BE-BI Options for Satellite/Ghost Measurements

Ralph J. Steinhagen

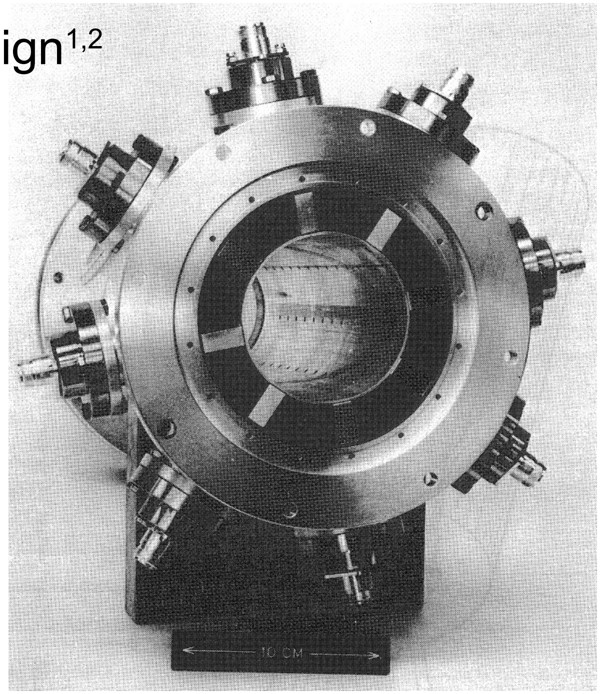
Special thanks to Th. Bohl, S. Bart-Pedersen and H. Damerau

Resumé:

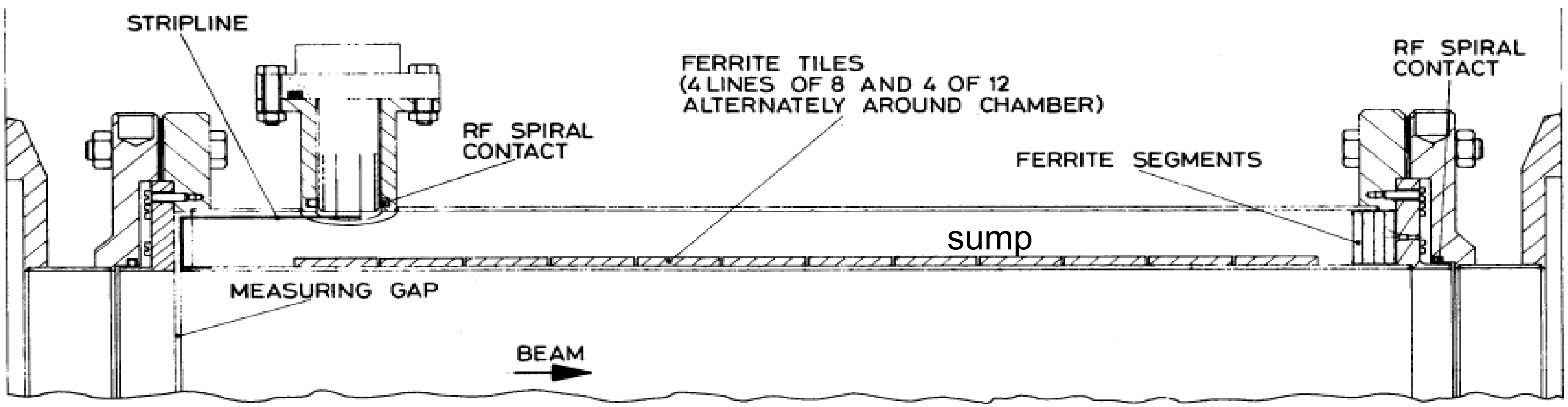
- Detection of ~1%-level Satellites:
  - existing pick-up hardware (WCM) fulfills most requirements
  - 'Visually' easy to detect but … fully automated 'turn-key' system requires system response compensation, further control room level integration
    - experience with LHC BI-WCM could be applied to PS/SPS
- Detection of sub-percent level Satellites ('ghosts') or un-bunched beam:
  - may require/install new high-bandwidth 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)



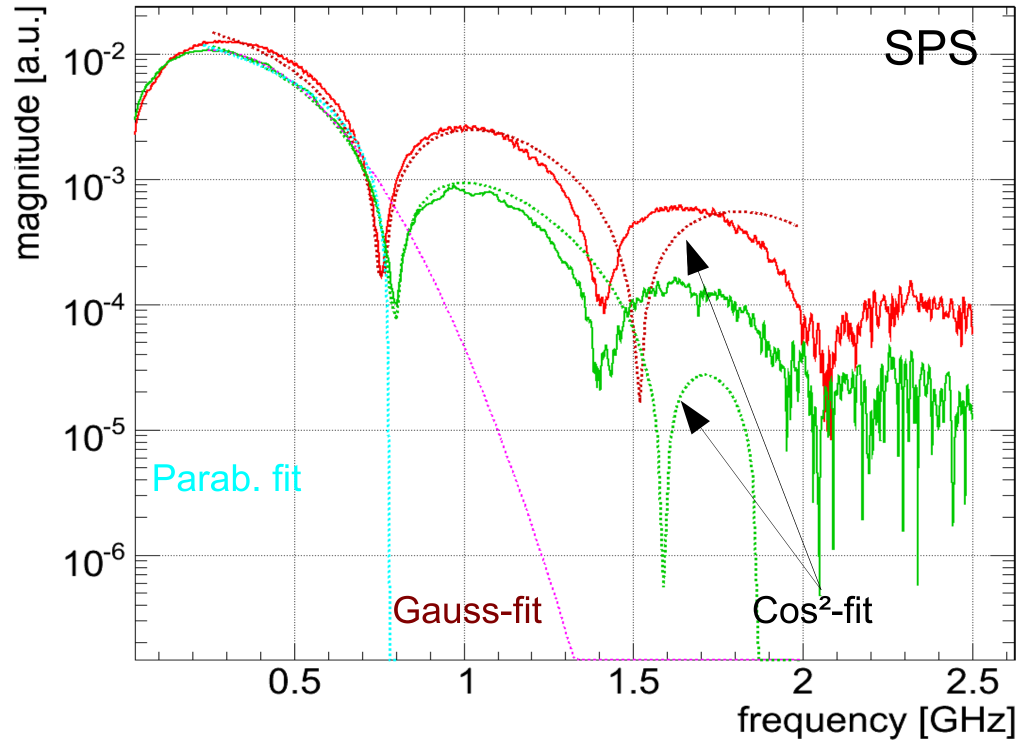
- Idea was not to re-build the turn-based BQM system:
  a) Tackling average signal over N-turns
     → overcomes scope quantisation/noise
  b) full compensation of measured system response
     → necessary to get (any hope of) %-accuracy



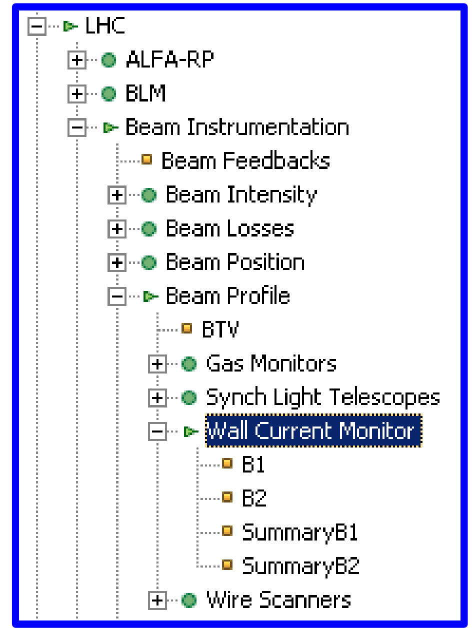
[1]T. Linnecar, "The high frequency longitudinal and transverse pick-ups used in the SPS", CERN-SPS/ARF/78-17, 1978
[2]Th. Bohl, "The APWL Wideband Wall Current Monitor", CERN-BE-2009-999, 2009

