Test Beam Results of 3D Detectors in CVD Diamond

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Outline of Talk

- Introduction – Motivation, Properties and RD42
- 3D Device in pCVD Diamond
- Test Beam Results of CMS, ATLAS 3D Diamond Pixel Devices
- Summary

Introduction - Motivation

Distinct properties interesting for HEP applications:

- Large band gap → no free carriers, low leakage current, I_L
- High thermal conductivity → no cooling required
- Large displacement energy → high radiation tolerance
- Low dielectric constant, I_L → low capacitance, low noise

Disadvantages:

- Large band gap → planar detectors give ~1/2 signal of Si (same t)

At the HL-LHC the innermost detectors may see

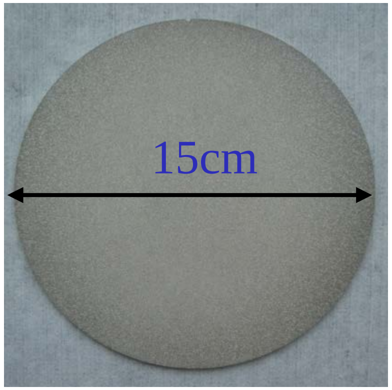
- Extreme conditions → fluences up to 10^{16}-10^{17}/cm^2 and
  → rates up to 200MHz-1GHz/cm^2

At large radiation doses, w/o gain, the drift distance relative to the mean free path determines signal size

