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

RD42 Status Report

Harris Kagan
for the RD42 Collaboration

LHCC Open Session – Sep 11, 2019

Outline of Talk

- The RD42 Collaboration
- The RD42 Program
- Recent Results
- Collaboration with LHC Experiments: ATLAS BCM', CMS
- The RD42 Request

The 2019 RD42 Collaboration

The 2019 RD42 Collaboration

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114 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/

- 9 papers published in 2019; all listed on RD42 website
- 7 conference talks in 2018; all listed on RD42 website
- 2 Ph.D. students graduated in the last year
- 9 Ph.D. students continuing in 2019

The RD42 Program, Publications, and more

CVD Diamond Radiation Detector Development

RD42 Collaboration

Bonn University - CEA (Saclay) - CERN (Geneva) - Czech Technical University - ETH (Zurich) - GSI (Darmstadt) - INFN (Perugia) - IPHC (Strasbourg) - ITEP (Moscow) - Jozef Stefan Institute (Ljubljana) - Karlsruhe Institute of Technology - LPSC (Grenoble) - MEPHI Institute (Moscow) - Ohio State University - Rutgers University - Sacramento State University - Syracuse University - University of Bristol - Universita di Catania - University of Colorado (Boulder) - University of Florence - University of Goettingen - University of Manchester - University of New Mexico (Albuquerque) - Universita del Salento (Lecce) - University of Tennessee - University of Torino - University of Toronto

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The LHC offers unique physics opportunities in an extremely difficult operating environment. Diamond is a material with such extraordinary physical properties that we wish to explore its use as a particle detector.

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public

- RD42 2018 LHCC Status Report and Original RD42 Proposal
- RD42 LHCC Presentations and LHCC Reviews of RD42
- Recent Talks, Recent Publications and Recent Theses
- RD42 Organization Chart
- CERN Directory, Contact RD42

All updated

private

- Notes and Drafts
- Pictures
- Projects: Sample Characterization, Tracker Tests, Pixel Detectors, Irradiations
- Companies
- Administration

