SYNCHRONISATION NEEDS FOR NEW PSB INJECTION WITH LINAC4

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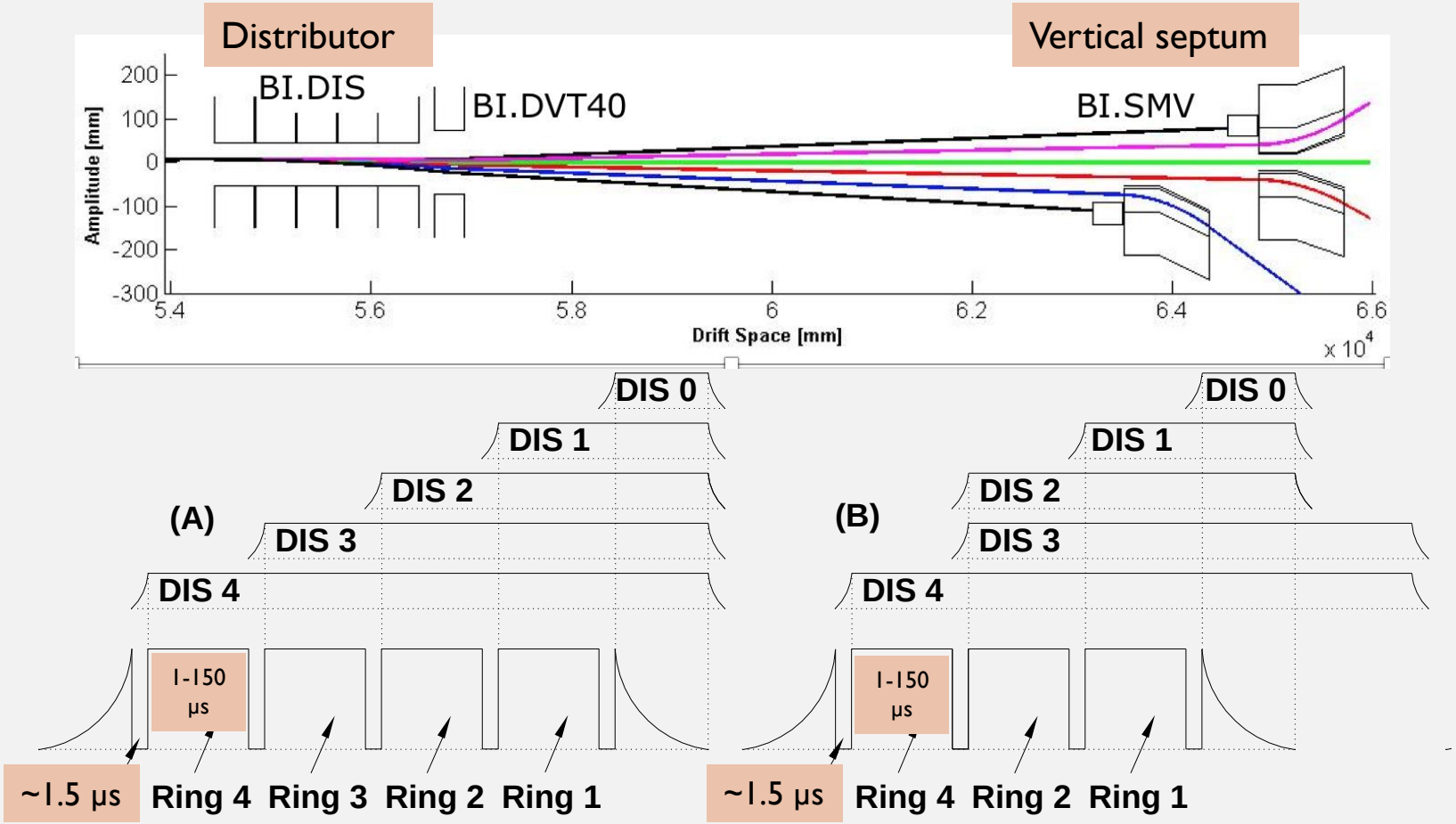
INTRODUCTION

After LS2:

- Injection of 160 MeV H^- beam from Linac4 into PSB
- New injection principle
  - **Stripping foil** (H^- beam → p beam)
  - **Injection chicane** (4 BSW magnets producing bump of circulating beam)
  - **Transverse and longitudinal phase-space painting** (optimise transverse emittances and minimise space charge detuning)
- Injection into **accelerating waiting** buckets

- Keep principle of beam distribution into 4 PSB rings (distributor + septum + correctors/quads/bend)
- Have to **make sure to maintain current operational flexibility of the PSB** (e.g. several hundreds of different beam cycles covering O(10^4) in intensity; use betw. 1-4 rings; adjust regularly intensity/ring (number of injected turns corresponding to pulse length); parasitic cycles etc.)
- **Improve performance**

DISTRIBUTOR OPERATION

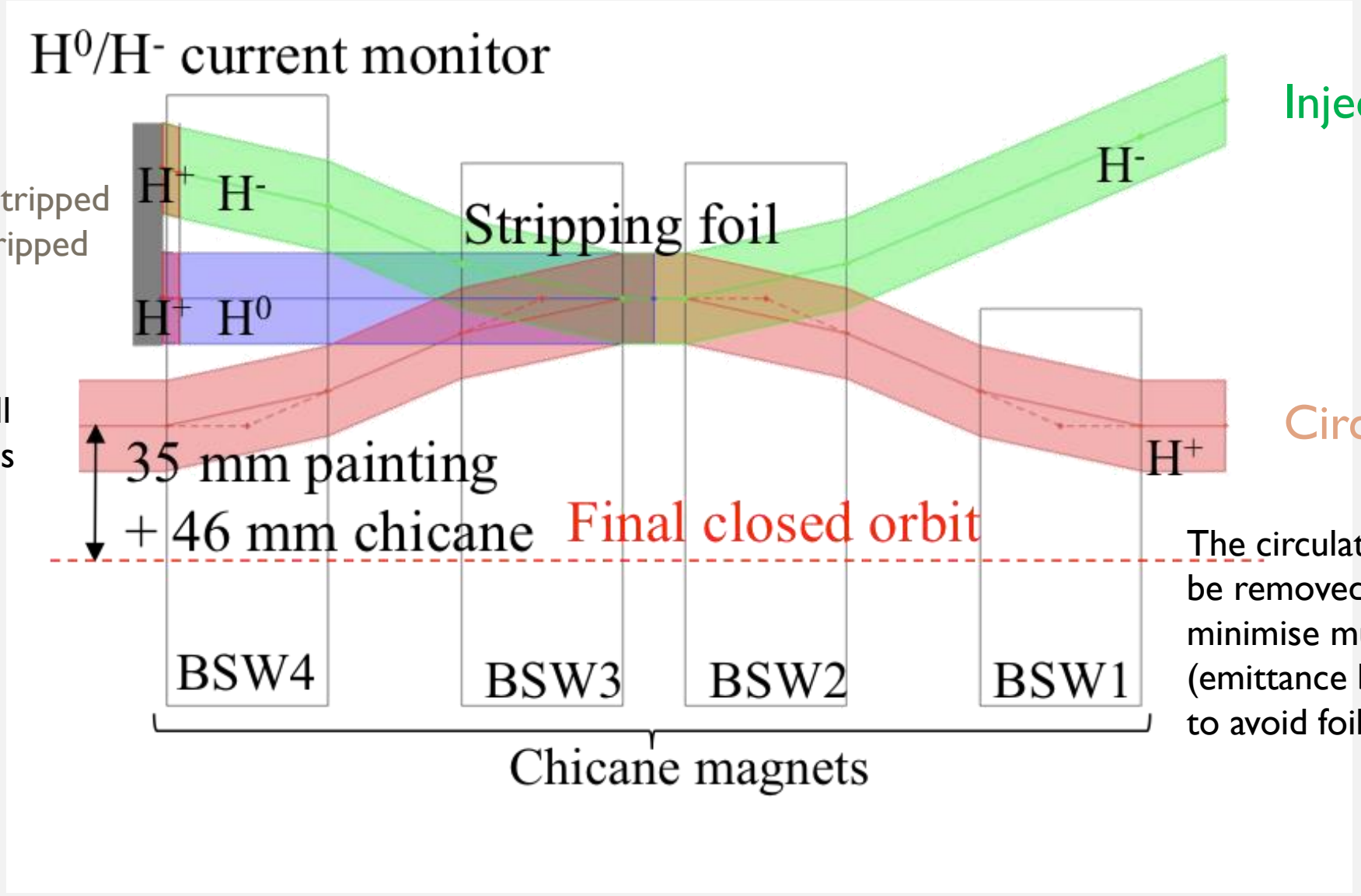


- **Start time of different distributor levels flexible**, taking into account:
  - Programmed number of injected turns per ring (pulse length), by-ring interlocks (External Conditions) and software interlocks (SIS); example (B): No beam for Ring 3; adjusted 'on-the-fly' with External Fast Timings