- Next talk (A. OH) → mean free path

Introduction - Properties

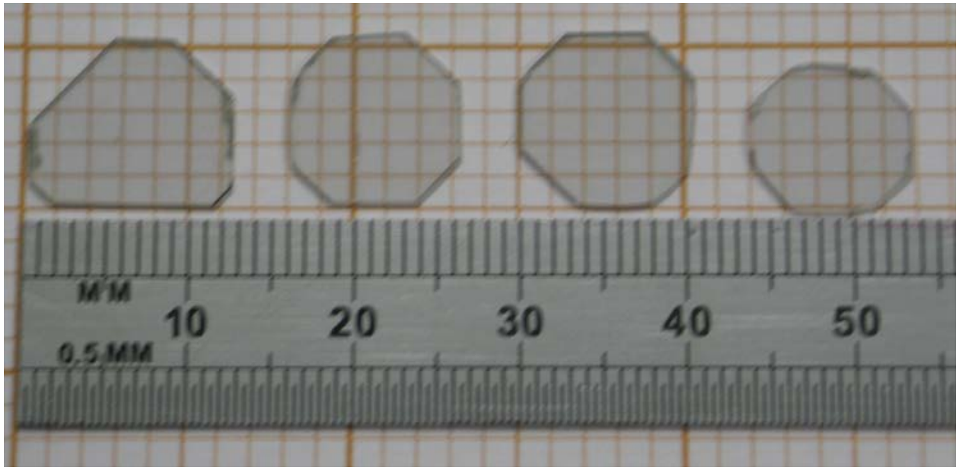
Polycrystalline CVD (pCVD) Wafer Growth



Wafers 14-15cm diameter; wafer collection distance 400μm-500μm

Uniformity across wafer ~5%

Single-crystal CVD (scCVD) Wafer Growth



Wafers 5-10mm x 5-10mm; scCVD diamond collects full charge

Uniformity better than 1%

Introduction - The 2018 RD42 Collaboration

The 2018 RD42 Collaboration

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123 participants

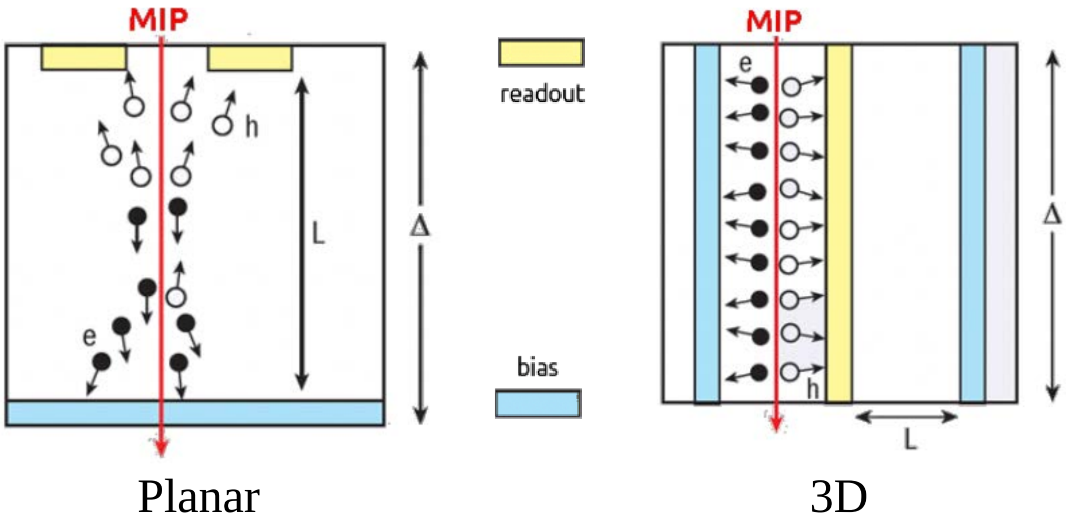
30 institutes

3D Device in pCVD Diamond

After large radiation fluence all detectors are trap limited
- Mean free paths λ < 50μm
- Need to keep drift distances (L) smaller than mfp (λ)

Comparison of planar and 3D devices

Can one do this in pCVD diamond?

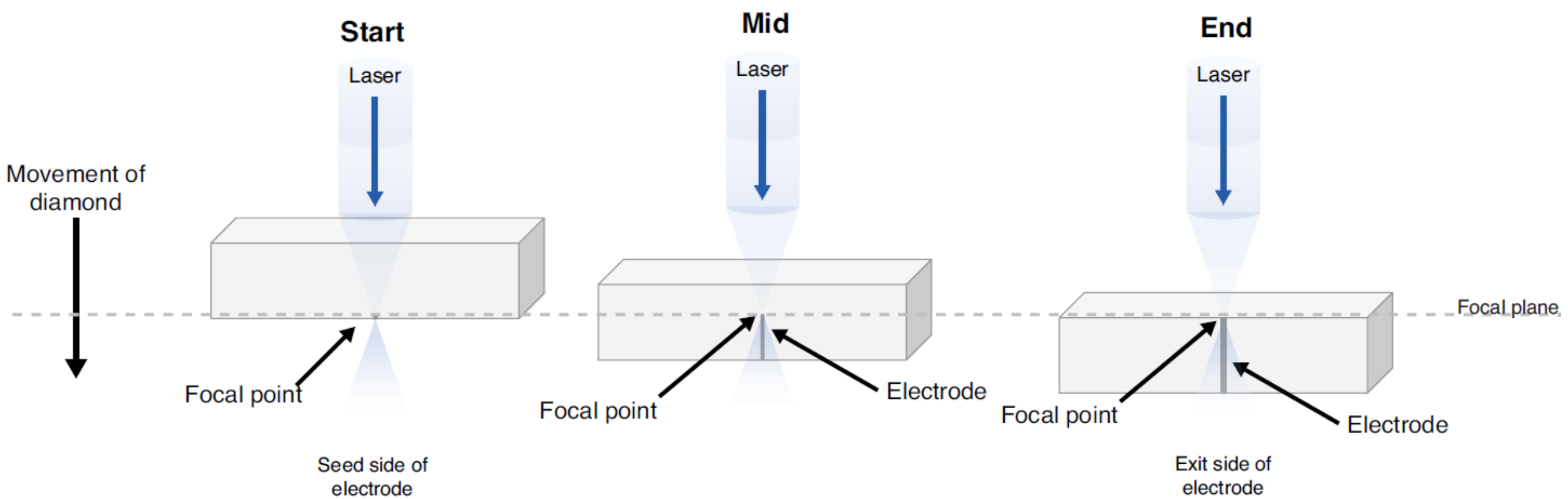


Have to make resistive columns in diamond for this to work
- -columns made with 800nm femtosecond laser
- -initial cells 150μm x 150μm; columns 6μm diameter

