PSB to PS recombination kicker waveform measurements

Vincenzo Forte

CERN TE-ABT-BTP

LIU-PSB meeting

18-07-2016

Acknowledgements:

M. A. Fraser , W. Bartmann, E. Benedetto, M. Bozzolan, T. Kramer, L. Sermeus, G. Sterbini, J. Tan

Outline

This presentation extends the one given at the **MSWG on 10th June 2016**. The work is still **in progress**…

- A **new and automatic method** for beam-based kickers waveforms measurements.
- **Rise time** evaluation
- **BTM line sem-grids** for bunch length limits evaluation

Previous methods for beam-based kickers waveforms measurements.

WEPD088 Proceedings of IPAC'10, Kyoto, Japan

BEAM-BASED MEASUREMENT OF THE WAVEFORM OF THE LHC INJECTION KICKERS

M.J. Barnes, L. Ducimetière, B. Goddard, C. Hessler, V. Mertens, J. Uythoven
CERN, Geneva, Switzerland

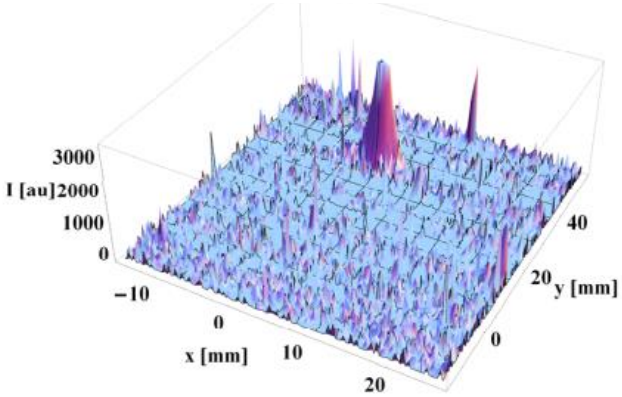
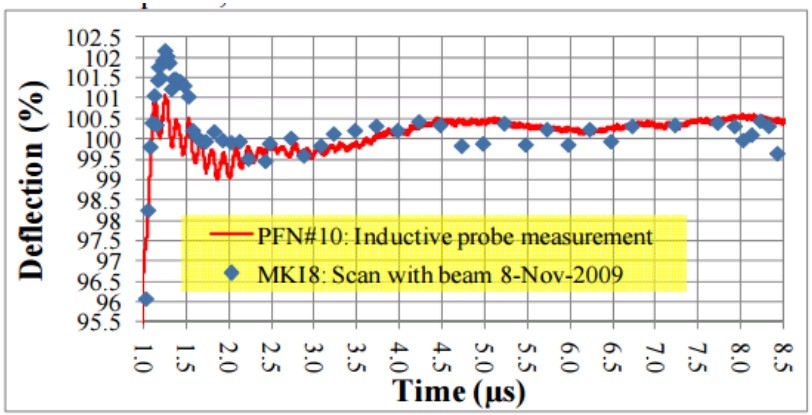


Figure 2: 3D display of beam position.



LHC BTV based **25 ns resolution**

Bunch length much smaller than rise time → beam can be used as a short sampler

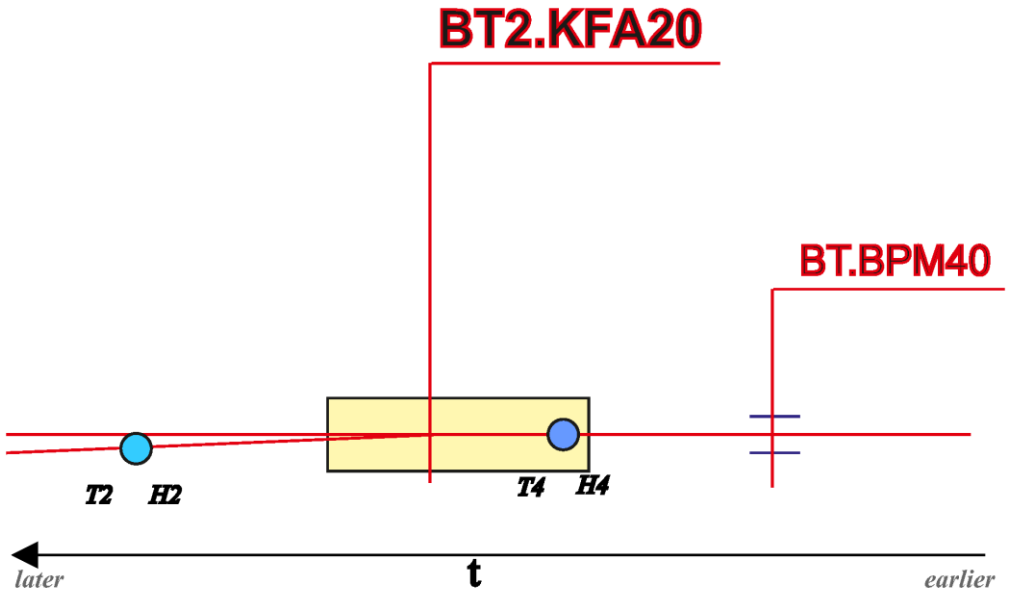
Bunch lengths in the PSB are comparable to the rise time… How can we measure it?

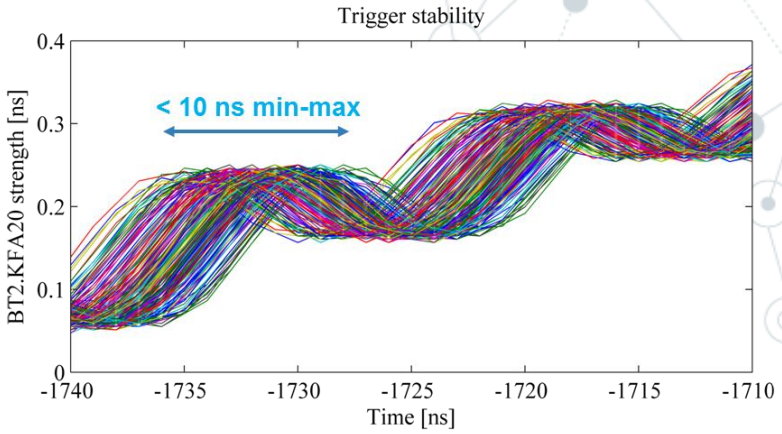
A **new and automatic method** for beam-based kickers waveforms measurements

Requirements of the method:

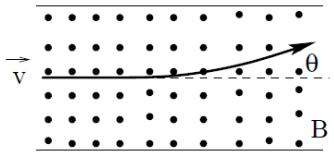
- **Best time resolution:** in the order of the max sampling frequency of the OASIS scopes -> **1-2 ns**
- **High granularity** for **reliable statistics**
- **Low losses**
- **Suitable for automated measurements**
- **To complement and validate lab measurements with search coil**

A **new and automatic method** for beam-based kickers waveforms measurements





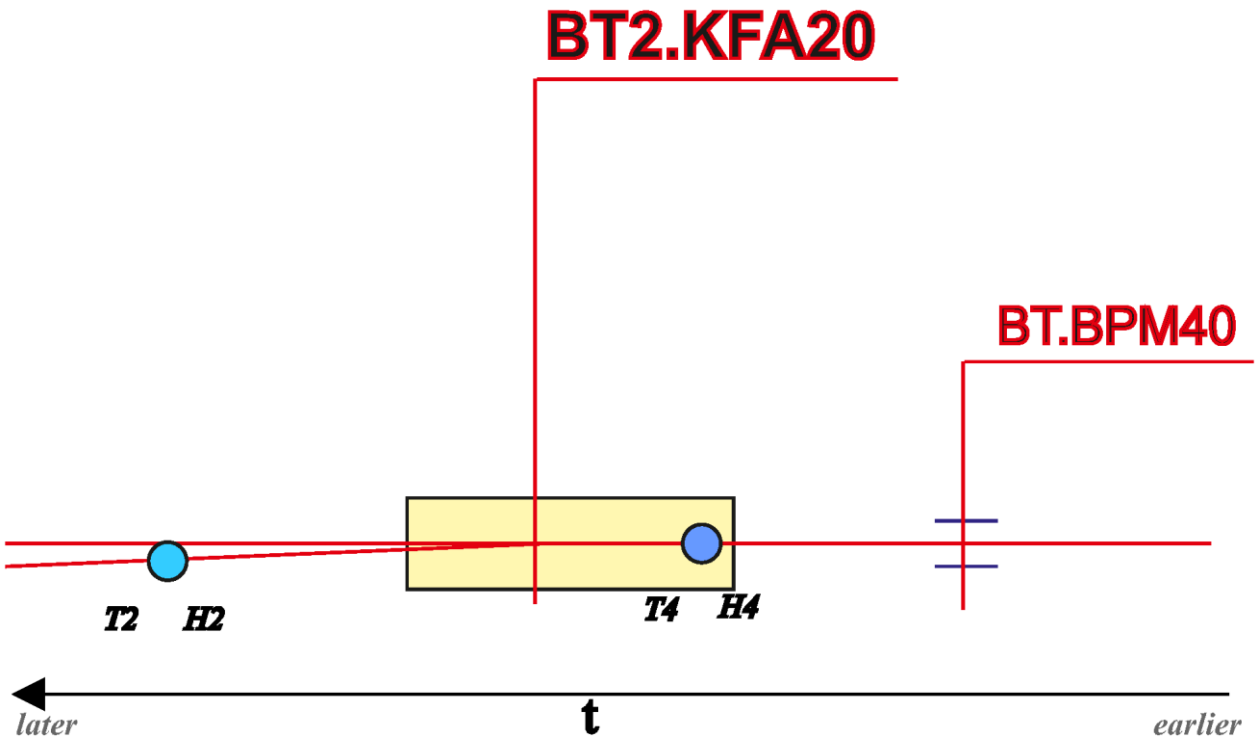
- **Kickers displace the beam** horizontally or vertically imposing a deflection angle $\theta_{x,y}$ –> **BPMs** are the main device to measure displacement, statically and **dynamically** (BTVs are available but with bad resolution performances).



$$\theta_y = \frac{e}{p}\int_0^L B_x\,dz$$

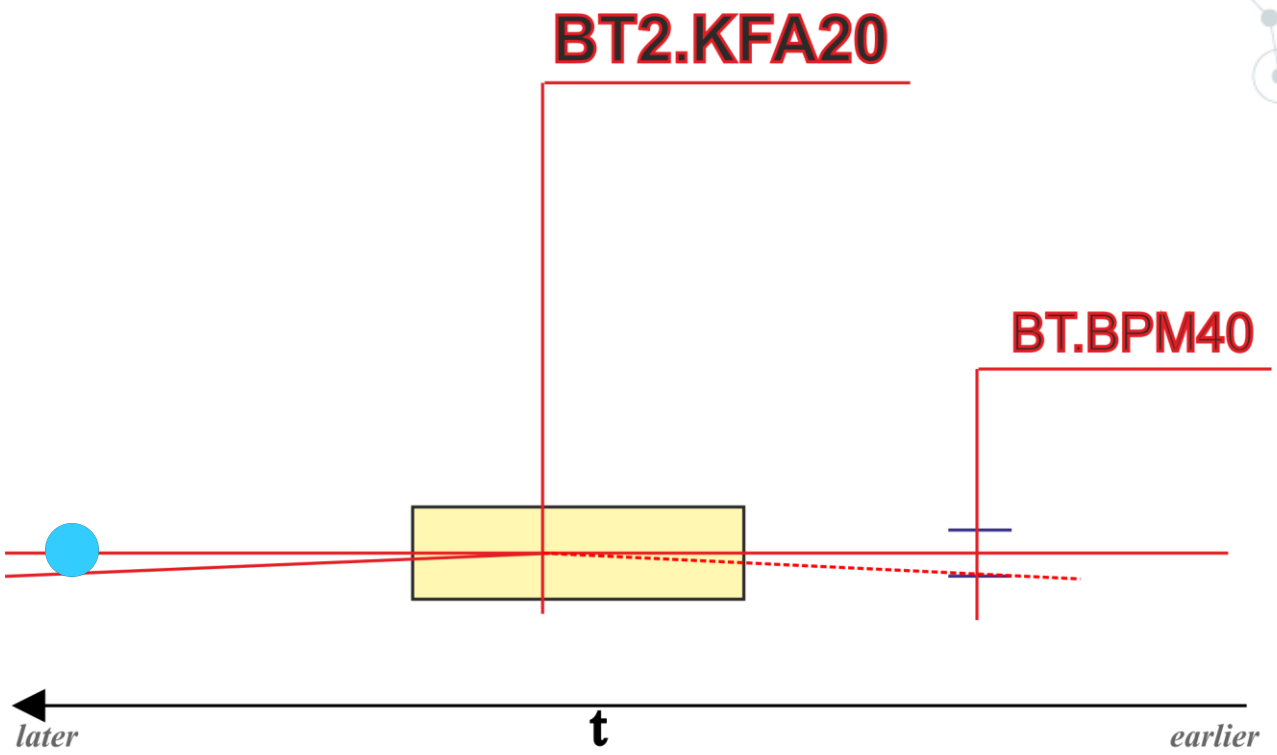
- The BPMs need a minimum current (line density) to work properly – intensity used from 30e10 to 200e10 ppb.
- Kicker T.O.F. is around 5.6 ns (kickers length ~1.5 m, β_{rel}=0.916) and limits the resolution.
- The kickers in the line can be pulsed with fine time delays in minimum steps of 1 ns.
- The stability of the trigger (<10 ns min-max jitter) can be a limit to the dynamics resolutions
- Loss limits can be guaranteed though the BLMs in the line and the surveillance (counter interlock).