NEW INJECTION SECTION

Dump for unstripped or partially stripped particles

Chicane bump will collapse after 5 ms



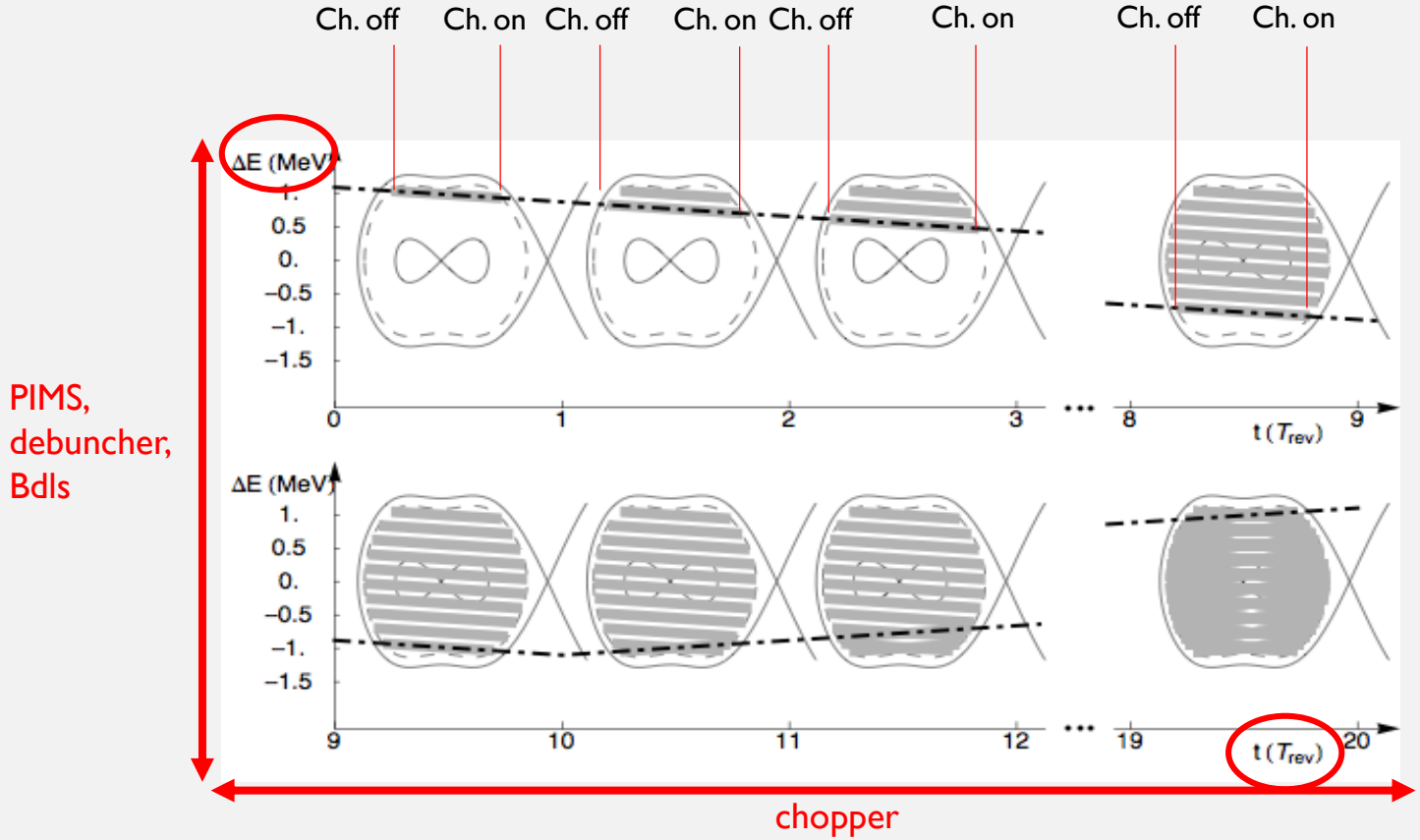
Injected beam

Circulating beam

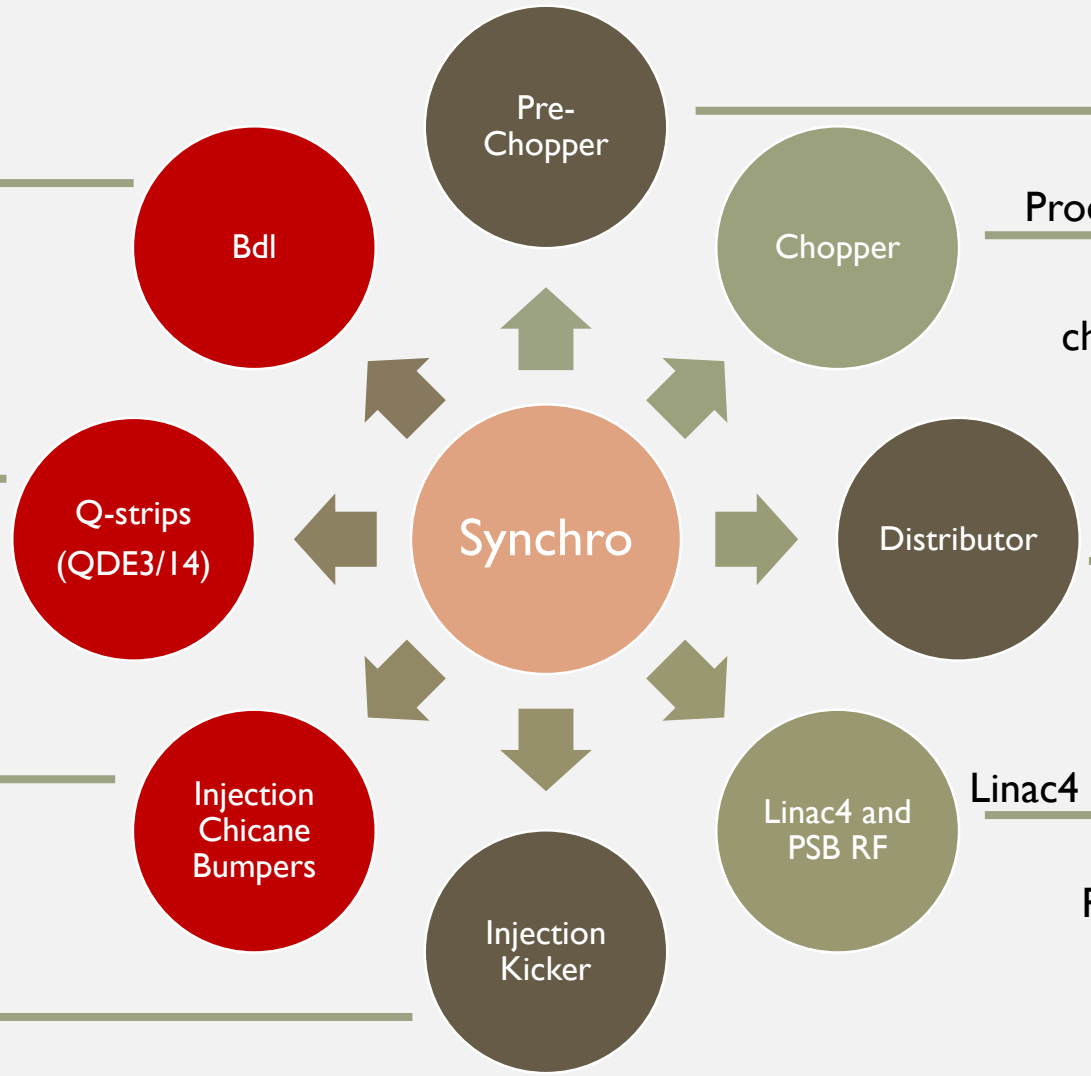
The circulating beam has to be removed from the foil to minimise multiple scattering (emittance blow-up, losses) and to avoid foil destruction

FILLING OF PSB BUCKETS

- **Chopper ON/OFF** (no beam/beam) pattern needs to correspond to desired filling factor of accelerating PSB buckets → **optimise line density and long. parameters, minimise losses**!
- Irregular chopping pattern during **longitudinal painting** (for more homogenous bucket filling), where also synchronisation with **2 last Linac4 PIMS cavities + the debuncher** is needed
- Correction of **energy differences between rings at injection due to ramping B-field** through **Bdls**



SYNCHRONISATION NEEDS FOR NEW PSB INJECTION



Defines length of Linac4 pulse

Produces 1.5 us holes betw. rings to avoid losses during distributor rise-time; chopping pattern for loss-free beam-to-bucket transfer; longitudinal painting

Distributes beam slices of flexible length into 4 PSB rings

Linac4 RF: Ramping of last 2 PIMS cavities for longitudinal painting + debuncher

PSB RF: To align RF buckets per ring to Linac4 beam slice arrival

By-ring correction of magnetic field at injection (injection during ramping B-field)

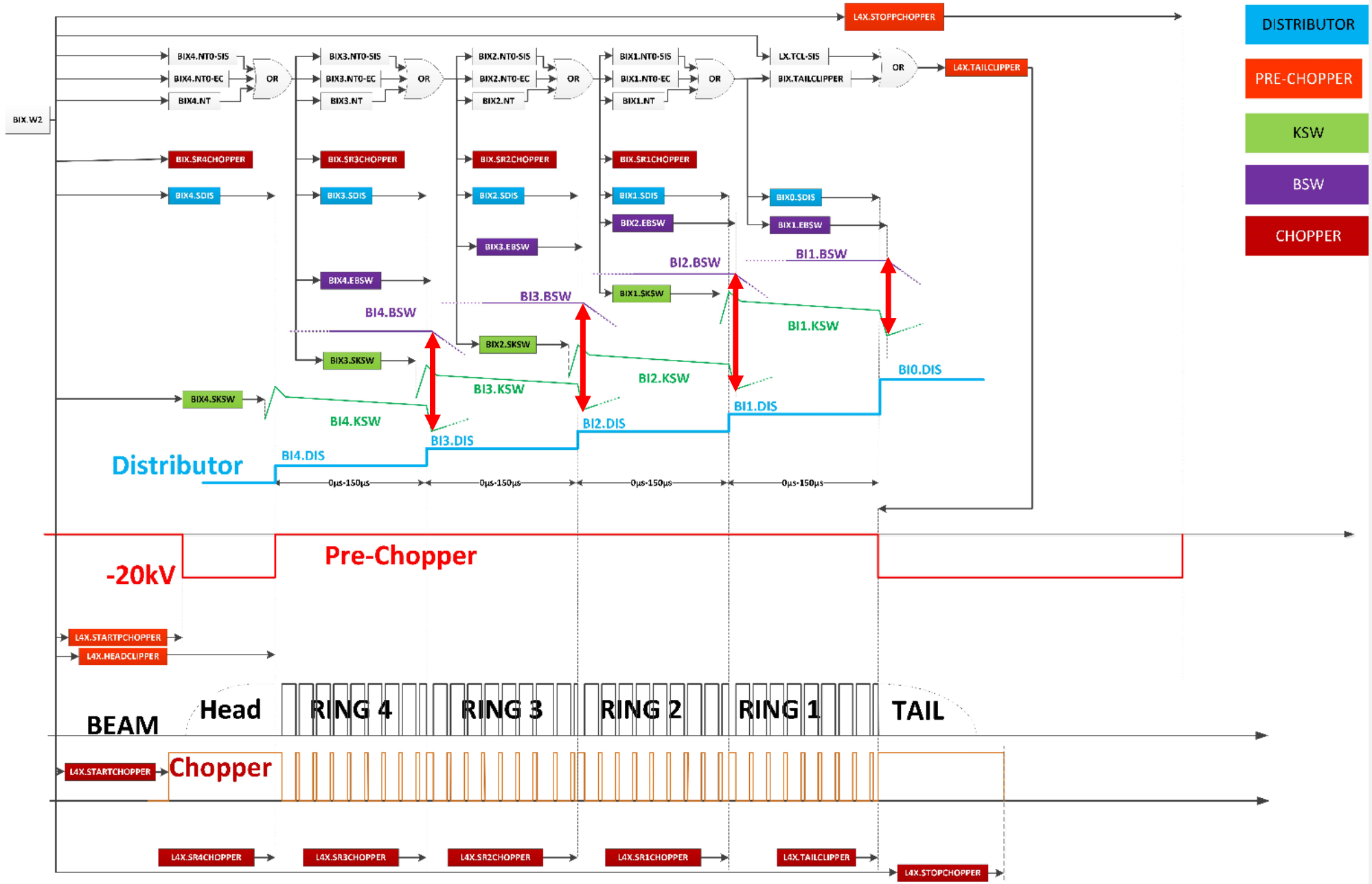
Correction of vertical beta-beating introduced by BSW magnets (+ working point)

