The University of Manchester

3D Diamond Detectors

Alexander Oh

3D Diamond Research

- **2009: Small Collaboration (Manchester/Saclay/CERN)**
  - **Manchester:**
    Alexander Oh, Stephen Watts, Mahfuza Ahmed, Cinzia Da Via
  - **CEA Saclay**:
    Benoit Caylar, Michal Pomorski
  - **CERN**:
    Thorsten Wengler

- Started activity in **2009**
  - Cubic samples to study influence of grain boundaries (‘09)
  - **Lasered graphitic structures** in pCVD (’10)
  - **Single crystal** with column structure (‘11)
  - **Femto second laser** for improved graphitic electrodes (‘12)
  - Several Prototypes tested at **Diamond Light Source** and at **CERN test beam.**

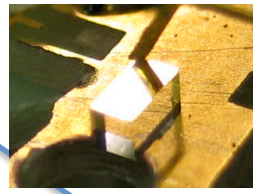
3D Diamond Research

- **<u>Growing in 2011</u>**
  - Iain Haughton (Manchester)
  - Vladyslav Tyzhnevyi (Manchester)
  - David Whitehead (Manchester)
  - Lin Li (Manchester)
  - Lars Baeni (Zuerich)
  - Felix Bachmann (Zuerich)
  - Rainer Wallny (Zuerich)
  - Dmitry Hits (Zuerich)
  - Harris Kagan (Ohio)

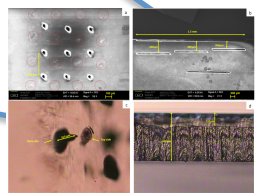
- **2012:**
  Tested 3D sample with CERN test beam with the help of RD42.
  Zagreb RBI testbeam with proton IBIC.

3D Diamond Research

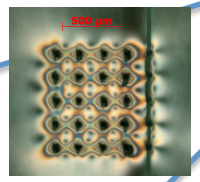
Cubic samples to study influence of grain boundaries (‘09)



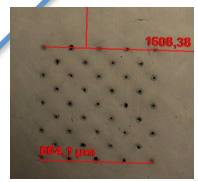
Lasered graphitic structures in pCVD (’10)



Single crystal with column structure (‘11)



Femto second laser for improved graphitic electrodes (‘12)



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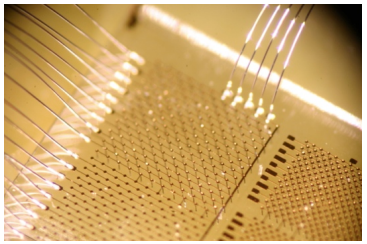

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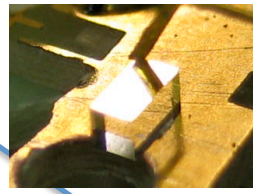
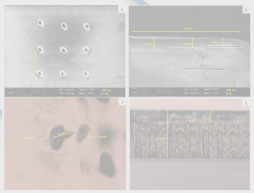
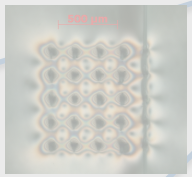
Cubic samples to study influence of grain boundaries (‘09)



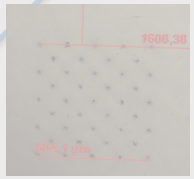
Lasered graphitic structures in pCVD (’10)



Single crystal with column structure (‘11)



Femto second laser for improved graphitic electrodes (‘12)



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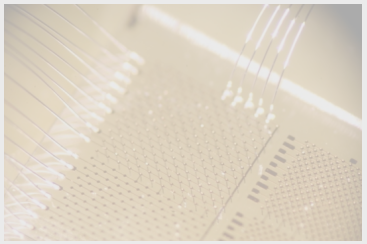
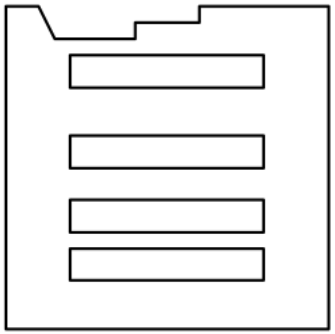
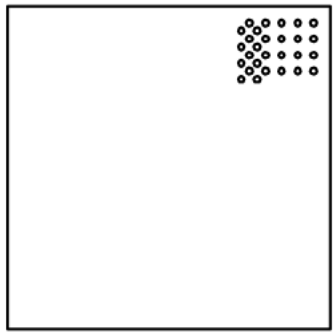


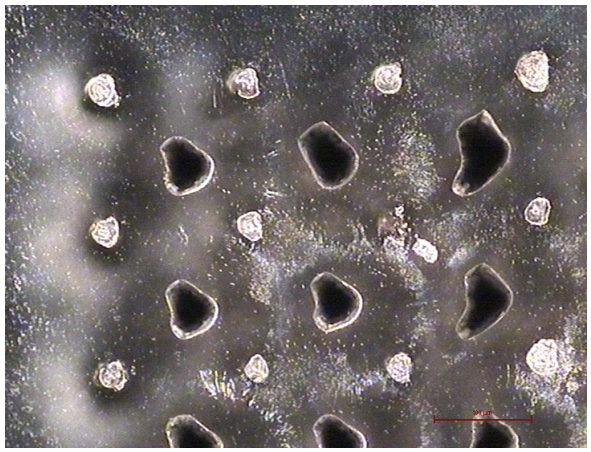
Graphitic structures

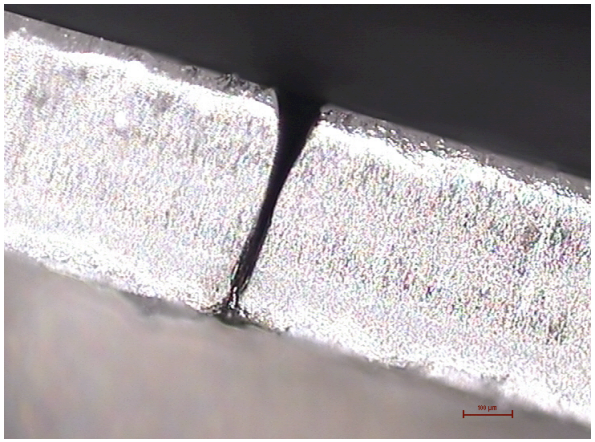
2011

- Work with CEA Saclay to fabricate graphitic bulk electrodes.
- Samples:
  - single crystal samples for normalisation.
  - Polycrystalline samples with structures
    - Ridge structures of varying width.
    - Graphite electrodes -> 3D





