testbeam results of
3D diamond detectors

marc dünser on behalf of the RD42 collaboration

the RD42 collaboration

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128 members

31 institutes

introduction

advantages of diamonds w/r/t silicon

large displacement energy -> radiation hard
large bandgap -> less leakage current & noise
high thermal conductivity -> less cooling

there are some disadvantages though

large bandgap -> less signal

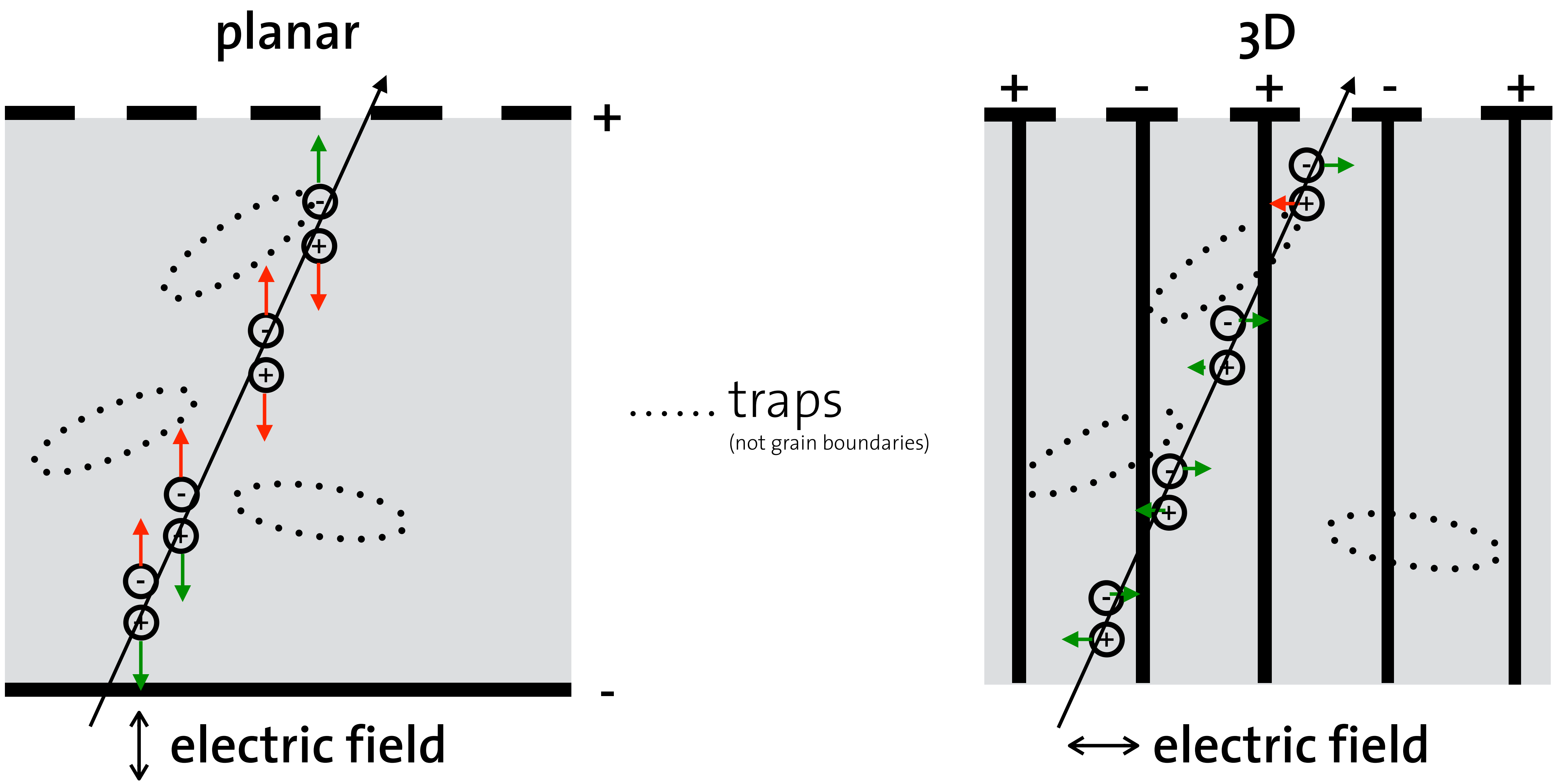
radiation damage in all trackers (si, diamond, etc.) reduce mean free path of charges

charges are trapped
once mfp << d charges are lost.

solution: why not decrease the distance for signal collection?

