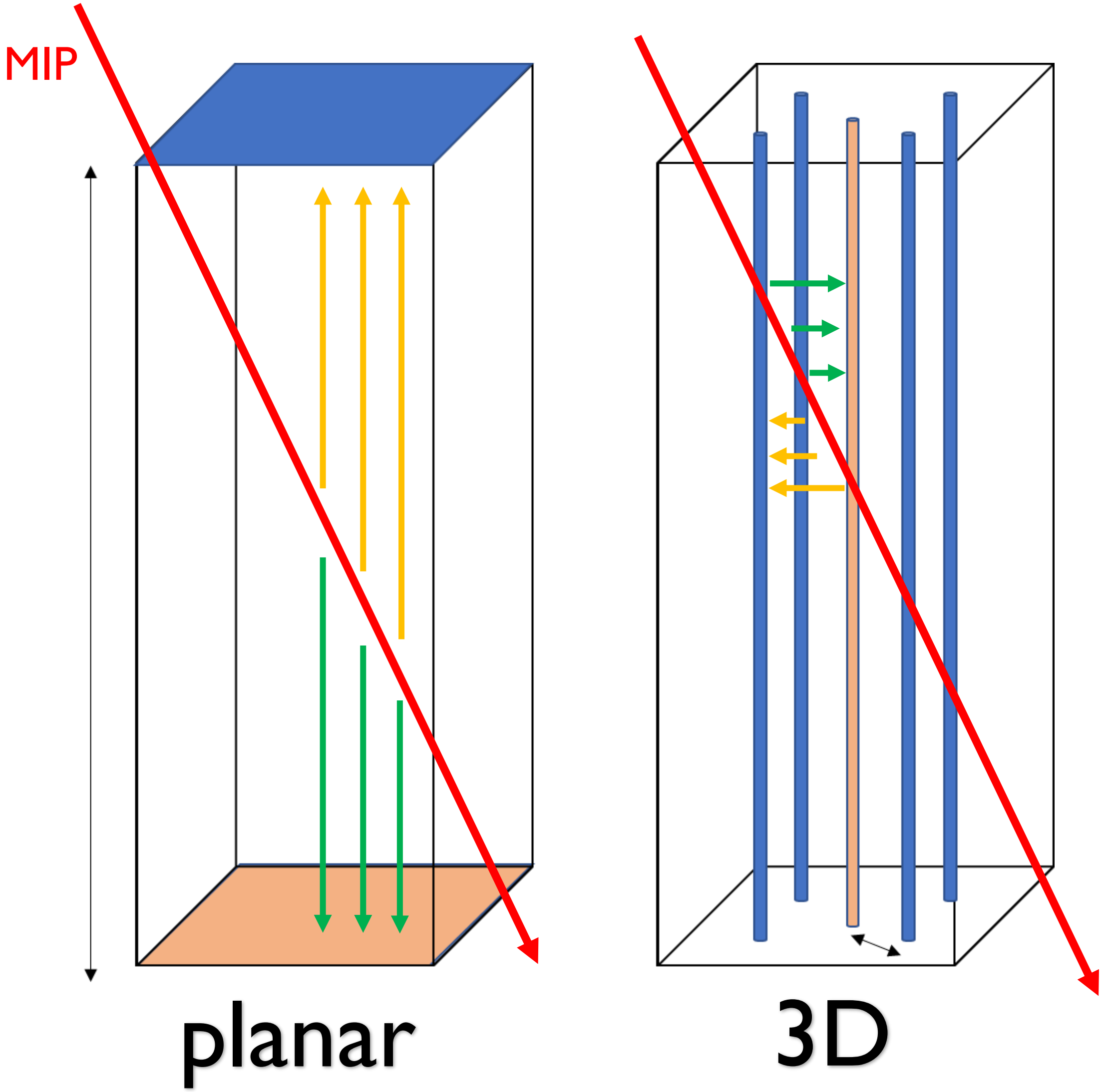
Principle of operation of a solid state ionisation chamber