Produce bump during injection; chicane fall after 5 ms to nominal orbit

Transverse phase-space painting and fast beam removal from stripping foil

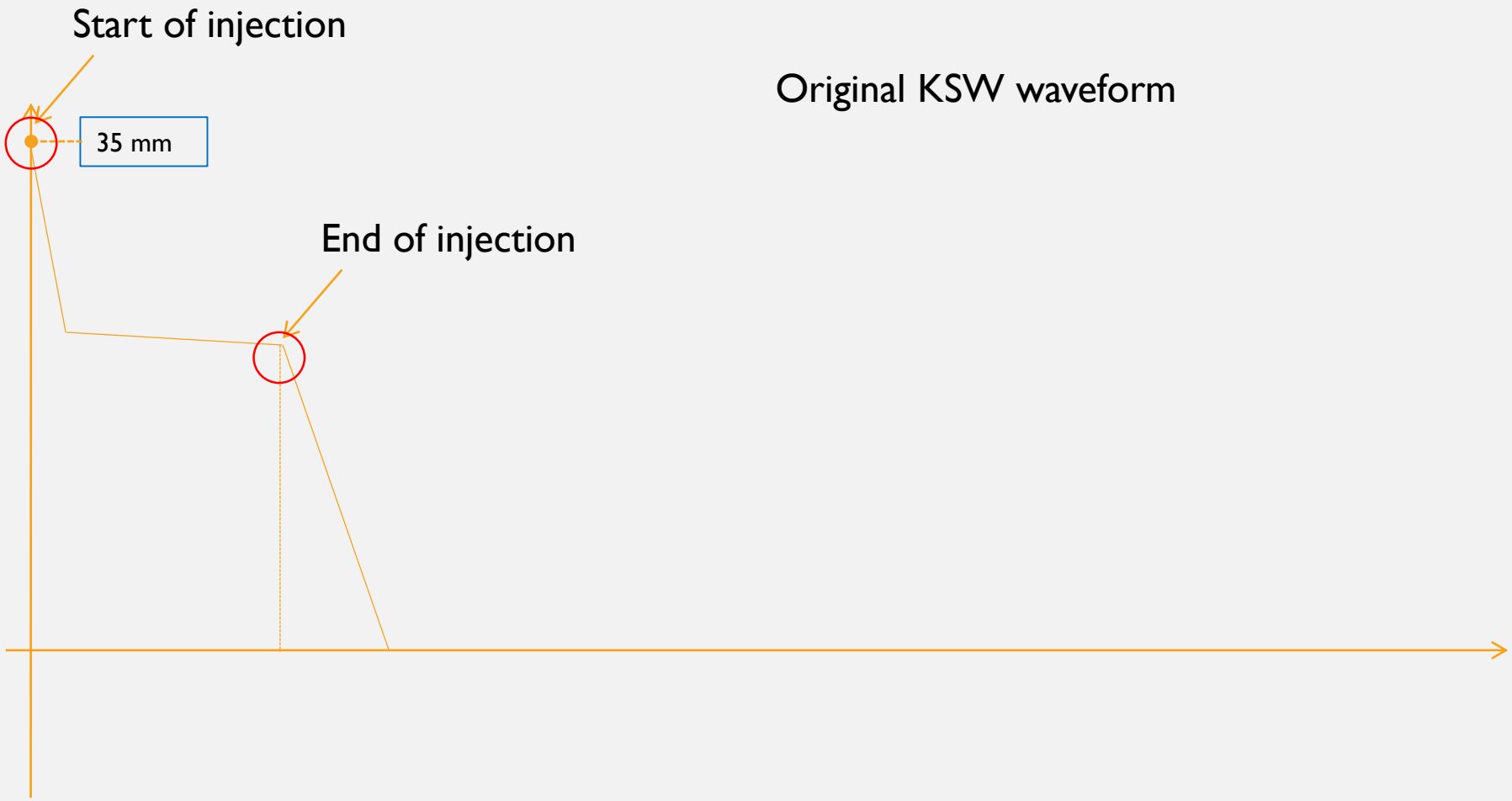
PSB Injection Timing Diagram

October 18, 2013

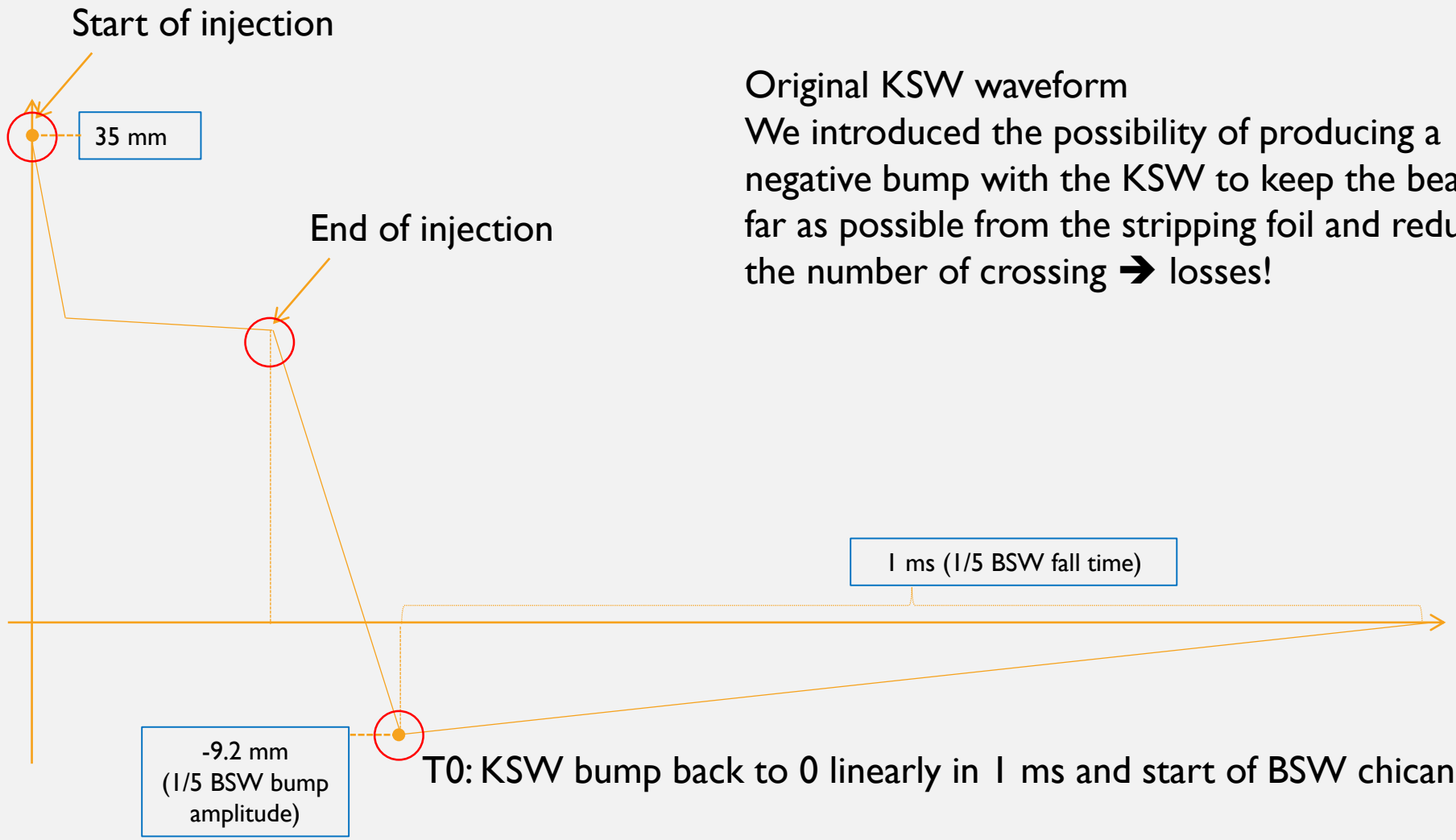


SYNCHRONISATION KSW - BSW

KSW WAVEFORM



KSW WAVEFORM



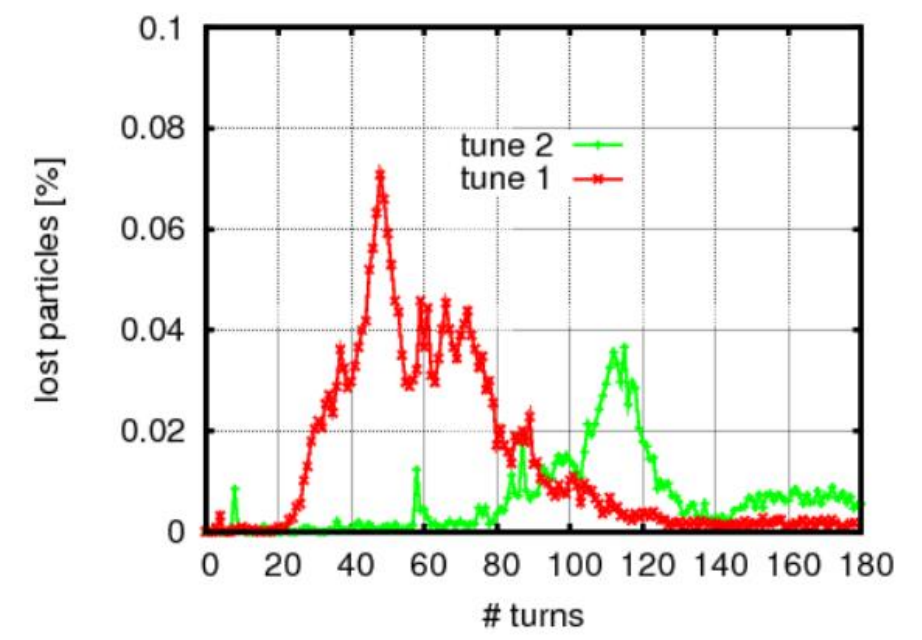
Original KSW waveform
We introduced the possibility of producing a negative bump with the KSW to keep the beam as far as possible from the stripping foil and reduce the number of crossing ➔ losses!

TOTAL LOSS BUDGET ISOLDE BEAMS

Full cycle up to PSB extraction: 5% of total beam

At injection: 2.5% of total beam

Present situation according to simulations (no imperfections included)

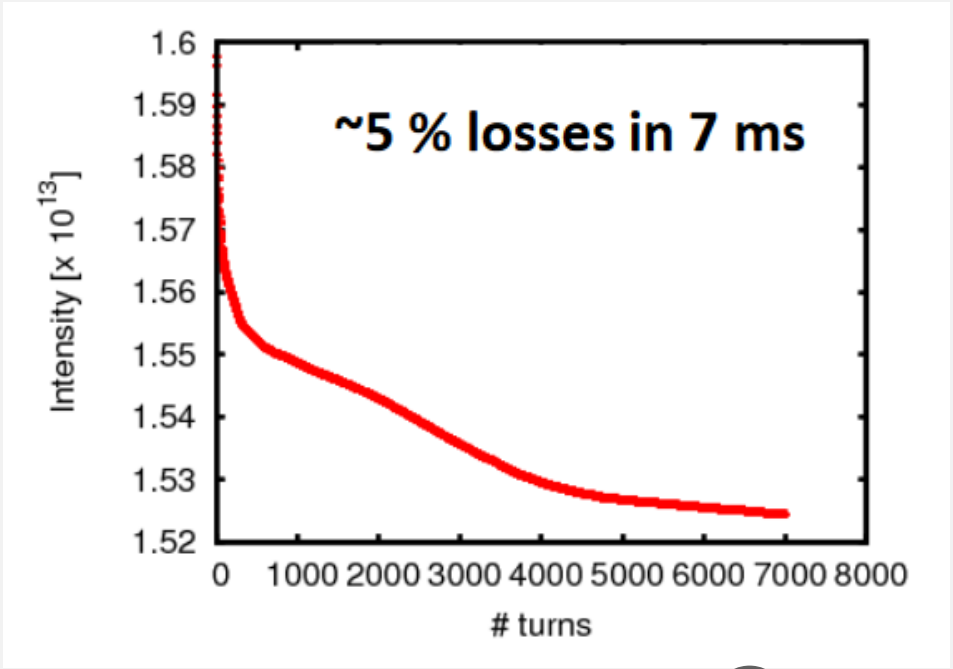


Integrated losses

Turn 120	Turn 180
2.3 %	2.4 %
0.8 %	1.6 %

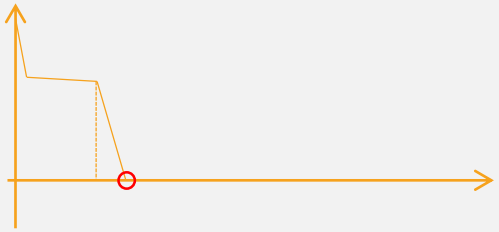
Tune 1: Q_x=4.28, Q_y=4.55
Tune 2: Q_x=4.43, Q_y=4.60

Remark: The total int. losses were ~independent of the tune.