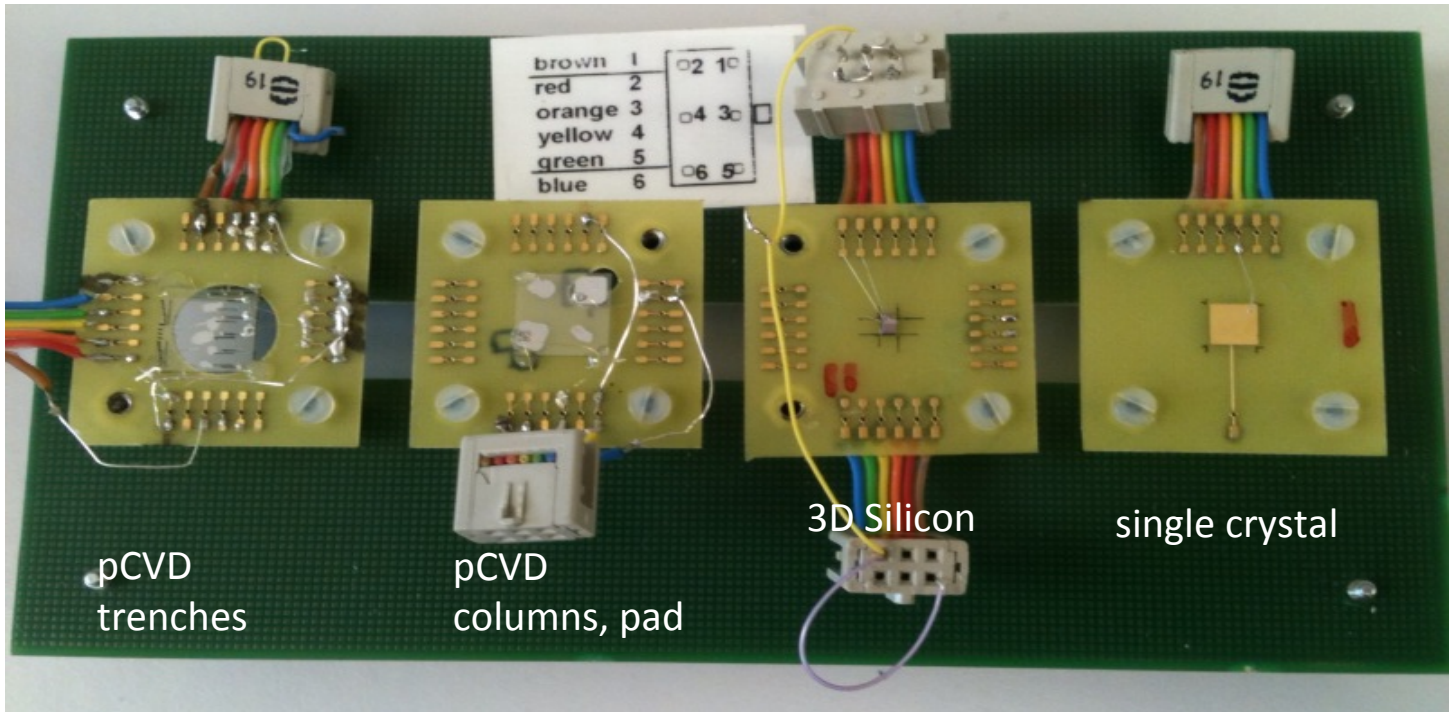




Michal Pomorski

Samples

- Set-up to measure four samples.

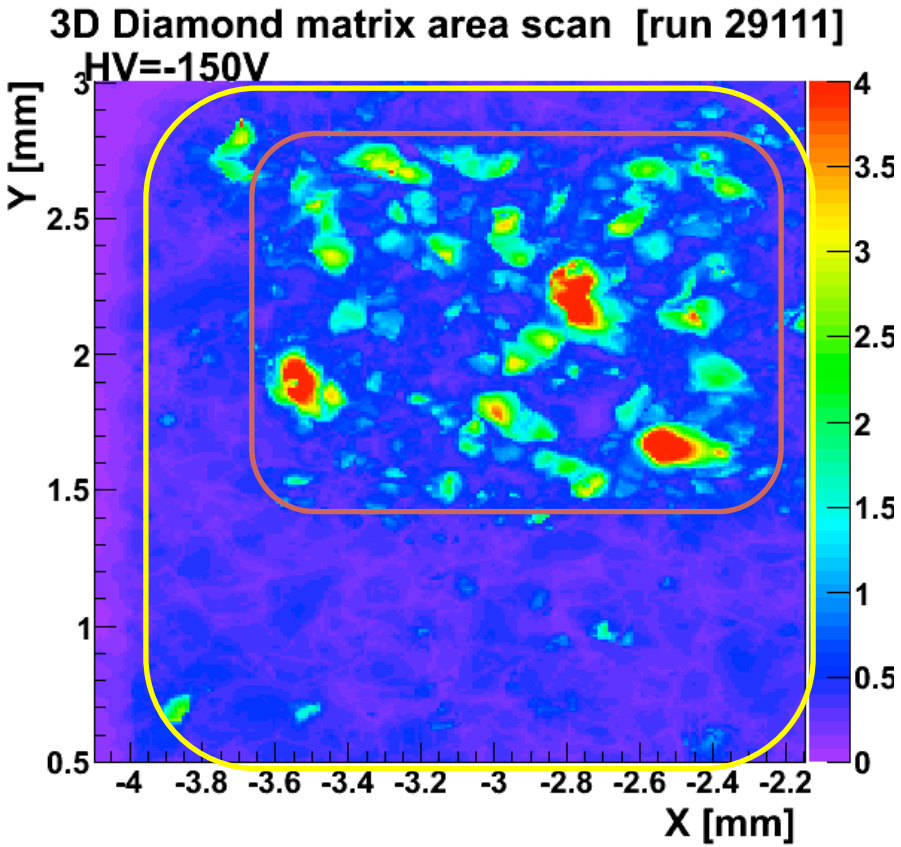


Results: pCVD diamond

- Three types of electrical contact patterns were tested:
  - Matrix of cones
  - Single graphitic cones
  - Trench structures

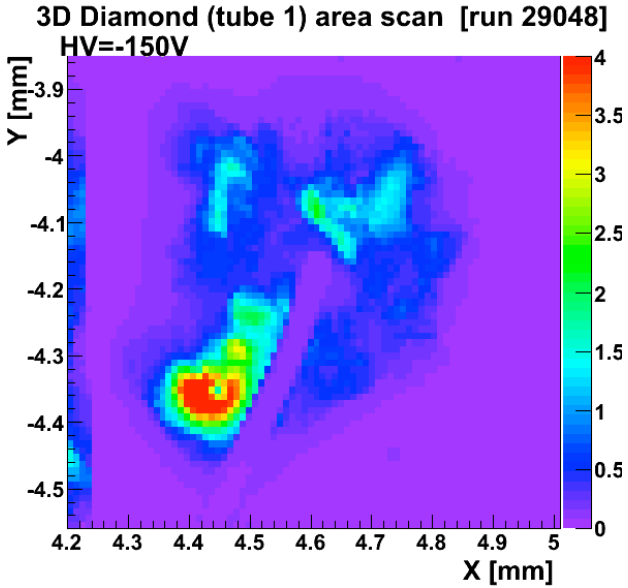
Results: pCVD diamond

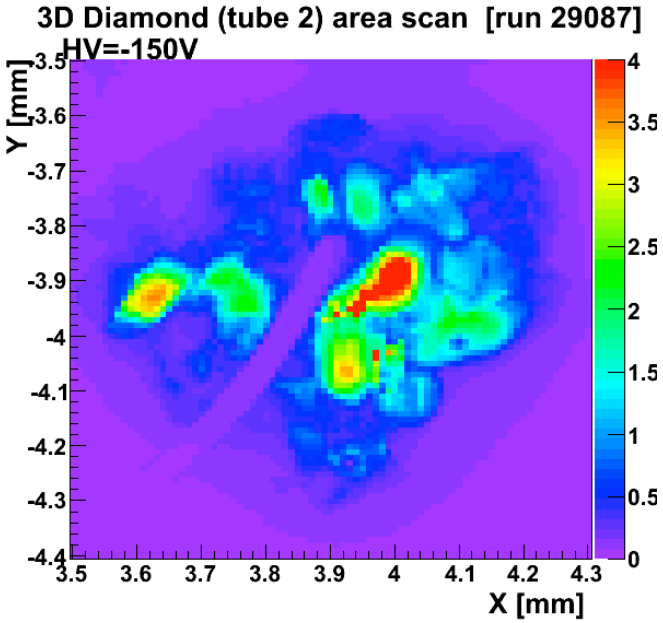
- Matrix of cones
  - Area scan of matrix of columns
  - Embedded in a planar contacts
  - Allows to compare the signal response at the same bias voltage
  - Response of the matrix (red) is clearly visible and higher then the planar contact response (yellow).

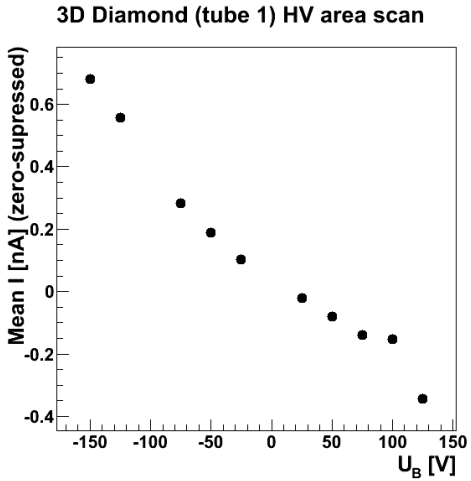


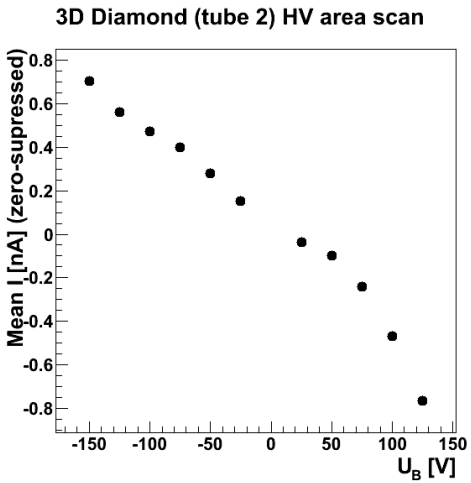
Results: pCVD diamond

- Scan on **single columns** show **strong non-uniform signal**.
- Response pattern is **dependent on polarity**, different contribution from electrons and holes.
- Pattern likely related to grain-structure.