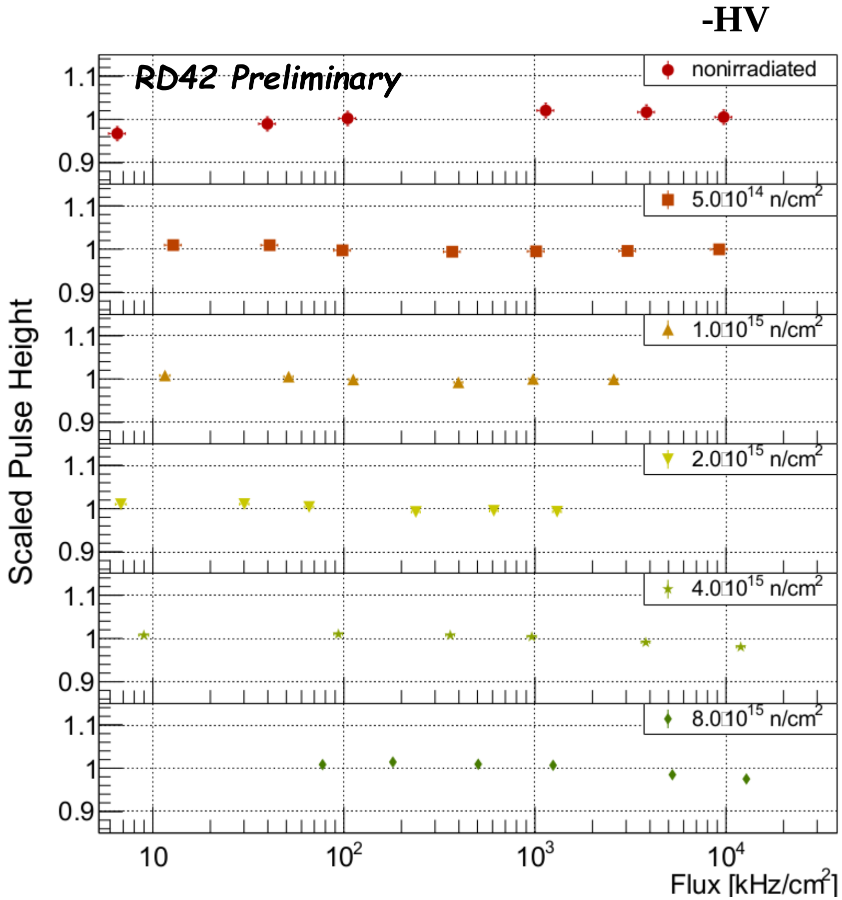
Specific Sites

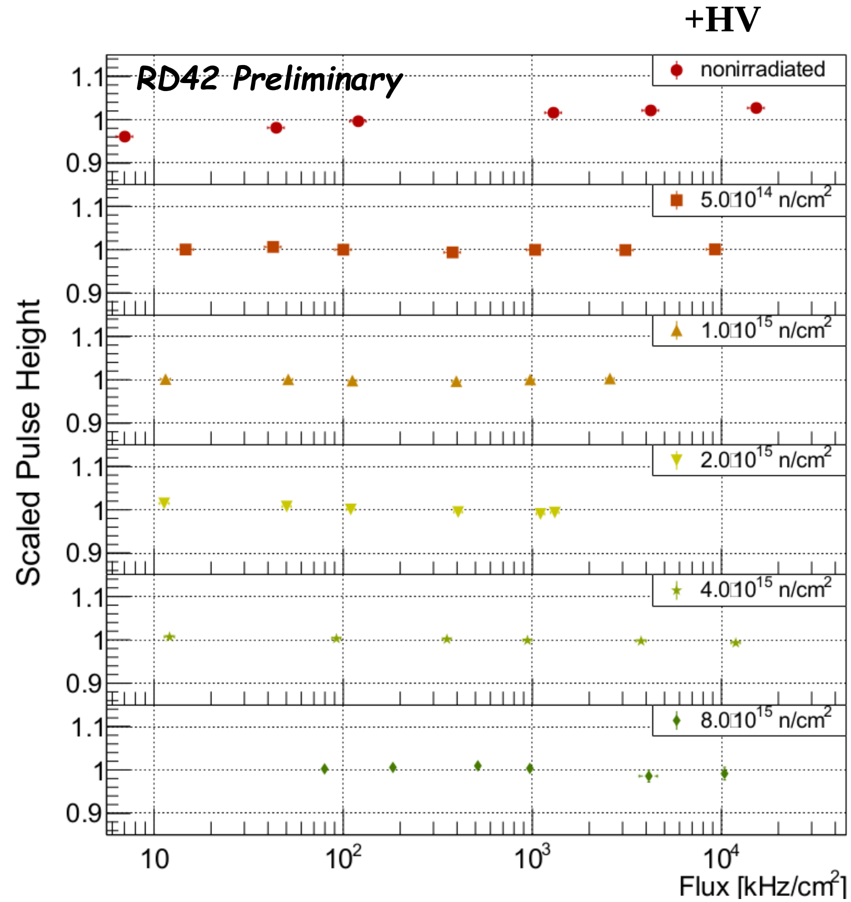
- RD42 at CERN
- RD42 at Rutgers University
- RD42, Spin-Offs

Last modified: Mon Sep 02, 2019 14:54:23 CETDST PageSupport, Diamond.Detector@cern.ch

Recent Results: Rate Tolerance

Characterization in beam tests let us deduce the rate independence of pCVD material up to $8x10^{15}$n/cm^2.





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'

