
CERN

PSB Upgrade
LIU Project

Recombination kicker beam-based waveform measurements

Vincenzo Forte (TE-ABT/BTP)

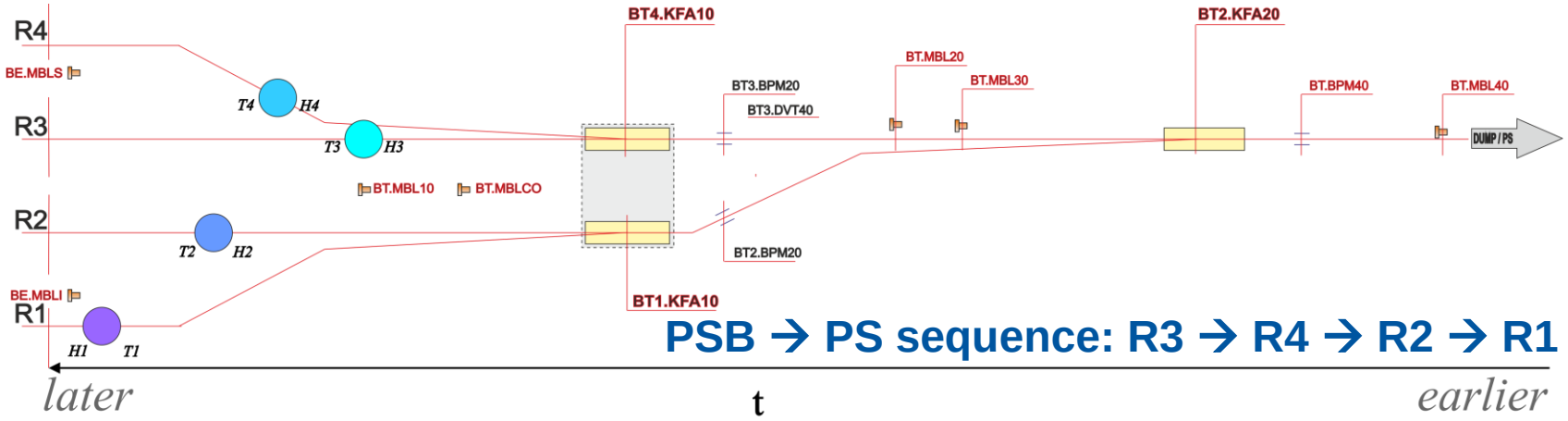
Acknowledgements:
S. Albright, W. Bartmann, J. Borbough, M. A. Fraser, B. Goddard, L. Sermeus, G. Sterbini, the PSB OP team

Outline

- Motivations of the study
- A ‘quick’ recap of the methodology
  - KFA10 and KFA20 measurements
    - Magnetic waveforms
    - Rise time and steady state ripple
- Time margins for transfer
  - Brightness and emittance blow-up measurements
  - Emittance blow-up simulations
- Summary and conclusions

Motivations of the study

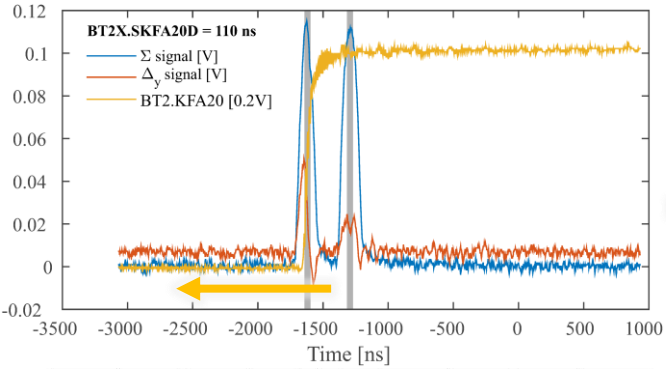
- **The rise time of the recombination kickers BT1.KFA10, BT4.KFA10 and BT2.KFA20 has to be determined in order <u>to grant clean transfer</u>** (no vertical losses nor emittance blow-up) **for the 220 ns** 'long' **bunches** from the PSB to the PS.
  - **The rise time must be ≤105 ns***.
  - **The steady state ripple must be inside ± 2%*.**

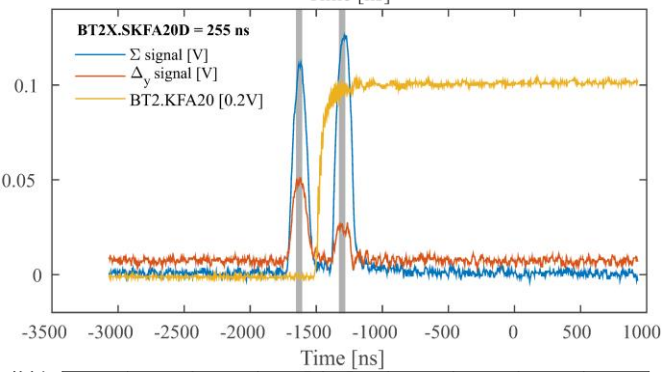


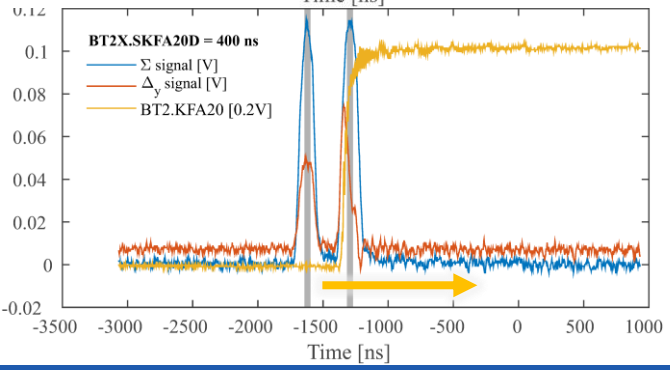
- This presentation is a follow-up of various meetings (LIU-PSB, MSWG, BT and PS injection kicker meeting).

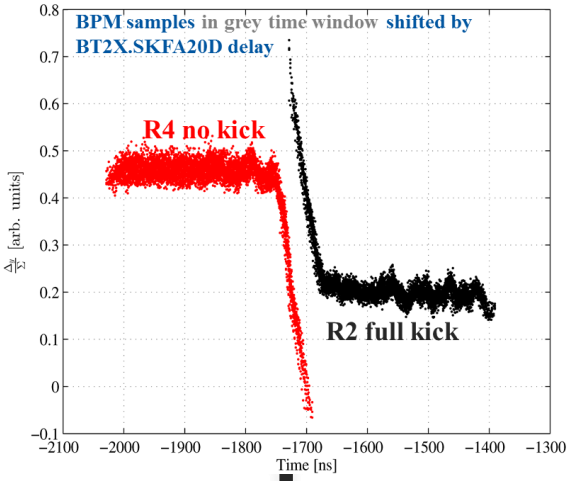
*** Reference:** Specification for KICKER SYSTEMS FOR 2.0 GeV PSB to PS BEAM TRANSFER - PS-MKKIK-ES-0001