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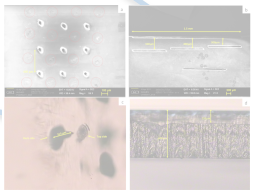
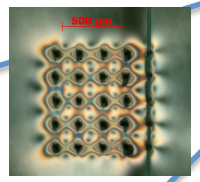


Single crystal with column structure (‘11)

See Benoit’s talk



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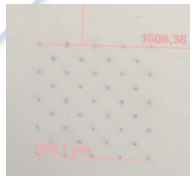

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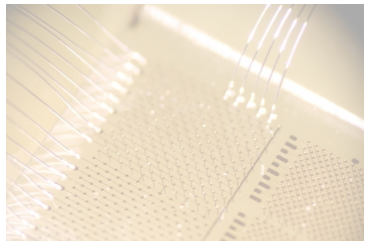

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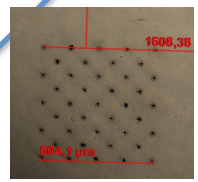

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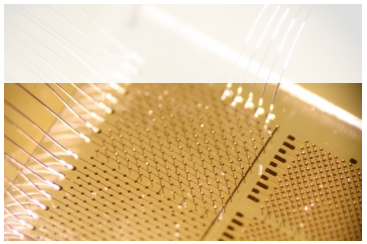
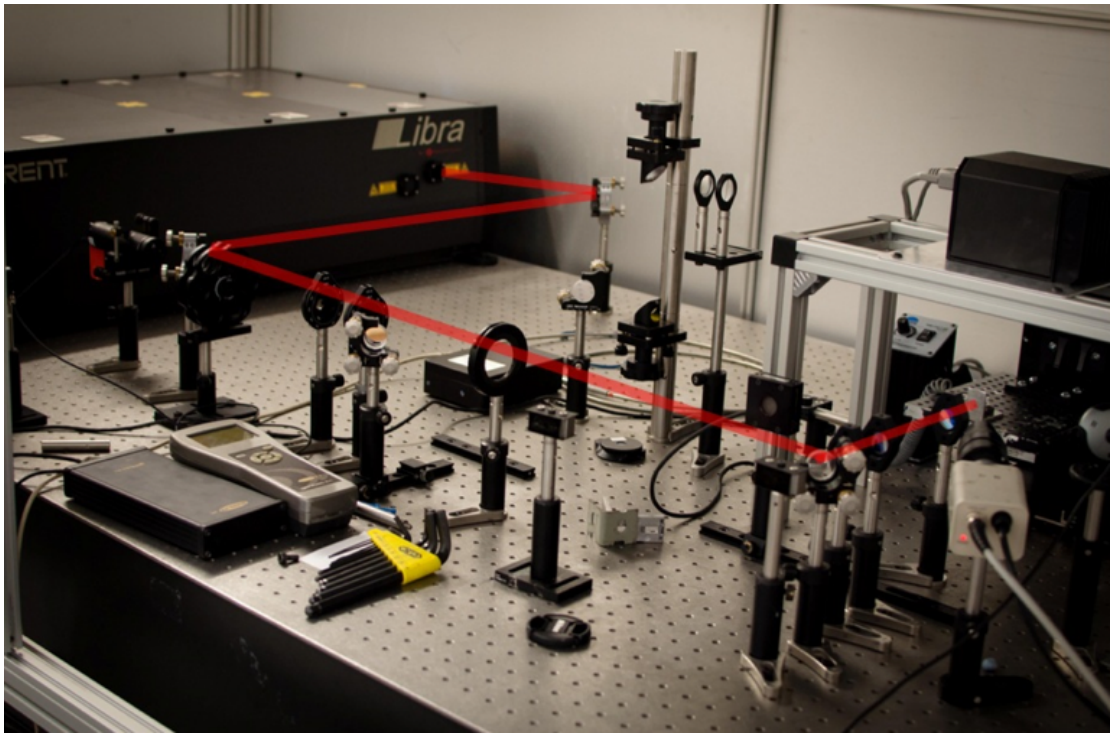


femto second laser set-up (2012)

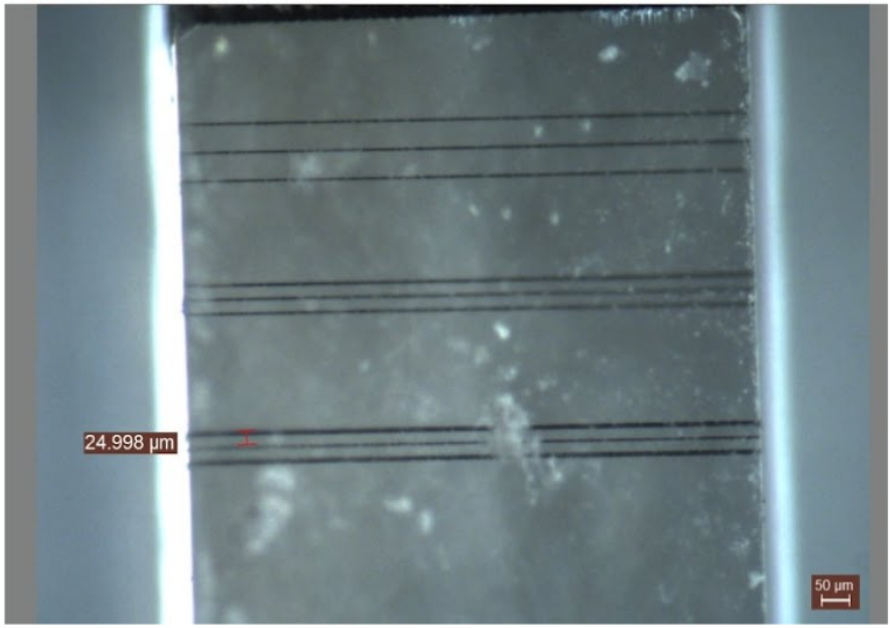
University of Manchester, Laser Processing Research Center.

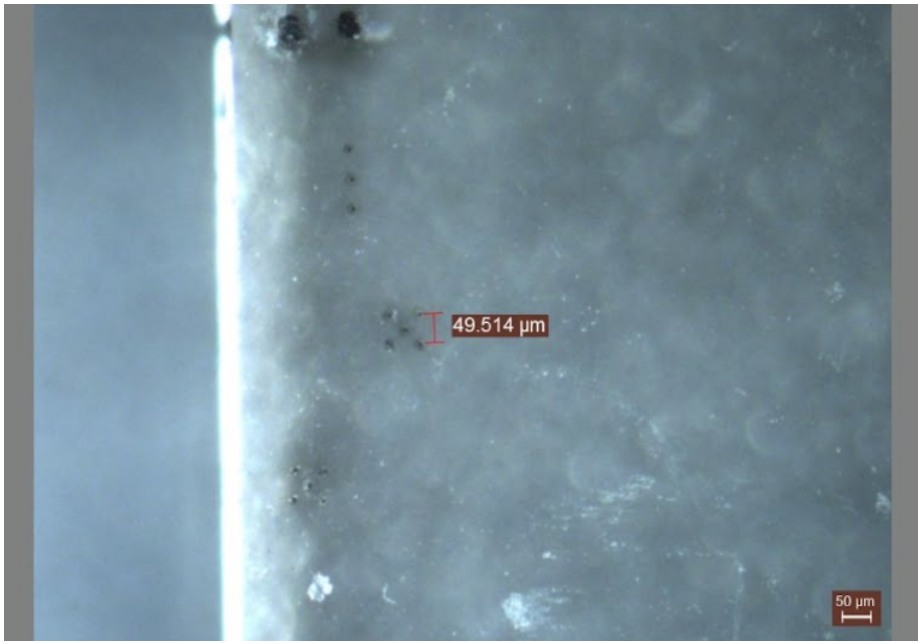
- Wavelength = 800 nm
- Repetition rate = 1kHz
- Pulse duration = 100 fs
- Spot size = 10µm
- Pulse Energy :
  - E = 700 nJ/pulse for scCVD diamond (absorber 5-4)
  - E = 1.3 µJ/pulse for pcCVD diamond (absorber 5-1)



femto second laser set-up

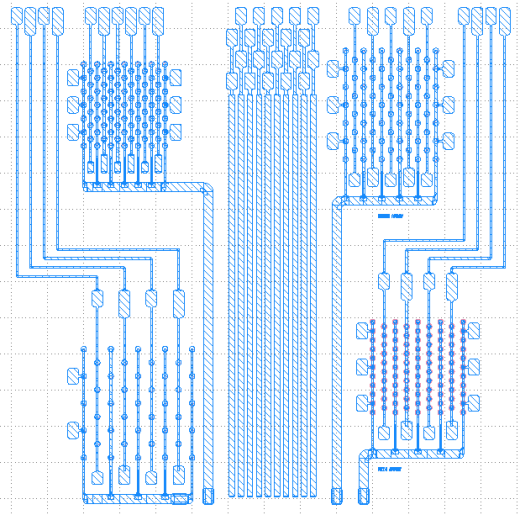
- Some first results on single crystal diamond.
  - Find good parameters for continuous thin graphitic wirers.
  - Achieved ~3-5 um diameter
  - R ~ 1 Ωcm (AF tip measurement)

