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

RD42 Status Report

Harris Kagan
for the RD42 Collaboration

LHCC Meeting – May 25, 2016

Outline of Talk

- The RD42 Collaboration
- The RD42 Program
- Development of Material and Production Capabilities
- Diamond Devices in the LHC and Experiments
- Diamond Device Development – 3D Diamond
- Rate Studies
- Summary

The 2016 RD42 Collaboration

The 2016 RD42 Collaboration

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31 Institutes

The RD42 Program, Publications, and more

Areas of work in RD42:

- Characterization of diamond (materials work)
- Work with manufacturers (feedback)
- Development of machine devices (BLM, lumi)
- Development of detectors (pad, strip, pixel, 3D)
- Irradiation (JSI,LANL) and Beam tests (CERN, PSI)

RD42 meetings: https://indico.cern.ch/category/3177/

- 11 published papers in the last year
- 11 conference talks in the last year
- 3 Ph.D. students graduated in the last year
- 11 Ph.D. students continuing in 2016

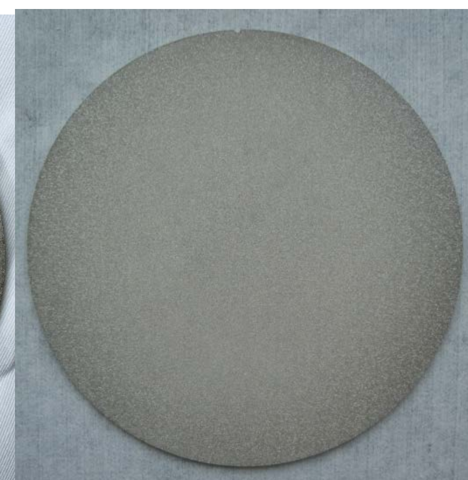
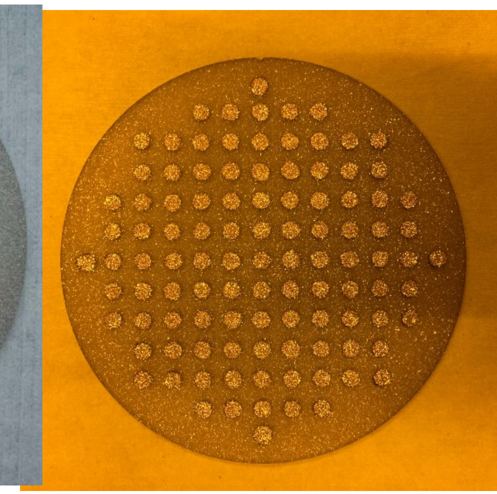
LHCC Milestones/Priorities of Research-2015

- Continue to develop pCVD and scCVD material.
- Expand sensor grade manufacturing capability.
- Beam tests of the highest quality material.
- Test radiation tolerance and rate tolerance of highest quality pCVD and scCVD material.
- Develop diamond devices for the LHC (BLM's) and LHC experiments (pixel detectors, lumi).
- Develop diamond devices for future HL-LHC experiments (3D diamond devices) and machine.
- Record publications/talks/theses/students

Development of material and production

- E6/II-VI provided first sensors for ATLAS DBM in 2013
  - 200-225um collection distance
- Wafer production capabilities expanded/higher quality
  - 300-325um collection distance in production
  - 400um goal in sight!



Diamond devices in the LHC

Plan

1. Cryogenic BLMs
2. Fast diamond BLMs

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Diamond devices in the LHC

Fast diamond BLMs

* 2015 LHC beam commissioning
  * **high injection losses** were observed at the LHC internal beam absorber blocks (TDI) in IP2 and IP8.
  * Theses losses reached up to **90% of the dump threshold** of the respective beam loss monitors (BLM).
* **Diamond based particle detectors** are installed downstream of the TDIs in the injection regions of the LHC.

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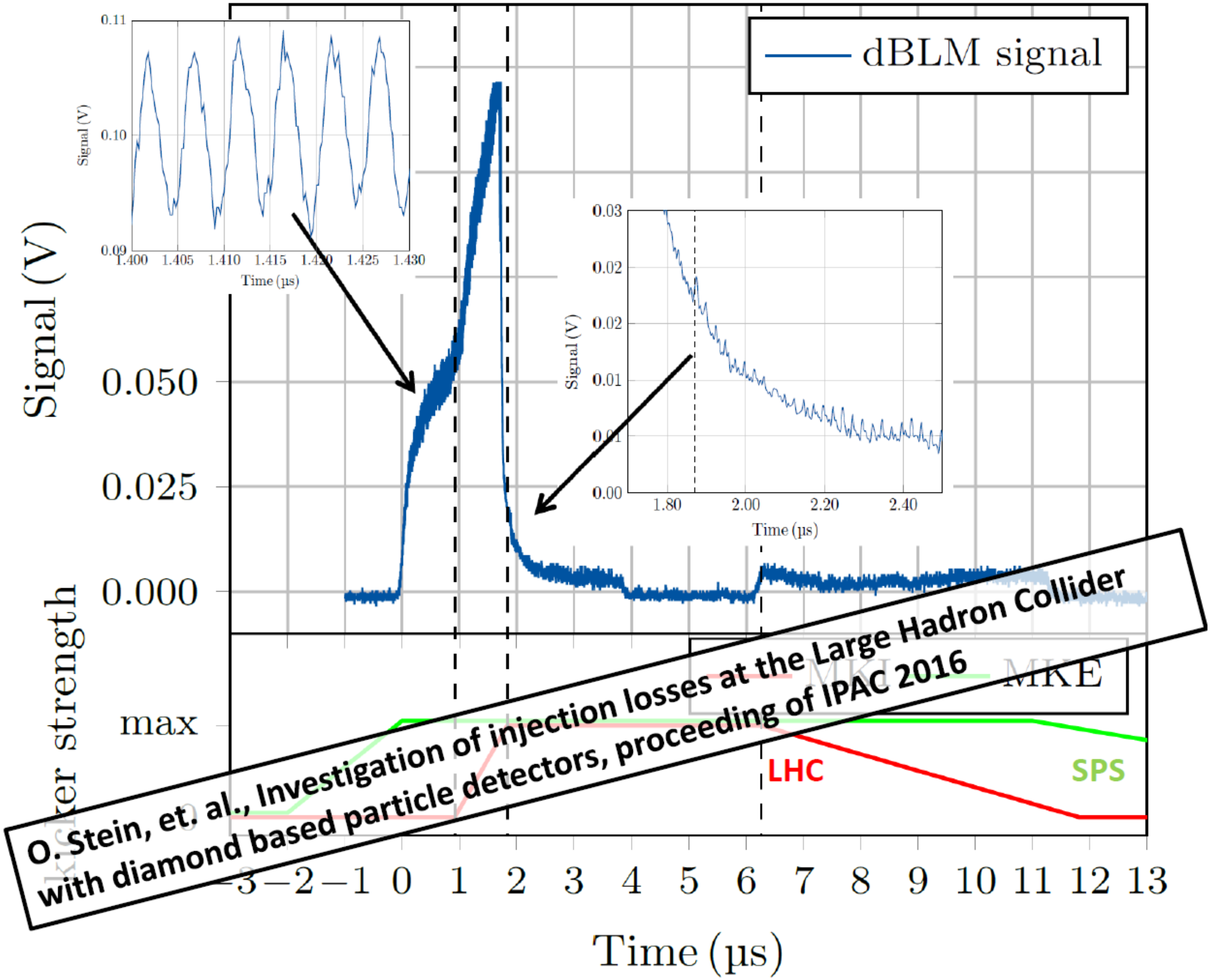
Diamond devices in the LHC