3D principle was invented first in the silicon community

principle of 3D detectors



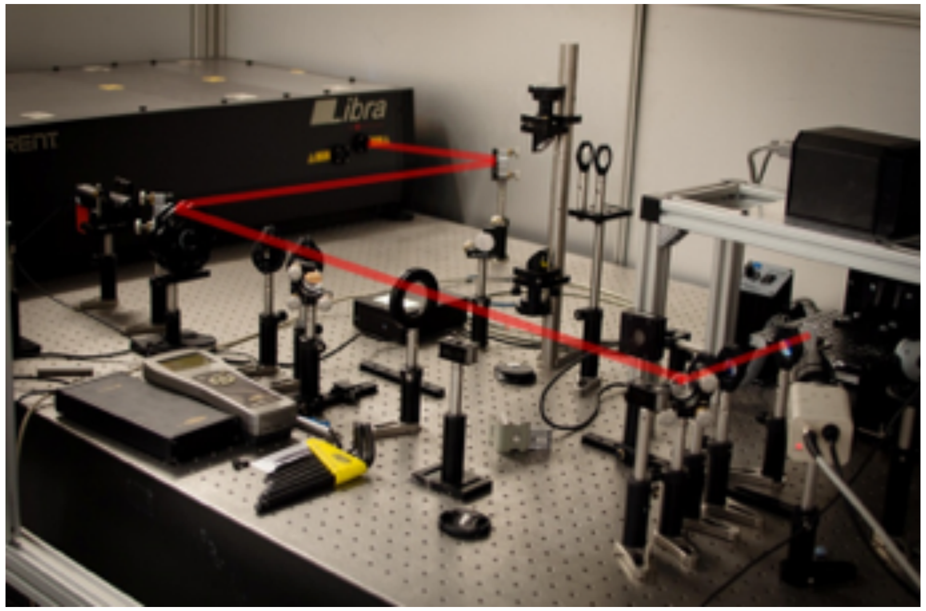
advantages of 3D versus planar pixels

- same |E| for lower voltage
- smaller distance to electrode
- full charge easier to attain

disadvantages

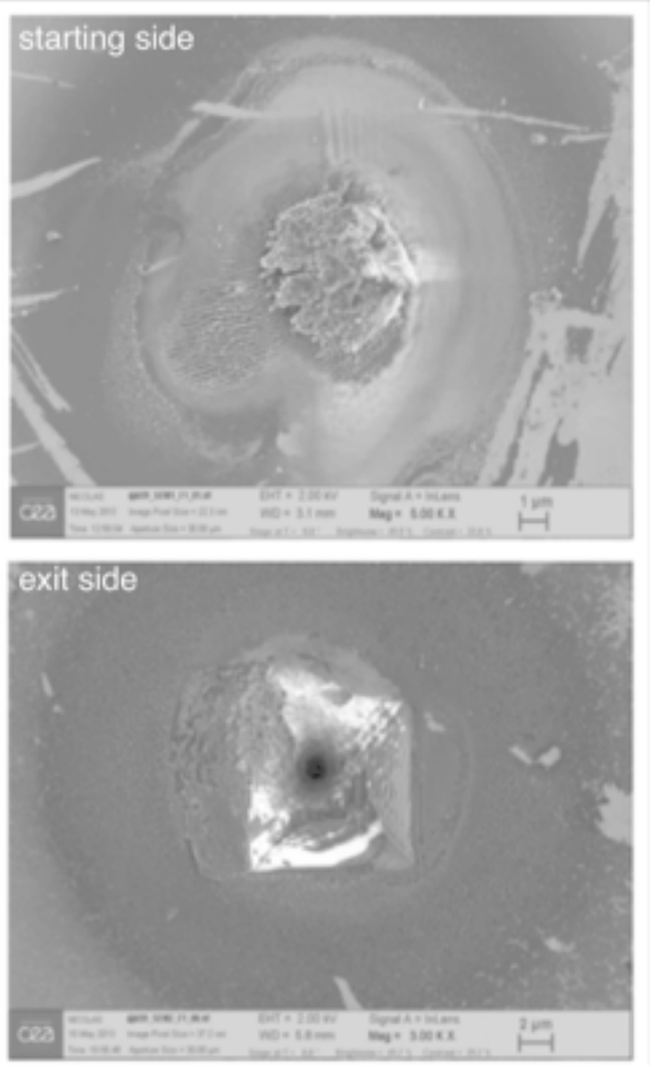
- larger capacitance
- complicated processing

production of 3D diamond



diamond details
- single crystal CVD diamond
- 440 μm thick at an area of 4.7 x 4.7 mm²

fabrication of 3D electrodes is more complex than making planar pixels
- femto-second lasers for hole fabrication
  - phase transition insulating -> conductive phase
- tested device was made at
  - university of manchester



hole efficiency ~92%
- making one hole takes ~20 seconds
- columns are drilled grids of 150 μm
- holes are 6 μm across

metallization and readout

not the full diamond was 'drilled'

