Diamond tracking detectors: present and future

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ETH zürich

ETH Institute for Particle Physics

Outline

- ATLAS Diamond Beam Monitor (DBM)
  - Design
  - Construction
  - Selected preliminary performance results with pre-production modules
- Diamond 3D detector
  - Principle
  - Fabrication
  - Beam test results

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ATLAS DBM - purpose and specs

- Purpose
  - Bunch-by-bunch luminosity monitor (aim < 1 % per Bunch Crossing per Luminosity Segment)
    - ➡ Finer segmentation (~27k pixels !)
    - ➡ Never saturates
    - ➡ Internal stability monitoring by tracking
  - Bunch-by-bunch beam spot monitor
    - ➡ Need triple-module telescopes for (limited) tracking
    - ➡ Can distinguish hits from beam halo tracks
    - ➡ Unbiased sample, acceptance extends far along beam axis
- Design considerations
  - Baseline: four telescopes of 3 modules per side → 24 total
    - ➡ Design of the modules is identical to Insertable B-Layer (IBL) modules (the innermost pixel layer of ATLAS Detector)
  - Avoid IBL insertion volume and ID acceptance (η>2.5)
  - Place in pixel support structure close to detector and beam pipe

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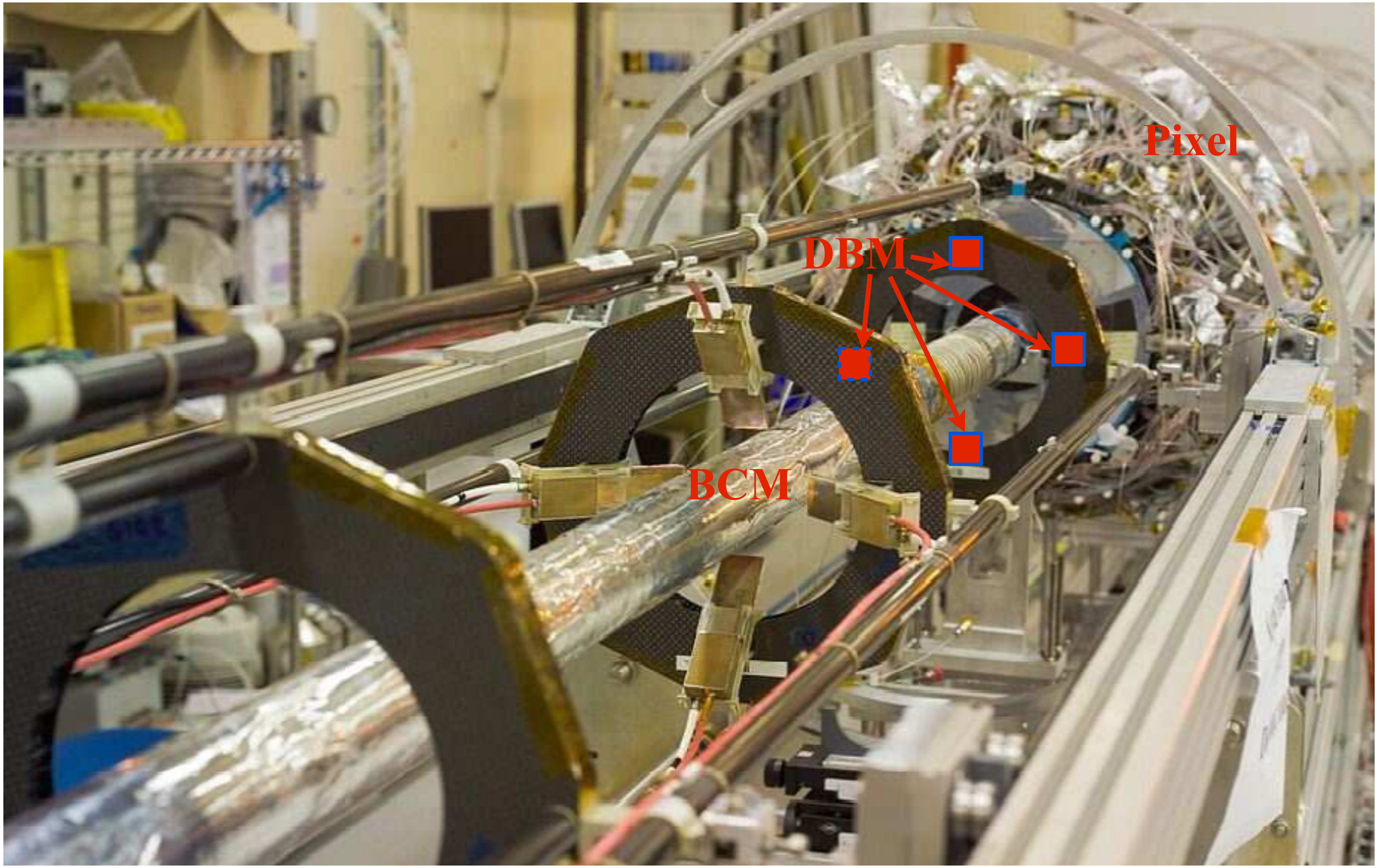
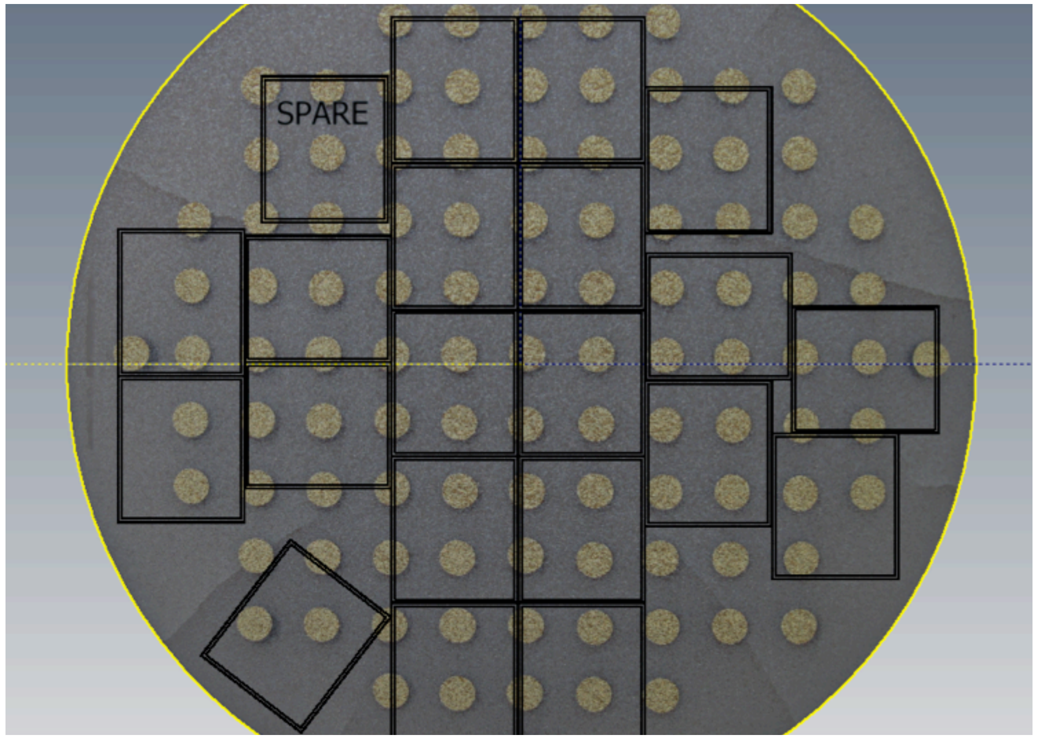
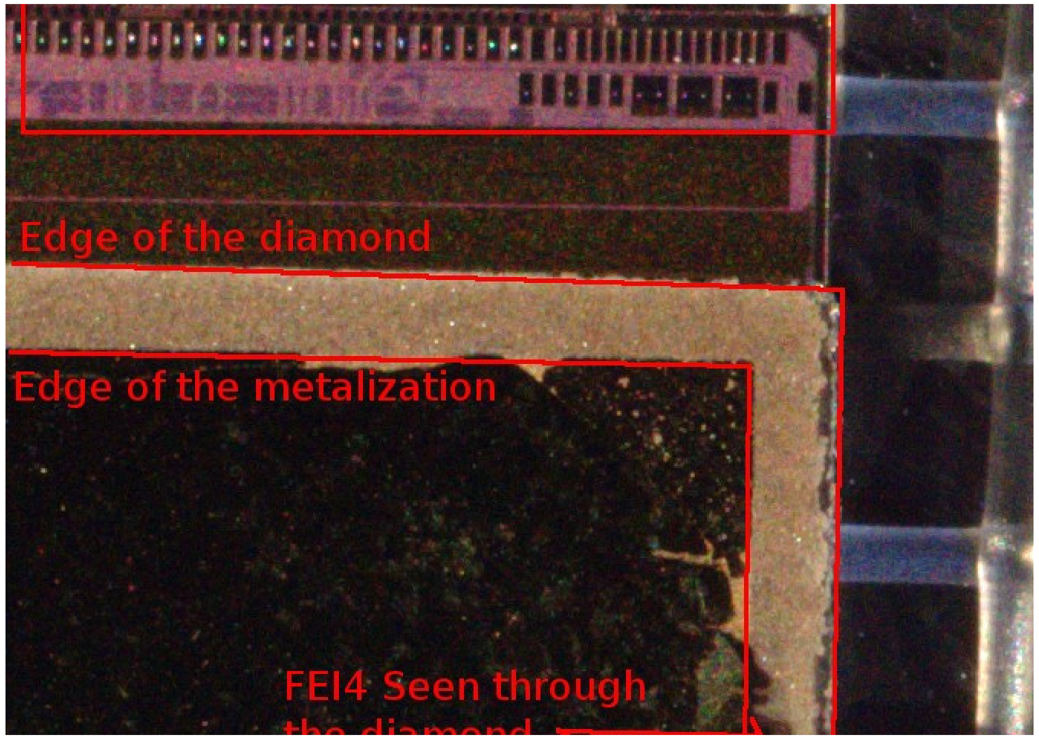
DBM Installation location

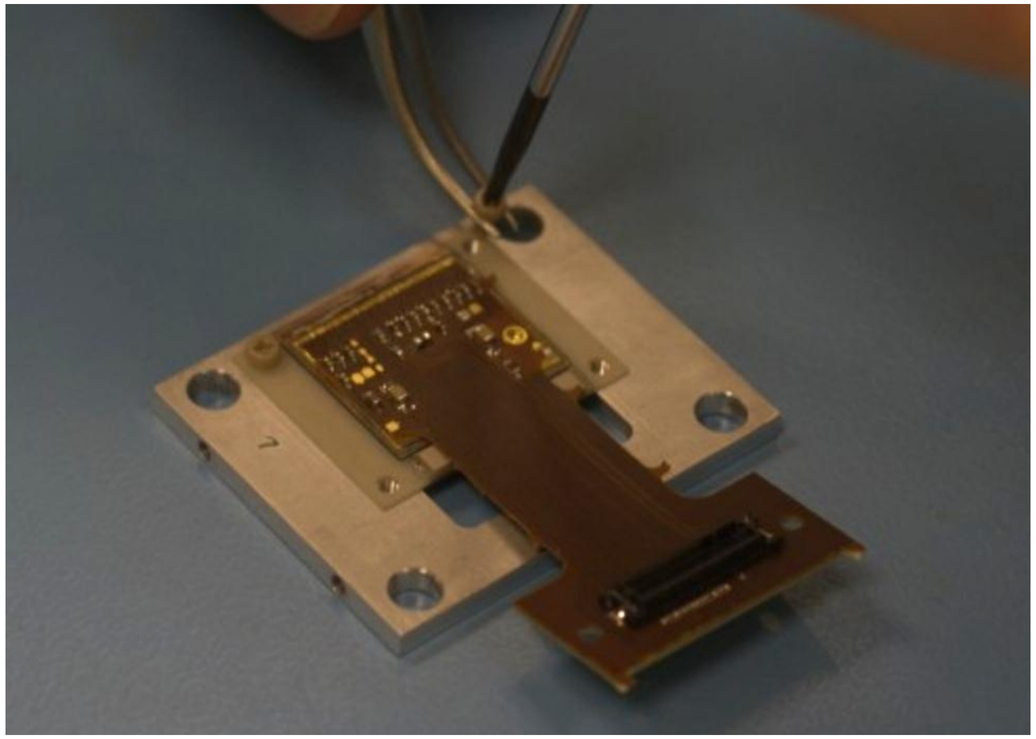


DBM production



- 6 inch diamond wafer grown by II-VI infrared
  - Pieces from the wafer selected based on leakage current and collected charge
- pieces are cut out from the wafer and thinned down/polished by II-VI infrared
  - 18 mm x 21 mm x 0.5 mm polyCVD
- sensors are metallized by OSU and IZM
- bump bonded to FE-I4 chips by IZM
- assembled into modules at CERN.