A **new and automatic method** for beam-based kickers waveforms measurements (BT2.KFA20 example)



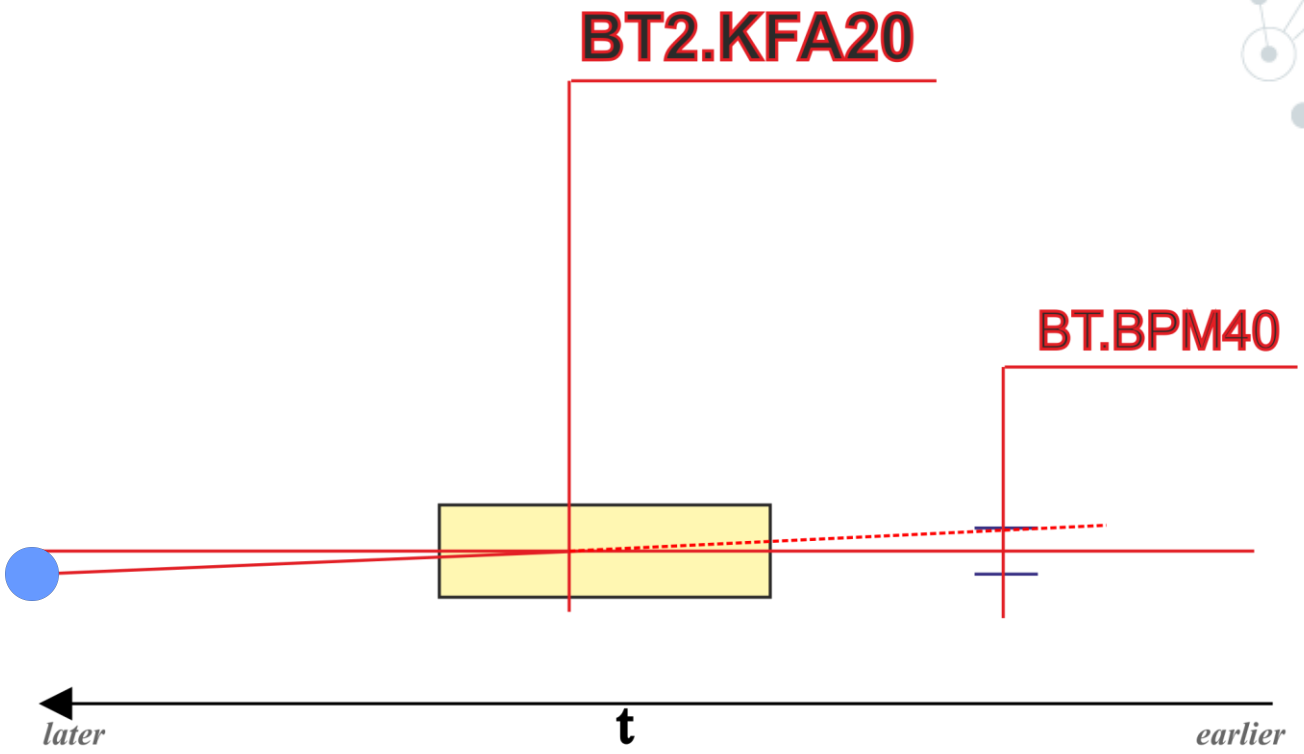
- The kicker magnetic field rise in time between two (consecutive) bunches (ex. after R4 and before R2)
- The kicker is started with different delays touching eventually the two adiacent bunches…

A **new and automatic method** for beam-based kickers waveforms measurements



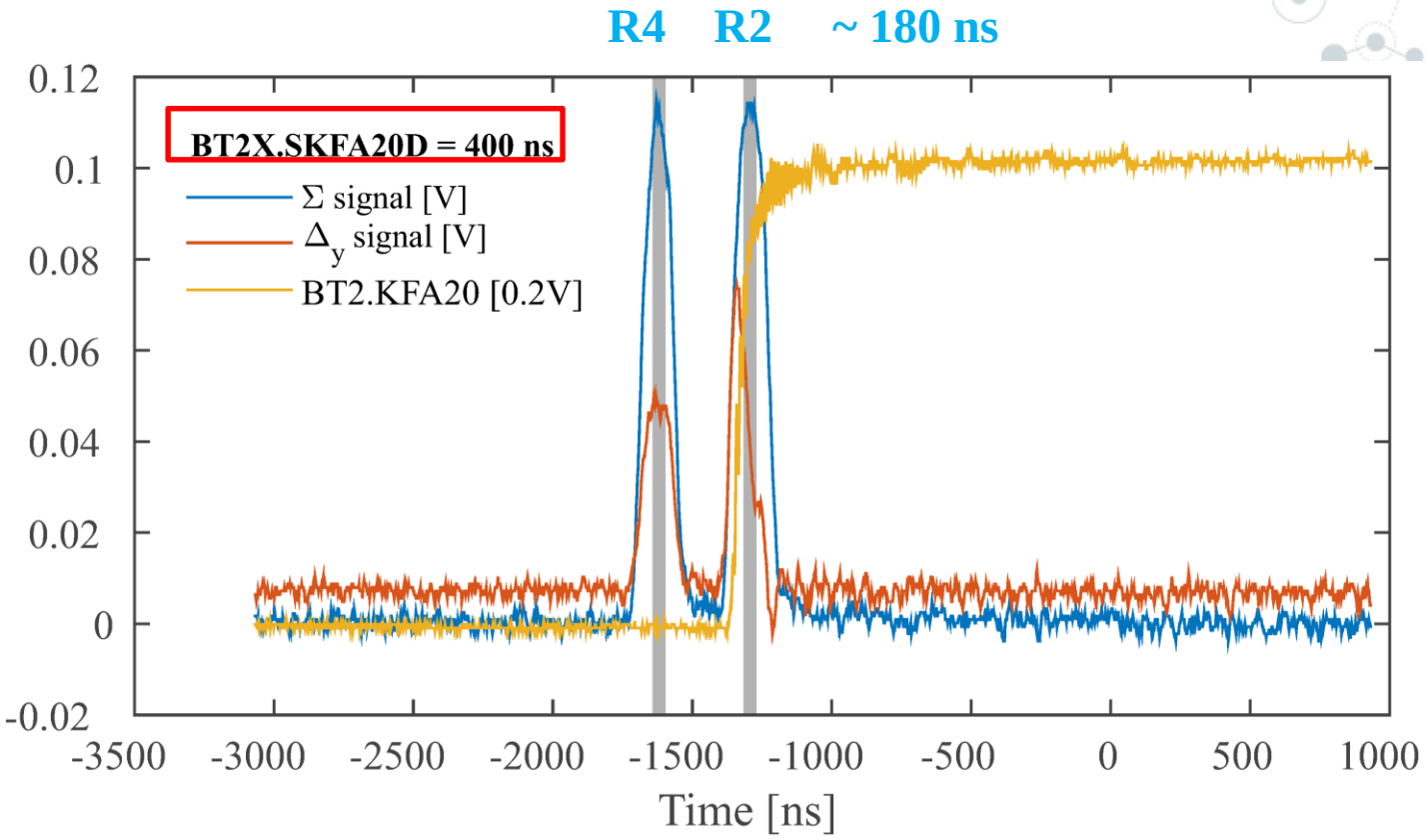
- The kicker magnetic field rises in time between two (consecutive) bunches (ex. after R4 and before R2)
- R4 is un-kicked and passes first
- **If R4** were **fully kicked**, it would **get vertically lost at one side** of the vacuum chamber

A **new and automatic method** for beam-based kickers waveforms measurements



- The kicker magnetic field rise in time between two (usually consecutive) bunches (ex. after R4 and before R2)
- R2 is fully kicked and passes after R4
- **If R2** were **un-kicked**, it would get **vertically lost** on the vacuum chamber, **at the opposite side w.r.t. to R4**.

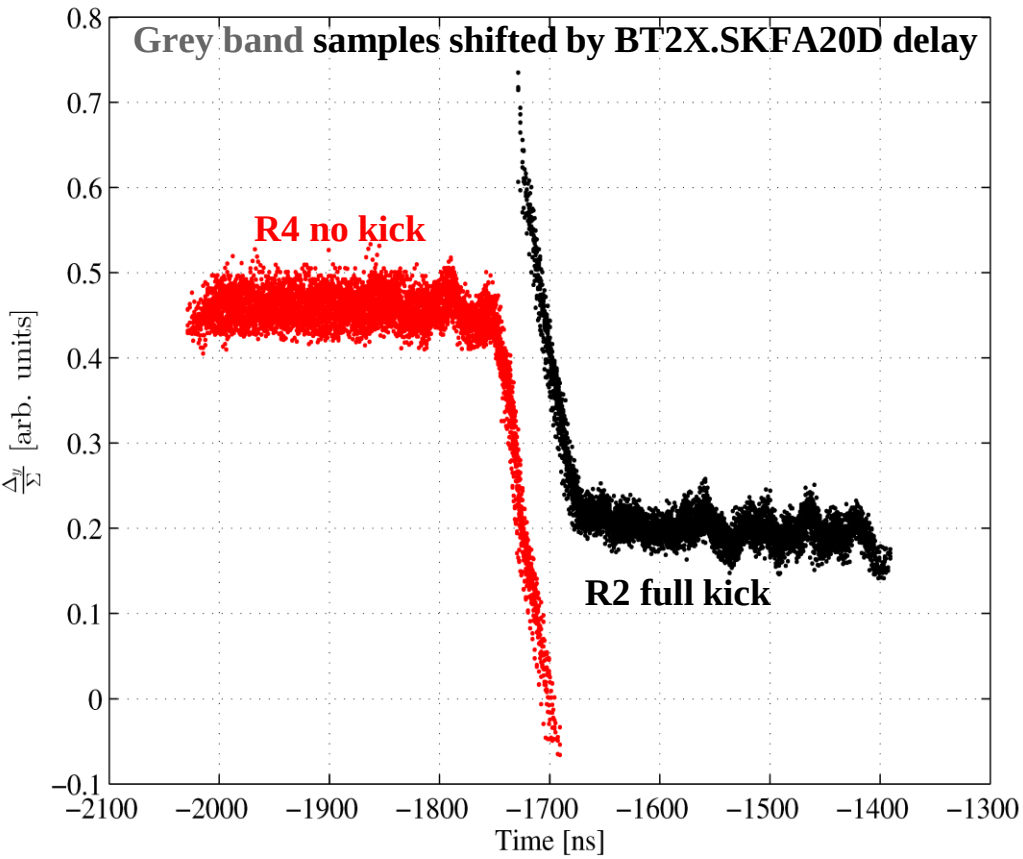
A new and automatic method for beam-based kickers waveforms measurements



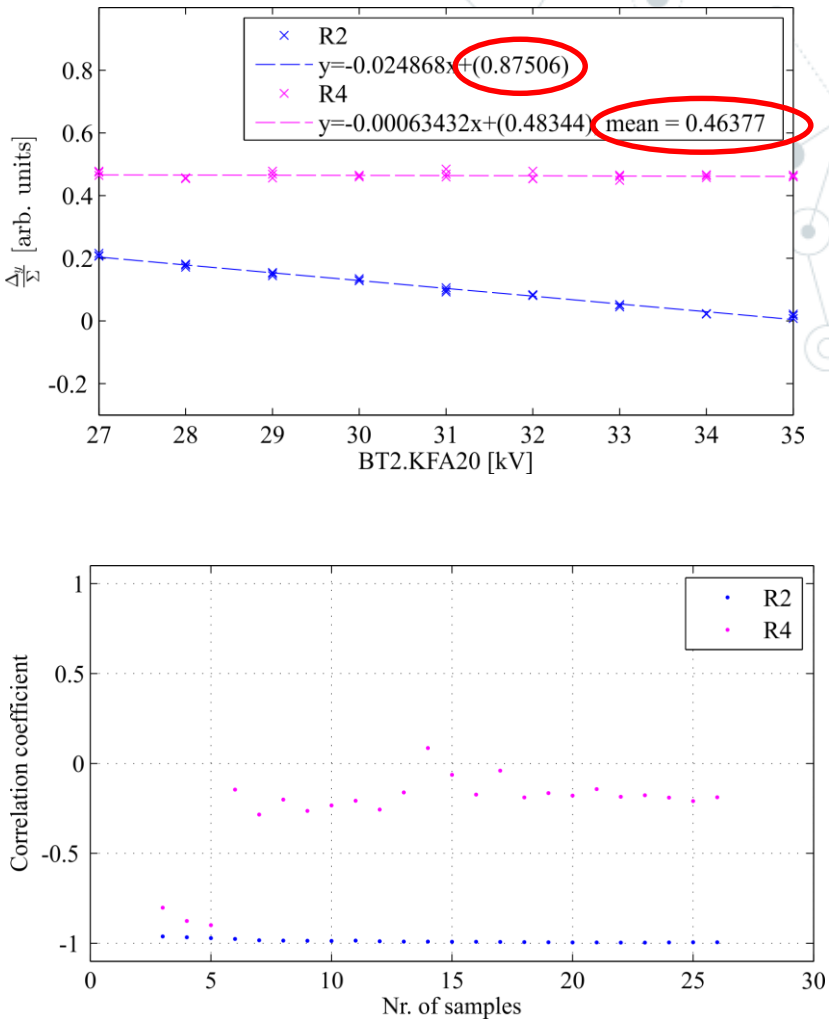
- BPM signals for different time delays of the KFA20
- The grey band is the fixed - gating - time window kept for the signal reconstruction