Stay within pixel part inside Pixel Inner Support Tube

- removable after 2/ab

Put it close to ideal position z~1900mm

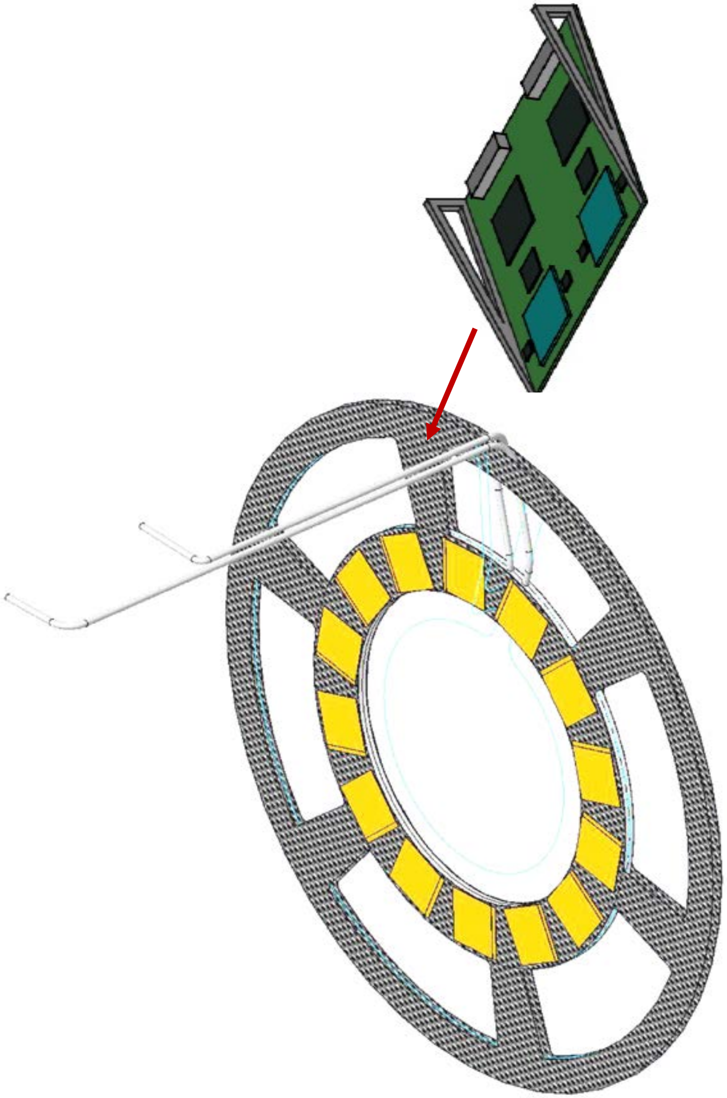
- space available at r~100mm η~3.6

Outer part of endcap shorty ring

- 4 stations/side each with abort, lumi-BCM', BLM

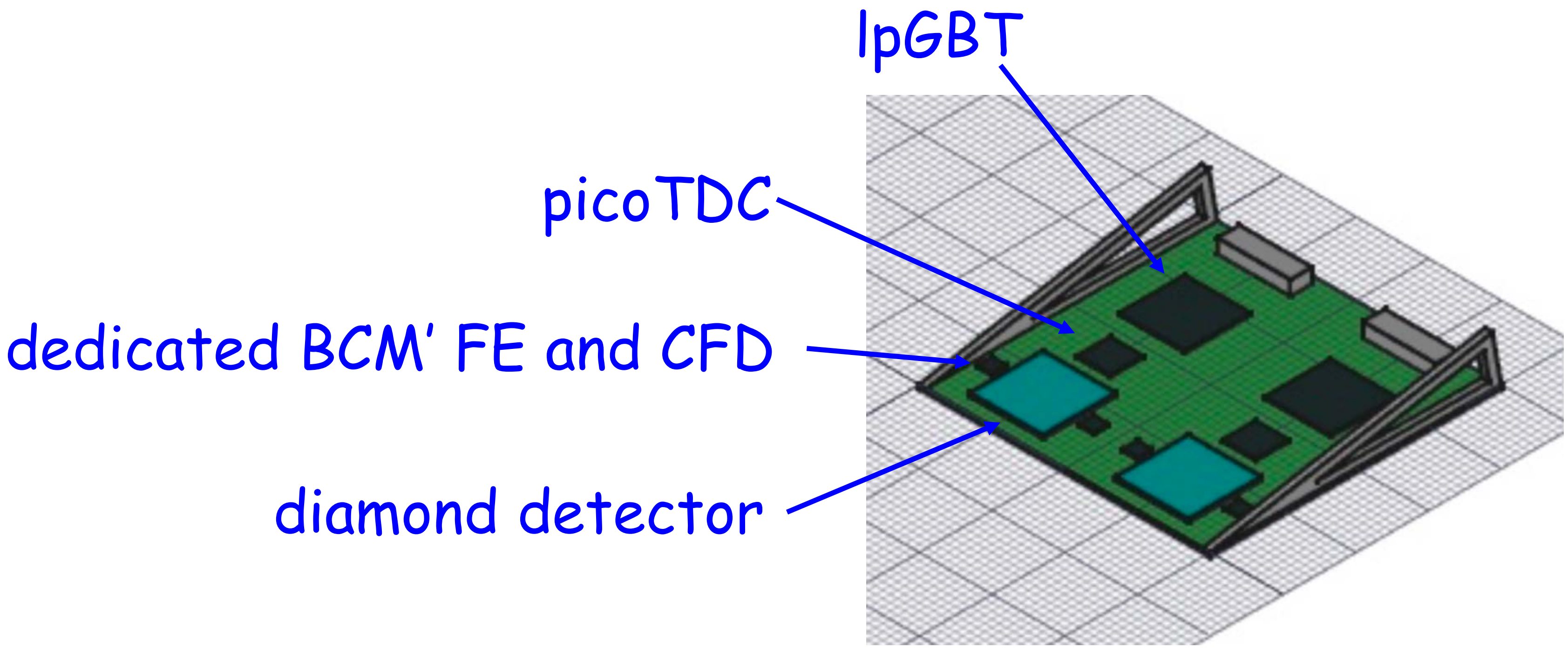
Radiation level at 2/ab luminosity

- 200 Mrad and 2e15n/cm^2



Collaboration with experiments: ATLAS BCM'

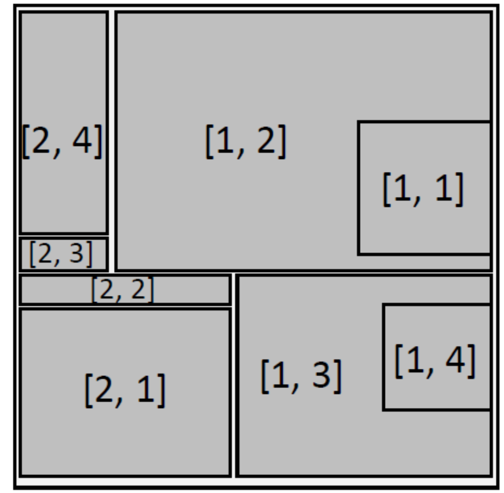
Preliminary Module Conceptual "design"