3D pixel device fabricated in pCVD diamond

3D DIAMOND SENSORS

- 3D detector design has electrodes as columns inside the bulk
  - Electrode separation no longer coupled to the substrate thickness
- A 3D and planar device of the same substrate thickness will produce the **same** amount of induced charges
  - 3D geometry has a **shorter drift length**
- Large fluences of radiation causes all detectors to be trap limited
  - Mean drift path of charge carries <50μm
- Therefore, a 3D geometry will increase the collected charge in detectors with limited mean free path = **radiation tolerant** design
- Compliments the high displacement energy of diamond



LASER PROCESSING IN DIAMOND

- Convert insulating diamond to **resistive phases of carbon**: graphite, amorphous carbon, DLC, nano-diamond
- Action of a **femtosecond laser** (800nm)
- First methods: 90% column yield, column diameter 6-10μm
- Improvements made with inclusion of **a Spatial Light Modulator** (SLM) to correct for wavefront aberrations allowing for uniform illumination throughout the diamond depth
- With SLM: Yield >**99%**, column diameter **2.6μm**
- Processing parameter space explored
- High quality (highest continuous graphitic content) columns are fabricated with lower writing speeds, and repetitions of writing. However **SLM is key**

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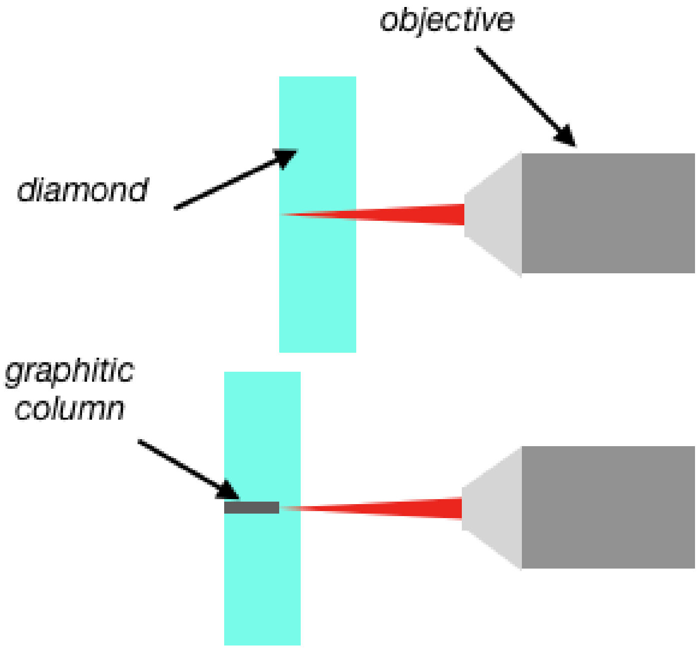
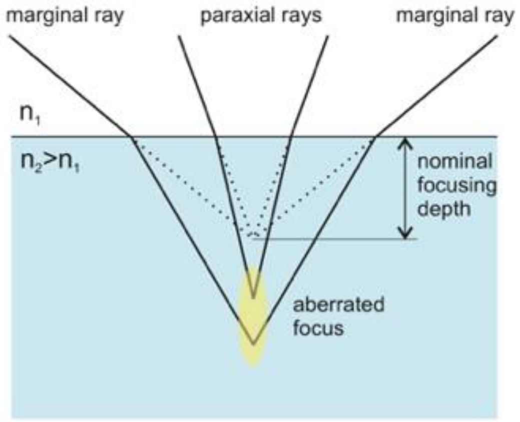
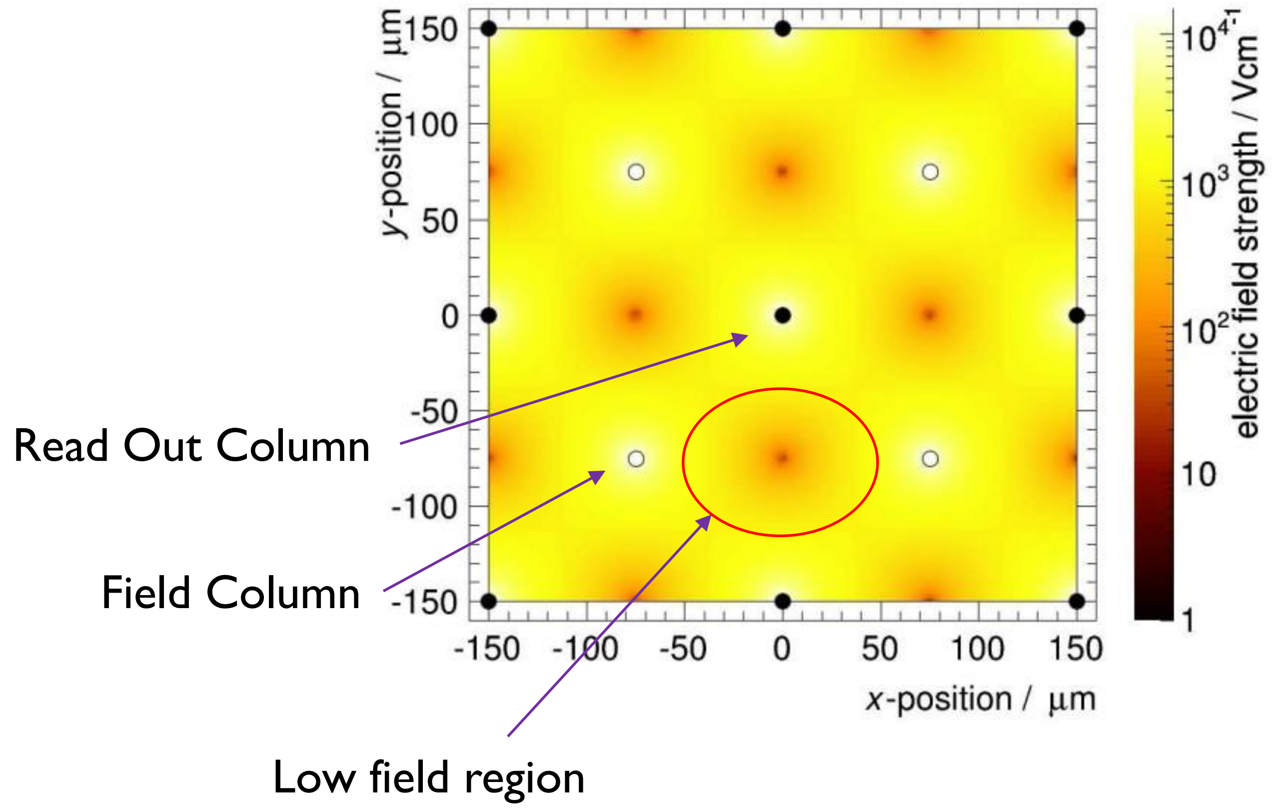




I. Haughton, talk at 12th Trento Workshop (2017)

LOW ELECTRIC FIELD REGIONS

- Successful 3D diamond detectors have been fabricated and shown to be >99% efficient
- Main drawback is the introduction of low electric field regions
  - Large cells and large diameter columns cause lower field regions at the saddle points between field electrodes