O. Stein, et. al., Investigation of injection losses at the Large Hadron Collider with diamond based particle detectors, proceeding of IPAC 2016

Diamond devices in the LHC

Fast diamond BLMs

* Their nanosecond time resolution allowed to **identify the time structure of the injection losses** for the first time.
* During dedicated beam time at the LHC methods for mitigating these injection losses were successfully demonstrated.
* By exciting the recaptured beam around the nominal bunch train with SPS tune kicker magnet **a reduction of the loss signal by 35% was achieved.**

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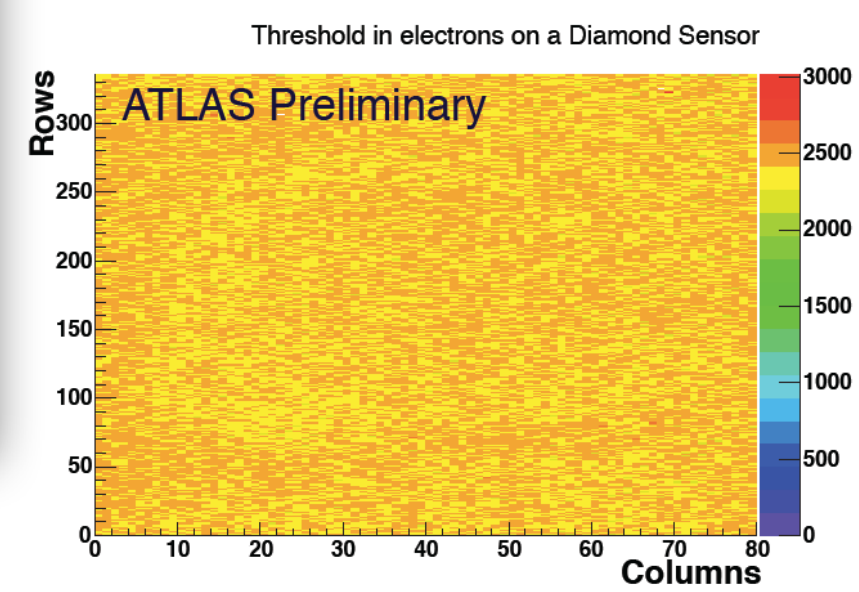
Diamond devices in experiments

- Beam Conditions Monitors
  - Alice, ATLAS, CMS, LHCb
- Current generation Pixel Detectors
  - ATLAS DBM (low threshold operation)
- Future HL-LHC Trackers
  - ATLAS
  - 3D diamond

Diamond devices in experiments

- ATLAS DBM integrated in ATLAS readout in 2015
- Thresholds tuned to 2500e (lower than silicon)
  - Would like to lower this (1100e possible on bench)
- Took data – found operation issues with FE-I4
  - Revamped safeguards almost ready now



Diamond devices in experiments

Testbeam Results of ATLAS DBM Modules
at CERN SPS

RD42 Meeting
CERN

13.05.2016

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universitätbonn

SI LAB Silizium Labor Bonn

Diamond devices in experiments

Beam Test at CERN SPS 2015

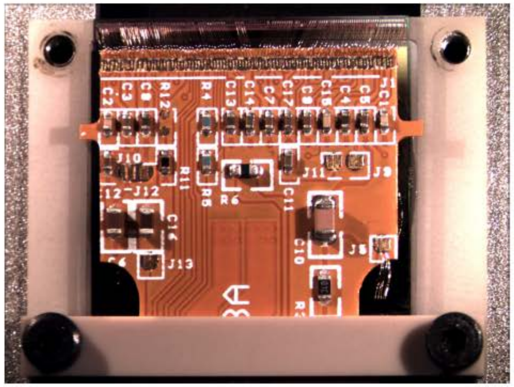
July/August 2015:
- 77 Mio triggers
- 57 runs

October 2015:
- 115 Mio triggers
- 56 runs

May 2016

Modules:
- MDBM-30 (ADBM-33 (E6-old), mounted in 2013)
- MDBM-120 (ADBM-58 (II-VI), mounted in 2014)
- MDBM-107 (ADBM-17 (E6), mounted in 2015)
- MDBM-37 (ADBM-19 (E6), mounted in 2015)
- MDBM-108 (ADBM-18 (E6), mounted in 2015)
- MDBM-119 (ADBM-60 (II-VI), mounted in 2015)
- CD182 (scCVD)
- DDL7 (scCVD)

