MEASUREMENT OF BEAM LOSSES USING OPTICAL FIBRES AT THE AUSTRALIAN SYNCHROTRON

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Background: *T. Obina and Y. Yano, IBIC'13,* **WECL1**

Summary

- An introduction to the Australian Synchrotron (AS)

- The AS as a Damping Ring (DR): CLIC DR and AS common parameters

- Optical fiber Beam Loss Monitors (OBLM) and the experimental setup

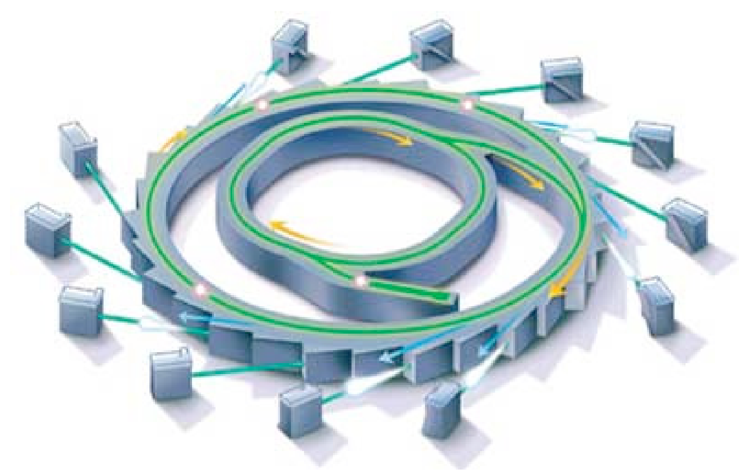
- Measurement discussion:
  - Intensity calibration
  - OBLM single shot calibration
  - User fill measurements (Topup injections)
  - Dynamic aperture and coupling scans (CLIC-like fill scans)

- Summary and conclusions

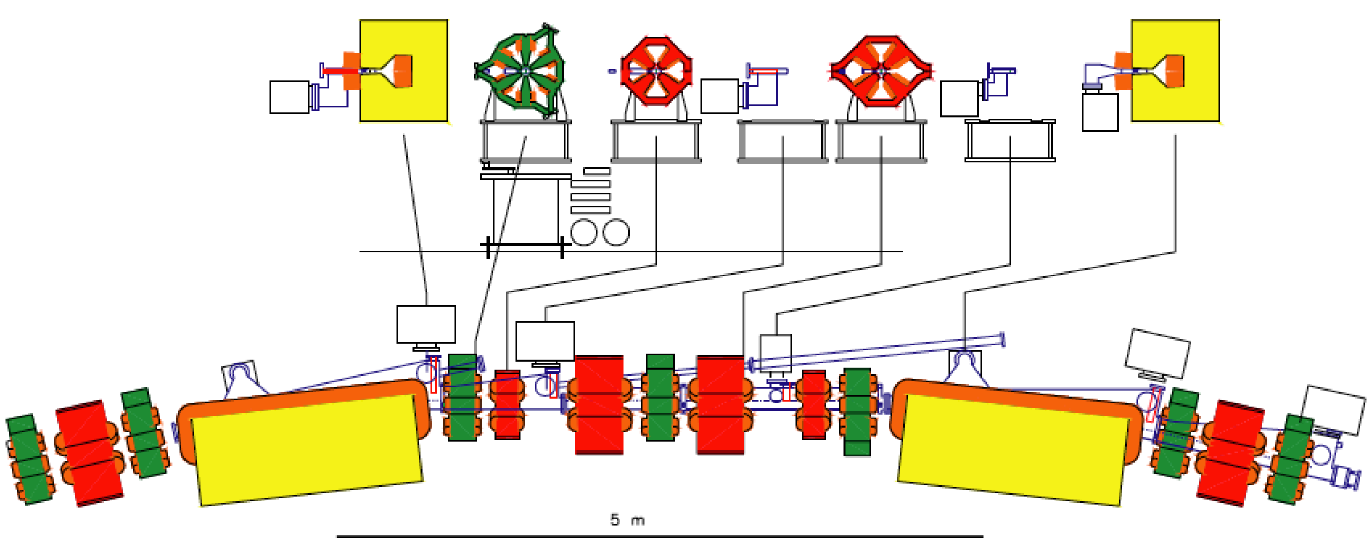
The Australian Synchrotron

• The AS comprises

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

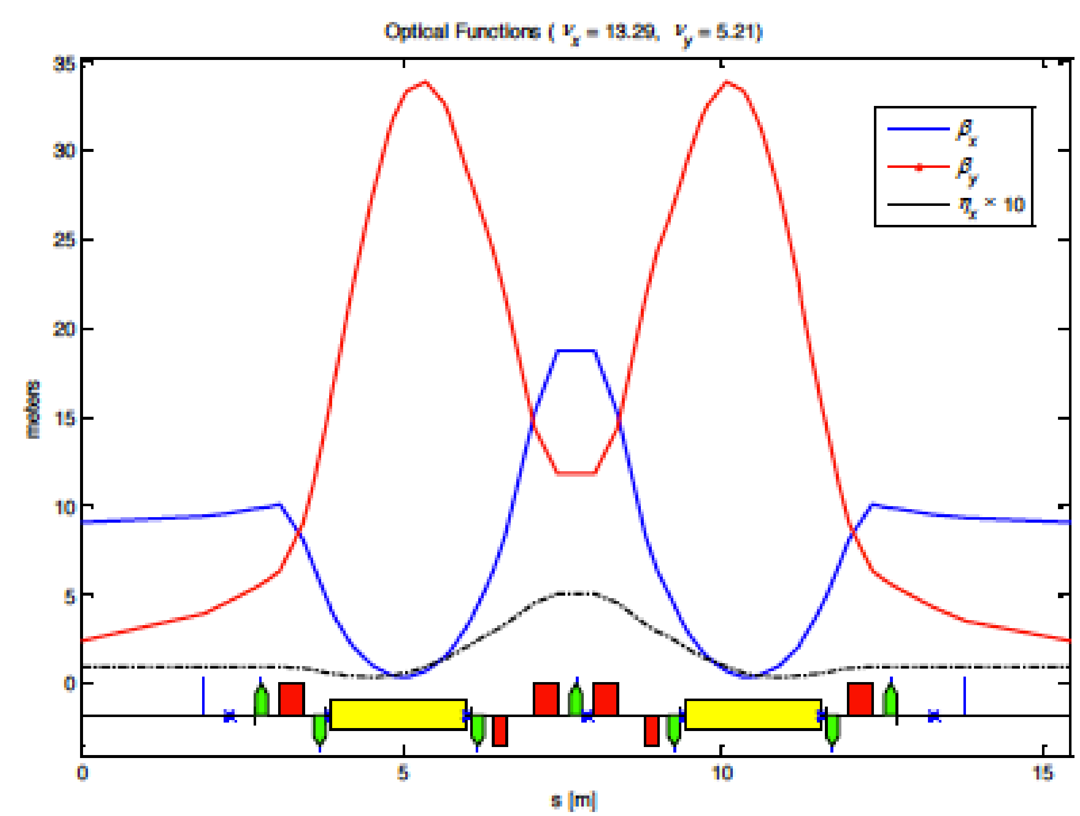


Schematic view of a DBA cell in the SR arc



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	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%



