Fibre Beam Loss Monitoring system development

BI - day

10 March 2016

M. Kastriotou, E. Nebot del Busto

M. Boland, F. S. Domingues Sousa, E. Effinger,
E.B. Holzer, W. Viganò, C. P. Welsch

all CTF3 operators …

Outlook

Optical fibre BLM

1. The OBLM system

2. OBLM at a linac: Test Beam Line (TBL)
   - Long pulses
3. OBLM at a Storage Ring:
   the Australian Synchrotron Light Source (ASLS)
   - Single bunch
   - Multi bunch

Position resolution

4. OBLM as an RF cavity diagnostics tool

5. Conclusions

Optical fibre Beam Loss Monitors (OBLMs)

OBLM system is based on Cherenkov light

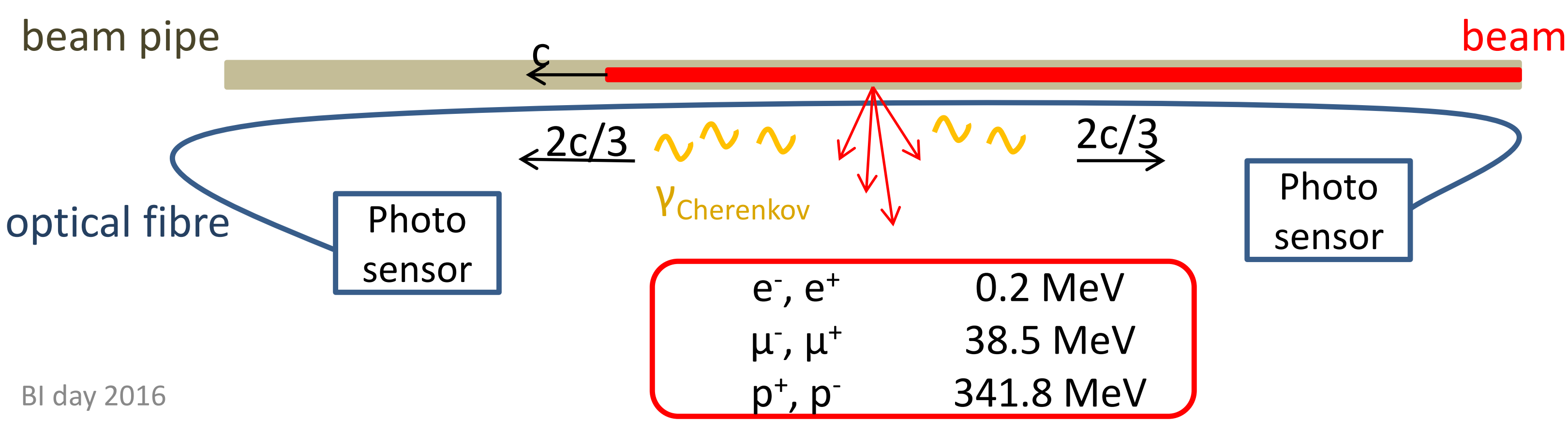
Operation principle

i. Beam loss shower particles cross the optical fibre ⟶ **Cherenkov photons**

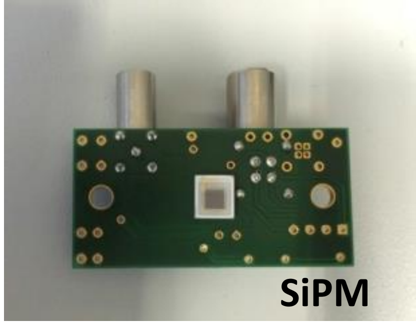
ii. Cherenkov photons propagate in the optical fibre ⟶ **photosensor!**

✓ **Covering long distances , cost-effective, n,γ insensitive** ⟶ ideal for linacs

- Optical fibre:
  - variable core Ø depending on application (larger core for higher sensitivity)
  - Pure Silica, high OH content (⟶radiation hardness)
  - Nylon jacket to protect against: humidity, ambient light



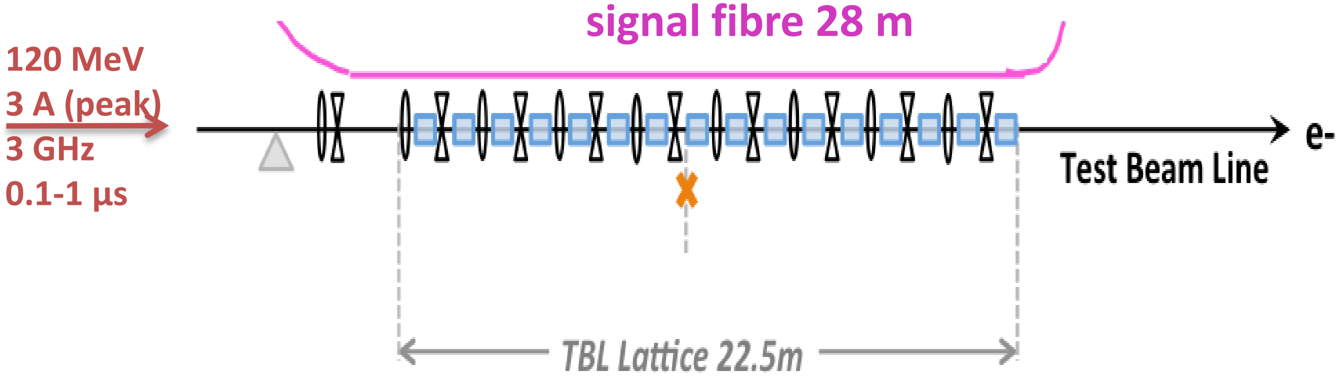
OBLM system development

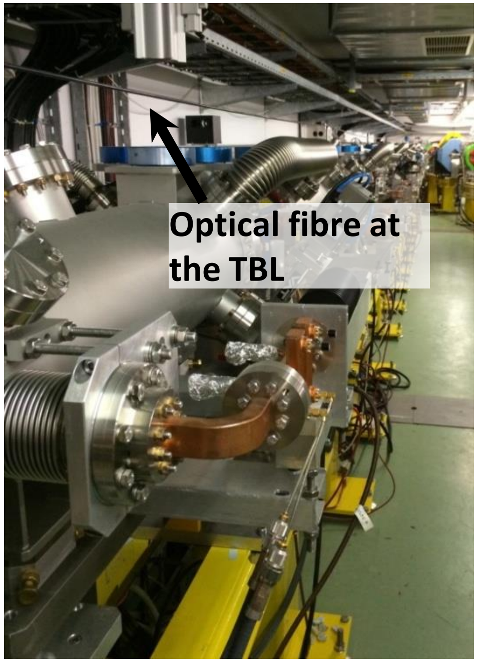


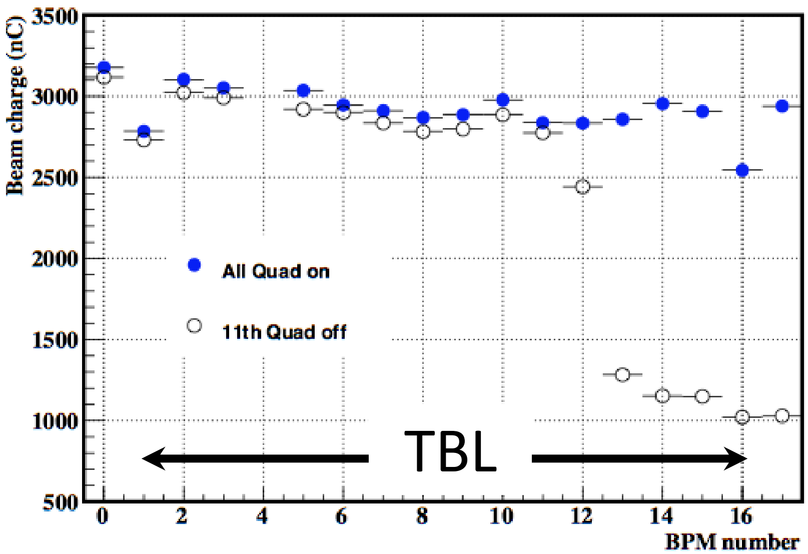
- Photosensor selection makes a timing / price difference
  - ⟶ Investigation on **Silicon PhotoMultipliers (SiPM)**
  - (3x3 mm^2, default 40000 pixels, G =10^{+5} - 10^{+6})
- Development of **custom made , shielded** photon sensing modules
  - Low pass filters (bias input) for noise filtering
  - SiPM with different readouts, depending on the application
- Design of RF shielded chassis to include the modules & Power Supplies
- High sampling (1-4 GS/s) and high bandwidth (250 MHz - 2 GHz) ADCs

