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

RD42 Status Report

W. Trischuk
for the RD42 Collaboration

LHCC Meeting – June 12, 2013

Outline of Talk

- RD42 Collaboration
- LHCC Milestones 2012
- New Manufacturer
- Radiation Hardness
- Applications in Experiments
- Plans and Request

The 2013 RD42 Collaboration

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◇ Spokespersons

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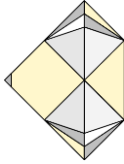
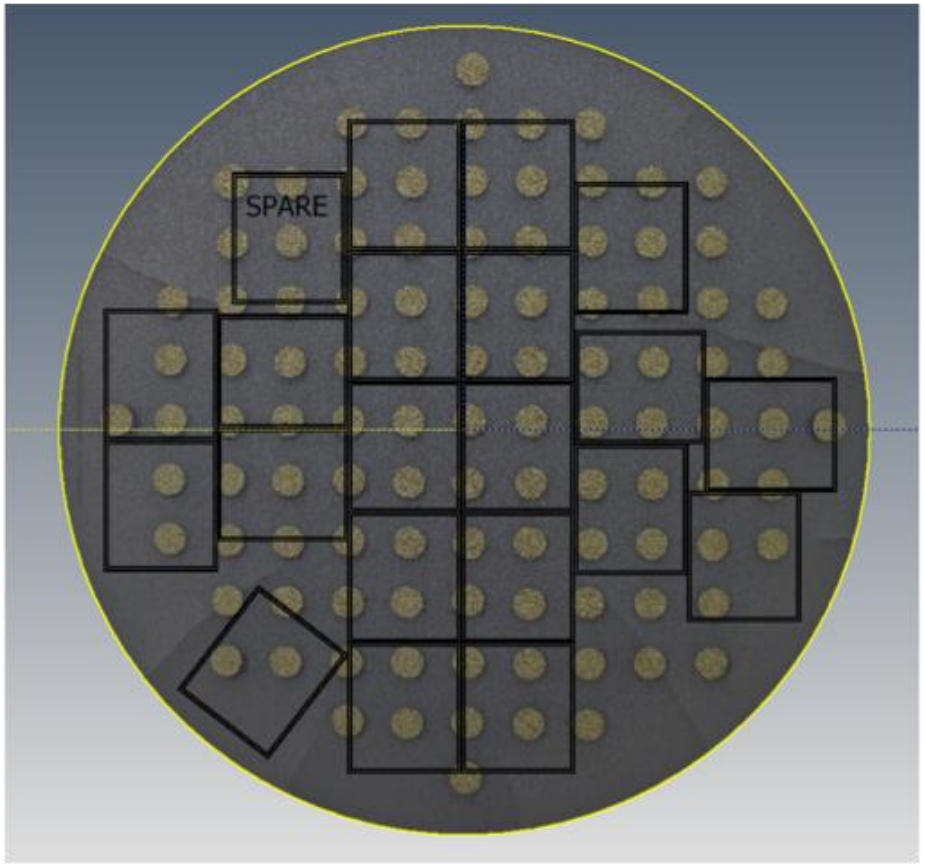
LHCC Milestones/Priorities of Research-2012

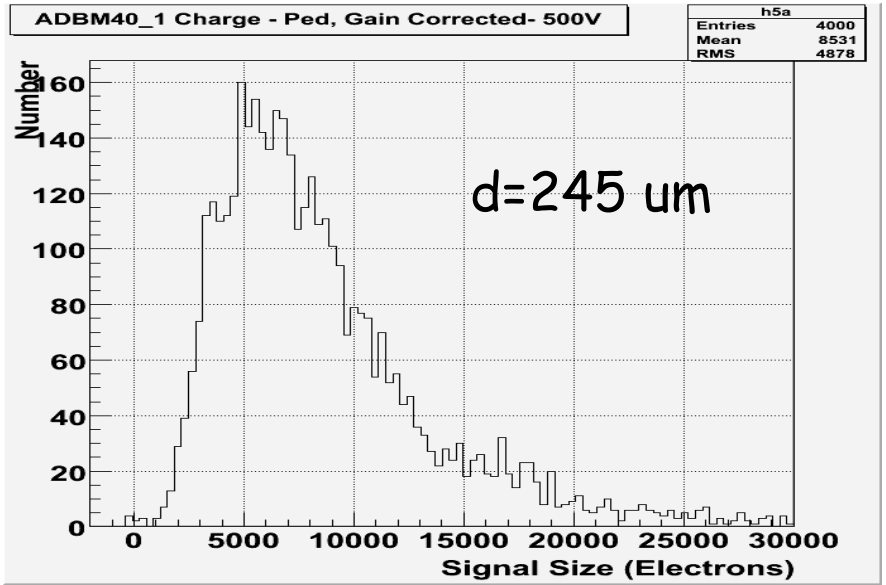


- Continue the development of pCVD and scCVD material.
- Expand sensor grade manufacturing capability for use at LHC.
- Test radiation hardness of highest quality pCVD and scCVD diamonds
- Develop diamond pixel modules for LHC experiments. Industrialize module production.

