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

H. Henschel et. al, "*Fiber optic radiation system for TESLA*". TESLA-Report No. 2000-25 (2000).	D. Di Giovenale et. al, "*A read-out system for online monitoring of intensity and position of beam losses in electron linacs*". NIM A665 (2011) 33.	L. Devlin et. al, "*Update on Beam Loss Monitoring at CTF3 for CLIC*", Proc. IBIC13 (2013)
M. Körfer et. al, "*Fiber optic radiation sensor systems for particle accelerators*" NIM A526 (2004) 537.	M. Marechal et. al, "*Design, development and operation of fiber-based Chernkov beam loss at Srping-8*". NIM A673 (2012) 32.	E. Nebot et. al, "*Measurement of Beam Losses Using Optical Fibers at the Australian Synchrotron*", Proc. IBIC14 (2014)

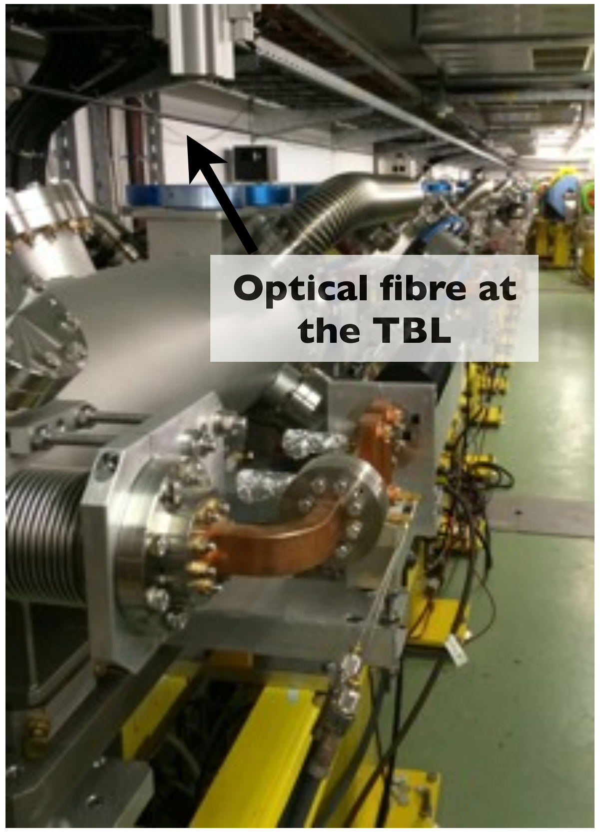
Is beam loss position determination possible in machines with long pulses?

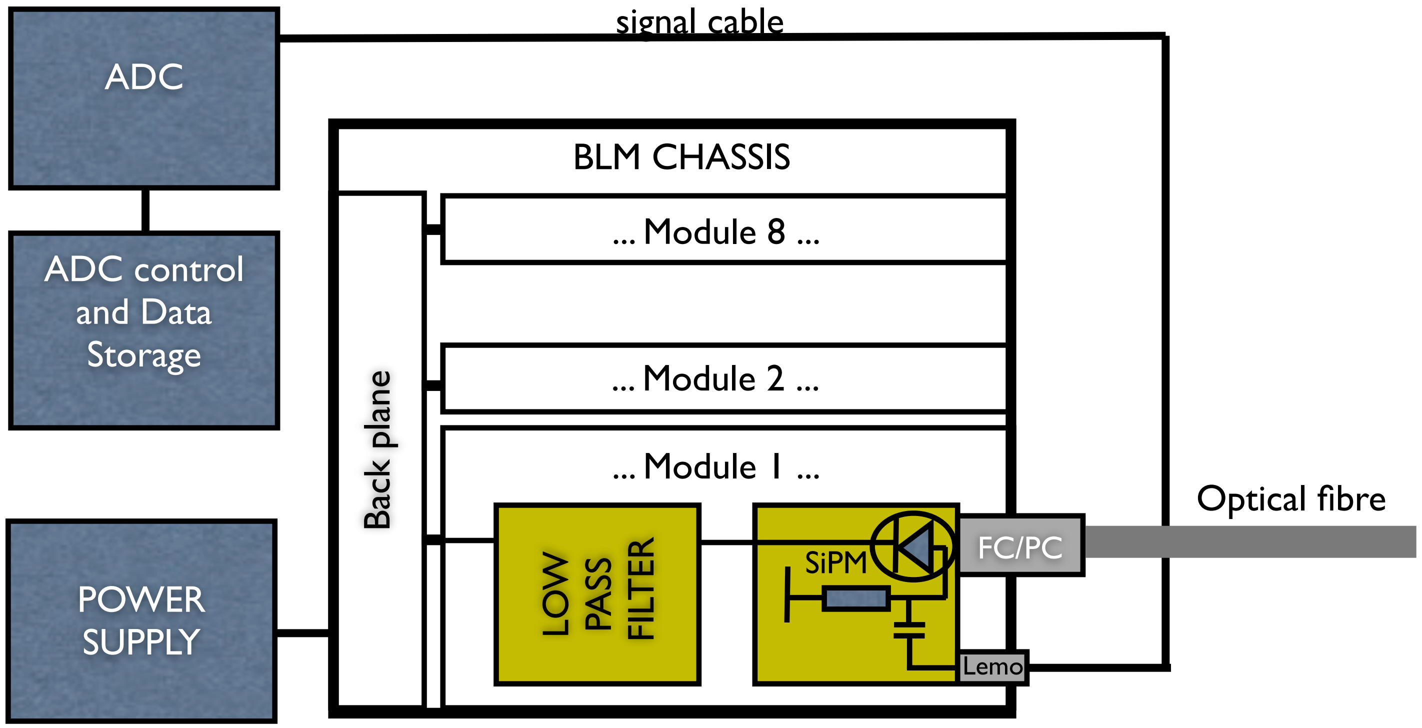
- e.g CLIC bunch pulse of 150 ns length

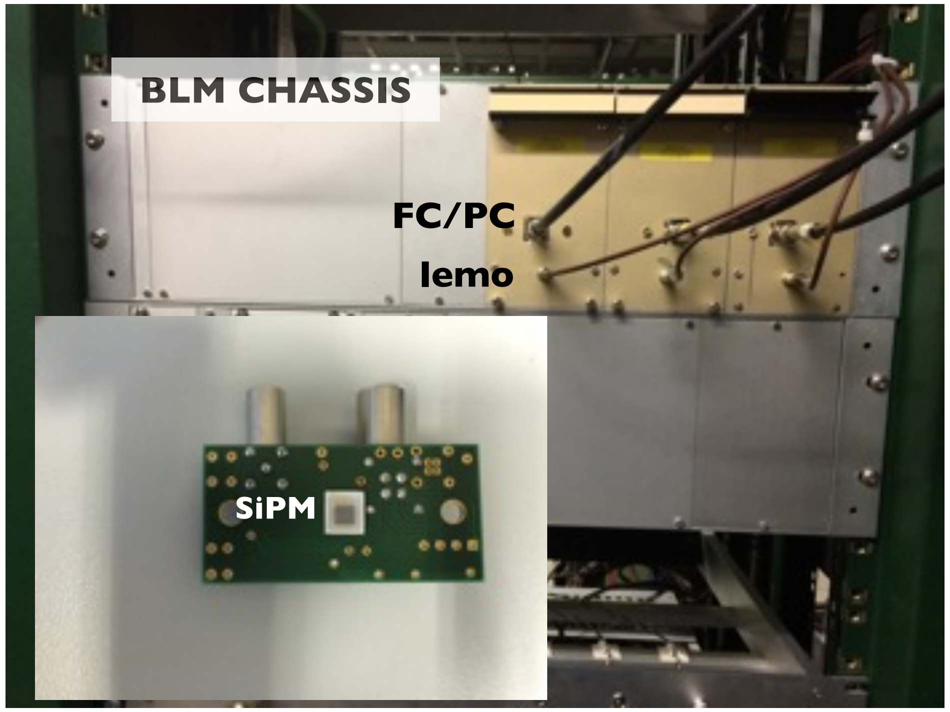
The oBLM system

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 mm^2,14000 pixels, G $=10^{+5}$ - 10^{+6})
  - Low pass filters (bias input) for noise filtering
- Custom high sampling (1-4GS/s) and high bandwidth (250 MHz- 2 GHz) ADCs