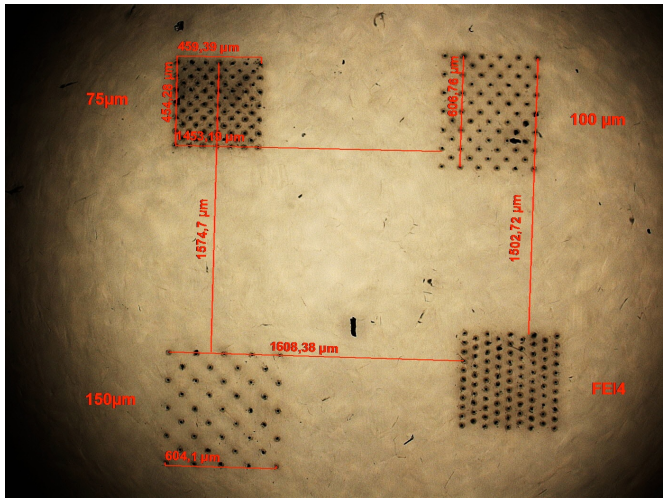




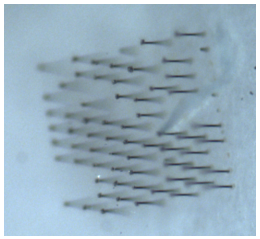
Prototypes

- **Batch 1 Samples**
  - First 3D prototypes (SC,PC)
    - Good yield for PC, not so good for SC.
  - 4 patterns
    - FE-I4, 2E readout
    - Cubic, 50um pitch
    - Cubic, 100um pitch
    - Cubic, 150um pitch
  - First Beam test in July 2012.
    - Took several million events
    - First indication of signal collection.
    - Problems with metallization (Al).
    - Re-metallization procedure failed for second beam test.

