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LHC Injectors Upgrade

Update on BT.KFA10(20) recombination kickers

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BT.KFA10 test 12 in B867: kick

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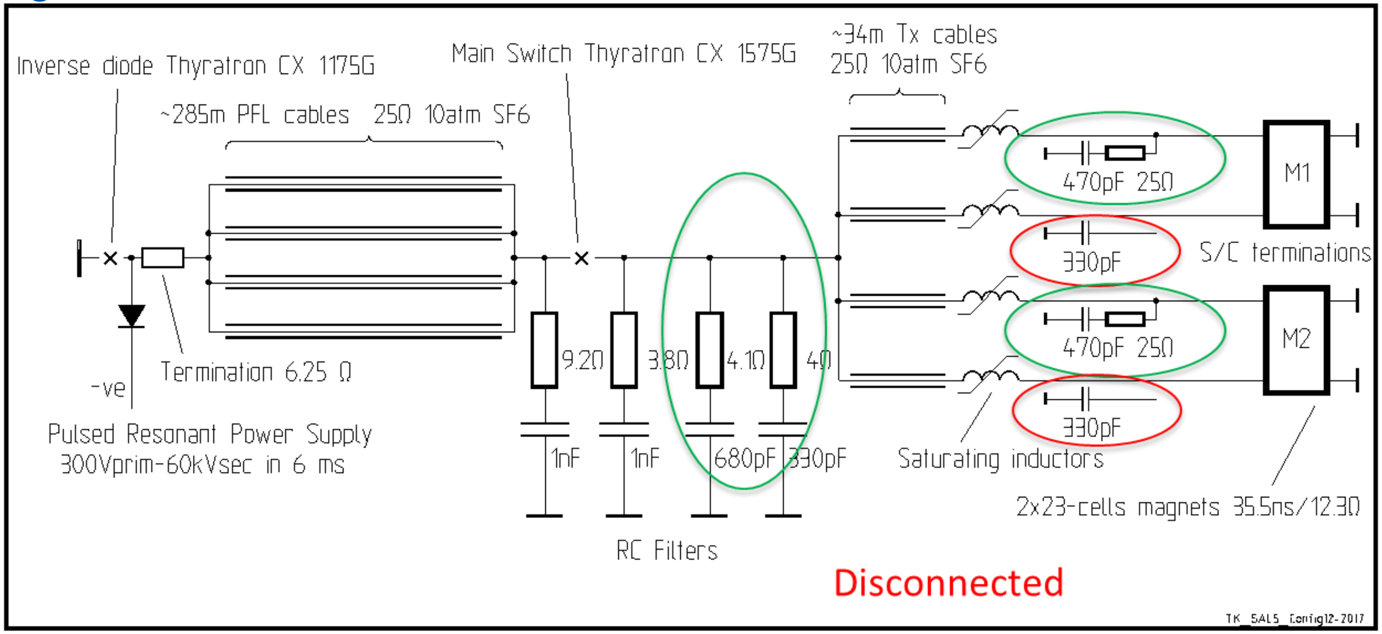
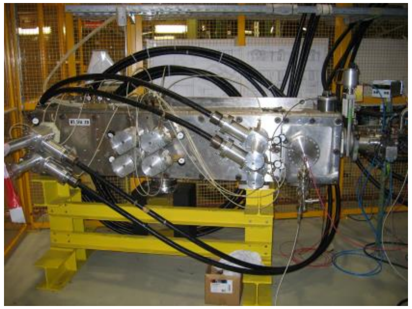
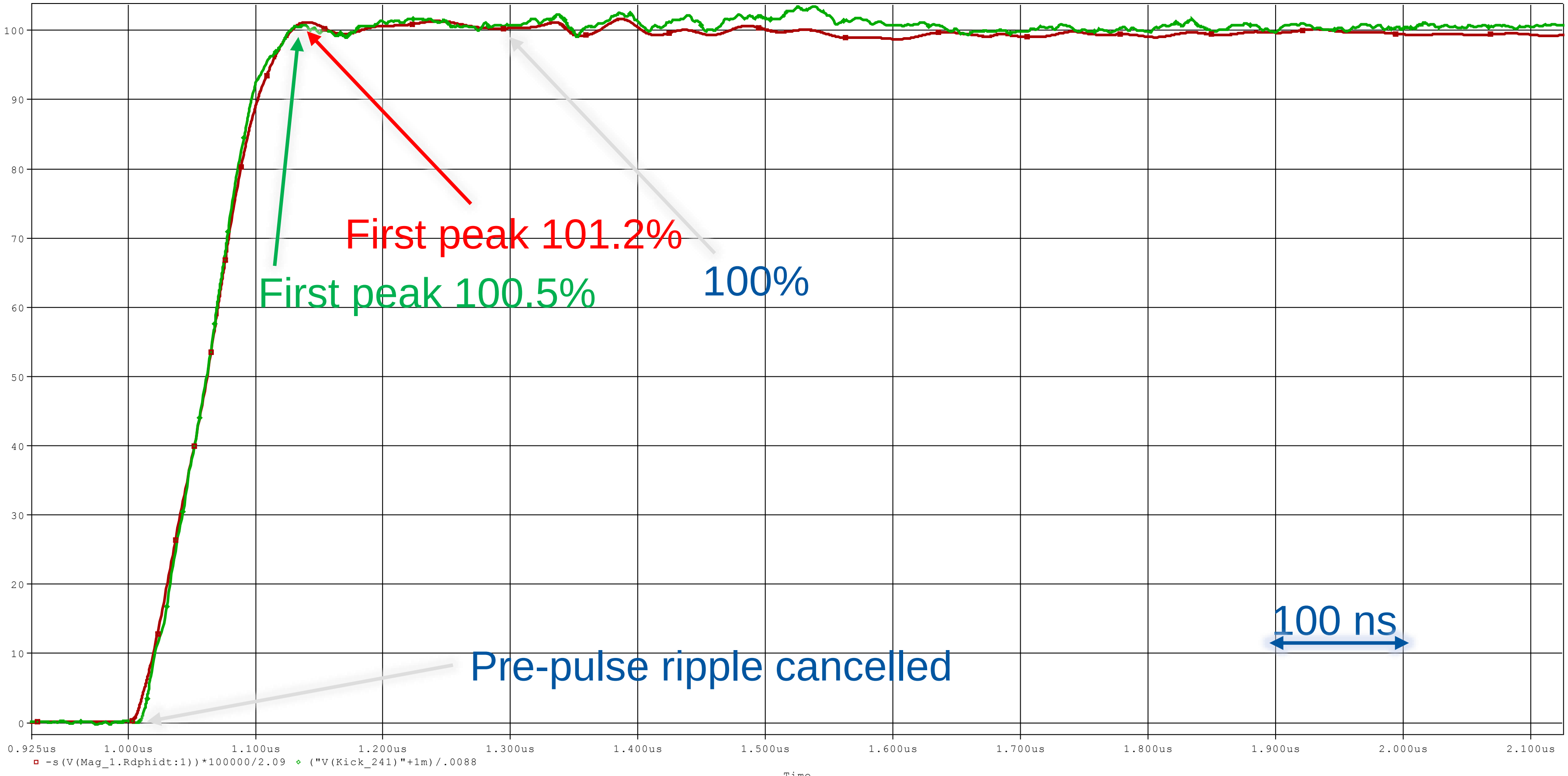
- After 17th January 2017 LIU-PSB presentation → Two magnets connected with saturating inductor and filters, MS cathode&anode filters.



