Development of CVD Diamond Tracking Detectors for Experiments at High Luminosity Colliders

RD42 Status Report

William Trischuk
for the RD42 Collaboration

LHCC Meeting – June 3, 2015

<u>Outline of Talk</u>

- RD42 Collaboration
- LHCC Milestones 2014
- New Diamond manufacturers
- Rate studies of diamond signal
- Results from 3D sensors
- Plans and Request

The 2015 RD42 Collaboration

M. Artuso[24], F. Bachmair[28], L. Bäni[28], M. Bartosik[3], J. Beacham[16], V. Bellini[2], V. Belyaev[15], B. Bentele[23], E. Berdermann[8], P. Bergonzo[14], A. Bes[32], J-M. Brom[10], M. Bruzzi[5], M. Cerv[3], C. Chau[19], G. Chiodini[31], D. Chren[22], V. Cindro[12], G. Claus[10], J. Collot[32], S. Costa[2], J. Cumalat[23], A. Dabrowski[3], R. D'Alessandro[6], W. de Boer[13], B. Dehning[3], D. Dobos[3], W. Dulinski[10], M. Dünser[28]V. Eremin[9], R. Eusebi[29], G. Forcolin[26], J. Forneris[18], H. Frais-Kölbl[4], K.K. Gan[16], M. Gastal[3], M. Goffe[10], J. Goldstein[20], A. Golubev[11], L. Gonella[1], A. Gorišek[12], L. Graber[27], E. Grigoriev[11], J. Grosse-Knetter[27], B. Gui[16], M. Guthoff[3], I. Haughton[26], D. Hidas[17], D. Hits[28], M. Hoeferkamp[25], T. Hofmann[3], J. Hosslet[10], J-Y. Hostachy[32], F. Hügging[1], H. Jansen[3], J. Janssen[1], H. Kagan[16,◊], K. Kanxheri[33], G. Kasieczka[28], R. Kass[16], F. Kassel[13], M. Kis[8], G. Kramberger[12], S. Kuleshov[11], A. Lacoste[32], S. Lagomarsino[6], A. Lo Giudice[18], C. Maazouzi[10], I. Mandic[12], C. Manfredotti[18], C. Mathieu[10], N. McFadden[25], G. McGoldrick[19], M. Menichelli[33], M. Mikuž[12], A. Morozzi[33], J. Moss[16], R. Mountain[24], S. Murphy[26], G. Oakham[21], A. Oh[26], P. Olivero[18], G. Parrini[6], D. Passeri[33], M. Pauluzzi[33], H. Pernegger[3], R. Perrino[31], F. Picollo[18], M. Pomorski[14], R. Potenza[2], A. Quadt[27], A. Re[18], G. Riley[30], S. Roe[3], M. Sapinski[3], M. Scaringella[5], S. Schnetzer[17], T. Schreiner[4], S. Sciortino[6], A. Scorzoni[33], S. Seidel[25], L. Servoli[33], A. Sfyrla[3], G. Shimchuk[11], S. Smith[16], B. Sopko[22], V. Sopko[22], S. Spagnolo[31], S. Spanier[30], K. Stenson[23], R. Stone[17], C. Sutera[2], A. Taylor[25], M. Traeger[8], D. Tromson[14], W. Trischuk[19,◊], C. Tuve[2], L. Uplegger[7], J. Velthuis[20], N. Venturi[19], E. Vittone[18], S. Wagner[23], R. Wallny[28], J.C. Wang[24], P. Weilhammer[3], J. Weingarten[27], C. Weiss[3], T. Wengler[3], N. Wermes[1], M. Yamouni[32], M. Zavrtanik[12]

[1] Universität Bonn, Bonn, Germany;
[2] INFN/University of Catania, Catania, Italy;
[3] CERN, Geneva, Switzerland;
[4] FWT, Wiener Neustadt, Austria;
[5] INFN/University of Florence, Florence, Italy;
[6] Department of Energetics/INFN, Florence, Italy;
[7] FNAL, Batavia, USA;
[8] GSI, Darmstadt, Germany;
[9] Ioffe Institute, St. Petersburg, Russia;
[10] IPHC, Strasbourg, France;
[11] ITEP, Moscow, Russia,
[12] Jožef Stefan Institute, Ljubljana, Slovenia,
[13] Universität Karlsruhe, Karlsruhe, Germany,
[14] CEA-LIST Technologies Avancees, Saclay, France,
[15] MEPHI Institute, Moscow, Russia,
[16] The Ohio State University, Columbus, OH, USA,
[17] Rutgers University, Piscataway, NJ, USA,
[18] University of Torino, Torino, Italy,
[19] University of Toronto, Toronto, ON, Canada,
[20] University of Bristol, Bristol, UK,
[21] Carleton University, Ottawa, Canada,
[22] Czech Technical Univ., Prague, Czech Republic,
[23] University of Colorado, Boulder, CO, USA,
[24] Syracuse University, Syracuse, NY, USA,
[25] University of New Mexico, Albuquerque, NM, USA,
[26] University of Manchester, Manchester, UK,
[27] Universität Goettingen, Goettingen, Germany,
[28] ETH Zürich, Zürich, Switzerland,
[29] Texas A&M, College Park Station, TX, USA,
[30] University of Tennessee, Knoxville, TN, USA,
[31] INFN-Lecce, Lecce, Italy,
[32] LPSC-Grenoble, Grenoble, France,
[33] INFN-Perugia, Perugia, Italy

◊ Spokespersons

131 Participants

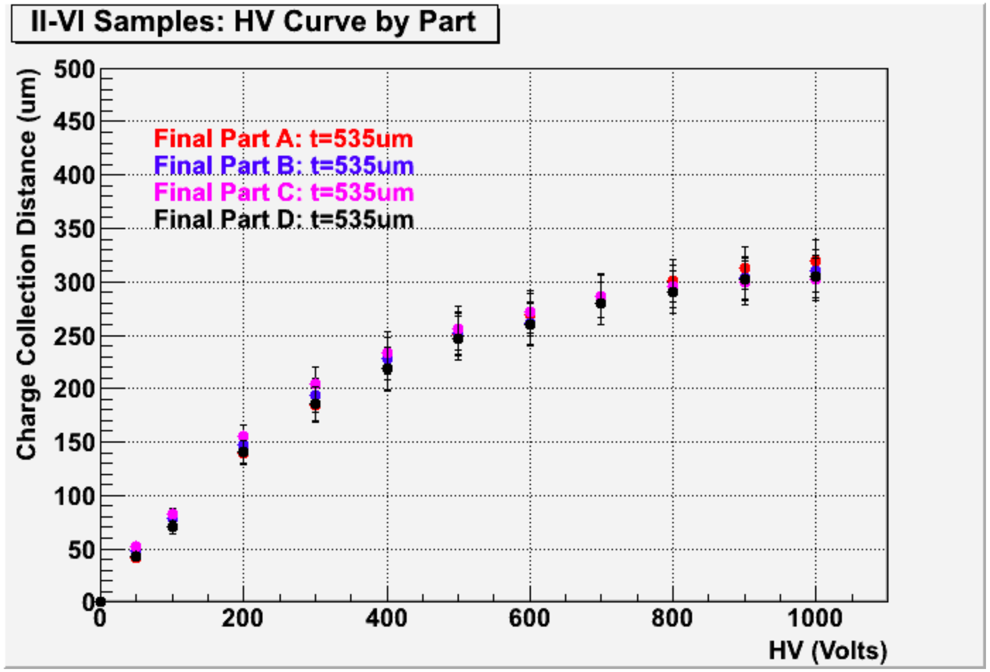
33 Institutes

LHCC Milestones/Priorities of Research-2012

- Continue to develop pCVD and scCVD material.
- Expand sensor grade manufacturing capability for use at LHC.
- Test radiation hardness and rate tolerance of highest quality pCVD and scCVD material
- Develop diamond pixel modules for LHC experiments. Industrialize module production.