Beam-Parameter Measurement and Integration

- Real bunches do not necessarily obey 'Gaussian' shapes

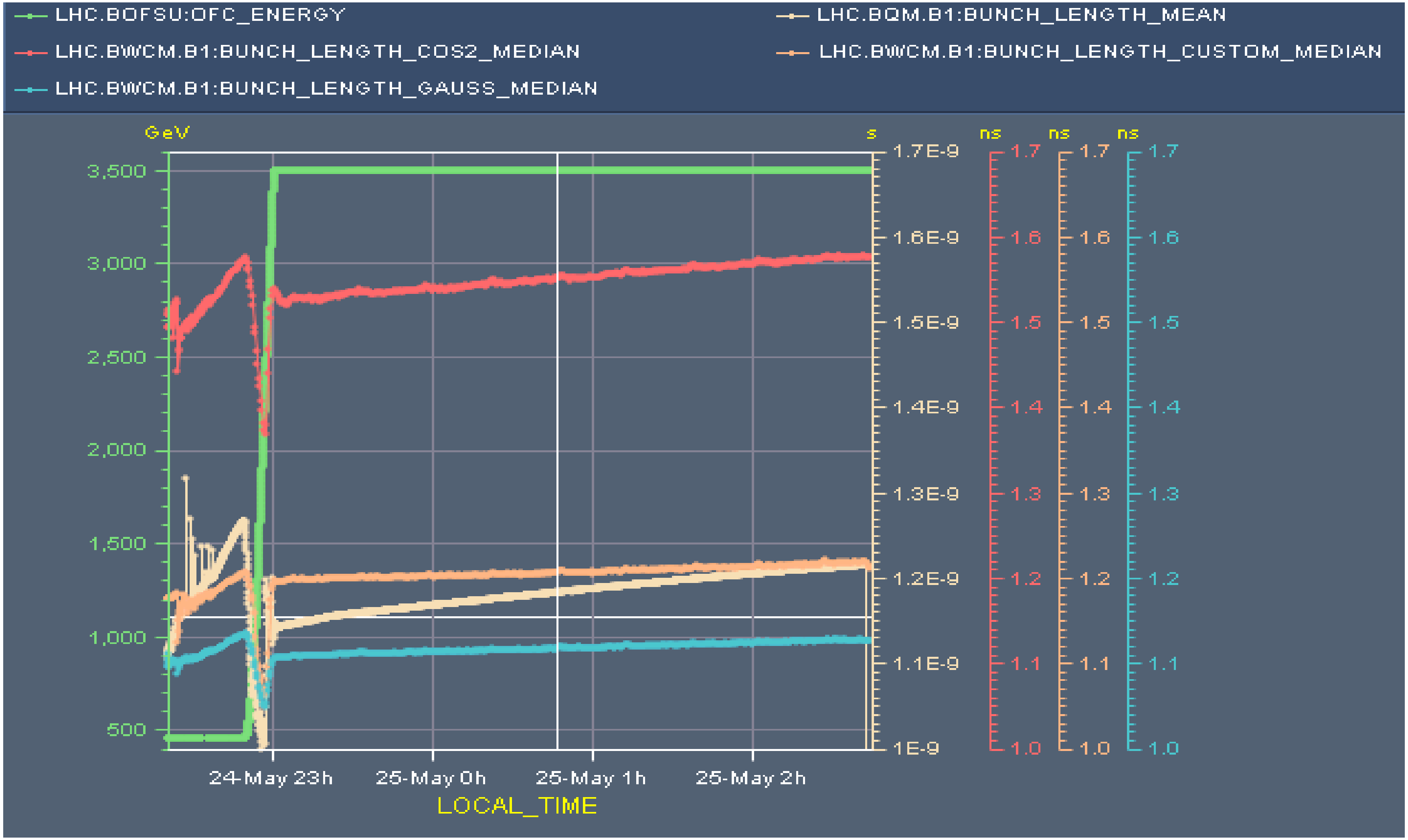


In Timber:



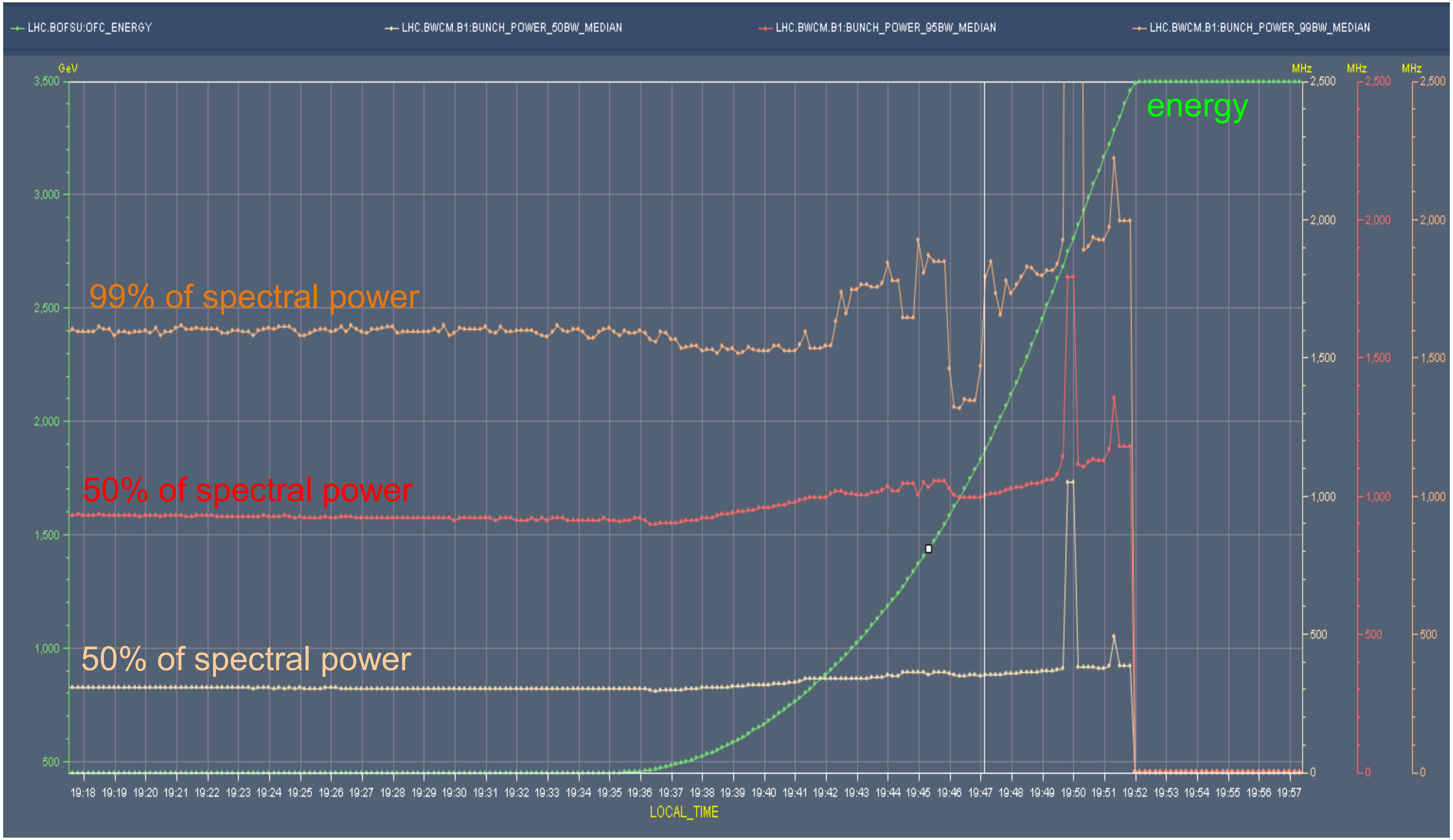
- What's being computed so far:
  - number & intensities of bunches & satellites (per 400 MHz bucket above thres.)
  - true Cos²- , Parabolic- & Gaussian bunch length χ^2-fits
  - Frequency containing 50/95/99% of bunch power/intensities, peak voltages, ...
- Most difference/details are only visible at very high frequencies > 1 GHz
- Response of pick-up, cables, scope at these frequency need compensation!

Comparison of Bunch Length Estimates



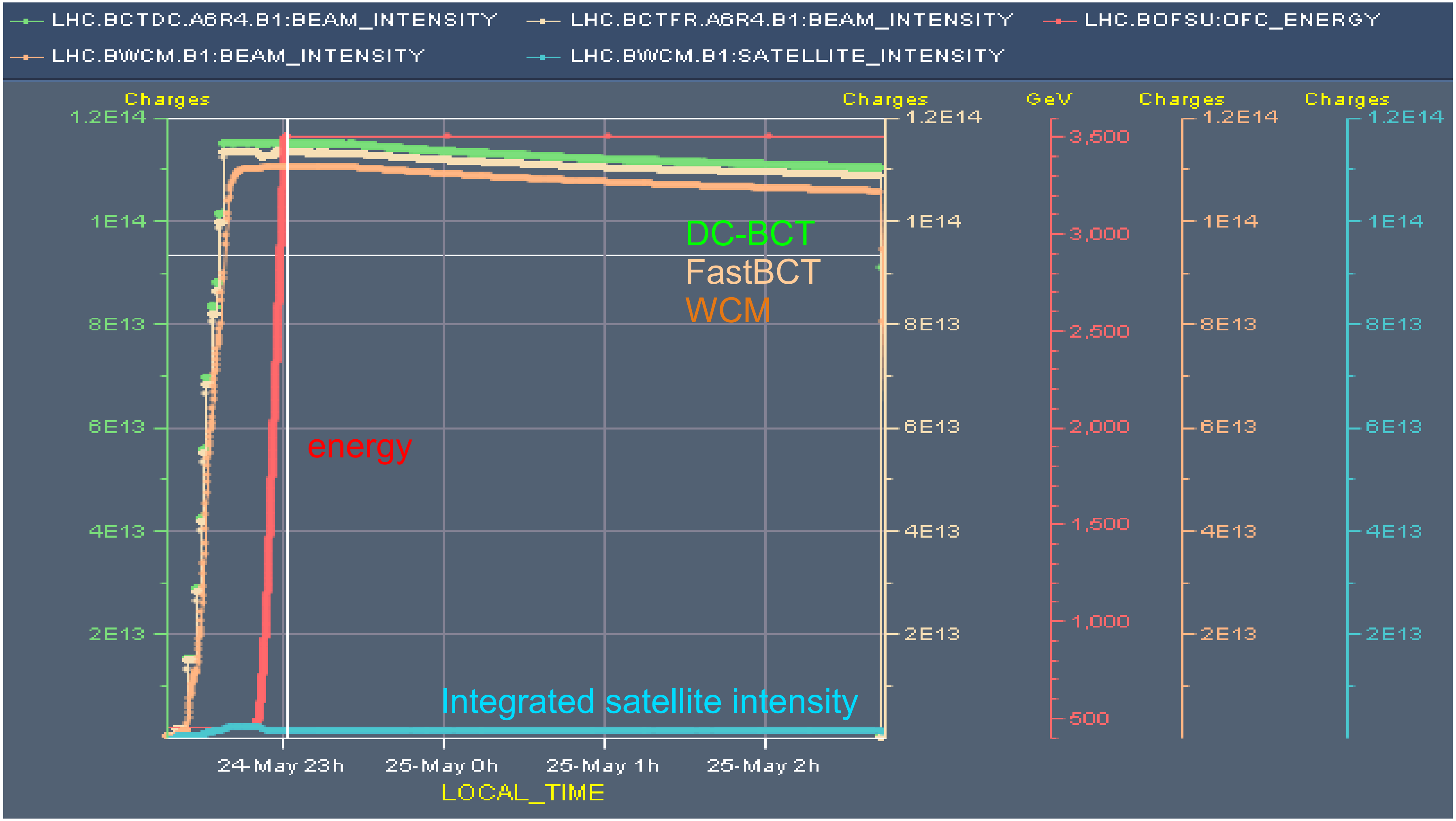
- … there is no obvious bunch length → shape changes are important
  - difference between FWHM (BQM) and x^2-fit Gaussian length estimate

