Diamond Sensors for Future HE Frontier Experiments

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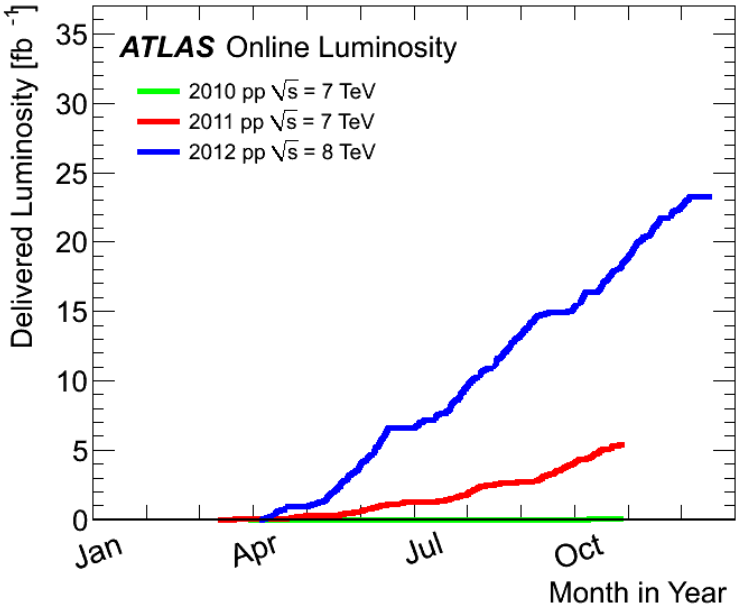
Outline of Talk

- The ATLAS Diamond Detectors – ongoing projects
- Metalization/Surface quality
- Sensor Qualification/Bump bonding
- Manufacturing/Scale-up
- Geometry
- Summary

The ATLAS Diamond Detectors - motivation

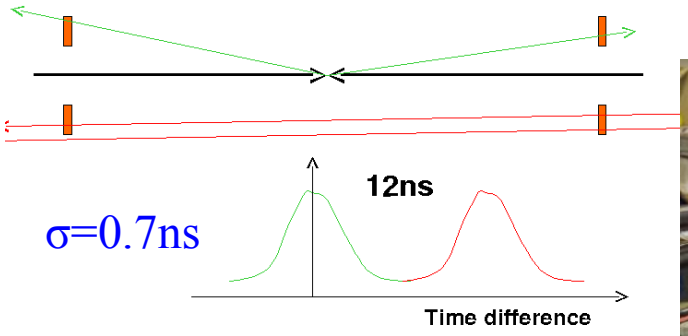
- Luminosity at the LHC has risen rapidly to ~7.5x10^{33}cm^{-2}s^{-1}



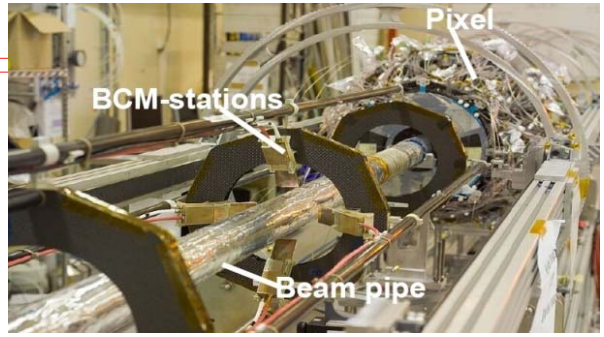
- Luminosity is a counting issue – requires good segmentation in space or time
- Problems occur when particle multiplicity reaches a point where all segments have high probability of having a hit in every bunch crossing

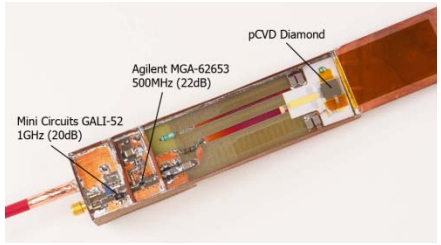
The ATLAS Diamond Detectors - lessons

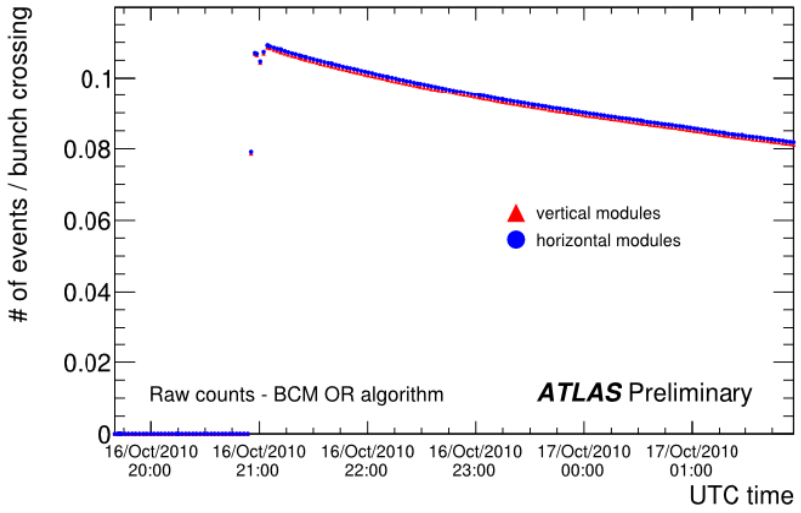
- Luminosity measurement with the ATLAS diamond BCM

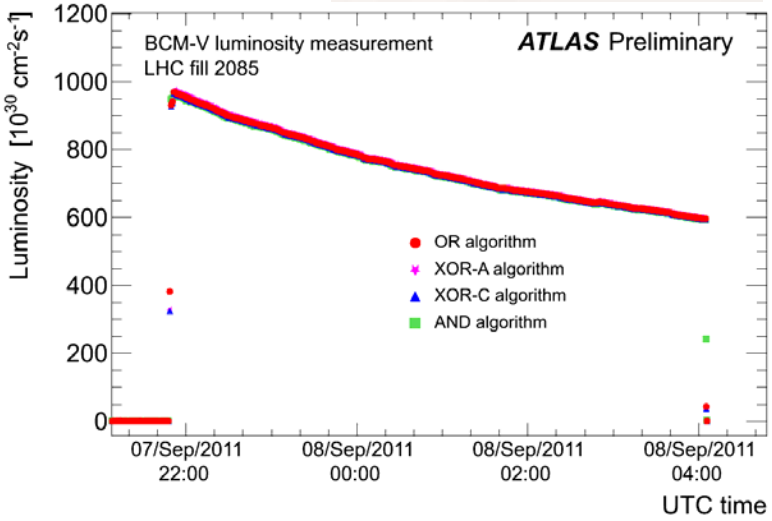


Single Particle Counting: single ch/detector
in-time - Luminosity
out-of-time Background





