Frequency Measurement and Sub-Ns Phase fit for the GSI/FAIR Bunch-to-Bucket System

Synchrotron

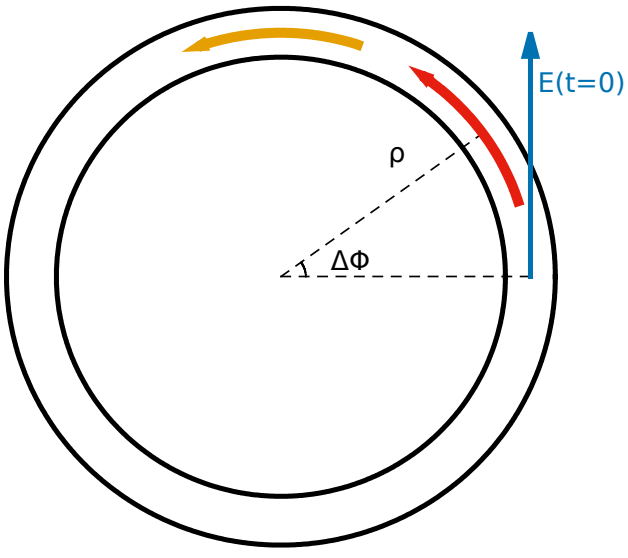
B2B System

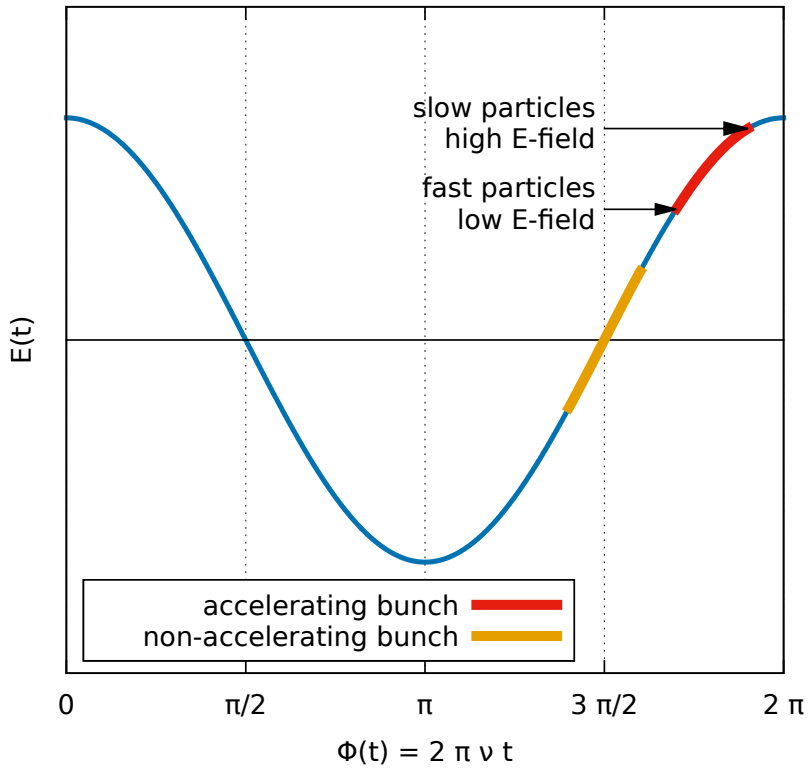
Frequency Measurement

Sub-ns Phase Fit

Synchrotron Accelerator

- Orbit of constant radius ρ and revolution frequency f_r. (Rigidity $B\rho = p/q$)
- RF system at a distinct place on the ring with frequency $\nu = h\, f_r$

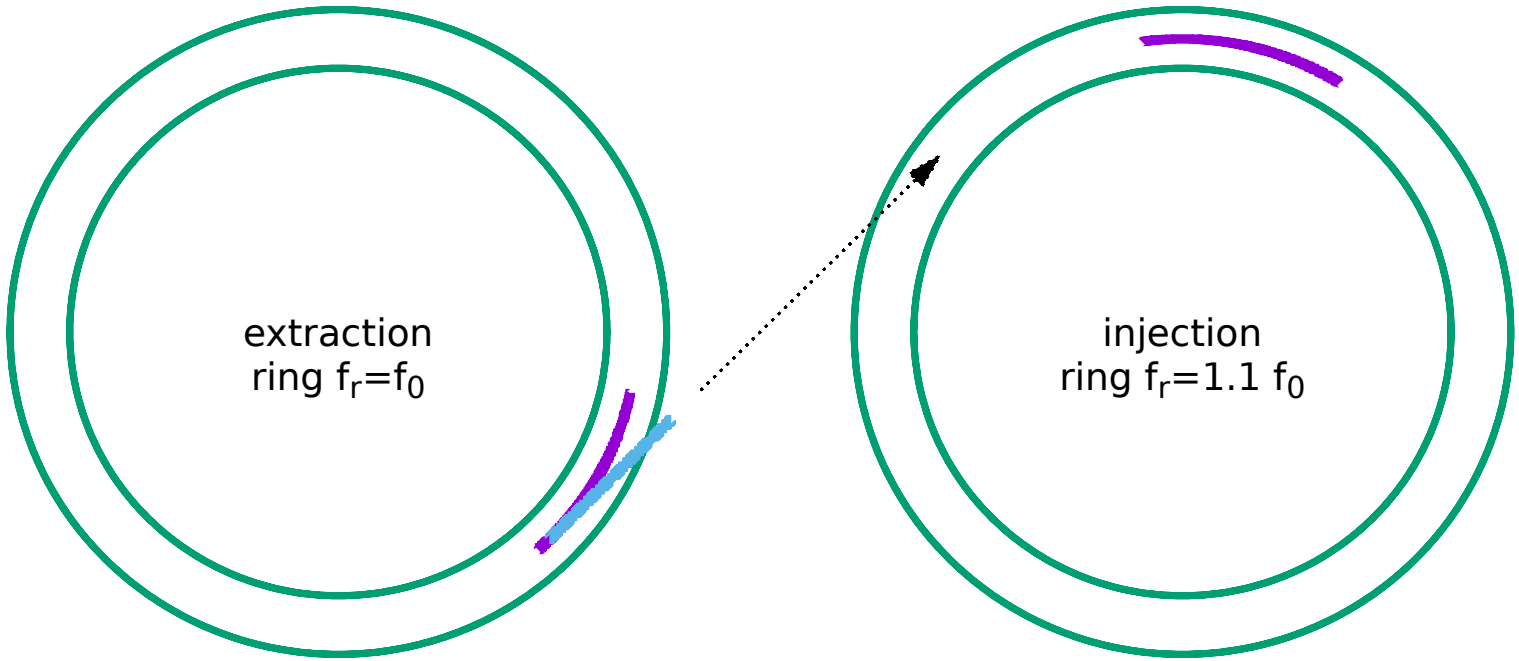




Bunches and Buckets

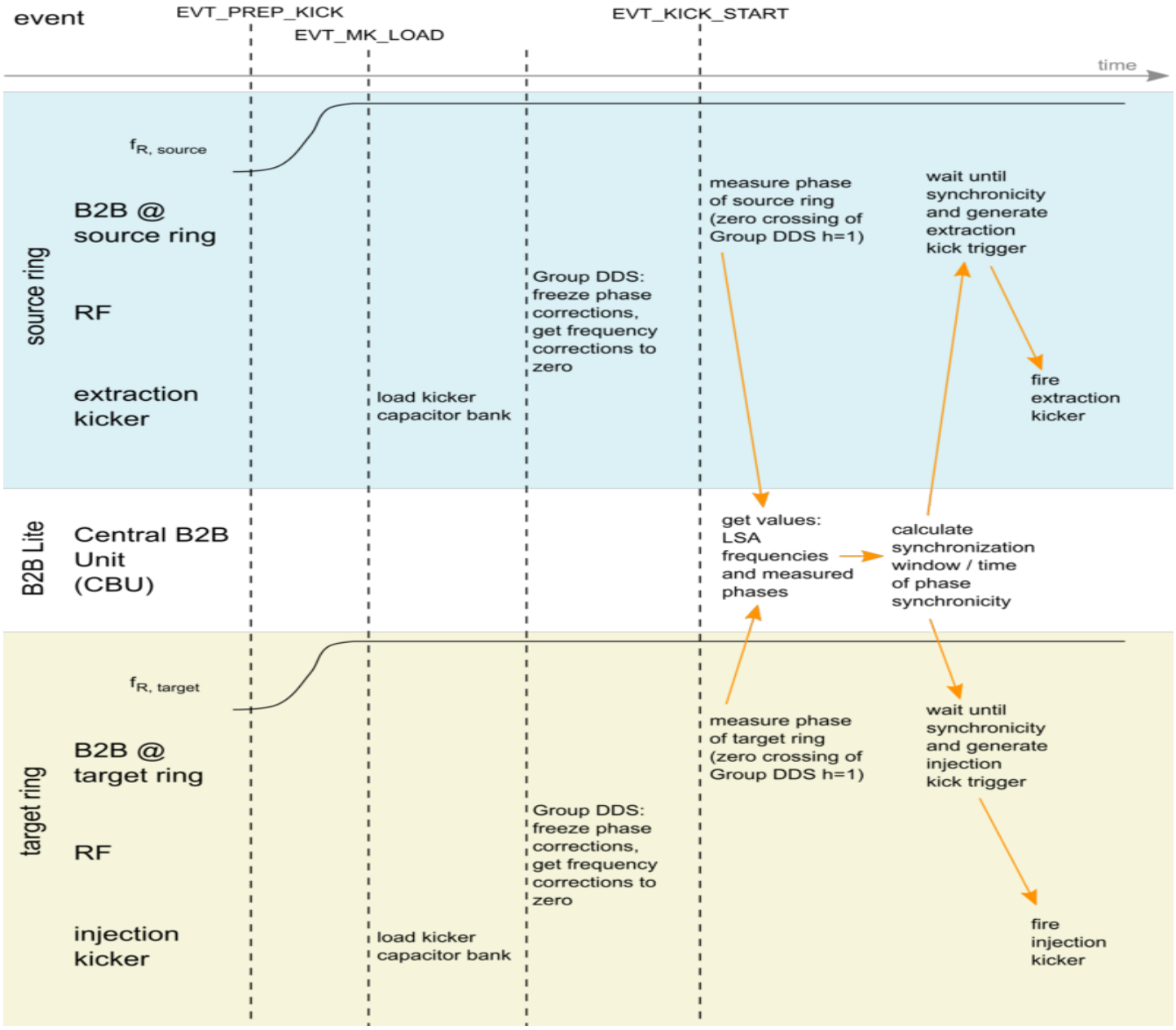
- Bunch: Set of particles with a stable orbit and longitudinal focusing by the RF
- Bucket: Time dependent stable bunch location inside the synchrotron