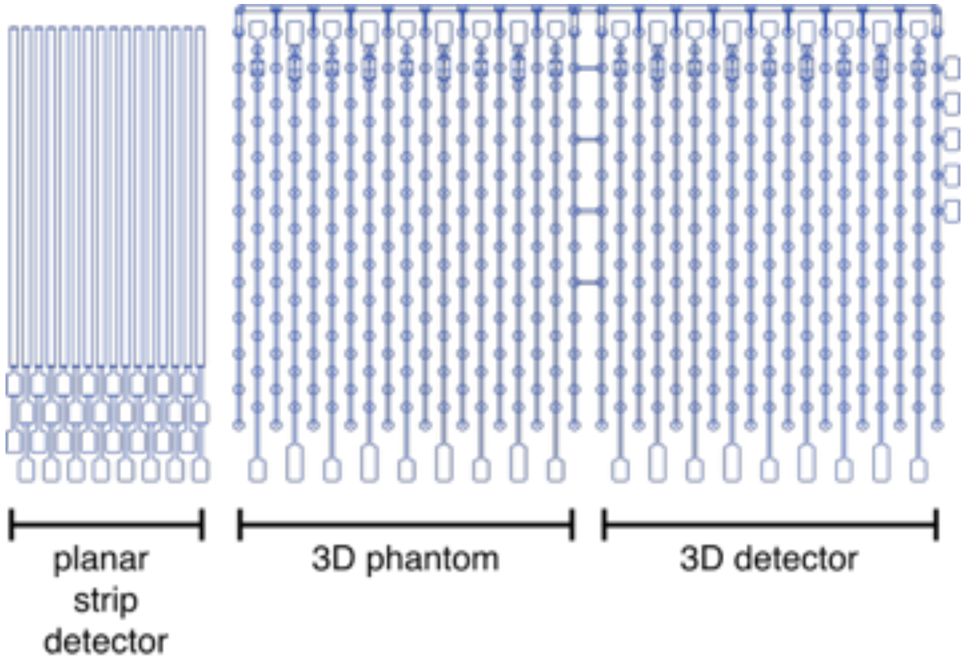
- 3 areas on diamond:
  - 3D detector, 3D phantom, and strips
- metallization Cr-Au

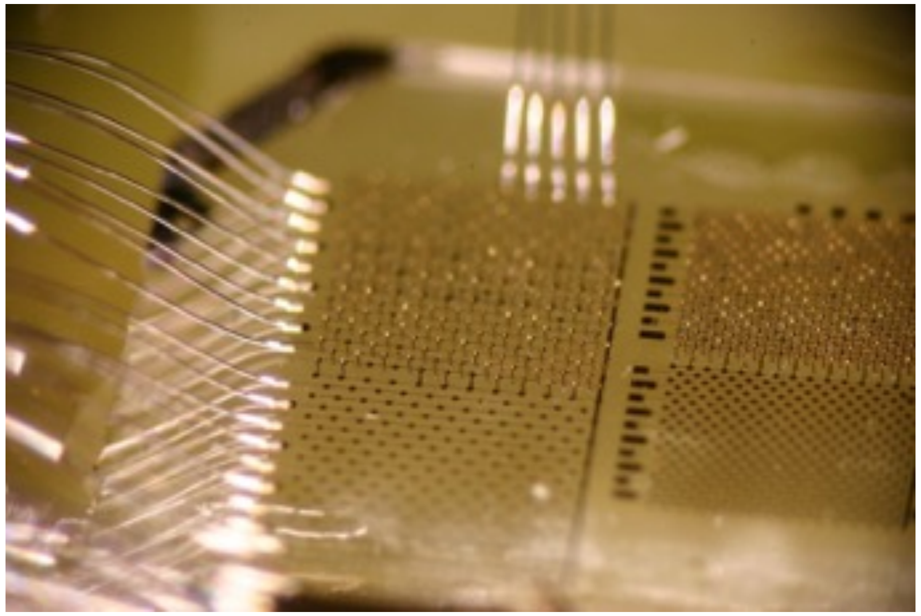
great for reference measurements

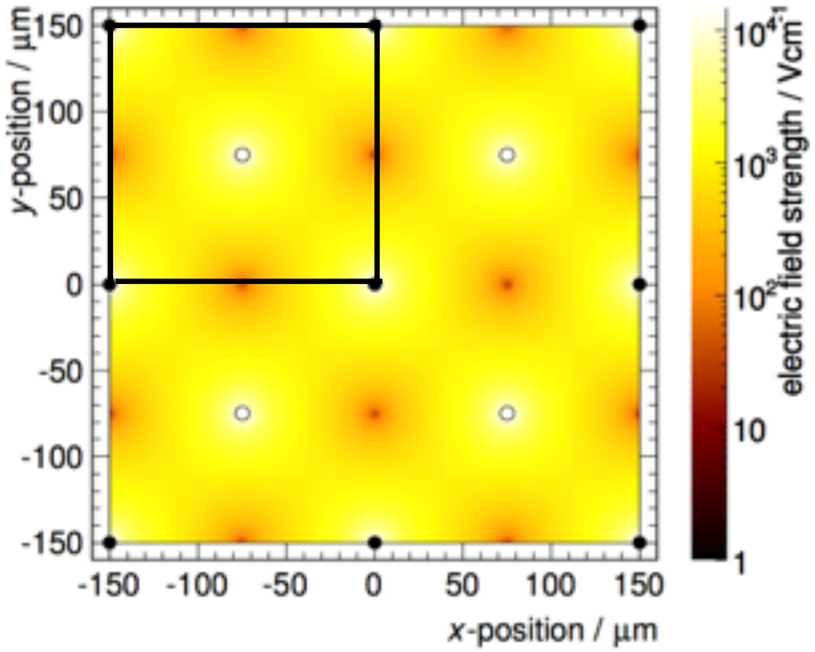
- exact same diamond!