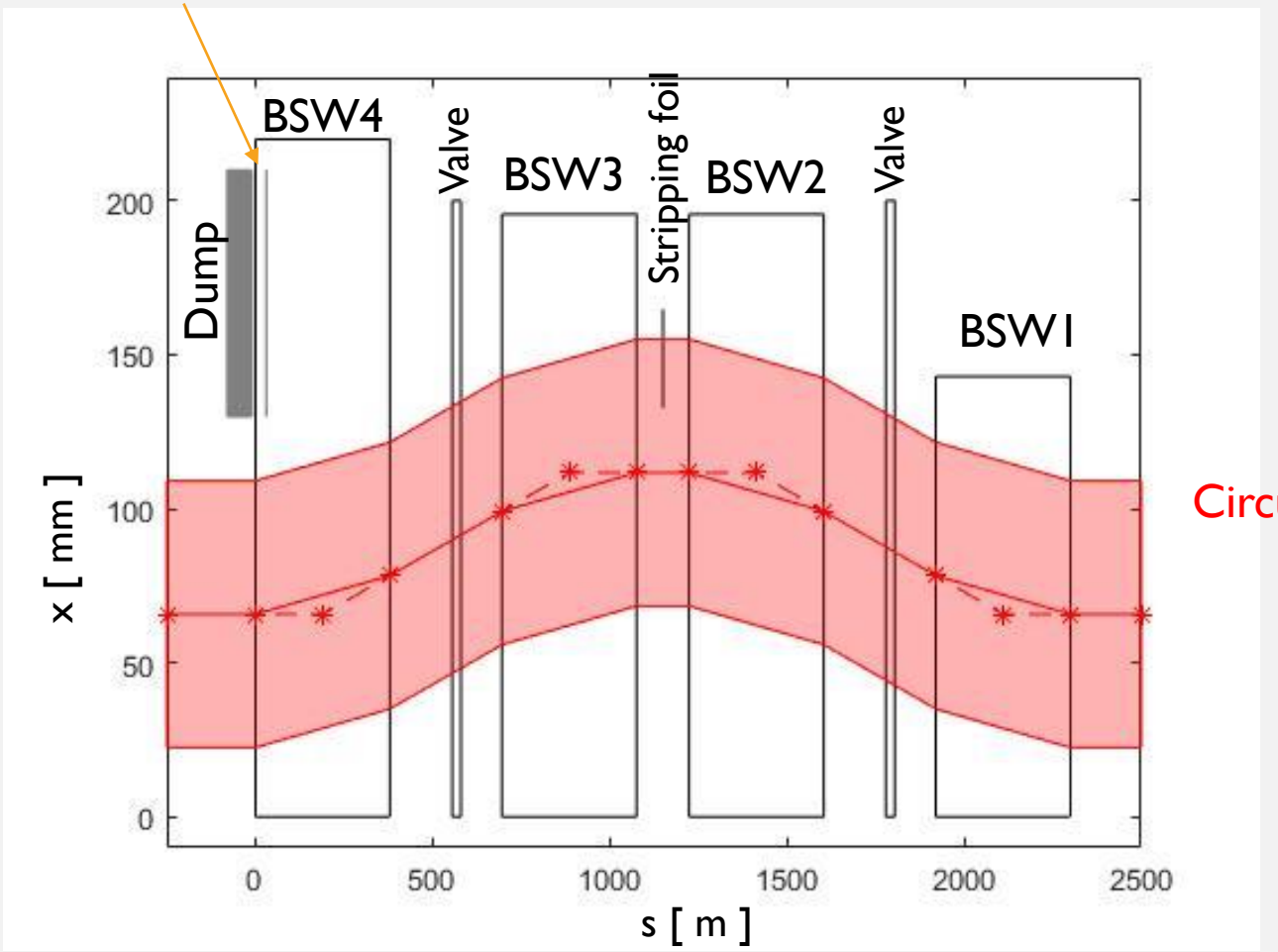
ISOLDE BEAM

ISOLDE beam envelope = +/- 43.3 mm
(3 sigma, 20% beta error, 10 mm mrad normalised emittance, Dp/p = 0.0044, +/-2 mm orbit normalized by beta function)



BSW bump = 45.9 mm
KSW bump = 0 mm

Stripping foil for current measurements



Circulating beam

ISOLDE BEAM

ISOLDE beam envelope = +/- 43.3 mm
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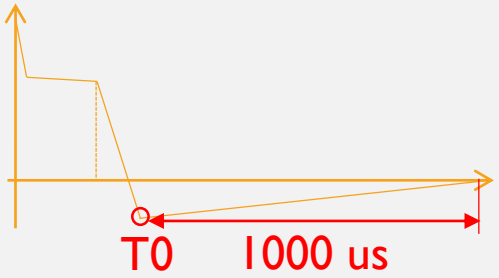
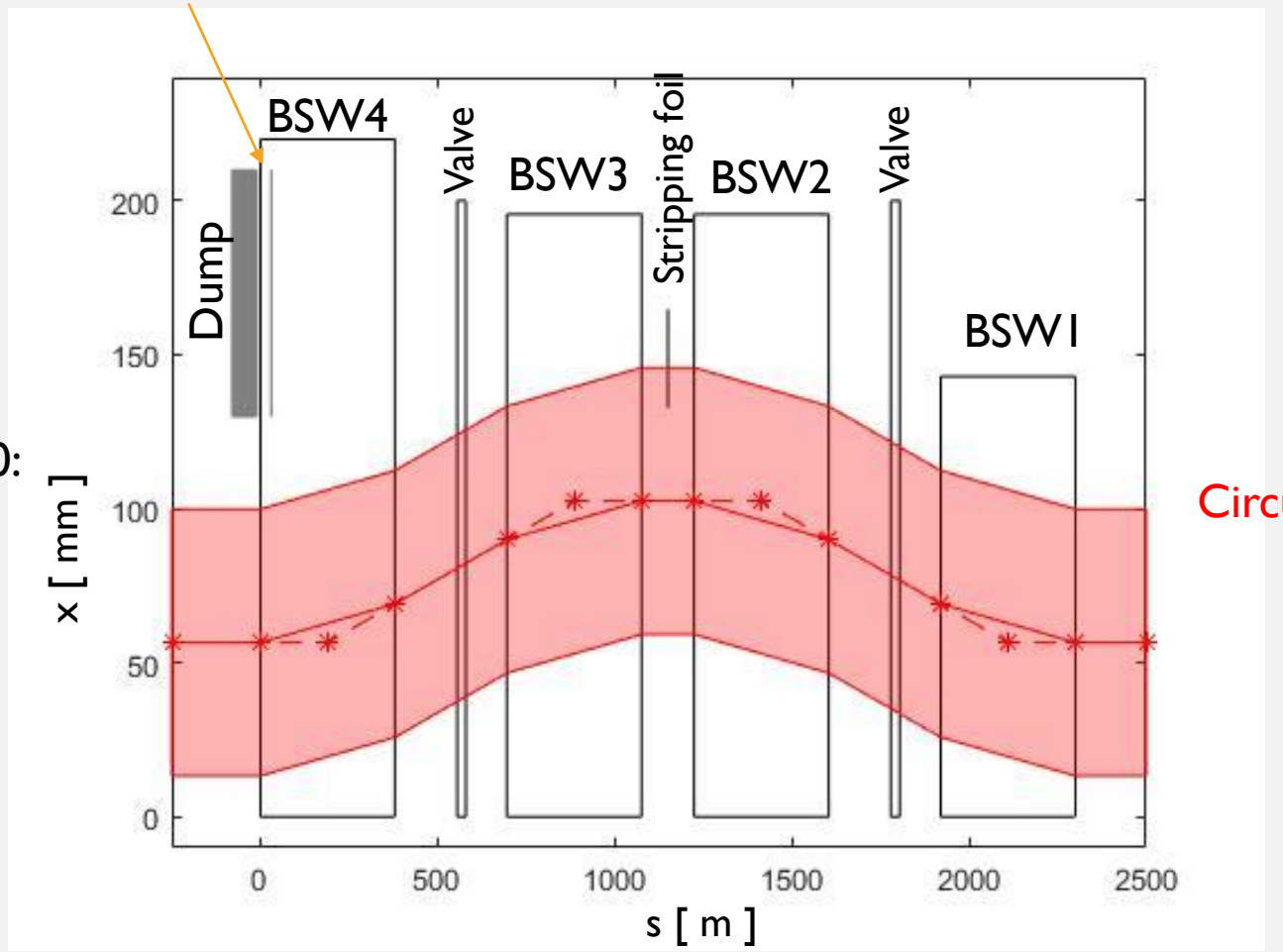


BSW bump = 45.9 mm
KSW bump = -9.2 mm

Stripping foil for current measurements

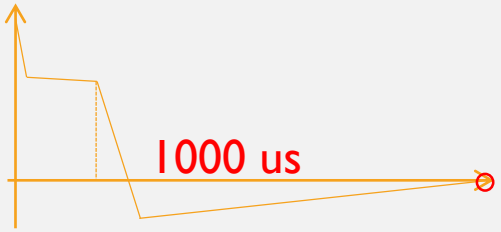


Circulating beam

Total losses over 1000 us from T0:
without negative bump = 0.081%
With negative bump: 0.036%
> X2 loss reduction

