

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 ($1\ \mu\text{s}$) 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 Cherenkov beam loss at SPring-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?

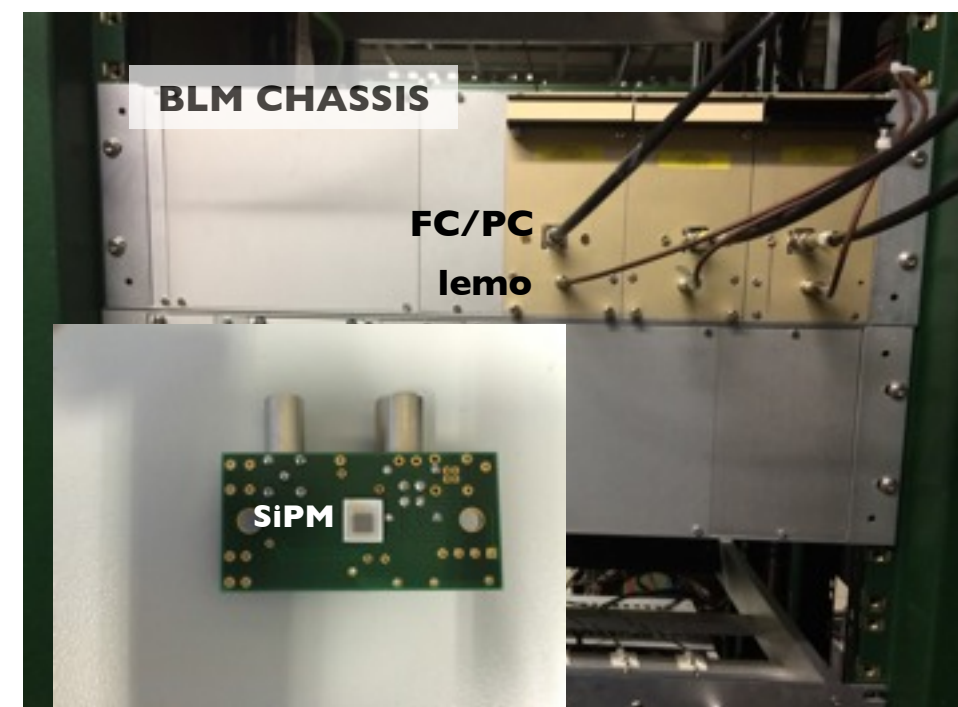
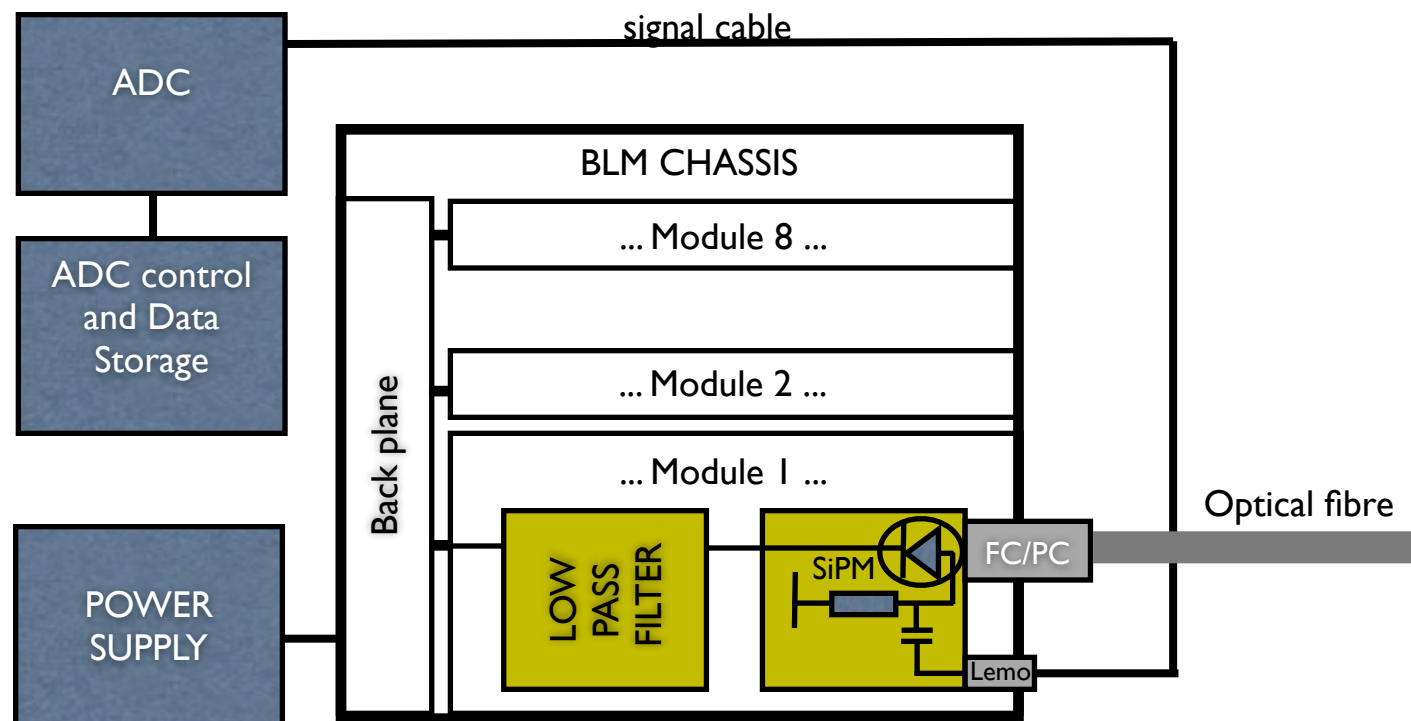
- e.g CLIC bunch pulse of 150 ns length

The oBLM system



BLM system based on Cherenkov light

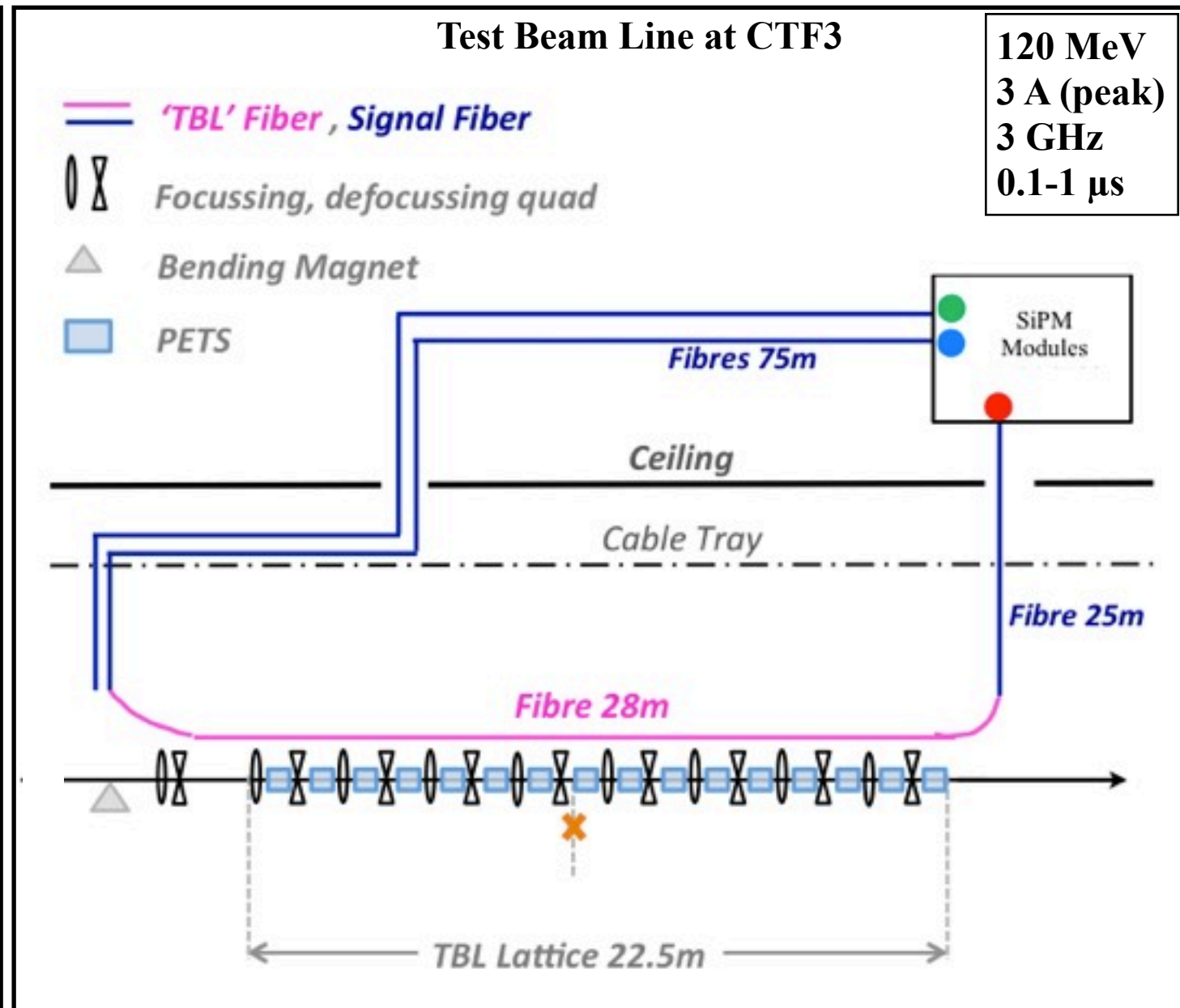
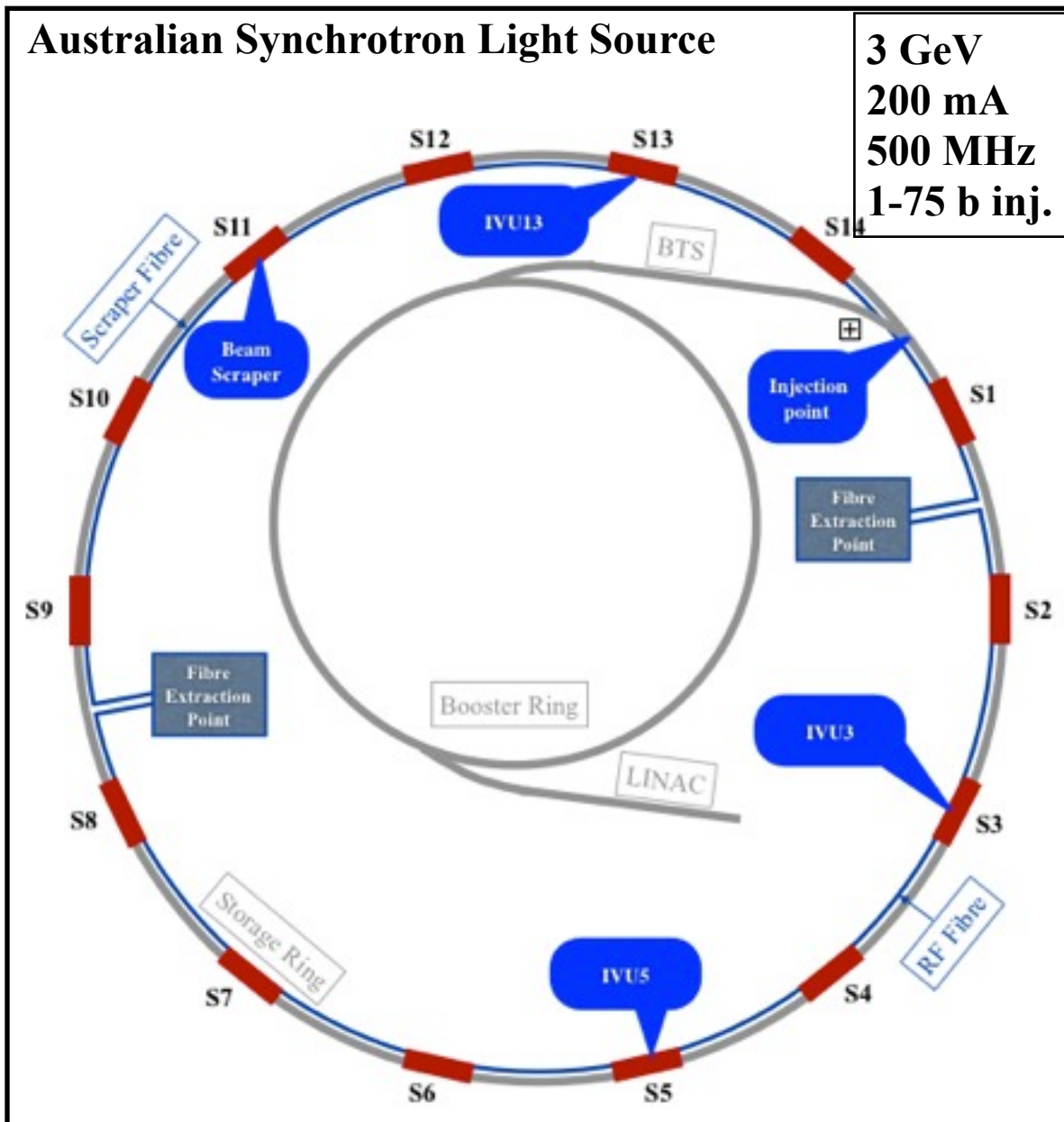
- Optical fibre:
 - 200/245/365 um core/cladding/coating pure Silica
 - High OH content
 - Nylon jacket to protect against: humidity, ambient light
- Custom made photon sensing modules
 - Silicon Photomultiplier (3x3 mm², 14000 pixels, $G = 10^5 - 10^6$)
 - Low pass filters (bias input) for noise filtering
- Custom high sampling (1-4GS/s) and high bandwidth (250 MHz- 2 GHz) ADCs