Losses with long bunch trains in linacs

Measurements at the CTF3 Test Beam Line (TBL)





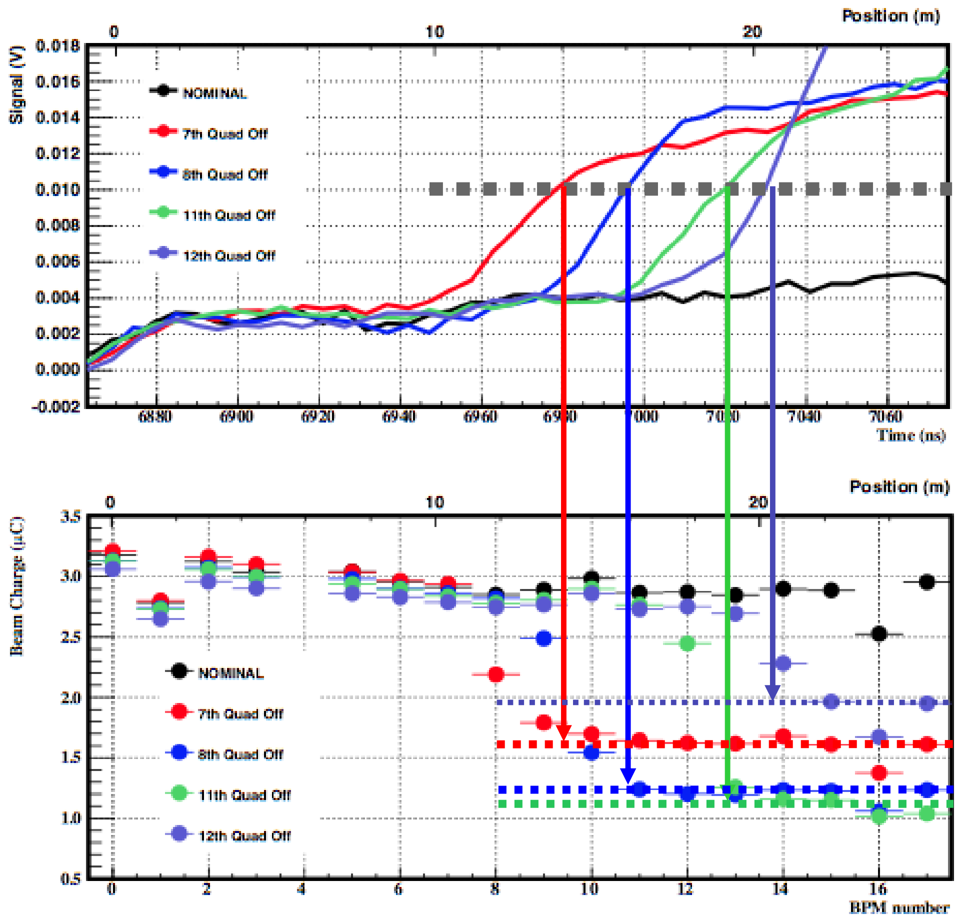


- **1µs long pulse**
- Controlled losses generated by switching off quadrupoles
- BPM signals to correlate

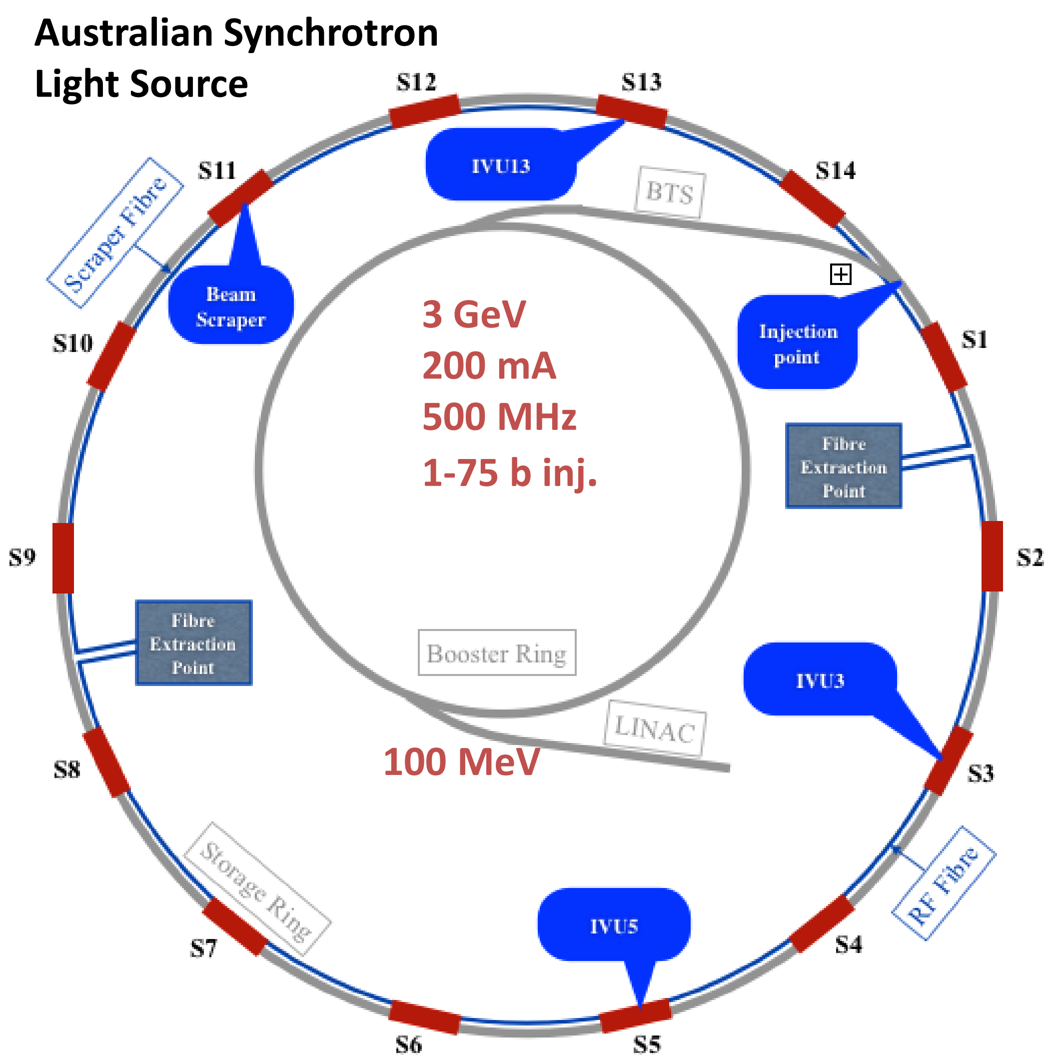
Resolution during losses with long bunch trains

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!



