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

RD42 Status Report

Harris Kagan
for the RD42 Collaboration

LHCC Open Session – May 30, 2018

Outline of Talk

- The RD42 Collaboration
- The RD42 Program
- Recent Results
- Collaboration with LHC Experiments: CMS BCM1F update
- Collaboration with LHC Experiments: ATLAS BCM'
- The RD42 3 Year Program
- The RD42 Request

The 2018 RD42 Collaboration

The 2018 RD42 Collaboration

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123 participants

30 institutes

The RD42 Program, Publications, and more

Areas of work in RD42:

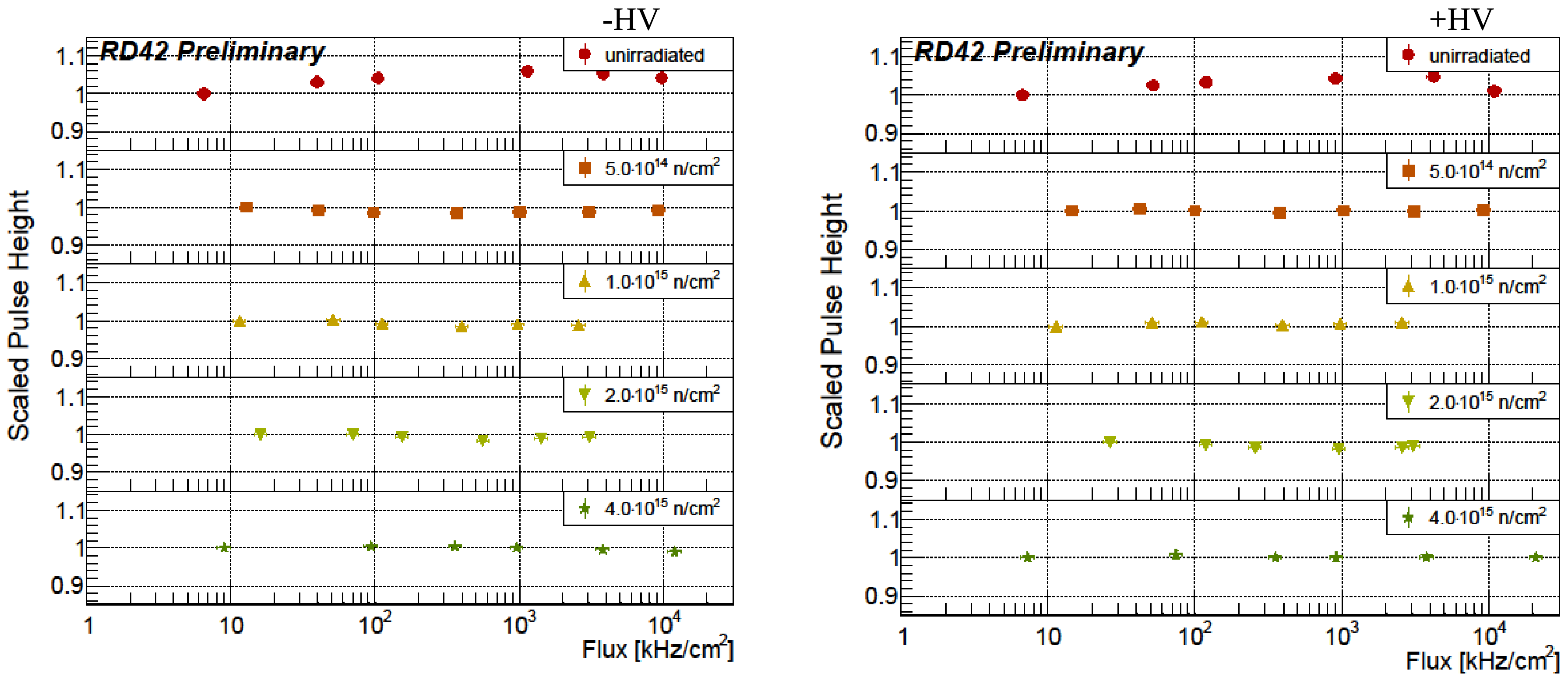
- Materials work (characterization of diamond)
- Work with manufacturers (feedback)
- Development of detectors (pad, strip, pixel, 3D)
- Development of machine devices (BLM, lumi)
- Irradiation (JSI, LANL) and Beam tests (CERN, PSI)
- Work with LHC experiments

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

- 7 papers published in 2017
- 9 conference talks in the last year
- 4 Ph.D. student graduated in the last year
- 11 Ph.D. students continuing in 2018

Recent Results: Rate Tolerance

Characterization in beam tests let us deduce the rate independence of pCVD material.