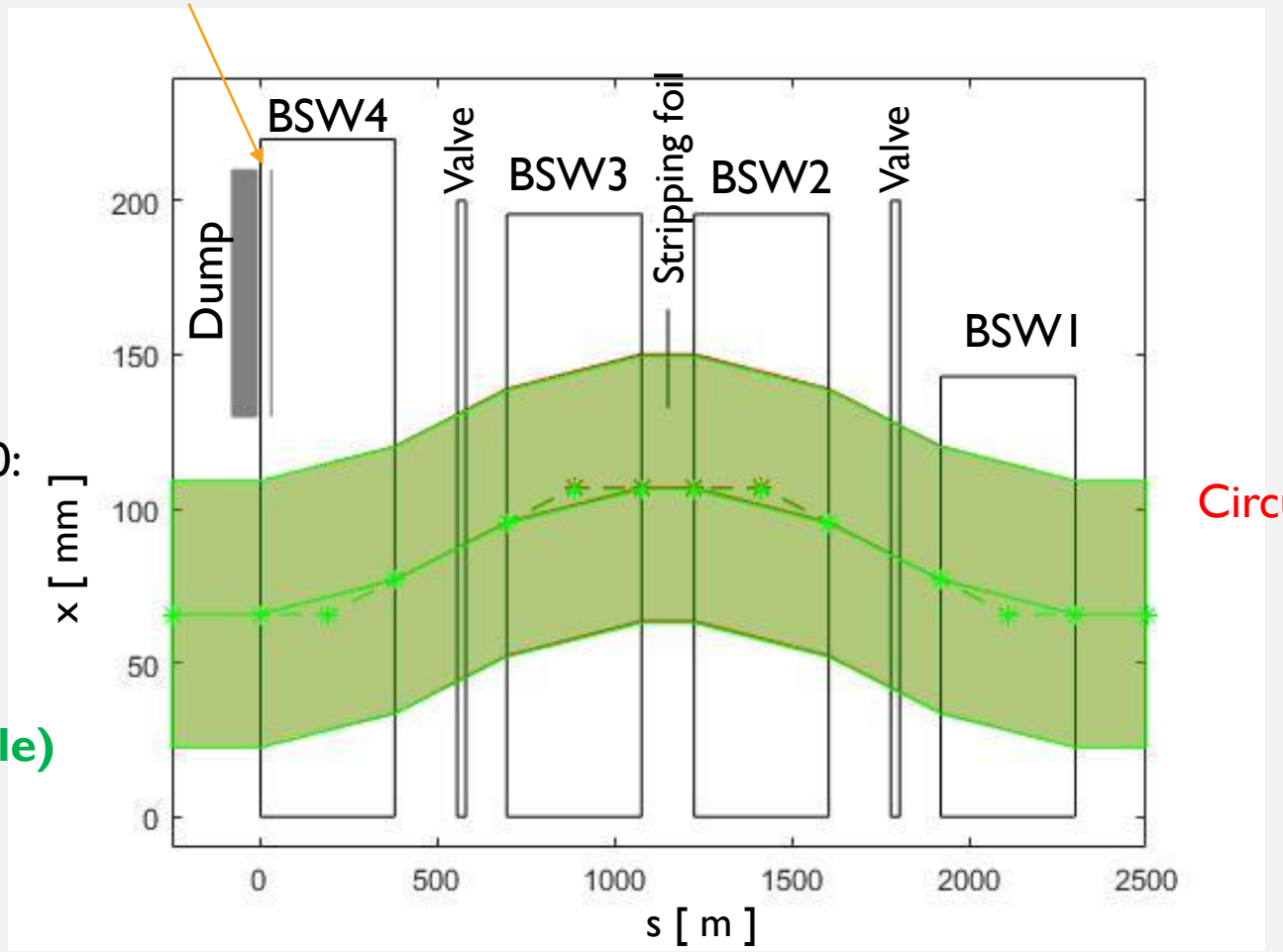
ISOLDE BEAM 100 μS

ISOLDE beam envelope = +/- 43.3 mm
(3 sigma, 20% beta error, 10 mm mrad normalised emittance, Dp/p = 0.0044, +/-2 mm orbit normalized by beta function)



Stripping foil for current measurements

BSW bump = 41.1 mm/40.4 mm
KSW bump = 0mm



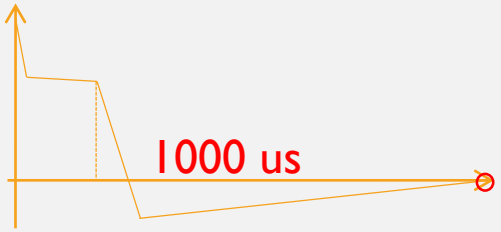
Total losses over 1000 us from T0:
Sync. BSW-KSW: 0.036%
100 us delay BSW-KSW = 0.038%

<10% higher losses (negligible)

Circulating beam

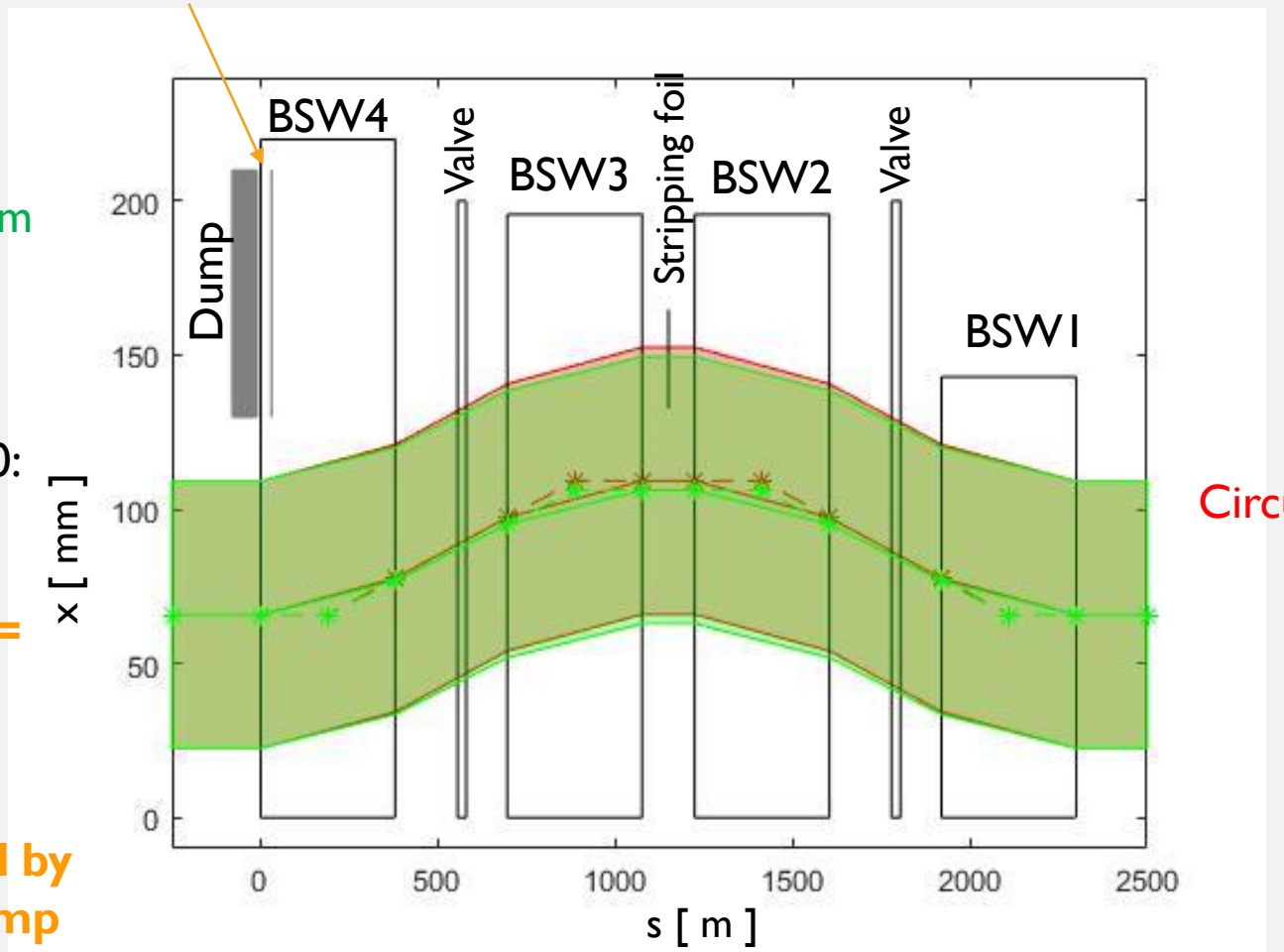
ISOLDE BEAM 500 μS

ISOLDE beam envelope = +/- 43.3 mm
(3 sigma, 20% beta error, 10 mm mrad normalised emittance, Dp/p = 0.0044, +/-2 mm orbit normalized by beta function)



Stripping foil for current measurements

BSW bump = = 43.4 mm/40.4 mm
KSW bump = 0mm



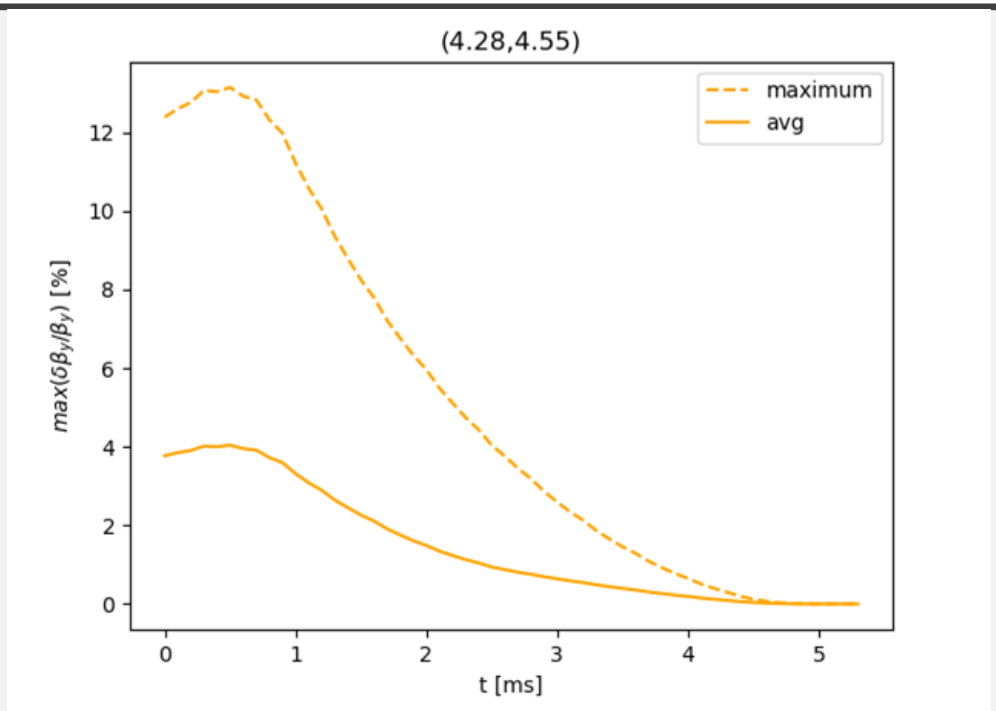
Total losses over 1000 us from T0:
Sync. BSW-KSW: 0.036%
500 us delay BSW-KSW (interlock on R4, R3 and R2) = 0.053%

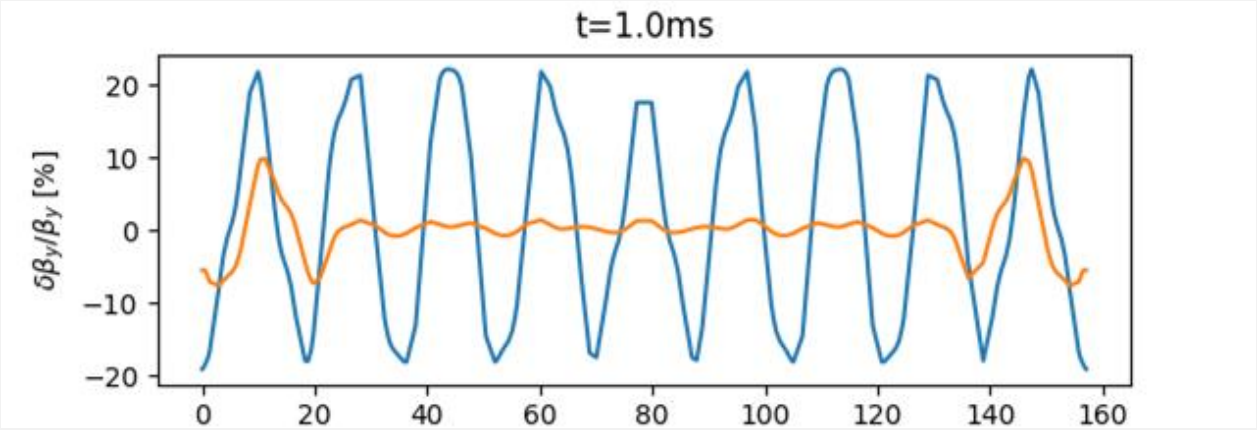
45% higher losses
Lost half of the gain achieved by introducing the negative bump