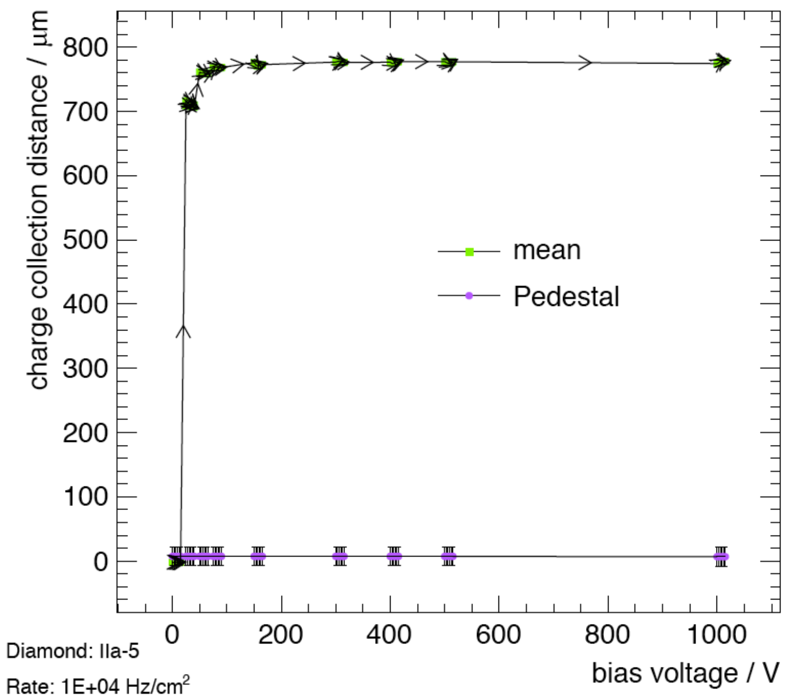
Improvements at new supplier: II-VI

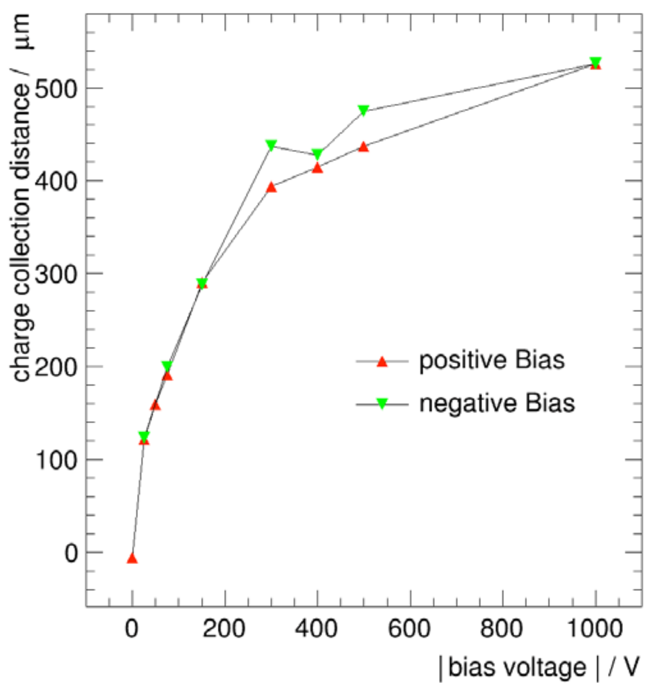
- II-VI provided first sensors for ATLAS DBM in 2013
  - 225um collection distance comparable to E6/DeBeers
- Delivered growing numbers of samples
  - To ATLAS and CMS
  - Typically have 300um collection distance



Development of new Diamond Supplier: IIa

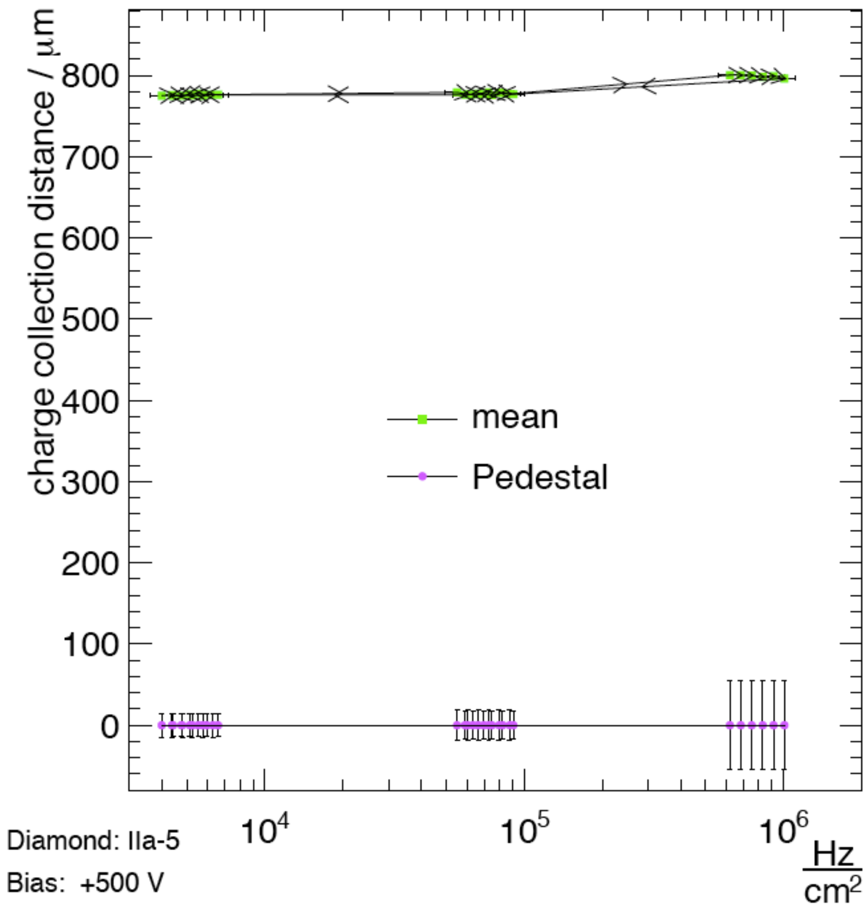
- A new diamond supplier IIa Technologies (Singapore)
  - Have delivered O(10) scCVD samples for evaluation
  - Have tested these for rate effects (eg. CMS-PLT)
  - Show less signal loss at high rate than E6
- Committed to further improvement and expansion to pCVD





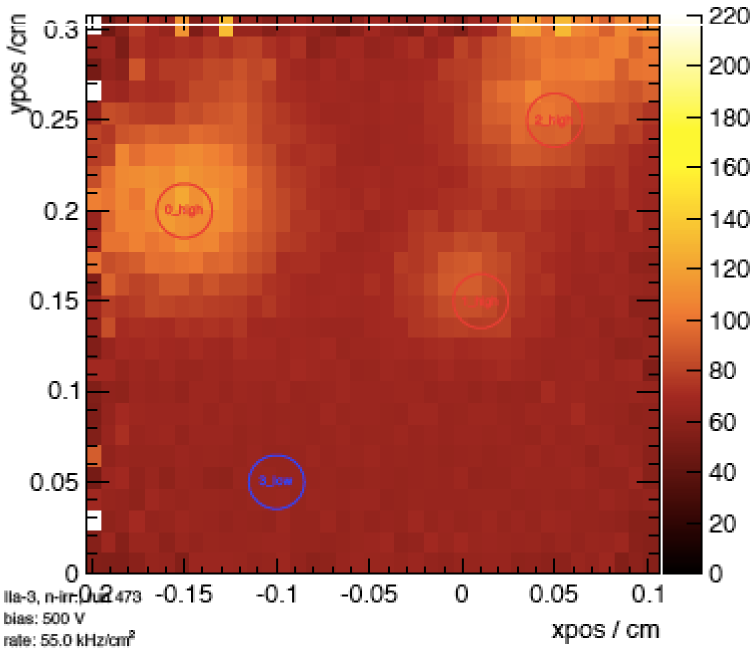
Development of Diamond Supplier: IIa

- Have tested IIa samples for rate dependence
- Show less signal loss at high rate than E6

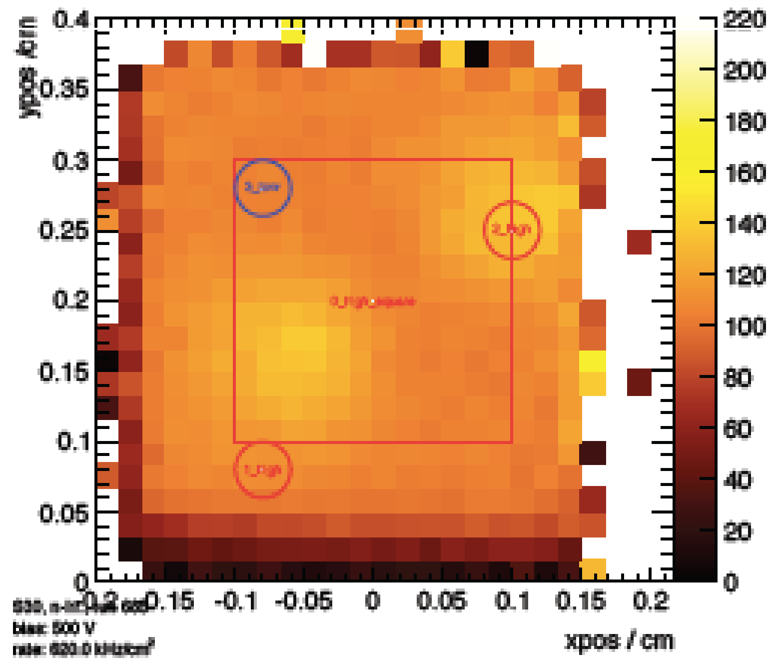


New Tool: Spatial Structure of diamond signal

- Using CMS (silicon) pixel telescope to determine particle position in diamond sensor
- Studying spatial uniformity of signal in scCVD and pCVD samples as well as time/rate dependence of hot spots