A recap of the measurement methodology

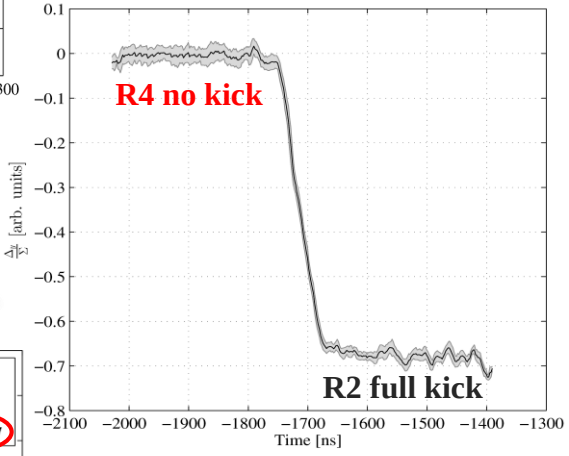


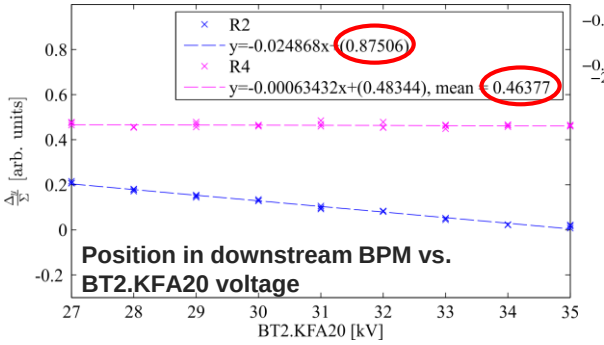






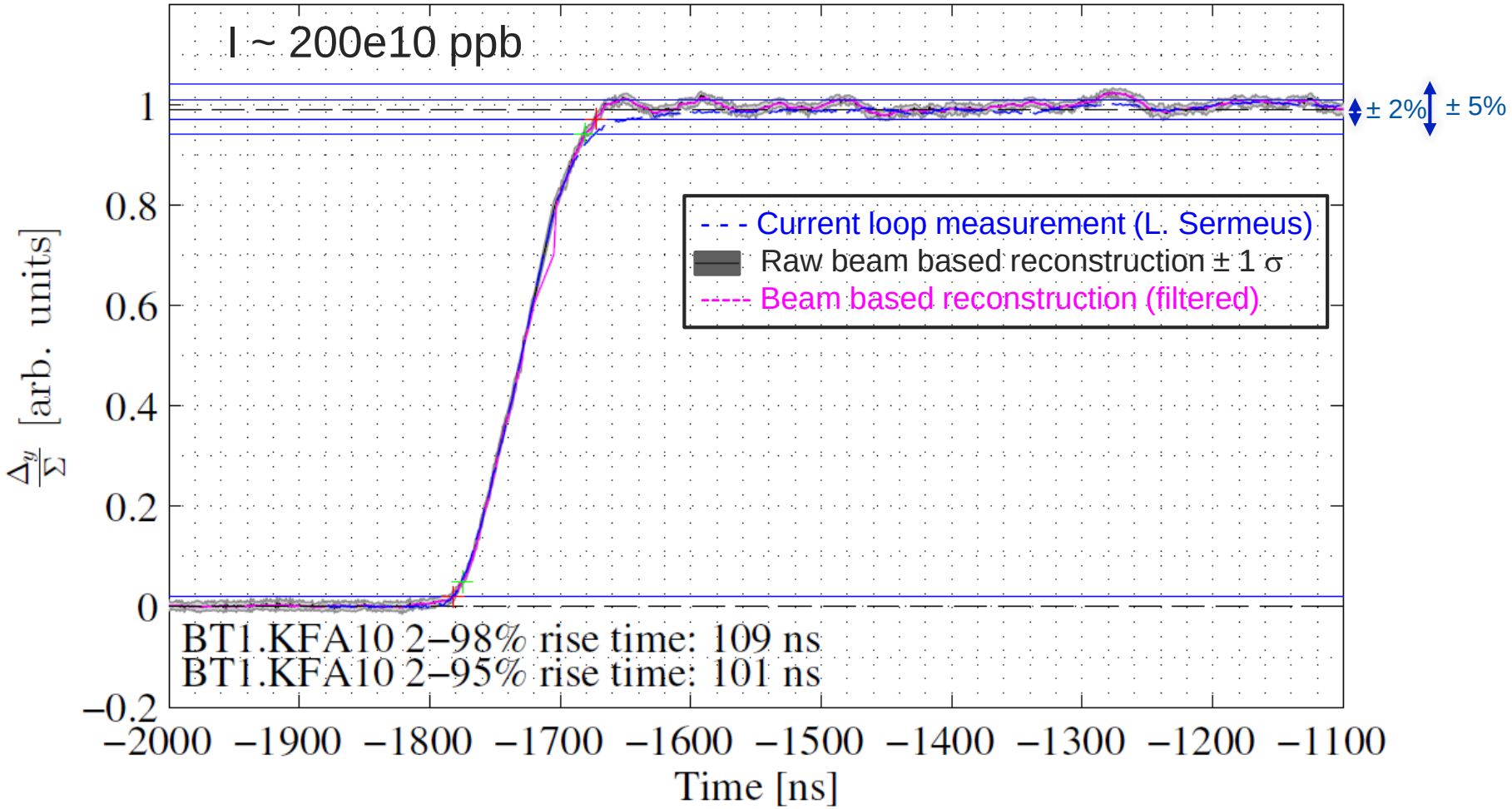
Subtracting the calibration shifts…





KFA10 and KFA20 measurements

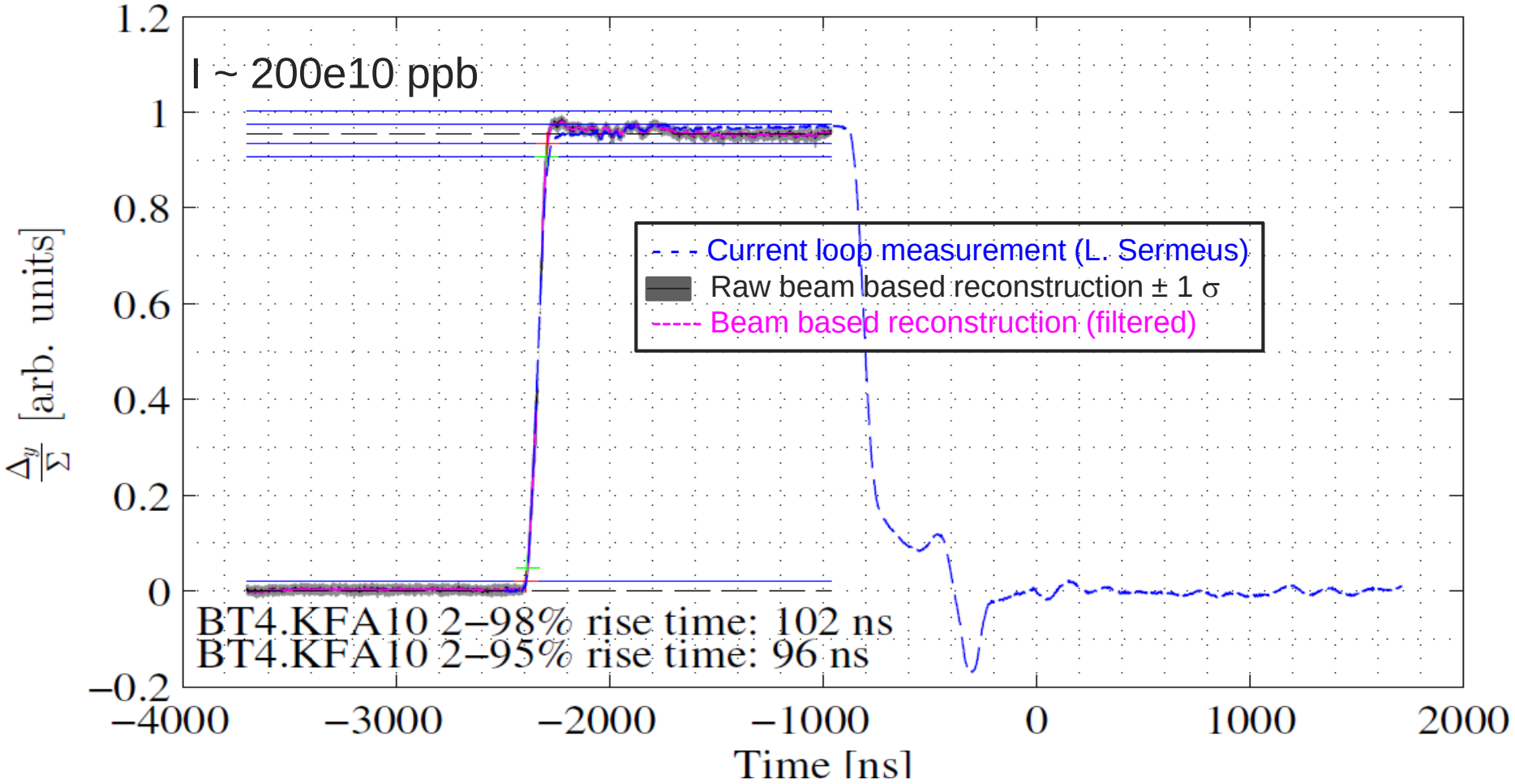
- **BT1.KFA10**



Good agreement with current loop measurements

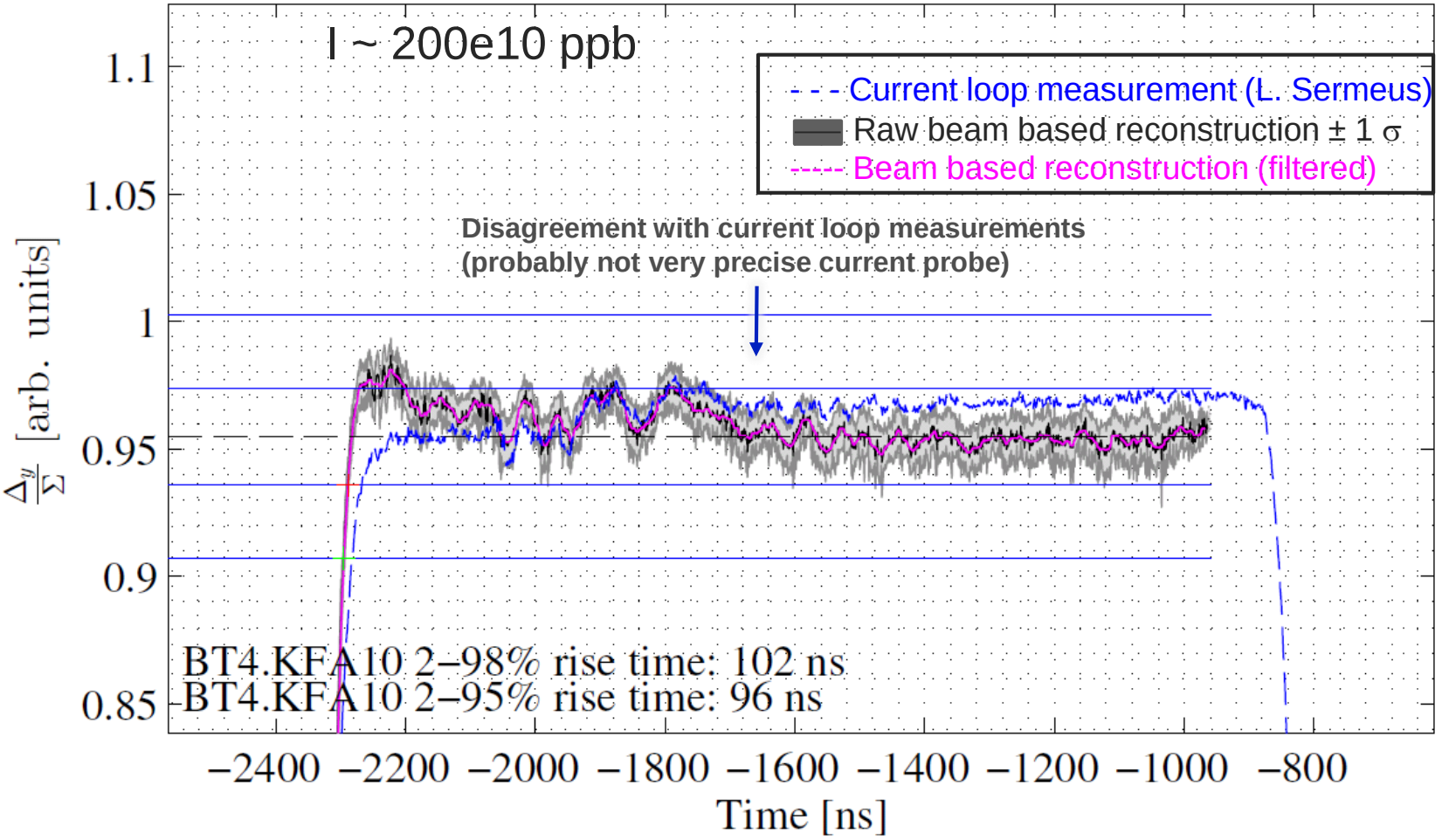
KFA10 and KFA20 measurements

- **BT4.KFA10**



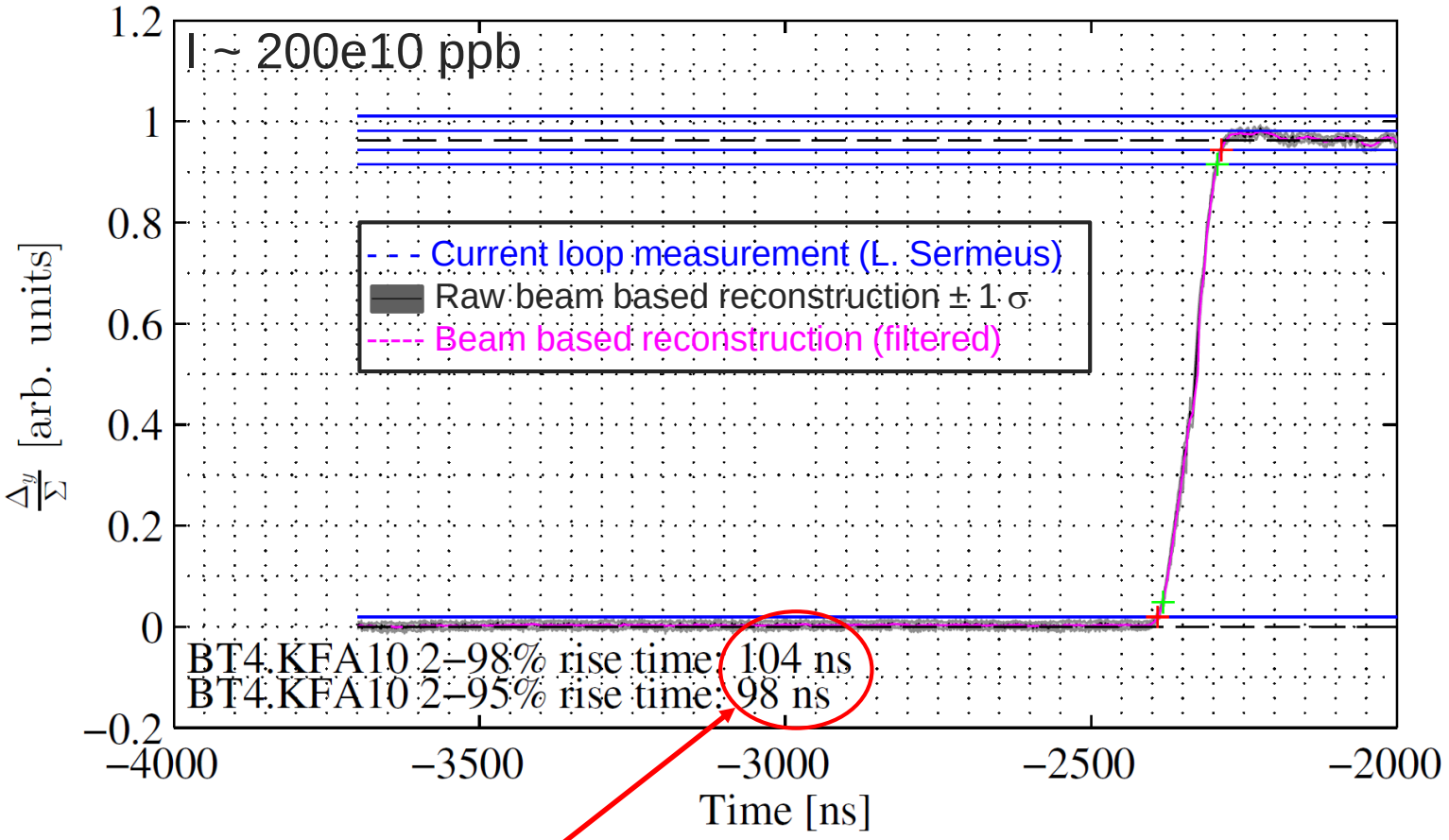
KFA10 and KFA20 measurements

- **BT4.KFA10**



KFA10 and KFA20 measurements

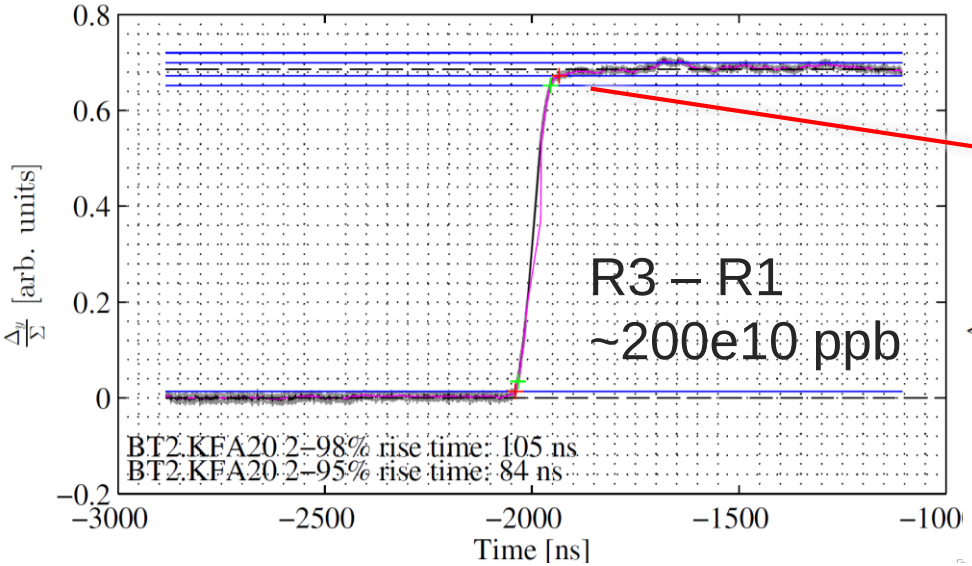
- **BT4.KFA10**



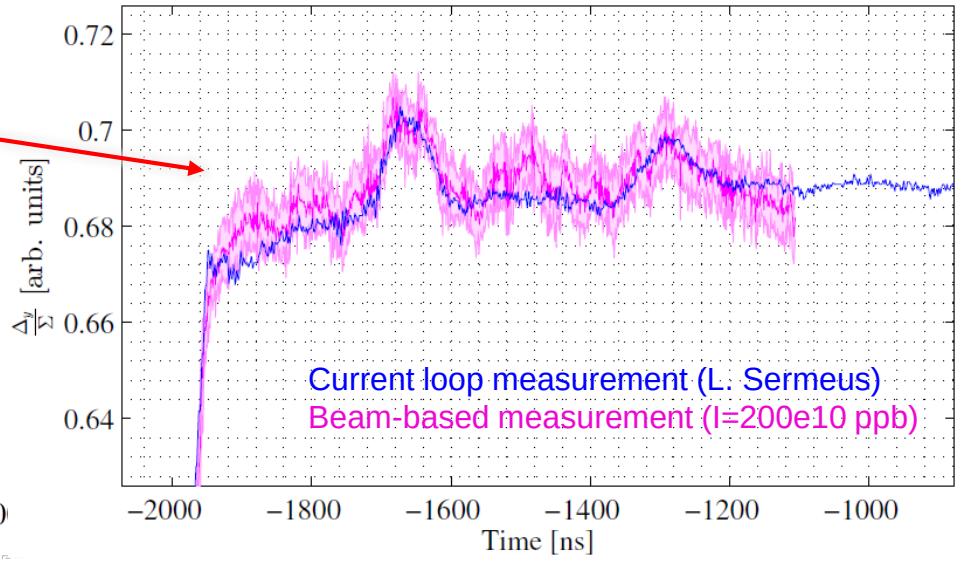
Slightly different rise times can depend on flat-top 100% level choice