- One generator supplying two magnets connected the same way as KFA10.
- Four cables connected for 6.25Ω impedance.
- Magnets equipped with CMD5005 ferrite type.
- Filters added and modified. Saturating inductor at magnet input.
- PFL voltage: 56kV (required for 2GeV beam)
- Magnet current: ~4500A (thyratron current: 9000A)



BT.KFA10 test 7 in B867: kick of upstream magnet



Normalised kick of upstream magnet. Measured with strip-line probe – Simulated with PSPICE

	Measured	**Calculated**
2-98% rise time	**~107ns**	**112ns**
Flat-top ripple	**±2%**	**<±2%**

BT.KFA10 measurements in SAL5

- **PSpice simulations** of installed systems (BT.KFA10s & 20)

- Optimisation of filters done and **calculated kick waveforms performed for emittance growth estimate → See next slides**

- Spare design/order status

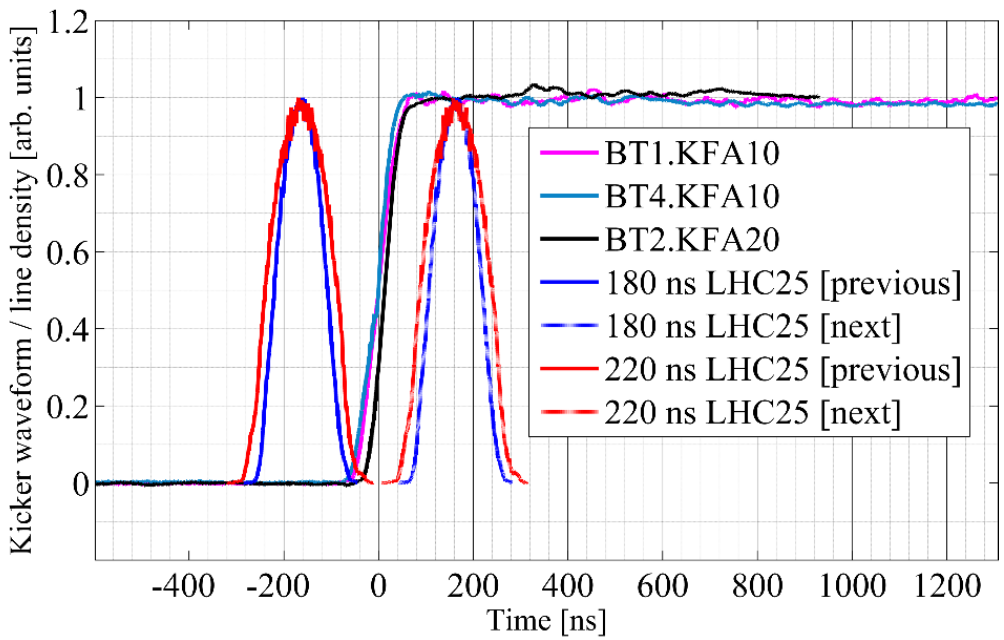
- **Spare KFA10 tank ordered**, **drawings complete, raw material sent to supplier**.
- **Ferrite samples tested by TE/VSC and approved**. Production started but **delivery delayed** by the supplier. **Should be ok**.
- **Magnet drawings finished** but still **to be checked. Inquiries sent**.
- **Material** for capacitor plates (6mm thick) **received**.
- **HV feedthroughs** should be delivered soon.

- The **new tank** should be **ready for tests by the end of 2017**.

Present beam-based waveforms: rise time and flat-top ripple

- The beam-based measurements (at 200 ppb) show that we are just within specification*

	Rise time 2-98% (± 10 ns)	Rise time upper limit*	Flat-top ripple max(B/avg(B))	Peak ripple upper limit*
BT1.KFA10	109 ns	105 ns	2%	2%
BT4.KFA10	104 ns		2%	
BT2.KFA20	105 ns		2%	



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

Presented at LIU beam parameters meeting - 03-03-2017

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HW specifications → emittance blow-up expectations

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

h_{PS}=7	Rise time (2-98%)	Flat-top ripple
1.4 GeV	104 ns	±2%
2 GeV	105 ns	

- From **simulations** assuming a **20 MHz sinusoidal flat-top ripple of ±2%, one can deduce:**

h_{PS}=7	Estimated emittance blow-up $\Delta\varepsilon_y/\varepsilon_{y,0}$
1.4 GeV	2%
2 GeV*	2.6%*

* $\beta\gamma_{\,2\ \mathrm{GeV}} / \beta\gamma_{\,1.4\ \mathrm{GeV}}$ scaling factor