The Australian Synchrotron as Damping Ring

- Ultra-low beam sizes at the interaction points in future colliders will be achieved via damping rings
  - synchrotron light production as a means of beam cooling
  - targeting ultra low (pm level) normalized emittances
  - Current 3rd generation light sources, e.g the AS, reach some of those conditions

Parameter	AS	CLIC DR
Energy (GeV)	3.0	2.86
Intensity (elec)	$9.0 \cdot 10^{+11}$	$1.28 \cdot 10^{+12}$
Number of bunches	300	312
Pulse lenght (ns)	600	156
Circ. lenght (m)	216	427.5
f_{rev} (MHz)	1.38	0.73
Bunch spacing (ns)	2	0.5
$\gamma\epsilon_x$ (nm rad)	58708	472
$\gamma\epsilon_y$ (nm rad)	< 5	4.8

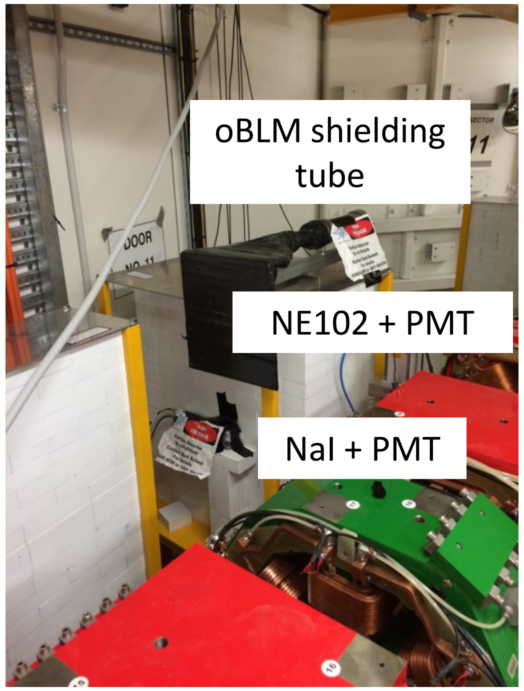
- Many similarities on main parameters between AS and CLIC DR

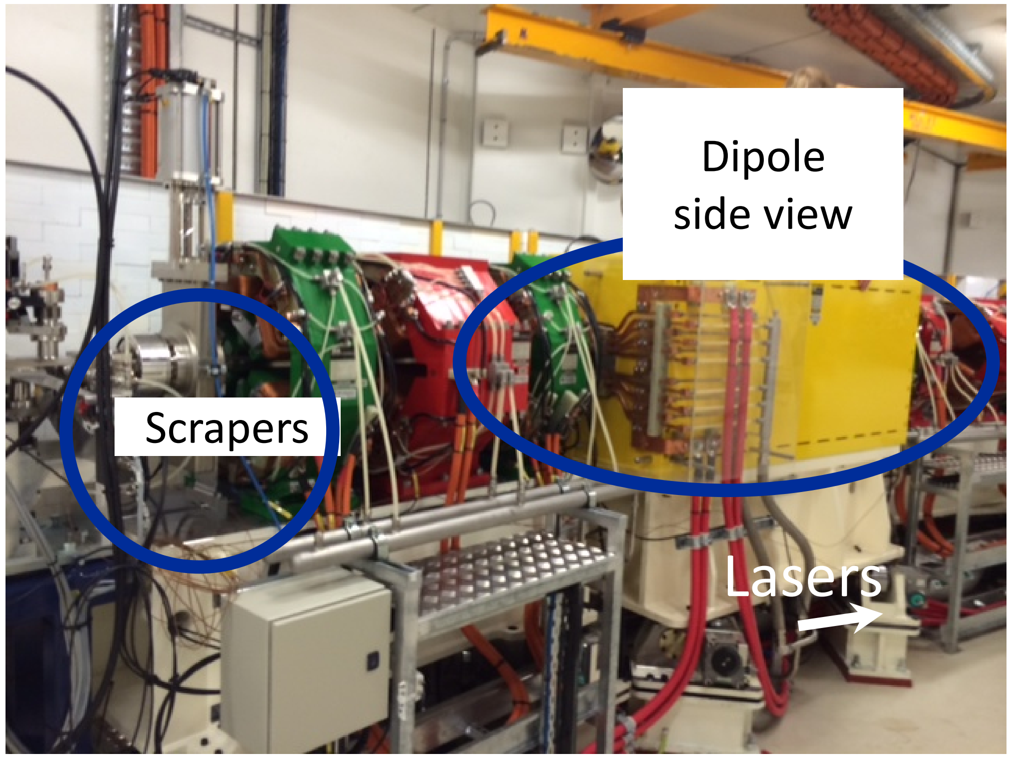
- Flexibility to approach other important parameters
  - e.g ~150 ns pulse length by filling dedicated RF buckets

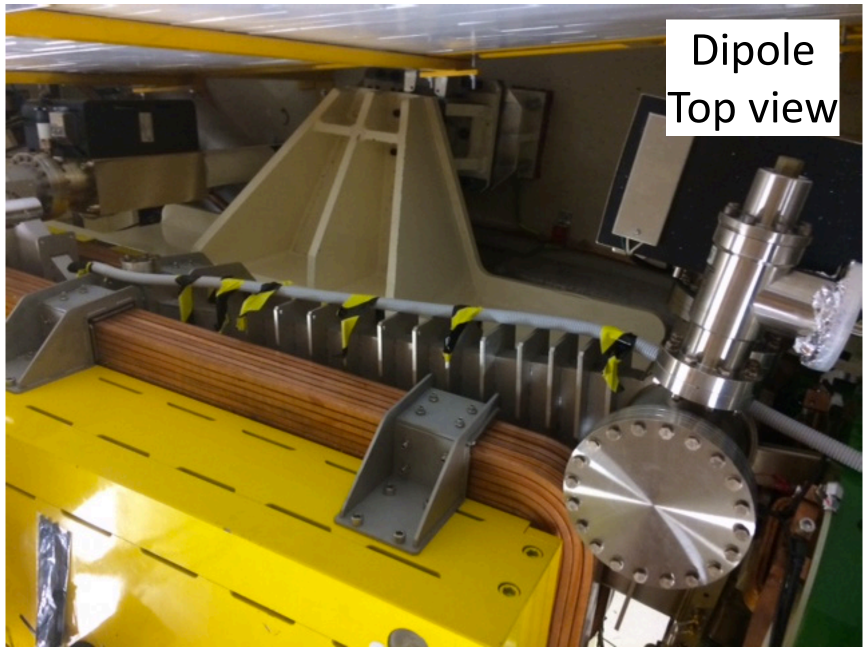
- Ideal facility for testing DR dedicated instrumentation
  - e.g Beam Loss Monitoring (BLM) systems