Development of Diamond Supplier: II-VI

- All large samples this year from II-VI
  - 26 ATLAS DBM sensors arrived over last few months
  - 20 CMS sensors will be delivered soon
- All of these will be made into Pixel modules





Relationship between CCD and MFP

When CCD approaches thickness use Mean Free Path

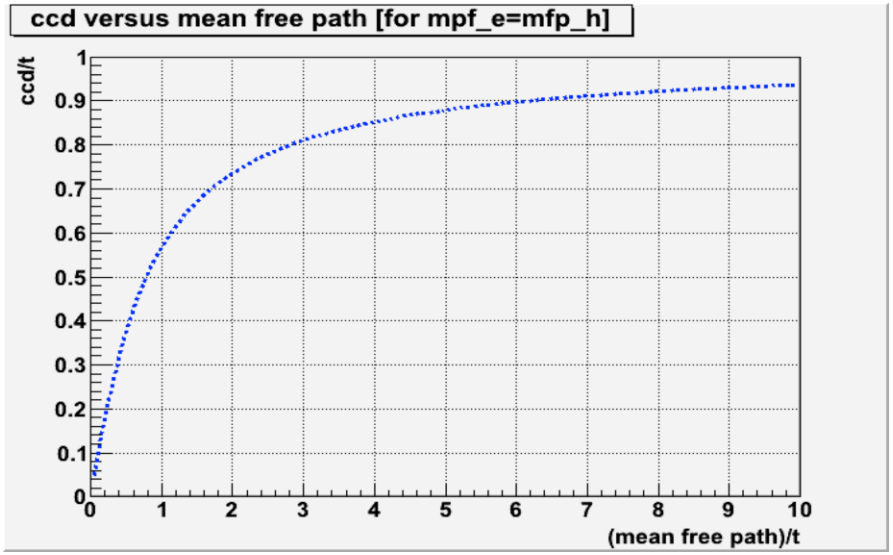
$$\frac{1}{\text{mfp}} = \frac{1}{\text{mfp}_0} + k_{\text{mfp}}\,\phi$$

Relation between CCD and Mean Free Path:

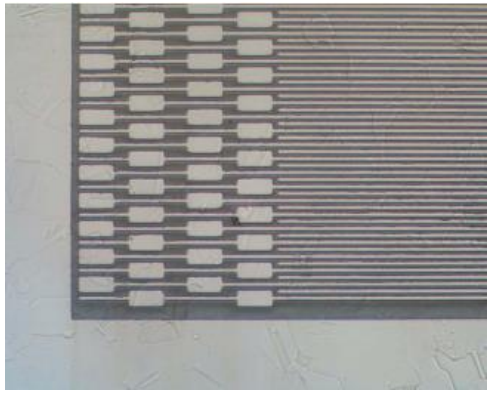
$$\frac{\text{ccd}}{t} = \sum_{i=e,h} \frac{\text{mfp}_i}{t}\left[1 - \frac{\text{mfp}_i}{t}\left(1 - e^{-\frac{t}{\text{mfp}_i}}\right)\right]$$

In what follows assume:

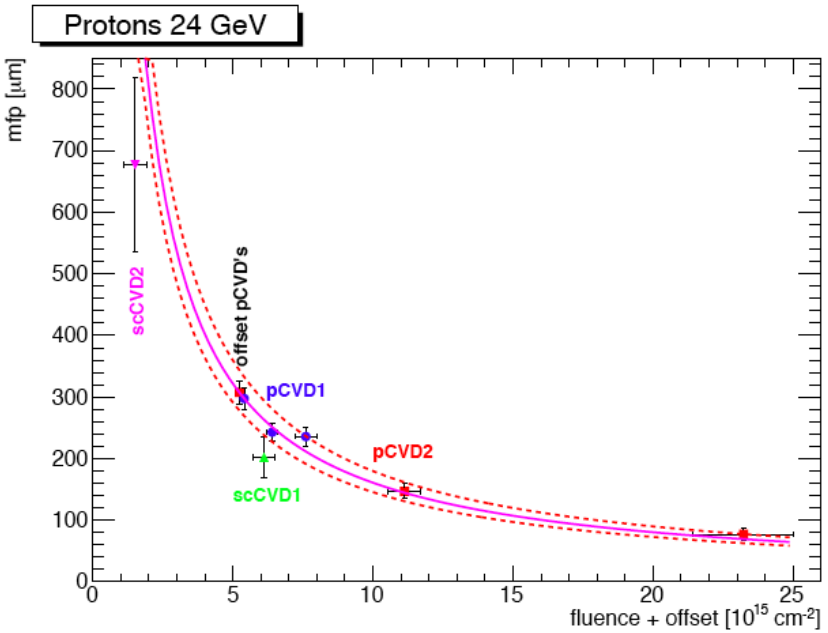
$\text{mfp}_e = \text{mfp}_h$



Radiation Damage Fits to 24 GeV Protons



$$\frac{1}{\text{mfp}} = \frac{1}{\text{mfp}_0} + k_{\text{mfp}}\,\phi$$



Test beam data

- mfp_0 initial traps in the material, k is the damage constant
- Test beam data shown
- Single-crystal CVD and poly CVD fall along the same damage curve
- Damage constant stable: $k_{\text{mfp}} \sim 0.63 \pm 0.06 \times 10^{-18}\ \mu\text{m}^{-1}\text{cm}^{-2}$

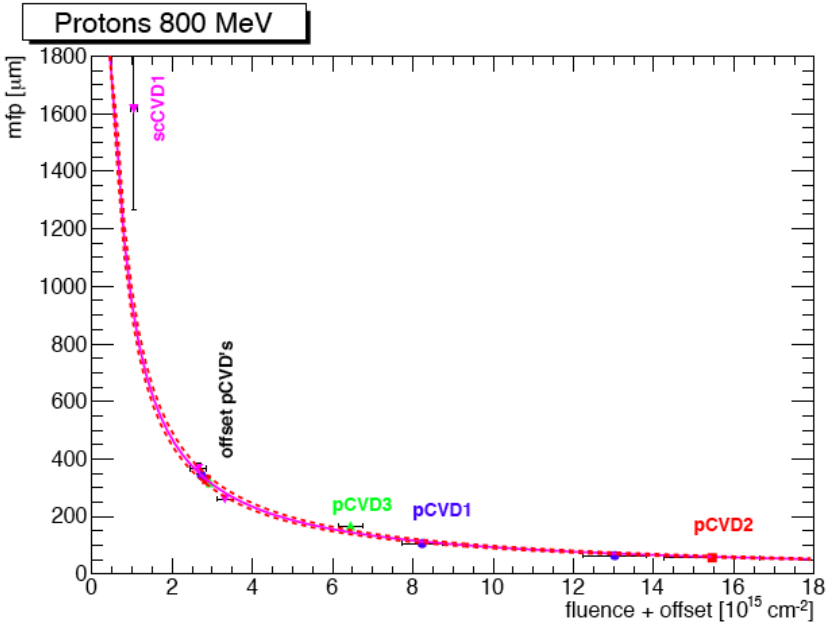
Radiation Damage Fits to 800 MeV Protons