Presented at LIU beam parameters meeting - 03-03-2017

Est. emittance growth: **present LHC25 beam 1.4 GeV**

Presented at LIU beam parameters meeting - 03-03-2017

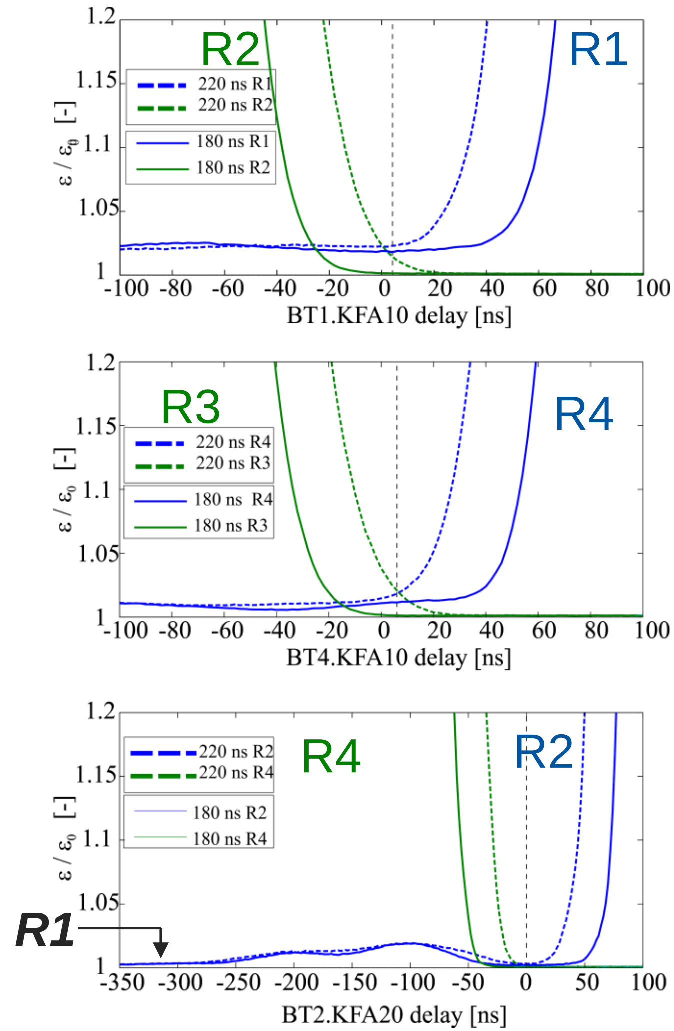
- **From** the **present (beam-based) reconstructed waveforms** we **simulate the vertical emittance growth**
- LHC25 'Standard' beam production: $\varepsilon_{0,y,n}$ **= 1.8 um**

- **1.4 GeV – 327 ns bunch spacing – 180 ns bunch length**

$\Delta\varepsilon_y/\varepsilon_{y,0}$ [%]	**R1**	**R2**	**R3**	**R4**
BT1.KFA10	2.0	0.0	0.0	0.0
BT4.KFA10	0.0	0.0	0.0	1.0
BT2.KFA20	0.4	0.4	0.0	0.0
Sum in quadrature	***2.0***	***0.4***	***0.0***	***1.0***