B2B Frequency Beating Method



- RF for extraction ring and injecting ring are slightly de-tuned: $\nu_{\text{extr}} \approx \nu_{\text{inj}}$
- Possibility of transfer occurs with the beating frequency: $\nu_{\text{extr}} - \nu_{\text{inj}}$
- Transfer time can be calculated from relative phases of RF_{extr} and RF_{inj}

B2B Procedure



by D.Beck

B2B System

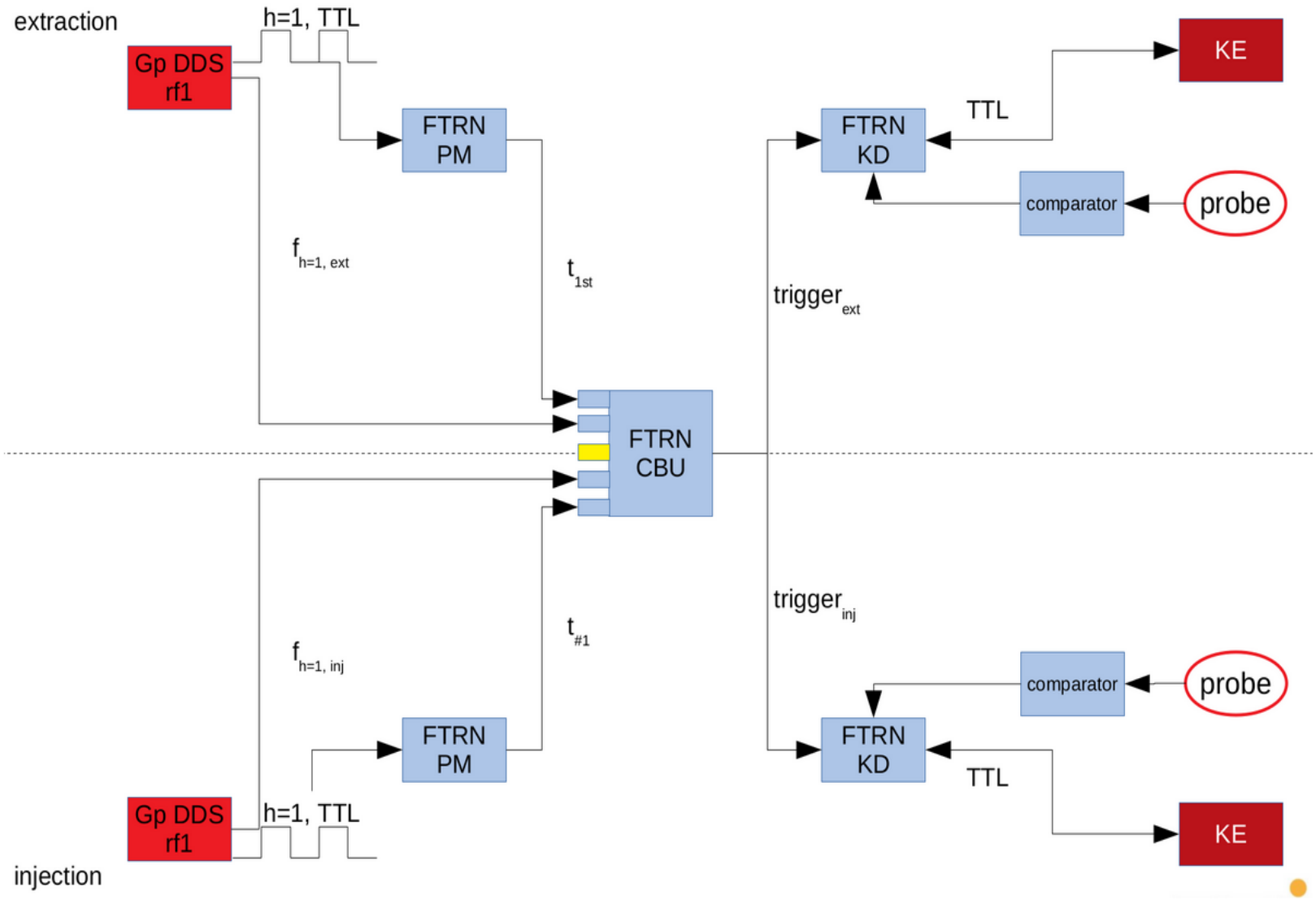


Figure: Extraction (top) and injection (bottom).

by D.Beck

Frequency Measurement: Motivation

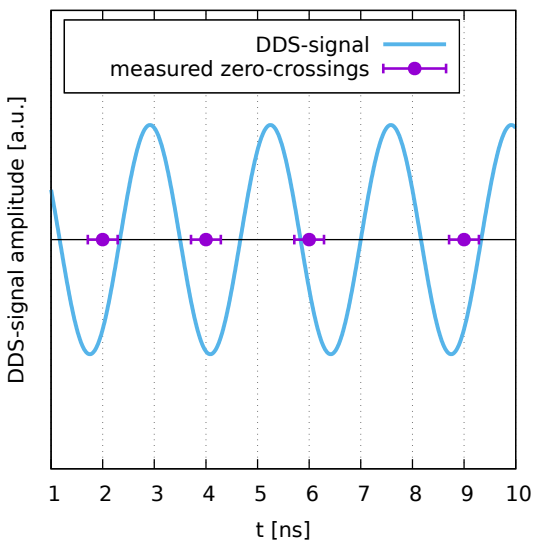
Independent measurement of DDS output frequency ν

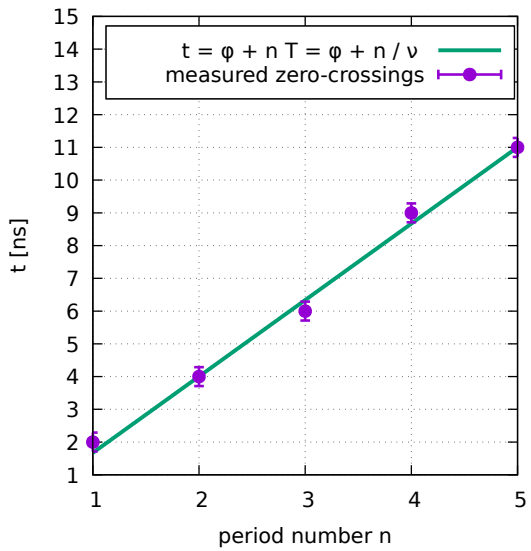
- verify RF set value
- implicit check of WhiteRabbit and Butis synchronization
- hardware is already there
  - comparator units
  - 1 ns TLU (TDC) from B2B-PM unit
- only software development

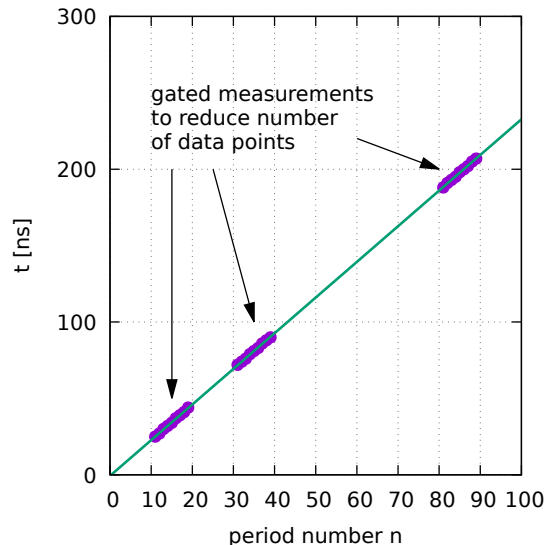
Implementation

Basic idea

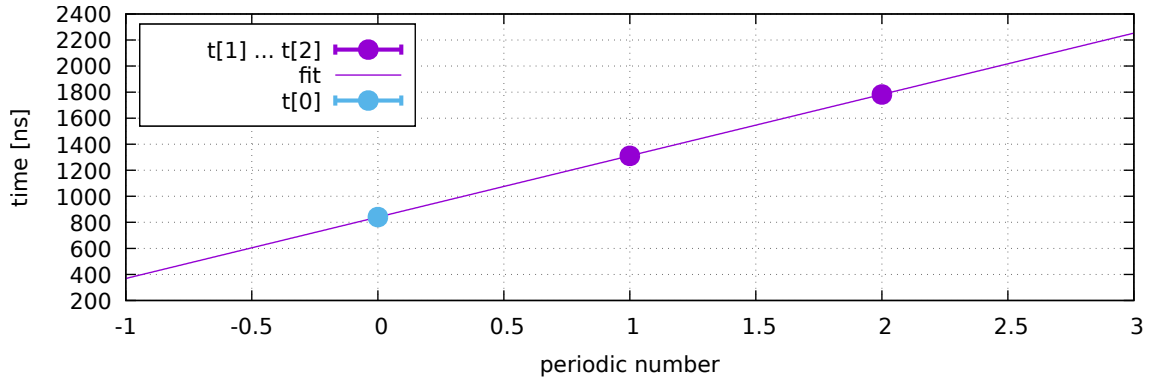
- B2B-PM firmware measures 3 data sets during RF-flat-top
- straight-line fit to the data (period number, zero-crossing time)
- frequency ν and phase φ are fit parameters
- period number is not measured $\Rightarrow$ iterative fit
  - calculate period number using fit to previous data
  - identify outlier using the variance of the fit to previous data

