BE-BI Options for Satellite, Ghost, Debunched Beam and Bunch Length Measurements – Part I/II

Ralph J. Steinhagen

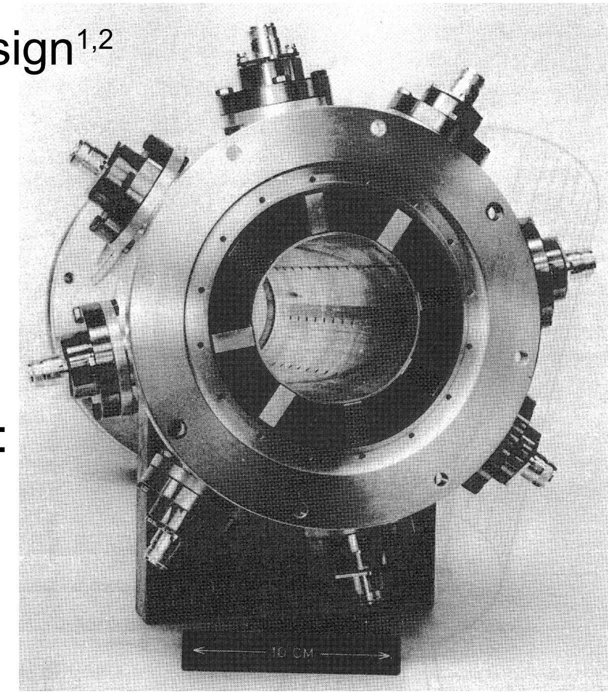
Special thanks to Th. Bohl, S. Bart-Pedersen and H. Damerau

Resumé:

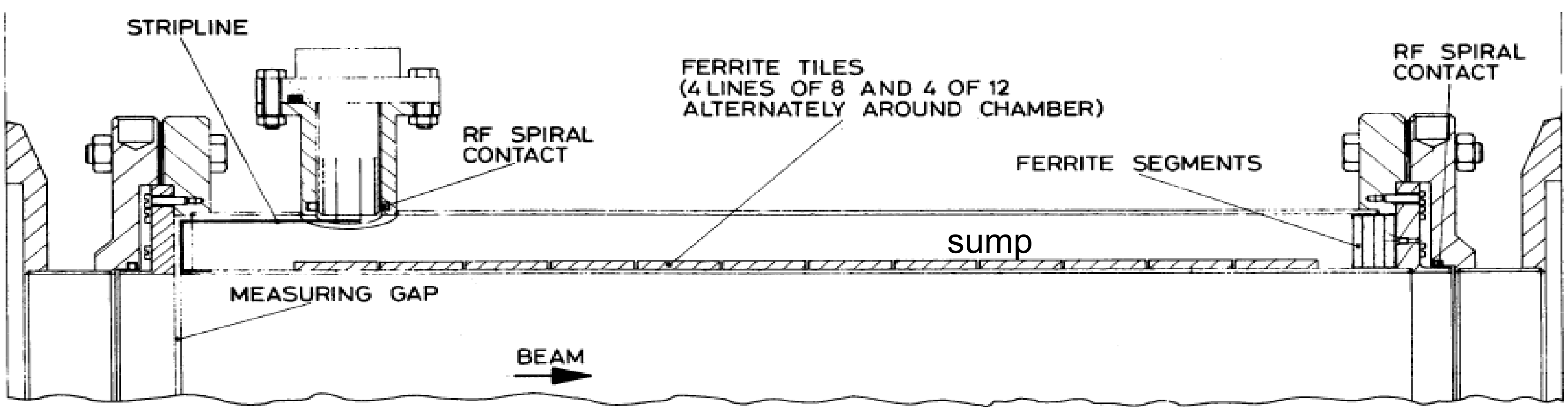
- Detection of ~1%-level Satellites:
  - existing PS/SPS pick-up hardware (WCM) fulfills most requirements (except de-bunched beam detection)
  - 'Visually' easy to detect but … fully automated 'turn-key' system requires system response compensation, further control room level integration
    - leverage experiences with LHC BI-WCM could be applied to PS/SPS
- Detection of sub-percent level Satellites ('ghosts') or un-bunched beam:
  - require/install new high-bandwidth, low-noise pick-ups
  - can re-use existing acquisition, post-processing and CCC integration

Wall Current Monitor as used by BI

- LHC/SPS WCM pickup based on established 78' design[1,2]
- Simplicity is key necessity to control systematics and reflections on the 10^{-3} level at GHz frequencies:
  WCM + “combiner” → 3/8” → 30 (100) m 7/8” cable → 40 dB attenuator → 3 GHz fast sampling scope
  (N.B. Implies control of every single transition/bend/connector on mm-level)



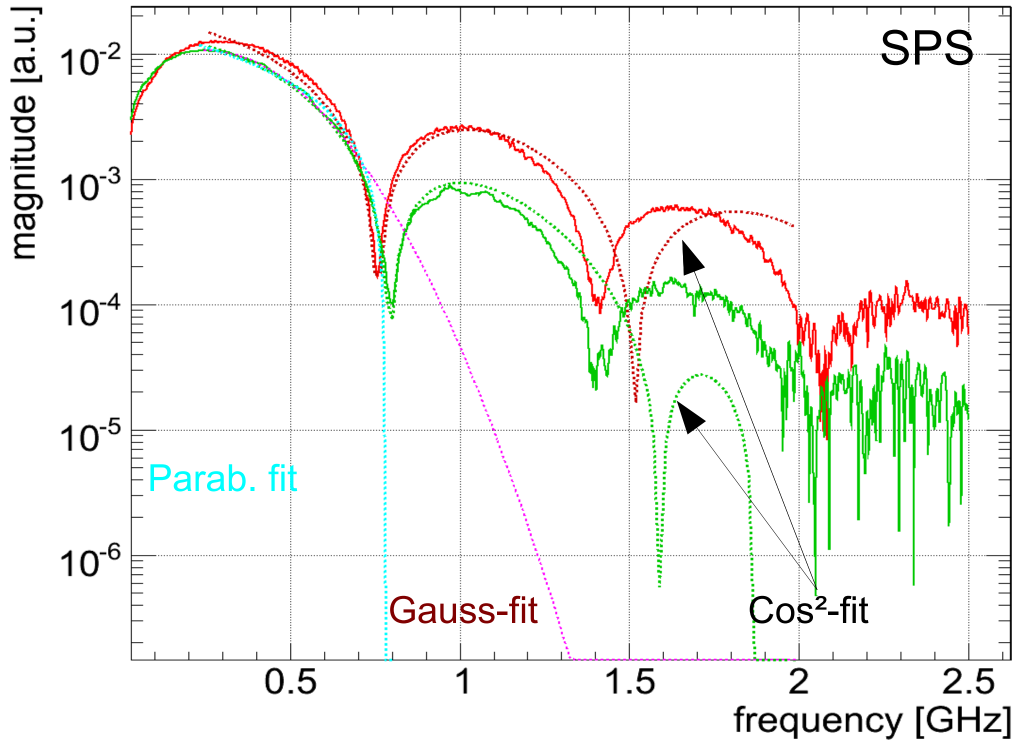
- Idea was not to re-build the turn-based BQM system:
  a) Tackling average signal over N-turns
     → overcomes scope quantisation/noise
  b) full compensation of measured system response
     → necessary to get (any hope of) %-accuracy