MDBM-120



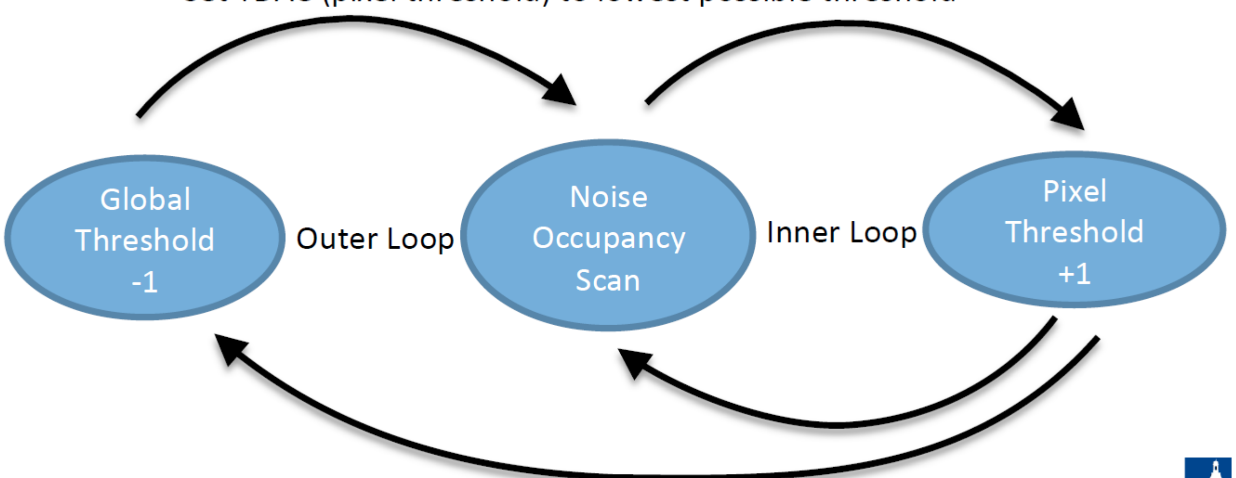
CD182

Diamond devices in experiments

Compare standard "Low Threshold" tuning (1500-2500e) and new Threshold Baseline tuning (1000e)

Threshold Baseline Tuning

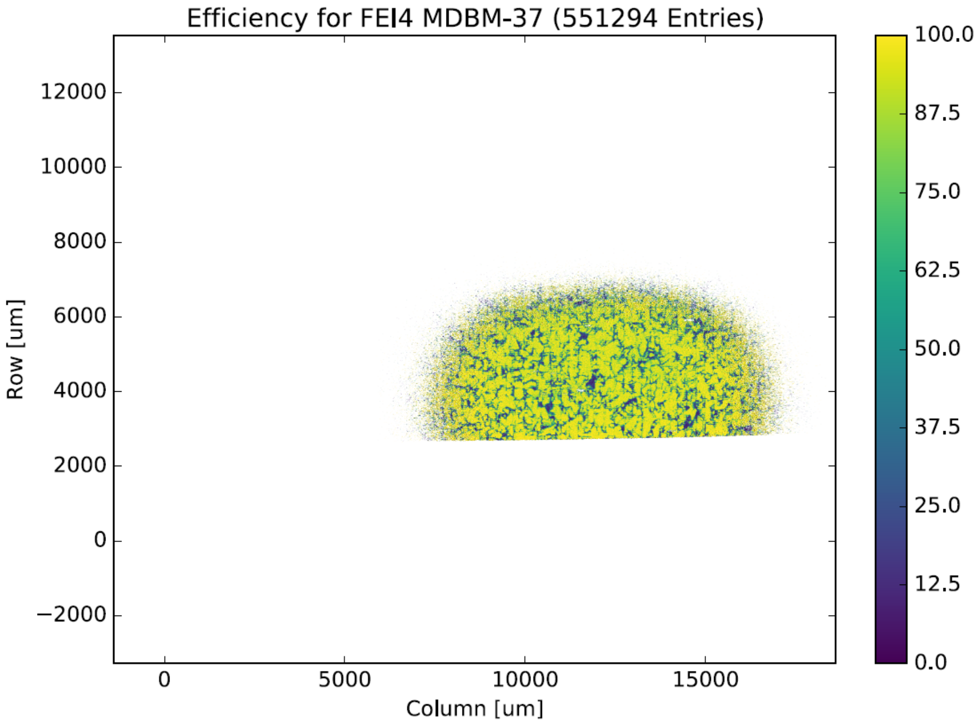
- Avoid using on-chip charge injection circuit
- Two loops:
  - Outer loop **decreases global threshold**
  - Inner loop **increases pixel threshold**
- Initial condition:
  - Set GDAC (global threshold) to a rather high value
  - Set TDAC (pixel threshold) to lowest possible threshold



