LEL 2022: 3rd Workshop on low emittance lattice design
26-29 June 2022

ESRF-EBS injection status and plans

S. White

Acknowledgments:
T. Brochard, N. Carmignani, L. Carver, M. Dubrulle, L. Hoummi, M. Morati,
S. Liuzzo , T. Perron, B. Roche

ESRF | The European Synchrotron

OUTLINE

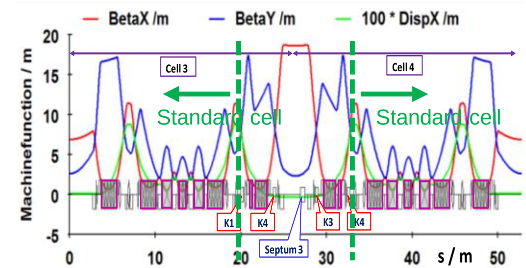
ESRF-EBS injection systems

Performance and limitations

Future plans

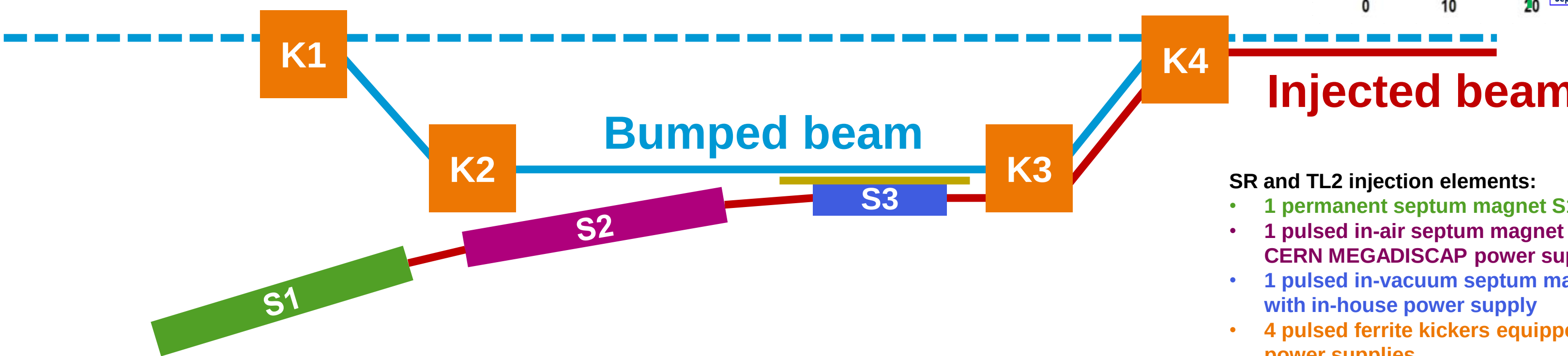
Summary

STORAGE RING INJECTION



SR injection is done in in top-up using off-axis injection scheme:

- The refill frequency is 1h in multi-bunch mode (>20h lifetime)
- The current variation is 5-10mA between 2 refills



SR and TL2 injection elements:

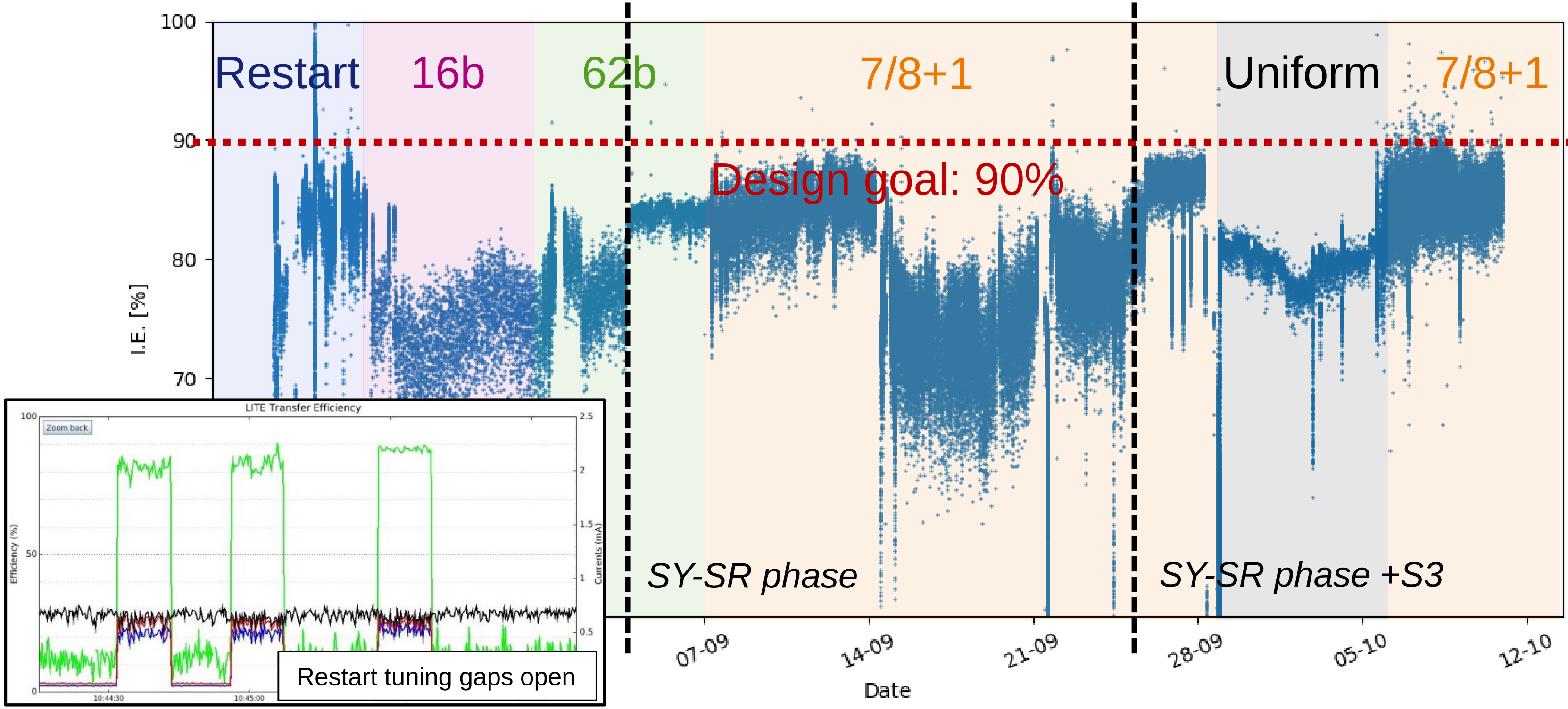
- 1 permanent septum magnet S1
- 1 pulsed in-air septum magnet S2 equipped with CERN MEGADISCAP power supply
- 1 pulsed in-vacuum septum magnet S3 equipped with in-house power supply
- 4 pulsed ferrite kickers equipped with 4 thyratron power supplies

