Investigation of the Use of Diamond, Silicon and Liquid Helium Detectors for Beam Loss Measurements at 2 K

B. Dehning, T. Eisel, C. Kurfuerst, M. Sapinski, CERN
V. Eremin, IOFFE, Russia
C. Fabjan, HEPHY, Austria
Outline

- Motivation
  - LHC Beam Loss Monitoring
  - CryoBLM project
- Beam test measurement setup
- Beam characteristics
- Results
  - Semiconductors
  - Liquid helium chamber
- Conclusions and outlook
LHC Beam Loss Monitoring

- **Purpose**: damage and quench protection of sensitive elements (magnets and collimators)
- **Method**: measurement of secondary shower particles from beam losses
- **Detectors**: Ionisation chambers, Secondary Emission Monitors and Diamonds
- **Fastest active machine protection system**

Fast    Reliable    Available
BUT
Limit close to interaction regions

Problem: in triplet magnets signal from debris with similar height as simulated beam losses in steady state case.

7 TeV, nominal luminosity

Also see poster THPPR039, M. Sapinski
Cryogenic BLM as solution

- Future BLMs placed closer to:
  - where losses happen and
  - the element needing protection (so inside cold mass of the magnet, 1.9 K)
- Measured dose then better corresponds to dose inside the coil
Specifications for CryoBLM

- Present conditions:
  - low temperature of 1.9 K (superfluid Helium)
  - radiation of about 1 MGy in 10 years
  - magnetic field of 2 T
  - pressure of 1.1 bar, withstanding a fast pressure rise up to about 20 bar
- Linearity between 0.1 and 10 mGy/s
- Detector response faster than 1 ms
- Stability, reliability and availability: after installation no access possible
Investigated detectors

- **Silicon**
  - Successfully used at 1 K at CERN in 1976 - ““Frozen Spin” Polarized Target”

- **Diamond**
  - Successfully in use as LHC BLM at room temperature
  - Radiation harder than Si at room temperature
  - Less leakage current than Si at room temperature
  - **Does it work in liquid helium?**

- **Liquid helium ionisation chamber**
  - + No radiation hardness issue
  - - Slow (charge mobility of 0.02 cm²/V/s)
CERN PS Beam test area
Inside cryostat - detectors

Semiconductors: 
- Silicon $p^+\text{-n-n}^+$ with 300 $\mu$m thickness and single crystal chemical vapor deposition (CVD)
- Diamond with 500 $\mu$m thickness

LHe chamber
10 cm length
New setups used just last week!

In liquid helium

At room temperature

With Erich Griesmayer and Christina Weiss
Due to long cables advantage of low noise at LHe temperatures is partly lost.

Cable length between detectors and preamplifiers ~ 2 m
Remark - Cold Amplifier
Courtesy CIVIDEC

Goal: No noise at 2 K, no long cable

Tested in liquid nitrogen and liquid helium with pulser and alpha source

Amplifier survives cold+vacuum

Downsides: characteristics change, 1 W power dissipation, 3 feedthroughs needed

→ Not used for beam tests
Beam characteristics

- Particles consist of **protons** (dominating), positive pions and kaons
- 9 GeV/c particles
- Beam intensity **350 000 particles/spill**
- Size at focus about 1 cm$^2$
- Spill duration of 400 ms (**less than 1 particle/µs**)
Single Particle detection

40 dB current amplifier from CIVIDEC (courtesy Erich Griesmayer)
Silicon results
Single particle (response averaged from ~5000 pulses)

Drift time change at liquid helium temperatures of 54%
Additionally: leakage current below pA at liquid helium temperature
Silicon 680 nm laser measurement

Transient current technique measurements: laser applied on one side of Silicon. Charges travel through bulk, giving information about their characteristics.

- **Electrons**: Si electron pulses at 3330 V/cm
- **Holes**: Si hole pulses at 3330 V/cm

Temperature scan
Silicon characteristics at 4.2 K with 4 mV trigger

Mean charge: 5.2 fC

Mean FWHM: 2.5 ns
Single particle signal in diamond at room temperature

Does diamond work in liquid helium?
Diamond results
Single particle (response averaged from ~5000 pulses)

Drift time change of about 28%

Reflections with 20 ns delay
Diamond characteristics at 4.2 K with 4 mV trigger

- Mean charge: 8.7 fC
- Mean FWHM: 3.6 ns
Electronic setup for DC measurements
(preferred for final BLM application)

Keithley 6517 electrometer

SMA-Feedthroughs

Cable shielding

Cryostat

Beam
Liquid helium chamber
Intensity variation

LHe chamber collected charge per spill at 800 V and 1.7 K

Linearity is observed in the range from 5 to 140 pC
Applied voltage

Current BLM Ionisation chamber operated at 1.5 kV in proportional region → no influence of voltage variation on detector signal
Situation in liquid helium:

| Liquid Helium chamber signal at 1.76 K |

![Graph showing the relationship between applied voltage and relative signal amplitude.]
Liquid helium chamber fast read out (from last week)

Goal: find **timing properties** of LHe chamber
Conclusions

• All tested **detectors work** at superfluid helium temperatures:
  - Reduction of the drift time by 28 % for Diamond and 54 % for Silicon
  - Reduction of Silicon dark current from 5 nA at 100V at room temperature to below pA at 2 K
• With semiconductors a **fast detection system** for **bunch by bunch resolution** in the LHC and DC measurements for steady state losses possible
• Liquid helium chamber elegant solution as CryoBLM in the triplet magnets - **no issues with radiation hardness**
• Ongoing tests and data analysis
Two critical missing characteristics

1. **Radiation hardness** of the semiconductors at low temperatures - no annealing effect
2. **Exact charge collection time** of the liquid helium chamber

Issues will be addressed during challenging irradiation beam tests in 2012.
Acknowledgements

Thank you!!!

- CERN Cryogenic team,
- Jaakko Haerkoenen with RD39,
- Erich Griesmayer with CIVIDEC electronics,
- Heinz Pernegger,
- Hendrik Jansen,
- Alessio Mereghetti and
- Colleagues from BE-BI