A new and automatic method for beam-based kickers waveforms measurements

Un-calibrated measurement

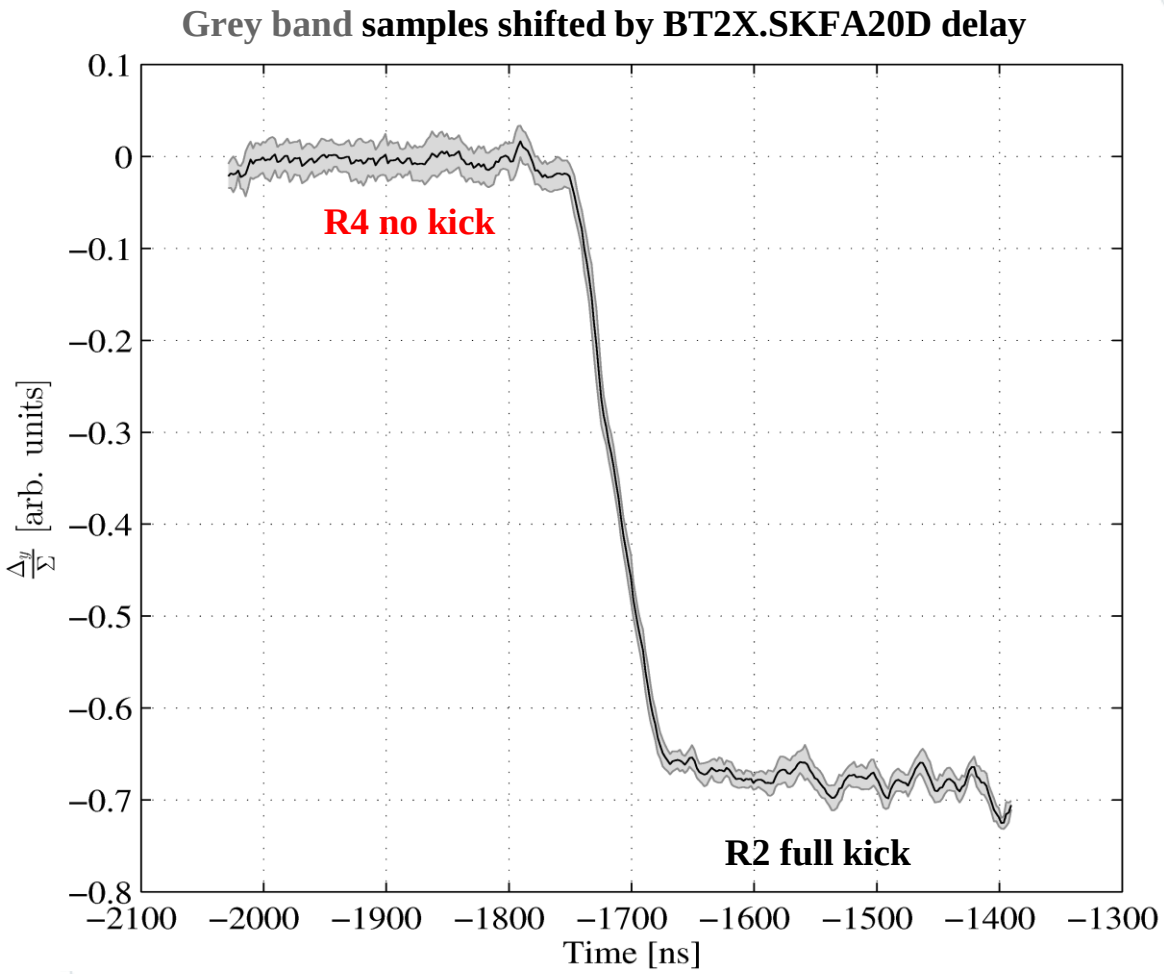


Calibration BPM40 vs. KFA voltage



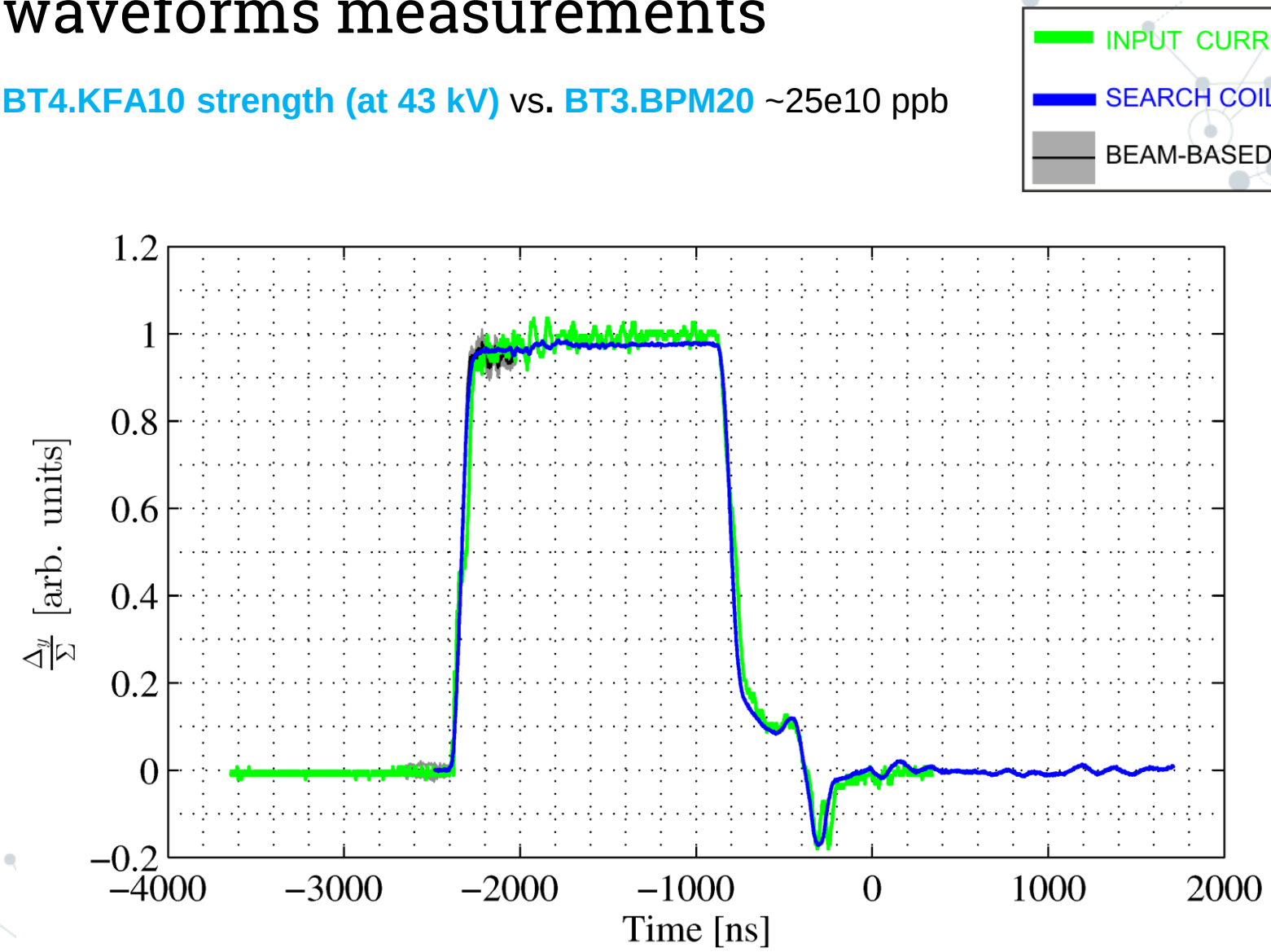
A new and automatic method for beam-based kickers waveforms measurements

Calibrated measurement



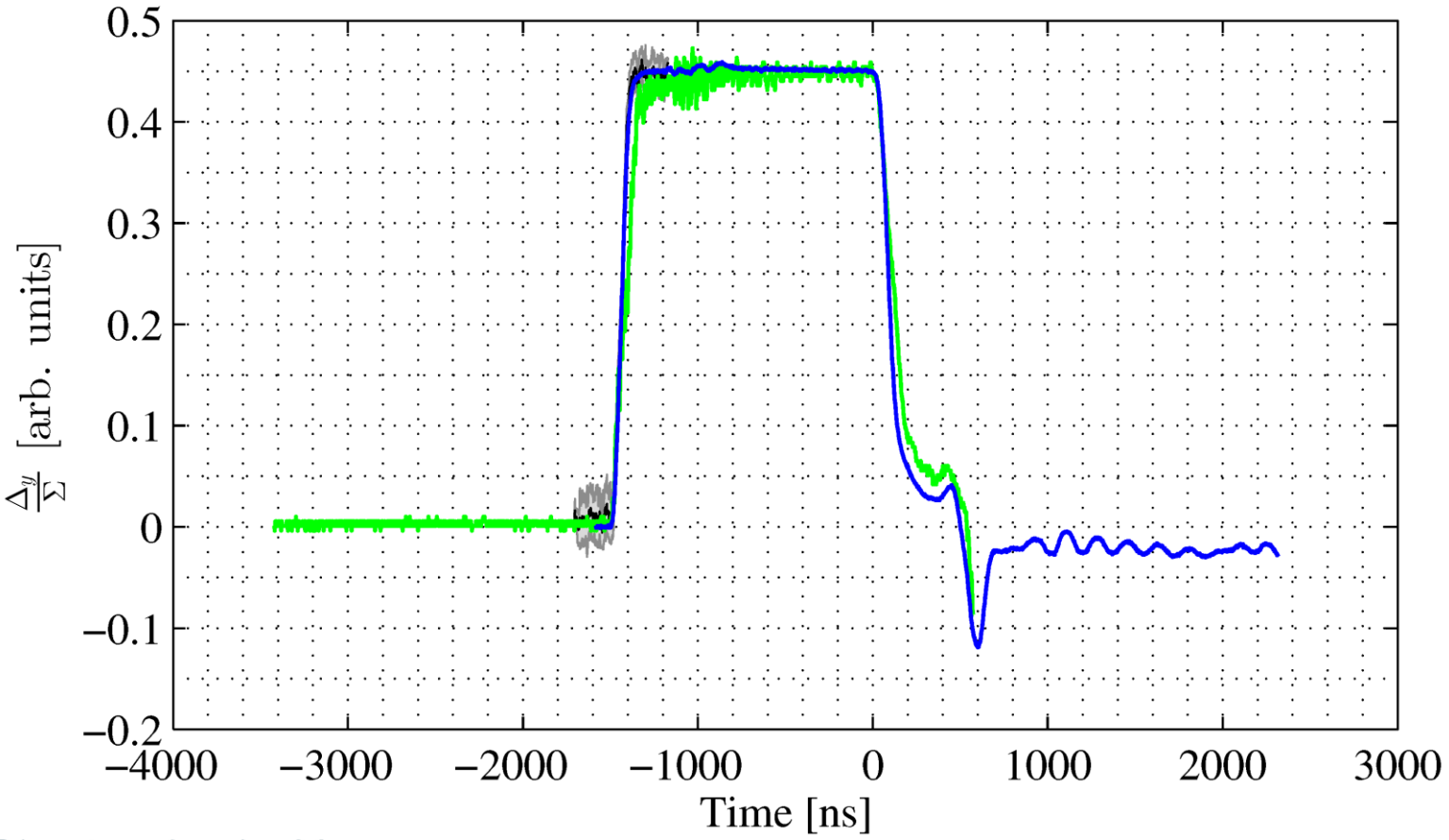
A **new and automatic method** for beam-based kickers waveforms measurements

- **BT4.KFA10 strength (at 43 kV)** vs. **BT3.BPM20** ~25e10 ppb



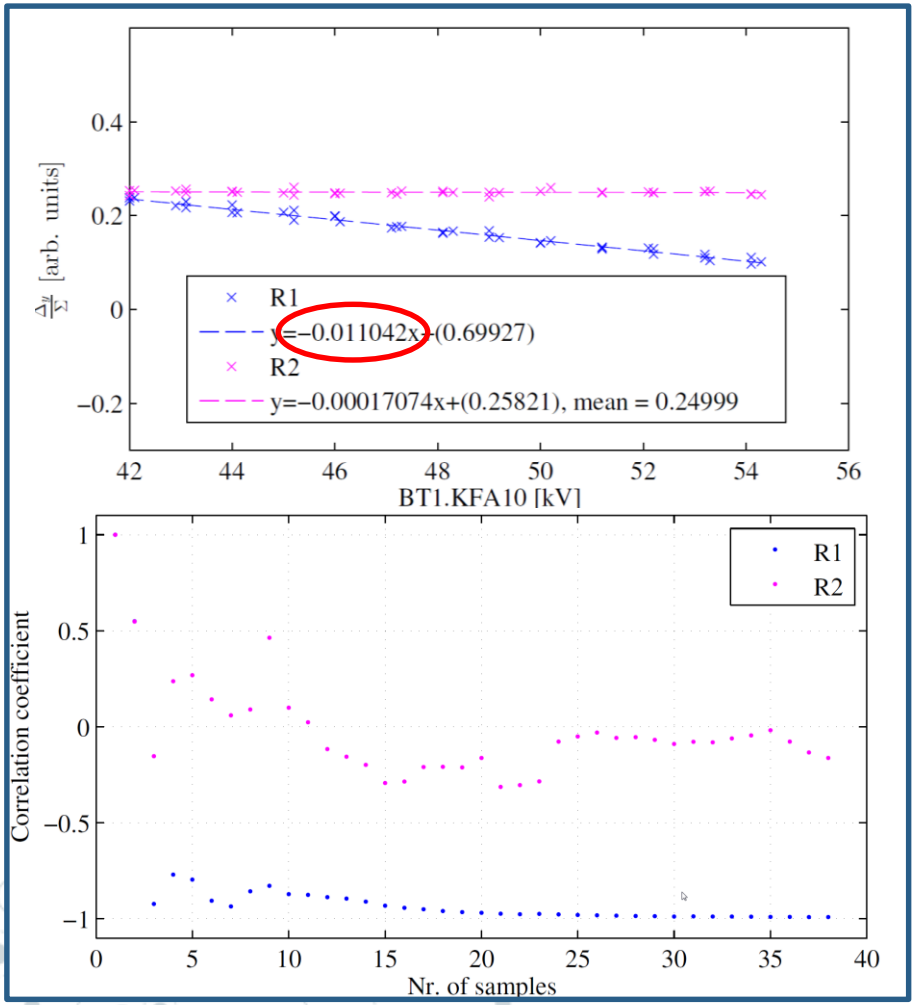
A **new and automatic method** for beam-based kickers waveforms measurements