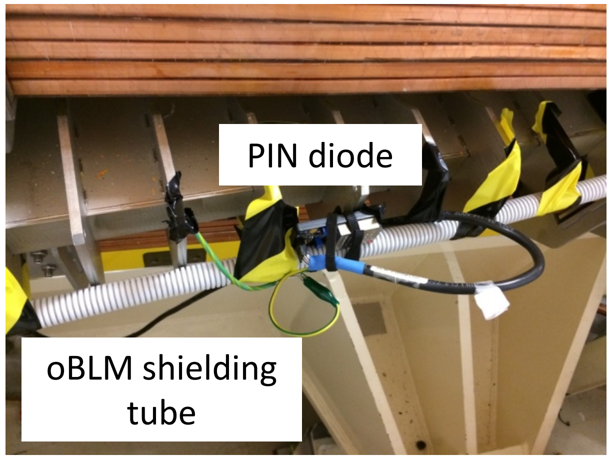
Optical fibre BLMs: Experimental setup

- Why an Optical fiber BLM (oBLM) system in the AS (CLIC DR)?
  - The full ring can be covered with a few (< 10) BLMs
  - Cherenkov-based fiber BLMs would be insensitive to synchrotron radiation
- Two (one) 7 m (5 m) optical fibers with 365 μm (200 μm) SiO_2 core, coupled to:
  - Multi Pixel Photon Counter (MPPC)
  - PMT
  - APD
- Pin diode, NaI and NE102 scintillators in neighbouring locations for comparison purposes





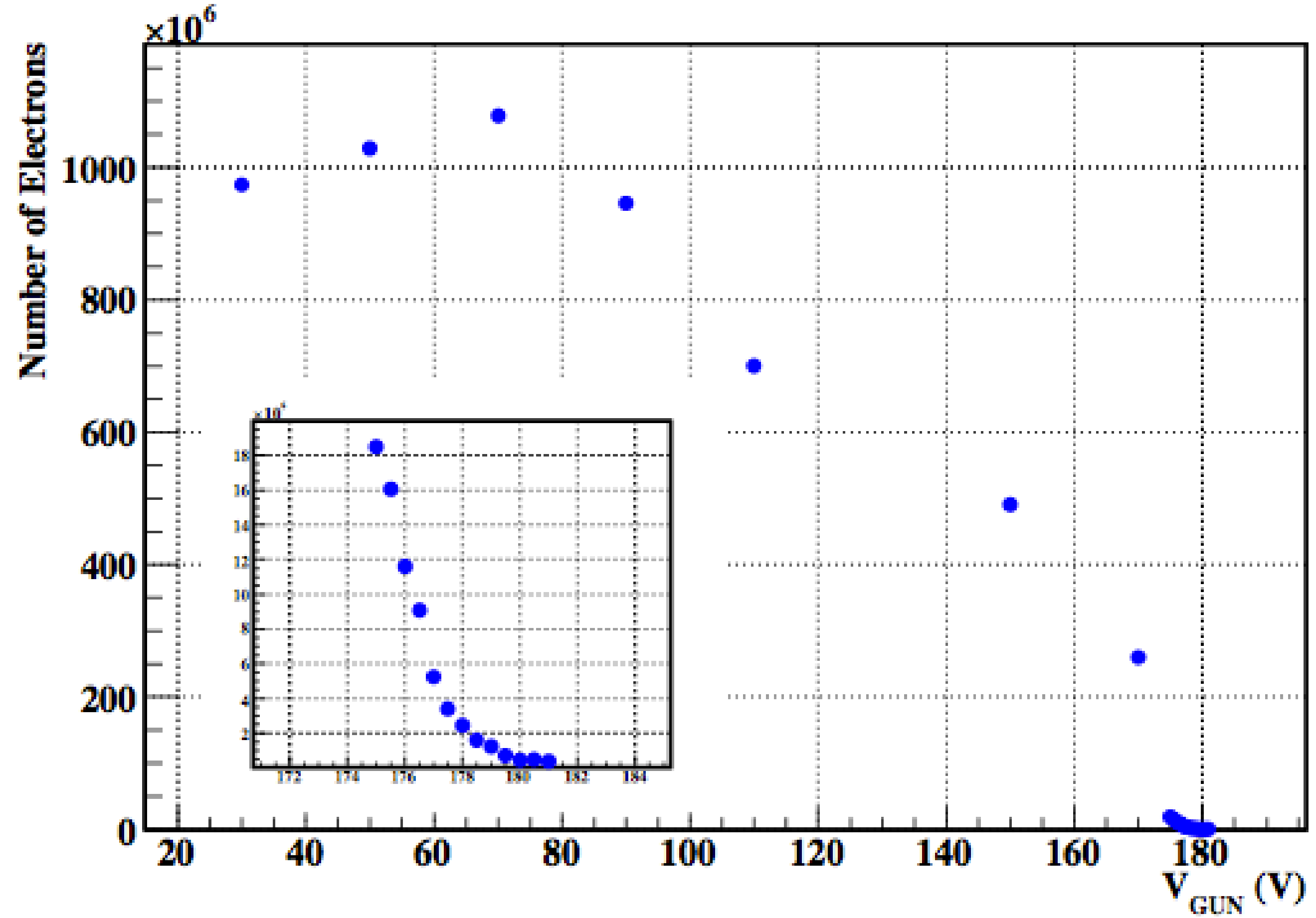




BLM Calibration. Sensitivity studies

- The oBLM systems needed to be calibrated against known number of lost particles
- Single bunch, of known intensity, directed onto a closed scraper:
  - Booster or BTS charge monitor of no use due to uncertainty on injection efficiency
  - No SR DCCT (single turn exercise)
  - Statistical calibration: charge accumulation in storage ring (with open scrapers)

- Varying parameter: Voltage of electron gun grid



- Intensity range achieved: $5.0 \times 10^{+5}$ - $1.1 \times 10^{+9}$ electrons