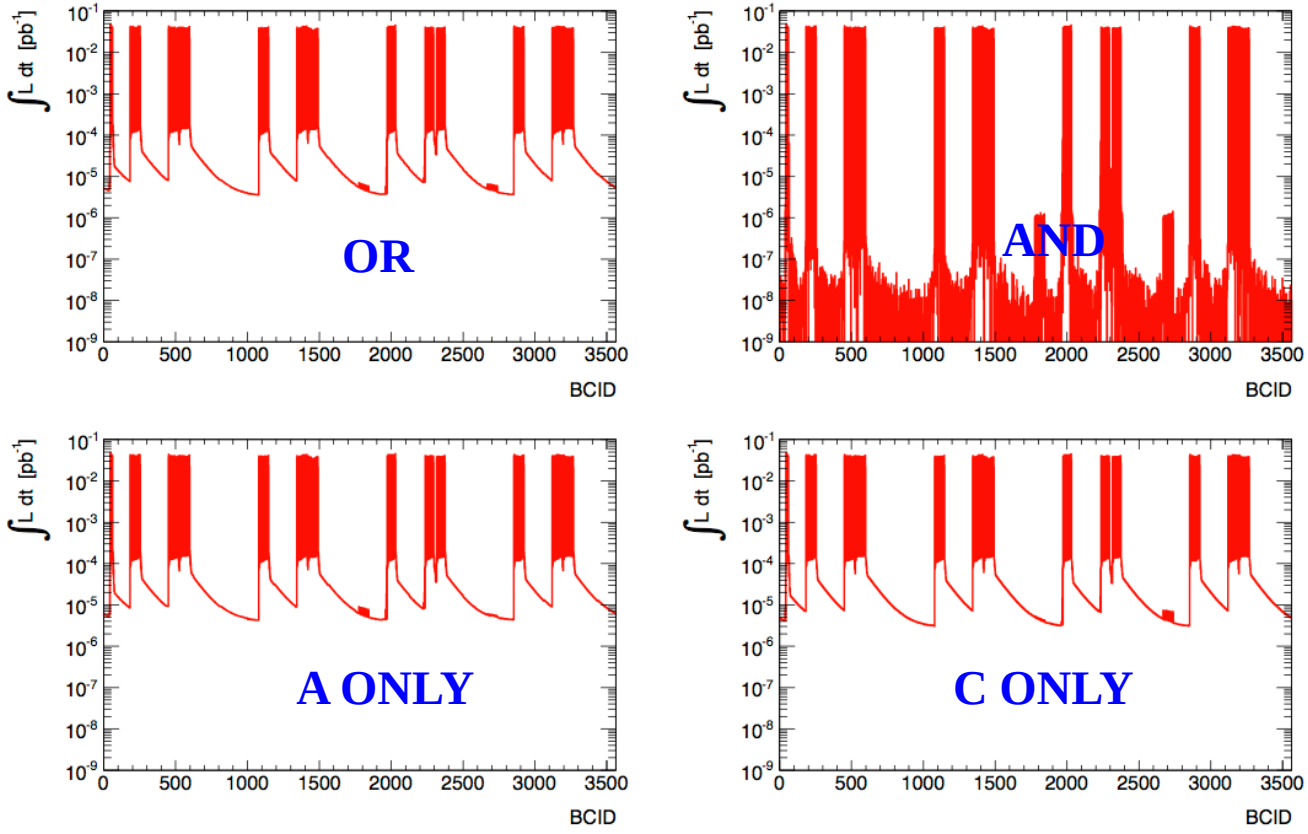




- Speed, robustness, stability, redundancy required for good luminosity

The ATLAS Diamond Detectors - lessons

- The BCM rate (speed) is BCID aware

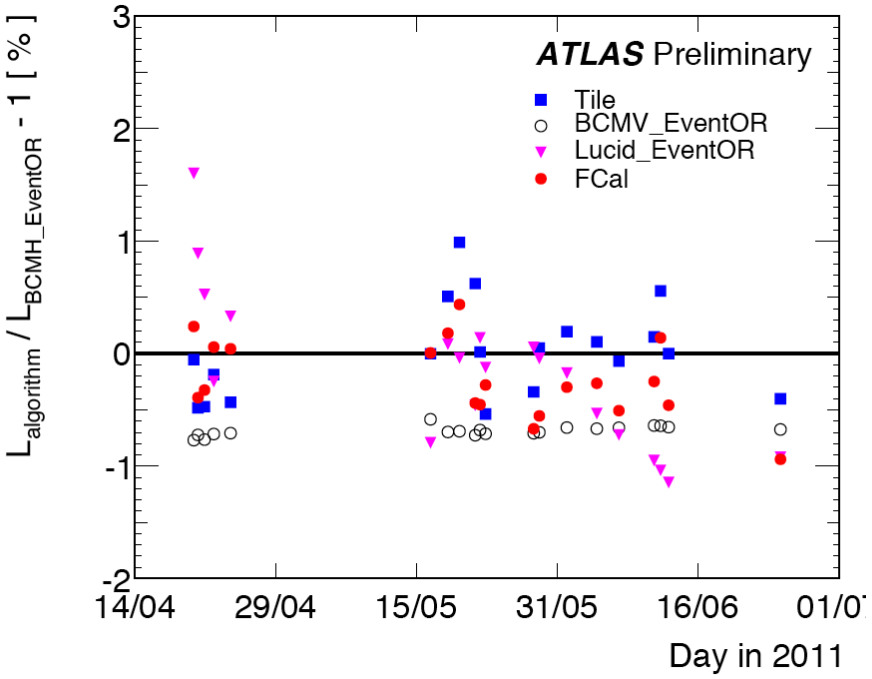


- To provide robust rate measurements
  suppress backgrounds by 10^{-3}-10^{-6}

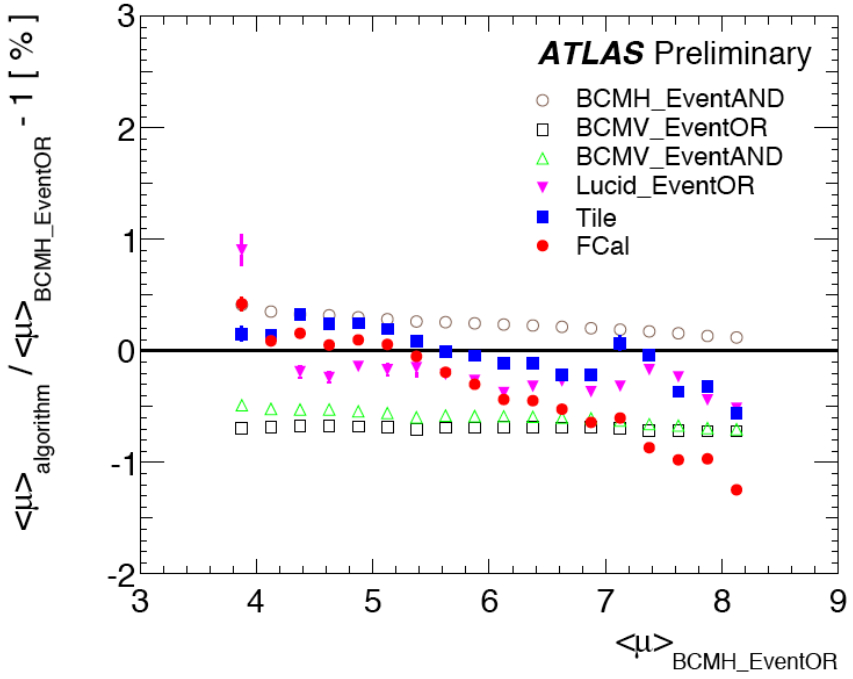
The ATLAS Diamond Detectors - lessons

- Stability of two independent measurements BCMH and BCMV:

Stable over months



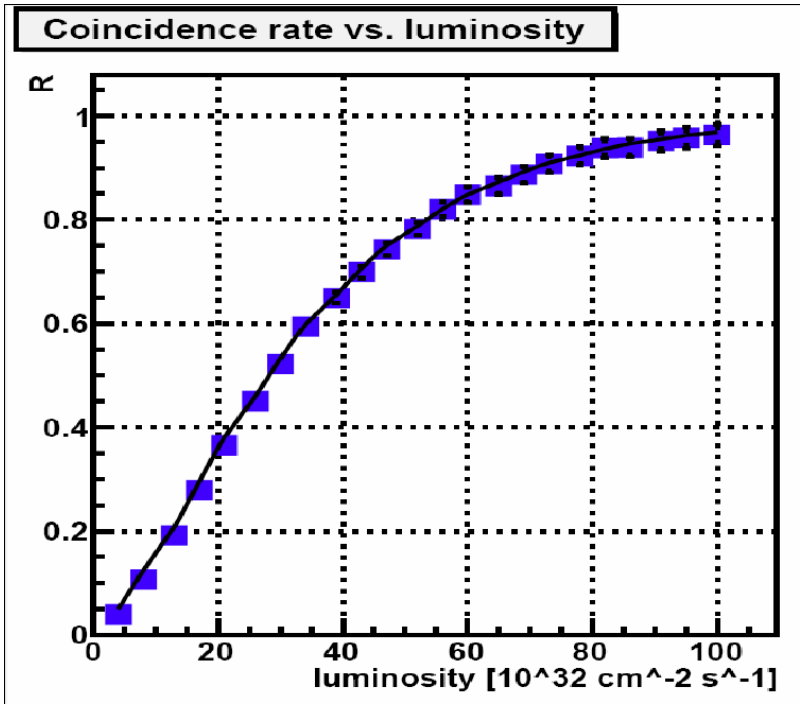
Stable against pile-up



- In 2011 data BCM achieved a 1.8% luminosity measurement!

The ATLAS Diamond Detectors - limits

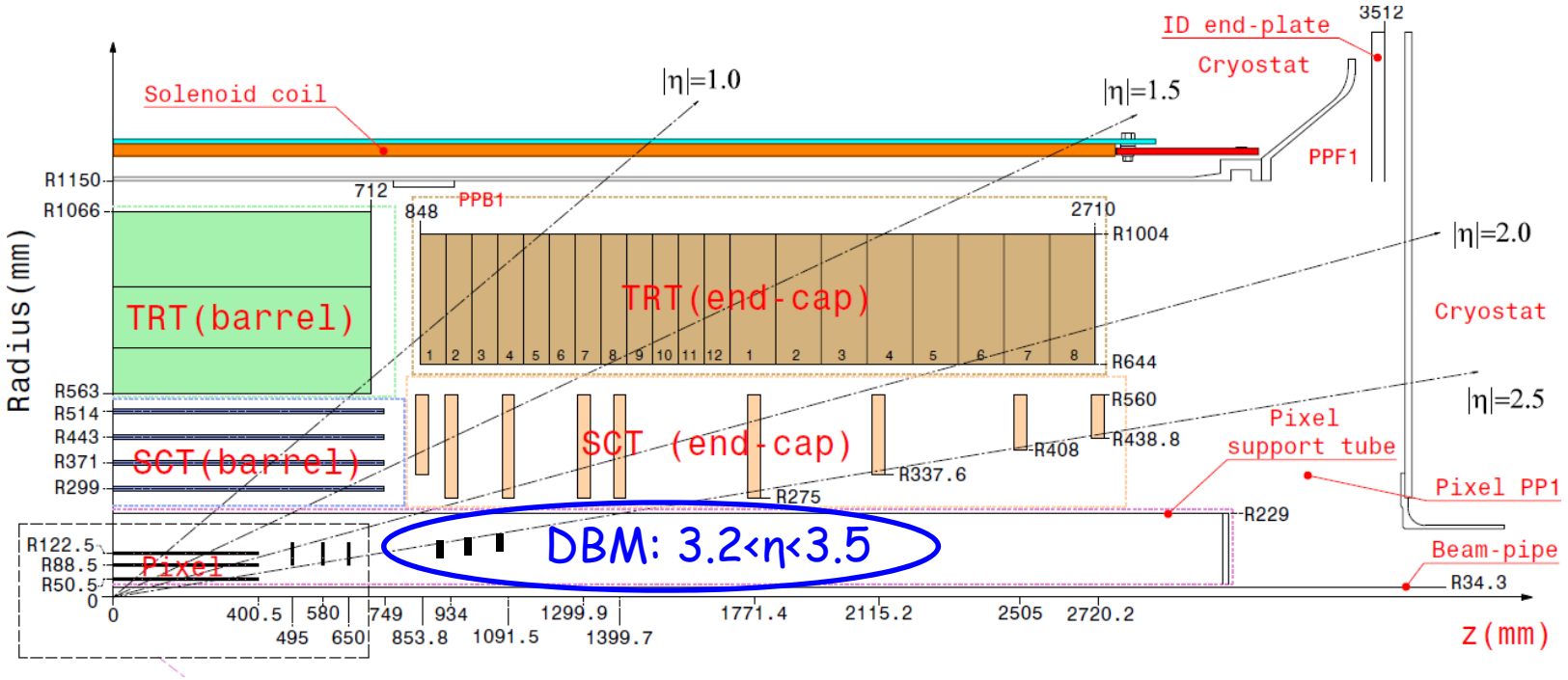
- But the BCM will begin to saturate at ~10^{34} $cm^{-2}s^{-1}$:



- More segmentation → pixels → Diamond Beam Monitor (DBM)

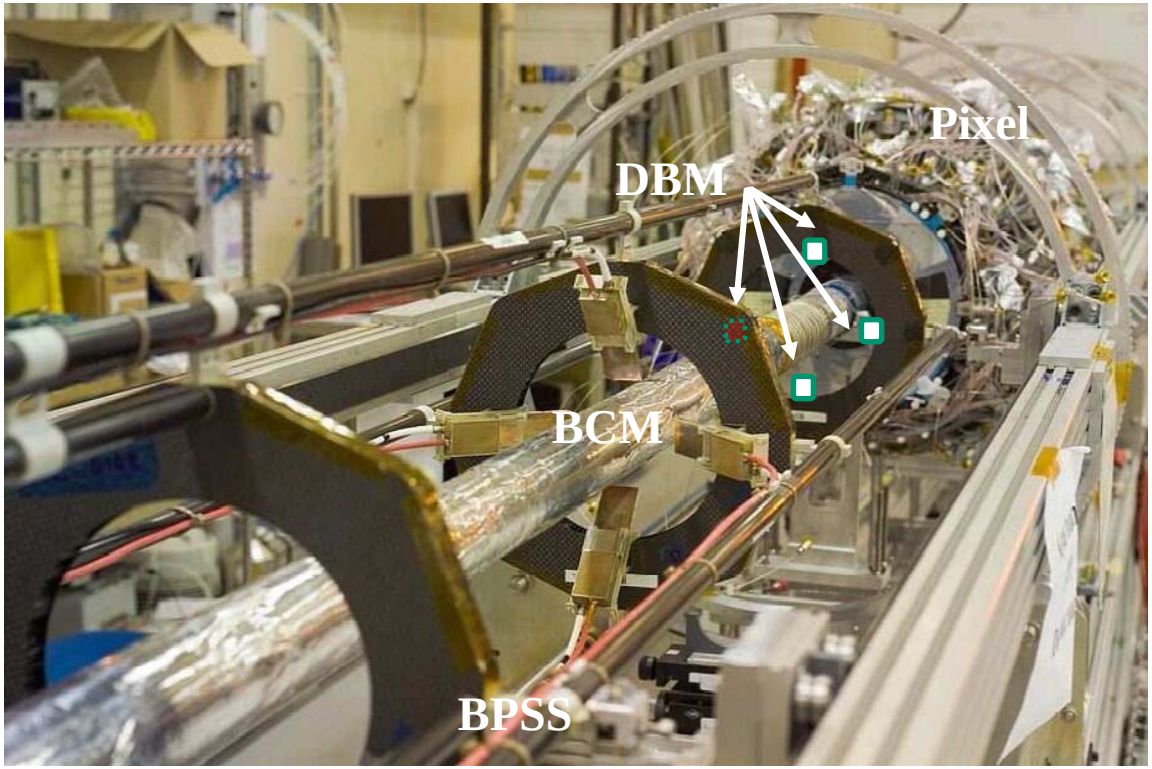
The ATLAS DBM Concept

- Build on success of BCM – pixelate the sensors
  - Use IBL diamond pixel demonstrator module
  - Install during new Service Quarter Panel (nSQP) replacement
  - Four 3-plane stations on each side of the IR
  - Collaboration: Bonn,CERN,Göttingen,Ljubljana,UNM,OSU,Toronto