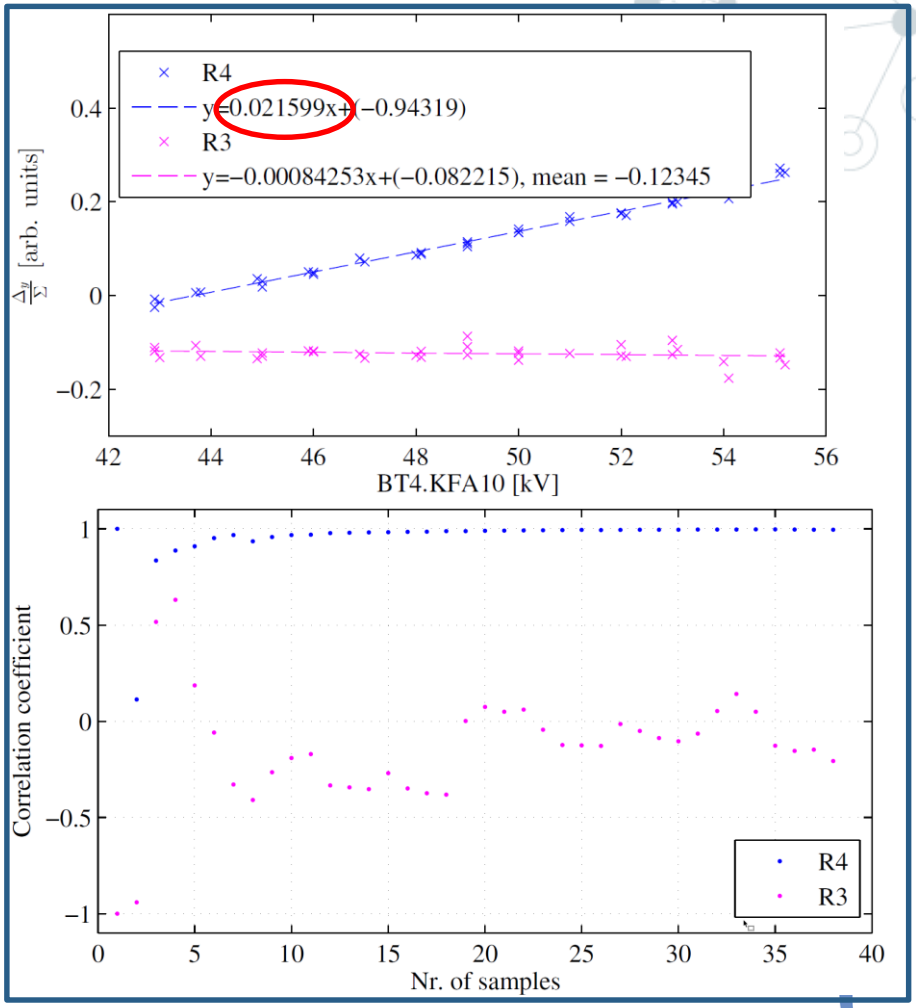
- **BT1.KFA10 strength (at 42 kV)** vs. **BT2.BPM20** ~25e10 ppb



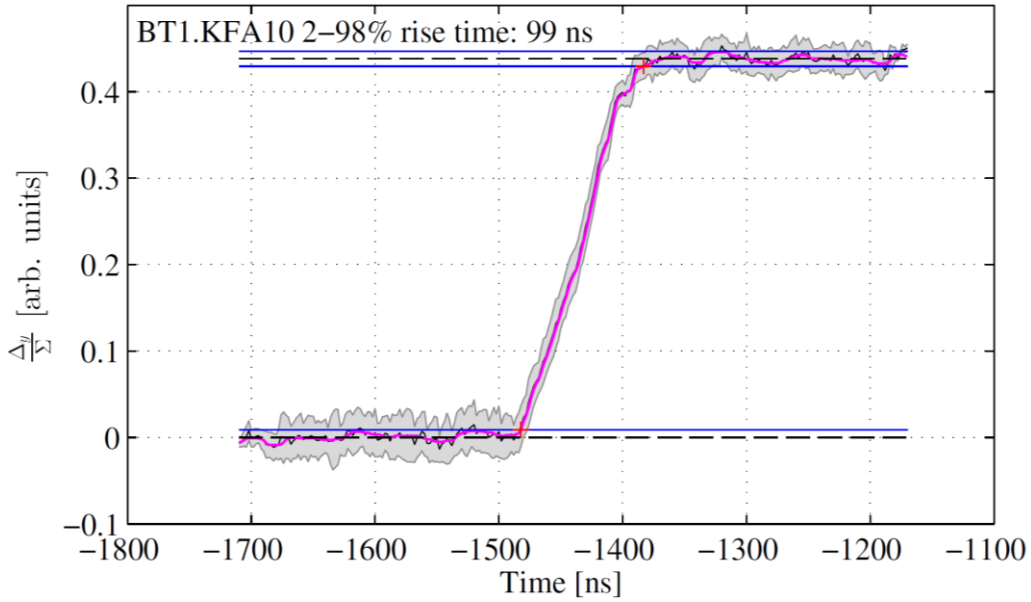
A new and automatic method for beam-based kickers waveforms measurements

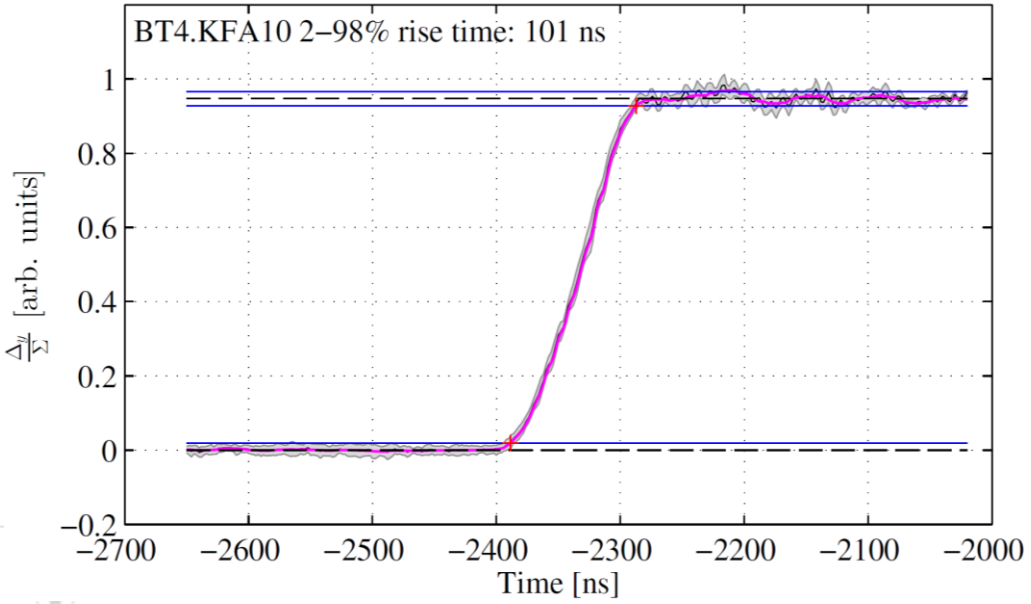
- **BT1.KFA10** and **BT4.KFA10**, even if identical, gave different calibration (~factor 2 in the DC-gain) due to different hw amplification settings → BI issue, then fixed.
- This is an important check as BPMs are used to validate optics models.