Recent Irradiation with 800 MeV protons at LANSCE Facility in Los Alamos, US

- Result: 800 MeV protons 1.7+/-0.1 times more damaging than 24 GeV protons:

$k_{mfp} \sim 1.07+/-0.05 \times 10^{-18}\ \mu m^{-1} cm^{-2}$

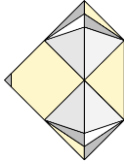
- Displacement per Atom best model of damage in diamond



M.Mikuž, RD42, CERN, May 24, 2013

Final Testbeam Results

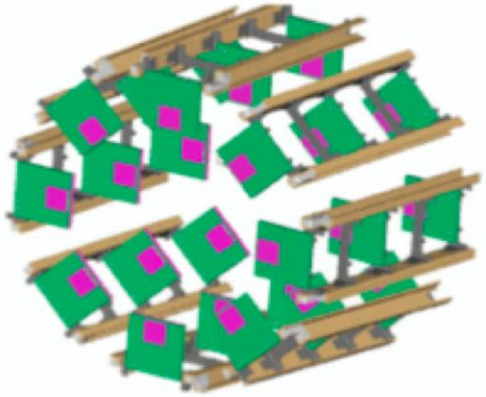
Diamond Devices for Experiments

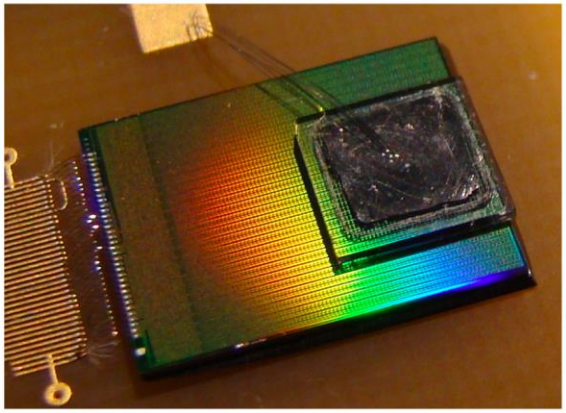


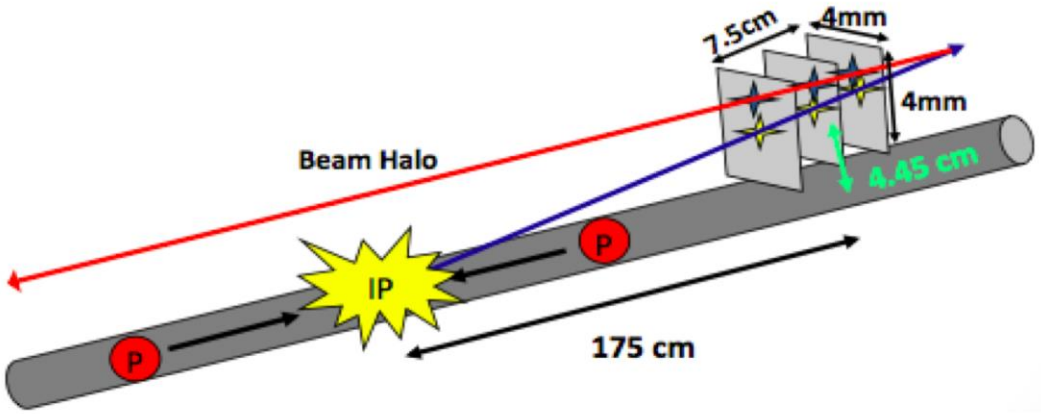
- Beam conditions monitors
  - Alice, ATLAS, CMS, LHCb
- LHC machine BLMs ➔ New for RD42
  - Operating in cryogenic conditions
- Current generation Pixel Detectors
  - CMS PLT, ATLAS DBM
- Future LHC trackers
  - ATLAS, CMS, LHCb
  - 3D diamond devices