3D pixels organized as cells of 5 columns

- readout in center, bias at the edges
- 99 cells in total



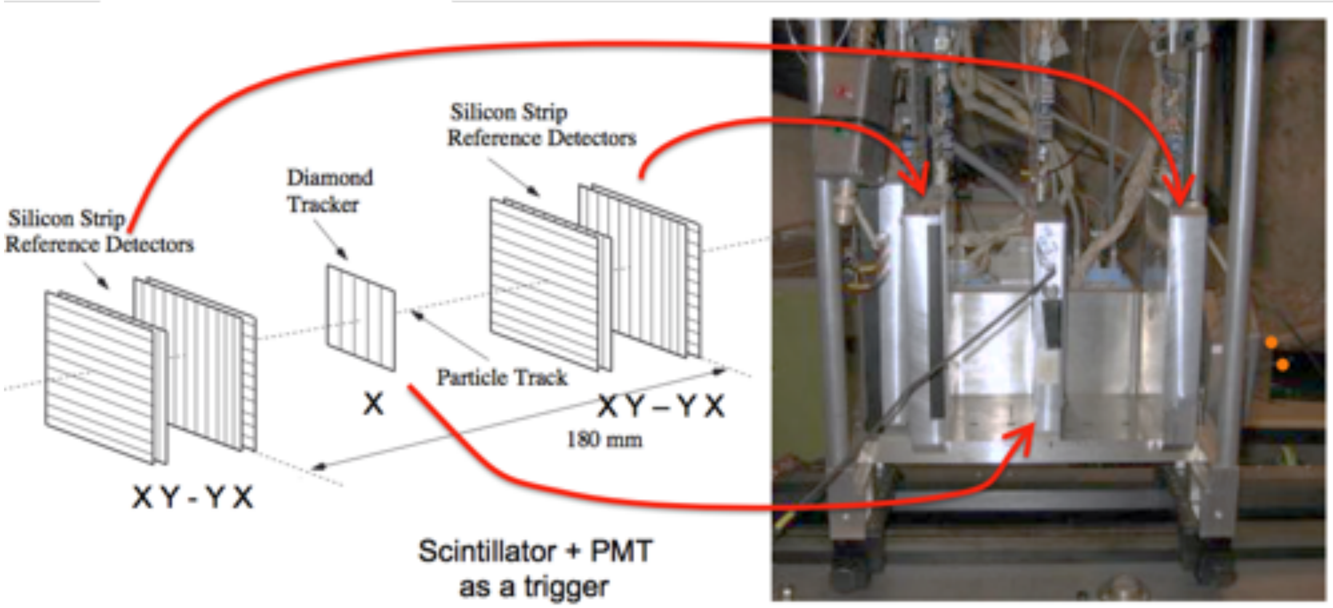




testbeam setup

testbeam to test 3D geometry versus strips
- in terms of efficiency and charge collection
- 120 GeV protons from the SPS
- happened back in 2012

diamond placed in the center of four double strip planes
- enables tracking
  - -> spatial resolution 3-5 μm