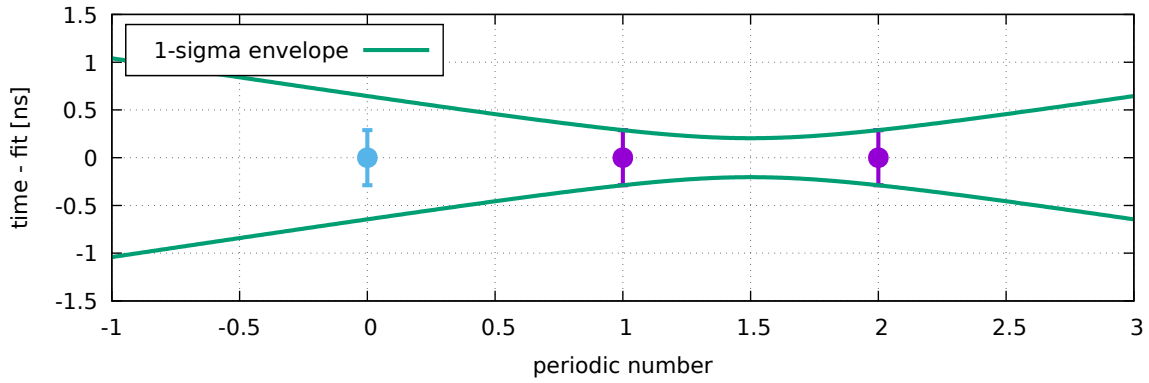


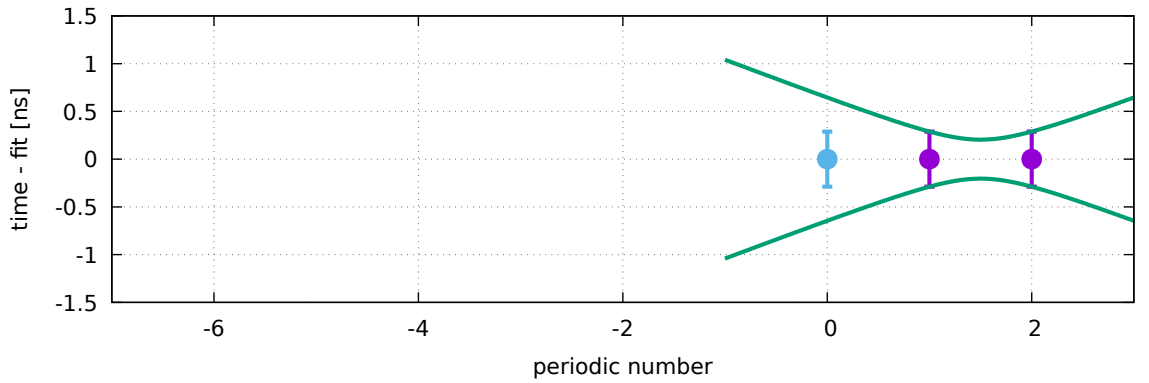




Iterative Fit

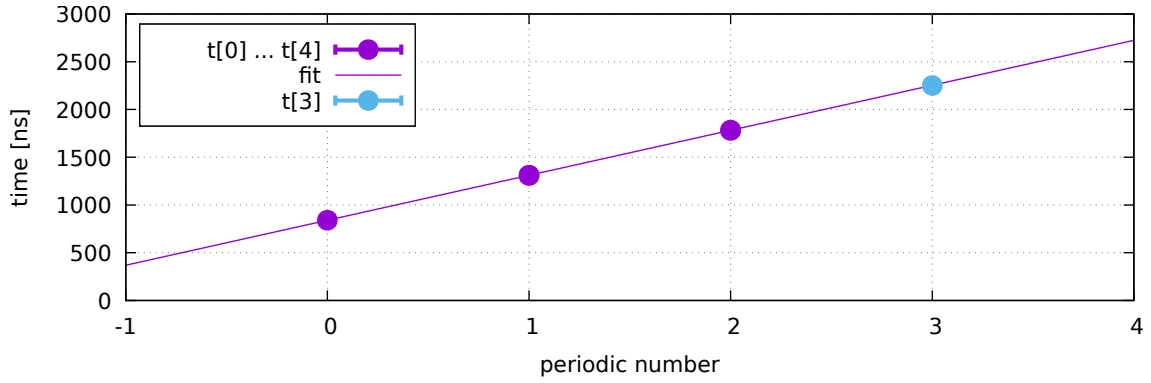


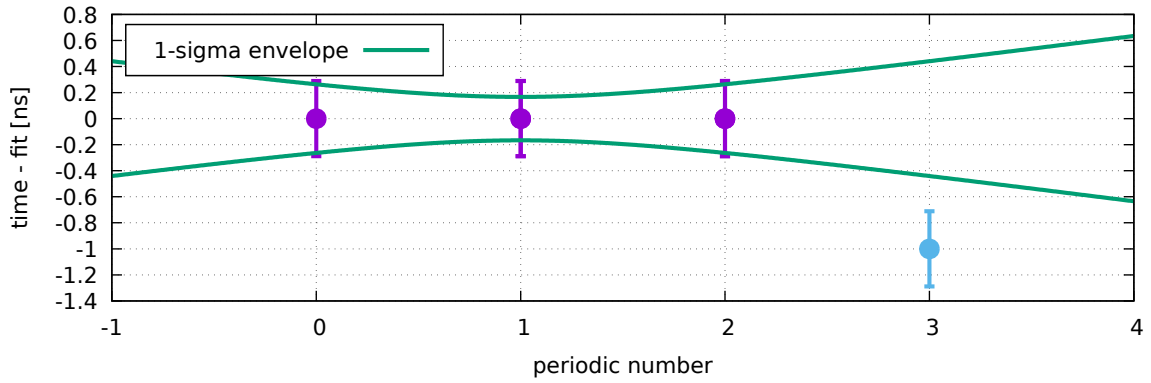


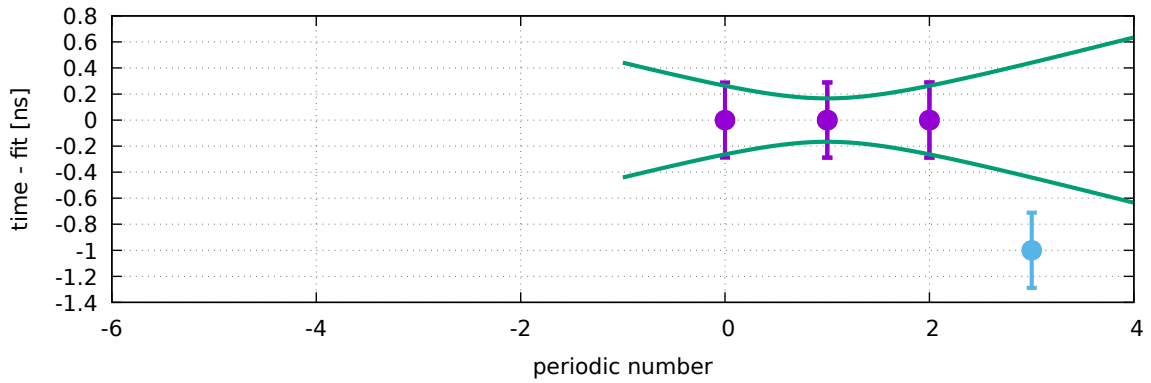


- fit to points 1,2
- check if point 0 is close enough $< 6\sigma$ to the fit
- yes $\Rightarrow$ include point 0 in the fit

Iterative Fit

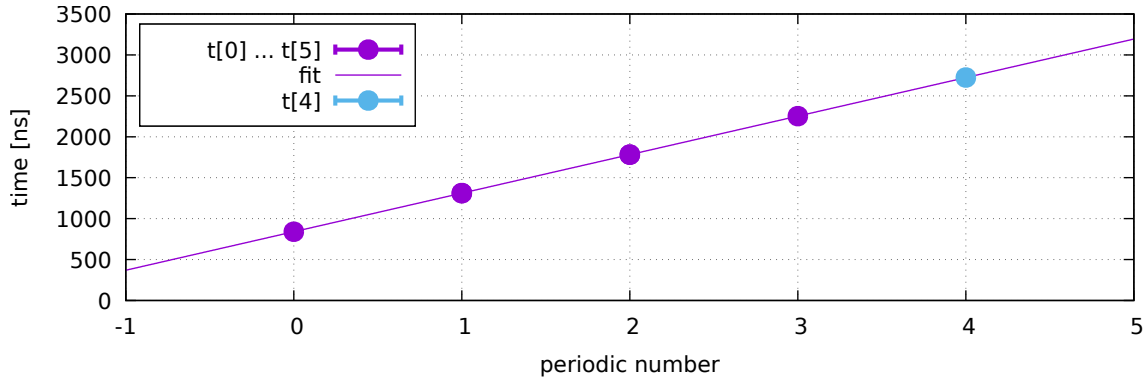


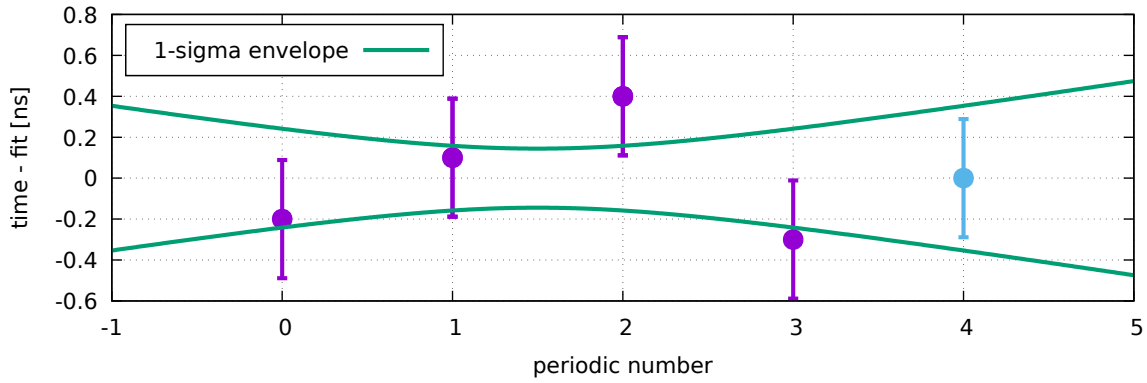


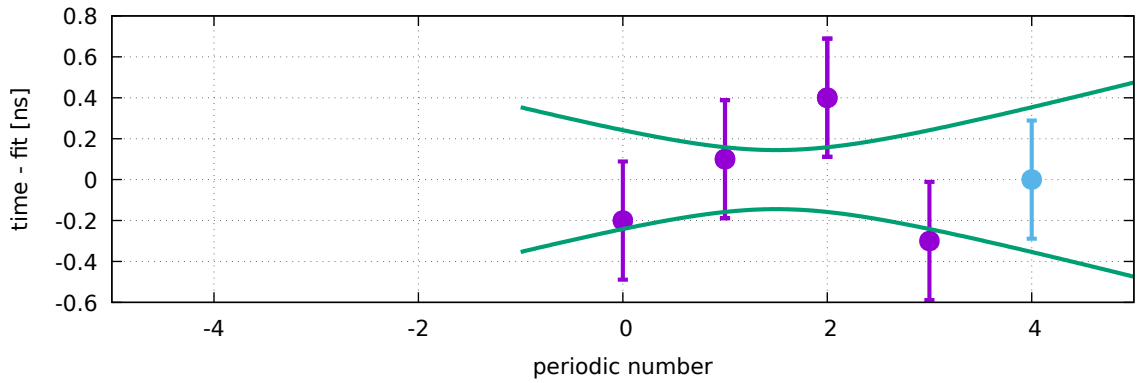


- check if point n close to the fit
- yes $\Rightarrow$ include point n in the fit