Main limitations:

- Large acceptance needed to provide high injection efficiency. Depends on SR optics, injected beam size, septum blade thickness
- Injection bump acts on the stored beam. Ideally local, in reality imperfections are leaking throughout the ring causing perturbations to the beam lines

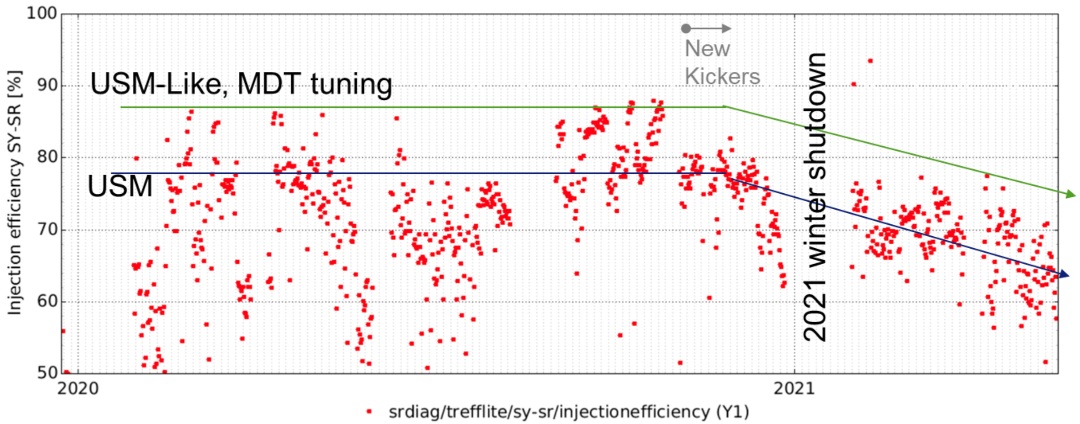
This scheme was used in the previous machine and adopted for EBS as a low risk, robust solution: we may have to re-evaluate this choice

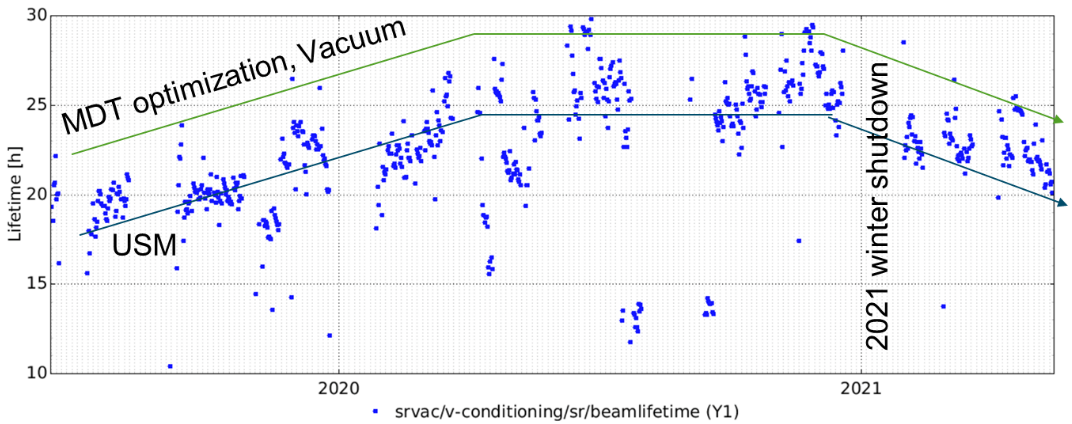
INJECTION EFFICIENCY (2021)



- **Design goal of 90% (almost) achieved** with freshly tuned machine in long pulse with gaps open, **in USM ~80%**
- Fluctuation mostly related to injector tuning not to the mode: **degradation down to ~70%, could benefit from more frequent adjustments**

ISSUES IN 2022?