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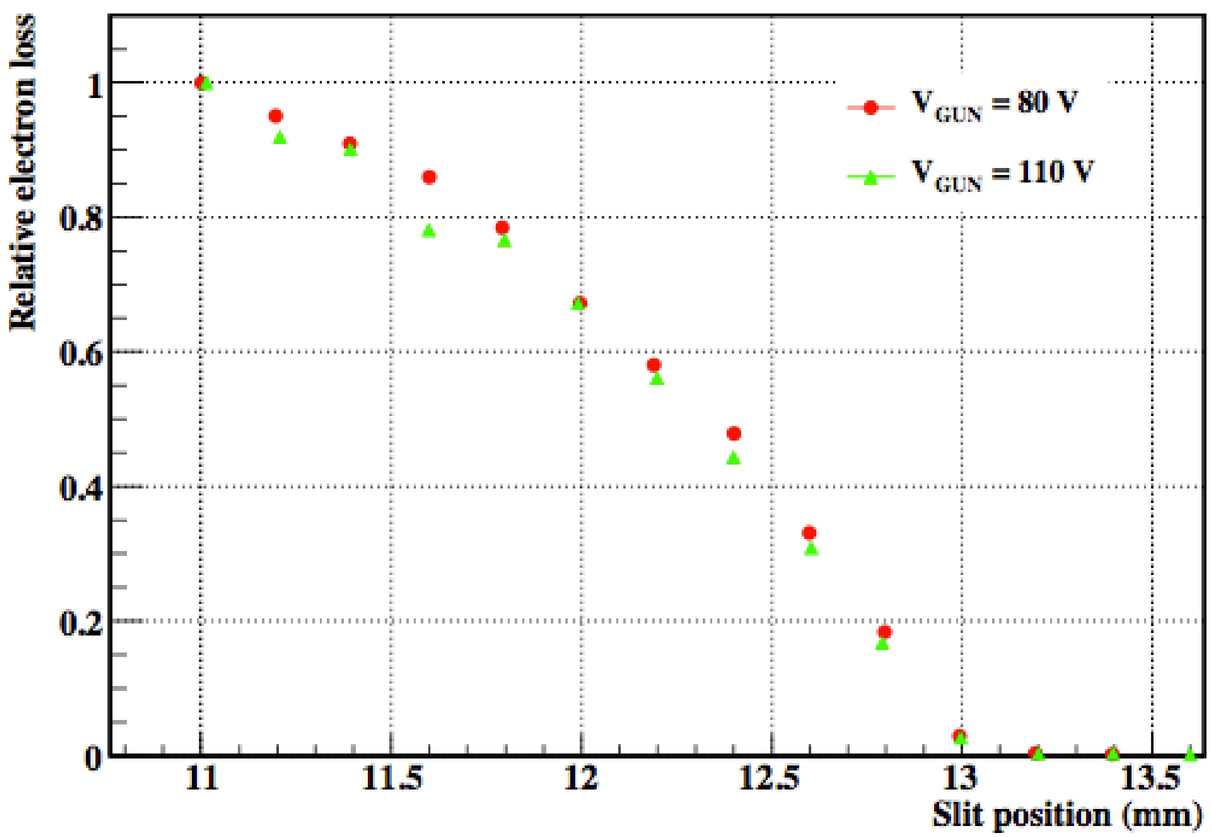
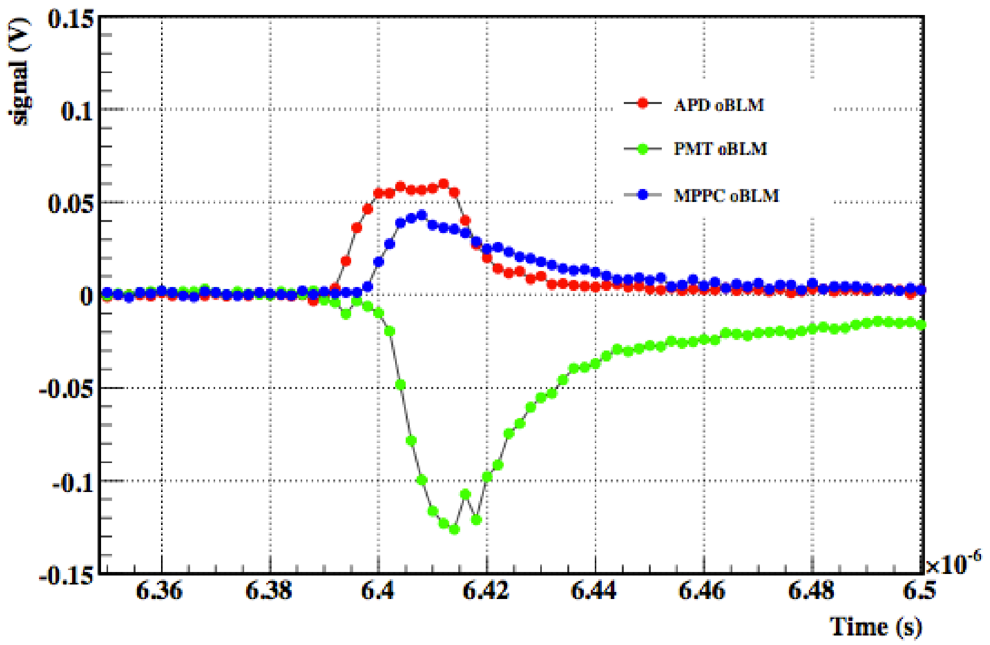


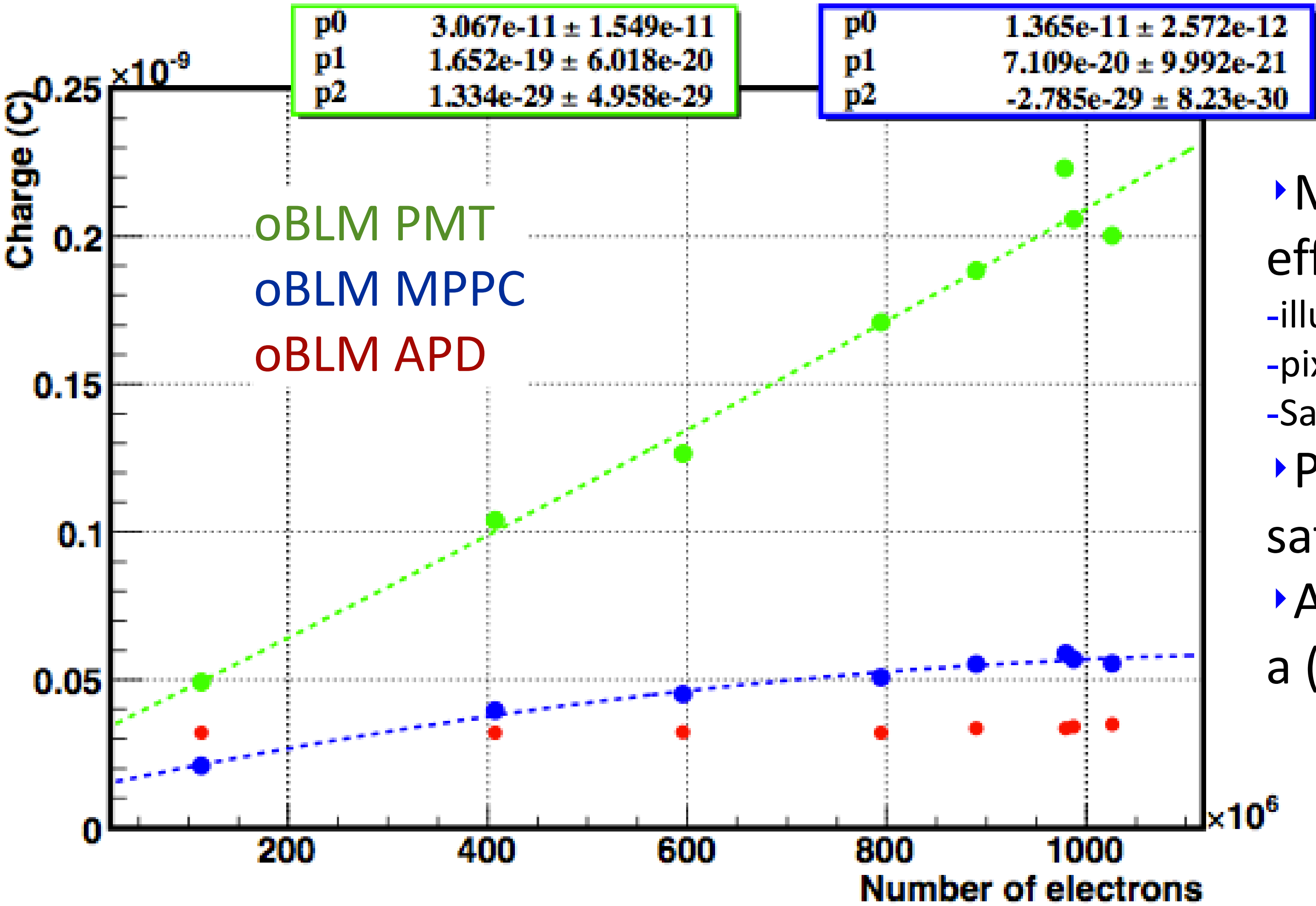
- Varying parameter: Position of energy selection slit grid on BTS