Collaboration with experiments: CMS BCM1F

RD42 expertise helped BCM1F Upgrade in the following ways:

- Sensor Pre-selection and Characterization
- Cleaning
- Surface Preparation (plasma)
- Geometry
- Metalization
- Interface with vendor (II-VI Inc)
- Delivery
- Provided 2 3D diamond detectors for CMS to install

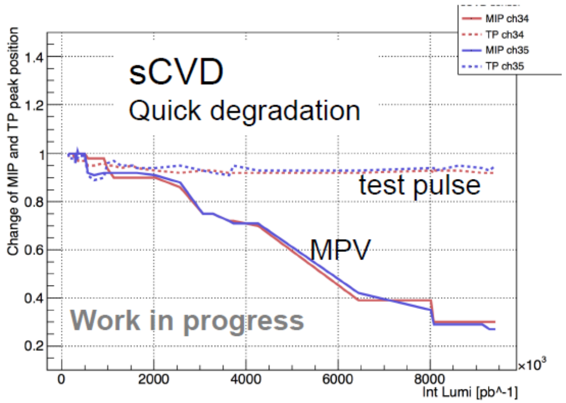
- **Great effort by everyone to achieve production in time**

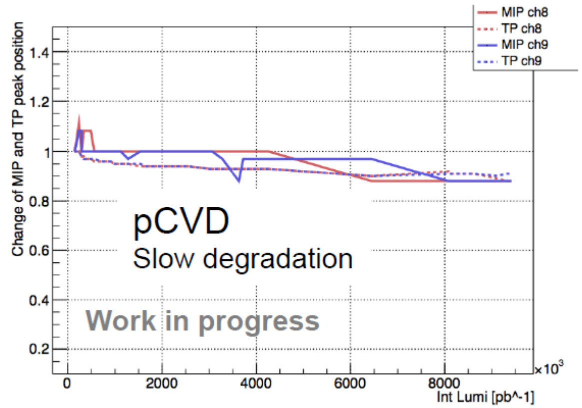
Moritz Guthoff (CMS)

Collaboration with experiments: CMS BCM1F

ADC spectrum analysis

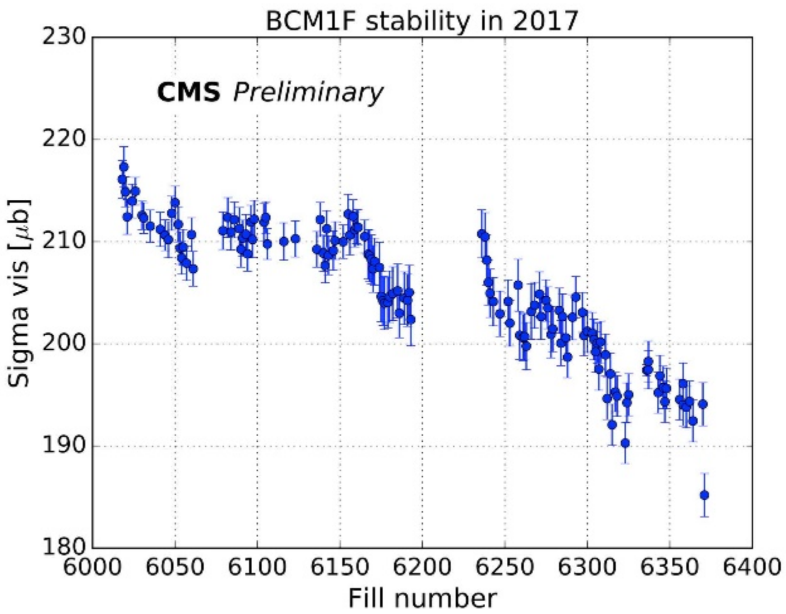
- ADC data is recorded every fill
- Software peak finder and pulse height measurement
- Histogramming of pulse heights to find most probable value.
  - Landau fit does not reveal good fitting with pCVD sensors.
  - Peak of distribution is found by averaging the position of the highest bin +/- 2 bins.
- Additionally the height of a test pulse is measured.
  - Measurement of stability/degradation of optical readout





Collaboration with experiments: CMS BCM1F

Luminosity Performance



10% decrease in σ_{vis} over the year includes effects from:

- Radiation damage to optical readout system decreasing efficiency
- Change of filling scheme
- Decrease of detector efficiency

BCM1F luminosity is corrected by emittance scan results giving a very good and highly reliable luminosity measurement.