PLT Overview

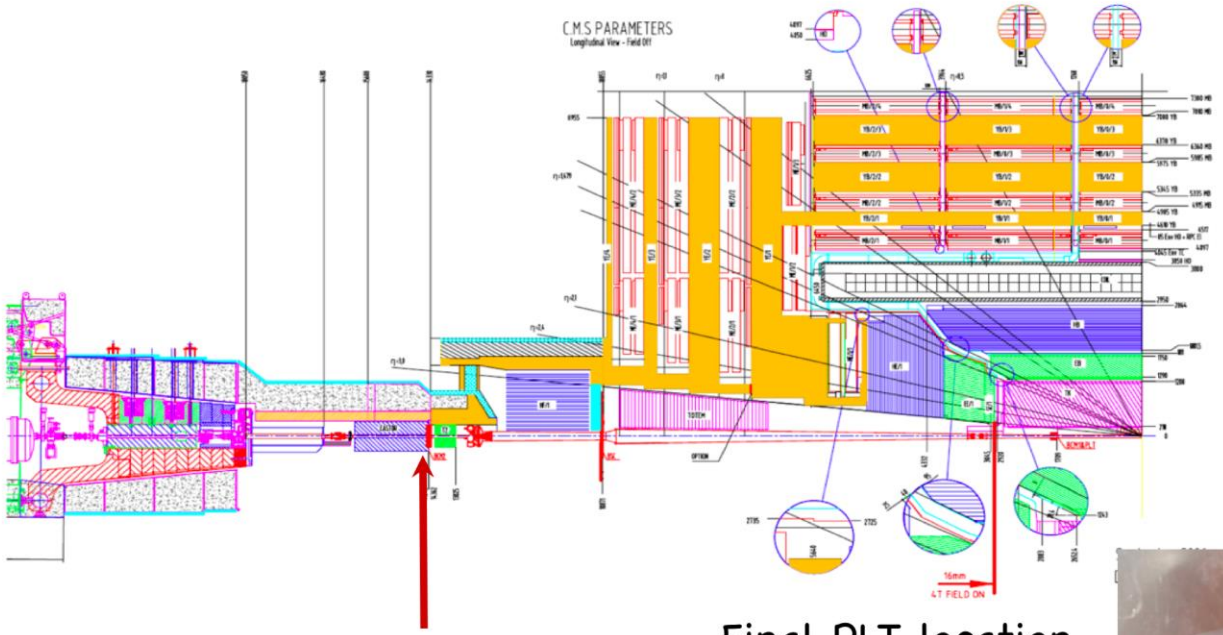
- Dedicated stand-alone luminosity monitor
- High precision bunch-by-bunch luminosity
- Array of eight 3-plane telescopes each end of CMS
- Single-crystal diamond pixel sensors
- Measure bunch-by-bunch 3-fold coincidence rate
- Pixel readout for tracking and diagnostics





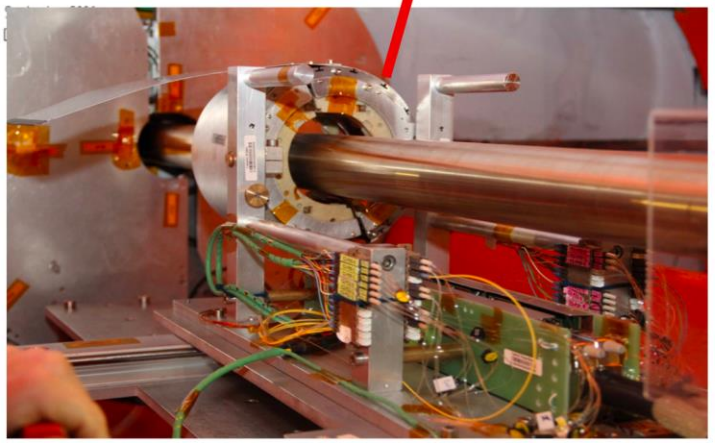


PLT Pilot Run



Pilot run location

Final PLT location



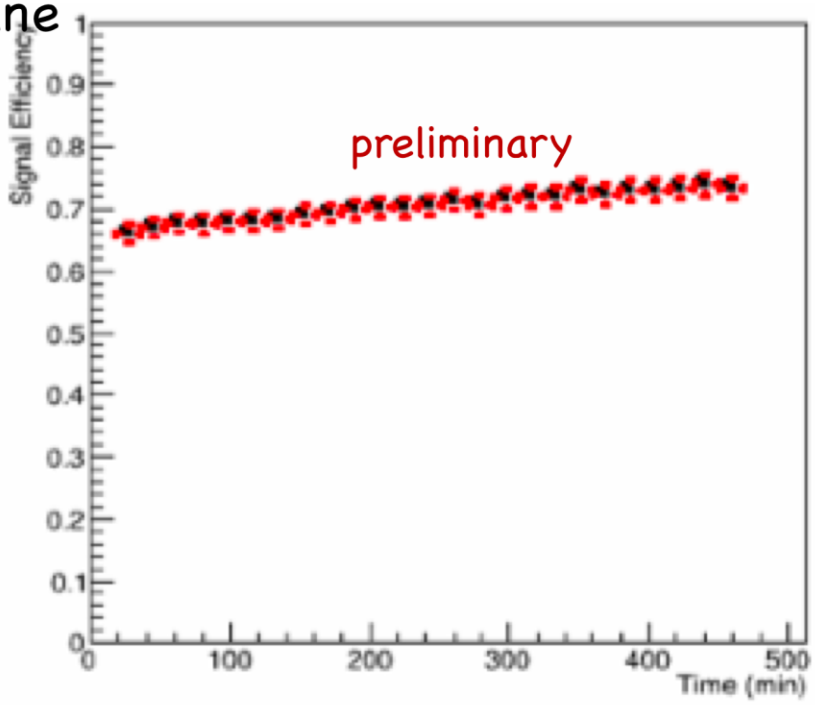
14.5 m from IP eight times
further than nominal location