BT1.KFA10 – BT4.KFA10 ~25e10 ppb

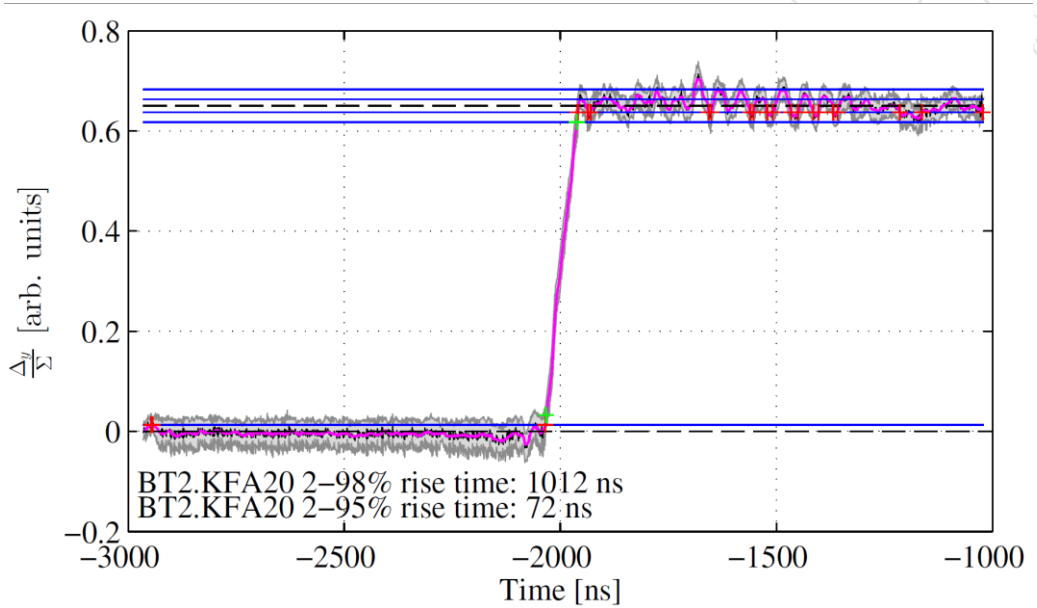




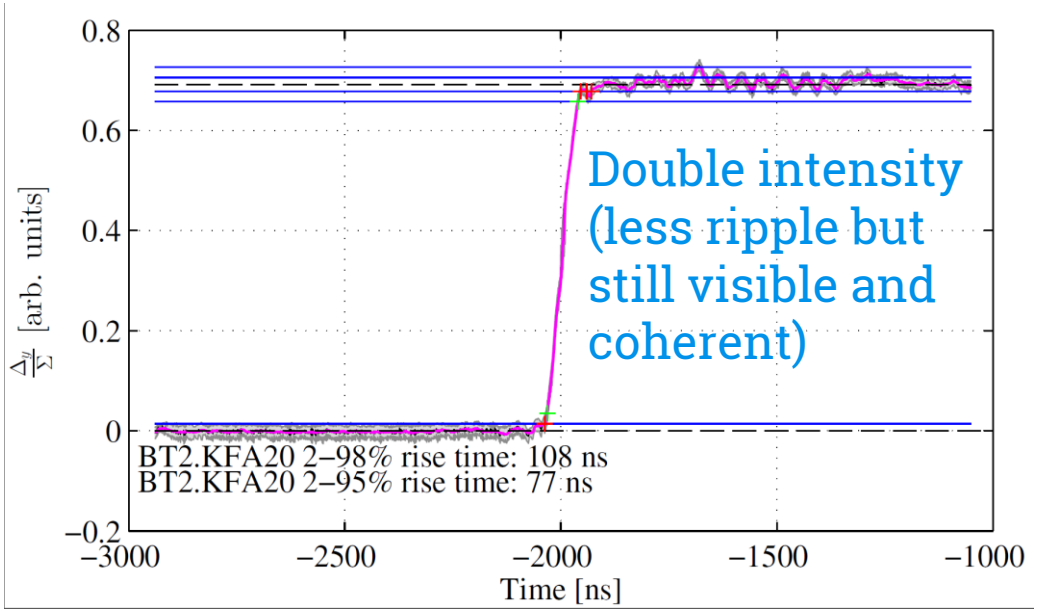
BT2.KFA20

- **BT4.KFA10 strength (at 43 kV)** vs. **BT3.BPM20** ~25e10 ppb

~25e10 ppb



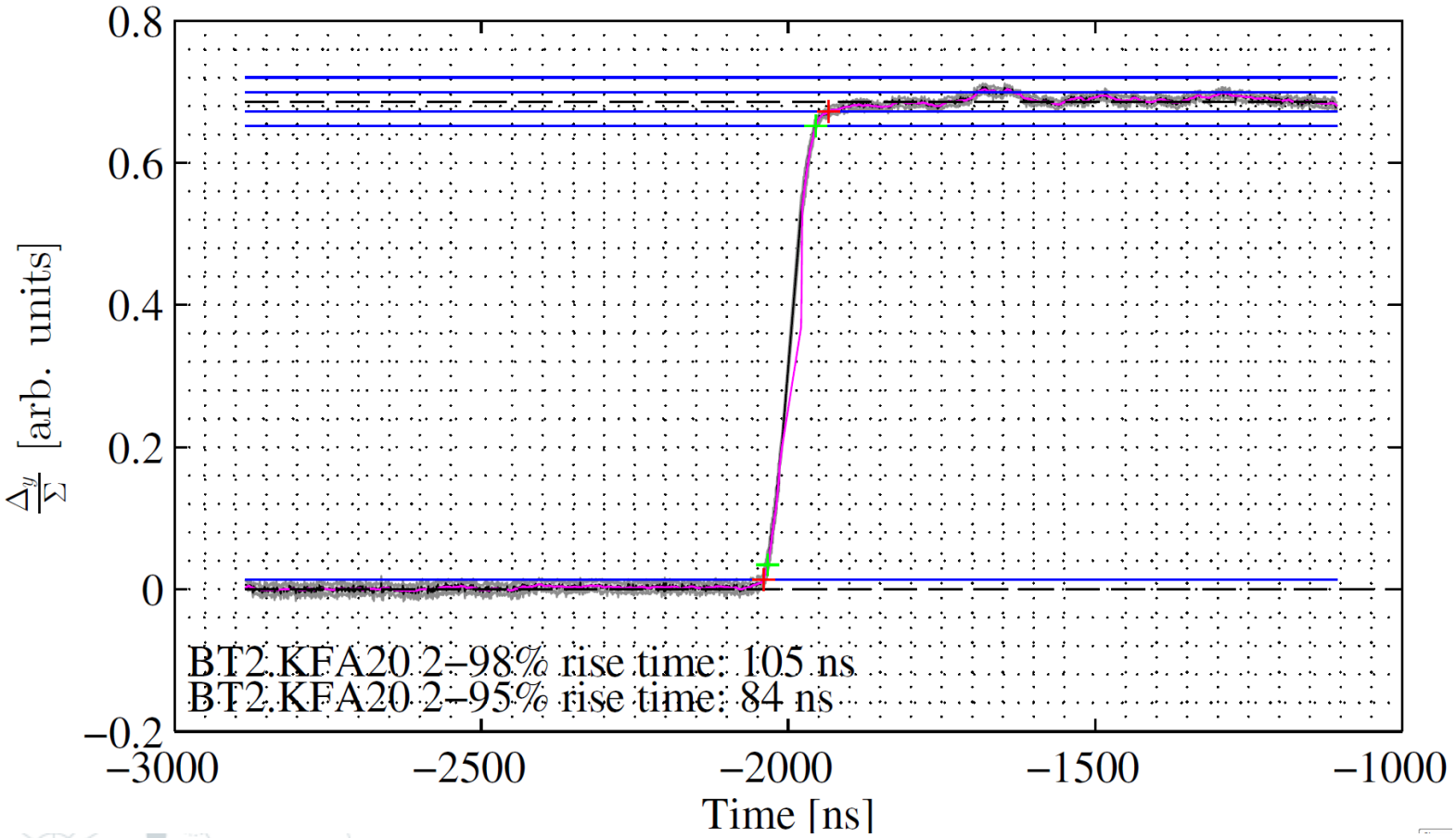
~50e10 ppb



BT2.KFA20

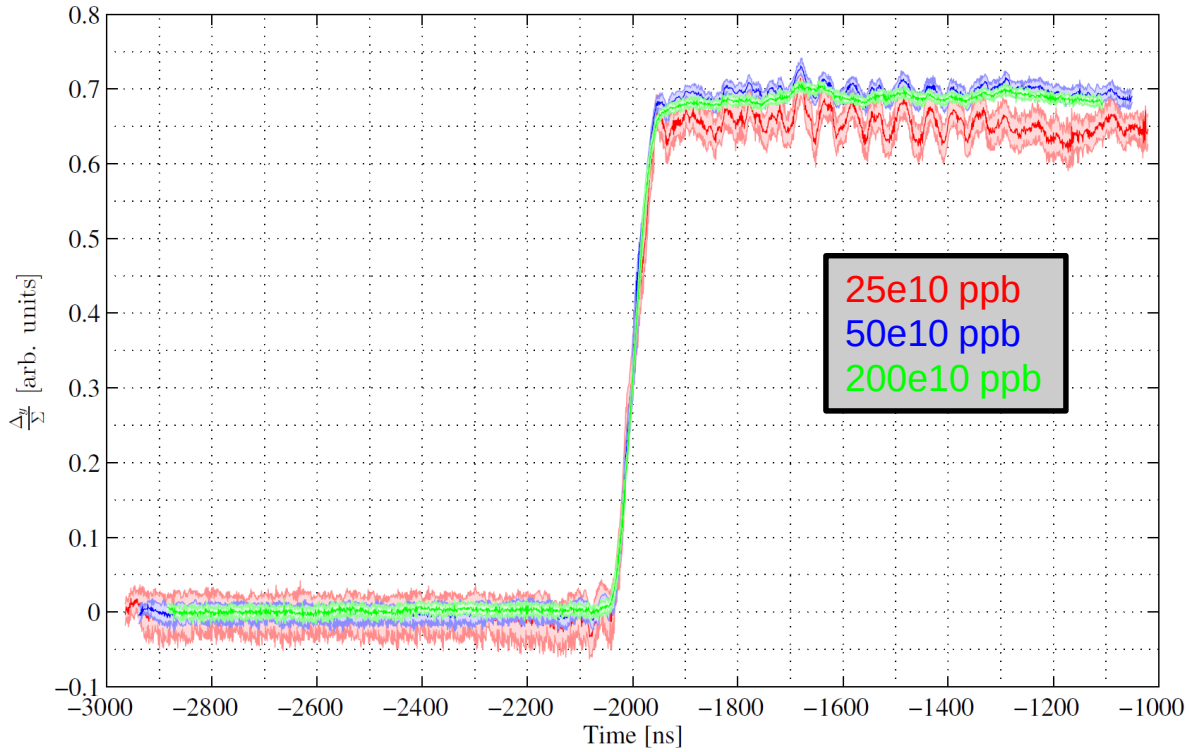
- **The large flat-top ripple** almost **disappears at higher intensity (~200e10 ppb)**.
- The measurement looks cleaner and smoother.
- Measurement performed with R3 and R1 (respectively first and last in batch) to have a large inspection window.

~200e10 ppb



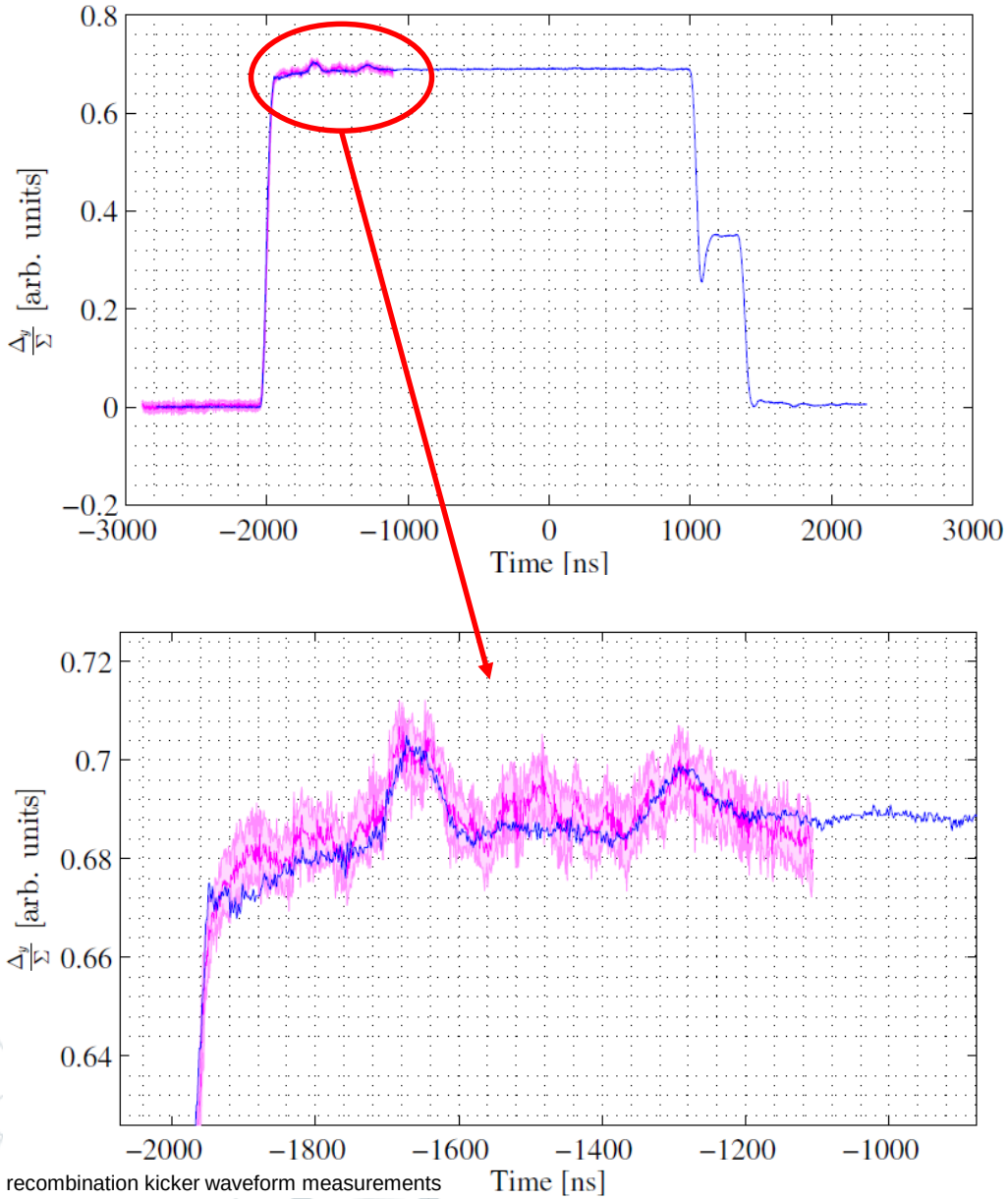
BT2.KFA20

- **The large flat-top ripple almost disappears at higher intensity (~200e10 ppb)**.
- The measurement looks cleaner and smoother at higher intensity (better BPM response).



BT2.KFA20 ~200e10 ppb

- **The agreement with lab measurements** (courtesy L. Sermeus) is **very good**

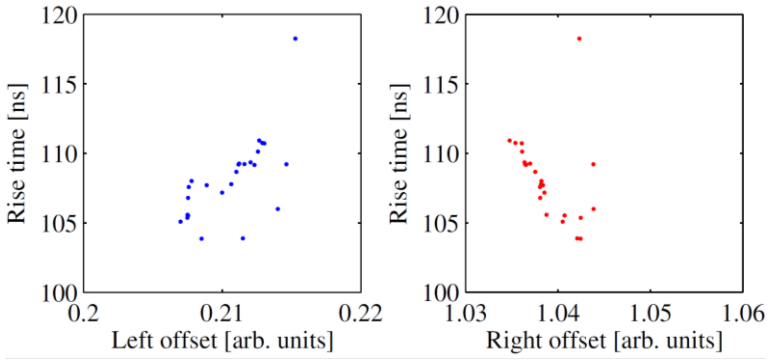


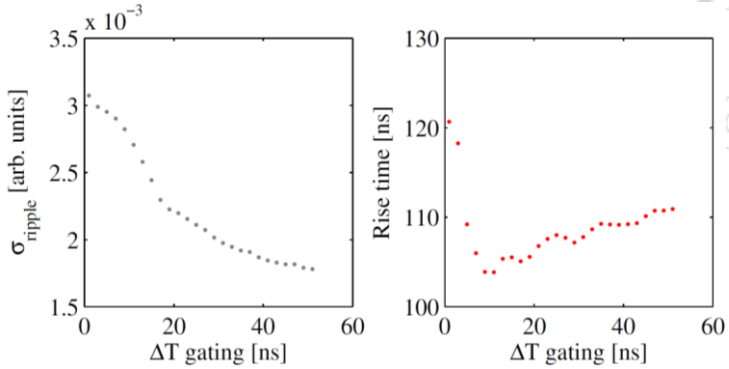
Current loop measurement (L. Sermeus)
Beam-based measurement (I=200e10 ppb)

Recombination kickers rise time estimations

- The **2-98% rise times** have been estimated
- The sources of errors for the rise time estimation are being investigated. Common error sources are:

➢ 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.





➢ The jitter in time of the kicker waveforms (~10 ns p-p)

	Rise time 2-98% (± 10 ns)	Intensity	Upper limit*
BT1.KFA10	99 ns	30e10 ppb	105 ns
BT4.KFA10	101 ns	30e10 ppb	
BT2.KFA20	109 ns	200e10 ppb	

*From "Specification for KICKER SYSTEMS FOR 2.0 GeV PSB to PS BEAM TRANSFER"
Ref: **PS-MKKIK-ES-0001**
HL-HLC limit (@ 2 GeV) **≤ 105 ns**

A **new and automatic method** for beam-based kickers waveforms measurements

Emittance (beam size) blow-up due to **un-synched kicks** can be evaluated through the **sem-grids.**

3 sem-grids in the **BTM line** provide shot-by-shot the information about the **beam sizes** (**thus** the **emittances**) at 3 consecutive locations.

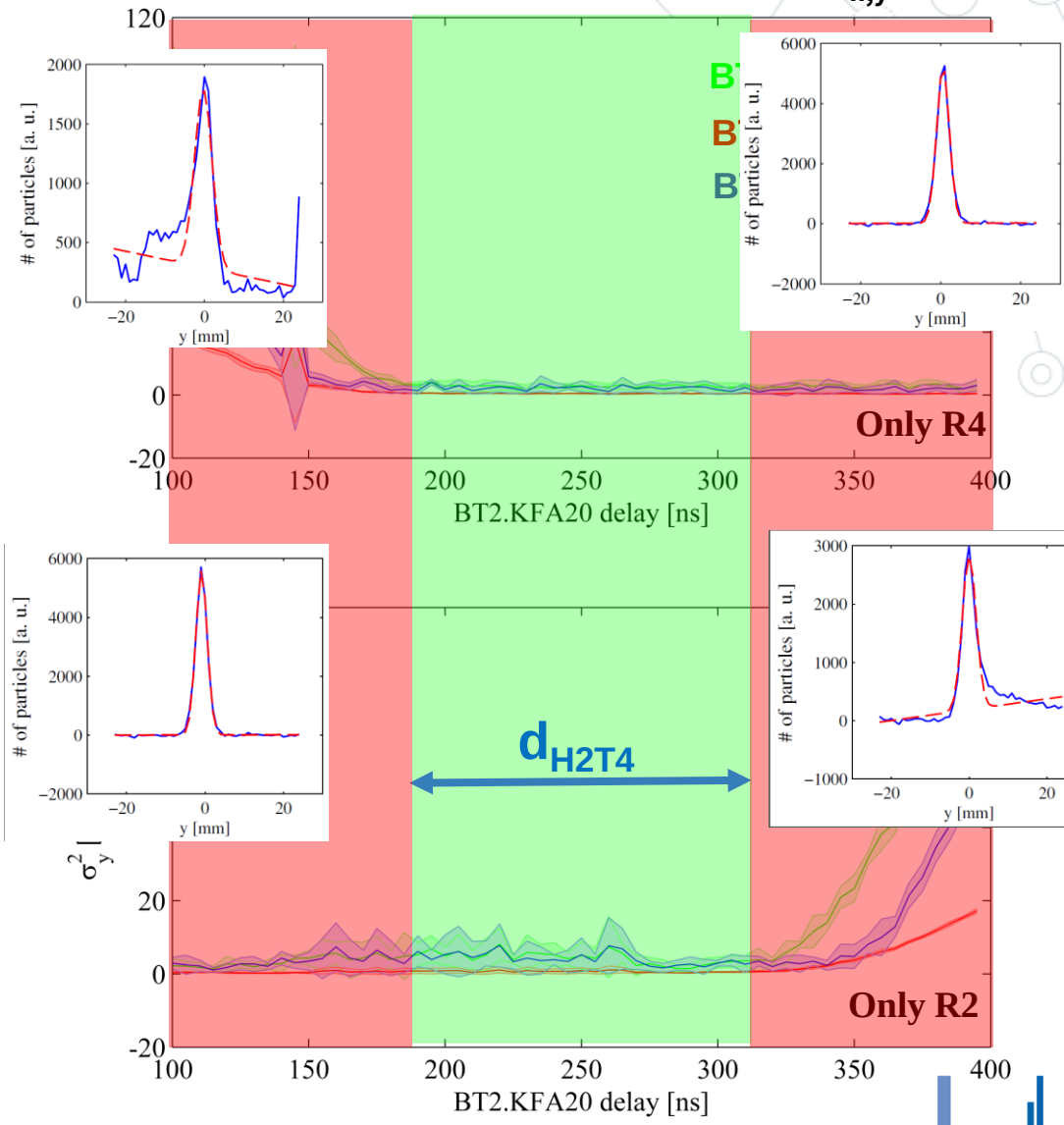
For a given vertical emittance the length in time of the intersections, where the emittance is un-touched (no kicker-dependent mismatch), gives directly space for bunch lengthening d_{H2T4}.