OBLMs at Storage Rings: The Australian Synchrotron

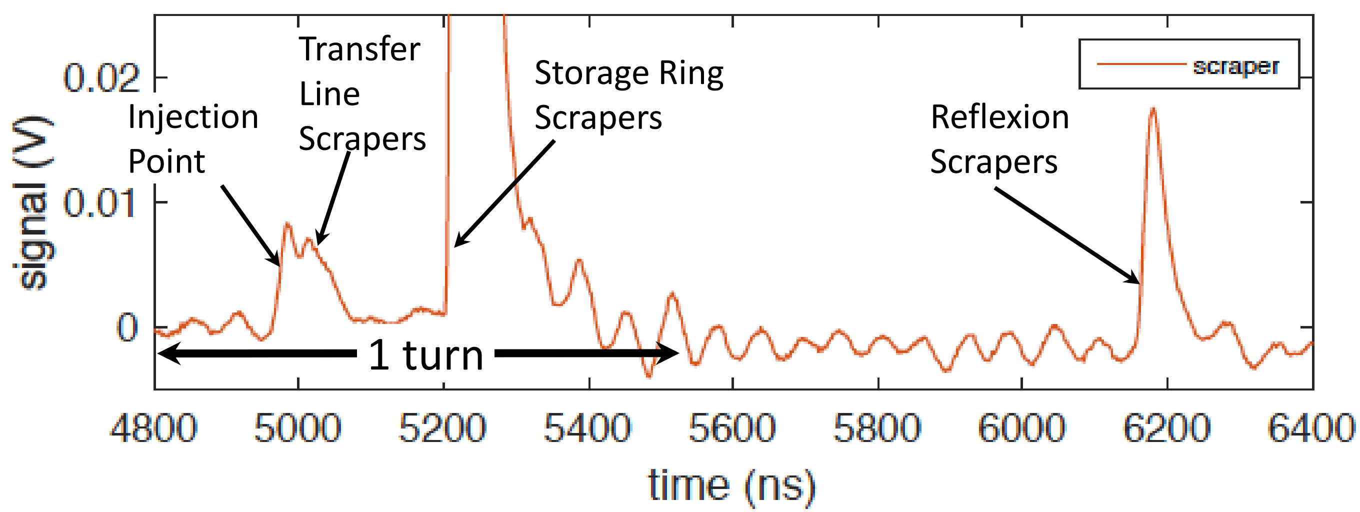


- 216 m storage ring
- 2 optical fibres covering the ring
  - 200 µm core Ø
  - 125 m
- Scraper fibre
  - Scraper
  - Injection point
- RF fibre
  - 2 In Vacuum Undulators (IVUs)
  - 2 RF cavities

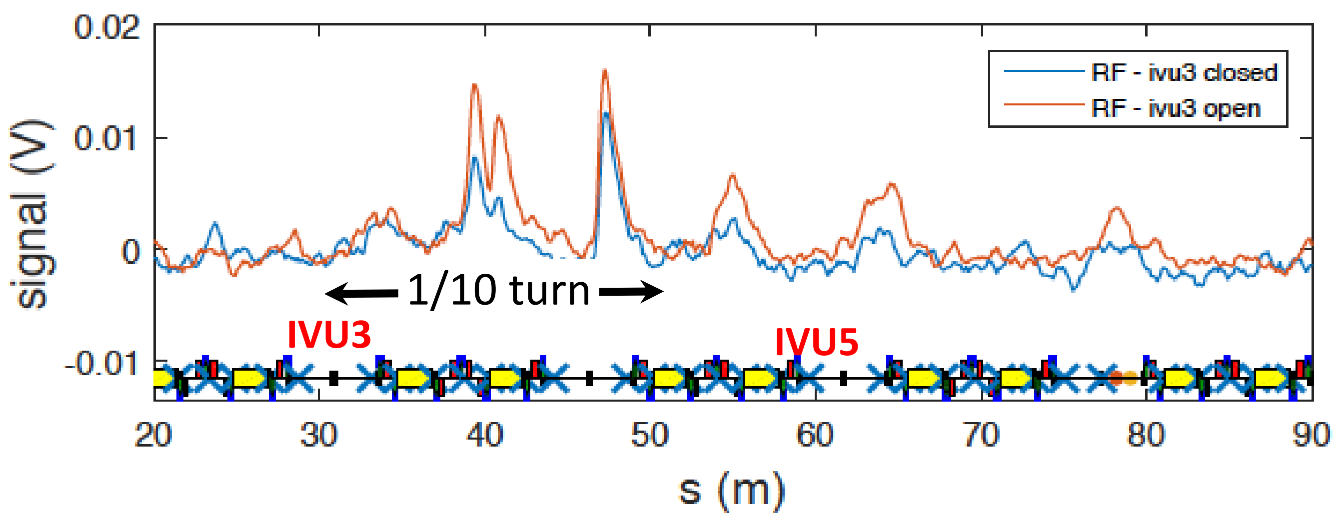
AS: understanding beam losses, single - bunch

Multi peaks observed due to losses in different positions

Scraper Fibre



RF Fibre

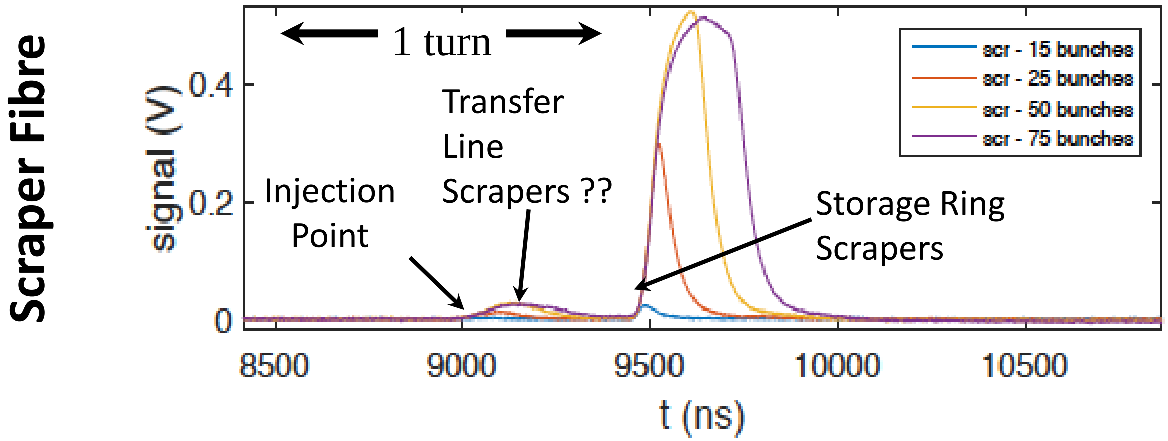


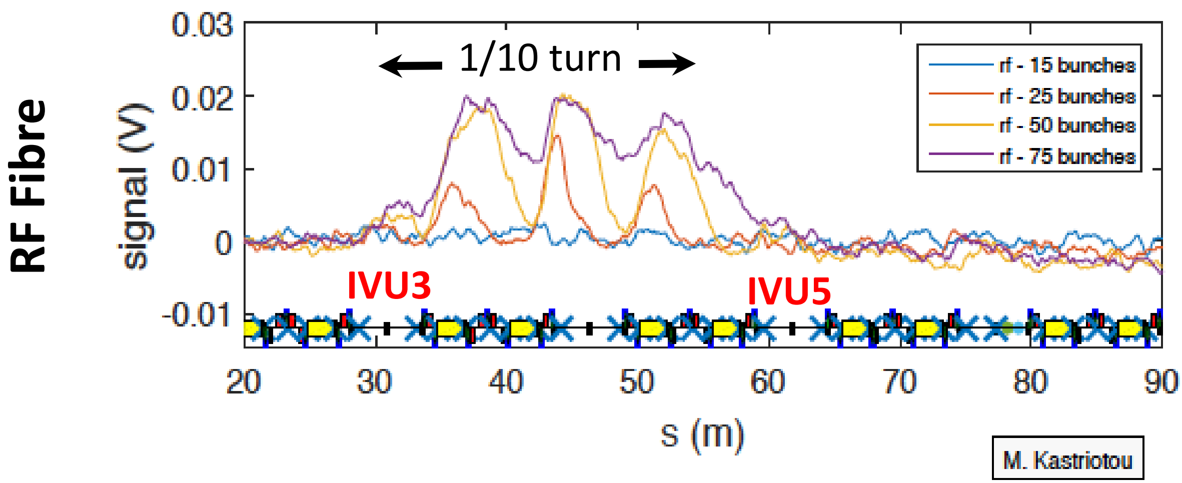
AS: understanding beam losses, multi - bunch