3D Device in pCVD Diamond

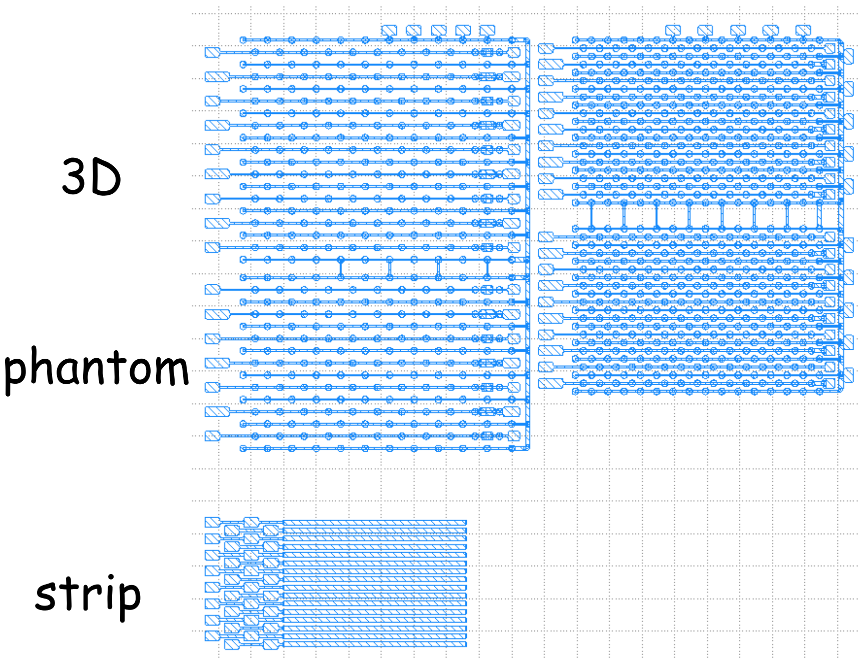
Femtosecond laser converts insulating diamond into resistive mixture of various carbon phases: amorphous carbon, DLC, nano-diamond, graphite.

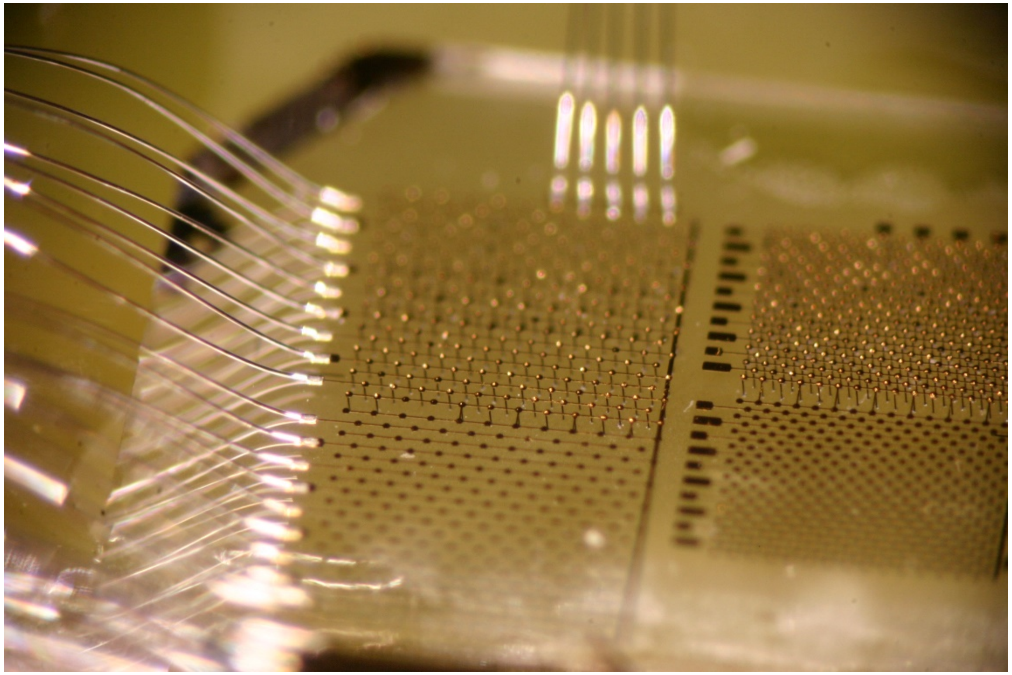
- Initial methods had 90% column yield → now >99% yield with Spatial Light Modulation (SLM)
- Initial column diameters 6-10μm → now 2.6μm



3D Device in pCVD Diamond

Simultaneously readout all 3 devices





Two years ago we showed the results in scCVD diamond

- -Compared scCVD strip detector (500V) with 3D (25V)