- **1.4 GeV – 327 ns bunch spacing – 220 ns bunch length**

$\Delta\varepsilon_y/\varepsilon_{y,0}$ [%]	**R1**	**R2**	**R3**	**R4**
BT1.KFA10	2.3	1.0	0.0	0.0
BT4.KFA10	0.0	0.0	1.9	1.9
BT2.KFA20	0.4	0.4	0.0	0.0
Sum in quadrature	***2.3***	***1.1***	***1.9***	***1.9***



PSpice simulations for future post-LIU set-up

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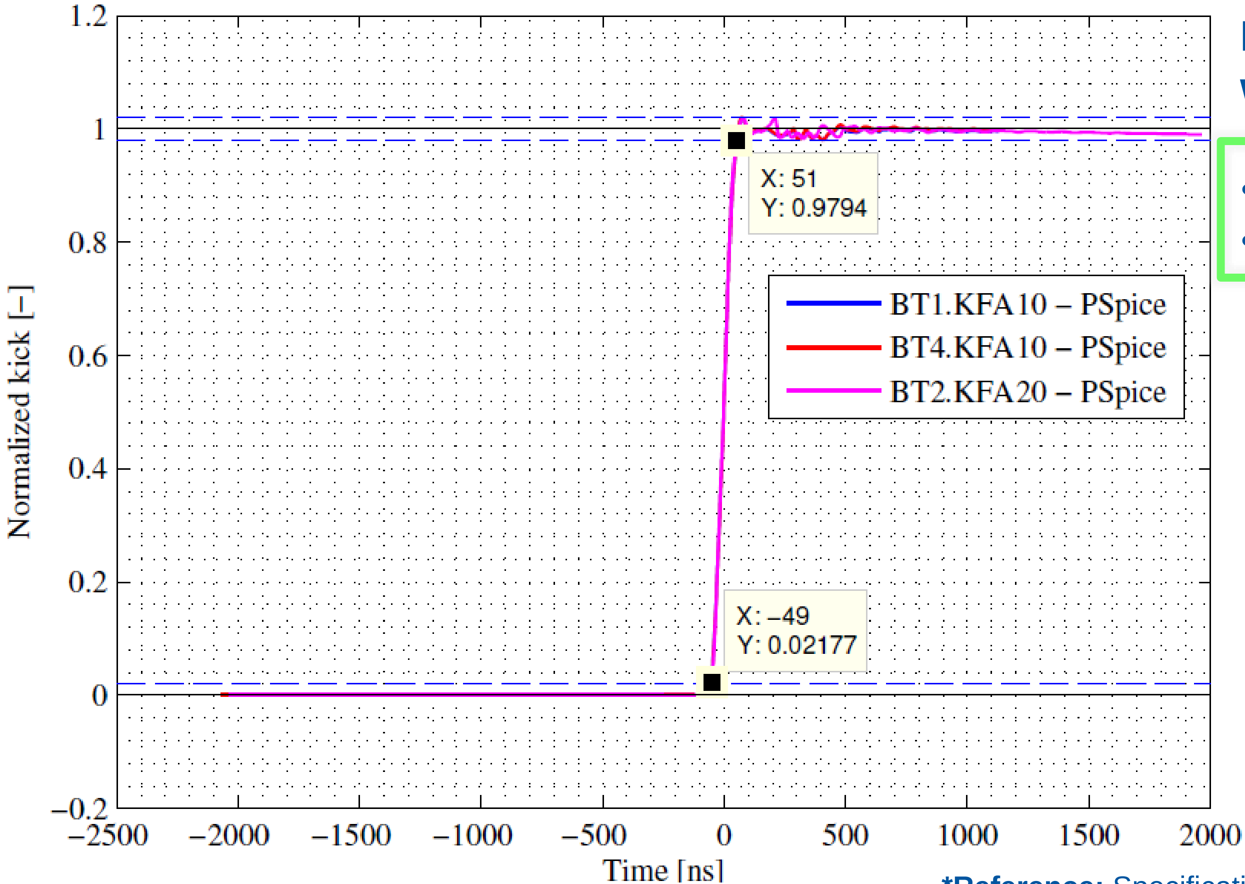
- **PSpice simulations for** future KFA10 and KFA20 set-up have been performed for **the future post-LIU set-up**
- **From PSpice simulations** it is possible to **simulate future realistic vertical emittance growth** induced by the KFAs.



