CERN PS Multi Turn Extraction

Mitigation measures for extraction losses

M. Giovannozzi, C. Hernalsteens

- Dummy septum in SS15
- Extraction with electrostatic septum in SS31
- Faster kickers
- Outlook

Acknowledgements: G. Arduini, H. Bartosik, D. Bodart, R. Brown, G. Dumont, S. Gilardoni, V. Mertens, M. Newman, Y. Papaphilippou, S. Roesler.

Introduction

- General criteria
  - Minimise the changes to be made to the machine
    - To reduce cost
    - To allow quick tests with beams
  - In a second stage deeper revisions might be studied whenever these would bring a real added value.
- These solutions have been discussed and endorsed by PSRWG.

CERN PS MULTI TURN EXTRACTION

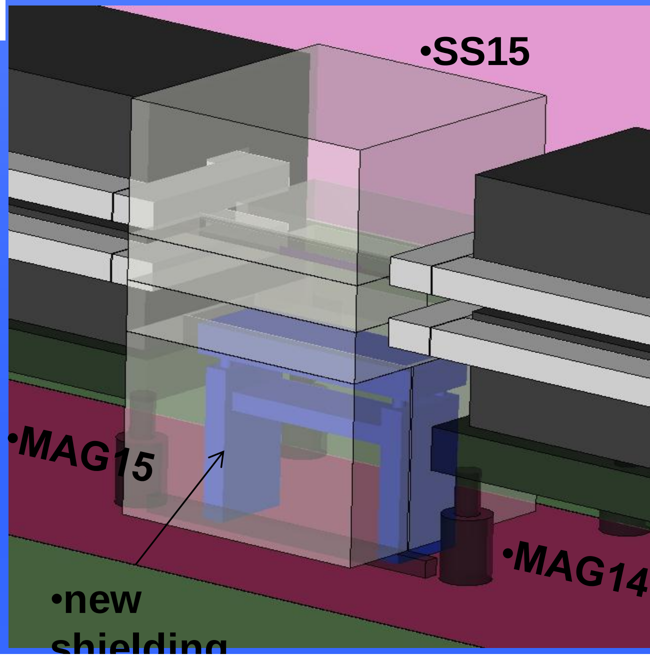
Dummy septum in SS15: generalities

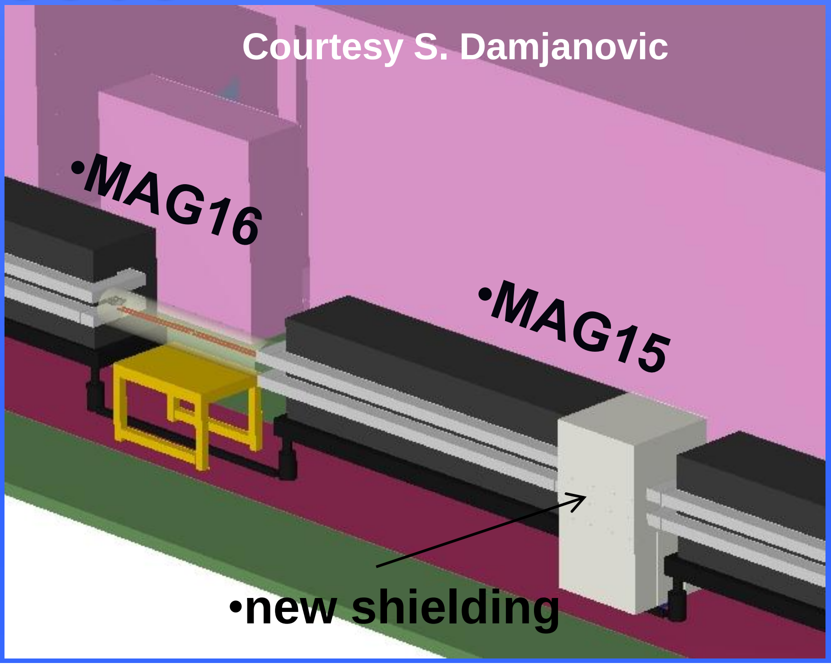
- Impact on losses studied by RP
- Allows concentrating losses in a well-shielded location (should this require reviewing the planned shielding increase on SEH16?)
- In principle, it provides a reduction acceptable for RP (factor of 10).
- Improvement of the radiation released outside the tunnel due to the corridor in front of the tunnel
- Linac3 radiation field to be revised
- New points considered here:
  - Re-location of hardware (DHZ15, gamma-jump quadrupole)
  - Trajectories of extracted beams in SS15: is it possible to find a position for the dummy septum?

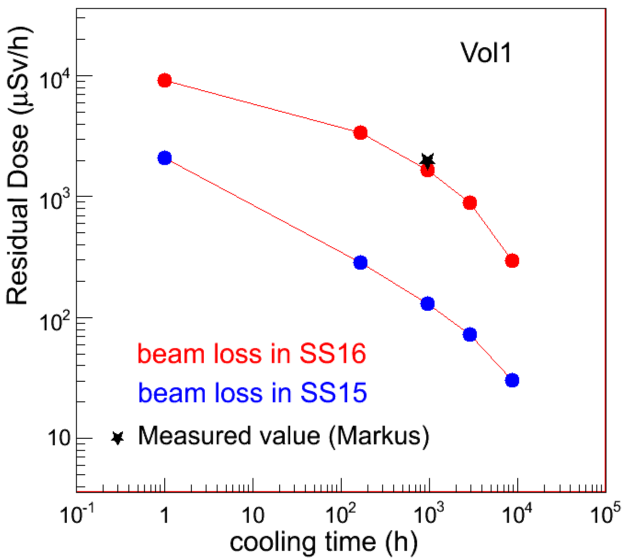
Original proposal by Brennan

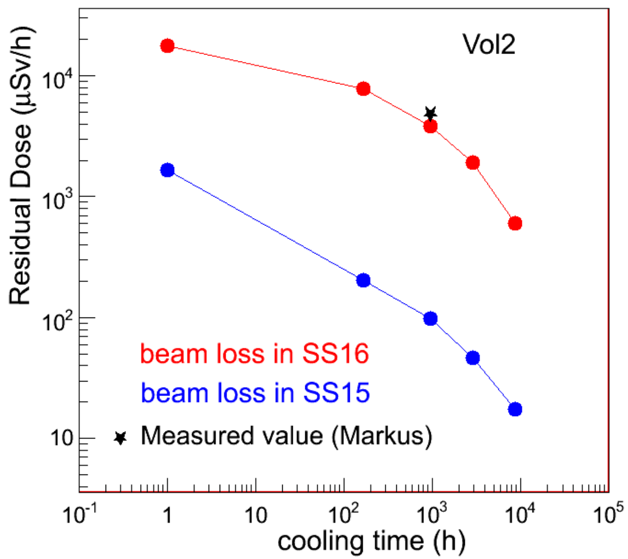
CERN PS MULTI TURN EXTRACTION

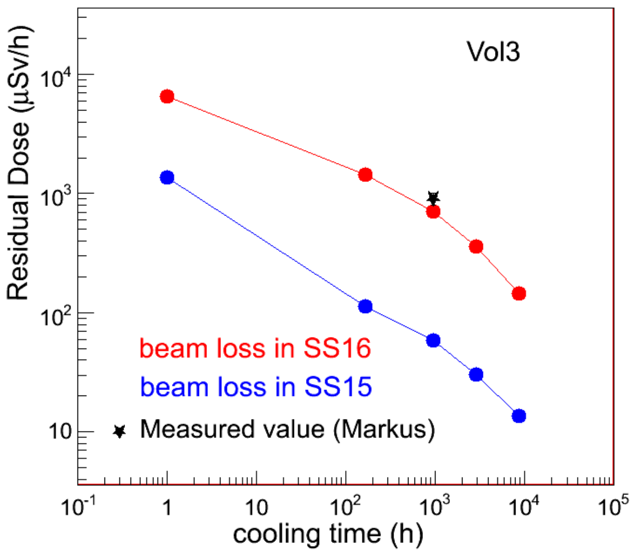
Dummy septum in SS15: impact on losses







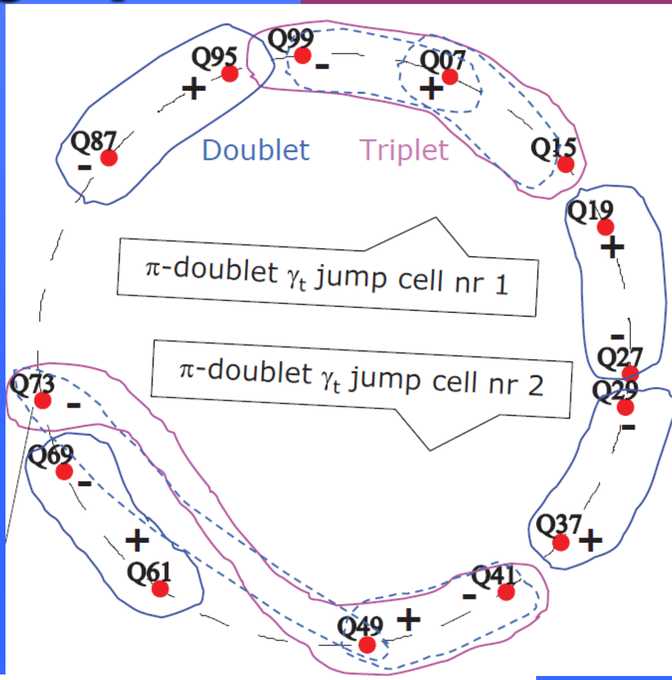




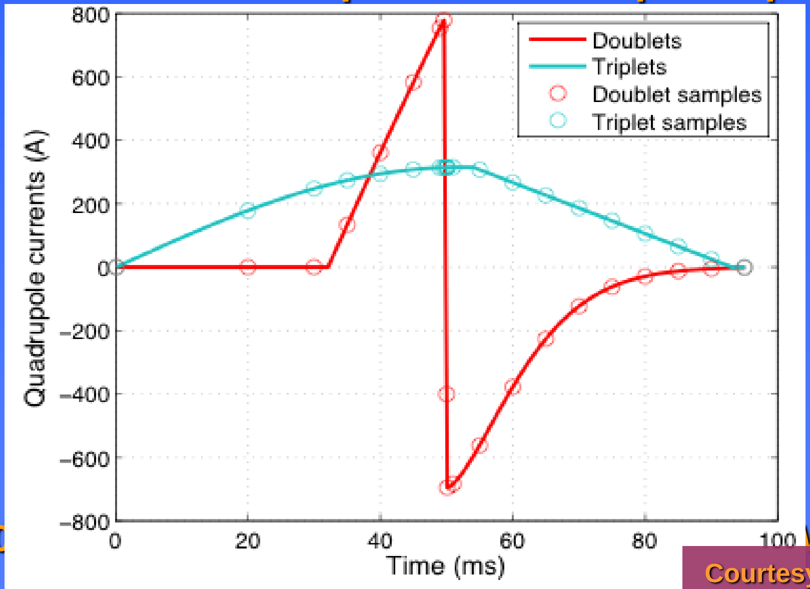
CERN PS MULTI TURN EXTRACTION

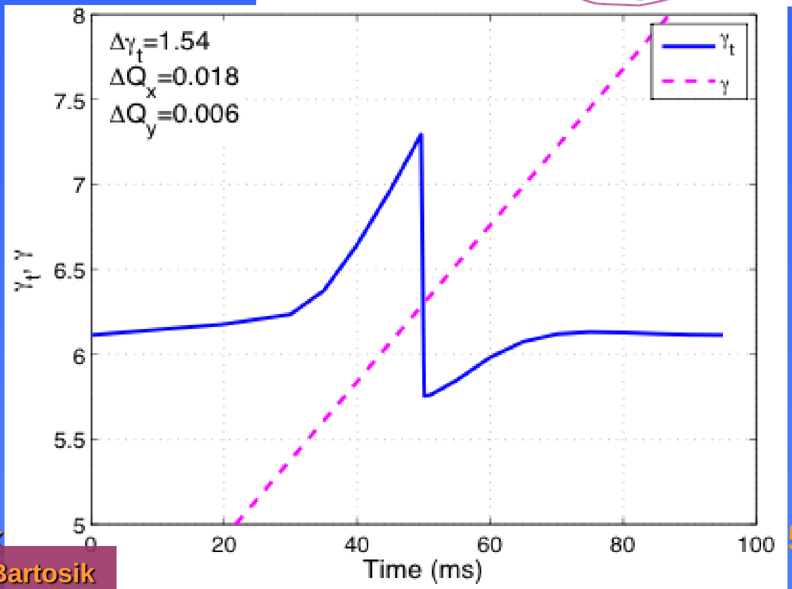
Dummy septum in SS15: relocation of hardware - I