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

Two Options to Achieve sub-% Resolutions (within << 1s)

- Assume main limit is given by noise of the oscilloscope 8-bit (Flash-)ADC

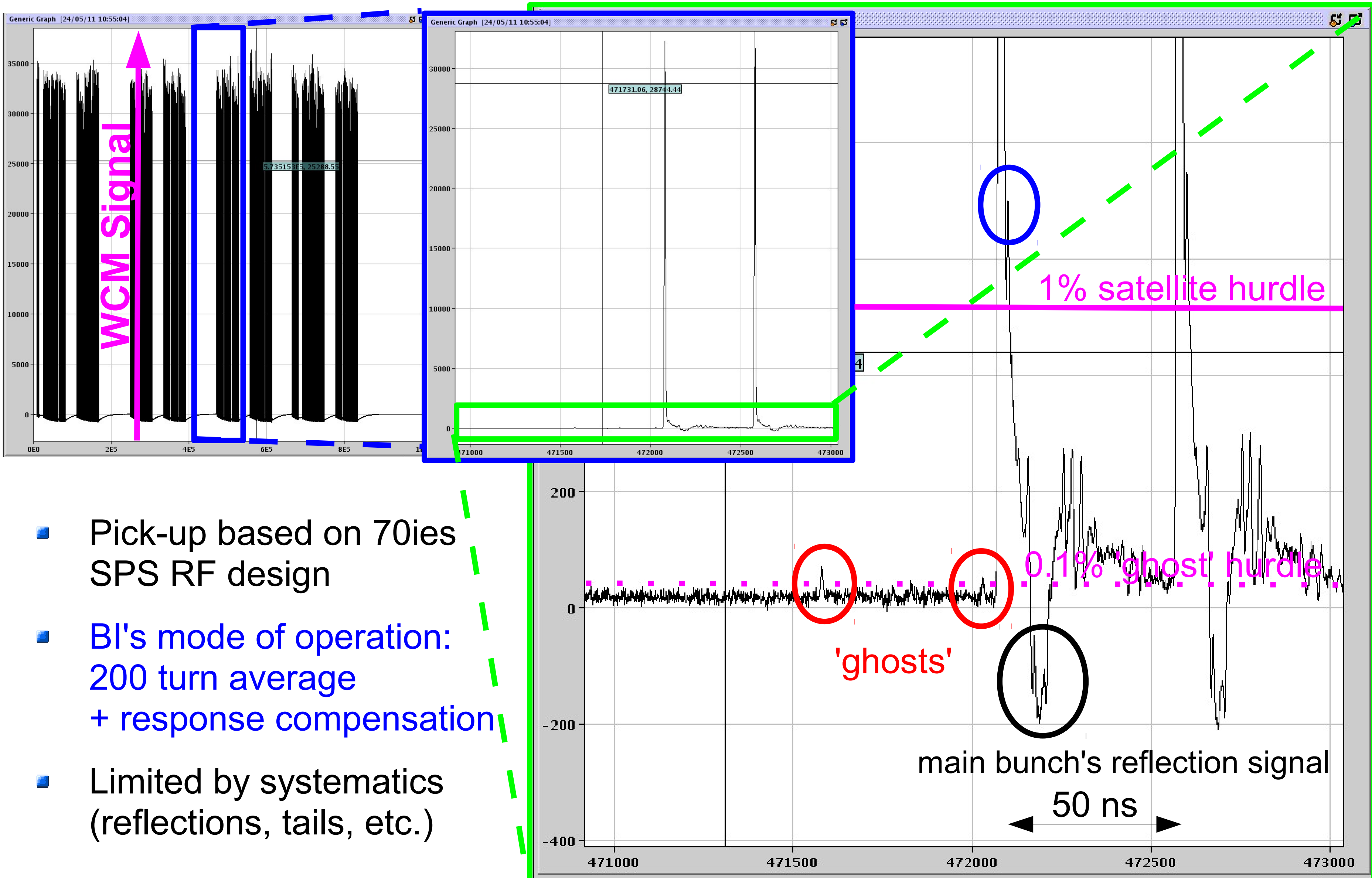
- Noise is sufficiently random/white
  → synchronise and integrate signal over given number of turns
  - Demonstrated and implemented for LHC → resolution 10^{-3}@0.1 Hz
    - Main limit: numeric performance and data transfer limits (DAQ→scope→PC)
      → second (or newer generation) oscilloscope would alleviate this (~ 35 kCHF)
  - Tested at the PS for 50 turns (== maximum duration with stable beams)

- Split signals and saturate one copy to zoom-in on satellites
  - possible due fast-recovery time of oscilloscope's input pre-amplifier
  - saturated channel can be normalised w.r.t. full range copy
  - limit: non-linearity and stability of the Flash-ADC on the sub-10^{-3} level
  - most scopes can deal with this but DAQs need some home-brewn Dev.
  - big advantage: get reasonable results within few turns!!
  - However: read-out speed limit this probably to 1-2 measurements/cycle
    →may need more than one scope/DAQ and fair amount of memory

- N.B. for faster nominal bunch-by-bunch shape measurements we have the BPCLs.

LHC Wall-Current-Monitor Measurement Example

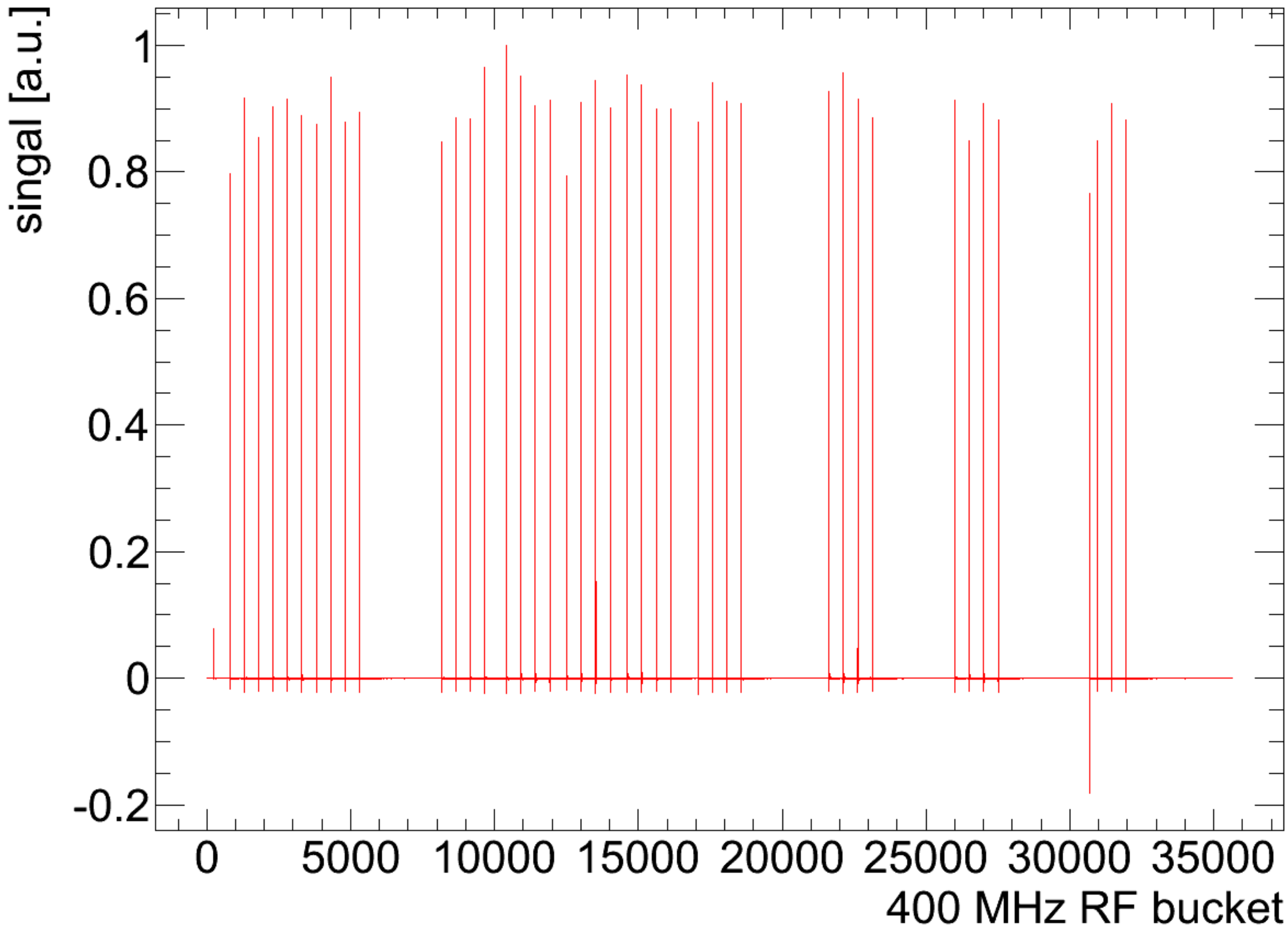
- LHC setup: WCM → short (30 m) 7/8” cable → 3 GHz Scope → post-processing...