KFA10 and KFA20 measurements

BT2.KFA20



Very good agreement with current loop measurements



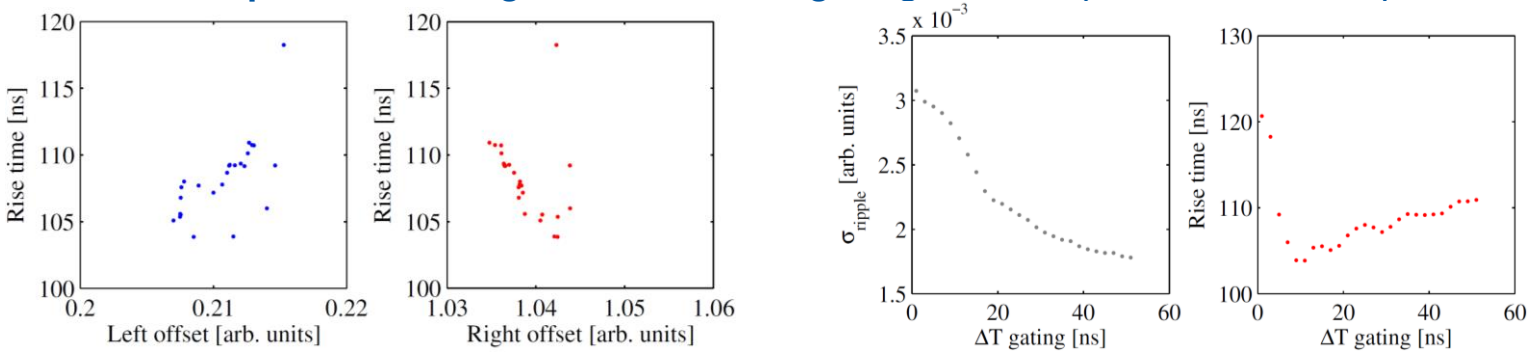
Rise times and steady state ripples

- The **2-98% rise times and the steady state ripples** have been estimated

*** PS-MKKIK-ES-0001**

Common **sources of error** are:

- The **choice of the flat-top 100% level**
- The **bunch intensity**, as it affects the BPMs response.
- The **beam reproducibility:** measurements last typically 3-9 hrs (in parallel !) …
- The **calibration technique** and the **length in time of the gating window** (BT2.KFA20 example below).



- The **jitter in time** of the kicker waveforms (~10 ns p-p) is included in the measurements.