The Machines

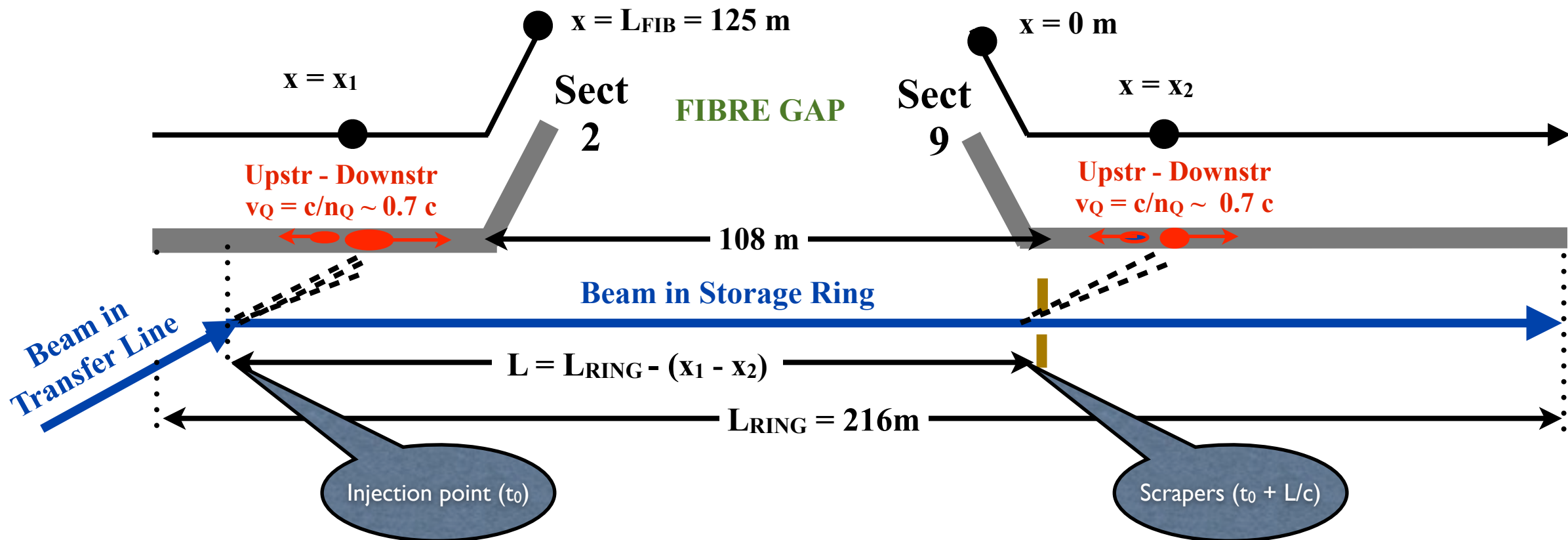
oBLM installed for testing in two electron machines

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



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**

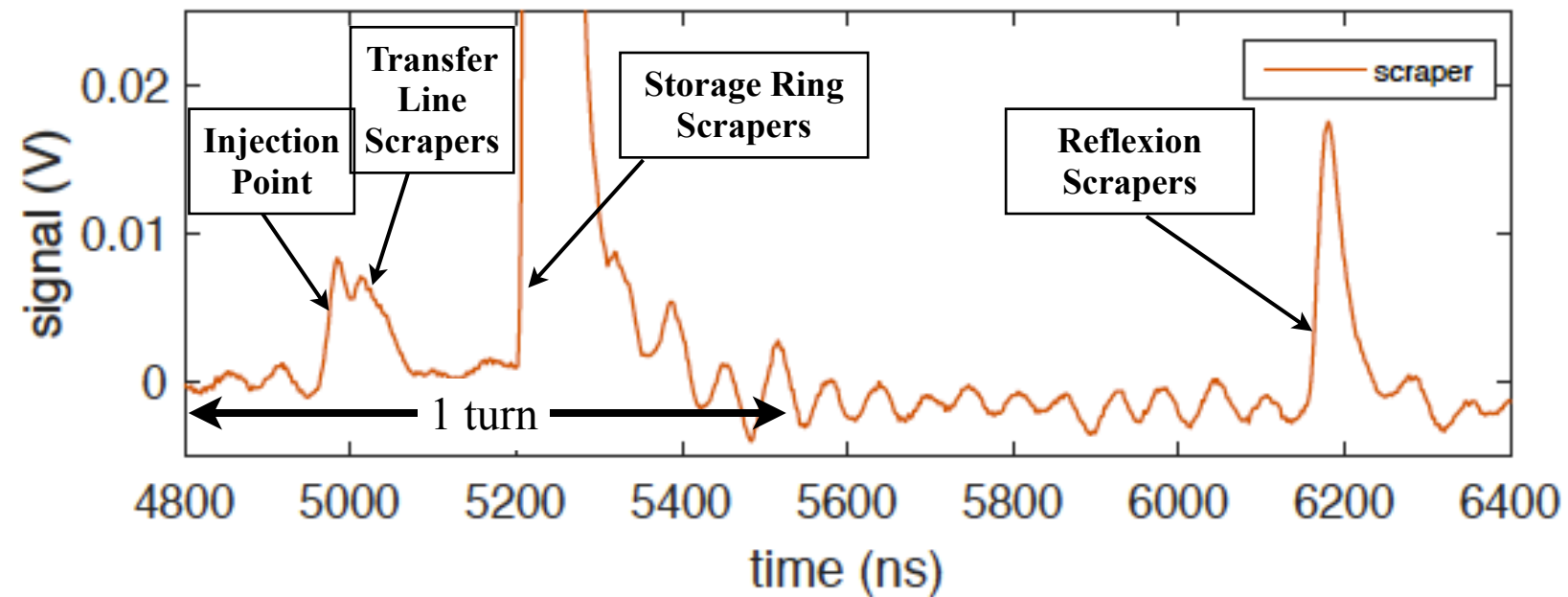
$$\Delta x = \frac{c\Delta t}{1 + n_Q}$$