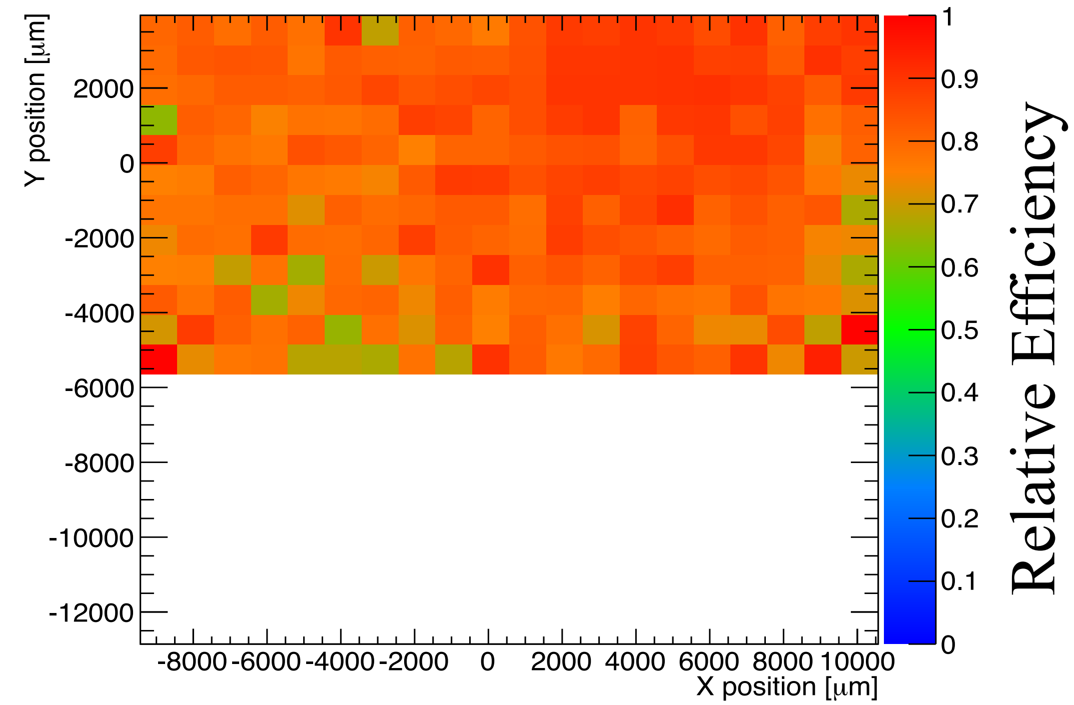


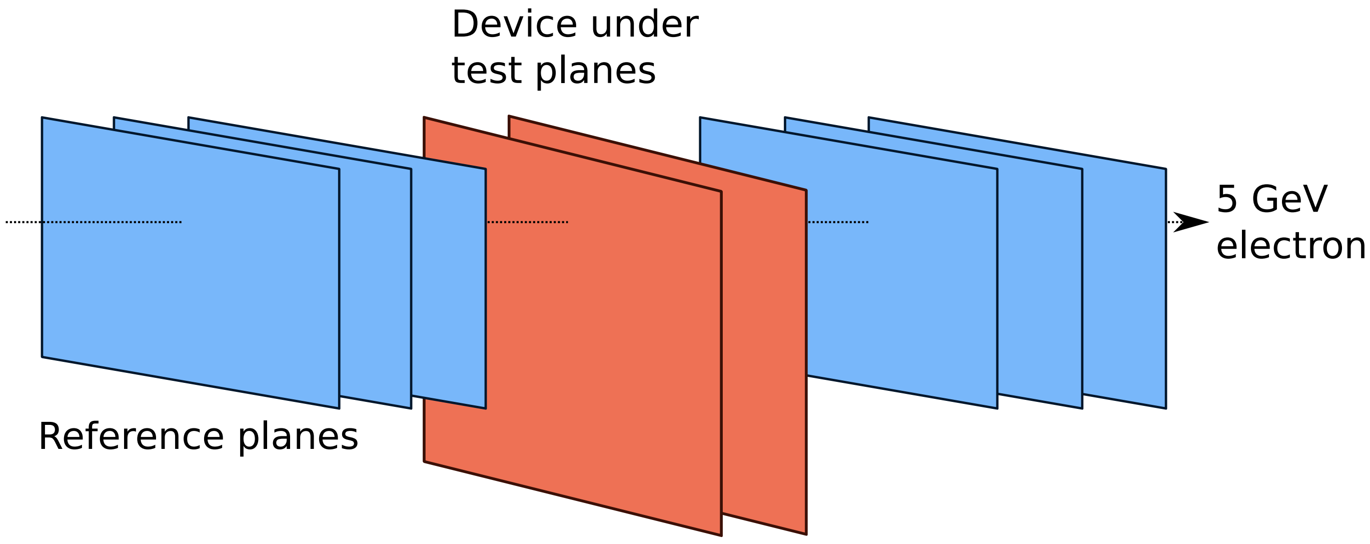


DBM: DESY beam test results

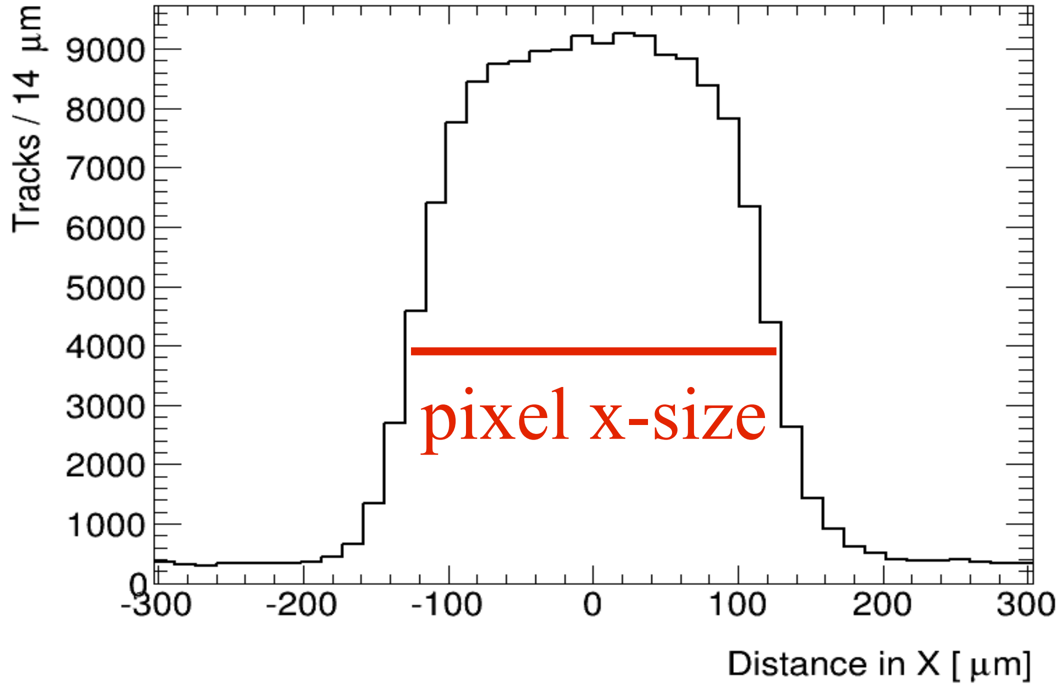
- Pre-production diamond planes bump bonded to FE-I4 chips
- Silicon sensor, also bump bonded to FE-I4 readout chip, was used as a reference plane
- Studied relative efficiency and resolution vs applied sensor bias and for several readout chip thresholds.
  - Bias: 660 V, 800 V, 1000 V
  - Threshold: 1100 e^-, 1500 e^-, 2000 e^-, 2500 e^-