Current layout of γ-jump quadrupoles



- Quadrupole of the triplet (SS99/7/15) should be relocated.
- Perfect symmetry already broken by second triplet due to SMH57.
- Criteria:
  - Currents of γ-jump quadrupoles are sampled
  - For each sample beam envelope is computed
  - Largest beam envelope is stored
  - Iterate for each possible new quadrupole location





Courtesy H. Bartosik

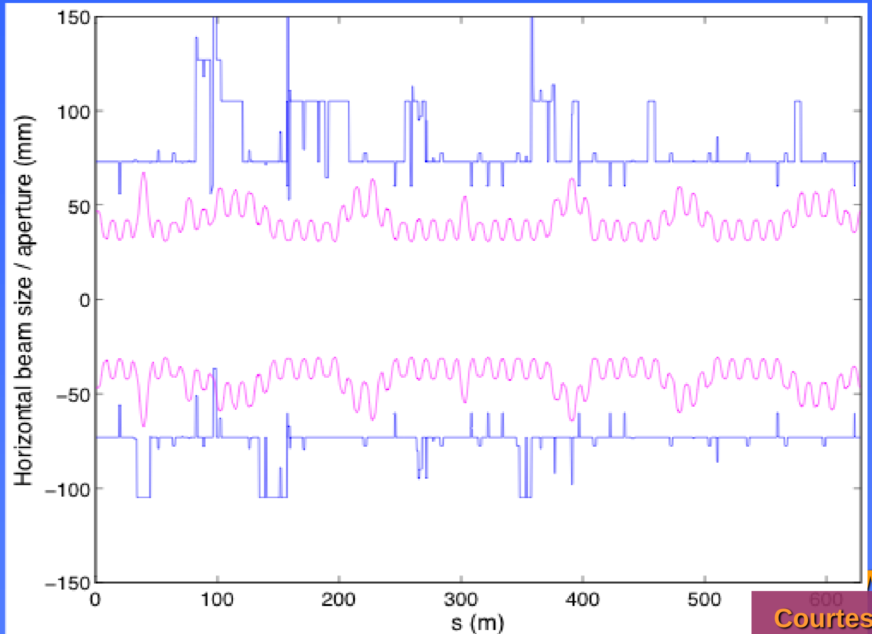
Dummy septum in SS15: relocation of hardware - II

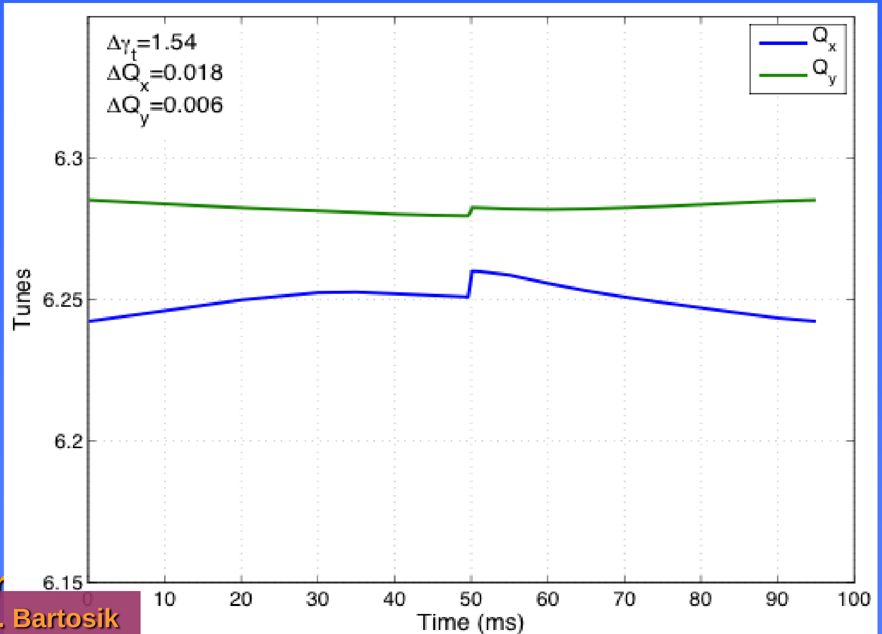
- **Beam parameters used for the simulation**
  - Physical emittance at jump: $\varepsilon_x=\varepsilon_y=4.03$ µm*
  - RMS momentum spread: $\delta p=3.5e\text{-}3$
- **Beam envelope is calculated as**

$$a_x = x \pm \sqrt{N_{\sigma t}^2 \beta_x \epsilon_x + N_{\sigma l}^2 \delta p^2 D_x^2}$$

  - $N_{\sigma t}=3$, $N_{\sigma l}=2$*
  - ε_x changed during gamma jump simulation according to $1/\beta\gamma$
- **Present layout provides $\Delta\gamma_t=1.54$ with $\Delta Q<0.02$**

* As in S. Aumon, EPAC08

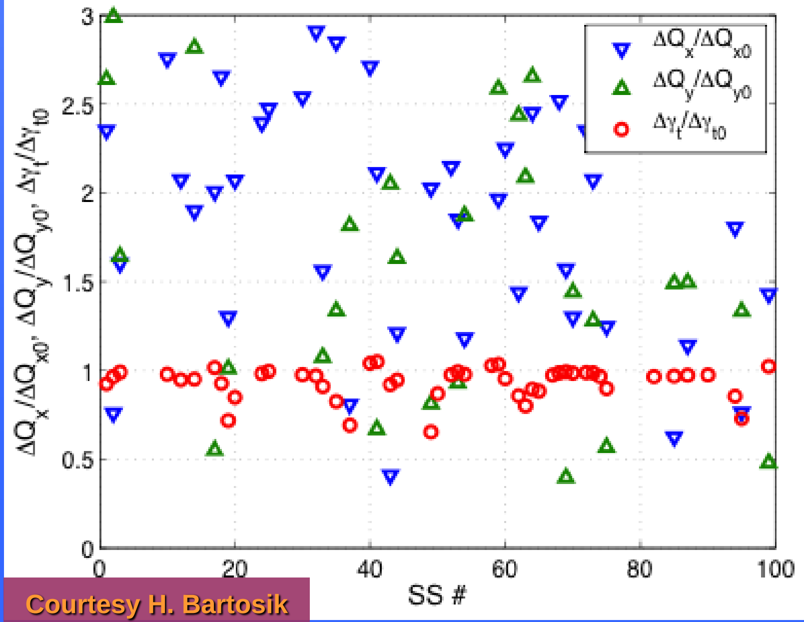




Courtesy H. Bartosik

Dummy septum in SS15: relocation of hardware - III

- From simulation results, retained SS:
  - 54, 59, 70, 85, 99
- SS99 seems the best candidate:
  - Enough space for γ-jump quadrupole
  - The triplet will be converted into a doublet
  - $\Delta\gamma_t$=1.58, ΔQ ~ 0.025
  - Aperture or tune excursion may be optimized



Courtesy H. Bartosik

- Proposal (checked and OK by R. Brown and D. Bodart):
  - Install a quadrupole in SS99 during next winter TS
  - Connect quadrupole for special tests and assess performance

- NB: in current simulations the gradient keeps the same sign as in the current configuration. Removing this constraints might provide additional SS.

CERN PS Multi Turn Extraction

Dummy septum in SS15: relocation of hardware - IV

- **DHZ15 has multiple functions:**
  - **All beams:**
    - **correction of the closed orbit distortion at high energy. It could be moved by π or 2π away.**
    - **It is also used to correct the non-closure of the slow bump, but for this there are enough free parameters in the system to achieve the same result differently.**
  - **MTE:**
    - **generation of the slow bump around SMH16. Slow bump have been re-computed without it.**

Re-location of DH15 does not seem to be critical!

CERN PS MULTI TURN EXTRACTION

Dummy septum in SS15: relocation of hardware - V

L = 249 mm

	Straight section	Device installed	Used for
π	PS23	SEH23	East Hall extraction
2π	PS31	SEH31	CT
π	PS39	Sext. and oct.	MTE
2π	PS47	Internal dump	All beams
π	PS55	Sext. and oct.	MTE
2π	PS63	Mostly empty but East Hall line just behind	
π	PS71	KFA71	Fast extraction
2π	PS79	KFA79	Fast extraction
π	PS87	QND87 and QSE87	Tune
2π	PS95	WCM and Q doublet	Tune
[π]	PS02	Mostly empty, should check the exact phase	
π	PS03	Empty (WCM)	~530mm free space
[2π]	PS10	Empty, should check the exact phase advance	

