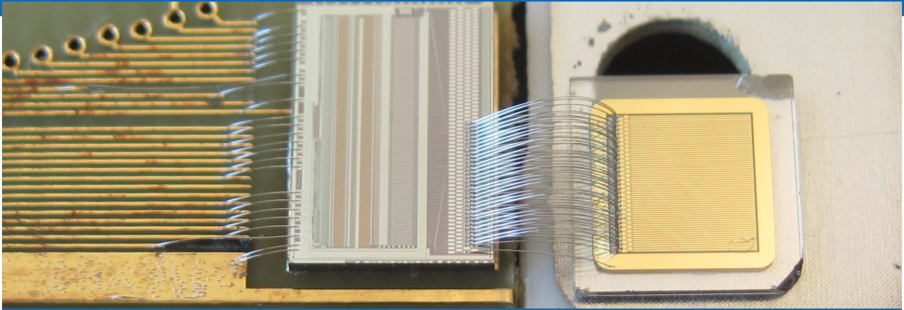

Latest Results on the Radiation Tolerance of Diamond Detectors

29th International Symposium on Lepton Photon Interactions at High Energies

Lukas Bäni on behalf of the RD42 Collaboration

Toronto, 08.08.2019

LP2019

Motivation

- Present Situation at CERN LHC Experiments
  - Innermost layers $\rightarrow$ highest particle rate, highest radiation damage
  - Current detectors presently can not withstand the GHz/cm^2 rate and 2×10^{16}/cm^2 fluence of the HL-LHC
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- RD42 collaboration investigates signals and radiation tolerance in various detector designs
  - pad (full diamond as a single cell)
  - strip
  - pixel (diamond sensor on pixel chips)
  - 3D to reduce drift distance $\rightarrow$ M. Reichmann's talk

The RD42 Collaboration

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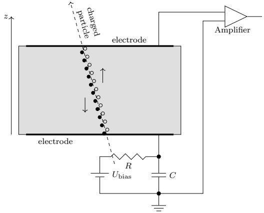
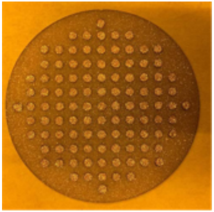
118 Participants

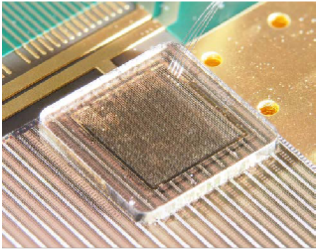
29 Institutes

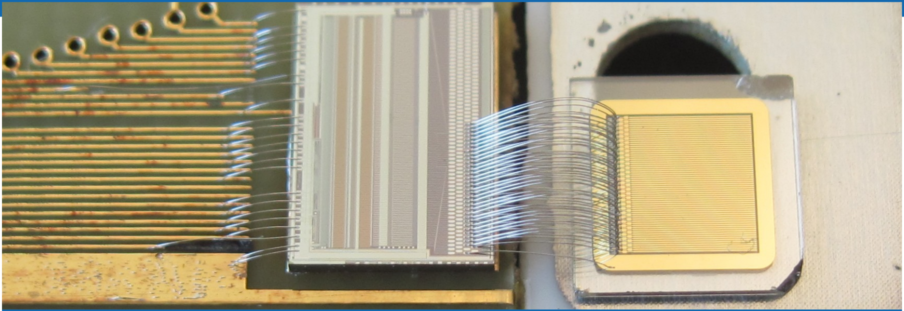
Diamond as a Particle Detector

- Diamond detectors are operated as ionization chambers
- Poly-crystalline material comes in large wafers
- Metalization on both sides
  - Pad
  - Strip
  - Pixel
- Connected to low noise electronics





