BI Wall-Current-Monitor

Description of the

required FESA class functionality

– first iteration –

Ralph J. Steinhagen

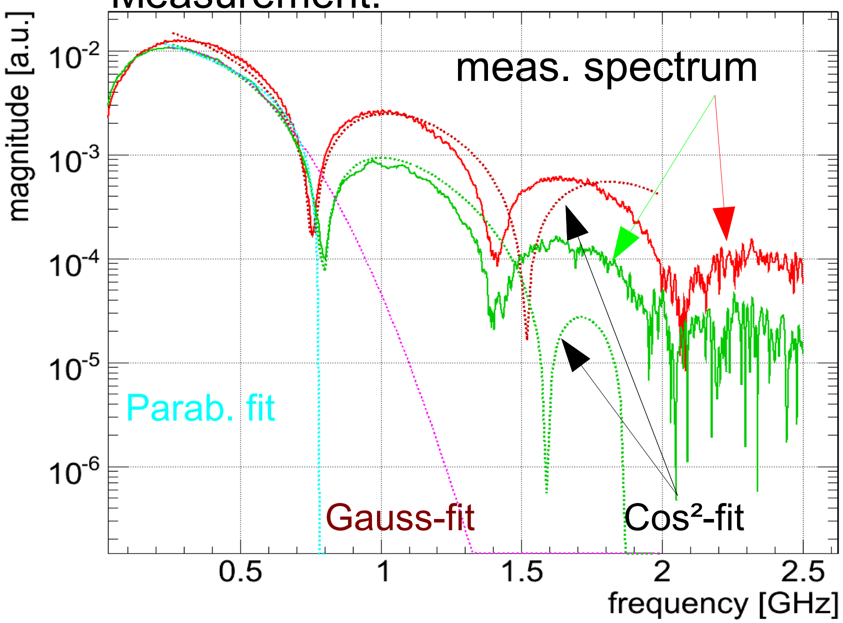
Definitions and Conventions

- Some definitions:
  - LHC RF frequency 400 MHz
    - 35640 RF buckets
    - 3564 bunch slots, however only 2808 will be nominally filled
- Some conventions:
  - Too many (mostly empty) RF buckets → stick to nom. 25 ns bunch slots and possibly note the nx2.5ns shift if not in nominal bucket
  - Distinguish
    - 'bunch': requested bunch in nominal RF bucket
    - 'satellite': undesired bunch elsewhere
      - mostly much below nominal bunch intensity, but
      - could be a nominal bunch with a RF injection bucket error
- Targeted time-scale of observations: few-seconds → hours (via IIR average filter)
- Calculate each parameters per bunch/satellite (arrays) and provide statistic summary of each parameter per beam for quick access/analysis in logging:
  - e.g. '_MEAN', '_MAX', '_MIN', '_STDEV', '_MEDIAN' (?)
  - Example: 'BUNCH_INTENSITY_MEAN', etc....

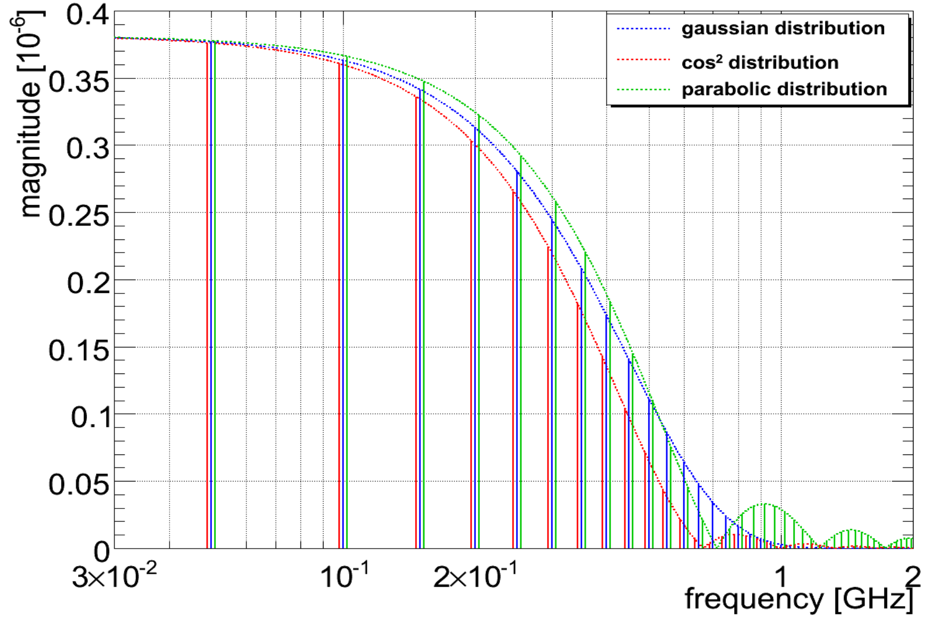
Compensation of WCM System Response On the Bunch Shape