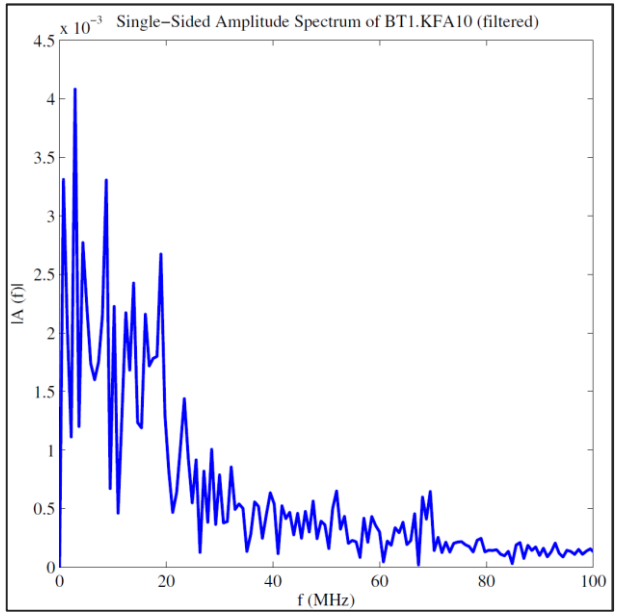
As a "conservative" educated guess, **an overall 10 ns tolerance has to be added** in the measurements.

	Rise time 2-98% (± 10 ns)	Intensity [1e10 ppb]	Rise time upper limit from specs*	Steady state peak ripple max(B/avg(B))	Peak ripple upper limit*
BT1.KFA10	105-110 ns	200	105 ns	2% - 2.7%	2%
BT4.KFA10	102-104 ns	200		2.9%	
BT2.KFA20	105-110 ns	200		2.6%	

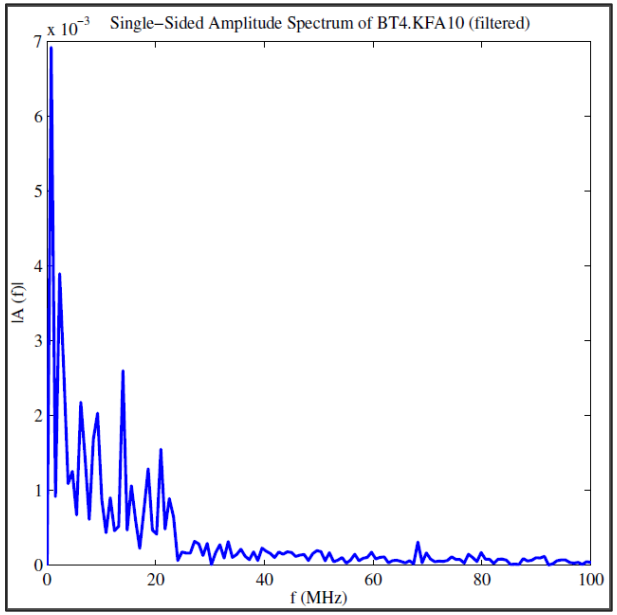
Frequency response

- **The frequency analysis** is interesting to deliver specs **for the PS tr. feedback** and evaluate field quality.
- There are **no significant components over 20 MHz (maximum -3dB bandwidth of PS tr. feedback)**

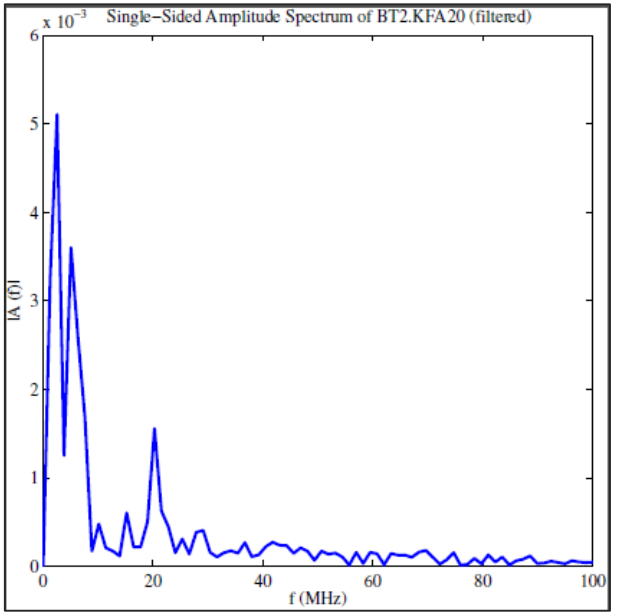
BT1.KFA10



BT4.KFA10



BT2.KFA20

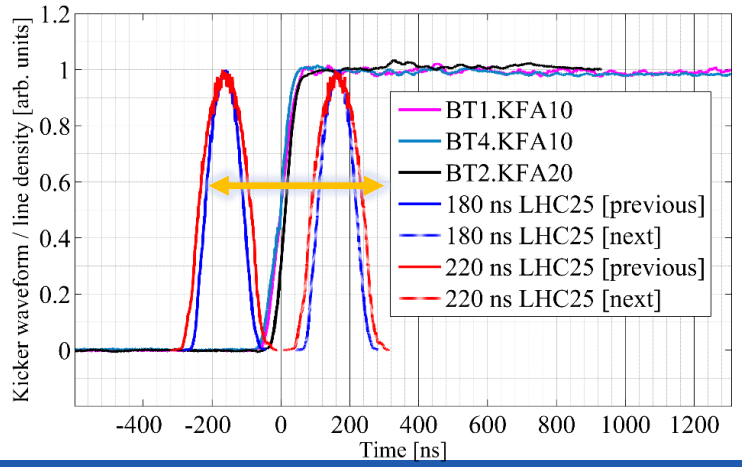


Time margins for transfer

- **Un-synchronized kicks perturb the bunches**…

Un-synchronized vertical kick → Vertical mismatch → Vertical emittance blow-up → Intensity loss

- The **constraints on rise time and steady-state ripple are NOT sufficient to guarantee a clean transfer**.
- **The most important figure of merit** that should be used **is the brightness** (**or the emittance** in this case)**.**
- **Measurements of the brightness as a function of the kicker timing** have been performed in order **to evaluate possible extra time margins** using LHC25 nominal (180 ns) and long (220 ns) bunches.
- **Simulations using the measured waveforms** have also been carried out **to asses expected emittance growth**



Time margins for stationary transfer

➢ Brightness measurements

- 'Nominal' (180 ns) and 'long' (220 ns) LHC25 bunches have been used.
- The dumped intensity (at BTM.BCT10) and the sem-grid profiles (in the BTM line) have been used to evaluate the time margins.
- The results are evaluated in terms of 'brightness' ratio for each of the three sem-grids profiles:

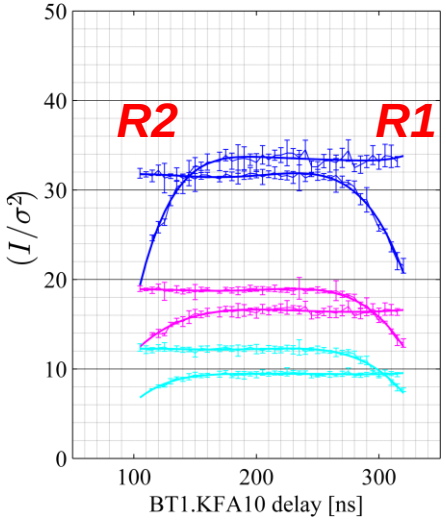
$$\frac{Intensity}{(1\sigma_y\ beam\ size)^2} = f(delay_{KFA}) \xrightarrow{\text{Constant brightness}} \frac{d}{dt}\left(\frac{Intensity}{(1\sigma_y\ beam\ size)^2}\right) = 0$$

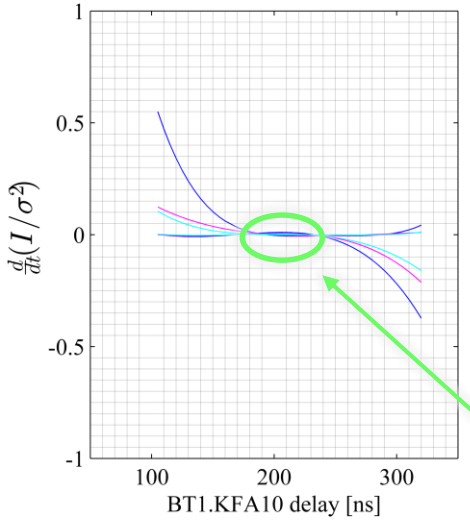
- The brightness has been used as it is a constant in the PSB→ this compensates the shot-by-shot intensity jitters (in the order of 5%).
- The **minimum value of** $delay_{KFA}$, between all the recombination kickers, **represents the possible measurable time margin to avoid any beam emittance blow-up and/or particle loss** during the vertical recombination.
- The **scans have been performed** for two consecutive rings **keeping ON only one ring for time** for each recombination kicker.
- The measurements bunch spacing is **338 ns**.