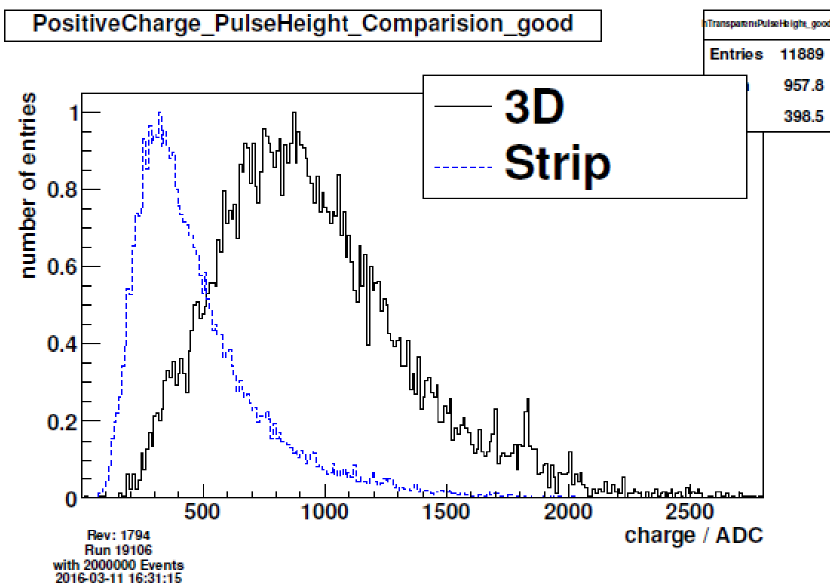
Last year the first 3D device in pCVD diamond

- -Compare pCVD strip detector (500V) with 3D (60V)

This year the first 3D pixel detectors in pCVD diamond

3D Device in pCVD Diamond

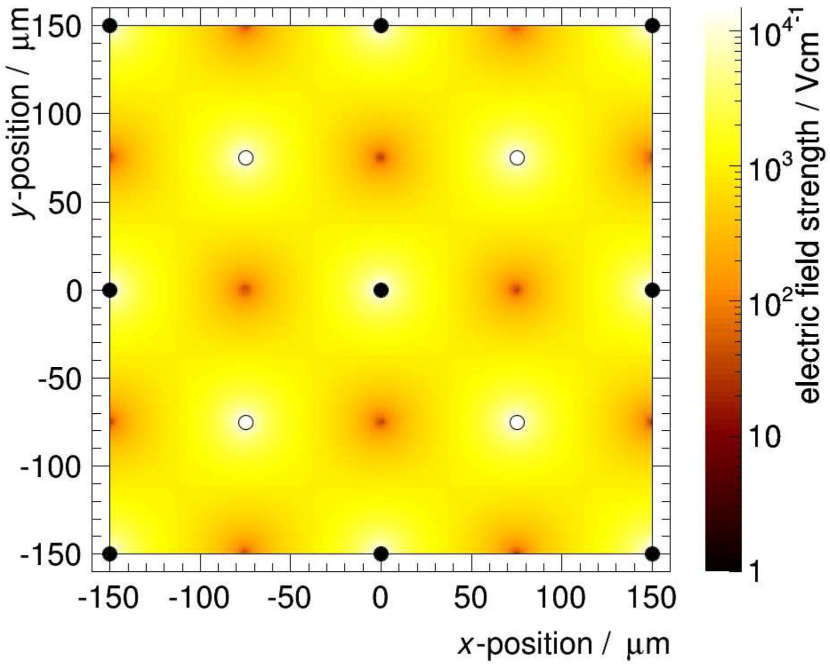
- Measured signal (diamond thickness 500μm):
  - Planar Strip ave charge
    6,900e or ccd=192μm
  - 3D ave charge
    13,500e or ccd_{eq}=350-375μm
- For the first time collect >75% of charge in pCVD



3D cell size:
150μm x 150μm

3D Device in pCVD Diamond

- Measurements consistent with TCAD simulations:
  - Large cells, large diameter columns →
    lower field regions in saddle points



