Challenges for Diamond Sensors for Future HE Frontier Experiments

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8th Trento Workshop on Advanced Detectors
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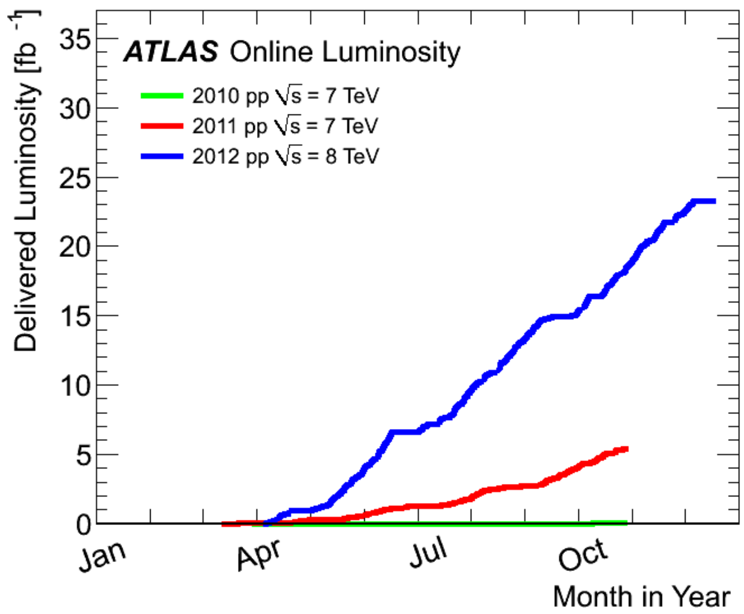
Outline of Talk

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

The ATLAS Diamond Detectors - motivation

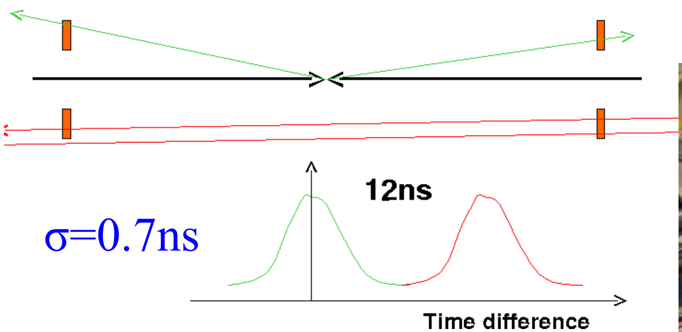
- Luminosity at the LHC is rising rapidly – now ~$7.5 \times 10^{33} cm^{-2} s^{-1}$



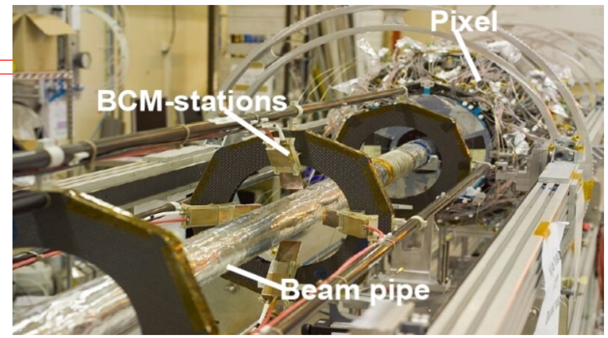
- Luminosity is a counting issue – requires good segmentation in space or time
- Problems occur when particle multiplicity reaches a point where all segments have high probability of having a hit in every bunch crossing

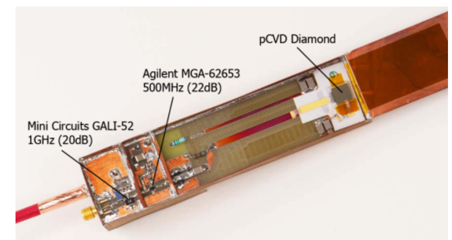
The ATLAS Diamond Detectors - lessons

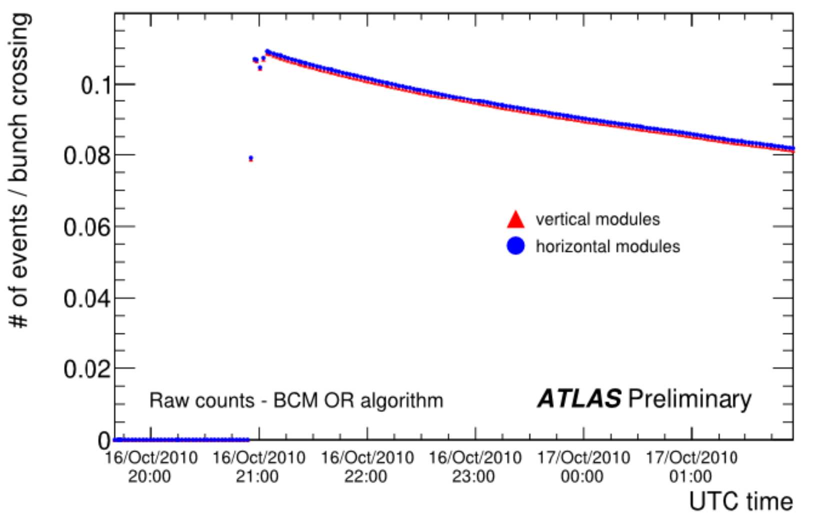
- Luminosity measurement with the ATLAS diamond BCM

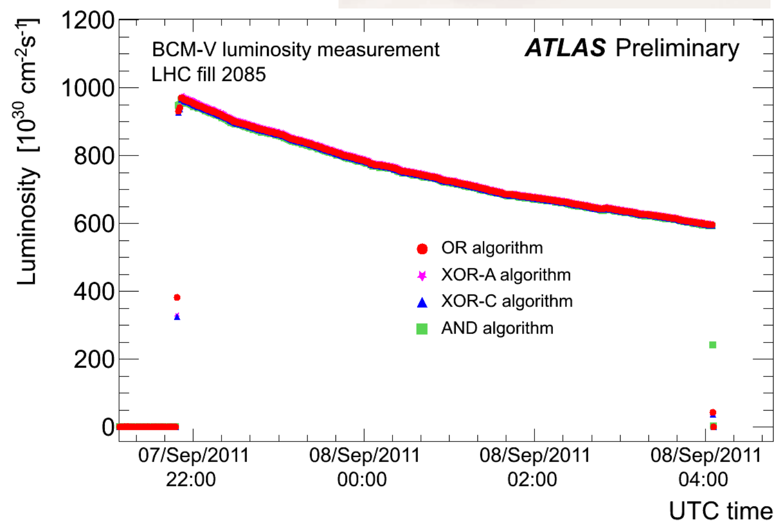


Single Particle Counting: single ch/detector
in-time Luminosity
out-of-time Background





