

# Overcoming Injection constraints and dynamic aperture, acceptance and lifetime problems

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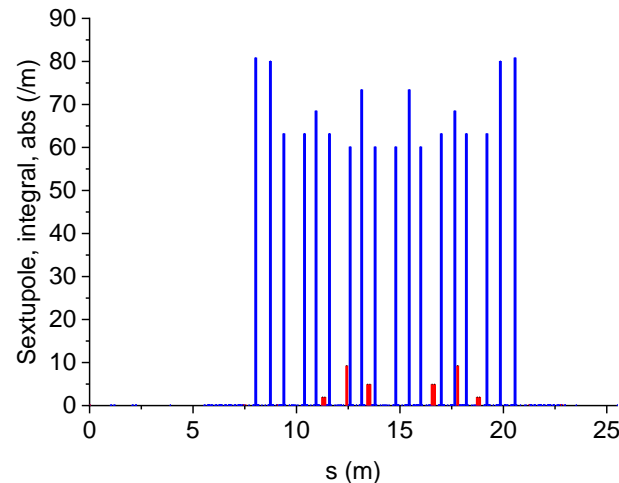
11.07.2019


Ioannina, Greece

# Introduction

- Low emittance ring → Multi-bend achromat → Strong focusing / low dispersion → Strong chromaticity correction sextupoles → Strong nonlinearity → Small dynamic aperture...

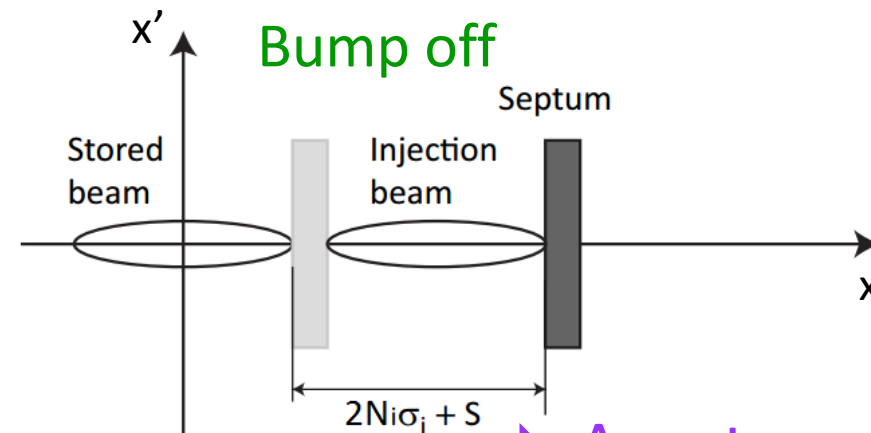
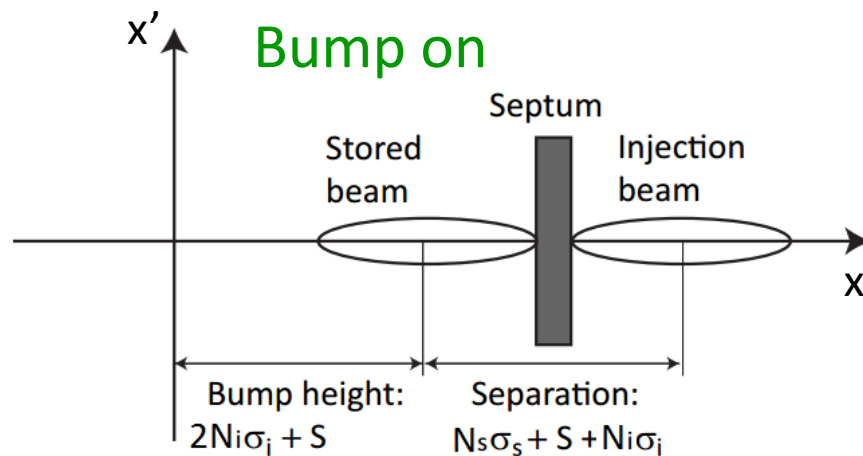
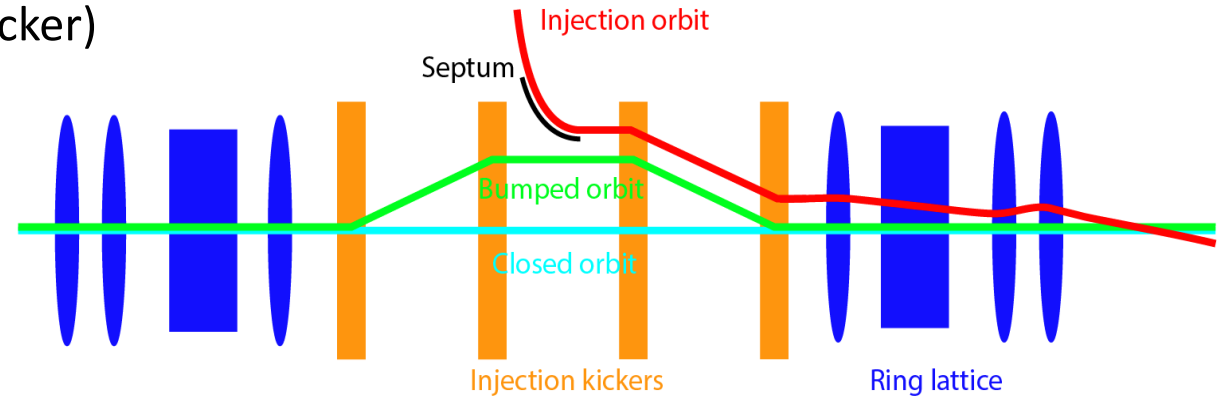
Chromaticity correction  
sextupole strength (K2L) of  
SLS and SLS2 (One arc)