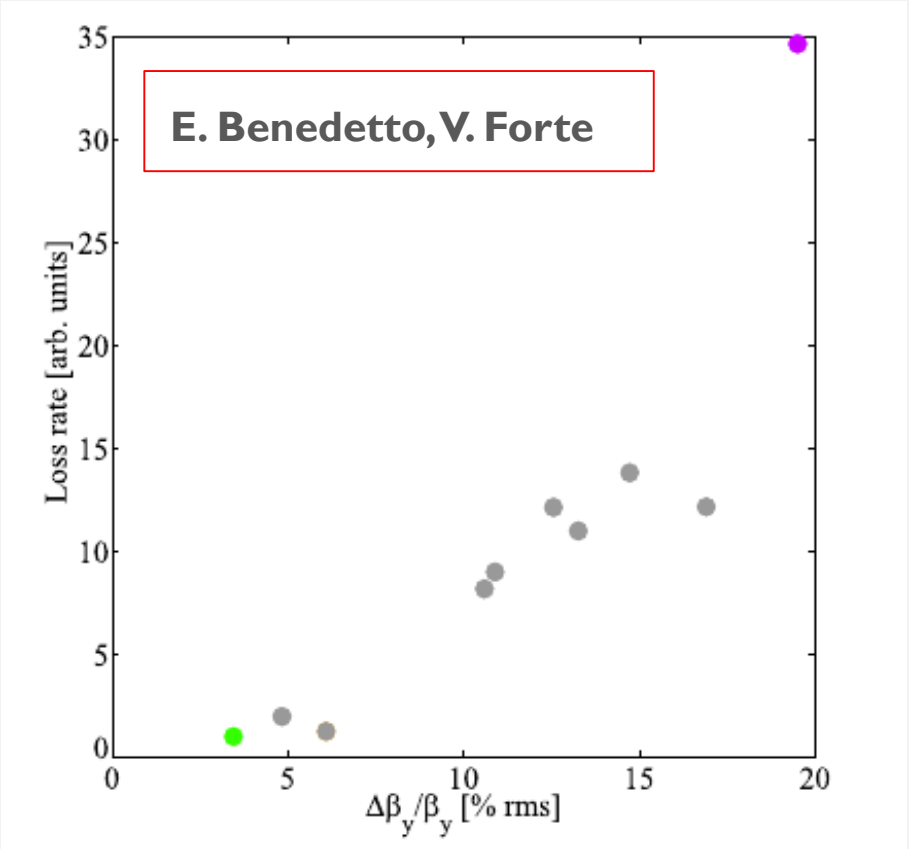
Circulating beam

SYNCHRONISATION BSW – Q-STRIPS

BETA BEATING DURING THE FALL OF THE CHICANE: Q3, Q14



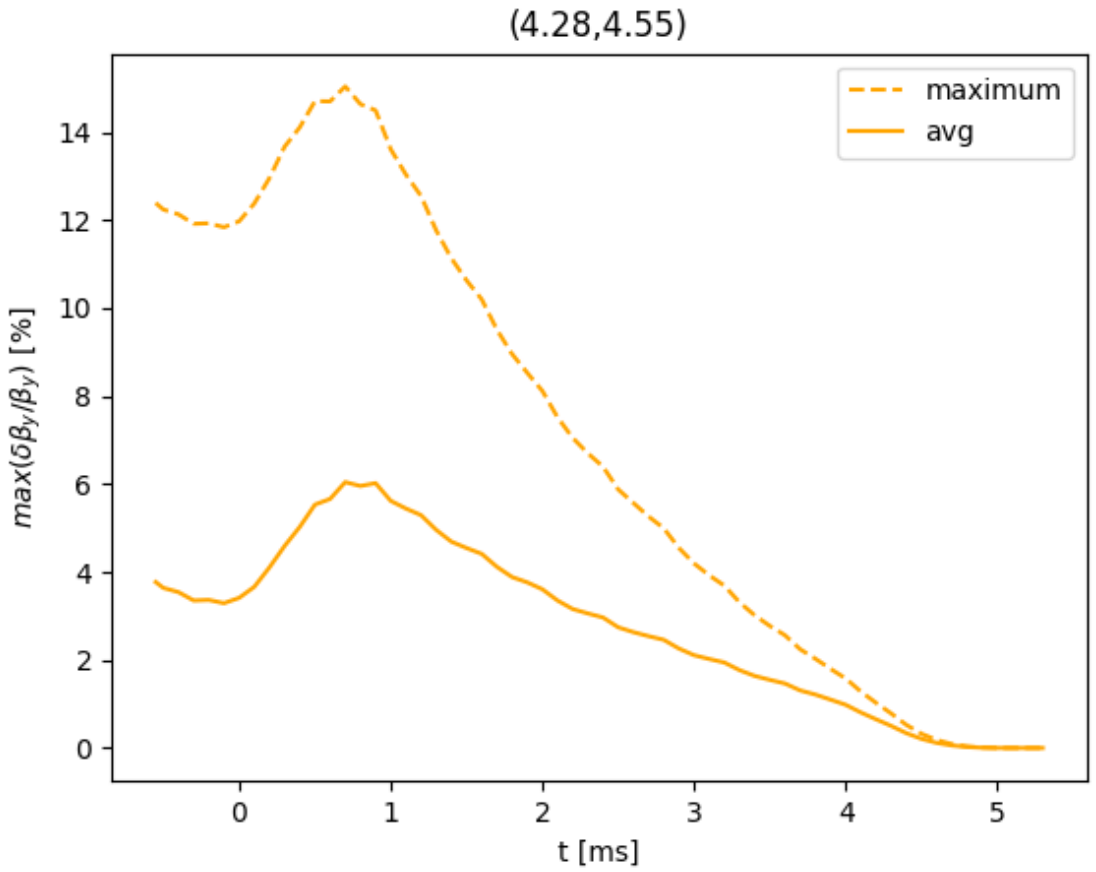


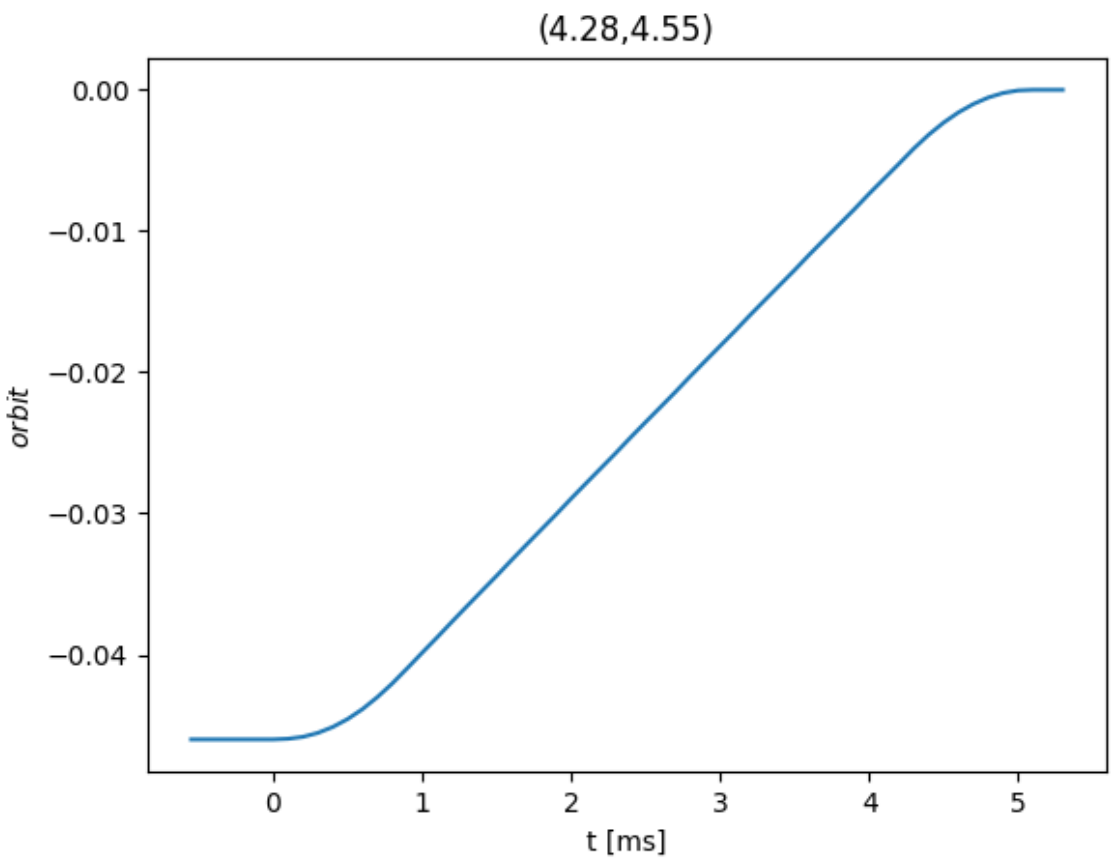


Vertical beta beating versus loss rate

DELAY OF THE BSW BY 550 μS

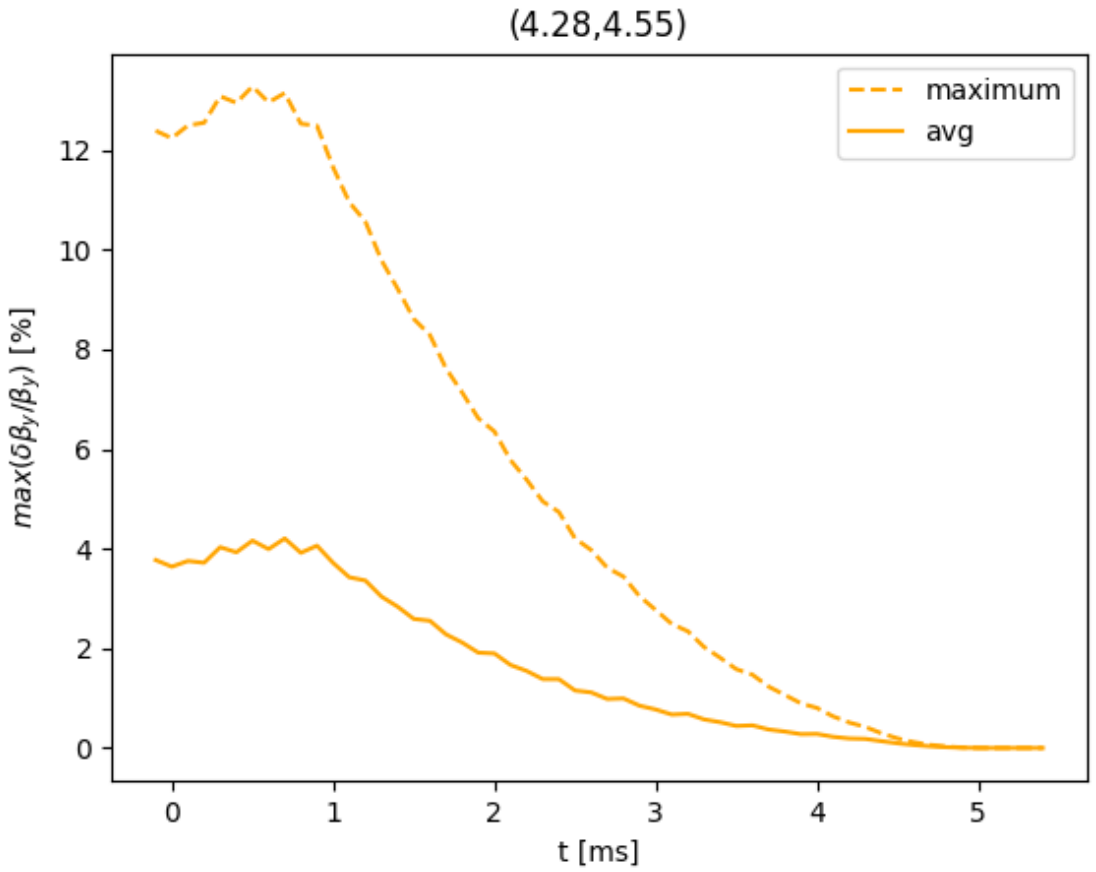
(interlocking of rings 4, 3 and 2) + 100 us jitter