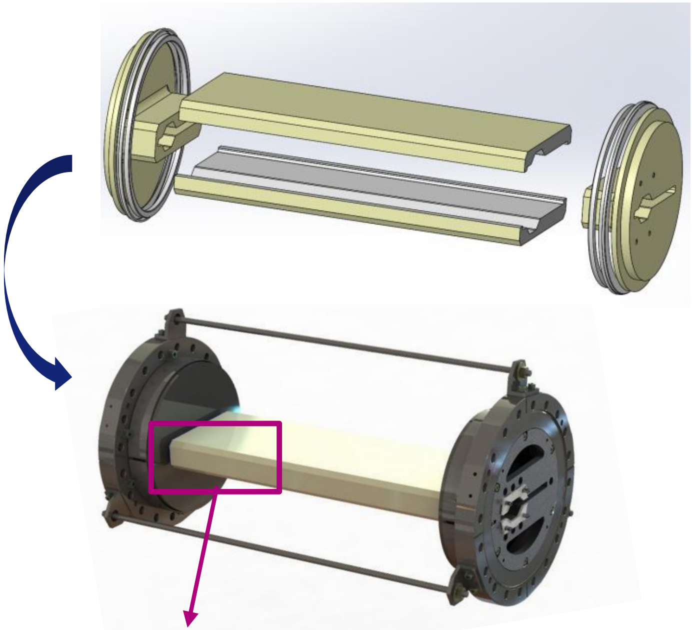
Correlated reduction of lifetime and injection efficiency observed since winter shutdown 2021

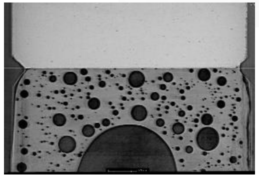
Source of the problem not yet understood. Combination of detrimental effects?:

- High chromaticity optics, reduction of 1.5h lifetime
- Lifetime reduction of ~7% due to collimators tuning for operation
- Stronger of injection efficiency dependency on gap and collimators settings (variable, as high as 10%)

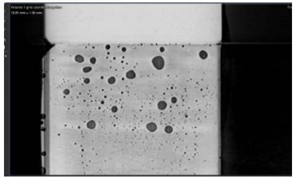
Recently it was found that a 100Hz frequency offset would increase I.E. by 10%: to be investigated

CERAMIC CHAMBERS





Broken chamber



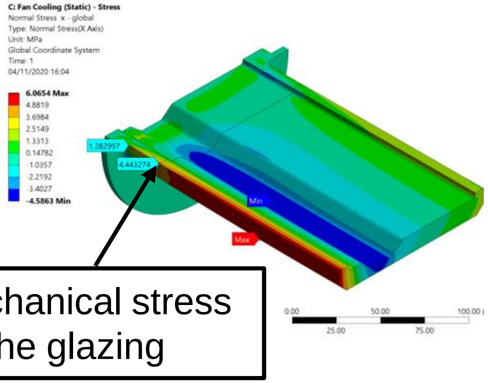
Spare chamber

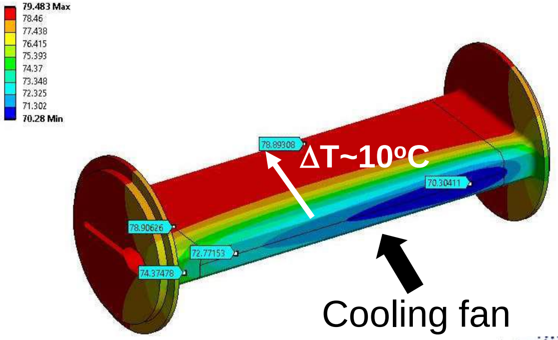
Complex design: 4 pieces glazed together:

- Cracked at glazing location when ramping 16 bunch mode to nominal current: overheating + mech. weakness
- **Temporary solution:** increase coating thickness, temperature ok, IVU RF fingers are now limiting the current
- **Long term solution:** new chambers (next year)

	7/8 + 1	Uniform	32*12	28*12+1	62 b	16 b	4 b
I_{max} (mA)	196+4 * (~~192+8~~)	200	150 * (~~200~~)	125+3* (~~200~~)	65*	35* (~~90~~)	20* (~~40~~)
LT [h]	> 22	> 25	> 22	> 23	~ 14	~ 8	~ 5
ε_v (pm)	10	10	20	20	20	20	20

- *Design current for each mode and limit set by ceramic chambers: removed with thicker coating*
- *Vertical emittance artificially increased from 1 to 10/20 pm rad to increase lifetime*



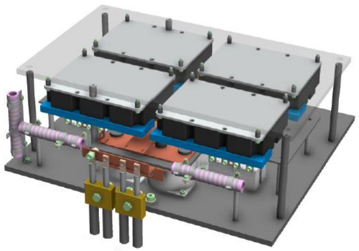


NEW KICKERS POWER SUPPLIES

Injection perturbations are presently a severe limitation for some beam lines: full injection period (~60s) excluded from data acquisition

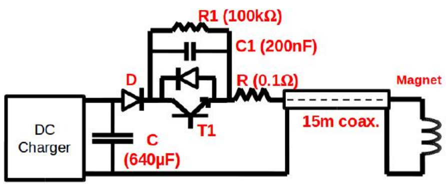
These perturbation are reduced using a fast feed-forward compensation: bandwidth limitations