MDBM-01, Threshold 1100 e



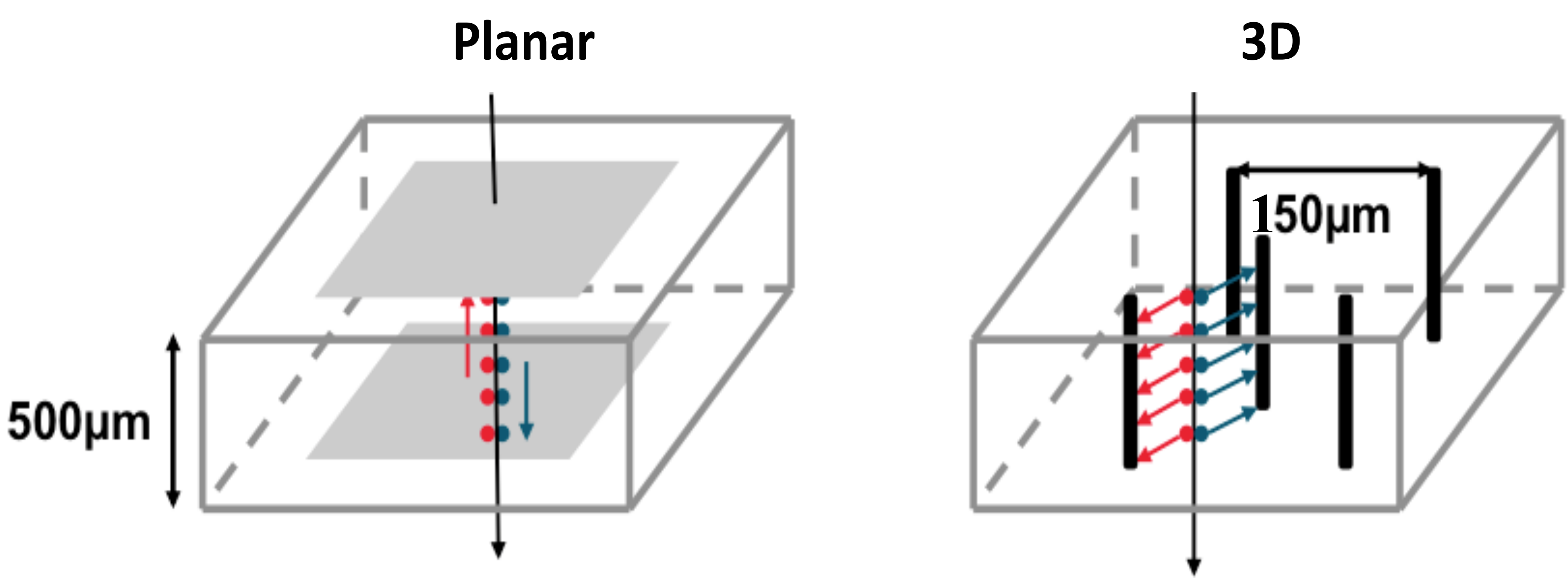


MDBM-01, X-residual



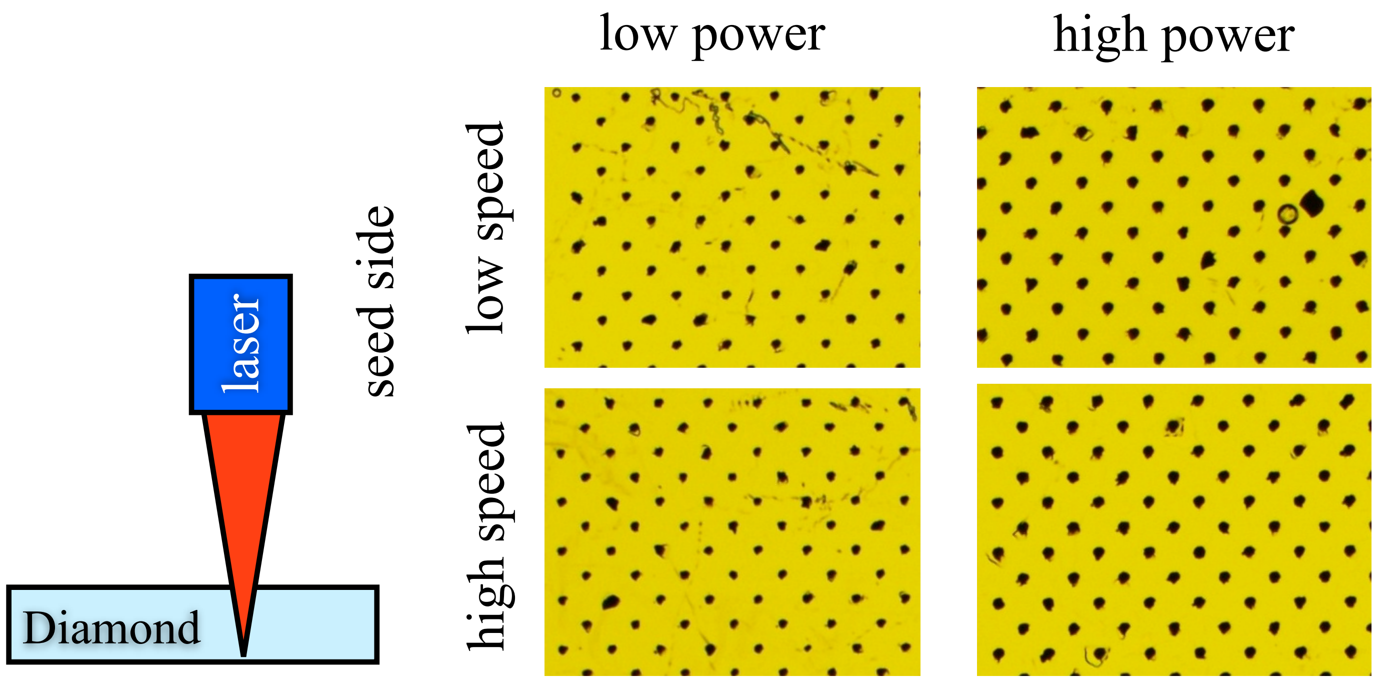
Diamond 3D devices

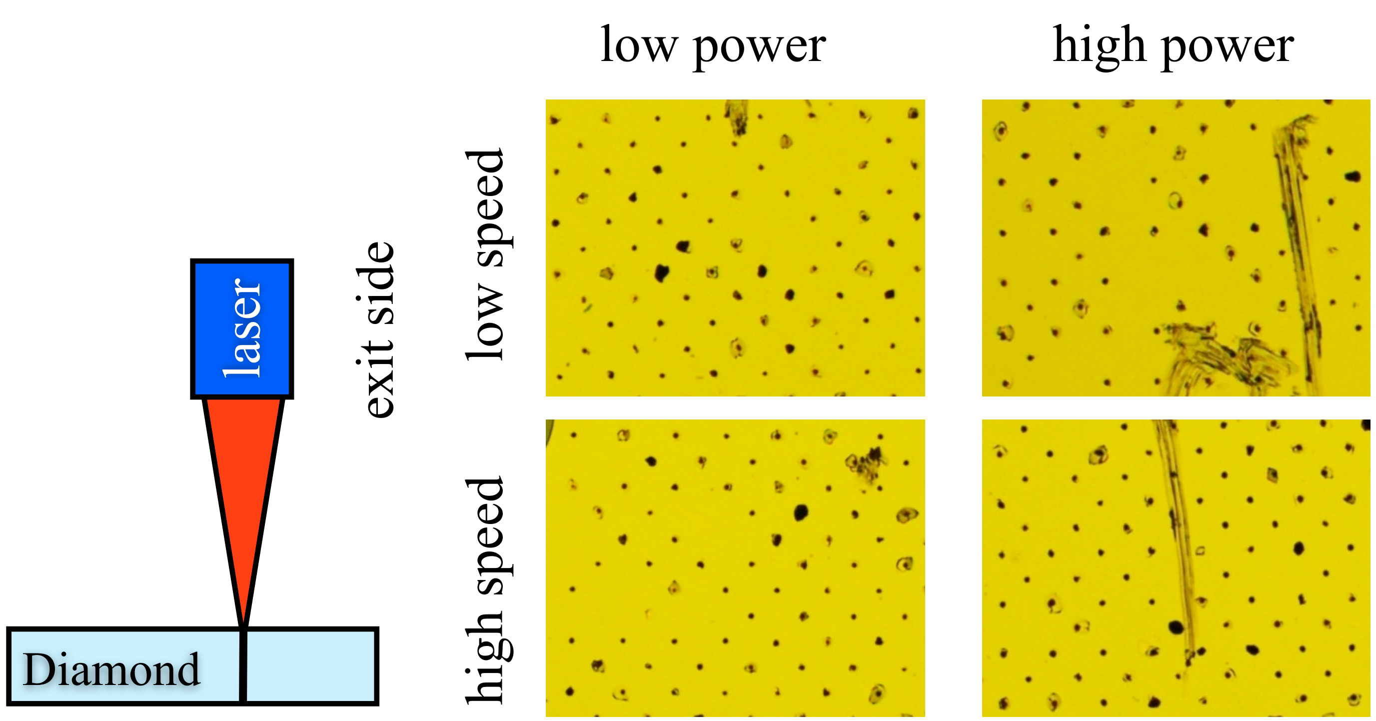
3D principle



- Same amount of charge deposited by ionizing particle
- Drift distances shorter than in planar (≈ 100µm vs. 500µm)
  - Comparable to mean free path of charge carriers in irradiated diamond (few 10^{15} p/cm^2)
  - More efficient charge collection

Drilling efficiency



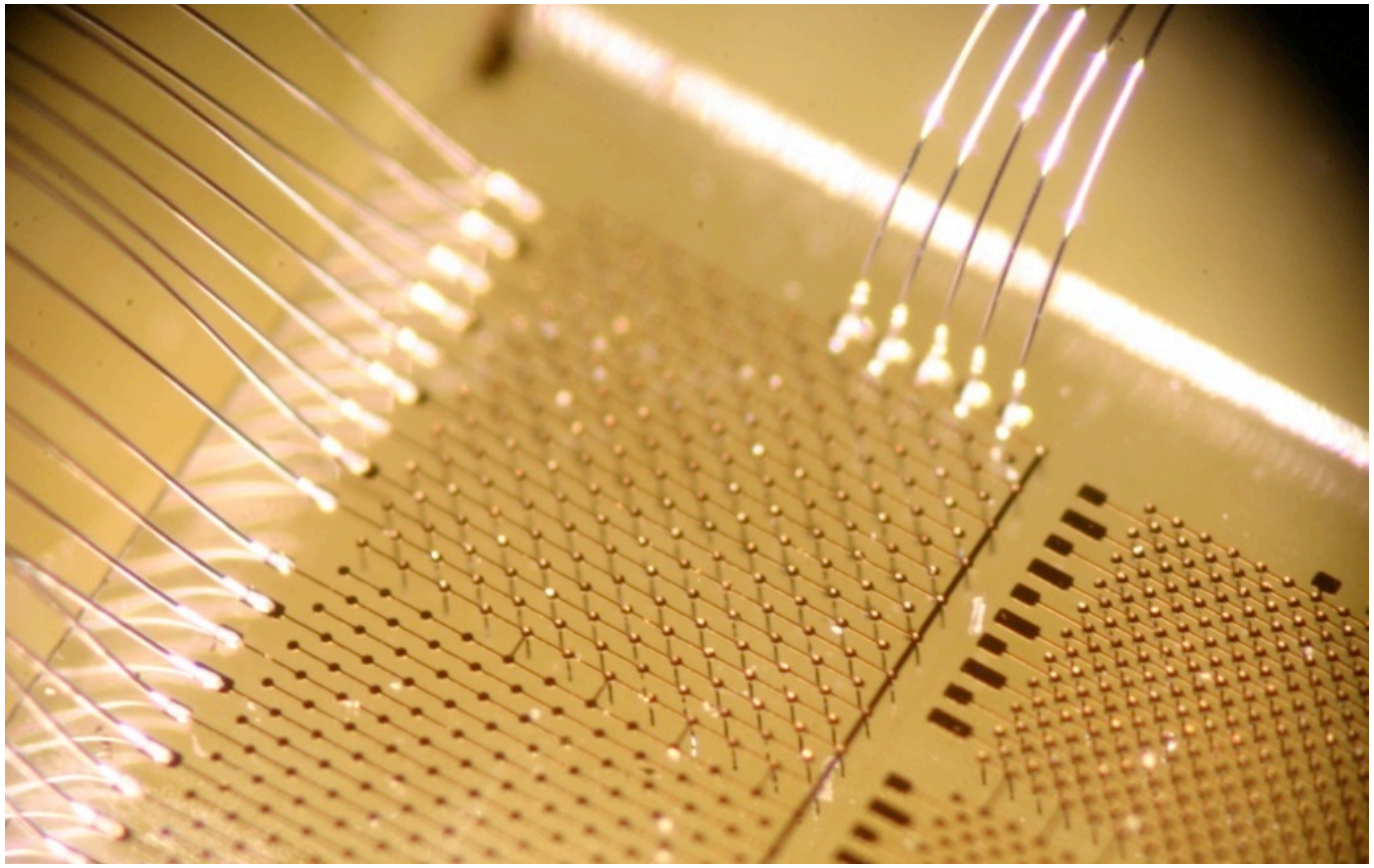


- "Drill" columns in diamond with 800 nm femtosecond laser
- Tried 4 different "drilling" parameter
  - best is to "drill" fast and with low power

	low power	high power
low speed	92.2 ± 1.4 %	78.7 ± 2.1%
high speed	**93.3 ± 1.3 %**	87.6 ± 1.7 %

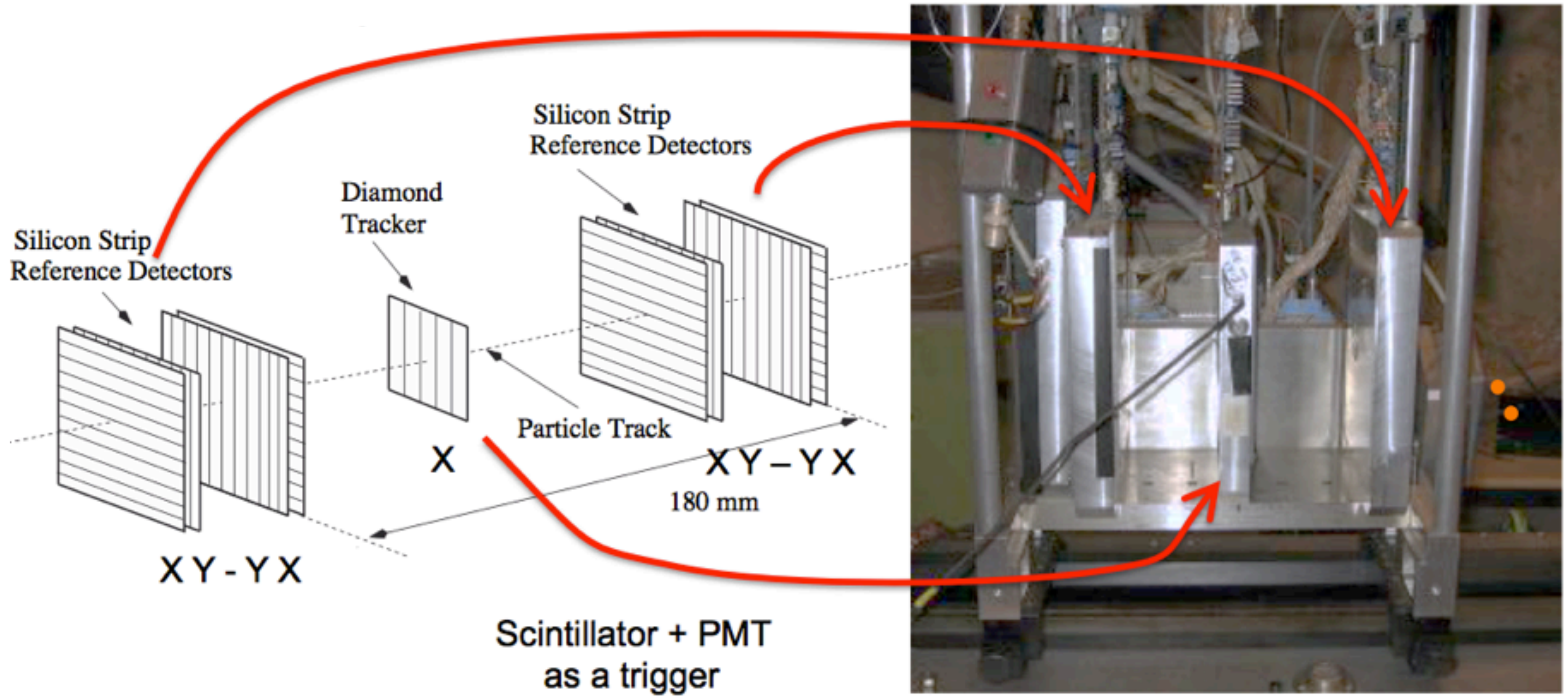
Metallization

- Cr/Au electrodes
  - Connecting a row of laser drilled columns with one strip
    - readout strips interdigitated with bias strips
- Wire bonded to VA2 readout chip



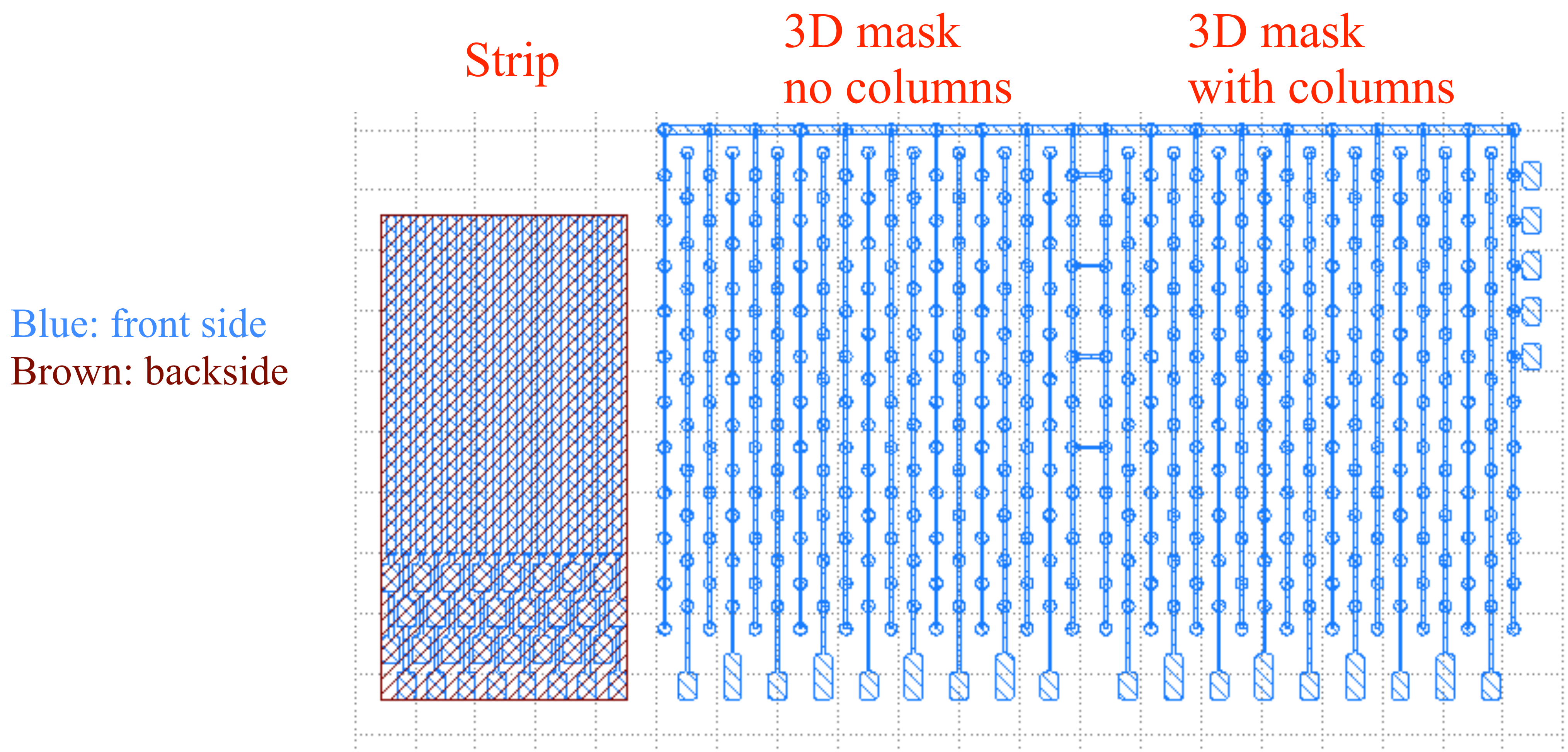
Beam test: setup

- CERN SPS H6 line
  - 120 GeV protons
- Strasbourg strip telescope
  - 4X, 4Y planes,
  - Resolution: a few μm
- Trigger - coincidence of 2 scintillators