- Intensity range achieved: 100 - 0.5 % of nominal (i.e slit at 11 mm)
  - For Vgun = 181V → $5 \times 10^{+3}$ - $2.5 \times 10^{+5}$ electrons

BLM Calibration. Sensitivity studies

- Numerical integration of the signals forms was performed to compare the sensitivity of the oBLM system for 3 photo-sensors





- MPPC require 2nd order fit due to saturation effects
  - -illuminated area 1.04 $\times 10^{+5}$ μm^2
  - -pixel area 25 x 25 μm^2
  - -Saturation expected for $N_{ph} > 1.04 \times 10^{+5}/625 = 167$
- PMT fit compatible with straight line (no saturation observed)
- APD shows flat behaviour as system provides a (binary) TTL output

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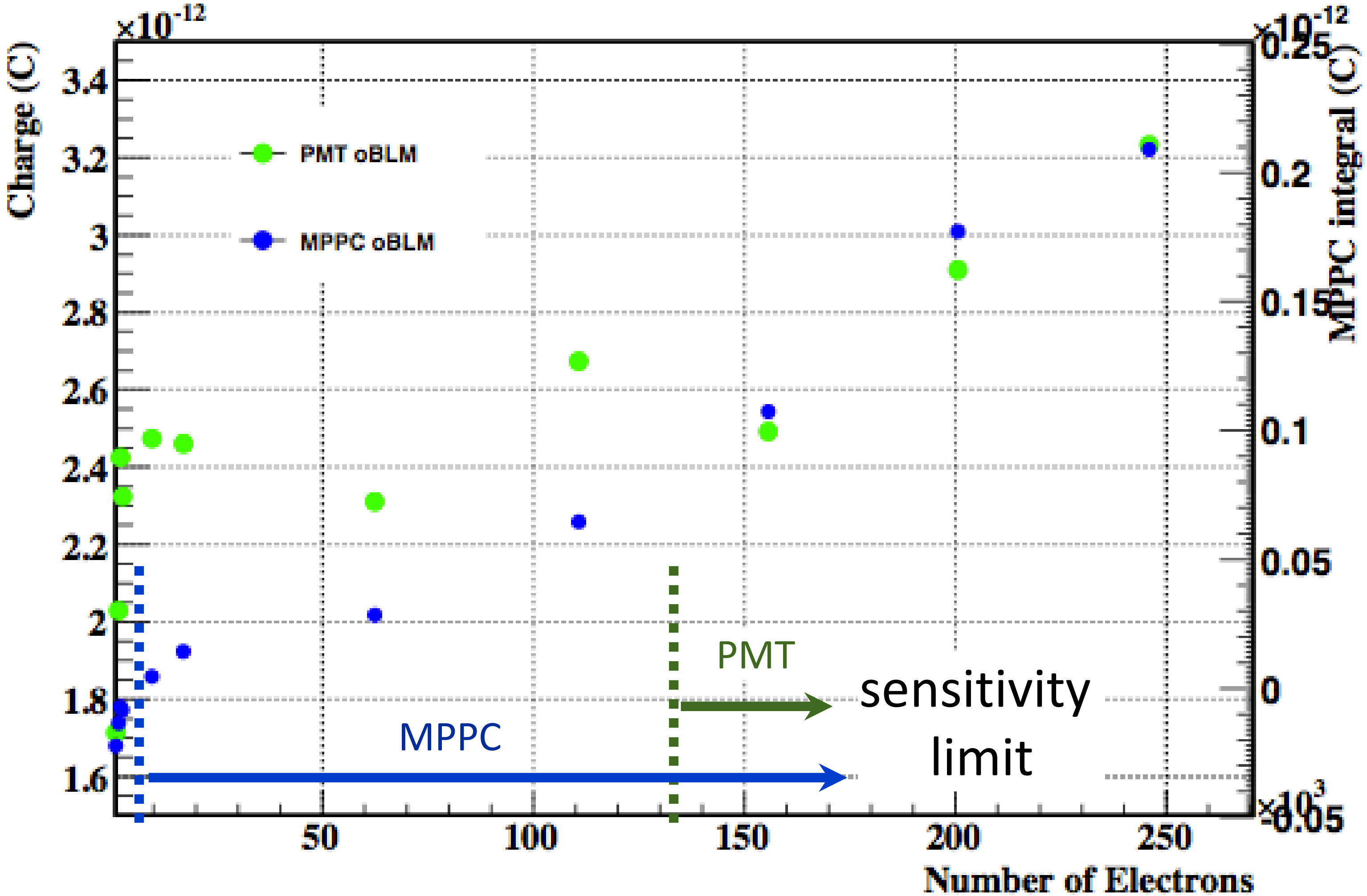