The minimum of these **gaps** (including KFA10s and PI.KFA45) will give the possible increase in bunch length for the 4 bunches.

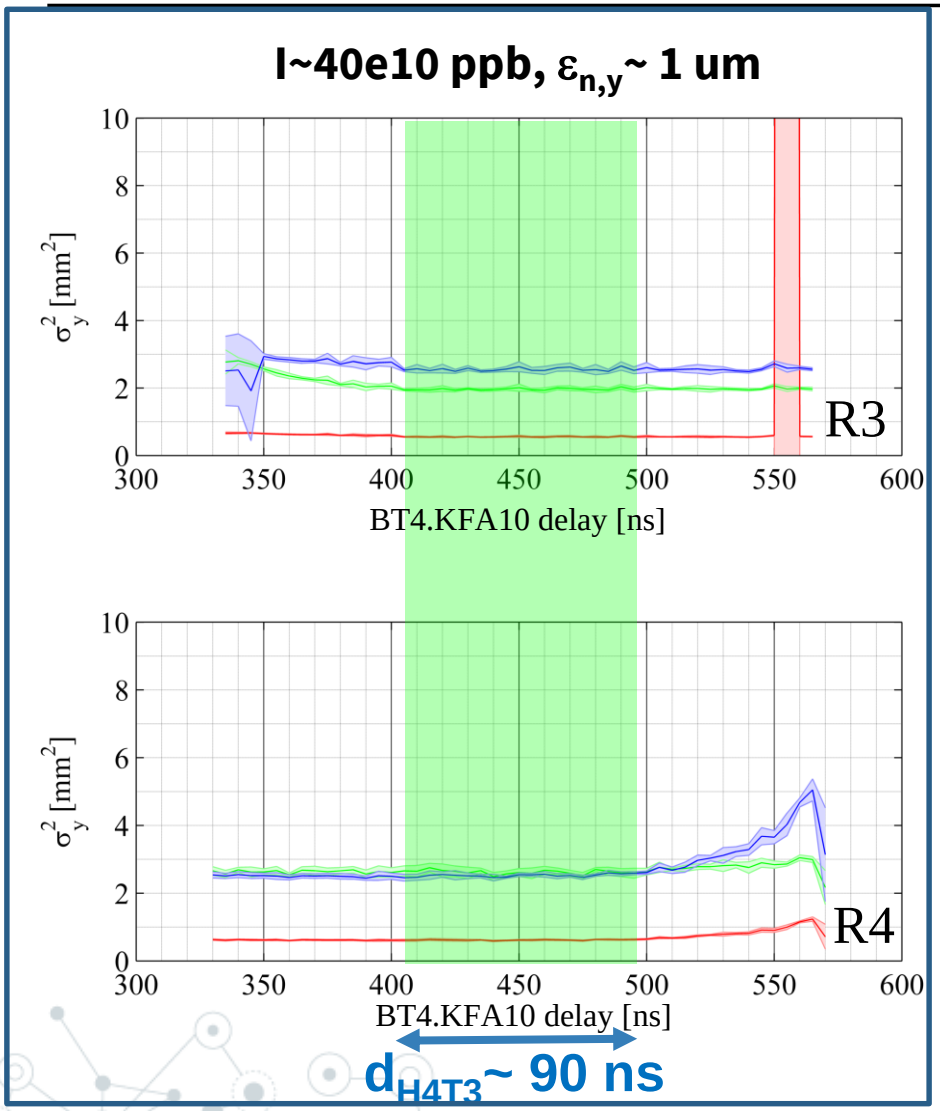
Over this distance emittance blow-up (by mismatch) and losses occur!

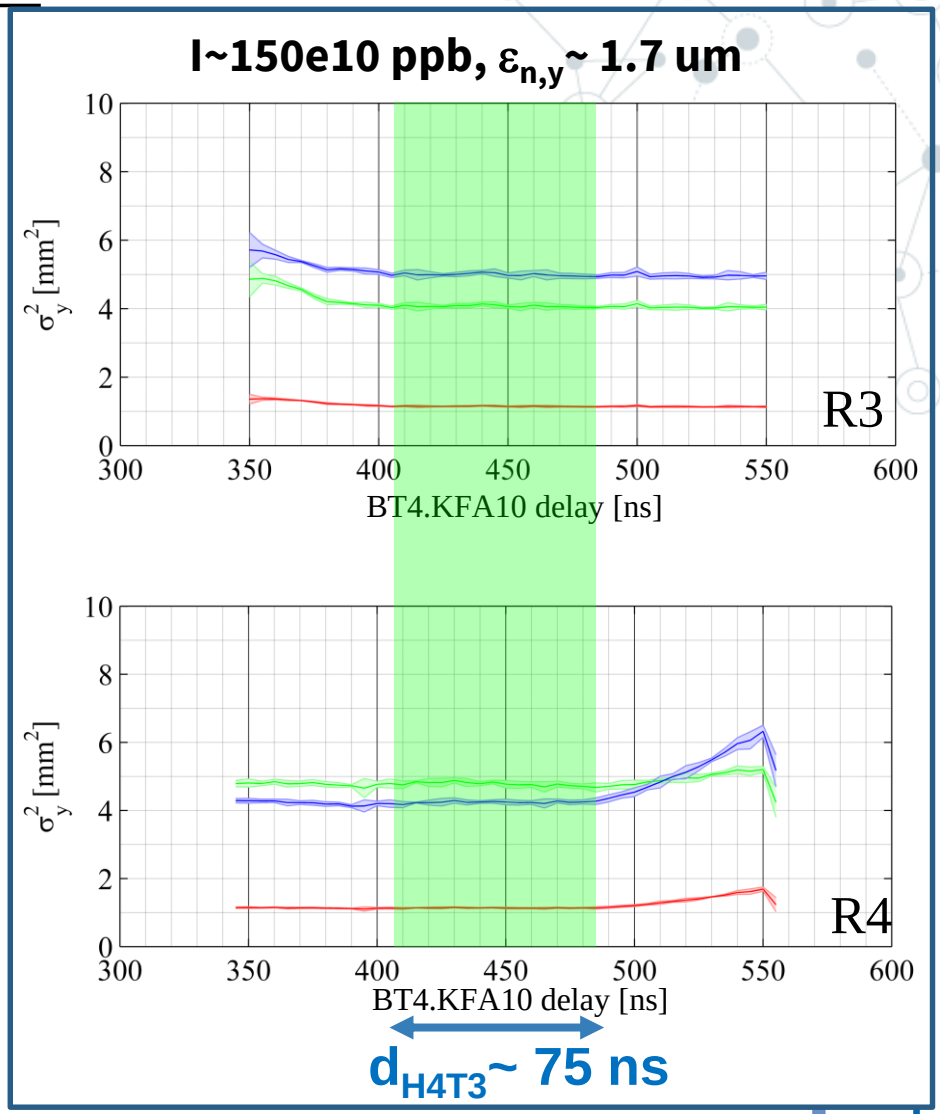
Halo particles get lost at entrance in the PS

Example: BT2.KFA20 @ $\varepsilon_{n,y}$ = 1 um



A new and automatic method for beam-based kickers waveforms measurements





d_{H4T3} = measured possible best-case margin for bunch lengthening (excluding PI.KFA45)

Summary and next steps

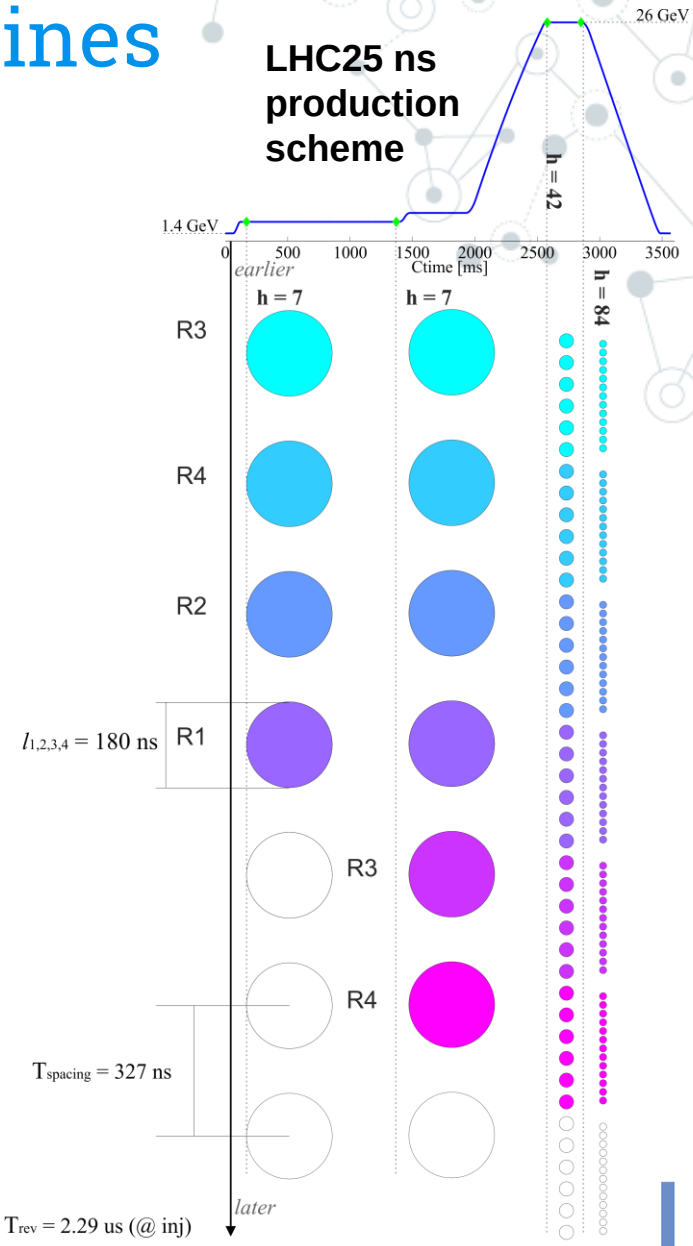
- The necessity of knowing the maximum acceptable bunch lengths extracted from the PSB to the PS have driven the beam-based study for the KFA kickers rise-time.
- It is difficult to produce with no losses from the PSB bunches much shorter than the kicker rise times
- A new method has been elaborated to derive the kickers waveforms from the BPM deflections in long nominal consecutive bunches (~180 ns vs rise times in the order of 100-140 ns)
- The method minimizes losses, uses nominal bunches, has shown excellent results compared with lab measurements and is suitable for MD automation
- 2-98% rise times have been computed: KFA10s are in agreement with requirements for the update. KFA20 is at the edge of the requirements.
- The sem-grids have also been used to check the distance limits in terms of emittance blow-up and mismatch caused by un-synch KFA kicks → also useful for LIU parameters definition
- From the sem-grids analysis the recombination kickers gave a measured best margin of ~75 ns for bunch lengthening in order to keep a target vertical emittance of 1.7 um and ~150e10 ppb (~present LHC type beams). The margin depends on emittance for vertical losses due to scraping and on intensity, for RP limits.
- First WS tests in the PS demonstrated that the vertical halo induced by the un-synchronization of the recombination kickers gets lost at the entrance in the PS and no blow-up has been seen in the PS ring.
- New tests will be performed with the new 220 ns bunches (if stable!), prepared by S. Albright (BE-RF), in order to check the sem-grids criterium with future LHC bunch lengths.
- Further analysis have to be performed to evaluate the resolution of the measurements and the frequency response of the system… is the beam perturbed at some frequencies at the PS entrance? Important for PS tr. feedback assessment…

Thanks

Appendix

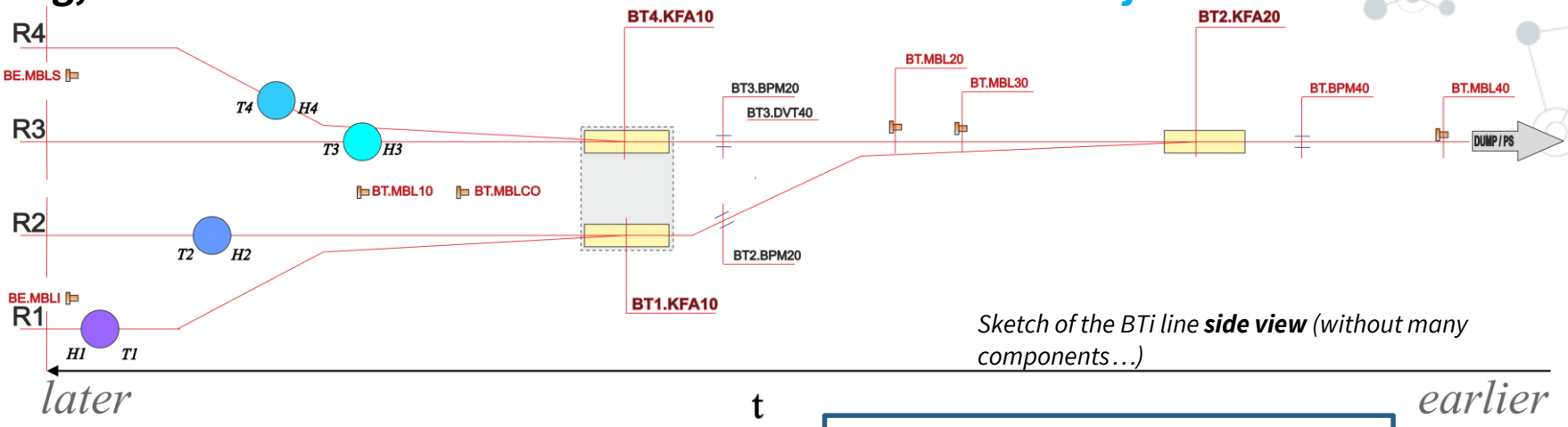
Purpose of beam-based kickers waveforms measurements in the BTi-PI lines