Understanding Beam Losses II

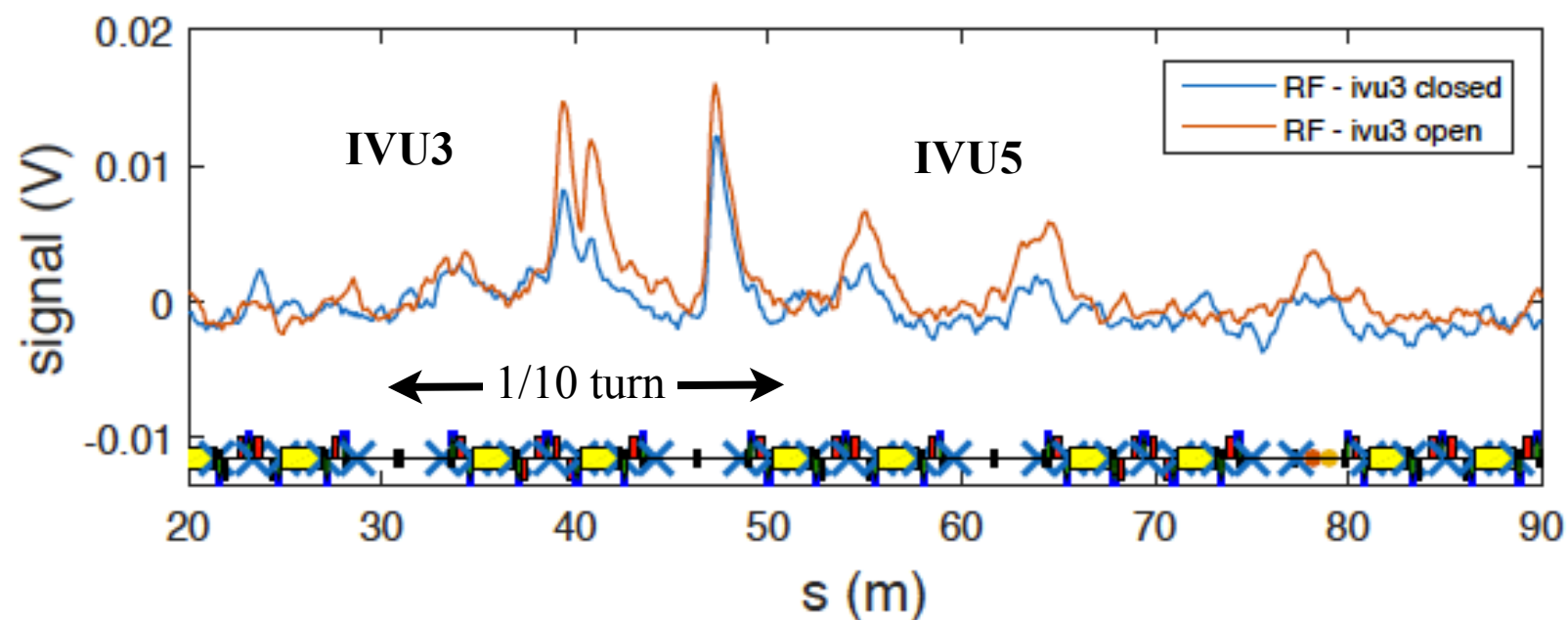


Multi peaks observed due to losses in different positions

Scrapper Fibre



RF Fibre



Intrinsic time resolution I

Single bunch injection

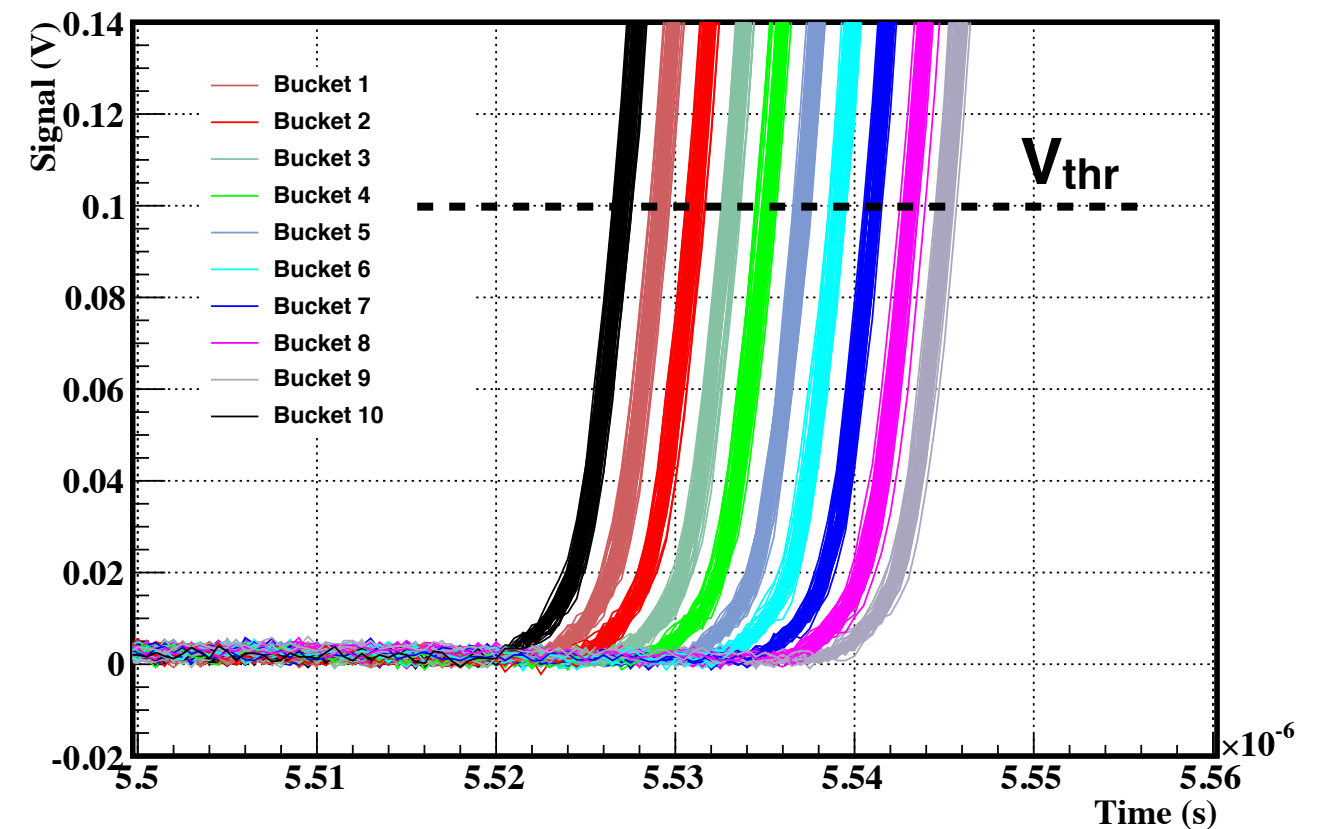
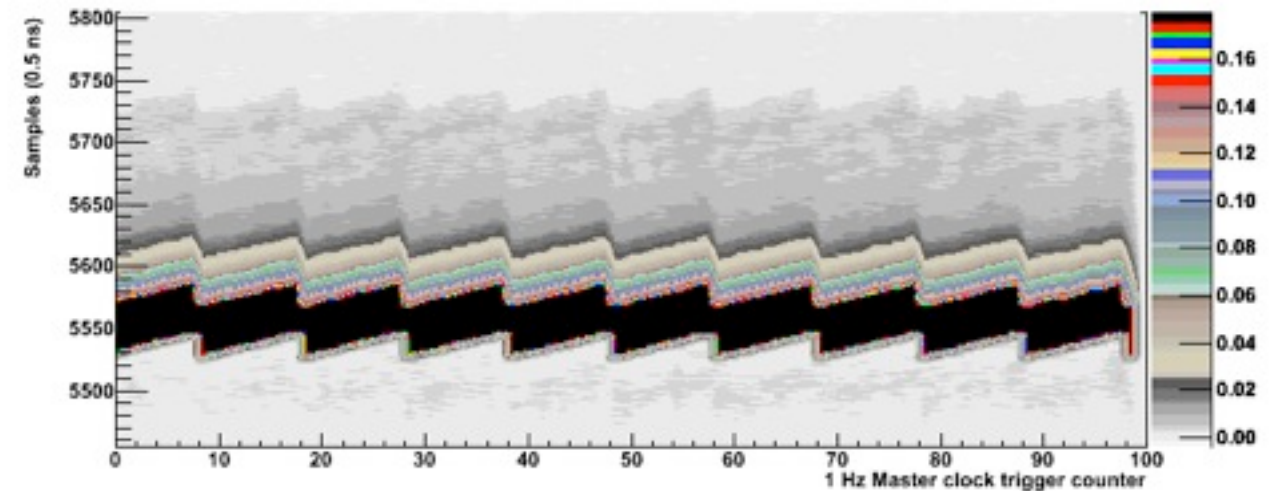
- Consecutive filling RF buckets 1-10

Looking at the raising edge of losses “at scrapers”

- Well defined loss location

One bucket (2 ns) shift disentangled shot by shot

- $V_{\text{oBLM}}(t = t_{\text{photon}}) = V_{\text{thr}}$
- $t_{\text{photon}} \rightarrow$ Photon arrival time (to upstream end)