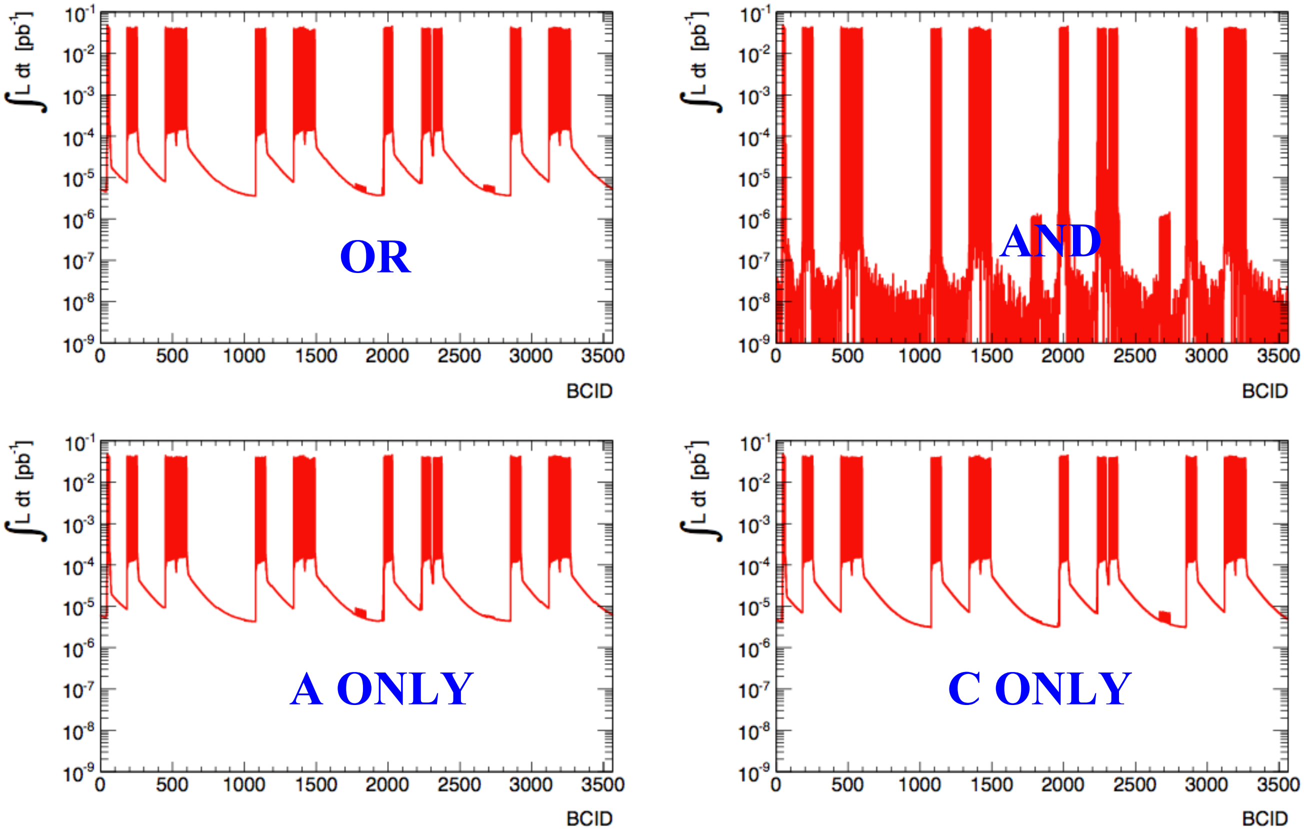




- Speed, robustness, stability required for good luminosity

The ATLAS Diamond Detectors - lessons

- The BCM rate (speed) is BCID aware

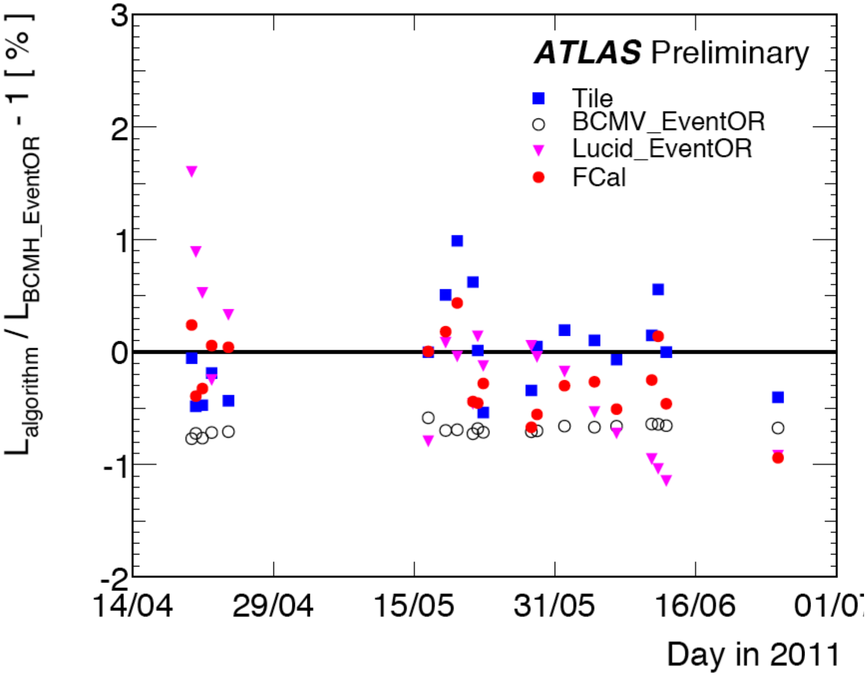


- To provide robust rate measurements
  suppress backgrounds by 10^{-3}-10^{-6}

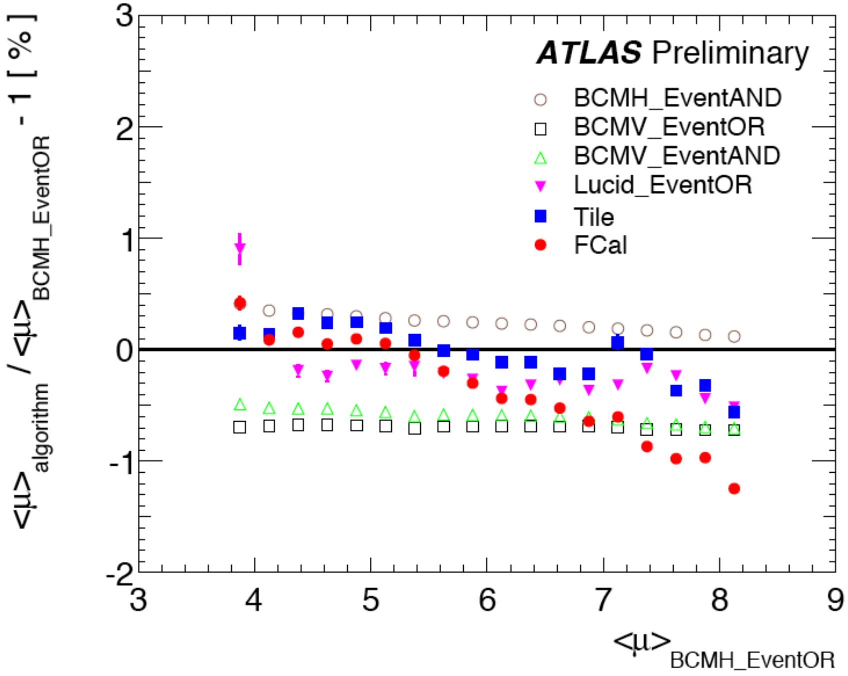
The ATLAS Diamond Detectors - lessons

- Stability of two independent measurements BCMH and BCMV:

Stable over months



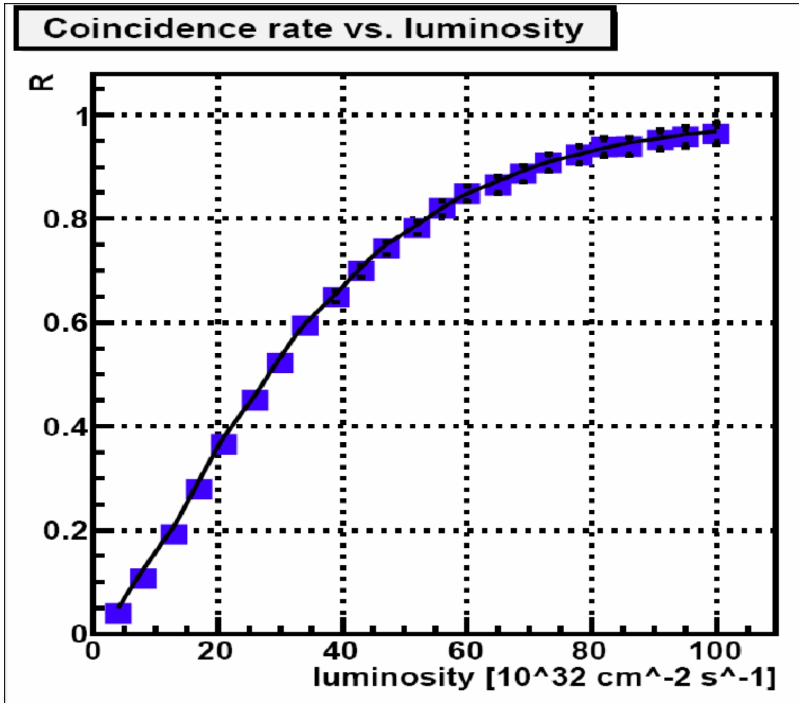
Stable against pile-up



- In 2011 BCM achieved a 1.9% luminosity measurement!

The ATLAS Diamond Detectors - limits

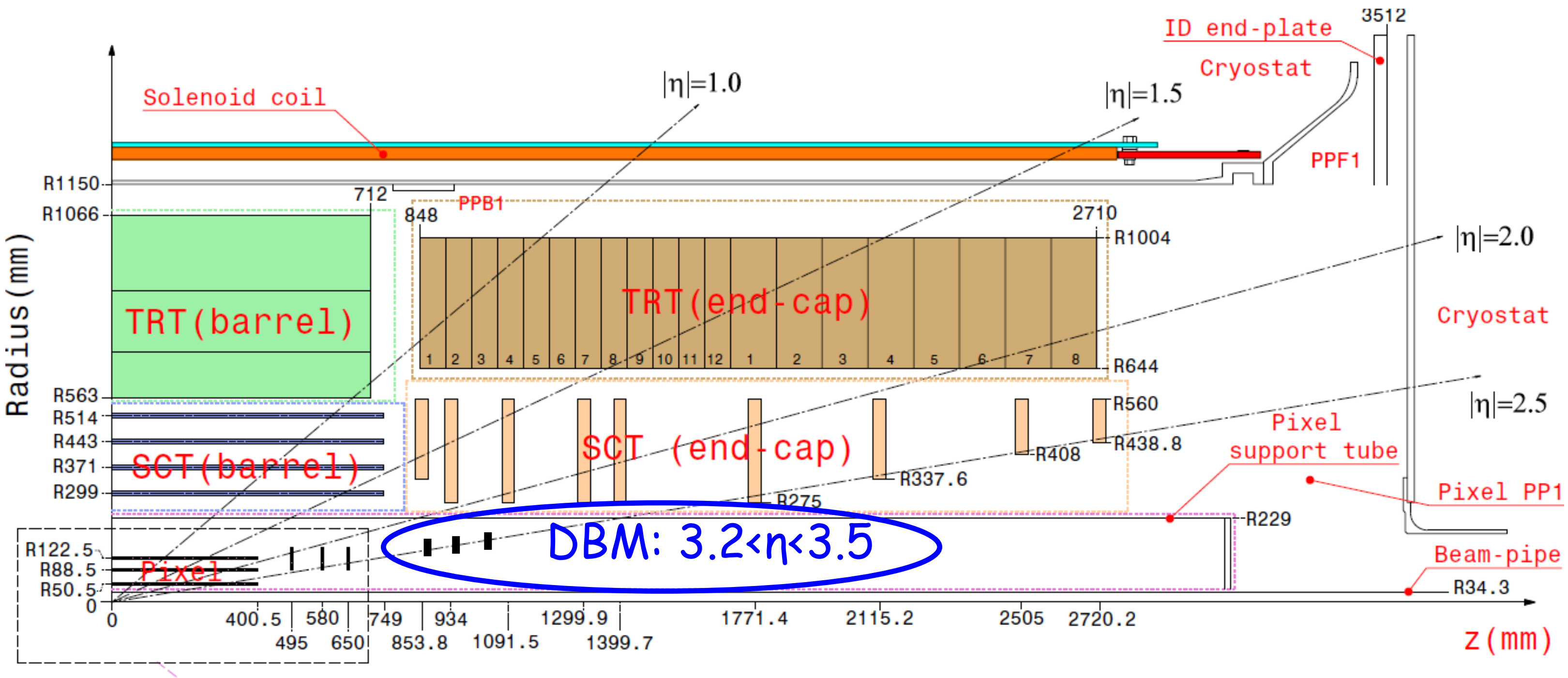
- But the BCM will begin to saturate at ~10^{34} $cm^{-2}s^{-1}$:



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

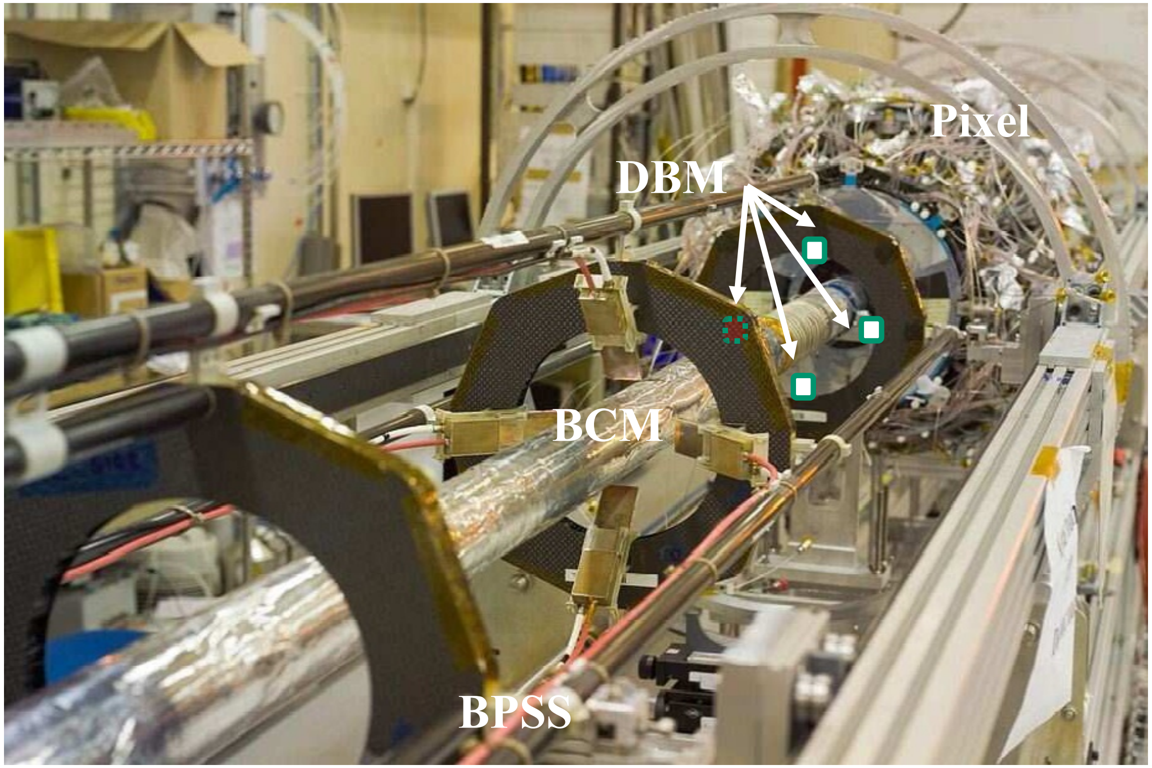
The ATLAS DBM Concept

- 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



The ATLAS DBM Concept

- 24 diamond pixel modules arranged in 8 telescopes provide
  - Bunch by bunch luminosity monitoring
  - Bunch by bunch beam spot monitoring
- Installation in July 2013