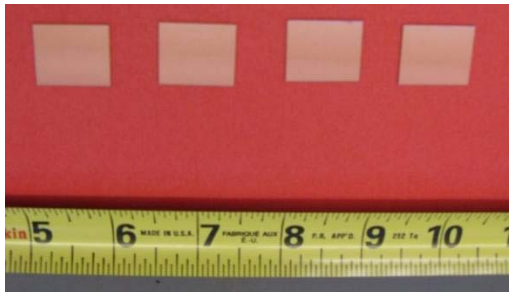
The ATLAS DBM Concept

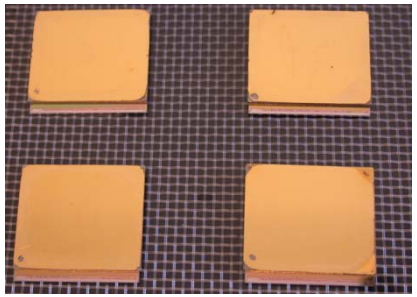
- 24 diamond pixel modules arranged in 8 telescopes to provide
  - Bunch by bunch luminosity monitoring (<1% per BC per LB)
  - Bunch by bunch beam spot monitoring (unbiased sample, ~ 1cm)
- Installation in ~~(July)~~ September 2013

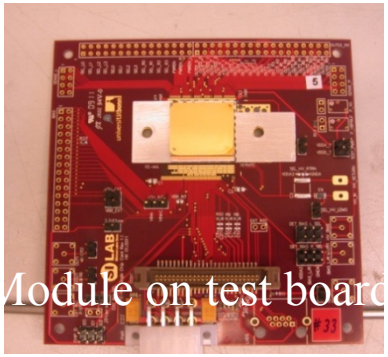


Lessons Learned: Module Production

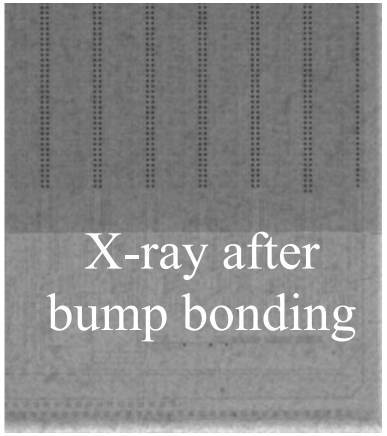
- Sensors
  - 38 old sensors recycled from E6 (UK) from IBL work
  - 10 new sensors in hand from E6 (UK)
  - 17 sensors in hand from II-VI (US)
- Quality Control
  - 6/38 old sensors+18/27 new sensors passed full QC(V,I,ccd)
  - 12/38 old sensors+21/27 new sensors passed reduced QC
- Bump bonding
  - 4 prototype modules bump-bonded by IZM
  - 28 sensors bump-bonded by IZM







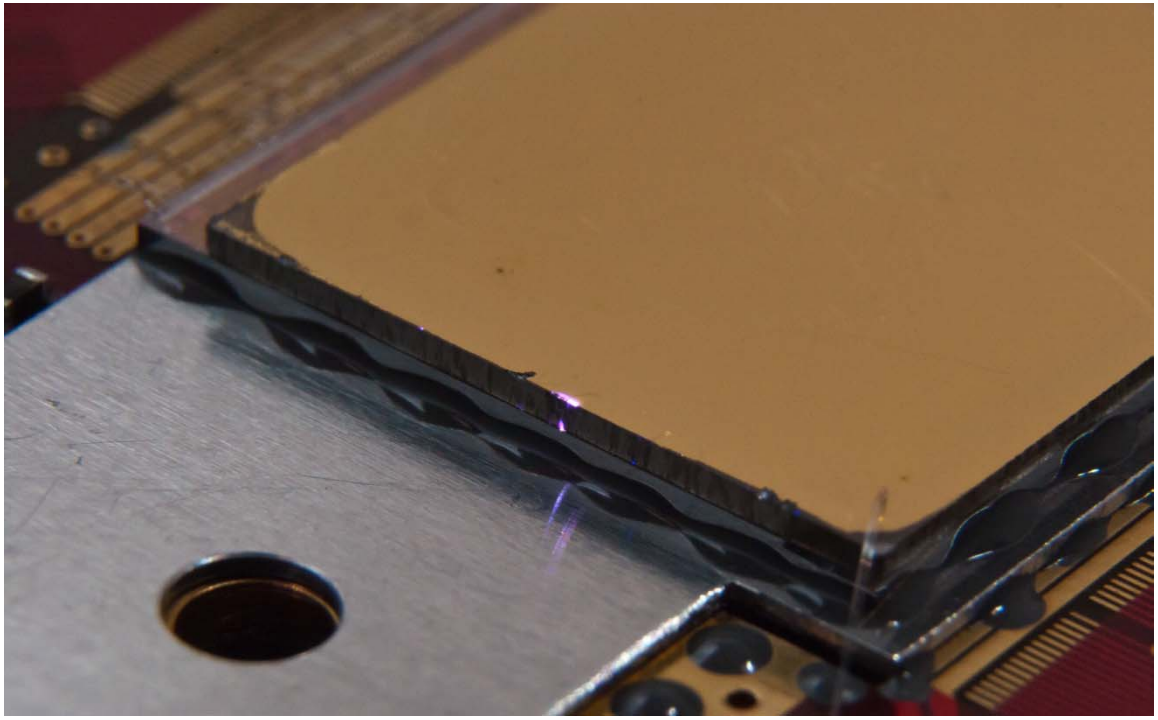
Module on test board



X-ray after bump bonding

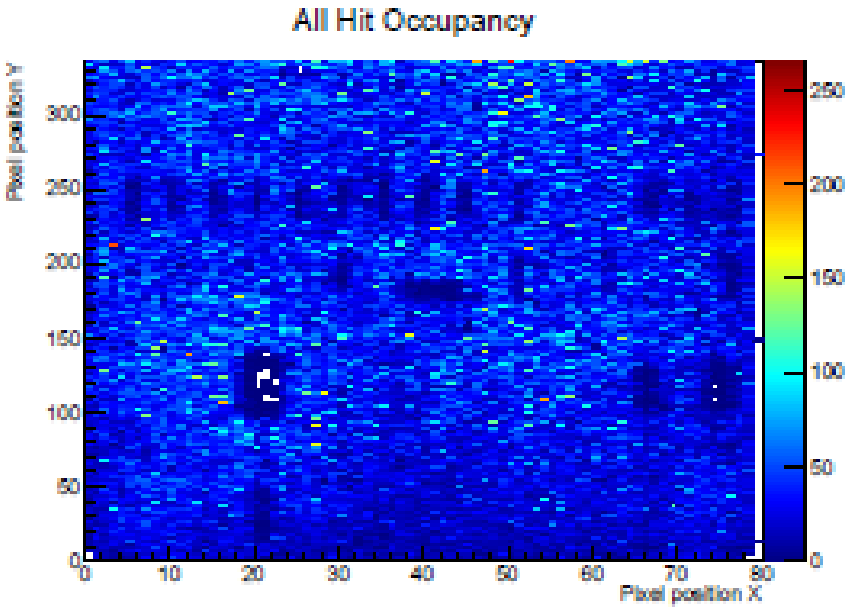
Lessons Learned: Module Production

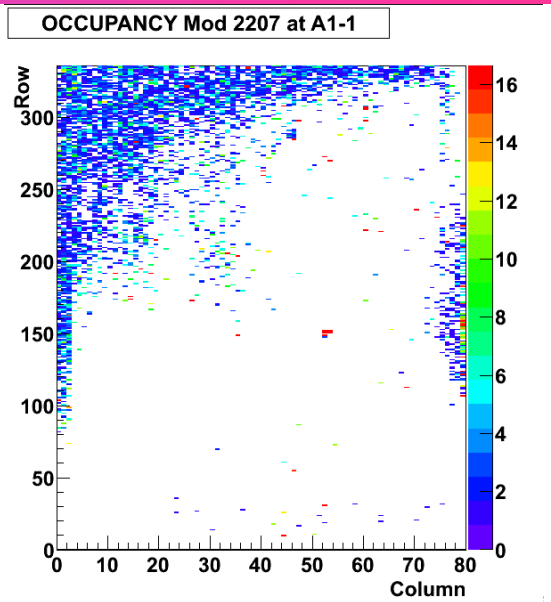
- HV Problems with first modules
  - Backside metalization goes to the edge of diamond and breaks down
  - Fixed by changing back metalization procedure – no longer performed by IZM

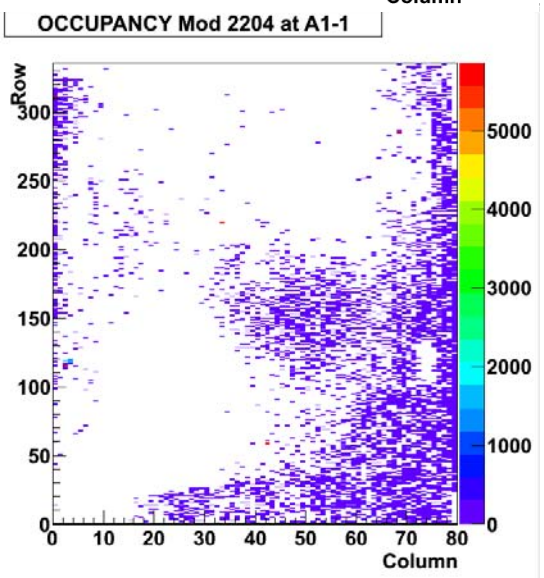


Lessons Learned: Module Production

- Bump Bonding Problems with modules
  - Some modules are fully connected - most modules are not
  - Bump-bonding turn out to be a large problem
  - Still working on this problem