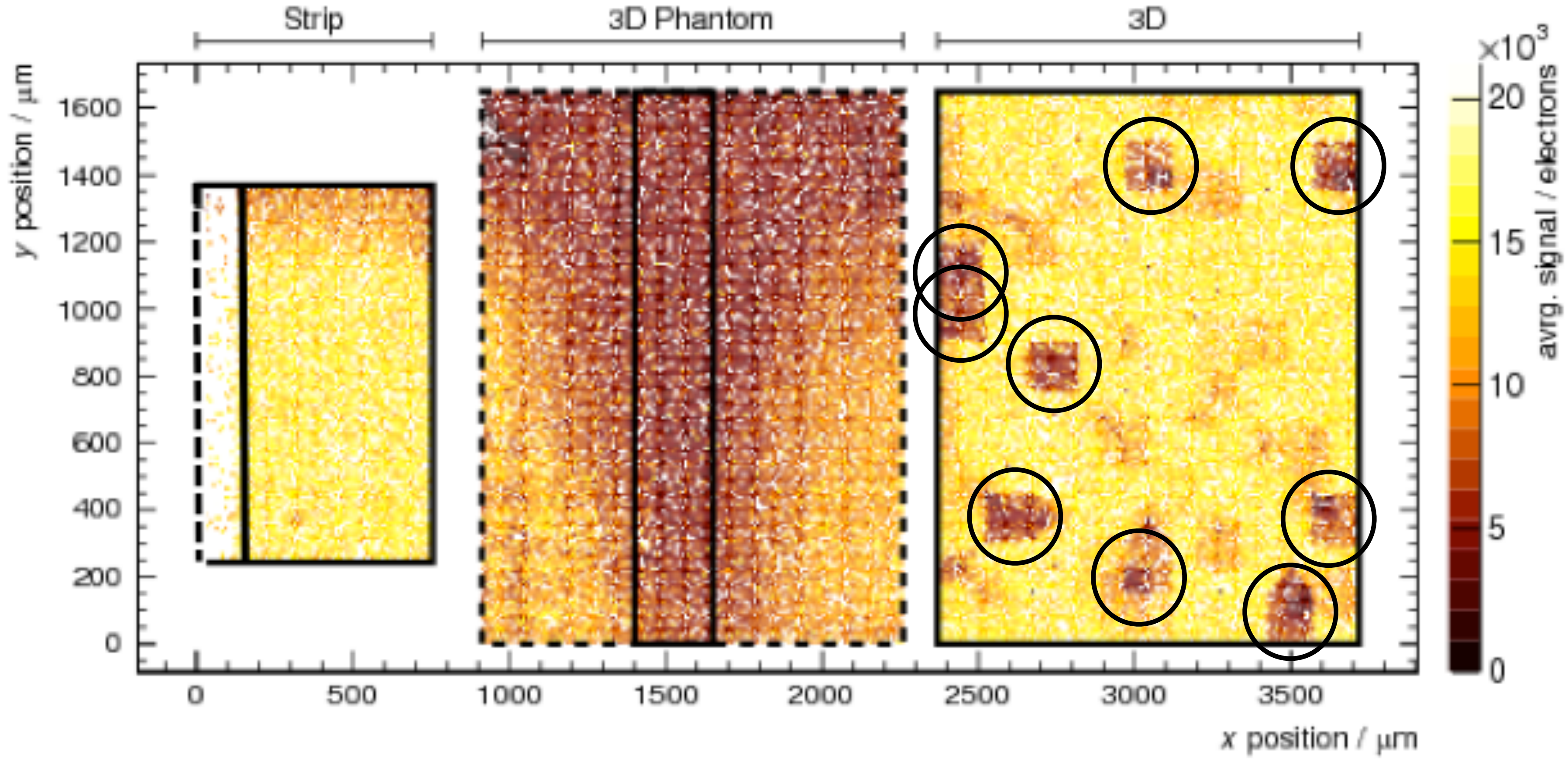
applied voltages to diamond

3D phantom:	25 V
3D detector:	25 V
strip part:	500 V (full charge at 450 V)

pulse height maps

first check if the diamond works: map of pulse height

small fiducial loss due to scintillator trigger



dead cells already visible due to faulty readout columns

roughly 9 broken readout columns
(expect 8 from 92% efficiency)