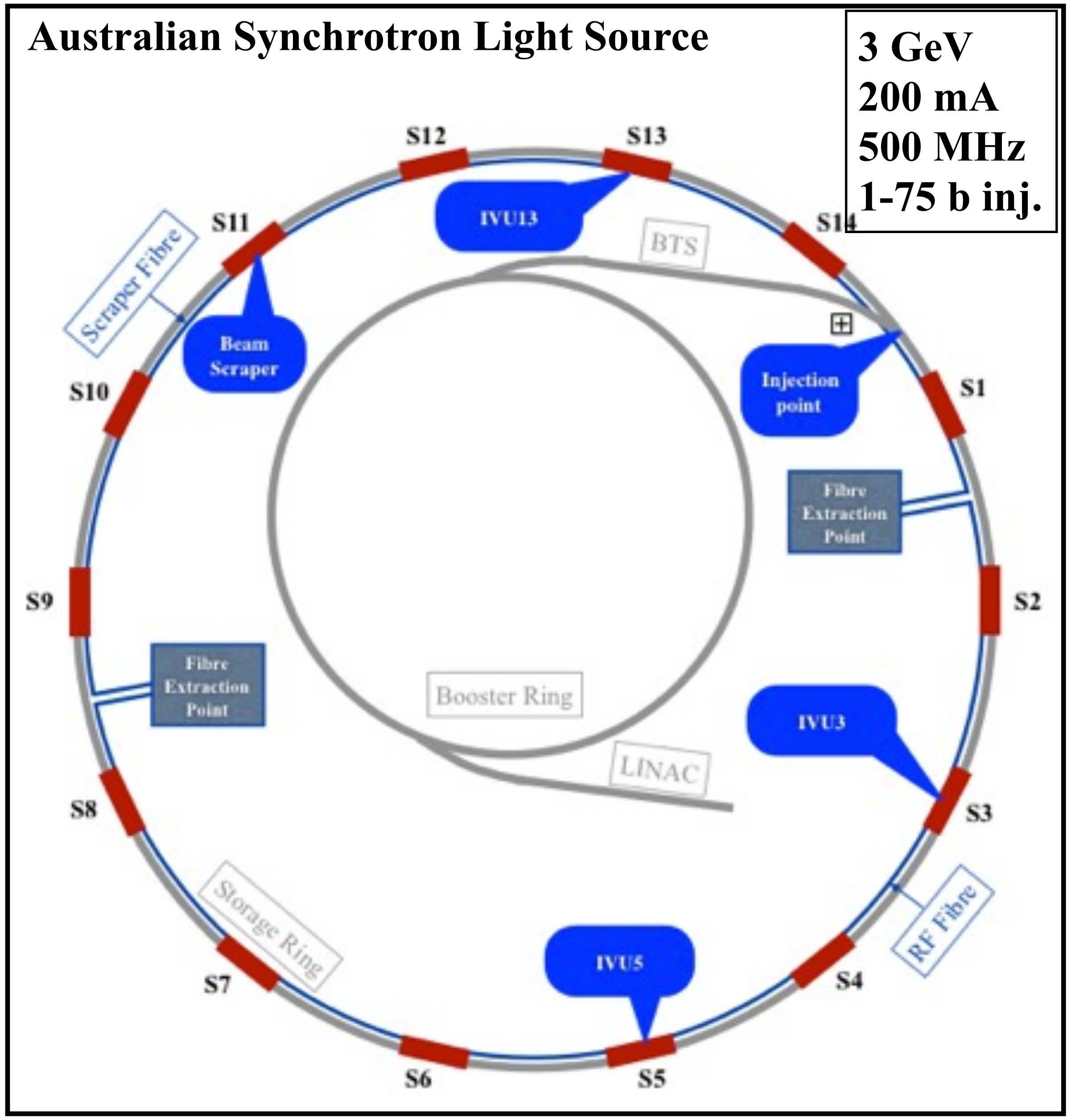


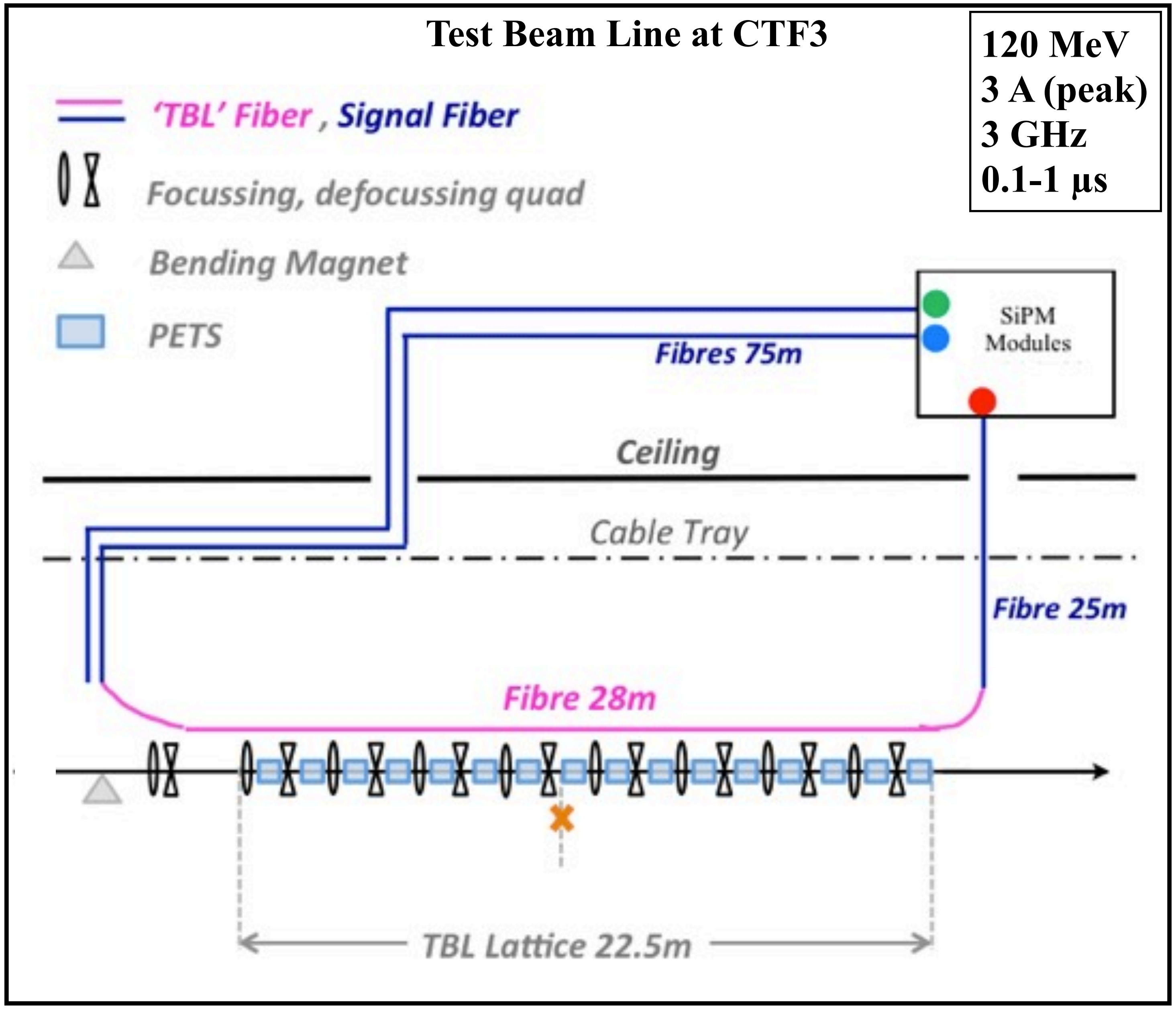




oBLM installed for testing in two electron machines

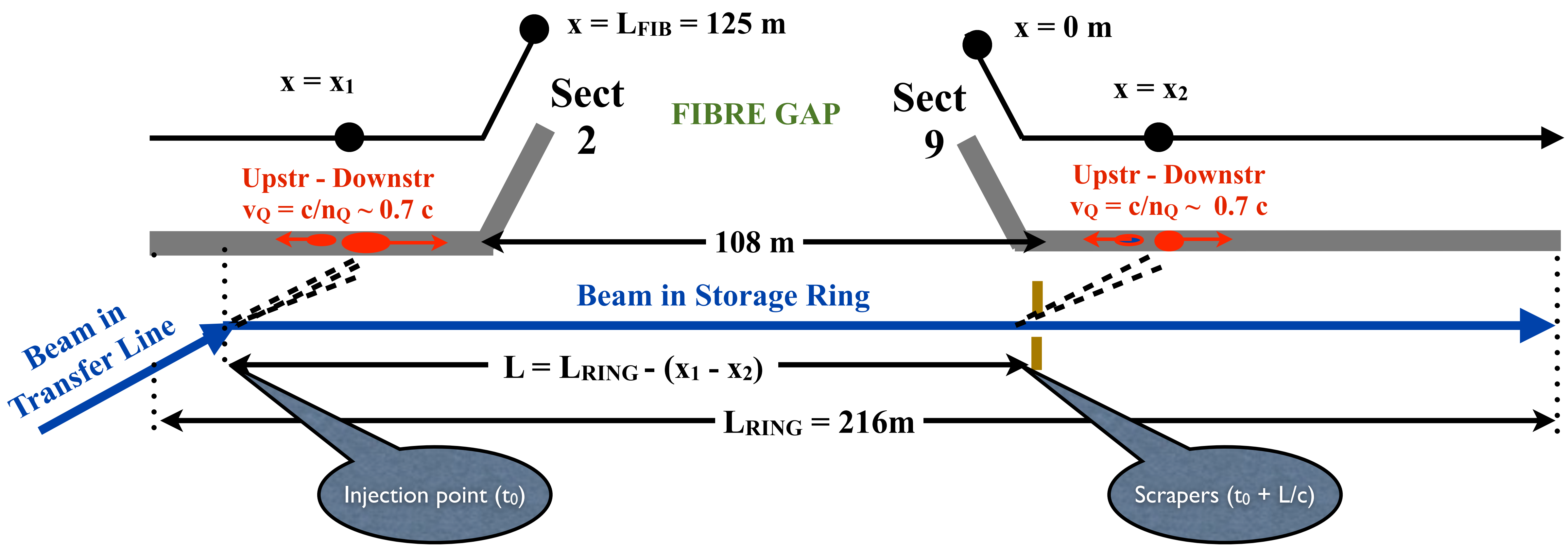
- The Storage Ring of the Australian Synchrotron
- The Test Beam Line in the CLIC Facility (CTF3) at CERN





Understanding Beam Losses I

- Most studies performed on losses generated in the first turn



- Two loss points on opposite sides of FIBRE GAP

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

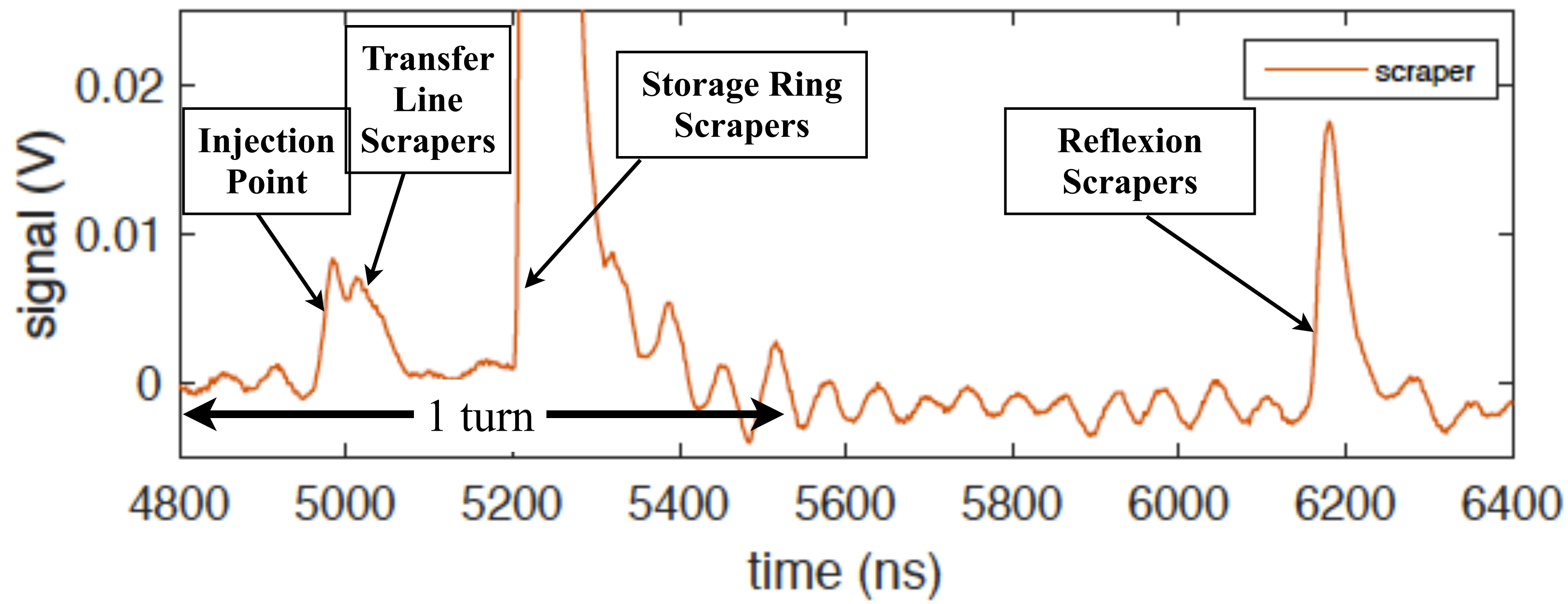
- Two loss points on same side of FIBRE GAP