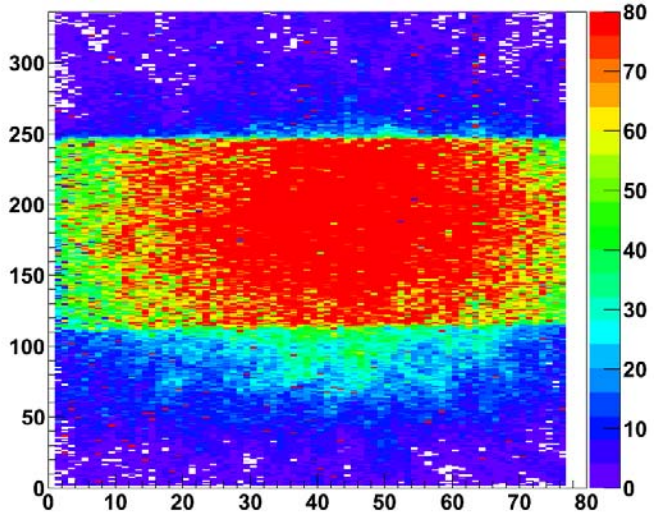
Lessons Learned: Testbeam

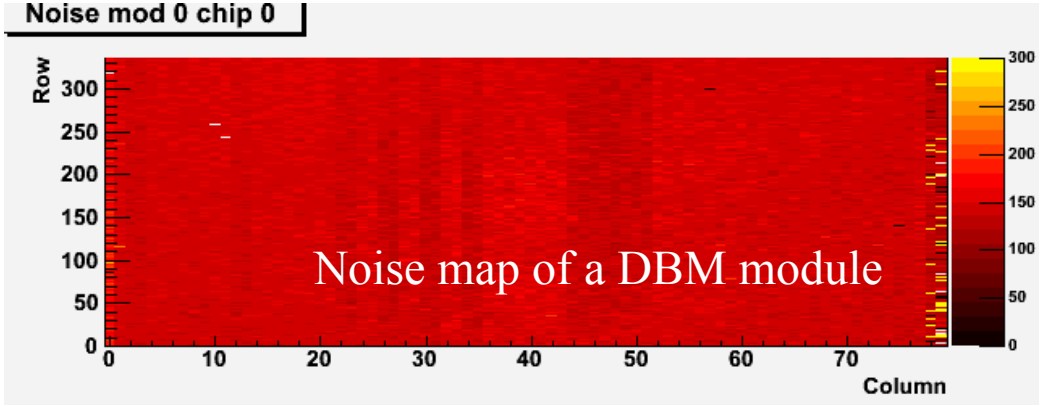
Many TestBeam Campaigns:

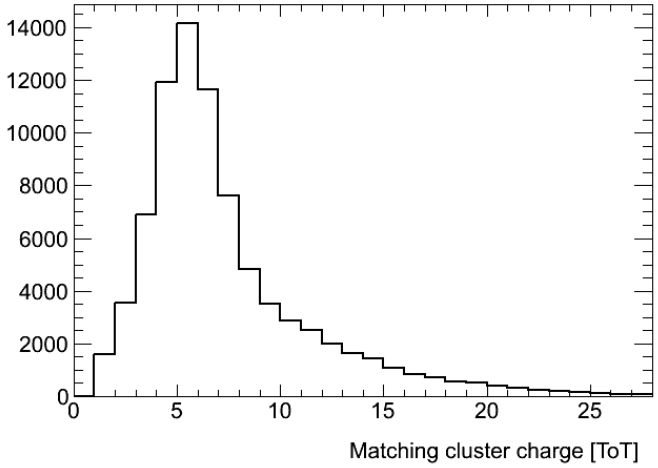
- Oct 11, Mar 12, Jun 12, …
- 21mmx 18mm pCVD diamond w/FE-I4A
- 50x250μm^2 pixel cell/336x80=26880ch

Results

- Can not always get calibration/tuning for low threshold
- Noise map uniform, efficiency high







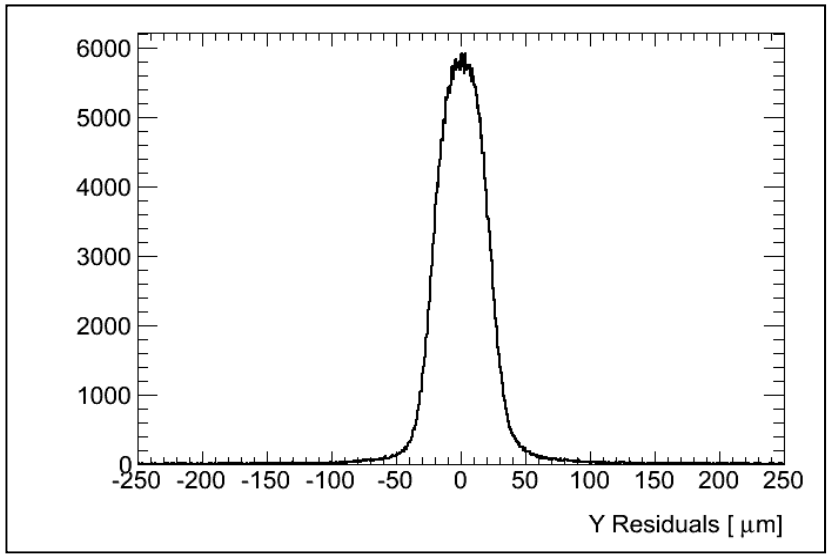
Lessons Learned: Testbeam

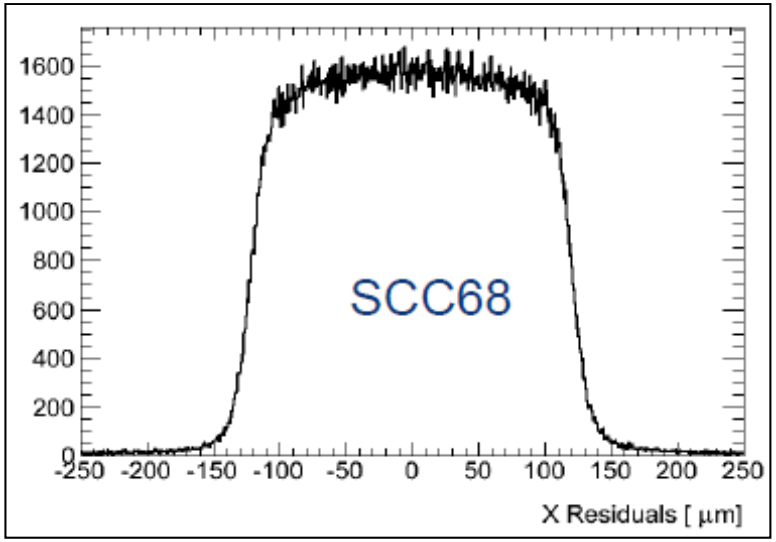
Prototype Modules Tested:

- 21mmx 18mm pCVD diamond w/FE-I4A
- 336 x 80 = 26880 channels
- 50 x 250 μm^2 pixel cell

Results

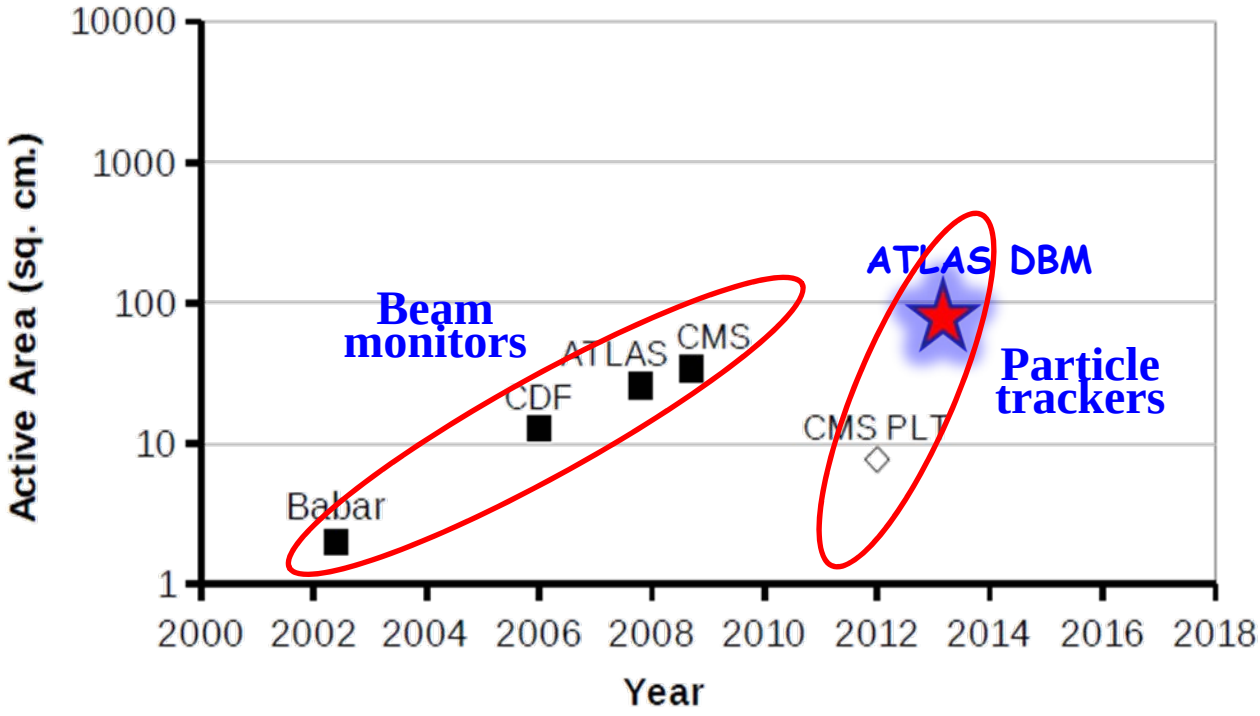
- Spatial resolution looks digital





Diamond Production

Future detectors will require 10x – 100x more devices



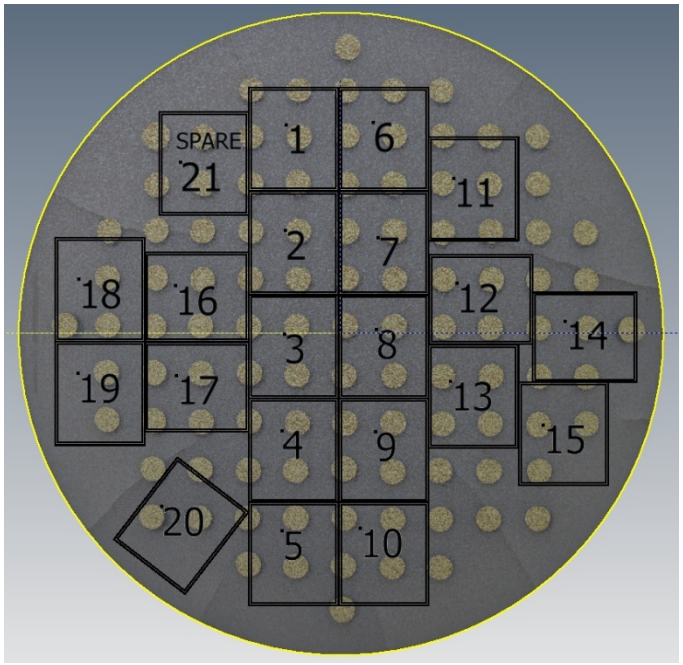
Production and Scale-up demand additional manufacturers:

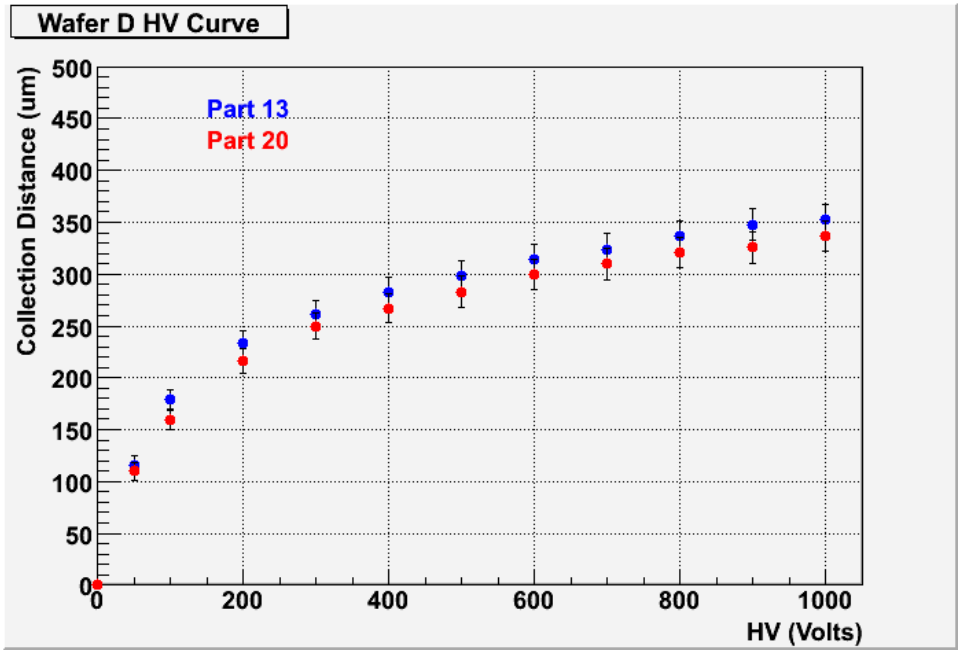
- For ATLAS DBM it was Element6 & II-VI
- Future: Micron Semiconductor, 2 US companies interested

Lessons Learned: Production

It can take a very long time to qualify additional manufacturers:

- II-VI has now produced large, superb wafers

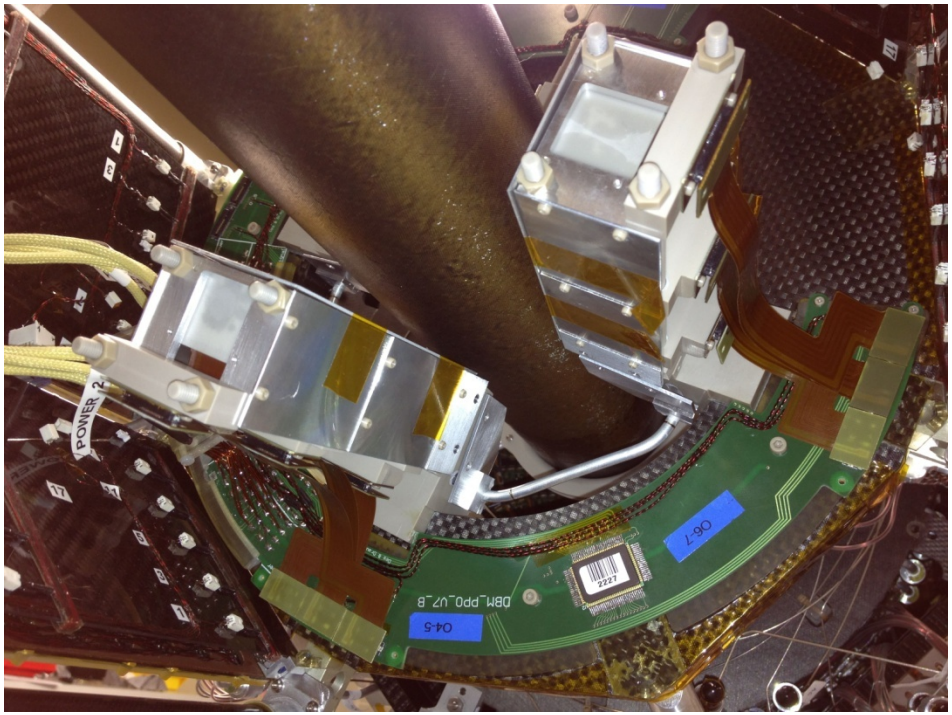




Lessons Learned: Installation

Installation on-going:

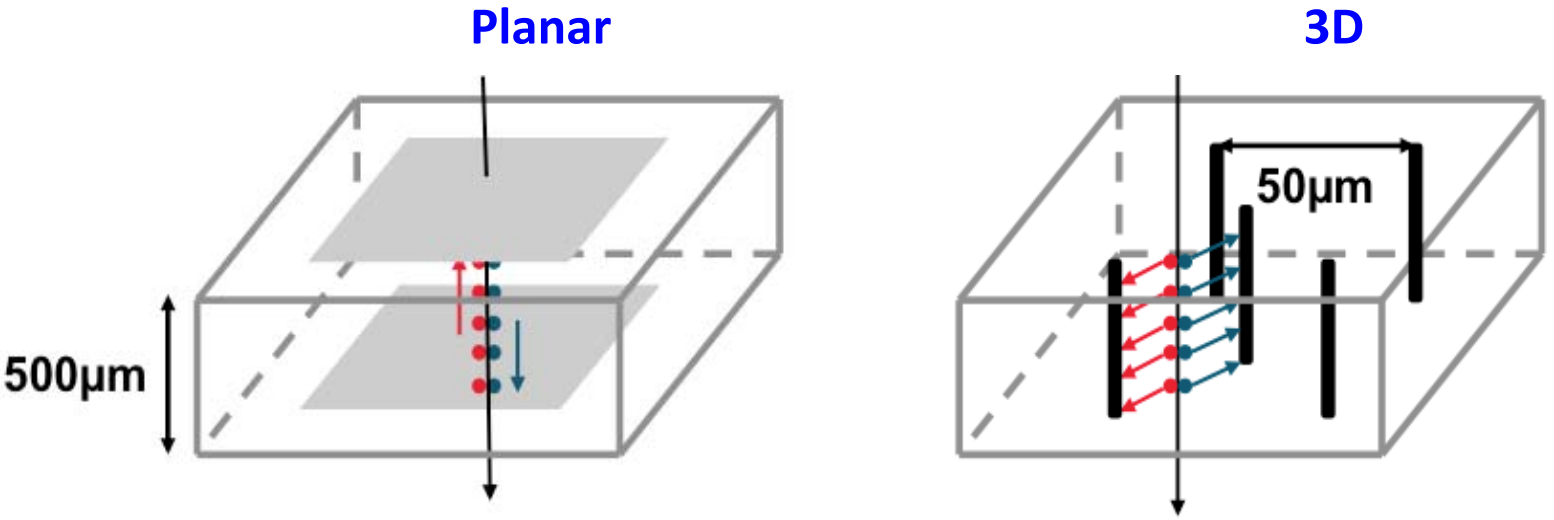
- Mechanics installed for first 4 telescopes
- First diamond telescope constructed
- Last 14 modules to be bump bonded at IZM next week



New Geometry: 3D Diamond

After severe radiation damage all detectors are trap limited

- Mean free paths < 75μm
- Would like to keep drift distances smaller than mfp

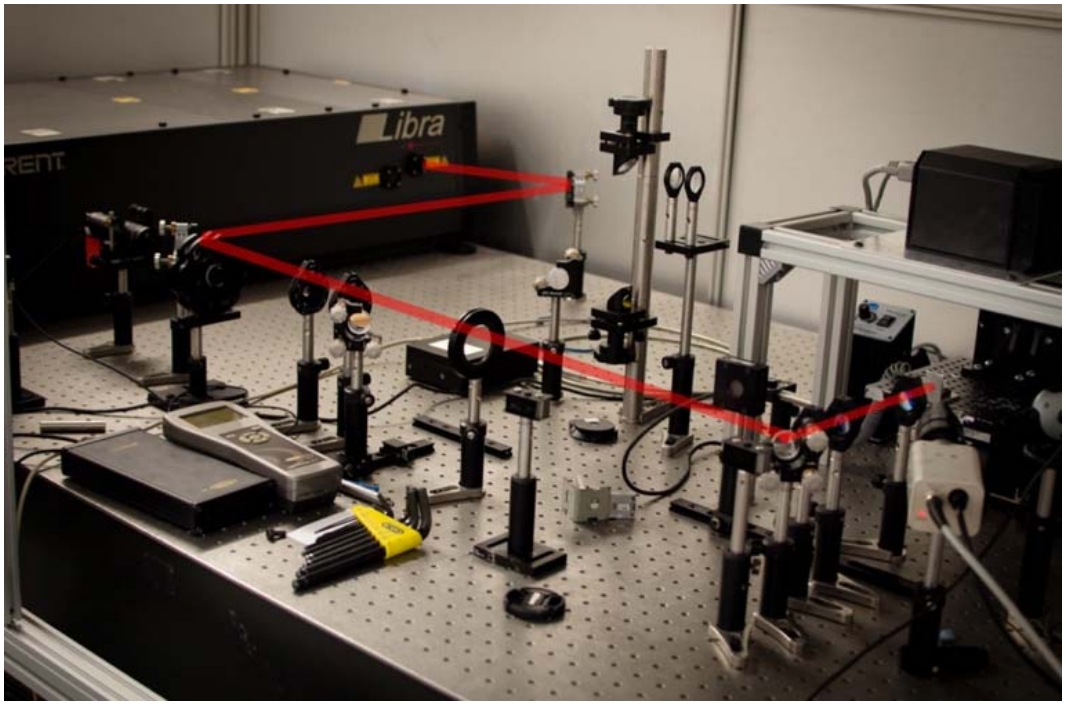


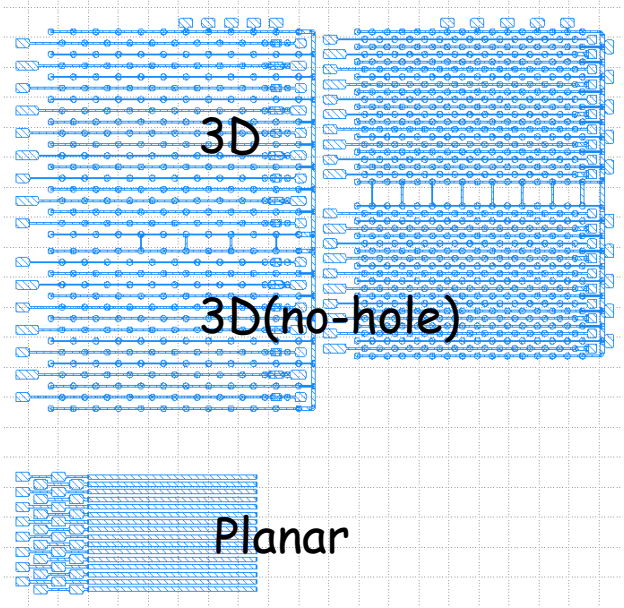
Can one make conducting hole structures in diamond?