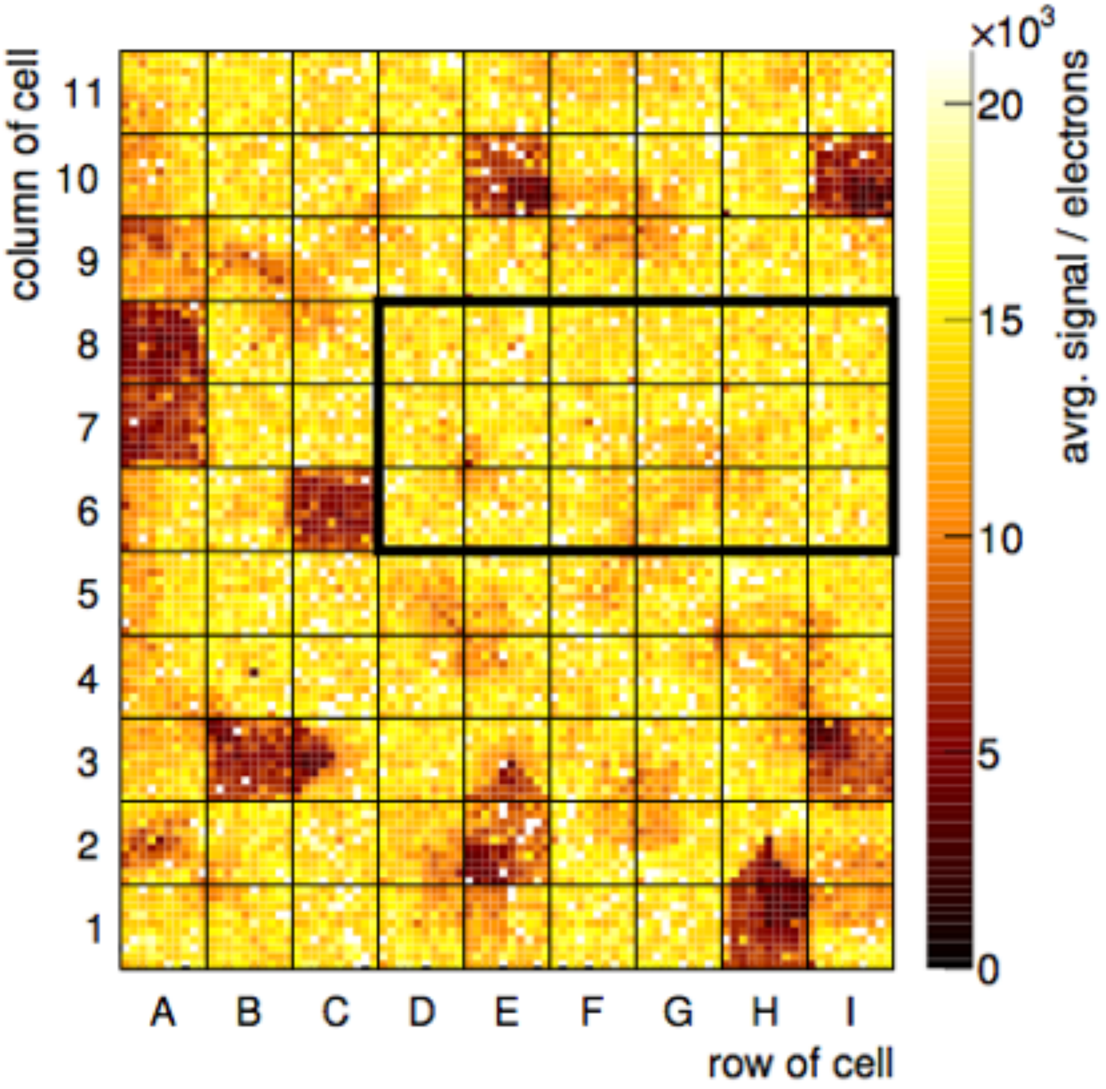
analysis strategy

only events with one track pointing to ROI used

no cut on diamond signal - ‘transparent analysis’