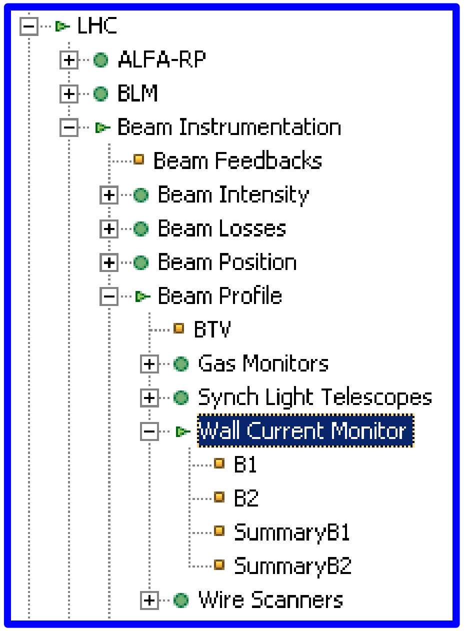
[1]T. Linnecar, “The high frequency longitudinal and transverse pick-ups used in the SPS”, CERN-SPS/ARF/78-17, 1978
[2]Th. Bohl, “The APWL Wideband Wall Current Monitor”, CERN-BE-2009-999, 2009

Beam-Parameter Measurement and Integration

- Real bunches do not necessarily obey 'Gaussian' shapes



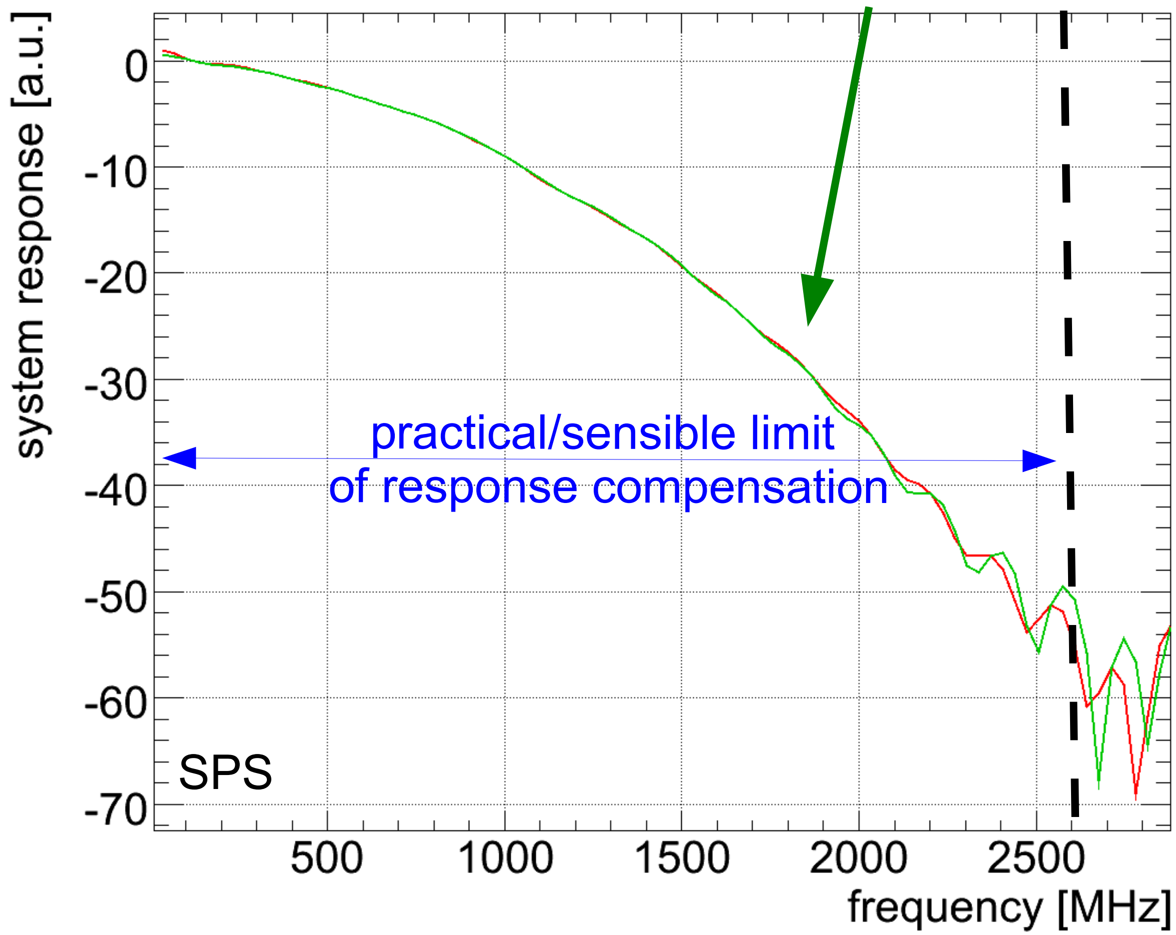
In Timber:



- What's being computed so far:
  - number & intensities of bunches & satellites (per 400 MHz bucket above thres.)
  - true $\cos^2$-, Parabolic- & Gaussian bunch length χ^2-fits
  - Frequency containing 50/95/99% of bunch power/intensities, peak voltages, ...
- Most difference/details are only visible at very high frequencies > 1 GHz
- Response of pick-up, cables, scope at these frequency need compensation!