IIa-5



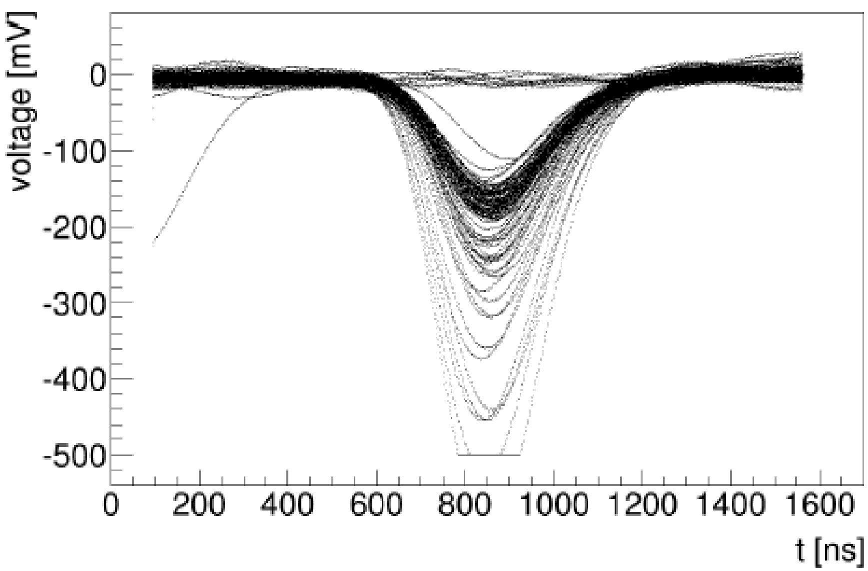
E6- S30

Diamond Signal vs. Rate

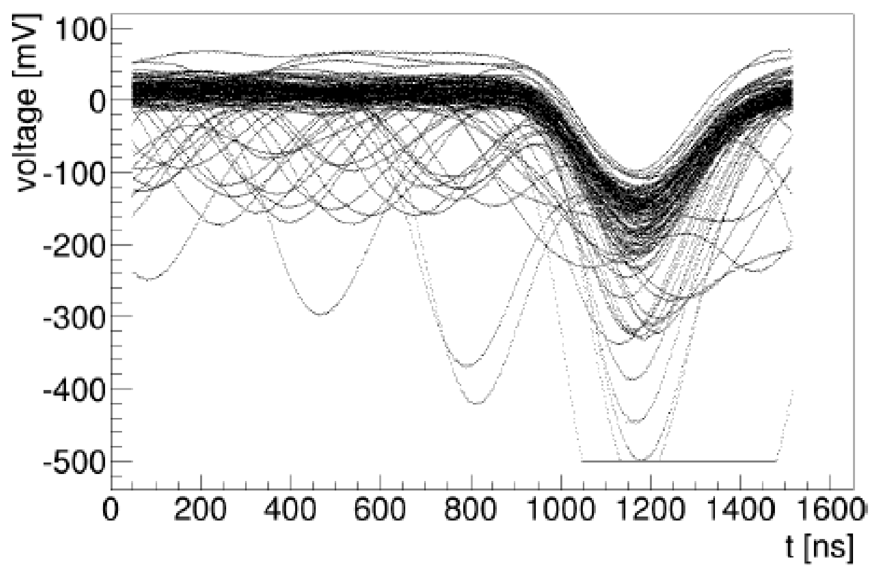
- Have published analysis of 2014 testbeam
  - JINST_006P_0115
- Improved understanding of pedestal shifts due to flux at highest rates
- Irradiated scCVD (E6) still shows signal loss
- pCVD signal stable up to fluxes of $10^6 cm^{-2}$
  - Even after irradiation to 10^{15} neutrons/cm

Signals in Low/High Flux Environment

- Studying diamond pads and pixel detectors
  - In high rate beam at PSI

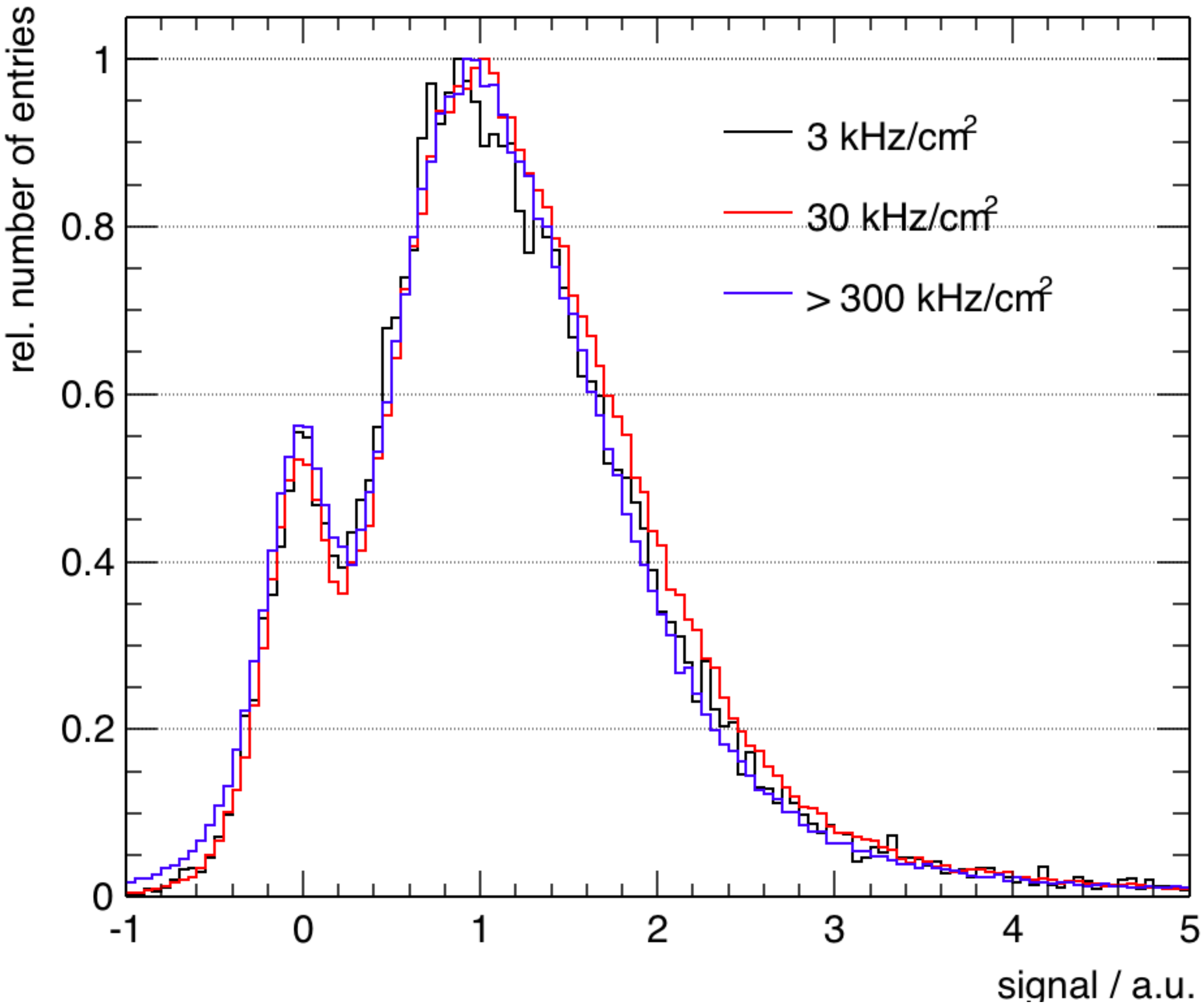


low flux (kHz/cm^2)