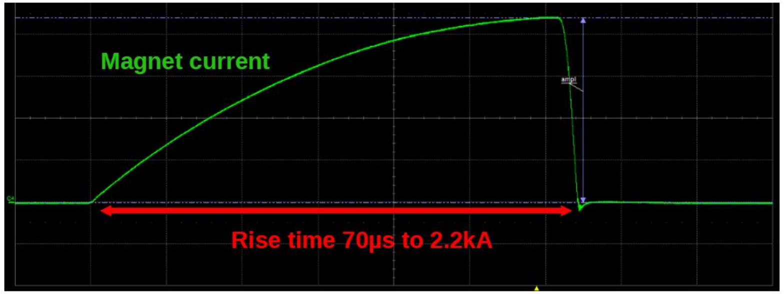
Proposed to install slow(er) power supplies based on solid state technology to reduce the frequency of the perturbations



Prototype assembly

Topology principle



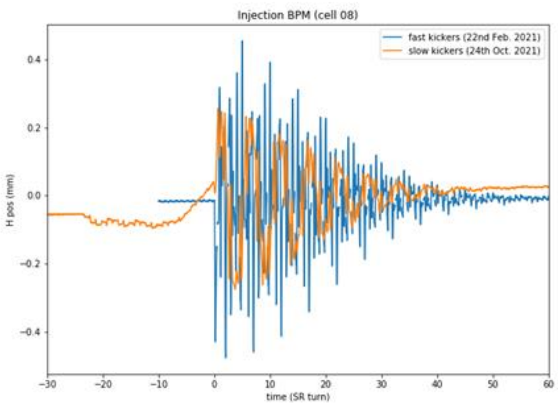


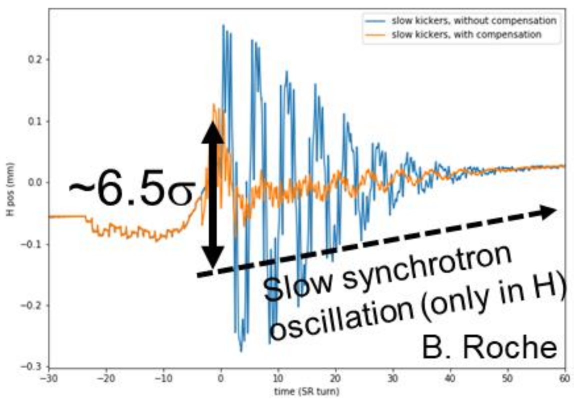
M. Dubrulle and M. Morati

	Thyratron	New design
Voltage rating	30 kV to 40 kV	600 V
Max. current	2200 A	2200 A
Flat-top	1 µs	No flat-top
Rise/fall time	450 ns / 800 ns	70 µs / <2 µs
Pulse-to-pulse jitter	±0.2 %	±0.05 %

- **In-house design and construction:** simpler maintenance
- Achieved fall time 2.2µs
- Significant improvement of pulse-to-pulse jitter
- **Eddy currents in Ti coating reduced:** this allowed to increase the thickness and reduce beam induced heating

REDUCTION OF PERTURBATIONS





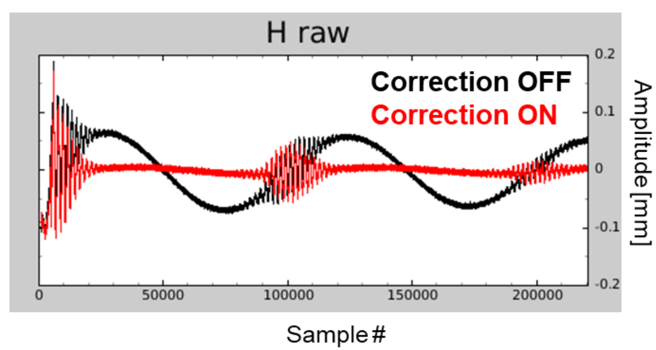
Initial perturbation equivalent to the fast kickers but much lower frequency:

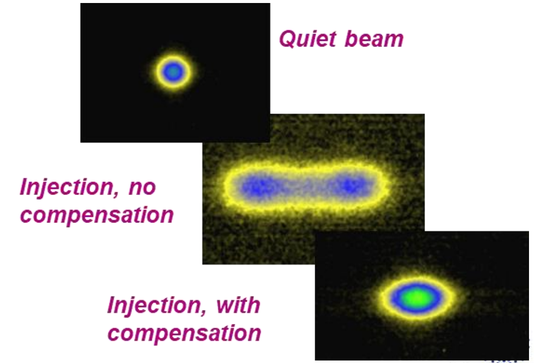
- Easier to correct
- The peak perturbation remains large, however it damps to ~+/-1σ in a few turns
- Similar observations in the vertical plane

Joint MDTs with beam lines indicated that another factor 2 is needed

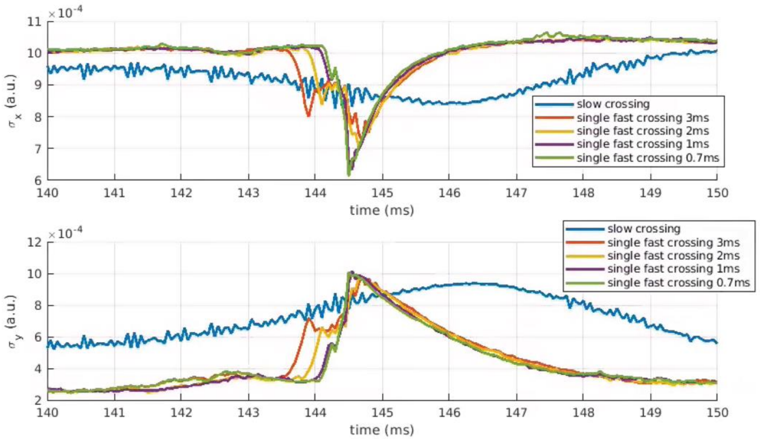
Further improvements to be investigated: slower ramp-down, better equalized pulses, correct synchrotron oscillations (validated)