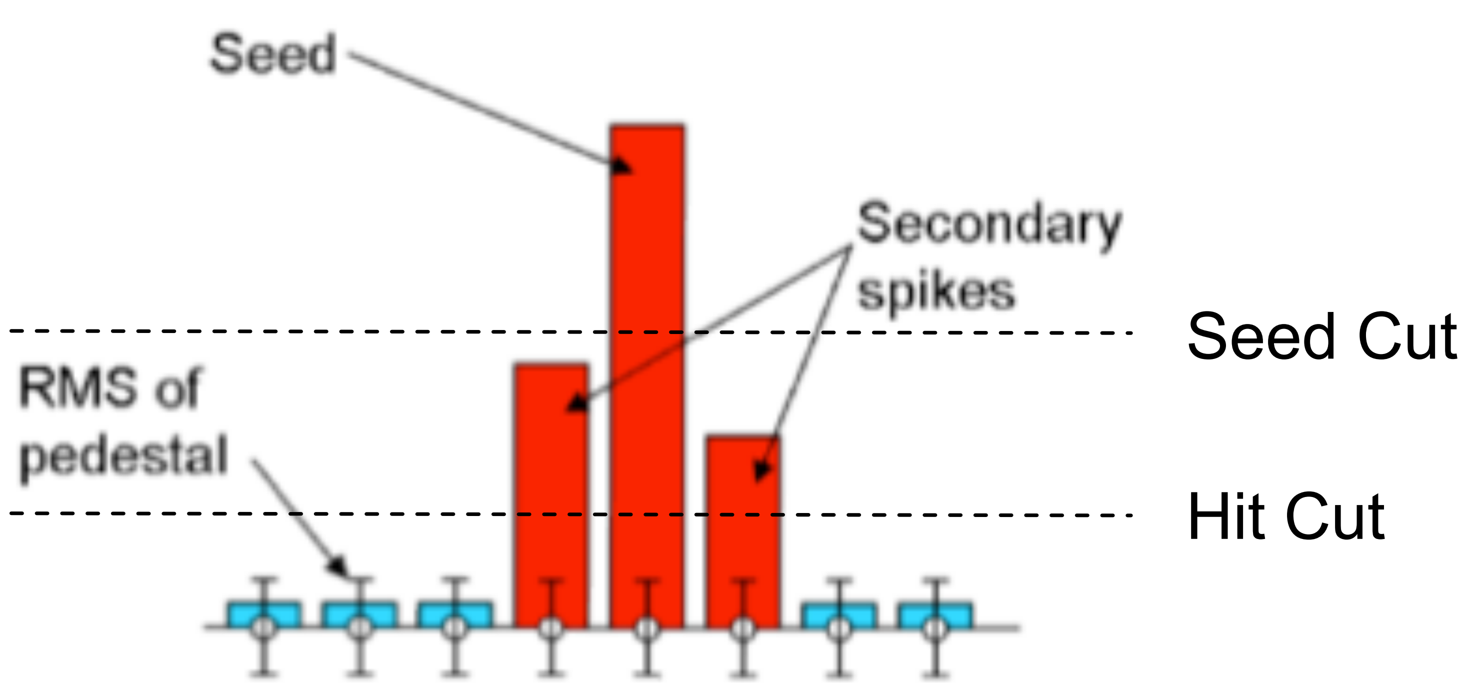
Beam test: DUT

- Single crystal CVD diamond
- Three test structures:
  - Strip detector as a reference to compare to with backplane (bias voltage)
  - Two 3D mask layouts (bias and readout from the same side)
    - Without machined columns (to understand influence of the electric field from surface metallization on charge collection efficiency)
    - With machined columns



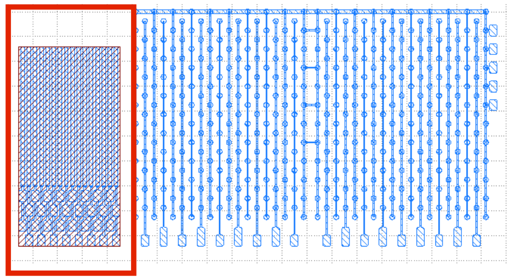
Beam test analysis: clustering

- pedestal subtraction
- clustering
  - seed cut 5σ
  - hit cut 3σ



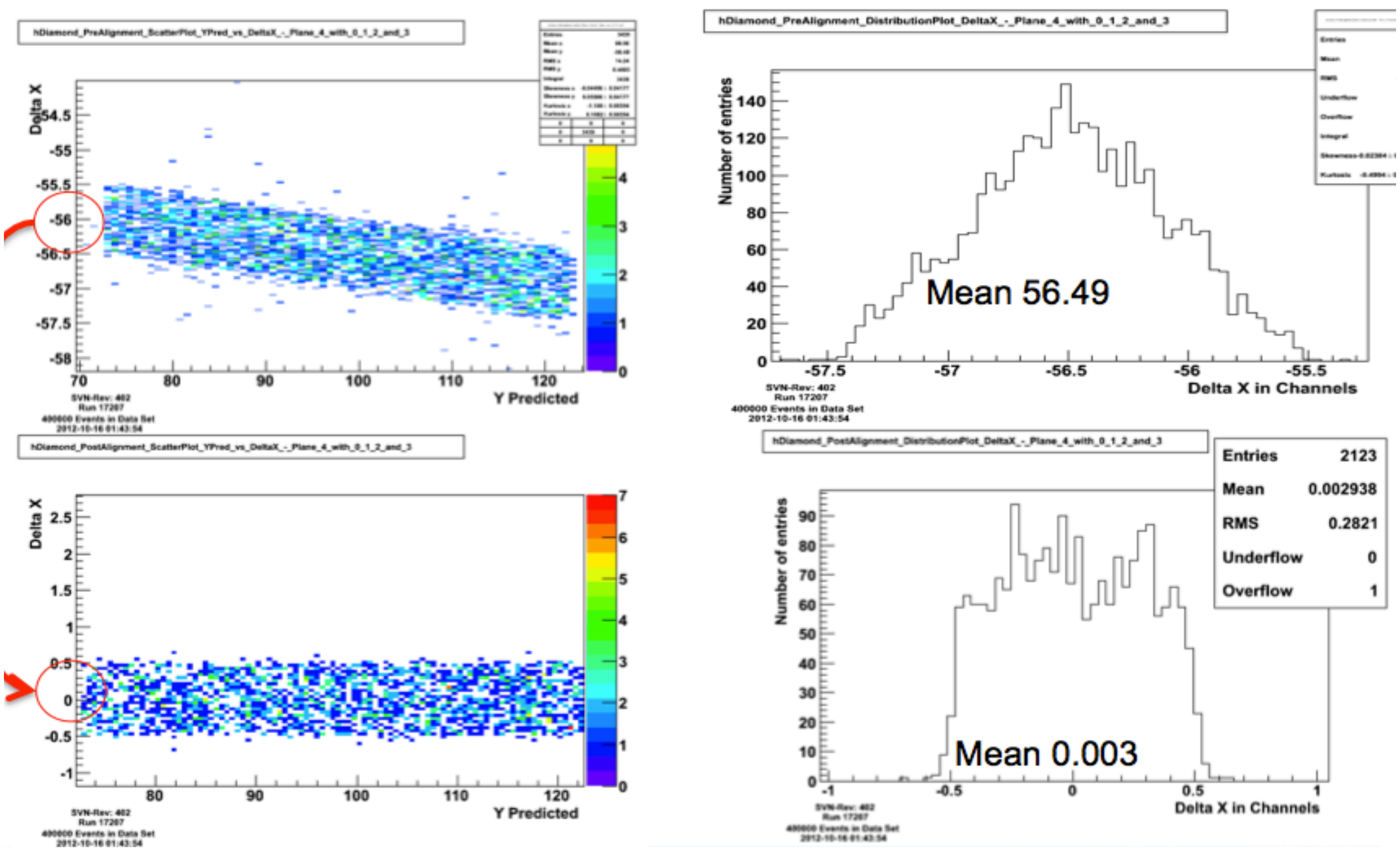
Beam test analysis: alignment

- Use the strip detector structure for precise alignment in X-direction
  - Using strip with the highest signal



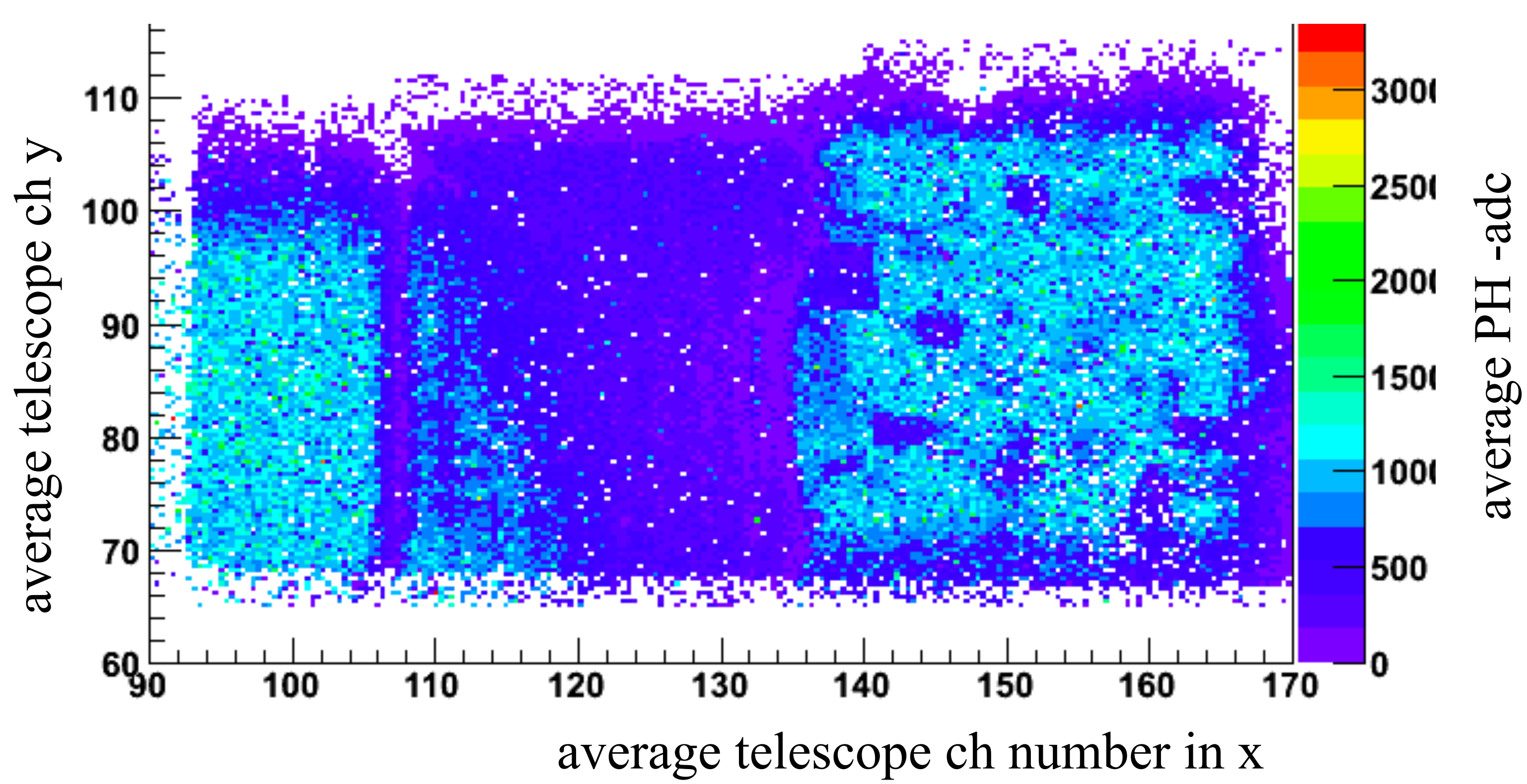
Before alignment

After alignment



Beam test analysis: Fiducial regions

- Require one and only one cluster in each telescope plane
- Require at least one diamond cluster
- Plot PH in diamond for an average telescope position
- Overlay with a mask pattern
  - select a rough fiducial region