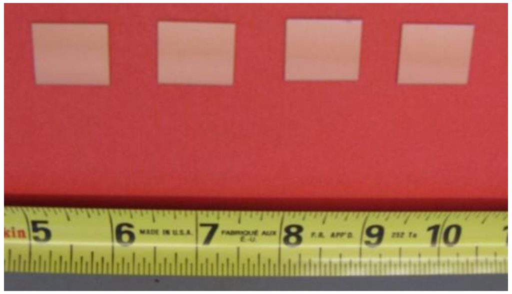
The ATLAS DBM Specs and Collaboration

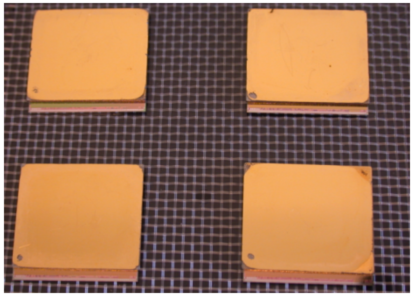
- Specs:
  - Bunch by bunch luminosity monitoring (<1% per BC per LB)
  - Bunch by bunch beam spot monitoring (unbiased sample, ~ 1cm)
- Installation in July 2013

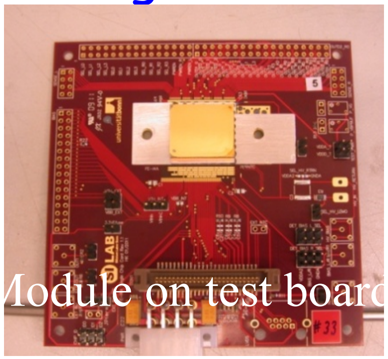
Bonn CERN Göttingen Ljubljana N.Mexico OhioSt Toronto

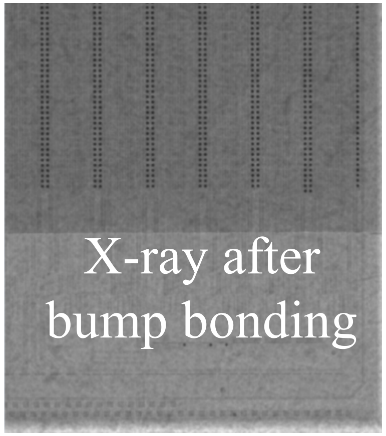
Lessons Learned: Module Production

- Sensors
  - 38 old sensors recycled from E6 (UK) from IBL work
  - 10 new sensors in hand from E6 (UK)
  - 17 sensors ordered from II-VI (US) – sensors in processing
- Quality Control
  - 6/38 old sensors + 8/10 new sensors passed full QC (V,I,ccd)
  - 12/38 old sensors + 9/10 new sensors passed reduced QC
- Bump bonding
  - 4 prototype modules bump-bonded by IZM
  - 21 sensors at IZM for bump-bonding



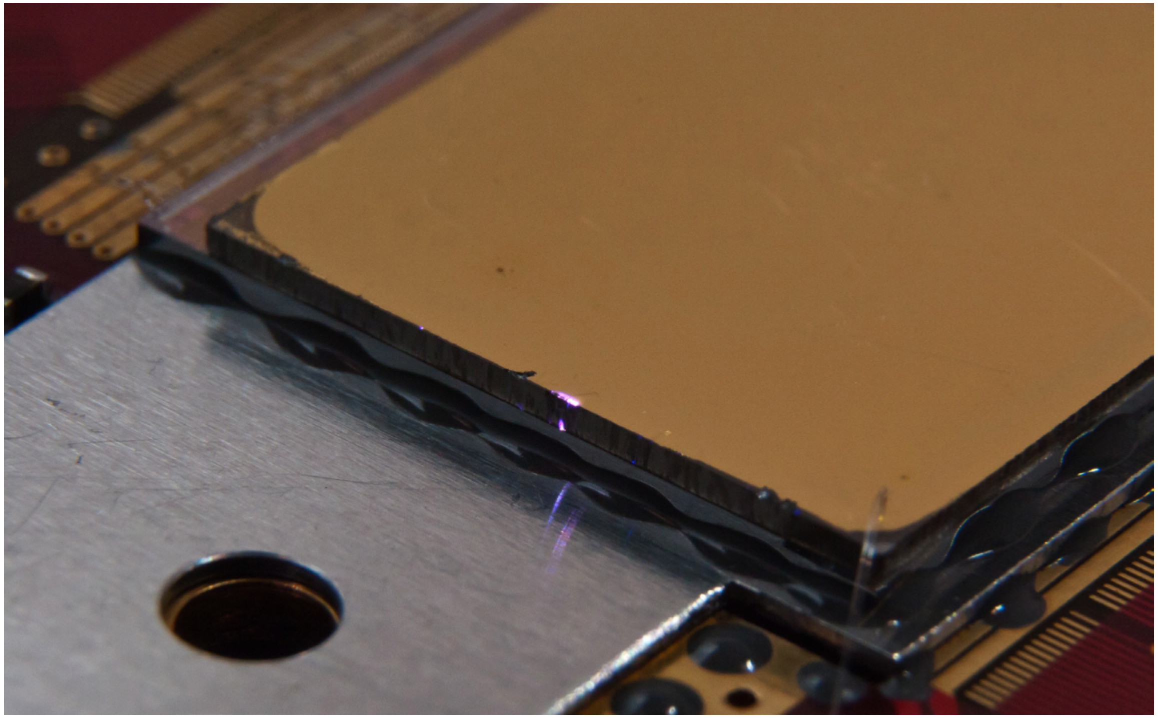






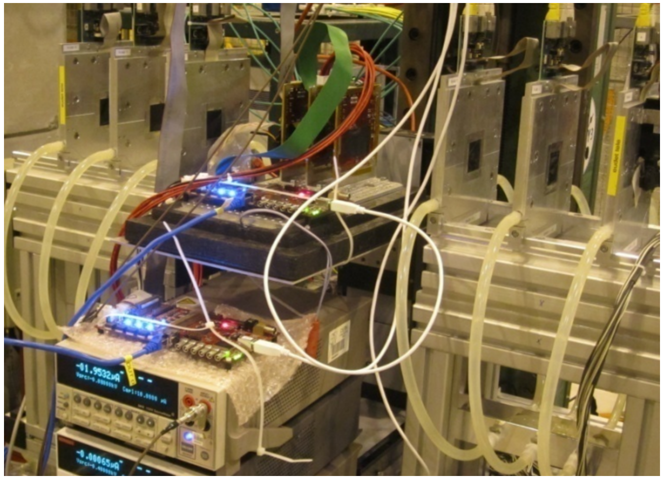
Lessons Learned: Module Production

- 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: Testbeam

- Many Testbeam campaigns
  - Oct 11, Mar 12, Jun 12, …
- Lessons: electronic performance
  - Can not always get calibration/tunings for low threshold performance
  - Need electronics with proper design to take advantage of diamond detector properties



What is possible?

x = October 2011 DBM Test Beam

Threshold / Gain	500e	800e	1000e	1500e	2000e
8ToT@3ke	x	x			
8ToT@5ke	x	x		x	
8ToT@8ke	x	x		x	x
8ToT@10ke		x			
8ToT@15ke					

„Green Valley“

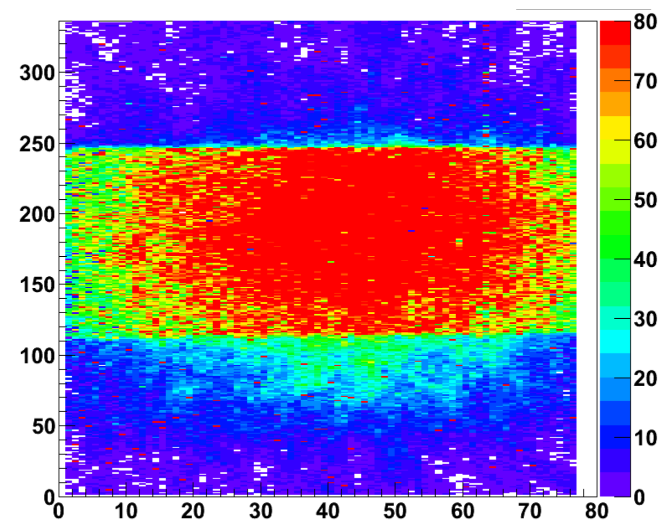
Lessons Learned: Testbeam

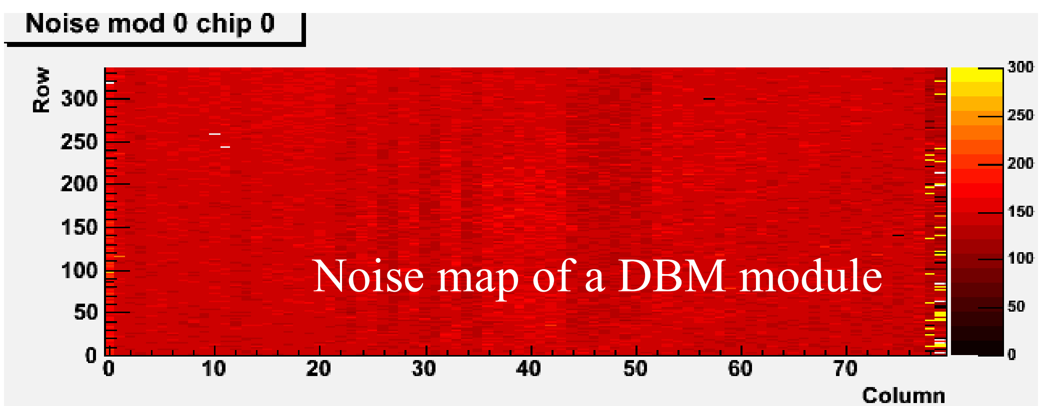
Prototype Modules Tested:

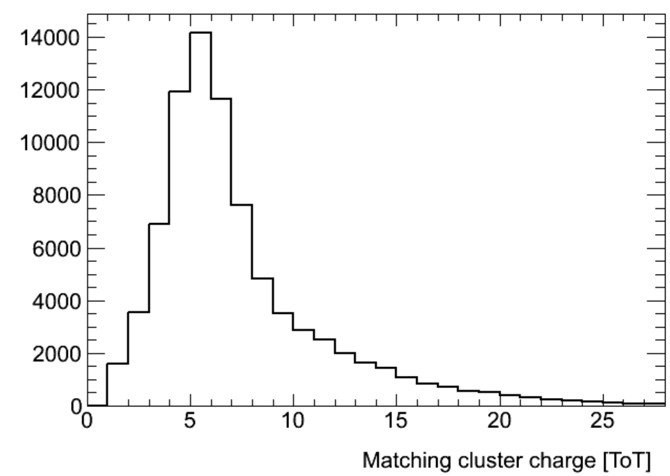
- 21mmx 18mm pCVD diamond w/FE-I4
- 336 x 80 = 26880 channels
- 50 x 250 μm² pixel cell