Time margins for transfer

- **Brightness measurements**

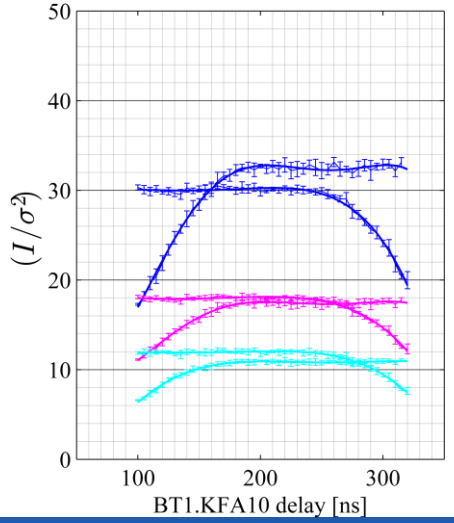
BT1.KFA10
180 ns bunch length

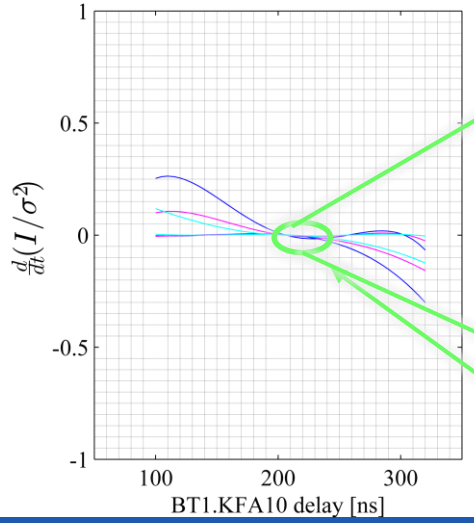


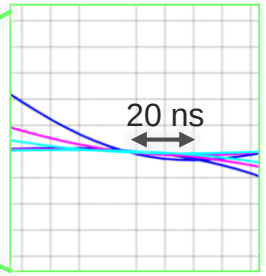


Constant brightness

BT1.KFA10
220 ns bunch length



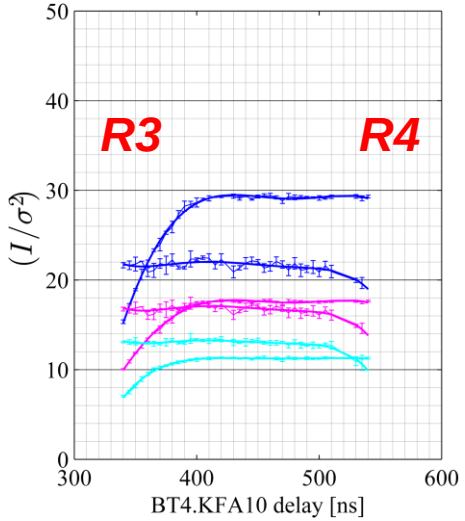


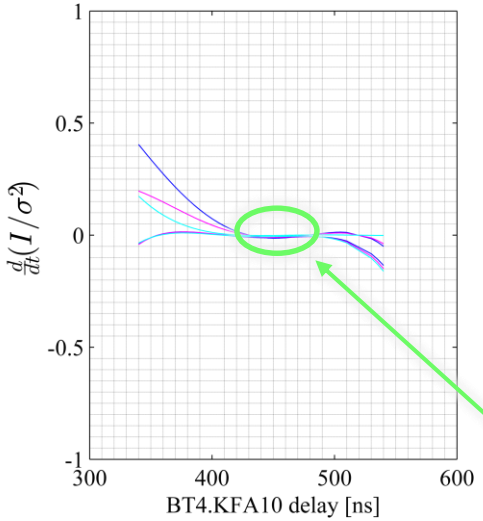


Time margins for transfer

- **Brightness measurements**

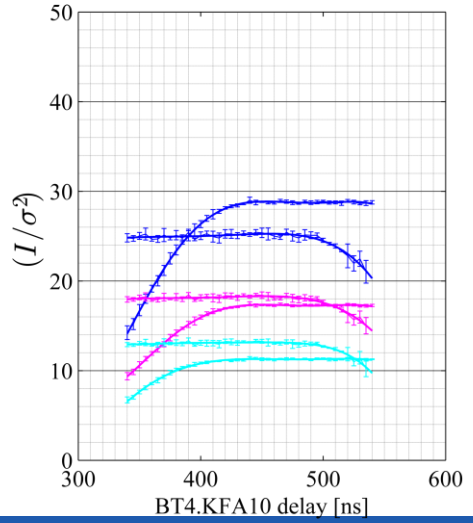
BT4.KFA10
180 ns bunch length

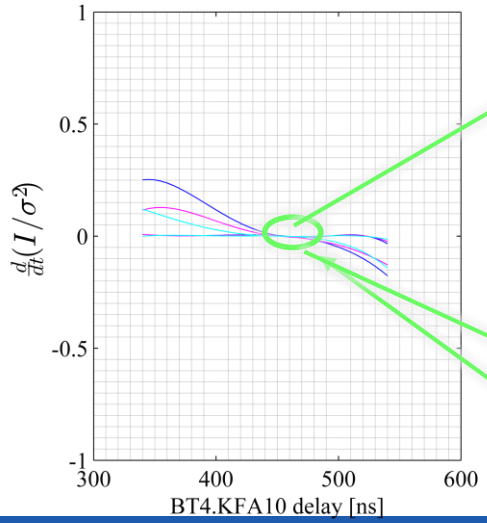


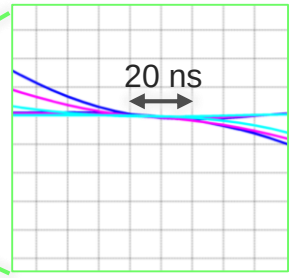


Constant brightness

BT4.KFA10
220 ns bunch length



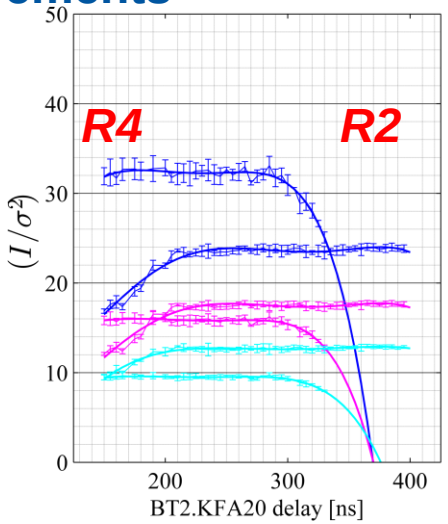


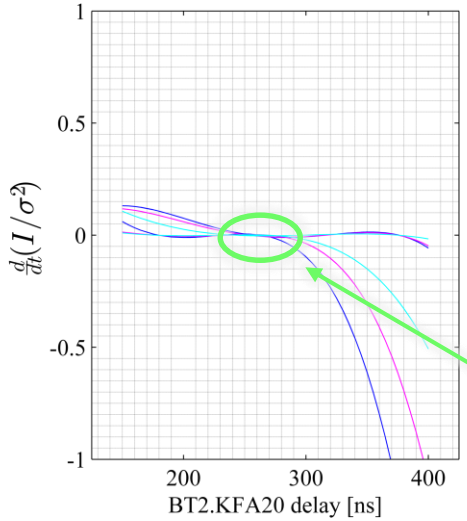


Time margins for transfer

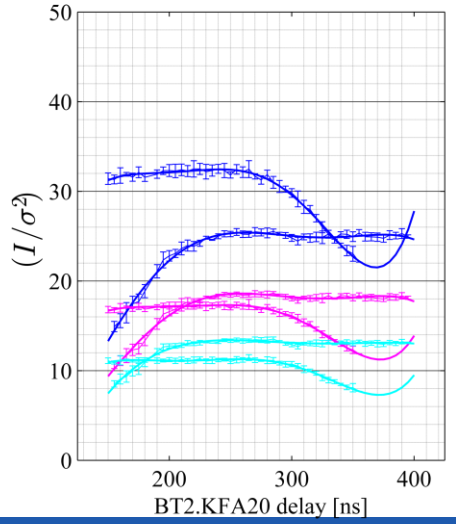
- **Brightness measurements**

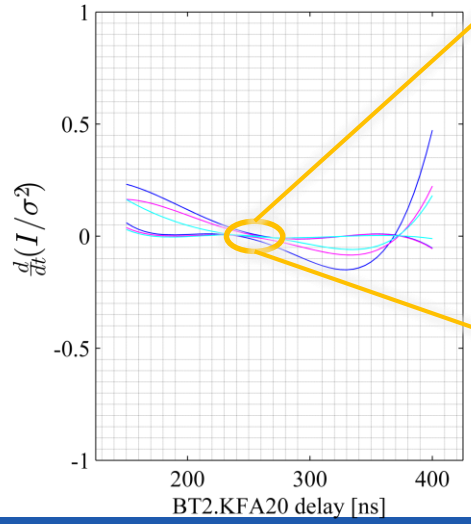
BT2.KFA20
180 ns bunch length

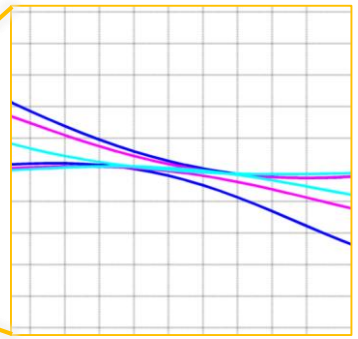




BT2.KFA20
220 ns bunch length



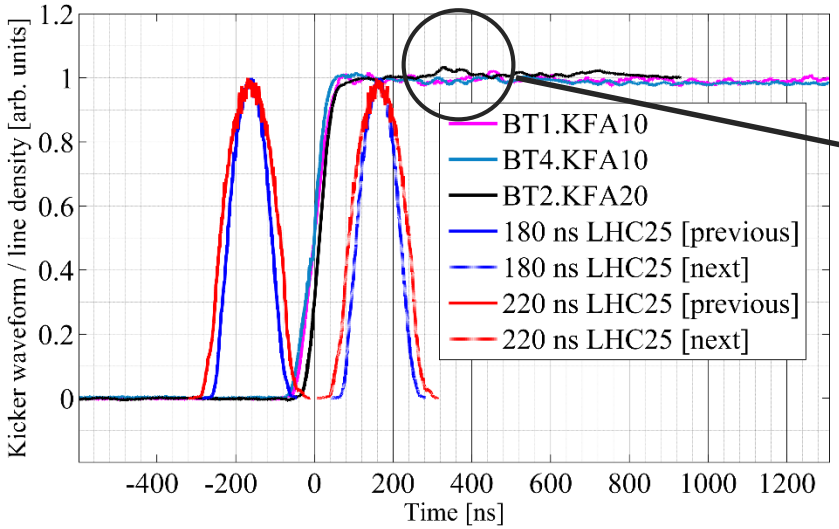


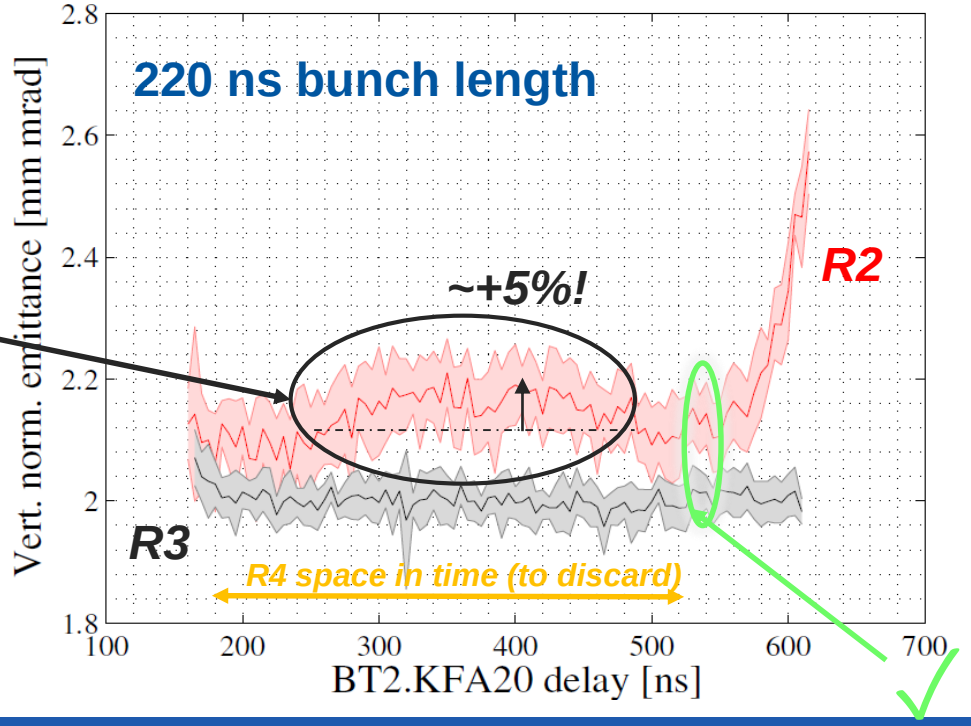


More tests required!