- Dynamic aperture must be sufficient for injection, including machine imperfections
- Momentum acceptance must be sufficient for Touschek lifetime
  - A lifetime of ~10 hours would be comfortably long but the requirement may vary from facility to facility
- In the following  indicates where hardware R&Ds are suggested / required / of interest

# Conventional injection scheme

- Septum + Kicker bump (Series of kicker)
- Kicker bump is very efficient to “pull out” the injection beam
- Difficult to fulfill the dynamic aperture requirement in low emittance rings
- Bump leakage is practically unavoidable, disturbing the stored beam...



Aperture required

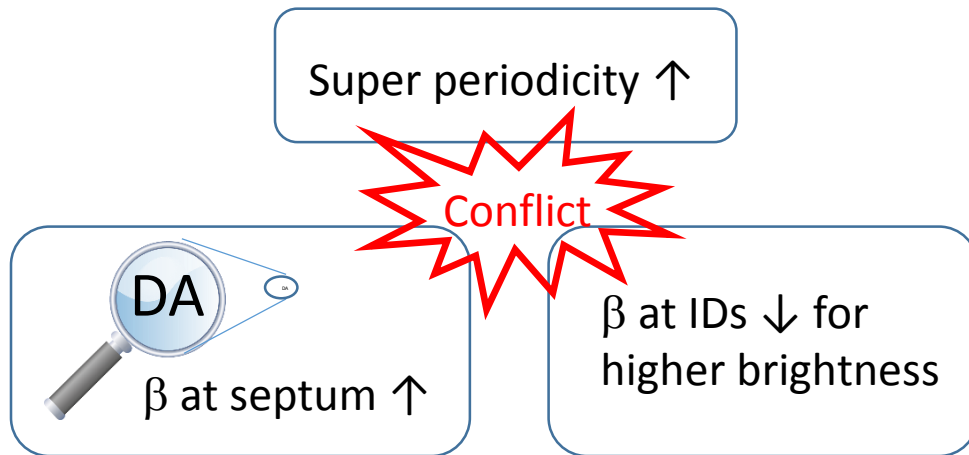
# Approaches to enable/improve LER injection

- Enlarging dynamic aperture
- Lowering injection beam emittance → Next talk by J. Kallestrup
- Making septum thinner
- On-axis injection

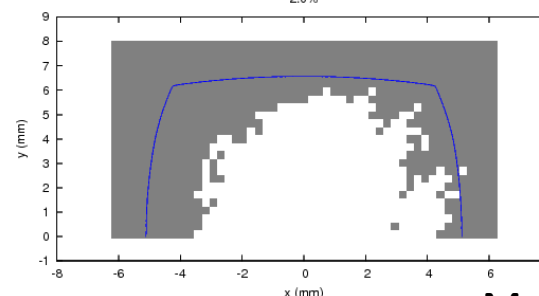
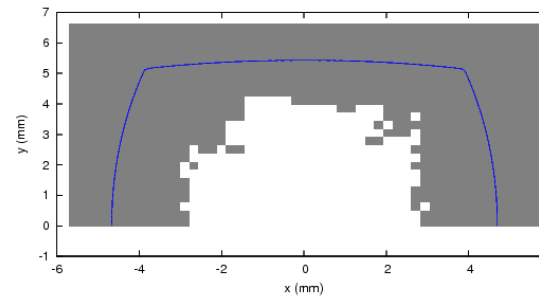
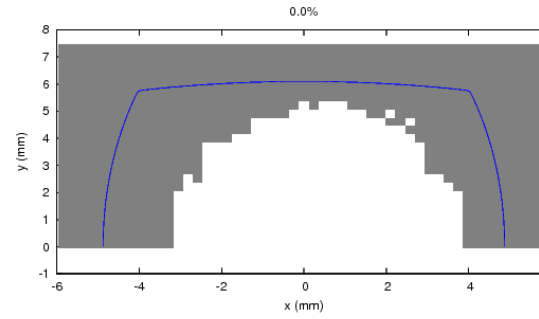
# Dynamic aperture (1)