- To relax the space charge limit on the PS injection plateau and increase the LIU beams performances, it is wanted to lengthen the LHC bunches from the PSB to the PS (from ~180 ns to 220 ns).
- Is it possible preserving the emittance and intensity?
- Which are the boundaries? One has to check whether the physical dynamic quantities along the line are compatible with the requirements…



Purpose of beam-based kickers waveforms measurements in the BTi-PI lines

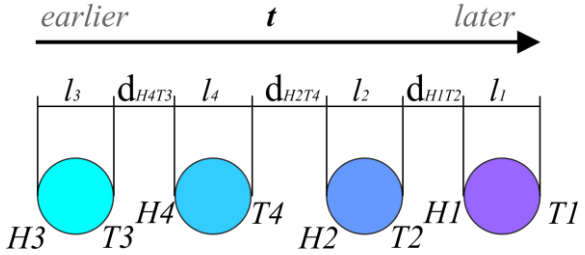
- **The vertical recombination kickers (BT1.KFA10, BT4.KFA10 and BT2.KFA20) are responsible for the PS batch formation, composed of max 4 "equal" bunches, 1 per PSB ring, in the BT-BTP line. The PI.KFA45 is the horizontal PS inj. kicker.**



*Sketch of the BTi line **side view** (without many components…)*

- **The KFAs are the main dynamic elements in the line.**
- **The magnetic field rise time τrise is an important parameter to see whether the kickers dynamics may influence the emittance and the intensity of the bunches.**

1st batch LHC25ns at PSinj



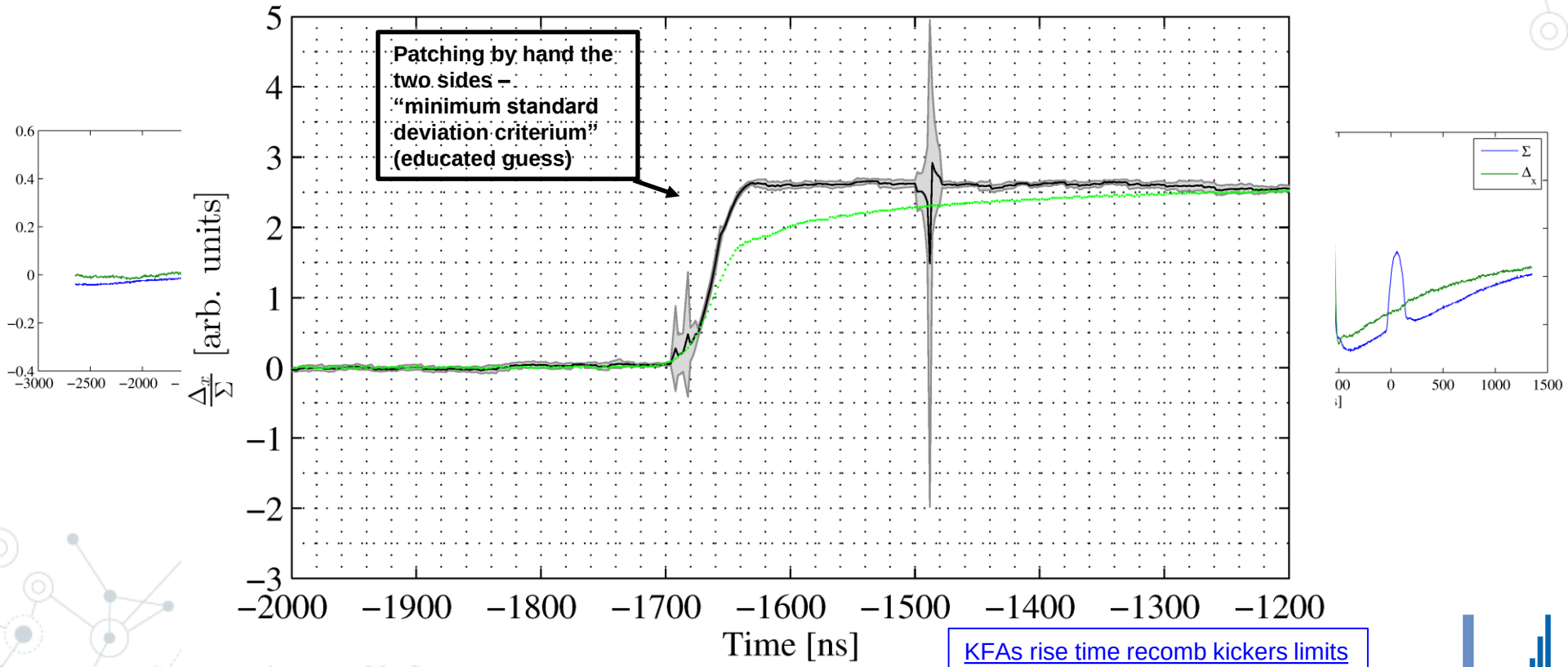
$$d_{H4T3} = f_1(l_3, l_4, \tau_{rise\ BT4.KFA10})$$

$$d_{H1T2} = f_2(l_2, l_1, \tau_{rise\ BT1.KFA10})$$

$$d_{H2T4} = f_3(l_4, l_2, \tau_{rise\ BT2.KFA20})$$

A **new and automatic method** for beam-based kickers waveforms measurements

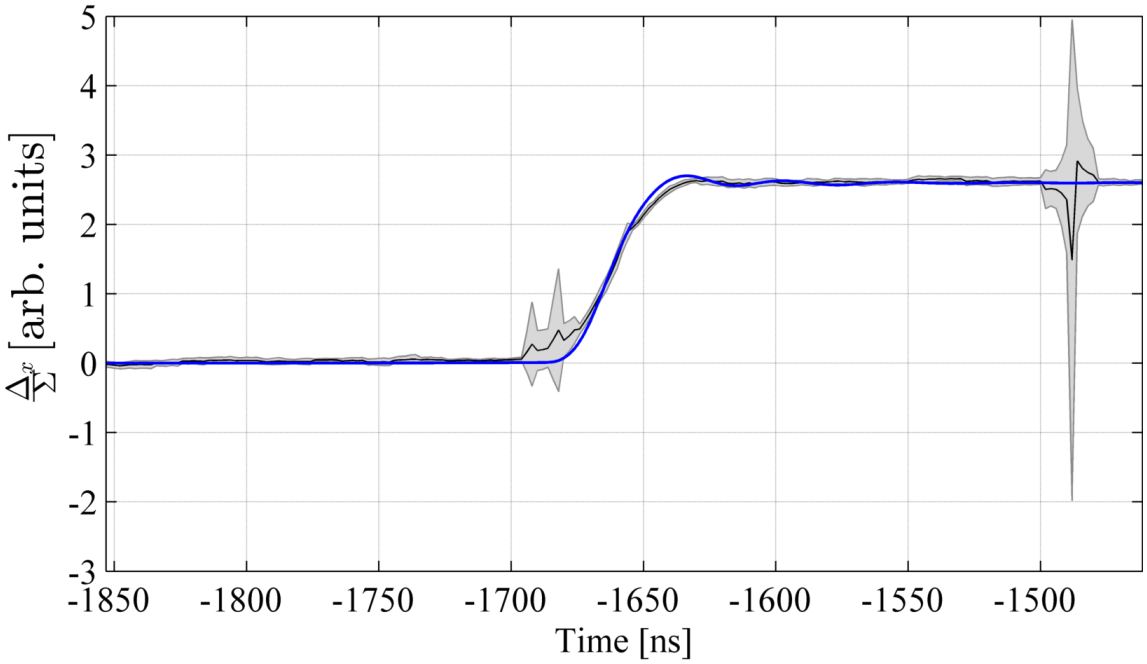
- **PI.KFA45 strength (at 308 kV)** vs **PR.UHZ47 (first BPM after injection)**
- **In this case the bunches were taken consecutive but not adjacent (1 empty bucket in between, ~655 ns spacing), at the very exact 2nd batch injection moment.**
- The **PS BPMs** are **capacitive, not wall current monitor** as in the BT line → **high sensitivity to losses** with **discharge** phenomena → **not easy for voltage calibration!**



KFAs rise time recomb kickers limits
HL-LHC limit (@ 2 GeV) **≤ 105 ns**
Ref: PS-MKKIK-ES-0001

A new and automatic method for beam-based kickers waveforms measurements

- **Comparison with simulations for the PI.KFA45.**
- ***Simulations courtesy of A. Ferrero Colomo (TE-ABT)***

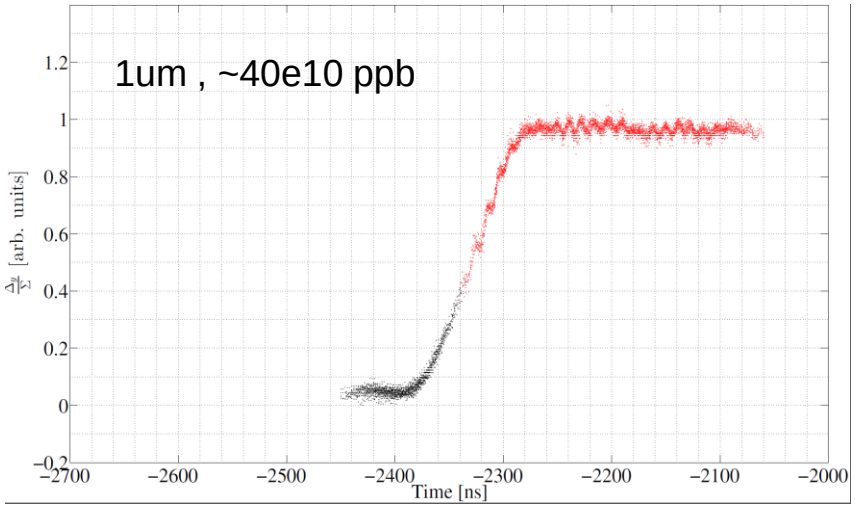


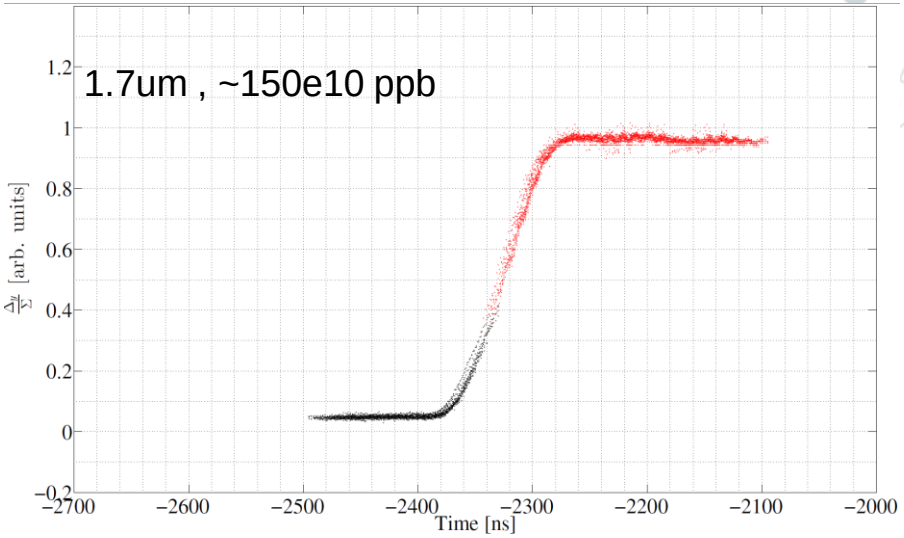
KFAs rise time recomb kickers limits
HL-LHC limit (@ 2 GeV) **≤ 105 ns**
Ref: PS-MKKIK-ES-0001