- Stability over the year around 2% compared to other luminometers.

Moritz Guthoff (CMS)

Collaboration with experiments: ATLAS BCM'

Present ATLAS BCM suffers from abort-lumi incompatibility

- Abort thresholds can not be set higher without abandoning lumi
- Fast timing needed for abort lowers S/N thus limiting lumi stability

Separate functions at the HL-LHC

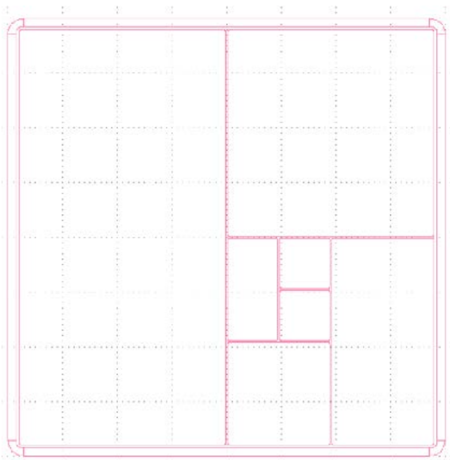
- Two fast devices from sensor to off-detector
- Keep as much commonality as possible
- 4 stations/side with abort, lumi-BCM', BLM

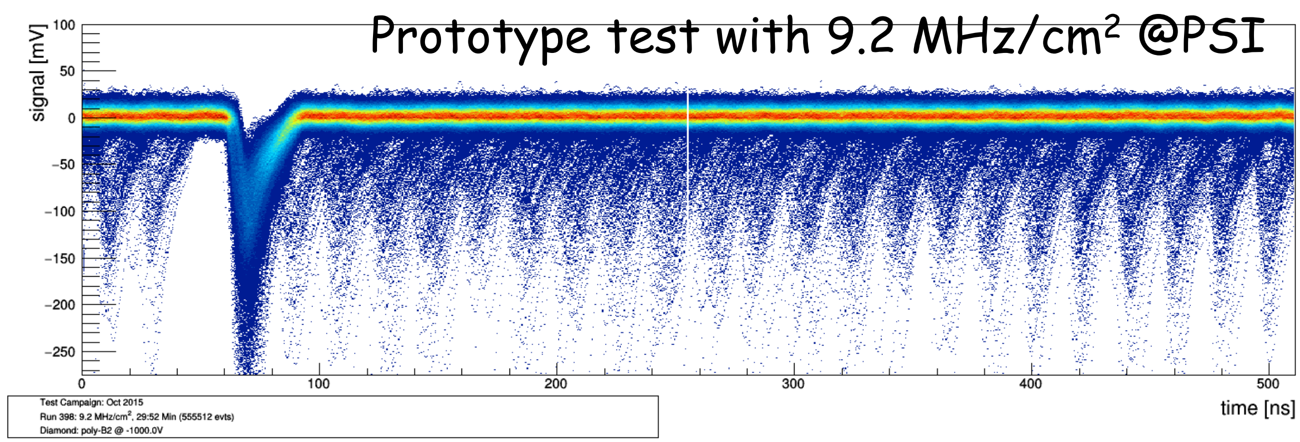
Requires new sensor geometry and appropriate electronics

Collaboration with experiments: ATLAS BCM'

Initial Sensor Design Idea

- Build some dynamic range into sensor ✓
  - pad sizes from $1mm^2$-$32mm^2$ work well
- Compare 300μm vs 500μm thick sensors - in progress
  - 500μm thick sensors work well
- Test wire bonding sensor to chip ✘
  - lose sensitivity of small pads – bump bond instead
- Test with existing RD42 fast electronics ✓