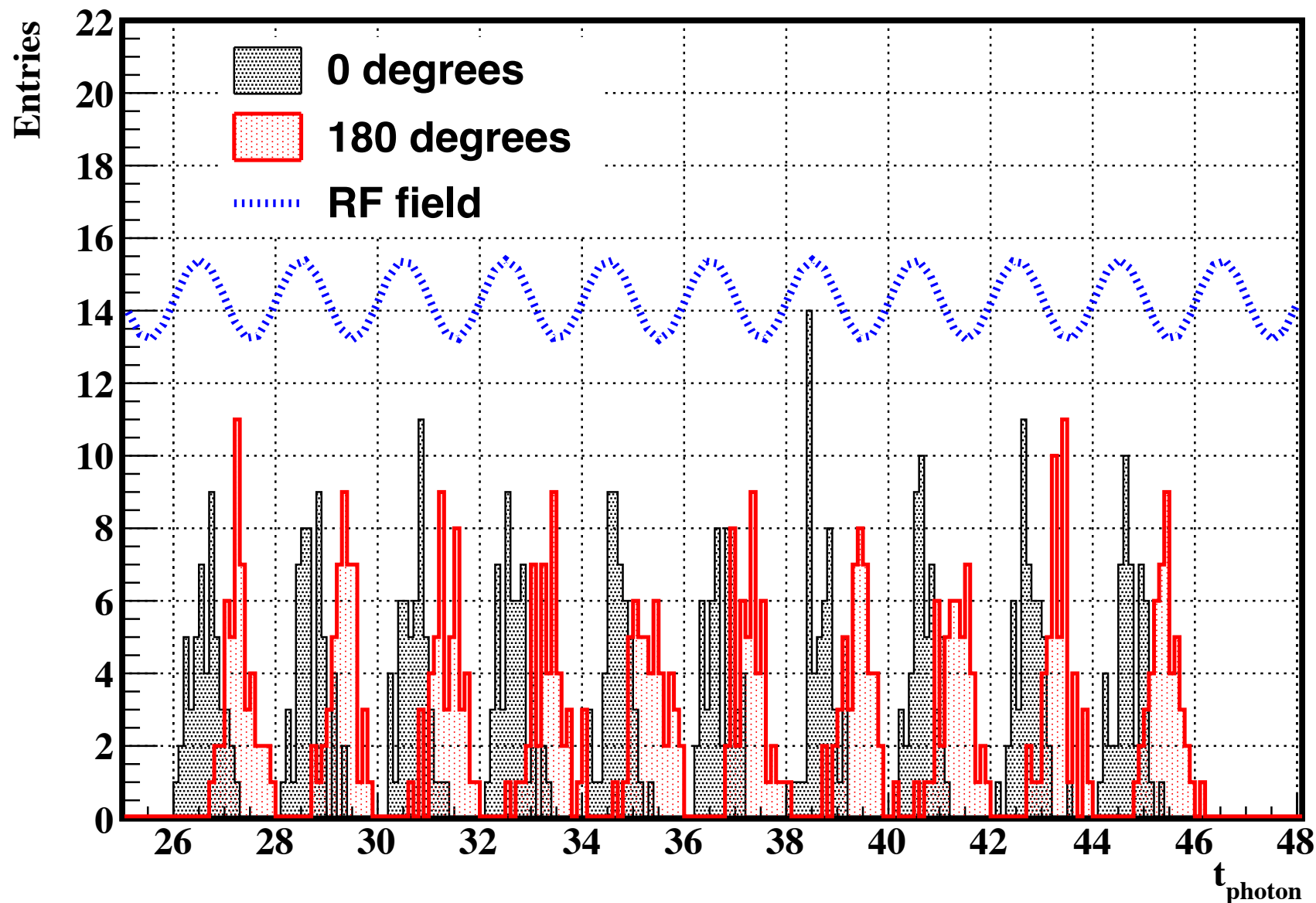


Intrinsic time resolution II



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

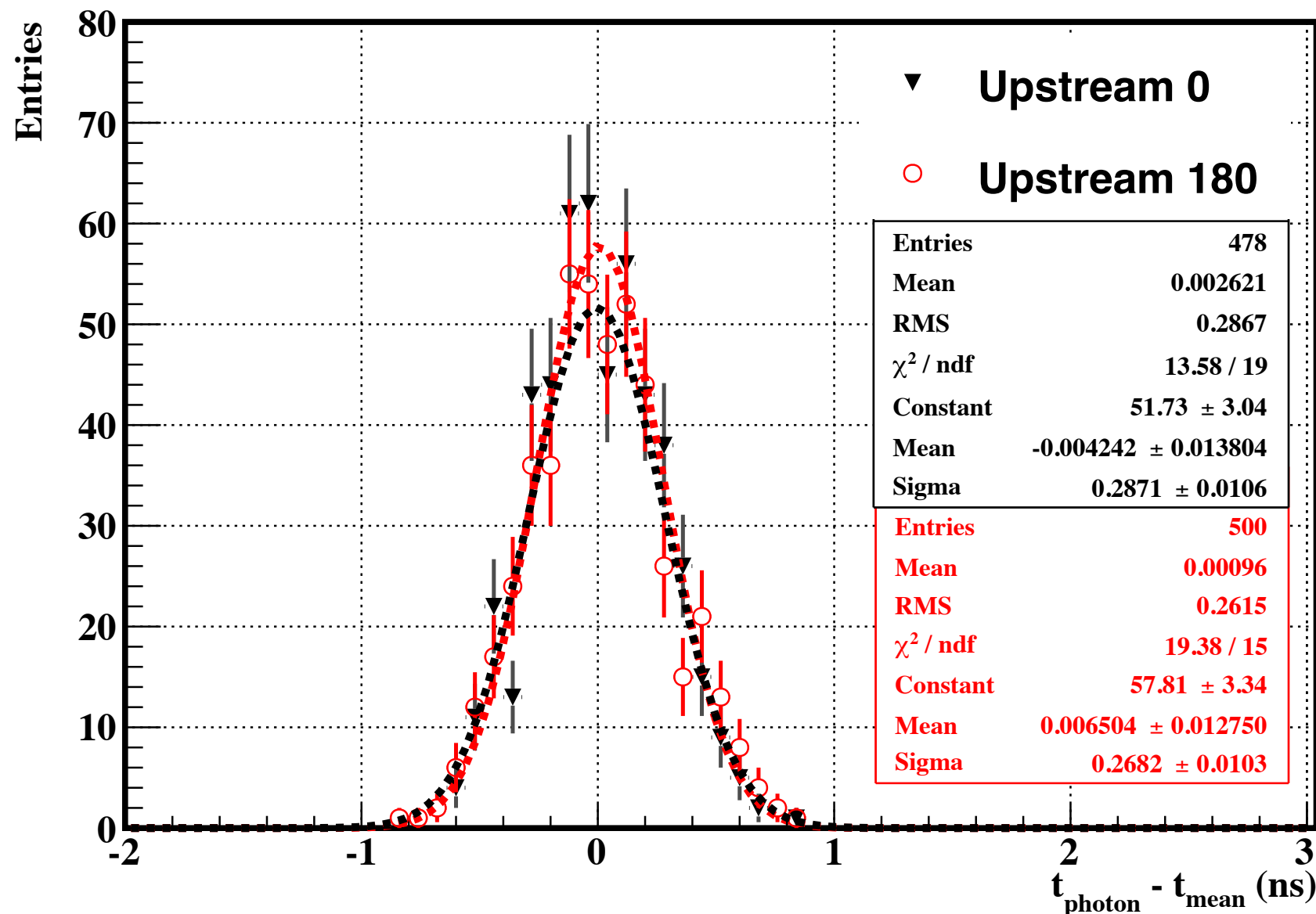


Intrinsic time resolution III



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^{th} bucket)