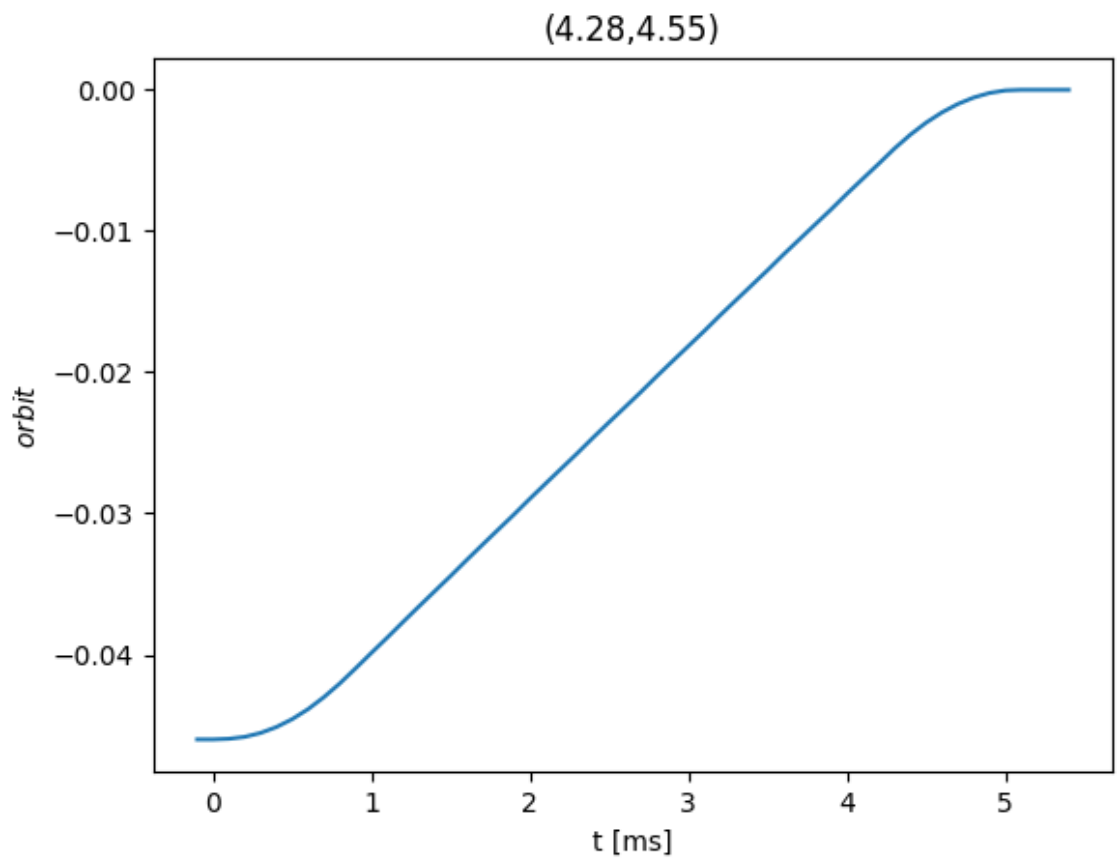




DELAY OF THE BSW BY 100 μS

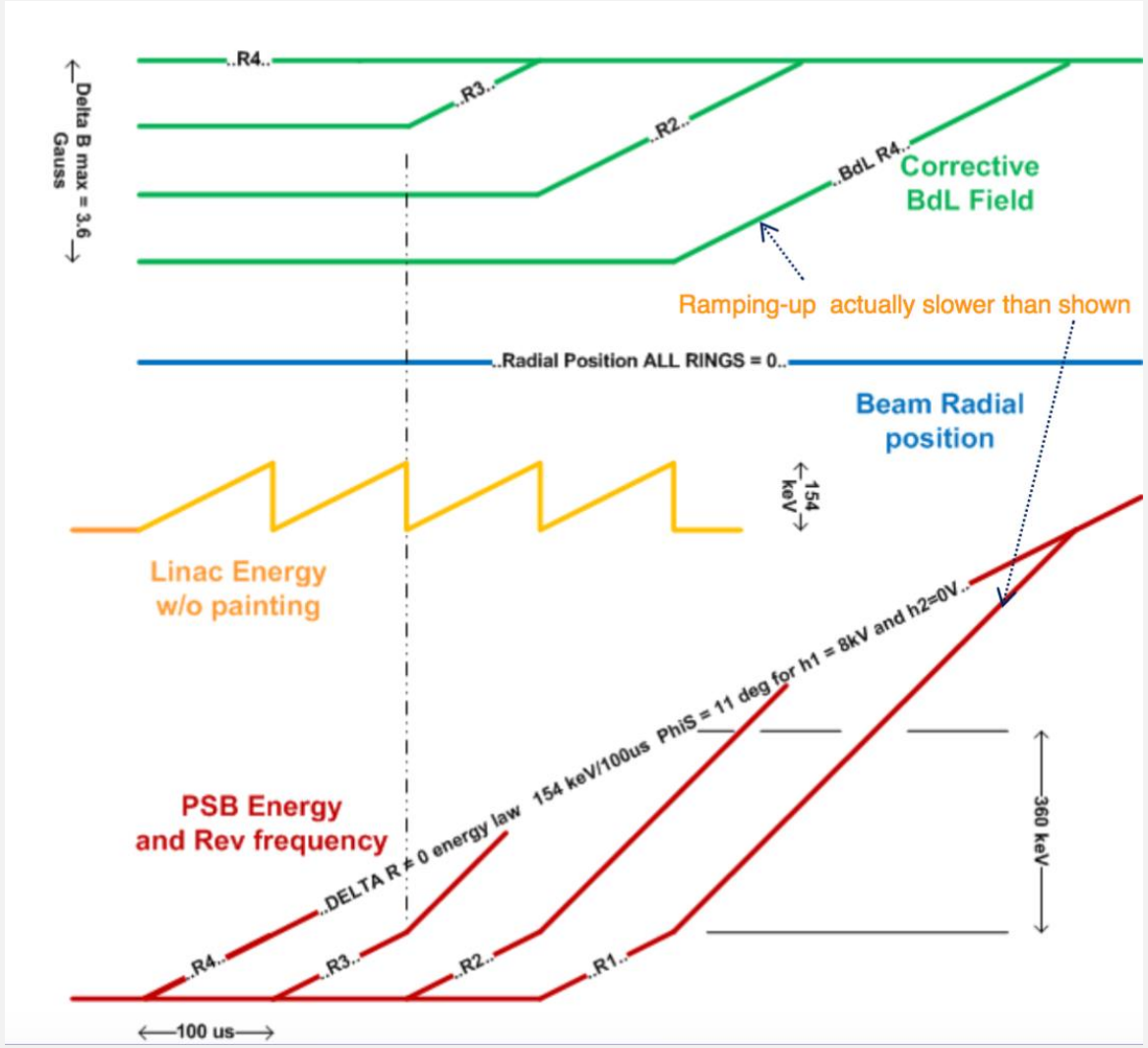
100 us jitter





SYNCHRONISATION BDLS – B-FIELD

BDL CORRECTION



- Injection: R4-R3-R2-R1
- Injection on ramping B-field

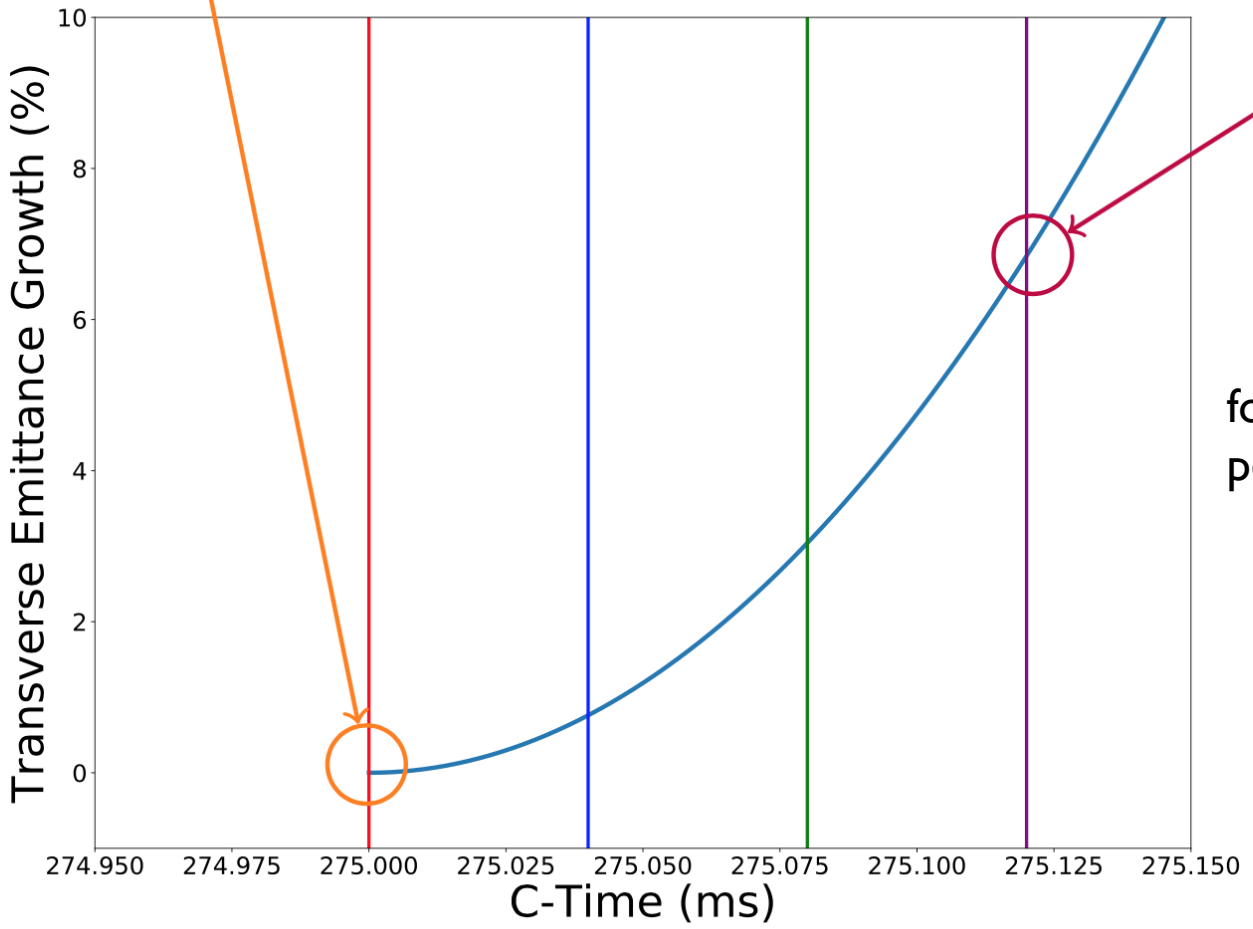
➢ R1 arrives at same energy, but B-field at injection is already higher than for R4 → beam not anymore centred in bucket; also important for longitudinal painting