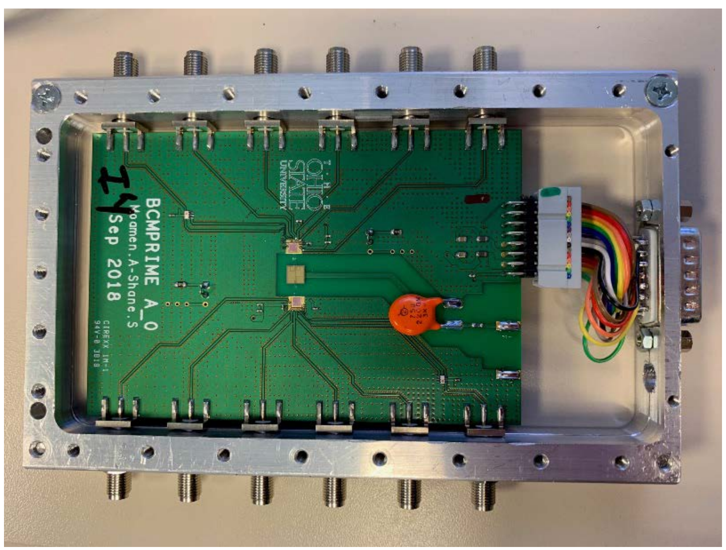


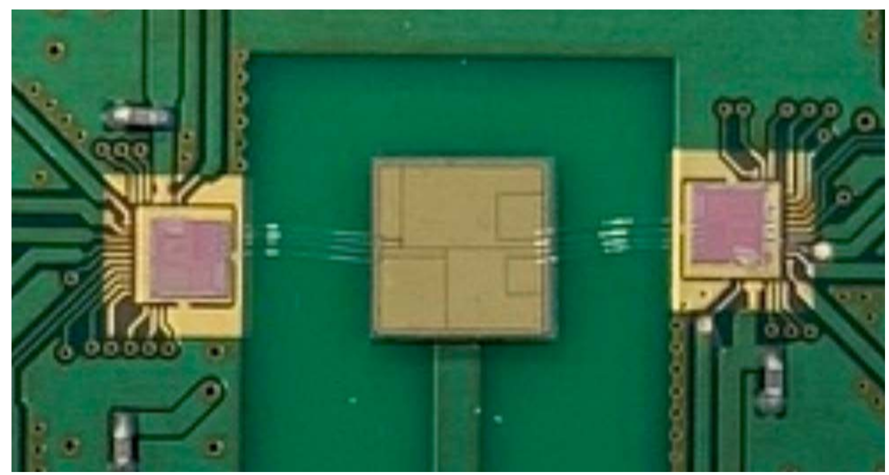
Collaboration with experiments: ATLAS BCM'

Revised Sensor Design Idea

- Build dynamic range into sensor
  - pad sizes from $1mm^2$-$32mm^2$ work well
- Bring bonds to edge. Can be wire bonded or bump bonded



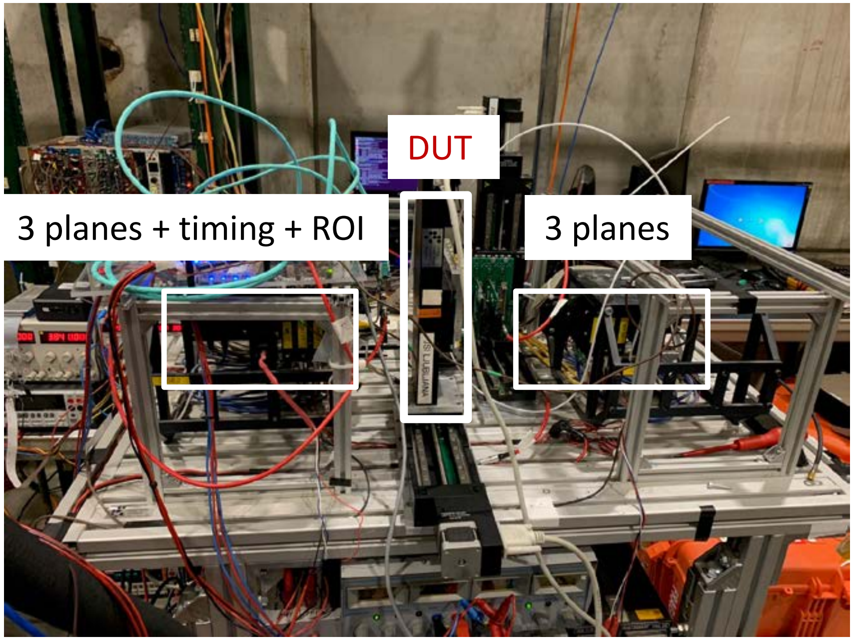


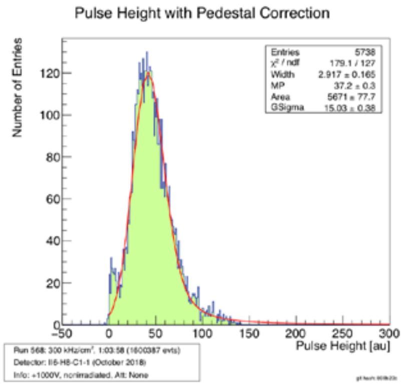


Collaboration with experiments: ATLAS BCM'

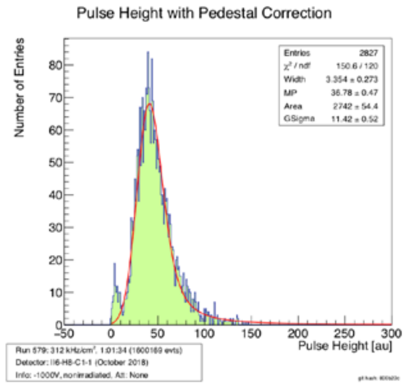
Test beam results of first 65nm Preamp

- At CERN and PSI
  - S/N > 40 achieved @±1000V
- Discovered a few issues which were resolved

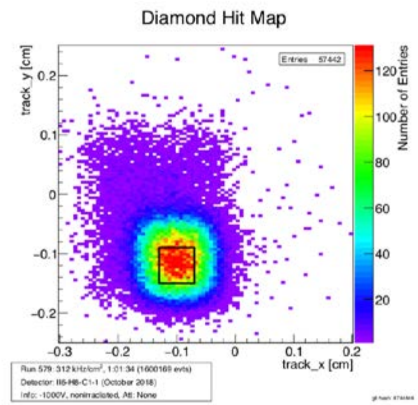




(a) +1000 V



(b) −1000 V



(a) Signal larger than 10

Collaboration with experiments: ATLAS BCM'