New Directions: 3D Diamond

Collaboration of: ETH-Z, Manchester, Ohio State, Saclay, CERN in RD42

- Holes drilled with 800nm femto-second laser
- Operate planar (500V), 3D(no-holes) (25V), 3D (25V)
- Simultaneous comparison on same diamond
- Analysis/simulation first results

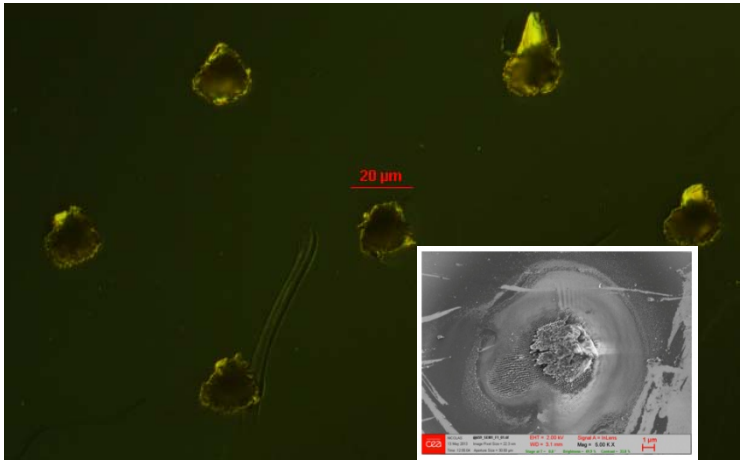




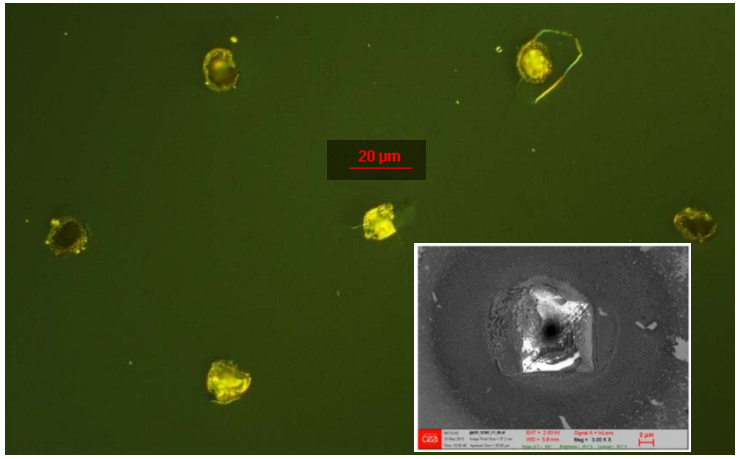
New Directions: 3D Diamond

Conducting Columns – first look at efficiency

Seed Side

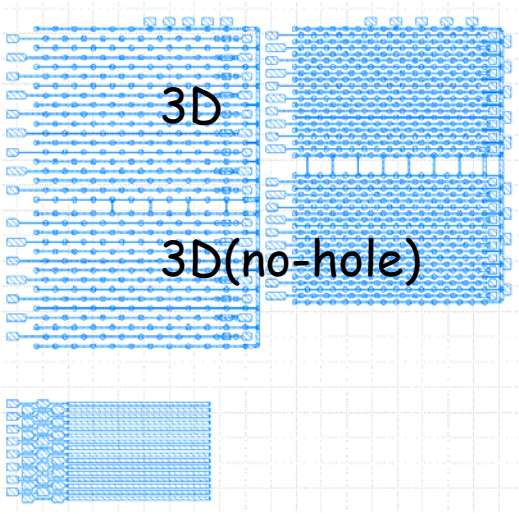


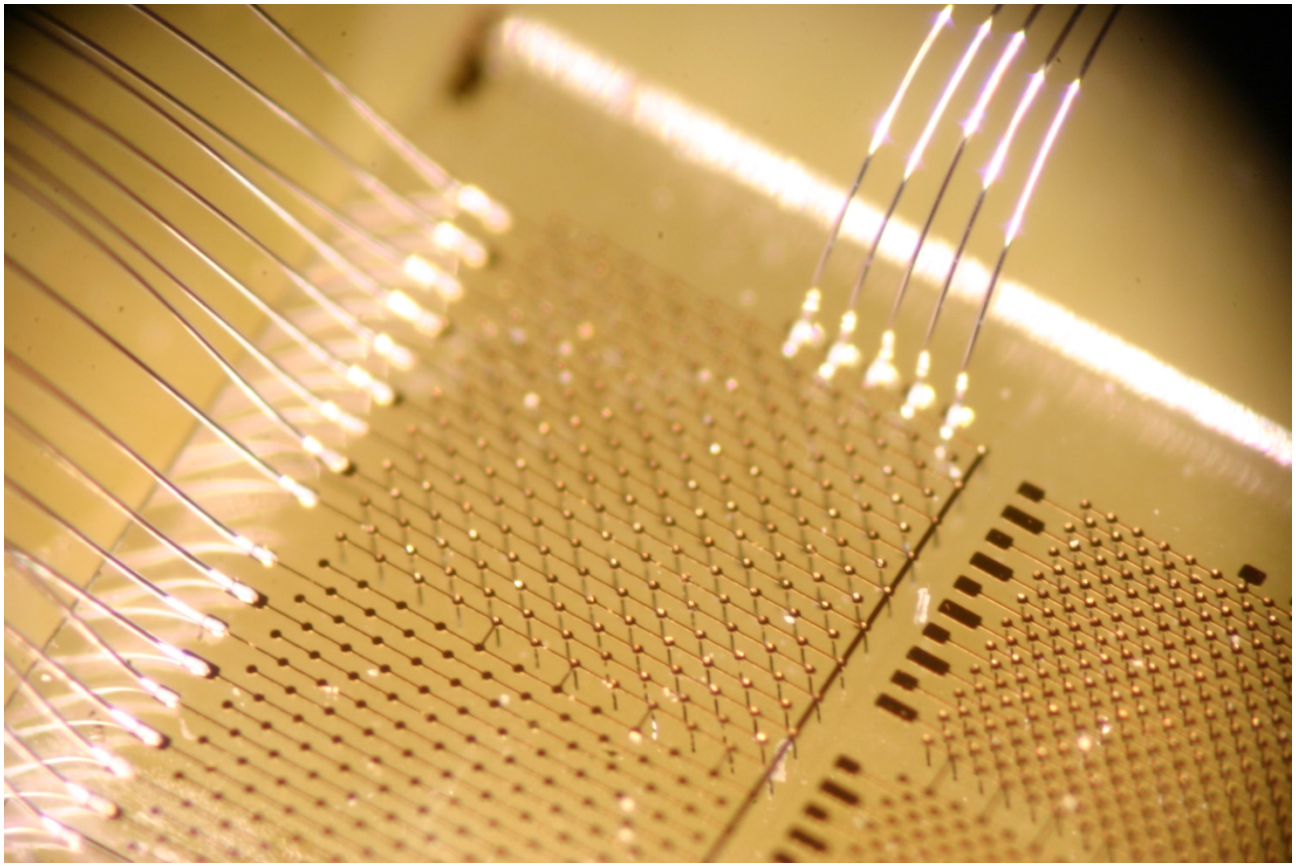
Exit Side



	Low Power	High Power
Low Speed	92.2 ± 1.4 %	78.7 ± 2.1%
High Speed	93.3 ± 1.3 %	87.6 ± 1.7 %

