Fibre BLM studies in the Australian Synchrotron

Topical Workshop on Beam Loss Monitors

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Outlook

1. Properties of Optical fibre BLMs examined in the Australian Synchrotron
2. Potential of optical fibres for the machine protection of the Synchrotron

Optical fibre BLM

- The OBLM system
- Position Resolution Studies
- Steady state losses
- Beam Losses of a full acceleration cycle (Booster)
- Conclusions

Optical fibre Beam Loss Monitors (OBLMs)

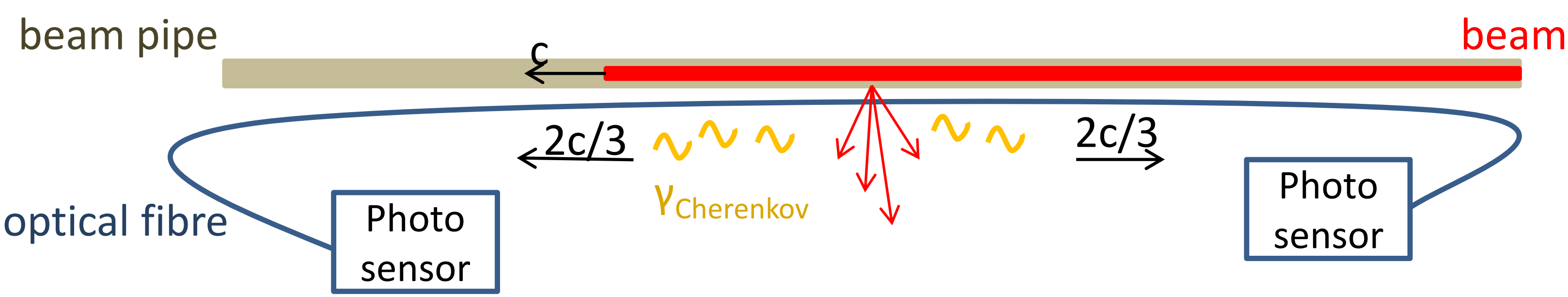
OBLM system is based on Cherenkov light detection

Operation principle

i. Beam loss shower particles cross the optical fibre → (e^{-}-e^{+}, 0.2 MeV) **Cherenkov photons**
ii. Cherenkov photons propagate in the optical fibre → **photosensor!**

✓ Covering long distances
✓ Cost-effective
✓ Insensitive to n, X-rays

⟹ Ideal for linacs, Storage Rings



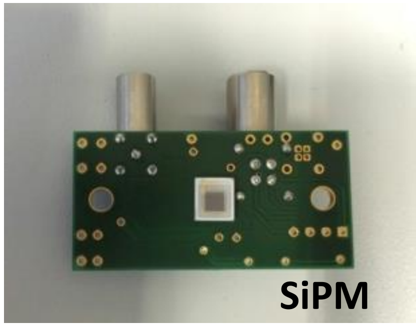
Basic Setup

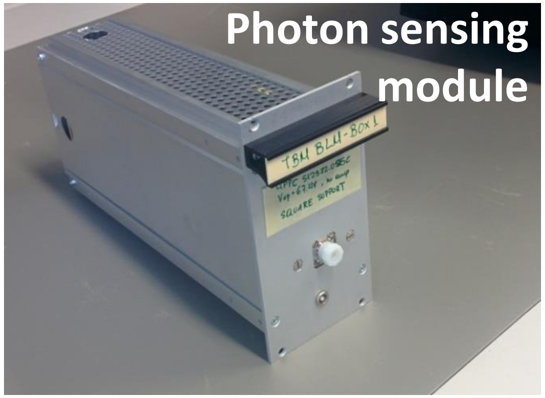
- Optical fibre length and diameter depends on application
  - Sensitivity increases with diameter

  Use Silica fibers with high OH content recommended.
- Photosensors:

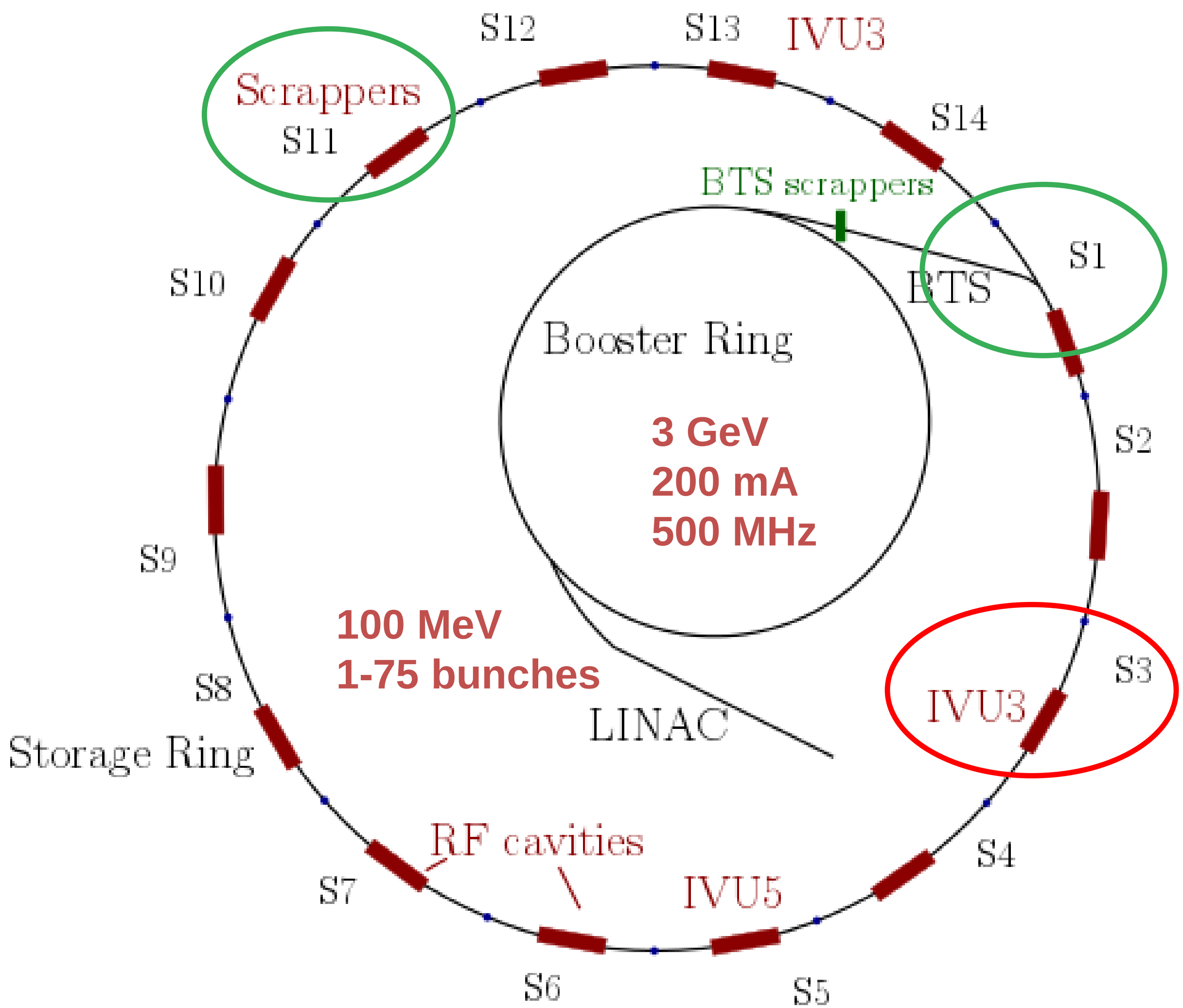
1. Silicon PhotonMultipliers (SiPM) [Hamamatsu S12572-015 C]
   - Low pass filters (bias input) for noise filtering
   - SiPM with different readouts, depending on the application
   - Contained in RF shielded modules
2. Photon Multiplier Tubes (PMT) [Hamamatsu H10721-210]

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





The Australian Synchrotron Light Source



14 m LINAC

130 m Booster

216 m Storage Ring

Important locations:

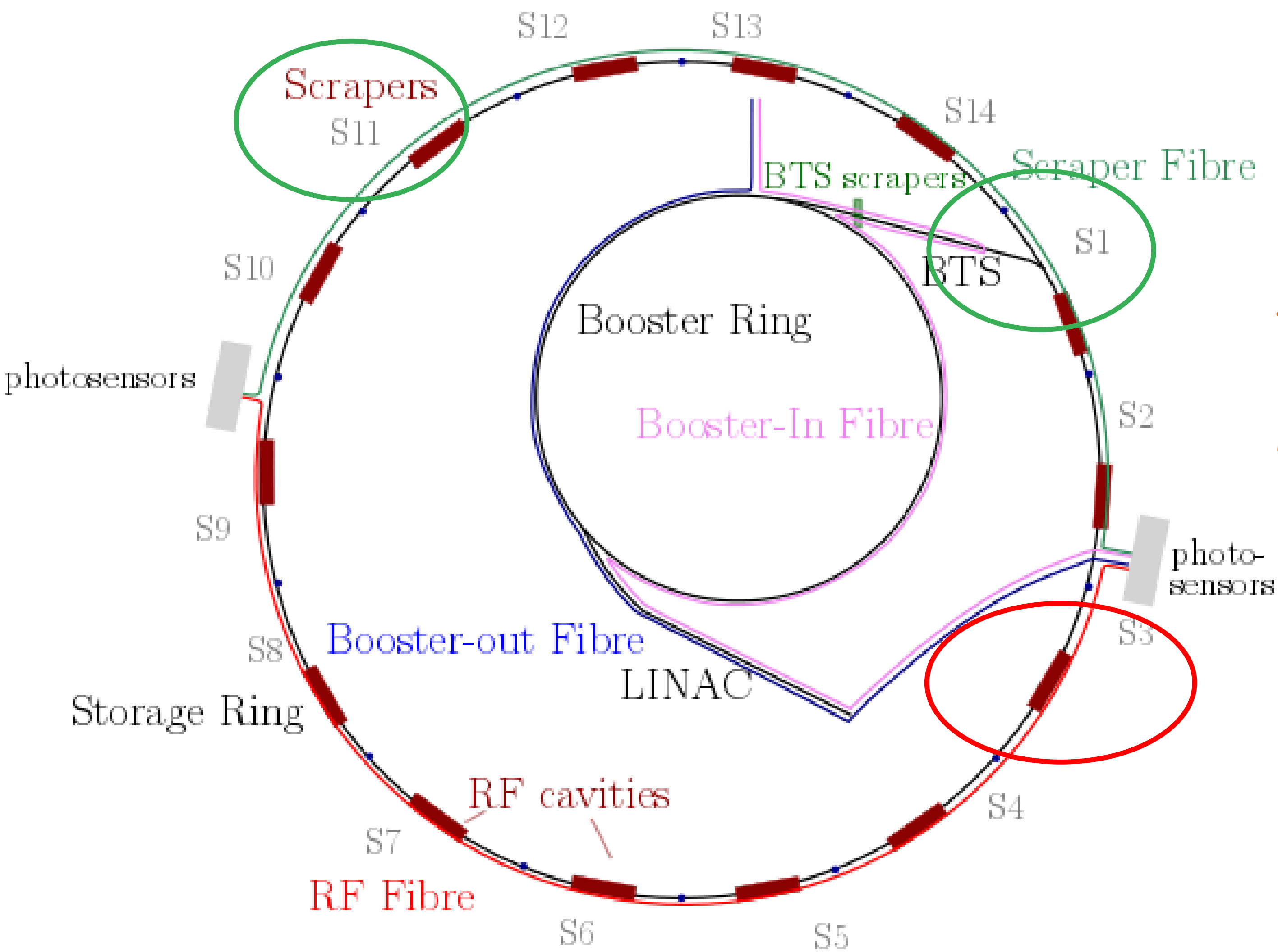
Booster Ring

- Injection to booster
- Beam To Storage ring (BTS) transfer line

Storage Ring

- Injection (Sector 1)
- In Vaccuum Undulator (IVU) 3 (Sector 3)
- Scrapers (Sector 11)

Fibre Installation



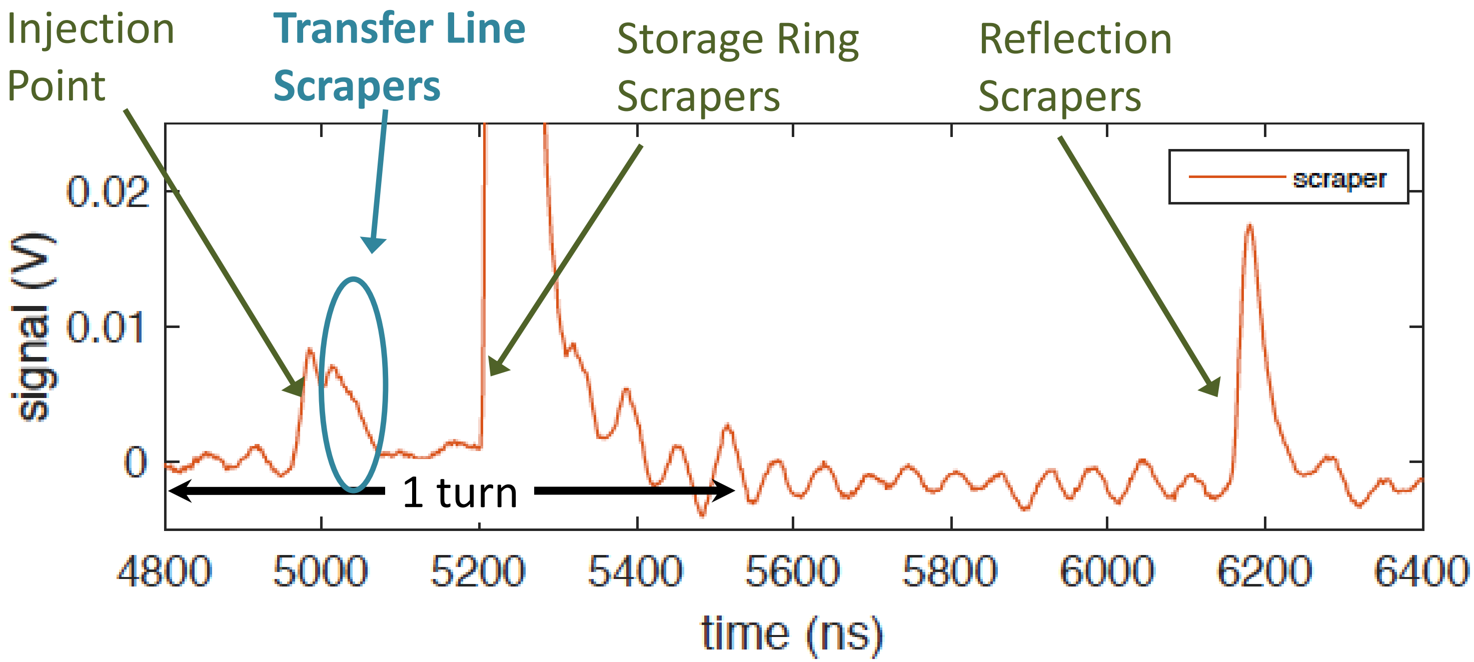
- Silica fibres
- 200 µm core Ø
- 125 m

The full facility covered with only 4 fibres!

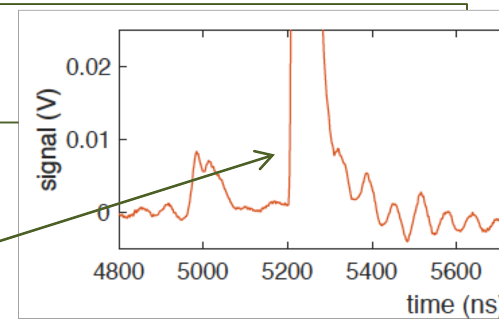
Single bunch beam loss measurements

- Multiple peaks are observed due to losses in different positions
- Storage Ring Scrapers closed → high loss signal and reflection
- Losses from BTS transfer line visible
  - Despite the designated shielding
  - Beam losses not detected otherwise

Highlights the importance of distributed BLMs!

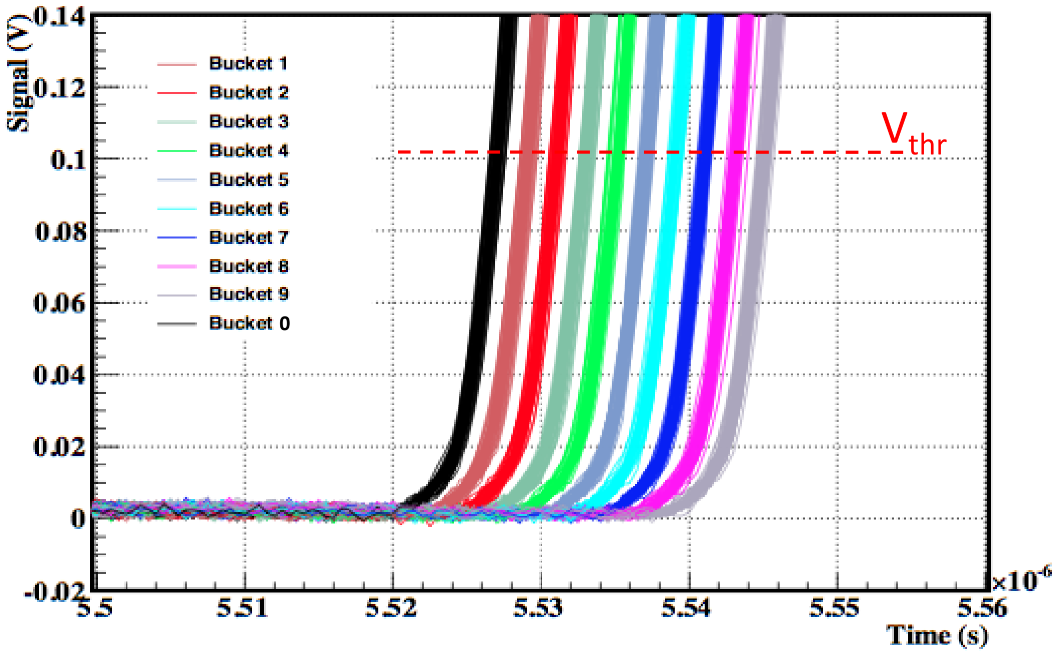


Intrinsic Time Resolution



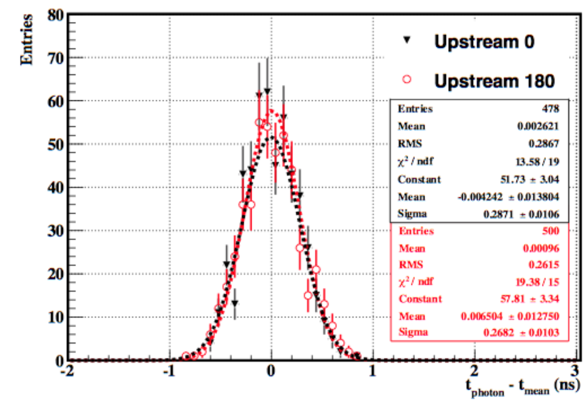
- Single bunch injection
  - Consecutive filling RF buckets 1-10
  - Looking at **raising edge** of losses at scrappers (well defined location)

One bucket (2 ns) shift disentangled shot by shot!