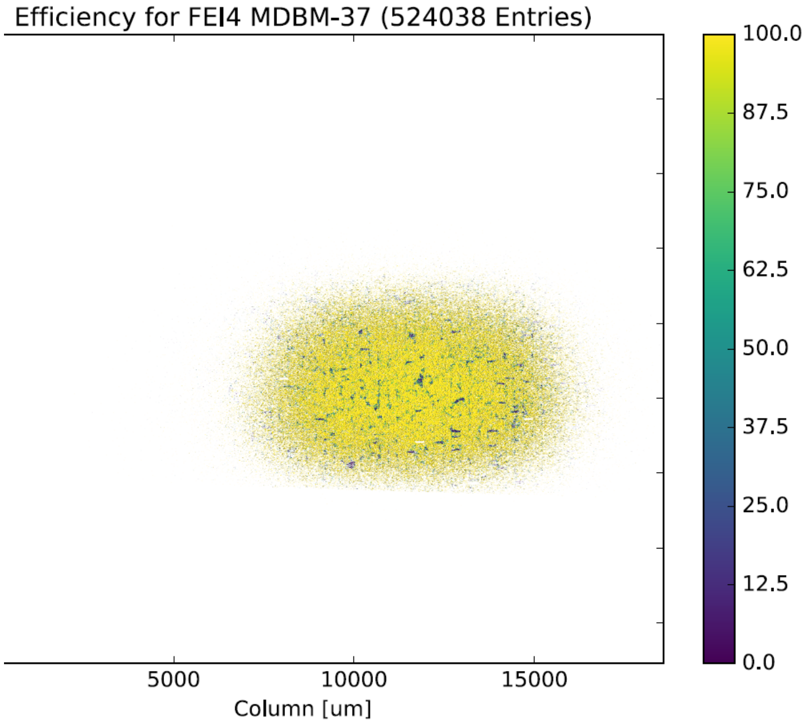
6 13.05.2016 RD42 - Jens Janssen universitätbonn

Diamond devices in experiments

"Low Threshold" (1500-2500e)

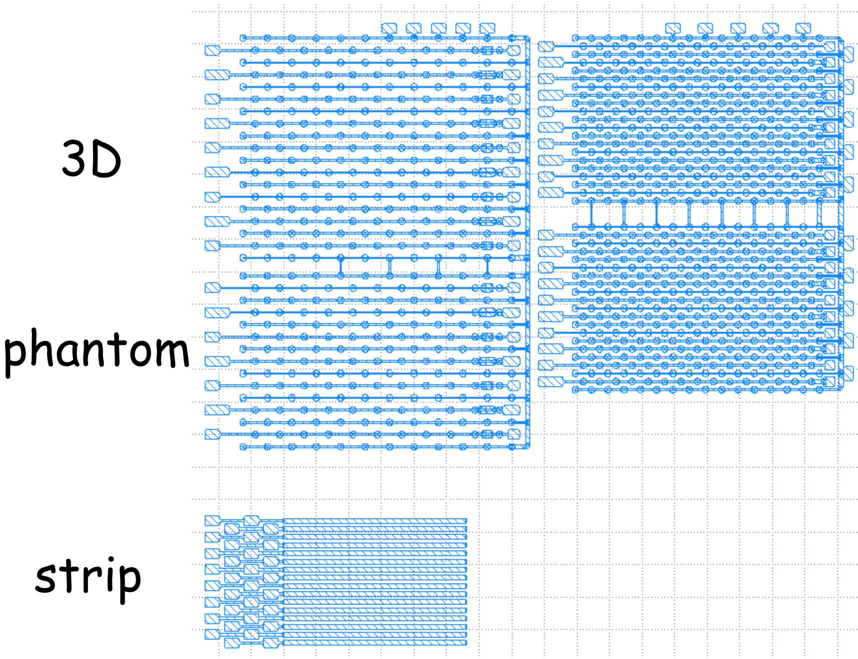


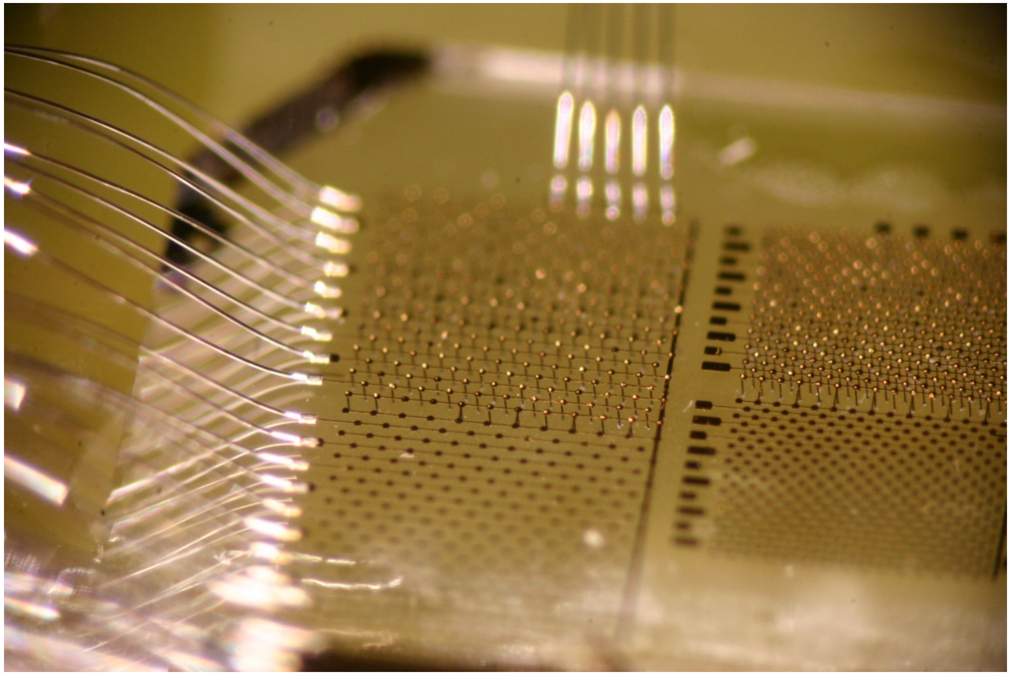
Threshold Baseline (1000e)



Results applicable in ATLAS – something like this will be necessary for irradiated silicon as well