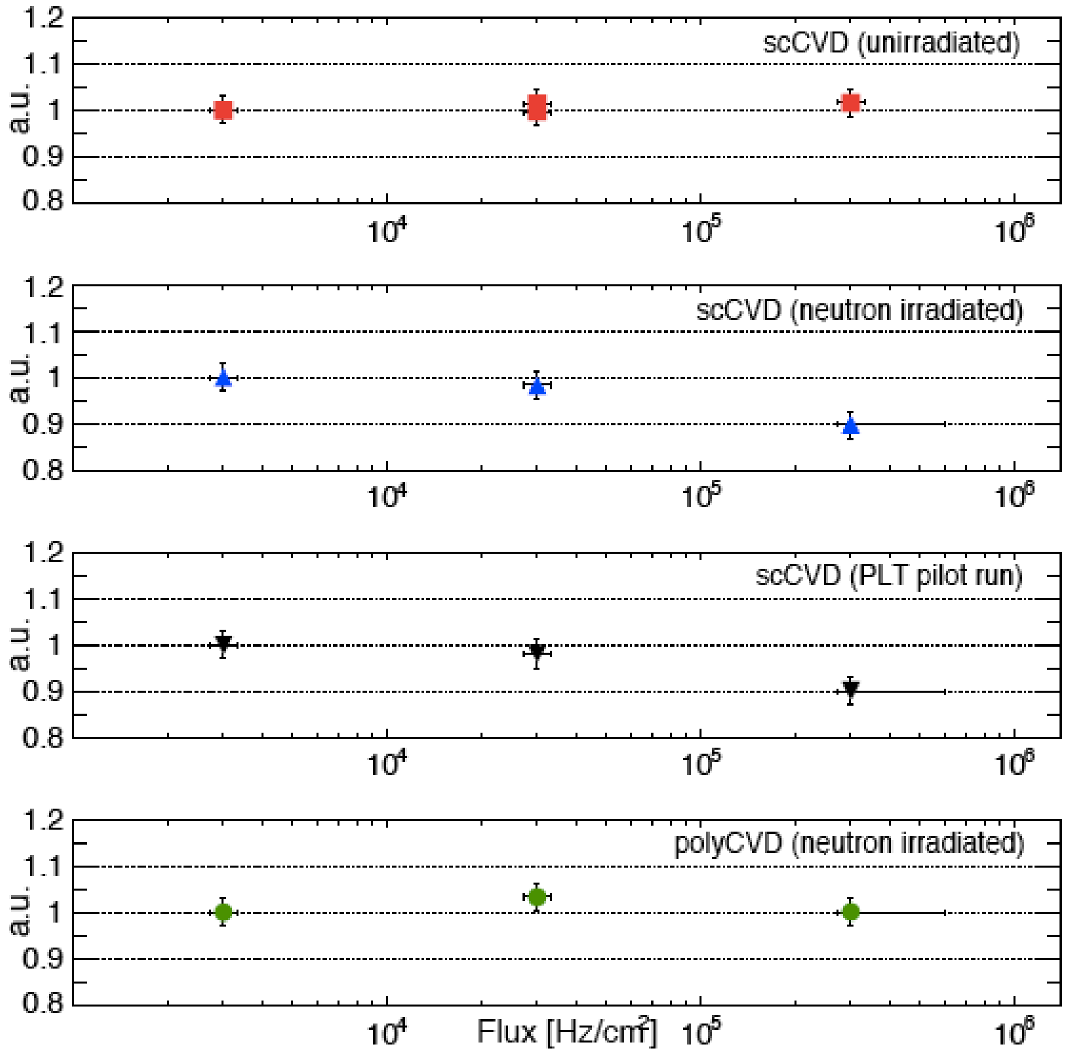
High flux (MHz/cm^2)

pCVD Signal vs. Flux



- pCVD diamond shows little variation in signal size vs. fluence
- LHC rates about a factor of 10 higher at inner radii

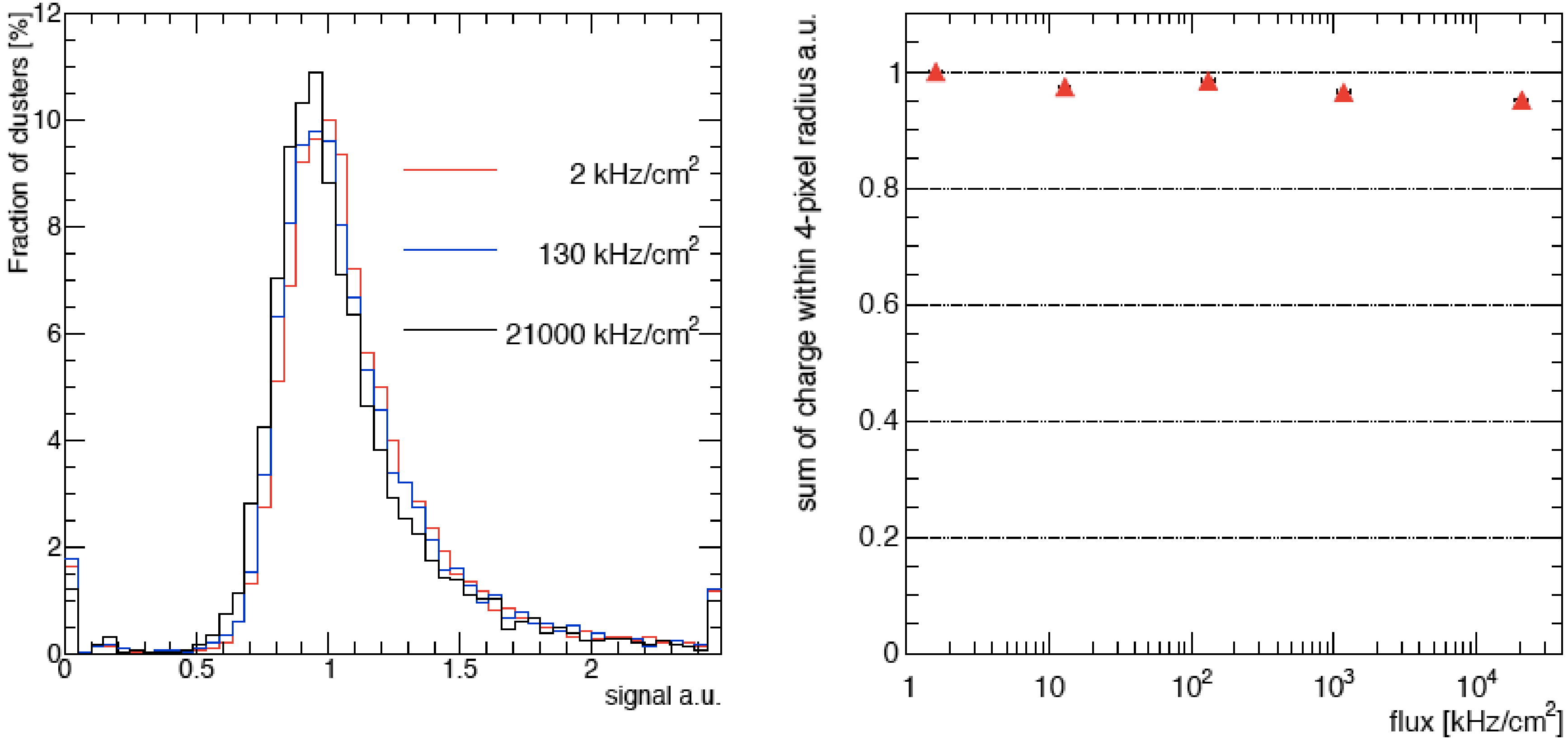
Pulse Height vs. Flux



- scCVD uniradiated and pCVD irradiated show less than few % signal variation up to 3×10^5 Hz/cm^2
- scCVD irradiated with neutrons and in CMS (PLT pilot run 2012) show 10% drop in signal
  - Consistent with signal loss seen in PLT

Pulse Height Variation using Pixel Readout

- Unirradiated scCVD gives robust pulse heights to 20 MHz/cm² in CMS Pixel prototypes