$\Delta t = t_{photon} - t_{mean}$

(central time of nth bucket)



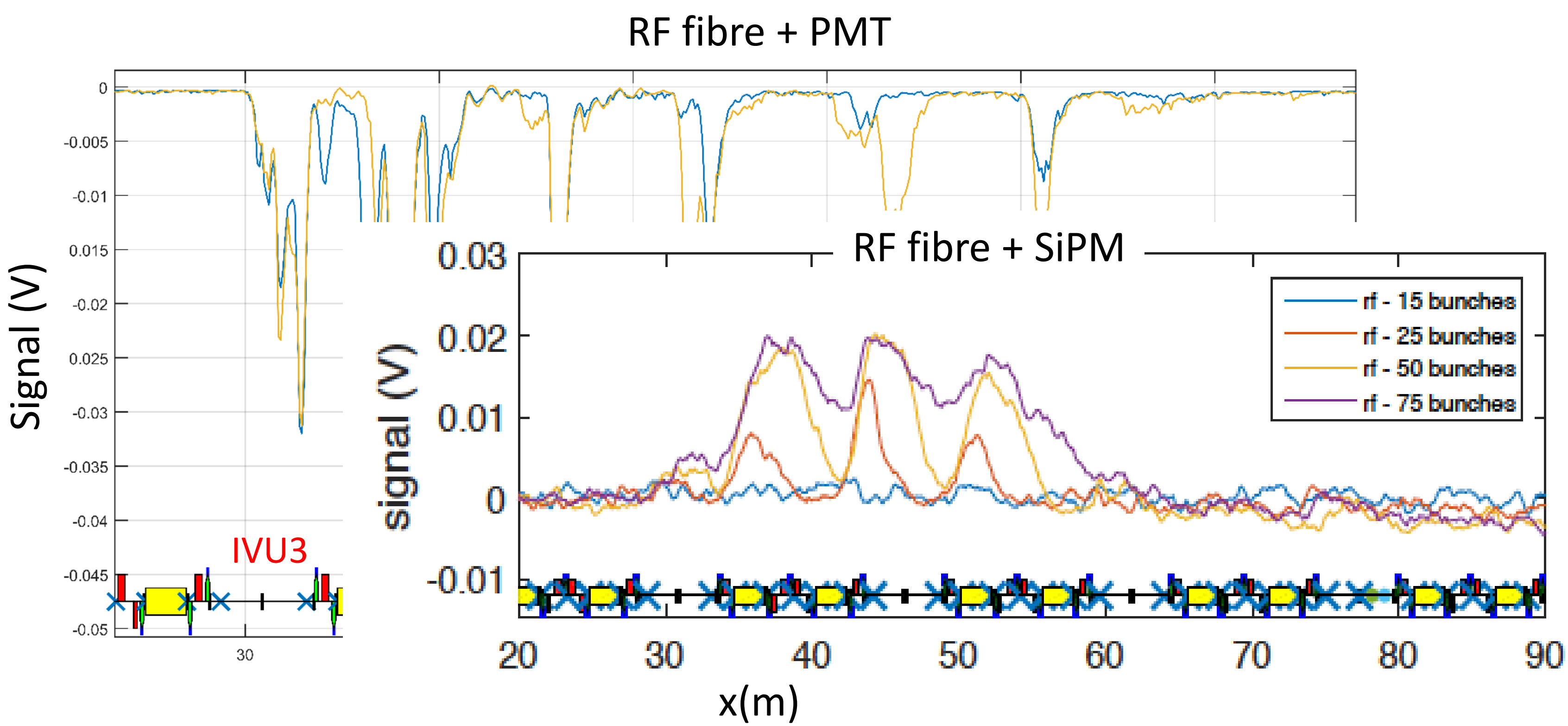
$$\Delta x = \frac{c\Delta t}{1 + n_O}$$

$\sigma_t \lesssim 300$ ps → $\sigma_x \lesssim 4$ cm

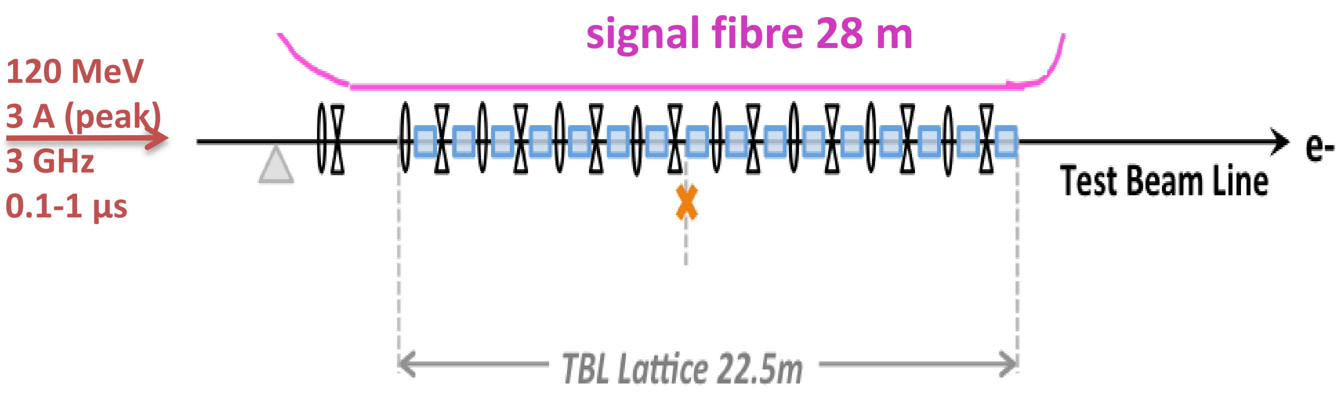
Position resolution <10 cm achieved!

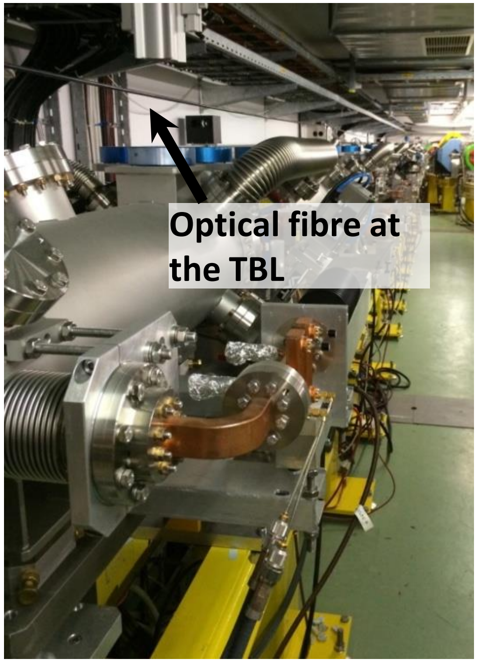
Single bunch beam loss measurements (RF fibre)

- Multi-location losses observable
- IVU3 acting like scrapers, protecting the rest of the machine
- With multi-bunch beams multi peaks are not observable – wider signals



Losses with long bunch trains





Measurements at the Clic Test Facility 3 (CTF3) Test Beam Line (TBL)

Optical fibre: 28 m, 200 μm core Ø

Controlled losses generated by switching off or moving quadrupoles

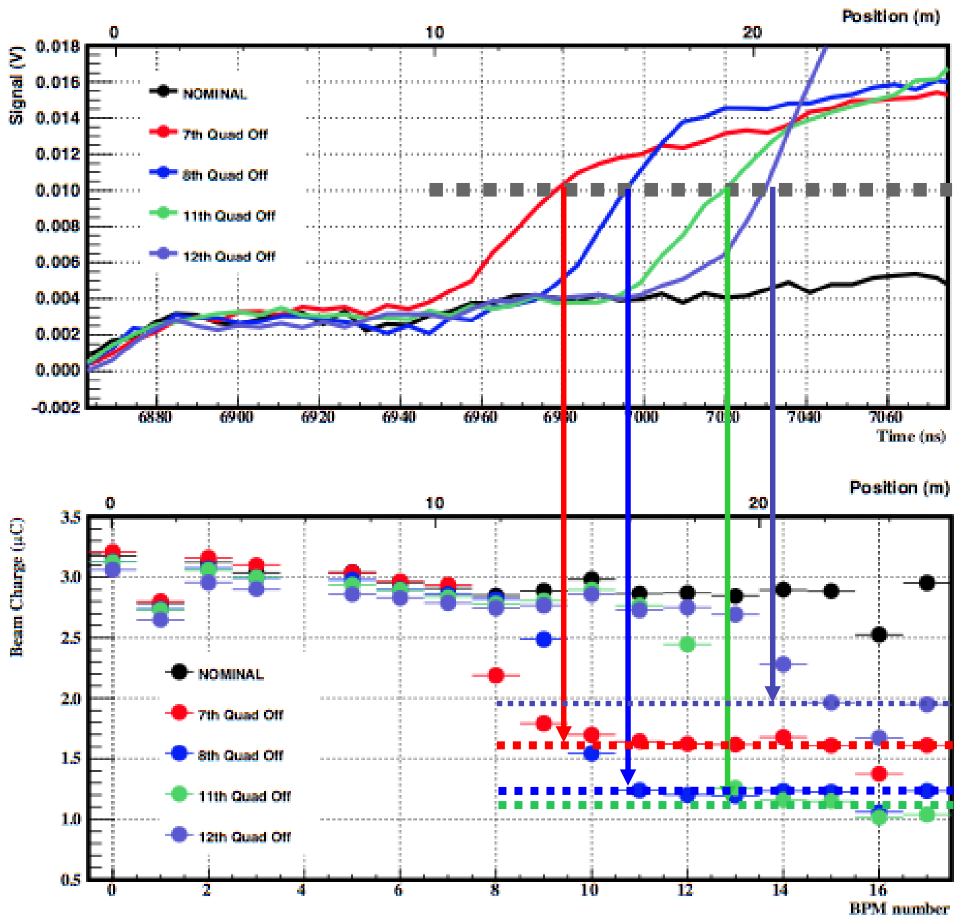
BPM signals to correlate

Long bunch trains – single location losses

Quads turned off - Determination of loss location from signal leading edge

- Good qualitative agreement between oBLM and BPM profile loss measurements

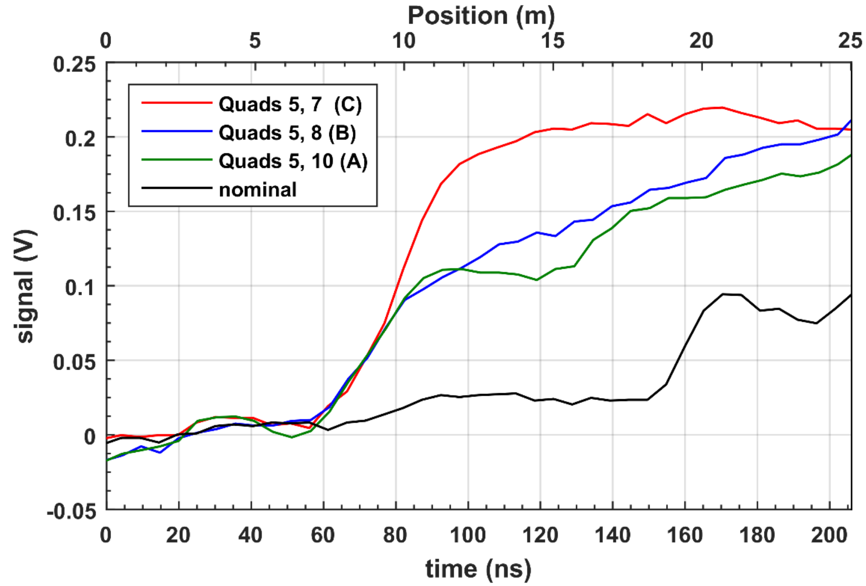
✓ Localisation of loss down to (below) 2 m achieved!