Compensation of WCM System Response

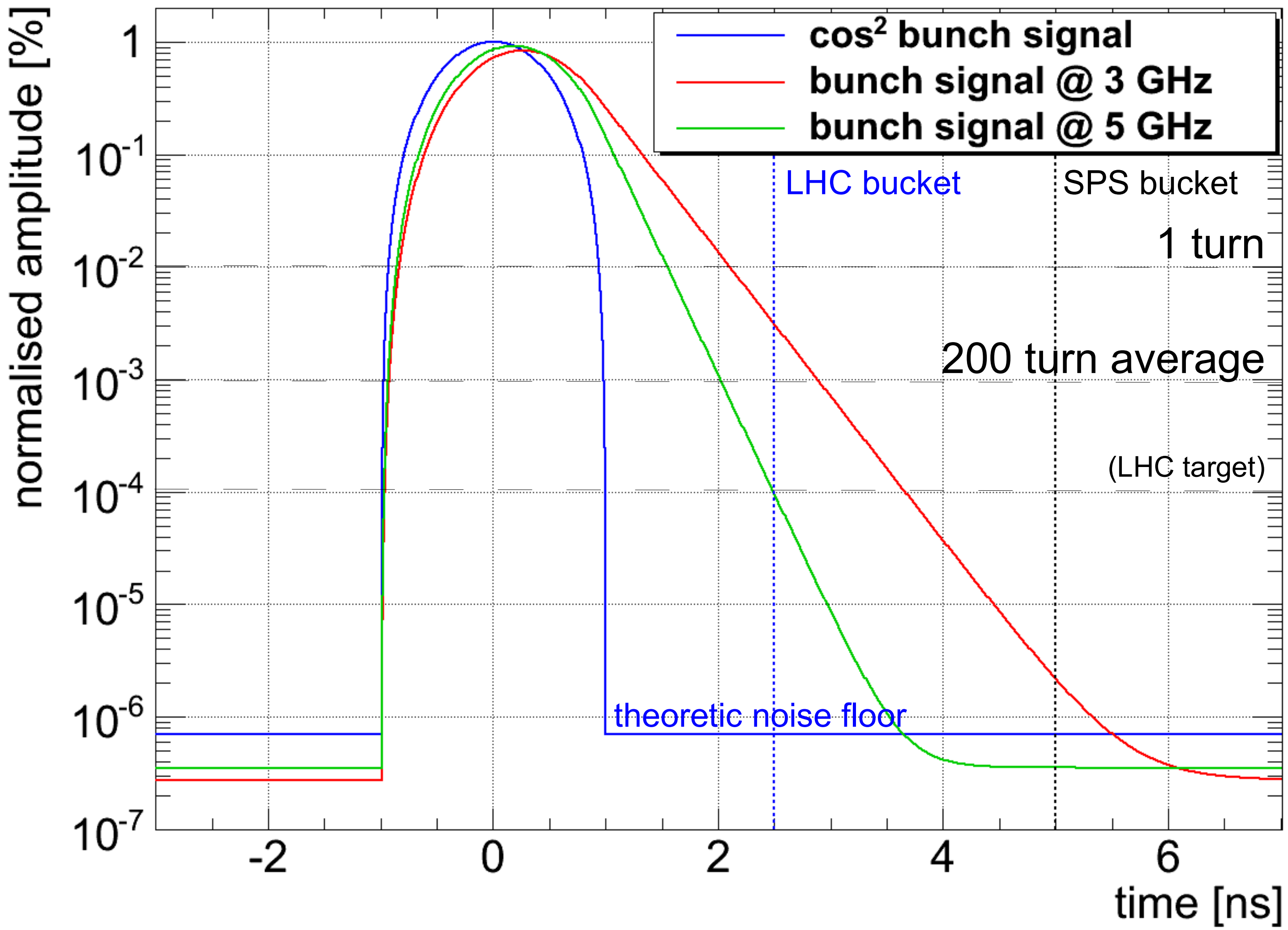
- True longitudinal bunch profile measurement is distorted by:
  a) WCM pick-up response → design values + measurements by T. Bohl & U. Wehrle
  b) combiner-response (star-topology) → only design (re-measure end '10)
  c) Dispersion due to 7/8” Heliax cabling & analogue scope bandwidth



- Historical: (very) high numerical complexity if treating raw 20 (100) us frames

Fundamental limits of the WCM-based Scheme: 'Satellite' → 'Ghost' Detection Potential

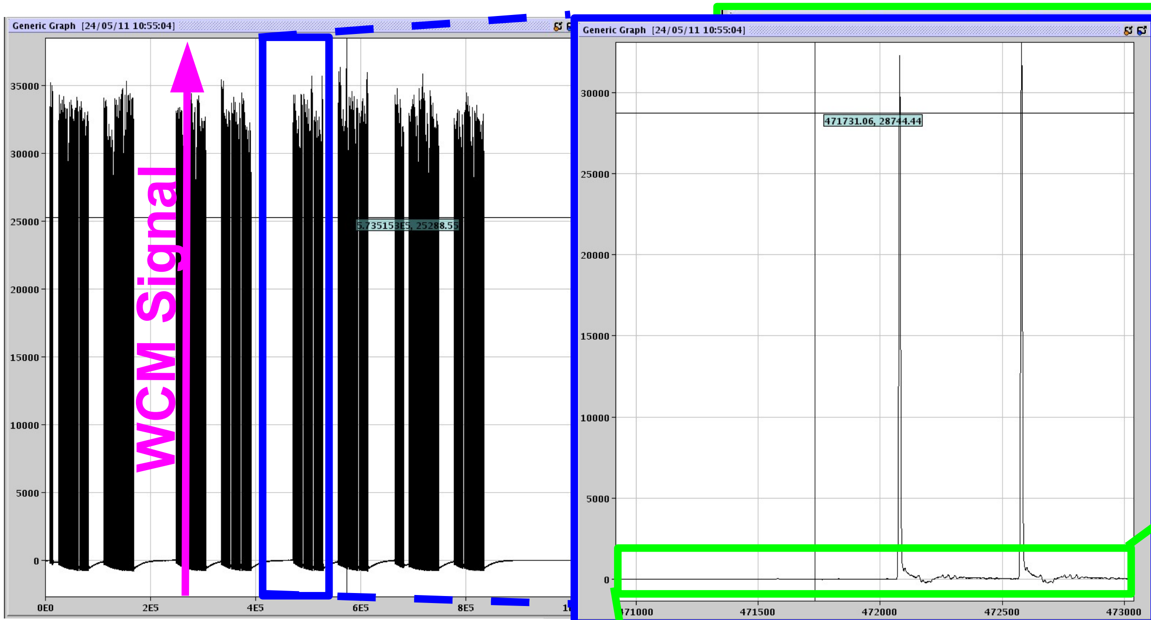
- … limited by total system bandwidth for below percent-level detection:

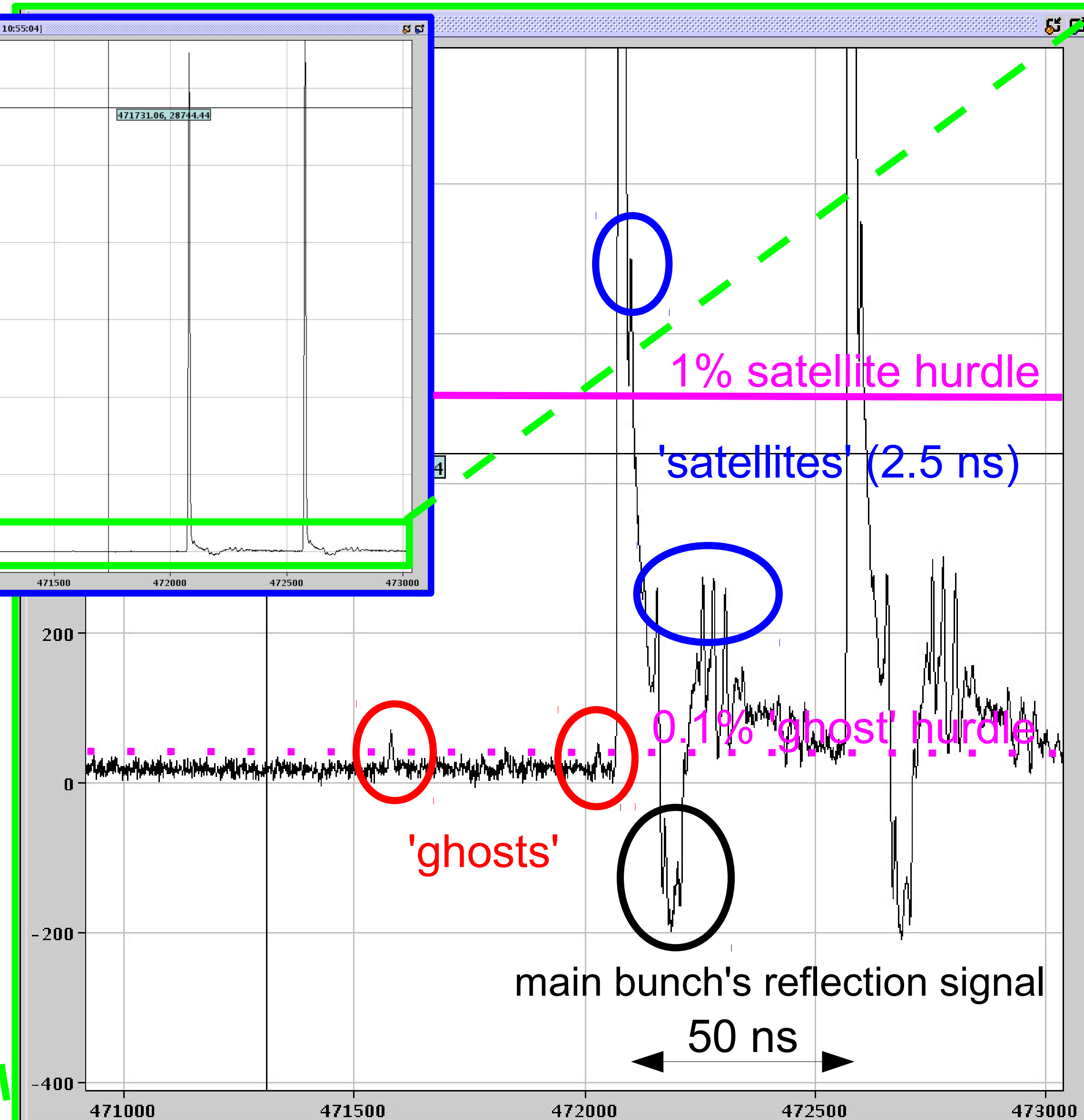


- … limited by unavoidable systematic due to transmission line transitions, reflections, etc. (N.B. difficult to control better than 10^{-3} on > 2 m distances)

LHC Wall-Current-Monitor (based on old SPS RF design)

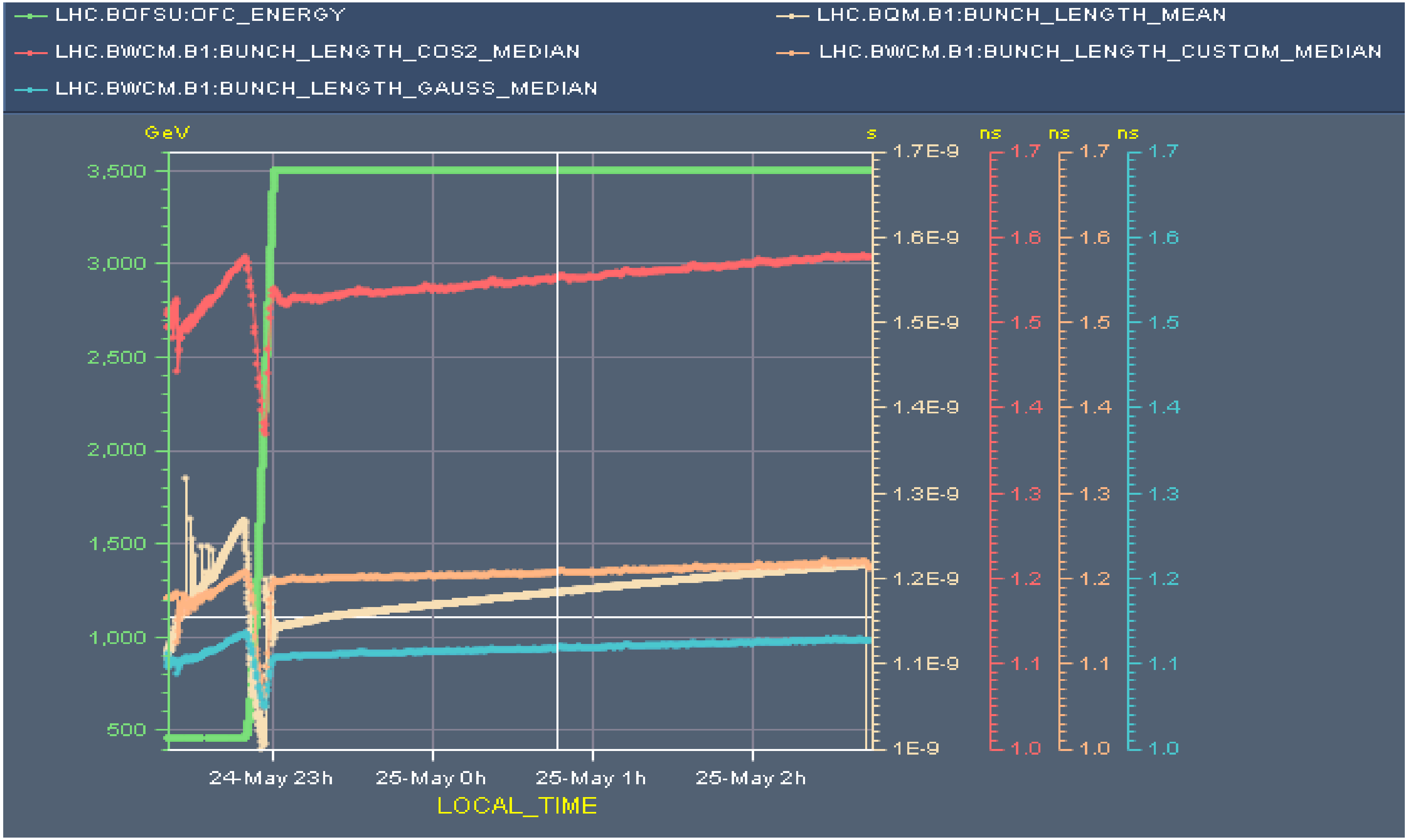
- LHC setup: WCM → short (30 m) 7/8” cable → 3 GHz Scope → post-processing...