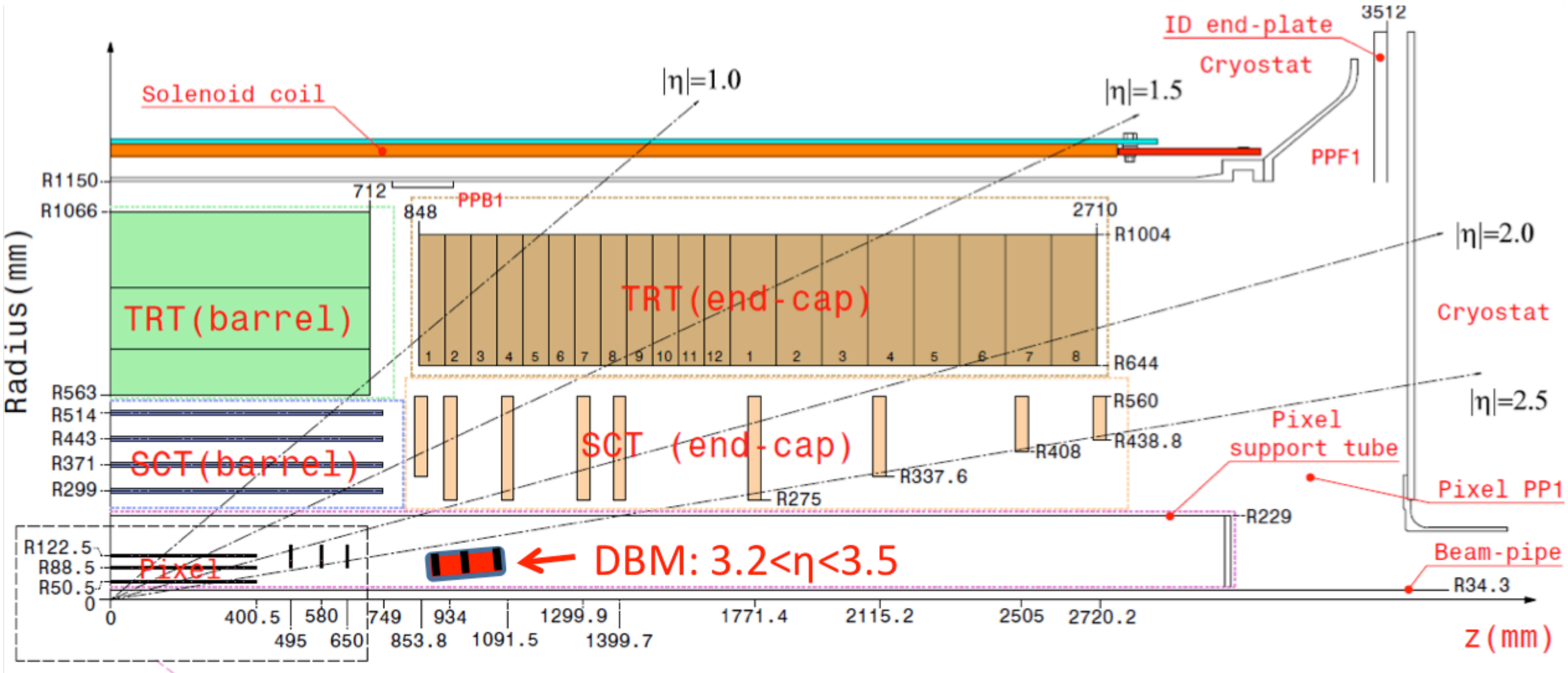
(a) single-crystal, pixel, pulse height spectra (b) single-crystal, pixel, average pulse heights

Diamond Devices for Experiments

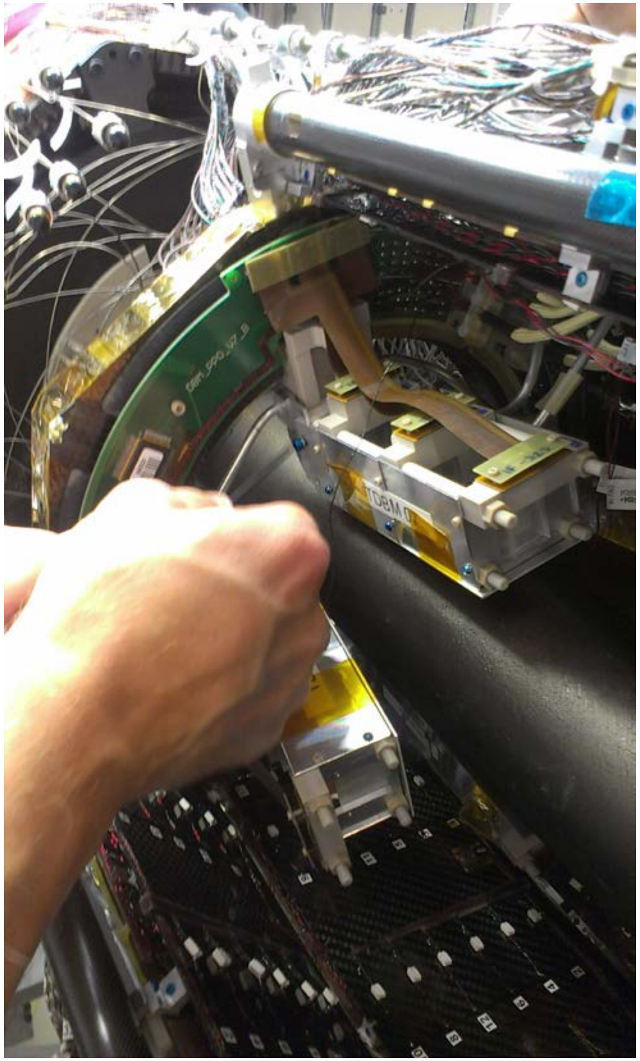
- Beam conditions monitors
  - Alice, ATLAS, CMS, LHCb
- LHC machine BLMs ➔ New for RD42
  - Operating in cryogenic conditions
- Current generation Pixel Detectors
  - ATLAS DBM, CMS PLT
- Future LHC trackers
  - ATLAS, CMS, LHCb
  - 3D diamond devices

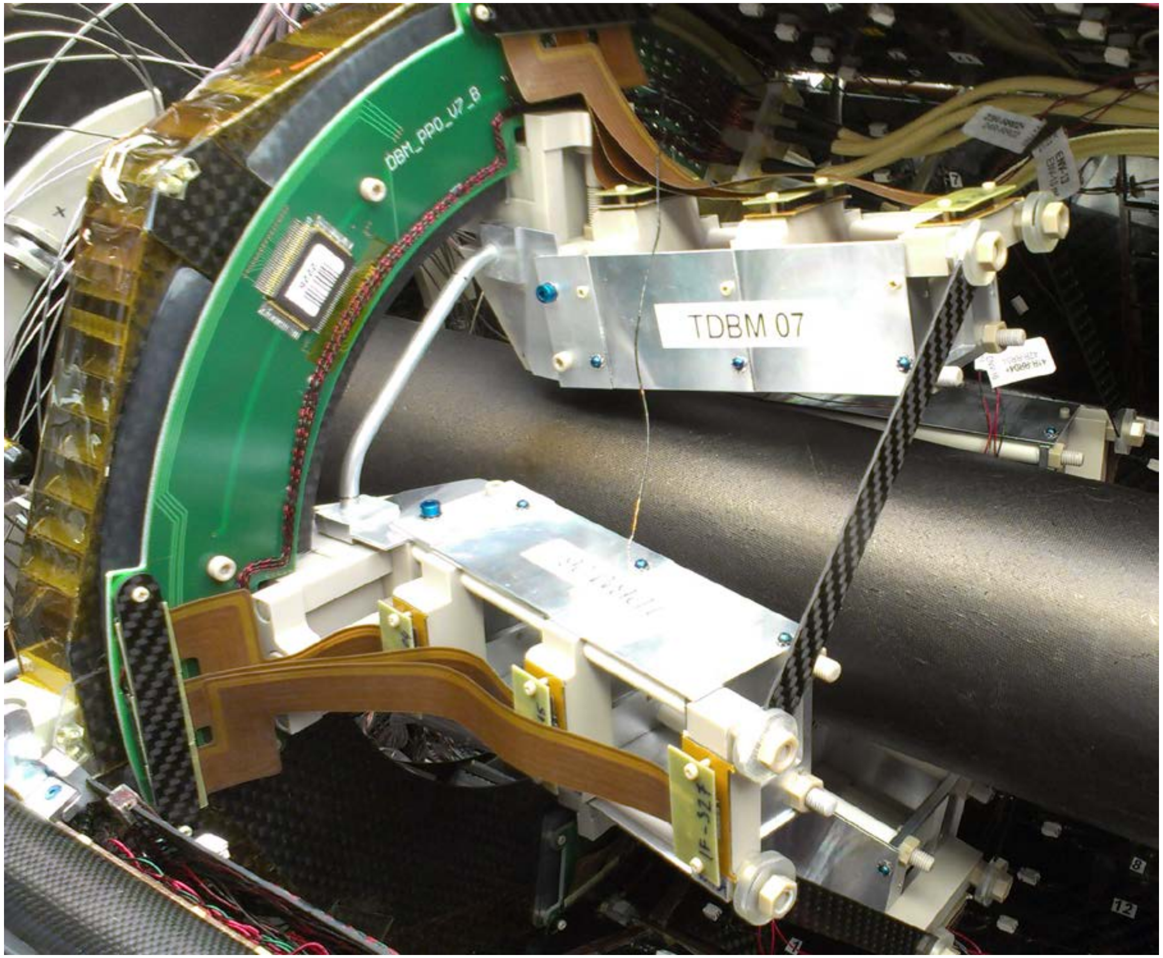
The ATLAS Diamond Beam Monitor

- Build on success of BCM – pixelate the sensors
  - Use IBL demonstrator modules
  - Installed in 2013 during service panel replacement
  - Four 3-plane stations on each side of ATLAS