First manual measurements with sem-grids

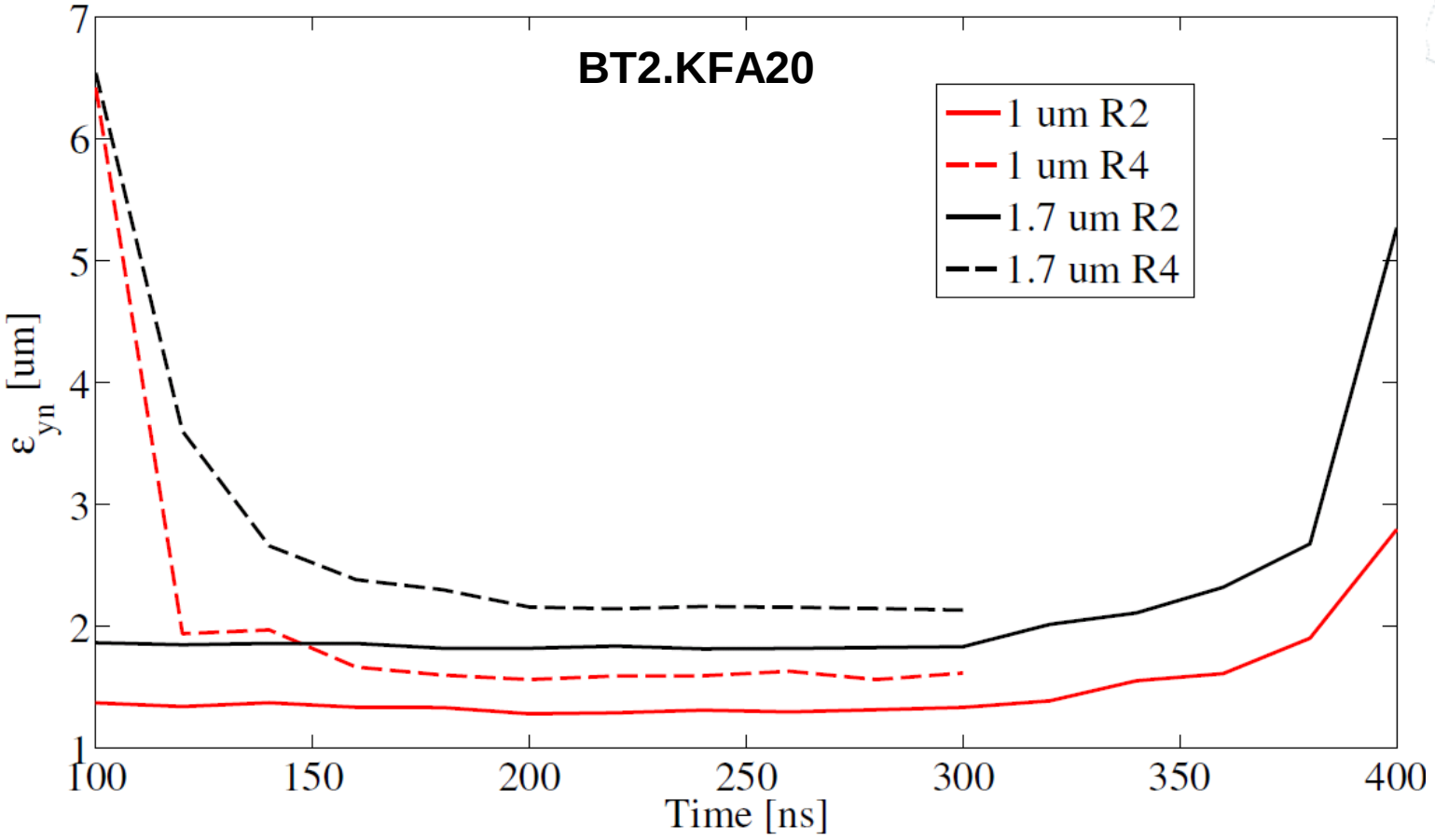
BT4.KFA10 ripple reduction with intensity

- **May be due to BPM frequency response?**

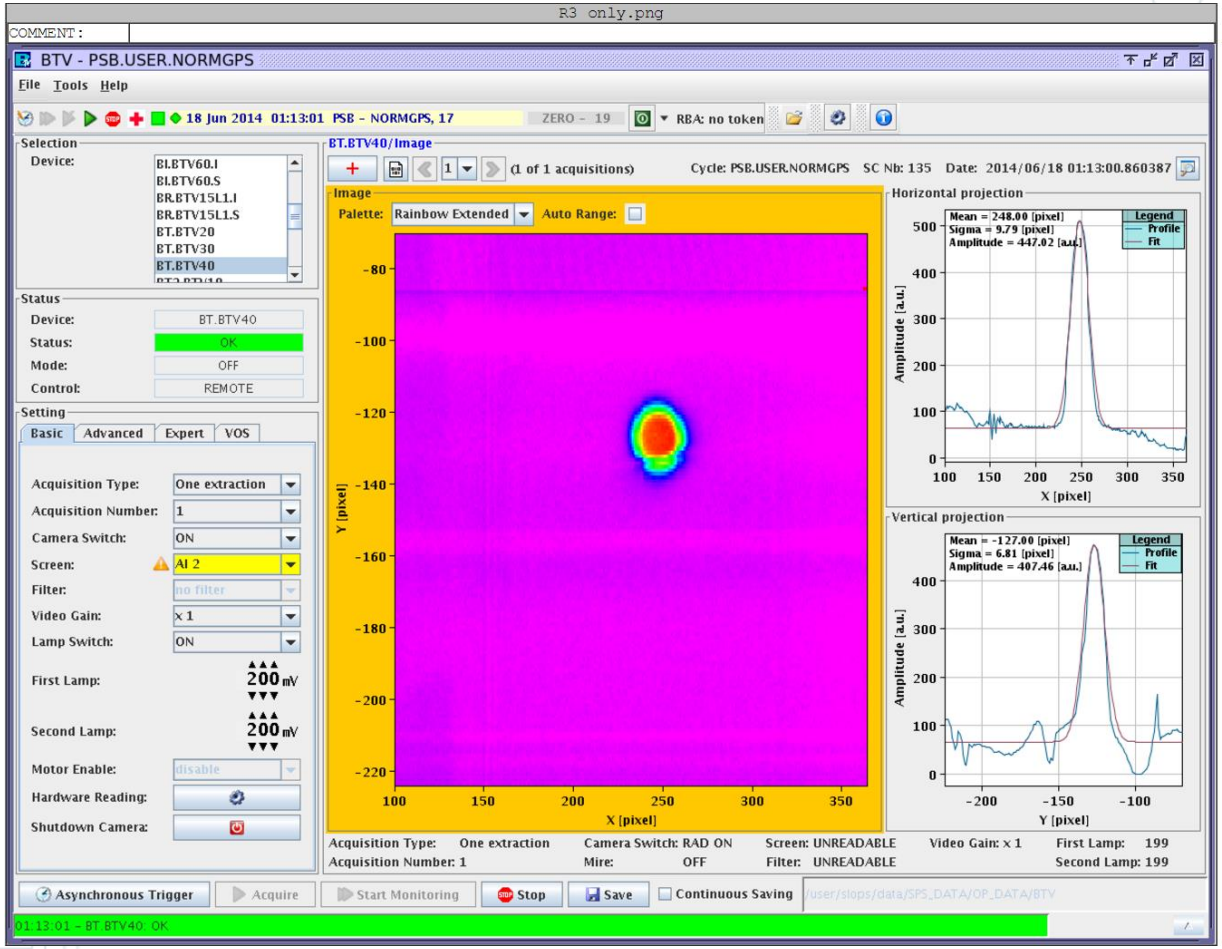




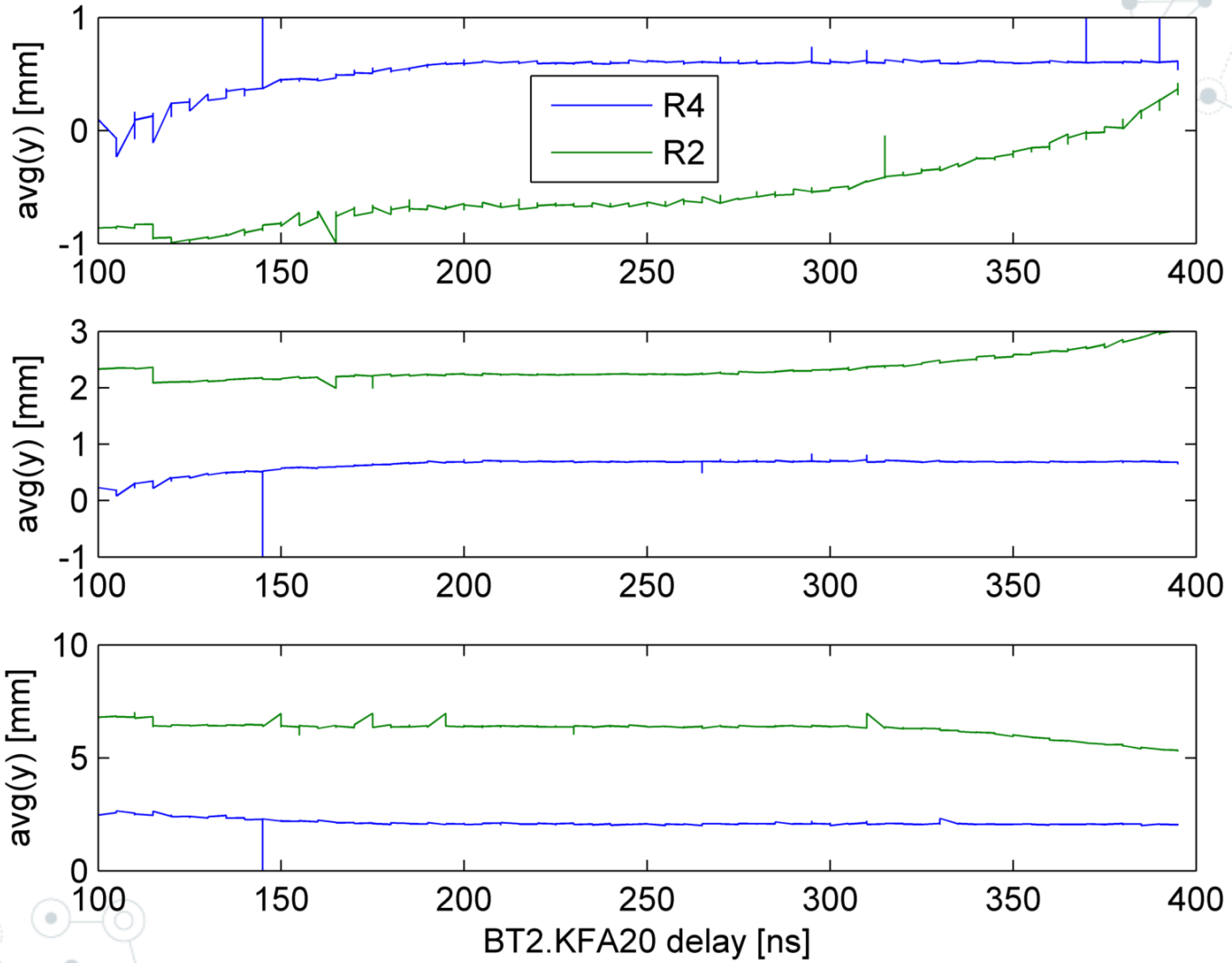
First manual measurements with sem-grids

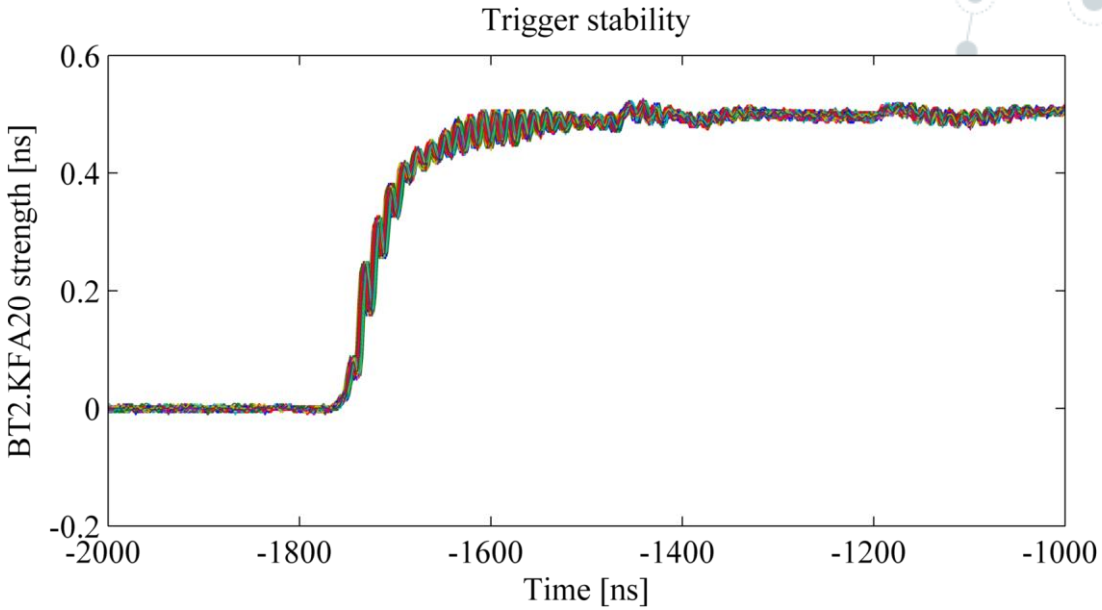


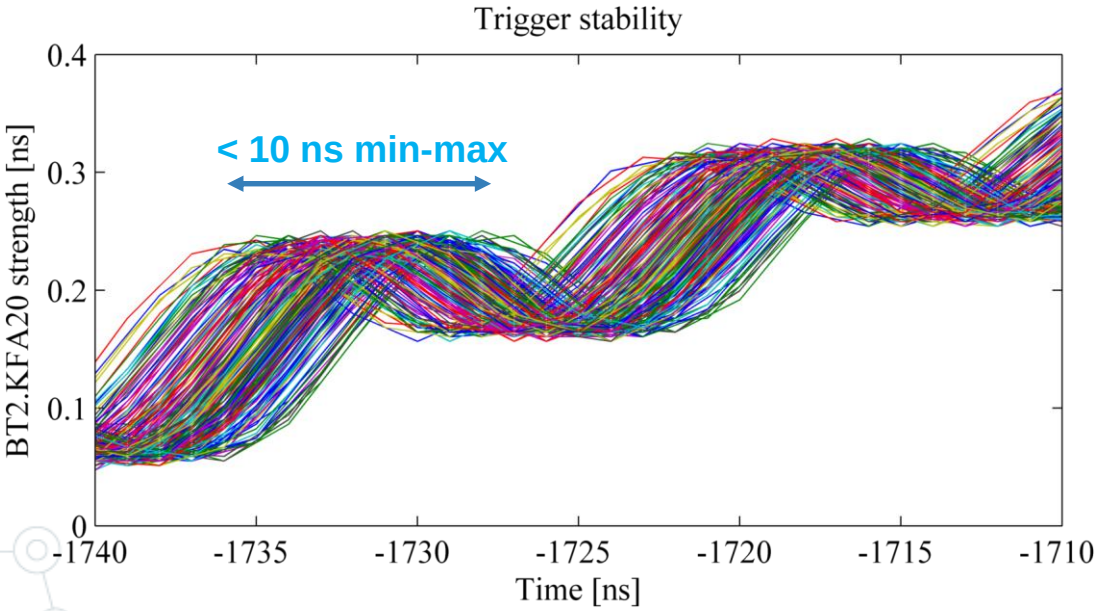
BT.BTV40 example with NORMGPS user (very high intensity beam ~800e10 ppb)



Average position from sem-grid




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]

Credits

Special thanks to all the people who made and released these awesome resources for free:

- Presentation template by SlidesCarnival