Total exposure of about 20 fb^{-1}

PLT Performance in Pilot Run

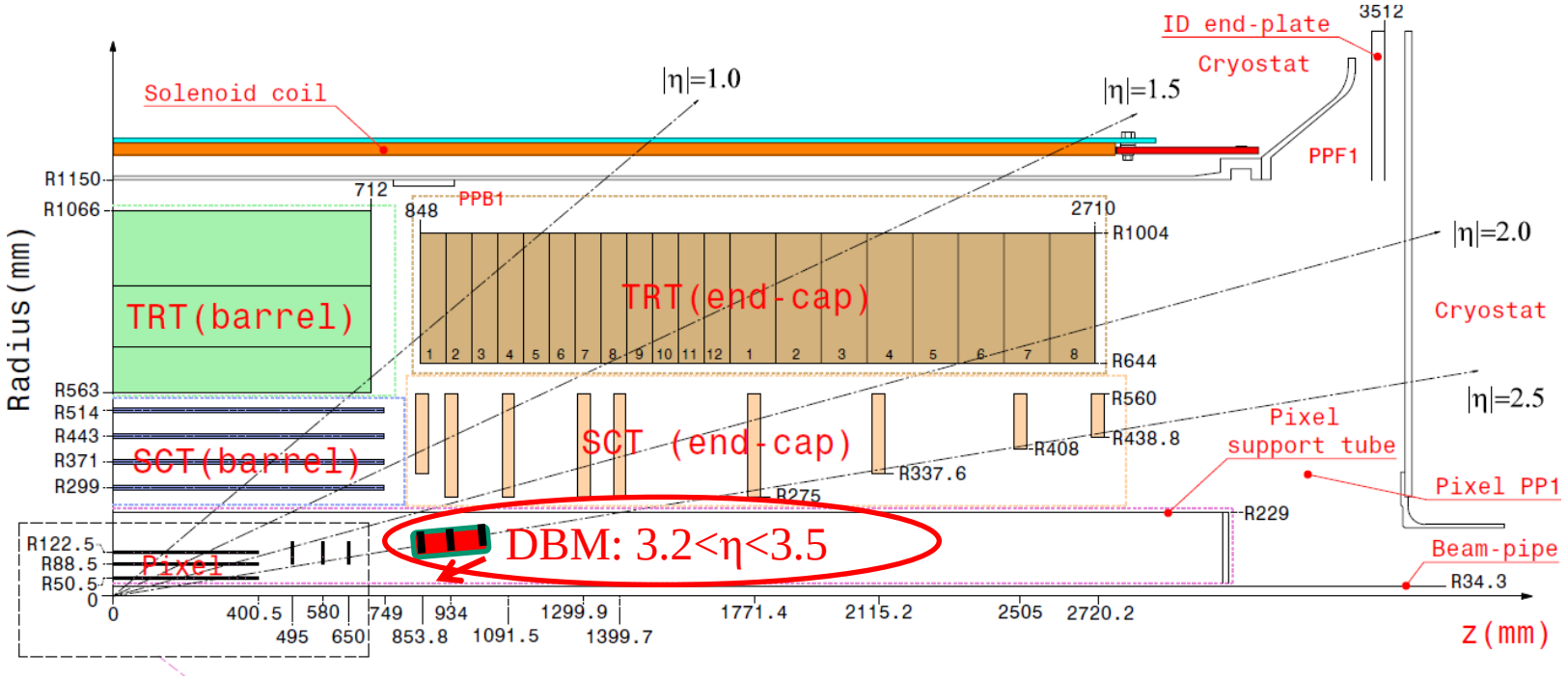
- Efficiency stable during fill
- About 5% increase over a few hours
- Readily monitored and corrected for
- Efficiency about 70% for single plane
- 30% for 3-plane track

- Improved efficiency seen with surface treated sensors
- Applying to all sensors now
- Then re-bond to new ROCs
- Install PLT at nominal location for 2015 running



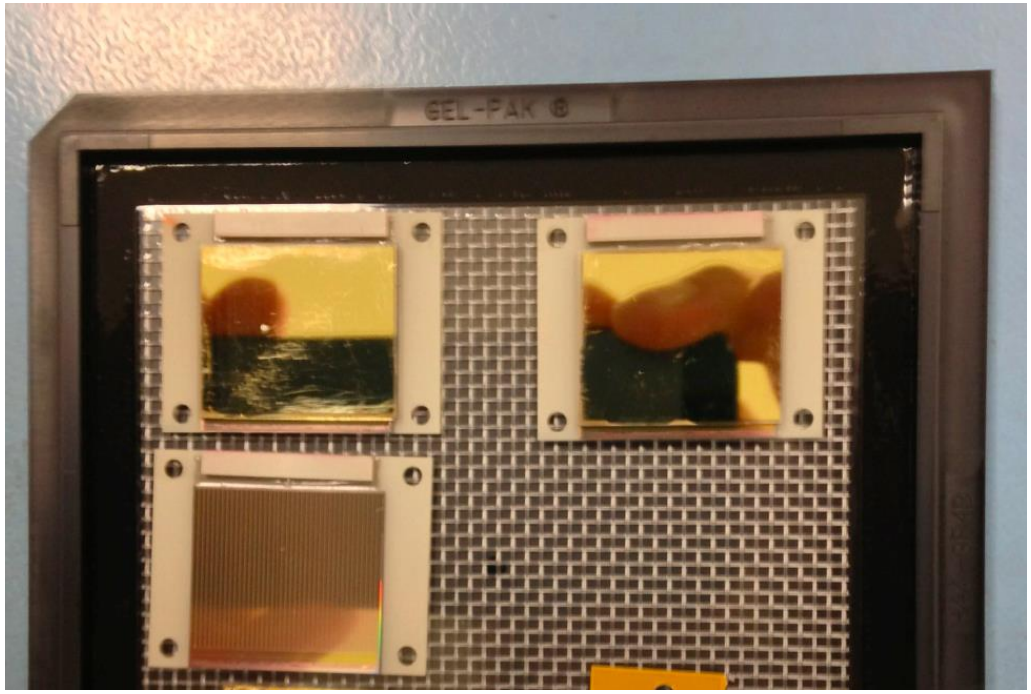
The ATLAS Diamond Beam Monitor

- Build on success of BCM – pixelate the sensors
  - Use IBL demonstrator modules
  - Installing now during service quarter panel
  - Four 3-plane stations on each side of ATLAS