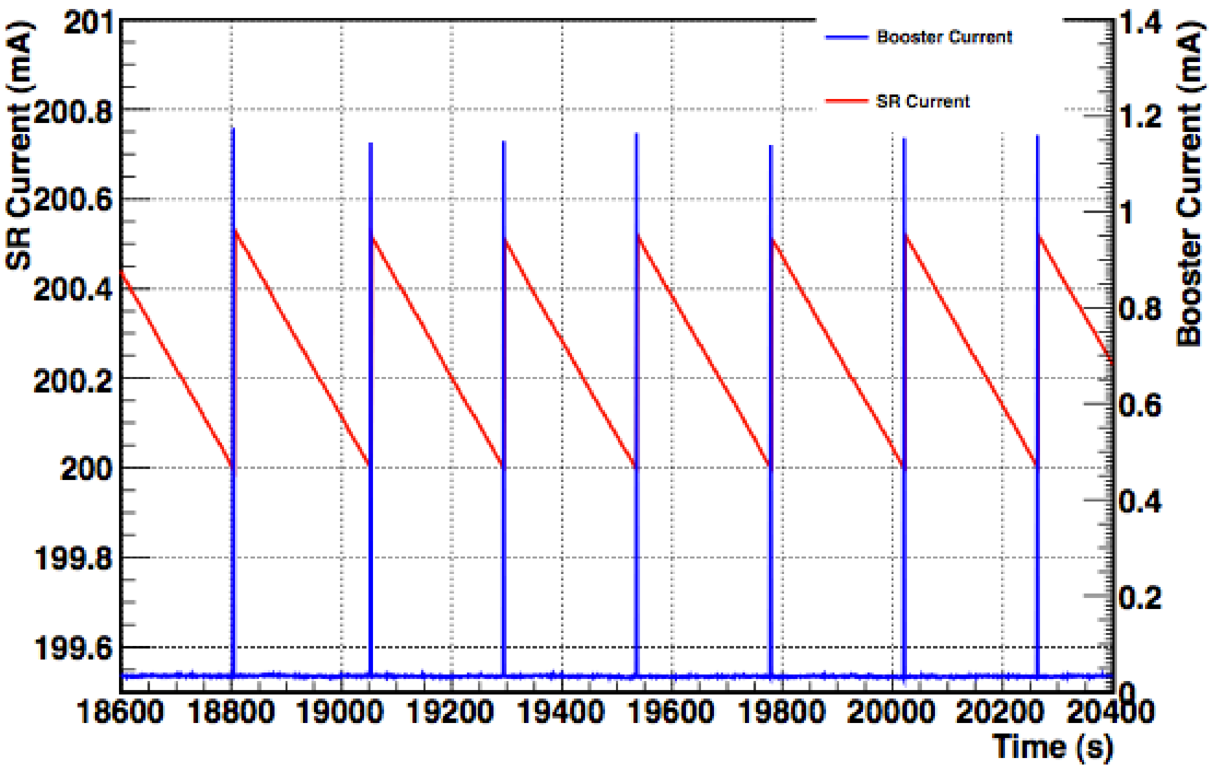
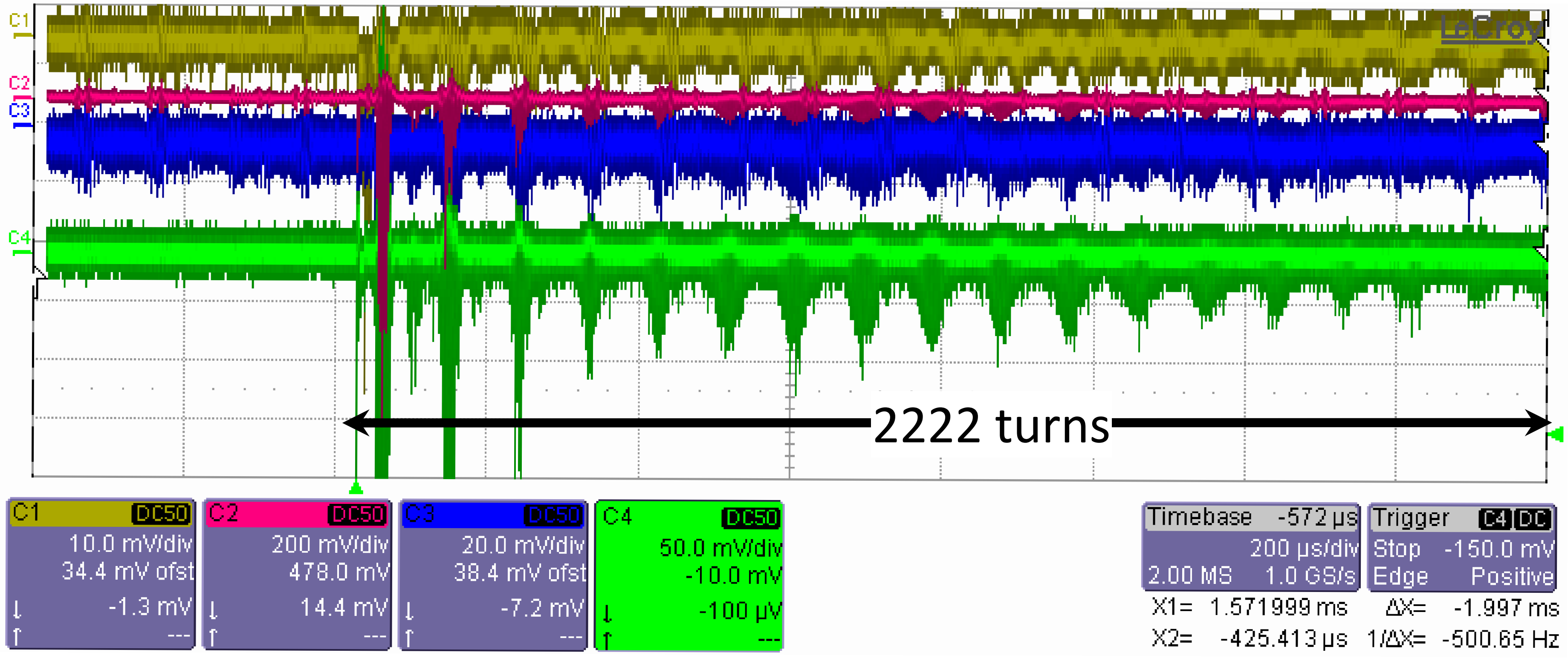


- APD oBLM not sensitive for this intensity range due to:
  - -optical losses (lens coupling)
  - -limited active area 25 x 25 µm^2 of sensor
- PMT oBLM sensitive down to 1.5 x 10^{+5} electrons
- MPPC oBLM sensitive down to 1.0 x 10^{+4} electrons:
  - -30 dB signal amplification after ~5.5 x10^{+5} gain
  - -better single photon counting capabilities

Topup injection

- AS works on topup mode to keep a constant 200 mA for > 24 hours
  - SR ~ 0.5 mA / Booster ~ 1.1mA / Injection efficiency ~80%
  - harmonic number Booster/SR = 216/360
  - $1.25x10^{+9}$ electrons lost within the first several turns