Cell size: 150 μm x 150 μm
Voltage: 25V

From G. Forcolin Ph.D. Thesis, University of Manchester 2017

ADD THE CAGE

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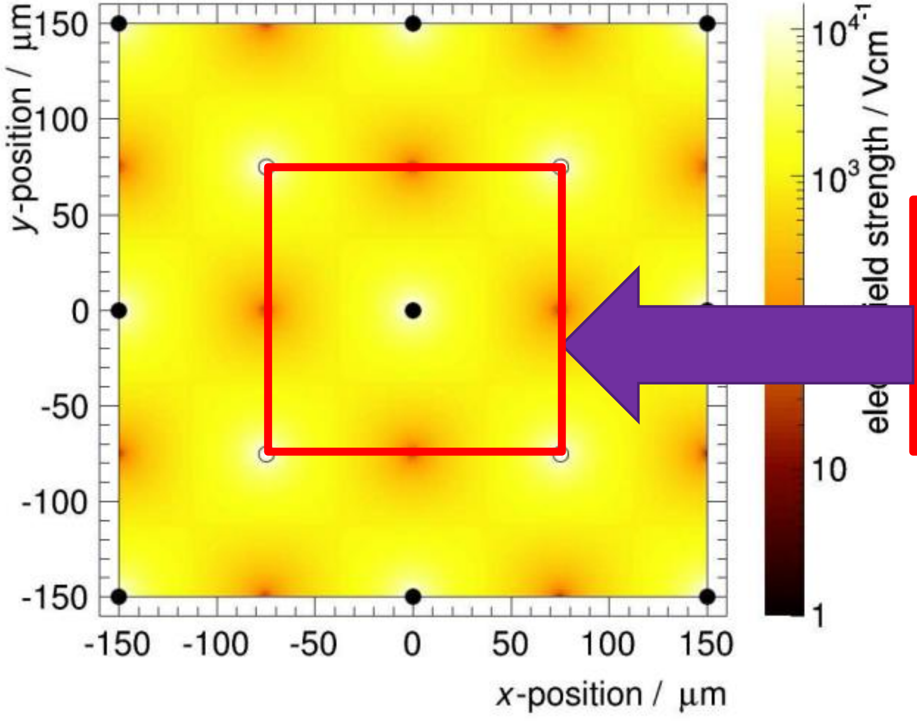
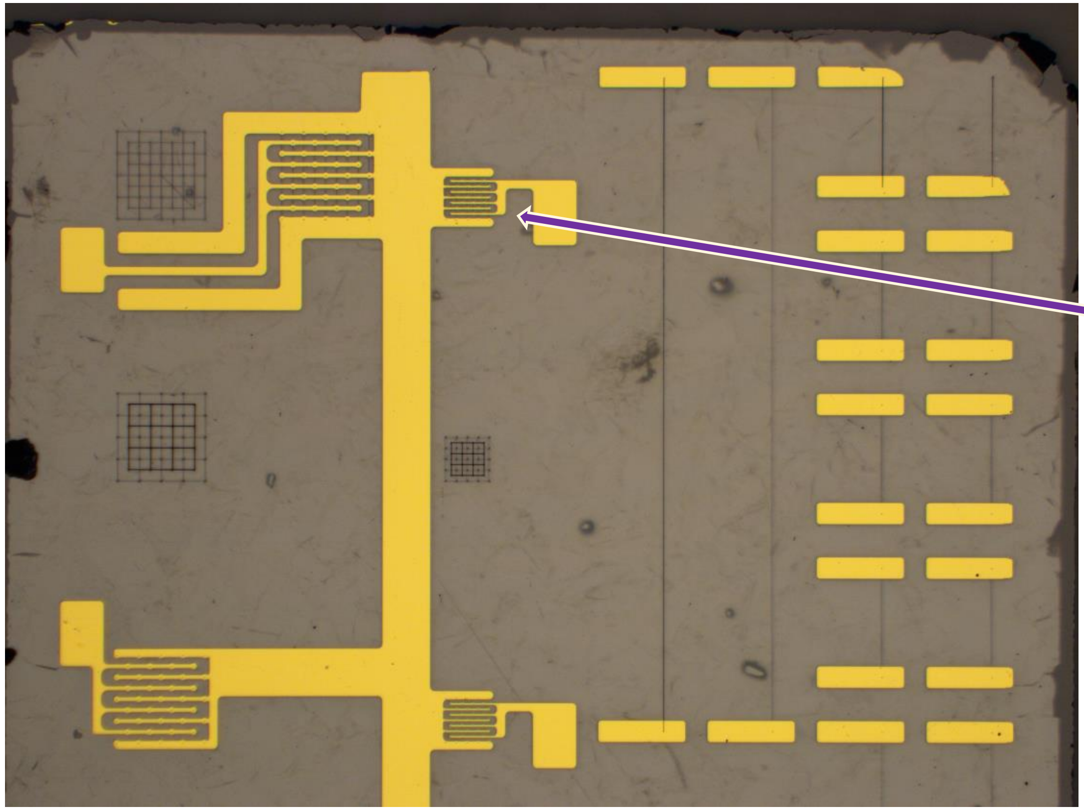