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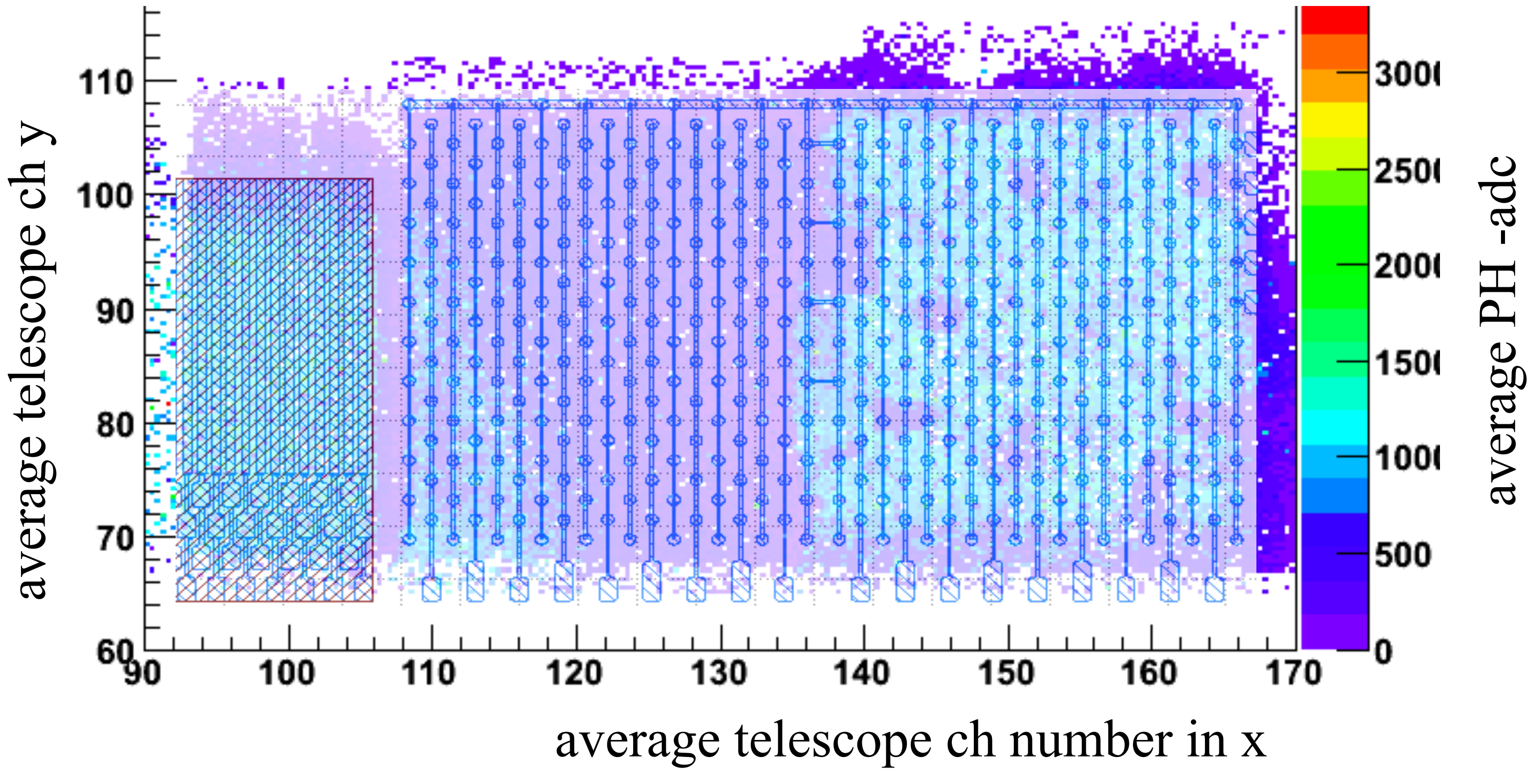
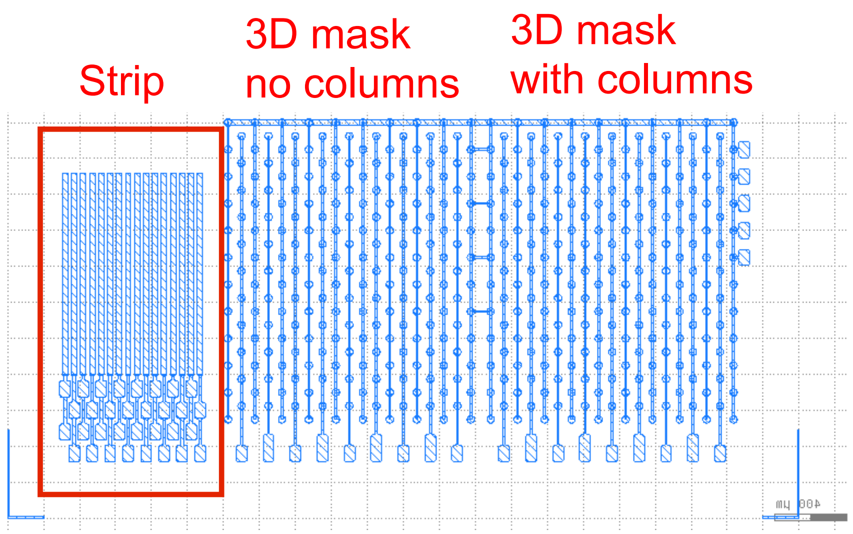
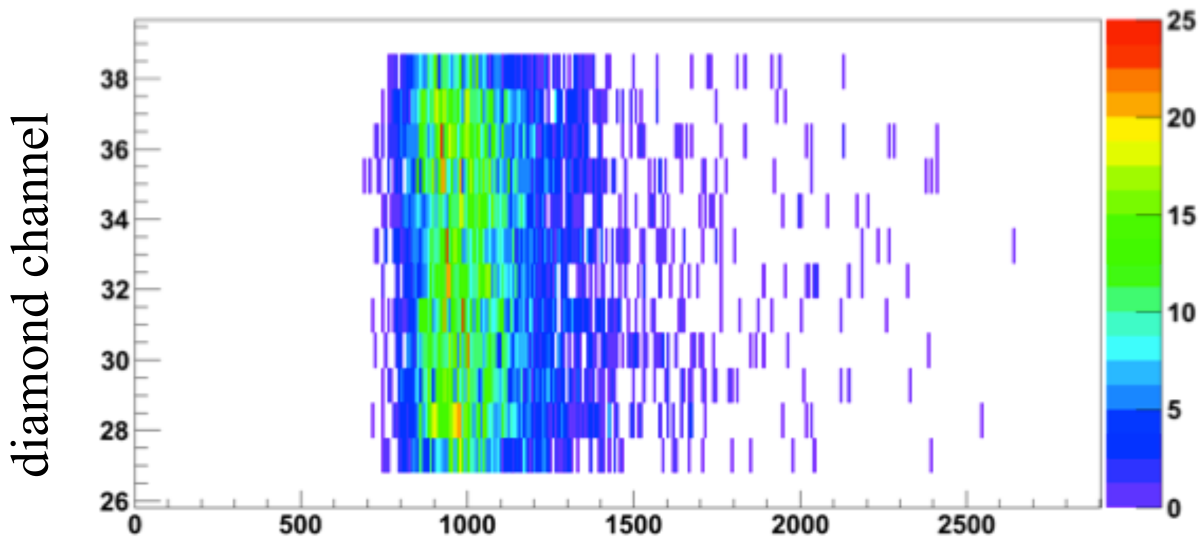


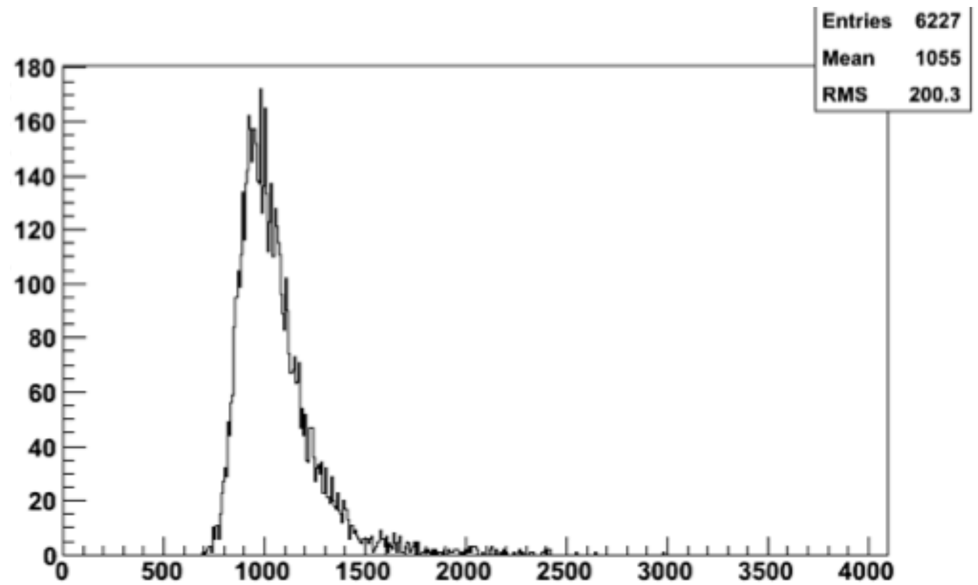
Beam test analysis: Pulse heights

- Similar pulse height in every channel
- Landau distribution, MP @ ~1000





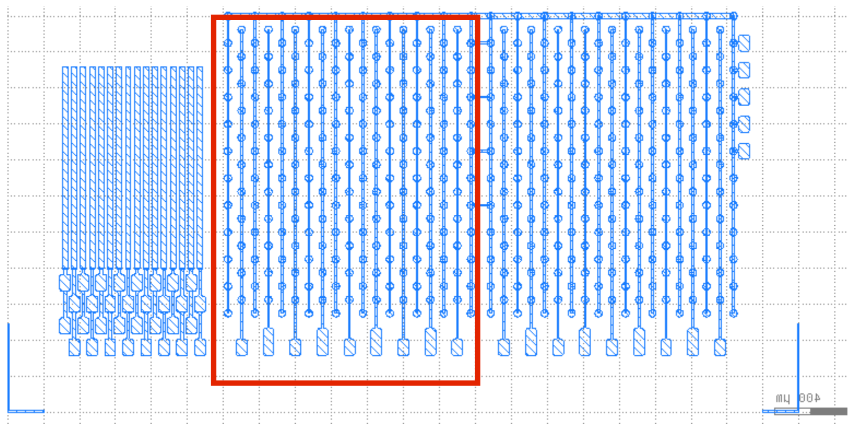
average cluster PH in adc counts



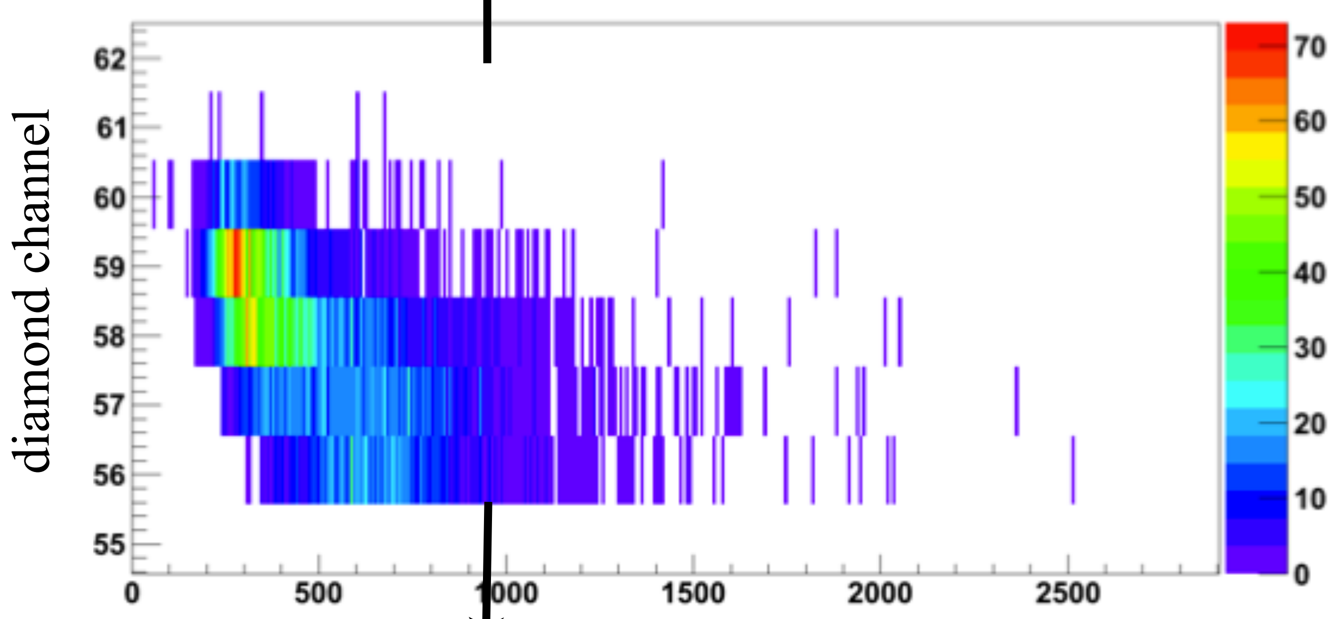
average cluster PH in adc counts

Beam test analysis: Pulse heights

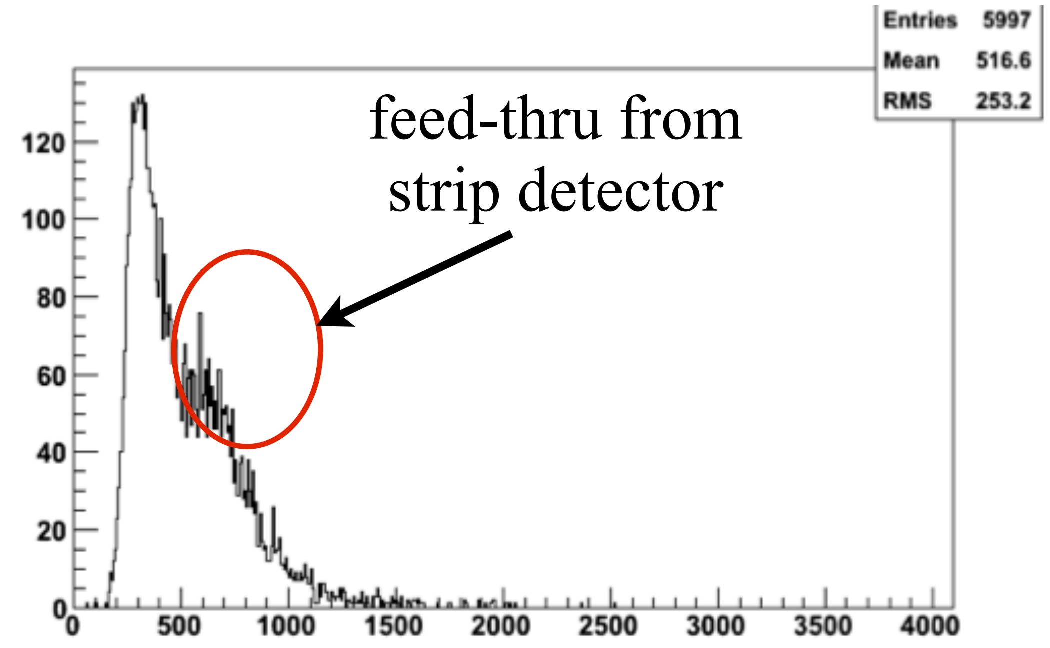
- Influence of strip structure (500V vs. 25V)
  - at lower channel numbers