Dummy septum in SS15: relocation of hardware - V

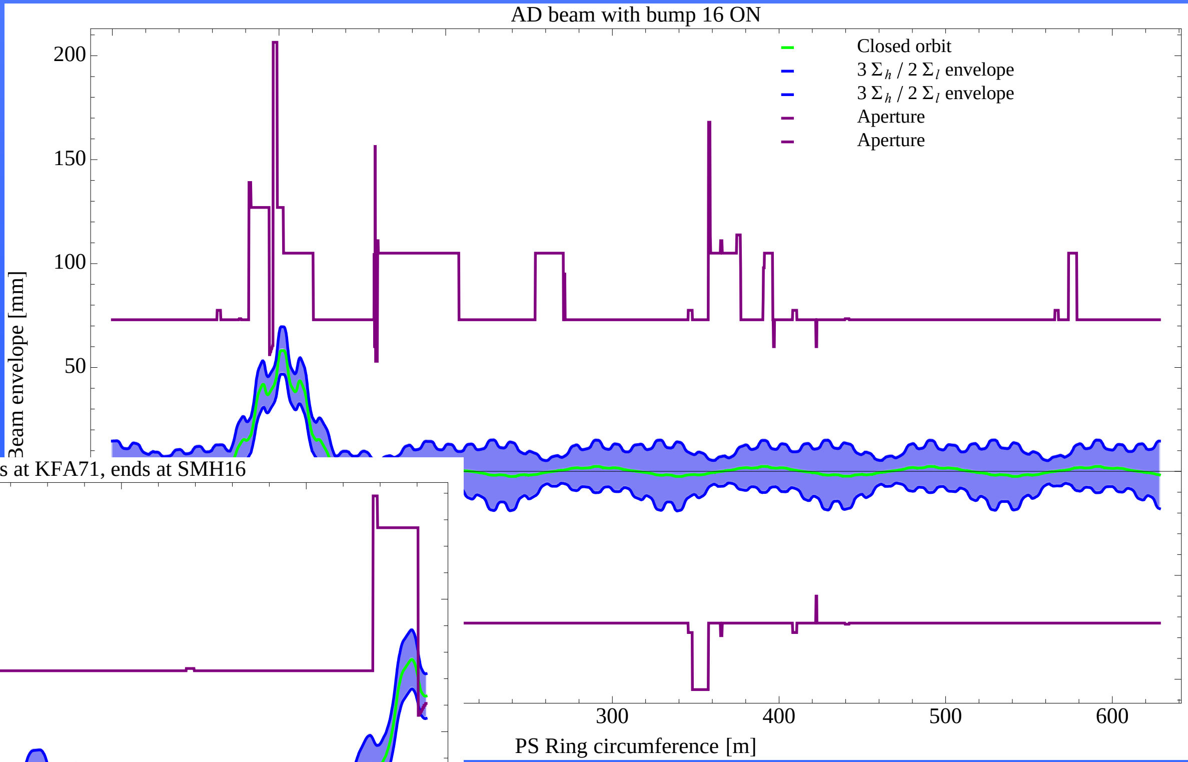
SS03 seems to be a very good candidate

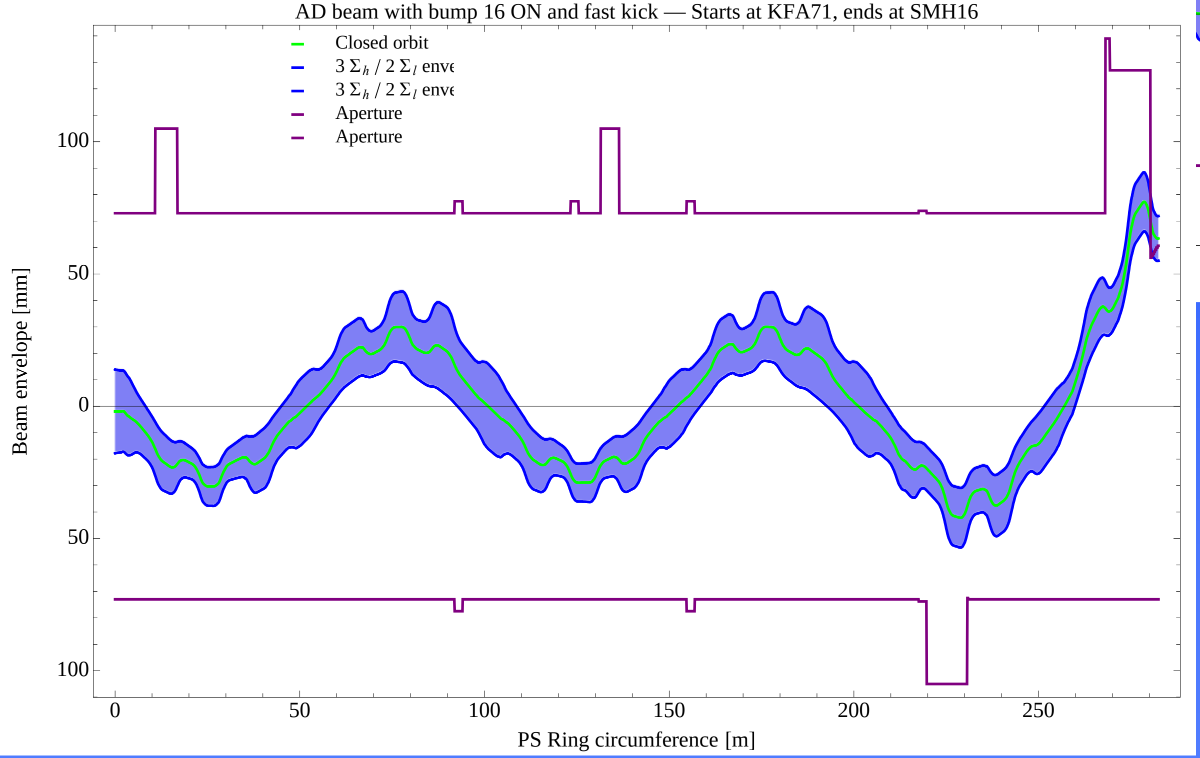
Dummy septum in SS15: extraction conditions - I

- Beams to be considered
  - MTE
  - All fast extracted beams:
    - AD
    - TOF
    - LHC
- Trajectories with
  - Slow bump (before extraction)
  - Fast bump (last turn before extraction)

Dummy septum in SS15: extraction conditions - II

Example: AD beam

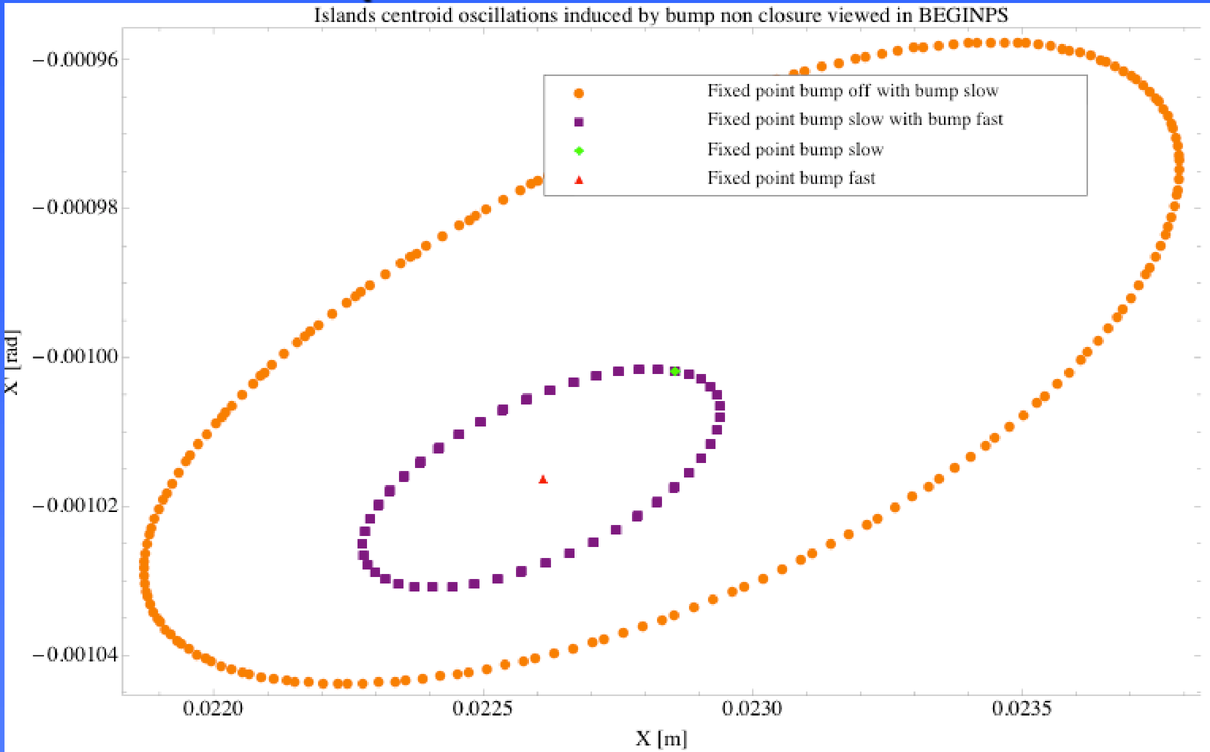




Dummy septum in SS15: extraction conditions - III

- MTE:
  - Considered: 1% error on bumpers and kickers. This was added to the envelope estimate
  - No particular optimisation performed, yet.
  - Kicker strength at maximum (but it could be optimised)

Element	Needed	Maximum
KFA13	~ 80 KV	80 KV
KFA21	~ 80 KV	80 KV
BFA09	0.1 mrad	0.5 mrad

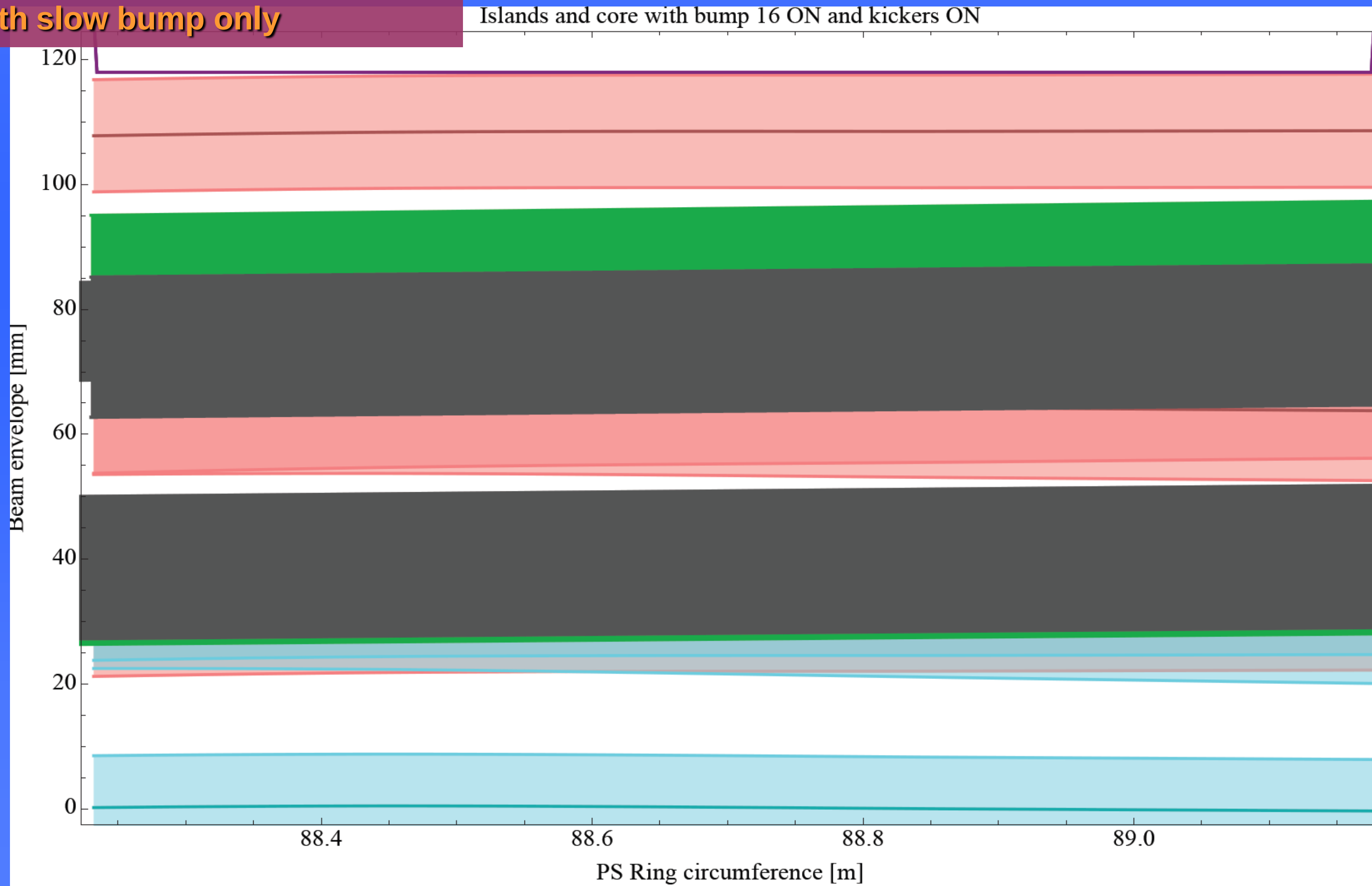


Dummy septum in SS15: extraction conditions - IV

CERN PS MULTI TURN EXTRACTION

- Green is TOF
- Black is the maximum[LHC, AD]
- Red : islands with fast bump (and slow bump)
- Blue : islands with slow bump only