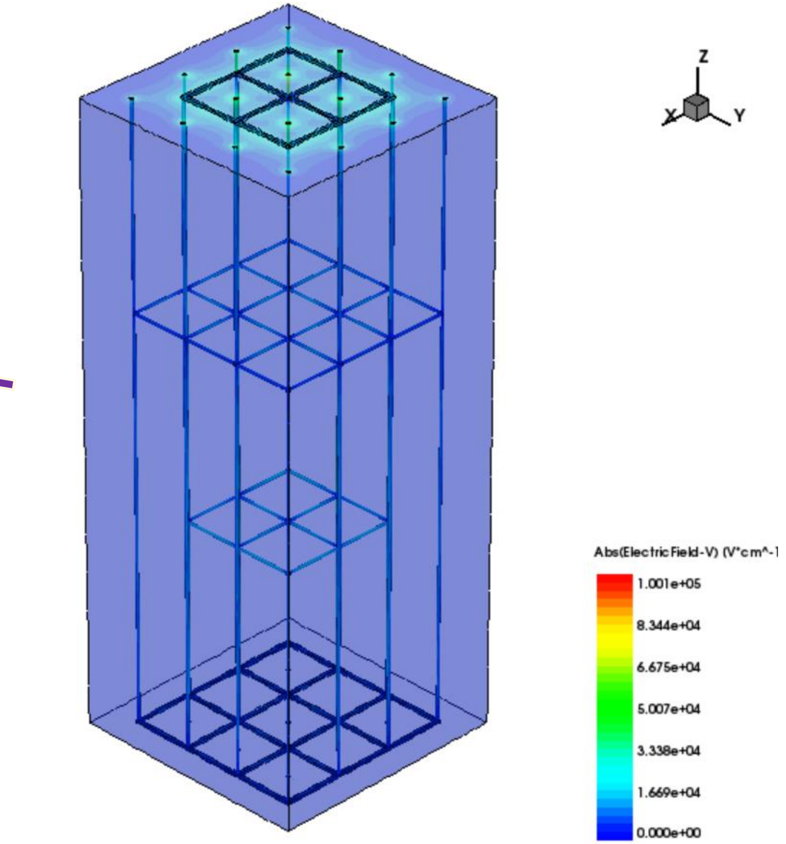
Add horizontal graphitisation inside the diamond bulk

Proposed solution to this = reduce the volume of low field regions by embedded horizontal ganging structures

FIRST TEST STRUCTURE WITH "CAGE" DESIGN

- Fabricated March 2020 (~week of UK Lockdown) first 3D diamond device with horizontal ganging
- Test structure has horizontal wires at depths of 125 and 375 μm in a 500 μm thick substrate (ρ measurement)
- Metallised 3D detector with alternating ganging (~model) read out in current mode in **RD42 Zagreb Testbeam 06-2021**