Multi peaks observed due to losses in different positions

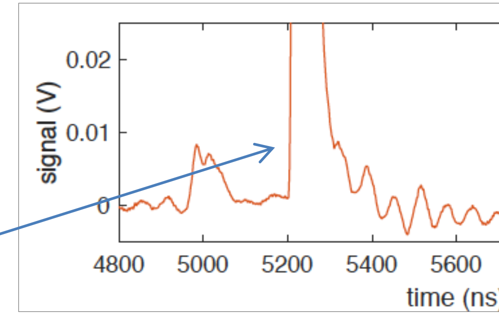
Limited by pulse length

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



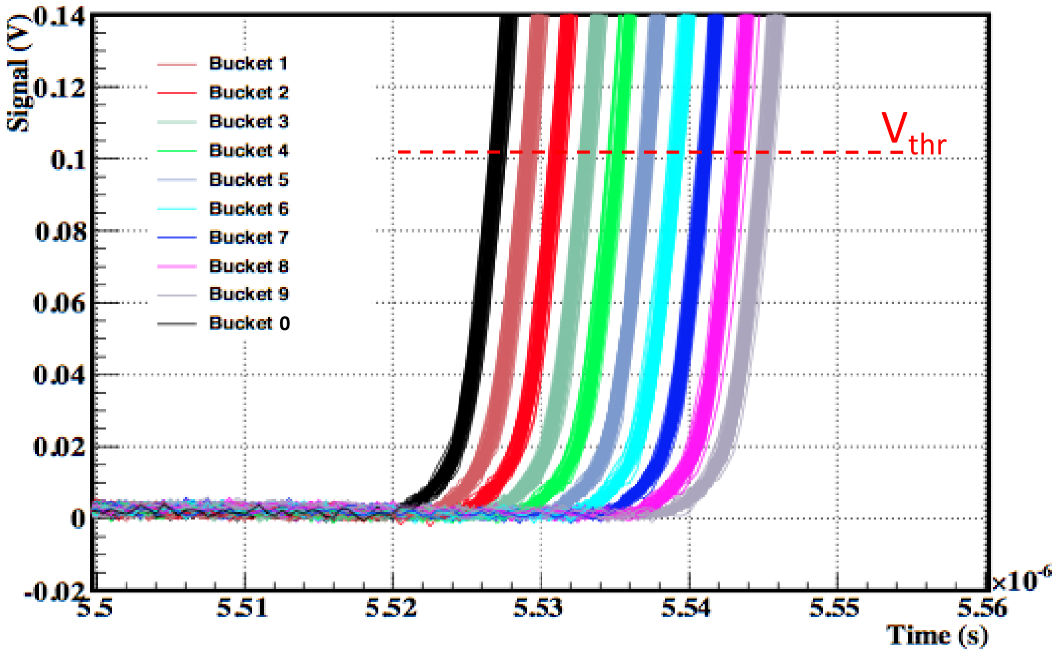


Intrinsic time resolution

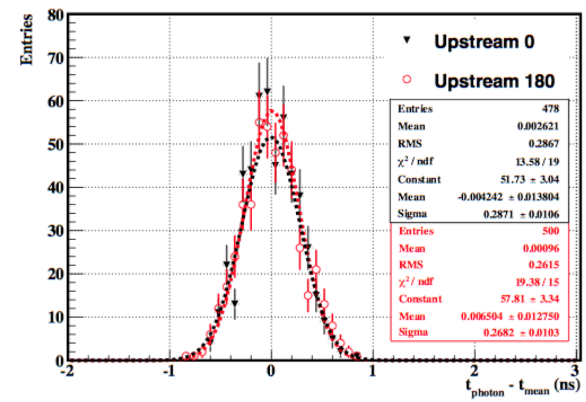


- Single bunch injection
  - Consecutive filling RF buckets 1-10
  - Looking at **raising edge** of losses at scrappers (well defined location)

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



$\Delta t = t_{photon} - t_{mean}$ (central time of n[th] 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!

High gradient RF cavities

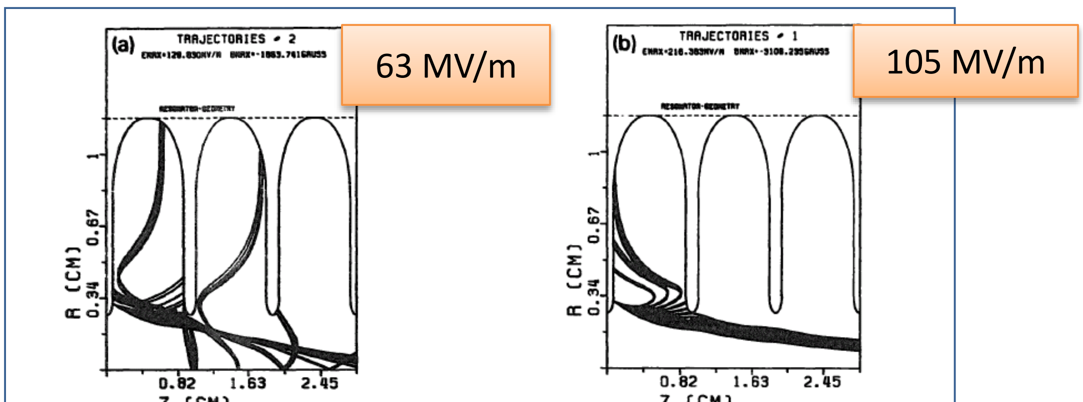
- High gradient (~100MV/m accelerating gradient!) RF cavities are being investigated to be used in high energy linacs (CLIC), FELs etc.

→ Electron Field Emission
Electrons emitted from the cavity walls (mA), accelerated, some impacting on the walls

→ RF Breakdowns
EM field collapses, emission of ~100 A of electrons in the cavity

Faraday Cups (e^- in cavity)
Radiation monitors

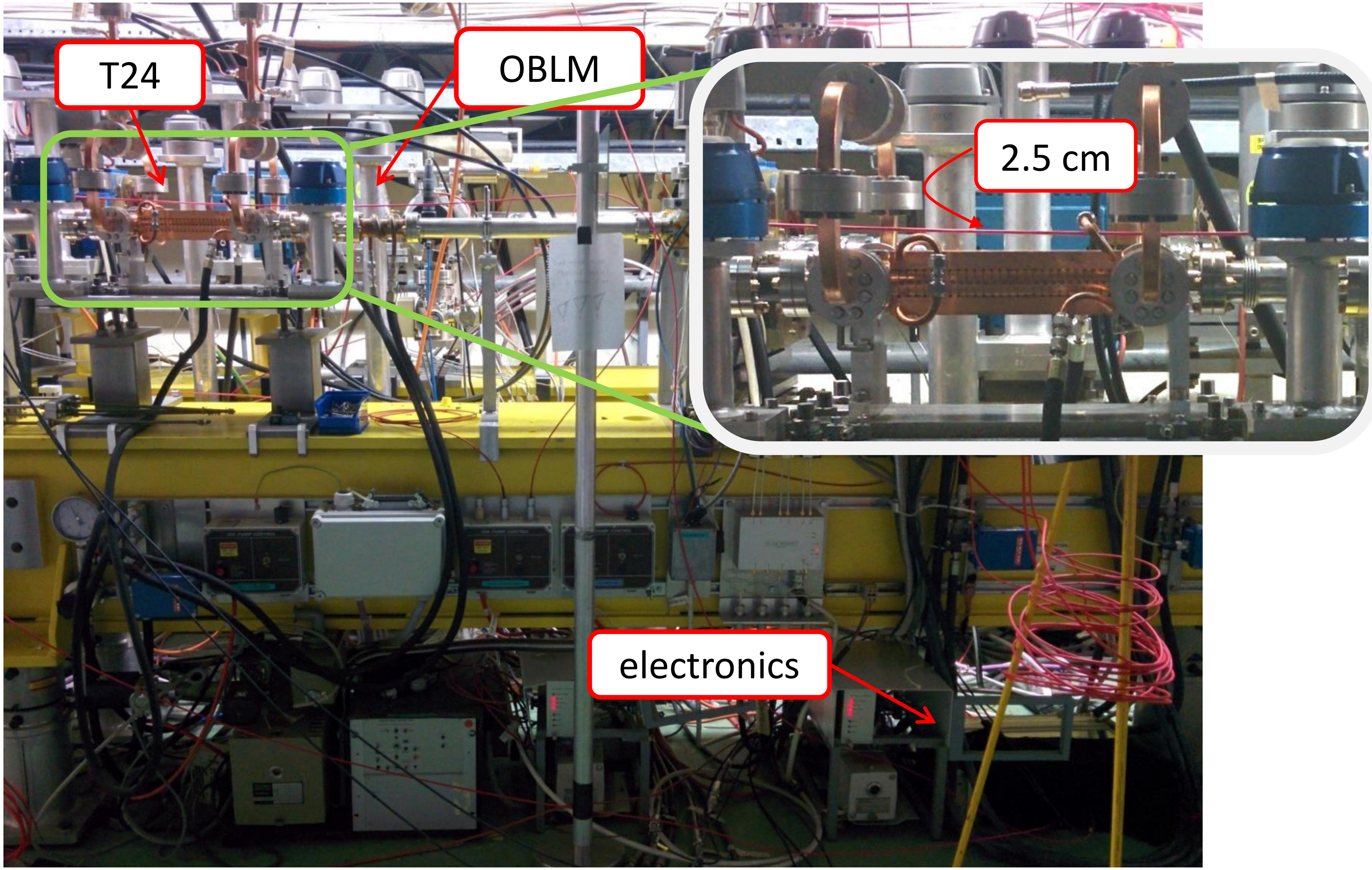
- Studies only for X-rays outside the cavity