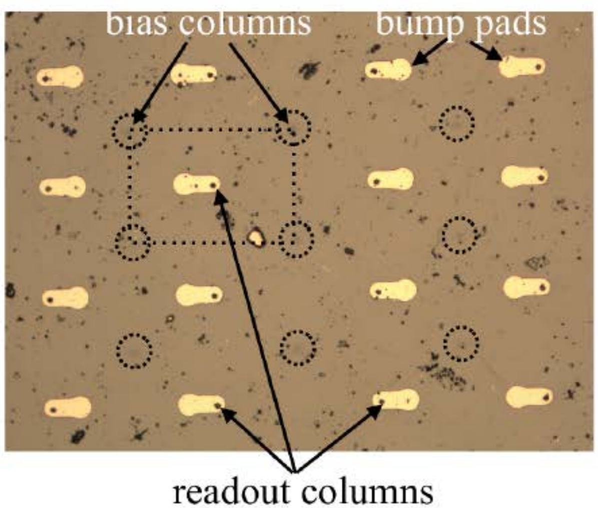
Cell size: 150µm x 150µm
Voltage: 25V

Worked well enough to construct first pCVD 3D diamond pixel device

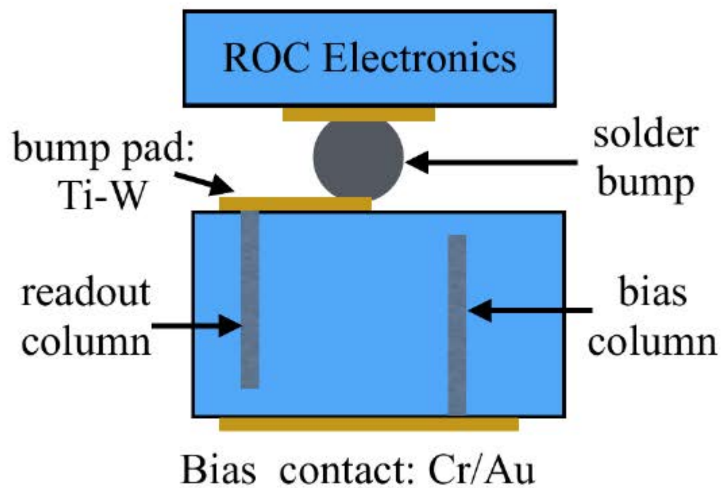
Results of CMS, ATLAS 3D pCVD Pixel Devices

First 3D pixel device in pCVD (2017) – [150μm x 100μm cells]

- Produced cells with 150μm x 100μm size for CMS pixel readout chip
- Cleaning, photolithography, metal contact to pixel and bias – RD42
- Bump and wire bonding - Princeton



(a) pixel readout metalisation



(b) final scheme

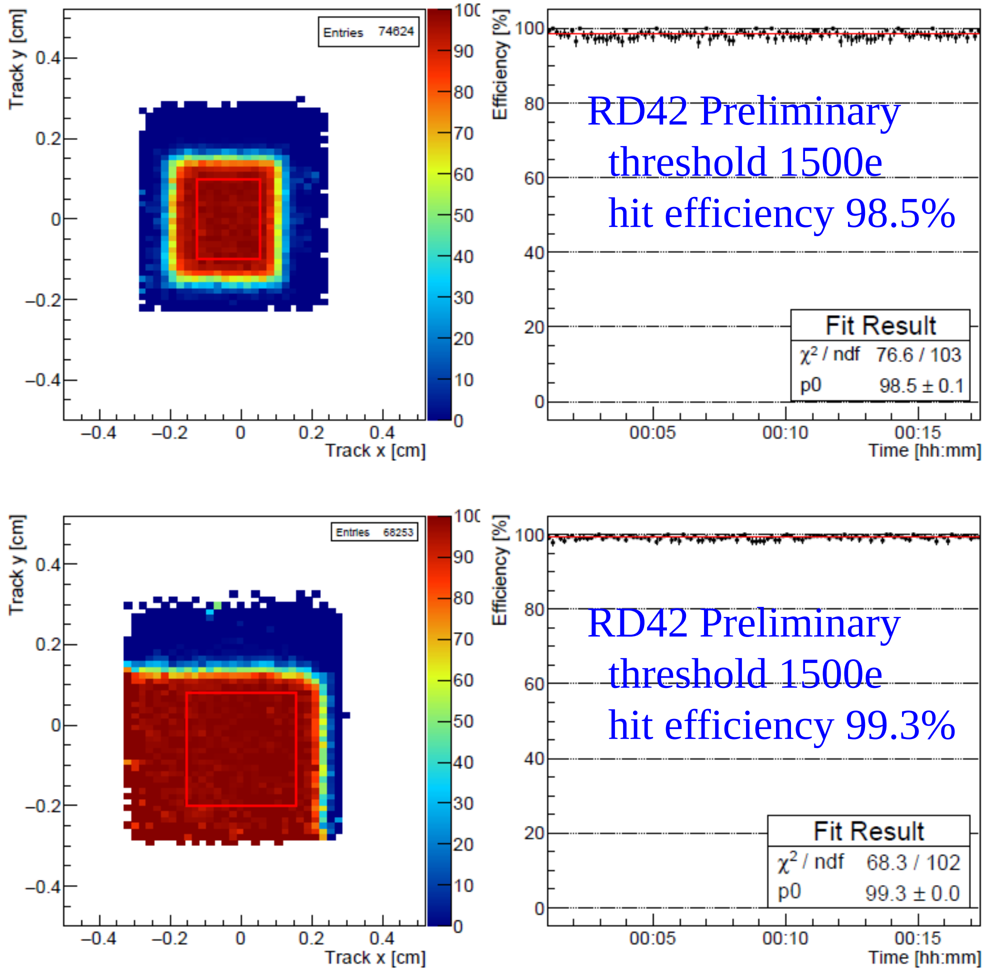
Results of CMS, ATLAS 3D pCVD Pixel Devices