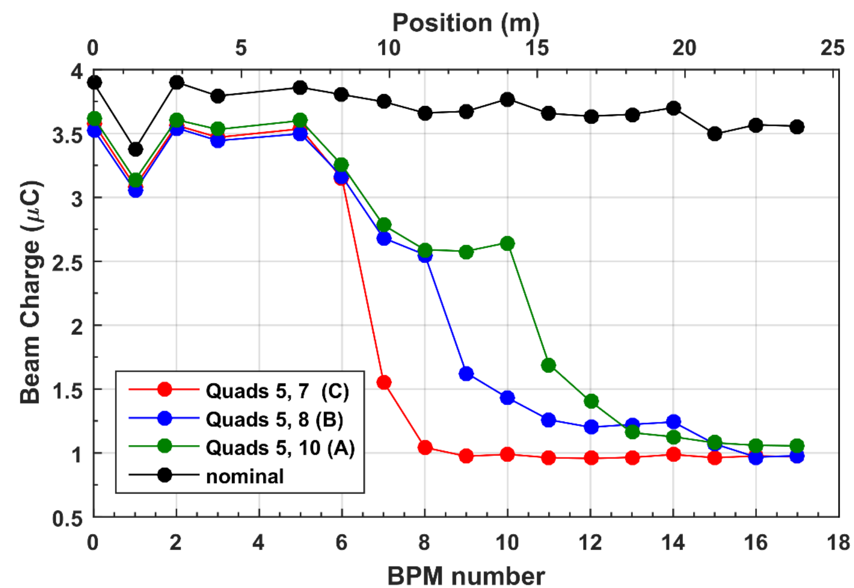


Long bunch trains – multi location losses

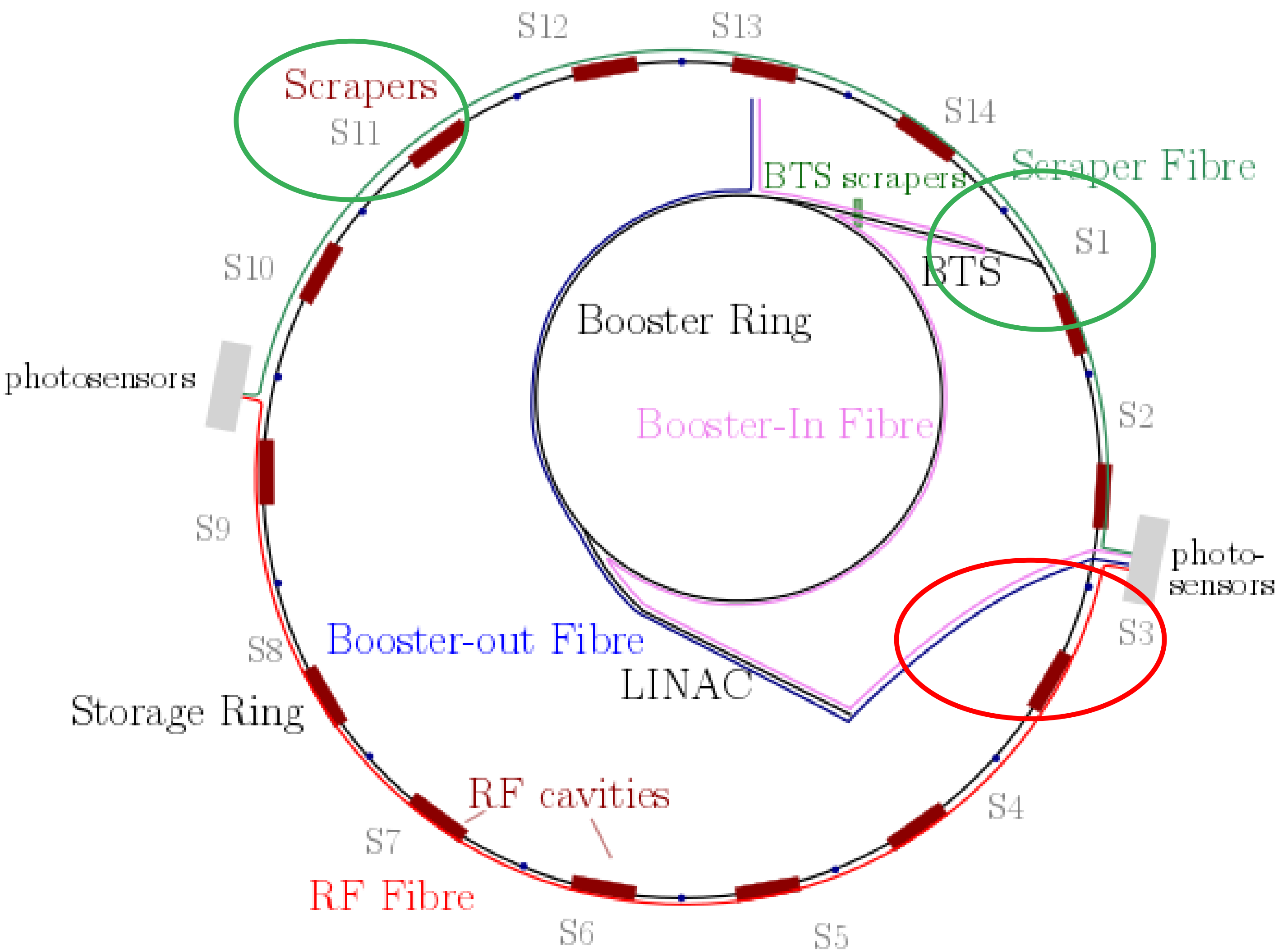
- Quads shifted to generate losses
- Not distinct loss location but spread losses over a distance
- ✓ Excellent agreement with BPMs
- ✓ Good indication of the loss pattern
- Resolution better than 5 m

Case	Shifted Quads	Distance
A	5 and 10	7.0 m
B	5 and 8	4.2 m
C	5 and 7	2.8 m





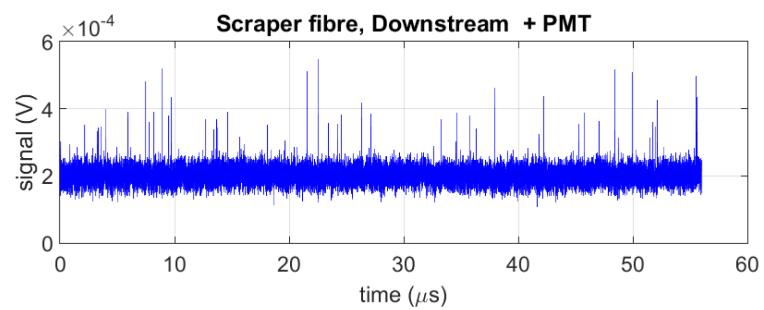
Fibre Installation

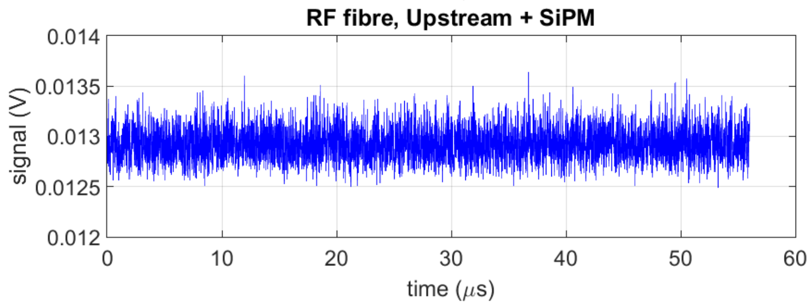


Steady-state losses

- Can a distributed BLM system like optical fibre BLMs detect steady-state losses ?
- Good knowledge of the background will be necessary

	fibre	Photon direction	photosensor	V_{cutoff}
Channel A	Scraper	downstream	PMT	0.0006 V
Channel B	RF	upstream	SIPM	0.0137 V



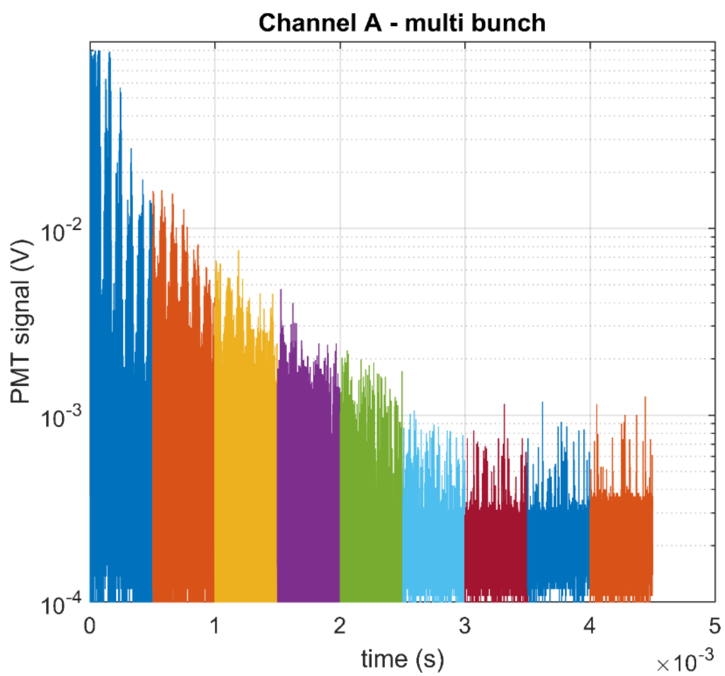


Steady-state losses

Two types of measurements performed:

1. **Single Bunch – Scrapers ALL OPEN**
2. **Multi Bunch – Scrapers NOMINAL (11 mm)**

To study different points of the Storage Ring cycle after injection,
the trigger timing was accordingly delayed.