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

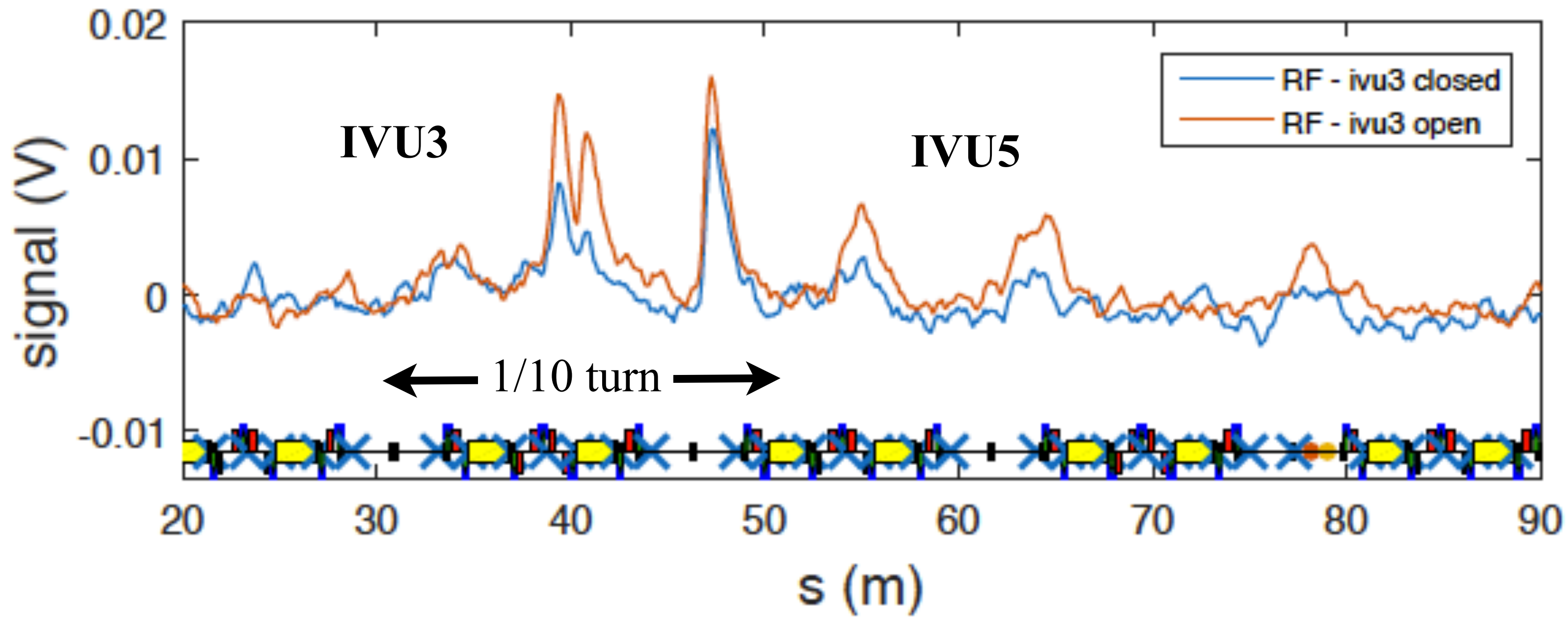
Understanding Beam Losses II

- **Multi peaks observed due to losses in different positions**

Scraper Fibre

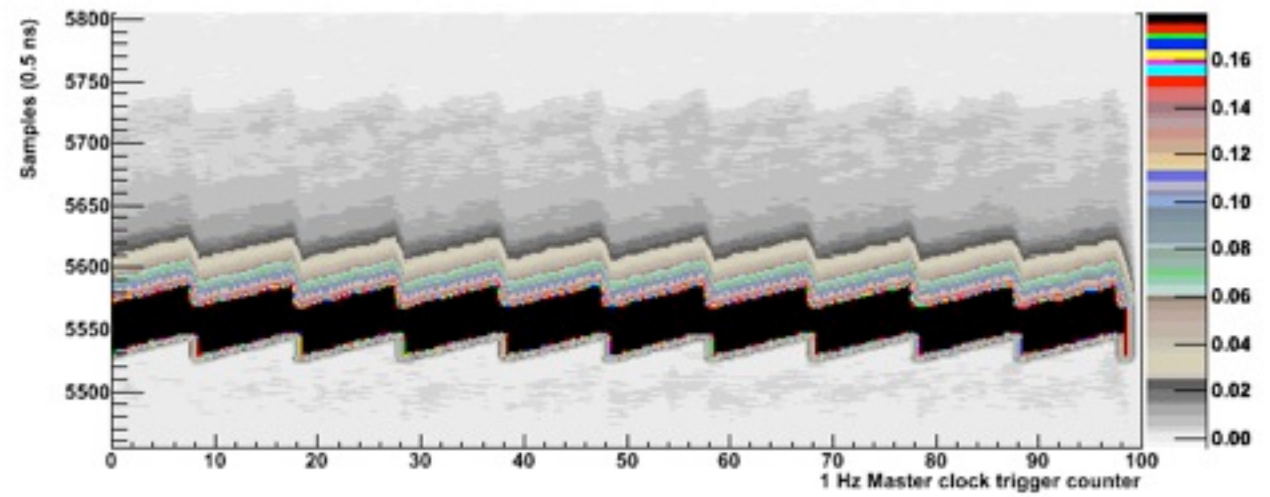


RF Fibre

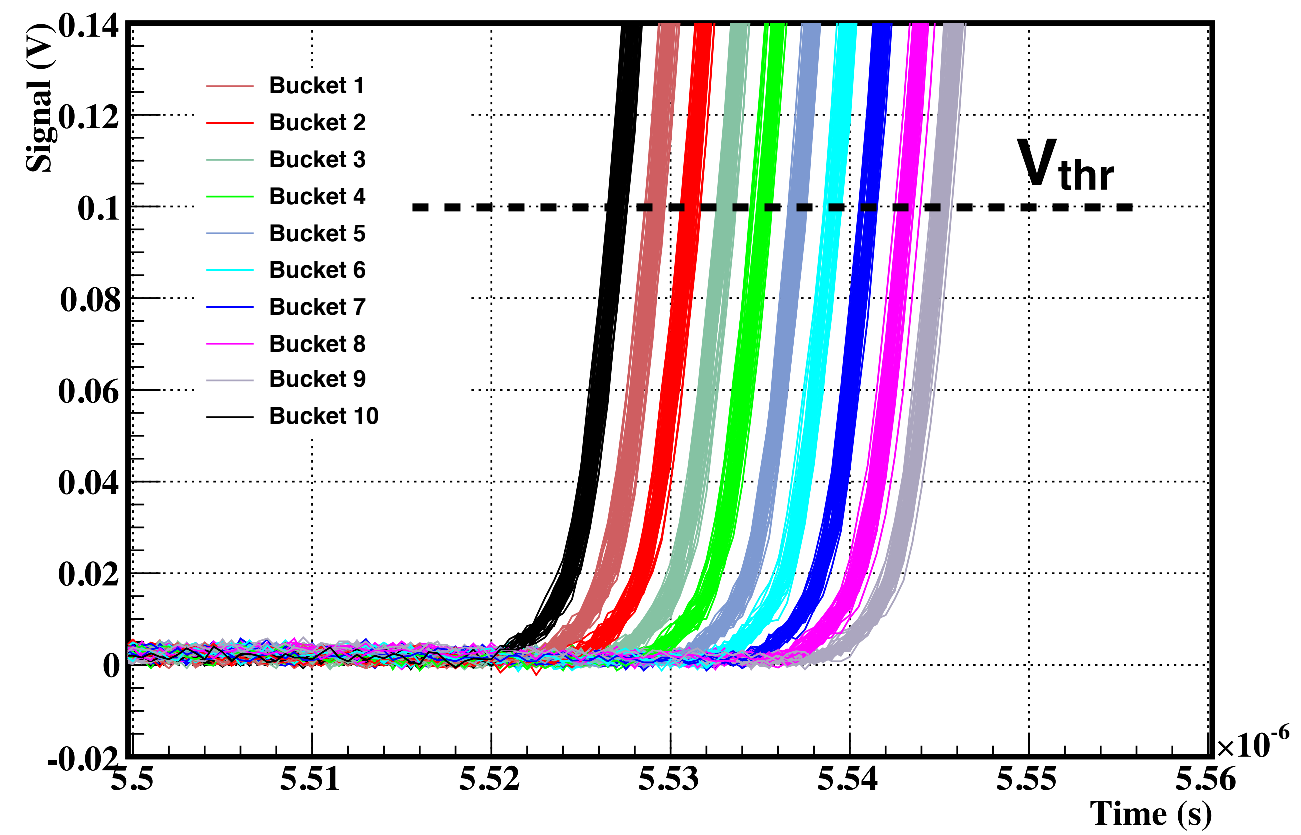


Intrinsic time resolution I

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



- **Looking at the raising edge of losses "at scrapers"**
  - Well defined loss location

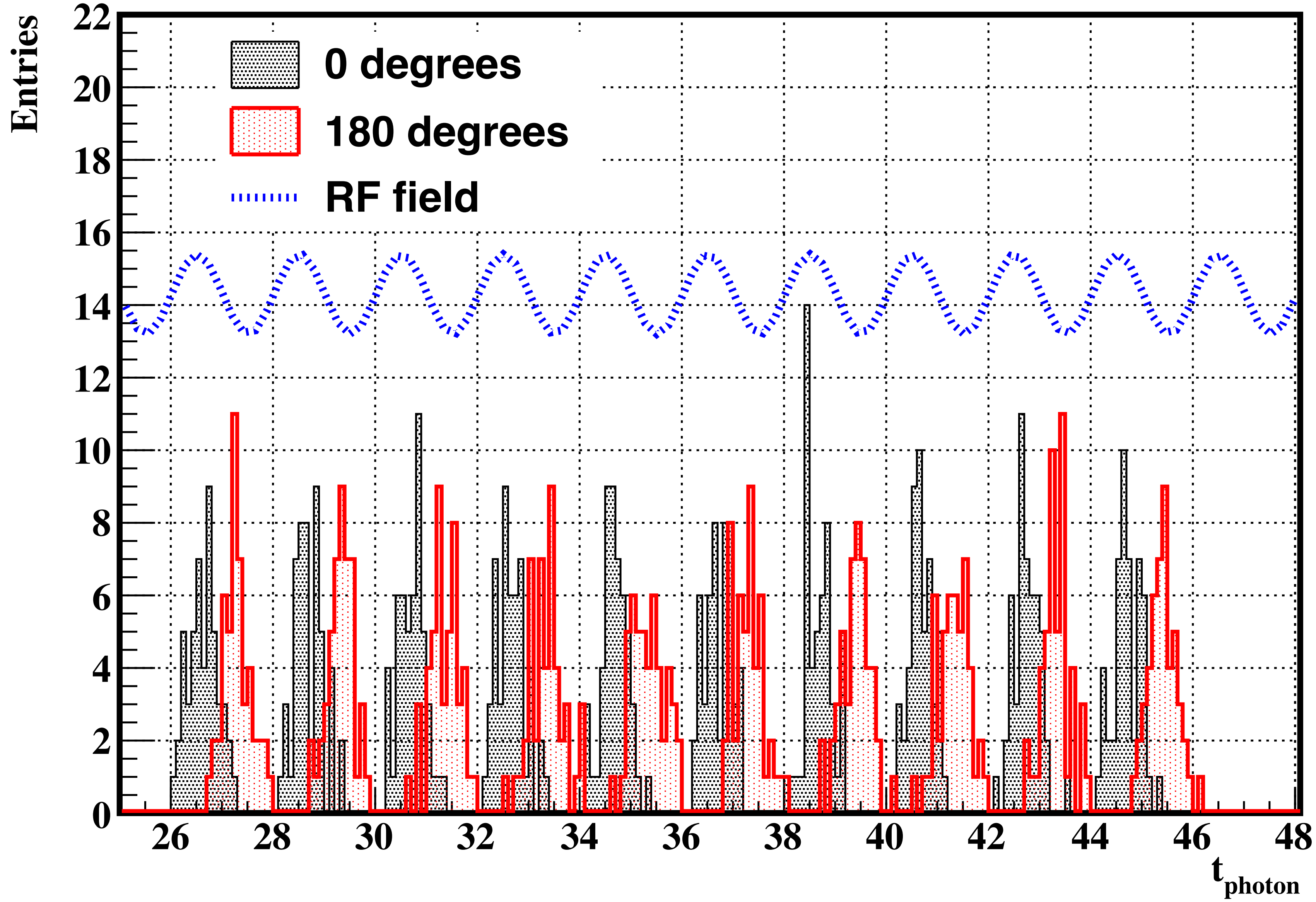


- **One bucket (2 ns) shift disentangled shot by shot**
  - $V_{oBLM}(t = t_{photon}) = V_{thr}$
  - t_{photon} → Photon arrival time (to upstream end)