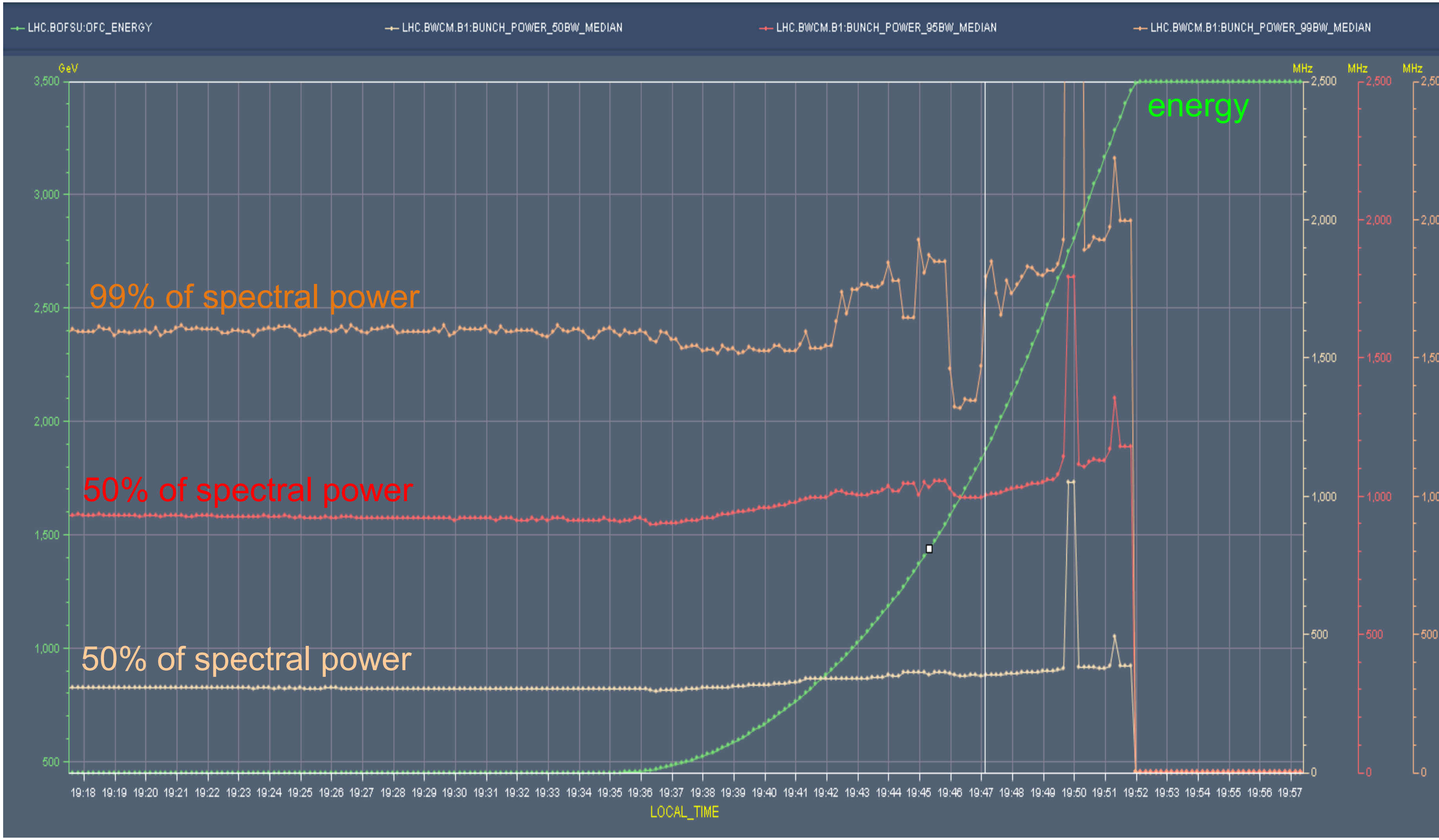
- Pick-up based on 70ies SPS RF design
- BI's mode of operation:
  200 turn average
  + response compensation
- Limited by systematics (reflections, tails, etc.)