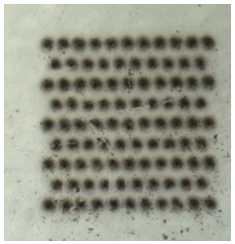




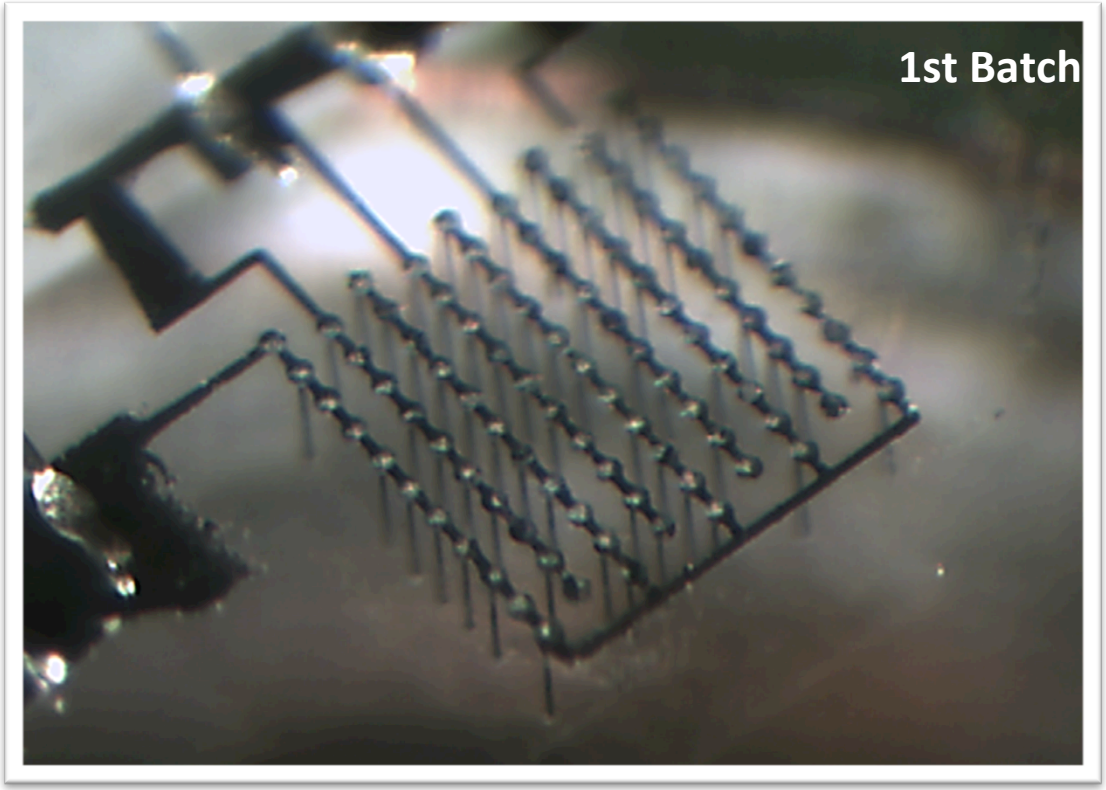
SC



PC

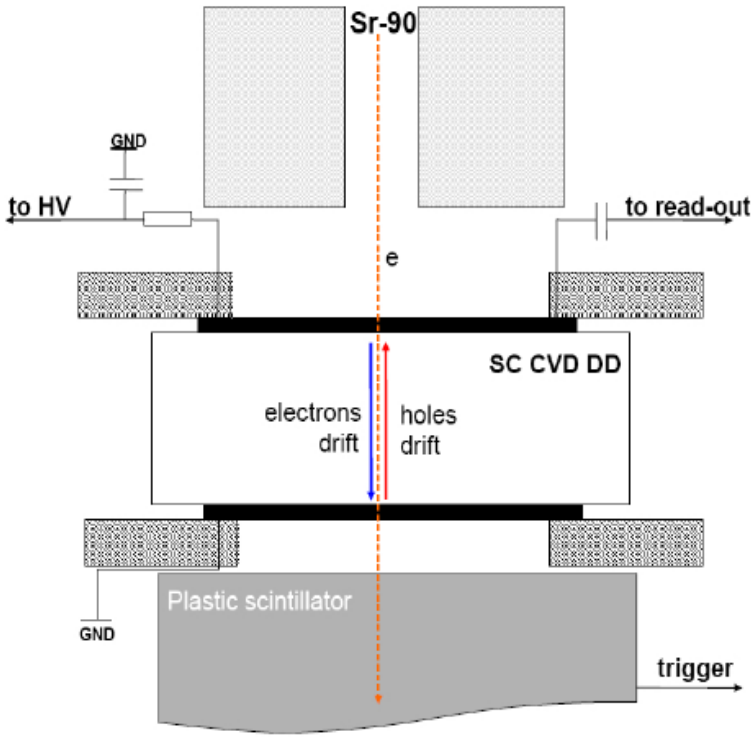


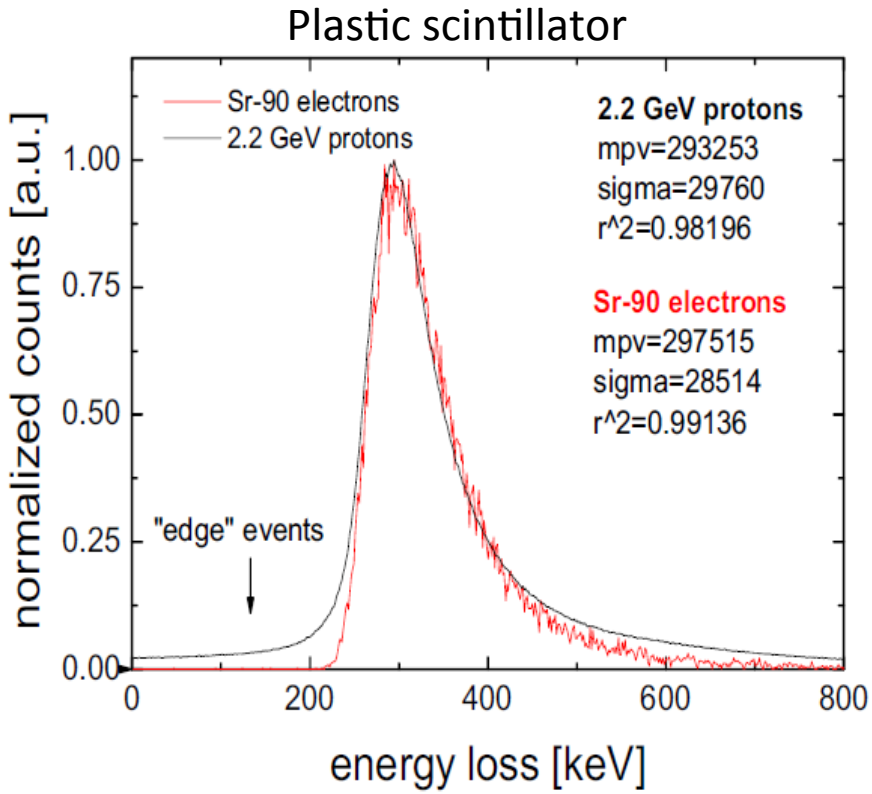
Final detectors - 45° tilted



» **First batch 70% success rate**

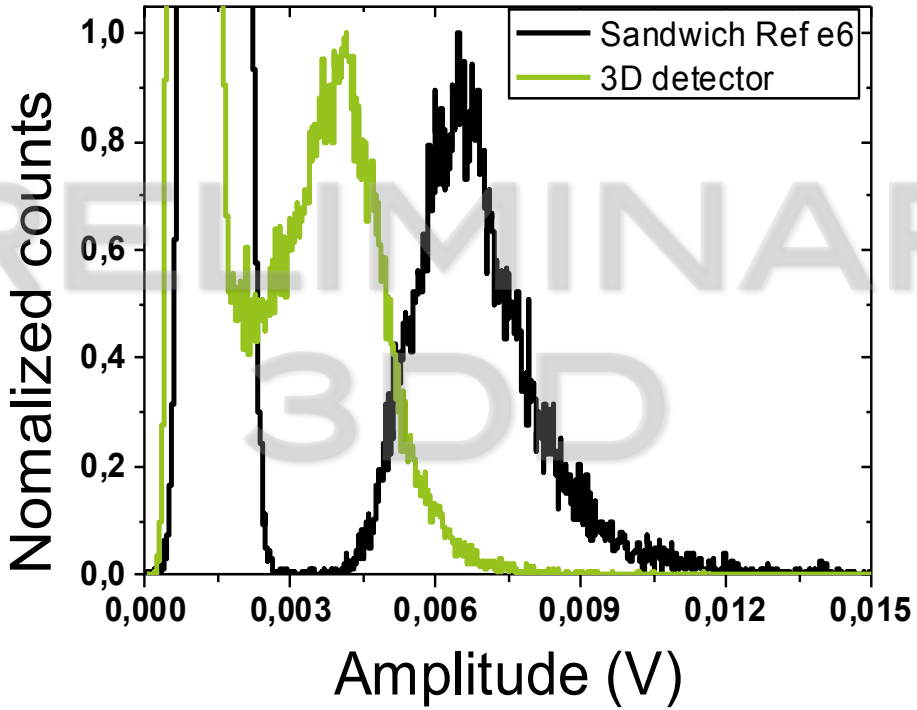
^{90}Sr experiment to approximate MIP in lab





Charge collection efficiency measurement (Single Crystal – Batch 1)

- HV = -200V

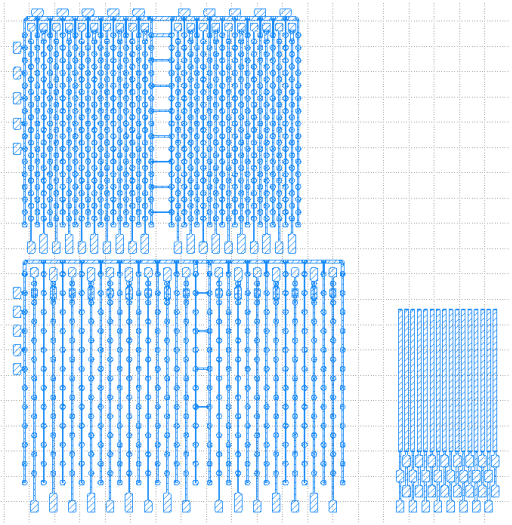


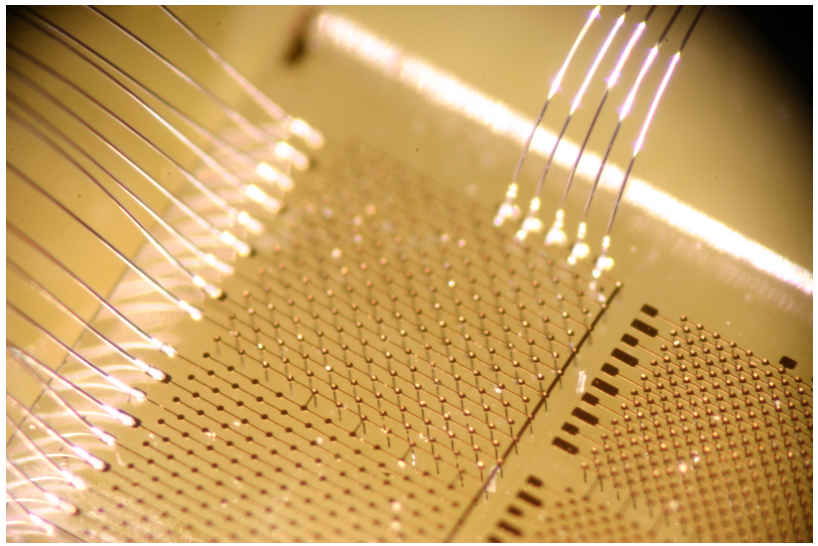
~65% CCE at maximum

» Most probably due to bad metallization and photolithography process

Prototypes

- **Batch 2 samples**
  - Again SC and PC.
  - Larger active area.
  - Including strip detector and "no-hole" detector for calibration.
  - 2 patterns
    - cubic 100 um
    - cubic 150 um
  - Tested in August test-beam
    - only 150 um pattern was read-out.
    - took O(10^6) events at different bias voltages
    - clear signal in SC, PC had problems ! (see Lukas talk).
  - Radiated SC in Los Alamos to ~$4*10^{14}ncm^{-2}$
  - Re-tested in October test-beam
    - Both SC and PC gave good signals.
    - Analysis ongoing
    - Some very preliminary results ->



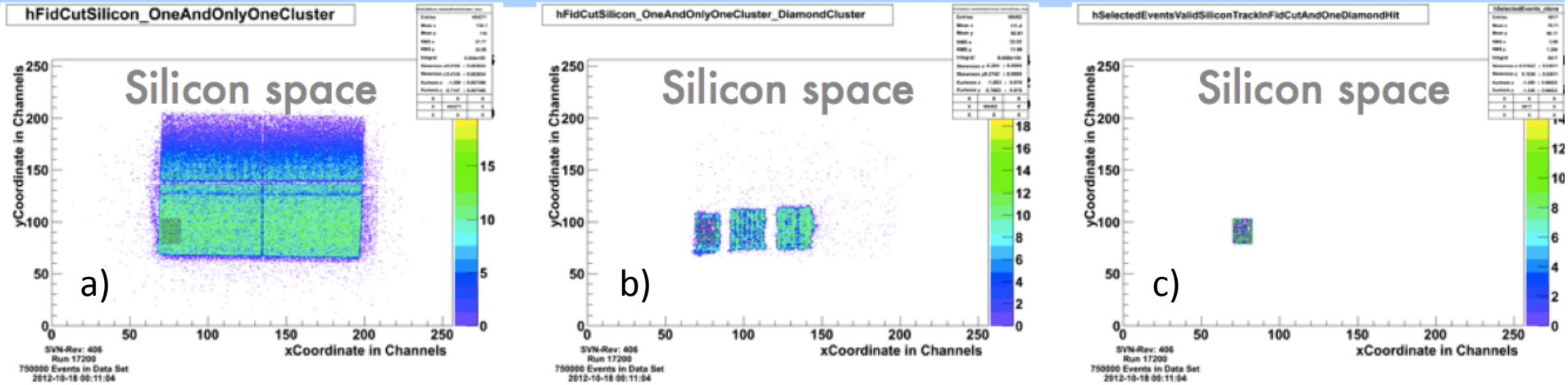


CERN test beam (Aug/Oct/Nov)