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

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

$$\sigma_t \approx 4 \text{ cm}$$

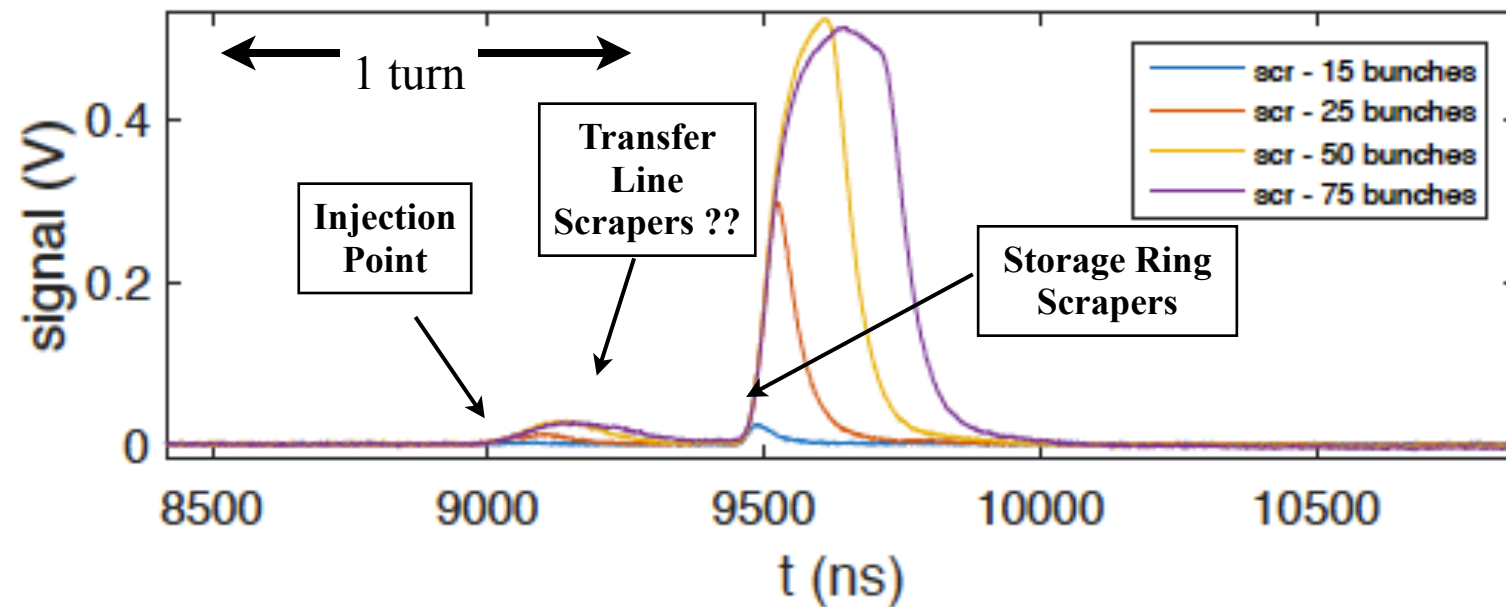
Multi bunch Beam Losses



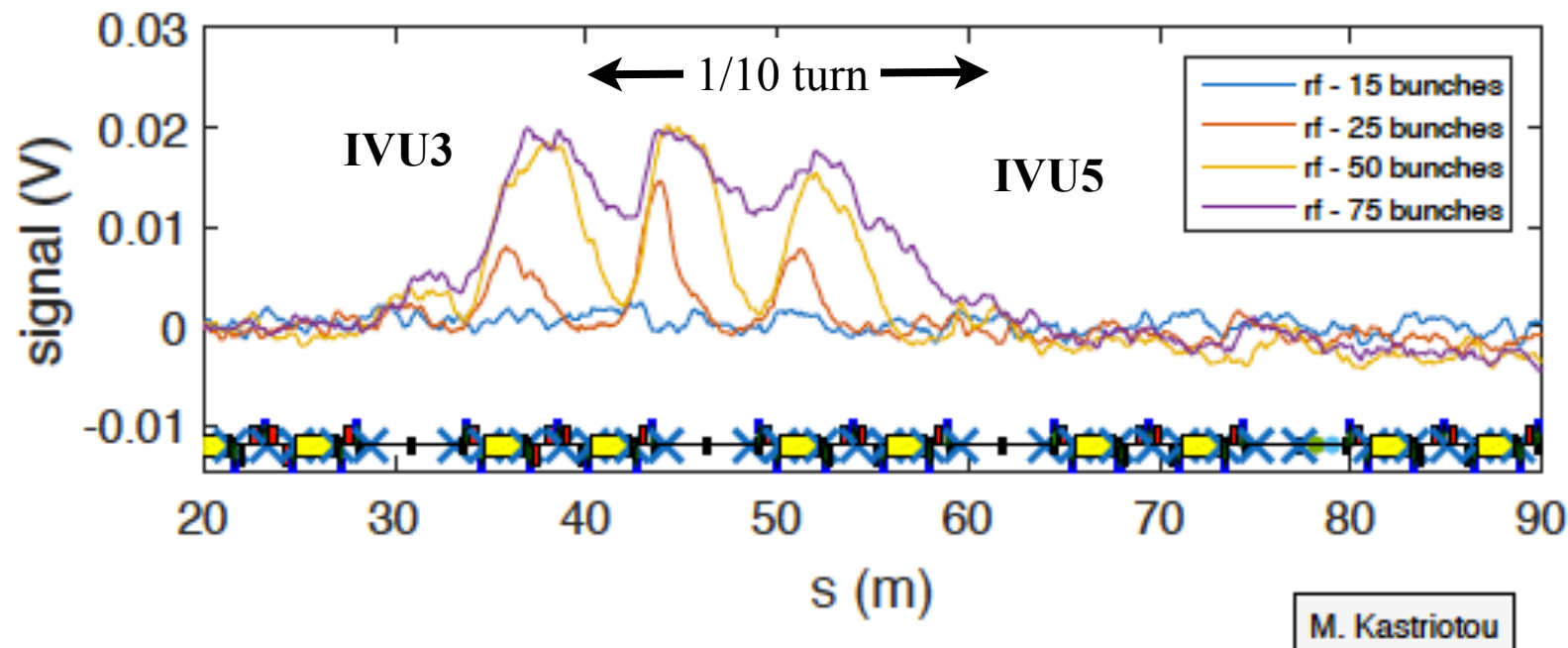
Multi peaks observed due to losses in different positions

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

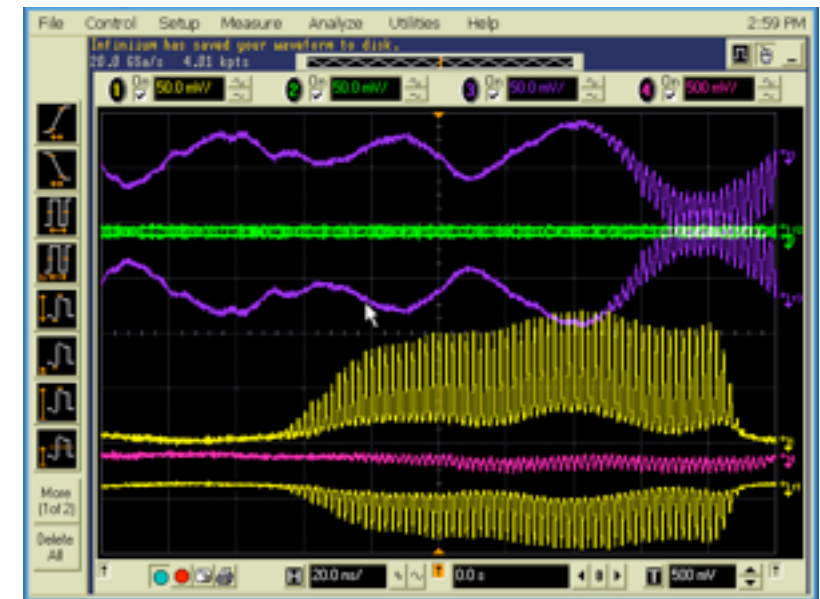
Scrapers Fibre



RF Fibre



Current profile of 75 bunch train

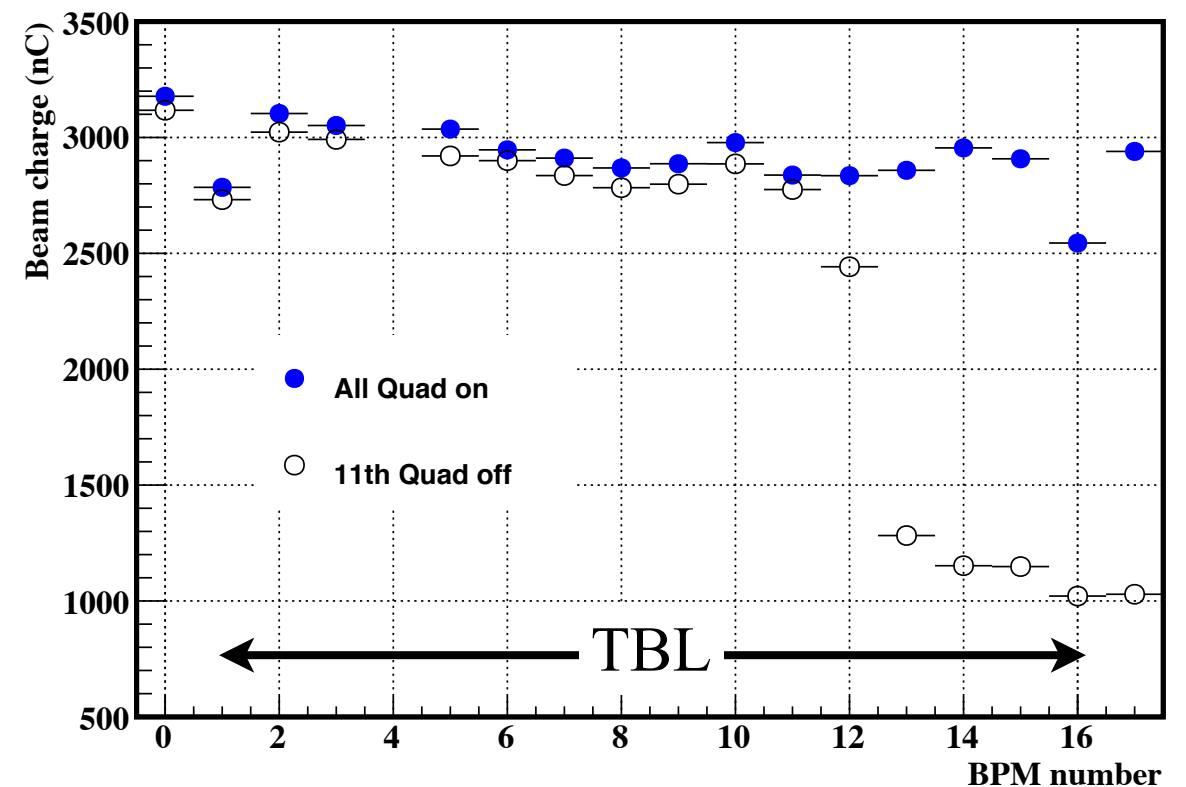
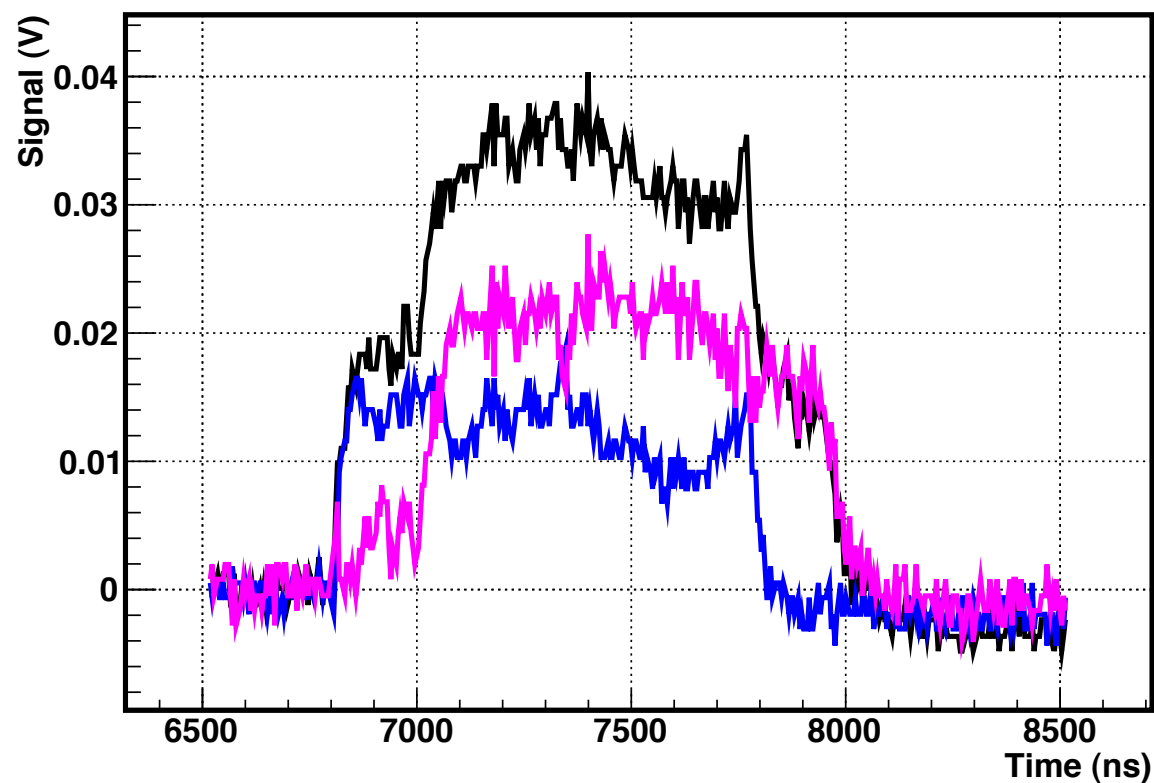
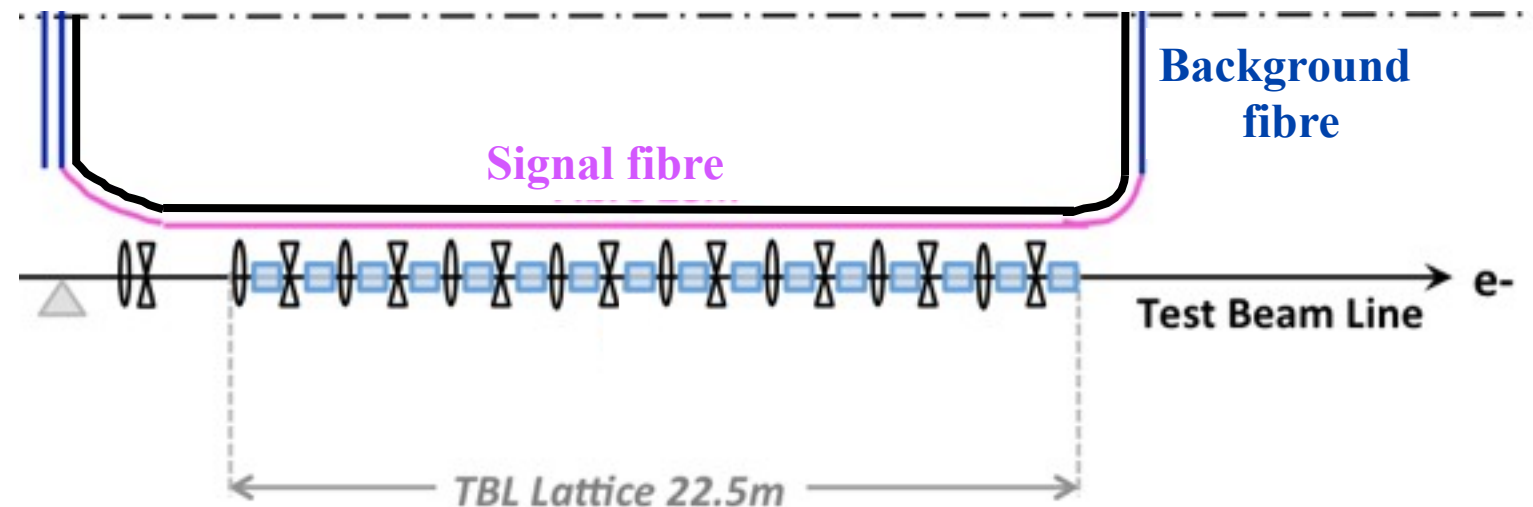