3D device in pCVD diamond





Last year we showed the results in scCVD diamond

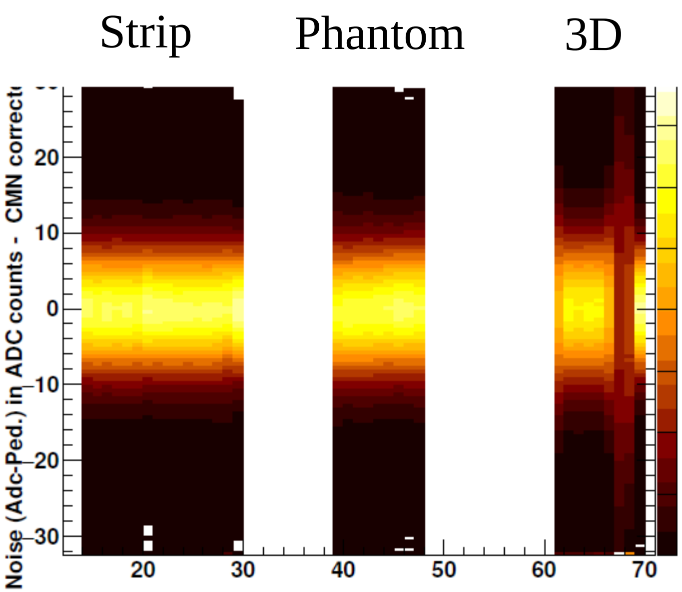
- -Compared scCVD strip detector (500V) with 3D (25V)

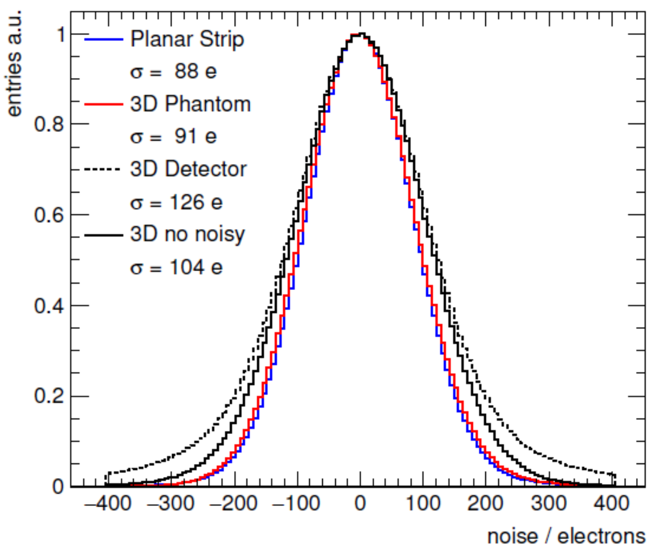
This year the first 3D device in pCVD diamond

- -Compare pCVD strip detector (500V) with 3D (60V)

3D device in pCVD diamond

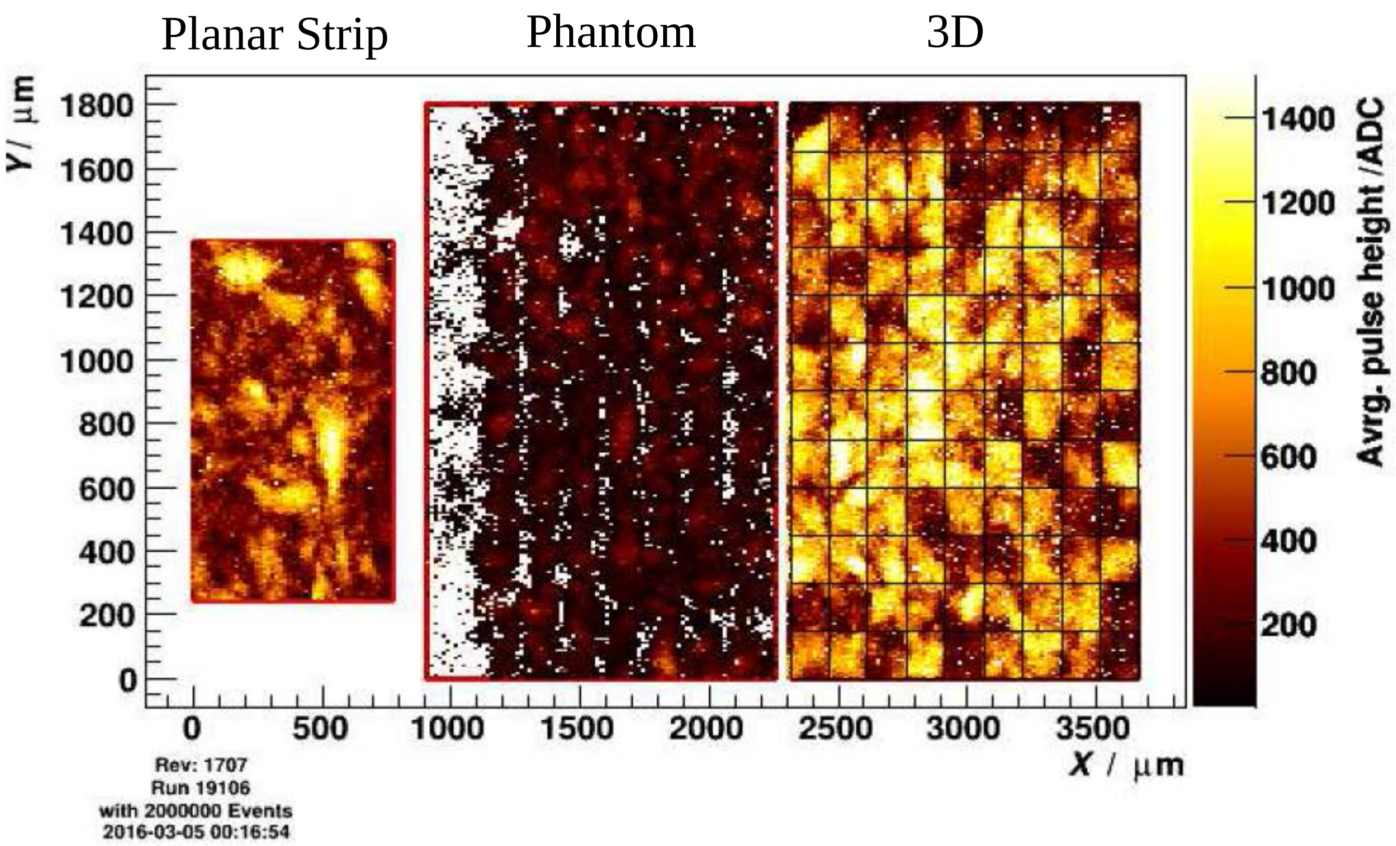
- Measured noise:
  - Planar strip: 88e
  - Phantom: 91e
  - 3D no noisy strips: 104e