Comparison of Bunch Length Estimates



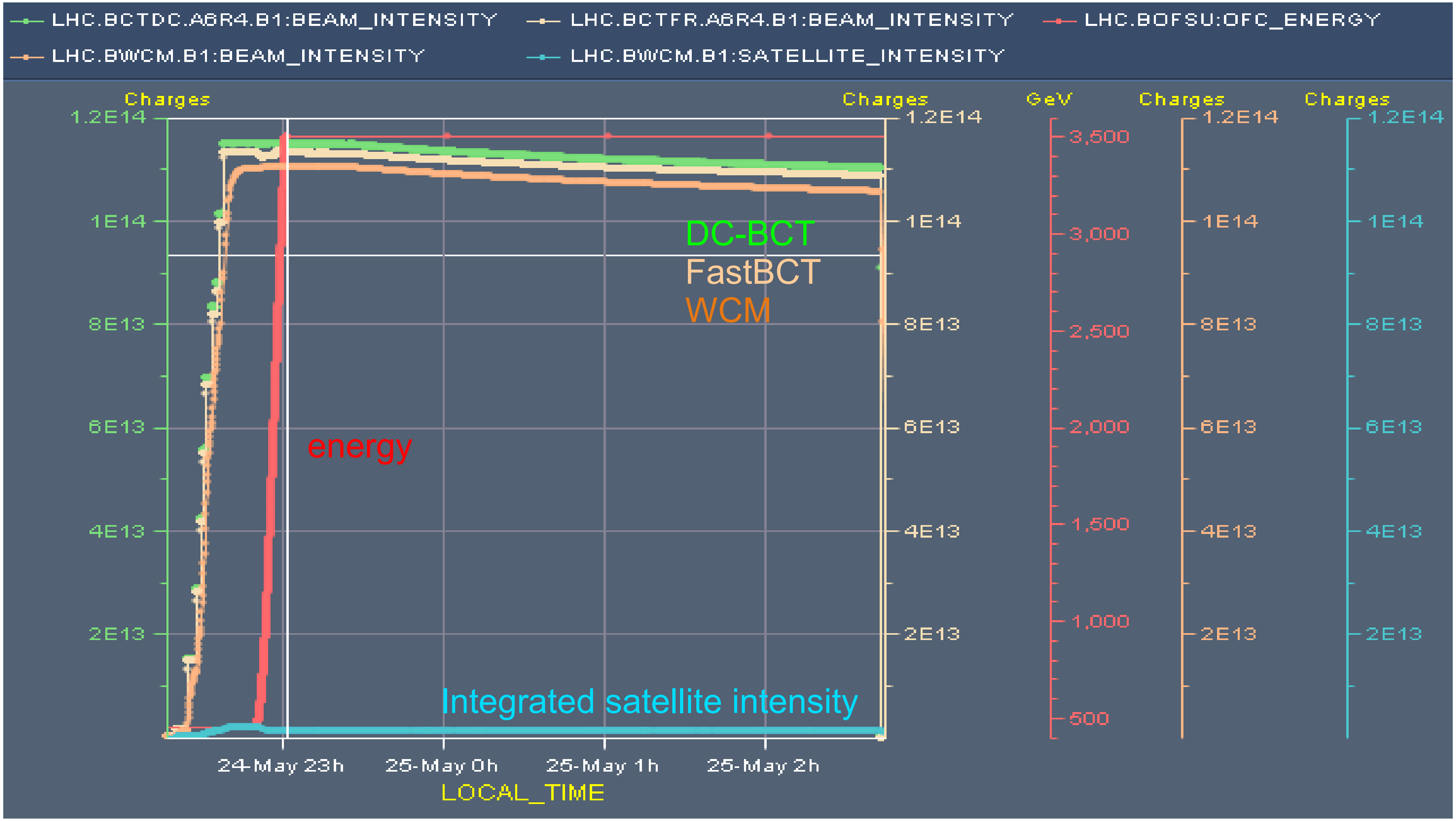
- … there is no obvious bunch length → shape changes are important
  - difference between FWHM (BQM) and x^2-fit Gaussian length estimate

Comparison of Bunch Power Estimates



- Estimates give an indication of shape and required device bandwidths

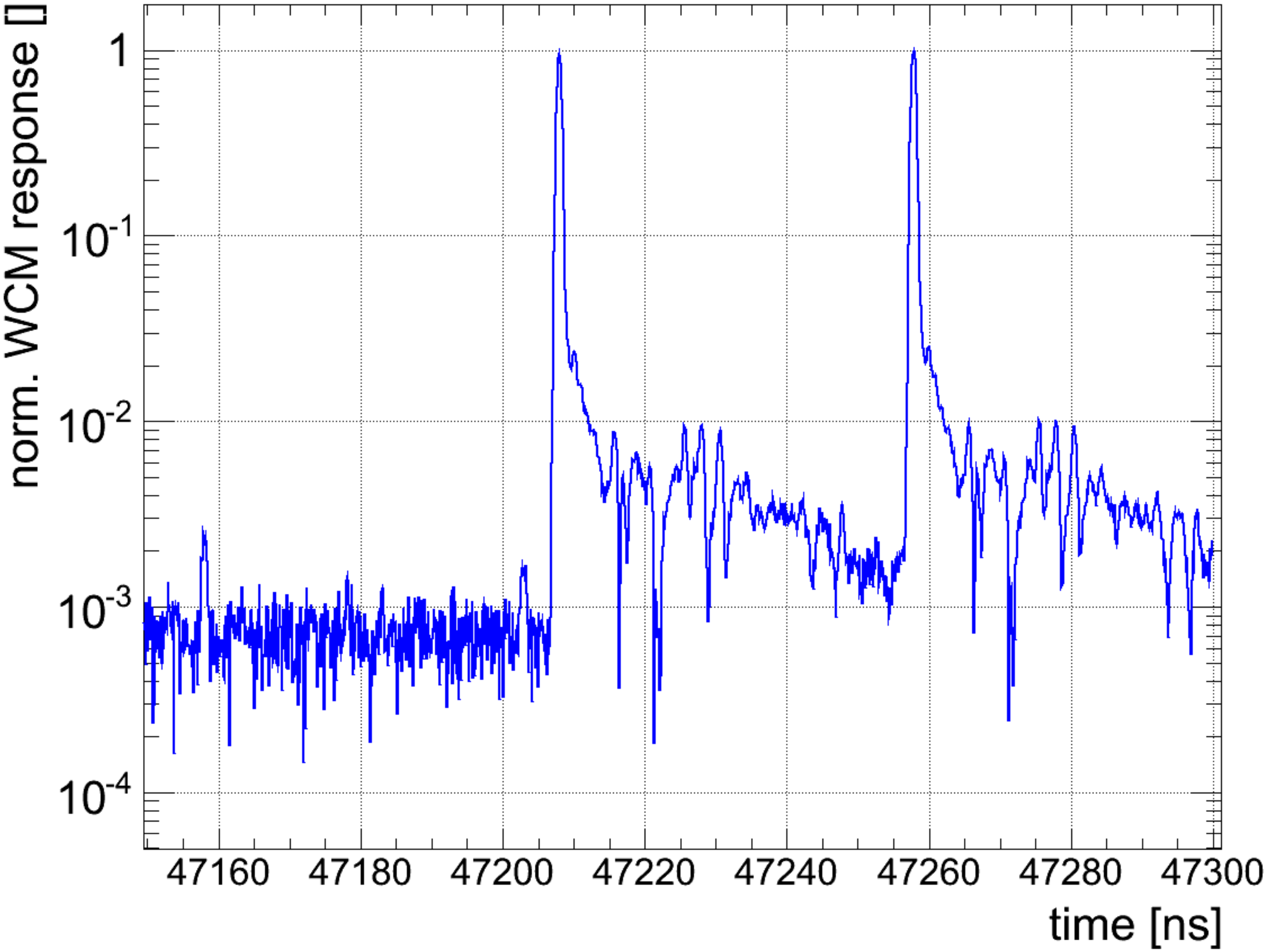
Comparison of Bunch Intensity Estimates



- WCM cross-calibrated to DC-BCT using a single nominal bunch (satellite free)
  - Typically percent-level beam outside nominal bucket
- Being addressed: local 400 MHz phase stability → affects 1st satellite after main bunch