Losses with long bunch trains I



Observing losses from a $1\mu\text{s}$ long pulse

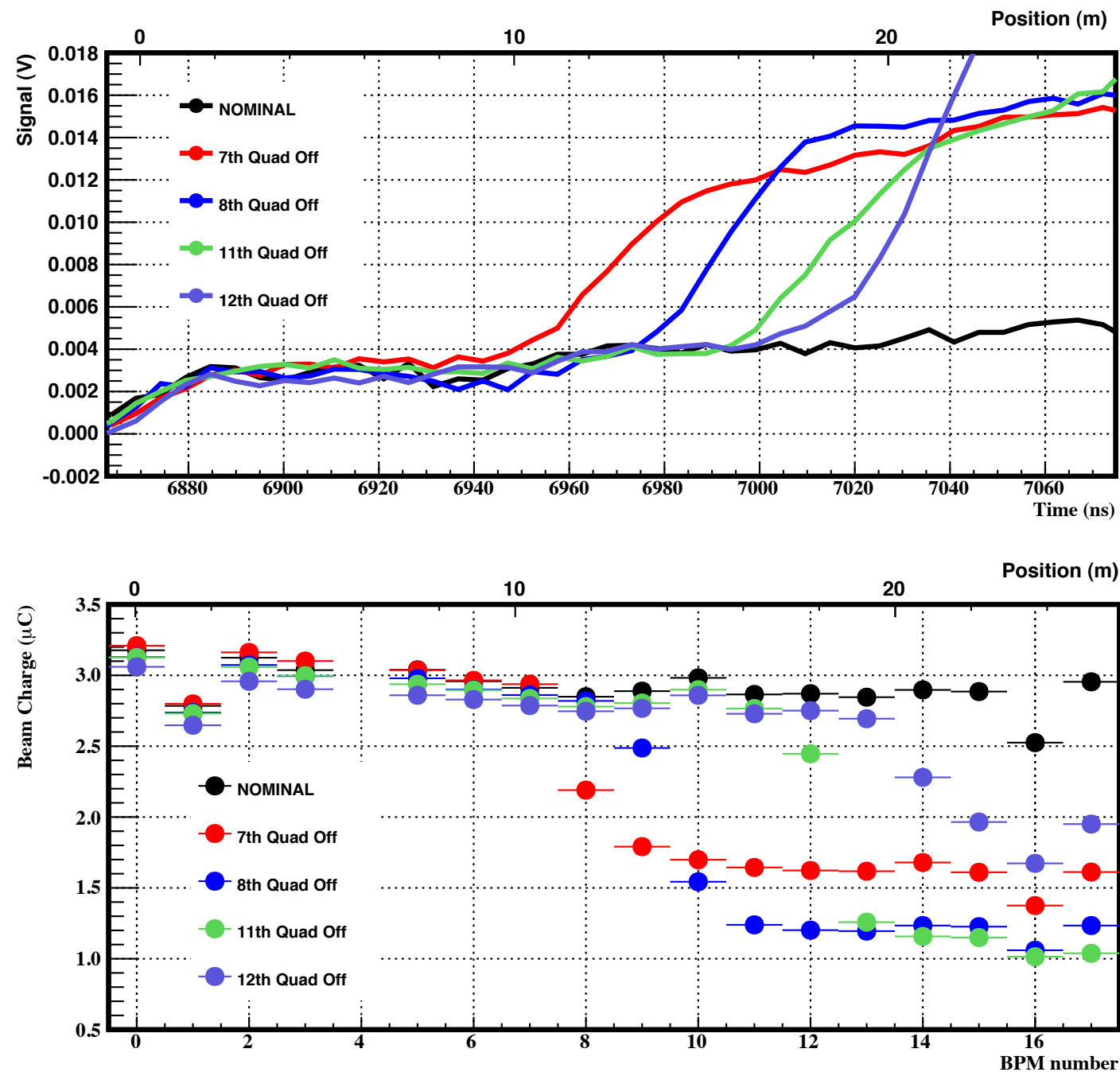
- Controlled Losses generated by switching off quadrupoles
- Signal subtraction to account for showers from TBL only



Losses with long bunch trains II

Determination of loss location from signal leading edge

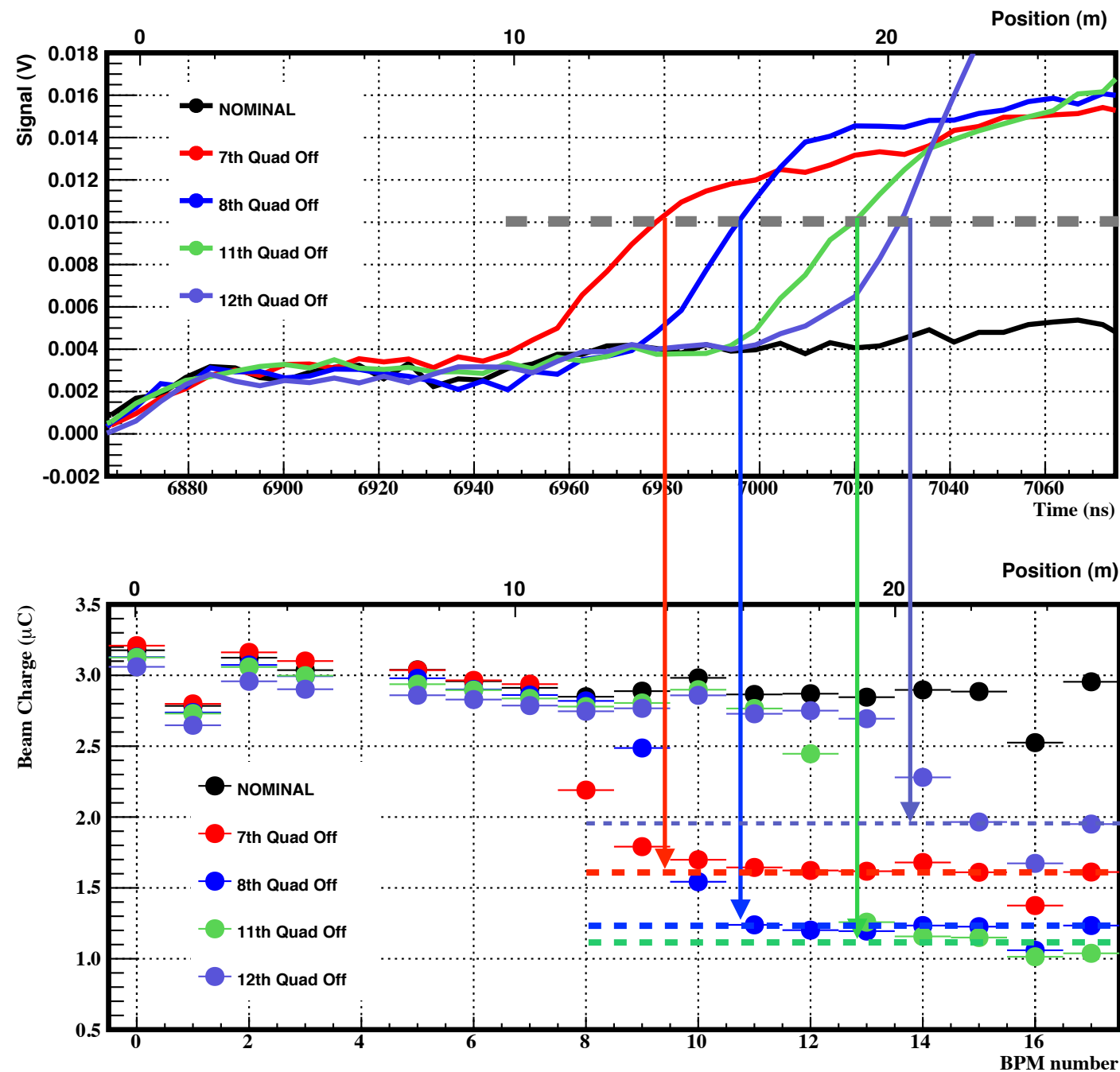
- Good qualitative agreement between oBLM and BPM profile loss measurements
- Localisation of loss down to (below) 2 m achieved



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



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 μ s) bunch trains achieved at CTF3
 - Further signal processing necessary due to increasing beam profile along bunch train at the Australian Synchrotron

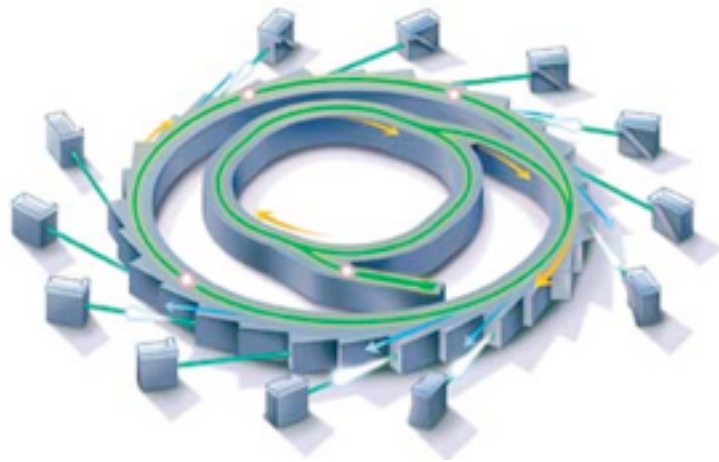
Thank you for your attention !!