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

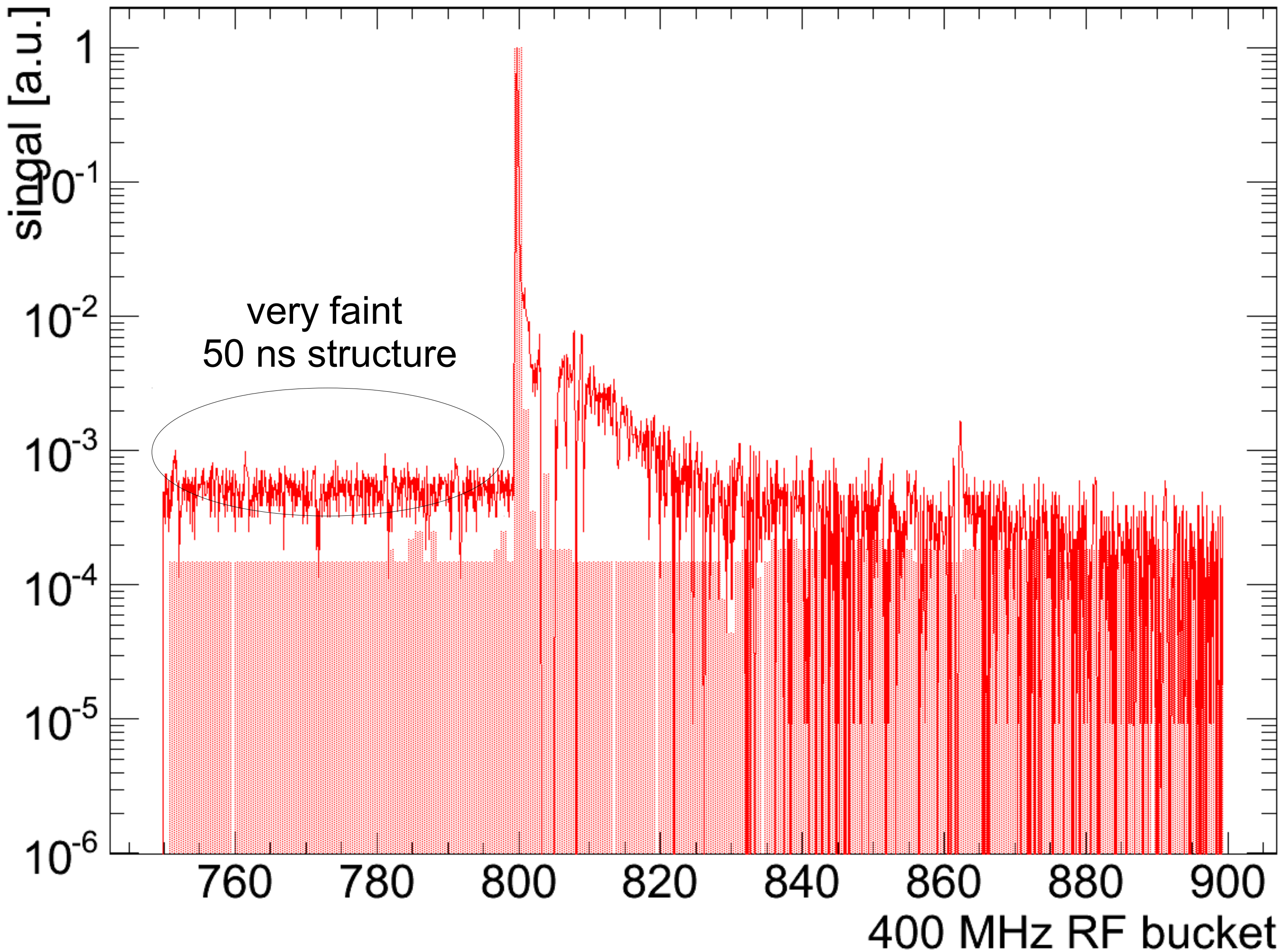
VdM Scan on 15th of May I/II

- Beam 2



VdM Scan on 15th of May II/II

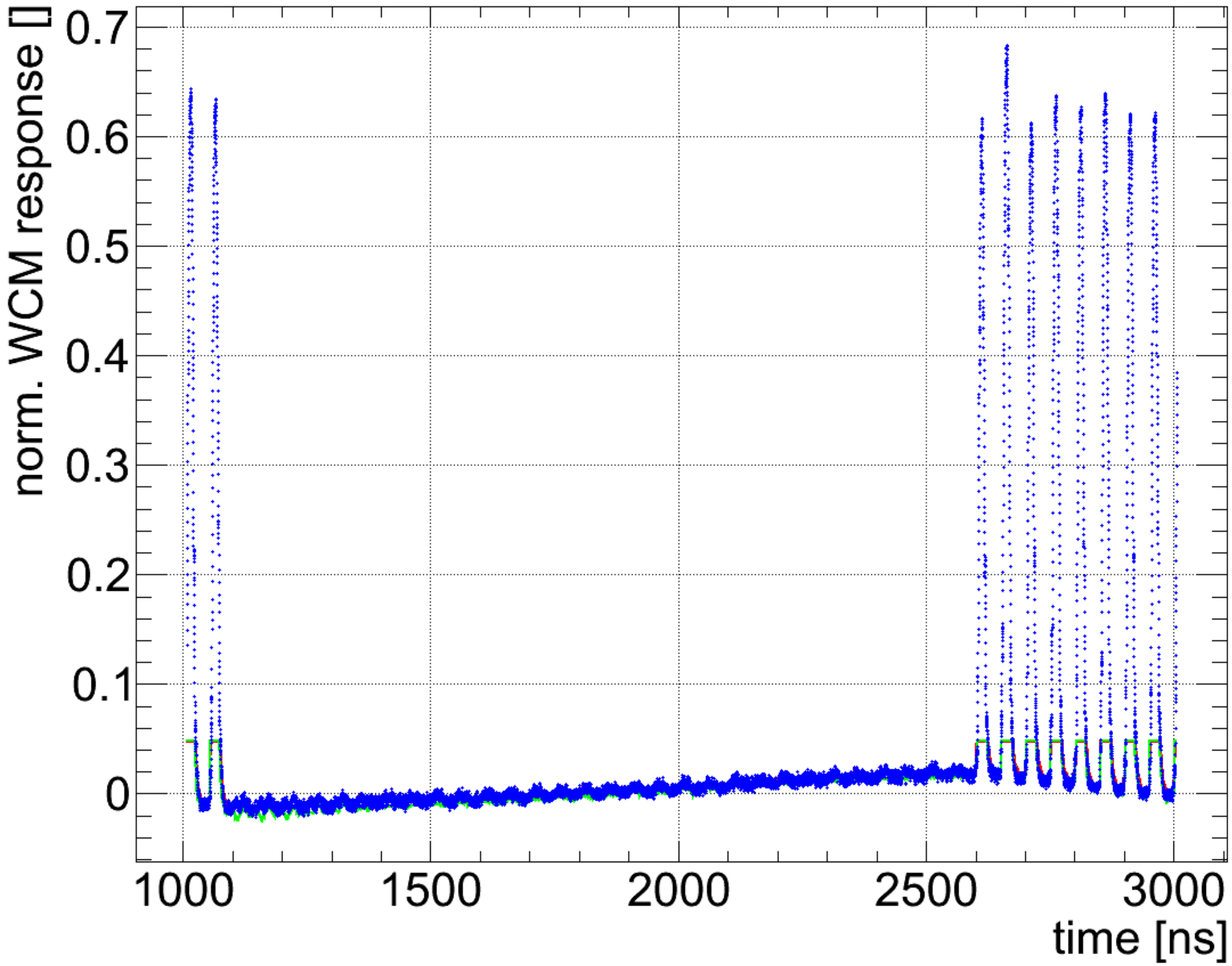
- Beam 2 – first nominal bunch



- WCM tails, reflections & droop → can be compensated (see later slides)