Time margins for transfer

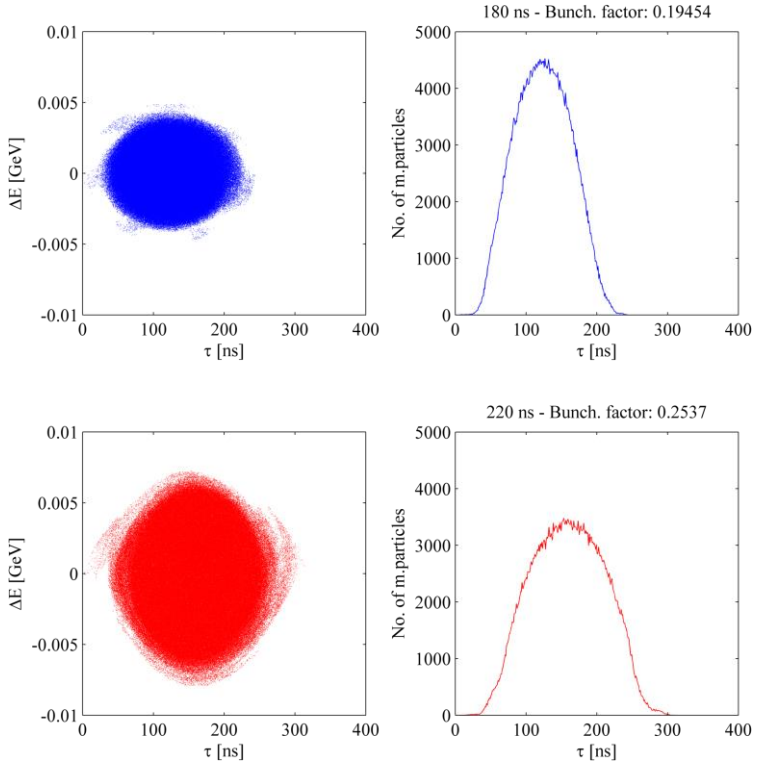
- **Further measurements on BT2.KFA20: emittance preservation**
  - **R3 and R2** have been used as they are **not kicked by KFA10 (remember R3→**R4**→R2), so one bunch spacing has to be subtracted**
  - **An emittance blow-up is visible due to the KFA20 ripple → the ripple must be reduced** in amplitude and/or in time
  - It is still possible to consider **a certain margin** for a clean transfer.



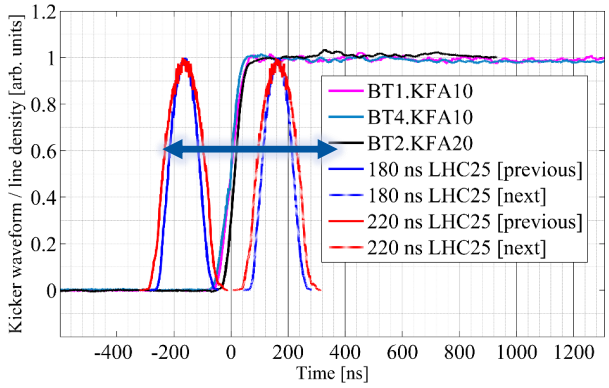


Time margins for stationary transfer

- **Simulations set-up**



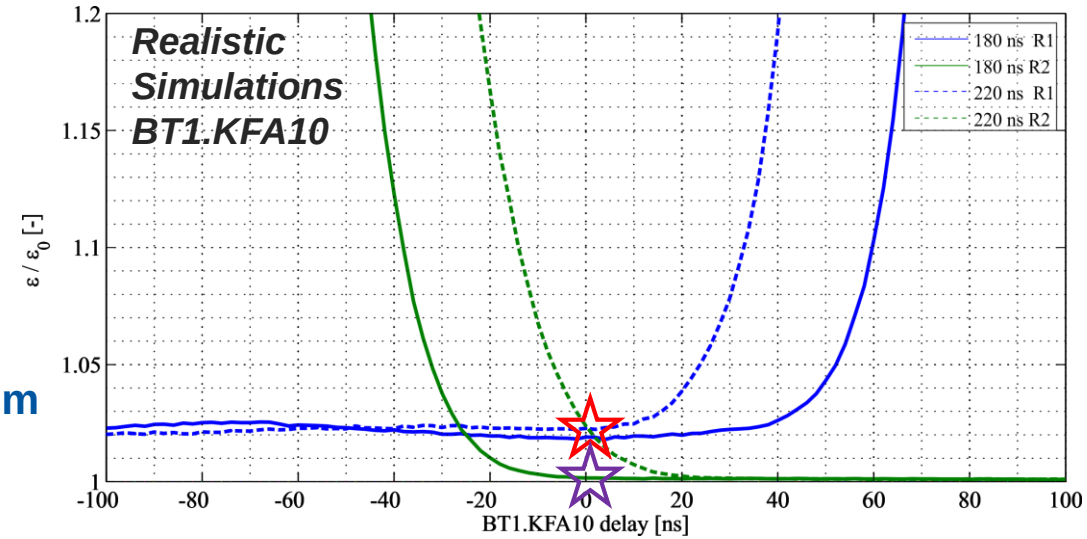
1. **Match bi-Gaussian transverse distributions** with Twiss parameters from transfer lines and **1.8 um transverse emittance**.
2. **Apply weighted kick** to sliced longitudinal coordinate τ.
3. **Re-compute statistical rms emittance** from perturbed distribution (no transport).
4. **Shift the kicker waveform in time**.

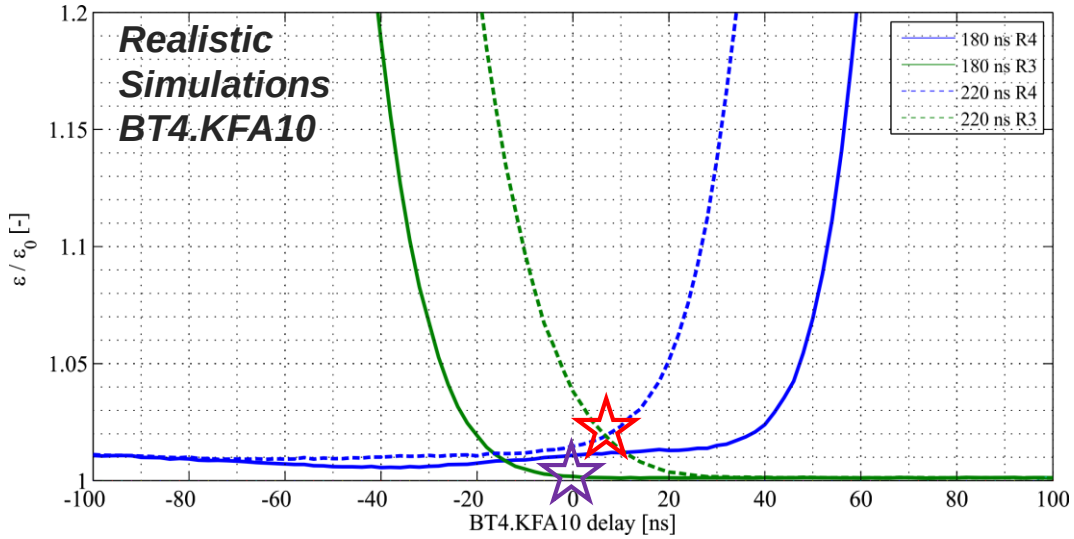


5. Go back to point 1.

Time margins for transfer

- **Simulations: realistic case**
  - **Real kicks from beam-based measurements**
  - **LIU bunch spacing = 327 ns***
  - Initial **normalized $\varepsilon_{n,x,y}$ (1σ) = 1.8 um**
  - **No dispersion**