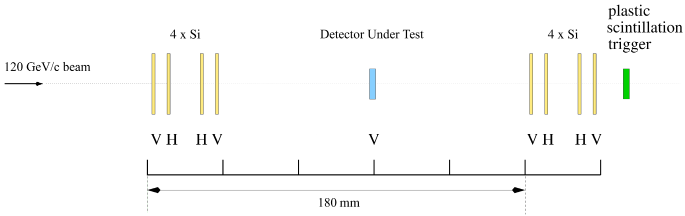




Radiation Tolerance

Study the pulse height dependance on the irradiation fluence

Beam Test Setup



- Irradiate diamond samples with various particle species and energies
- Re-metalize after each irradiation step to fabricate a strip detector
- Characterization of irradiated devices in beam tests
- transparent (unbiased) hit prediction from telescope
- tracking precision at detector under test: $\sim$ 2–3 μm

Analysis Strategy

- Measure the signal response as a function of predicted position
  $\rightarrow$ Direct measurement of charge collection distance (CCD)
  CCD = average distance e-h pairs drift apart under E-field

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- Convert CCD to «schubweg» (λ) – the mean free drift distance before being trapped in an infinite material

$$\frac{ccd}{t} = \sum_{i=e,h} \frac{\lambda_i}{t} \left[1 - \frac{\lambda_i}{t}\left(1 - \exp\left(-\frac{t}{\lambda_i}\right)\right)\right]$$

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- Damage equation

$$n = n_0 + k' \phi$$
$$\frac{1}{\lambda} = \frac{1}{\lambda_0} + k\phi$$

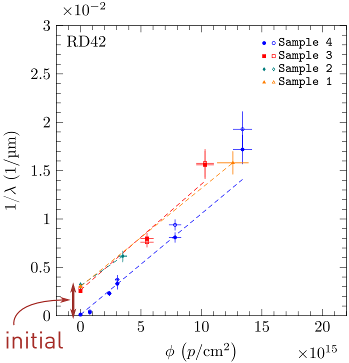
t	thickness
n	number of traps
n_0	initial traps in material
ϕ	fluence
λ	schubweg
λ_0	initial schubweg
k	damage constant

- Fit in $1/\lambda$ vs ϕ space to determine k, λ_0

Radiation Tolerance

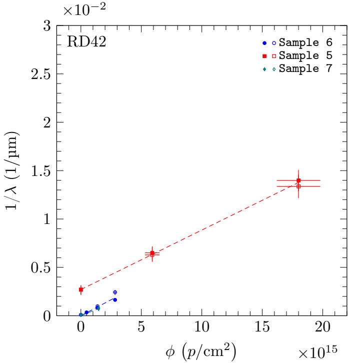
[DOI: 10.1088/1361-6463/ab37c6]

- Plot single- and poly-crystalline data on same graph
- Linear fit in $1/\lambda$ vs ϕ space
- Observe same damage constant (=slope) for single crystal and poly



due to initial traps in poly

800 MeV proton



24 GeV proton

Damage Curve Analysis

- Obtained radiation damage constants are compared to 24 GeV protons

Particle species	κ
24 GeV protons	1.0
800 MeV protons	1.67 ± 0.09
70 MeV protons	2.48 ± 0.25
Fast neutrons	4.5 ± 0.4

Damage Curve Analysis

- Obtained radiation damage constants are compared to 24 GeV protons
- Combined damage curve
  - Shift pCVD sample by

$$\phi_{0,i} = \frac{1}{\lambda_{0,i} k_i}$$

  - Scale fluence by relative k

$$\phi_{eq.} = \frac{k_i}{k_{24\,\text{GeV protons}}} \times \phi_i$$

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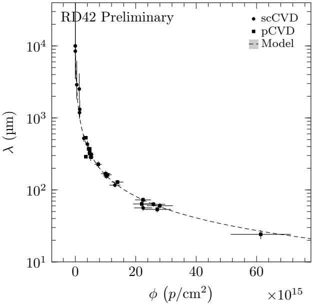
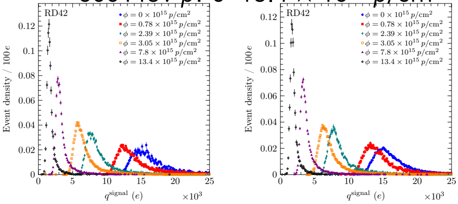