PSpice simulations (L. Sermeus) within specification*:

- **2-98% rise time ~ 100 ns**
- **Flat-top ripple = ±2%**

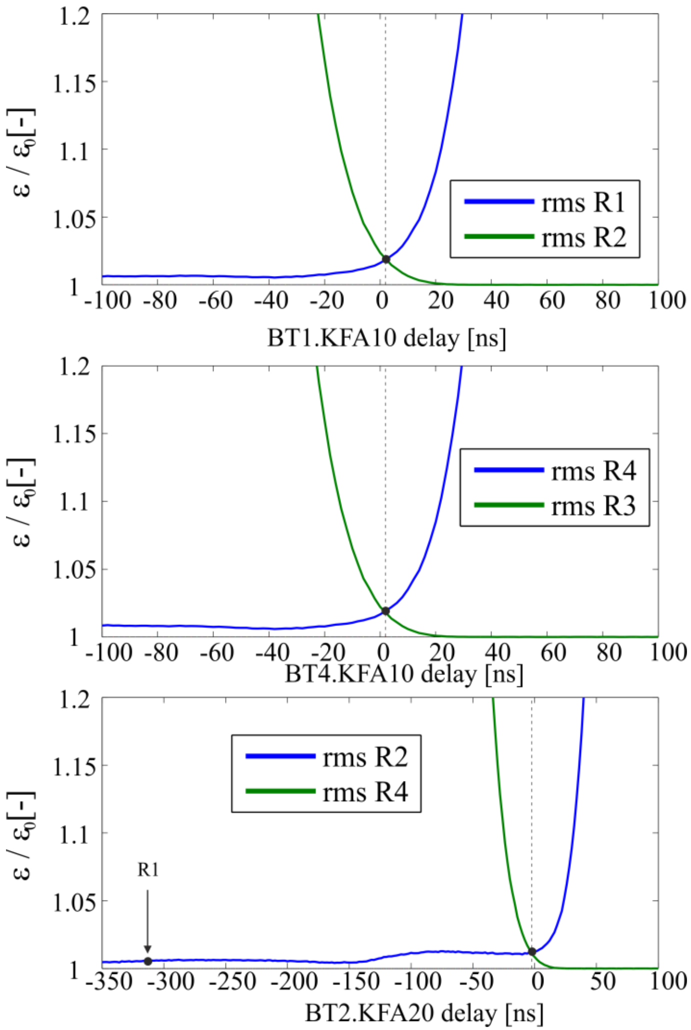
***Reference:** Specification for KICKER SYSTEMS FOR 2.0 GeV PSB to PS BEAM TRANSFER (PS-MKKIK-ES-0001**)**