- Real-life bunch does not necessarily obey 'Gaussian' or 'cos²' shapes

Measurement:



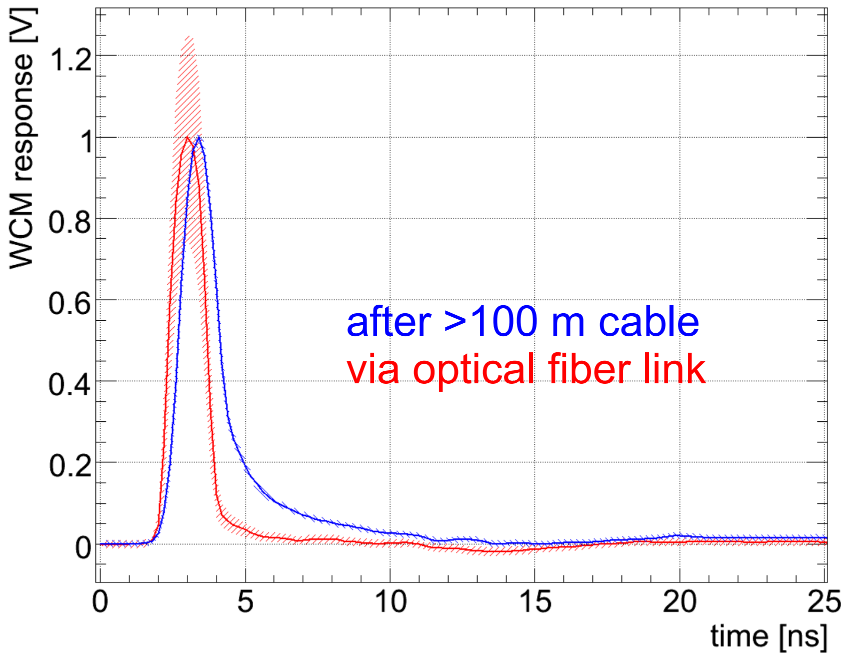
Model (multiple-)bunch spectrum:

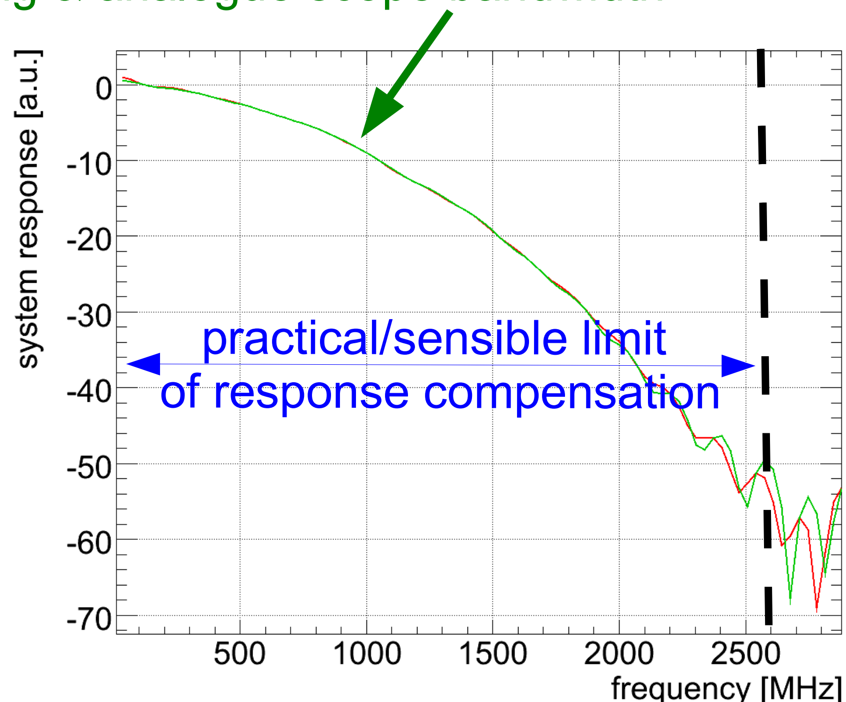


- Most difference/details are only visible at very high frequencies > 1 GHz
- Naïve assumption of bunch being shaped according to Gaussian distribution:
  - 1 σ → 68.27% of particles
  - 2 σ → 95.45 % of particles
  - 3 σ → 99.73 % of particles ↔ 0.3% error of intensity estimate (target?)
  - 4 σ → 99.99 % of particles
- 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





- Accuracies below 10% require compensation (i.e. short bunches)
  - Simple Fourier space deconvolution with measured system response
  - However: (too) high numerical complexity if treating raw 100 us frames
- Propose to:
  - split 100 us frames in 'nx50 ns' and shifted 'nx50 ns + 25 ns' slices
  - make compensation configurable: NONE, FULL, CABLE/SCOPE

Summary of Proposed Beam-Parameter Measurements

- number of bunches & satellites
- bunch length → various estimates:
  - Cos²-Distribution (best?), parabolic-distribution, Gaussian or n x RMS, FWHM, length containing 50/95/99% of power/intensities
  - time-constants of bunch-length increase
  - per-bunch and statistic summary
- long. bunch position → not relevant since we average over seconds
  - shifts w.r.t. nominal bucket position (n x 2.5 ns within 25 ns slot)
  - shift within 2.5 ns bucket
- bunch peak voltage
  - Rise/decay time-constant
  - per-bunch and statistic summary
- bunch intensity of 'bunches' and 'satellites' – $n_b(B1/2)$
  - time-constants of change
  - integrated beam intensity of 'bunches' and 'satellites'
  - per-bunch and statistic summary
- Luminous intensity in the IP – "$\Sigma_i \left(n_b(B1) * n_b(B2)\right)_i$"
  - IP1, 2, 5 & 8 statistics only
    → rationale: with beam sizes → estimates the machine-lumi life-times
  - time-constants of change

Following slides focus more on the technical implementation aspect

Compensation of System Response

- Straight deconvolution of the 100 us frame with the system response has probably a (too) high numerical complexity
- Propose to split 100 us frame into 4000 smaller frames,
  - each 50 ns long ↔ 500 samples each (or 512 samples → faster FFT)
  - Small frame start: 10 ns before nominal bunch slot } transient mitigation
  - Small frame stop: ~40 ns before nominal bunch slot
- Deconvolution of system response is easiest via Fourier-Transform:
  1. Perform FFT of measured frame with 'N'-samples
     - spectrum of containing Re- and Im-component
  2. Multiply beam spectrum with selected complex inv. system response: 'NONE', 'FULL', 'CABLE-SCOPE-ONLY'

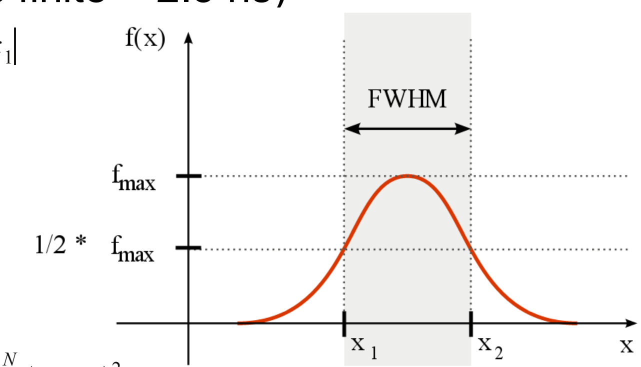
$$\Re_{comp} = \sum_{i=0}^{N/2} \Re_{data}(i) * \Re_{filter}(i) \quad \wedge \quad \Im_{comp} = \sum_{i=0}^{N/2} \Im_{data}(i) * \Im_{filter}(i)$$