Fast trigger signals provided to a beamline for test: exclude only the perturbed frames





INJECTION EFFICIENCY: BOOSTER IMPROVEMENTS

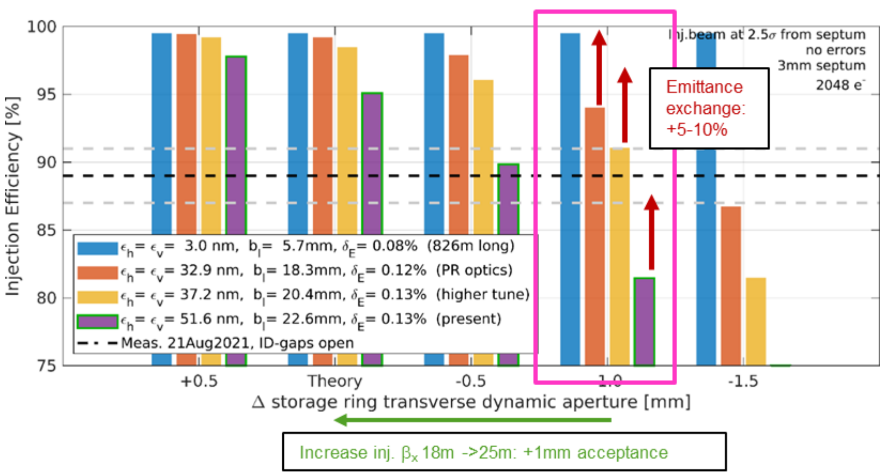


Emittance exchange introduced during commissioning:
- 5-10% gain in injection efficiency observed
- Losses on IVU gaps increased

Present optics with higher tunes:
- Commissioning ongoing, required new bumper power supplies
- Good intermediate proof of principle: validation this run

New optics with additional quads families:
- Reduced cost, low risk
- Potentially 100% I.E. with emittance exchange

→ Strategy to be confirmed in view of (potential) gain from high tune optics



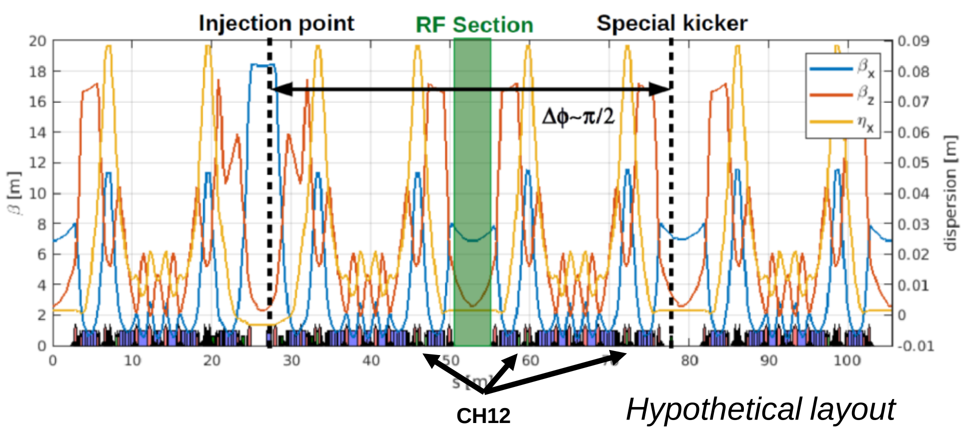
Parameter	Present booster	Higher tune	Higher H tune (P. Raimondi)	Full length (S. Liuzzo)
Quad families	2	2	5	4
Tunes (h, v)	11.75, 7.65	12.75, 7.65	13.39, 4.15	26.39, 20.44
ε_x (on-energy)*	120 nm	101 nm	80 nm	6 nm
ε_x (off-energy)*	83 nm	61 nm	54 nm	-
BL@9MV	22.6 mm	20.4 mm	18.3 mm	5.7 mm
Energy spread	1.30e-3	1.27e-3	1.24e-3	0.86e-3

Constraints: do not disrupt physics program, minimize changes in SR, keep present systems operational

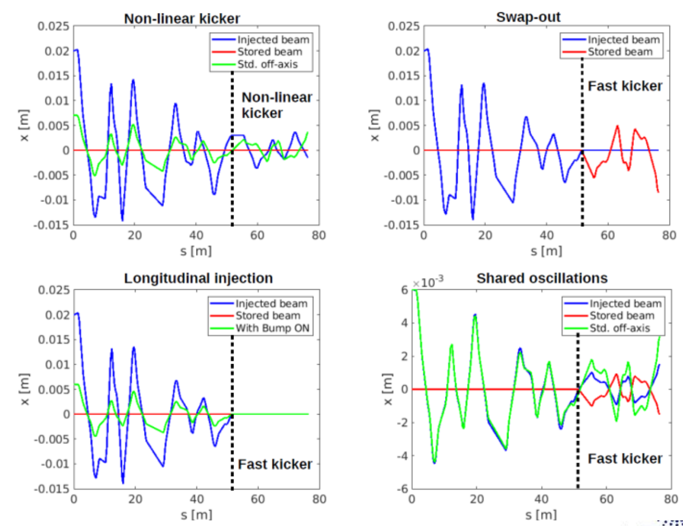
Proposed to integrate a special kicker downstream the injection cells:

- Compatible with several schemes: non-linear kicker, swap-out, shared oscillations
- Allow large oscillation across a few cells
- No aperture restrictions between injection point and the kicker
- Need sufficient space to integrate the kicker
- Phase advance constraints apply

	Pulse width	Kick [mrad]
Std on-axis	1 SR turn: 3 μs	2.0 (2.0)
NL kicker	1 SR turn: 3 μs	1.2 (1.0)
Swap-out	2 SR bucket: 6 ns	1.4 (1.4)
Long.	1ns	1.4 (1.4)
Long. + bump	1ns	0.7 (0.9)
Shared osc.	2 SR buckets: 6 ns	0.25 0.43)



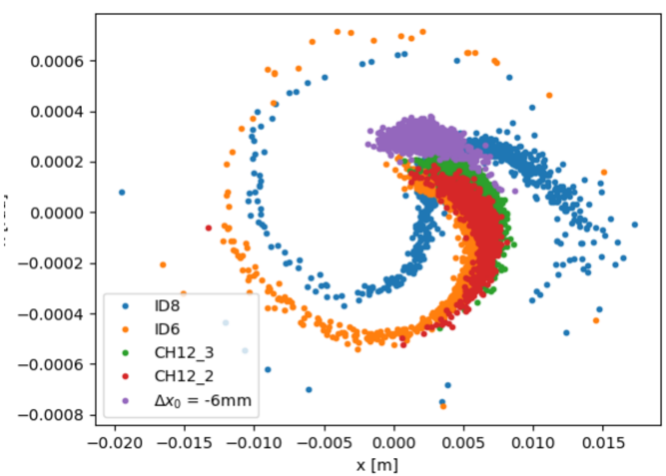
Hypothetical layout with the kicker in ID6



LARGE OSCILLATIONS ARE AN ISSUE (FOR HMBA)

Injected beam parameters: $\varepsilon_x=\varepsilon_y=45\times10^{-9}$ m, $\sigma_s=20.0$ mm, $\sigma_p=1.2\times10^{-3}$
Simulation: 2000 particles, 4000 turns, ideal lattice with radiations, initial β_x, α_x ~optimized

Case	Injection efficiency (dipole kicker)
x_0=6mm*	99.9%
CH12_2	99.4%
CH12_3	99.5%
ID6	94%
ID8	76.5%



Strong non-linear magnets:

- large oscillations through few cells enough to send injected beam tails outside the acceptance
- **ID8 (4 cells) clearly discarded**, significant degradation for ID6 (2 cells), CH12 (1-2 cells) cases look OK without errors

Oscillations through few (HMBA) cells are sufficient to degrade the injected beam properties:

- Only the shared oscillation scheme has reduced oscillations
- Has to be combined with bump (not transparent) or NLK

Only the CH12 closer to the injection point preserve efficiency:

- These drifts are only 0.4m long and have relatively large β
  Difficult to integrate fast stripline systems at these locations

→ Try with non-linear kicker (also not easy)

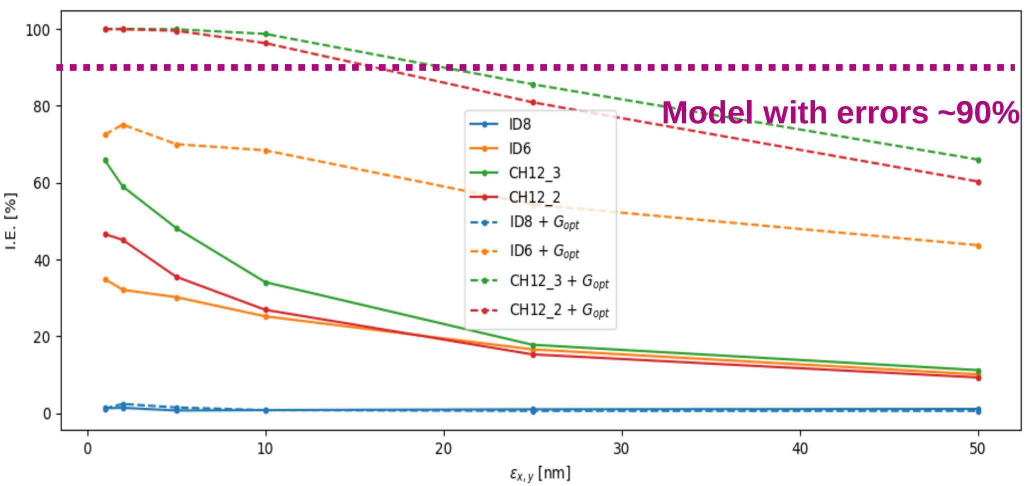
NON-LINEAR KICKER DOWNSTREAM THE INJECTION POINT