Capture field for LEP Injector Linac (LIL) type structure (10.5 GHz)
An investigation on the field emitted electrons in travelling wave accelerating structures – G. Bienvenu et al., NIM. A320 (1992) 1-8

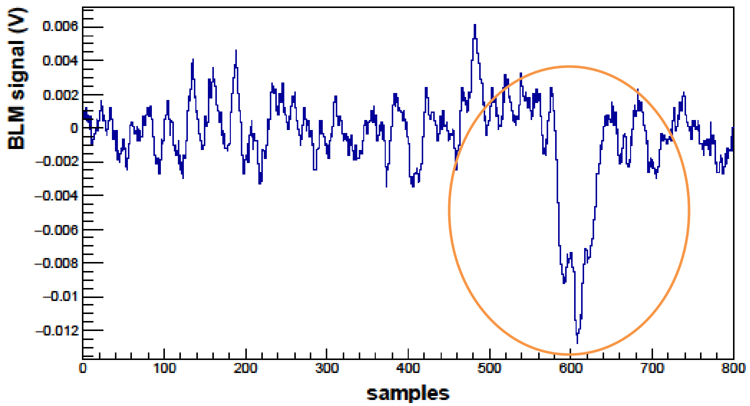
The dogleg experiment at CTF3

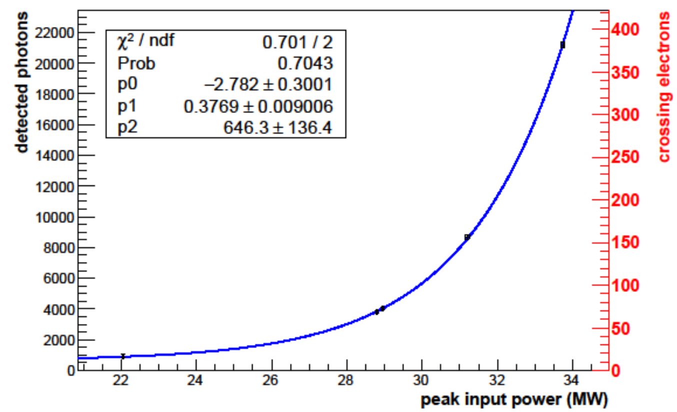
Study of loaded (with beam) and unloaded (only RF) accelerating structures



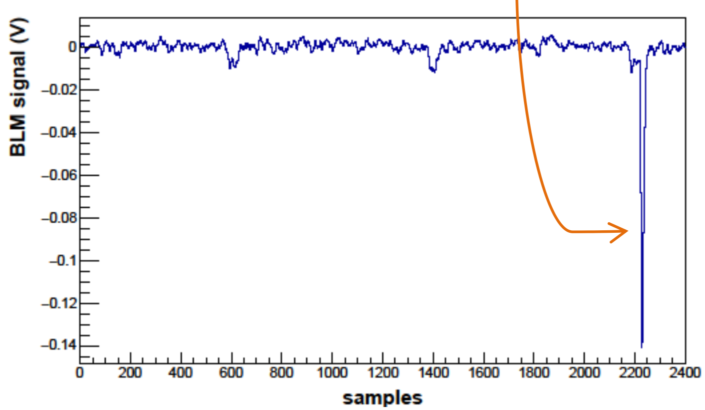
Measurements of RF cavity electrons

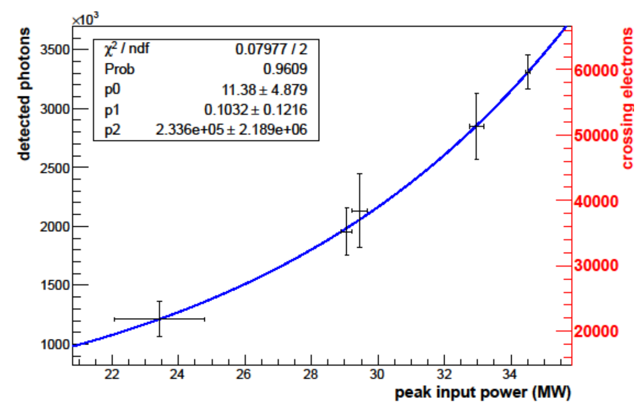
✓**Sensitivity to field emitted electrons** → Signal length same as pulse length





✓**Sensitivity to RF breakdowns** → First measurement of breakdown electrons





RF cavity diagnostics!

Conclusions

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

- First attempt at loss location reconstruction with long (1μs) pulses
  - ✓ Resolution better than 1.4 m achieved for single loss location
- ✓ Position resolution below 10cm can be achieved for single bunch
- Studies on de-convolution are necessary for the multi-bunch case