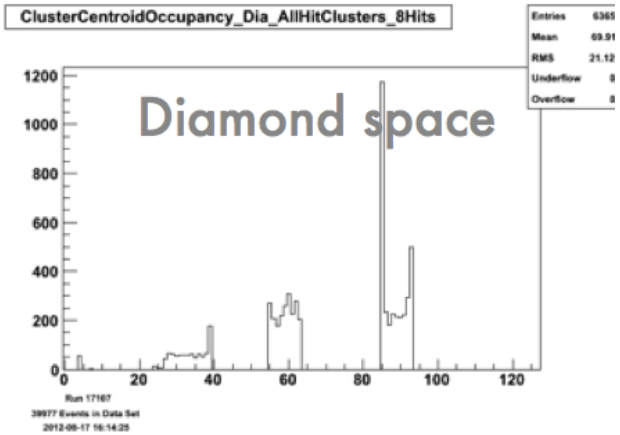
- SPS H6 line
  - 120 GeV protons
  - spill every 40 sec
  - ~ 60-100k triggers per spill
- Strasbourg telescope
  - 2 x and 2 y planes in front of DUT
  - 2 x and 2 y planes in back of DUT
  - ~3.6k events recorded per spill
  - Scintillator trigger
- DUT pumped before the start of the first measurement and after changing the sign of the voltage

CERN test beam

Analysis Team:
Lars Baeni (Zuerich)
Felix Bachmann (Zuerich)
Rainer Wallny (Zuerich)
Dmitry Hits (Zuerich)



- Fiducial Cuts defined by requiring hits in
  - a) Exactly one cluster in each silicon plane
  - b) + exactly one cluster in DUT
  - c) cuts used for analysis



CERN test beam

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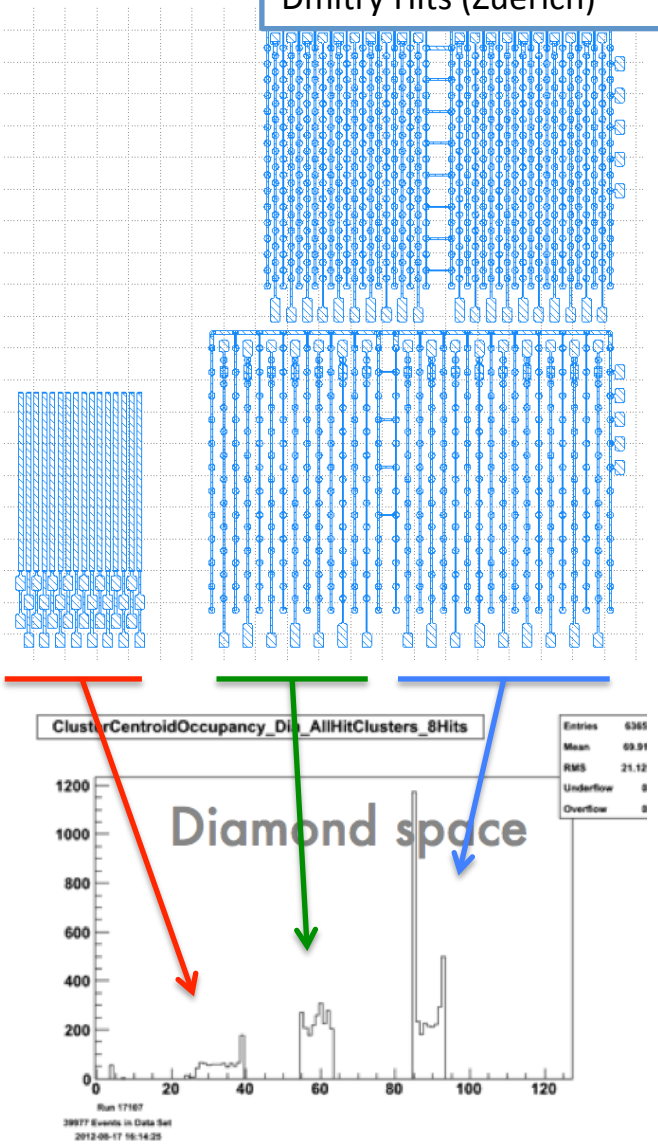
- **3D single crystal CVD (batch 2)**
  - Strip detector (16 strips, 50 µm spacing)
  - 3D no holes (9 strips, 150 µm readout,
  - 3D with holes (9 strips, 150 µm



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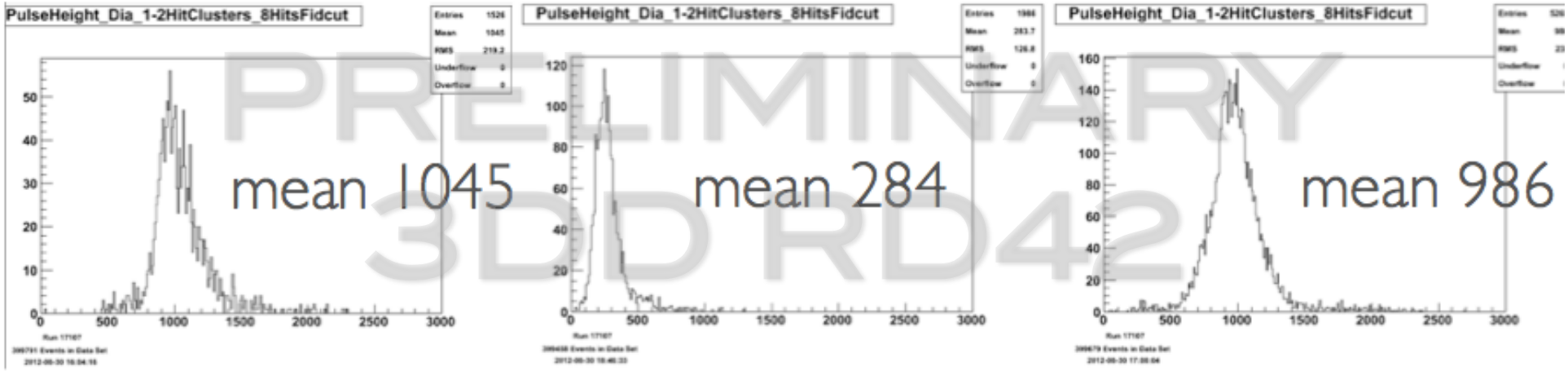