Zoom on SS15



Dummy septum in SS15: extraction conditions - V

CERN PS MULTI TURN EXTRACTION

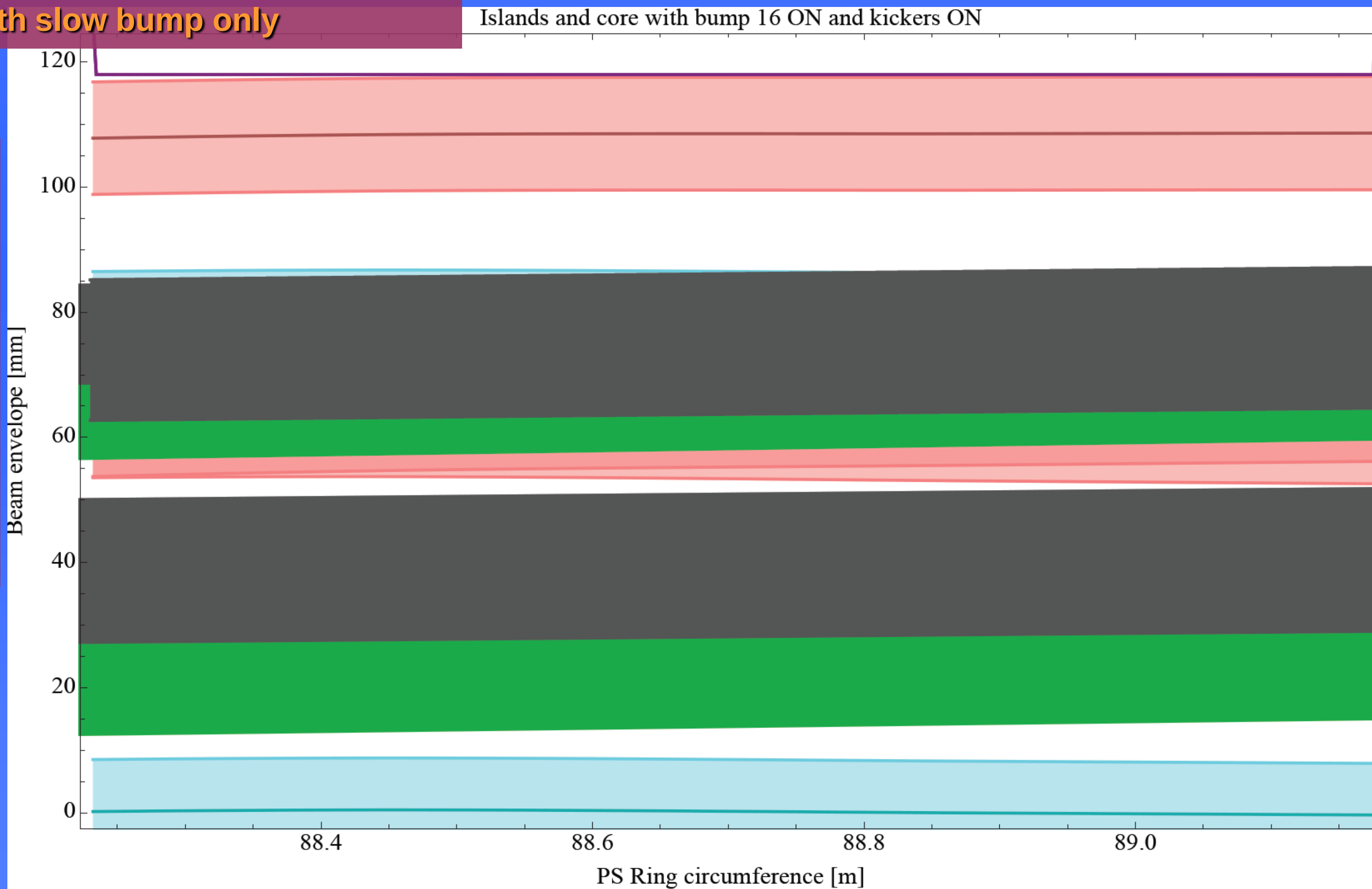
- Green is TOF
- Black is the maximum[LHC, AD]
- Red : islands with fast bump (and slow bump)
- Blue : islands with slow bump only

Zoom on SS15

Optimised TOF extraction conditions.

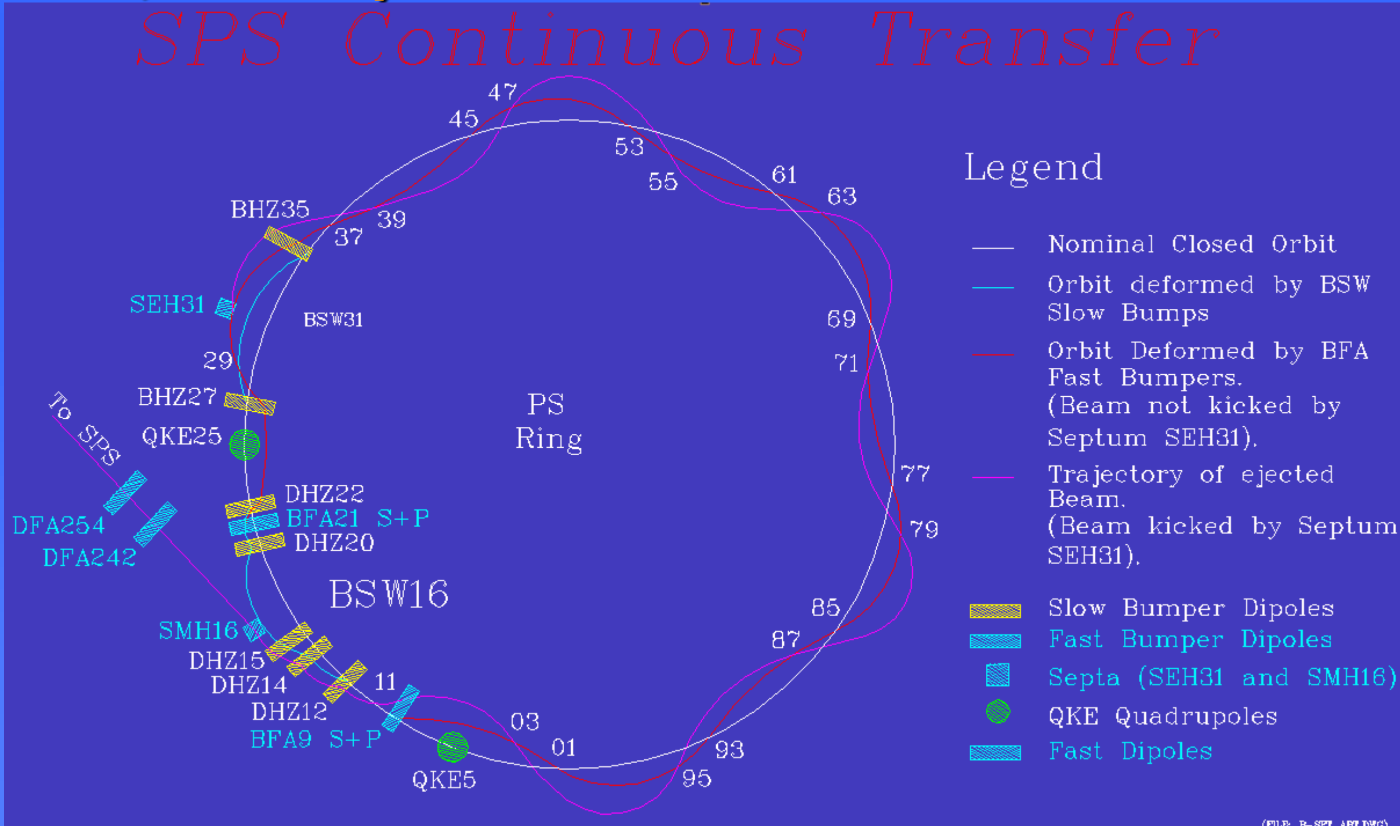
About 15 mm for dummy septum available.

The vacuum chamber limit should be reviewed.



Extraction with SEH31: recap of CT

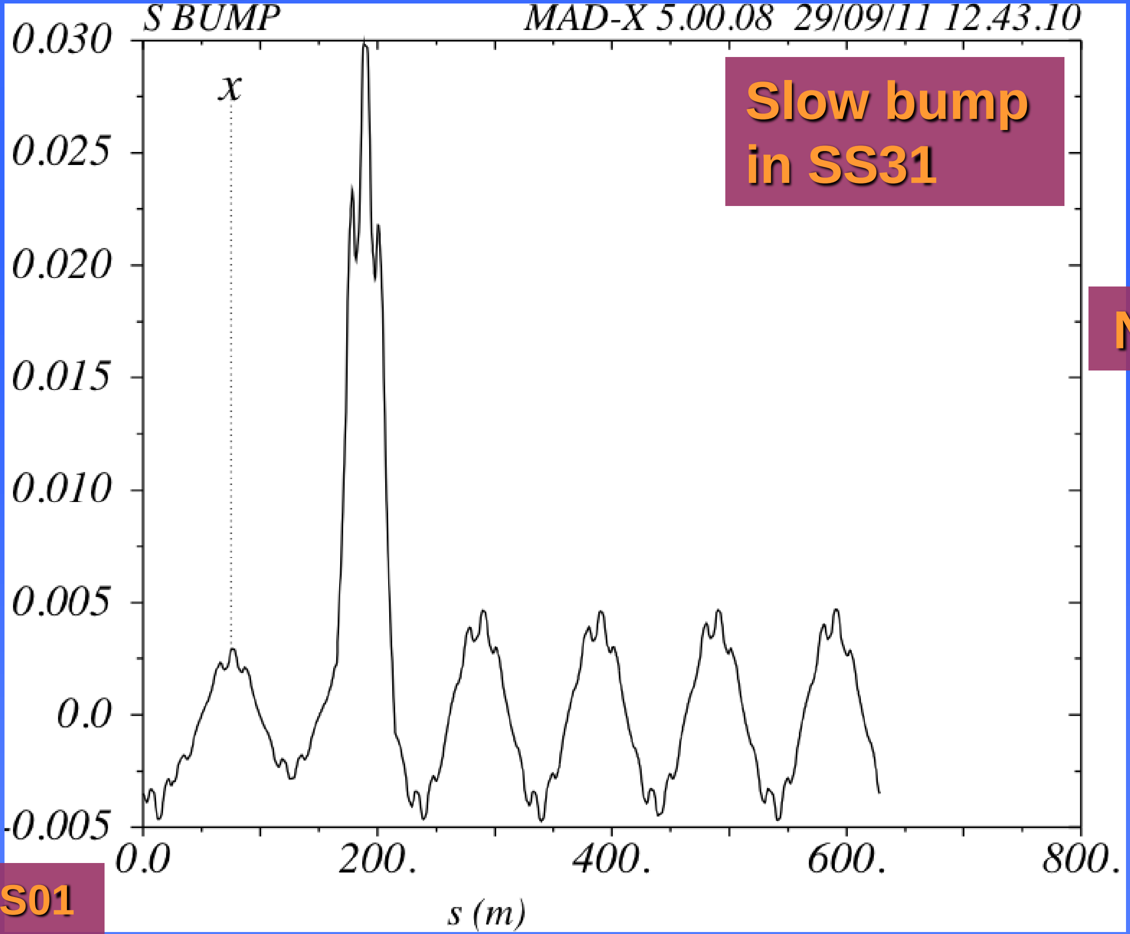
- **Two slow bumps (SS16, SS31)**
- **One fast bump (pedestal and staircase, between SS21 and SS9)**
- **QKE (in SS5/25 and SS25/73)**
- **Two septa (SMH16, SEH31)**
- **Two kickers in TT2 to correct the turn-by-turn trajectory differences**