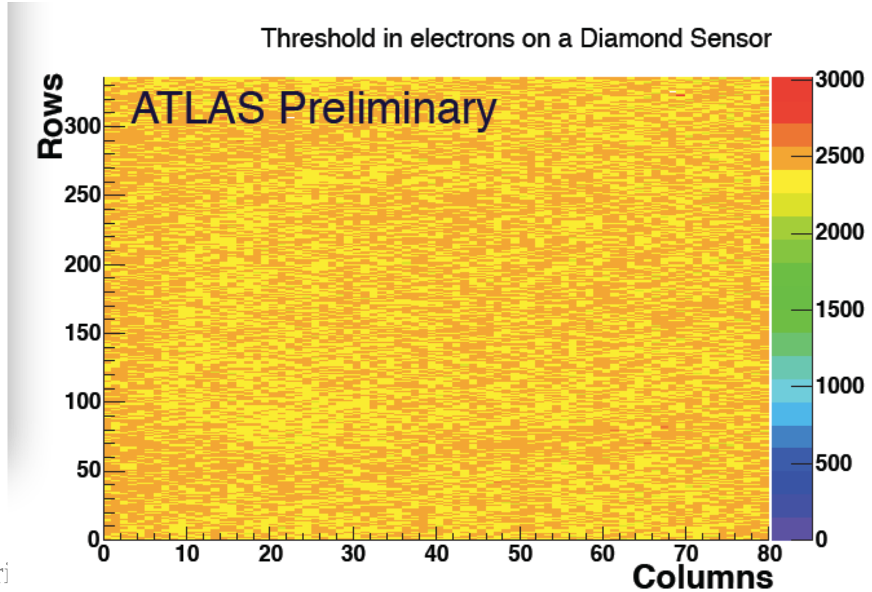
DBM Telescope Installation



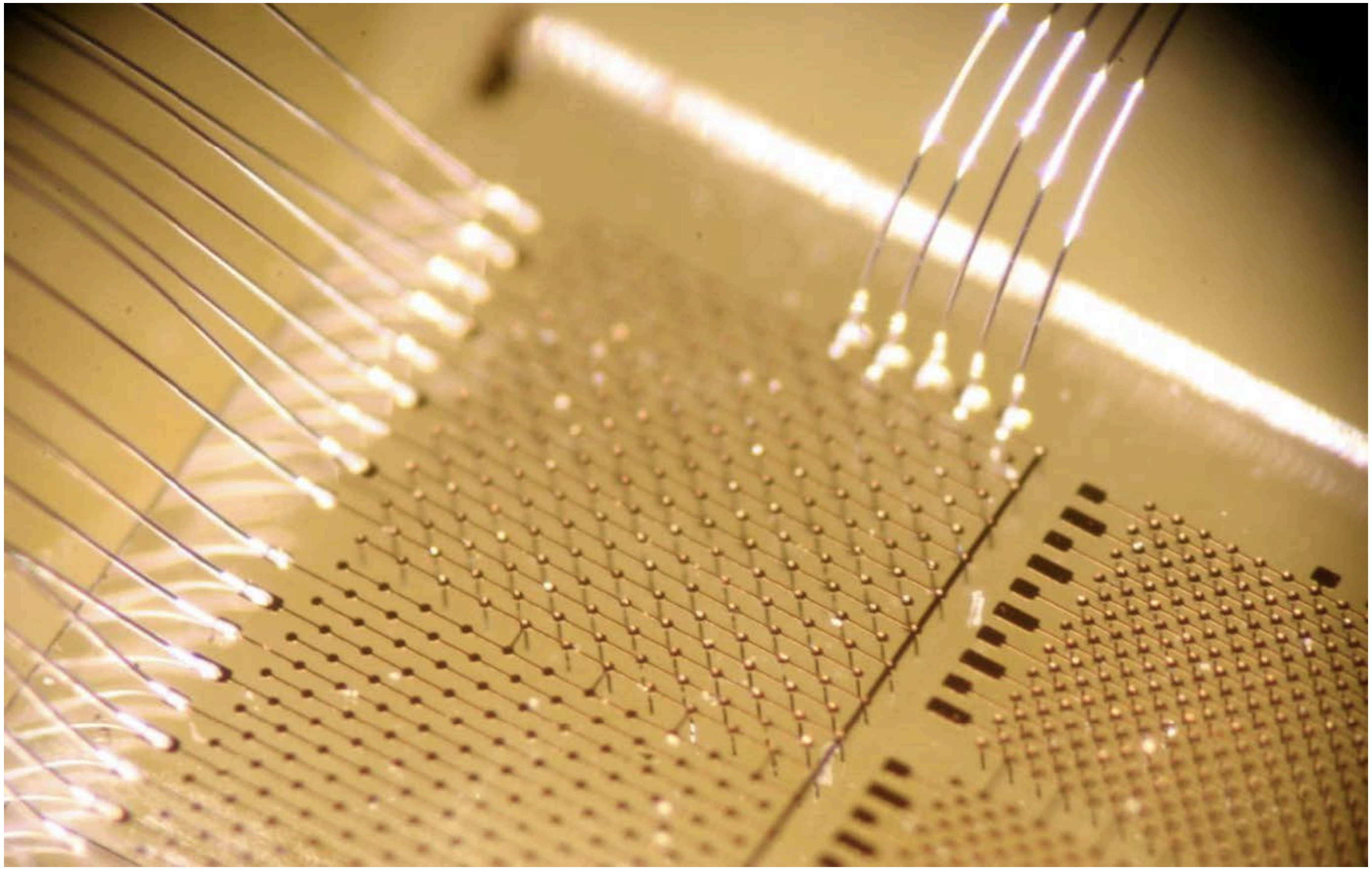


ATLAS DBM Latest News

- Detector being integrated in ATLAS readout
- Thresholds tuned to 2500 electrons (lower than silicon)
  - Want much lower (1100 possible on bench)
- Soon ready for beam