Strip
+500V

3D w/o holes
+25V

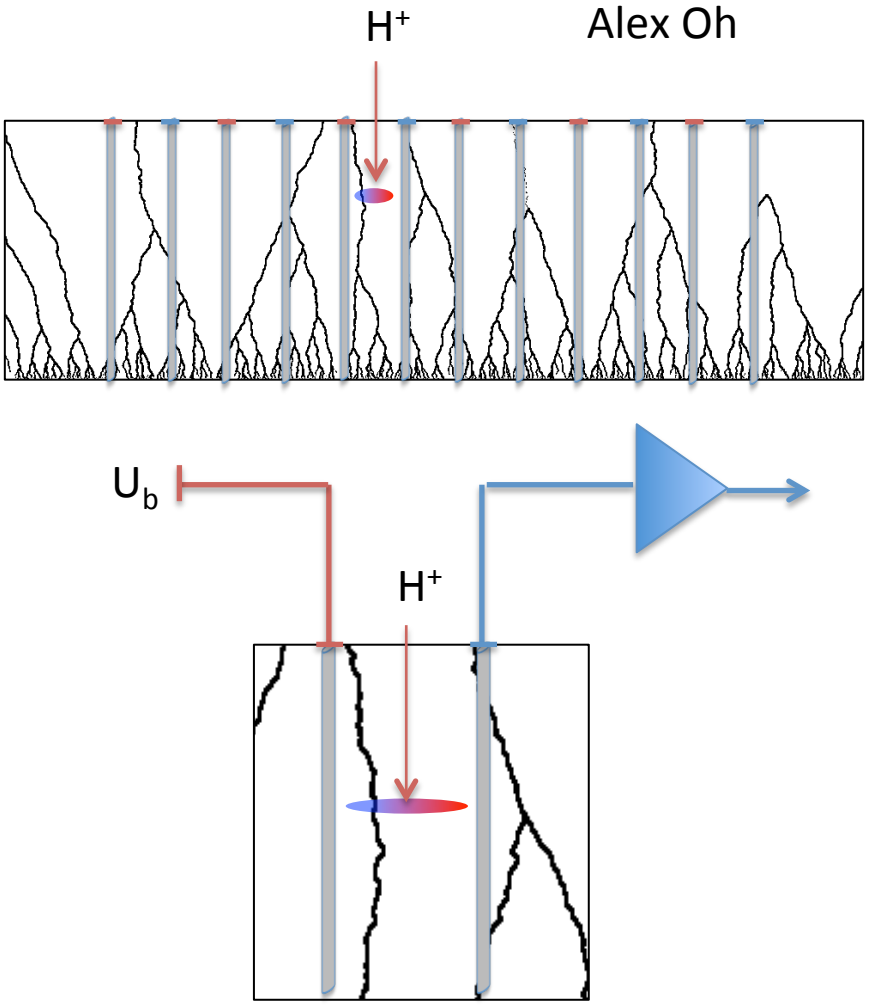
3D with holes
+25V

- 3D collects charge above w/o holes structure -> works!
- 3D area collects roughly the same charge as the strip detector, although smaller field
  - Strip ~ 10 kV/cm, 3D ~ 1.6 kV/cm
- Wider signal distribution -> Analysis in progress…

IBIC @RBI

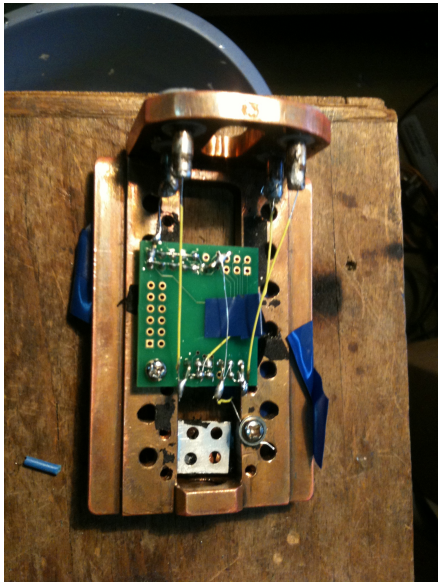
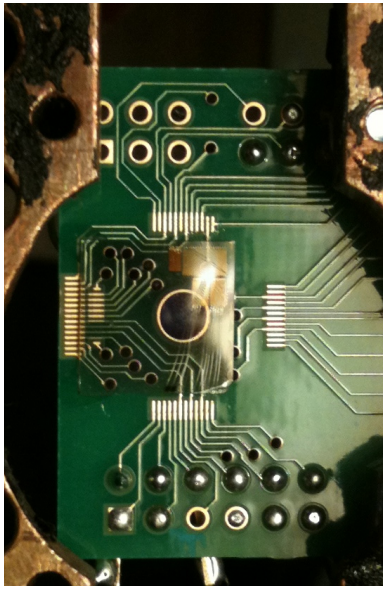
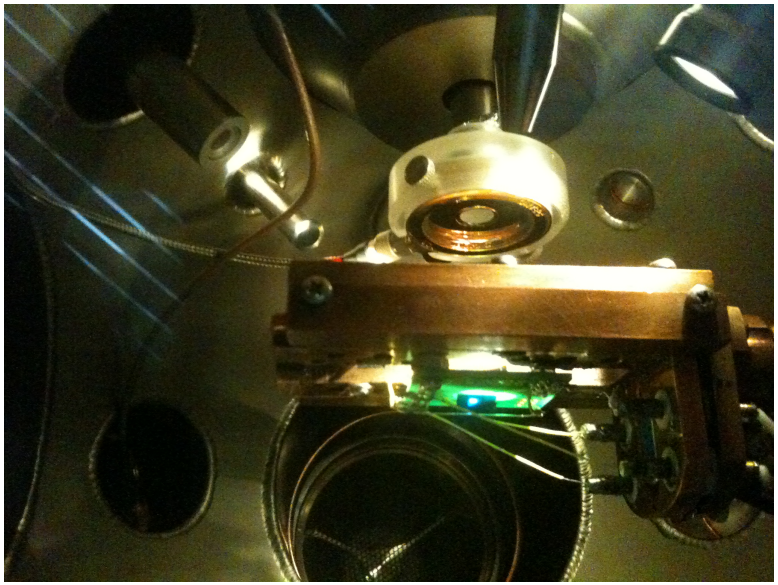
Natko Skukan
Milko Jaksic
Benoit Caylar
Iain Haughton
Alex Oh

- 4.5 MeV protons
- Single proton counting / irradiation possible
- Tested batch 1 SC and batch 2 pCVD 3D prototypes.
- Objective:
  - Map response with 4.5 and 4 MeV protons (~100 / 80 um penetration).
  - Lateral charge collection in 3D-> no polarisation!