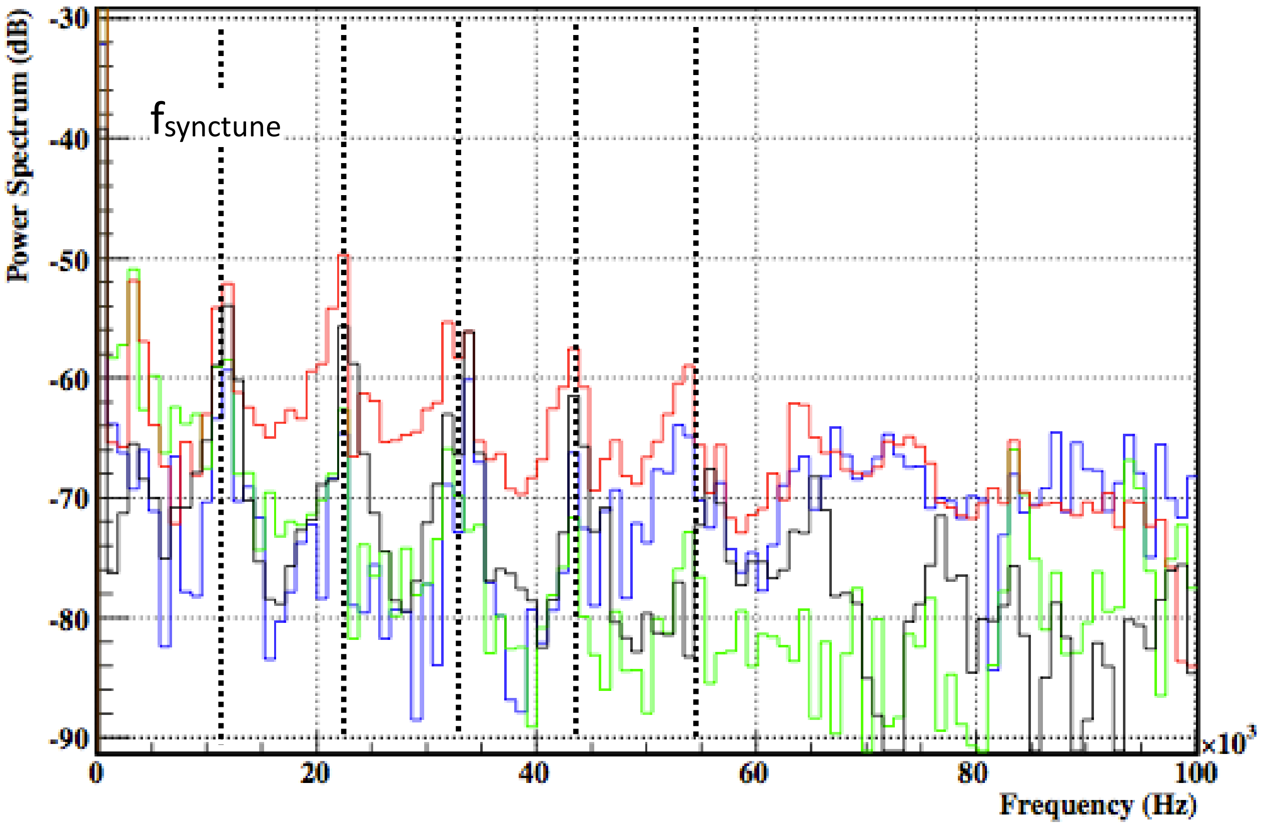


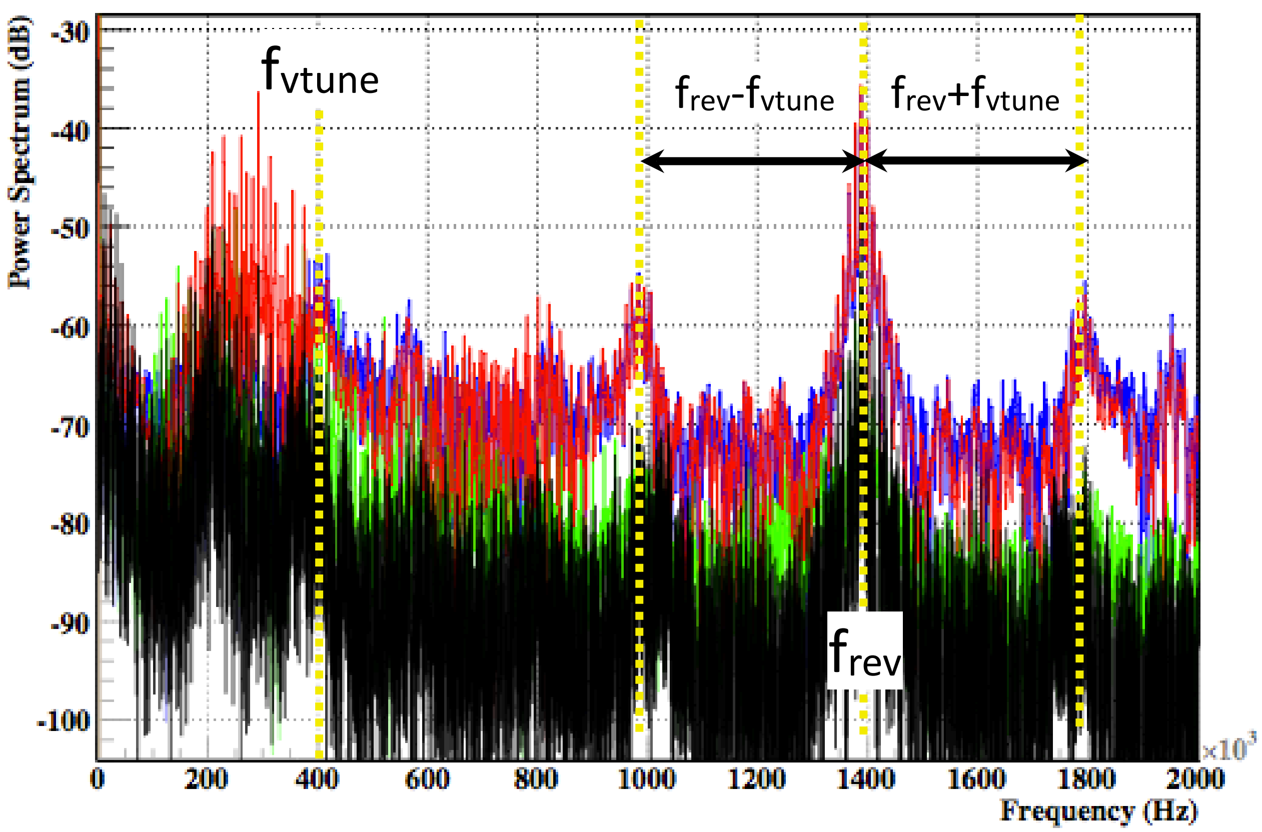


NaI
NE102
oBLM PMT
oBLM MPPC

Topup injection: Signal modulation

- Frequency Analysis
  - 11 kHz band (synchrotron tune)
  - 1.38 MHz (rev frequency)
  - 400 kHz band (vertical tune)