- Linear optics

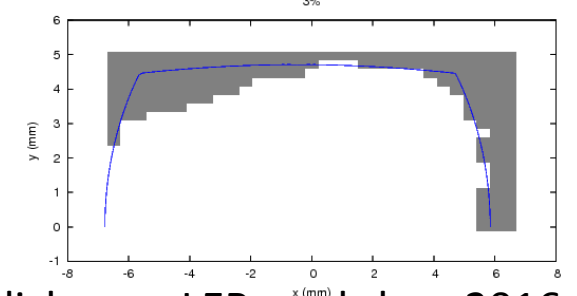
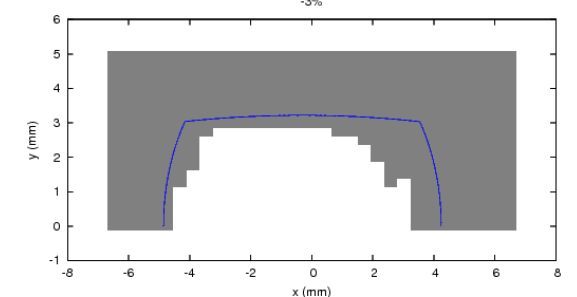
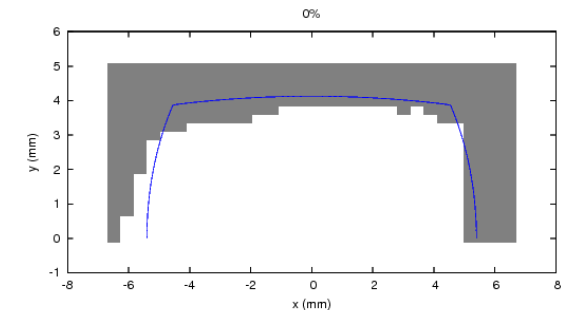
- Nonlinearity cancellation by adjusting phase advance among chromaticity correction sextupoles
  - -I transformation (ESRF-EBS type lattice)
  - Multi-cell cancellation
- Problem:



(Old) SLS2 lattice, S.P.=3

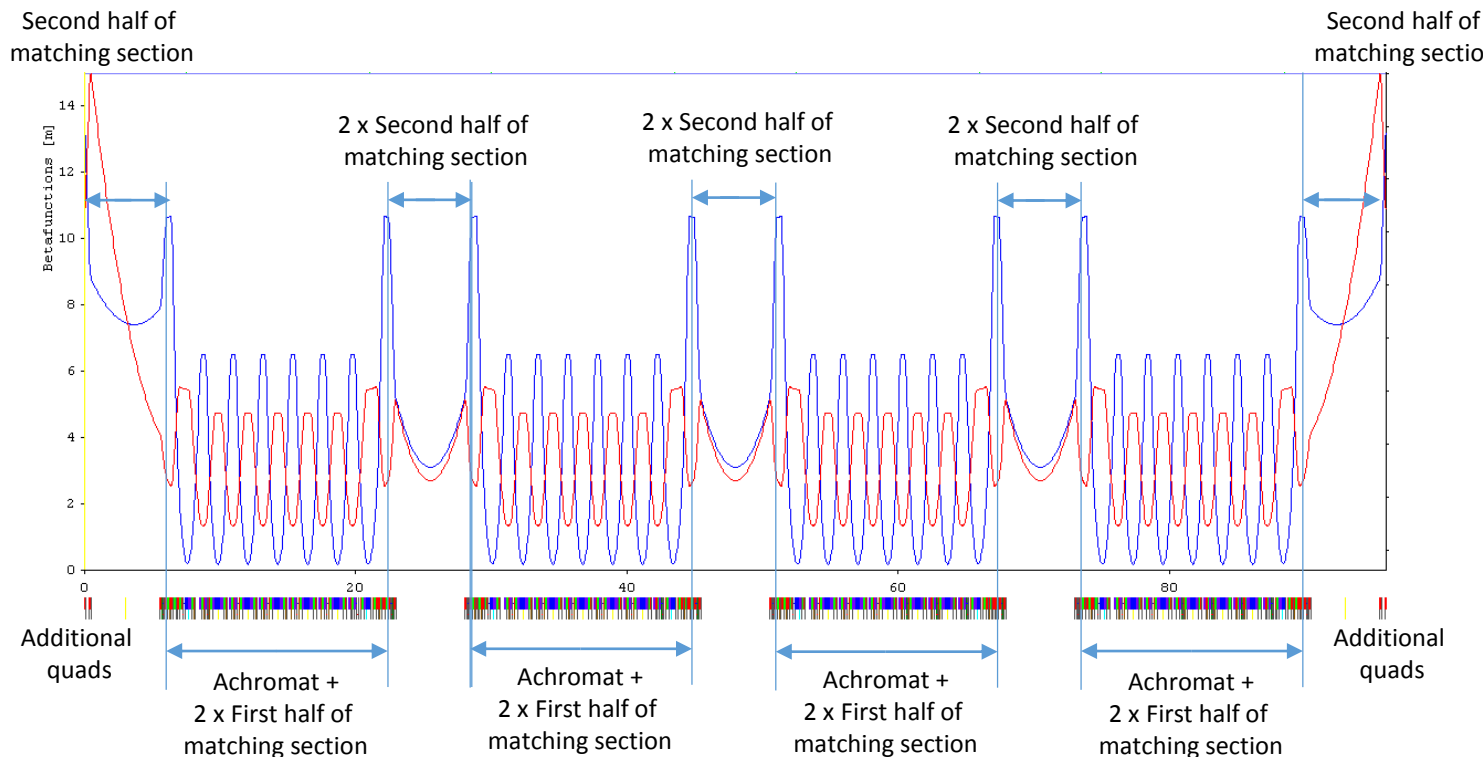


(Old) SLS2 lattice, S.P.=12



# Dynamic aperture (2)

- Linear optics - Pseudo super-periodicity, A. Streun

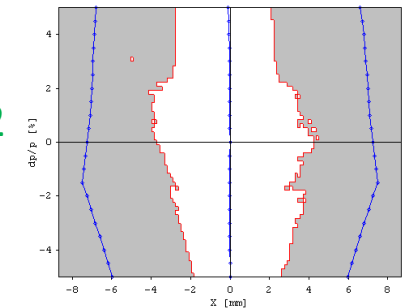
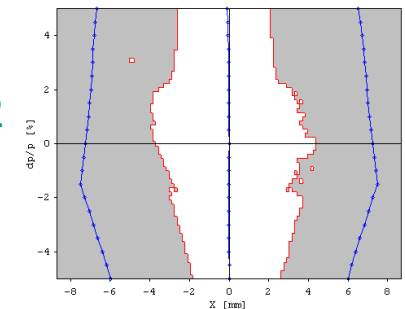
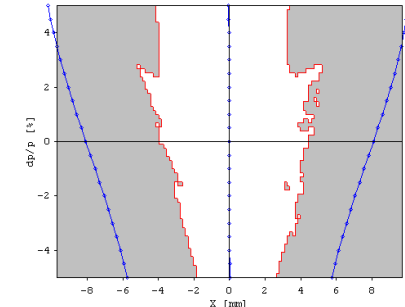


S.P.=12  
P.S.P.=12

S.P.=3  
P.S.P.=12

S.P.=1  
P.S.P.=12

DA vs  $dp/p \pm 5\%$   
@  $\beta_x = 2.95 \text{ m}$

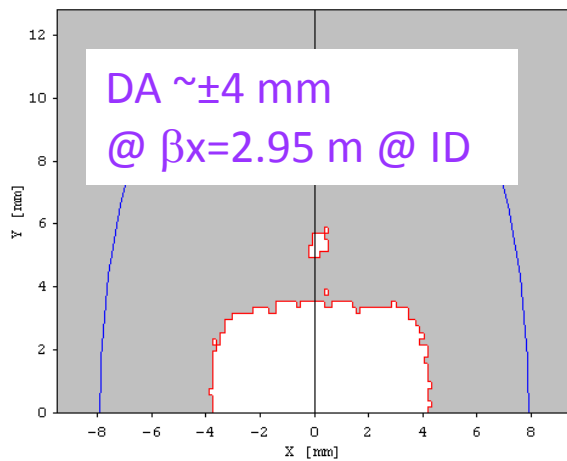


- Identical Achromat+ First half of matching section
- Second half of matching section (only quads) can be different but with the identical phase advance in H and V

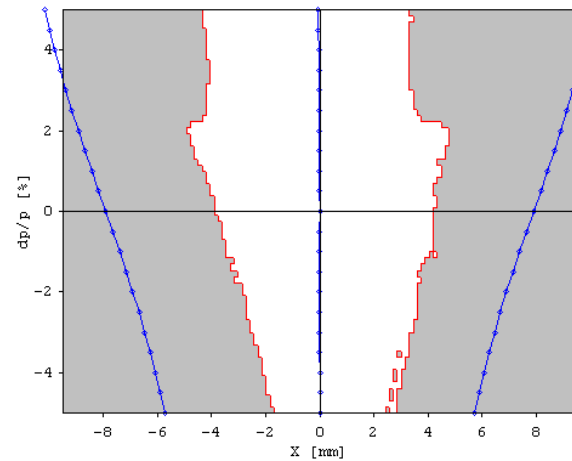
# Dynamic aperture (3)

- DA optimization
  - Harmonic sextupoles in addition to chrom. correction sextupoles
  - Octupoles may be useful if not essential
  - Goals (or constraints...)
    - DA sufficient for injection
    - Momentum acceptance:  $\sim 2\%$  for high energy machines,  $\sim 4\%$  for low energy machine
    - Small amplitude dependent tune shifts
    - Horizontal tune fractional part between 0.2 and 0.8 at the injection point (For conventional injection with a kicker pulse length longer than revolution)
    - Small higher order chromaticities
- Example, SLS2 lattice (no error), 9 sextupole and 6 octupole families:

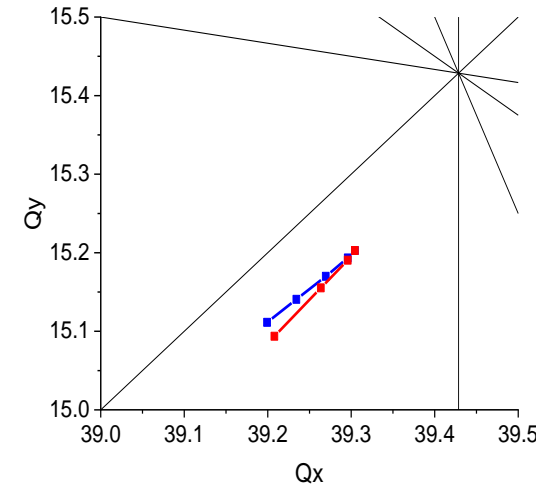
Dynamic aperture



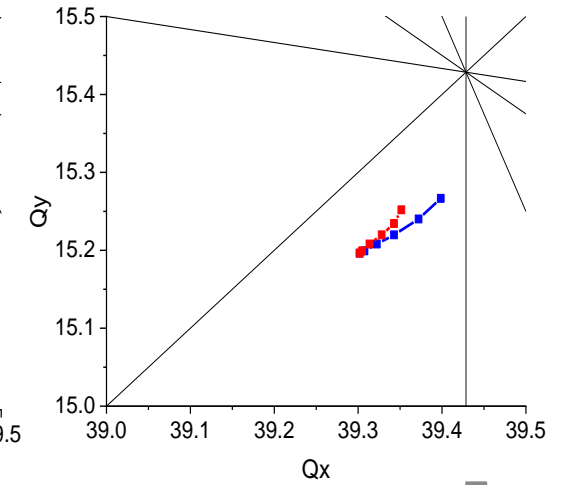
Acceptance x vs dp/p




ADTS up to DA

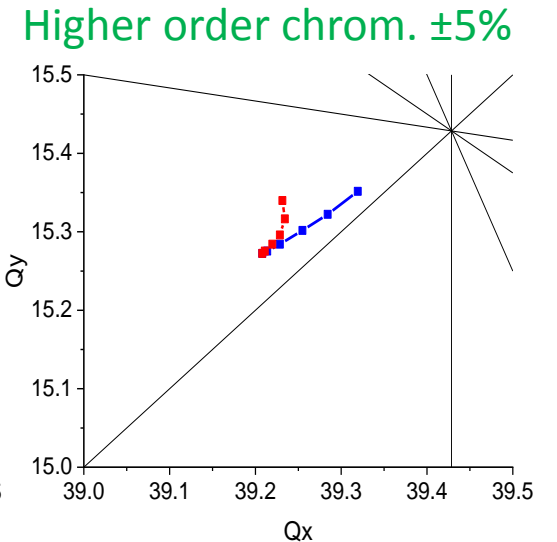
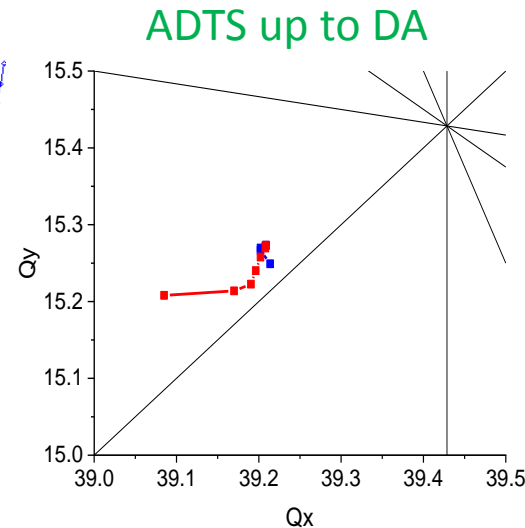
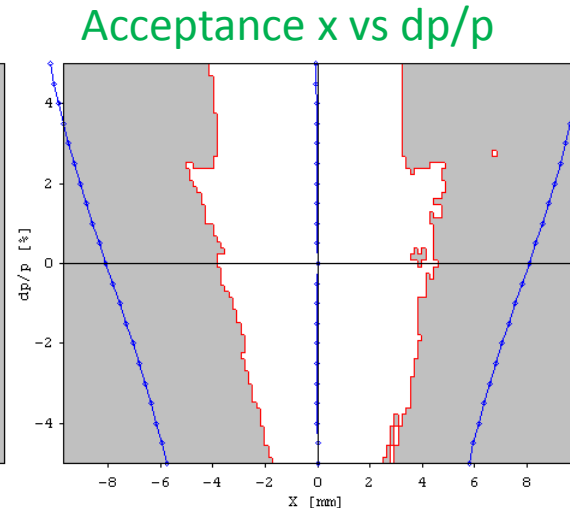
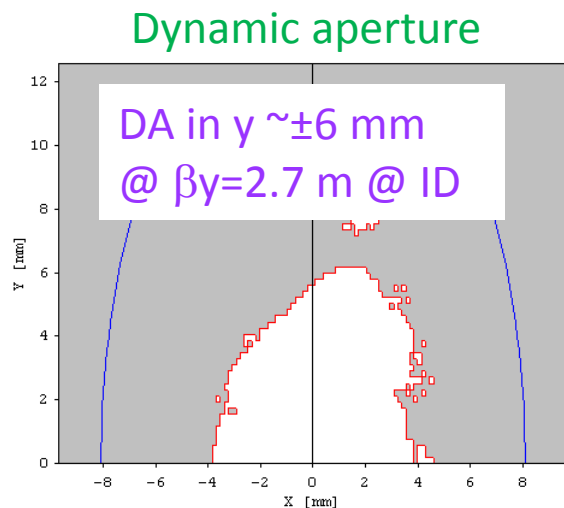