Iterative Fit







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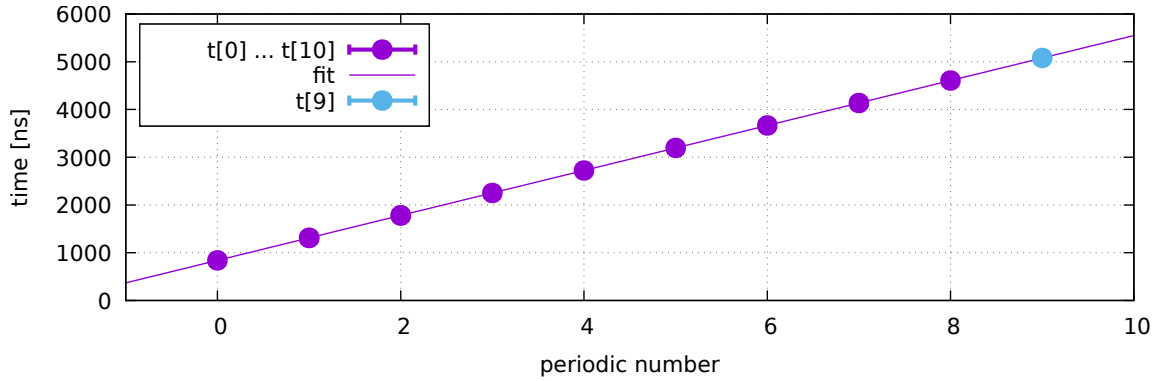

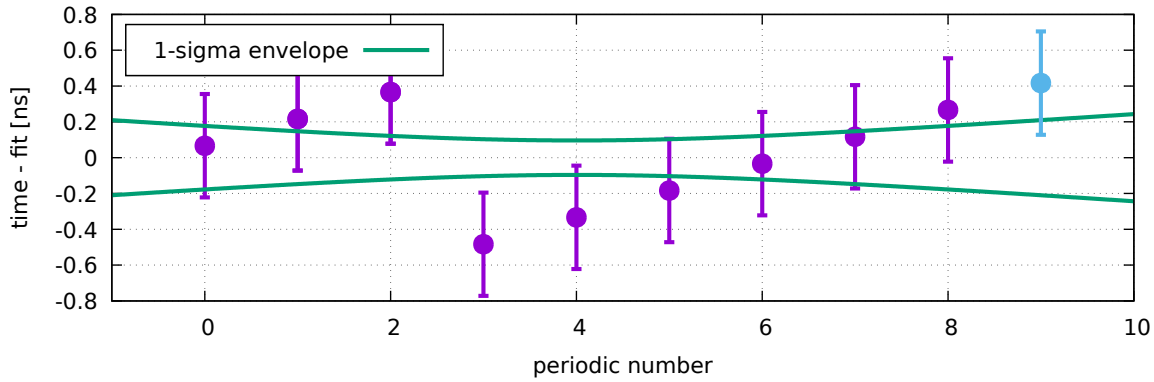

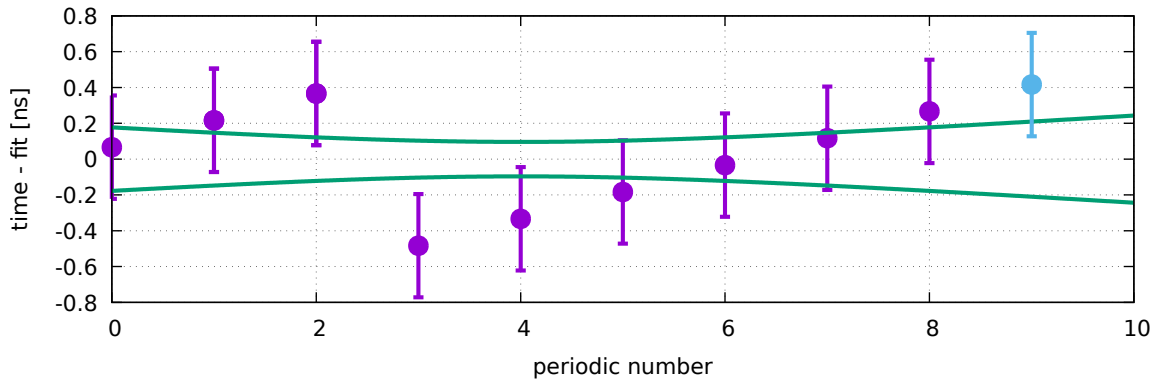

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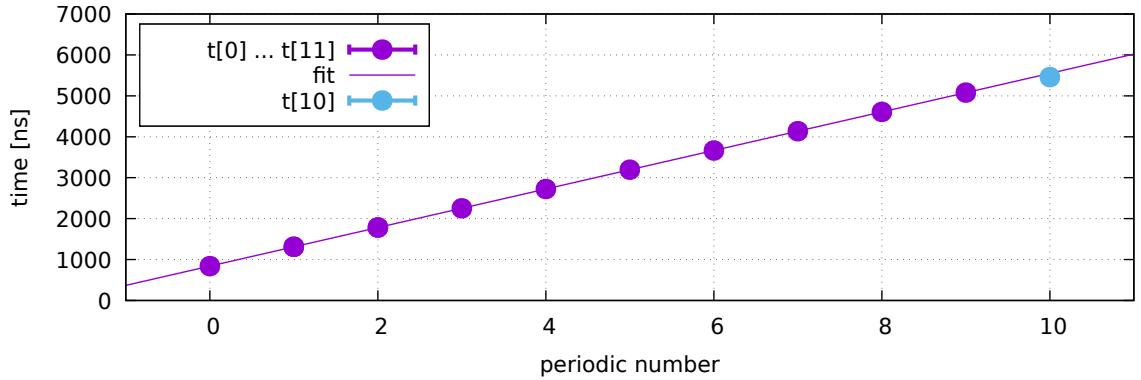
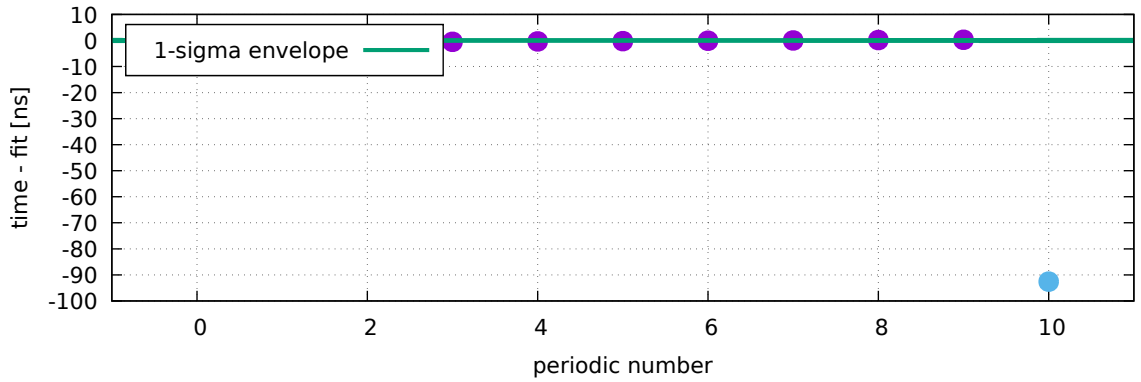
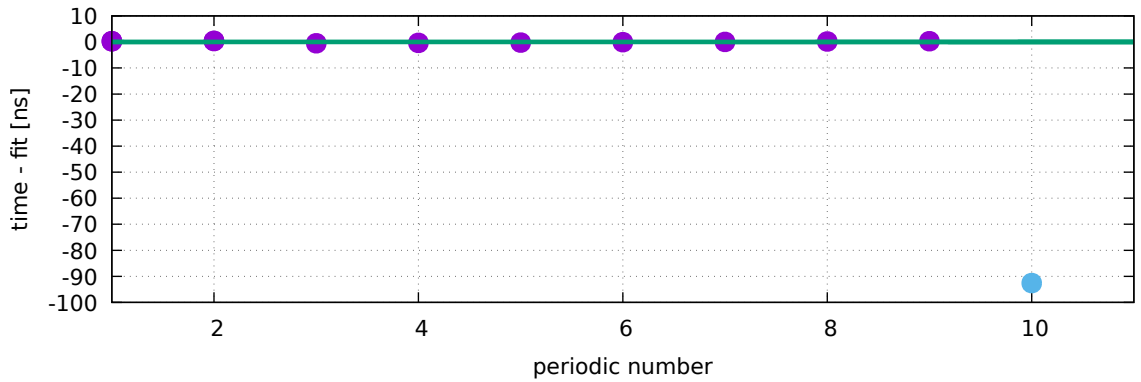
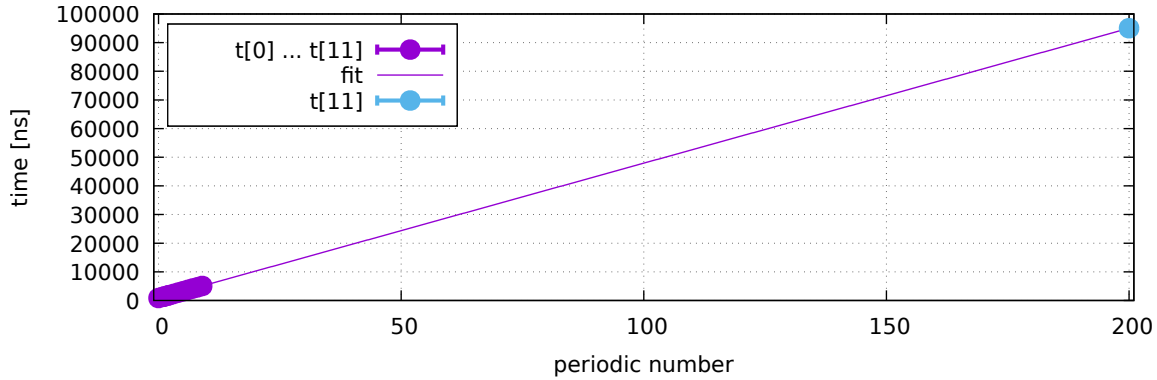