- OBLM system was demonstrated suitable for electron Storage Rings

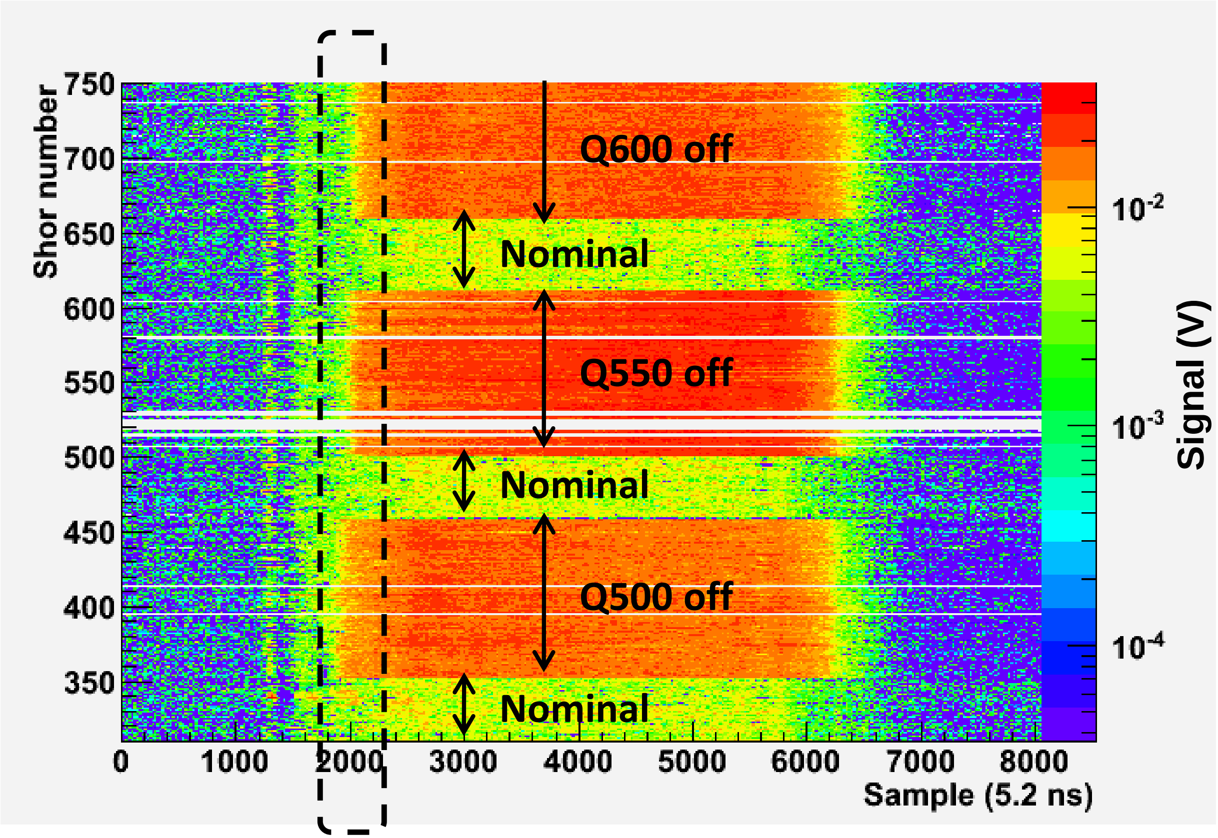
- OBLM can be (and is being) used for RF cavity diagnostics

Thank you for your attention!

Spare Slides

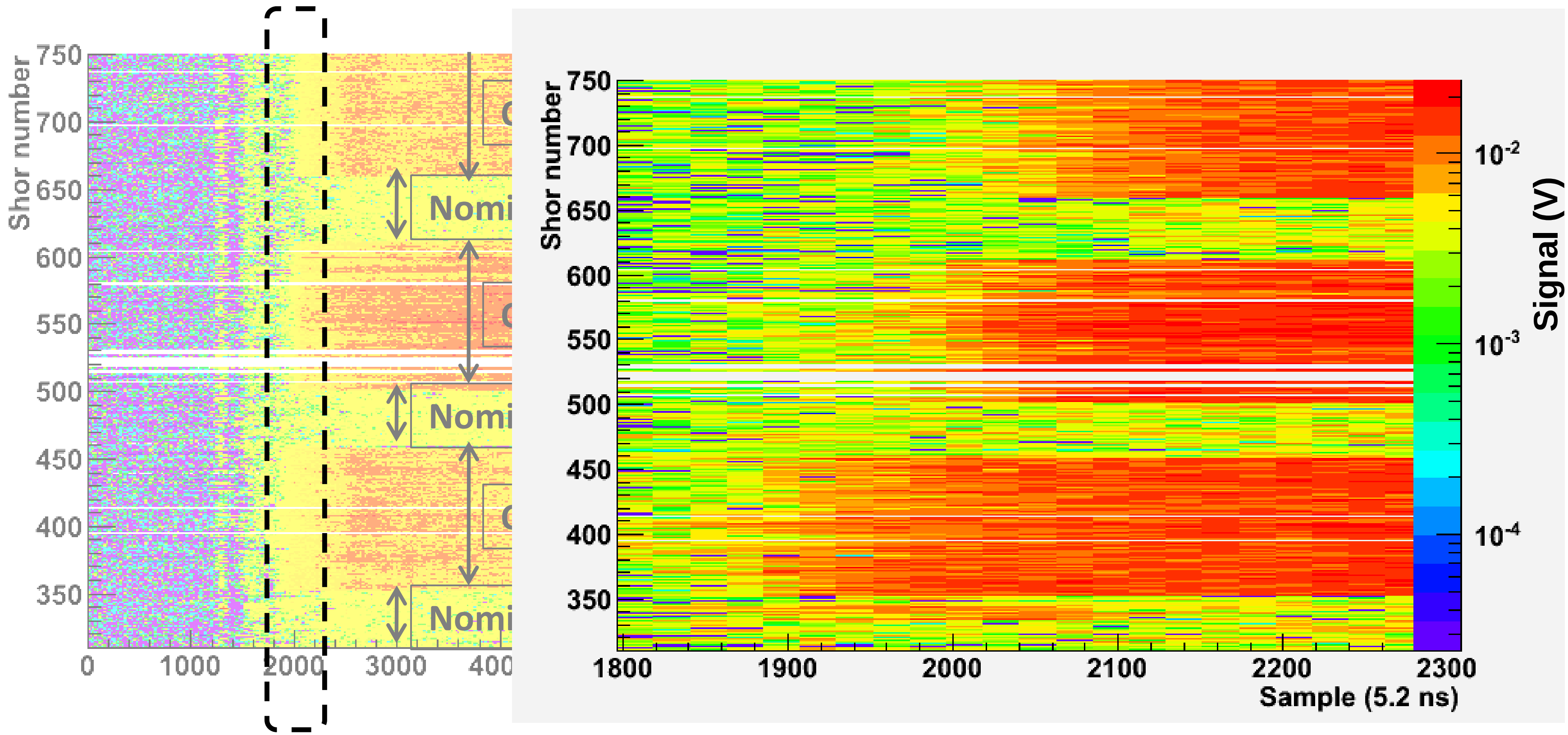
Losses with long bunch trains: measurements

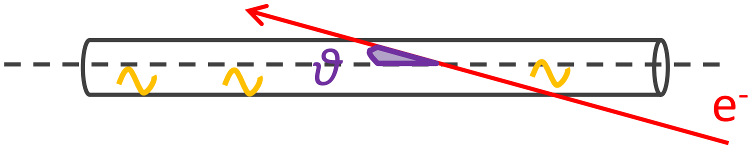
Switching off of consecutive quadrupoles



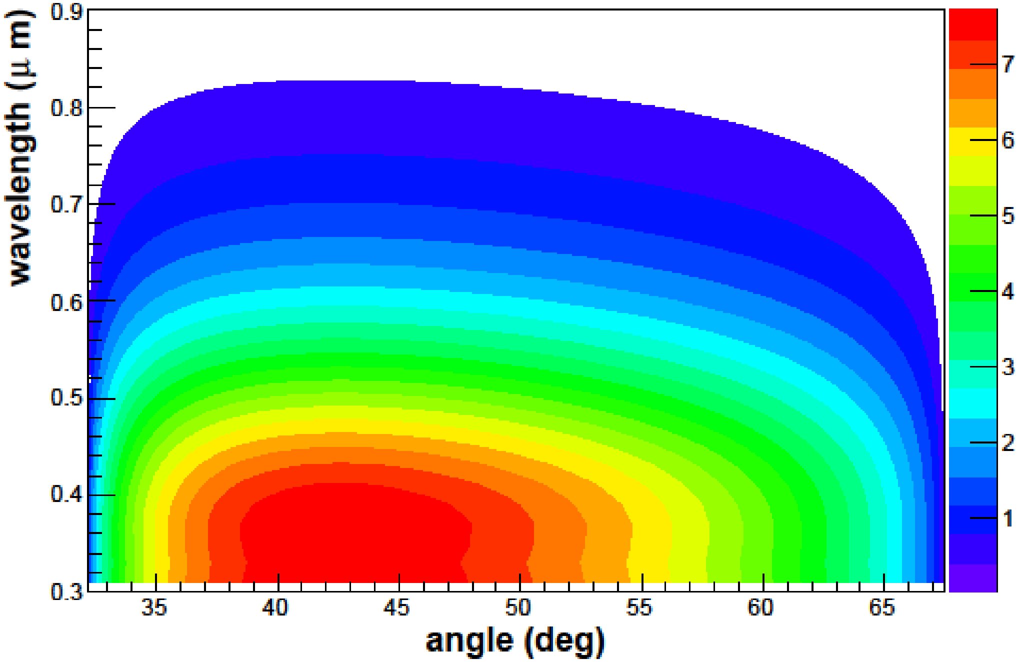
Losses with long bunch trains: measurements