Results

- Noise map uniform
- Efficiency >95%







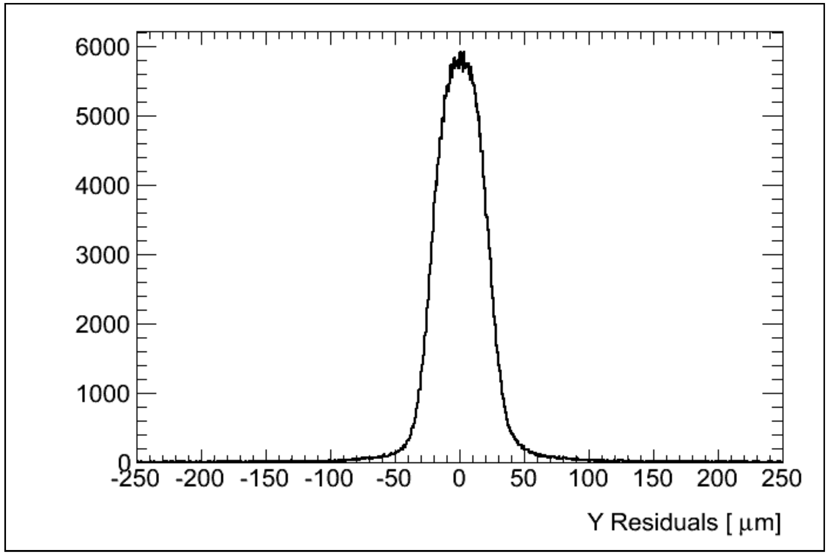
Lessons Learned: Testbeam

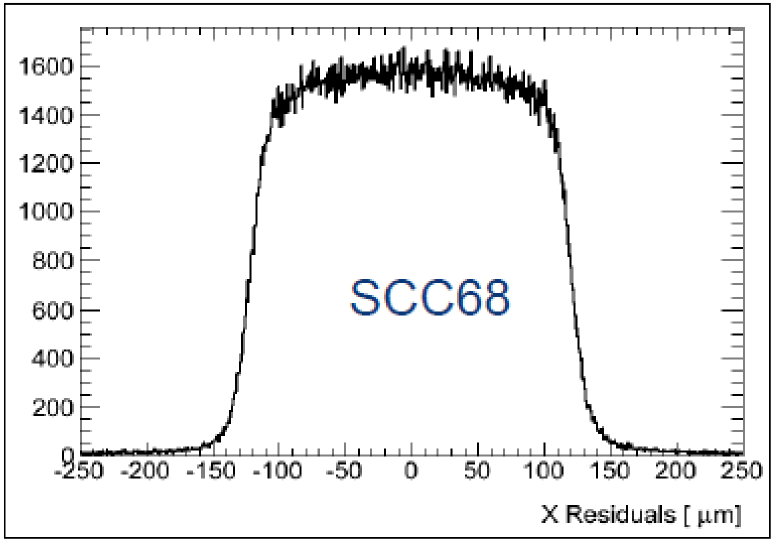
Prototype Modules Tested:

- 21mmx 18mm pCVD diamond w/FE-I4A
- 336 x 80 = 26880 channels
- 50 x 250 μm² pixel cell

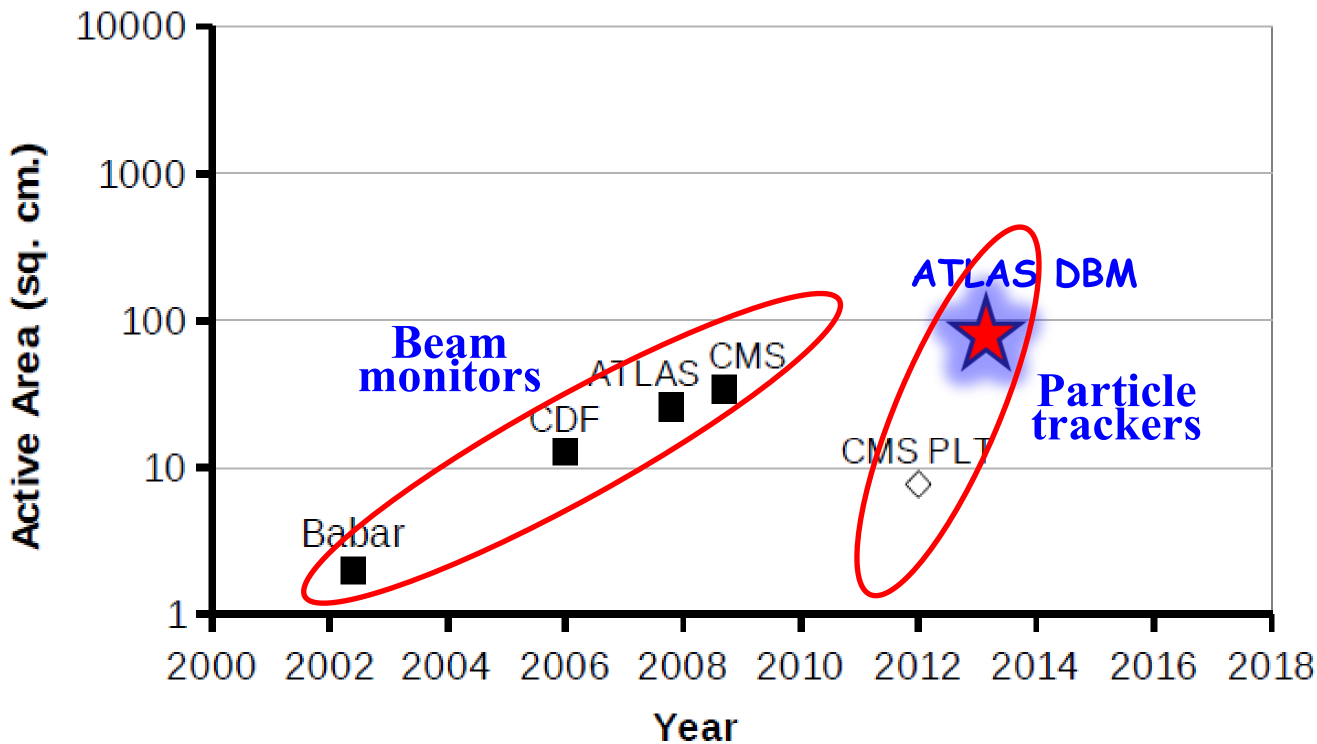
Results

- Spatial resolution looks digital





Diamond Production



Future detectors will require 10x - 100x more devices

Lessons Learned: Production

DDL: Out of Business

- After last RD42 meeting learned that DDL had ceased operations

DIAMOND DETECTORS LIMITED

DIAMOND DETECTORS LTD

Dear Customer

Diamond Detectors Limited

It is with regret that we announce that we have taken the decision to close the business.

Operations will cease on 25 May 2012. Please be advised that existing orders will not be completed and no future orders will be accepted. We apologise for any inconvenience this may cause.

- *After scrambling E6 filled ATLAS order*

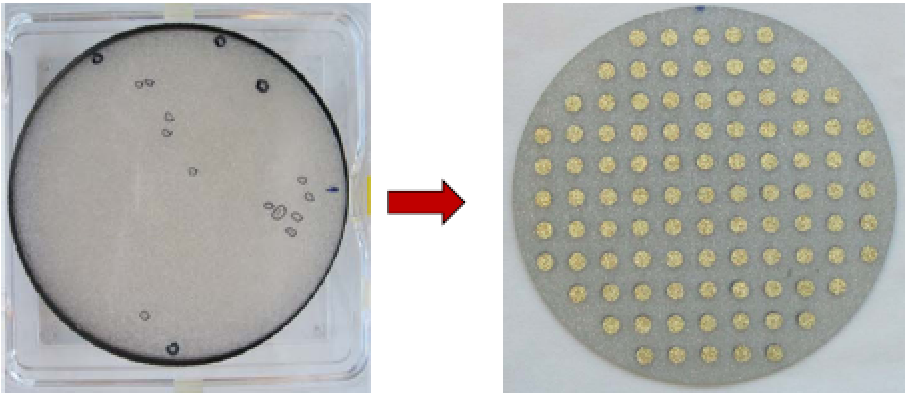
Lessons Learned: Production

Production and Scale-up demand additional manufacturers:

- For ATLAS DBM it was DDL & II-VI → E6 & II-VI
- II-VI now online
- Micron Semiconductor has purchased some of DDL equipment and personnel – interested in diamond devices
- Two other US companies are now manufacturing diamond

Material Qualification requires detailed tests

- Must avoid defects and dislocations

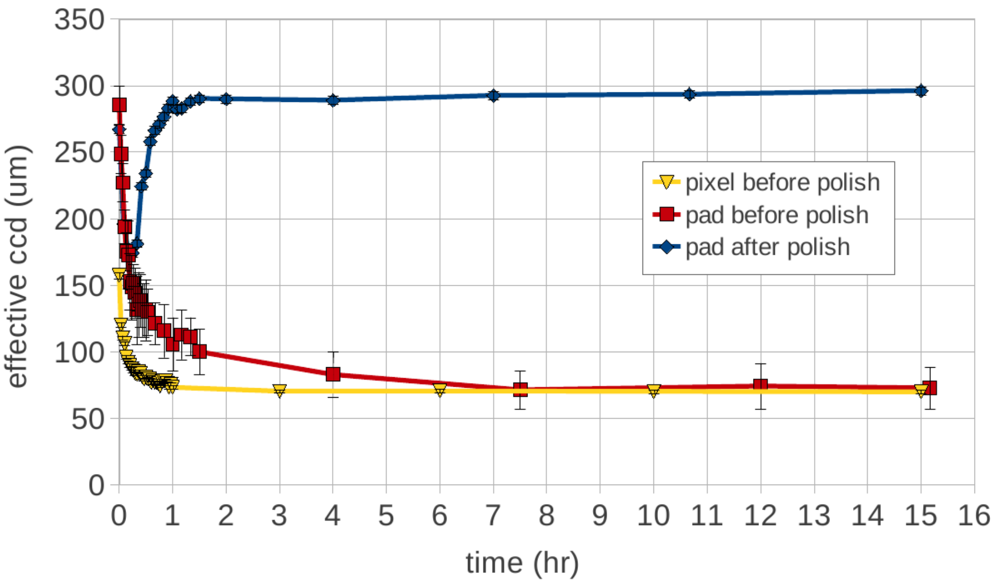


Lessons Learned: Production

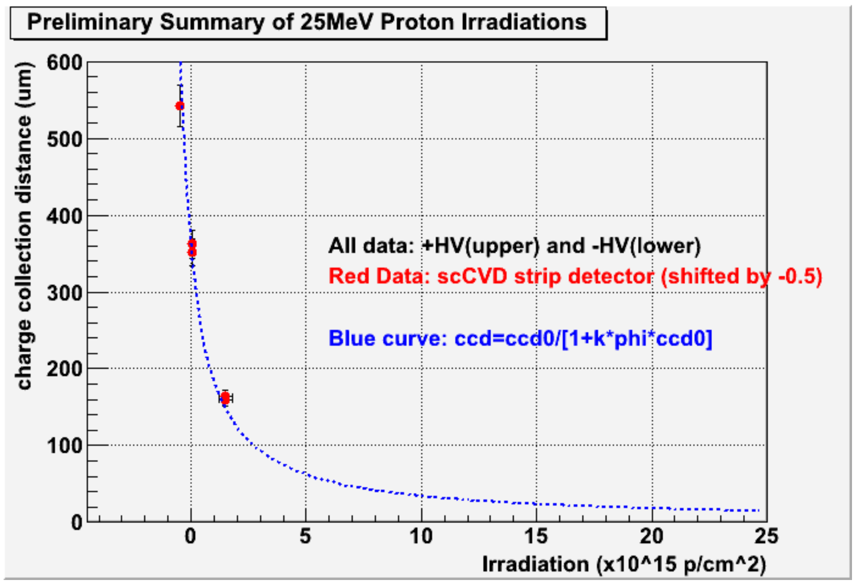
And surface preparation (last 5μm) is critical:

- Sub-surface damage effects

The Problem: measured w/source



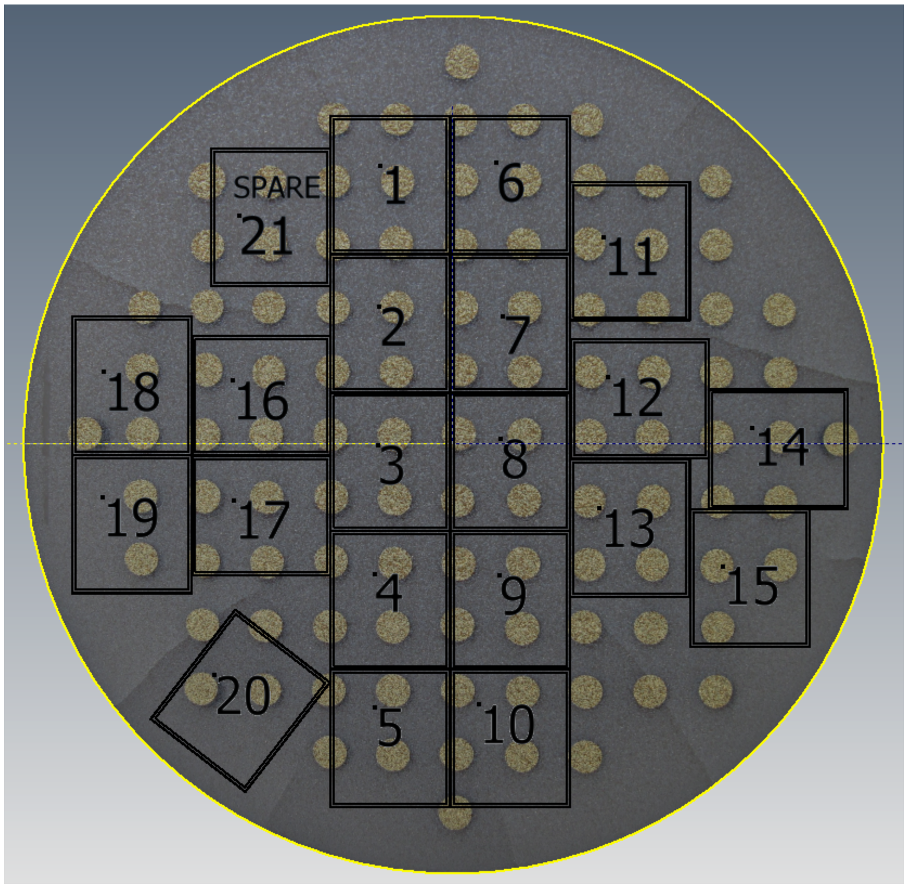
After: Measured in Test beam

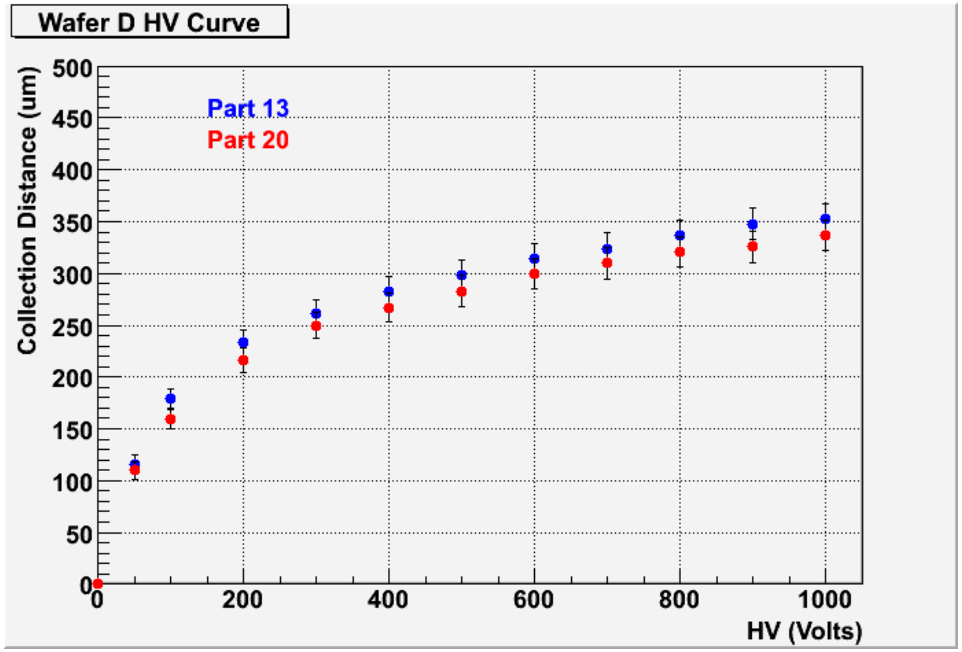


Lessons Learned: Production

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

- II-VI has now produced large, superb wafers

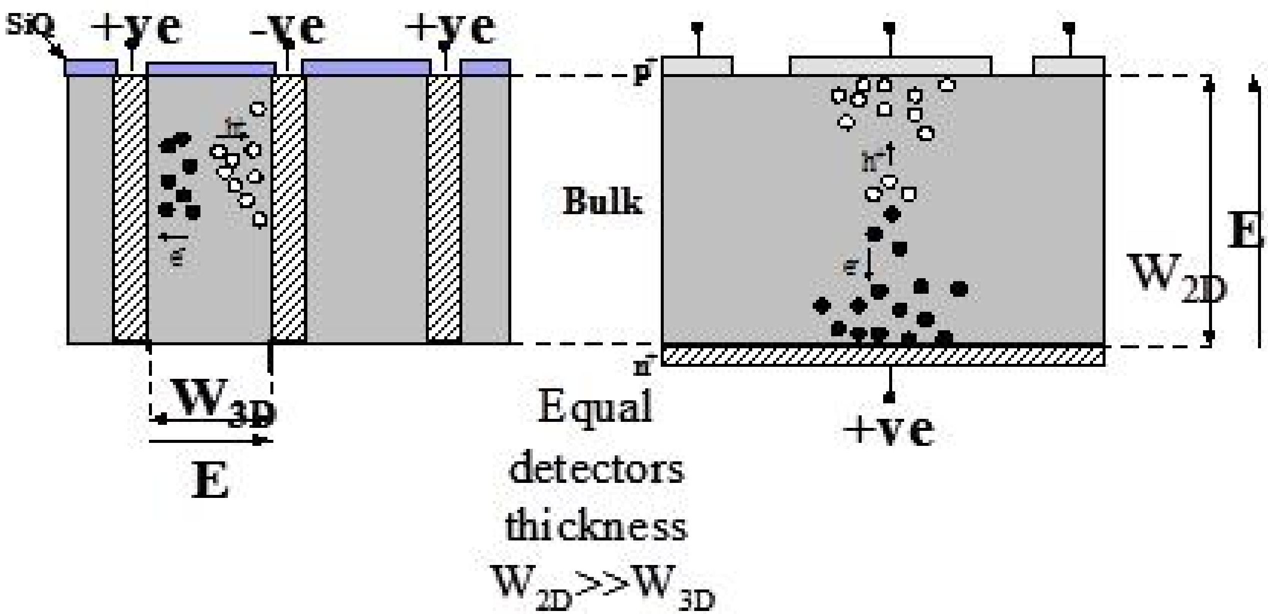




New Geometry: 3D Diamond

After severe radiation damage all detectors are trap limited

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

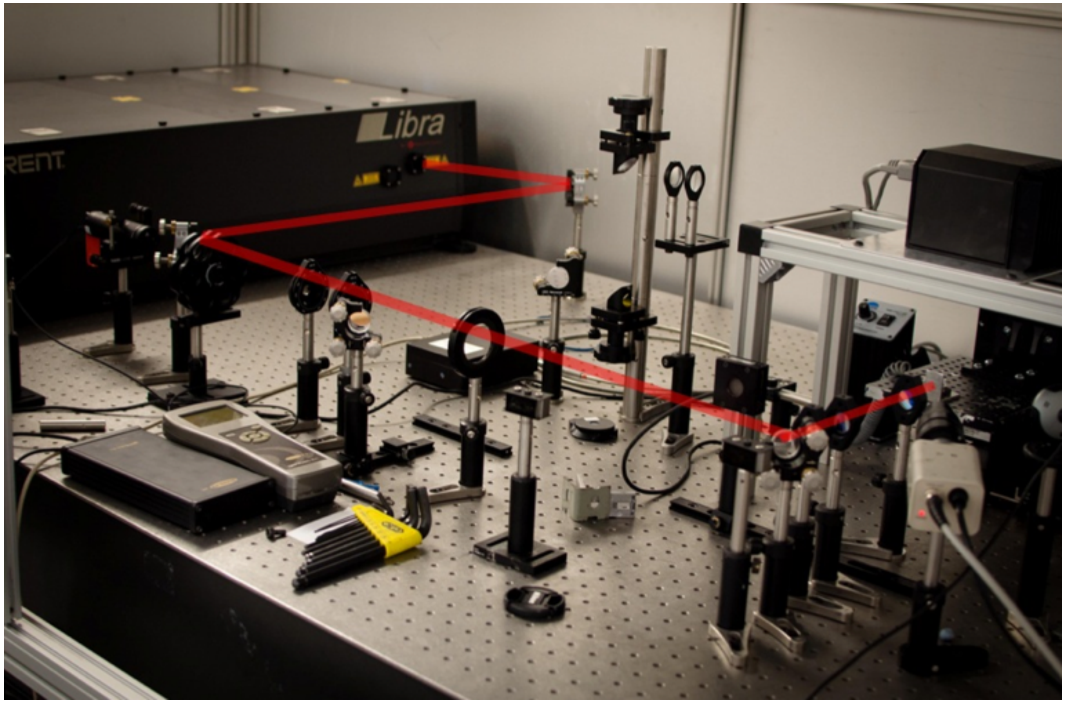


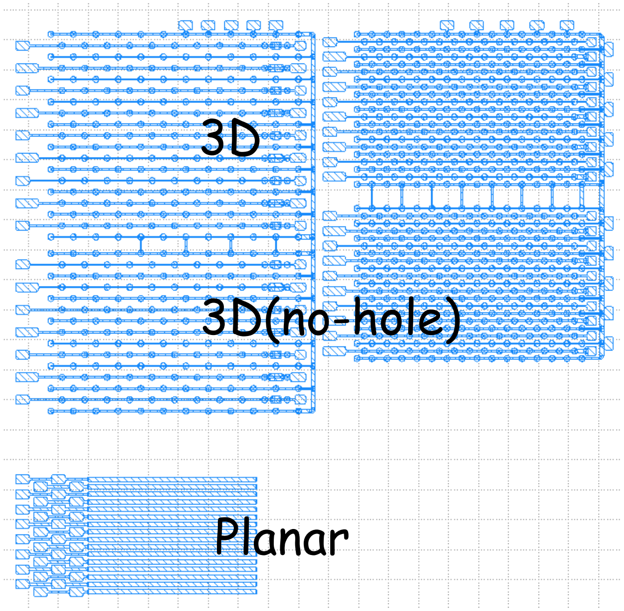
Can one make conducting hole structures in diamond?