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

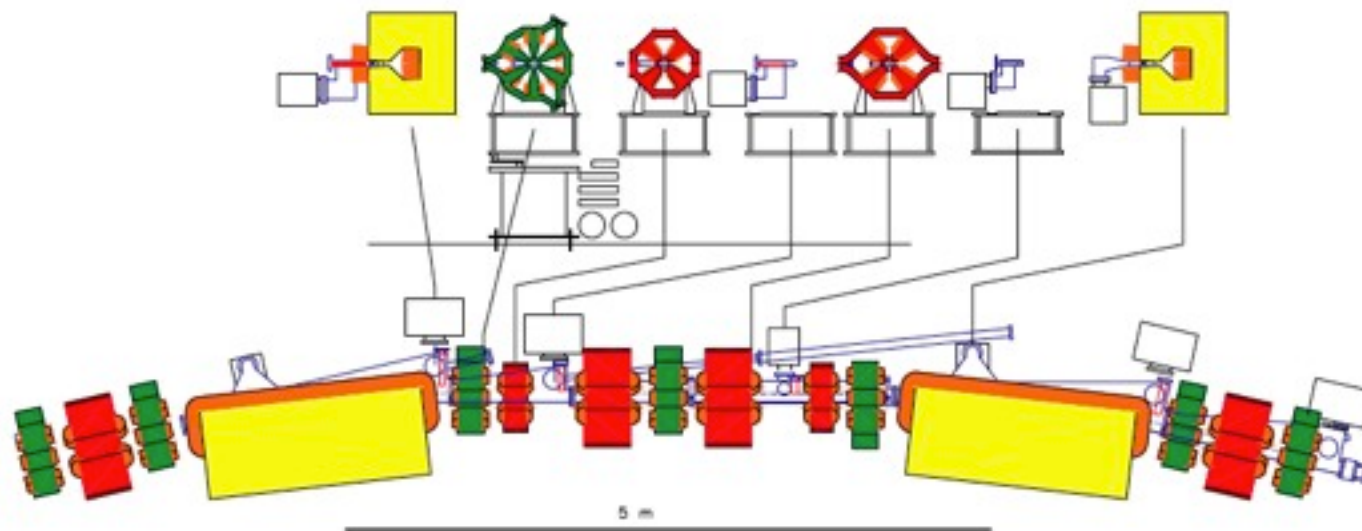
Back up slides

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

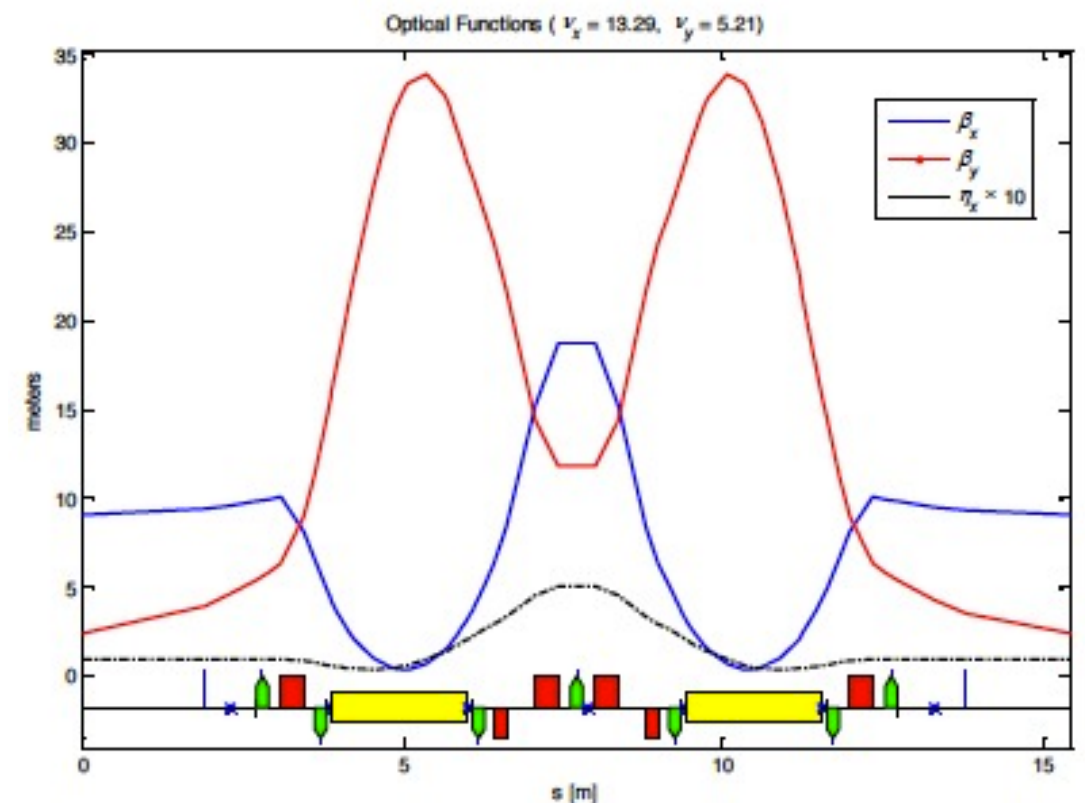


Schematic view of a DBA cell in the SR arc



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	$\sigma_x - 87\mu\text{m}$, $\sigma_y - 60\mu\text{m}$
Beam size in straights	$\sigma_x - 320\mu\text{m}$, $\sigma_y - 16\mu\text{m}$
Number of possible Insertion devices	12
Emittance	$\epsilon_x - 10$ nm
Coupling (nominal)	1%



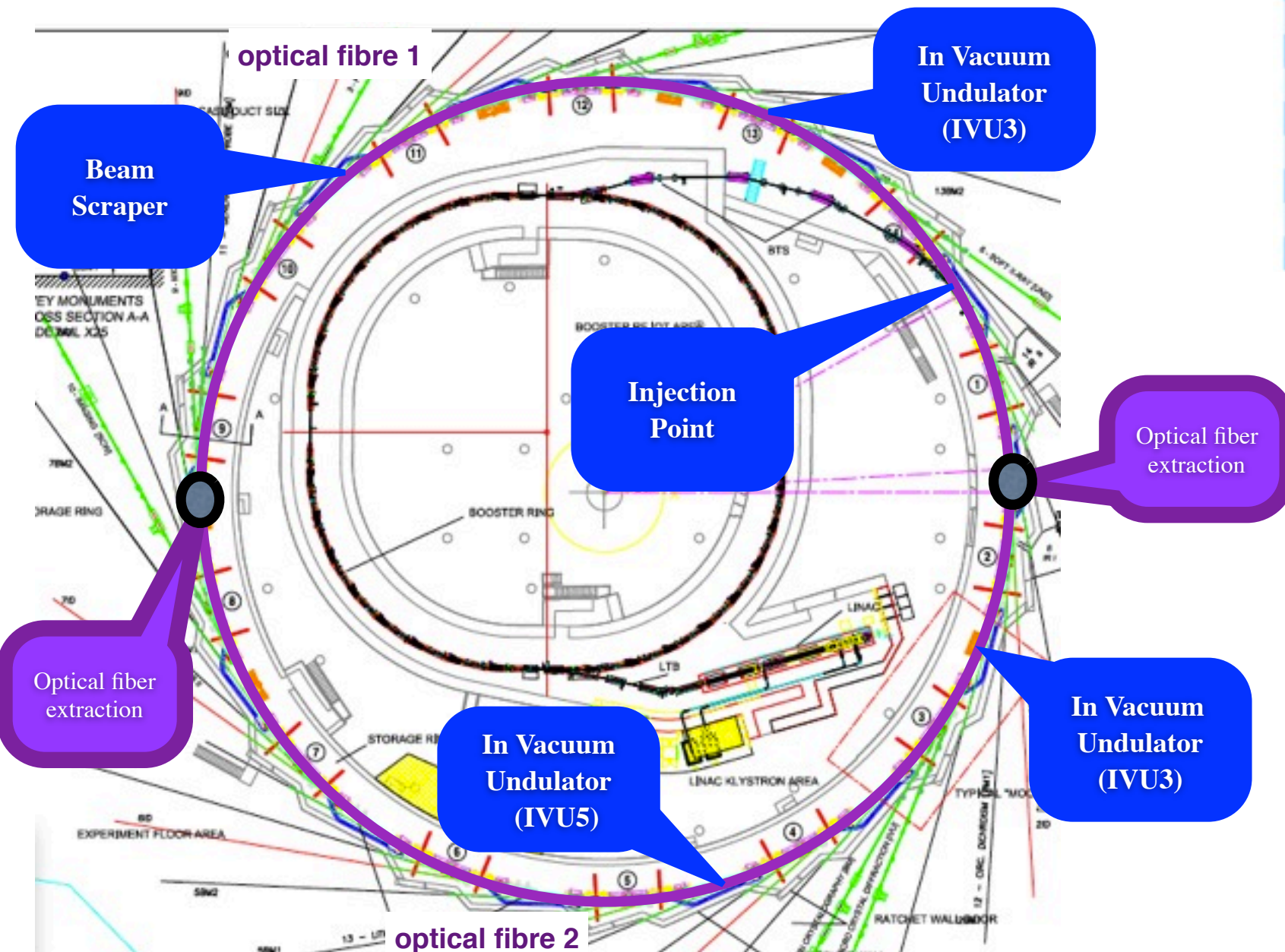
The machines: The Australian Synchrotron