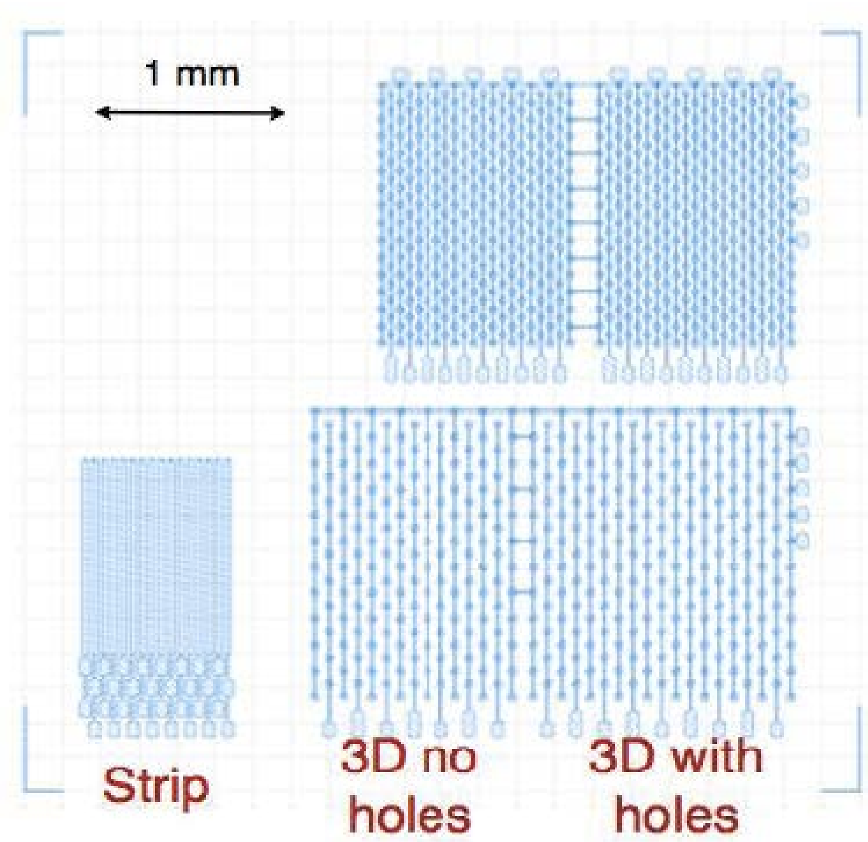


3D Diamond Trackers

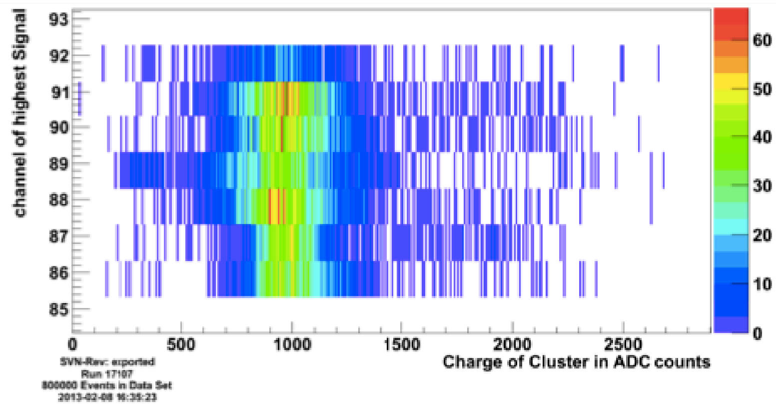


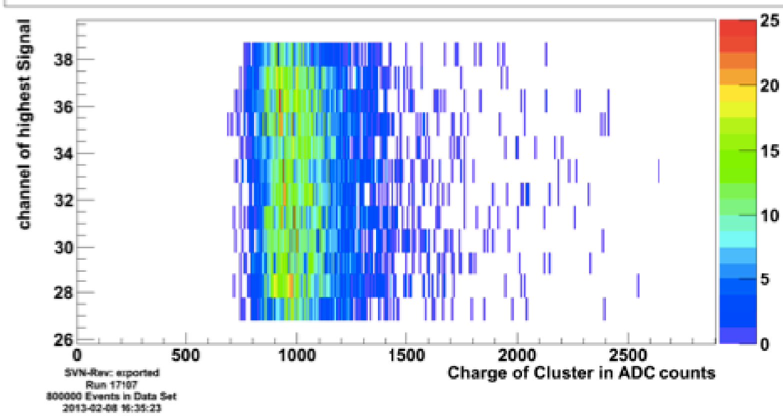
Now published in [NIM A 786 (2015) p97.]

Results from 2012 Testbeam



3D @ 25V

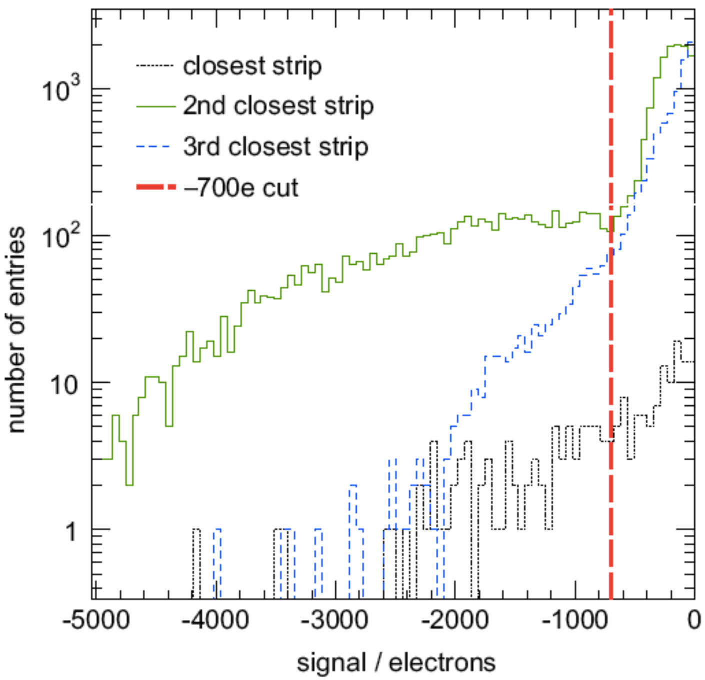


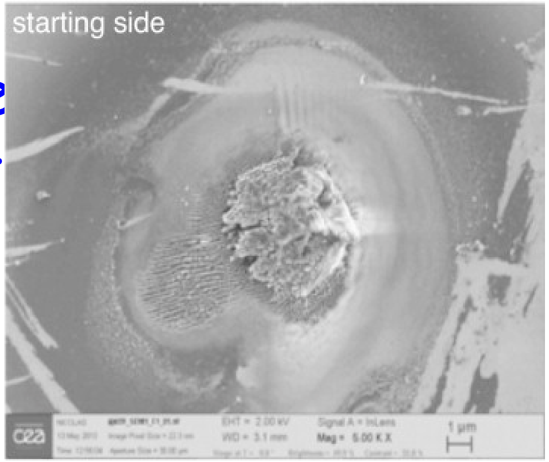


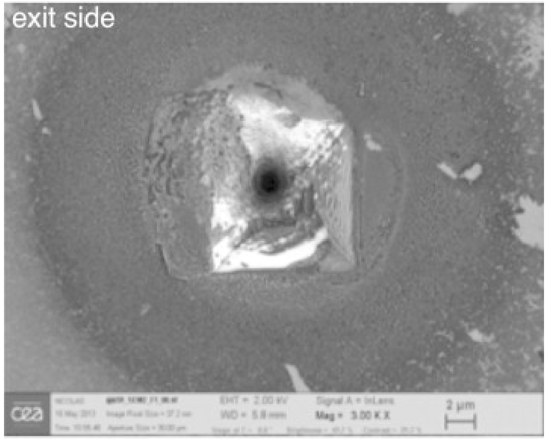
Strips @ 500V

Results from 2012 Testbeam

- Understood origin of negative pulses
  - Due to missing bias columns
- Simulated with Spice
  - Could fix by biasing from back side
  - Need to improve electrical contact with back side of columns