New Directions: 3D Diamond

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

- Holes drilled with femto-second laser
- Operate planar (500V), 3D(no-holes) (25V), 3D (25V)
- Simultaneous comparison on same diamond
- Analysis/simulation first results → Iain Haughton's Talk





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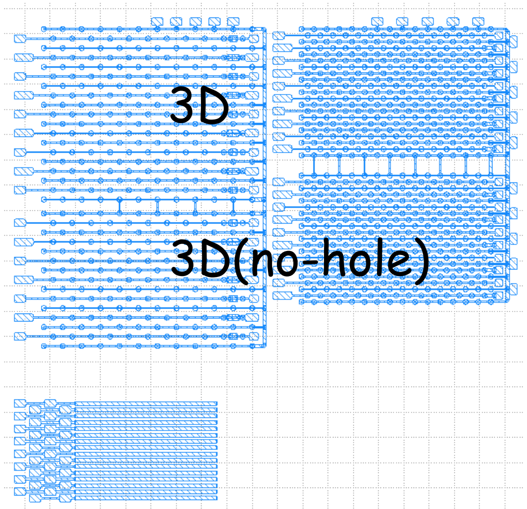

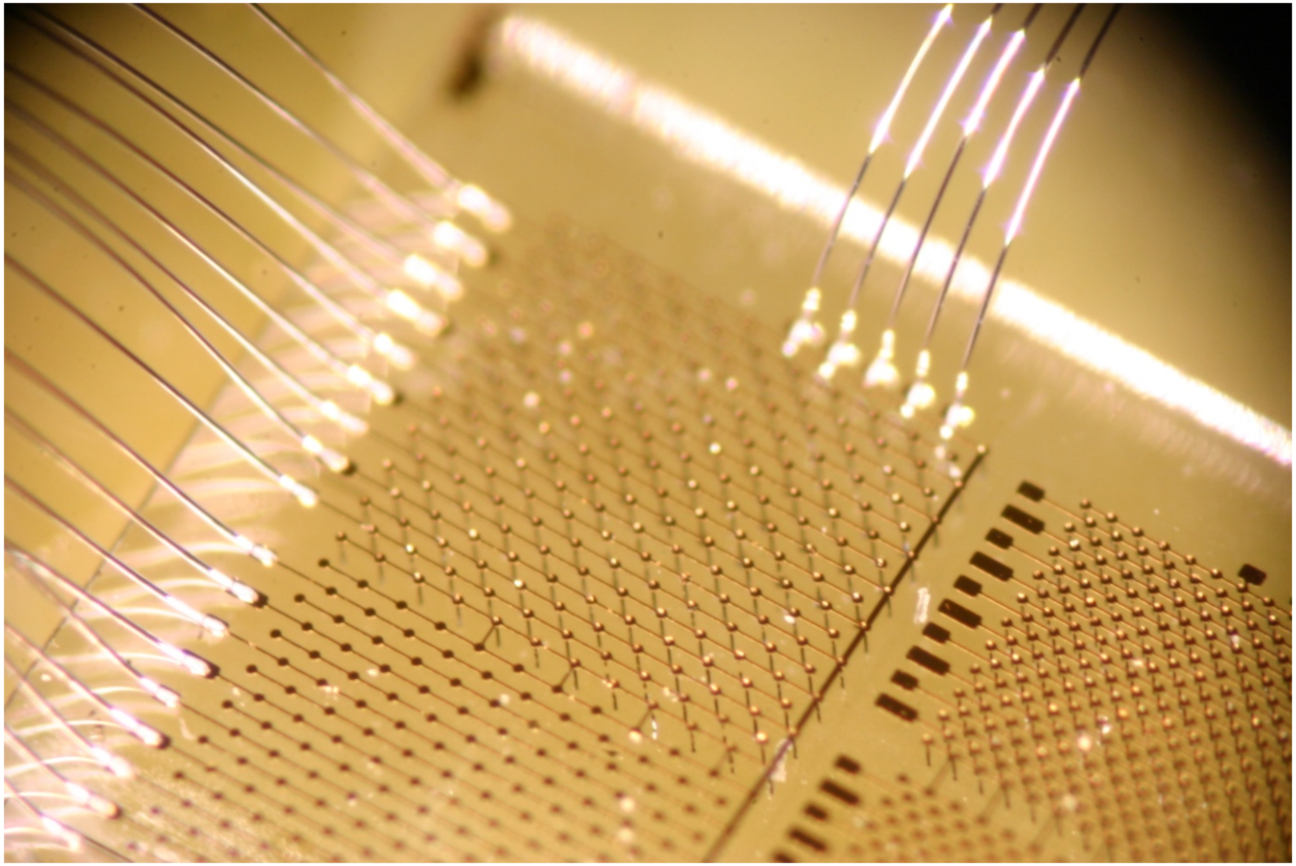

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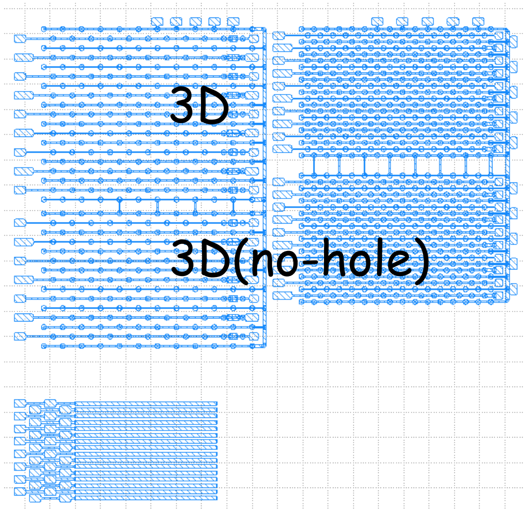
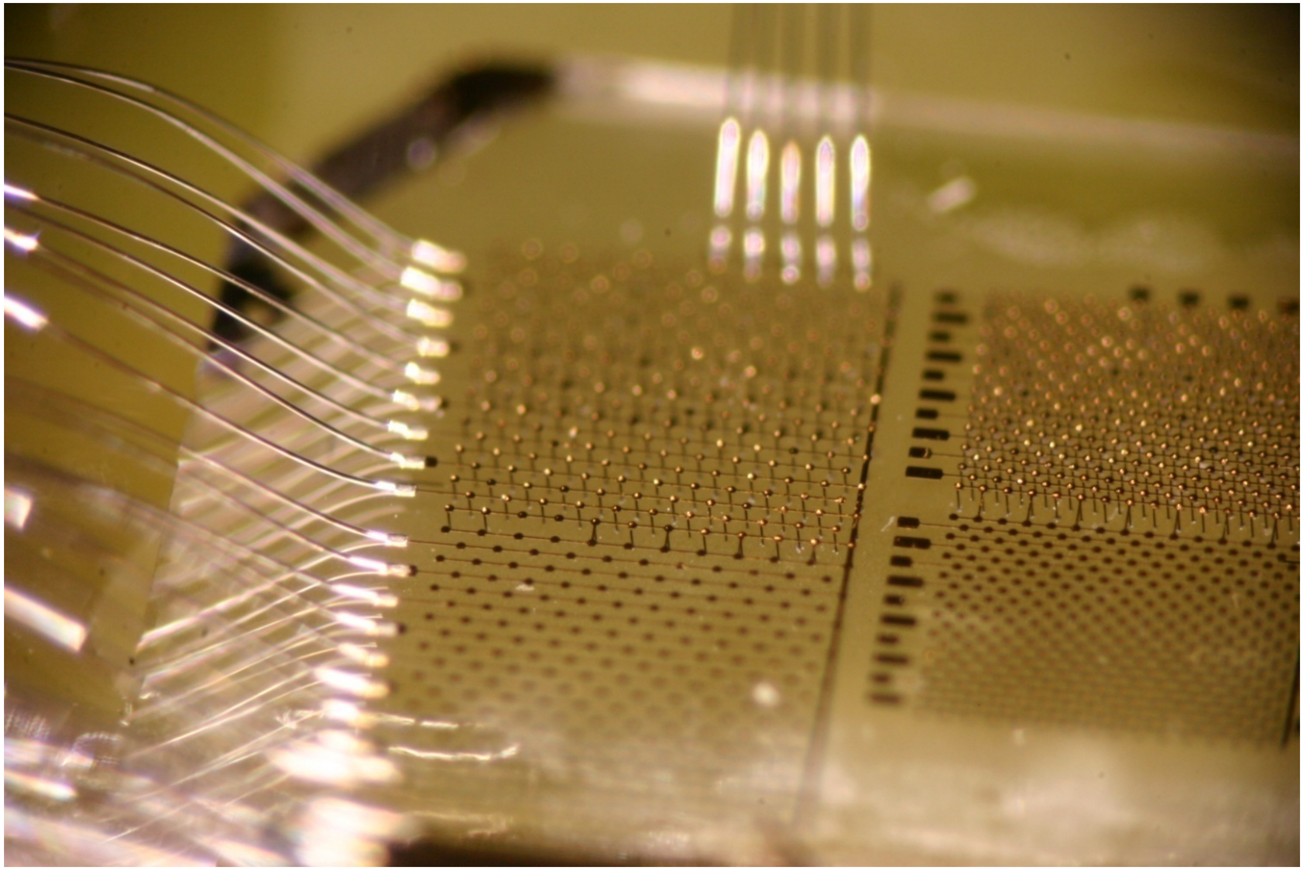
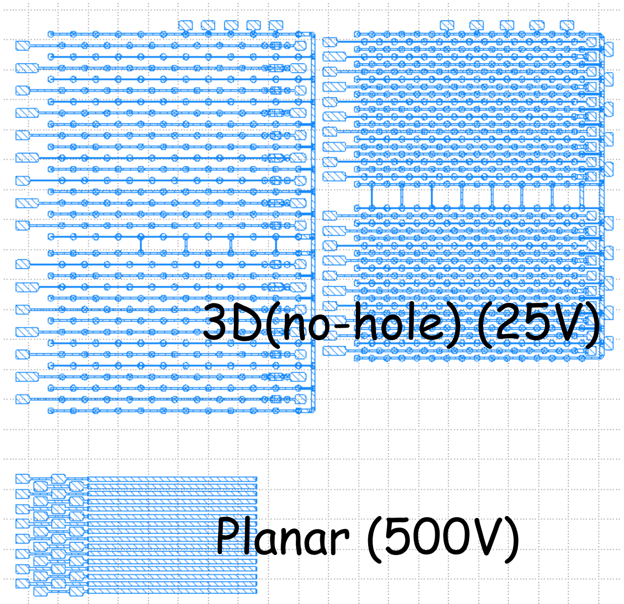