Electronics Design Path

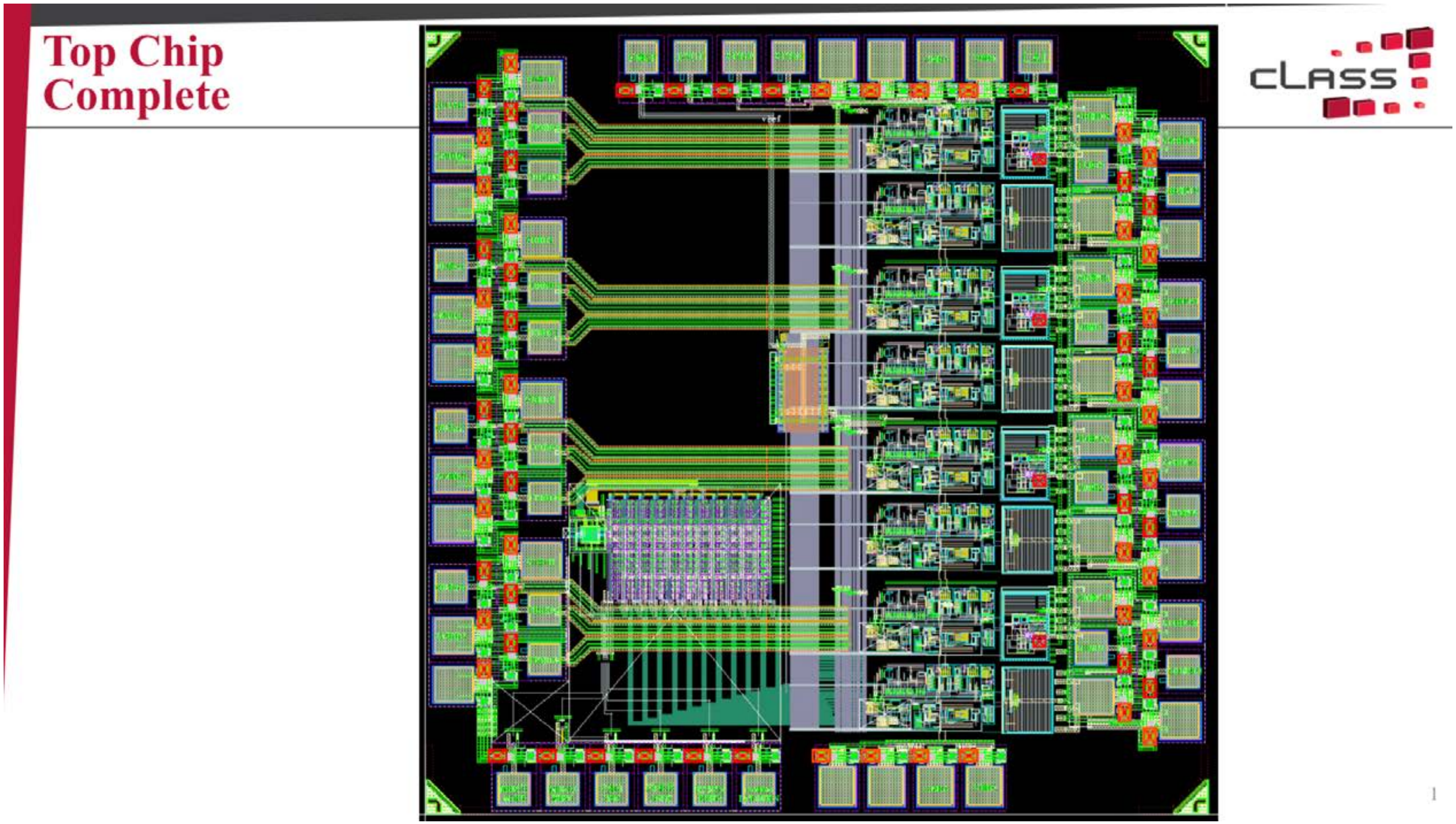
- Start with RD42 fast amp used in rate studies
  - designed in 130nm technology
  - risetime 3-6ns; baseline recovery time 12-18ns
  - noise for 2pf input: 550e
- Design 2 preamps to achieve large dynamic range
  - lumi sensitivity to MIPs at 7ke
  - abort threshold for safety at 25k-7.5M MIPS/cm^2
  - electronics dynamic range >100:1
  - risetime 1-2ns; return to baseline (<2%) 12ns
  - noise for 2pf input: 220e; S/N > 40/1; σ_{TOA} < 100ps
- Optimize gain and speed vs SNR for lumi, abort separately
- End with 8 channel amp (4 lumi, 4 abort) in 65nm

2nd 65nm Chip Submitted Aug 28, 2019

Collaboration with experiments: ATLAS BCM'