What can be achieved – LHC

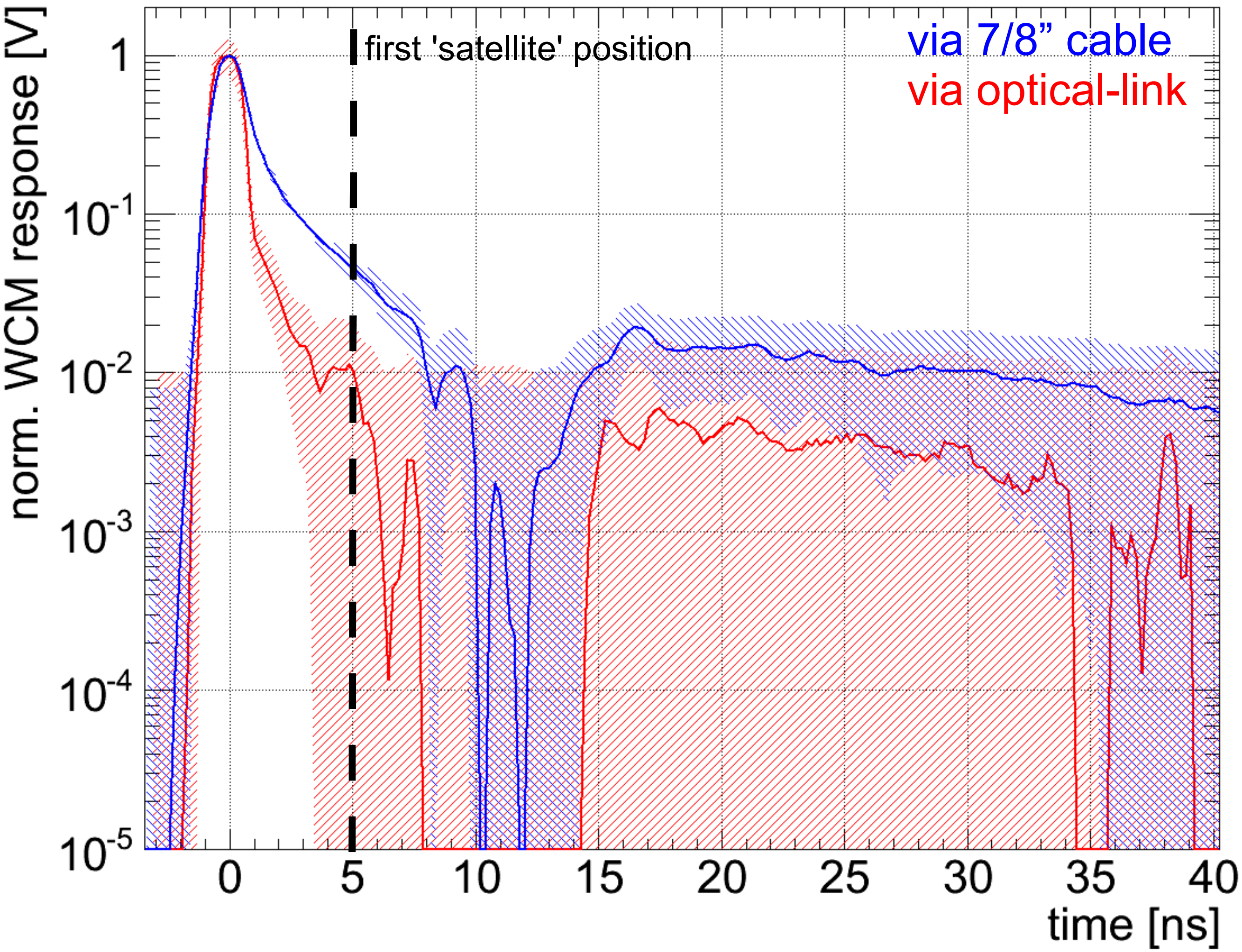
- Example: satellites 50 (PS?) and 2.5 ns (LHC) prior to bunch train



- 2.5 ns satellites after bunch visible but dominated by WCM tails/reflections...

What can be achieved – SPS

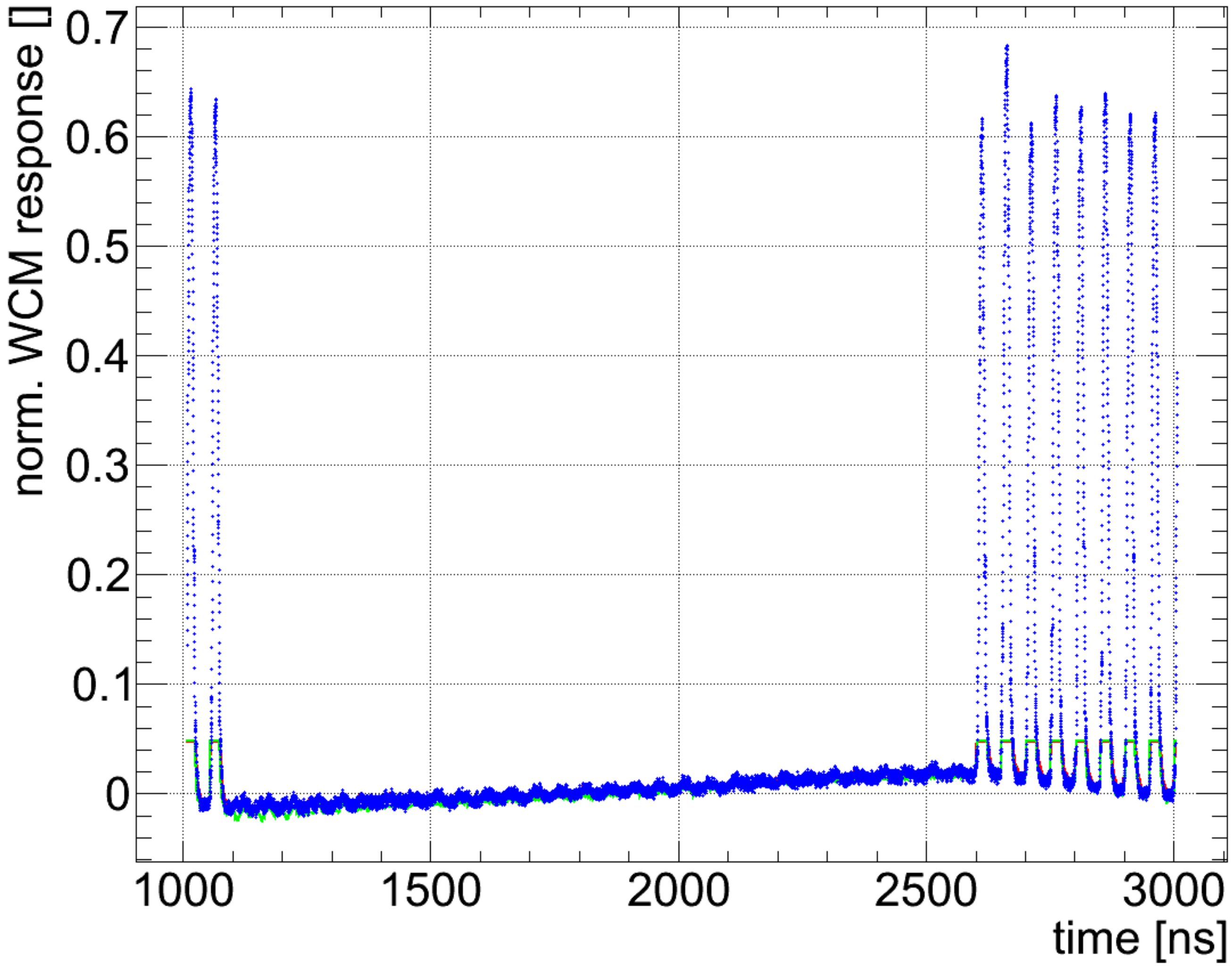
- “Mother” design for LHC APWL, would expect similar performance