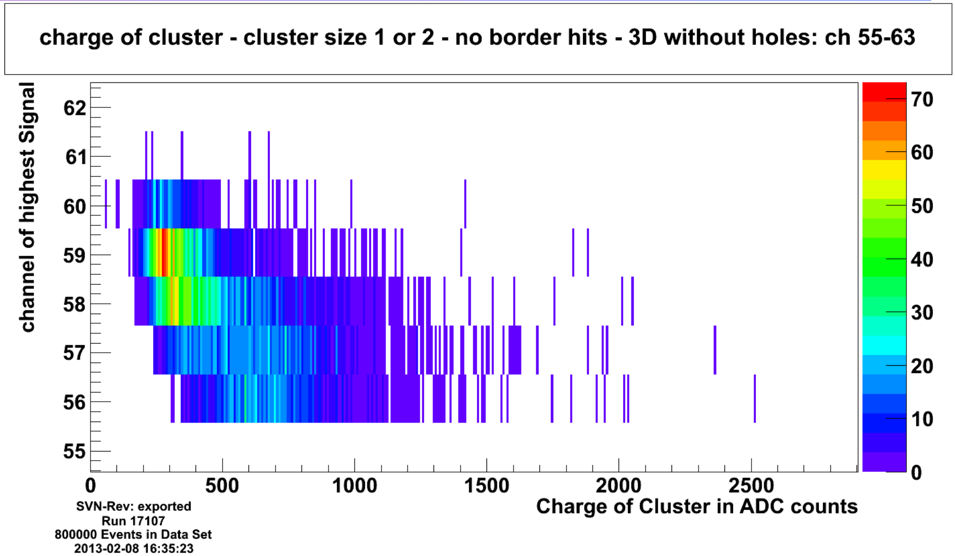


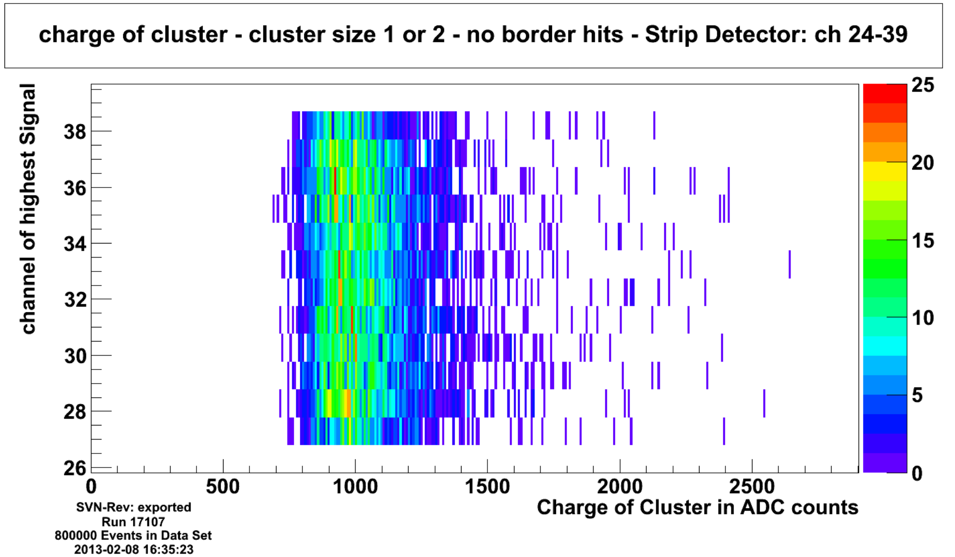
New Directions: 3D Diamond

Configure 3D devices as strip detectors

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







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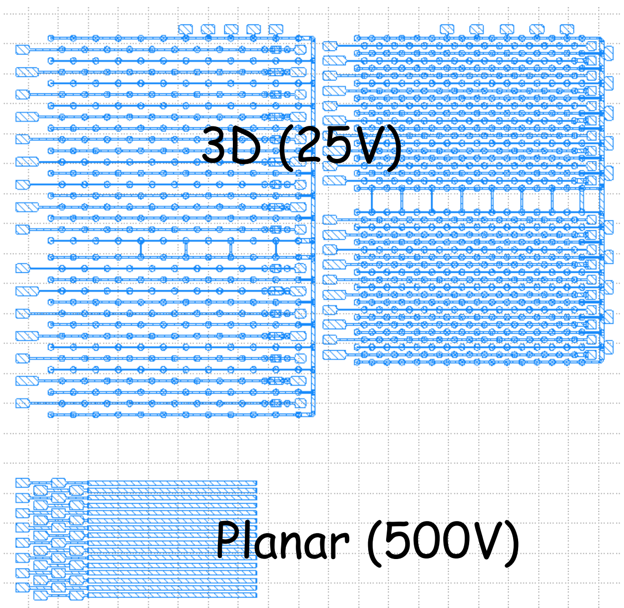
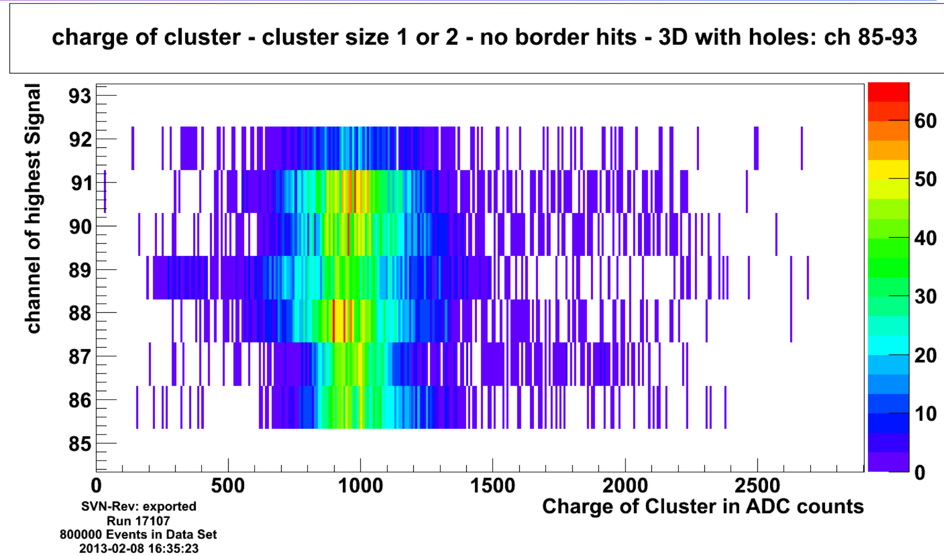
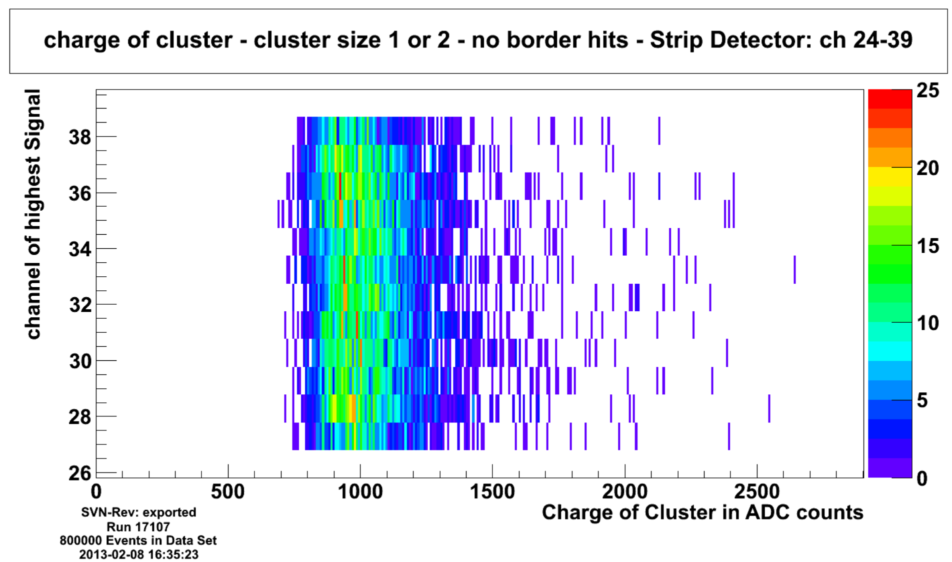