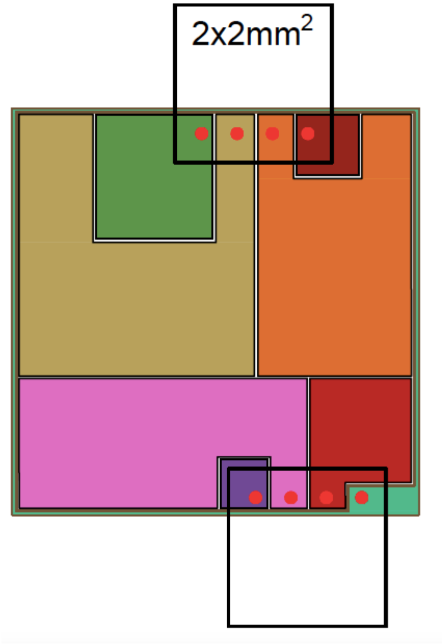


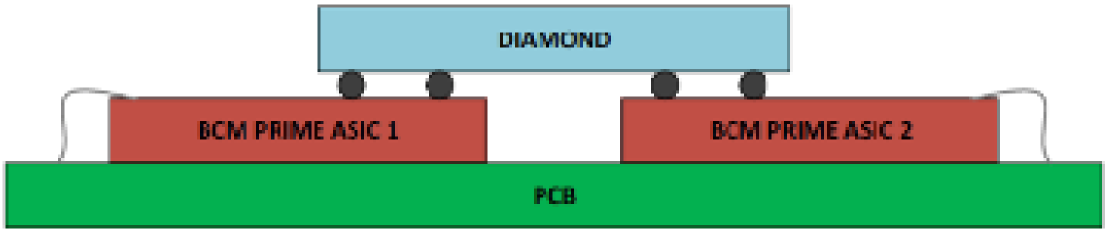


Collaboration with experiments: ATLAS BCM'