Intrinsic time resolution II

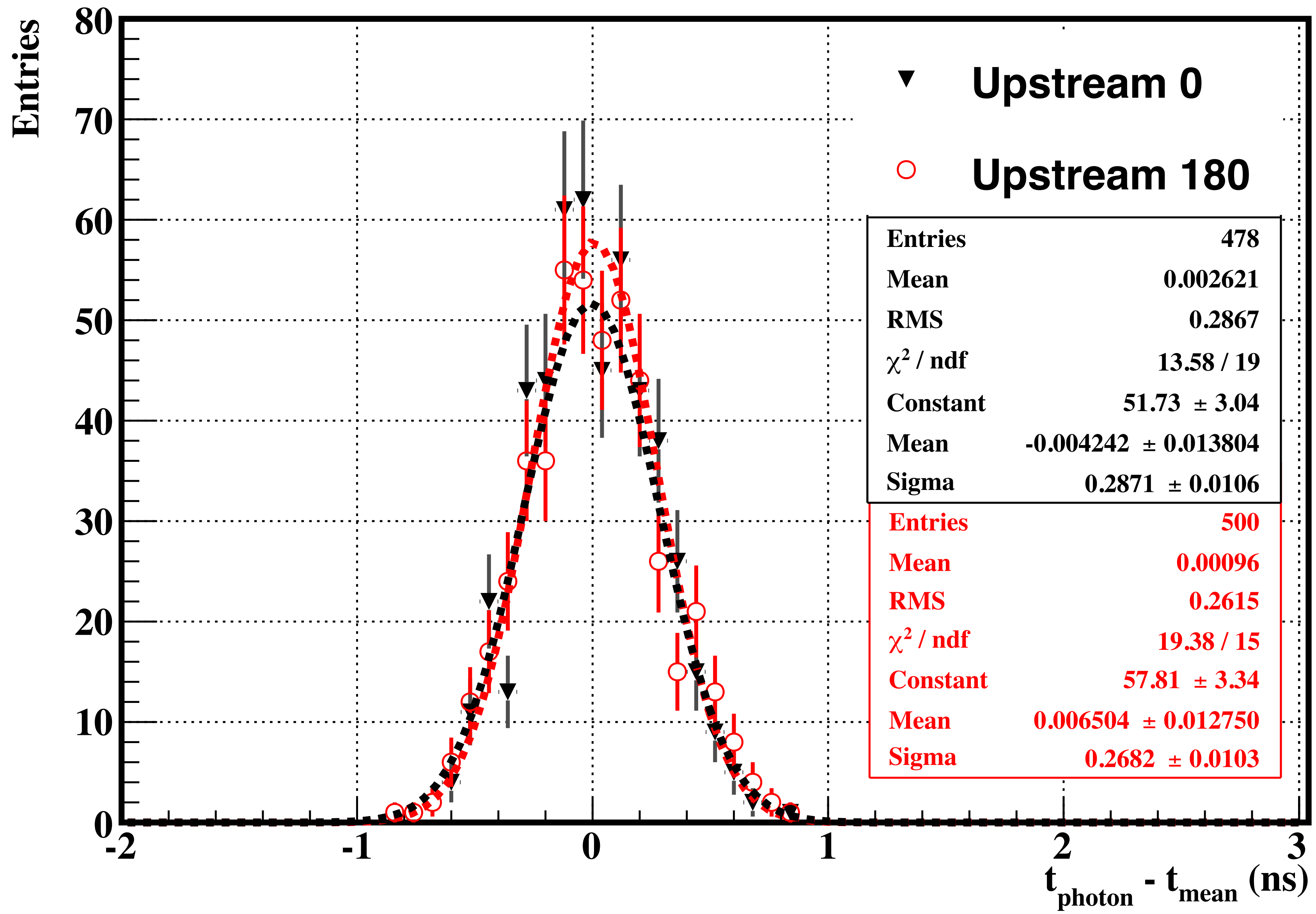
Time response study based on photon arrival time

- Δt < 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 $\Delta t = t_{photon} - t_{mean}$**
  - $t_{mean} = t_{off} + n_{bucket} \times T_{RF}$ (central time of n^{th} bucket)



$\sigma_t \lesssim 300$ ps

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

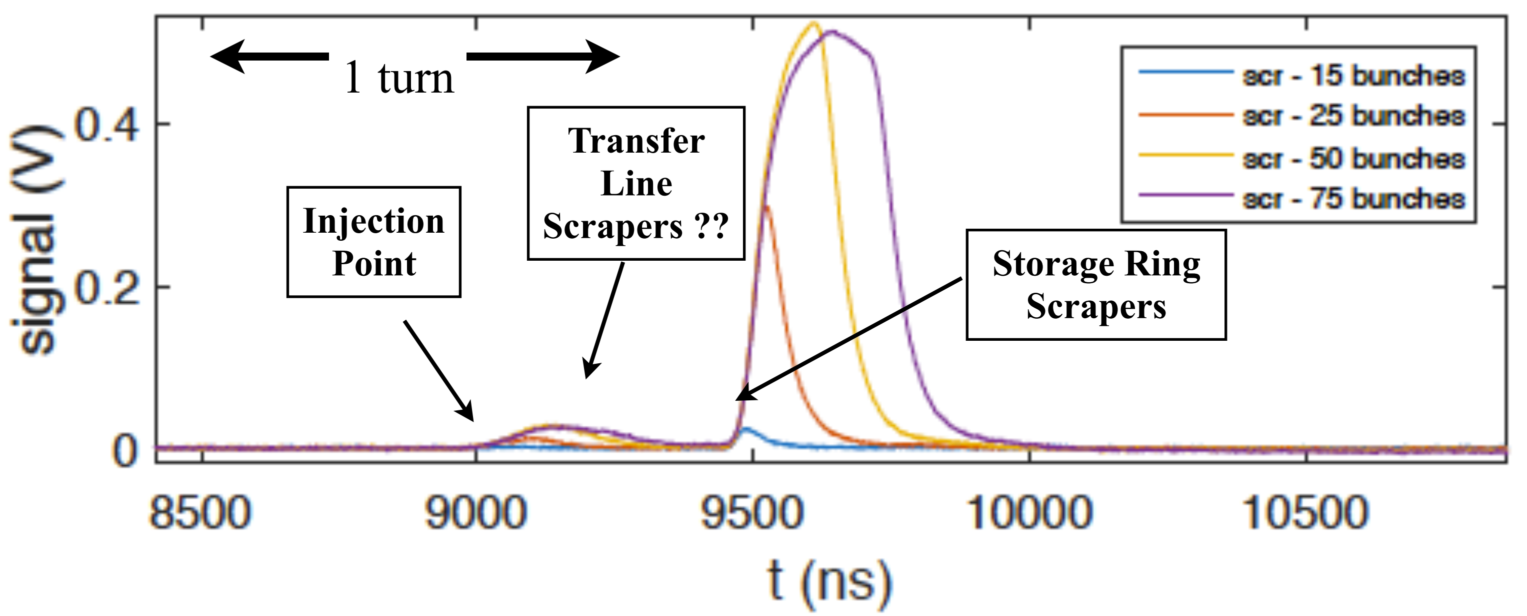
$\sigma_t \lesssim 4$ cm

Multi bunch Beam Losses

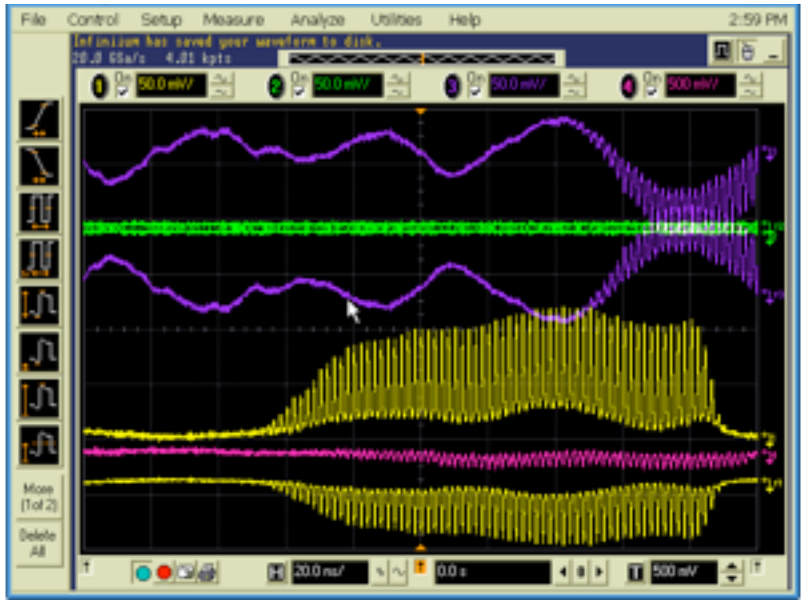
Multi peaks observed due to losses in different positions

- Rising edge still provides loss location information
- Signal de-convolution required for losses in near positions