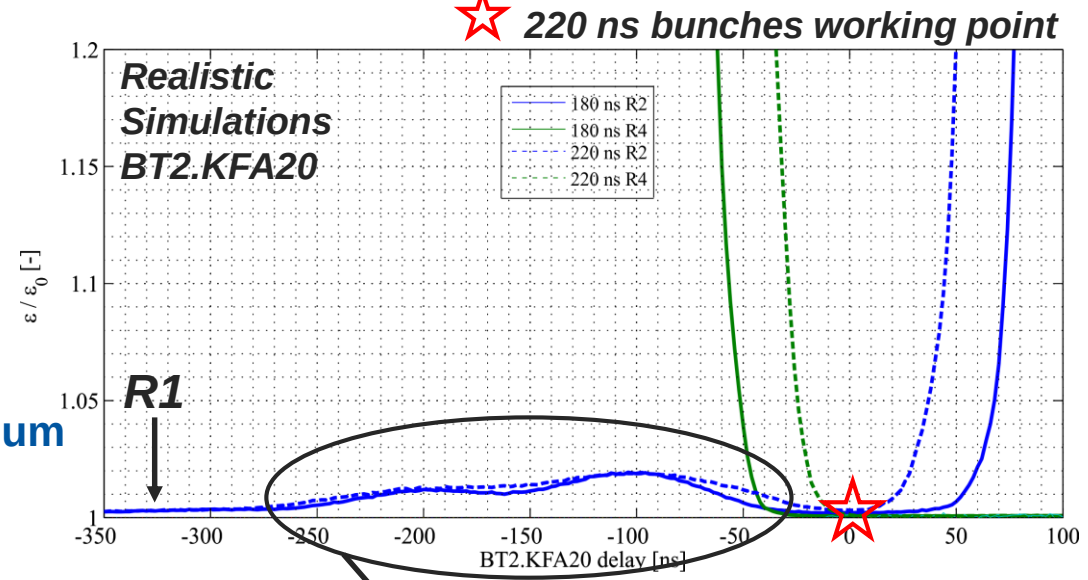
☆ *180 ns bunches working point*

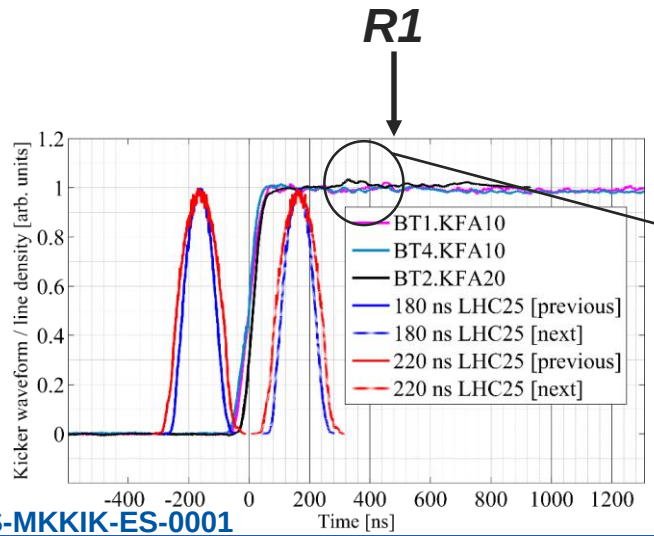
☆ *220 ns bunches working point*

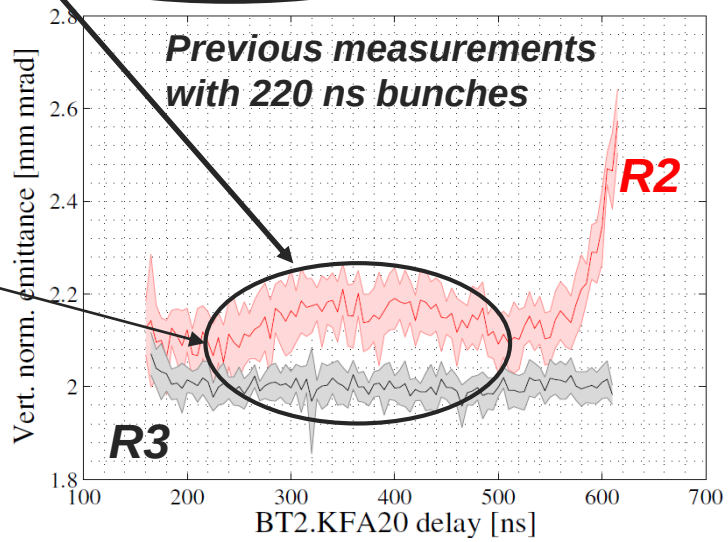
*** LIU 1.4 GeV - PS-MKKIK-ES-0001**

Time margins for transfer

- **Simulations: realistic case**
  - **Real kicks from beam-based measurements**
  - **LIU bunch spacing = 327 ns***
  - Initial **normalized $\varepsilon_{n,x,y}$ (1σ) = 1.8 um**
  - **No dispersion**







* LIU 1.4 GeV - PS-MKKIK-ES-0001

Summary and conclusions

- Beam-based results have been presented together with independent current probe measurements.
  - **Measured rise times and steady state ripples are, globally, at the edge of the specifications**.
  - **Measurements have limitation**: **roughly ± 10 ns estimated error on rise times.**
  - The frequency responses of the magnetic fields waveforms have significant components up to ~20 MHz.

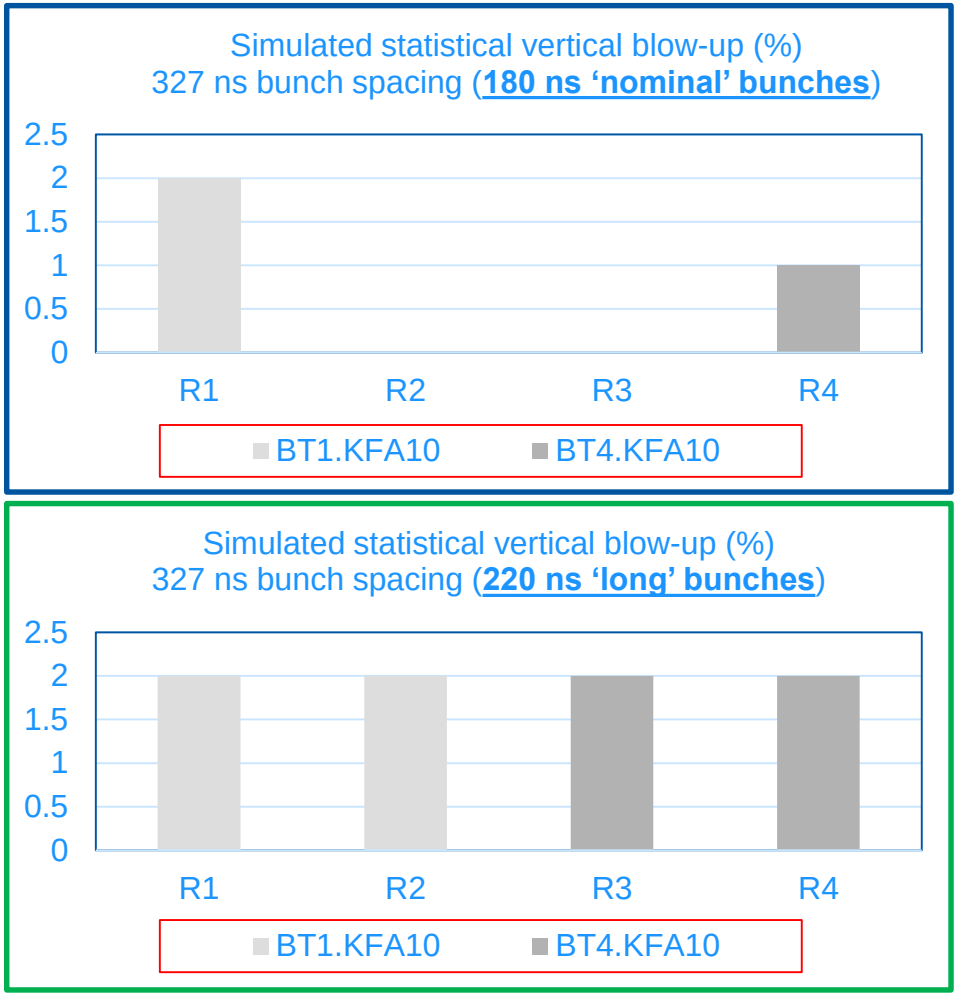
	Rise time 2-98% (± 10 ns)	Intensity [1e10 ppb]	Rise time upper limit from specs*	Steady state peak ripple max(B/avg(B))	Peak ripple upper limit from specs*	Simulated vertical rms emittance growth with 220 (180) ns bunches			
						R1	R2	R3	R4
BT1.KFA10	105-110 ns	200	105 ns	2% - 2.7%	2%	2% (2%)	2% (0%)	0	0
BT4.KFA10	102-104 ns	200		2.9%		0	0	2% (0%)	2% (1%)
BT2.KFA20	105-110 ns	200		2.6%		0	0	0	0

- The **brightness and the emittance** have been evaluated as **the most important figures of merit**.
  - **Measurements on the sem-grids** (with present 338 ns bunch spacing) have shown that **there is a small margin (10-20 ns) in time to avoid a mismatch induced by un-synchronized kick and 'long' (220 ns) bunches**.
  - **Realistic simulations** (LIU 1.4 GeV 327 ns bunch spacing) show that this **margin is very small** → trade-off with emittance blow-up of few percent.

*** PS-MKKIK-ES-0001**

Summary and conclusions

- Further reductions of the flat-top ripple and rise time could be beneficial for emittance preservation.

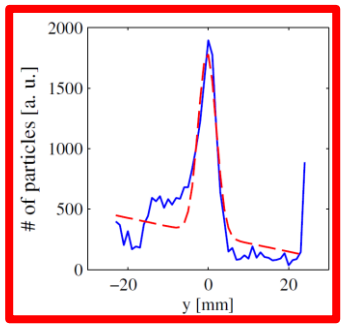


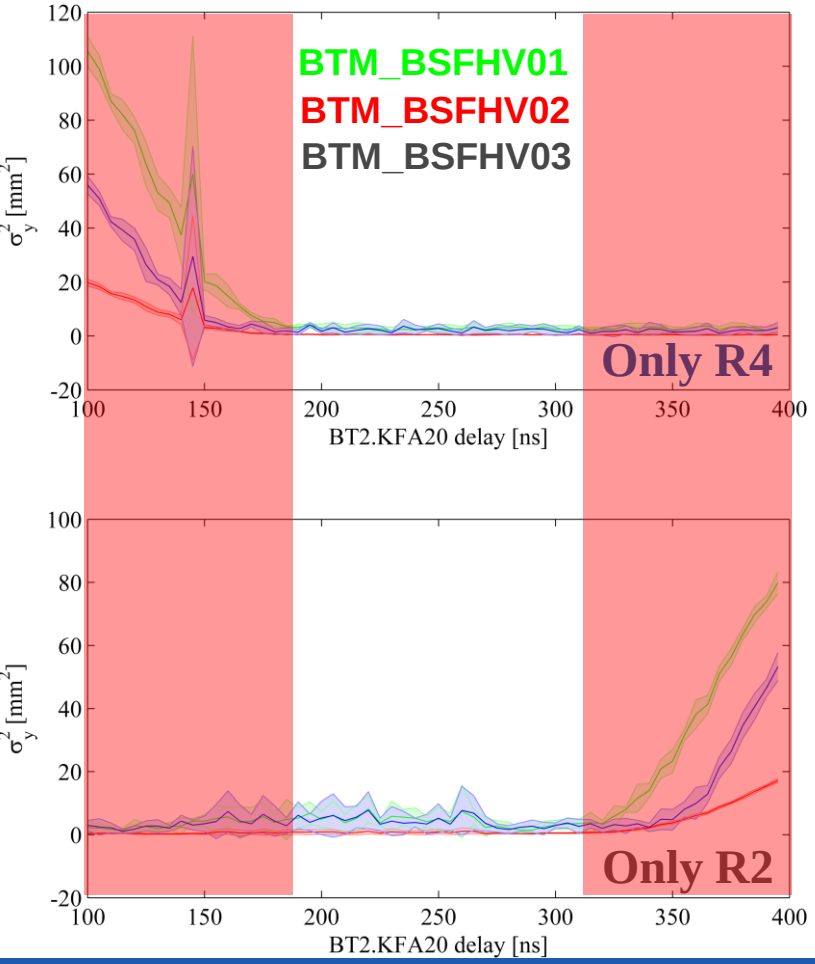
Appendix

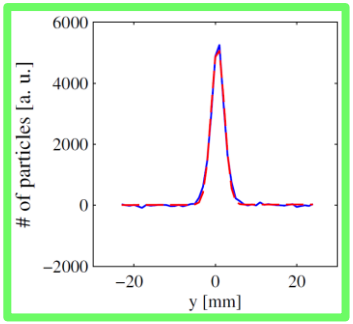
Time margins for transfer

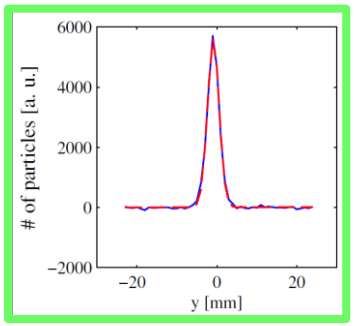
- **Un-synchronized kicks lead to bunch perturbation…**