New Sensor Design Idea

- Build some dynamic range into sensor
  - pad sizes from 1mm^2-32mm^2 work well

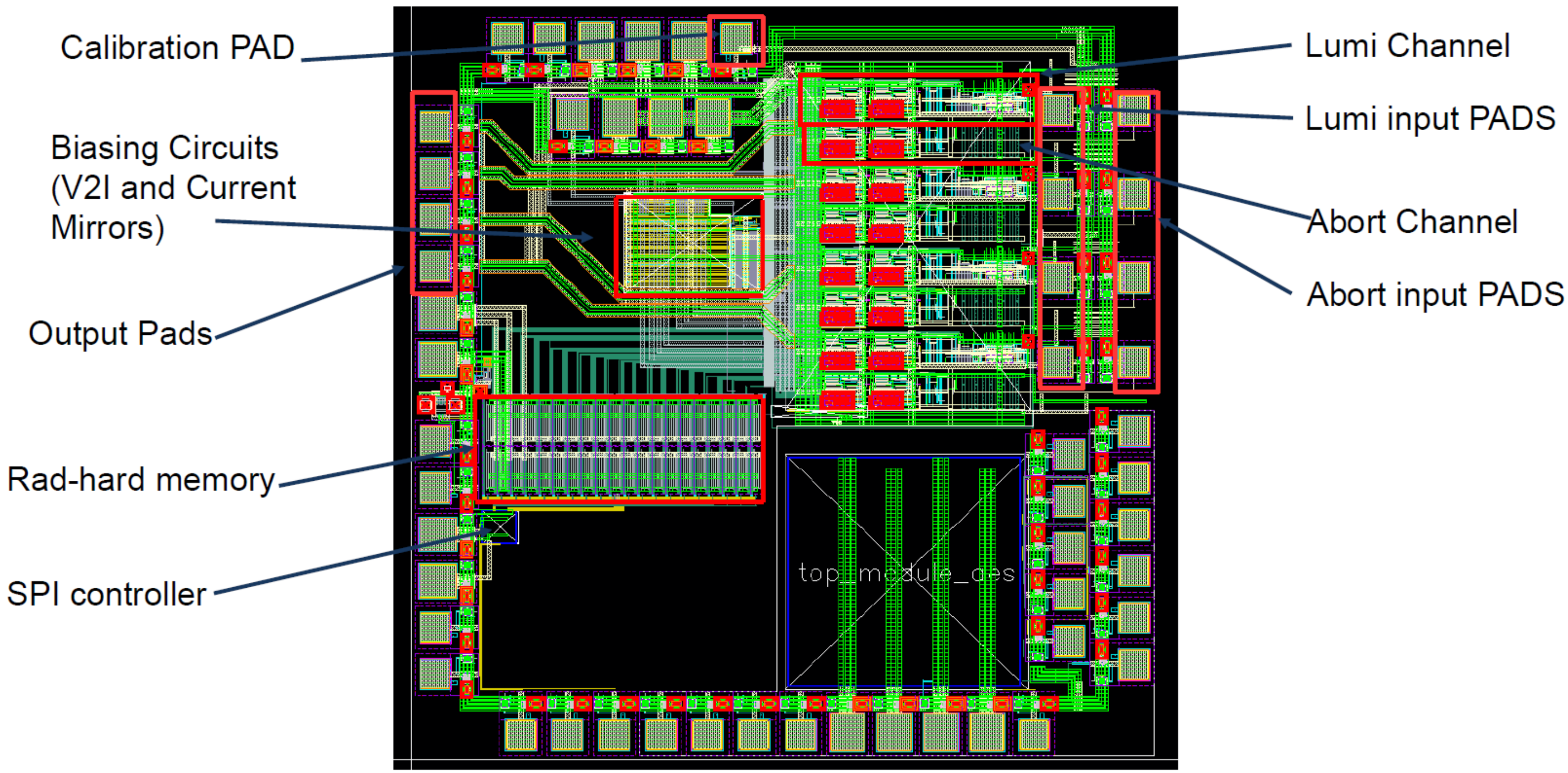




Collaboration with experiments: ATLAS BCM'

Electronics Design Path

- First version of preamp layout and simulations



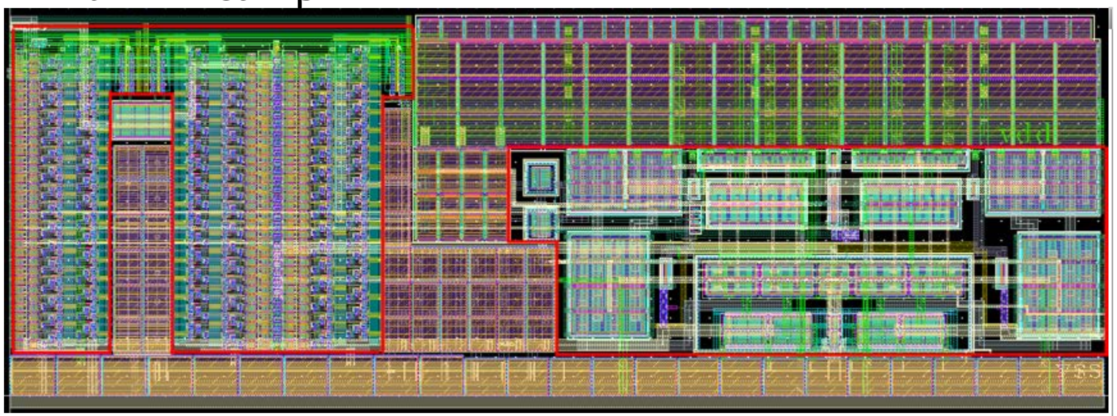
Collaboration with experiments: ATLAS BCM'