3D Diamond Pixel
98.5% efficiency

- applied voltage: -55V
- pixel threshold: 1500e
- efficiencies flat in time

Planar Silicon Pixel (ref)
99.3% efficiency

- lower efficiency in diamond most likely due to low field regions

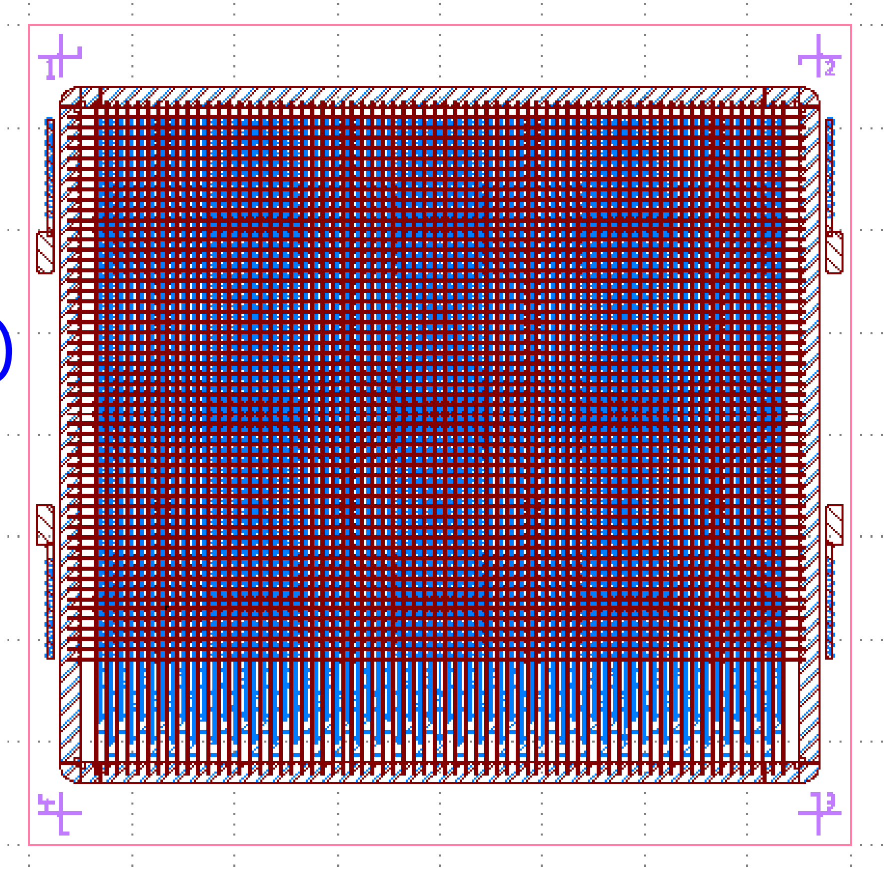


(a) efficiency maps (b) hit efficiencies

Results of CMS, ATLAS 3D pCVD Pixel Devices

Produced new 7200 cell pixel prototype w/50μm x 50μm pitch

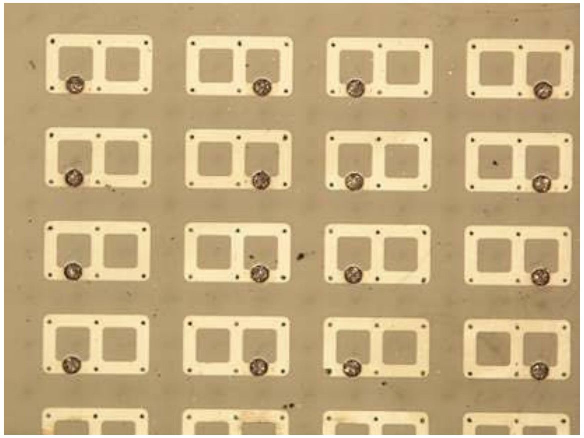
- Two fabricated:
  - Oxford complete
  - Manchester complete
- 50μm x 50μm cells ganged for CMS (3x2) and ATLAS (1x5)
- Metallization
  - CMS complete
  - ATLAS in progress
- Bump bonding
  - CMS @Princeton complete
  - ATLAS @IFAE in progress
- First one (CMS) tested in Aug 2017 Test Beam @PSI

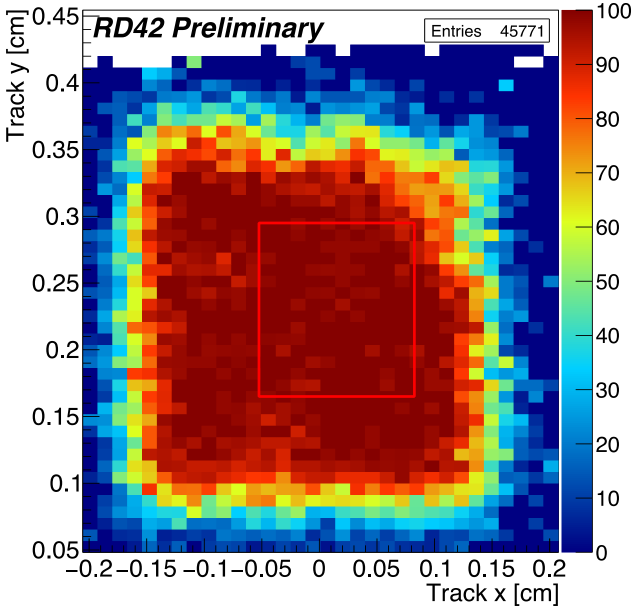