Switching off of consecutive quadrupoles



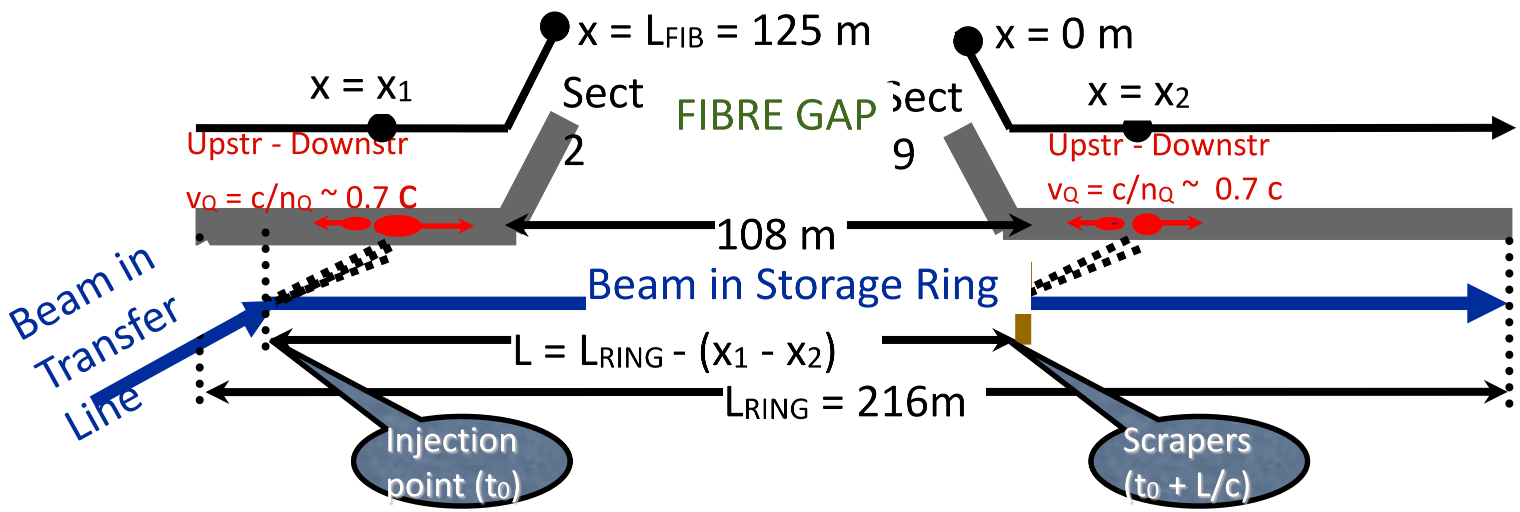


- **Photon Yield per e^- (β=1) crossing the fibre** as a function of photon λ
- Light attenuation in the fibre as a function of photon λ
- Dependency of Cherenkov photon yield and photon propagation on crossing angle
- SiPM efficiency dependence on wavelength



Understanding Beam Losses

Most studies performed on losses generated in the first turn



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

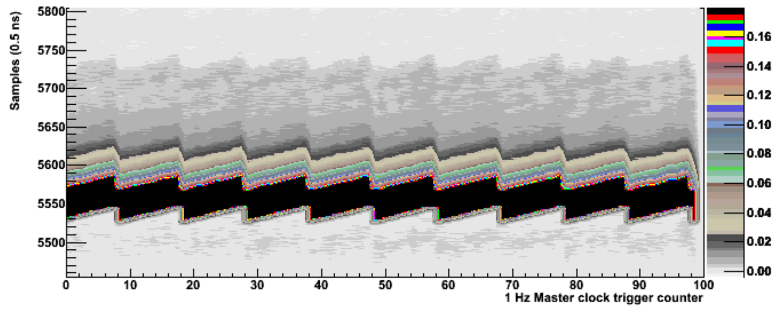
$$\Delta x = \frac{L_{RING} - c\Delta t}{1 + n_Q}$$

- **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)



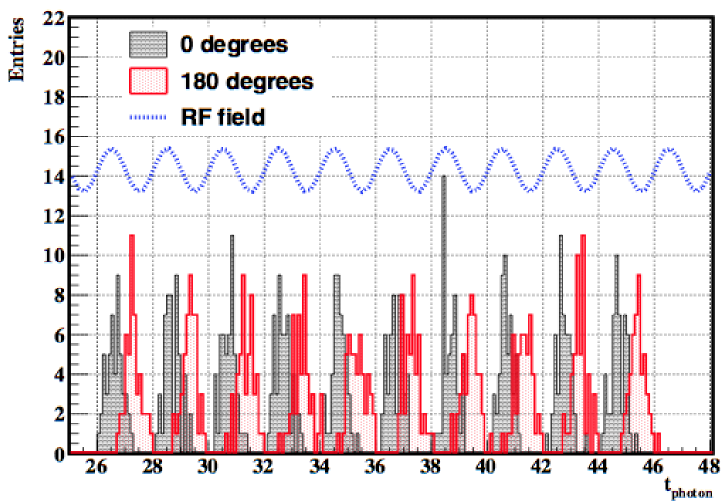
- Time resolution study based on

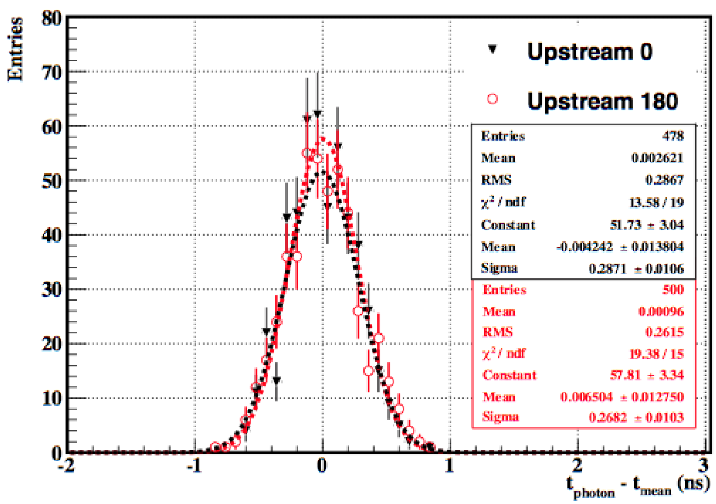
$$\Delta t = t_{photon} - t_{mean}$$

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

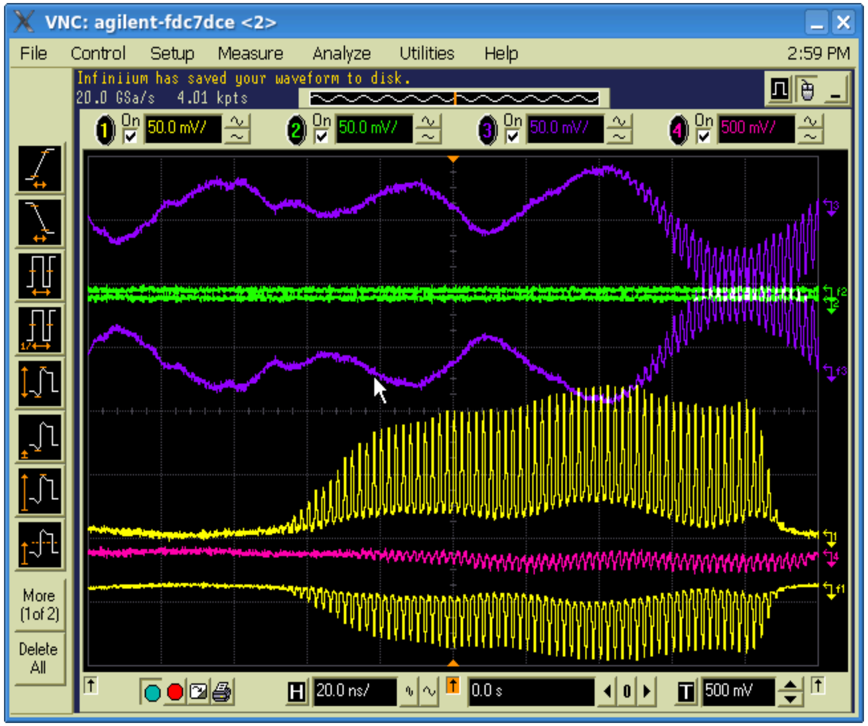
$\sigma_t \lesssim 300$ ps → $\sigma_x \lesssim 4$ cm