03/10/2011

Extraction with SEH31: delicate points - I

- Two slow bumps (SS16, SS31)
  - SS16: four magnets, with independent power converters, but used as if they were in series
  - SS31: two magnets in series

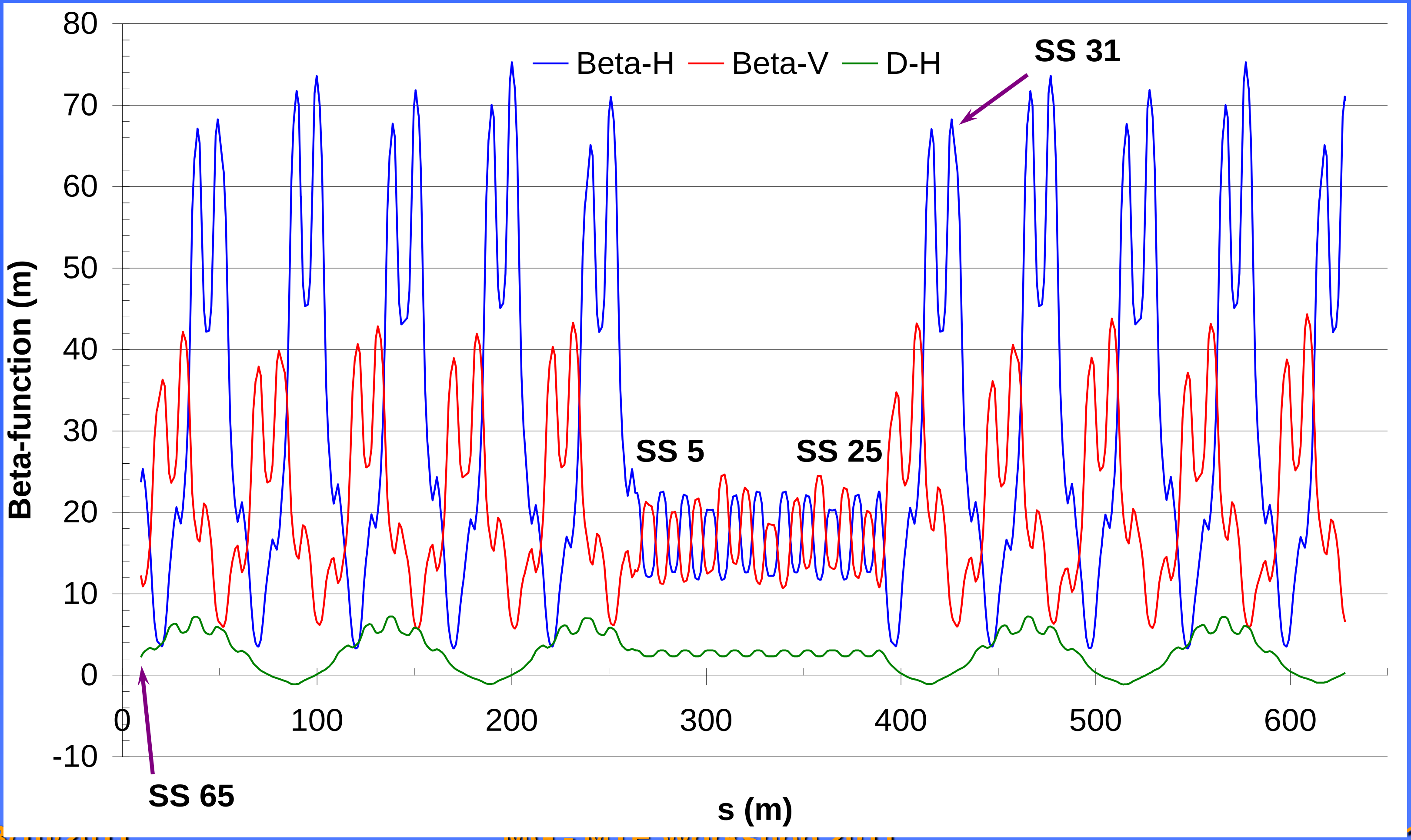


Not well closed

Origin is SS01

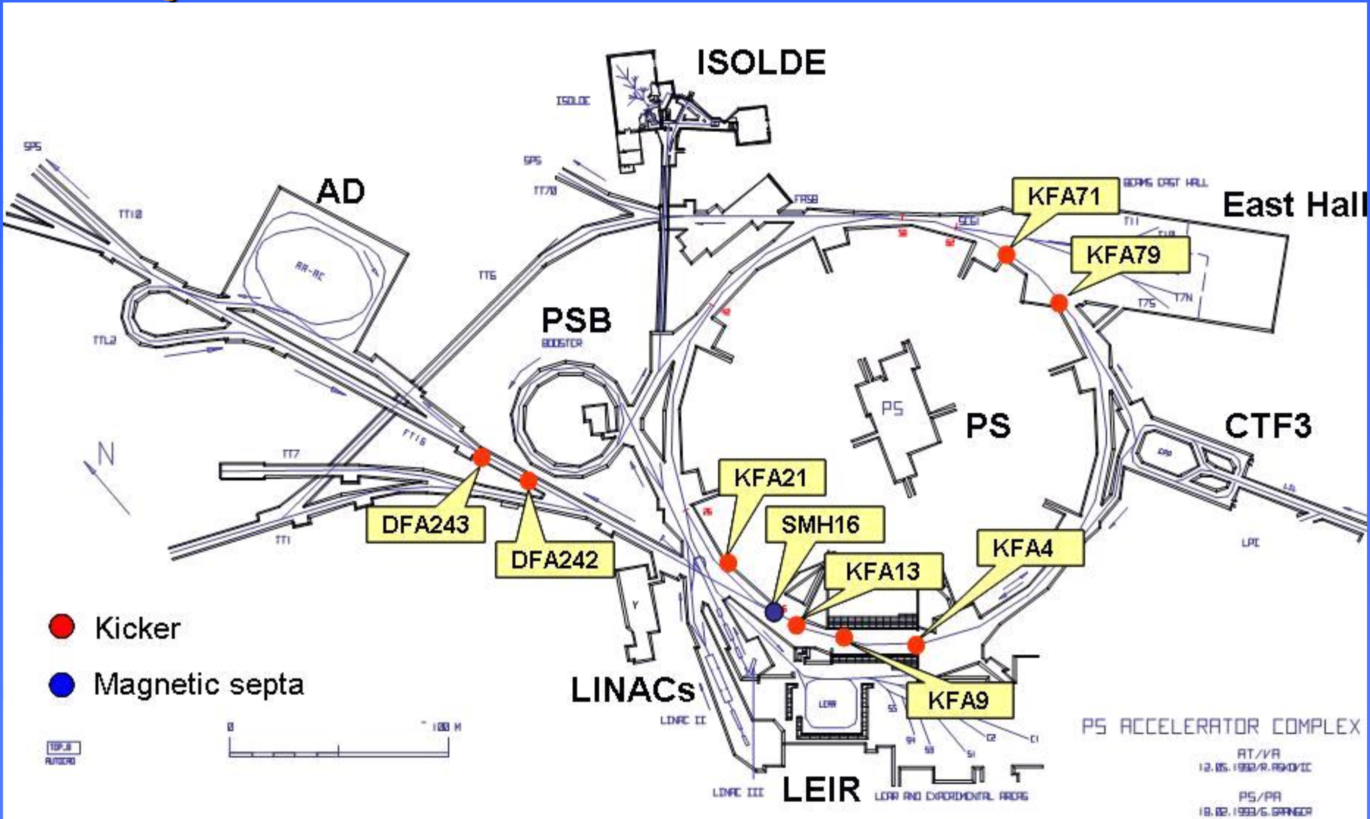
Extraction with SEH31: delicate points - II

- QKE (in SS5 and 25)
  - Induces strong distortions of PS optics



Extraction with SEH31: recap of MTE

- One slow bump (SS16)
- One fast bump (pedestal, between SS9 and SS13)
- Fifth turn extracted with KFA71 and KFA4
- No QKE
- One septum (SMH16)
- Two kickers in TT2 to correct the turn-by-turn trajectory differences



CERN PS MULTI TURN EXTRACTION

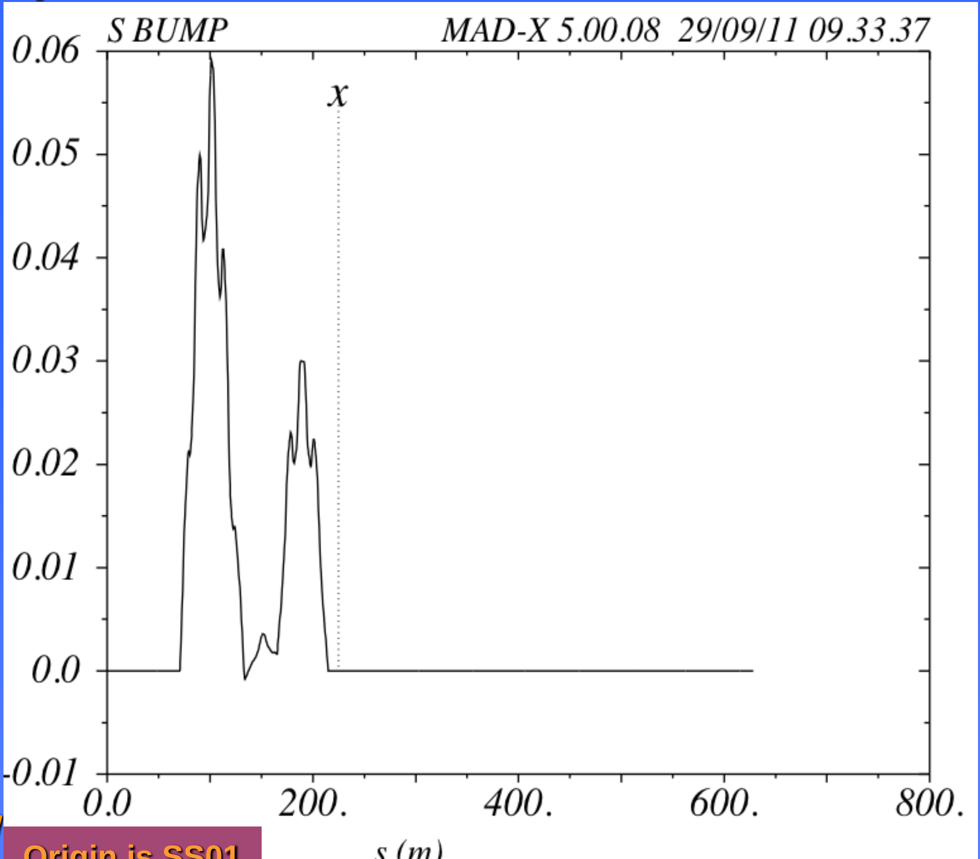
Extraction with SEH31: proposed solution - I

