Test beam measurements of irradiated CVD diamond

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Outline

✓ Time resolution
✓ Radiation damage in diamond
✓ Set-up at the test beam
✓ Results
Motivation: CMS Precision Proton Spectrometer (PPS)

Measures forward protons, joint project between CMS and TOTEM
In each arm:
2 stations of tracking detectors: Precise measurement of proton trajectory
1 timing station: Time-of-Flight of proton

Vertex measurement by timing eg.: $\sigma_t=10\,\text{ps} \rightarrow \sigma_v=2\,\text{mm}$
Needed time resolution depends on magnitude of pile-up,
Depending on beam optics needed resolution ranging from 10ps to 50ps
Note: Requirements for time precision are for detector package. Current timing detector package consists of 4 planes.

[LHCC-2014-021; TOTEM-TDR-003; CMS-TDR-13]
Time resolution

\[ \sigma_{\Delta t} = \sqrt{\sigma_{t_1}^2 + \sigma_{t_2}^2} \]

- \( \sigma_t \approx \text{SNR}/t_{\text{rise}} \)
- Stochastic signal generation
  - \( \rightarrow \) Initial charge distribution
- Stochastics in signal transport
- Direct measurement not possible
  - \( \rightarrow \) SNR & rise time characteristics

Measure \( \Delta t = t_2 - t_1 \)

Detector 1

\[ t_1 \]

Detector 2

\[ t_2 \]
Radiation damage in high purity single crystal diamond

✓ Ideal pure diamond

Single charge carrier traversing through crystal

Several charge carriers from MIP

Induced current

Induced current

time

time
Radiation damage in high purity single crystal diamond

- Radiation damage: Mono vacancies & interstitials -> deep level traps

Single charge carrier traversing through crystal

Several charge carriers from MIP

\[ i = i_0 e^{-kt} \]

- Reduced charge collection, faster signal
Radiation damage in high purity single crystal diamond: polarization

✓ Uneven charge density caused by trapped charge

Trapping in bulk

And interfaces

➢ Results in lower E-field
➢ Longer signals
Set-up at SPS Northern experimental area

- 180 GeV pions
- DUT
- Reference scintillator

✓ Irradiated single crystal chemical vapor deposited (scCVD) diamonds
  ✓ @ IRRAD, 24 GeV protons
✓ Fluence 0 p/cm$^2$, $10^{14}$ p/cm$^2$, $5 \times 10^{15}$ p/cm$^2$
✓ Sensor size 4.5x4.5x0.5 mm$^3$
Set-up at SPS Northern experimental area

✓ Sensor mounted on TOTEM hybrid [2]
✓ Three stage amplification chain
✓ Signal readout with fast oscilloscope (Agilent DSO9254A, LeCroy WaveRunner8104)
✓ Signal processed offline using ROOT

HV: Keithley 2410-C

Contact by pressure

• Piece of copper tape soldered directly to pre-amplifier leg (thank you Georgui!!)
• Surface leakage stop with kapton tape, contact pad raised with copper tape stack
• Pressure applied with pieces of rubber and recycled plexiglass
• In practice:
  • Single channel works as well as bonding
  • several channels -> increased noise (pick off)
Signals attributes:
Signal amplitude, Signal rise time

Amplitude

90% A

10% A

RMS = noise

Signal rise time
Signals attributes: Noise RMS

RMS before signal = noise RMS
Raw amplitude spectrum of proton irradiated diamonds under pion beam

HV=1000V

threshold

5e15 p/cm²  1e14 p/cm²

reference
Signal rise time spectrum of proton irradiated diamonds under pion beam

HV=1000V

- 5e15 p/cm²
- 1e14 p/cm²

Counts vs. Signal rise time (ns)
Signals attributes: Signal duration

Amplitude

Signal FWHM duration
Signals in amplitude-signal duration plane, separation using signal shape

**Diagram:**
- **Y-axis:** Signal FWHM duration (ns)
- **X-axis:** Amplitude (mV)
- **Legend:**
  - **Color Scale:** 10^-1 to 10
  - **Saturation in oscilloscope**
  - **Saturation in 2nd amp**

**Annotations:**
- **“Landau”**
- **Noise**

**Text:**
- Nois
Signals in amplitude-signal duration plane, separation using signal shape

Non-irradiated reference

Irradiated to $10^{14}$ p/cm$^2$

2D-gaussian fit:
Amplitude = 322 ± 1 mV
Duration = 3.144 ± 0.001 ns

2D-gaussian fit:
Amplitude = 288 ± 1 mV
Duration = 3.048 ± 0.008 ns
Signals in amplitude-signal duration plane, separation using signal shape

Non-irradiated reference

Amplitude (mV) vs. Signal FWHM duration (ns)

Irradiated to $5 \times 10^{15}$ p/cm$^2$

Amplitude (mV) vs. Signal FWHM duration (ns)

2D-gaussian fit:
- Amplitude $= 322 \pm 1$ mV
- Duration $= 3.144 \pm 0.001$ ns

2D-gaussian fit:
- Amplitude $\leq 100$ mV
- Duration $= 1.761 \pm 0.006$ ns
Signal amplitude with different bias voltages

- $\Phi=0$ p/cm$^2$
- $\Phi=10^{14}$ p/cm$^2$
- $\Phi=5\cdot10^{15}$ p/cm$^2$
Signal FWHM duration vs bias voltages

![Signal FWHM duration vs bias voltages](image-url)
Conclusions

✓ Basic signal attributes from 180 GeV pions was investigated
✓ Signal amplitude reduced with radiation damage
✓ Signal duration & rise time reduced as well
  ✓ Helps with time resolution
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