Higher order chrom.  $\pm 5\%$



# Dynamic aperture (4)

- Injection in the vertical plane
  - Dynamic aperture in the vertical plane can be much larger than in the horizontal plane
    - Only even order resonances,  $2Q_y$ ,  $4Q_y$ ,  $6Q_y$  ..., are excited in the vertical plane
  - Vertical in-vacuum undulator to remove the aperture bottleneck in the vertical plane \*



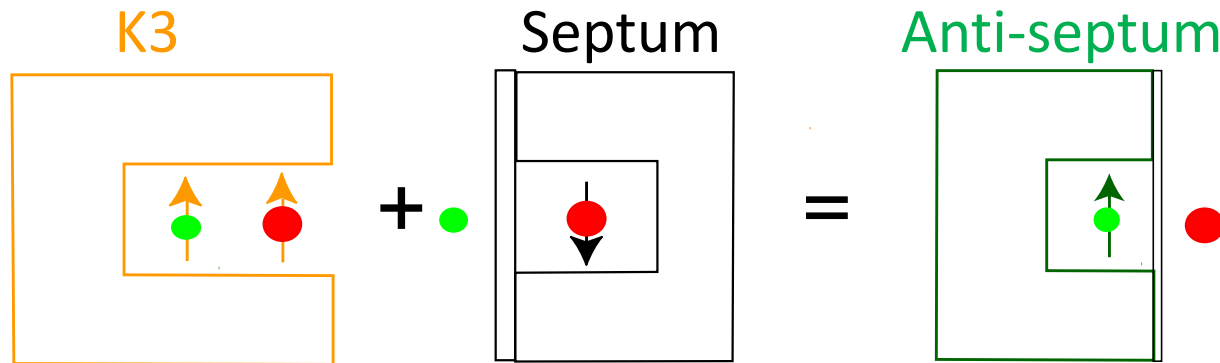
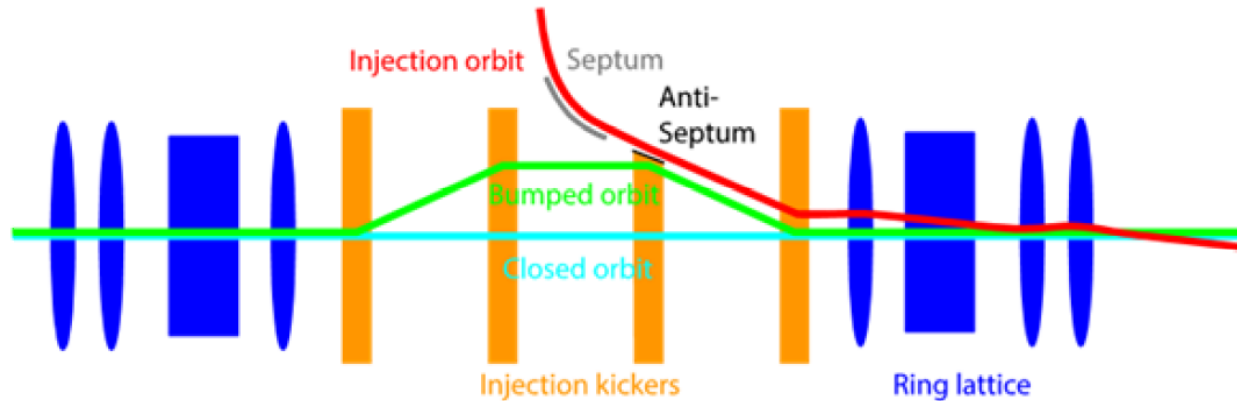
DA can be  $\sim 50\%$  larger in V !

\* Once an on-axis injection is realized, transverse impedance can be distributed over H and V planes with H and V undulators