Signal Shape Analysis

[DOI: 10.1088/1361-6463/ab37c6]

800 MeV p: 0–13.4 $\times 10^{15}$ p/cm^2

- Study the shape of the pulse height distribution after irradiation



−HV +HV

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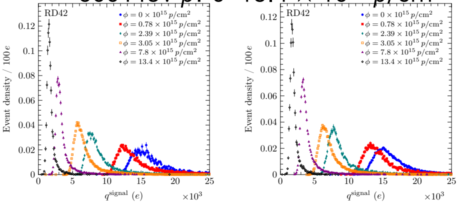

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Signal Shape Analysis

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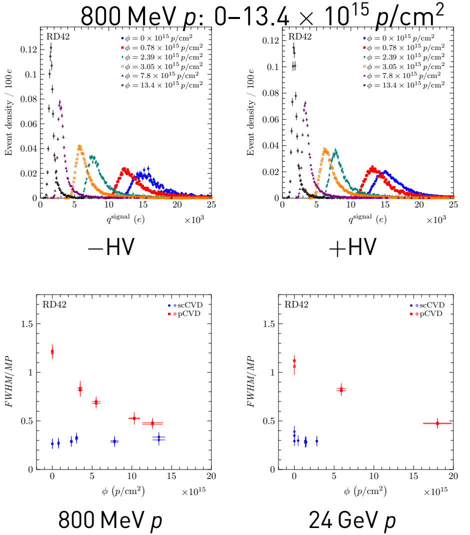
- Study the shape of the pulse height distribution after irradiation
- To compare pCVD and sCVD samples: *FWHM/MP*
- 800 MeV irradiated
  - pCVD samples
    - *FWHM/MP* decreases with dose
  - sCVD samples
    - Smaller initial *FWHM/MP*
    - *FWHM/MP* is flat with dose
  - Similar results for other irradiation energies and species



Uniformity in pCVD Diamond [DOI: 10.1088/1361-6463/ab37c6]

- *FWHM/MP* before and after irradiation

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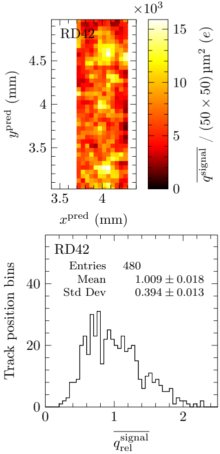
- Observe regions of different signal (λ) in unirradiated poly-crystalline diamond



unirradiated

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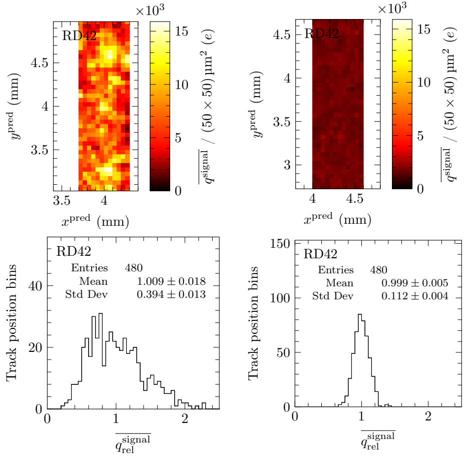
$\rightarrow$ Portions of material with the largest λ are damaged most for given fluence dϕ