NaI
NE102
oBLM MPPC
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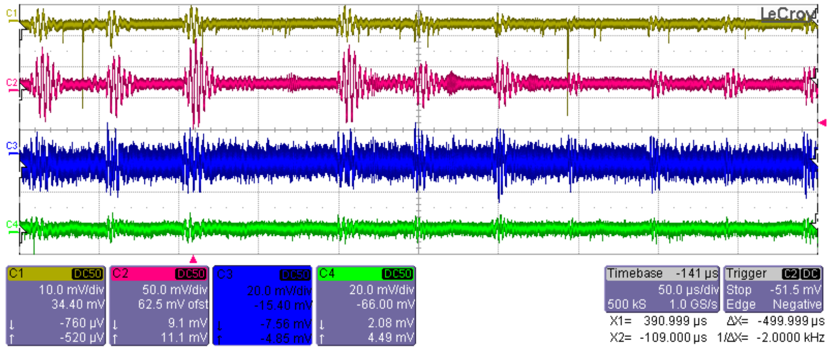
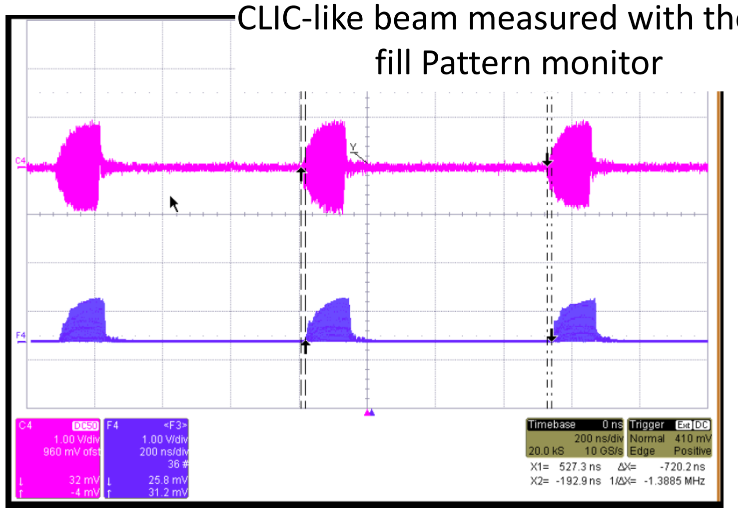
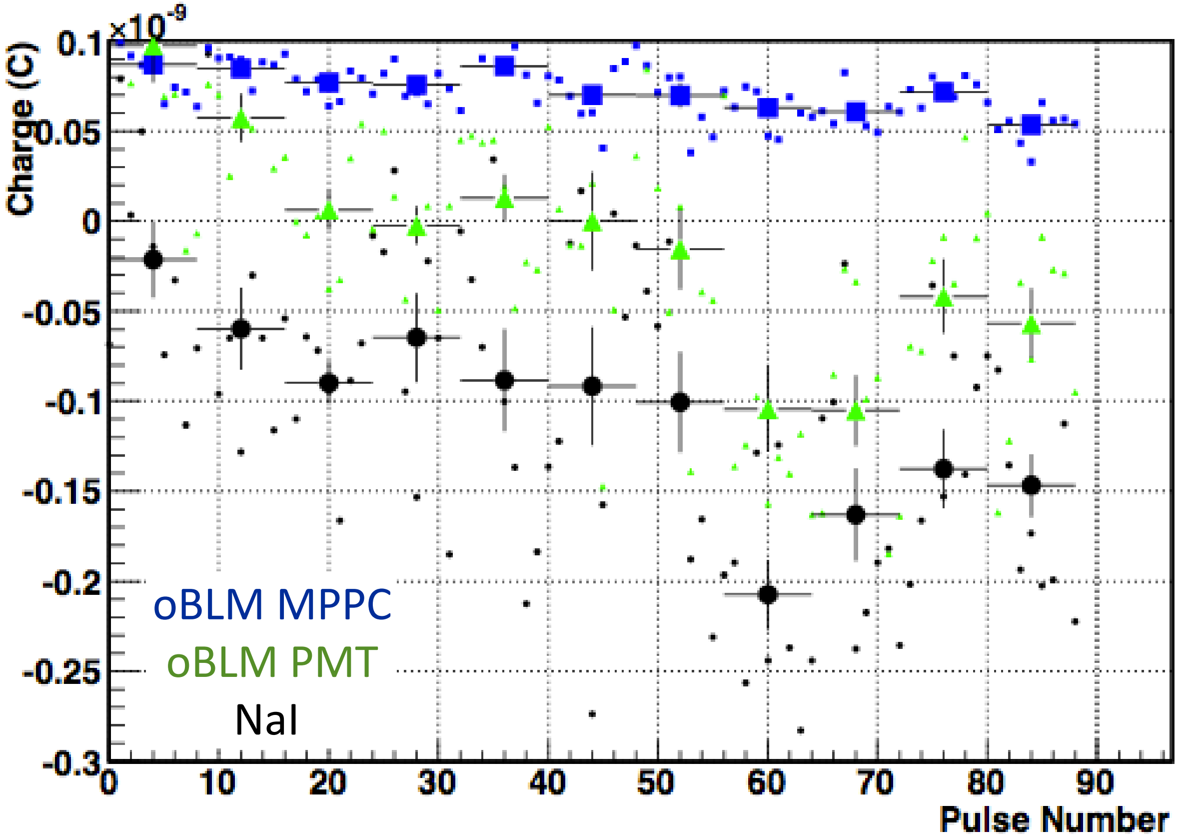
Dynamic Aperture and Coupling scans



- Observation of beam losses with user-fill while squeezing Dynamic aperture and changing betatron coupling unsuccessful due to large noise



- Measurement of beam losses during betatron coupling scan with CLIC-like beam



- 11 independent skew quadrupole settings: vert. emit. range 0.001 to 2 nm
- 8 pulses/quad setting
- scraper position at 15 mm to enhance beam losses

measurement	1	2	3	4	5	6	7	8	9	10	11
nm	0.001	0.002	0.005	0.01	0.02	0.05	0.1	0.2	0.5	1	2

Summary and conclusions

- The AS has proved to be an ideal facility for instrumentation targeting DR

- BLM system based on optical fibers is feasible
  - Sensitive down to ~10k electrons lost in single location with MPPC
  - Linear response up to 1.0 x 10^{+9} electrons with PMT
  - Combination of photon-sensors → dynamic range ~10^{+5}

- Potential for measuring tunes

- System sensitive to “steady-state” losses with charge integration
  - Increase on detector signal with betatron coupling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