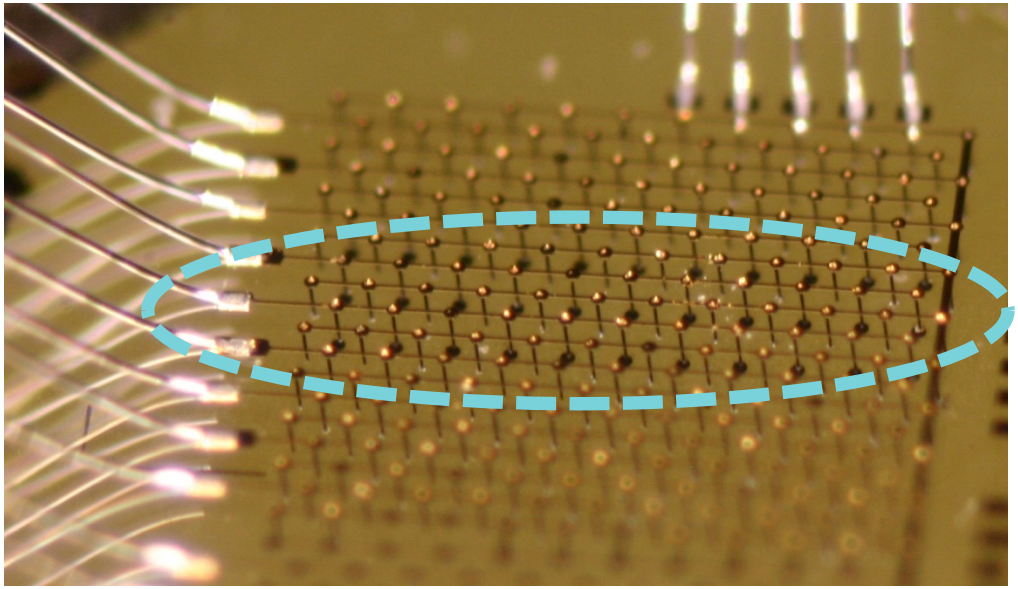
New Directions: 3D Diamond

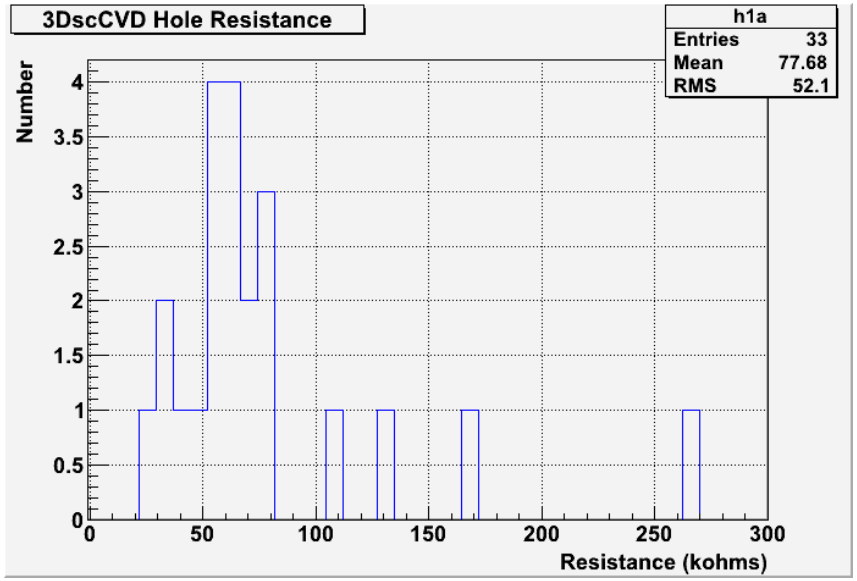




New Directions: 3D Diamond

Column Resistance





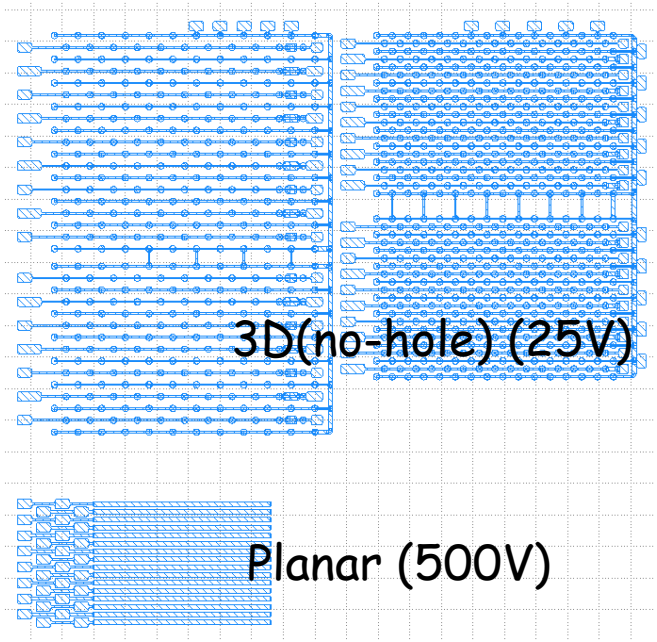
Columns conduct!

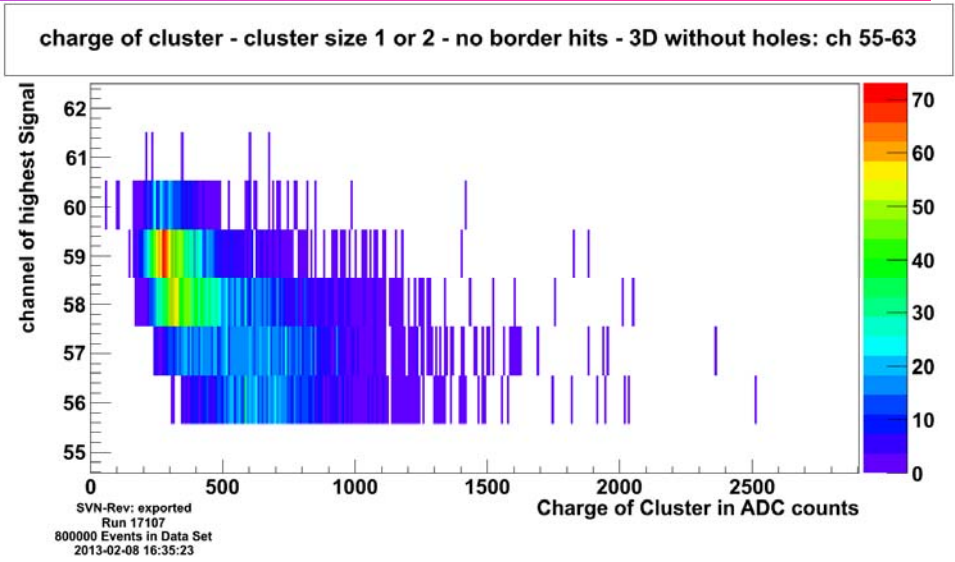
Resistivity ~1Ω-cm (somewhere between DLC and graphite)

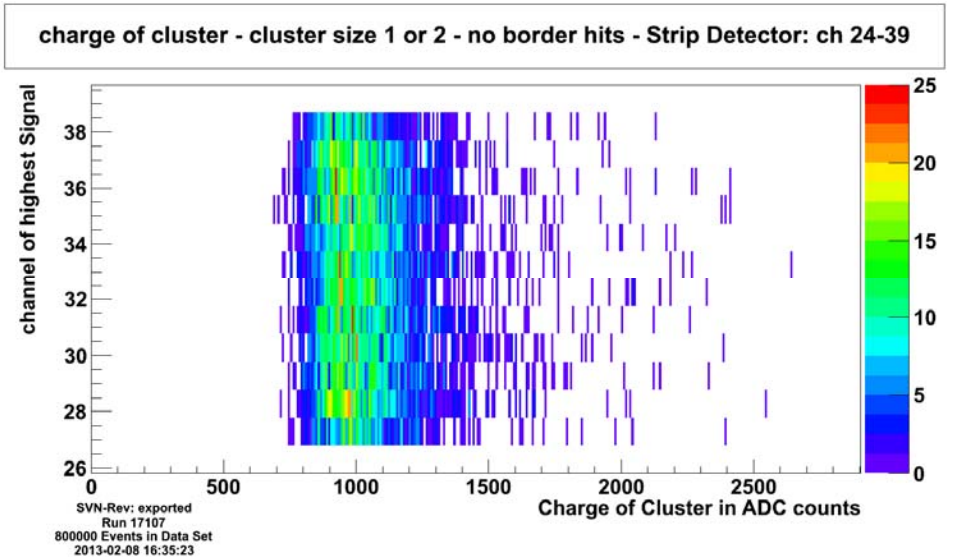
New Directions: 3D Diamond

Configure 3D cells as strip detector

- use VA2.2 electronics, test in beam at CERN
- Comparison of 3D(no-hole) w/Planar







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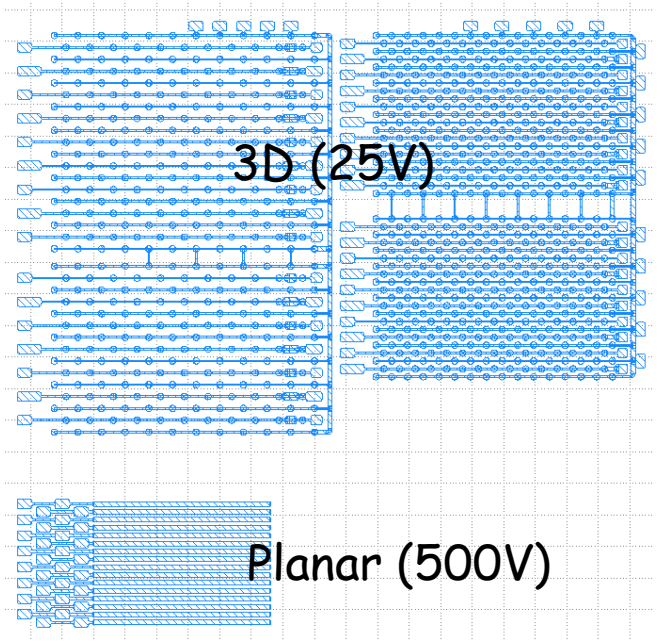
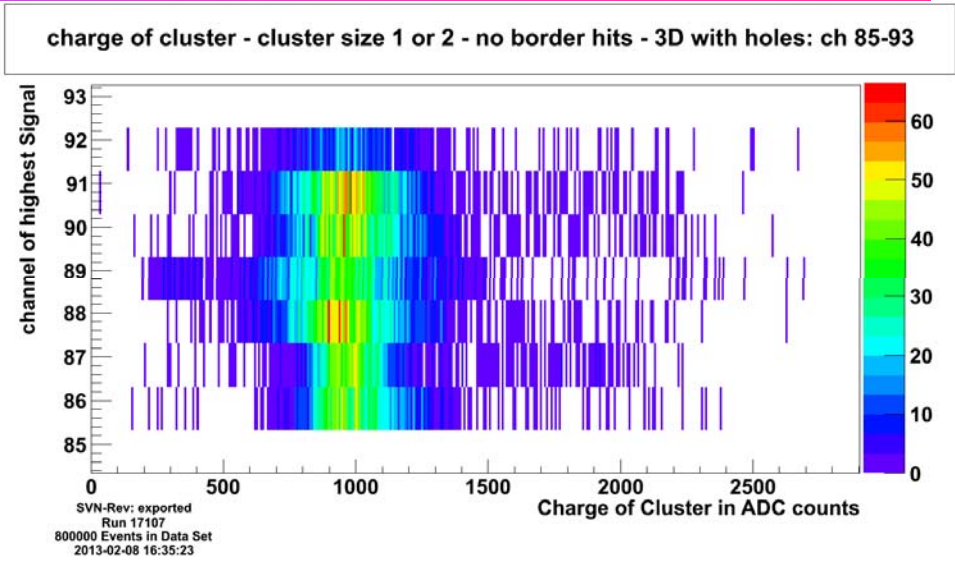
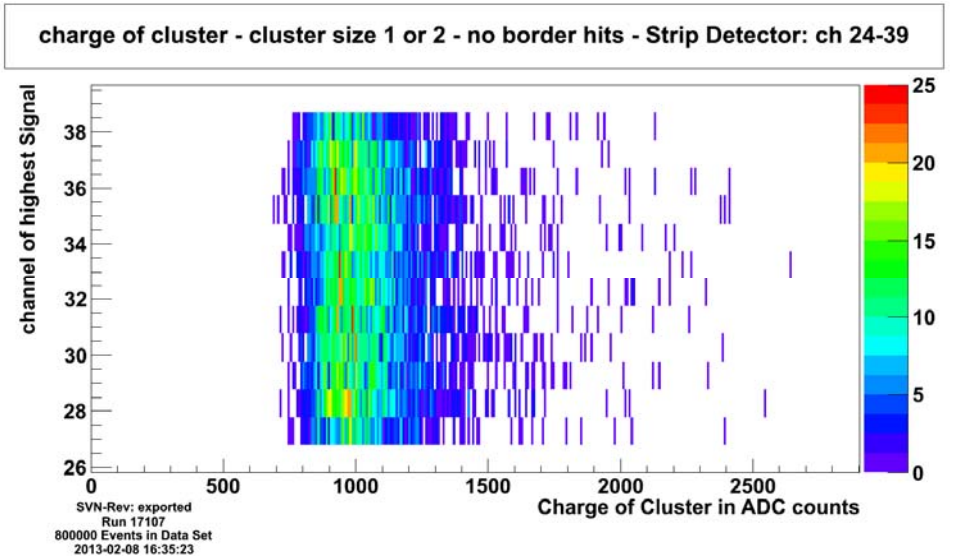
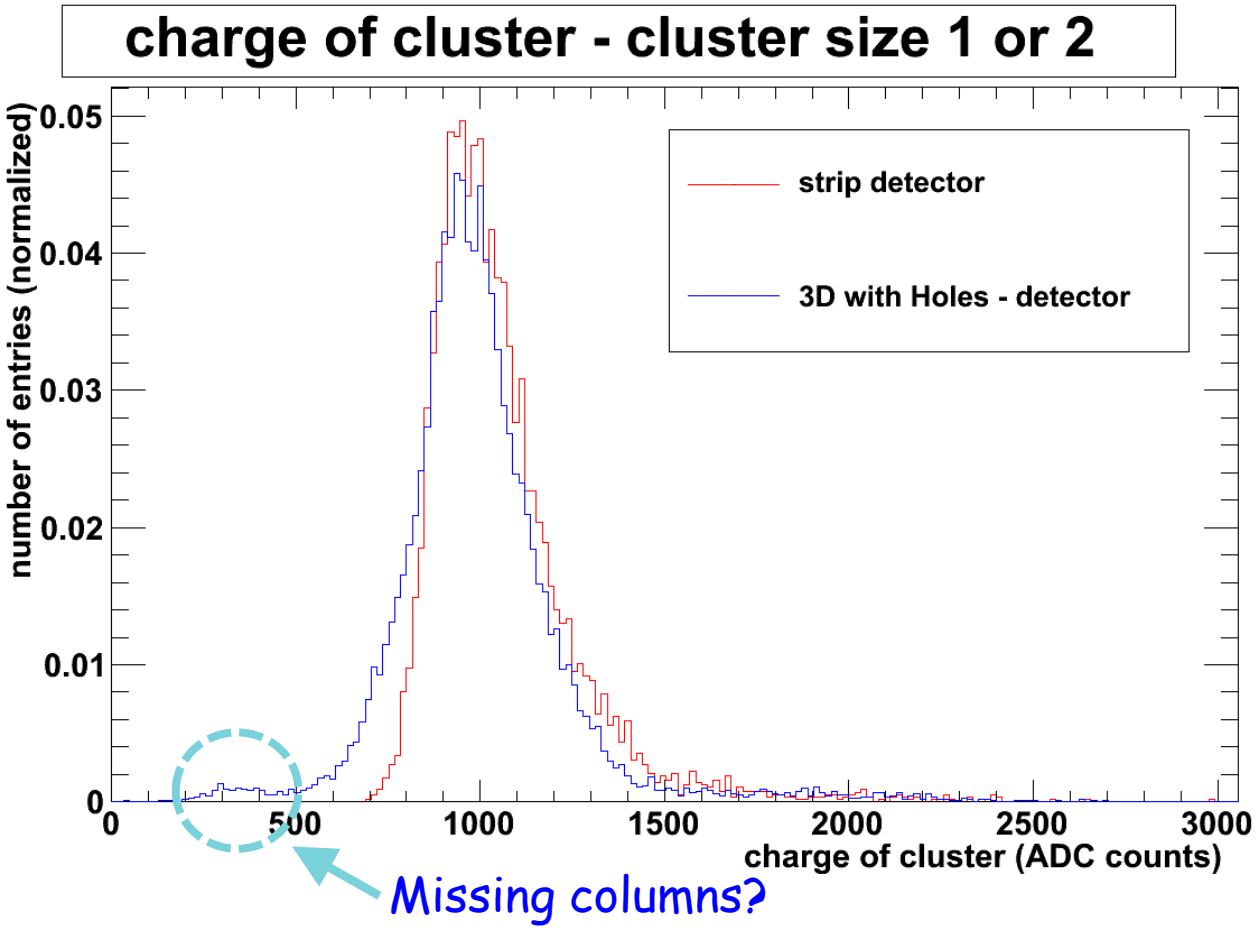