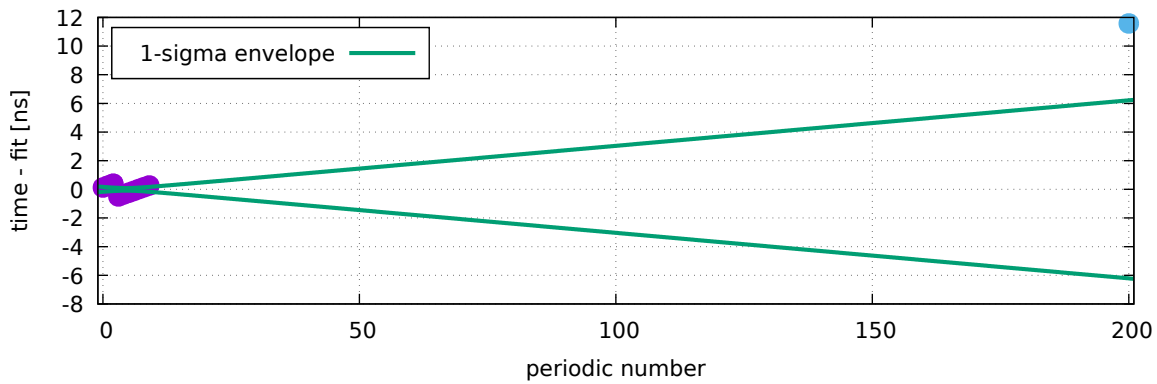


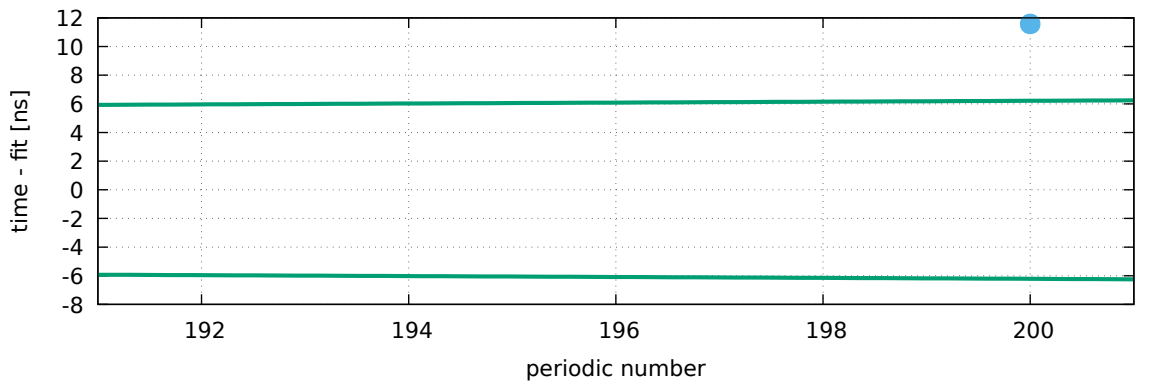


- detect outlier caused by the closing gate on the input (no real zero-crossing)

Iterative Fit

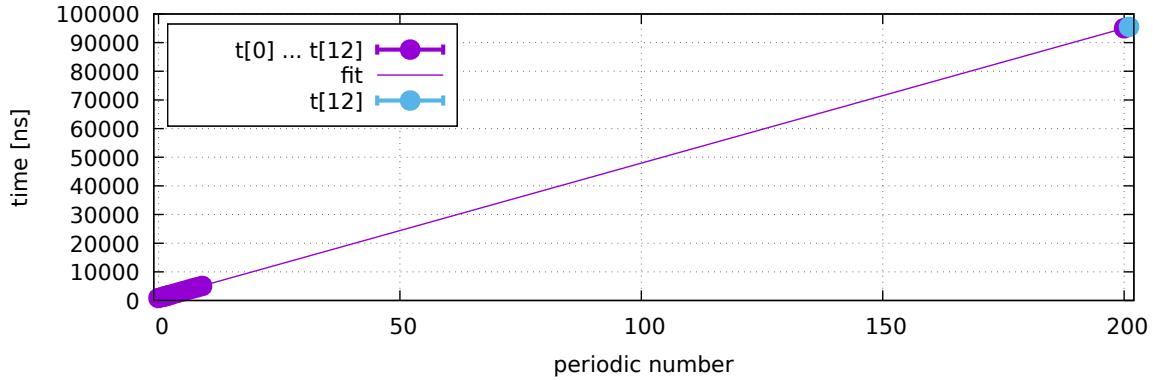


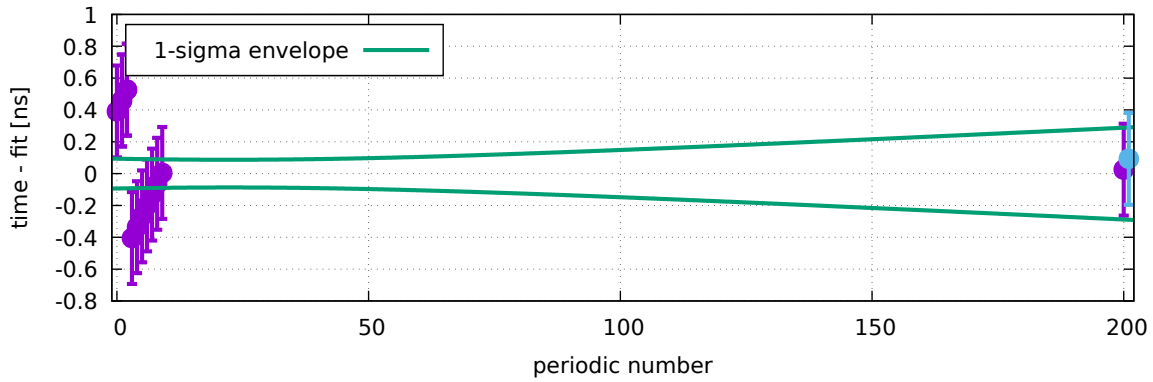


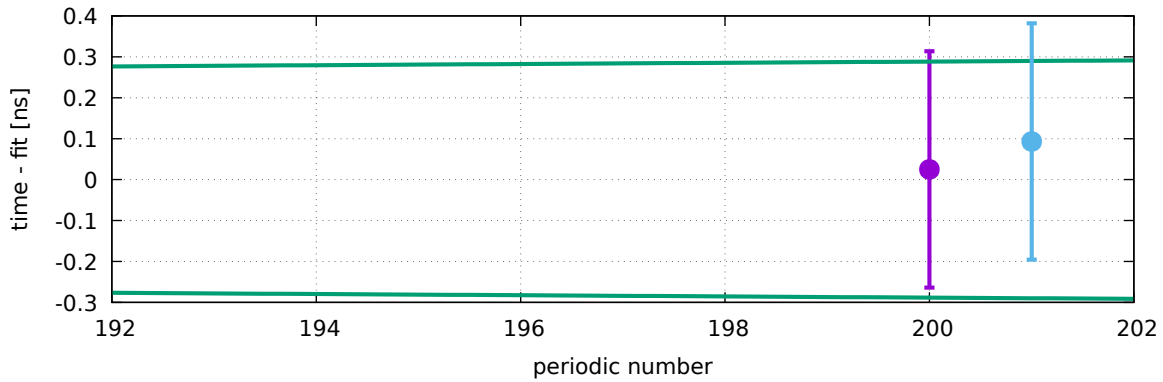


- fit to the previous data is good enough to bridge the gap to the next gate
- this allows to calculate the period number reliably

Iterative Fit

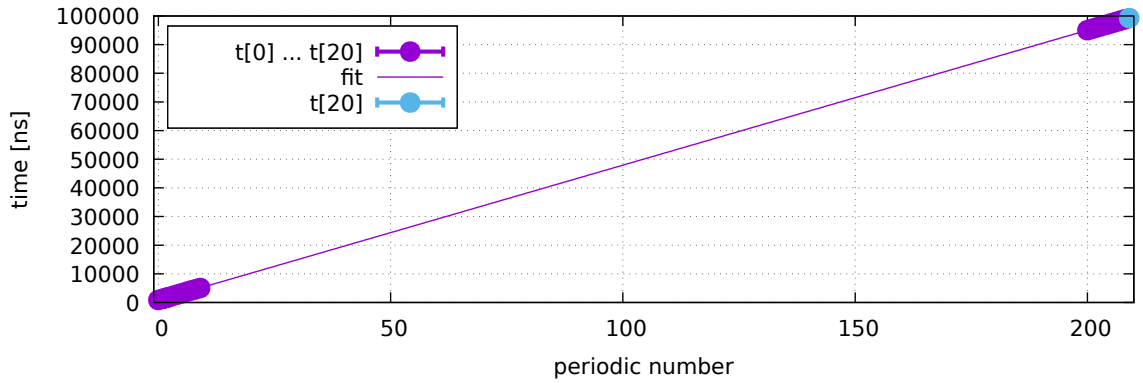


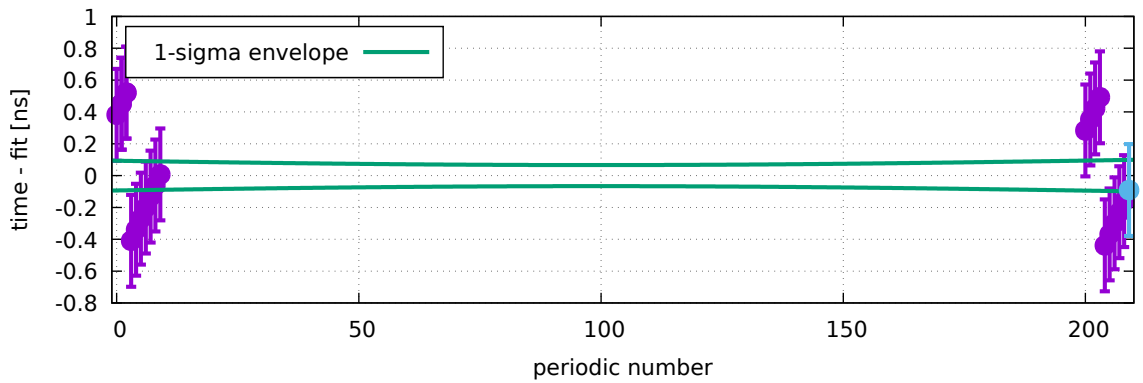


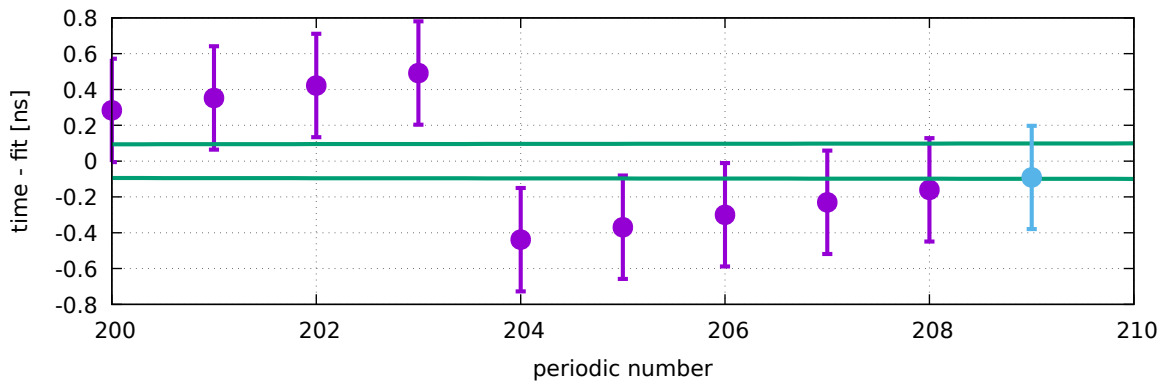


- including the first point of the next data burst drastically improves the fit because of the long lever