Electronics Design Path

- Second version of preamp+CFD layout– submitted Aug 28



Collaboration with experiments: CMS BCM1F

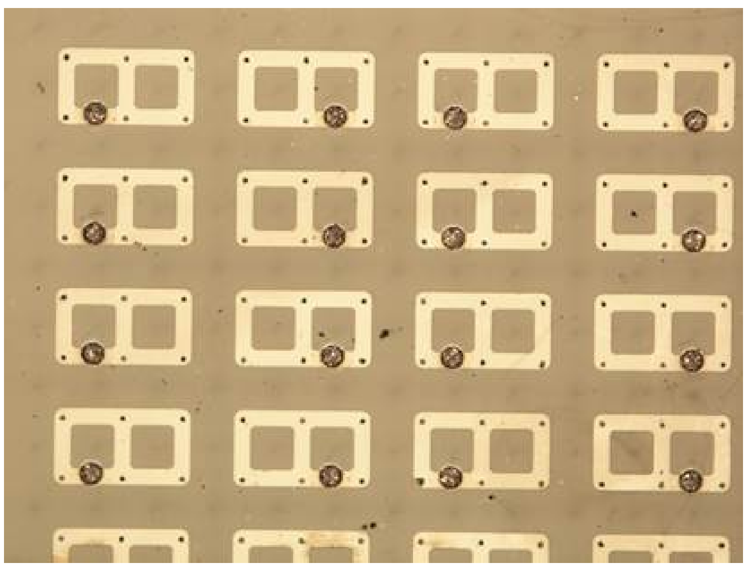
RD42 expertise helped the CMS BCM1F Upgrade (shown in last years RD42 LHCC report) to reach a 2% luminosity measurement.

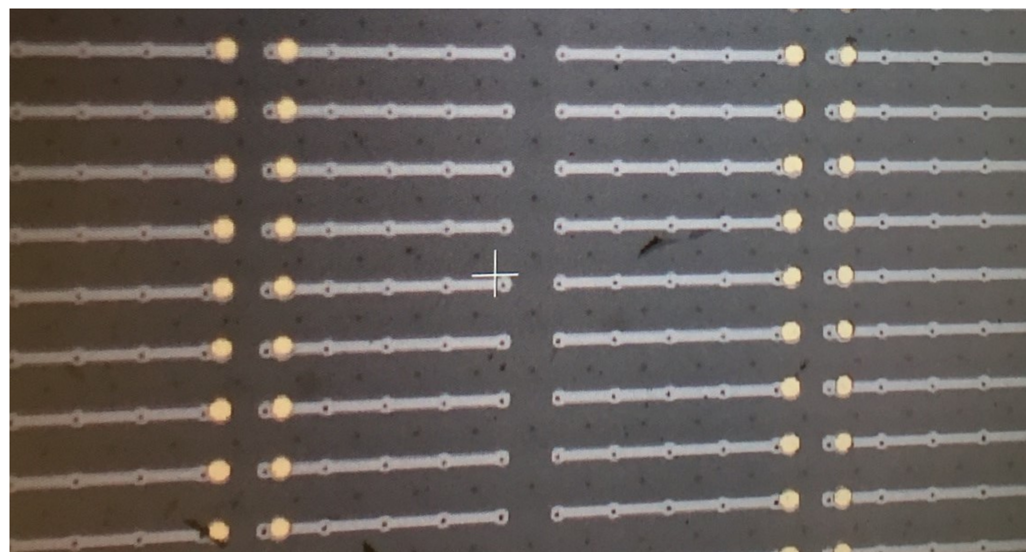
Recently CMS contacted the ATLAS BCM' group about collaborating on the upgrade; interested in a stand-alone CMS luminosity device using diamond and the electronics chain described above.

Development of 3D Diamond Pixel Modules

Produced two 4000 cell pixel prototype w/50μm x 50μm pitch

- Three fabricated: Oxford 2, Manchester 1
- 50μm x 50μm cells ganged for 3x2 (CMS) and 1x5 (ATLAS) readout
- Bump bonding: CMS@Princeton (In); ATLAS@IFAE (Sn/Ag)
- 3x2 ganged tested in Aug 2017@PSI, Sep, Oct 2018@CERN
- 1x5 ganged tested in Sep, Oct 2018@CERN