use only cells with functional columns for final analysis

some faulty bias columns result in less signal in cells with good readout column



results on charge collection

strip part should collect full charge at 450 V

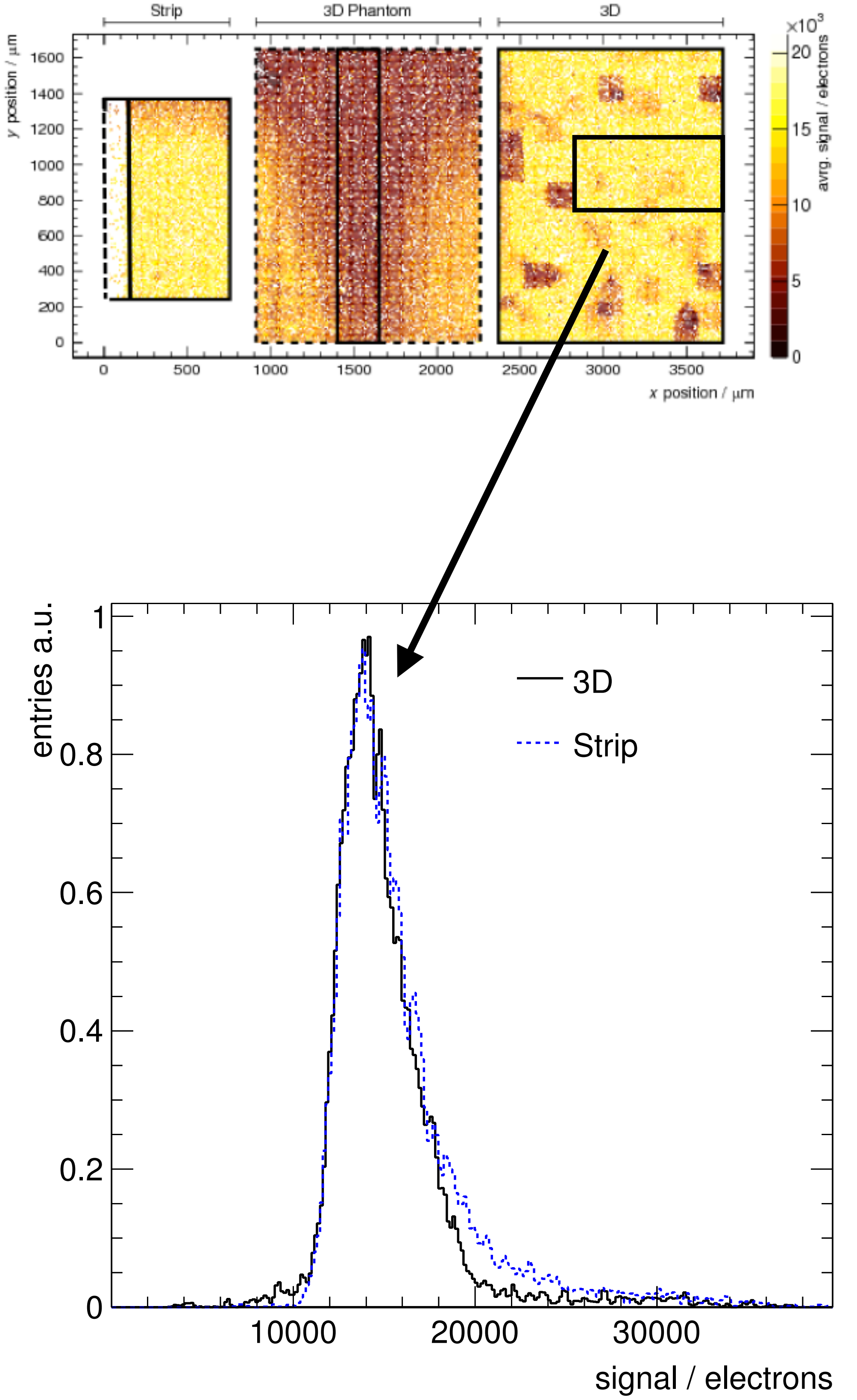
this expectation is confirmed

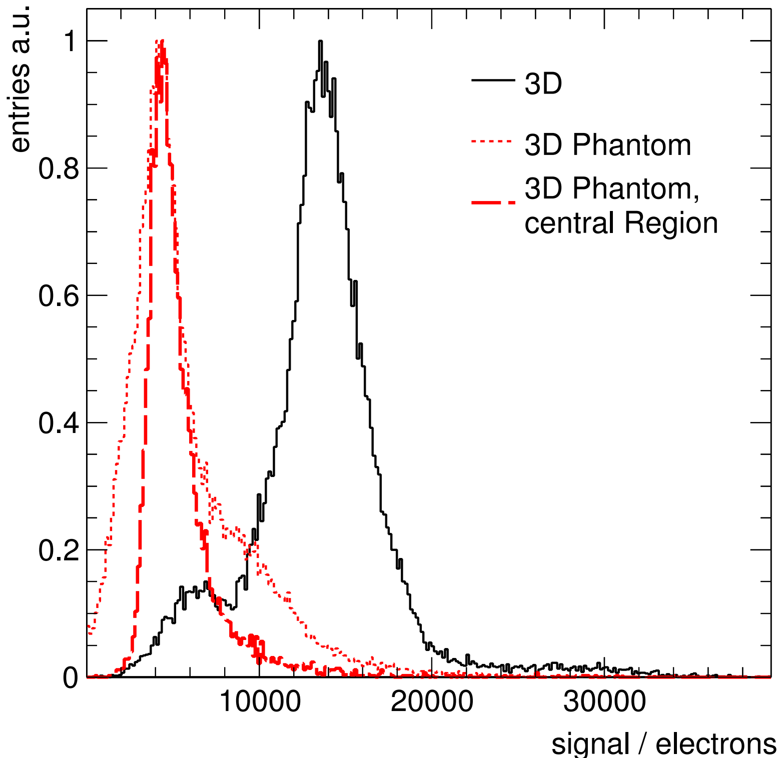
3D collects same charge at 5% of the voltage!