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

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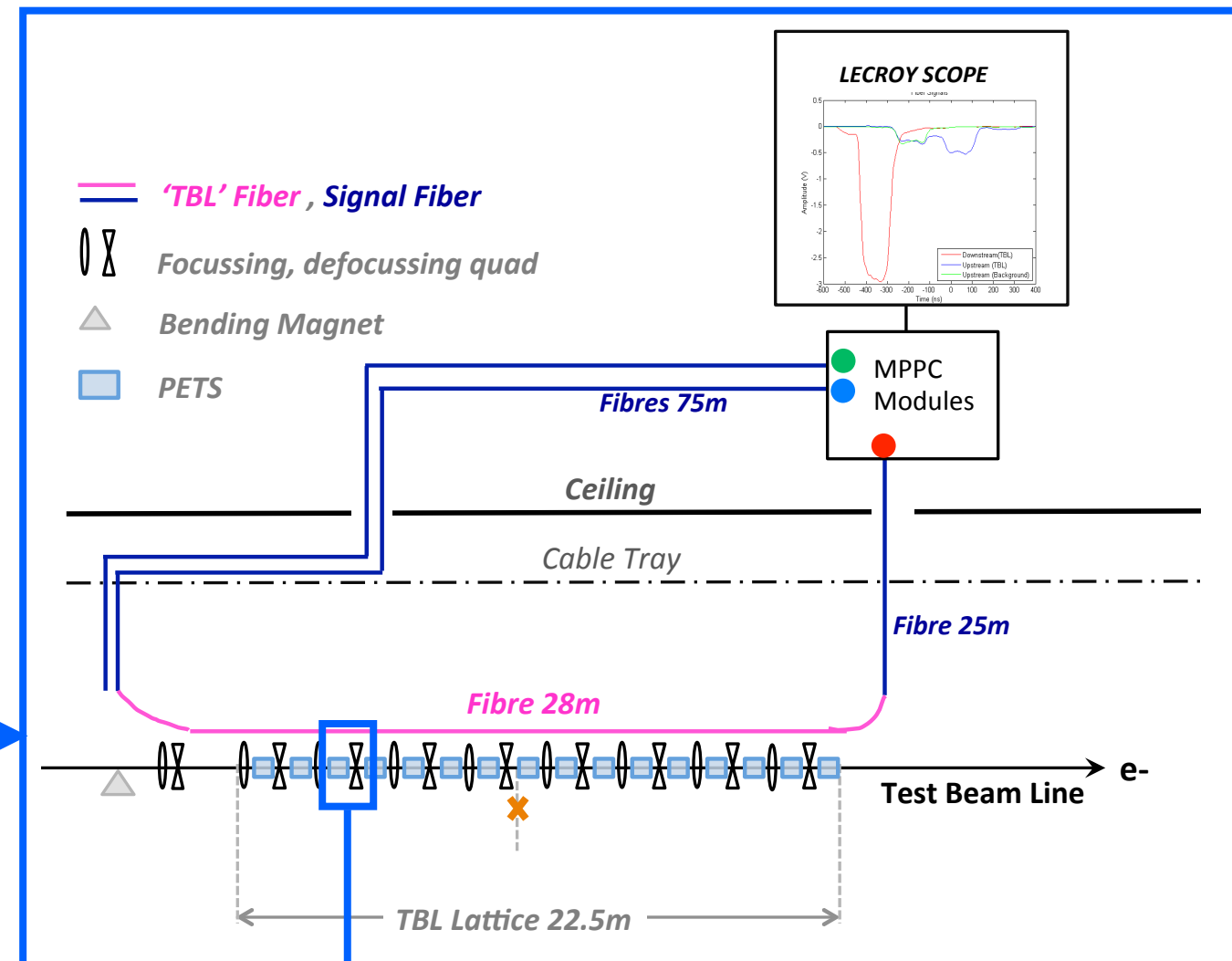
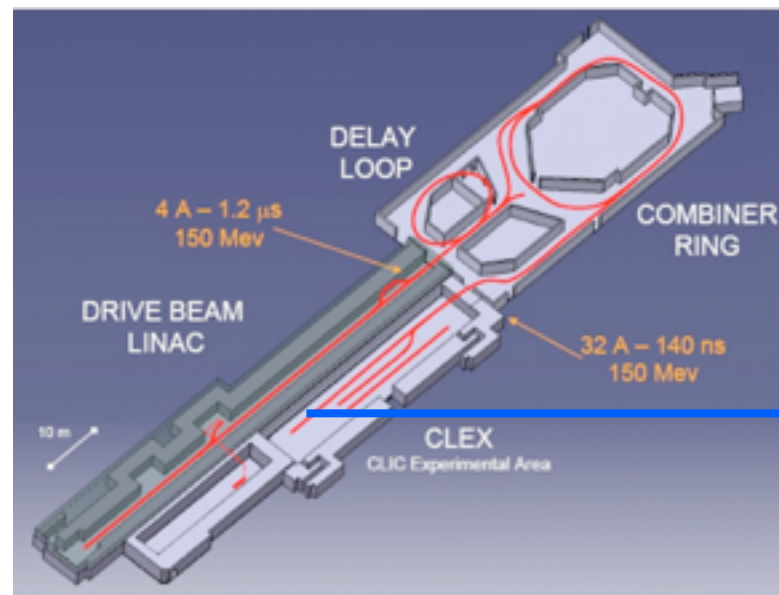
Flexibility

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

The machines: The Test Beam Line

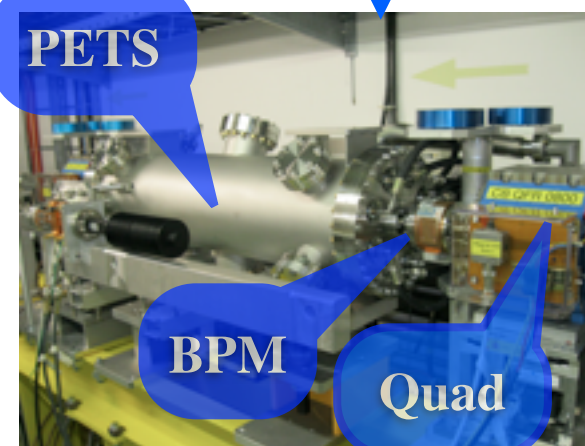
CLIC Test Facility (CTF3)

- 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

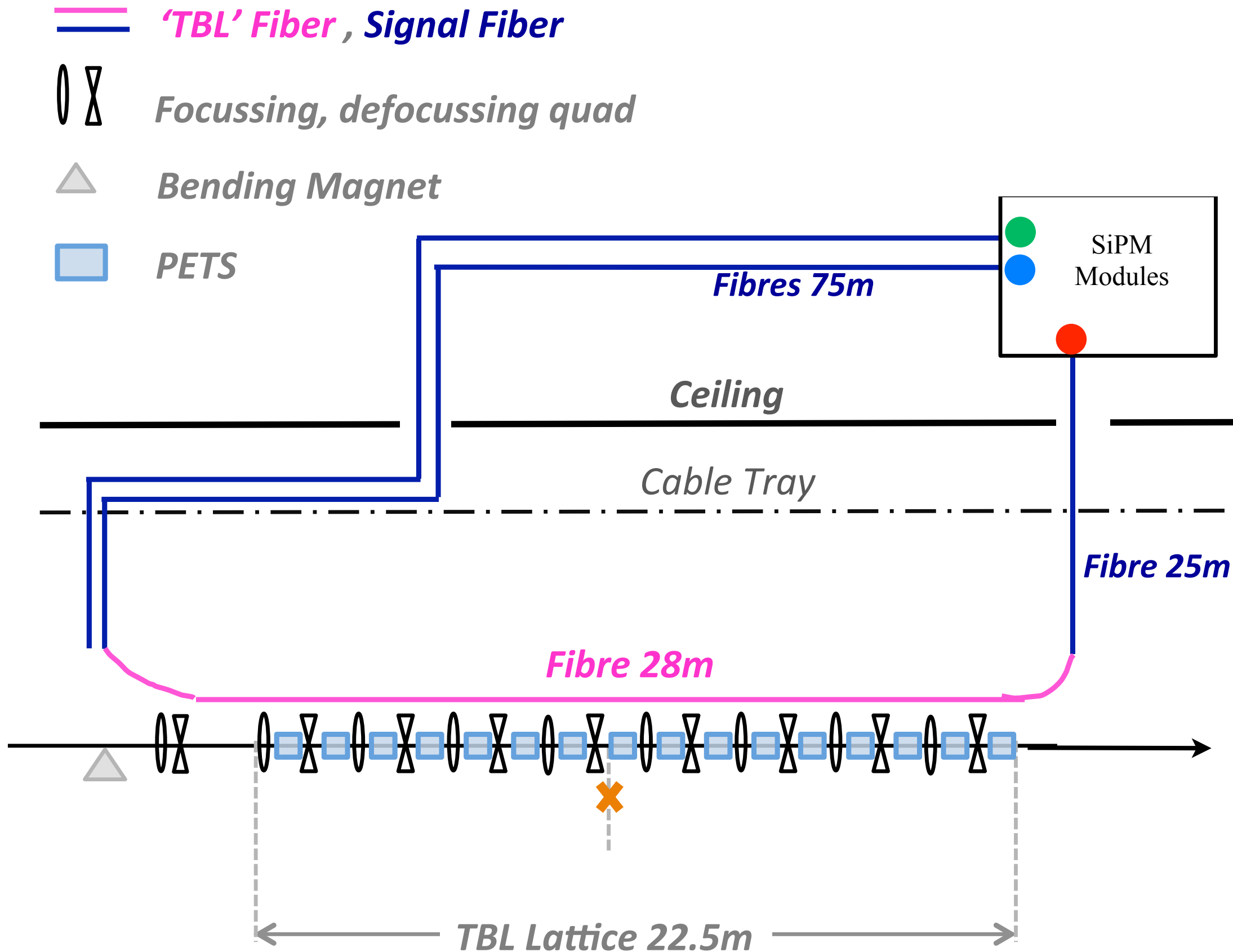
- Decelerating LINAC with 8 FODO cells
- Each half cell comprises:
 - 1 Power Extraction and Transfer Structure
 - 1 Beam Position Monitor
 - 1 Quadrupole
- Flexibility
 - beam current: 1 - 28 A (@ 3-12 GHz)
 - Pulse length: 100-1000 ns



TBL nominal parameters

Parameter	TBL
NPETS	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



ASLS Sketch