What could be achieved – PS I/II – Preliminary

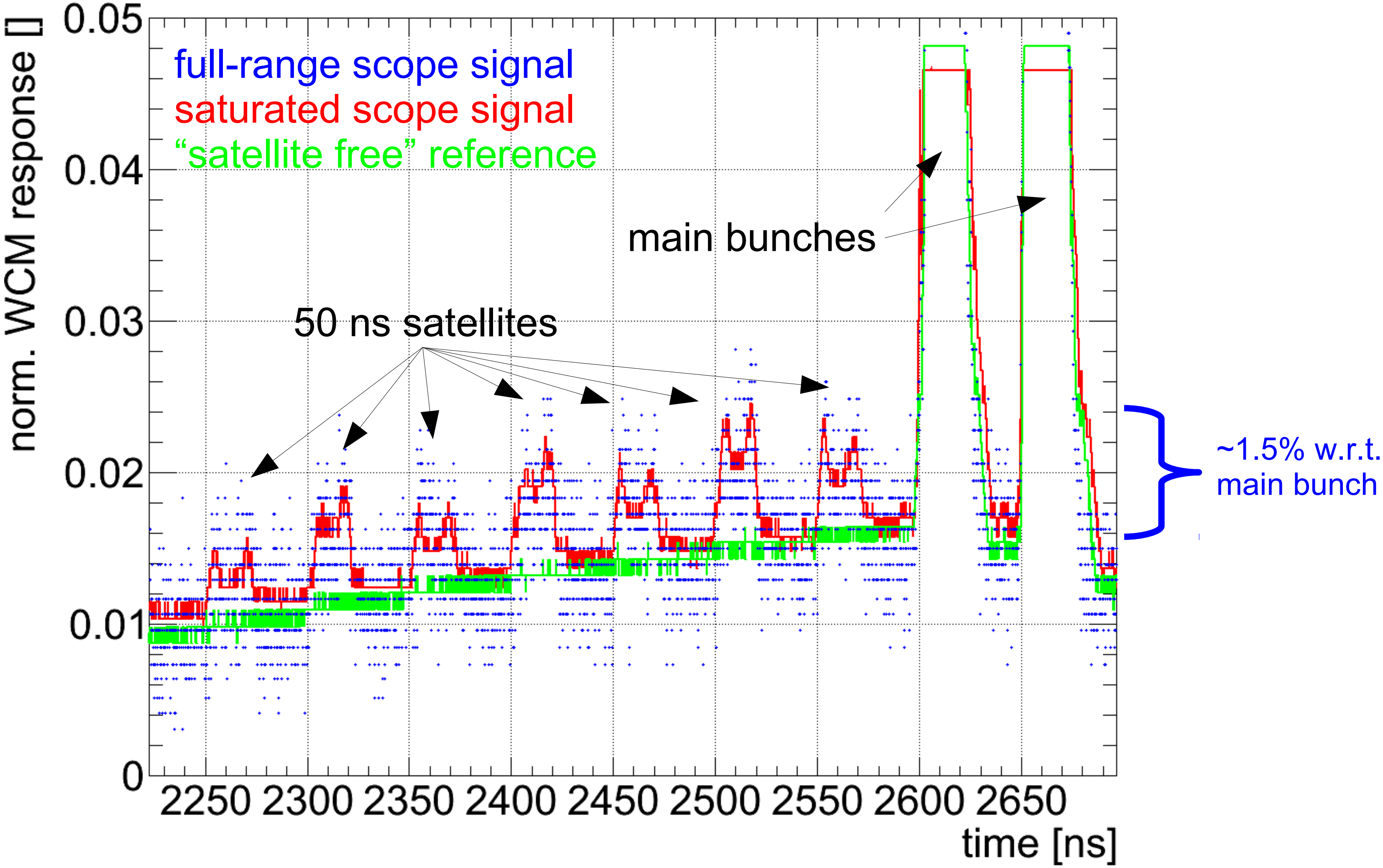
- Initial test comparing single turn acquisition (no 200 turn avg. yet … being analysed)



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

What could be achieved – PS II/II – Preliminary

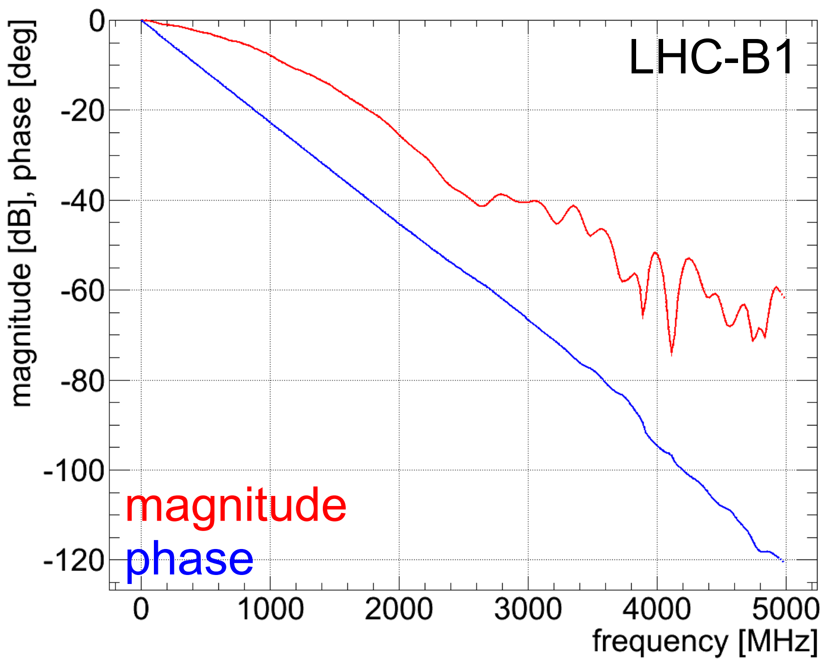
- Forcing satellites and saturating the scope input (fast recovery time)

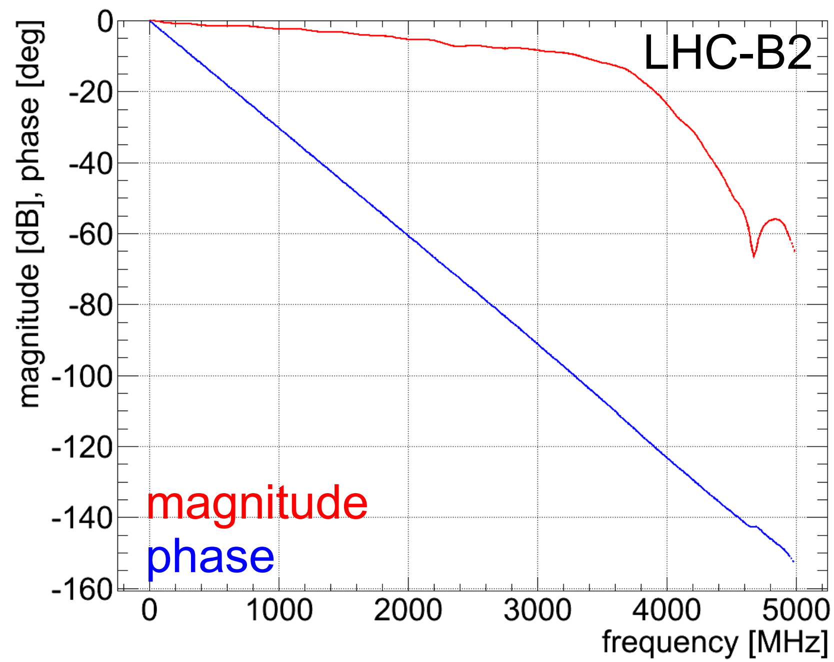


- Satellites 'visible' and results look promising but requires post treatment to compensate for reflections, pick-ups response, droop etc.

