Position Resolution of Optical Fibre-Based Beam Loss Monitors using long electron pulses

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Outlook

Introduction
- Motivation
- The optical fibre BLM (oBLM) system
- The machines

Measurements at the Australian Synchrotron
- Understanding beam losses: single bunch
- Intrinsic time resolution
- Beam Losses with Multi-bunch

Measurements at the CLIC Test Facility (CTF3)
- Position resolution with long (1 μs) bunch trains

Summary and conclusions
Introduction

Optical fiber BLM (oBLM) systems are becoming a popular technique since it provides several advantages

- Full coverage of beam lines
  - Optical fibres up to ~100m (limited by attenuation)
- Position resolution
  - Down to ~50cm with short (< 1 ns) beam pulses

Is beam loss position determination possible in machines with long pulses?

- e.g CLIC bunch pulse of 150 ns length

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<tr>
<th>Reference</th>
<th>Title</th>
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</table>
The oBLM system

BLM system based on Cherenkov light

- Optical fibre:
  - 200/245/365 um core/cladding/coating pure Silica
  - High OH content
  - Nylon jacket to protect against: humidity, ambient light

- Custom made photon sensing modules
  - Silicon Photomultiplier (3x3 mm², 14000 pixels, G =10⁵ - 10⁶)
  - Low pass filters (bias input) for noise filtering

- Custom high sampling (1-4GS/s) and high bandwidth (250 MHz- 2 GHz) ADCs
The Machines

oBLM installed for testing in two electron machines
- The Storage Ring of the Australian Synchrotron
- The Test Beam Line in the CLIC Facility (CTF3) at CERN

Australian Synchrotron Light Source

- 3 GeV
- 200 mA
- 500 MHz
- 1-75 b inj.

Test Beam Line at CTF3

- 120 MeV
- 3 A (peak)
- 3 GHz
- 0.1-1 µs

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Most studies performed on losses generated in the first turn

Two loss points on opposite sides of FIBRE GAP

Two loss points on same side of FIBRE GAP

\[ \Delta x = \frac{L_{RING} - c \Delta t}{1 + n_Q} \]

\[ \Delta x = \frac{c \Delta t}{1 + n_Q} \]
Multi peaks observed due to losses in different positions
Intrinsic time resolution I

- Single bunch injection
  - Consecutive filling RF buckets 1-10

- Looking at the raising edge of losses “at scrapers”
  - Well defined loss location

- One bucket (2 ns) shift disentangled shot by shot
  - $V_{\text{BLM}}(t = t_{\text{photon}}) = V_{\text{thr}}$
  - $t_{\text{photon}} \rightarrow$ Photon arrival time (to upstream end)
**Intrinsic time resolution II**

**Time response study based on photon arrival time**
- $\Delta t < 2$ ns explored by shifting Booster RF phase by 180 degrees with respect to Storage Ring RF phase
Intrinsic time resolution III

Time resolution study based on $\Delta t = t_{\text{photon}} - t_{\text{mean}}$
- $t_{\text{mean}} = t_{\text{off}} + n_{\text{bucket}} \times T_{\text{RF}}$ (central time of $n^{\text{th}}$ bucket)

$\sigma_t \approx 300 \text{ ps}$

$\Delta x = \frac{c \Delta t}{1 + n_Q}$

$\sigma_t \approx 4 \text{ cm}$
Multi bunch Beam Losses

Multi peaks observed due to losses in different positions
- Rising edge still provides loss location information
- Signal de-convolution required for losses in near positions

Current profile of 75 bunch train
Observing losses from a 1µs long pulse
- Controlled Losses generated by switching off quadrupoles
- Signal subtraction to account for showers from TBL only
**Losses with long bunch trains II**

**Determination of loss location from signal leading edge**
- Good qualitative agreement between oBLM and BPM profile loss measurements
- Localisation of loss down to (below) 2 m achieved
**Losses with long bunch trains III**

**Determination of loss location from signal leading edge**
- Good qualitative agreement between oBLM and BPM profile loss measurements
- Localisation of loss down to (below) 2 m achieved

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**Diagram:**
- Signal vs. Time (ns)
- Beam Charge vs. Position (m)
- BPM number vs. Position (m)
- Localisation of loss down to 2 m

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Summary and conclusions

An oBLM system based on quartz fibres and SiPMs has been installed and tested in two electron machines:
- The TBL at CTF3
- The Storage Ring of the Australian Synchrotron

Measurements with single bunch have been performed:
- To understand beam losses and verify loss location reconstruction
- To determine the intrinsic time resolution: better than 300 ps

First attempt to obtain loss location with multi bunch pulses
- Position resolution with long (1 μs) bunch trains achieved at CTF3
- Further signal processing necessary due to increasing beam profile along bunch train at the Australian Synchrotron
Thank you for your attention!!