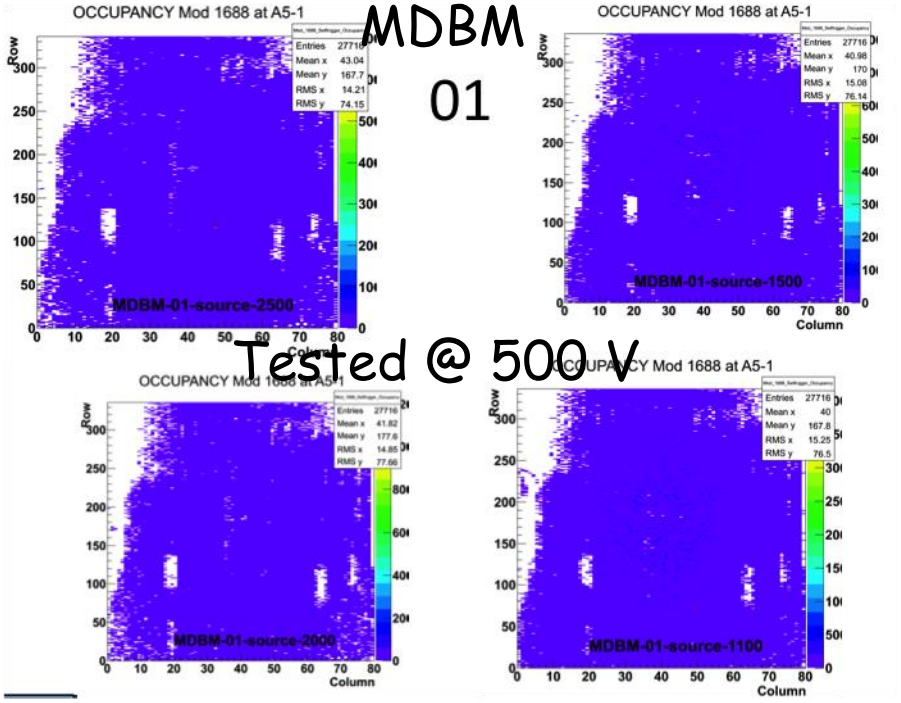


ATLAS DBM Module Production

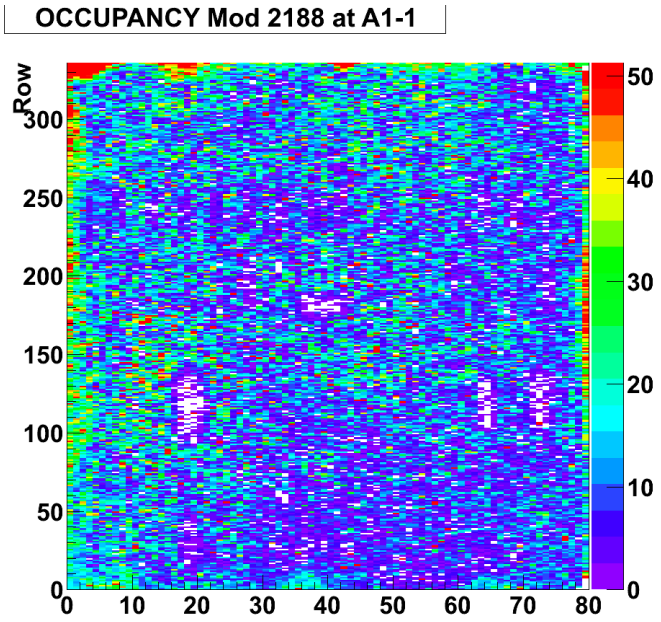
- IZM has all DBM sensors now
- Still learning to bump-bond reliably
- Expect 30 modules in time for installation this summer
- More than half of these will be from II-VI