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

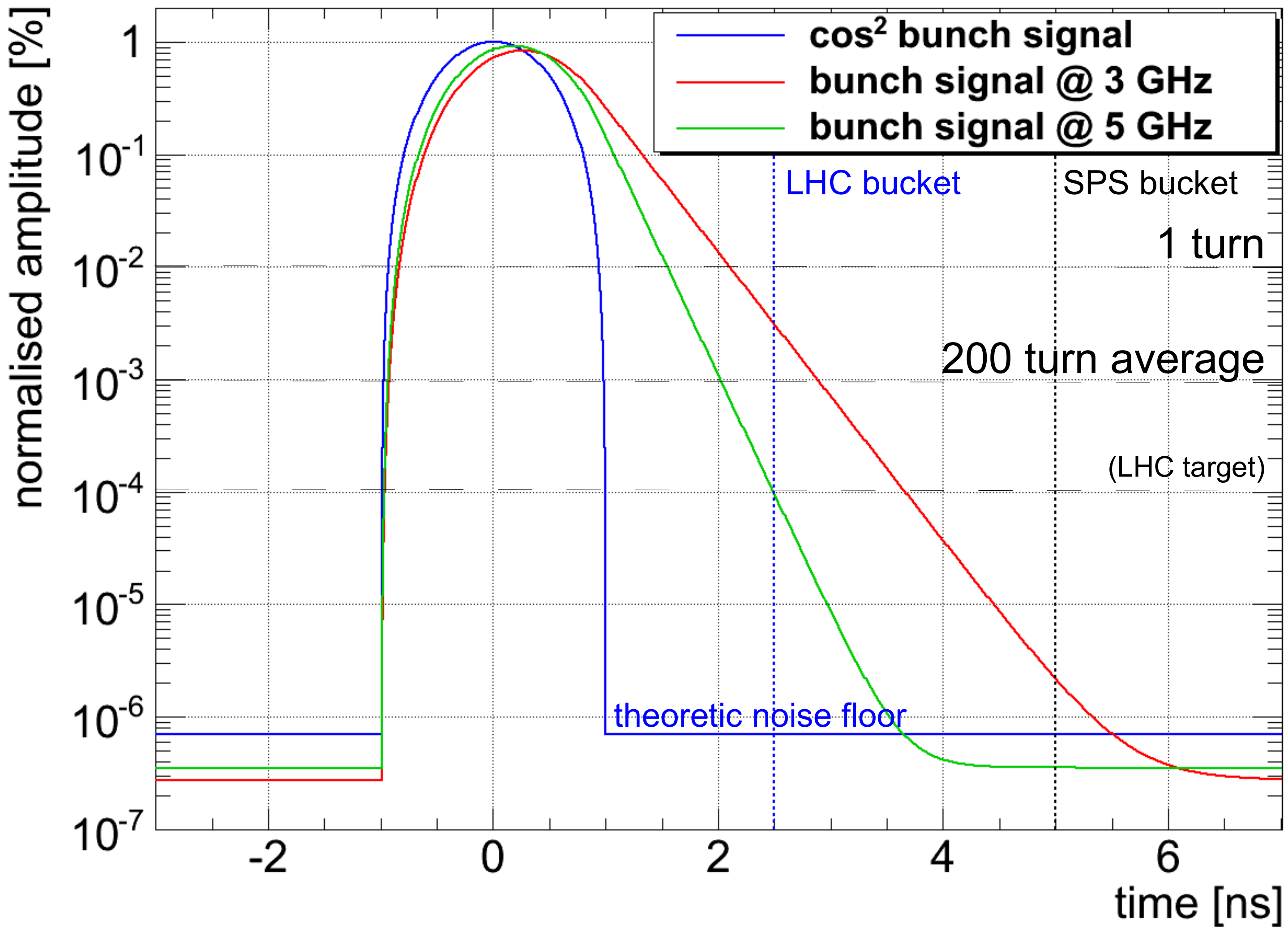




- Historical: (very) high numerical complexity if treating raw 20 (100) us frames

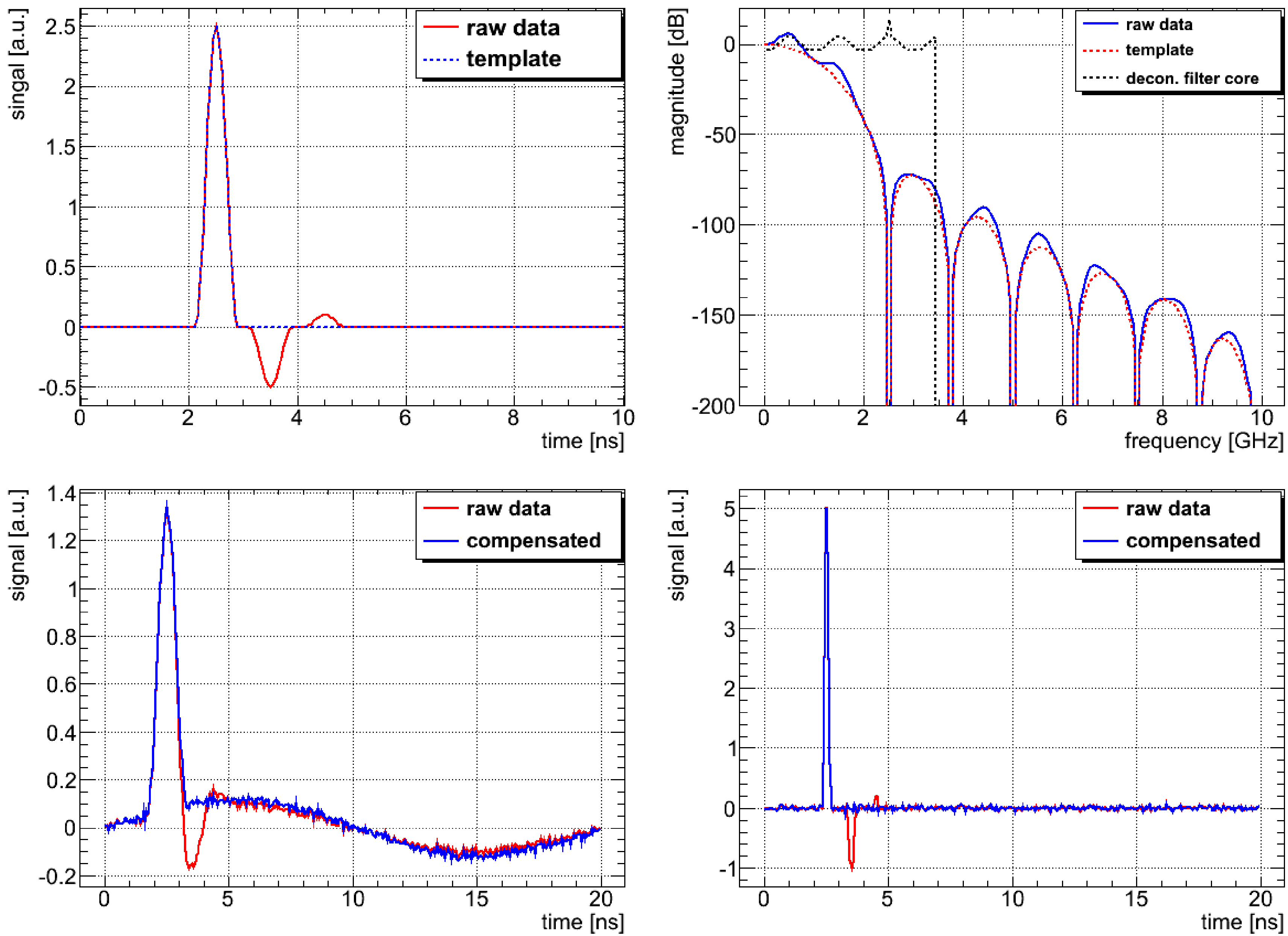
Fundamental limits of the WCM-based Scheme: 'Satellite' → 'Ghost' Detection Potential