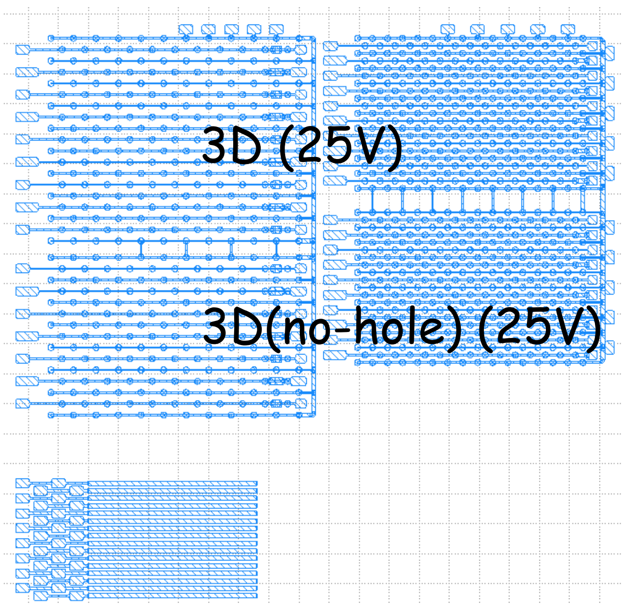


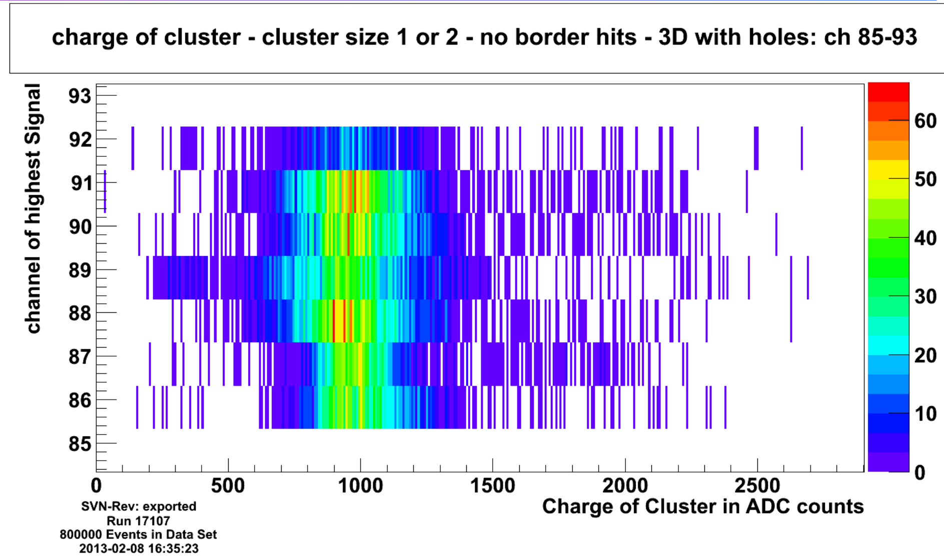


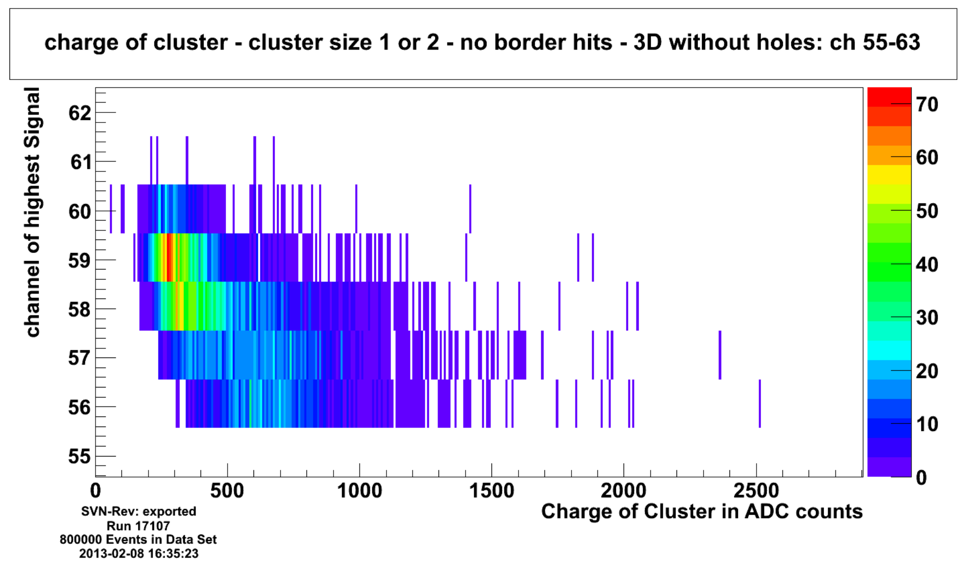
New Directions: 3D Diamond

Configure 3D devices as strip detectors

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







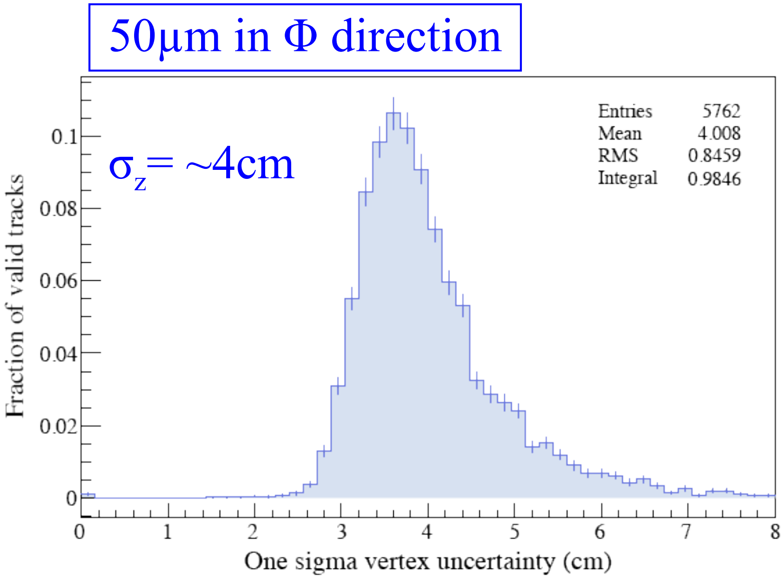
Summary

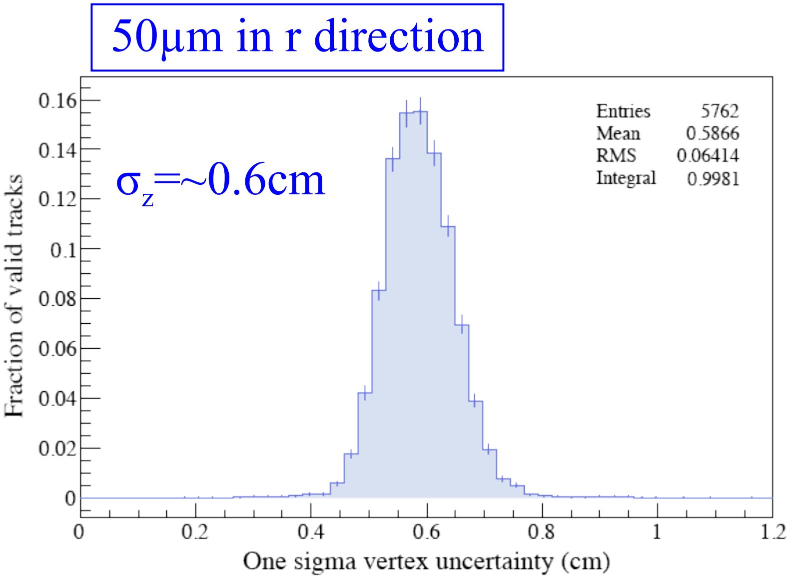
- Construction of the largest diamond pixel tracker underway
- Many design issues were brought to light:
  speed, robustness, stability, segmentation
- Many issues needed attention:
  metalization, electronics, sensor qualification, suppliers
- Some beliefs were modified or need more effort:
  recycling/re-use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

Backup Slides

The ATLAS DBM Tracking Simulation

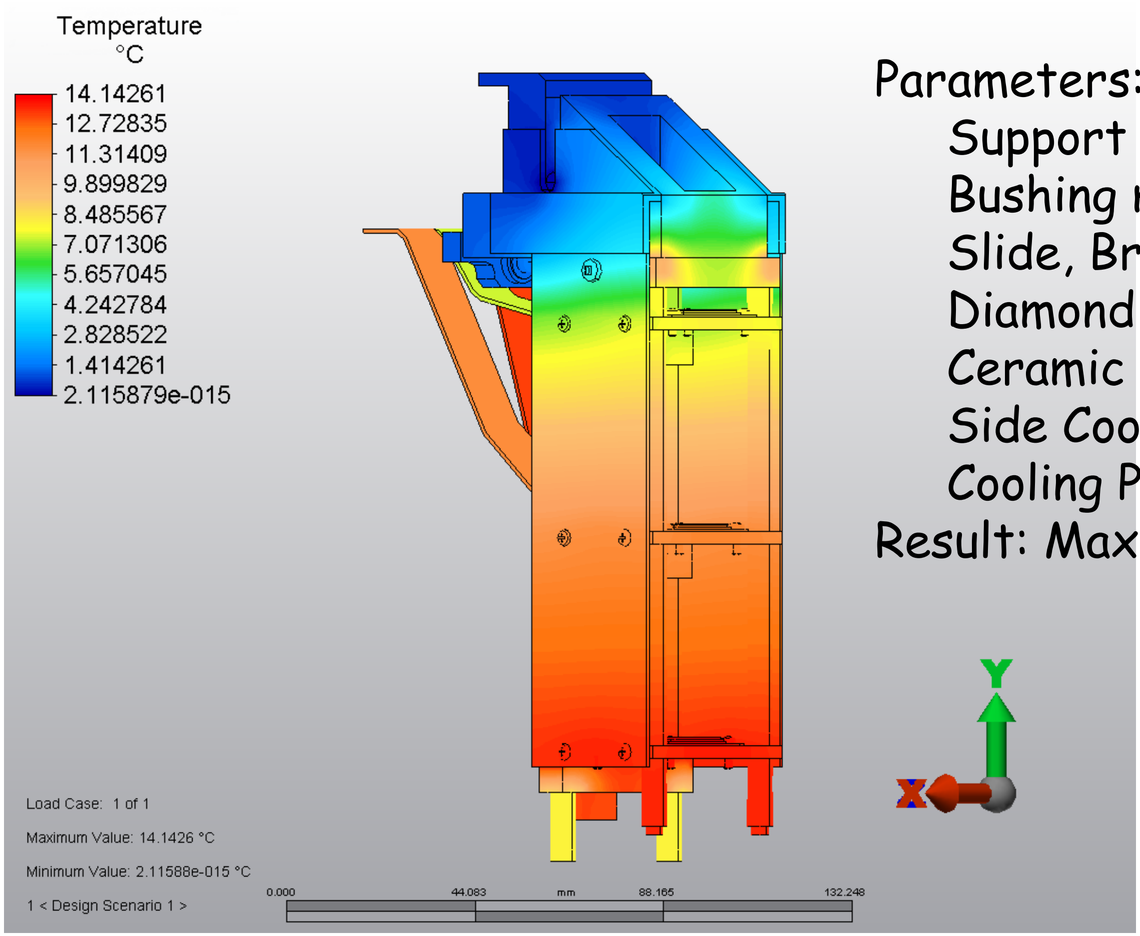
- Simulate DBM to find orientation and resolution
  - Focus on z vertex resolution (momentum resolution bad)





The ATLAS DBM Concept

- Cooling simulations for DBM telescope w/3 x 1W + AlN side plate



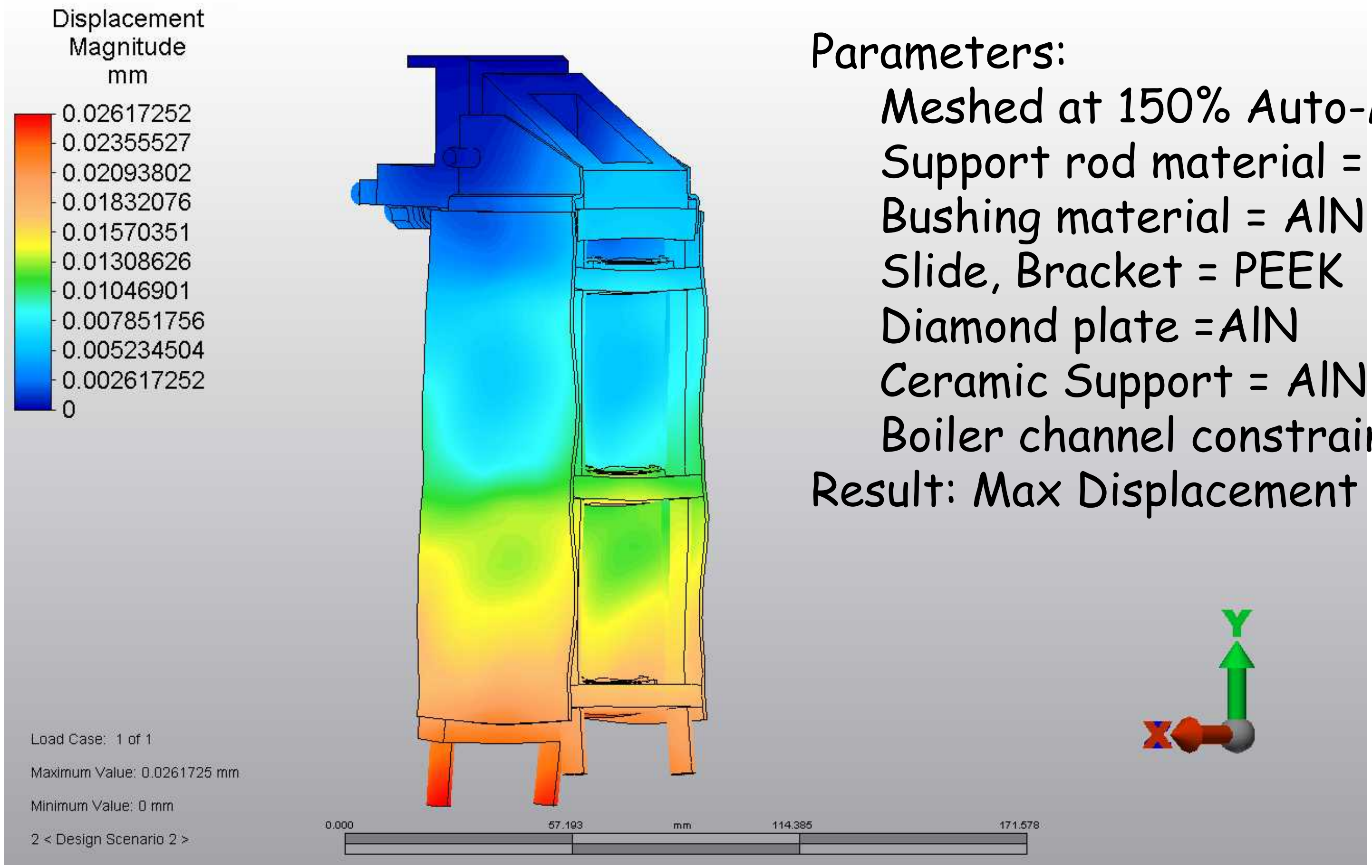
Parameters:

Support rod material = Aluminum
Bushing material = AlN
Slide, Bracket = PEEK
Diamond plate =AlN
Ceramic Support = AlN
Side Cooling Plate = AlN (1mm)
Cooling Pipe constrained to 0°C

Result: Max T = 14.2°C

The ATLAS DBM Concept

- Mechanical simulations for DBM telescope w/3 x 1W + AlN side plate



Parameters:
- Meshed at 150% Auto-Mesh size
- Support rod material = Aluminum
- Bushing material = AlN
- Slide, Bracket = PEEK
- Diamond plate =AlN
- Ceramic Support = AlN
- Boiler channel constrained to 0°C

Result: Max Displacement = 26.2 μm