- Phase of KFA13 is not suitable for a closed bump between 21 and 13.
- Kicker in 9 will always work at high strength, with KFA13 providing a small correction.
- QKEs are needed to “help” the kicker in 9 and provide extra kick to the beam deflected by SEH31.
- All this forces to go towards a nearly “carbon copy” of the CT optics.
- Guidelines for new solution:
  - Minimise the strength of QKEs
  - Close the combined SS16+SS31 slow bump
  - Close the fast bump

Extraction with SEH31: proposed solution - II

- Proposed closed (for core) combined SS16+SS31 slow bump
  - DHZ15 could be used to tune the bump
  - The position in SS25 could be optimised to increase the kick from QKE25

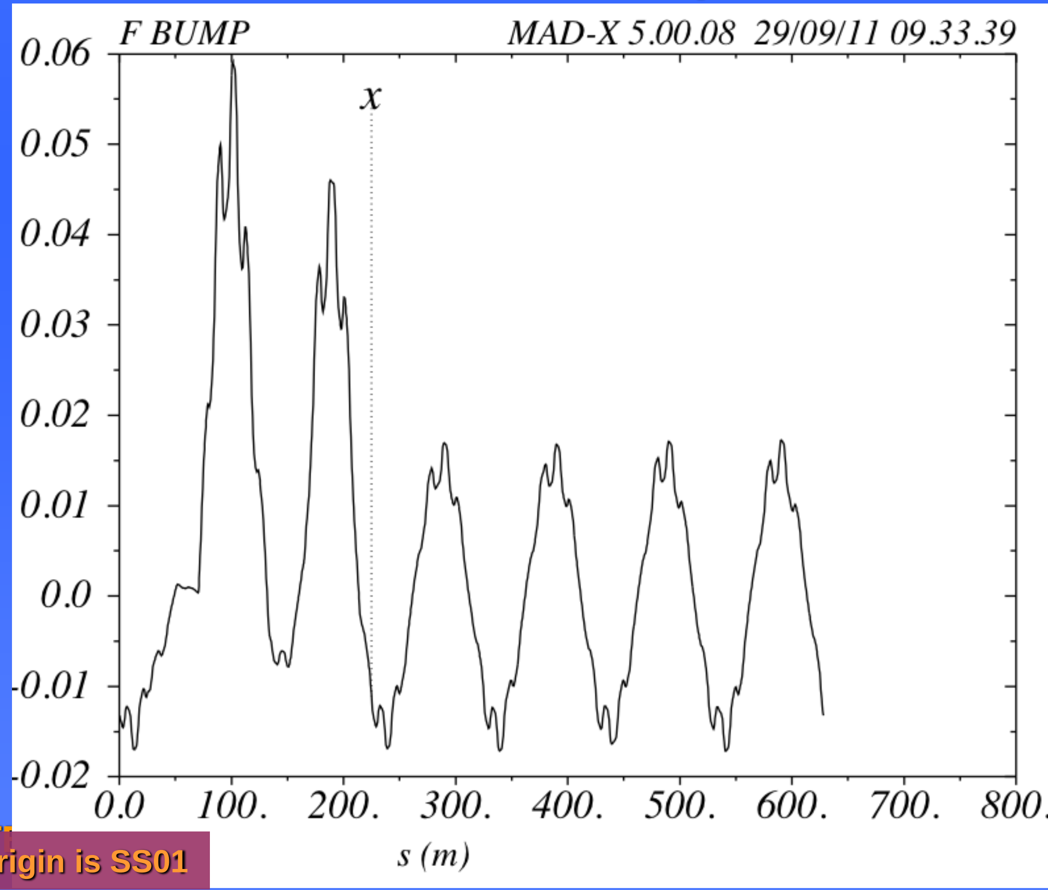
Magnet	Magnet type	Current [A]
PE.BSP12	D205	431.2
PE.BSP14	D205	139.9
PR.DLH15	D205	0
PE.BSP18	D205	86.6
PE.BSP20	D205	279.7
PE.BSP22	D205	313.9
PE.BLG27	D205	228.2
PE.BLG35	D210	228.2



Origin is SS01

Extraction with SEH31: proposed solution - III

- **Proposed closed (for core) fast bump**
  - **The staircase components might be needed to close the bump for the islands (see later)!**
  - **Would it be possible to have the two staircase independent?**

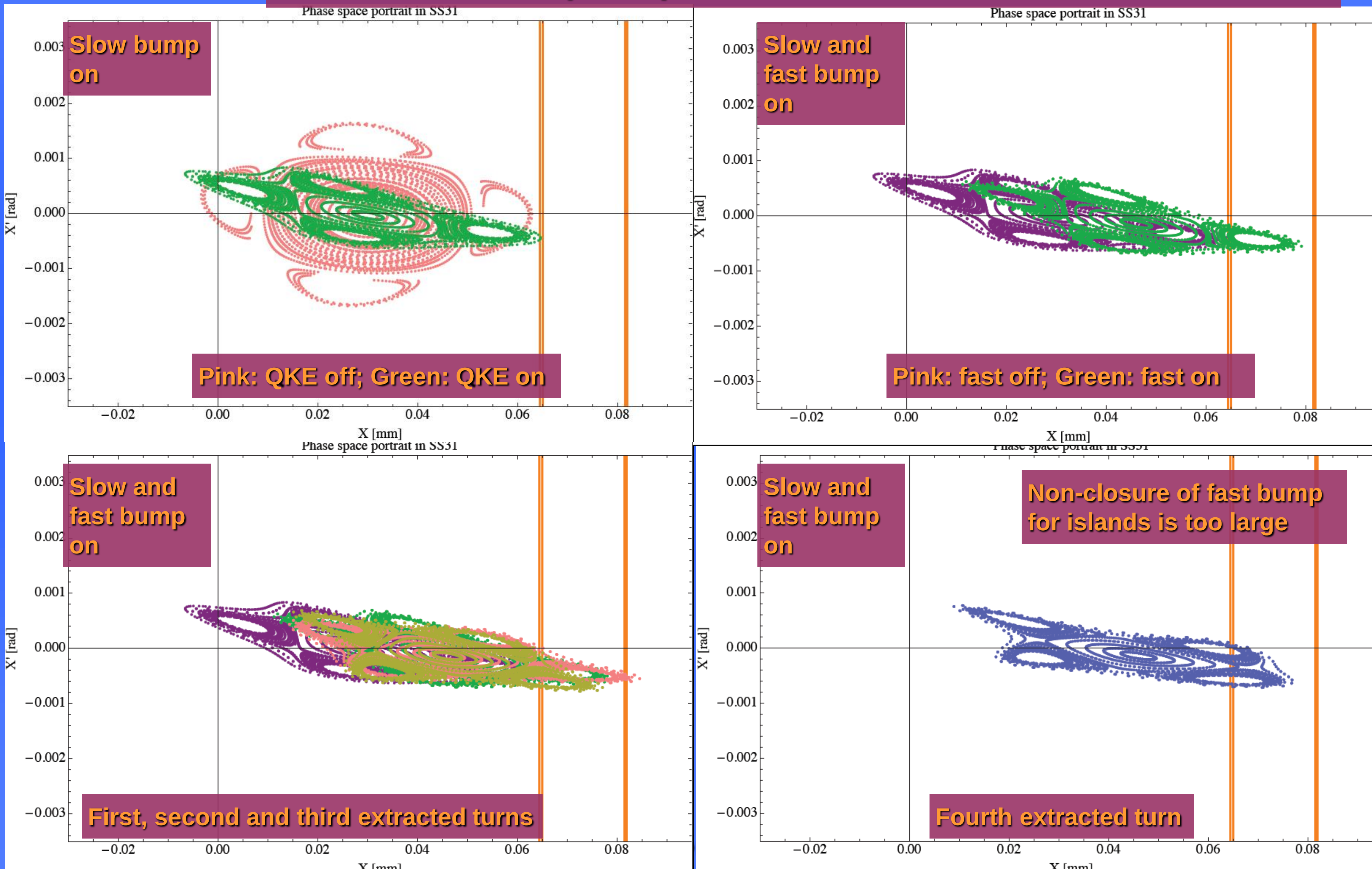


Magnet	Magnet type	Kick [mrad]
PE.KFA13	MTE kicker	0.06
PE.KFA21	MTE kicker	-0.54
PE.BFA09p	CT pedestal	0.47
PE.BFA21p	CT pedestal	0
PE.BFA09s	CT staircase	0
PE.BFA21s	CT staircase	0

Origin is SS01

Extraction with SEH31: proposed solution - IV

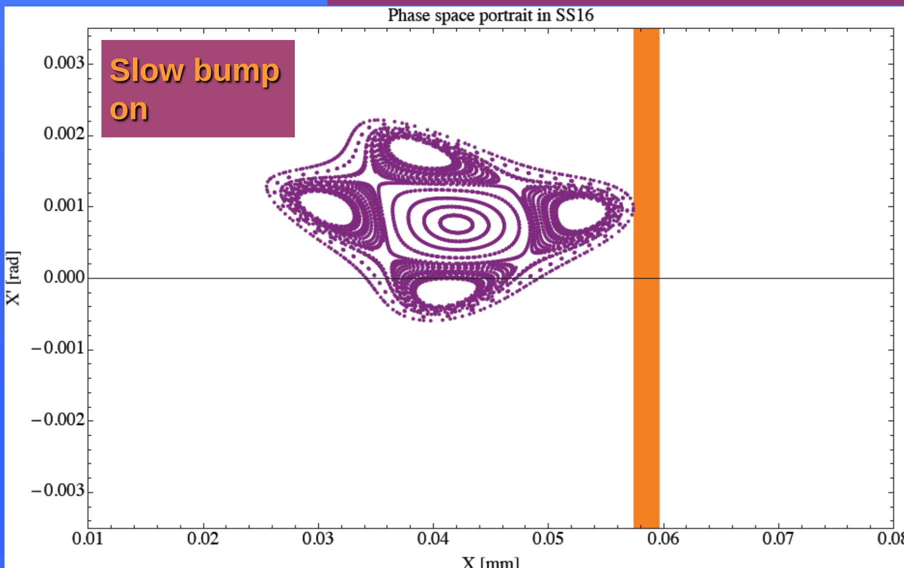
Phase space portraits at SS31. SEH31 is off

