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

RD42 Status Report

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for the RD42 Collaboration

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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

114 participants

30 institutes
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/](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
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

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.

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

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

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PageSupport, Diamond Detector@cern.ch
Recent Results: Rate Tolerance

Characterization in beam tests let us deduce the rate independence of pCVD material up to $8 \times 10^{15}$ n/cm$^2$. 

![Graphs showing rate independence](graph)
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/cm²
Collaboration with experiments: ATLAS BCM'

Preliminary Module Conceptual “design”

IpGBT
picoTDC
dedicated BCM’ FE and CFD
diamond detector
Revised Sensor Design Idea

- Build dynamic range into sensor
- Pad sizes from $1\text{mm}^2$-$32\text{mm}^2$ 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/cm²
  • 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
RD42 expertise helped the CMS BCM1F Upgrade (shown in last year's 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 (50μm x 50μm cells)

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

applied voltage -55V
threshold 1500e
hit efficiency > 99.2%
Preliminary Results (50\textmu m \times 50\textmu m cells)

- Readout w/FE-I4 ATLAS pixel chip
  5 cells (1x5) readout w/1 channel
- Preliminary efficiency >97.7%
- $5\text{ToT}=11,000e$; Mean $\text{ToT}=6.73=14,800e$
- Collect >80% of deposited charge!
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 $10^{16}$
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/cm²
- 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/cm² (reached few/cm²)
- 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%
7.4: Development of 3D Diamond Pixel Modules

**2019 Milestones**

- Finish testing 3x2 and 1x5 ganged 50μm×50μm pixel module
- Fabricate and test additional 50μm×50μm pixel modules
- Irradiate 3D pixel modules to $10^{15}$
- Characterize rad tolerance of 3D pixel module with RD53 chip

**2020 Milestones**

- Fabricate and test 25μm×25μm 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
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 website expeditiously to improve their communication with the scientific community.
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