- higher bandwidth with optical link but noise compared to 7/8” cable
  → shorter cables/acquisition system in the SPS tunnel needed

What could be achieved – PS I/II – Preliminary

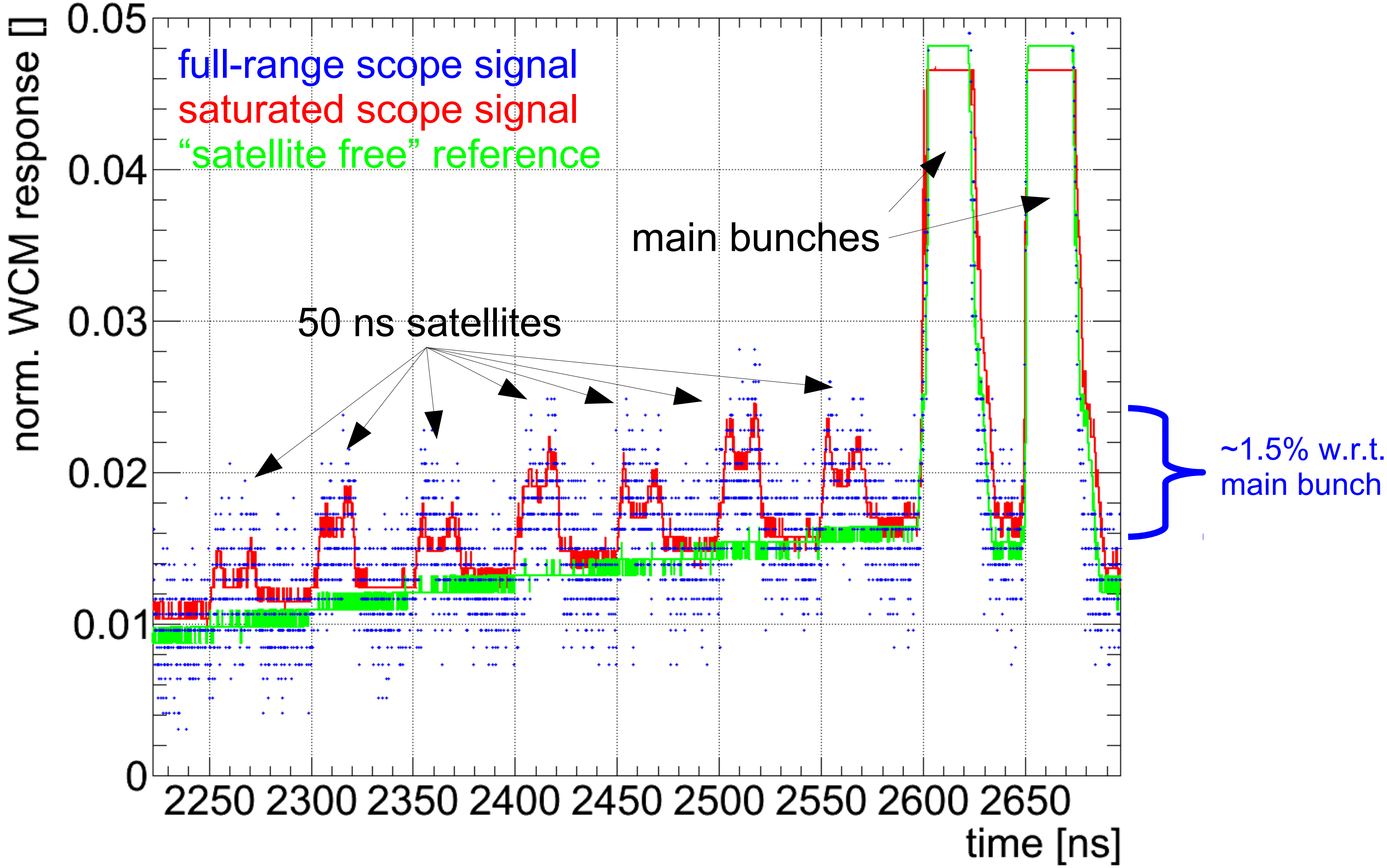
- Initial test comparing single turn acquisition (no 200 turn avg. yet … being analysed)



- Dominated by WCM systematic,known tails & reflections → upgrade planned

What could be achieved – PS II/II – Preliminary

- Forcing satellites and saturating the scope input (fast recovery time)



- Satellites 'visible' and results look promising but requires post treatment to compensate for reflections, pick-ups response, droop etc.

Following slides focus more on the technical implementation aspect

Bunch Length Estimates

- Finite Estimates (fit-limits <2.5 ns around peak or 3x noise-floor)
  - COS²-Distribution (probably best): $f(t) = I \cdot \frac{2}{B}\left[\cos(\pi \frac{t}{B})\right]^2 \; for \;\; t \in [-B/2, +B/2], 0 \;\; elsewhere$
    - BUNCH_LENGTH_COS2 (DB)/ bunchLengthCOS2 (FESA?)
  - Parabolic-distribution:
    - BUNCH_LENGTH_PARABOLIC/ bunchLengthParabolic
  - 50/95/99% power (by-product of deconvolution/intensity estimate)
    - BUNCH_LENGTH_POWER50,BUNCH_LENGTH_POWER90.../ bunchLengthPower50, bunchLengthPower95,
- Infinite estimates (N.B. non-physical since RF bucket is finite < 2.5 ns)
  - Full-Width-Half-Maximum (see plot): $FWHM = |x_2 - x_1|$
  - Gaussian distribution: $f(x) = \frac{1}{\sqrt{2\pi\sigma_t}} \cdot e^{-\frac{1}{2}\left(\frac{t-\mu}{\sigma_t}\right)^2}$
    - BUNCH_LENGTH_GAUSS/ bunchLengthGauss
  - RMS (alternate to Gaussian)
    - BUNCH_LENGTH_RMS/ bunchLengthRMS

$$\sigma = <x^2 - <x>> \;\approx \frac{1}{N}\sum_i^N (x-\mu)^2$$