unirradiated $\phi = 18 \times 10^{15}\ p/\mathrm{cm}^2$

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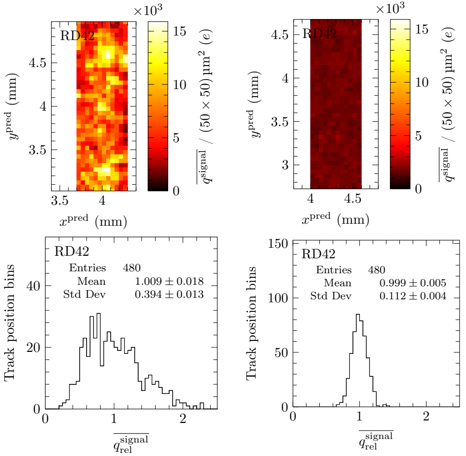
- *FWHM/MP* is a measure of the uniformity of the material



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Rate Studies

Study the pulse height dependance on the particle flux

Setup

- Characterization in 260 MeV π^+ beam at PSI

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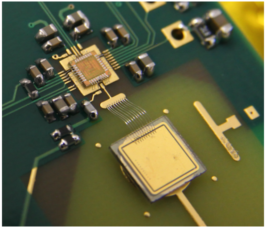
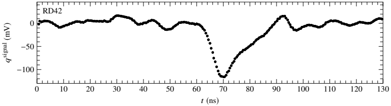
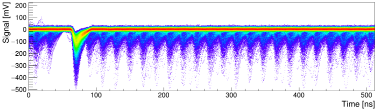
- Irradiated pad detectors tested in ETH (CMS Pixel) telescope







19.8 ns bunch spacing clearly visible

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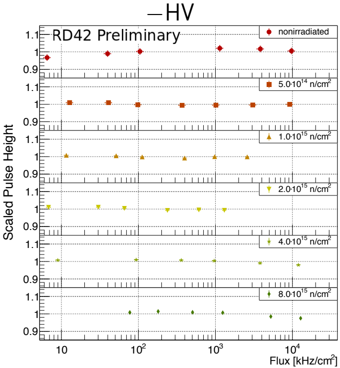

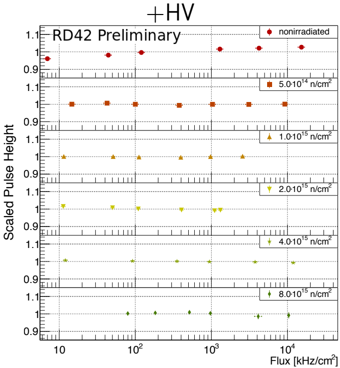

- No rate dependence ($<2\,\%$) observed in irradiated pCVD up to 10–20 MHz/cm^2
- No rate dependence ($<2\,\%$) observed in irradiated pCVD up to $8 \times 10^{15}\, n/\text{cm}^2$

Summary

- Quantified understanding of radiation effects
  - Measured radiation tolerance up to fluences of $10^{16}/cm^2$ (relevant for tracker application in HL-LHC experiments)
  - Measured signal uniformity of single- and poly-crystalline CVD diamond up to fluences of $10^{16}/cm^2$
  - Radiation damage studies were recently published in J. Phys. D: Appl. Phys. [DOI: 10.1088/1361-6463/ab37c6]

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  - Radiation damage studies were recently published in J. Phys. D: Appl. Phys. [DOI: `10.1088/1361-6463/ab37c6`]
- Expanded understanding of rate effects @2 V/μm
  - Irrad. pCVD diamond shows no rate effect (<2 %) up to 20 $\mathrm{MHz/cm}^2$
  - Irrad. pCVD diamond shows no rate effect (<2 %) up to $8 \times 10^{15}\ n/\mathrm{cm}^2$

Backup

CCD vs Schubweg

CCD vs mean free drift distance before being trapped in an infinite material

$$\frac{ccd}{t} = \sum_{i=e,h} \frac{\lambda_i}{t}\left[1 - \frac{\lambda_i}{t}\left(1 - \exp\left(-\frac{t}{\lambda_i}\right)\right)\right]$$