     - ~~keep intermediate result as it is needed for the intensity and power-based bunch length estimate~~ (too large window, multiple bunches)
     - Will provide the corresponding filters, as a start: 'NONE' ↔ Re(i) = 1 & Im(i) = 0
  3. Inverse FFT on compensated spectrum
     - yields compensated frame of 'N' sample length

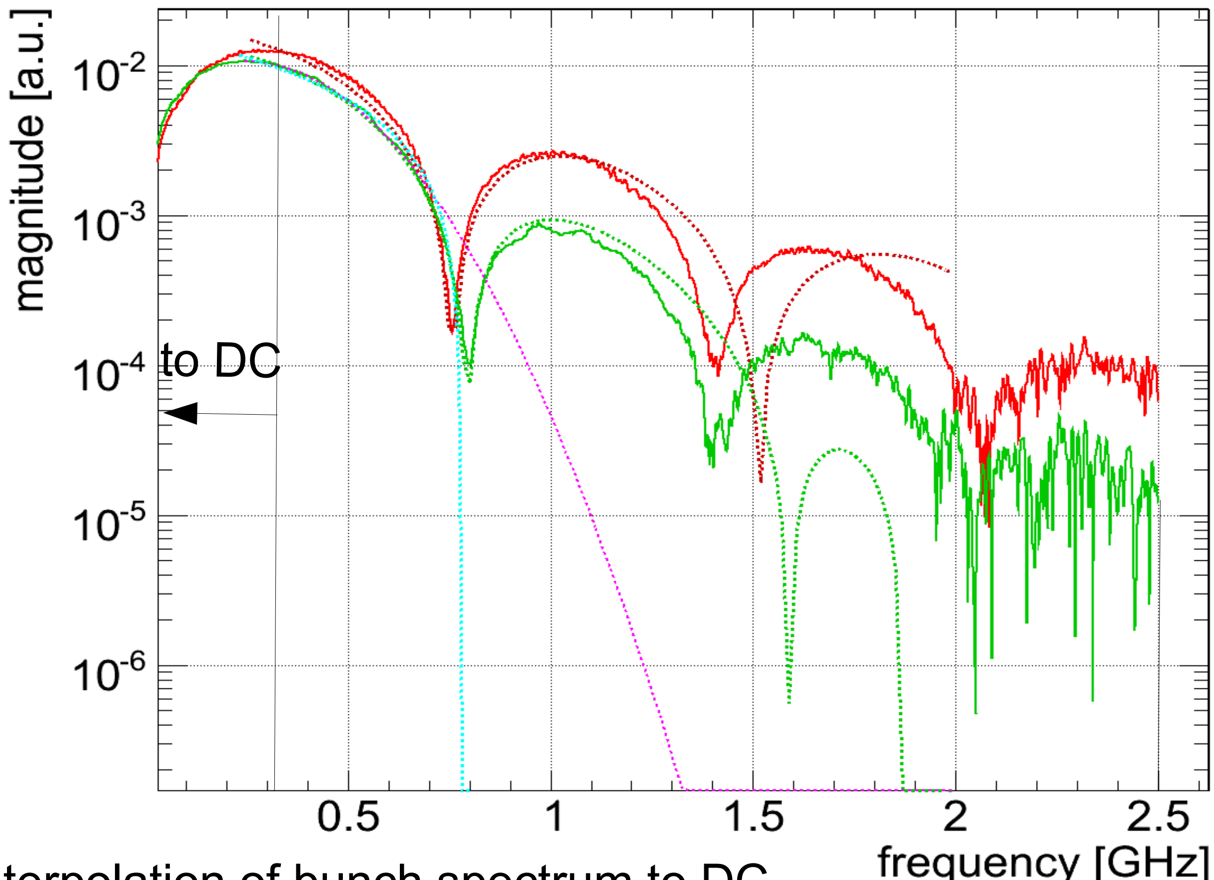
- For determinism/real-time performance of the FESA server → best to perform this for every slot (regardless whether there is a bunch or not)