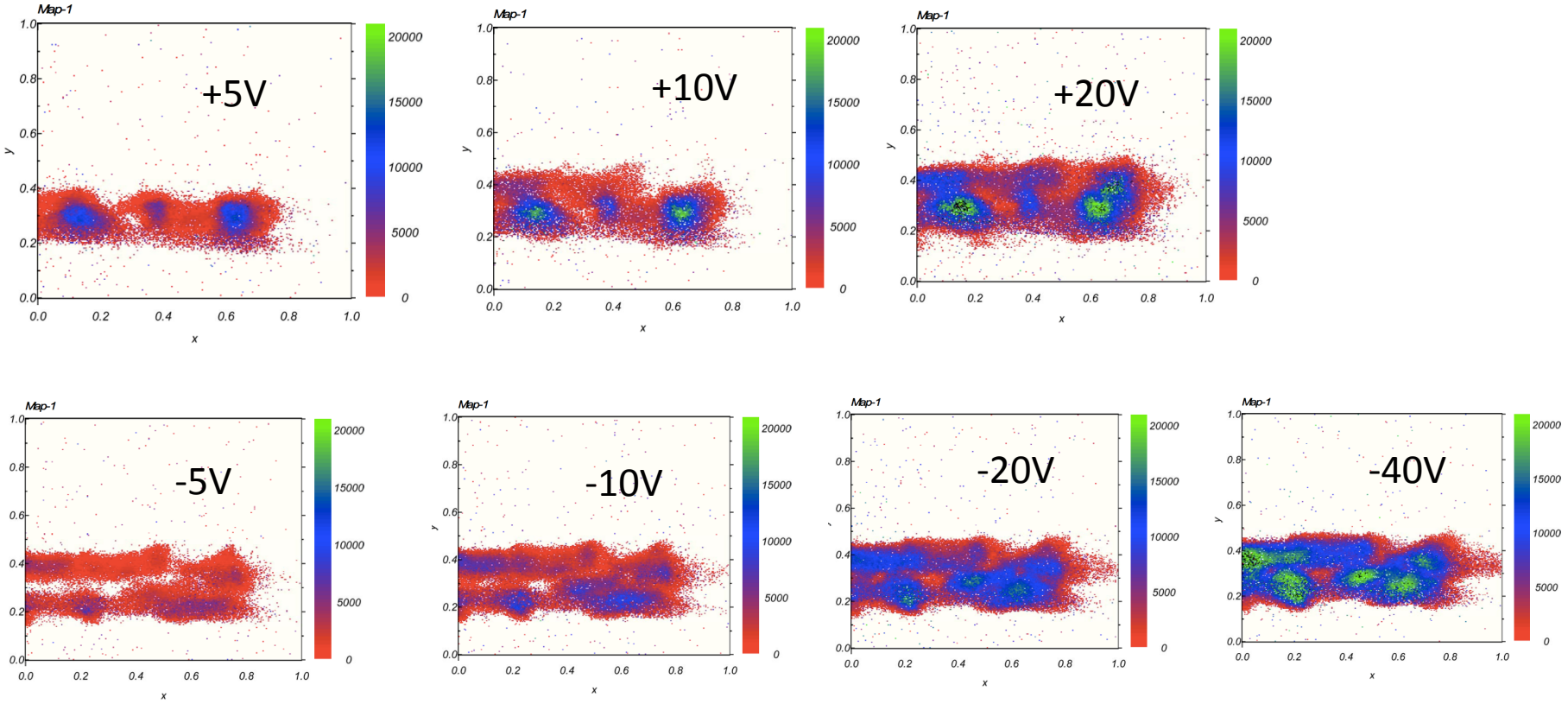
IBIC @RBI

- Sample Holder and pcCVD batch 2 device

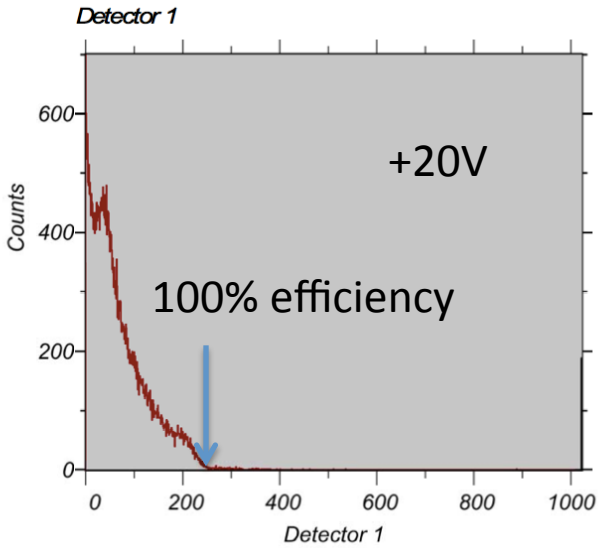
- Setup:
  - one strip A -> channel 1
  - two strips adjacent to A -> channel 2
- Response to 4.5 MeV protons.
- Areal response (~500x500 um):

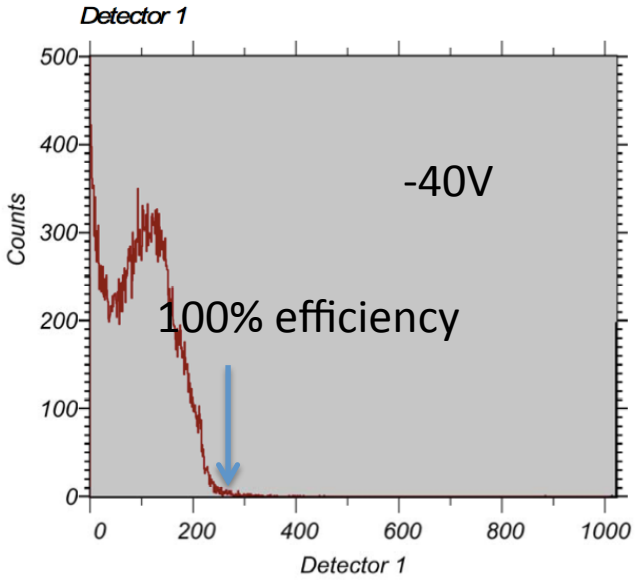
- Response contained in basic cell.
- Electrodes / grains are visible.
- Pos and neg polarity different response, one carrier type dominates at low fields?

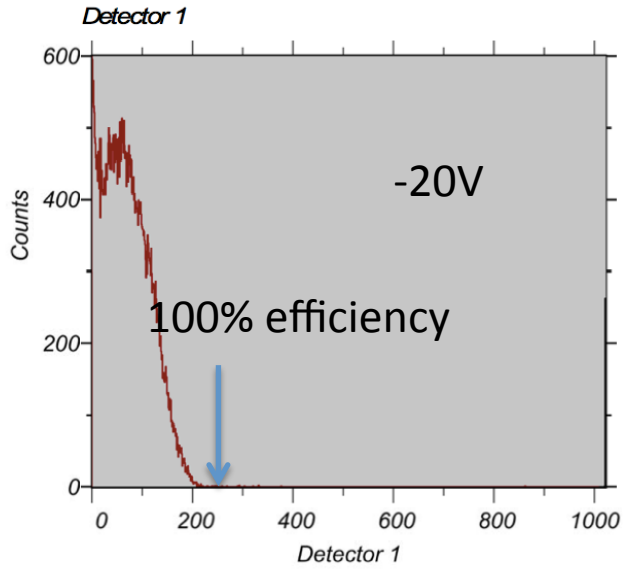


Spectra

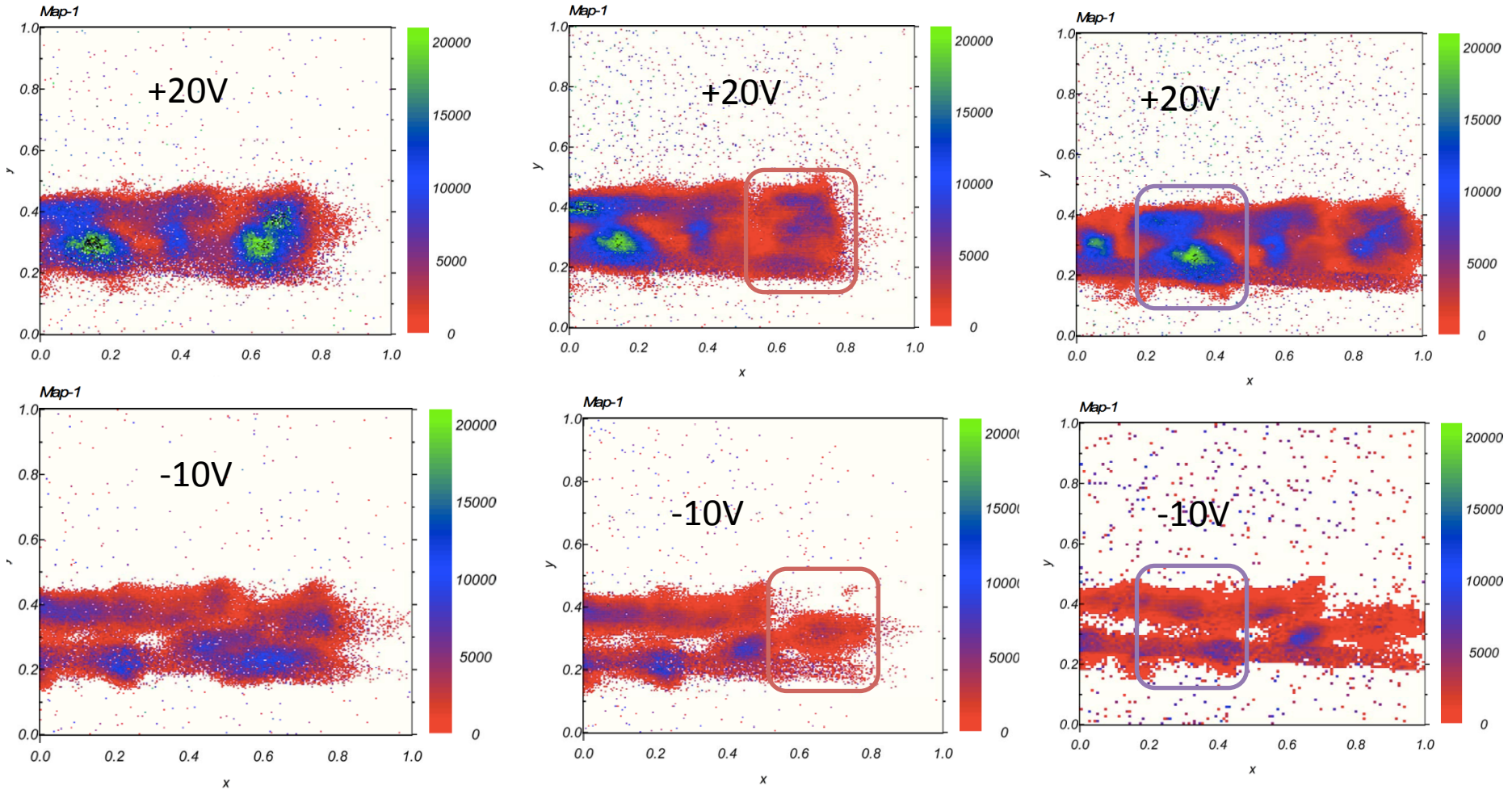
- MP efficiency ~50% ~ 250um collection distance @-40V.
- Ub limited by noise, need to improve metalisation.
- Spectra extends up to 100% efficiency.







- Irradiate to ~1e13 and 1e14 protons/cm^2, 4.5MeV.
- Probe beam 4.5 MeV.
- Analysis ongoing…



Conclusion

- Good progress made in the last three years towards 3D diamond detectors.
- CVD diamond samples with graphitic bulk electrodes were investigated with a micro-focused 15 keV photon beam and CERN test beam.
- 3D diamond configuration works for pCVD and single crystal diamond.
- Studies demonstrate the feasibility of 3D electrode structures in diamond.
- Last year's progress has been very impressive, and a lot of work is ahead toward a real 3DD vertex detector.