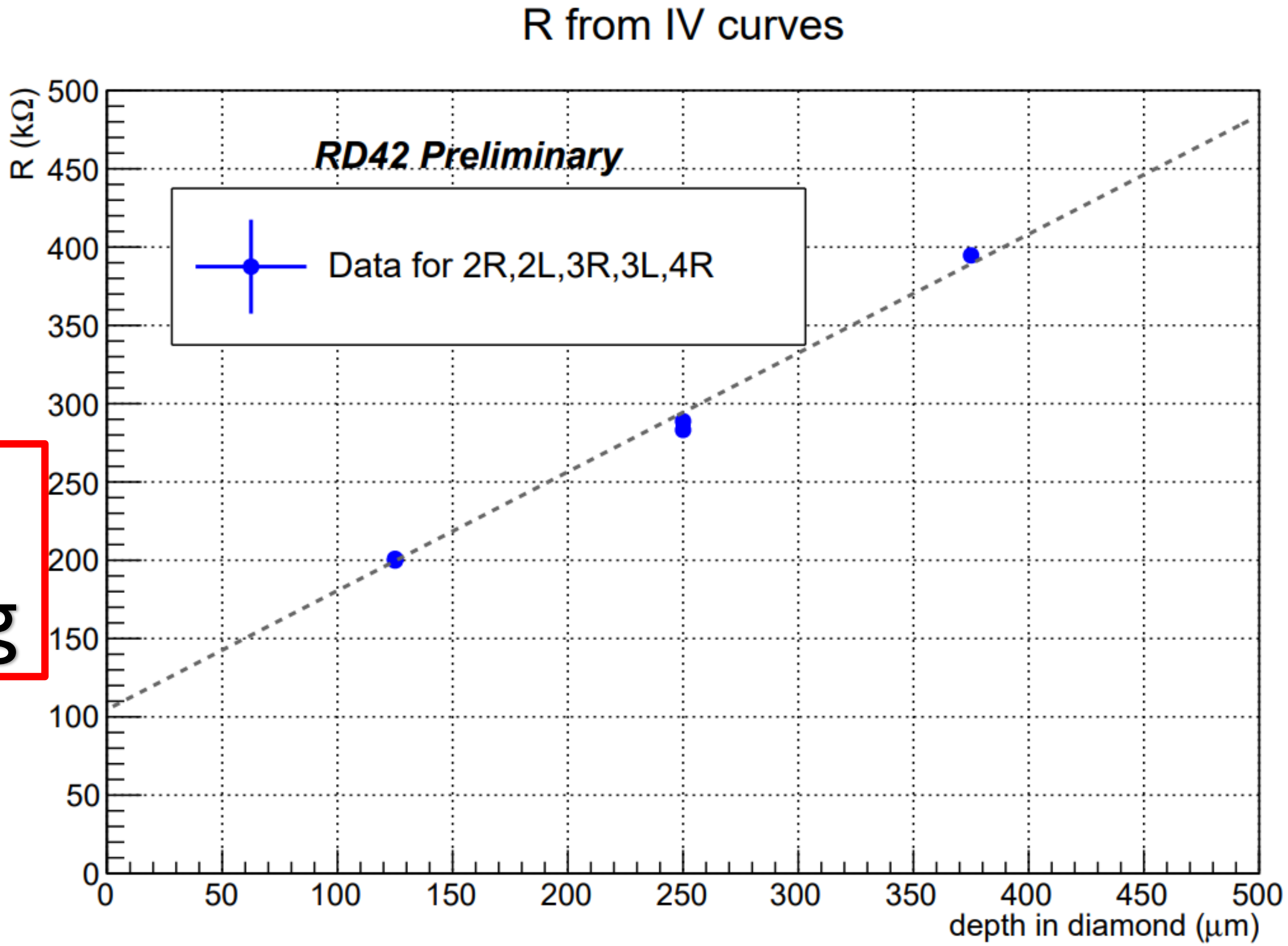


PRELIMINARY PROBE OF TEST STRUCTURES

- Resistivity measurements between horizontal columns at different depths have differing resistivity in the horizontal and vertical plane (line vs a column both 500μm length) from first probe of test structures
  - R_{line}(500μm) ~105K
  - R_{column}(500μm) ~ 380K