ATLAS DBM Source Scans



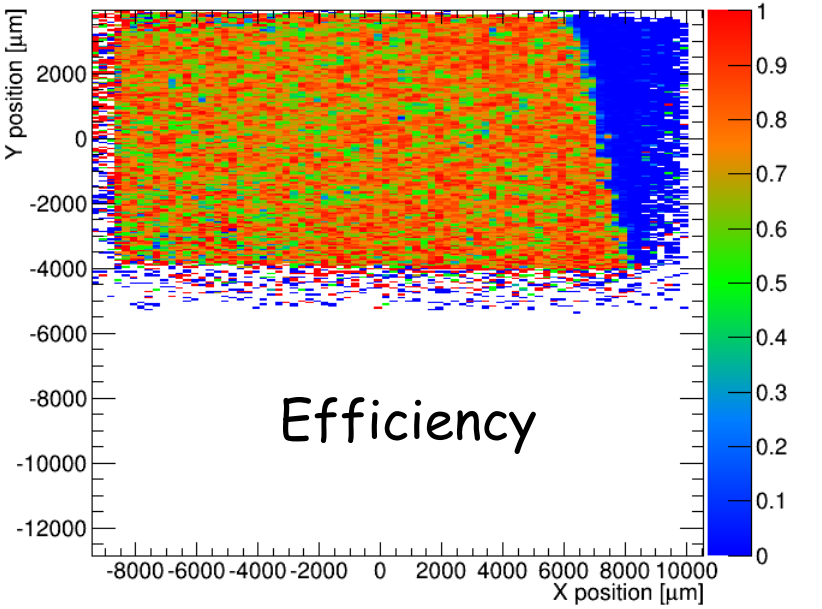
MDBM 08

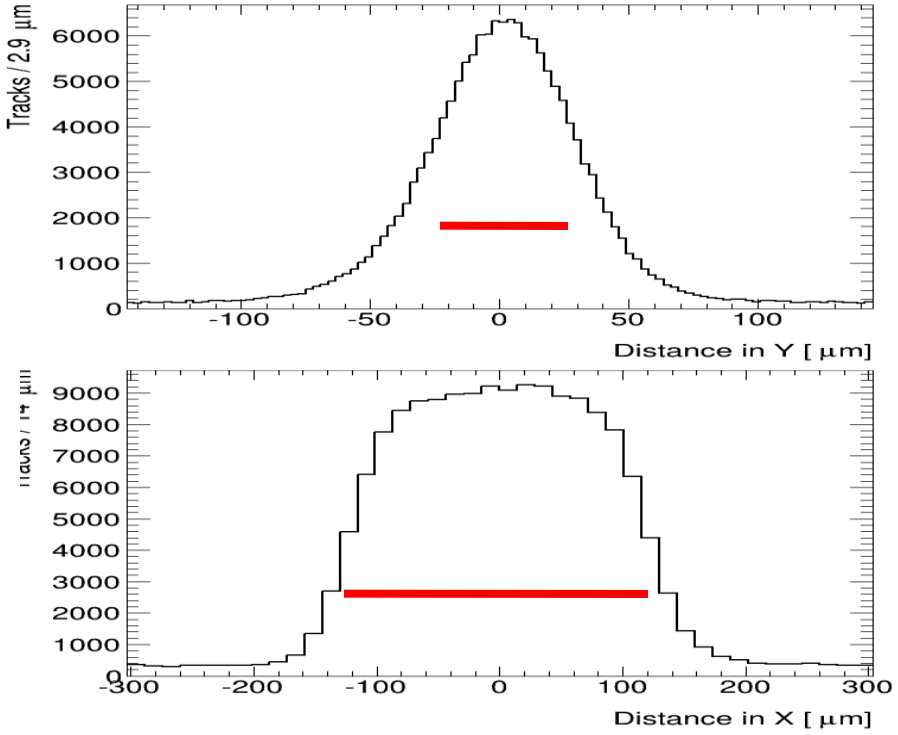


- First modules showed some missing corners
  - Differential thermal expansion during bumping?
- Recent modules show all pixels connected

ATLAS DBM DESY Testbeam

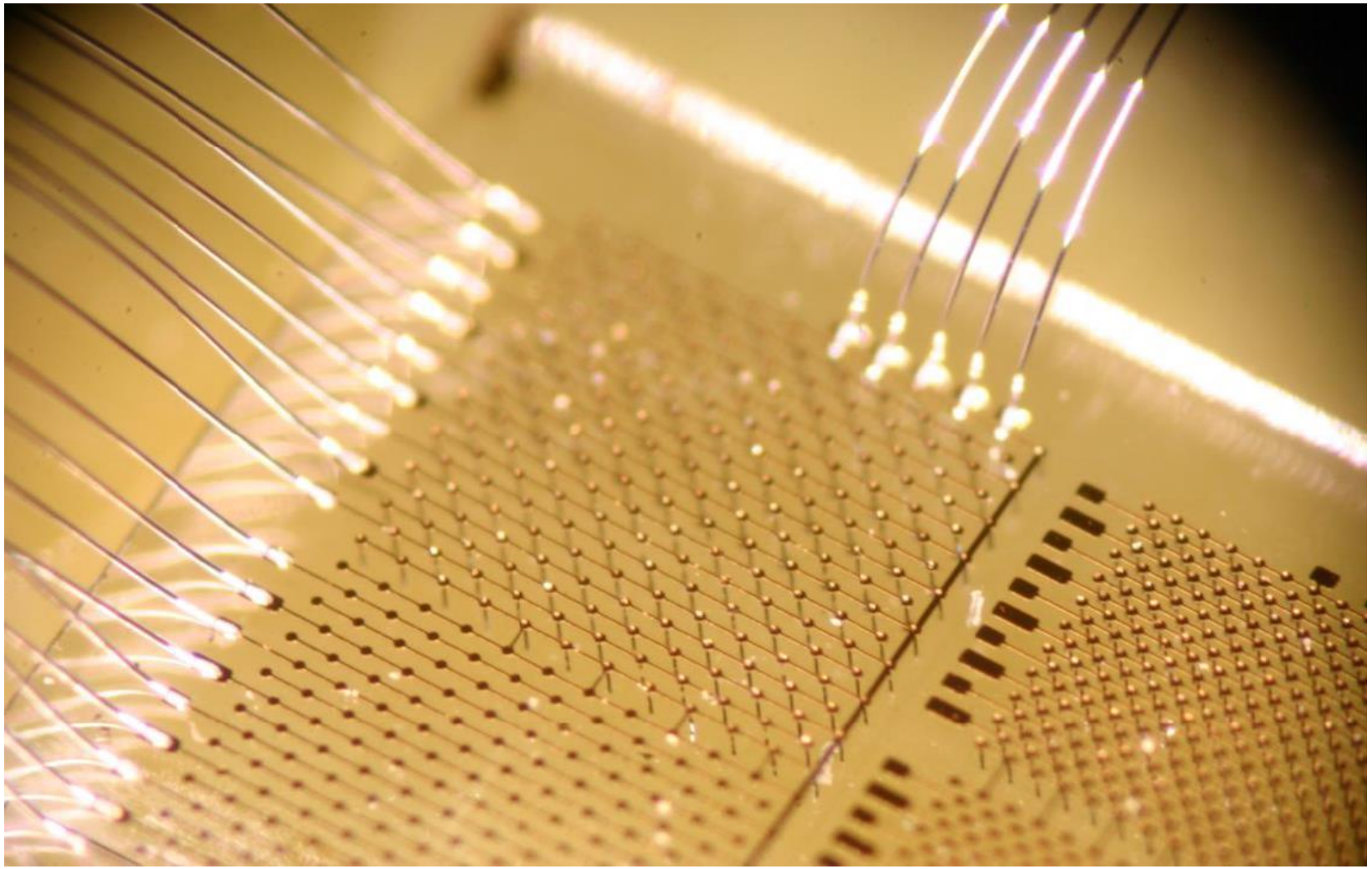
- MDBM-01 in 5 GeV electron beam at DESY
- 1100 electron threshold but only 600V
- Beam only populated top half of detector