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

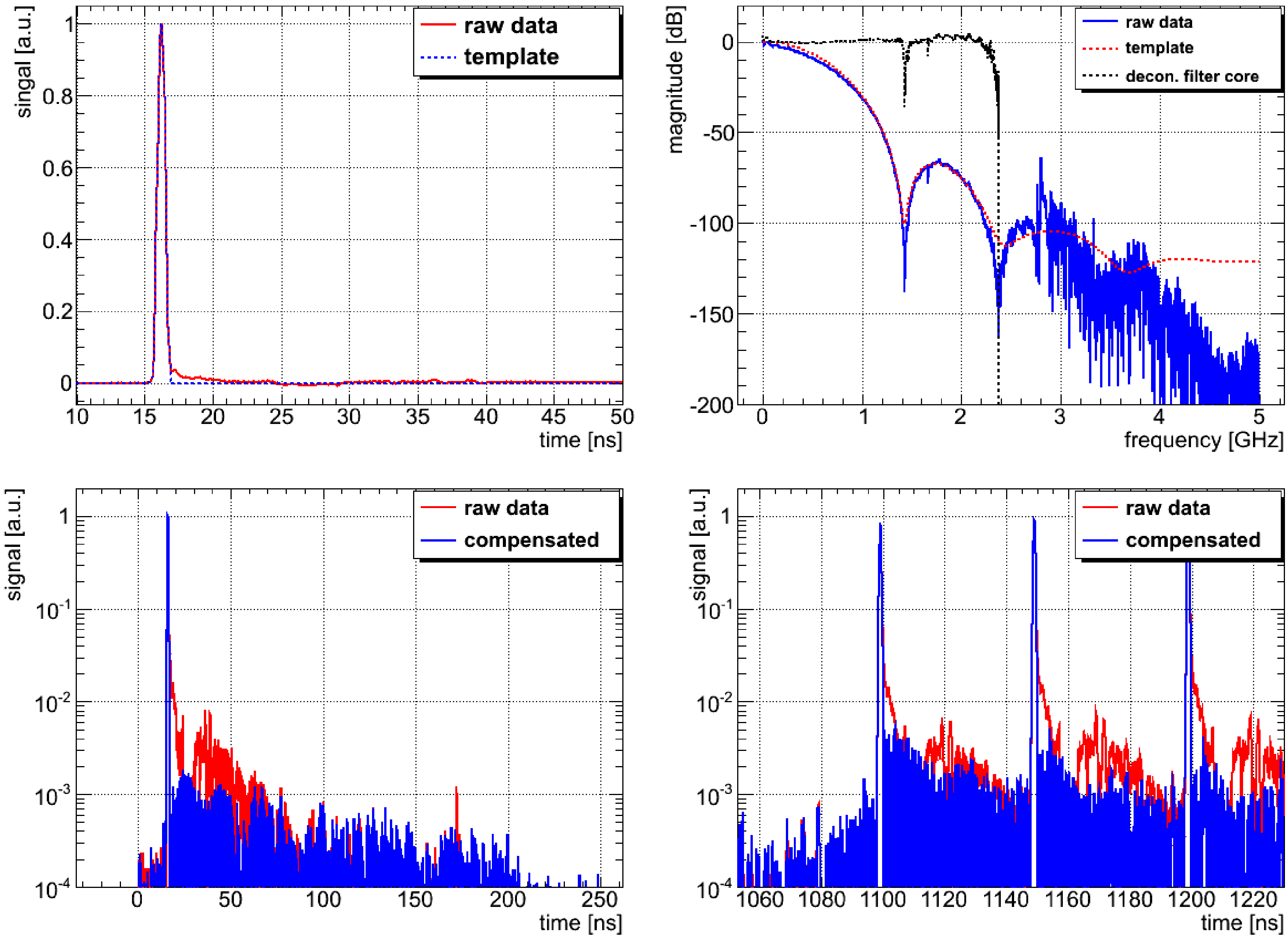


- … limited by unavoidable systematic due to transmission line transitions, reflections, etc. (N.B. difficult to control better than 10^{-3} on > 2 m distances)

Linear Response Compensation – Simulated Data



Linear Response Compensation – Life-Beam Data



Summary

- Detecting satellite/ghost bunches can be achieved with existing PS/SPS/LHC pick-ups infrastructures
- High resolution/bandwidth relative measurements easily possible via:
  a) Fast-Frame average over a couple of hundred turns
  b) Splitting signal and saturating its copy to specifically detect satellites
    - possible since Oscilloscope input pre-amplifier recovers within a few ns

  → For the LHC we would need a new 2nd scope, PS → DAQ/Scope

- A robust absolute accuracy of better than 10^{-3} remains probably a domain better tackled by the FastBCT/DC-BCT, main limitations:
  - Flash-ADC linearity, pick-up position sensitivity, cable drifts,
    … could a priori be compensated but system drifts continuously on < 10^{-3} level
  - Need a better "proto-response template" (→ BI-MD in '12!)

- Have been in contact/surveilled potential oscilloscope and DAQ suppliers
  - total of 44 out of which 12 (3) qualify w.r.t. the PS (LHC) requirements
  - cost estimate: 20-35 kCHF per system (depending on final requirements)

- Question: do and which options do we want to exploit for PS and LHC?
  - Hardware resources and integration (mostly BI-SW)? Users? Duplication/Synergies with RF & OP groups? Who drives the interest/use case? BI? OP?

Supporting Slides

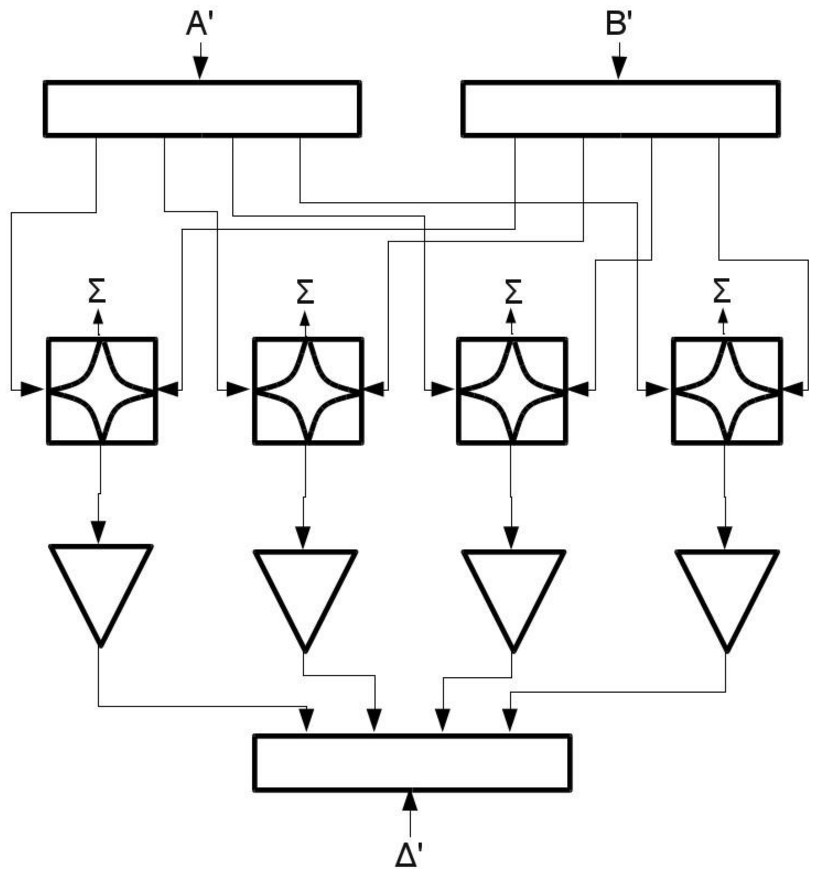
Some of the potential Oscilloscope/DAQ Suppliers

- Let me know if some company is missing

Company	Company URL	Max. BW [GHz]	Scop	DAQ?	Last checked	Comment
Acquitek	http://www.acquitek.com/	0.2		X	last checked: 2011-10-20	7GHz Transient Digitizer & iMSO-104 (5 MHz)
AEMC Instruments	http://www.aemc.com/	0.2	X		last checked: 2011-10-20	hand-held
Agilent Technologies	http://www.agilent.com/	33	X	X	2011-10-20	one of the usual suspects
Analog Devices	http://www.analog.com	0.5		X	2011-10-20	evaluation board
ATTEN	http://www.attenelectronics	0.2	X		2011-10-20	Agilent derivative?
BK Precision	http://www.bkprecision.con	0.1	X		2011-10-20	
BST	http://www.bstcaltek.com/	0.02	X		2011-10-20	Hand-held
CERN	http://wikis.cern.ch/display	0.05		X	last checked: 2011-10-20	VME card
CHAUVIN ARNOUX	http://www.chauvin-arnoux.	0.2	X		last checked: 2011-10-20	
EXFO	http://www.exfo.com/	0	X		last checked: 2011-10-20	500 GHz bandwidth sampling scope
Extech	http://www.extech.com/	0.06			last checked: 2011-10-20	hand-held
Fluke	http://www.fluke.com/	0.2	X		2011-10-20	
Gage	http://www.gage-applied.c	1.5		X	last checked: 2011-10-20	
GW Instek	http://www.gwinstek.com/	0.35		X	last checked: 2011-10-20	
Hamamatsu Photonics	http://www.hamamatsu.co	0	X		last checked: 2011-10-20	70 GHz bandwidth sampling scope
Iwatsu	http://www.iti.iwatsu.co.jp	0.5	X		2011-10-20	
Keithley	http://www.keithley.com/	0.00125	X		last checked: 2011-10-20	comment: PC card
Lab Kits	http://www.lab-kits.com/	0.2	X		2011-10-20	
Lecroy	http://www.lecroy.com/	45	X		2011-10-20	one of the usual suspects
Link Instruments	http://www.linkinstruments.	0.2		X	last checked: 2011-10-20	USB
Meilhaus Electronc GmbH	http://www.meilhaus.de/	0.001		X	2011-10-20	comment: PC cards
MEN Mikro Elektronik	http://www.menmicro.com/	0.01		X	last checked: 2011-10-20	
Metrix	http://www.metrix.com/	0.15	X	X	last checked: 2011-10-20	
National Instruments	http://www.ni.com	5		X	last checked: 2011-10-20	512 MB/ch
National Semiconductor	http://www.national.com	3.6		X	2011-10-20	evaluation board, 12 bit!!
OWON Technology	http://www.owon.co.uk/	0.2	X		last checked: 2011-10-20	
Pico Technology	http://www.picotech.com/	0.5		X	2011-10-20	USB, 12 GHz sampling scope (7 kEUR)
PROMAX ELECTRONICA	http://www.promax.es/	0.2	X		2011-10-20	
RigoIna	http://www.rigolna.com/	1	X		last checked: 2011-10-20	Agilent derivative?
Rohde Schwarz	http://www.hameg.com/ &	2	X		last checked: 2011-10-20	one of the usual suspects
Seeed Studio	http://www.seeedstudio.co	0.144	X		last checked: 2011-10-20	hand-held (custom)
Signatec	http://www.signatec.com/	2		X	last checked: 2011-10-20	comment: PC card
SP Devices	http://spdevices.com/	2		X	last checked: 2011-10-20	cooperative
Tecpel	http://www.tecpel.com/	0.15	X		2011-10-20	
Tektronix	http:// www.tek.com	33	X		last checked: 2011-10-20	one of the usual susp scopes only
Texas Instrument	http://www.ti.com	0.08		X	last checked: 2011-10-20	evaluation board
TiePie engineering	http://www.tiepie.com/	0.2		X	2011-10-20	(USB)
TPI Test Products Internatio	http://www.testproductsintl	0.02	X		2011-10-20	hand-held
UNI-T	http://www.uni-trend.com/	0.2		X	last checked: 2011-10-20	
Unisource Corporation	http://www.unisourceworld	0.1	X		last checked: 2011-10-20	
Velleman	http://www.velleman.eu/	0.03		X	last checked: 2011-10-20	box (parallel port)
Wuntronic GmbH	http://www.wuntronic.com/	1.5		X	2011-10-20	
Yokogawa	http://www.yokogawa.com	1.5	X	X	2011-10-20	