➢ Bdls act as a trim to reduce the B-field for rings <4 such that each ring sees the same B-field at injection

➢ Amplitude of Bdl correction is a function of total injection duration of all preceding rings

Motivation (LHC beams example)

Without Bdl Ring 4 is energy matched but dispersion will cause increasing emittance growth in subsequent rings up to ≈ 7% in Ring 1

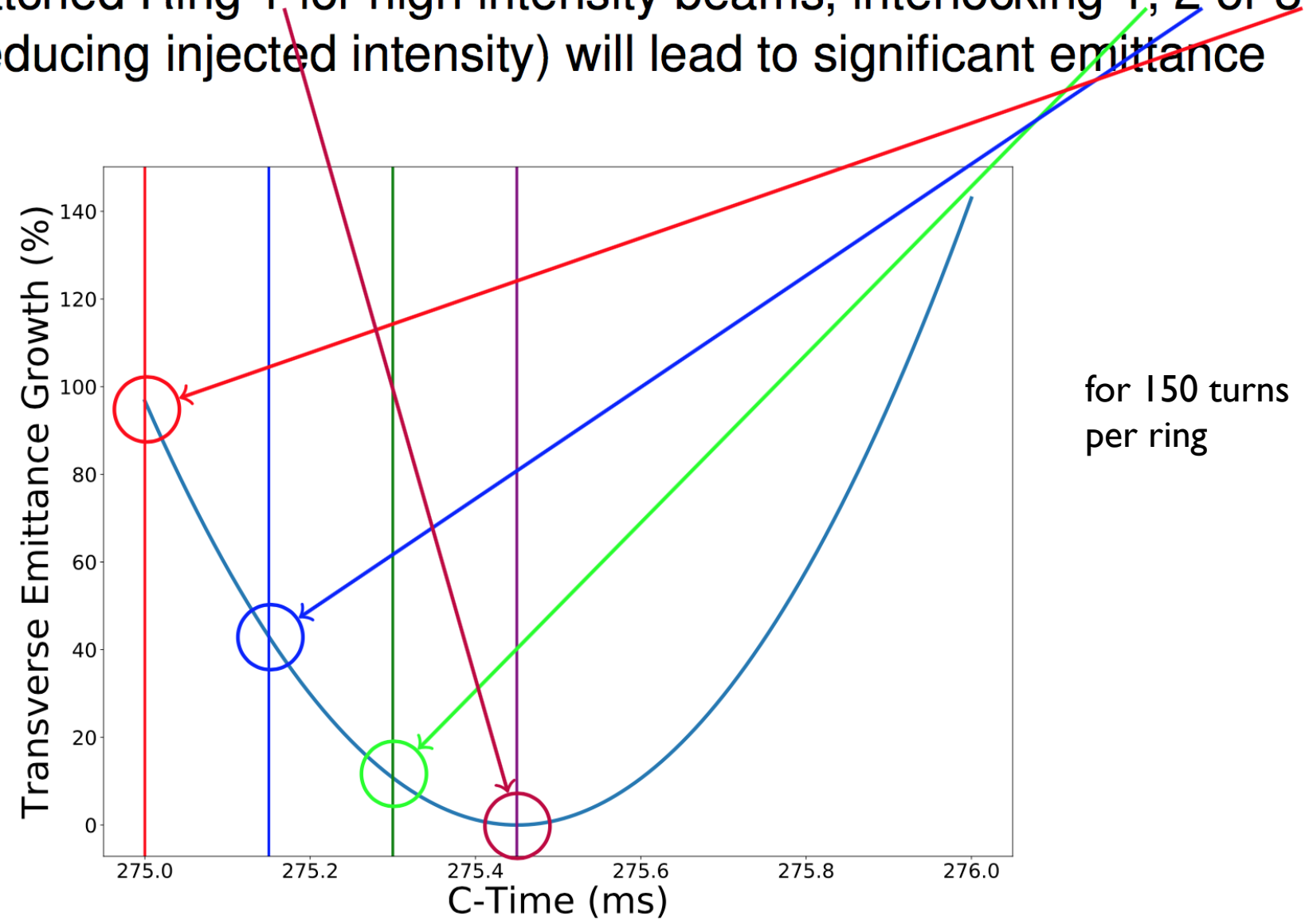


for 40 turns per ring

➢ Bdl current needs to be set from cycle to cycle to correct B-field with changing injection duration to preserve required beam quality

High Intensity Beams

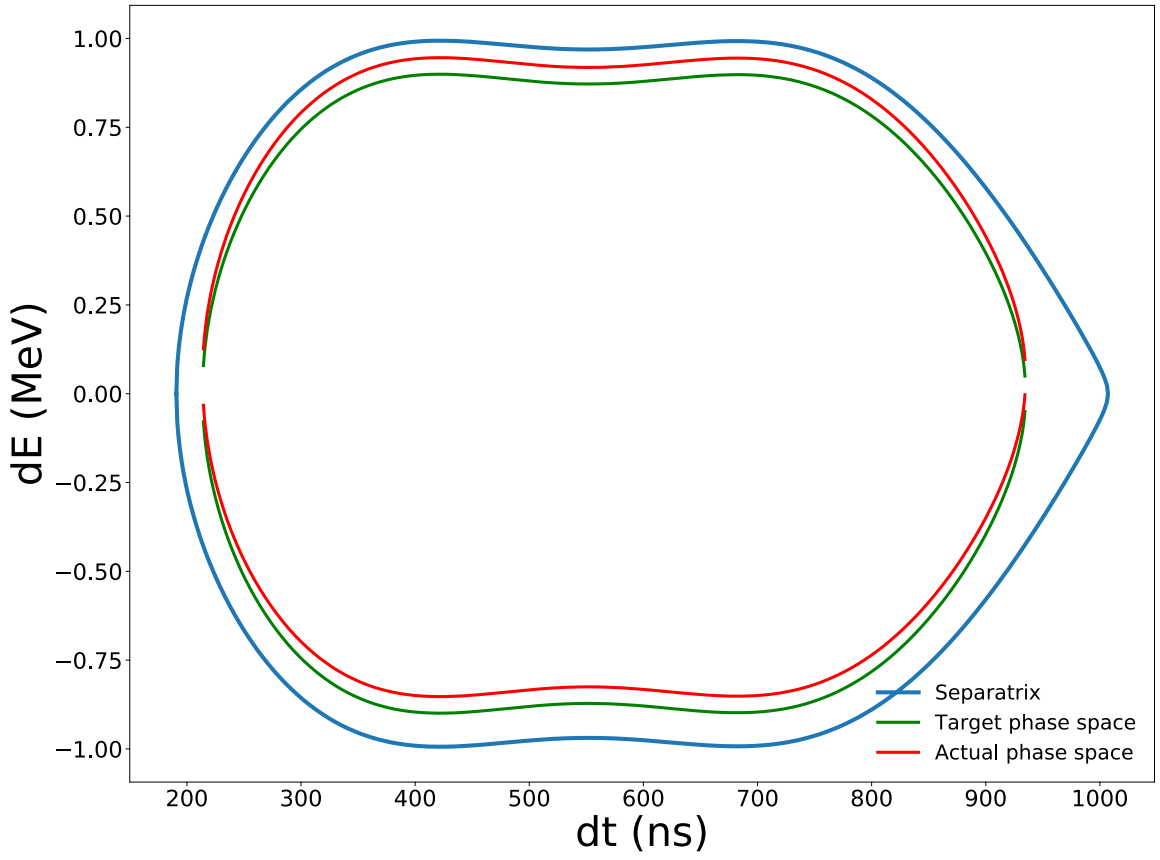
Energy matched Ring 1 for high intensity beams, interlocking 1, 2 or 3 rings (or reducing injected intensity) will lead to significant emittance growth.



for 150 turns per ring

LONGITUDINAL PAINTING

- Aim to fill the PSB bucket as uniformly as possible at ~80% filling factor
- If not synchronised with B-field, the painted beam will not anymore be correctly centred in the bucket
  - Longitudinal emittance blow-up
  - Possibly losses



SUMMARY SYNCHRONISATION STUDIES

- Simulations were redone by colleagues from TE-ABT, BE-ABP and BE-RF to evaluate implications of not using fast timings for the TE-EPC power converters (BSWs, Bdls) → synchronisation uncertainties of max. 100 us or max. 550 us in the worst case of simultaneous interlocks in rings 4,3 and 2 (3x150 + 100 us).
- **Synchronisation BSWs - KSWs**:
  - ~45% **higher losses at injection** in case of 500 us synchronisation error between KSWs and BSWs
  - This would mean losing half of the gain achieved by introducing a negative bump in the KSW function after injection
- **Synchronisation BSWs – Q-strips**:
  - **Increased vertical beta beating** → could lead to **increased losses**, which seem negligible with today's simulations, but the effect is difficult to quantify
- **Synchronisation Bdls – B-field at injection**:
  - Up to ~7% **longitudinal emittance blow-up** with incorrect Bdl current (in case of interlock on 3 rings)
  - **For LHC beams: Horizontal emittance growth around 3% for 100 us jitter**
  - **Significant (and variable) horizontal emittance growth for large intensity beams → losses?**
  - **Longitudinal painting** (to reduce space-charge effects): Would impose **limitations on the longitudinal emittance we can safely inject (losses) + long. emittance blow-up**

CONCLUDING REMARKS

- **Very complex new injection scheme with Linac4** that requires synchronisation of various equipment in Linac4 and PSB
- TE-ABT and BE-RF equipment have been designed to allow for highest performance related to the injection process
- Despite a lot of effort was put into trying to understand the repercussions of synchronisation errors, it is **very difficult to predict the final effects** in terms of beam losses, emittance growth, intensity limits and limitations to longitudinal painting (no higher order effects included etc.)
- **BE-OP would highly recommend that affected TE-EPC equipment (Bdls, QDE3/14 and BSWs) will accept fast external timings in order not to cancel optimisations already implemented in other equipment and to eat up operational (unknown) margins**