3D with columns @ 25 V

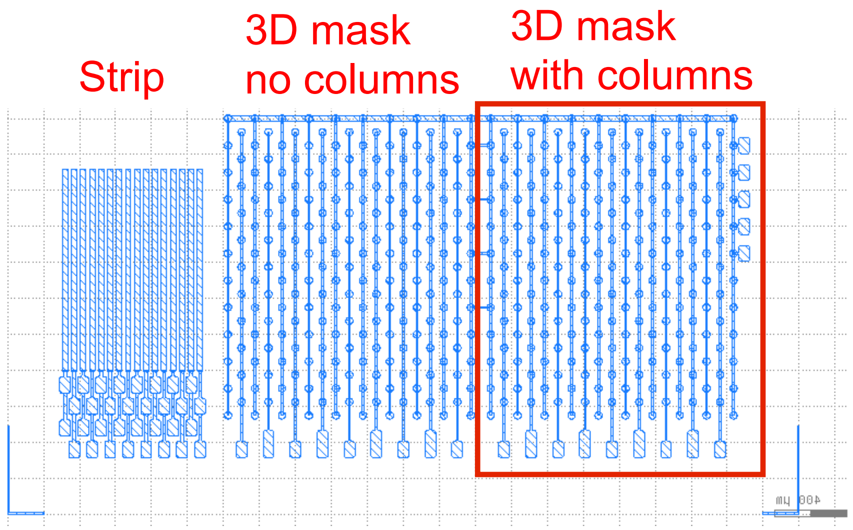


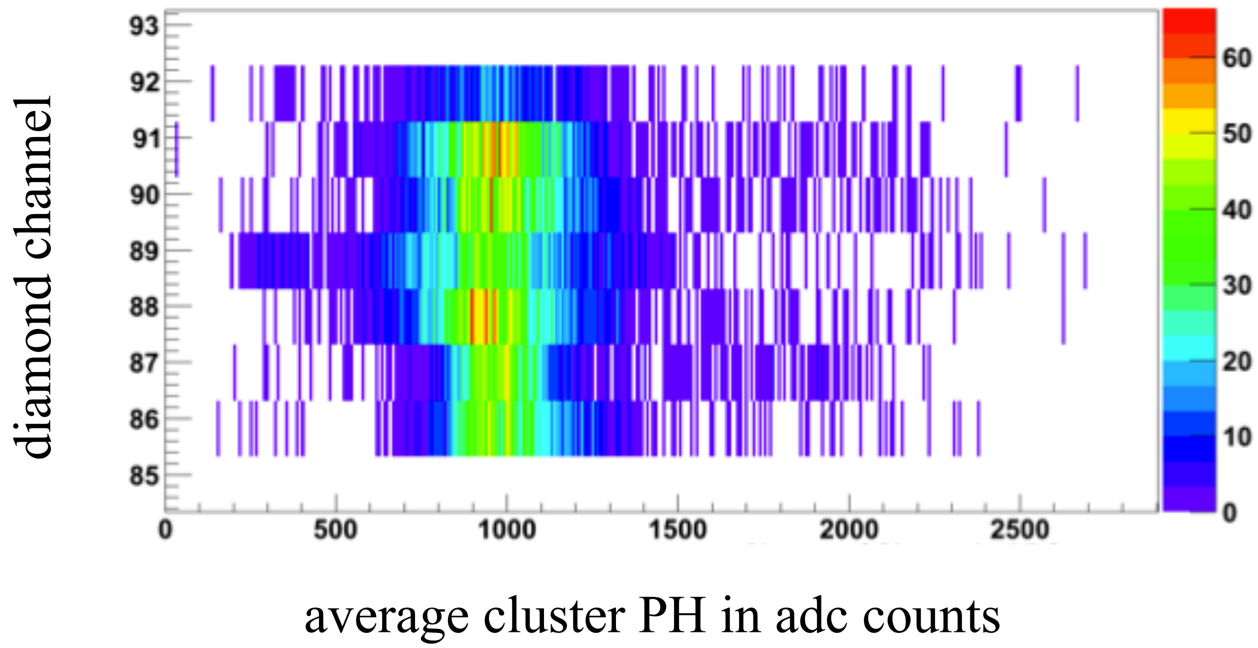
Strip detector @ 500 V

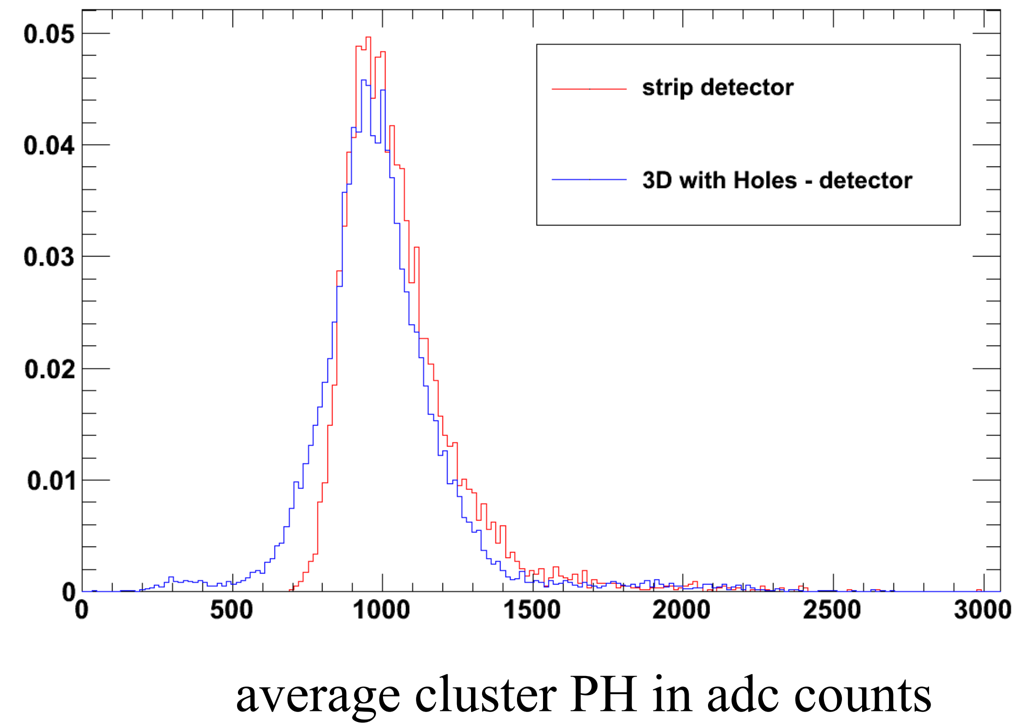


Beam test analysis: Pulse heights

- Pulse heights for the whole 3D structure with conductive columns are plotted
  - no fiducial cuts within 3D structure
- Pulse heights are approximately the same for strip detector and 3D detector
  - 3D detector has only 25 V bias vs 500 V in strip detector!
- 3D detector has non-landauish tails
  - too low on the lower side and not high enough on the higher side



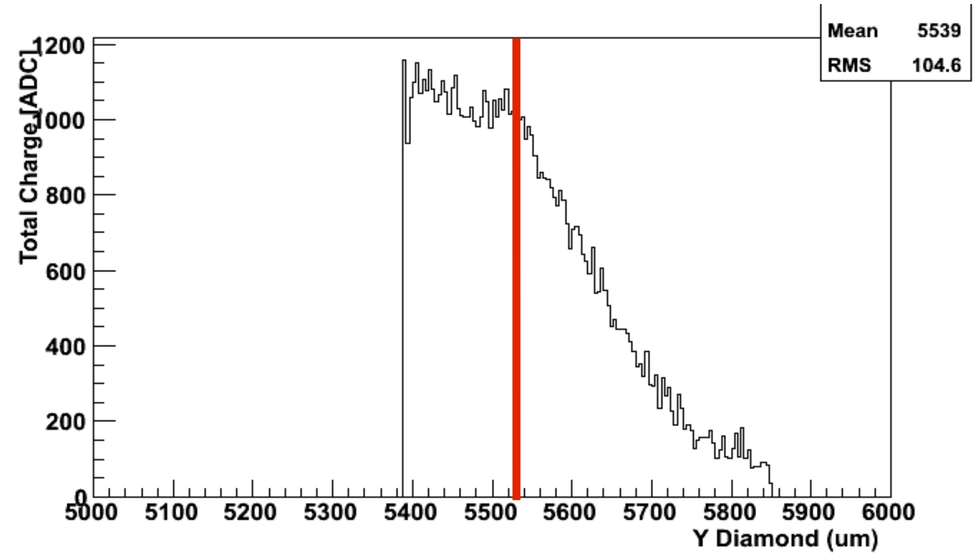


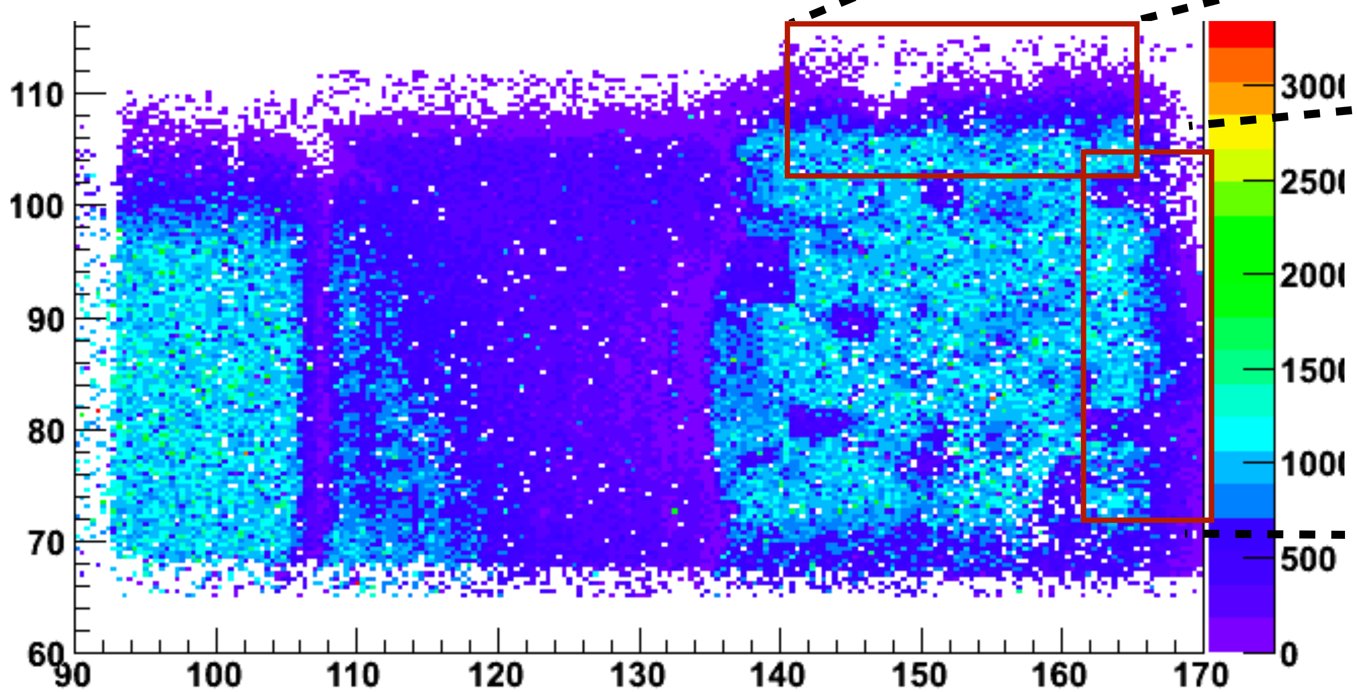


Y-alignment

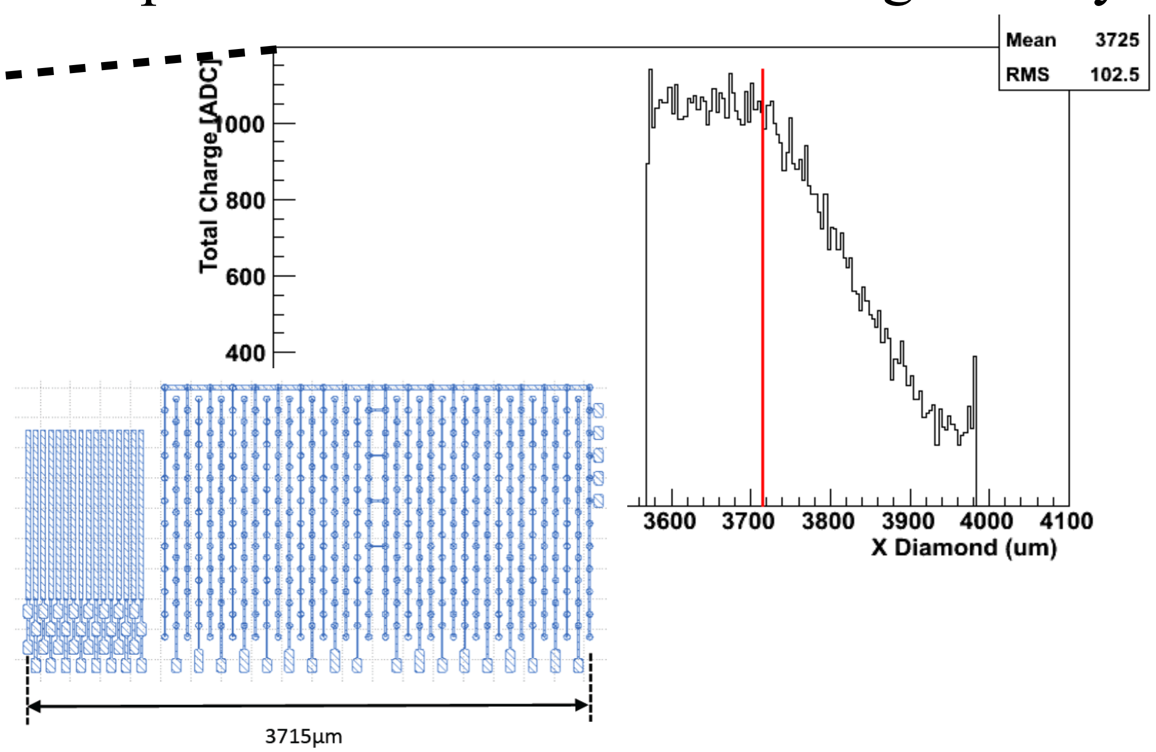
- Align using pulse height vs position distribution at the edges of the 3D detector
  - plot pulse height vs X and pulse height vs Y distributions for the edges of the 3D detector
  - predict the position of the right most edge in X direction based on geometry
  - compare shapes of the distributions to measure the position of the top most edge of the 3D detector in Y direction