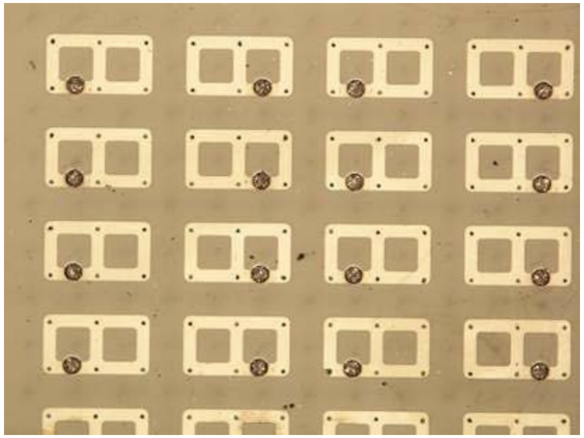


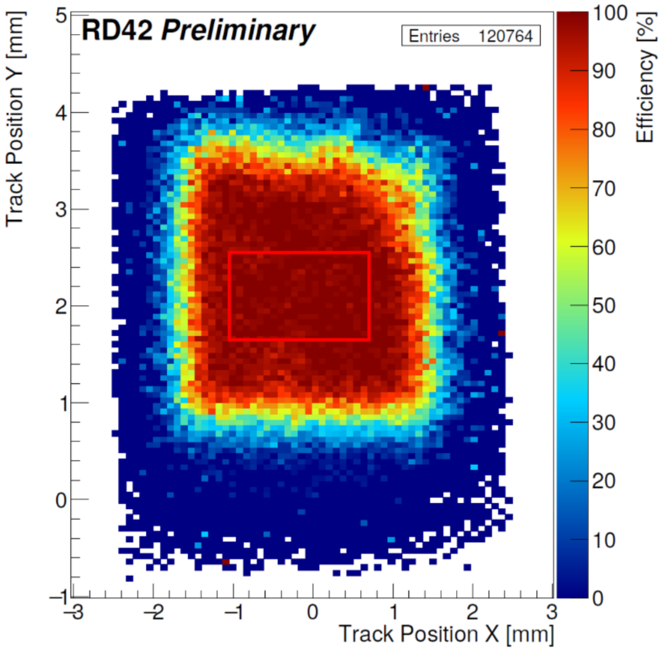


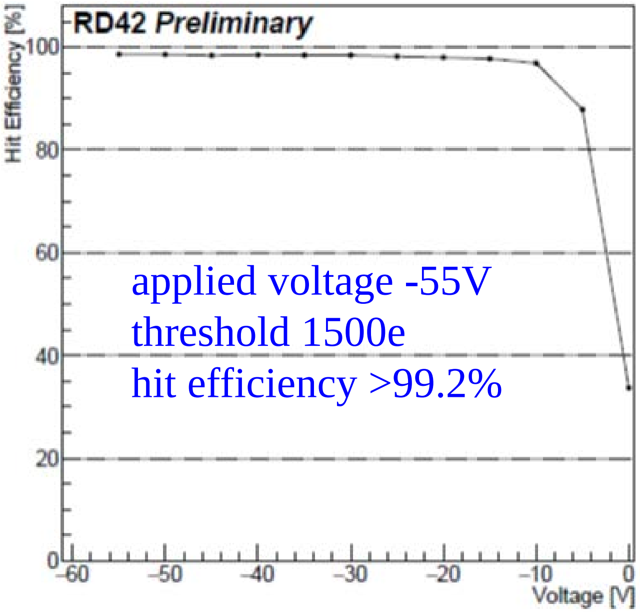
Development of 3D Diamond Pixel Modules

Preliminary Results (50μmx50μm cells)

- Readout w/PSI46digv2.1-respin CMS chip
  6 cells (3x2) readout w/1 channel
- Preliminary efficiency >99.2%
- Collect >85% of charge!