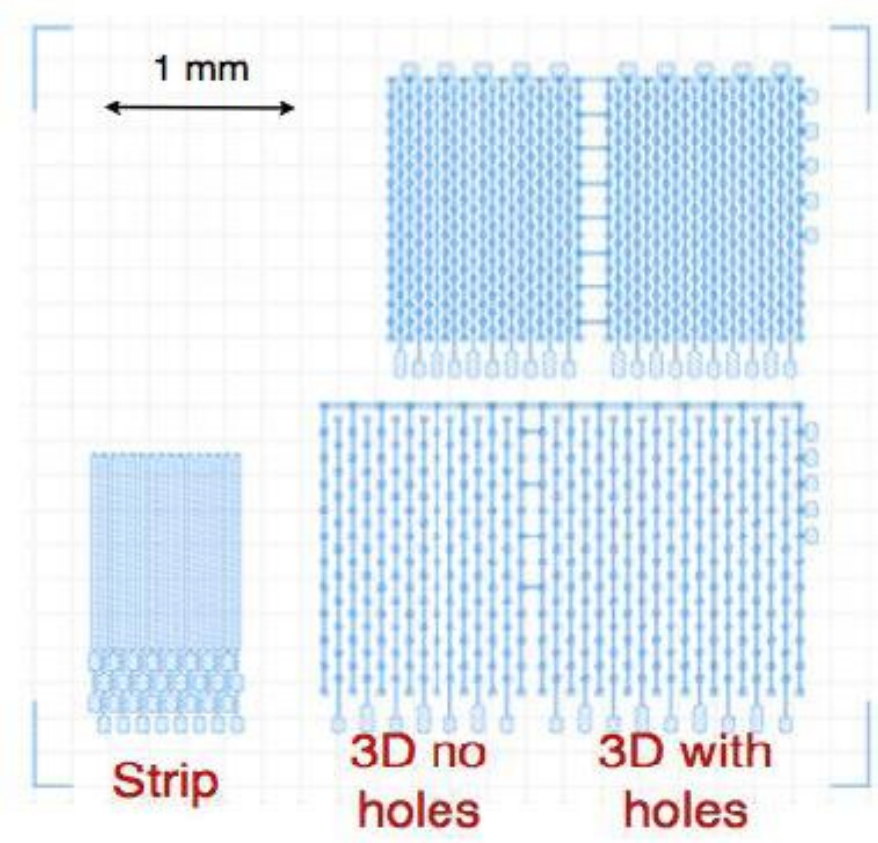


Hit residuals (pixel width)

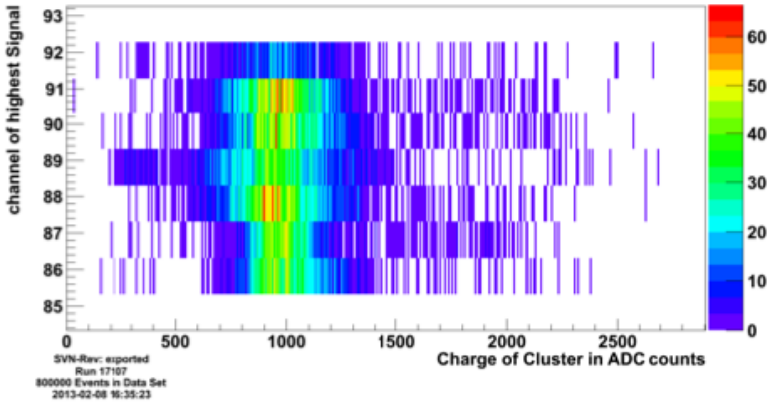
3D Diamond Trackers

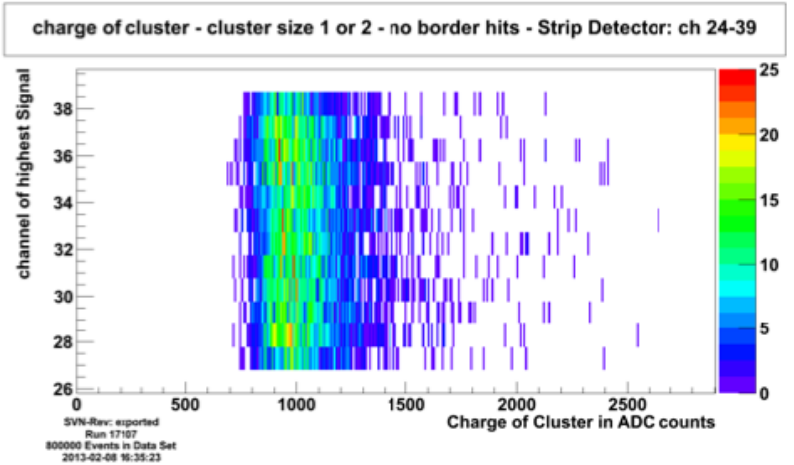


Results from 2012 Testbeam



3D @ 25V



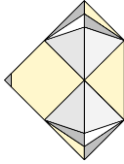


Strips @ 500V

Summary

- Large number of high quality parts are being produced
  - New manufacturer (II-VI) has delivered 26 DBM sensors
- Radiation hardness of CVD diamond is nearly quantified
  - pCVD and scCVD have the same damage constant
  - Now studying detector position resolution as a function of dose
- Devices in experiments working very well
  - Abort, luminosity and background functionality in all LHC expts
  - Building on this experience to expand coverage into LHC machine
- First pixel projects nearing completion
  - CMS PLT had a successful trial run in 2012
  - ATLAS DBM mounted in pixel package in the coming months
- 3D prototypes show great promise
- RD42 played a pivotal role in making this happen

RD42 Research Priorities for 2013



- Continue to expand diamond manufacturer production capabilities.
- Perform beam tests with diamond strip and pixel detectors.
- Characterize irradiated samples in test beams and compare the results to silicon and DpA hypothesis for pions and neutrons.
- 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
  - ➔ 25kCHF from CERN matching ~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