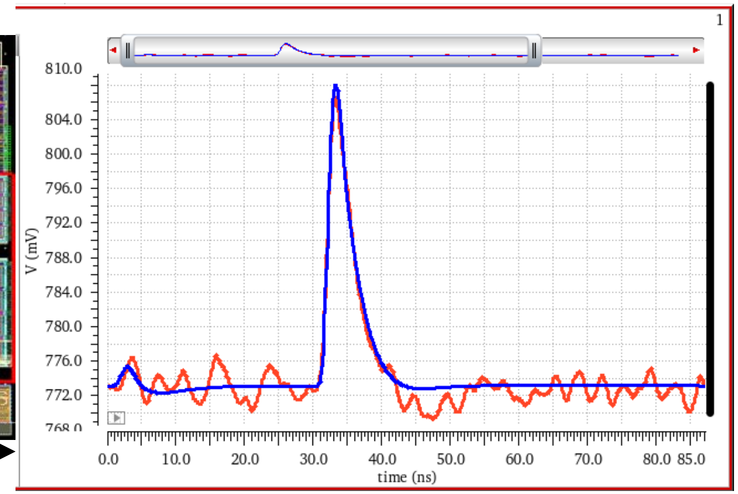
Electronics Design Path

- First version of preamp layout and simulations

Lumi Preamp

100µm

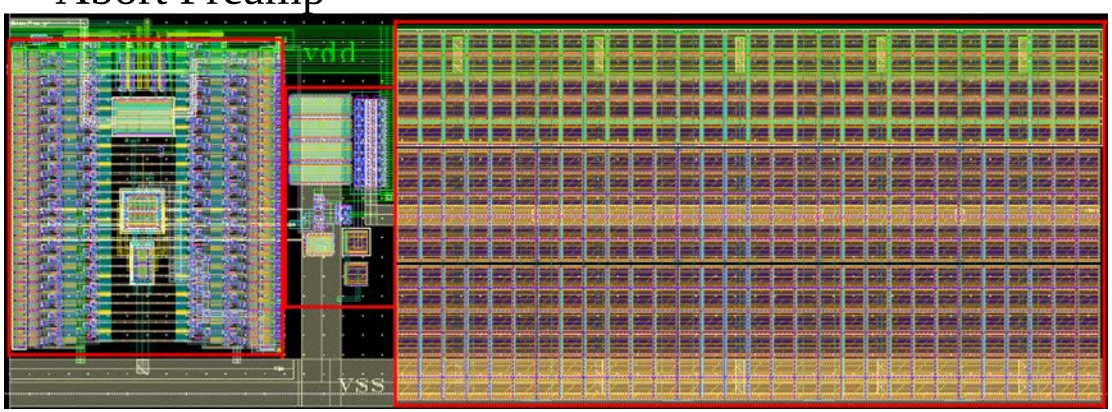


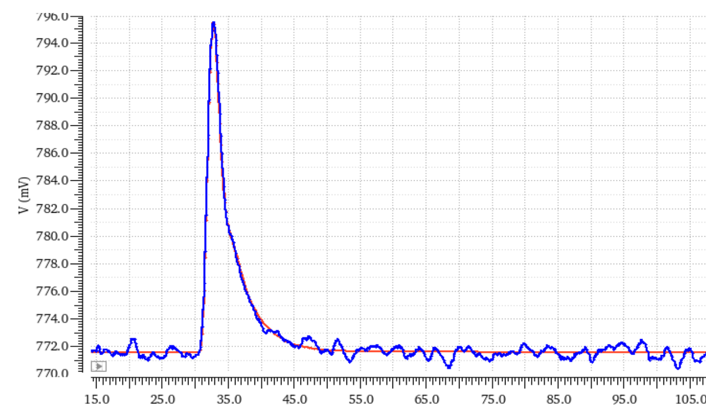


285µm

Abort Preamp

100µm





Collaboration with experiments: ATLAS BCM'

Electronics Design Path

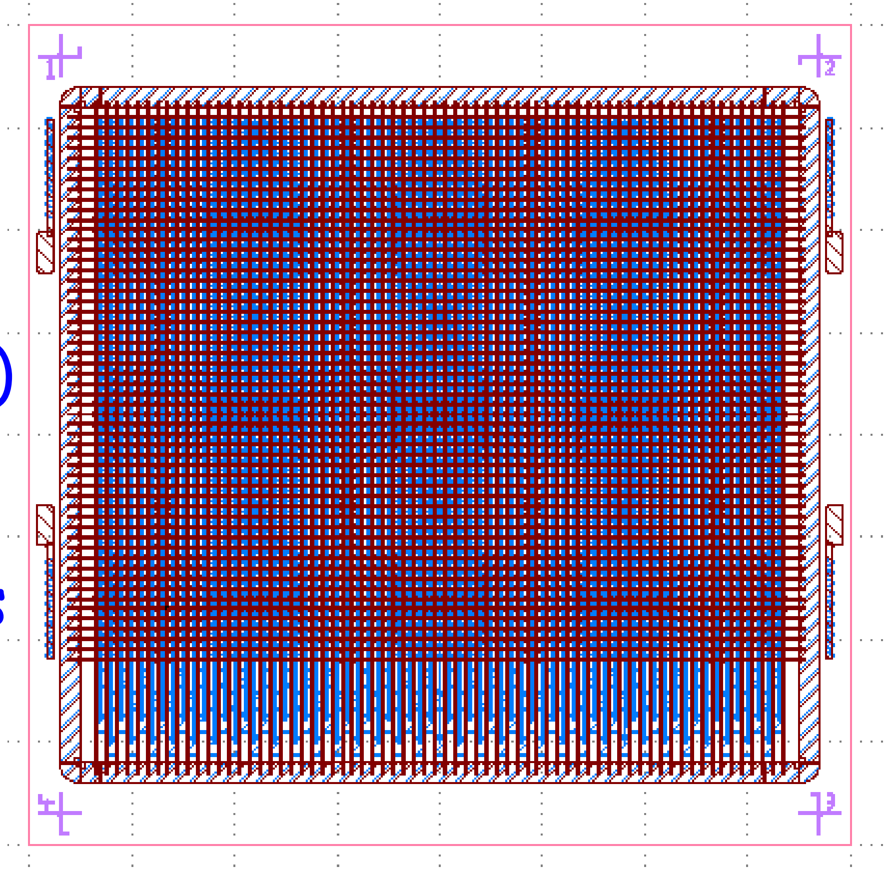
- Start with RD42 fast amp used in rate studies
  - designed in 130nm technology
  - risetime 3-6ns; baseline recovery time 12-18ns
  - noise for 2pf input: 550e
- Design 2 preamps to achieve large dynamic range
  - lumi sensitivity to MIPs at 7ke
  - abort threshold for safety at 25k-7.5M MIPS/cm^2
  - electronics dynamic range 100:1
  - risetime 1-2ns; return to baseline (<2%) 12ns
- Optimize gain and speed vs SNR for lumi, abort separately
  - tune parameters based on beam tests
- End with 8 channel amp (4 lumi, 4 abort) in 65nm