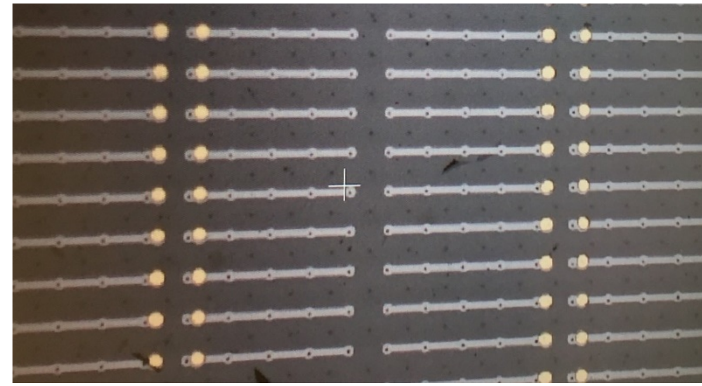


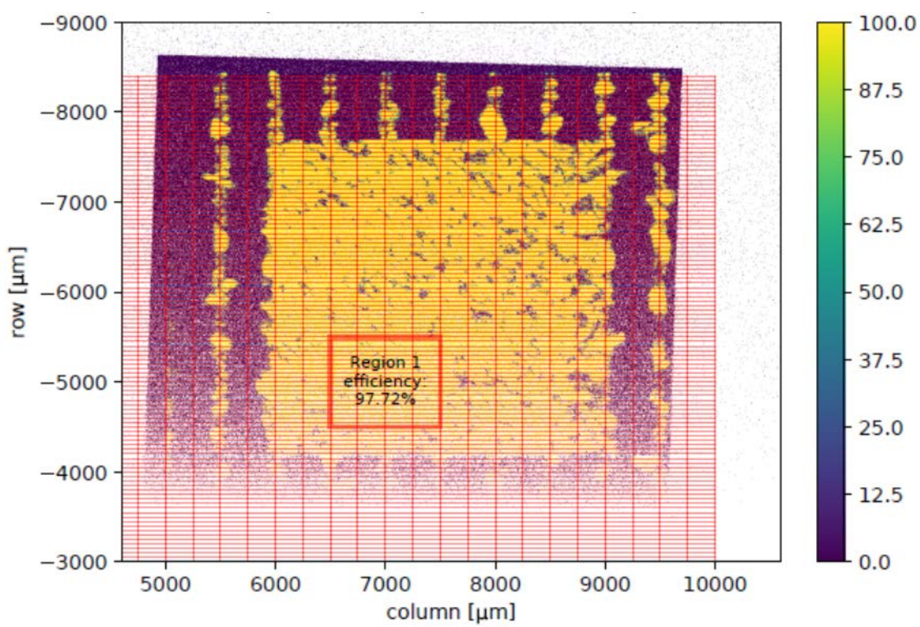


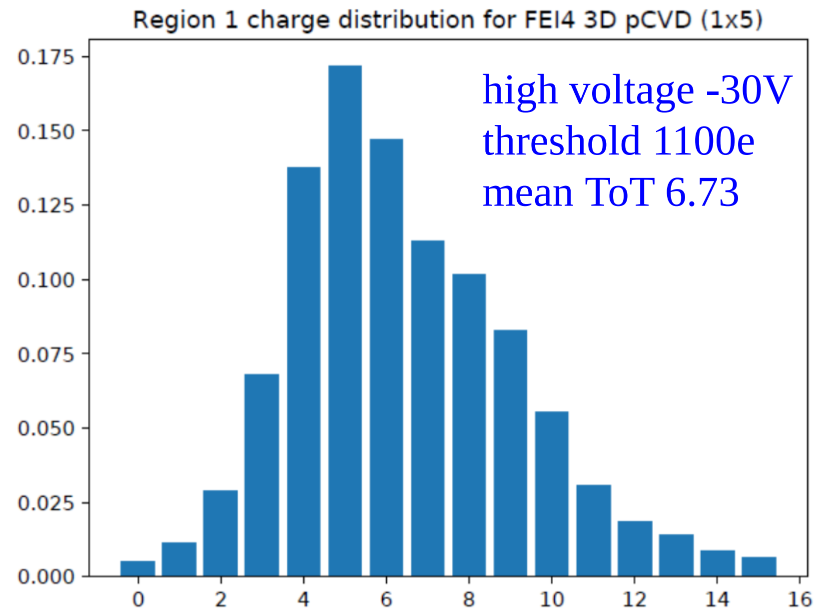
Development of 3D Diamond Pixel Modules

Preliminary Results (50μmx50μm cells)

- Readout w/FE-I4 ATLAS pixel chip
  5 cells (1x5) readout w/1 channel
- Preliminary efficiency >97.7%
- 5ToT=11,000e; Mean ToT=6.73=14,800e
- Collect >80% of deposited charge!







The RD42 Program

7.1: 3D Diamond Sensor Fabrication and Characterisation

2019 Milestones

- Complete testbeam analysis of early 3D prototypes to quantify HV and I operating points and collected charge
- Irradiate 3D device to 10^{15}
- Laser drilling of 50μm x 50μm 3D cells with 2.5μm diameter columns with >99.9% yield (measured 2.6±0.1μm diameter and 99.7±0.2% yield)
- First 3D columns from etching process produced and evaluated

2020 Milestones

- Testbeam studies of irradiated 3D sensors configured as pads
- Assess performance after fluences of 10^{15}
- Fabricate 25μm x 25μm 3D cells
- Scale up 3D columns produced by lasers
- Irradiate 50μm x 50μm 3D cells to 10^{16}

The RD42 Program

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

2019 Milestones

- Produce first 65nm HL-LHC beam loss/lumi ASIC
- Assemble first HL-LHC beam monitor
- Test @PSI up to fluxes of 20MHz/cm^2
- Irradiate one station to 10^{15}

2020 Milestones

- Produce revised 65nm HL-LHC beam loss/lumi ASIC
- Test unirradiated beam monitor station w/new ASIC w/source
- Test irradiated beam monitor station w/new ASIC @CERN
- Test irradiated beam monitor station w/MIPs @ CERN
- Irradiate one station to 10^{16}

The RD42 Program

7.3: Development of pCVD Material

2019 Milestones

- Work w/manufacturers to understand surface defect production
- Reduce surface defects to less than 1/cm^2 (reached few/cm^2)
- Develop additional characterization tools as needed

2020 Milestones

- Work w/manufacturers to increase ccd to 400µm

2021 Milestones

- Work w/manufacturers to increase uniformity to <2%

The RD42 Program

7.4: Development of 3D Diamond Pixel Modules

2019 Milestones

- Finish testing 3x2 and 1x5 ganged 50µmx50µm pixel module
- 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 Milestones

- Fabricate and test 25µmx25µm pixel modules
- Irradiate 3D pixel modules to 10^{16}
- Compare 25µm and 50µm modules in test beam

2021 Milestones

- Irradiate modules to 10^{17}
- Test rad tolerance at 10^{17} in beam tests
- Construct pixel based monitoring system

The RD42 Program, 2018 Referees Report

2018 LHCC Referees Report (CERN/LHCC 2018-018)

RD42: Development of Diamond Tracking Detectors for High Luminosity Experiments at the LHC

- Among the goals of the extension period are 3D diamond sensor fabrication and characterisation, proof-of-principle for diamond-based HL-LHC beam monitoring devices, further development of pCVD material and the development of 3D diamond pixel module prototypes.

- The **LHCC recommends** granting RD42 the 3-year extension requested, including CERN support at the level currently provided (access to CERN facilities, lab and office space, test beams). Progress will be reviewed every year by the LHCC.
- The **LHCC encourages** RD42 to keep sustaining and developing close links (and eventually projects) and commonalities with the LHC and future collider infrastructures and experiments.
- As it was already mentioned last year, the **LHCC strongly encourages** RD42 to update their web site expeditiously to improve their communication with the scientific community.

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