Diamond Detectors for CNGS

A new fast tool for intensity and timing measurements
Outline

1. Why diamond detectors in Secondary Beam Lines?
2. Diamond detectors in the SBL of CNGS
3. Intensity measurements for CNGS
4. Timing measurements for CNGS
Diamond is a semi-conductor based, solid state ionization chamber:

Amplification/ no amplification/ attenuation depending on signal
Why Diamond

Pros:

➢ High band gap (5.5 eV)
  → Very high breakdown field > 1e7 V/cm
  → Very high resistivity > 1e11 Ω cm
  → Large area
  → Very low leakage current ~ few pA

➢ Low dielectric constant (5.7)
  → Low capacitance → Low noise

➢ High displacement energy (43 eV/atom)
  → Radiation hard → No replacement

➢ High mobility (~2000 cm²/Vs)
  → Fast signals
  → High collision rate

➢ Very wide sensitivity range
  → Single MIP to 1 THz tested

➢ Wide operational temperature range

➢ No cooling (no “thermal run-away”)

Cons:

➢ High $E_{\text{pair-creation}}$ (13.5 eV)
  → Less signal, but S2N-ratio comparable to Si

➢ Rather high costs

➢ Not as well understood as Si
  → More R&D efforts needed
Modes of Operation

- **Counting Mode**

- **Calorimetric Mode**

Hole collection for reverse bias

\[ i_0 = \frac{Q \cdot v_d}{d} \]

\[ t_d = \frac{d}{v_d} \]

\[ i = \frac{Q}{2} \cdot \frac{v_d}{d} \]
pCVD vs scCVD

- **pCVD Diamond:**
  - very short signal
  - ~2ns FWHM @ 1V/um
  - optimal double pulse resolution
  - charges lost at trapping centres

- **scCVD Diamond:**
  - short signal
  - ~5ns FWHM @ 1V/um
  - optimal Signal-to-Noise ratio
  - lower trapping centre concentration

\[ \text{CCD} = d \times \frac{Q_{\text{sig}}}{Q_0} \]

**Graphs:**
- CCD ≈ 250 μm at 150 V
- Full charge collection distance up to 800 μm demonstrated
- Single crystal
In short...

- Diamond is fast:
  - Measure individual bunches up to \( \sim 200 \text{ MHz} \)
  - Depending on the signal-to-noise ratio, time resolution of \(< 1 \text{ ns} \) is easily achievable

- Diamond response is linear to particle flux:
  - Usable as fast intensity monitor
  - Even in high intensity beams
Diamond Detectors at CNGS

- Where?

![Diagram of CERN Neutrinos to Gran Sasso](image)

**Legend:**
- PS: Proton Synchrotron
- SPS: Super Proton Synchrotron
- LHC: Large Hadron Collider

**CERN Neutrinos to Gran Sasso**
Underground structures at CERN

- **Excavated**
- **Concrete**
- **Decay tube (2nd contract)**

**Key Features:**
- Target chamber
- Service gallery
- Decay tunnel
- Access galleries
- SPS tunnel
- TT41
- Access shaft PGGN
- LHC/T1B tunnel
- Beam holes
- Protons
- Connection gallery to T1B/LHC
- Hadron stop and first muon detector
- Second muon detector
- Neutrinos to Gran Sasso
- 140m
- 5.5m
Diamond Detectors at CNGS

- Where?

![Diagram of CERN Neutrinos to Gran Sasso](image)

**Beam Current Transformer**

**Diamond Detectors**
Diamond Detectors at CNGS

- **TNM 41:**

  Poly-crystalline CVD diamond detectors:
  - 8mm x 8mm
  - 500 um thickness
  - no amplification, direct scope read-out, 50 Ohm
Intensity/Profile Measurements

From Single Extraction:

- Centre Top
- Centre Bottom
- Left
- BCTF40
Compare p- to $\mu$-beam structure

- Signals from BCT and DDs agree nicely
- Even local features show up in both DDs and BCTF
Zoom:

-> 5 ns bunch structure from SPS RF evident
Intensity/Profile Measurements

2012 100 ns Beam:

Exp. charge: \(12.5 \times 10^{12} \text{ p} \times 2.4 \times 10^{-6} \text{ mu/p*cm}^2 / 64 \times 7200 \text{ e} \times 0.64 \text{ cm}^2\)  
\(= 345 \text{ pC / bunch (\(-10 \text{ to } 15\% \) cables losses} \approx 300 \text{ pC/bunch)}\)

Meas. charge: \(467 \text{ ADC/ns*bunch} \times 16 \text{ mV/ADC} / 50 \text{ Ohm} \times 2\)  
\(= 299 \text{ pC / bunch}\)
Time Resolution

- **Noise:**

\[ \sigma_t = \frac{\sigma_{\text{noise}}}{\text{max}(\text{slope})} \]

\[ \sigma_t = 15.4 \pm 1.7(\text{stat}) \text{ ps} \]

- **Max. slope:**
Diamond Detectors at CNGS

- Connection from detectors to Control Room:
Verification of CNGS Timing

- Measure all delays between read-out windows: \( \delta_{BCTF} \) and \( \delta_{DD} \)

- Measure timeline offset of signals within read-out window

- Calculate time-of-flight: \( \text{ToF}_{\hat{\Theta}_x} = (6205.4 \pm 3.6) \text{ ns} \)

\[
\text{ToF}_{\text{nom}} = \frac{1859.95 \text{ m}}{\nu} = (6205.3 \pm 2.5) \text{ ns}
\]
In short...

- **Diamond is fast:**
  
  -> Measure individual bunches up to ~200 MHz

  -> Depending on the signal-to-noise ratio time resolution of < 1 ns is easily achievable

  \[ \sigma_t = 15.4 \pm 1.7 \text{(stat)} \text{ ps} \]

- **Diamond response is linear to particle flux:**

  -> Usable as (fast) intensity monitor

  -> Even in high intensity beams:

  \[
  12.5e12 \text{ p} \times 2.4e-6 \text{ mu/p cm}^2 \\
  \times 0.64 \text{ cm}^2 / 64 / 10e-9 \text{ s} \\
  = 30 \text{ THz}
  \]
Thanks.
Questions?
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