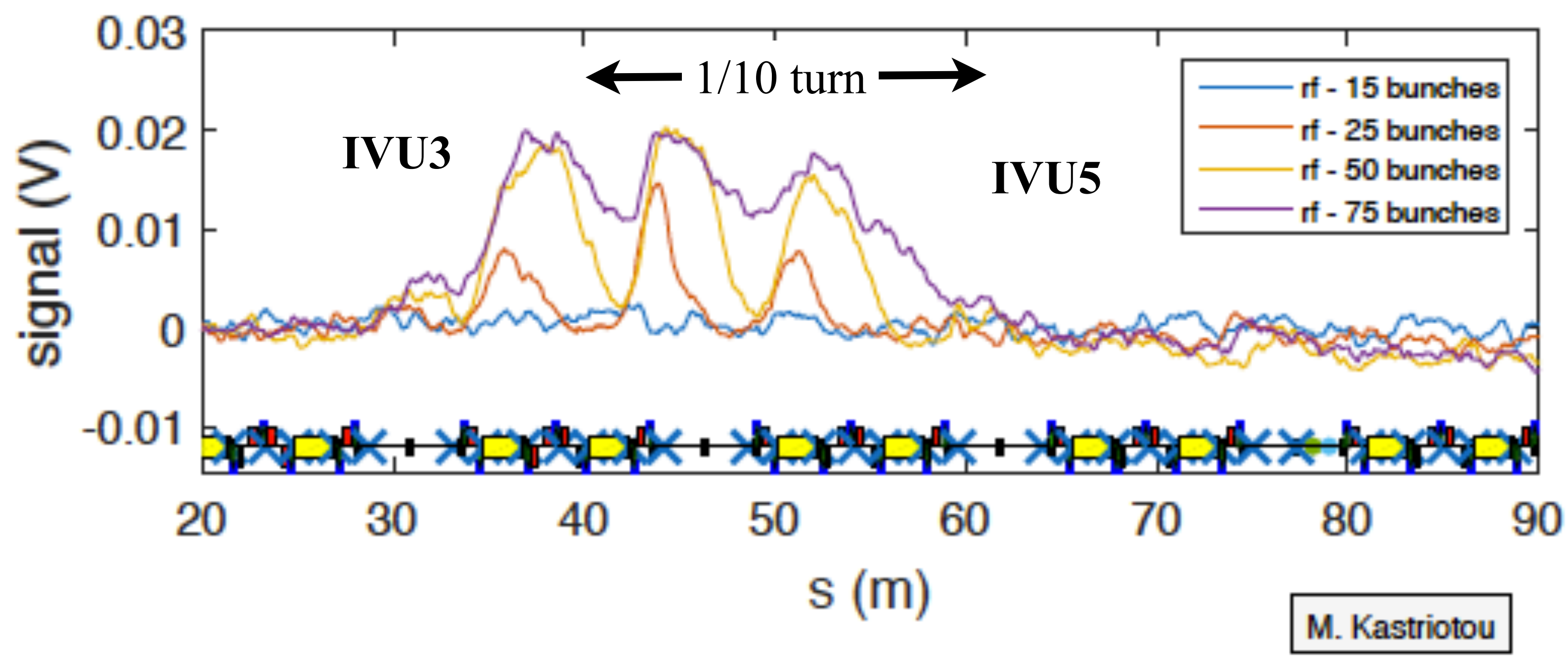
Scraper Fibre



Current profile of 75 bunch train

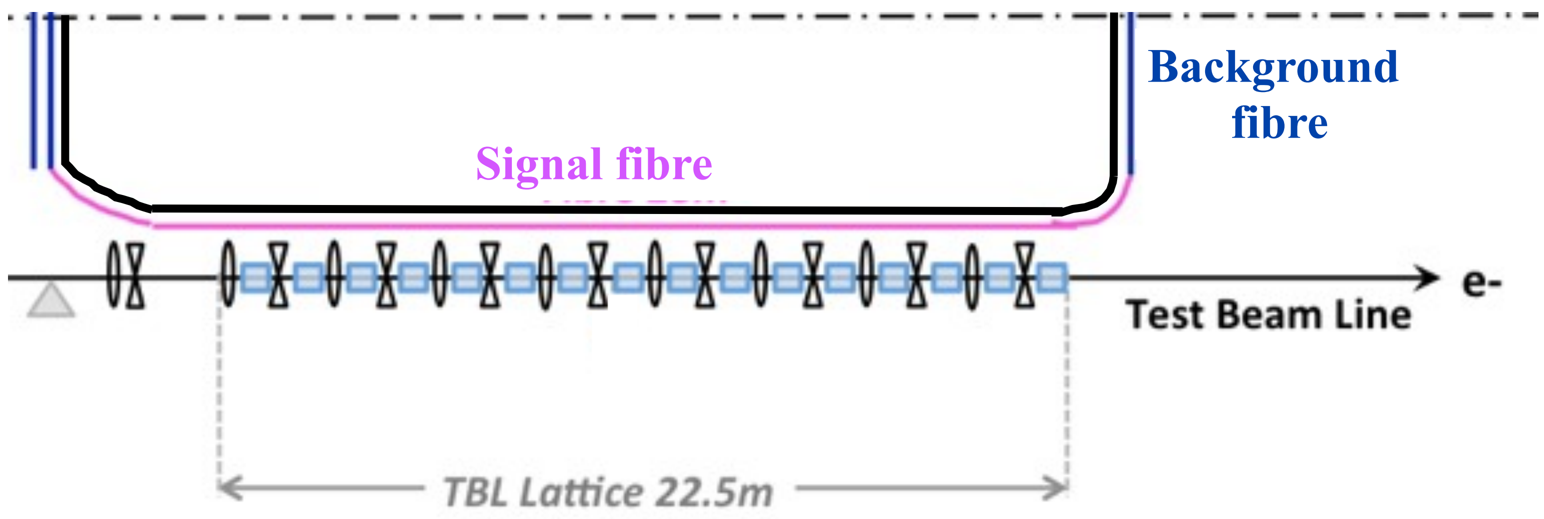


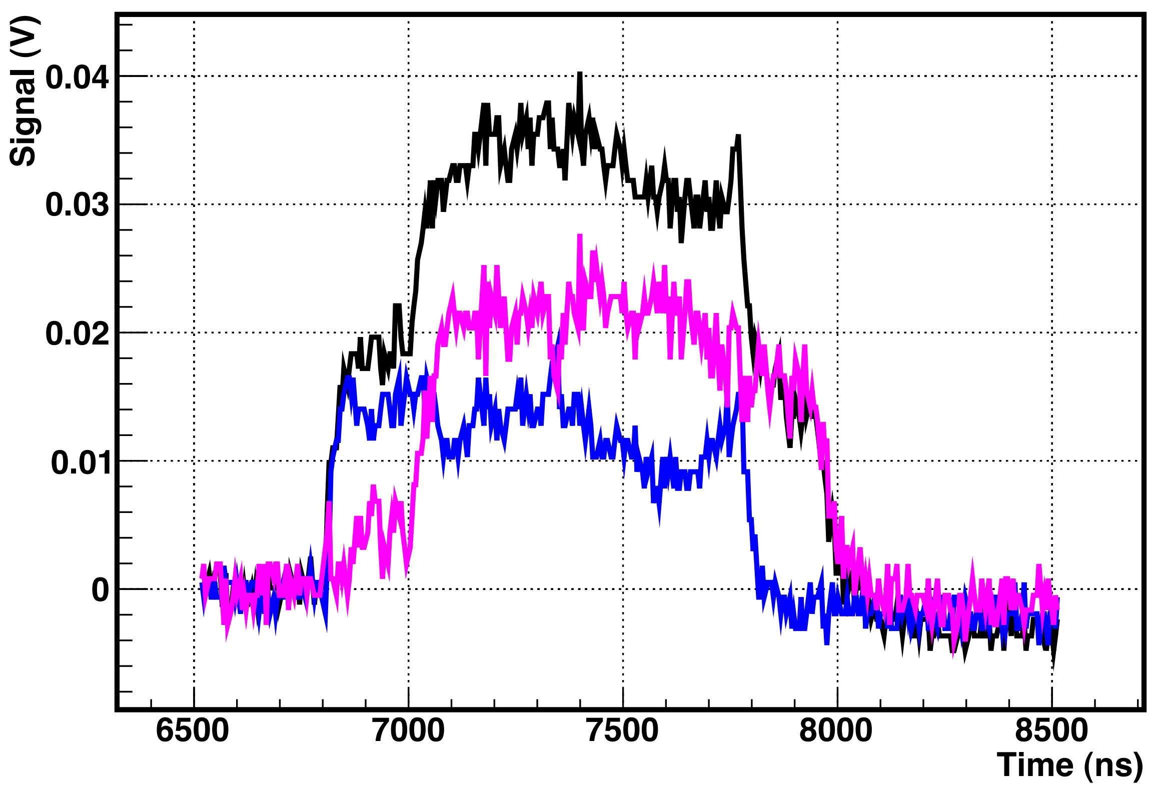
RF Fibre

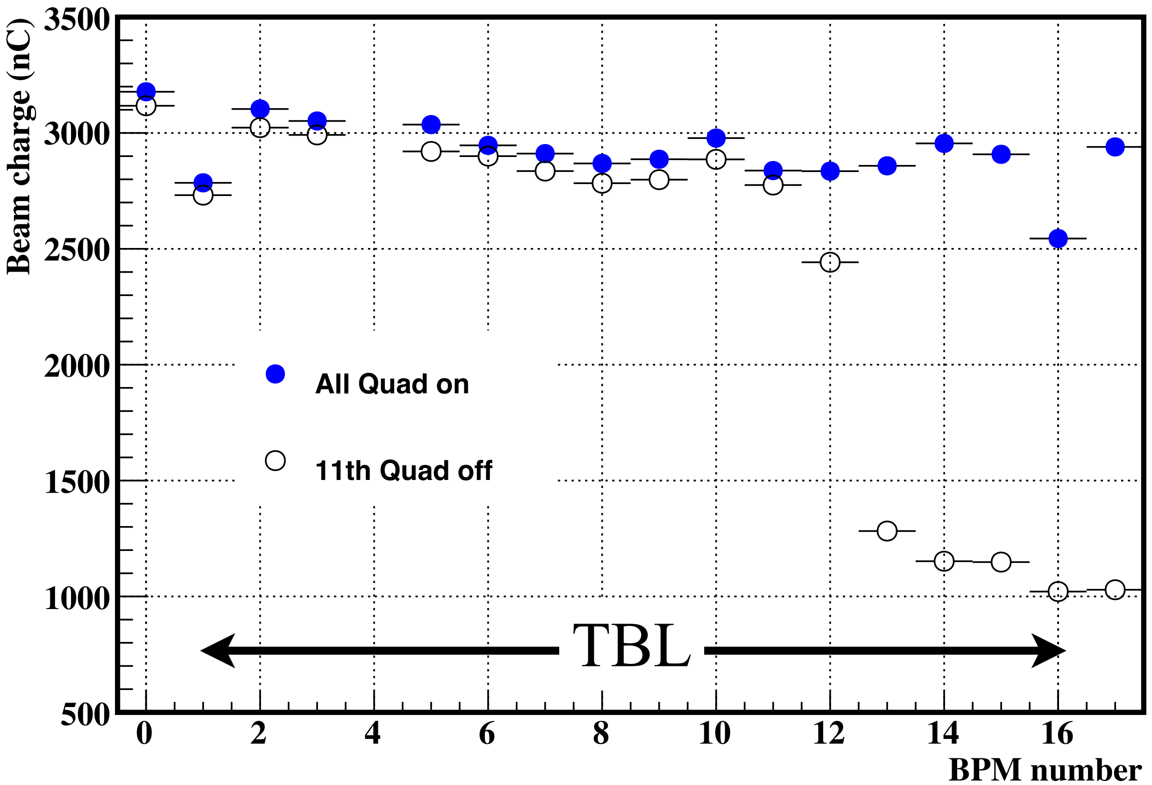


Losses with long bunch trains I

- **Observing losses from a 1μs long pulse**
  - Controlled Losses generated by switching off quadrupoles
  - Signal subtraction to account for showers from TBL only