measure from the shape comparison



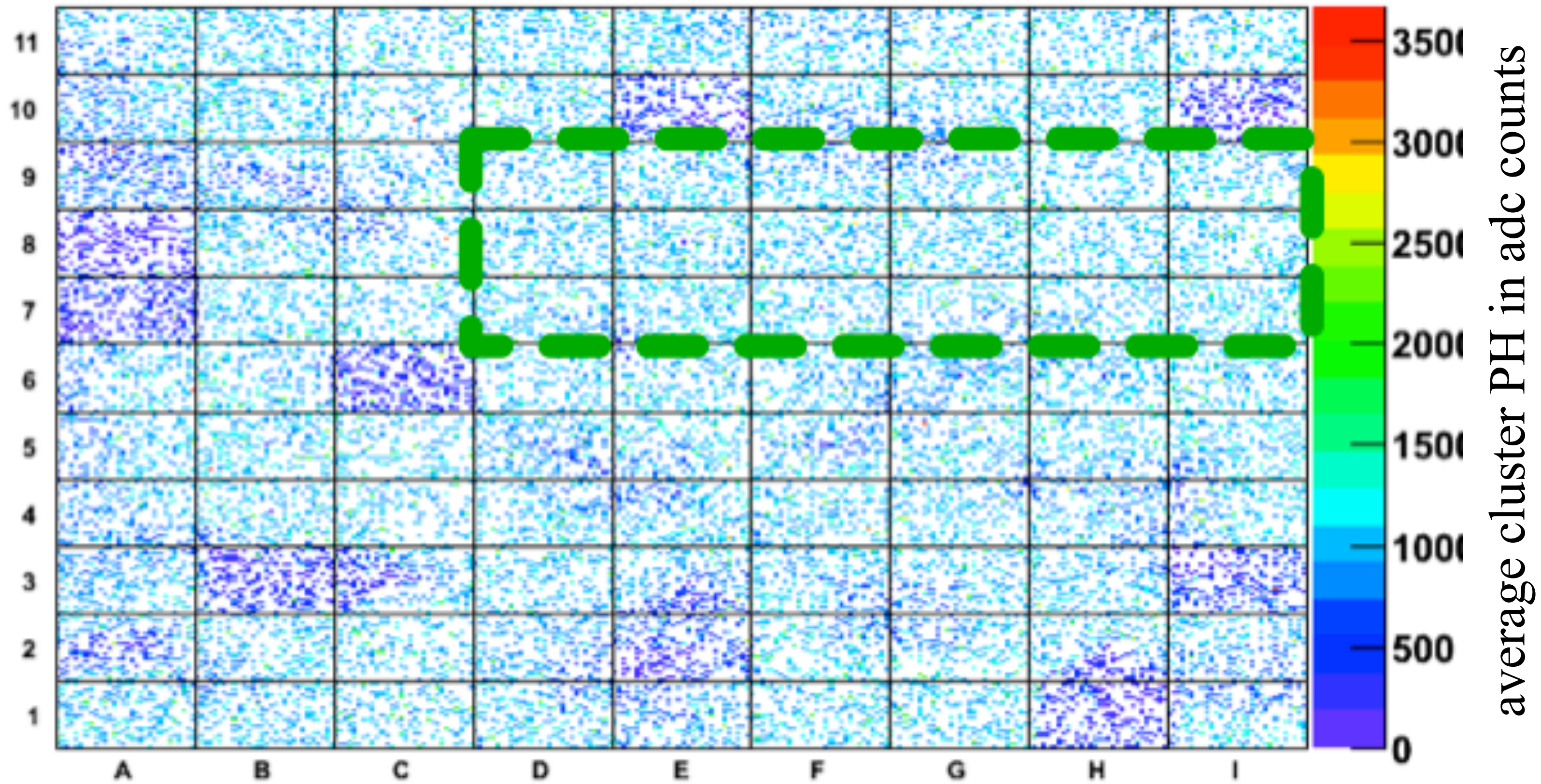


predicted based on the mask geometry



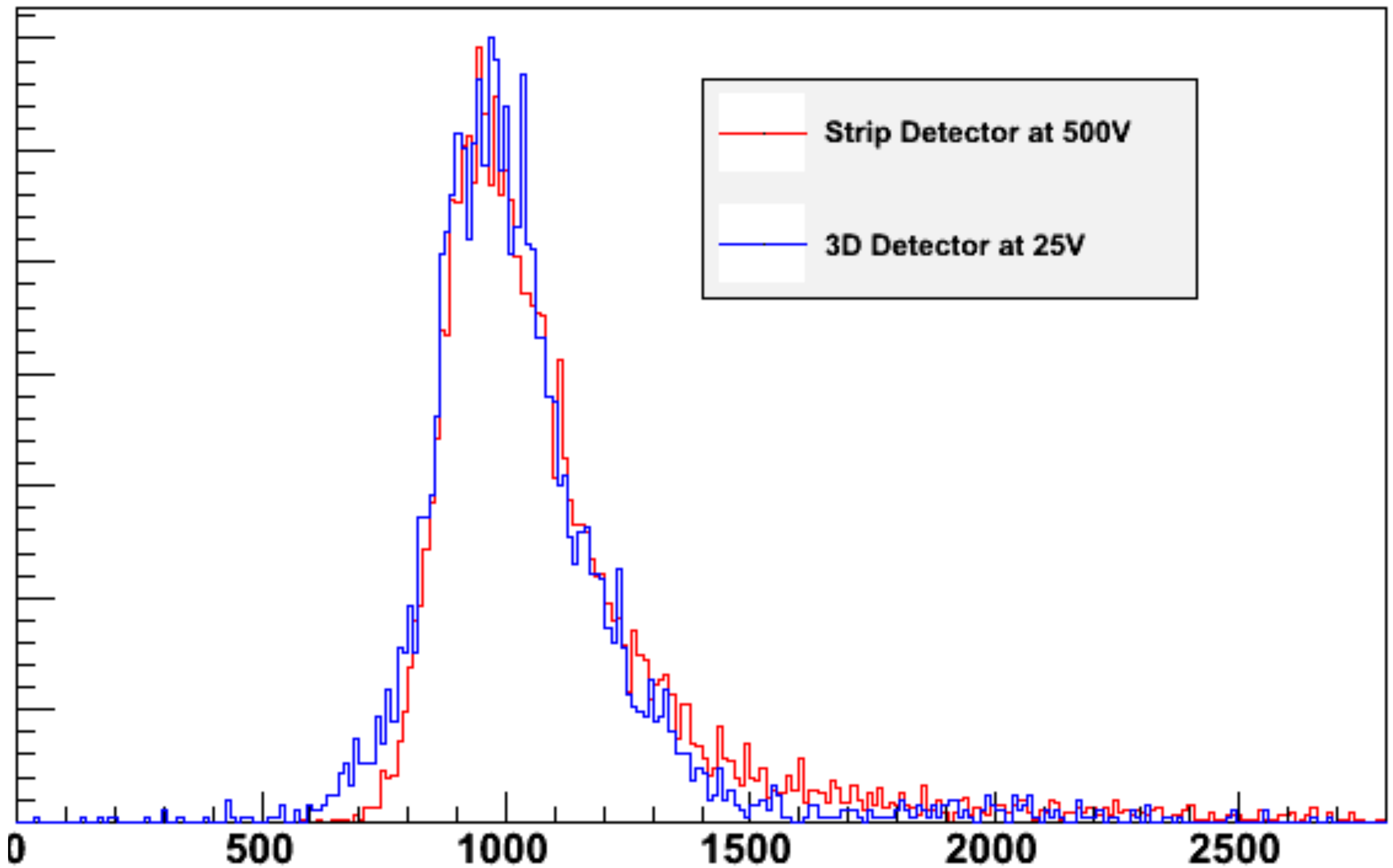
Beam test analysis: Pulse heights

- Overlay with 3D cell structure
  - about 8 out of 99 cells have broken readout column
- select fiducial region of 18 cells



Beam test analysis: Pulse heights

- better agreement of strip detector and 3D detector



Conclusions

- RD42 explores the use of diamond tracking detector in high luminosity experiments
- One of the first diamond pixel tracking detector is being installed in a working experiment
  - DBM in ATLAS
  - PLT in CMS (pilot run)
- 3D structures show promise in diamonds
  - Full charge collection at lower voltage
- The production of 3D electrodes needs to be further optimized
  - more efficient “hole” drilling
- The radiation hardness of 3D detectors needs to be studied

Additional slides

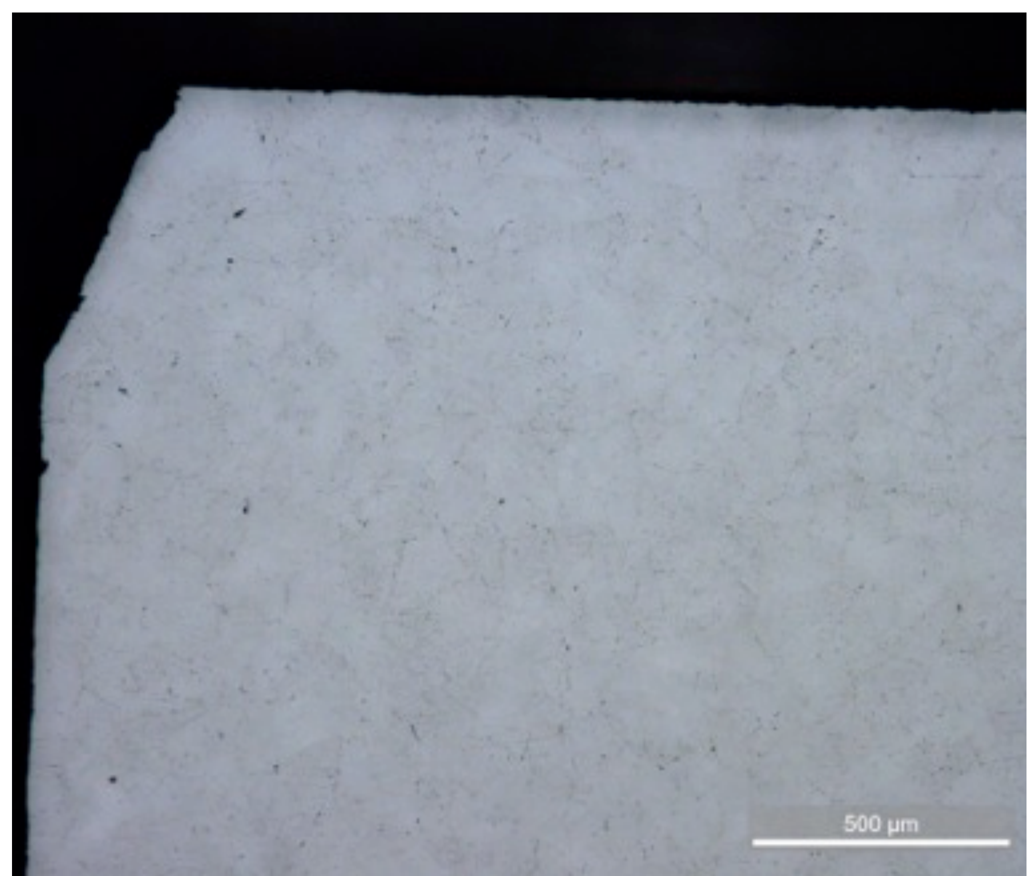
Fabrication

- As received diamond are cleaned with boiling acid(s).