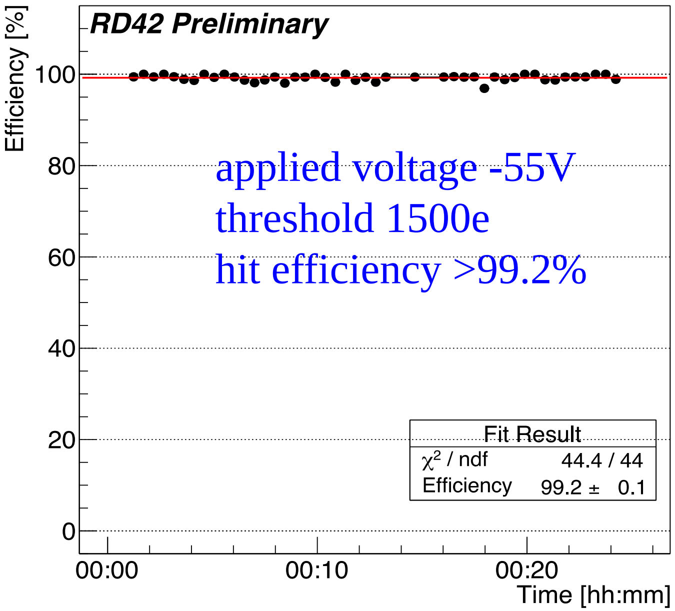
Results of CMS, ATLAS 3D pCVD Pixel Devices

Preliminary Results (50μmx50μm pixels)

- Readout with CMS pixel readout
  6 columns (3x2) ganged together
- Preliminary efficiency >99.2%
- Collect >90% of charge!







Summary

Lots of progress in diamond with HL-LHC in view

- 3D detector prototypes made great progress
  - 3D works in pCVD diamond
  - Scale up (x70) worked
  - Smaller cells (50μm x 50μm) worked
  - Thinner columns (2.6μm) worked
- 3D diamond pixel devices being produced
  - All work as expected
  - Visible improvements with each step
  - Efficiencies look good
- Future plans
  - Irradiate devices to 10^{17} this year
  - Continue scale up (x10) and/or smaller cells (25μm x 25μm)

Acknowledgements

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