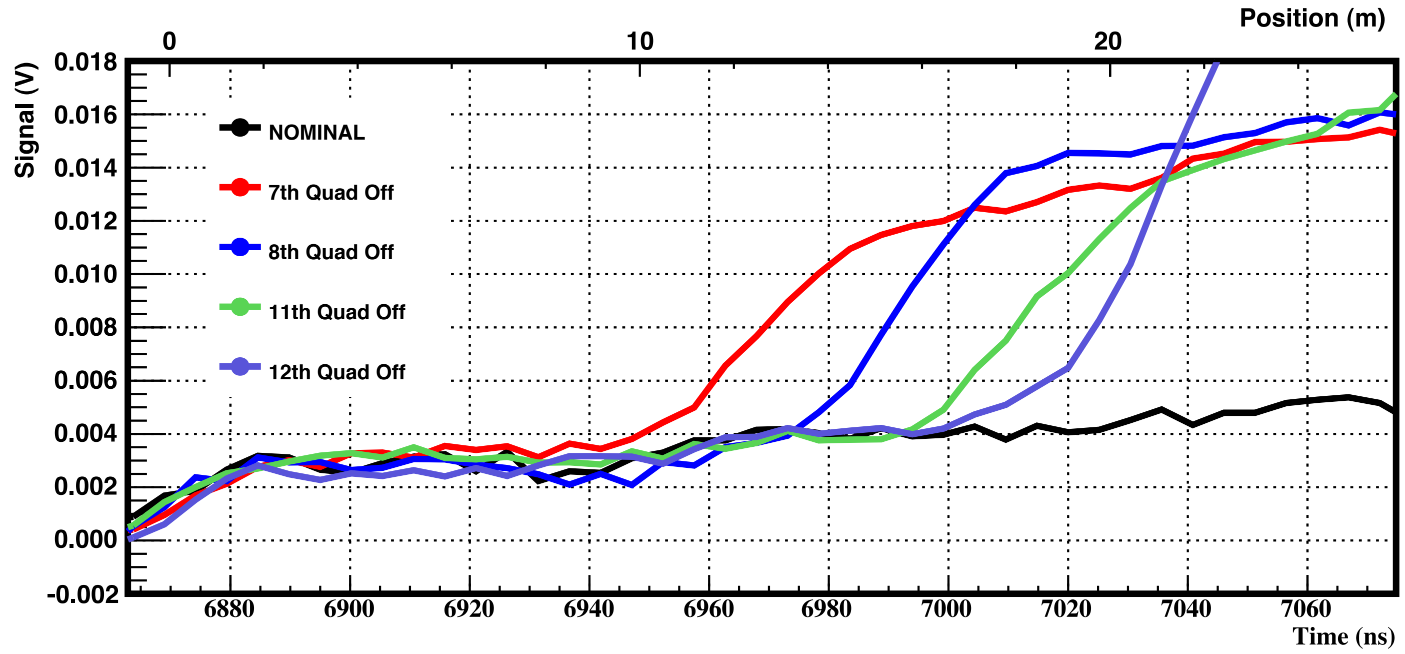


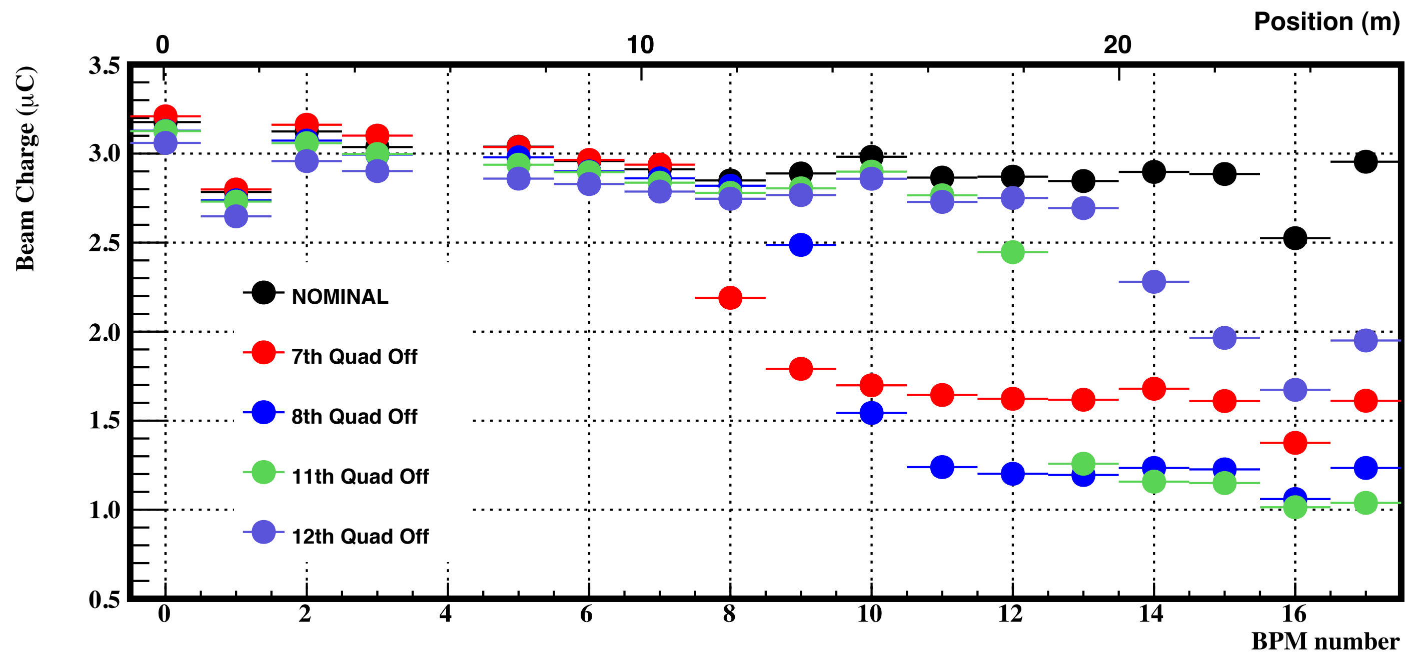


Losses with long bunch trains II

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

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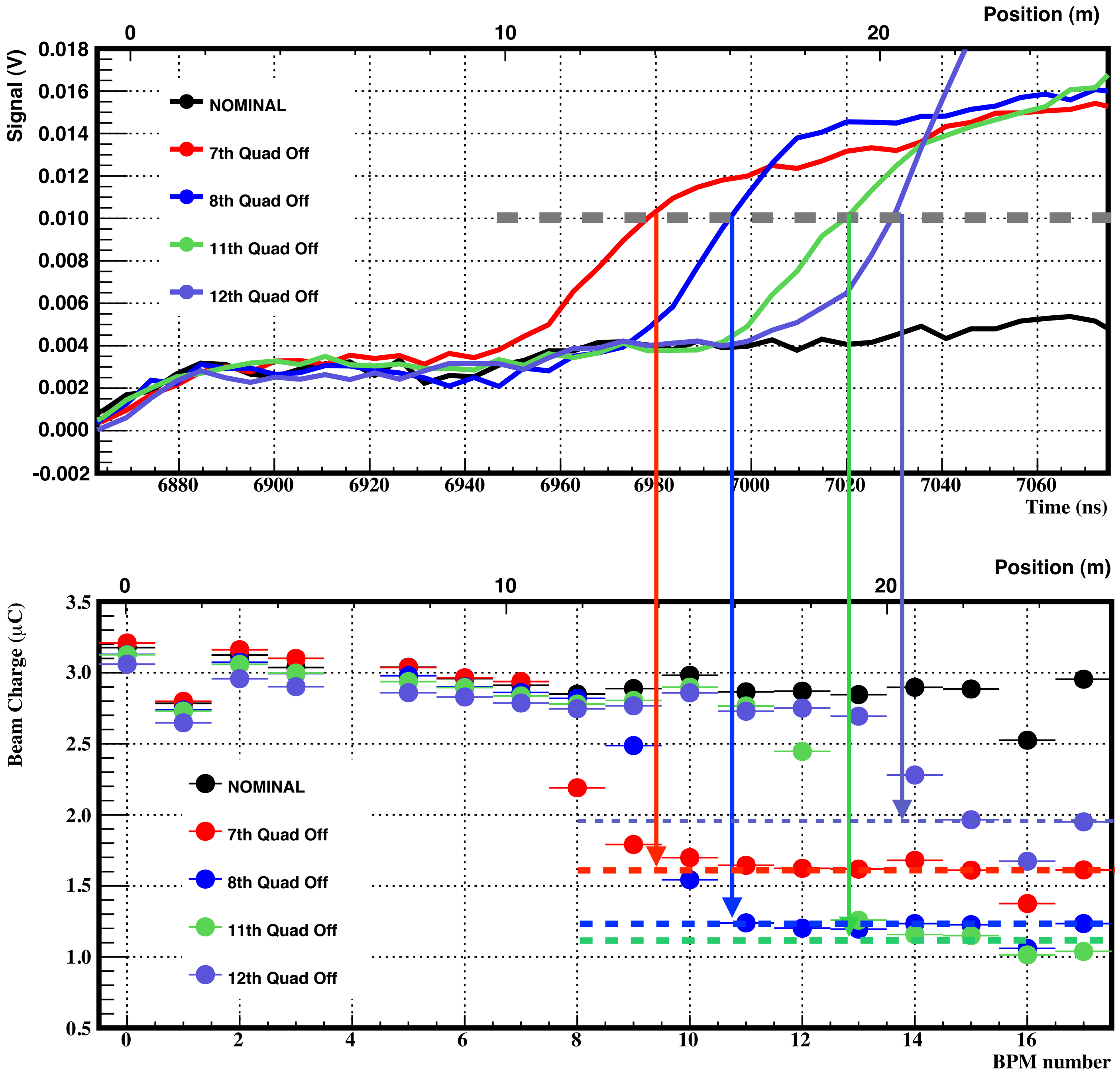
- Localisation of loss down to (below) 2 m achieved



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

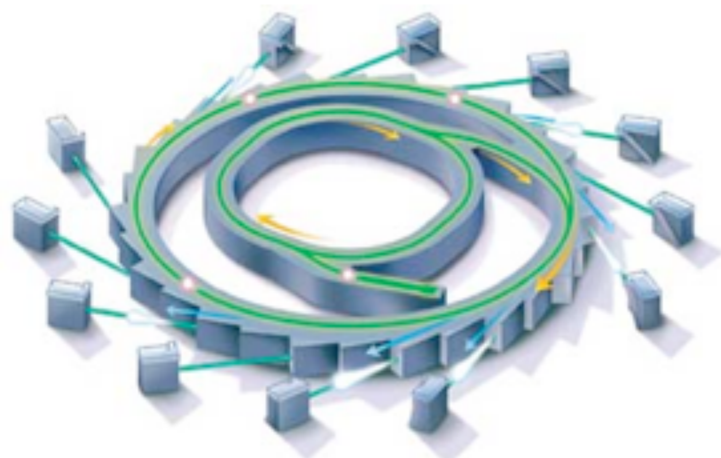
Thank you for your attention !!

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

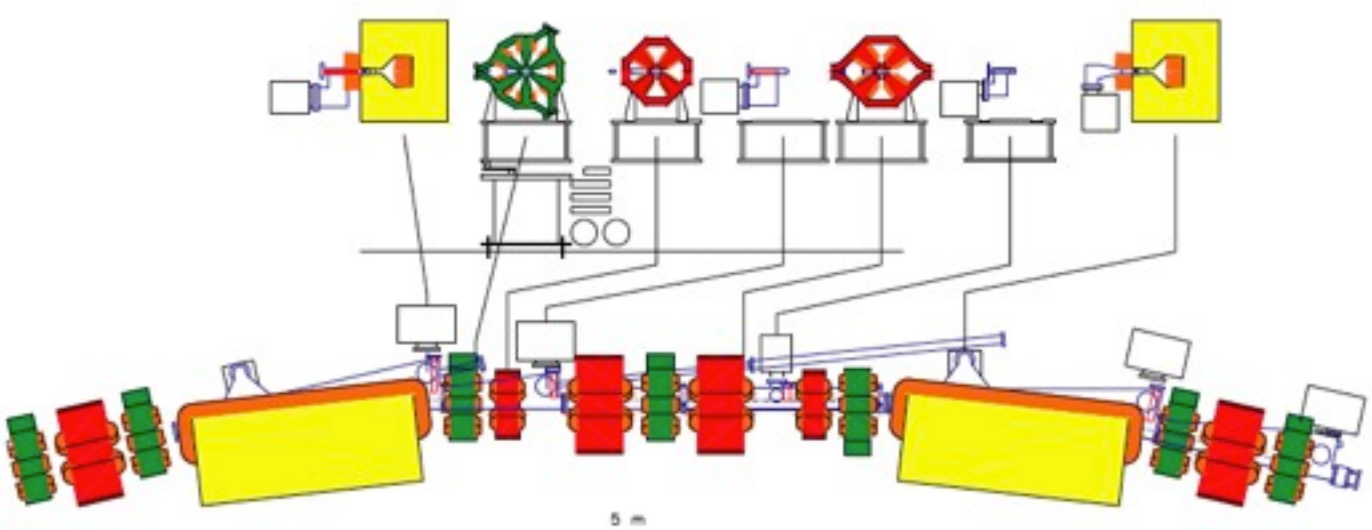
- The AS comprises
  - LINAC (10 m): 90 keV to 100 MeV
  - Booster (130 m): 100MeV to 3 GeV
  - Storage Ring (216 m): 3 GeV