Chip Submitted May 21,2018

Development of 3D Diamond Pixel Modules

Produced new 3500 cell pixel prototype w/50μm x 50μm pitch

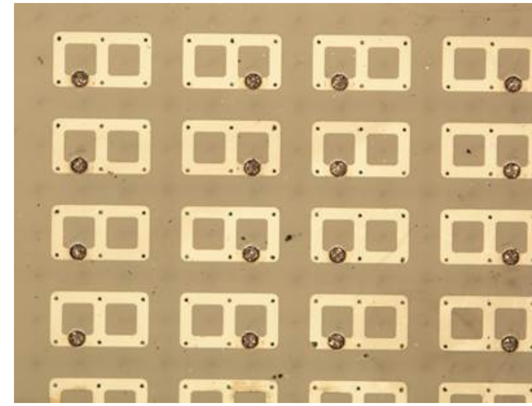
- Two fabricated:
  - Oxford complete
  - Manchester complete
- 50μm x 50μm cells ganged for CMS (3x2) and ATLAS (1x5)
- Metallization complete
- Bump bonding
  - ATLAS @IFAE in progress
  - CMS @Princeton complete
- First one (CMS) tested in Aug 2017 Test Beam @PSI

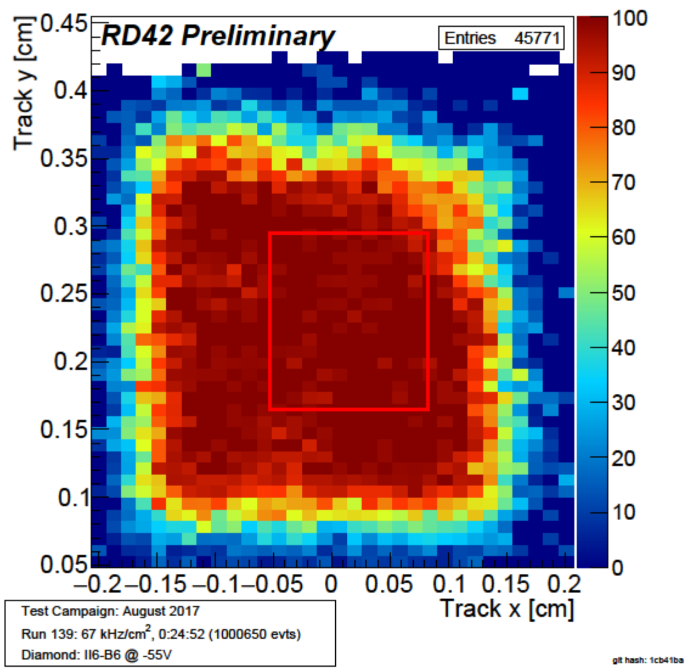


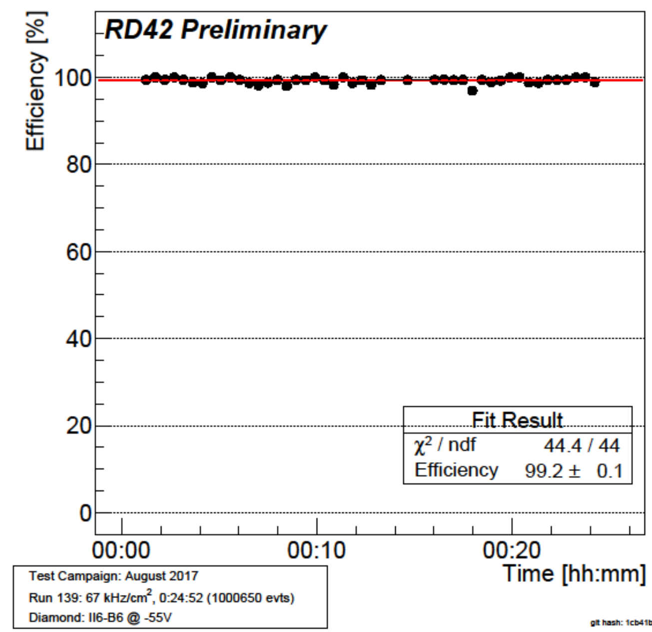
Development of 3D Diamond Pixel Modules

Preliminary Results (50µmx50µm pixels)

- Readout with CMS pixel readout
  6 columns (3x2) ganged together
- Preliminary efficiency 99.2%
- Collect >90% of charge!







The RD42 Program

7.1: 3D Diamond Sensor Fabrication and Characterisation

- 2019: irradiate devices 10^{15}, test beam analysis, determine 3D operating point, evaluate 3D column fabrication
- 2020: fabricate 25μmx25μm 3D cells, beam test, compare 25μmx25μm with 50μmx50μm cells, irradiate devices 10^{16} , test beam analysis, scale up number of cells by x10
- 2021: test beam analysis, irradiate devices 10^{17}, choose final column production method, scale up number of cells to final need

7.2: HL-LHC Beam Monitoring Proof-of-Principle

- 2018: submit preamp v1, beam test of pad+electronics
- 2019: assemble first HL-LHC beam monitor, test @PSI, irradiate beam monitor to 10^{15}
- 2020: produce preamp v2, beam test pad+electronics @CERN, irradiate to 10^{16}
- 2021: work w/manufacturers to make diamond, select, metalize diamond, build production modules

The RD42 Program

7.3: Development of pCVD Material

- 2018: develop methods to recognize surface defects, first version of edge-TCT system
- 2019: work w/manufacturers to understand surface defect production, reduce surface defects to less than 1/cm^2, develop additional characterization tools as needed
- 2020: work w/manufacturers to increase ccd to 400μm
- 2021: work w/manufacturers to increase uniformity to <2%

7.4: Development of 3D Diamond Pixel Modules