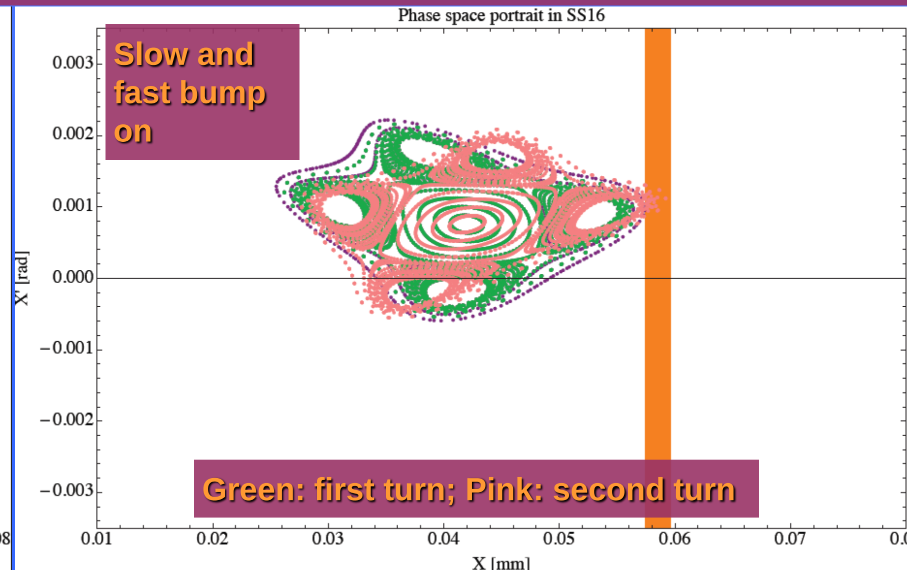


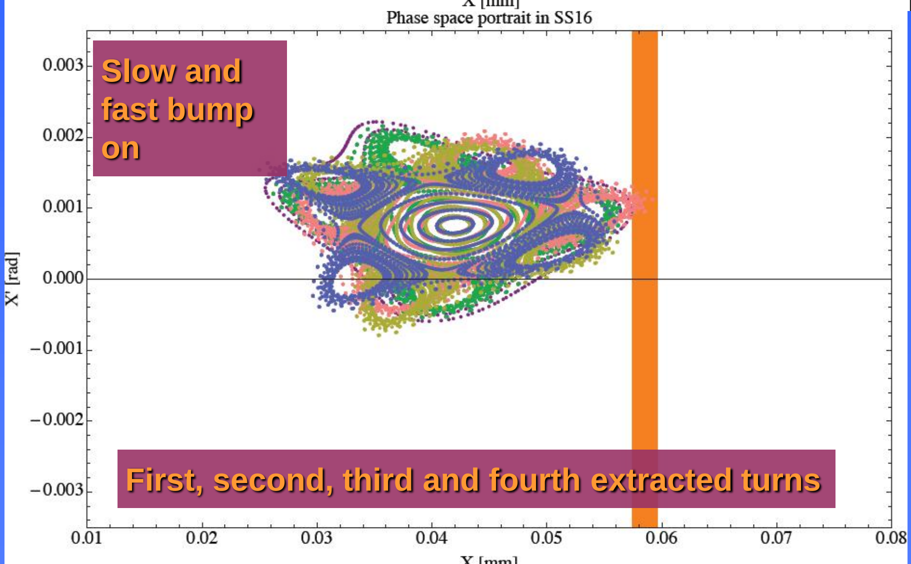
CERN PS MULTI TURN EXTRACTION

Extraction with SEH31: proposed solution - V

Phase space portraits at SS16. SMH16 and SEH31 are off



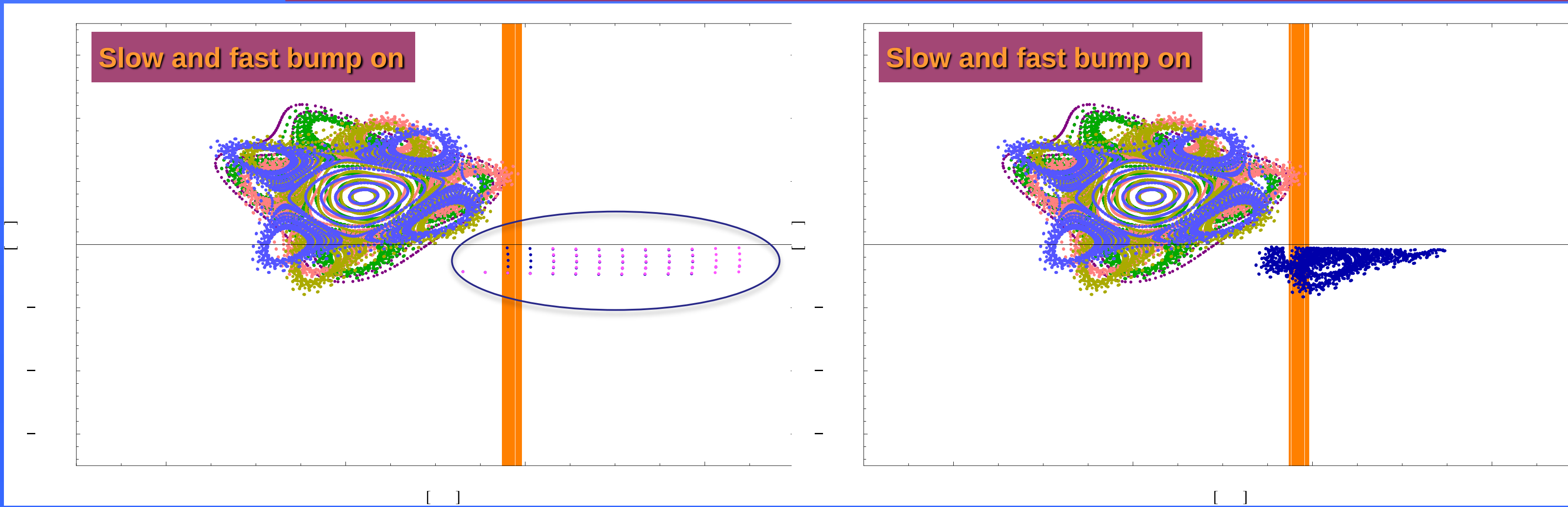




- The fast bump is closed and with zero value at SS16!
- The island position is changing with turn. The fast bump is not closed for islands (feed down from quadrupole components)
- The islands shape is changing (feed down from higher orders)

Extraction with SEH31: proposed solution - VI

Phase space portraits at SS16. SEH31 is on



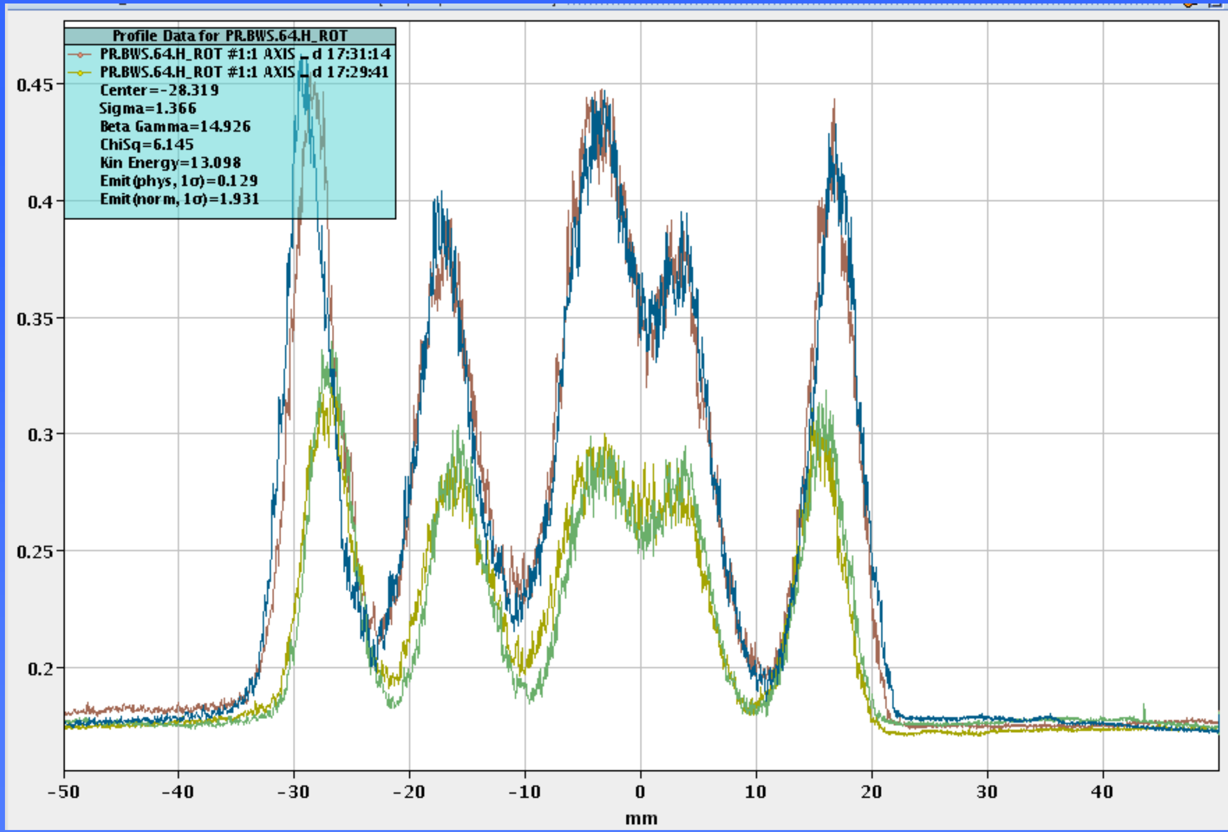
- The dots in the oval represent the image of initial condition in the SEH31 tracked from SEH31 to SMH16.

- The blue dots represent the image of islands in the SEH31 receiving the deflection.
- The SEH31 kick is a bit weak. The QKE strength should be increased (aperture in SS9 should be checked).
- A similar behaviour might occur for CT.