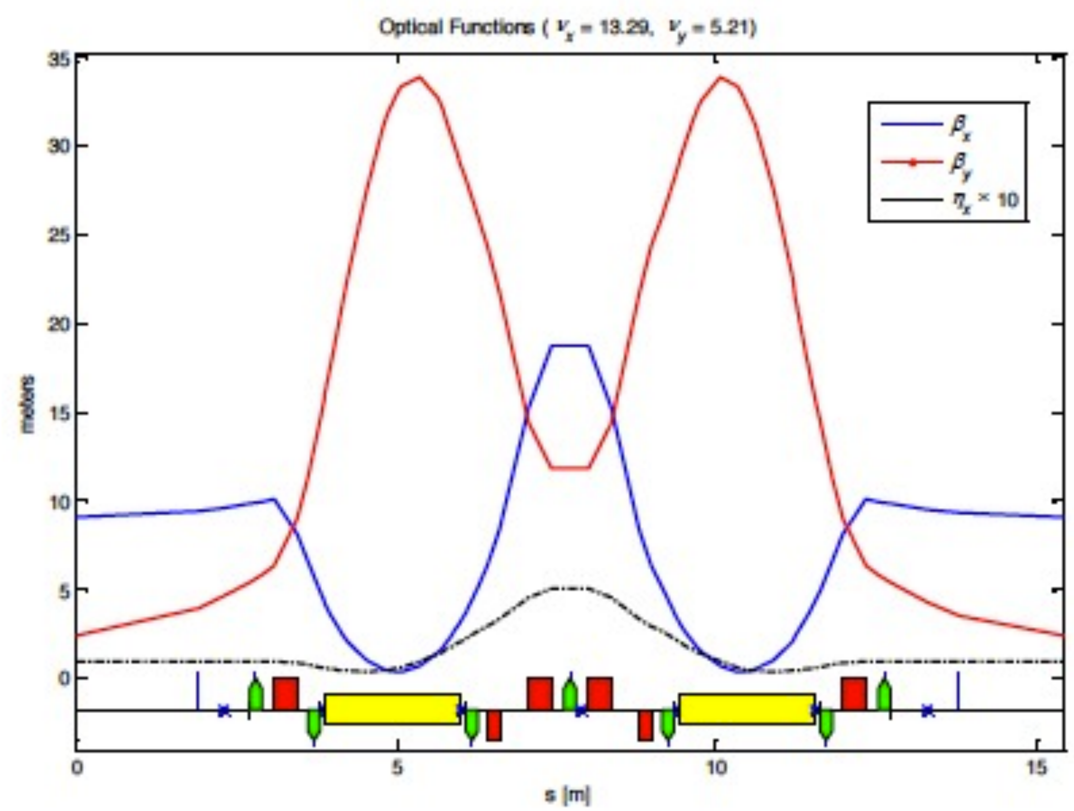


SR main parameters

Energy	3 GeV
Total design current	200 mA
Circumference	216 metres
RF frequency	499.654 ± 0.1 MHz
Energy loss per turn (dipoles only)	931 keV
Dipole field (nominal)	1.3 T
Beam size in dipoles	σ_x – 87µm, σ_y – 60µm
Beam size in straights	σ_x – 320µm, σ_y – 16µm
Number of possible Insertion devices	12
Emittance	ε_x – 10 nm
Coupling (nominal)	1%

Schematic view of a DBA cell in the SR arc





The machines: The Australian Synchrotron

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

Energy	3 GeV
Total design current	200 mA
Circumference	216 metres
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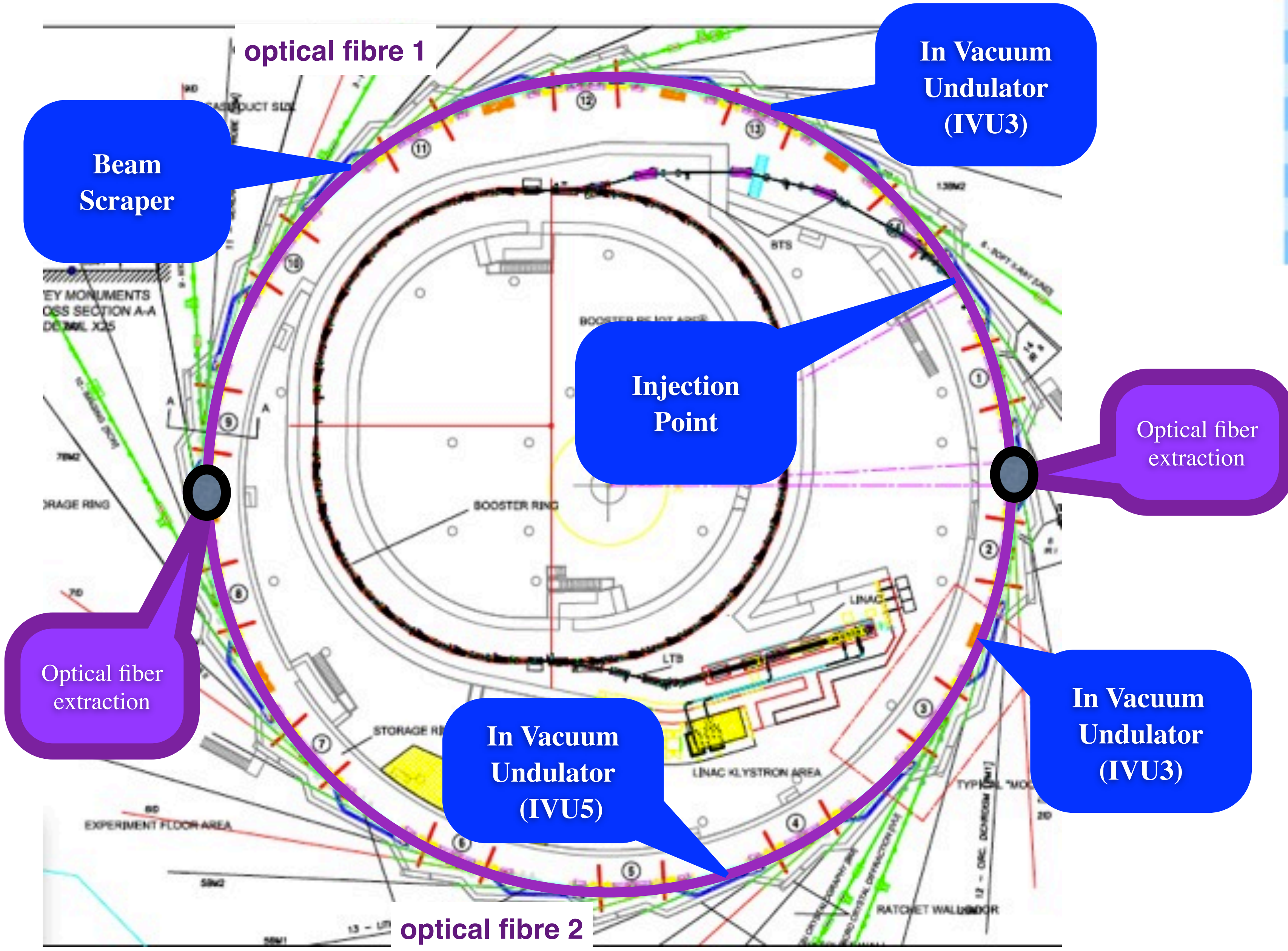


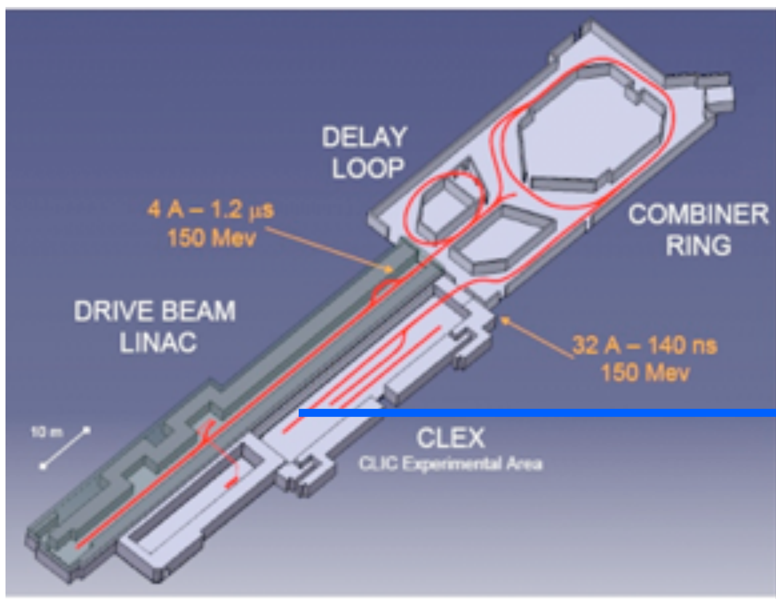
Flexibility

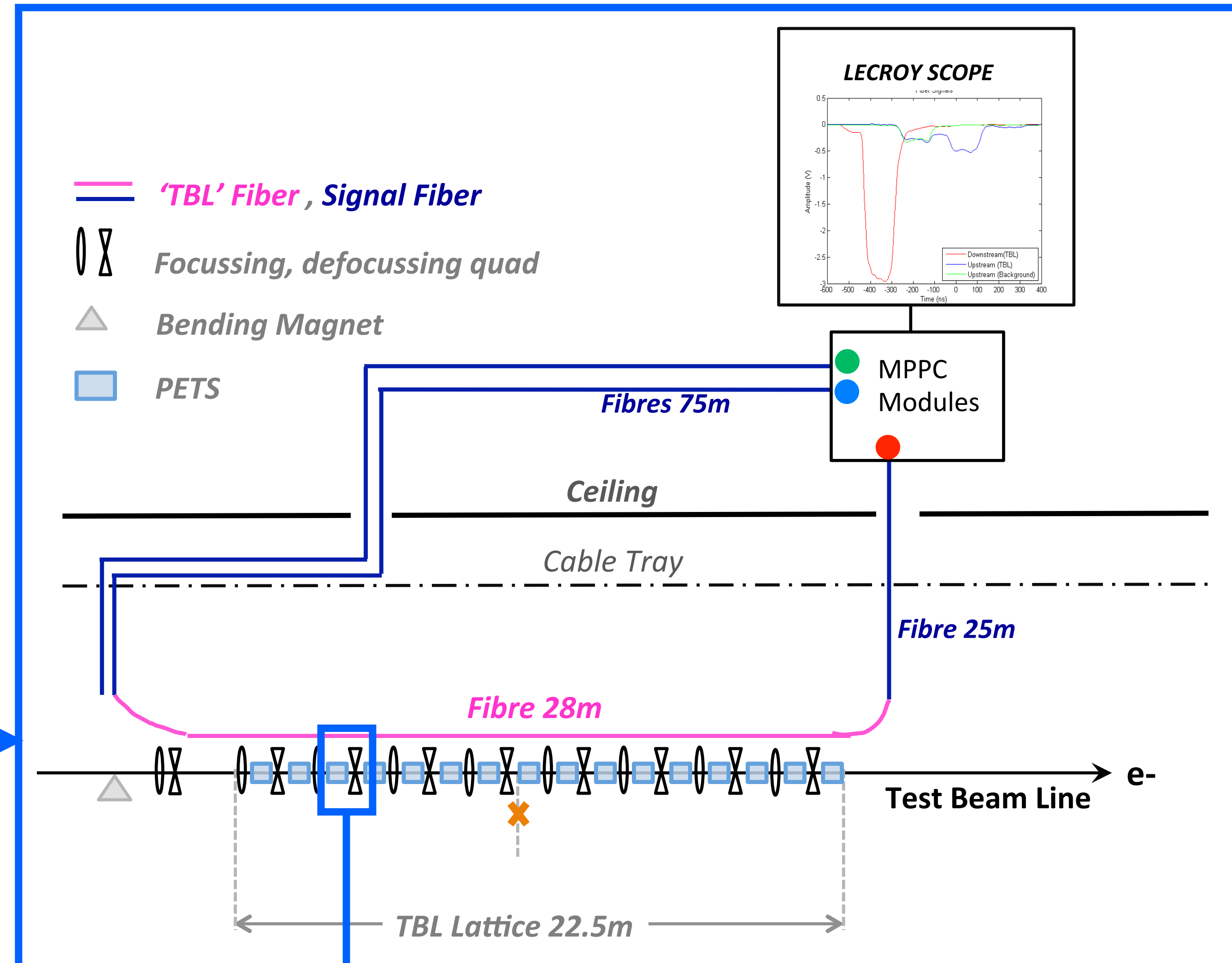
- Bunch charge
  - 10^{+5}-10^{+9} e^-
- Injection fill pattern:
  - Single bunch
  - Nominal: 75 bunches