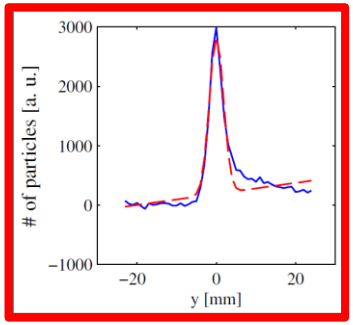
Un-synchronized vertical kick → Vertical mismatch → Vertical emittance blow-up → Intensity loss





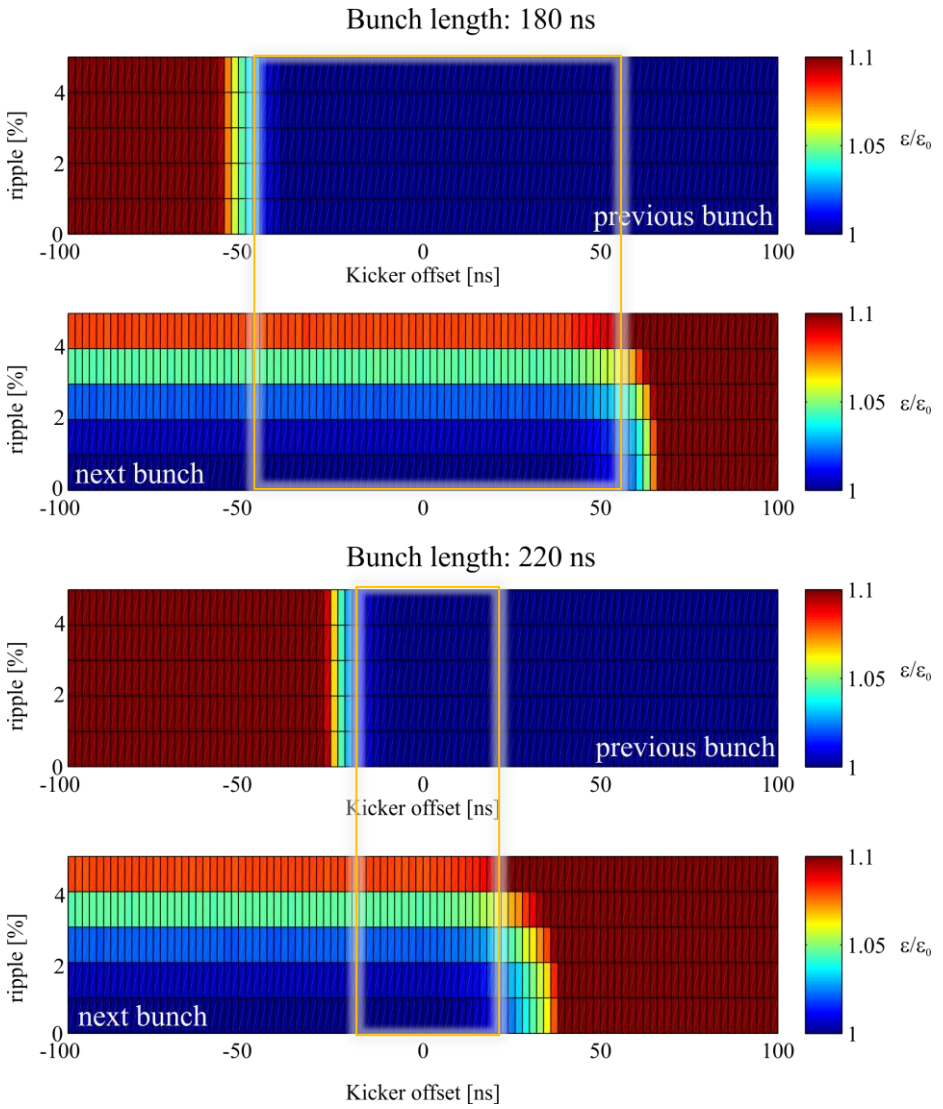




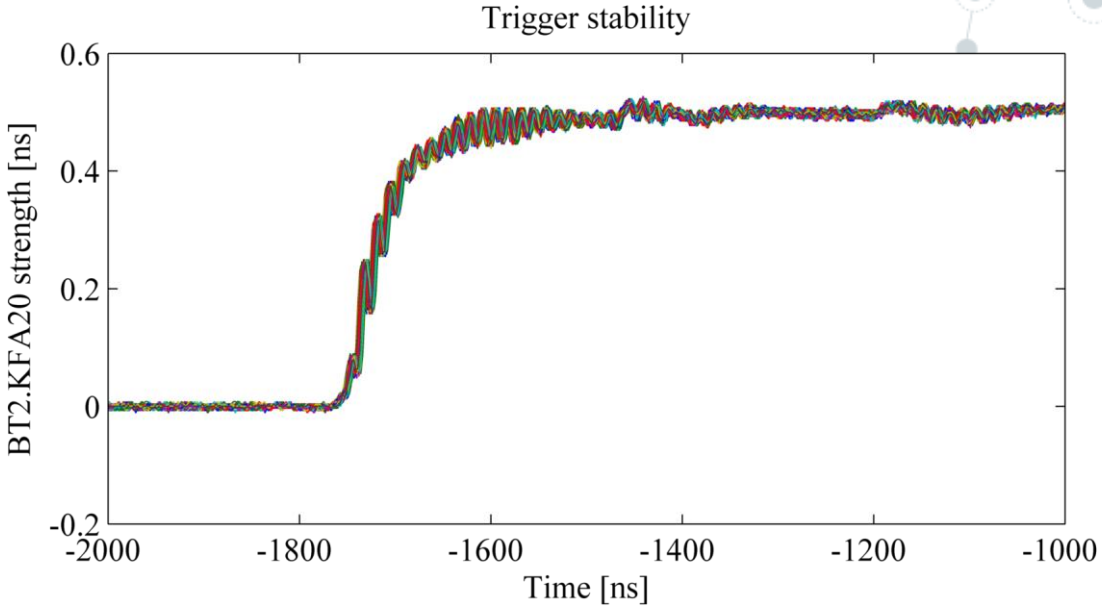


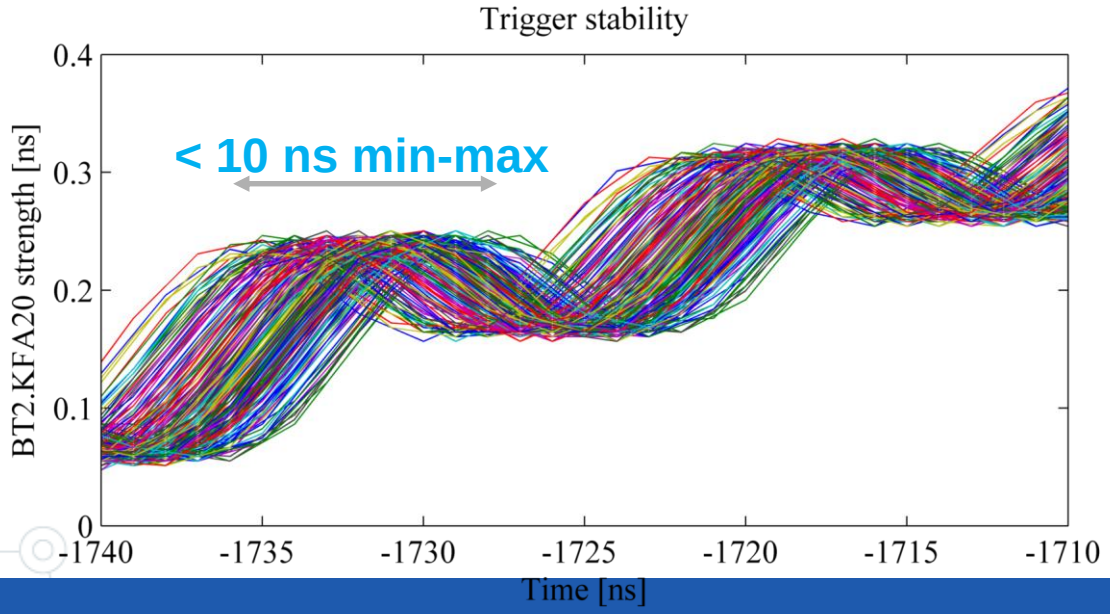
Time margins for transfer

- **Simulations example: an ideal case**
  - **Ideal kick: step function** (rise time → 0) **plus 20 MHz sinusoidal flat-top ripple with different amplitudes**
  - **Bunch spacing = 316 ns***
  - Initial **normalized $\varepsilon_{n,x,y}$ (1σ) = 1.8 um**
  - **No dispersion**
  - **Going over 2% of ripple start causing strong emittance growth**



*** LIU 2 GeV - PS-MKKIK-ES-0001**


Trigger stability
BT2.KFA20 strength [ns]
0.6
0.4
0.2
0
-0.2
-2000
-1800
-1600
-1400
-1200
-1000
Time [ns]


Trigger stability
< 10 ns min-max
BT2.KFA20 strength [ns]
0.4
0.3
0.2
0.1
0
-1740
-1735
-1730
-1725
-1720
-1715
-1710
Time [ns]

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