CERN PS MULTI TURN EXTRACTION

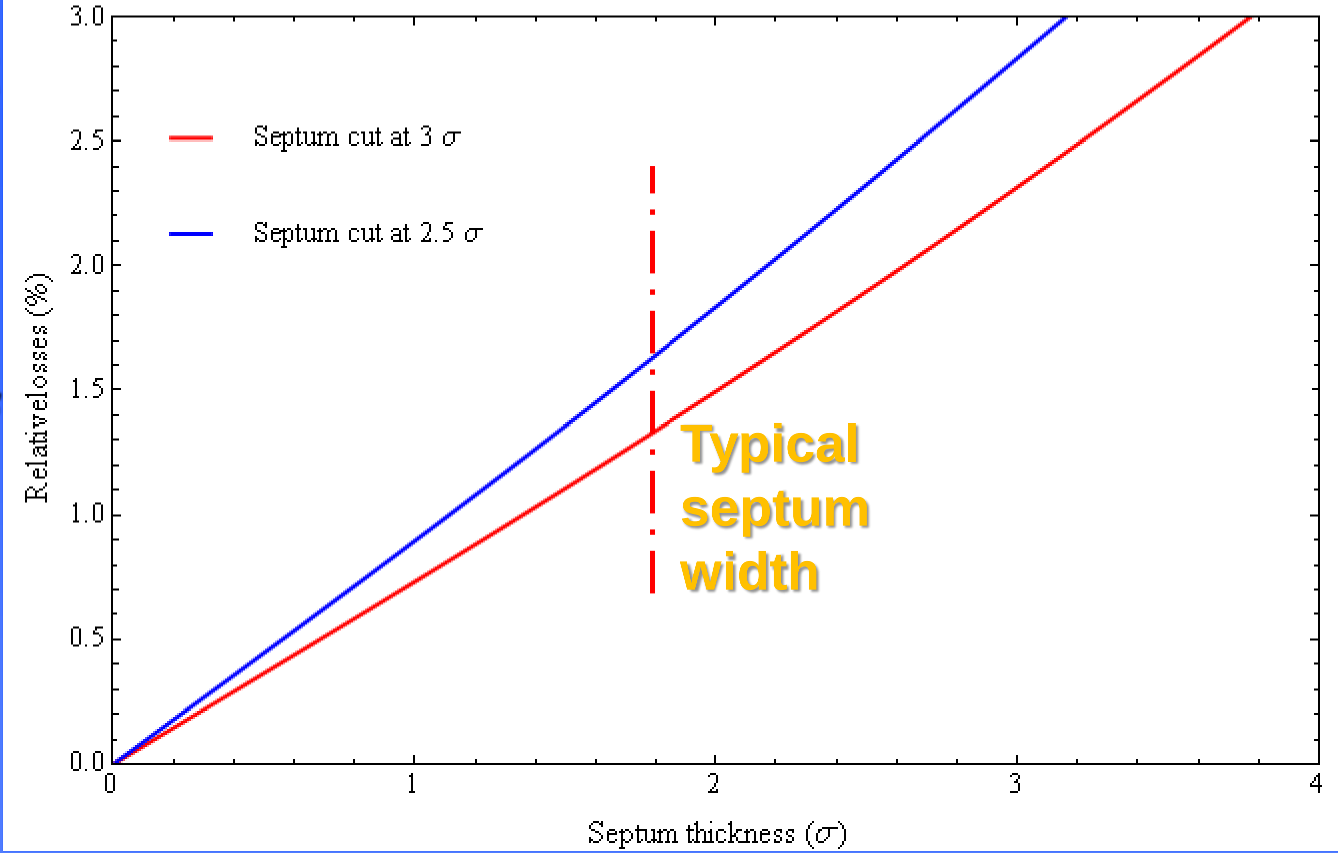
Faster kickers: assumptions

- Continuous beam.
- Rise time (τ) of the kickers is assumed 10%-90%
- Transverse beam distribution is a pure Gaussian
- Typical beamlet width is about 10 mm, corresponding to ±3 sigma.
- Septum width is 3 mm, corresponding to about 1.8 sigma.
- Nominal parameters:
  - τ = 350 ns -> **4 turns**
  - τ = 80 ns -> **fifth turn**



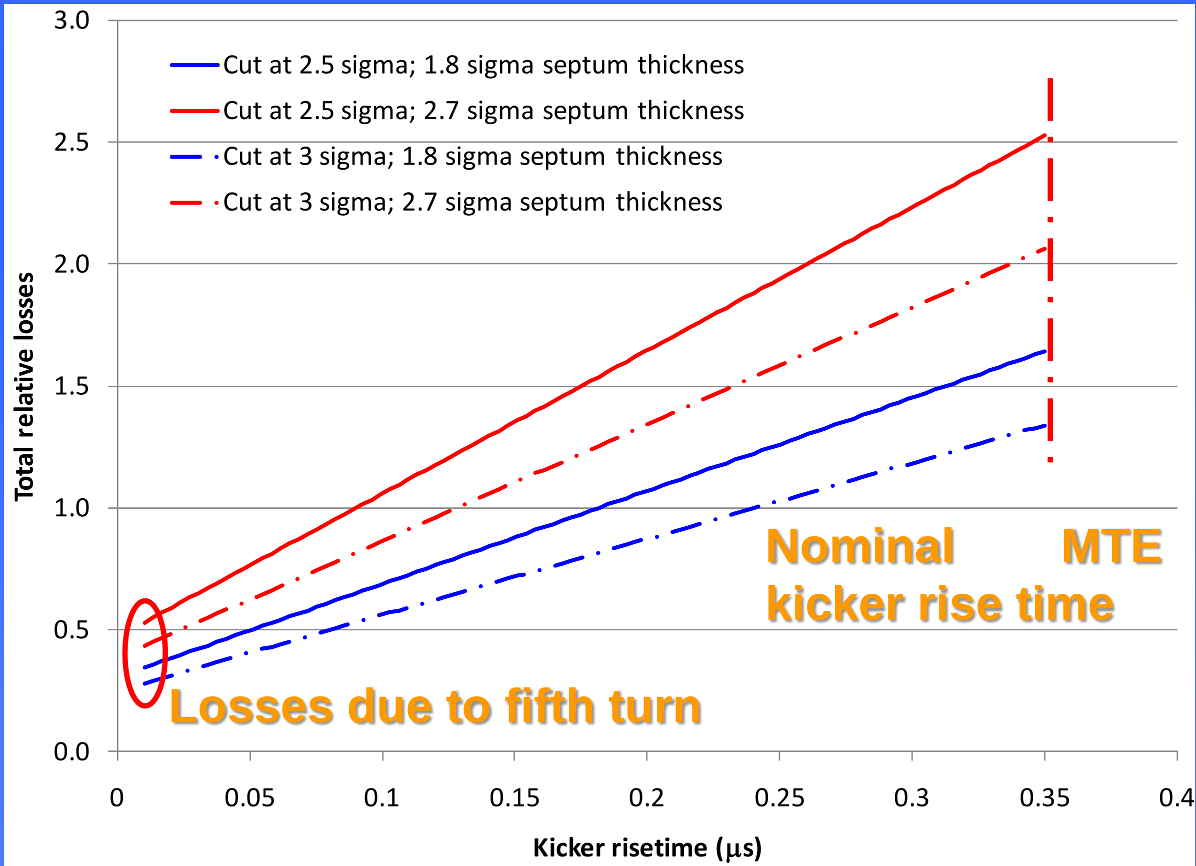
Faster kickers: losses - I

- The relative losses are computed adding the contribution from the first turn and the fifth one.
- The magnetic septum blade is assumed to cut the beamlet at either 2.5 or 3 sigma.
- Imperfections are not included in computations
- Parameters' range mimic effect of imperfections.



Faster kickers: losses - II

- The relative losses are essentially linear in the rise time.
- The different septum thicknesses represent the effect of imperfections (non correct angle of extracted beam with respect to septum).
- The different cuts stands for different options due to extraction settings (beamlets separation) and kicker strength.



Faster kickers: losses - III

- From the computations one obtains

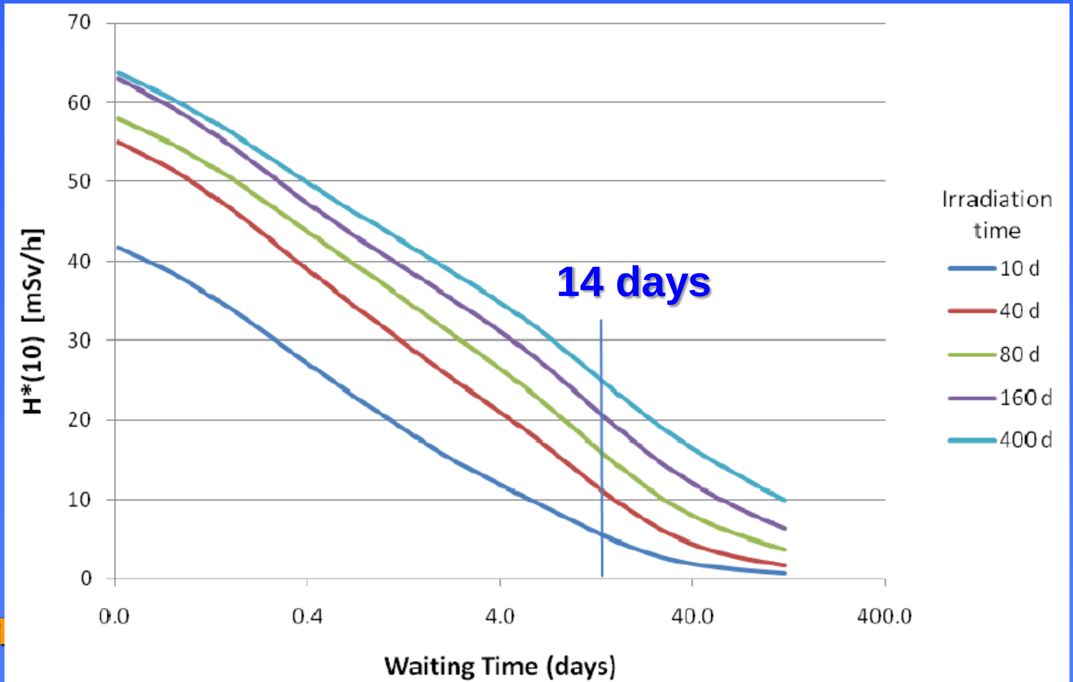
$$\frac{\Delta L}{L_0} = \alpha \frac{\Delta \tau}{\tau_0}$$

- In all the cases shown before, $\alpha \sim 0.814$:
- A **100% variation in rise time** generates a **81% variation in losses**.
- This should be compared against
  - The cost to achieve the reduction in kickers' rise time (see Laurent's presentation).
  - The reduction in cool down time before any intervention can take place in the septum region.

CERN PS MULTI TURN EXTRACTION

Faster kickers: cool down - I

- Acceptable cool down time: 14 days (from P. Collier, see CERN-ATS-2011-007).
- Simulations performed assuming:
  - 2% losses as for a well-tuned MTE extraction
  - Losses on septum of 6.4×10^{10} p/s (this depends on intensity and super-cycle composition)
- Assuming 10 mSv/h as reasonable level for starting an intervention, then the cool down
  - 160 d run -> ~ 40 d
  - Halving the losses -> ~ 30 d
- There is no hope that an optimisation of the intervention might cut the cool down time by a factor of two!



Faster kickers: cool down - II

Some comments:

- Material analysis aimed at reducing the activation of the septum showed that the current situation cannot be further optimised.

- Some reduction of the intervention time could be obtained by designing a SMH16 with quick installation concept. This, however, would not change the previous conclusions.

Outlook - I

- Dummy septum in SS15:
  - Extraction trajectories of FE beams require optimisation
  - Islands phase and trajectories need also tuning
  - Re-location of equipment seems feasible (pre-warning for γ-jump quadrupole)
  - Analysis for CT to be added
  - Tests with FE beams required to assess the feasibility
- Extraction with electrostatic septum in SS31
  - CT-like optics is imposed -> maybe more than SEH31 should be re-used…
  - Aperture to be studied in details
  - Fifth turn extraction to be studied
  - Closure of fast bump to be improved
  - Tests (trajectories) could be launched before the end of the run
- Faster kickers
  - Losses reduction is slightly less than a factor of two
  - The reduction in cool down time is not enough!

Outlook - II

- Time-line for decisions (go/no go for dummy septum) to be agreed (see ABT presentations).
- The fluctuations will in any case make losses worse than estimates, no matter what the extraction scheme will be...