Average signals of the Scraper fibre for the different trigger timings

Steady-state losses

Scraper fibre +PMT

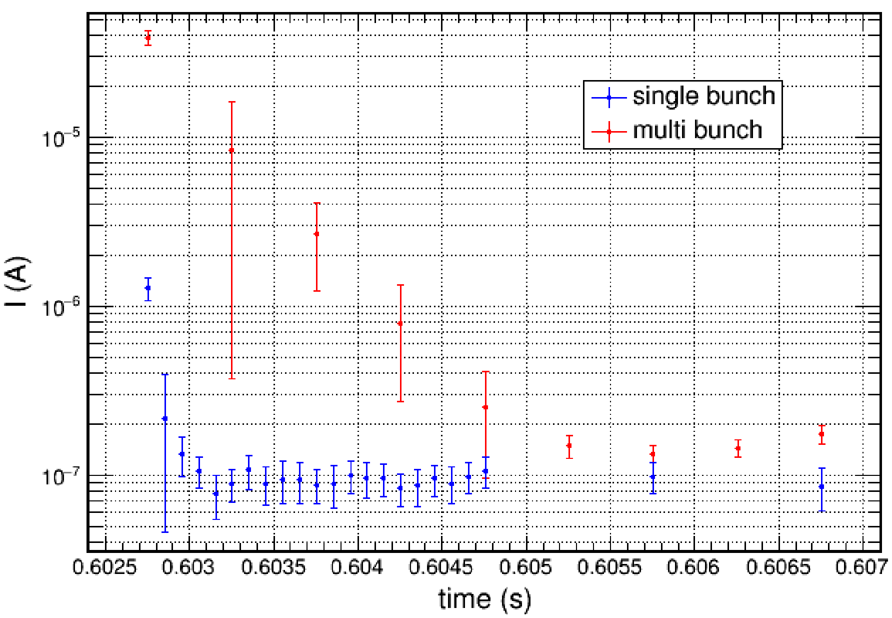
- Exponential decay, characteristic of the damping process, is observed
- multi bunch case + scrapers shows higher losses

RF fibre + SiPM

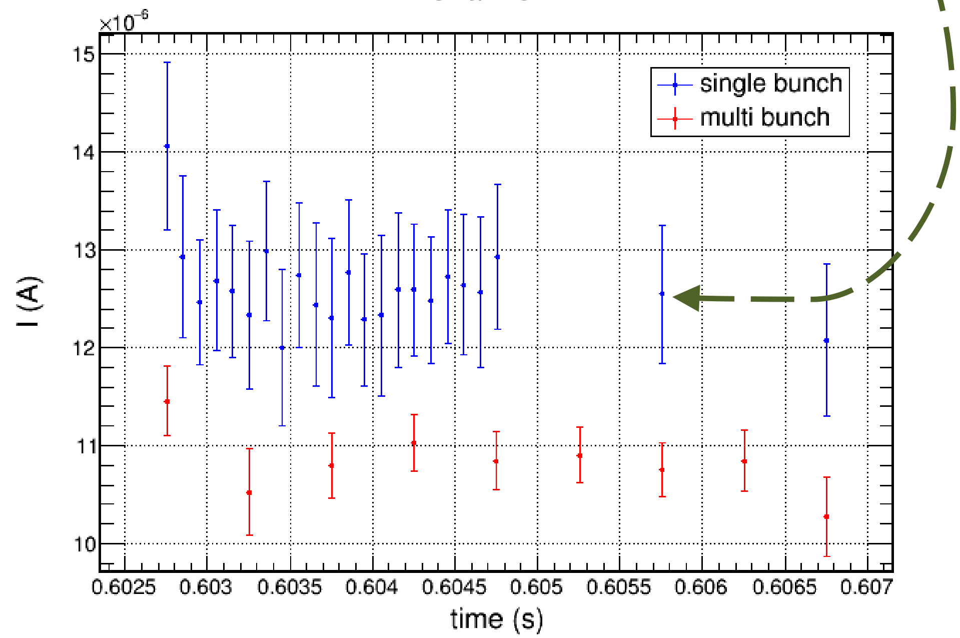
- multi bunch case has bean cleaned in the scrapers
- single bunch case shows higher signals

Steady-state losses!