SLM is key to consistent resistivity horizontal wiring

- Next test beam at CERN a few weeks a way
  - …watch this space



SUMMARY + OUTLOOK

- 3D Diamond detectors offer radiation tolerant design by offering shorter drift length than a planar design
- New **horizontal graphitisation** techniques offer new freedom of design to solve issues with low electric field regions
  - Results incoming
- 3D pCVD detectors are being implemented into the ATLAS BCM' (see earlier talk)
  - Benchmark for future 3D Diamond particle tracking for higher particle fluences past the HL-LHC, FCC and beyond

Thank you for your attention!

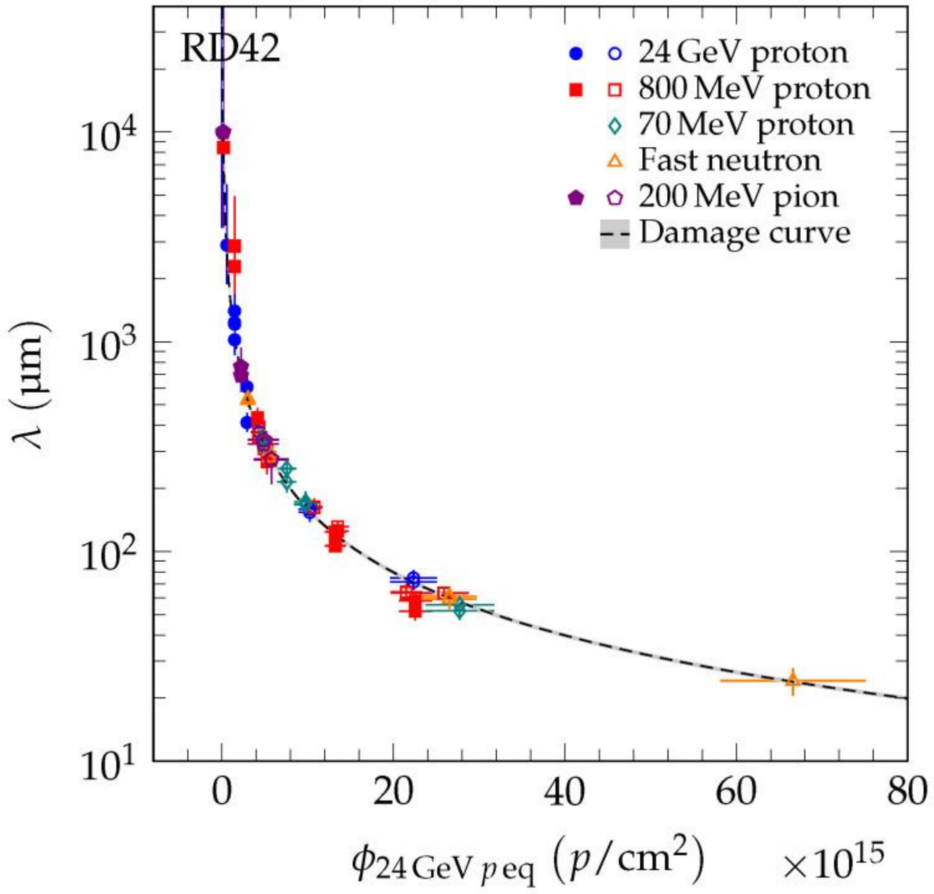
BACK UP – RADIATION DAMAGE IN DIAMOND

- Irradiation introduces traps in the diamond which lower the carrier mean free path (λ)
- Effect depends on:
  - Traps in the unirradiated material: λ_0
  - The fluence: Φ
  - The species of irradiation (protons, neutrons, etc): *k*

$$\frac{1}{\lambda} = \frac{1}{\lambda_0} + k_i\phi$$

- Put together and normalised damage to 24 GeV protons for **universal signal degradation curve**

sCVD pCVD



Sensors (Basel). 2020 : 6648