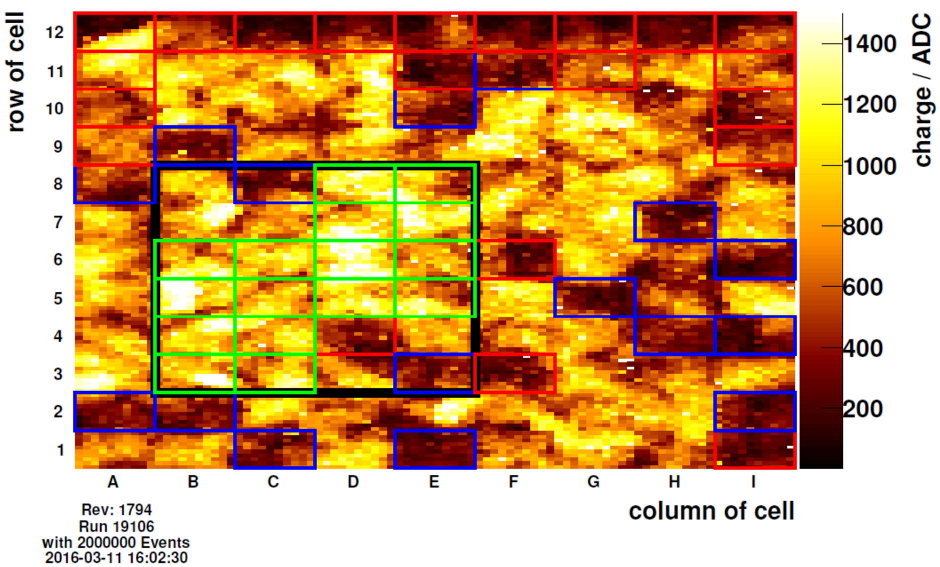
3D device in pCVD diamond

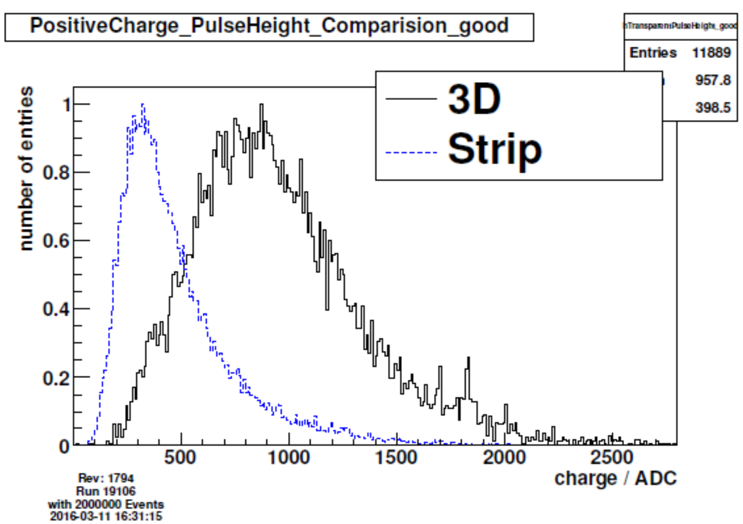
- Measured signal:
  - Visually 3D gives more charge that planar strip!



3D device in pCVD diamond

- Measured signal (diamond thickness 500um):
  - Planar Strip ave charge
    6,900e or ccd=192um
  - 3D ave charge
    13,500e or ccd=350-375um
- For the first time collect >75% of charge in pCVD