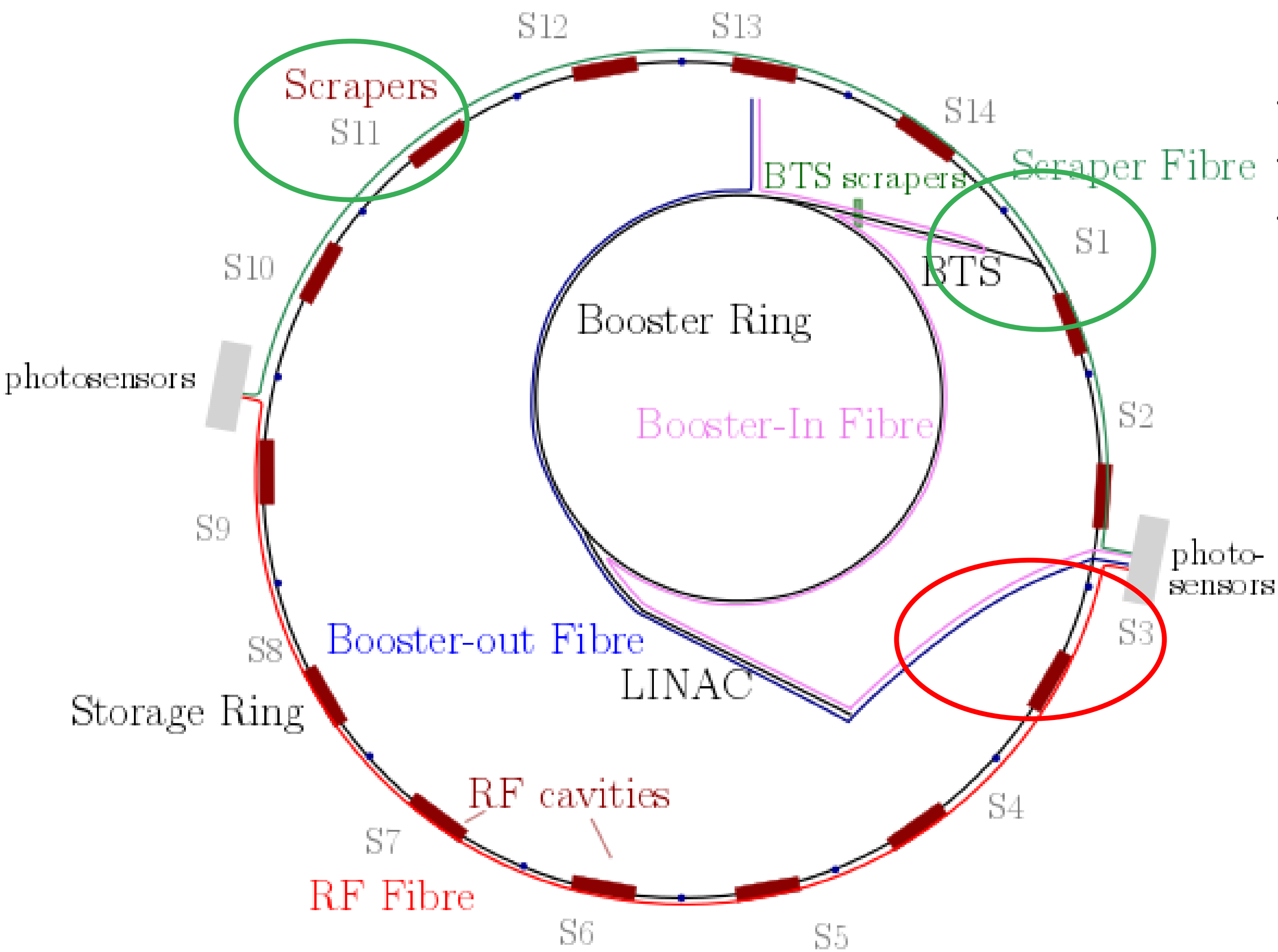
Channel A



Channel B



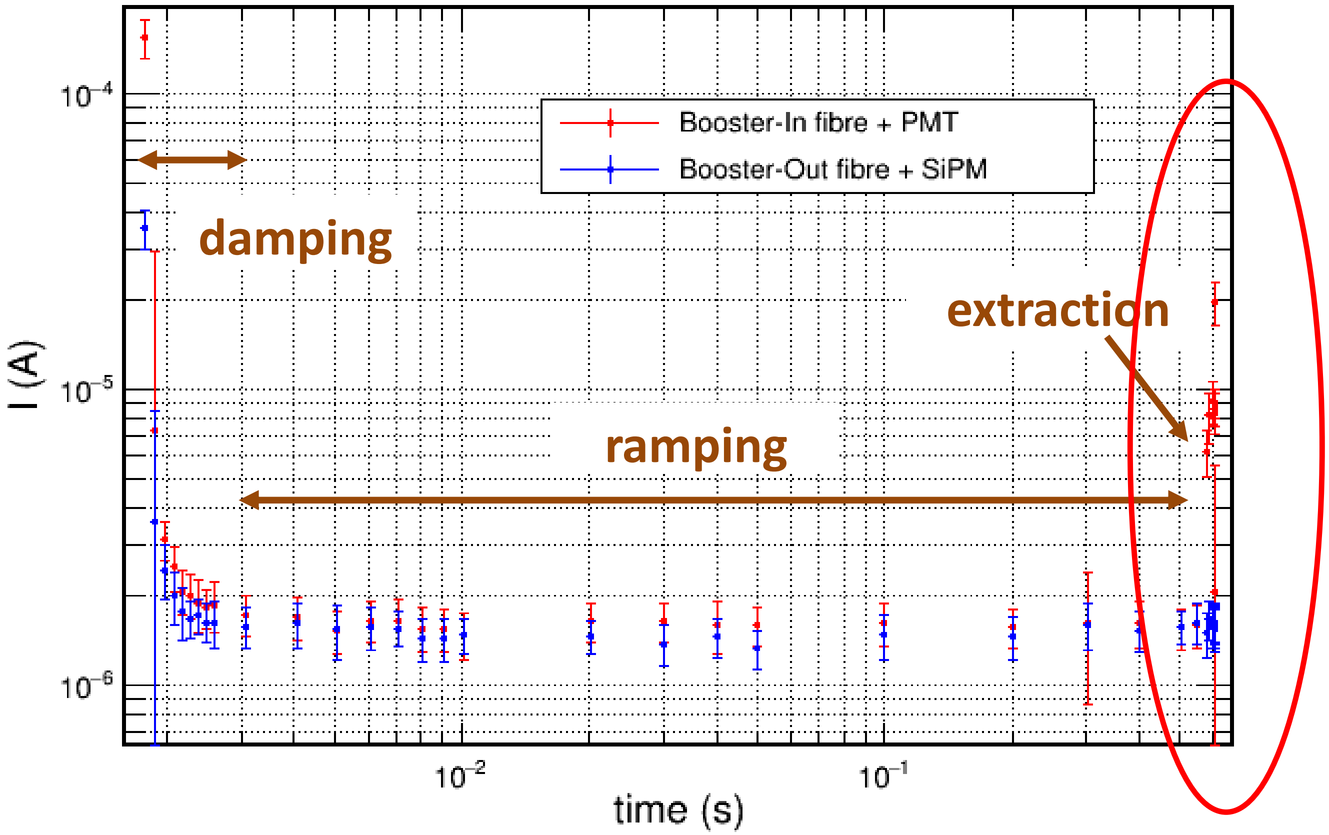
Fibre Installation



Only Booster-In fibre covers the BTS transfer line and the booster extraction point

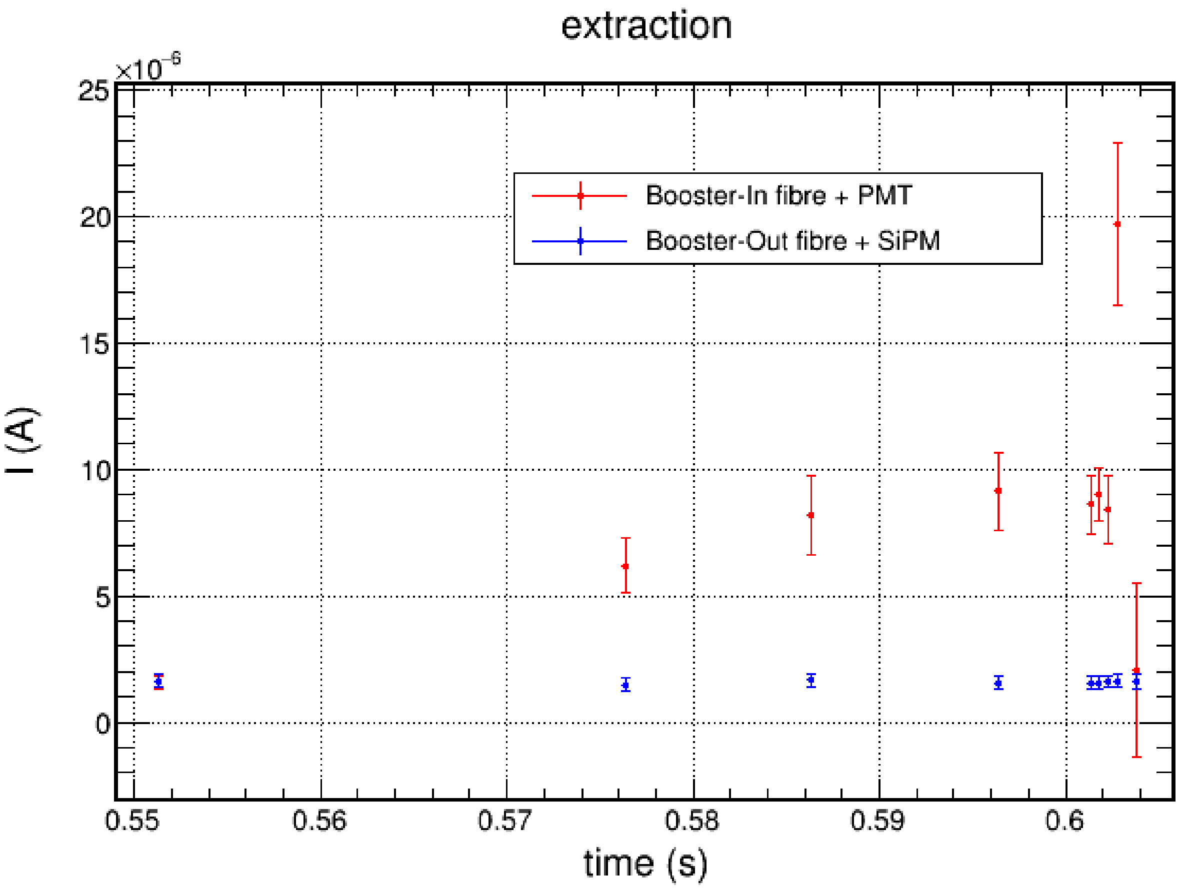
Booster Cycle (Or full cycle beam losses)

- Trigger time delayed to observe different point of the Booster Ring Cycle
- Damping process observable
- Plateau signals > photosensor dark current
- The signals can be compared only qualitatively



Booster Extraction

- Only Booster – In fibre detects the extraction beam losses
  - Covers the BTS transfer line
- Emphasizes the advantages of a distributed BLM system



Conclusions

- OBLMs are a cost-effective, customisable type of Beam Loss Monitor

✓ Position resolution below 10 cm can be achieved for single bunch

- Position resolution better than 2 m (single location loss) and 5 m (multi location loss) for long electron pulses

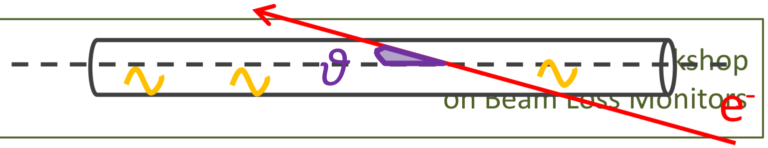
✓ Distributed BLMs very useful for machine protection, beam (and machine) diagnostics, and to achieve lower radiation levels in the environment

✓ Detection of steady-state losses has been demonstrated

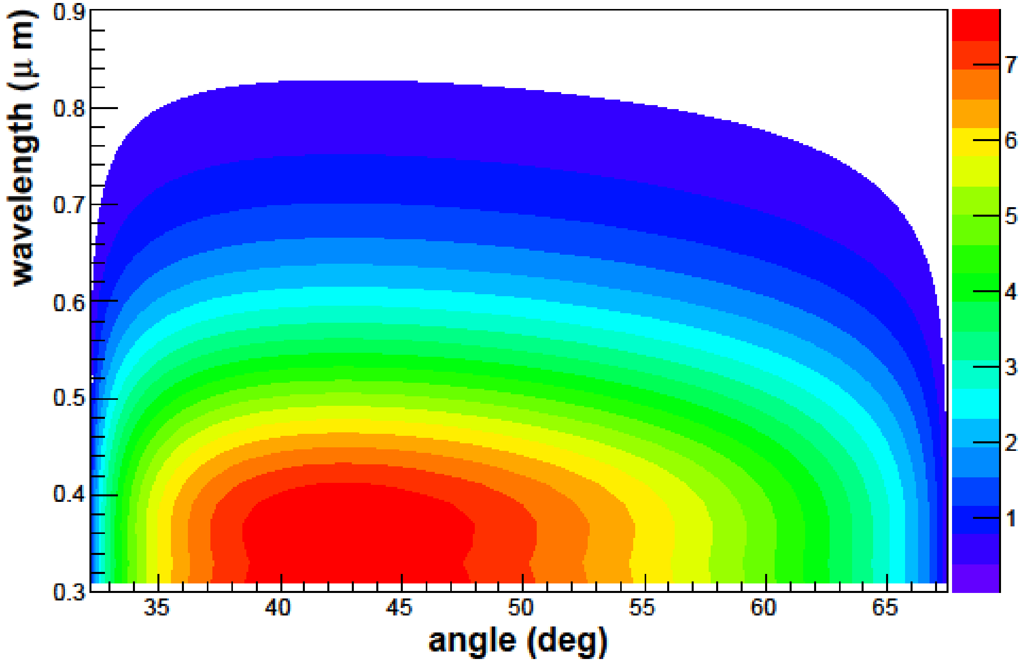
✓ OBLM system was demonstrated more than suitable for the machine protection and beam diagnostics of electron Storage Rings

Thank you for your attention!