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



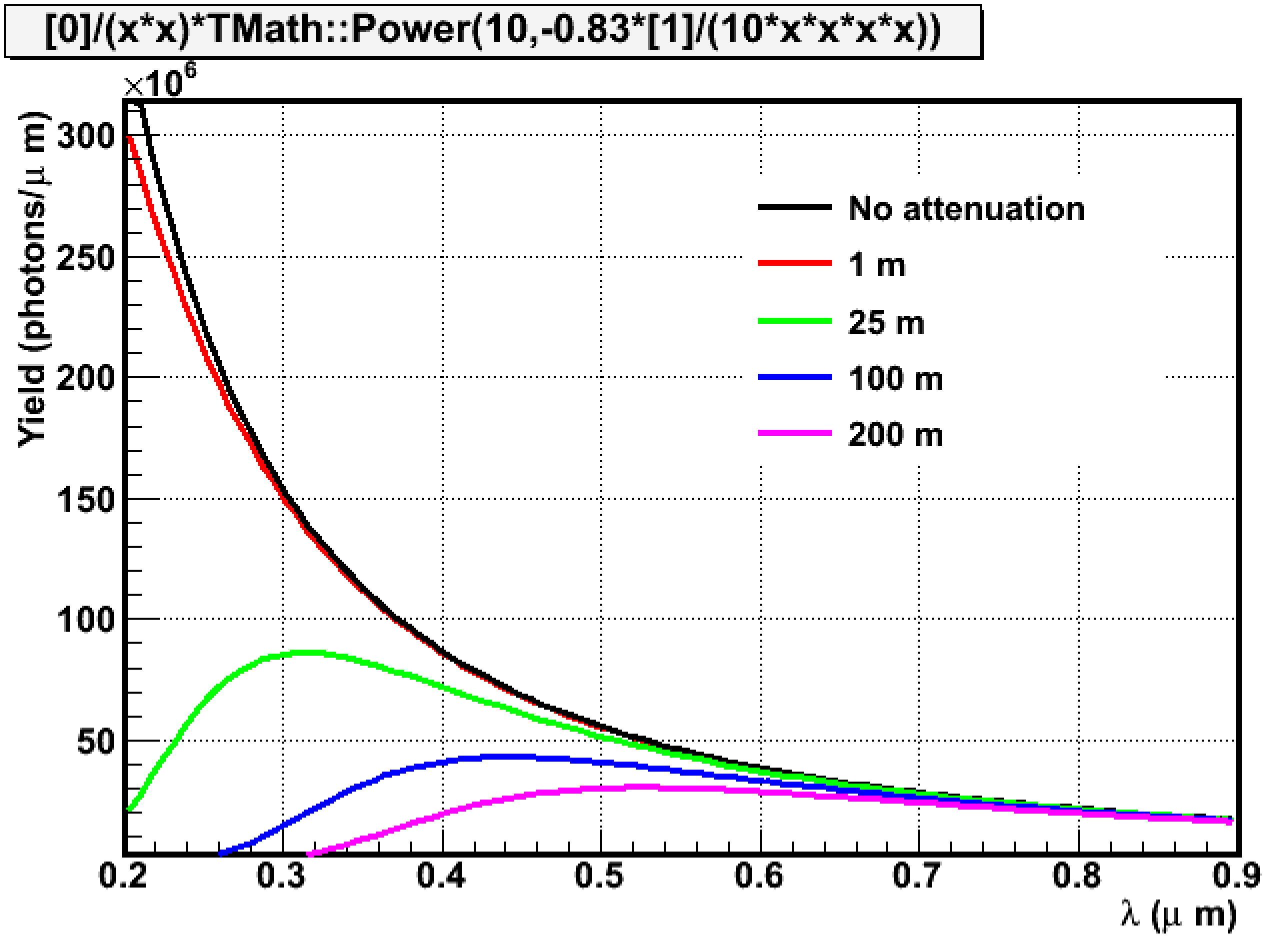


ASLS multi-bunch current



Current profile of 75 bunch train

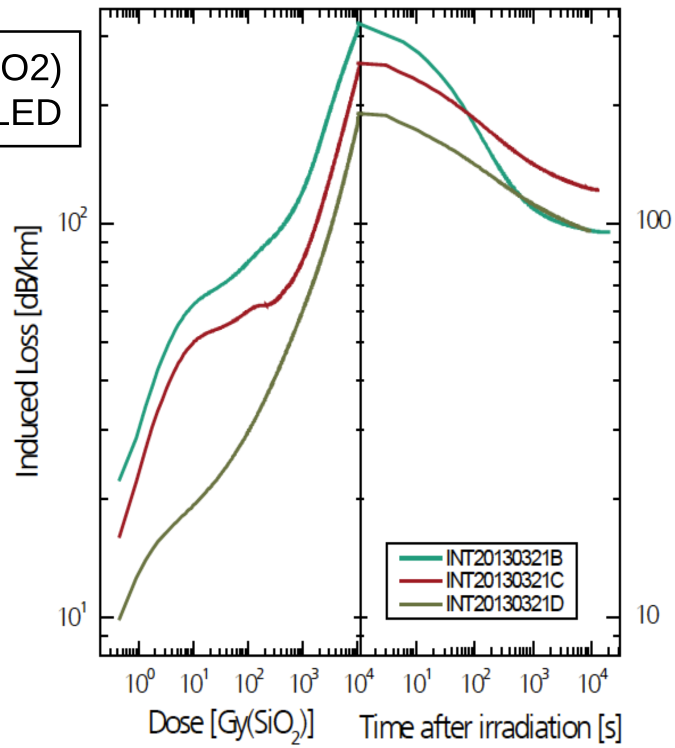
Cherenkov light spectrum and effect of fibre attenuation



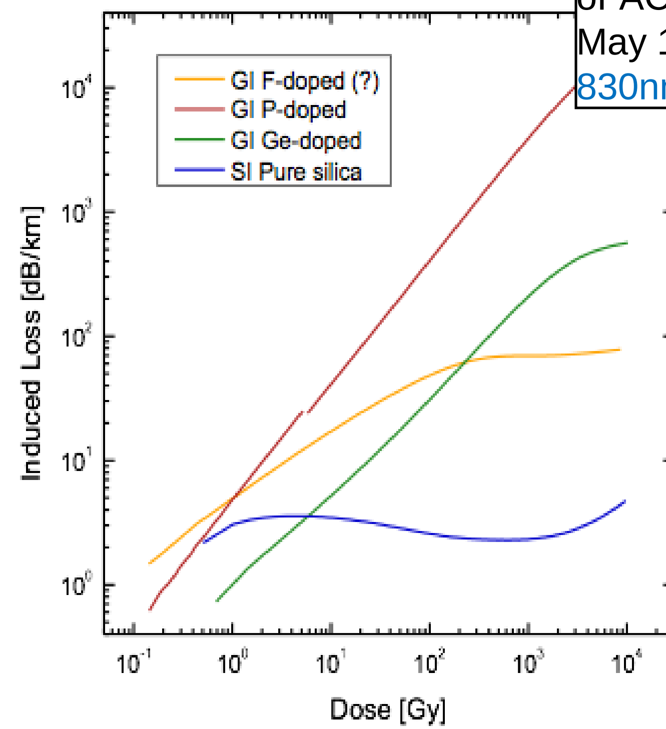
Cherenkov fibers: Radiation Hardness

- 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