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



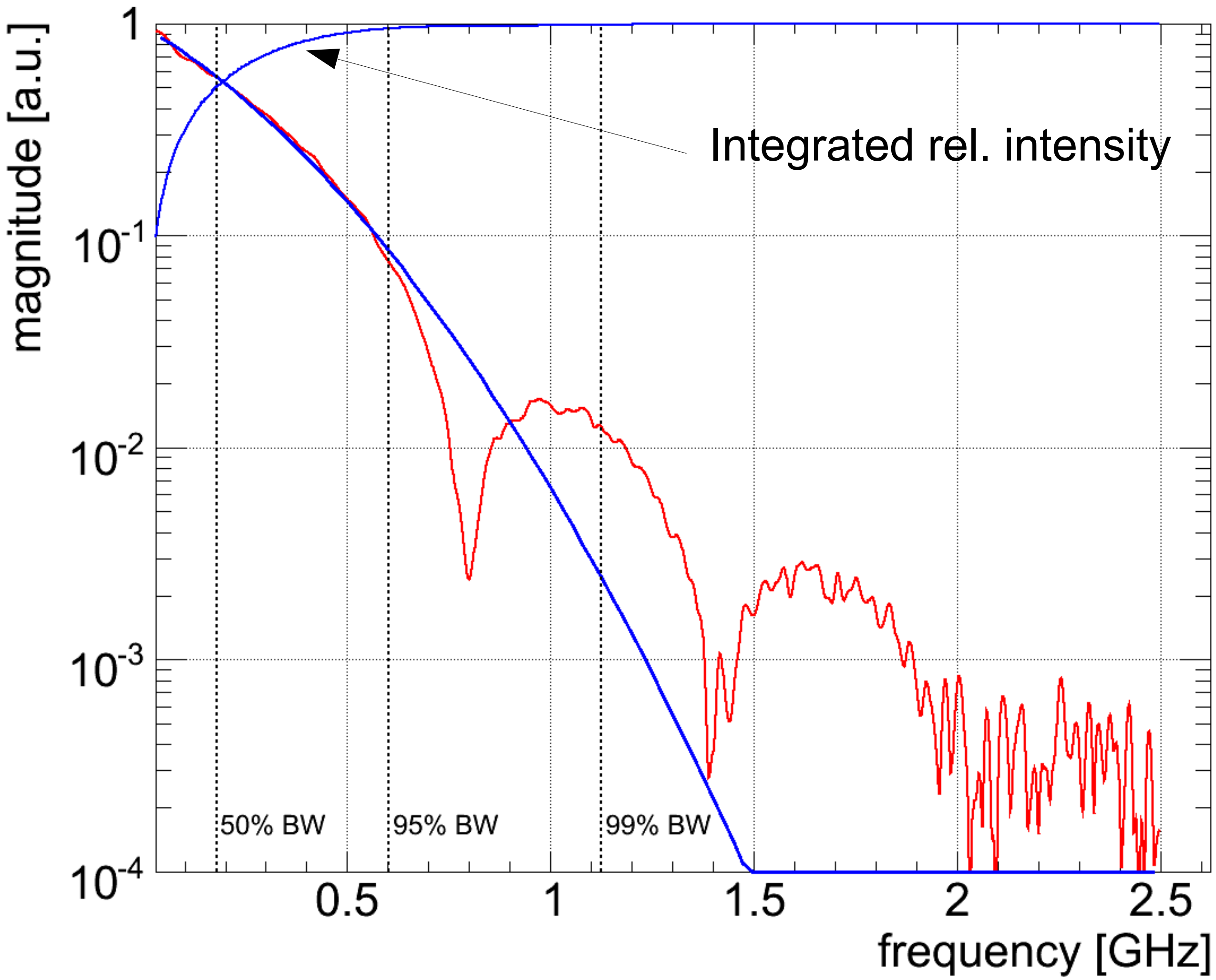
- Use system-response compensated spectra, e.g:



- ZOH-interpolation of bunch spectrum to DC
- Intensity n_b ~ integral of bunch spectrum up to 2.5-GHz
  - calibration (aka. 'fudge') factor to account for beam-to-pick-up transfer function
  - bunch-length if integral matches, e.g.: $\sigma_{50\%}$ = 1/f if $n_b(f)/n_b$(n-GHz) = 0.5, $\sigma_{95\%}$ = 1/f if $n_b(f)/n_b$(n-GHz) = 0.95, ...

Illustration of power-bandwidth

- Maximum frequency that contains 50%, 95% and 99% of bunch-spectral power (↔ bunch intensity)



Rise-/Decay-time Estimates

- → same algorithm as used for the beam-current transformers....
- More news asap.