Spare Slides

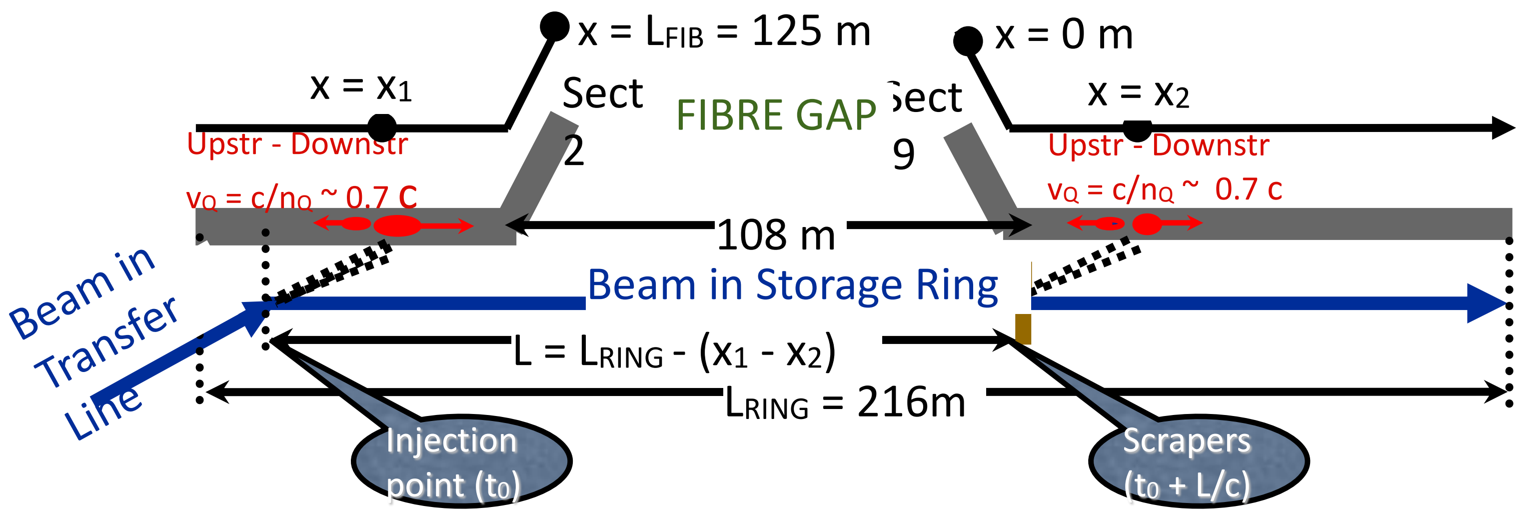


- **Photon Yield per e⁻ (β=1) crossing the fibre** as a function of photon λ
- Light attenuation in the fibre as a function of photon λ
- Dependency of Cherenkov photon yield and photon propagation on crossing angle
- SiPM efficiency dependence on wavelength



Understanding Beam Losses

Most studies performed on losses generated in the first turn



- **Two loss points on opposite sides of FIBRE GAP**

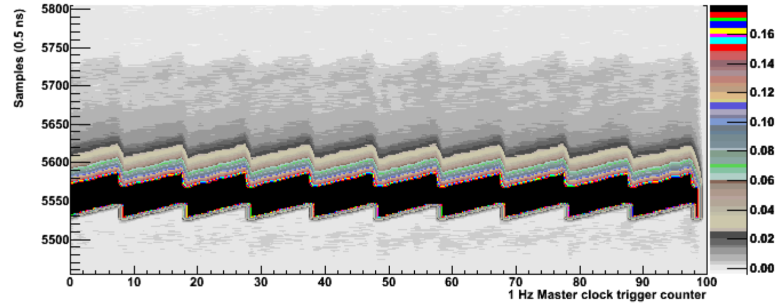
$$\Delta x = \frac{L_{RING} - c\Delta t}{1 + n_Q}$$

- **Two loss points on same side of FIBRE GAP**

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

AS intrinsic time resolution & Booster phase shift

- Repetition with Booster RF phase shift by 180°
  - $V_{oBLM}(t = t_{photon}) = V_{thr}$
  - t_{photon} → Photon arrival time (to upstream end)

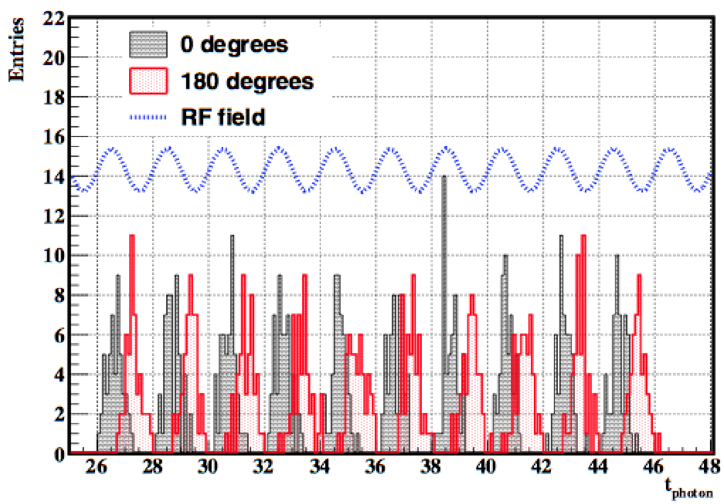


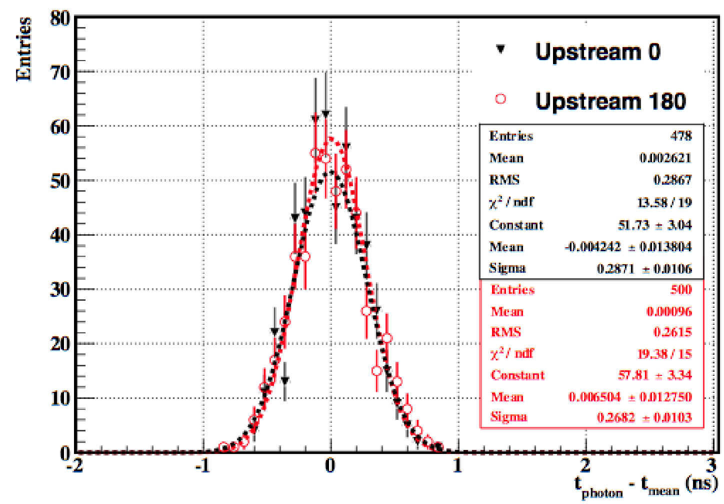
- Time resolution study based on

$\Delta t = t_{photon} - t_{mean}$

$t_{mean} = t_{off} + n_{bucket} \times T_{RF}$ (central time of n[th] bucket)

$\sigma_t \lesssim 300$ ps → $\Delta x = \frac{c\Delta t}{1 + n_Q}$ → $\sigma_x \lesssim 4$ cm