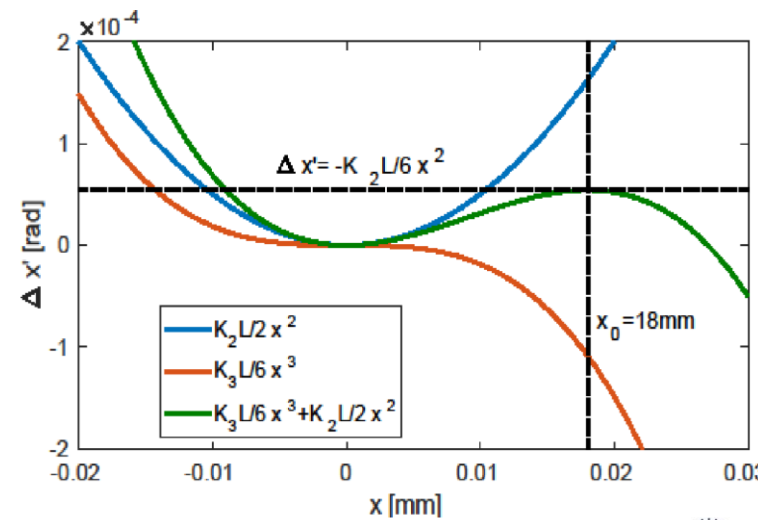
Major limitation of the NLK:
- Injected beam tails do not see the optimal field
- Degradation of injection efficiency
- For HMBA ~1.5mrad in 3-4mm: very strong variation

Possible solutions:
- **Reduce injected beam emittance:** injectors upgrade
- **Adapt kicker field shape:** more complex kicker design

→ **Combination needed:** major investment, development and intervention

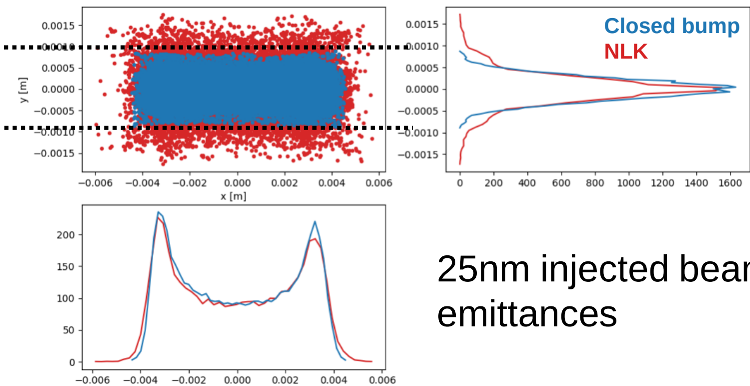
	Kicker type		
	Dipole	**Octupole**	**Oct. + Sext.**
x_0=6 mm	99.9%	99.9 %	99.9%
$ARC5_1$	99.4%	36.9%	95.0%
$ARC5_2$	99.5%	38.5%	96.5%
ID6	94.0%	31.3%	72.5%
ID8	76.5%	15.4%	50.1%



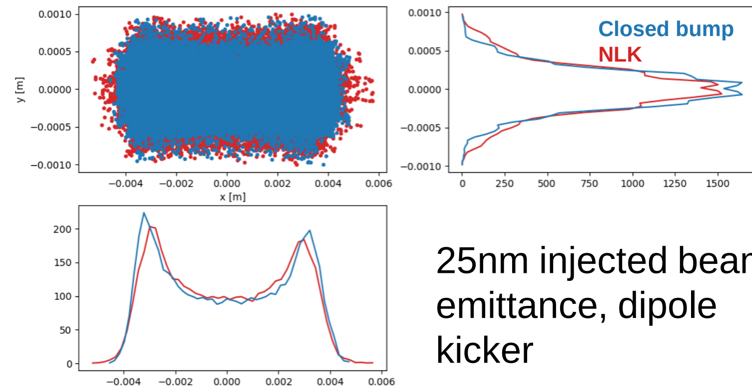


BEAM SPOT WITH NON LINEAR KICKER

DA @
x=7mm
seed#1



25nm injected beam emittances

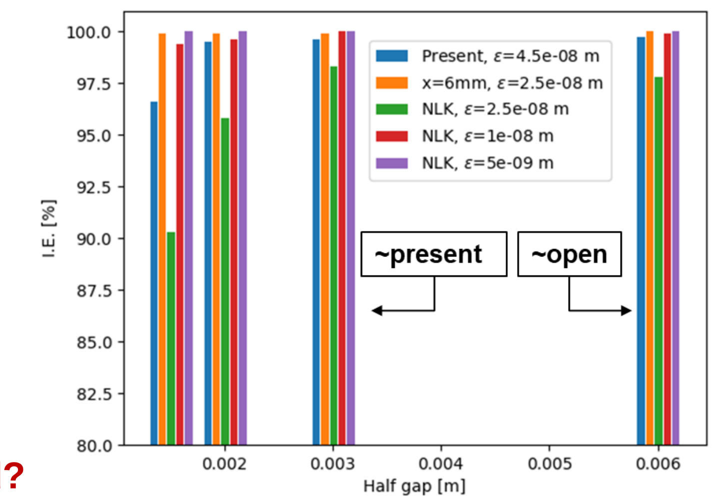


25nm injected beam emittance, dipole kicker

Ideal simulation:
Injected beam perfectly matched, no errors in the lattice
Gaps restriction applied in all straight sections