Est. emittance growth: **future LHC25 beam 1.4 GeV**

- **From the PSpice waveforms** it is possible to **simulate the vertical emittance growth** induced by the KFAs.
- LHC25 'Standard' beam production: **$\varepsilon_{0,y,n}$ = 1.8 um**

- **1.4 GeV – 327 ns bunch spacing – 220 ns bunch length**

$\Delta\varepsilon_y/\varepsilon_{y,0}$ [%]	R1	R2	R3	R4
BT1.KFA10	1.9	1.9	0	0
BT4.KFA10	0	0	1.9	1.9
BT2.KFA20	0.5	1.3	0	1.3
Sum in quadrature	***2***	***2.3***	***1.9***	***2.3***



Est. emittance growth: **future LHC25 beam 2 GeV**

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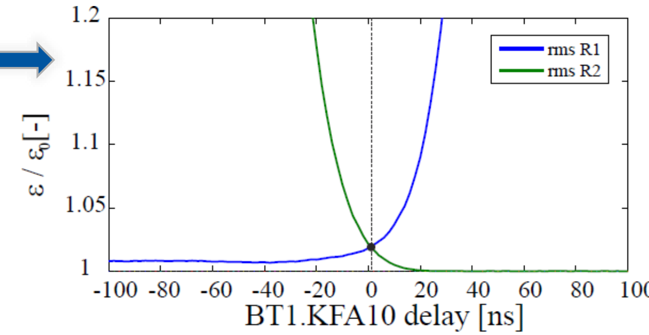
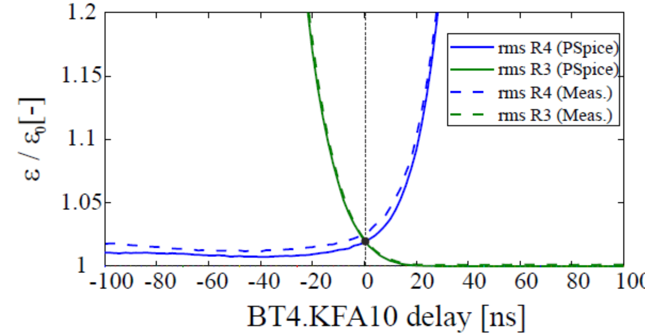
- **From the PSpice waveforms** it is possible to **simulate the vertical emittance growth** induced by the KFAs.
- LHC25 'Standard' beam production: **$\varepsilon_{0,y,n}$ = 1.8 um**
- **PSpice: 2 GeV – 316 ns bunch spacing – ~205 ns bunch length***

$\Delta\varepsilon_y/\varepsilon_{y,0}$ [%]	R1	R2	R3	R4
BT1.KFA10	1.9	1.9	0.0	0.0
BT4.KFA10	0.0	0.0	1.9	1.9
BT2.KFA20	0.8	1.4	0	1.4
Sum in quadrature	***2.1***	***2.4***	***1.9***	***2.4***

*LIU beam parameters table CERN EDMS : 1296306



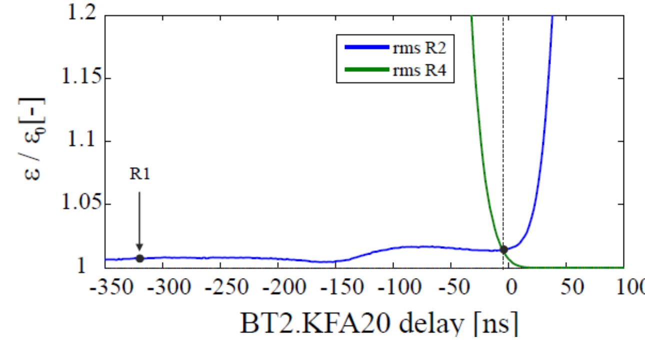


- **PSpice: 2 GeV – 316 ns bunch spacing – ~213 ns bunch length****

$\Delta\varepsilon_y/\varepsilon_{y,0}$ [%]	R1	R2	R3	R4
BT1.KFA10	2.7	2.7	0.0	0.0
BT4.KFA10	0.0	0.0	2.7	2.7
BT2.KFA20	0.8	1.6	0	1.6
Sum in quadrature	***2.8***	***3.1***	***2.7***	***3.1***