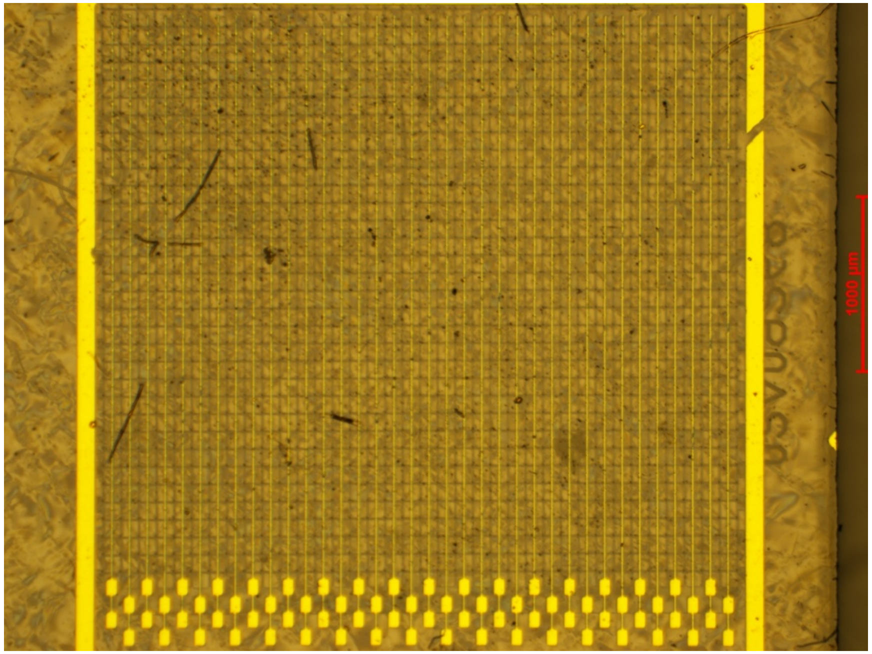




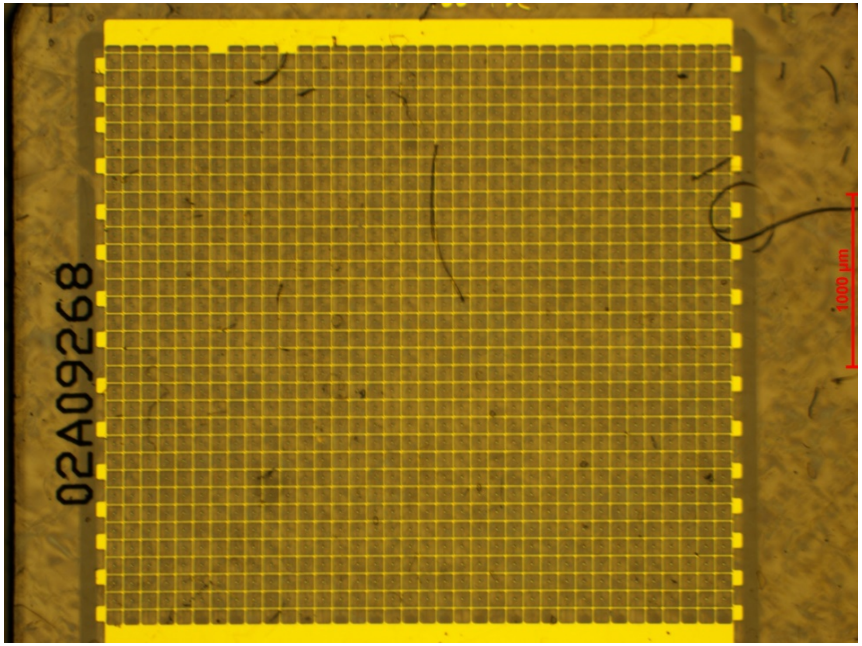
3D device in pCVD diamond

- In May 2016 tested first full 3D in pCVD with two dramatic improvements
  - An order of magnitude more cells (1188 vs 99)
  - Smaller cell size (100um vs 150um)