- 2018: finish testing 3x2 ganged 50μmx50μm pixel module
- 2019: fabricate and test additional 50μmx50μm pixel modules, irradiate 3D pixel modules to 10^{15}, characterize rad tolerance of 3D pixel module with RD53 chip
- 2020: fabricate and test 25μmx25μm pixel modules, irradiate 3D pixel modules to 10^{16}
- 2021: compare 25μm and 50μm modules in test beam, irradiate modules to 10^{17}, beam tests, build pixel based monitoring system

The RD42 Program, 2017 Referees Report

2017 LHCC Referees Report (CERN/LHCC 2017-007)

RD42 is continuing its close collaboration with diamond material manufacturers in order to improve the quality of the available material. Further goals for the coming year are continuing the development of HL-LHC devices and detector prototypes of different geometries, in particular 3D pCVD devices with 50 μm x 50 μm cells, and irradiation studies and test beams to test new materials.

The **LHCC recommends** a communication effort be make by RD42 to grant easier access to people external to RD42 to its work and achievements. Measures may include an update of the website and a category and document class ID on the CERN document server.

The **LHCC requests** a plan to be presented at the next LHCC review of RD42 for the next three years, with clearly identified and traceable milestones and goals.

Summary

1-Construct and measure a pCVD 3D device w/50μm x 50μm cells ✓
2-Illustrate a pCVD option for future luminosity measurements ✓
3-Scale up 3D by factor of 10 factor of 4 x 1.5 done - ongoing
4-Measure 3D-diamond pixel module - CMS done ✓, ATLAS ongoing
5-Request CDS ID under CERN Detector R&D Projects - ongoing
6-Continue rate studies, irradiation studies and test beams ✓

RD42 Request of CERN LHCC

The RD42 Role at CERN

- Irradiations, test beams, development of manufacturers, sample procurement
- Central facilities for all experiments

RD42 Request to CERN/LHCC

- Continuation of official recognition by CERN
- Access to CERN facilities
- Access to lab space and office space
- Access to test beams

RD42 and CERN play a critical role in diamond development