great confirmation of expectation

3D phantom collects significantly less charge

theory is that it collects charge only at surface, not in the bulk

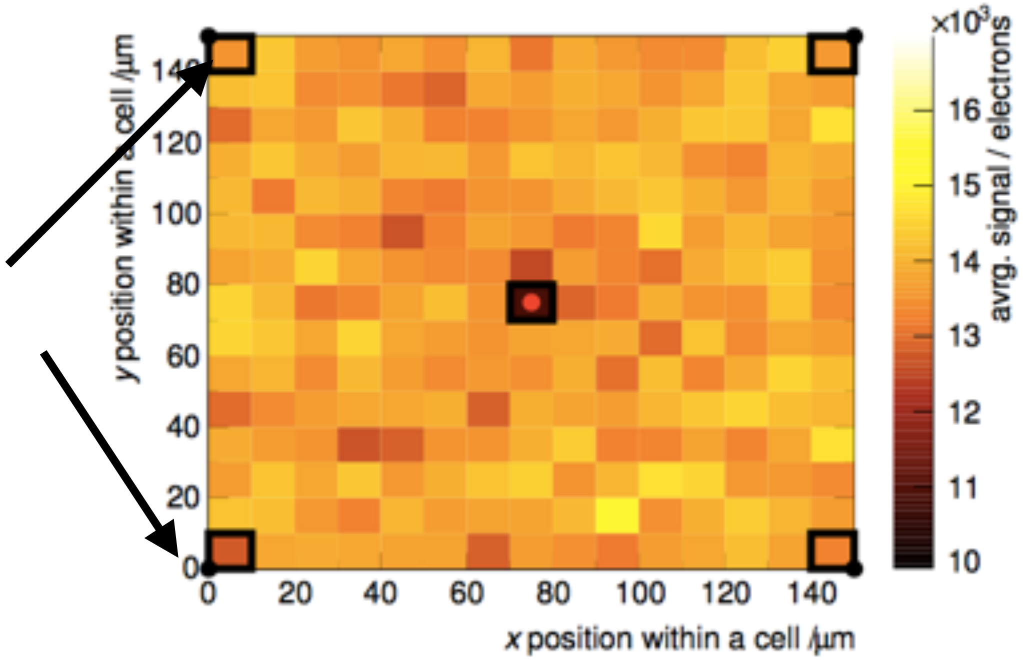




results on uniformity and resolution

split each cell into 10 x 10 µm² and overlay each subcell

nice uniformity ~3% across cell observed



nice test of subcells with columns

readout takes 28% of one subcell

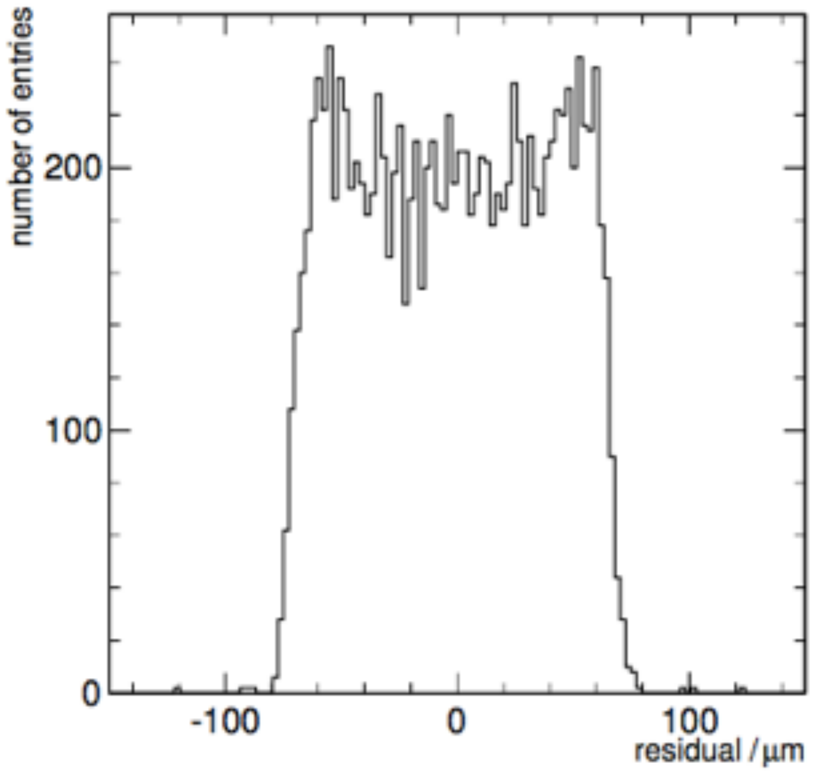
bias takes 7% of one subcell

resolution around the expected value

almost perfect agreement for residuals

40.2 ± 0.3 µm (expect 43)

little charge sharing



ongoing developments

improvement of column fabrication under intense investigation

- lasers are one option
  - cylindrical holes, yet slow, resistivity issues
- plasma is another option
  - fast, conical holes, tricky to make conductive

optimization is underway for these options

- progress made by several groups
- expect results within ~1 year

all results published in *"A 3D diamond detector for particle tracking"*

F. Bachmair, L. Bäni, P. Bergonzo, B. Caylar, G. Forcolin, I. Haughton, D. Hits, H. Kagan, R. Kass,
L. Li, A. Oh, S. Phan, M. Pomorski, D.S. Smith, V. Tyzhnevyi, R. Wallny, D. Whitehead

Nucl.Instrum.Meth. A786 (2015) 97-104

conclusion & outlook

once well produced, 3D diamonds perform very well

- disclaimer: based on one intense test
- very high charge collection

production clearly has to be improved for large scale production

- multiple approaches under study
- expect some results within a year or so

tests will be done this year in testbeams with new 3D diamonds

- next testbeam imminent (next week)

besides 3D detectors also planar diamond pixels and pads are being investigated

- irradiation studies
- (high) rate studies

the end

marc