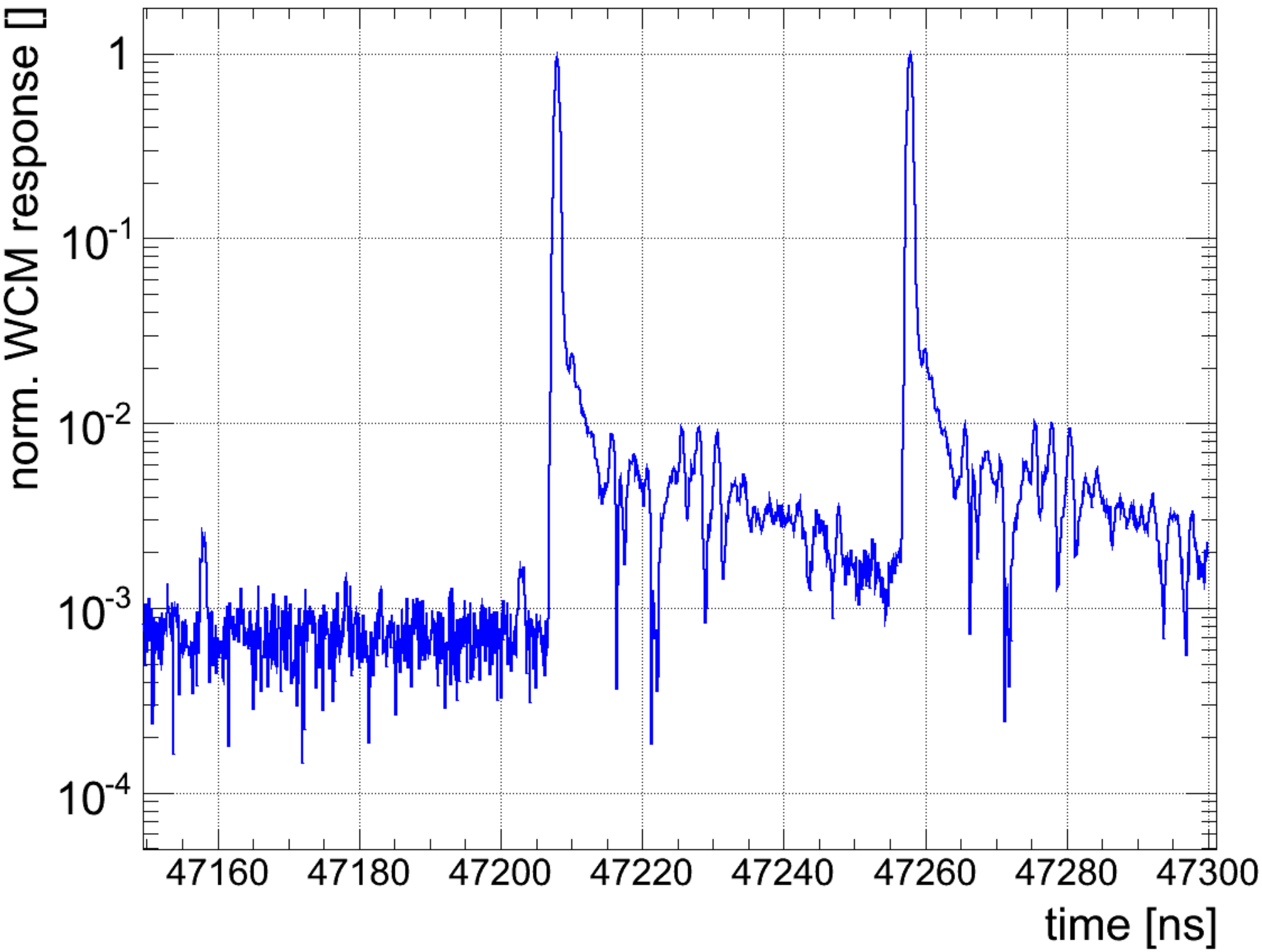
Divide and Concquer Strategy for higher System Bandwidths

- Split signal into manageable bandwidths and treat them separately and re-combine them in the end
  - Attenuate/amplify bands with expected strong/weak power contributions
  - Post-processing (de-convolution) probably mandatory (difficult to passively match each part)



What can be achieved – LHC

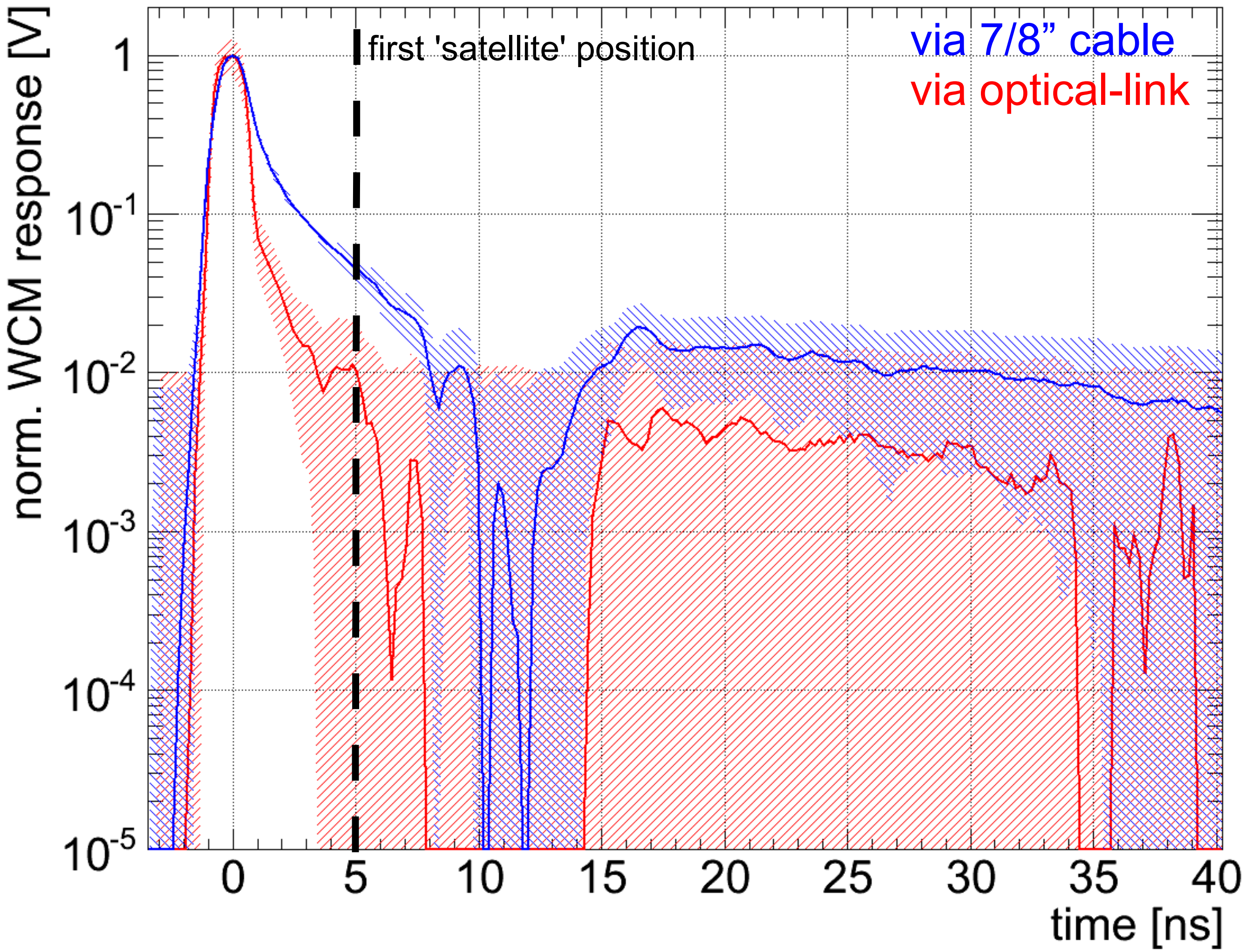
- Example: satellites 50 (PS?) and 2.5 ns (LHC) prior to bunch train



- 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