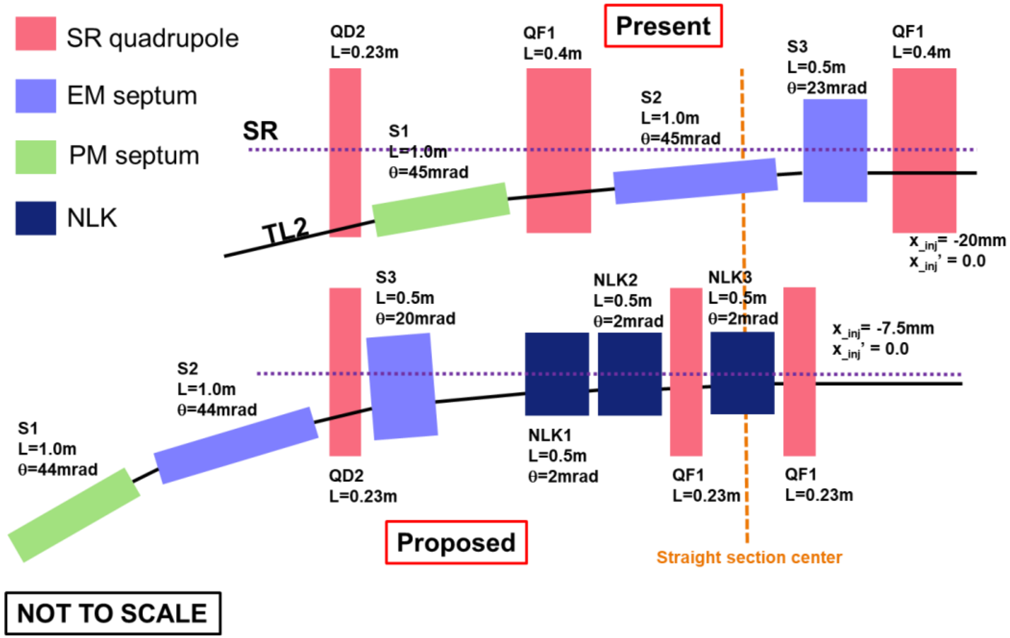
Non-linear-kicker: reduction down to 5nm needed
→ **Low emittance booster needed**

Off-axis injection: reduction of emittance to 25nm sufficient to prevent losses on gaps
→ **Compatible with new booster optics**



Inject on the NLK flat-top + new booster optics instead?

INTEGRATE THE NLK IN THE INJECTION CELL



Proposed by P. Kuske for Bessy-II @ Topical workshop on injection and injection systems (2017)

Strategy for ESRF HMBA:

- Replace QF1 by short (QD2) quadrupoles, reduce distance between them and increase β_x to 31.5m
- **Optics Changed locally:** symmetry conserved
- Acceptance = 6*√(31.5/18.6) = 7.8mm (in theory)
- Design NLK with flat top at 7.5mm (relaxed) to replace S3
- **Compatible with existing SR layout and hardware**

Most limitations removed (in theory):

- **Increase injection β:** relaxed NLK design, injected beam comes at larger offset, space to generate “flat-top”
- **Injection on field flat-top within acceptance:** performance (I.E. and injection oscillation amplitude) maintained, low emittance booster not needed
- **Can be combined with fast kicker:** shared oscillation, reduce oscillation amplitude by factor 2, provide 100% efficiency and allows for low gap operation

→ Still large intervention needed but much lighter than a full new booster

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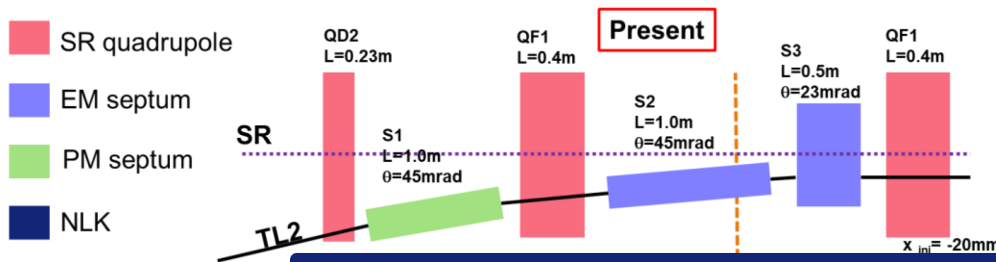

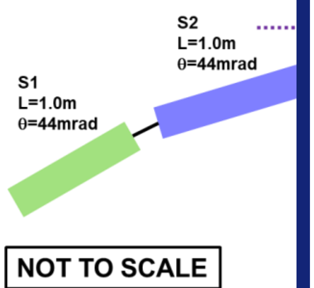

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- Replace QF1 by short (QD2) quadrupoles,
  ...d increase
  ...ry
  ...mm (in
  ...(relaxed)
  ...out and hardware

Main challenges:

- Mechanical integration, interference between SR and transfer line
- Non linear kicker design, clean flat-top required
- High beta optics optimization

→ Full validation study will start in the coming months

Most limitations removed (in theory):

- **Increase injection β:** relaxed NLK design, injected beam comes at larger offset, space to generate "flat-top"
- **Injection on field flat-top within acceptance:** performance (I.E. and injection oscillation amplitude) maintained, low emittance booster not needed
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SUMMARY

ESRF run with standard 4 kicker bump off-axis injection schemes:

- Smooth an efficiency commissioning
- Efficiency approaching the design in ideal conditions
- Difficult to maintain performance in USM condition
- Large perturbations disturb some users
- Over-heating of ceramic chamber limiting the few bunch modes current

Improvements since commissioning:

- New injection kickers power supplies to reduced perturbation: another factor 2 improvement needed
- New booster optics to improve efficiency: commissioning ongoing
- Increase Ti thickness + new ceramic chambers: not the limiting factor anymore

Achieving high efficiency transparent injection (for all beam lines) will be difficult with these systems:

- Look for alternative injection schemes
- Initially started with flexible design downstream injection point: strong degradation of performance, new low emittance booster needed
- **Now considering to re-design the injection straight to integrate a non-linear kicker: design studies will start in the coming months**

MANY THANKS FOR YOUR ATTENTION