Surface Treatment

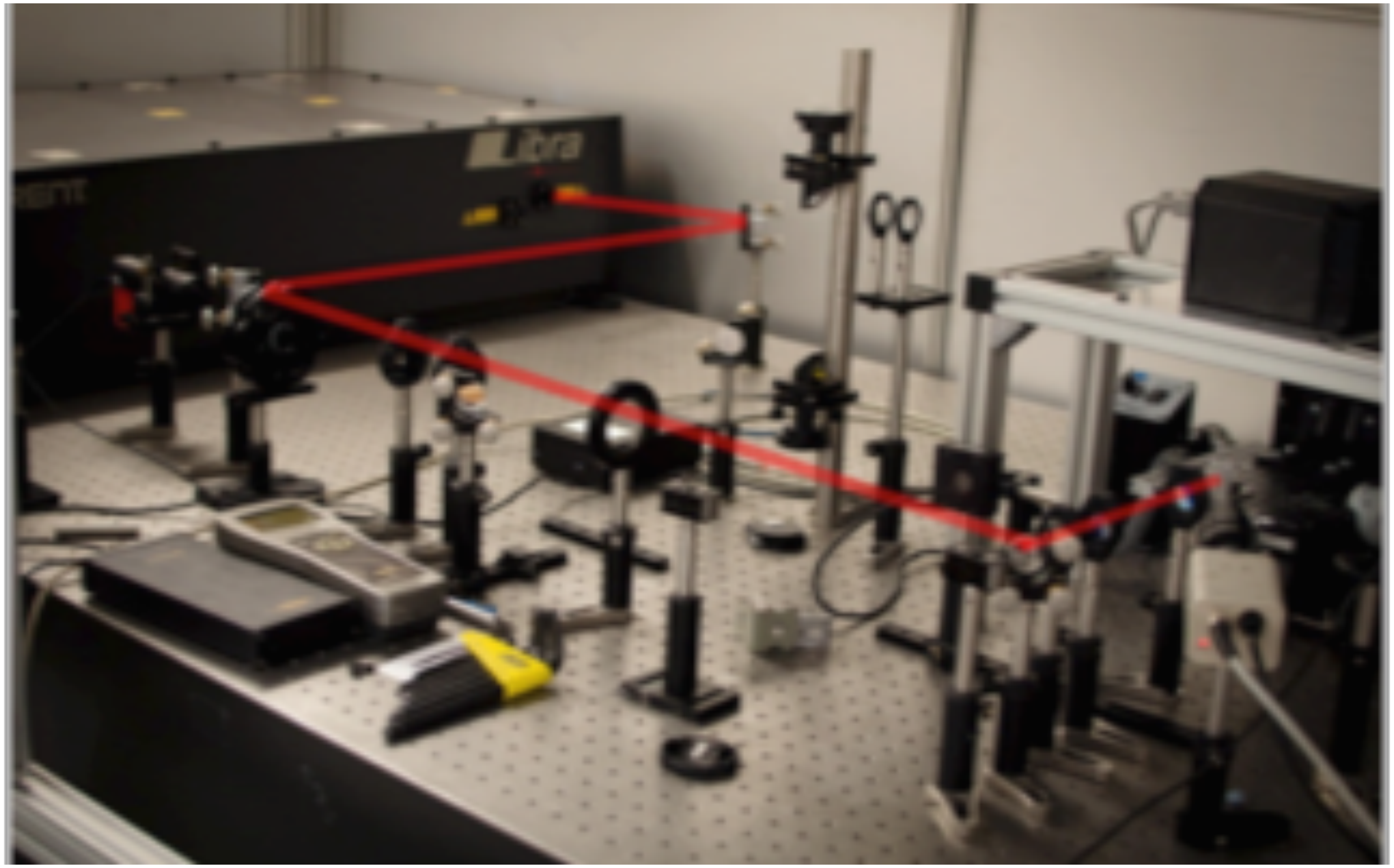
Column Fabrication

Metallization



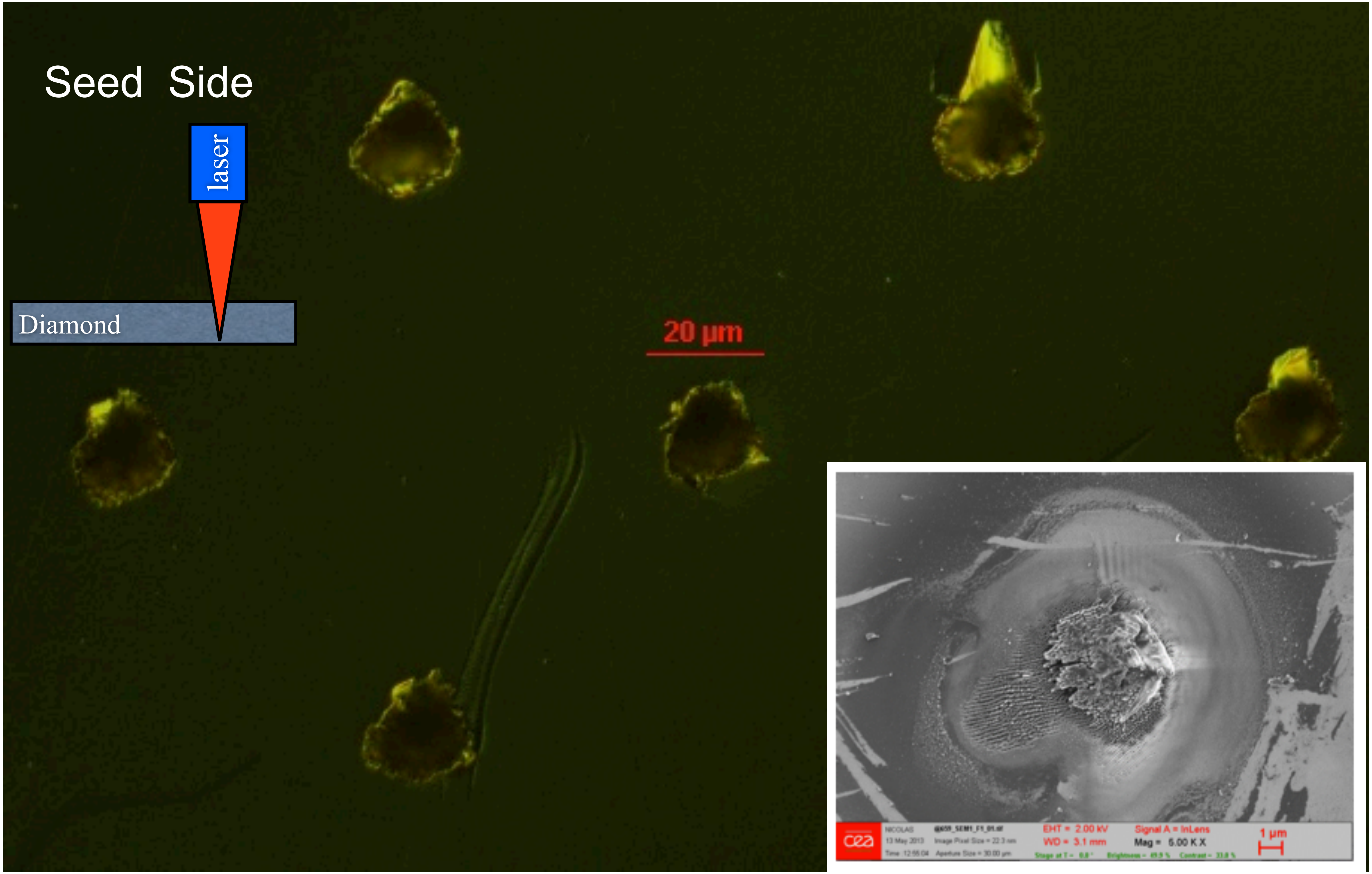
Fabrication – Column formation

- Femto second laser
  - Wavelength = 800 nm
  - Repetition rate = 1kHz
  - Pulse duration = 100 fs
  - Spot size = 6 μm
  - Pulse Energy:
    - E = 1 – 23 μJ/pulse
    - Φ = 1 – 30 J/cm2



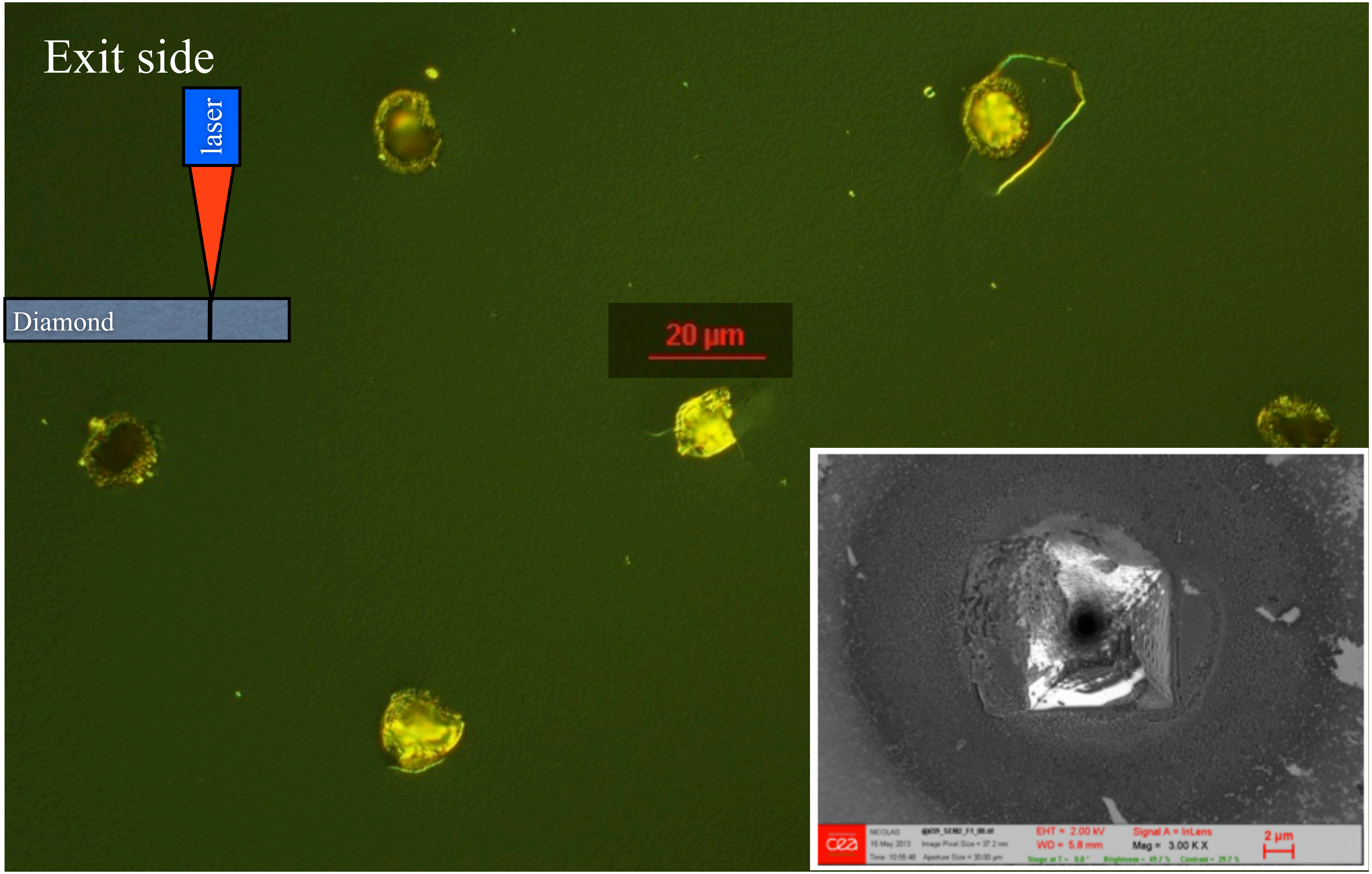
Column drilling

- extra material forms small bumps on the seed side



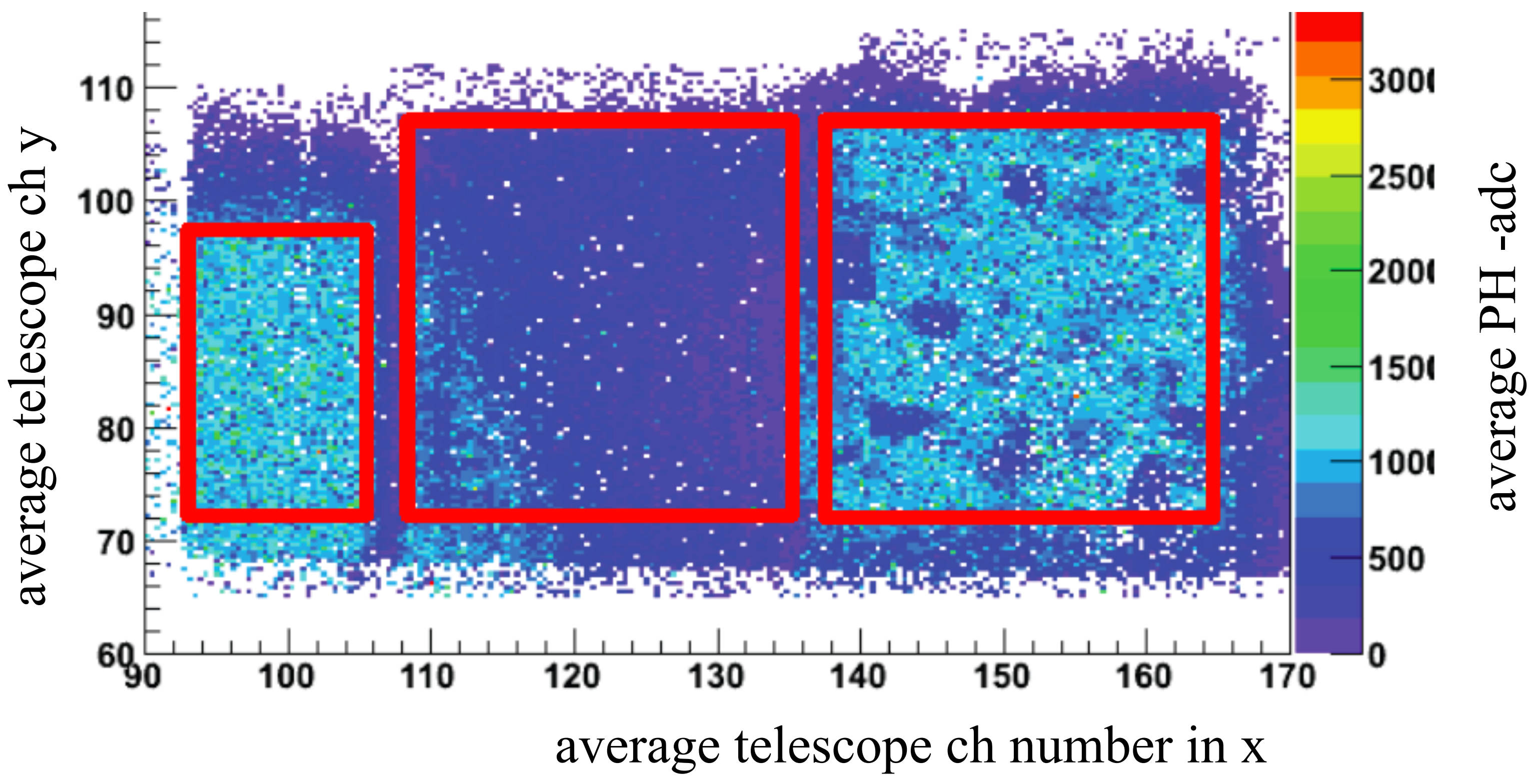
Column drilling

- On the exit side the "craters" are formed



Beam test analysis: Fiducial regions

- Fiducial regions for the three different patterns



First DBM modules