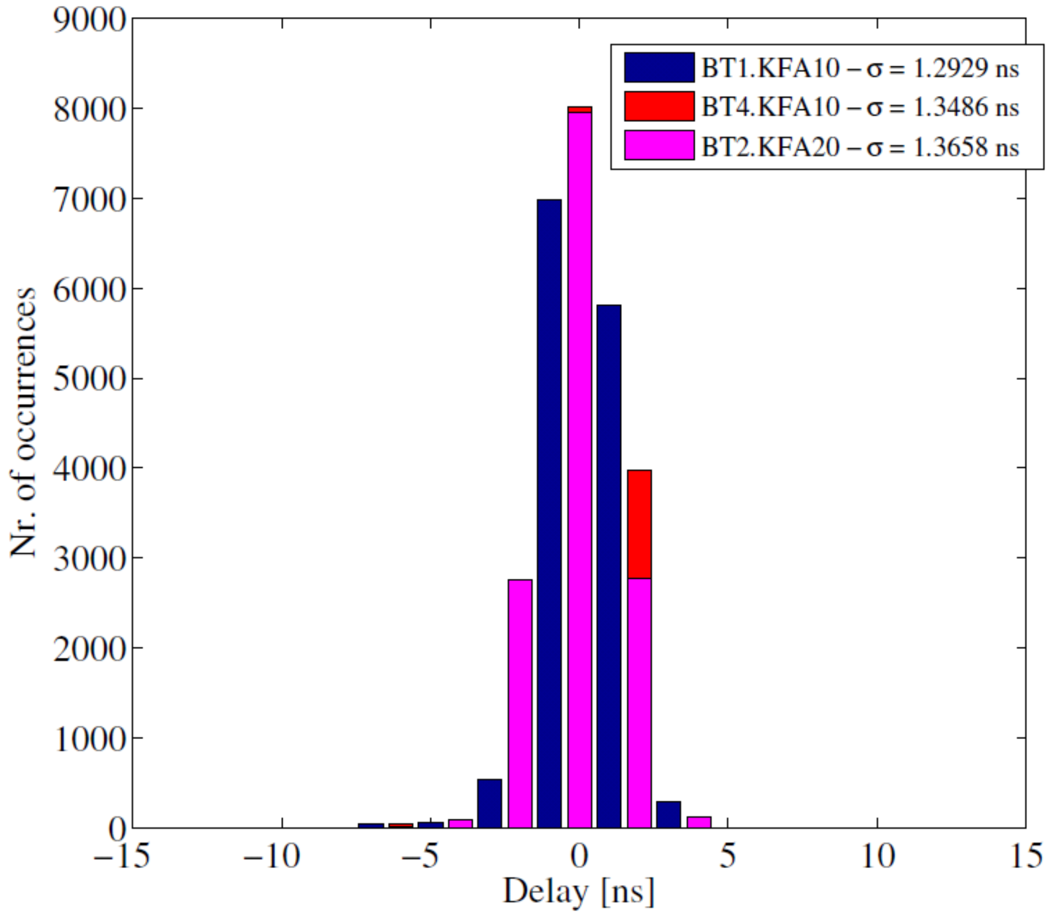
**similar to Specification for KICKER SYSTEMS FOR 2.0 GeV PSB to PS BEAM TRANSFER (PS-MKKIK-ES-0001)

→ 211 ns = 201 ns b. length + 10 ns jitter peak-to-peak



Jitter in time of recombination kickers

- **The jitter in time** of the recombination kickers has been observed over **~13700 ISOLDE cycles.**
- **The peak-to-peak jitter** is **~12 ns**
- **However, the maximum standard deviation** is **<1.4 ns**



Conclusions

➢**HW improvements for the BT1(4).KFA10 and BT2.KFA20 have been presented:**

- **BT.KFAs kicker rise time measurements in SAL5 test cage (May 2017)**
- **Status of spare design**
- **PSpice simulations in post-LIU configurations** (to simulate future expected emittance growth)

➢The **maximum estimated vertical emittance growth** due to the recombination kickers **for the present (beam-based) kicker waveforms (just within specification for rise time and flat-top ripple)** is**:**

- **2.0% / ring (1.1% average)** for **1.4 GeV** (**180 ns** bunch length, **327 ns** bunch spacing);
- **2.3% / ring (1.8% average)** for **1.4 GeV** (**220 ns** bunch length, **327 ns** bunch spacing);

➢The **maximum estimated vertical emittance growth** due to the recombination kickers **for the final LIU-PSB PSpice simulated waveforms** is:

- **2.3% / ring (2.1% average)** for **1.4 GeV** (**220 ns** bunch length, **327 ns** bunch spacing);
- **2.4% / ring (2.2% average)** for **2.0 GeV** (**205 ns** bunch length, **316 ns** bunch spacing);
- **3.1% / ring (2.9% average)** for **2.0 GeV** (**213 ns** bunch length, **316 ns** bunch spacing);

➢**Observations on the operational jitter in time** of the recombination kickers have shown **~12 ns peak-to-peak** and **standard deviation <1.4 ns**

➢**The vertical emittance growth quantities have to be considered in a global scenario** of emittance growth sources at PS injection (e.g. optics mismatch and space charge) → **PS TFB could be helpful for damping**

- **5% (horizontal and vertical) emittance growth budget along all PS cycle***
- **~4% remaining budget from other emittance growth sources** (e.g. optics, space charge, etc.)

*LIU beam parameters table CERN EDMS : 1296306

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Time margins: **measurements**

April 24, 2017 – Beam parameters at injection of each accelerator

PSB (H^- injection from Linac4)

		N (10^{11} p)	$\epsilon_{x,y}$ (μm)	E (GeV)	ϵ_z (eVs)	B_l (ns)	$\delta p/p_0$ (10^{-3})	$\Delta Q_{x,y}$
Achieved	Standard	17.73	2.14	0.05	1.0	1100	2.4	(0.51, 0.59)
	BCMS	8.48	1.15	0.05	0.9	1000	2.2	(0.46, 0.56)
LIU target	Standard	34.21	1.72	0.16	1.4	650	1.8	(0.58, 0.69)
	BCMS	17.11	1.36	0.16	1.4	650	1.8	(0.35, 0.43)

PS (Standard: 4b+2b – BCMS: 2× 4b)

		N (10^{11} p/b)	$\epsilon_{x,y}$ (μm)	E (GeV)	ϵ_z (eVs/b)	B_l (ns)	$\delta p/p_0$ (10^{-3})	$\Delta Q_{x,y}$
Achieved	Standard	16.84	2.25	1.4	1.2	180	0.9	(0.25, 0.30)
	BCMS	8.05	1.20	1.4	0.9	150	0.8	(0.24, 0.31)
LIU target	Standard	32.50	1.80	2.0	3.00	205	1.5	(0.18, 0.30)
	BCMS	16.25	1.43	2.0	1.48	135	1.1	(0.20, 0.31)

SPS (Standard: 4 × 72b – BCMS: 5 × 48b)

		N (10^{11} p/b)	$\epsilon_{x,y}$ (μm)	p (GeV/c)	ϵ_z (eVs/b)	B_l (ns)	$\delta p/p_0$ (10^{-3})	$\Delta Q_{x,y}$
Achieved	Standard	1.33	2.36	26	0.35	4.0 (3.0)	0.9 (1.5)	(0.05, 0.07)
	BCMS	1.27	1.27	26	0.35	4.0 (3.0)	0.9 (1.5)	(0.07, 0.12)
LIU target	Standard	2.57	1.89	26	0.35	4.0 (3.0)	0.9 (1.5)	(0.10, 0.17)
	BCMS	2.57	1.50	26	0.35	4.0 (3.0)	0.9 (1.5)	(0.12, 0.21)

LHC (≈10 injections)

		N (10^{11} p/b)	$\epsilon_{x,y}$ (μm)	p (GeV/c)	ϵ_z (eVs/b)	B_l (ns)	bunches/train
Achieved	Standard	1.20	2.60	450	0.45 (0.50)	1.65 (1.21)	288
	BCMS	1.15	1.39	450	0.35 (0.39)	1.50 (1.05)	96
LIU target	Standard	2.32	2.08	450	0.50	1.65	288
	BCMS	2.32	1.65	450	0.50	1.65	240

** Longitudinal emittance ϵ_z (2σ), momentum spread $\delta p/p_0$ (1σ), bunch length B_l (4σ): values are given at injection (first turn), values in parentheses are after filamentation (V_{SPS}=4 MV, V_{LHC}=6 MV). Longitudinal emittances at SPS injection and after filamentation are the same because they are measured with different conventions

LIU beam parameters table CERN EDMS : 1296306

Time margins: **measurements**

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- **Further measurements on BT2.KFA20 needed:**
  - **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 → **HW improvement needed**
  - SEM-grids have small precision
  - It is still possible to consider **a certain margin** for a clean transfer.