Readout side

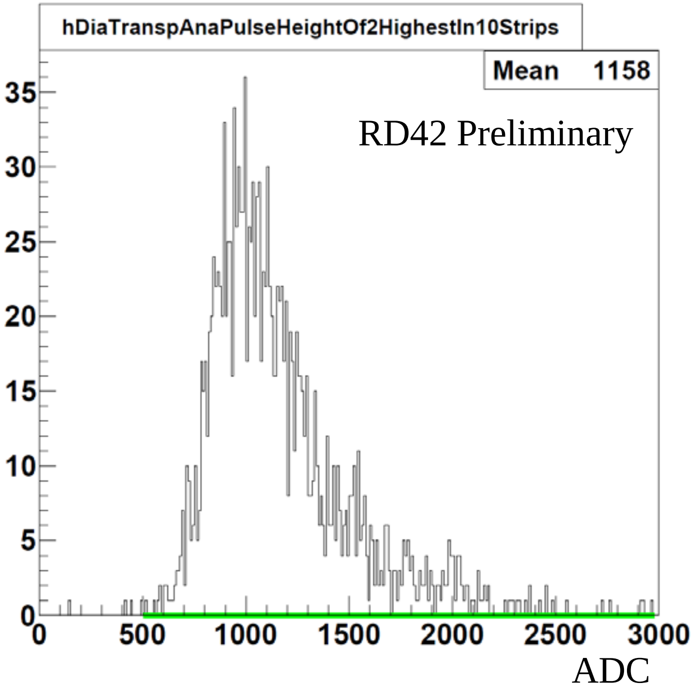


HV Bias side



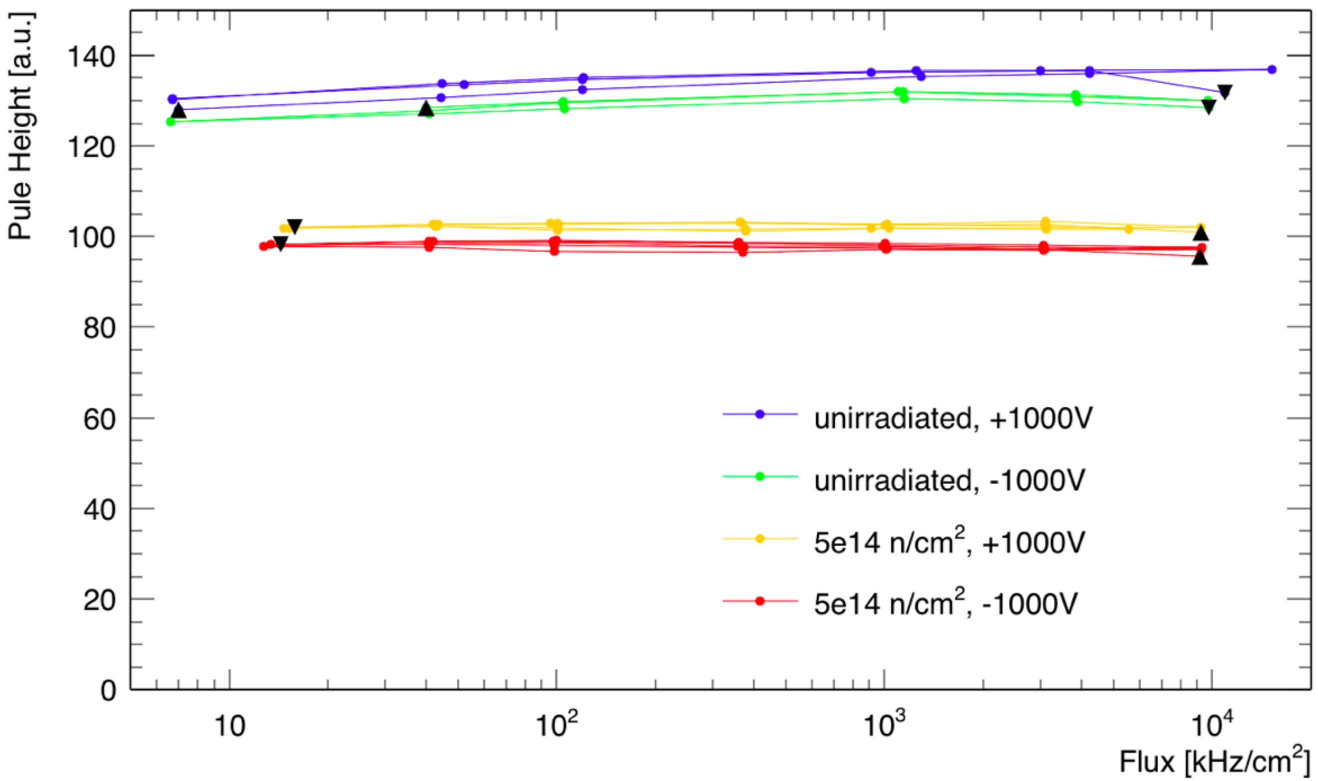
3D device in pCVD diamond

- Preliminary results of full 3D in pCVD
  - First plot of 3D ave charge in small "good" region
  - Largest charge collection in pCVD diamond
    - >85% of charge collected
- Full analysis in progress



Rate studies in pCVD diamond

- Done at PSI - Last year rates up to 300kHz/cm^2
- This year w/new electronics, rates up to 10MHz/cm^2



No rate dependence observed in pCVD up to 10MHz/cm^2

RD42 Summary

- Worked closely with manufacturers
  - Material quality increased
  - Production capabilities increased
- Diamonds in the LHC machine making impact moving forward
- ATLAS/CMS -BCM, BLM, DBM will see collisions again soon
  - Abort, luminosity and background functionality in all LHC expts
- First pixel project is about to start taking data
  - ATLAS DBM being commissioned for 13 TeV collisions
- 3D detector prototypes made great progress
  - 3D works in pCVD diamond; scale up worked; smaller cells worked
- Quantified understanding of rate effects in diamond
  - pCVD shows no rate effect up to 10MHz/cm^2
- RD42 played a pivotal role in making all this happen!

RD42 Research Priorities for 2016-17

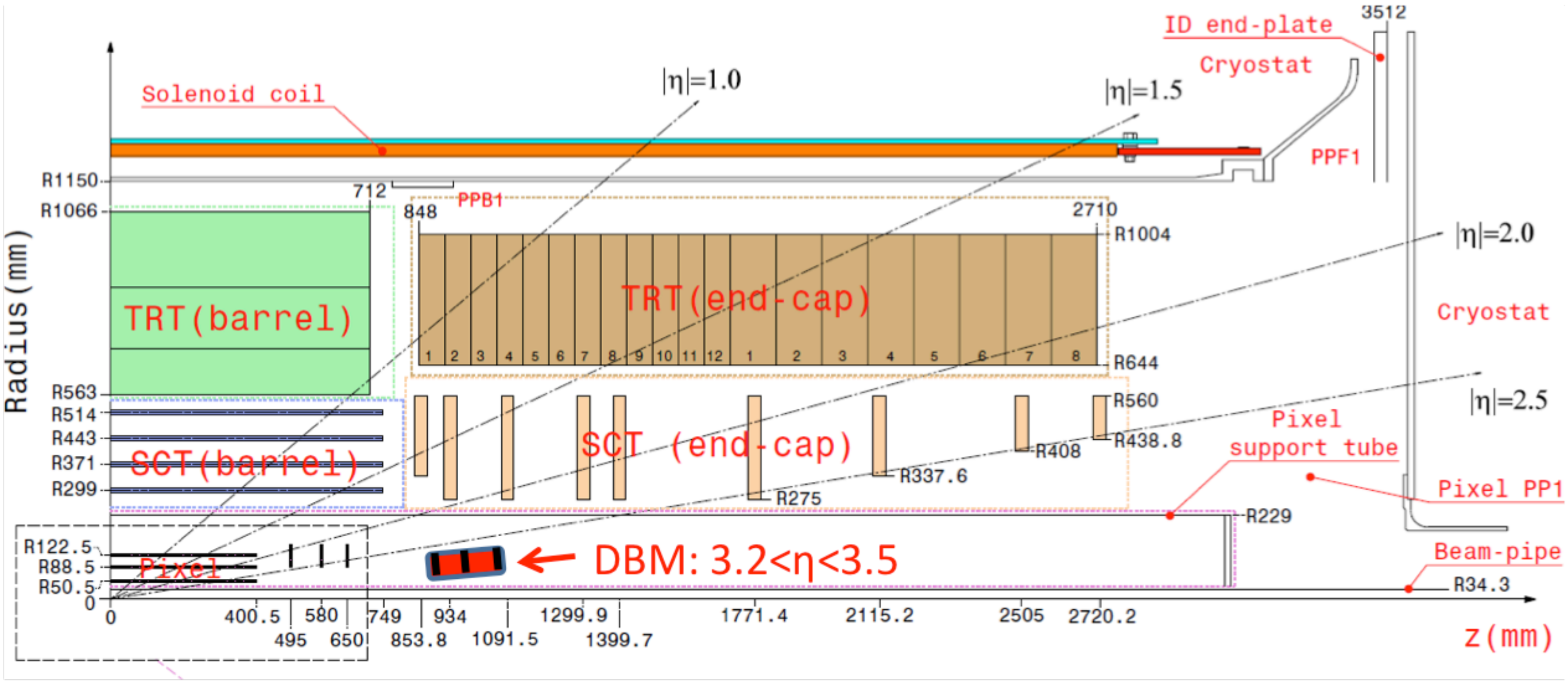
- Characterization of diamond (materials work)
- Work with manufacturers (feedback)
- Development of machine devices (BLM, lumi)
- Development of detectors (pad, strip, pixel, 3D)
- Irradiation(JSI,LANL,CERN) and Beam tests (CERN,PSI)

Diamond devices in experiments

Backup Slides

Diamond devices in experiments

- ATLAS DBM: built 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



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