Acknowledgments: N. Basten, P. Giansiracusa, A. Michalczyk, T. Lucas, ....and the operation team of CTF3 and the Australian Synchrotron
Back up slides
The Australian Synchrotron

• The AS comprises
  ‣ LINAC (10 m): 90 keV to 100 MeV
  ‣ Booster (130 m): 100 MeV to 3 GeV
  ‣ Storage Ring (216 m): 3 GeV

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<thead>
<tr>
<th>SR main parameters</th>
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<tbody>
<tr>
<td>Energy</td>
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<tr>
<td>Total design current</td>
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<tr>
<td>Circumference</td>
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<tr>
<td>RF frequency</td>
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<tr>
<td>Energy loss per turn (dipoles only)</td>
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<tr>
<td>Dipole field (nominal)</td>
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<tr>
<td>Beam size in dipoles</td>
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<tr>
<td>Beam size in straights</td>
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<tr>
<td>Number of possible Insertion devices</td>
</tr>
<tr>
<td>Emittance</td>
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<tr>
<td>Coupling (nominal)</td>
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Schematic view of a DBA cell in the SR arc
The facility comprises
- Linac (14m): 90keV to 100 MeV
- Booster resolution (130m): 100 MeV to 3 GeV)
- Storage Ring (216 m): 100 MeV to 3 GeV)

SR nominal parameters

<table>
<thead>
<tr>
<th>Energy</th>
<th>3 GeV</th>
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<tbody>
<tr>
<td>Total design current</td>
<td>200 mA</td>
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<tr>
<td>Circumference</td>
<td>216 metres</td>
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<tr>
<td>RF frequency</td>
<td>499.654 ± 0.1 MHz</td>
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<tr>
<td>Energy loss per turn (dipoles only)</td>
<td>931 keV</td>
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<tr>
<td>Dipole field (nominal)</td>
<td>1.3 T</td>
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<tr>
<td>Beam size in dipoles</td>
<td>σx = 87μm, σy = 20μm</td>
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<tr>
<td>Beam size in straights</td>
<td>σx = 320μm, σy = 16μm</td>
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<td>Number of possible Insertion devices</td>
<td>12</td>
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<tr>
<td>Emittance</td>
<td>εy = 10 nm</td>
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<tr>
<td>Coupling (nominal)</td>
<td>1%</td>
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Flexibility
- Bunch charge
  - 10^5-10^9 e⁻
- Injection fill pattern:
  - Single bunch
  - Nominal: 75 bunches
The machines: The Test Beam Line

CLIC Test Facility (CTF3)
- Designed for demonstration of CLIC accelerating concepts and test of equipment
- The Test Beam Line (TBL) is situated in the CLIC Experimental Area

The TBL
- Decelerating LINAC with 8 FODO cells
- Each half cell comprises:
  - 1 Power Extraction and Transfer Structure
  - 1 Beam Position Monitor
  - 1 Quadrupole
- Flexibility
  - beam current: 1 - 28 A (@ 3-12 GHz)
  - Pulse length: 100-1000 ns

TBL nominal parameters

<table>
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<tr>
<th>Parameter</th>
<th>TBL</th>
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<tbody>
<tr>
<td>N_PETS</td>
<td>16</td>
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<tr>
<td>Current (A)</td>
<td>28</td>
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<tr>
<td>Pulse Length (ns)</td>
<td>140</td>
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<td>Initial energy, E_{init}(MeV)</td>
<td>150</td>
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<td>Final energy, E_{end}(MeV)</td>
<td>80</td>
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<td>Norm. Emittance ε_{x,y}(μm rad)</td>
<td>150</td>
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<tr>
<td>Beam Pipe radius, r₀(mm)</td>
<td>11.5</td>
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</table>
TBL Sketch

‘TBL’ Fiber, Signal Fiber

Focussing, defocussing quad

Bending Magnet

PETS

SiPM Modules

Fibres 75m

Ceiling

Cable Tray

Fibre 25m

Fibre 28m

TBL Lattice 22.5m
ASLS Sketch