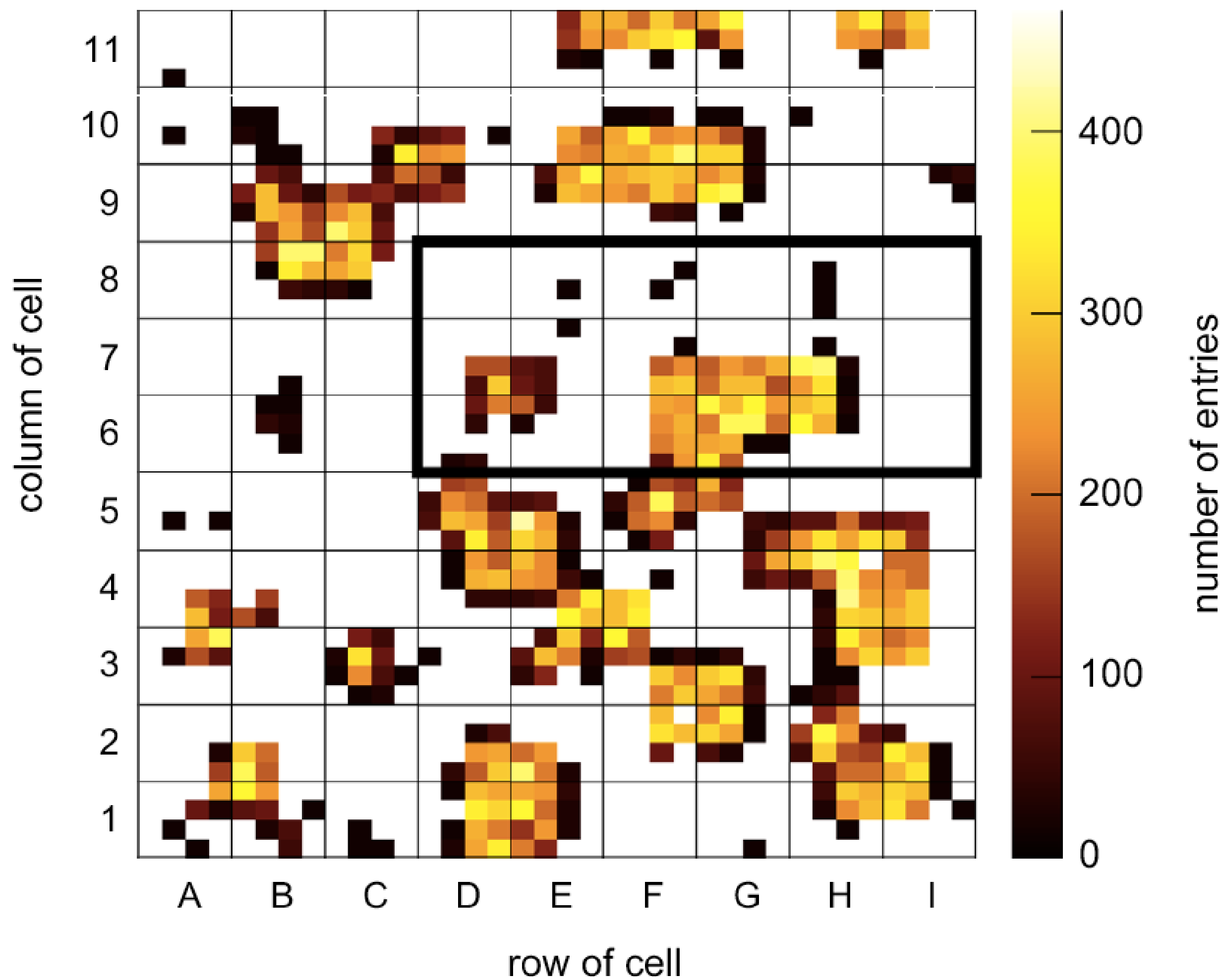






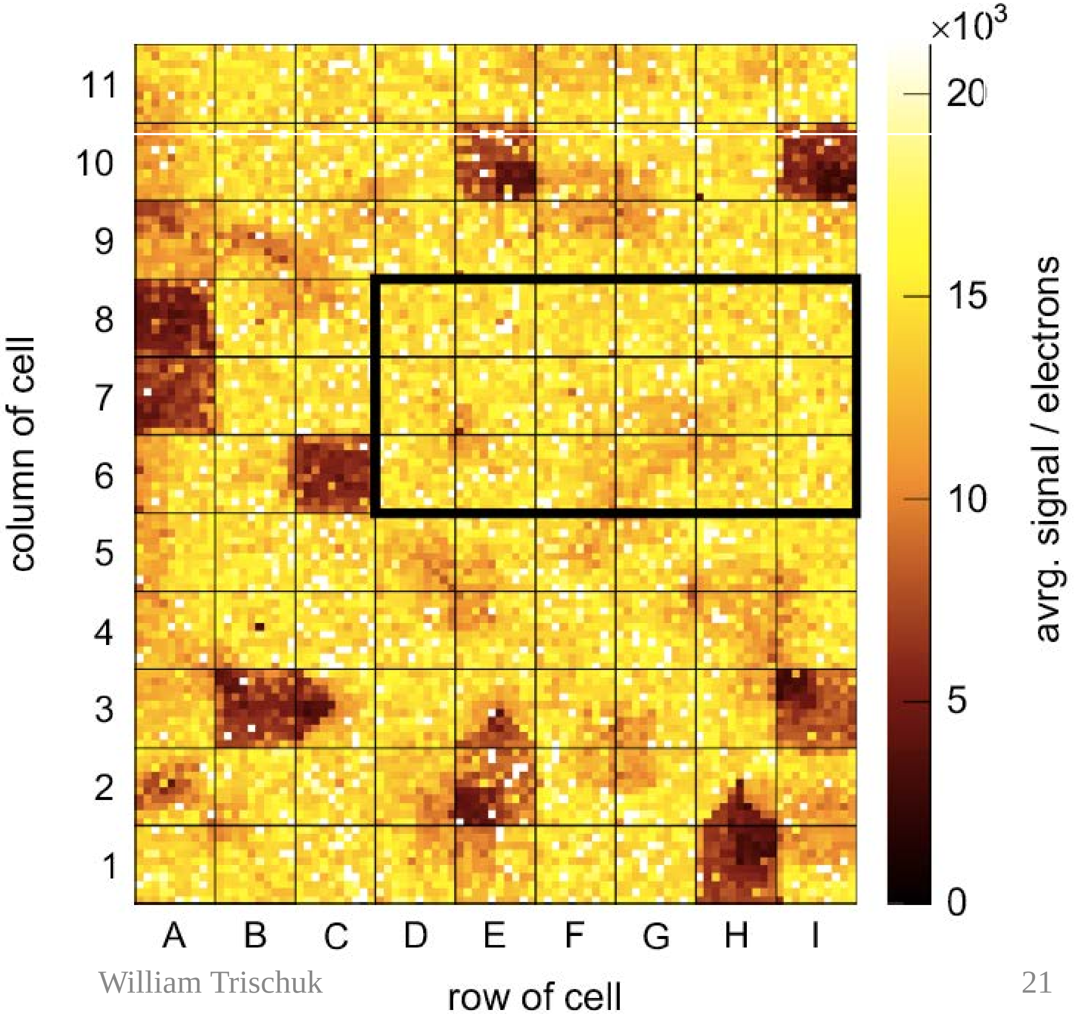
Location of Negative Pulses

- Clustered around ~16 missing bias columns



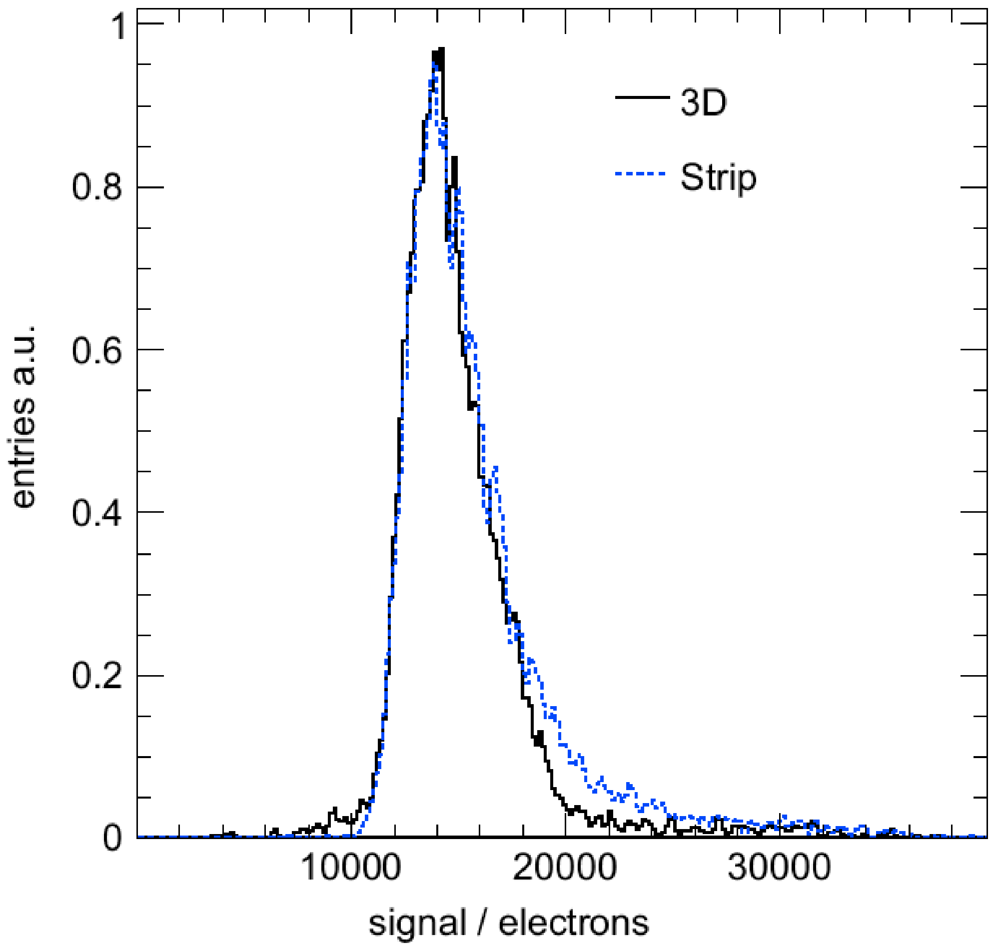
Pulse Height after negative pulses removed

- Missing charge around broken readout columns



Signal Seen in 3D Geometry vs. Planar Geometry

- Remarkable agreement between signal in 3D and planar/strip geometry
  - In good fiducial region, not summing charges < -700e
- 3D sensor @ 25V
- Planar @ 500V



Summary

- Working closely with two new manufacturers
  - II-VI has delivered even higher quality pCVD material
  - IIa is producing better scCVD samples than E6
- Quantifying understanding of high rate effects on diamond
  - pCVD appears immune to these effects
- ATLAS-DBM will soon see first collisions
  - Abort, luminosity and background functionality in all LHC expts
- First pixel project is about to start taking data
  - ATLAS DBM being commissioned prior to 13 TeV collisions
- 3D prototypes show great promise
- Published two important results for future diamond systems
- RD42 played a pivotal role in making all this happen

RD42 Research Priorities for 2015-16

- Continue to expand diamond manufacturer production capabilities.
- Perform beam tests with diamond strip and pixel detectors.
- Continue to support LHC upgrade pixel projects.

Request of CERN LHCC

The RD42 Role at CERN

- Irradiations, development of new manufacturers, sample procurement, ~~test beams~~2013
- Central facilities for all experiments ➔ this worked for BCM's
- CERN Group in RD42 to be maintained

RD42 Request to CERN/LHCC

- RD42 is supported by many national agencies:
  - ➔ continuation of official recognition by CERN critical
  - ➔ ~200kCHF from outside CERN
- RD42 requires access to CERN facilities:
  - ➔ maintain the present 20 m^2 of lab space (test setups, detector prep, ...)
  - ➔ maintain present office space
  - ➔ test beam time (2014++) critical for next generation of proposals

RD42 & CERN play a critical role in diamond development