Iterative Fit







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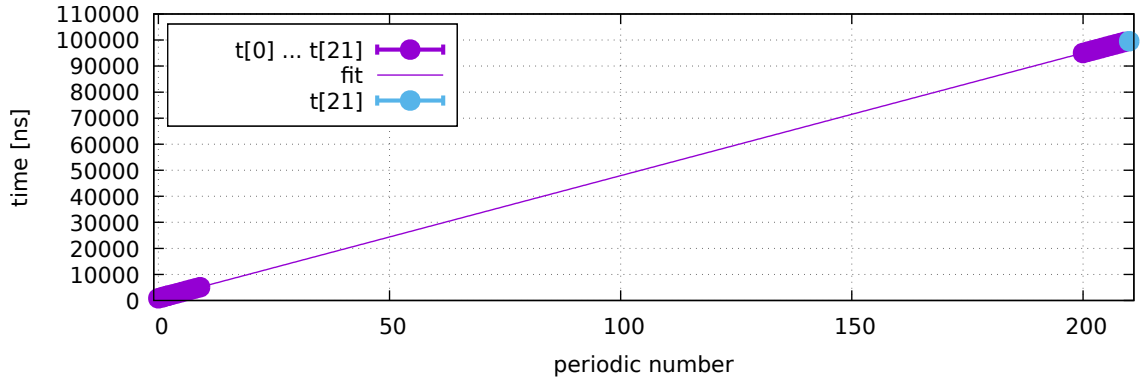

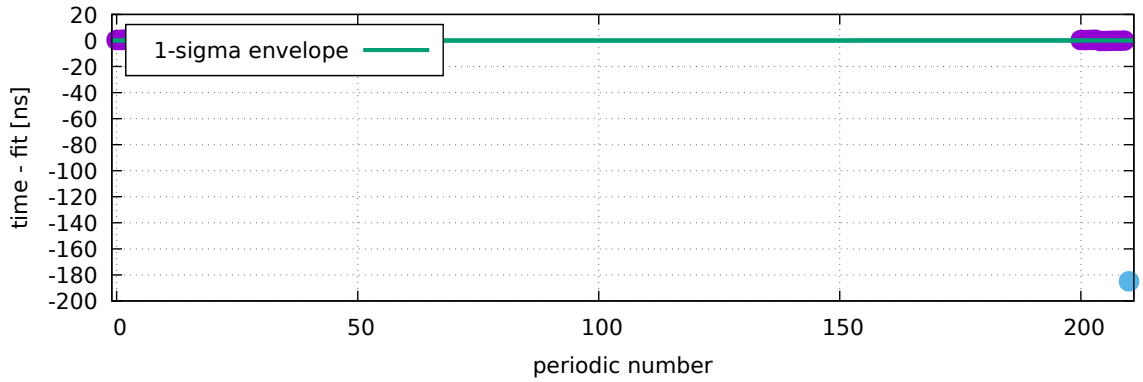

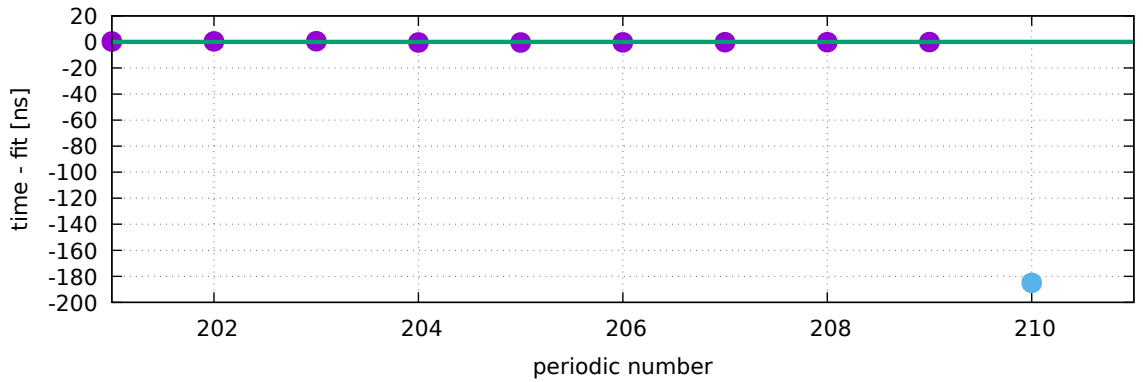

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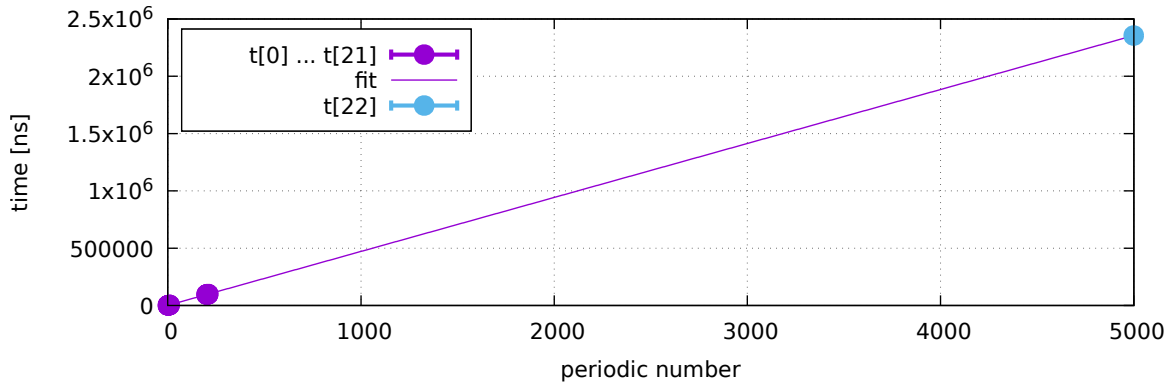

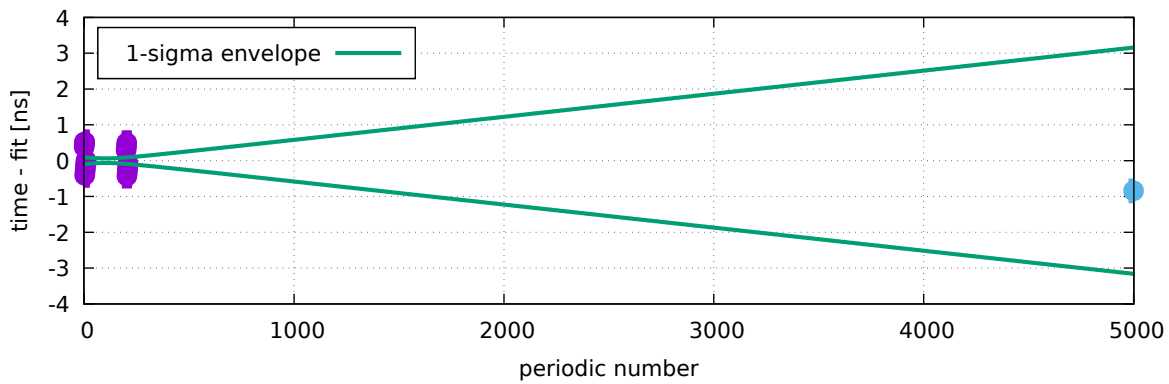

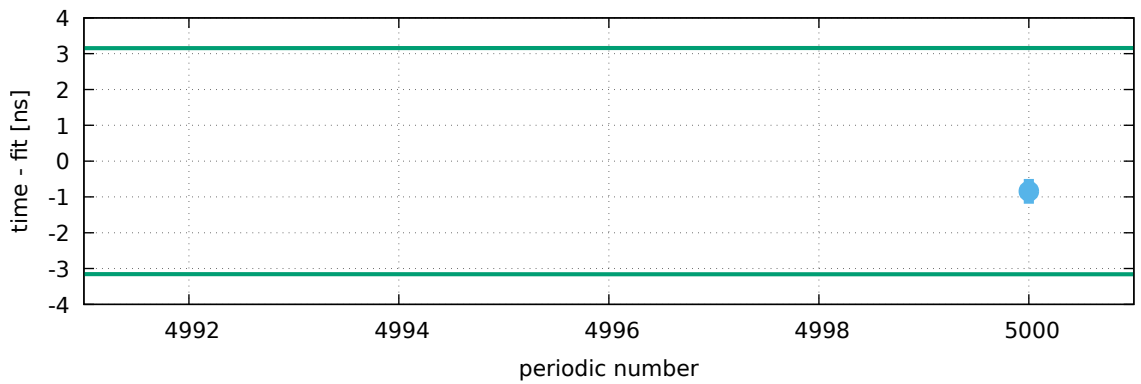

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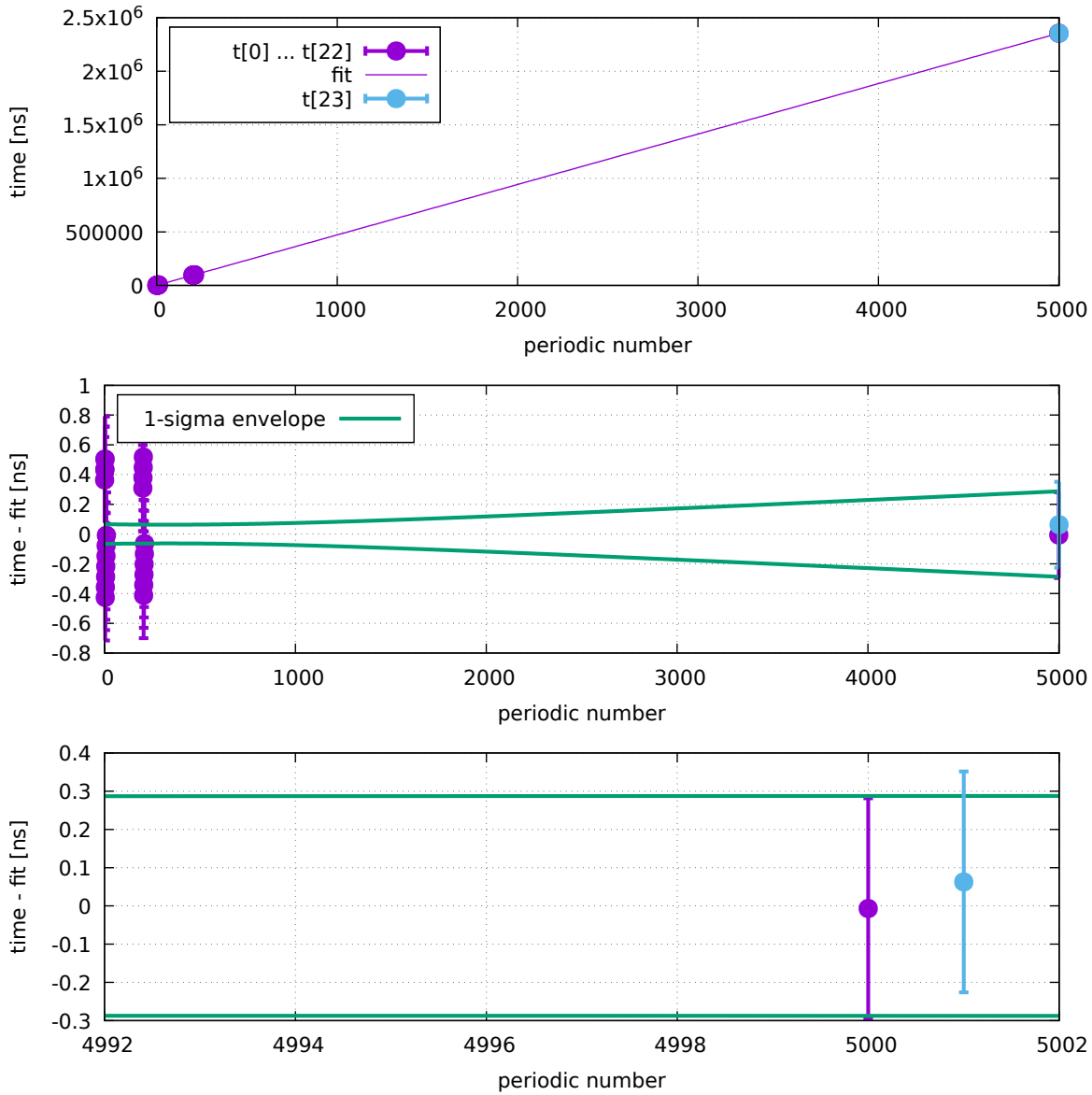