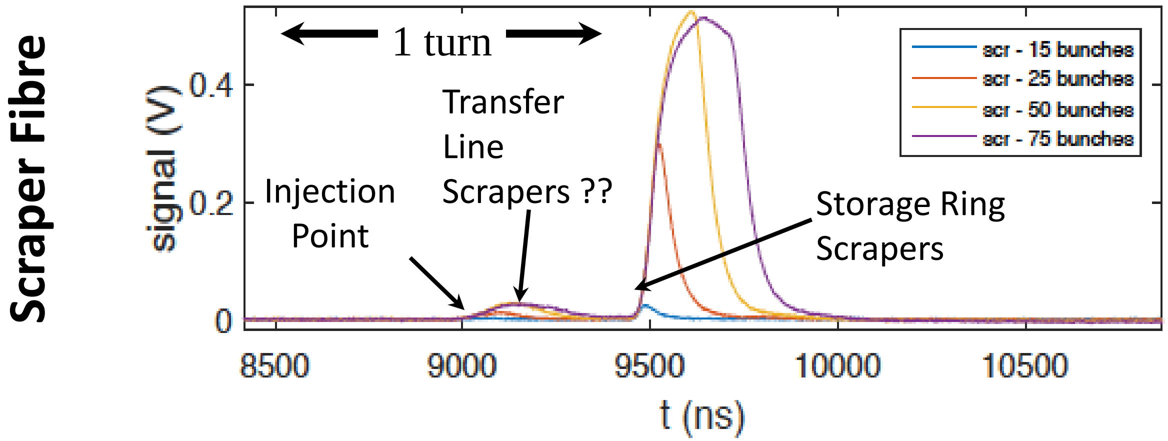


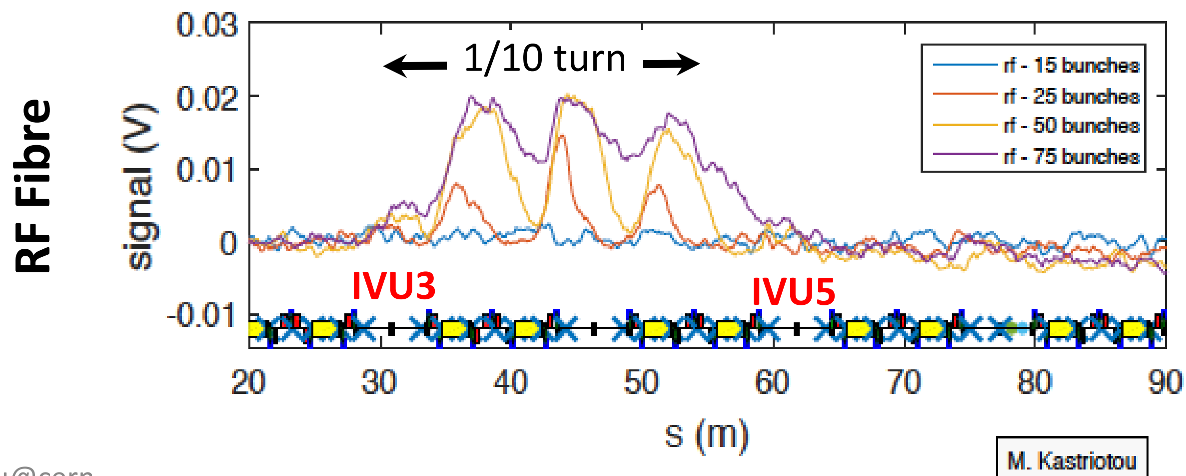


AS: understanding beam losses, multi - bunch

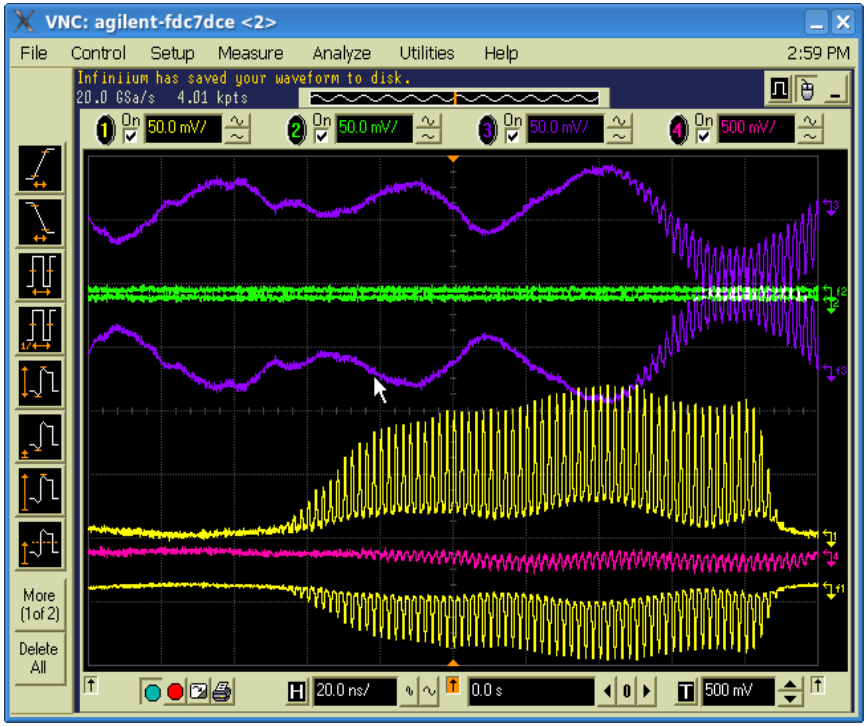
Signals Limited by pulse length

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



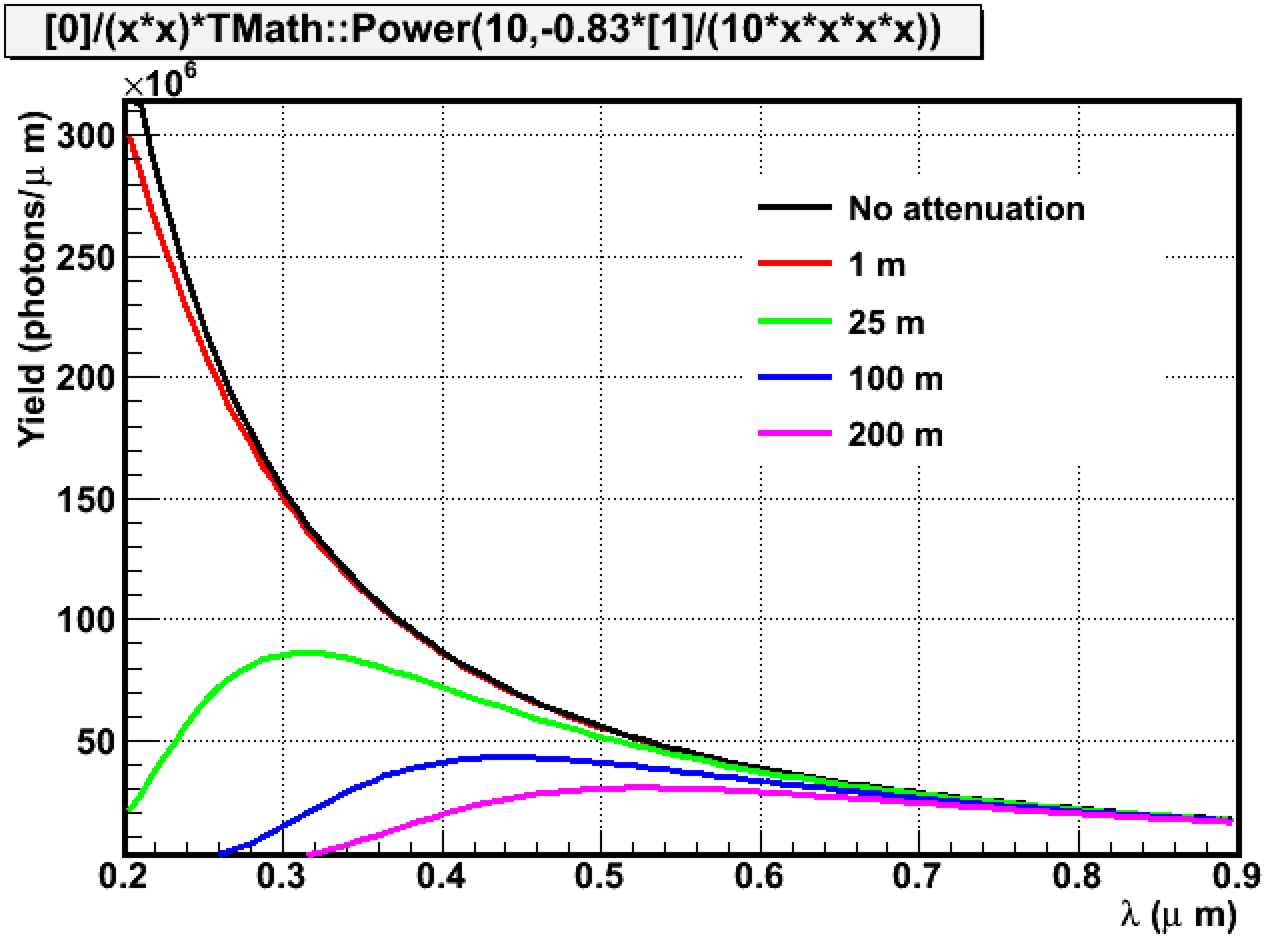


ASLS multi-bunch current



Current profile of 75 bunch train

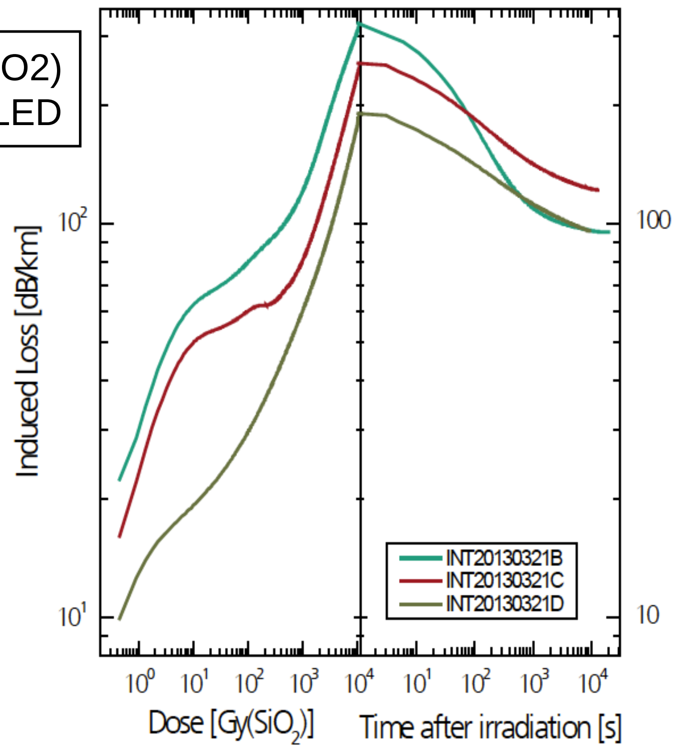
Cherenkov light spectrum and effect of fibre attenuation



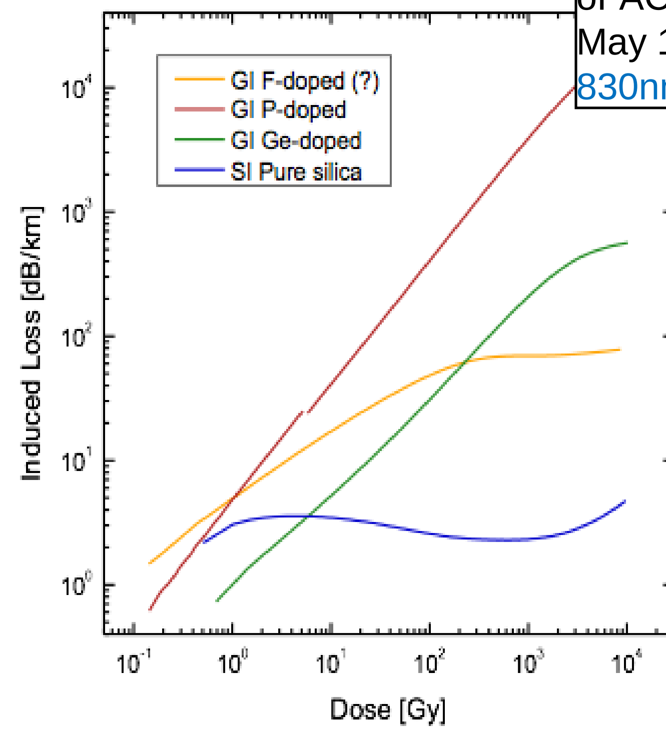
Cherenkov fibers: Radiation Hardness

- Radiation hardness
  - Material, manufacturer, type of radiation
  - Pure Si core with high OH recommended
  - Radiation Induced Attenuation strongly dependent on λ
  - SiO_2 fibers rather insensitive for 800 nm and above.

(Pure SiO2)
450nm LED



oPAC Workshop, May 14
830nm LED



J. Kuhnhenn

Fiber irradiation test at Fraunhofer institute 10kGy@0.22Gy/s