The machines: The Test Beam Line

CLIC Test Facility (CTF3)

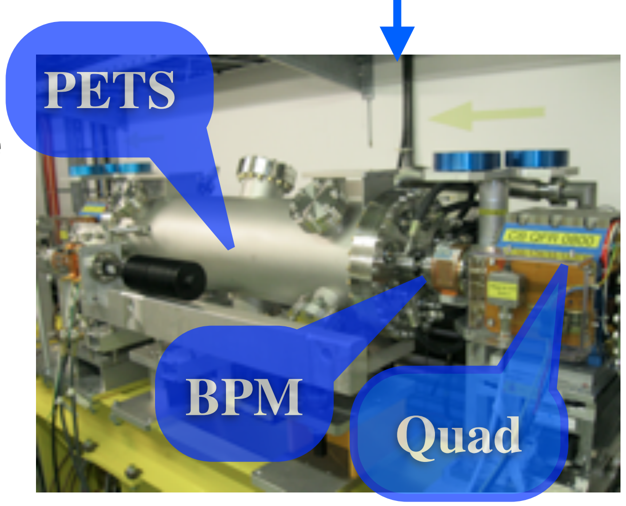
- Designed for demonstration of CLIC accelerating concepts and test of equipment
- The Test Beam Line (TBL) is situated in the CLIC Experimental Area





The TBL

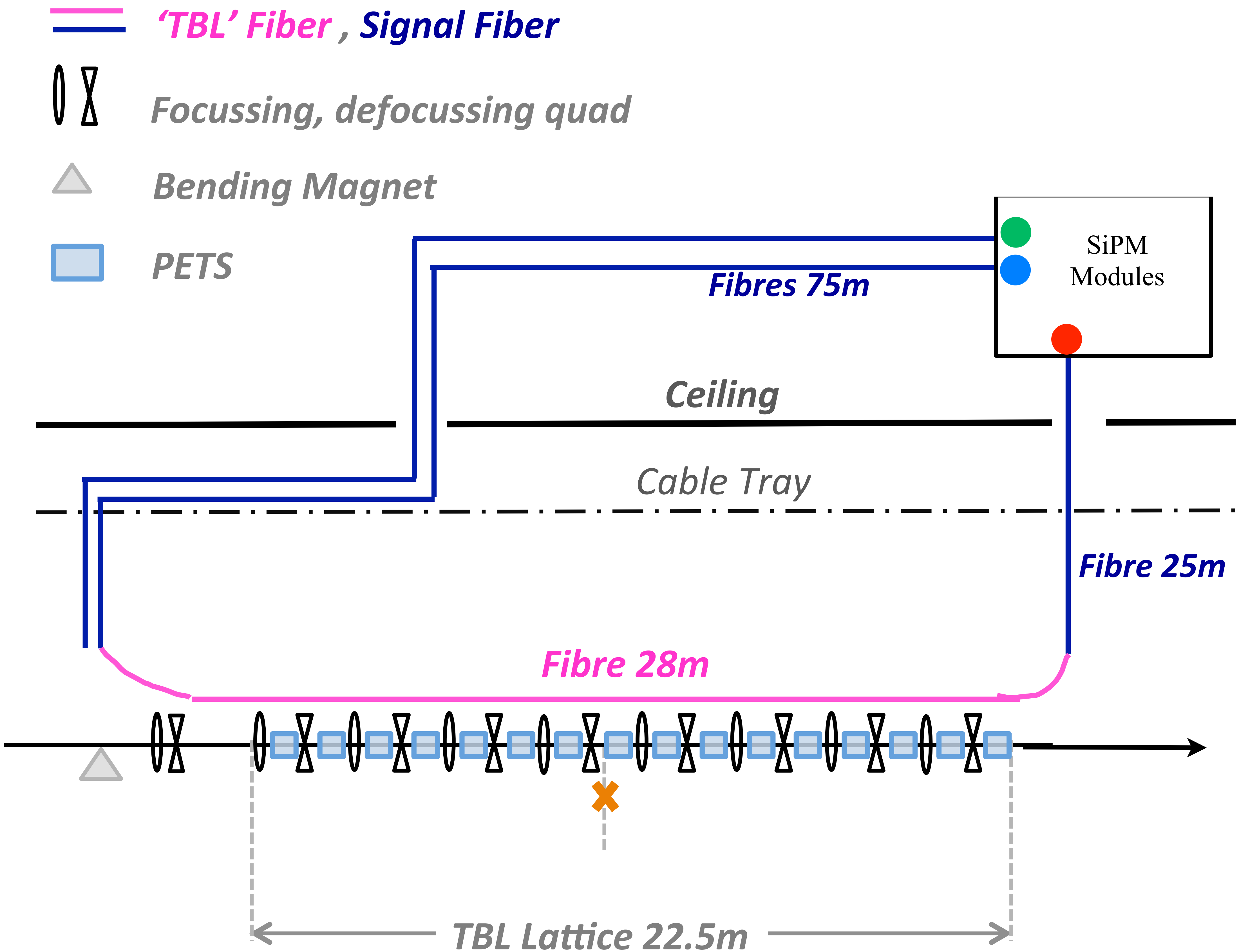
- Decelerating LINAC with 8 FODO cells
- Each half cell comprises:
  - 1 Power Extraction and Transfer Structure
  - 1 Beam Position Monitor
  - 1 Quadrupole
- Flexibility
  - beam current: 1 - 28 A (@ 3-12 GHz)
  - Pulse length: 100-1000 ns



TBL nominal parameters

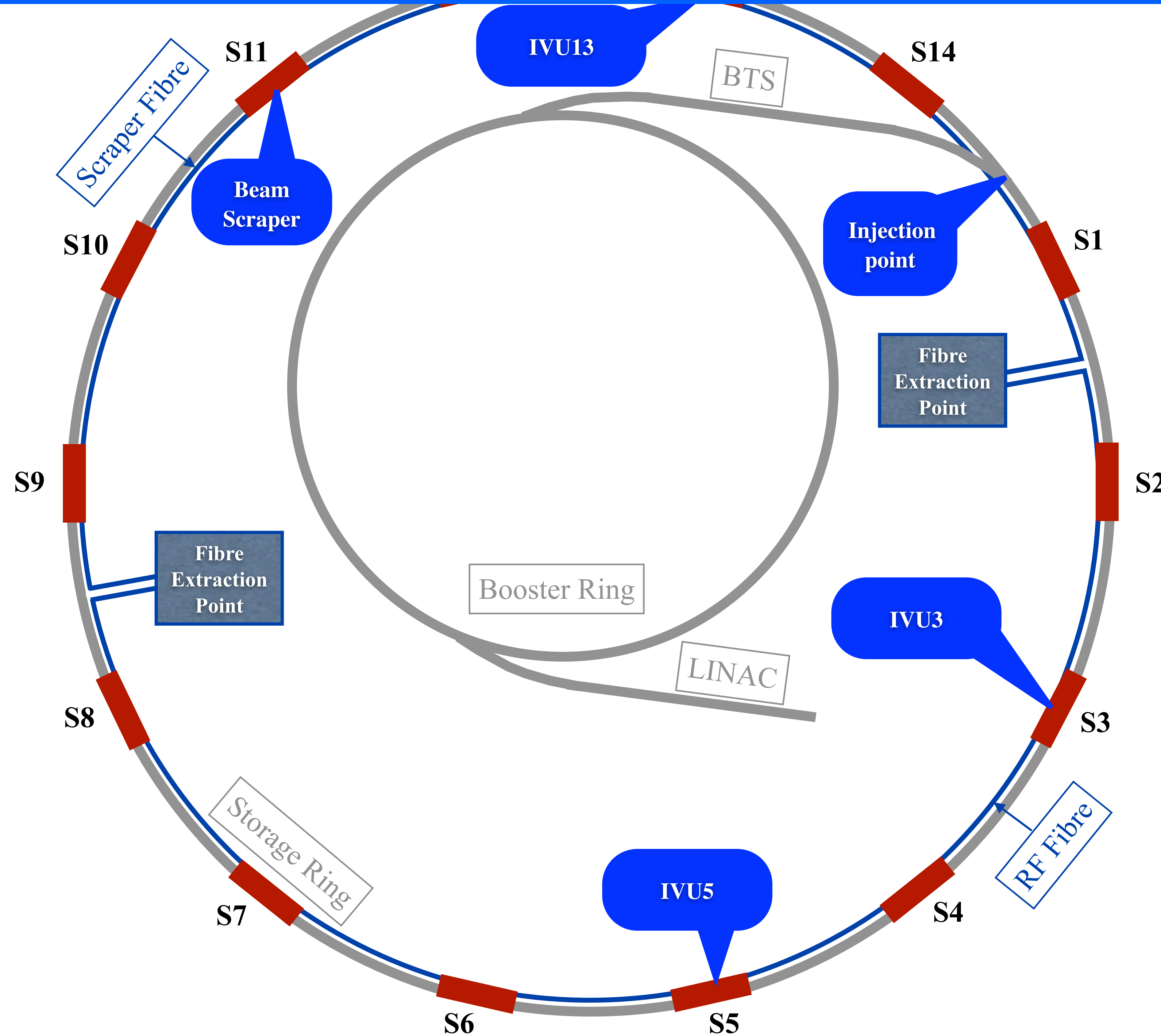
Parameter	TBL
N_{PETS}	16
Current (A)	28
Pulse Length (ns)	140
Initial energy, E_{ini}(MeV)	150
Final energy, E_{end}(MeV)	80
Norm. Emittance $\epsilon_{x,y}(\mu m\, rad)$	150
Beam Pipe radius, r_0(mm)	11.5

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



IVU13
BTS
S11
S14
Scraper Fibre
Beam Scraper
Injection point
S10
S1
Fibre Extraction Point
S9
S2
Fibre Extraction Point
Booster Ring
IVU3
LINAC
S8
S3
RF Fibre
Storage Ring
IVU5
S7
S4
S6
S5