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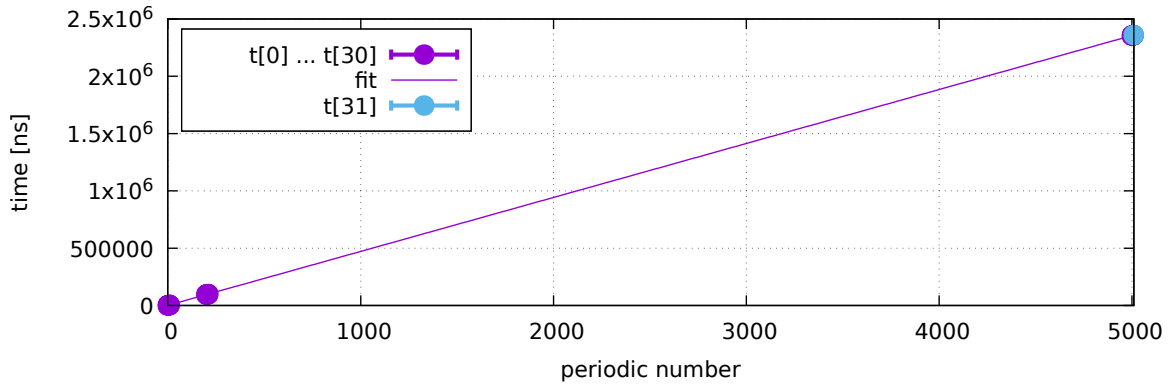
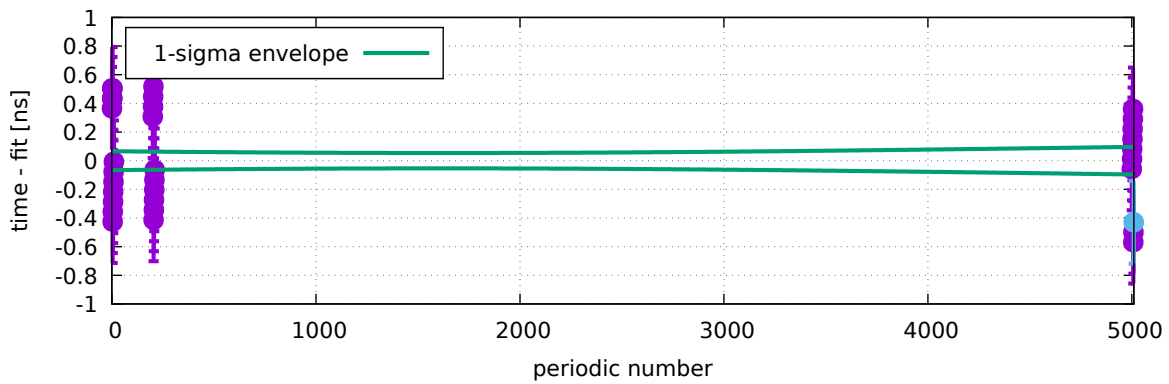
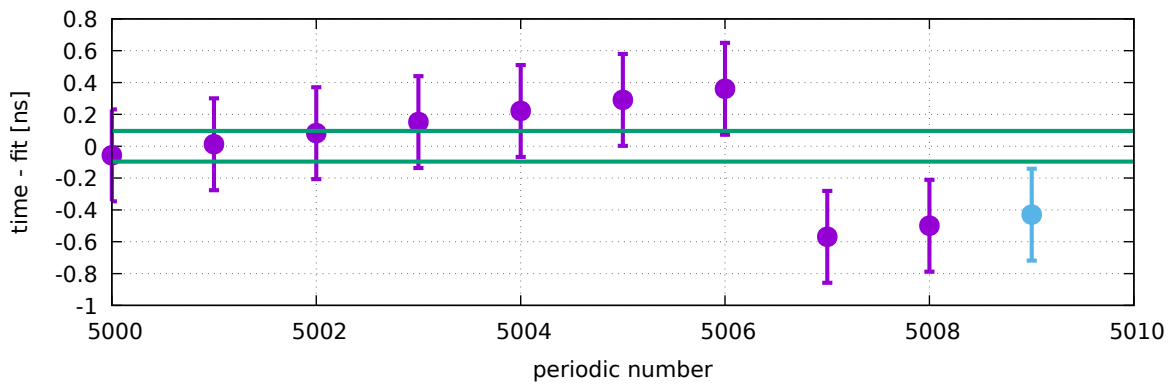






Sub-ns Phase Fit on Embedded CPU in the B2B-PM Units

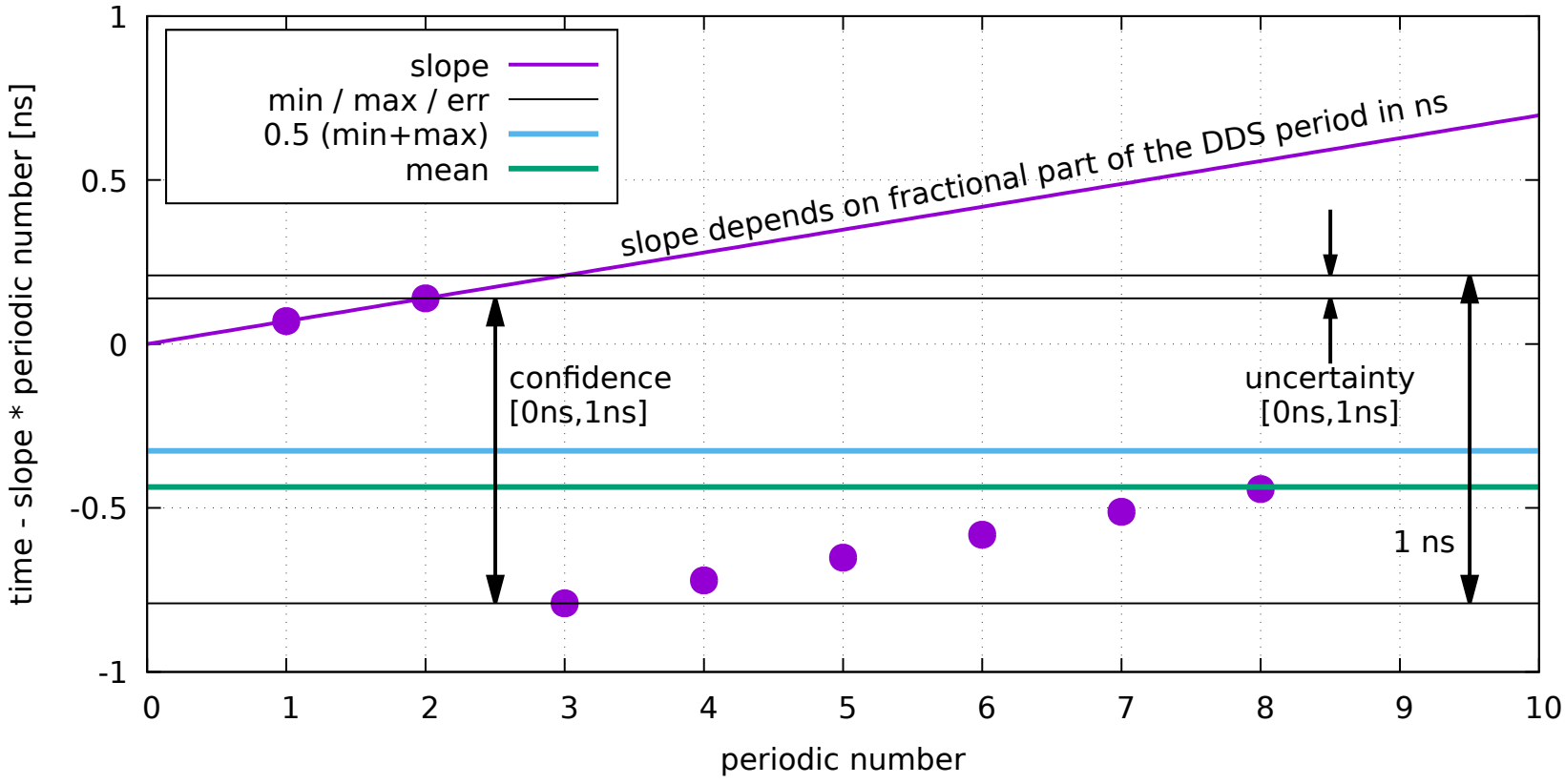
Is 1 ns resolution enough?