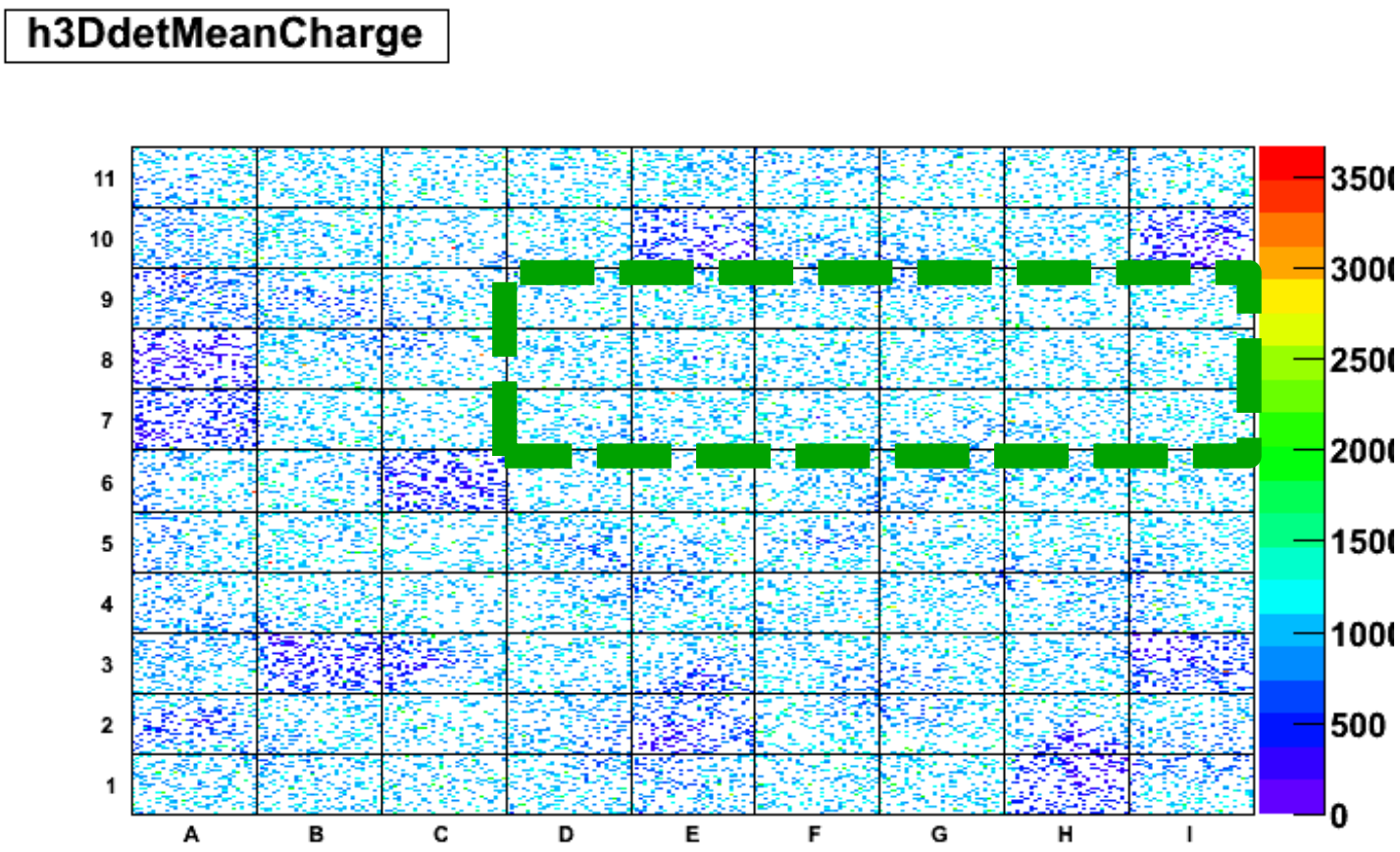
New Directions: 3D Diamond

Comparison of Planar(500V) and 3D w/holes(25V) – all cells



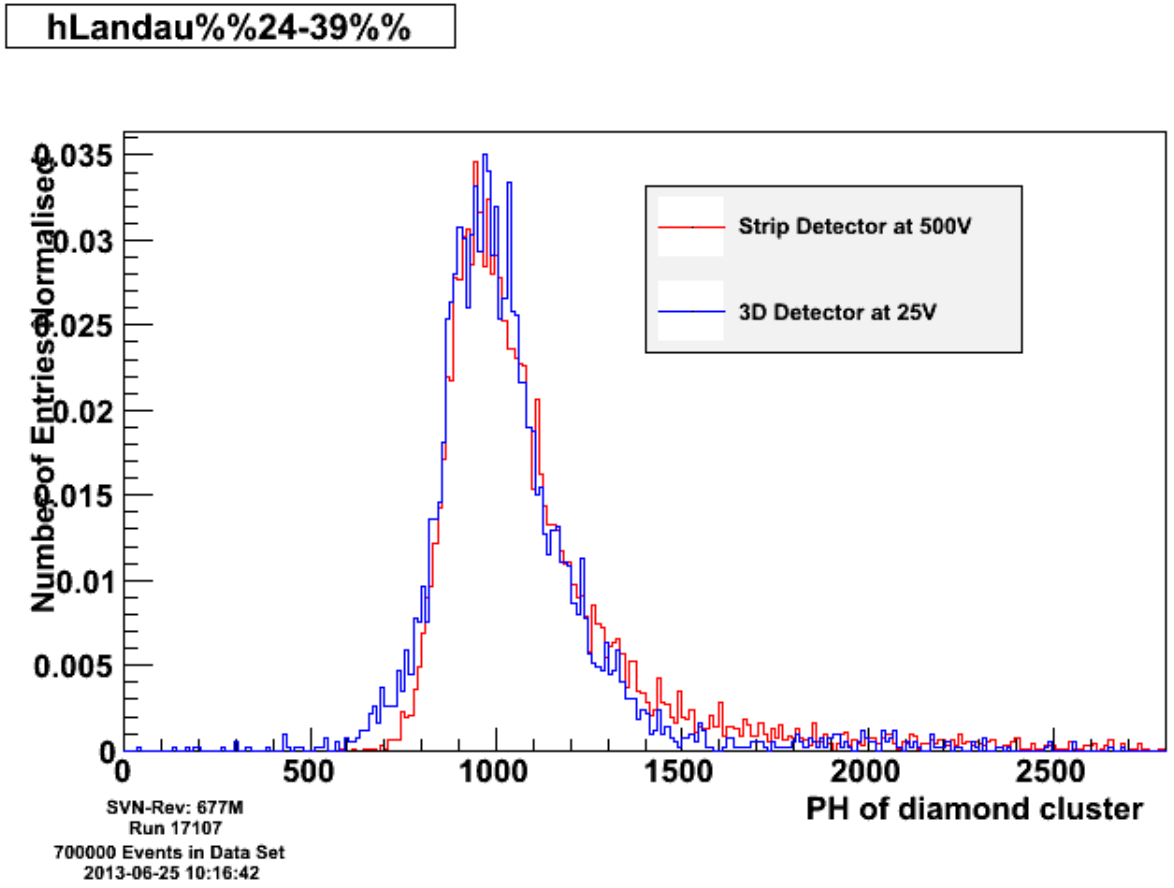
New Directions: 3D Diamond

3D Charge in Fiducial Region



New Directions: 3D Diamond

Comparison of Planar(500V) and 3D w/holes(25V) in Fiducial Region



Summary

- Construction of the largest diamond pixel tracker underway
- Many design issues were brought to light:
  speed, robustness, stability, segmentation, redundancy
- Many issues needed attention:
  metalization, electronics, sensor qualification, suppliers, bump bonding
- Some beliefs were modified or need more effort:
  recycling/re-use
- New geometry had initial successes:
  3D structures in diamond work