- B2B transfer should hit a the bucket with 1 degree precision
- for $\nu = 2\,\mathrm{MHz}$ that is $\approx 1.4\,\mathrm{ns}$
- resolution of the timing receiver of 1 ns is (just) enough
- improve resolution using multiple zero-crossing measurements

Phase Fit

- similar to frequency-phase fit seen before
- frequency is known, phase is the only free parameter
- should run on the LM32 CPU under real-time constraints

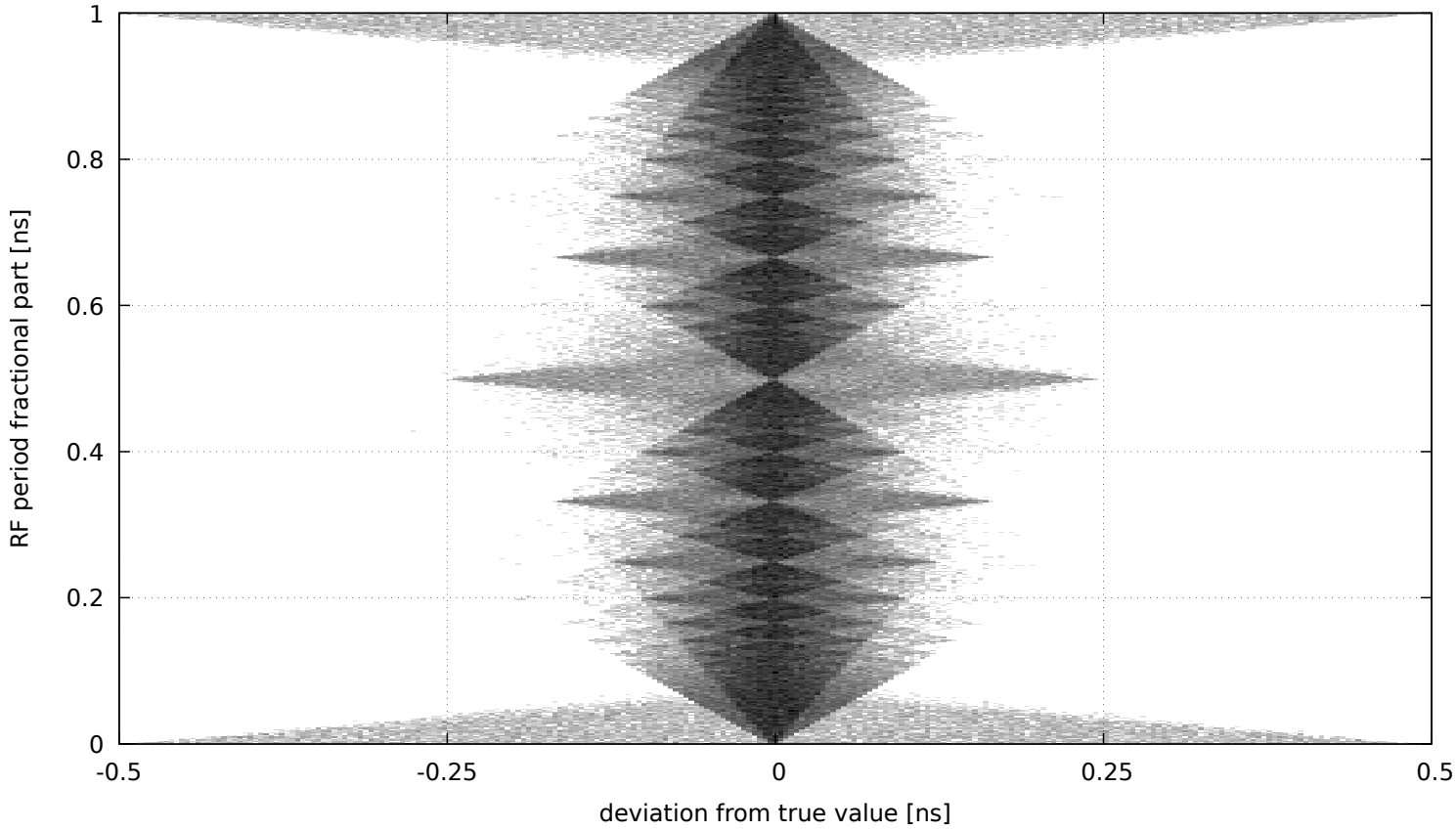
Sub-ns Phase Fit Algorithm



Calculate phase position from min/max values

- more precise than mean value in case of finite data
- is simpler to compute: additions and shift operations
- result is reported in units of 125 ps (3 bits)

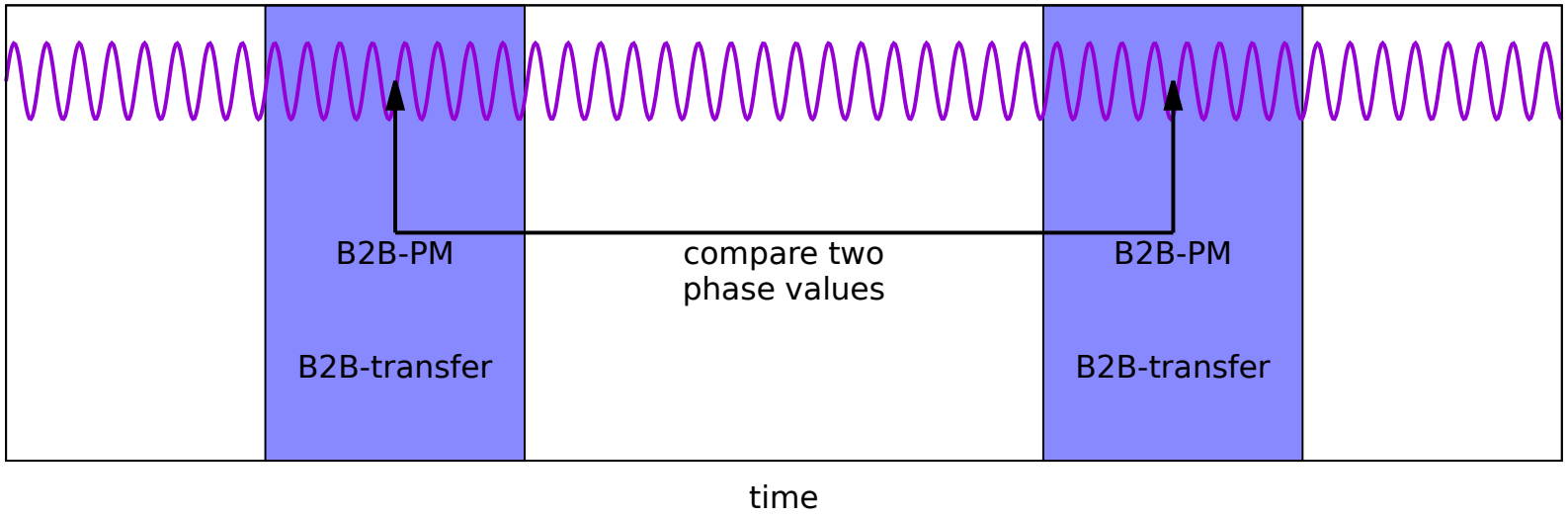
Performance of the Algorithm



Accuracy depends on fractional part of RF-period (in ns)

- Worst case (no improvement) if fractional part is zero
- Maximum performance can expected for small fractional parts, around 0.1 ns in this case

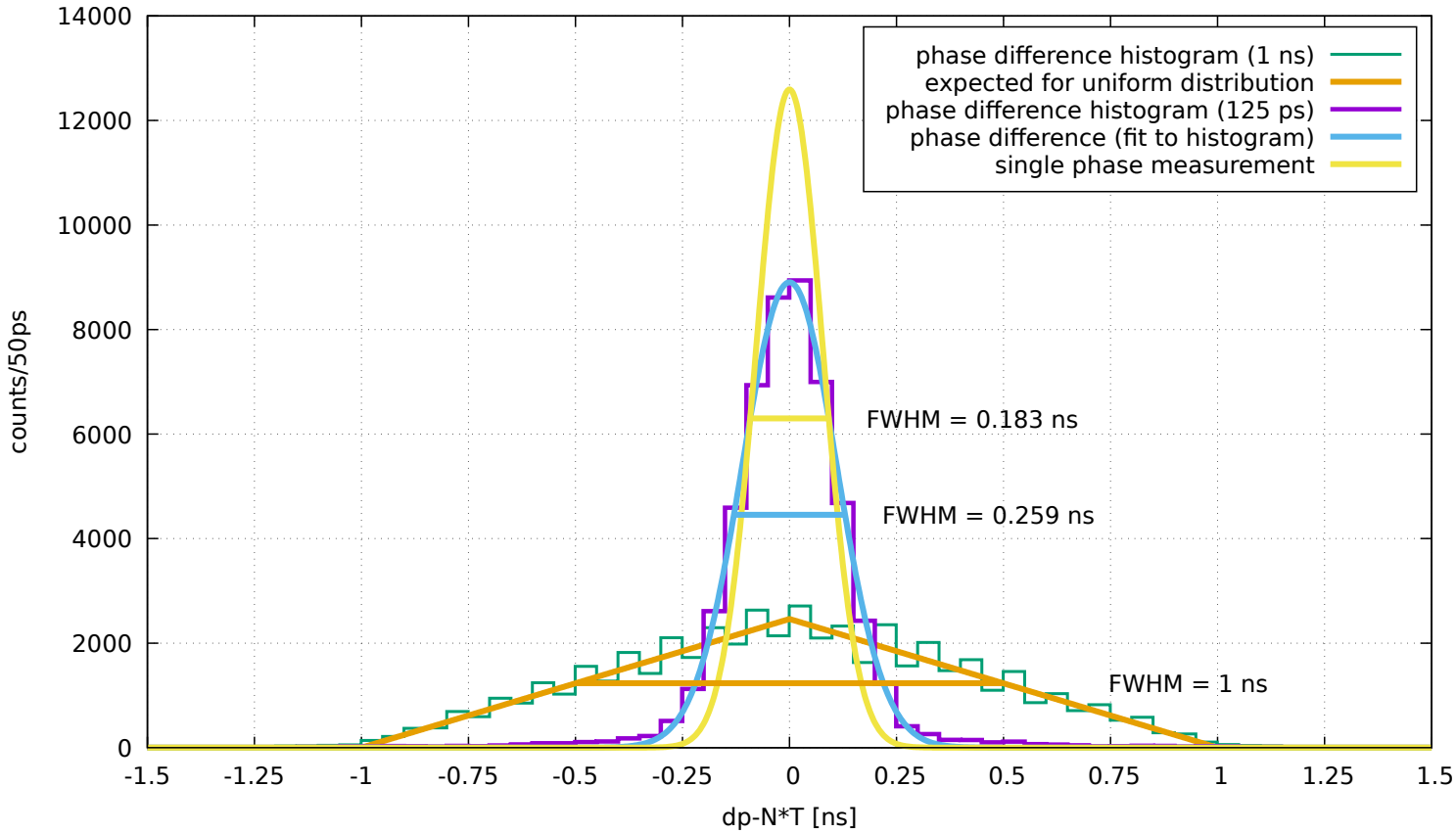
First Test in Integration System



B2B in the Integration System

- constant RF at flat-top frequency (from saft-clk-gen)
- regular B2B-transfers with phase fit
- evaluate differences of consecutive phase fit results
- width of the distribution depends on the accuracy of the phase fit result

First Test Results (period=880.525ns freq: 1.13569 MHz)



For one fixed value of ν (no ramps)

- difference between two consecutive phase values
- FWHM is improved by factor of 3.8