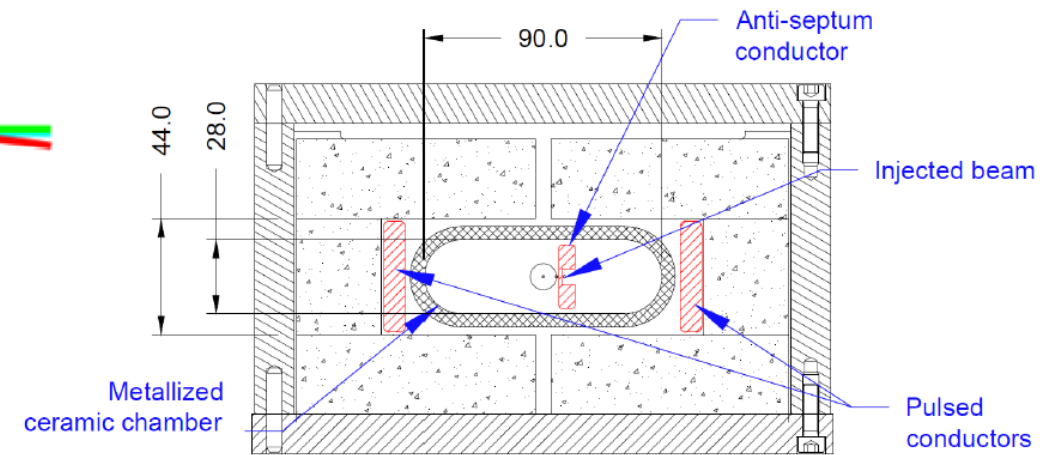


# Septum with 1-mm thick blade (1)

- Anti-septum



## Possible implementation

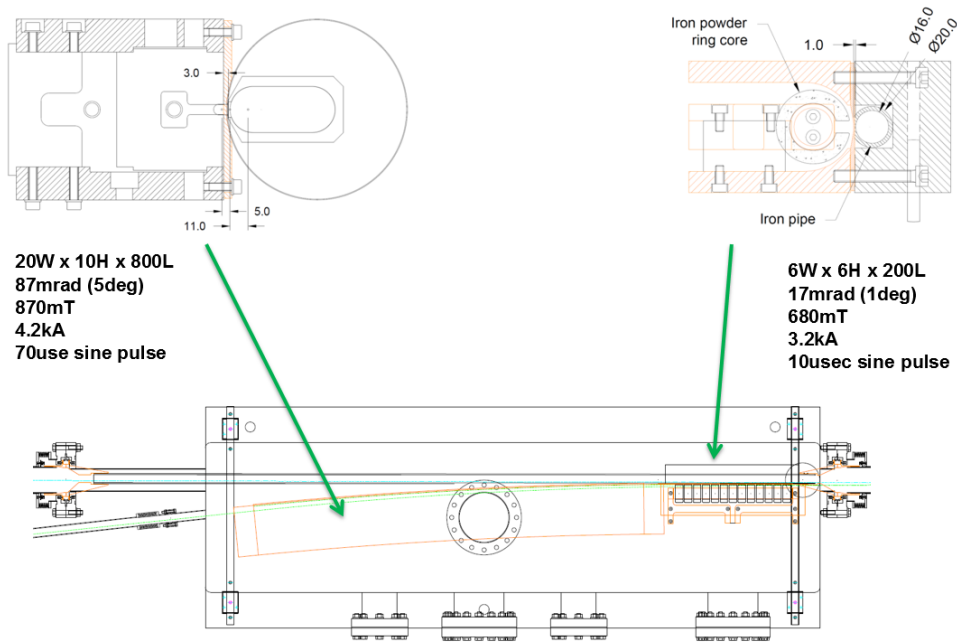


Drawing by C. Gough

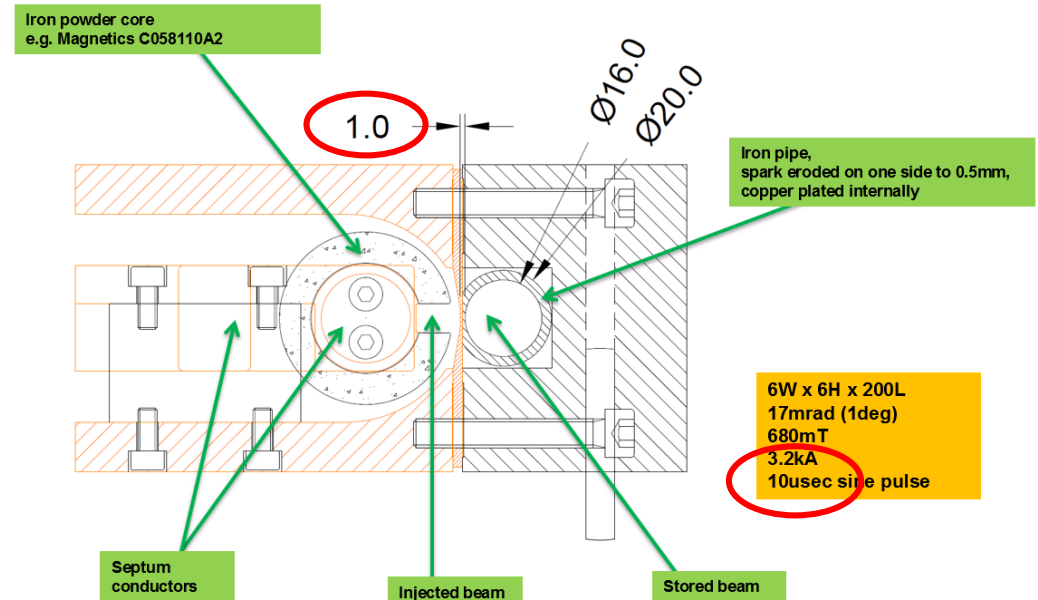
# Septum with 1-mm thick blade (2)

- Main thick septum + Final thin septum:

## SLS-2, including really really thin septum?

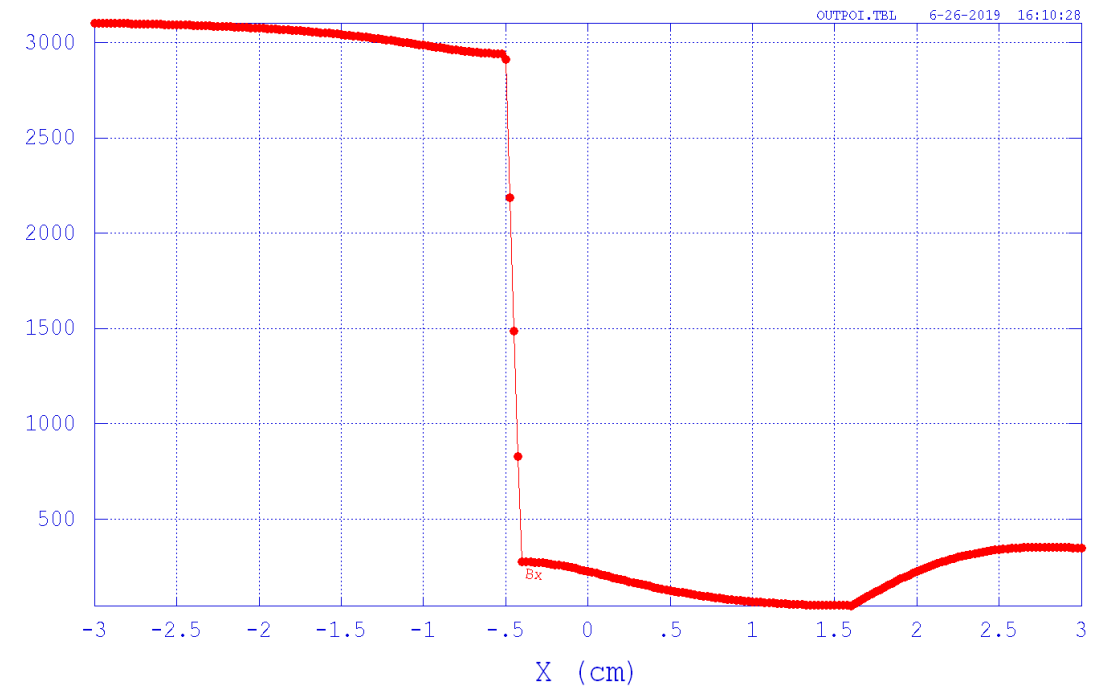
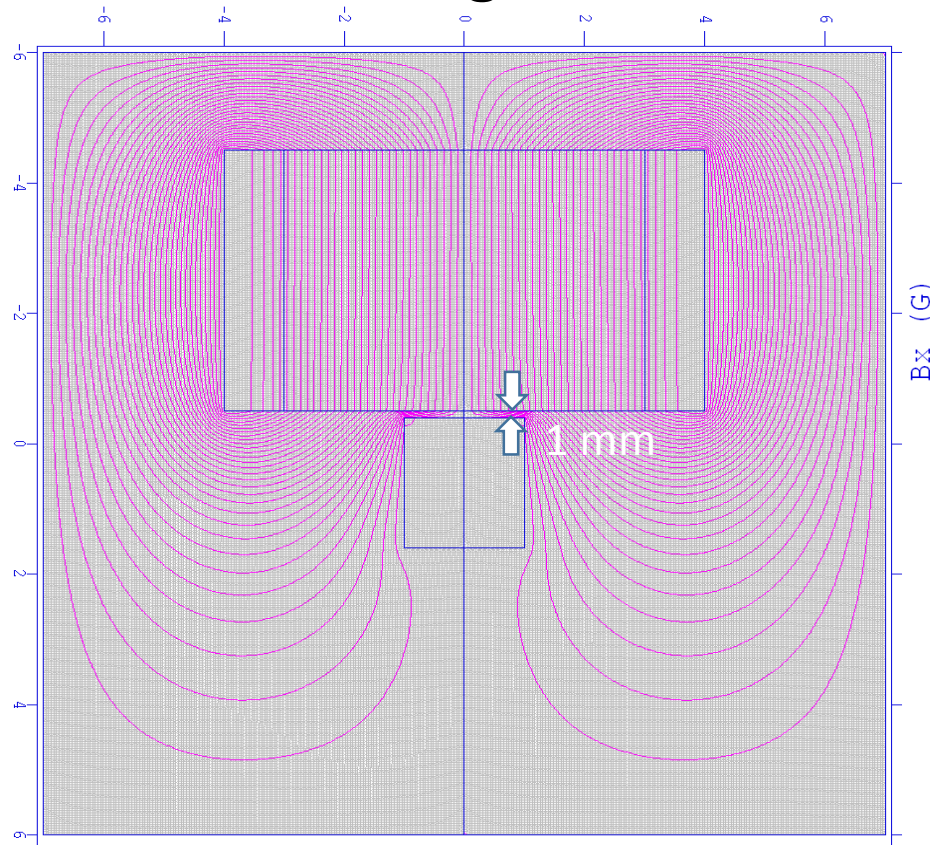


## SLS-2, including really really thin septum?



# Septum with 1-mm thick blade (3)

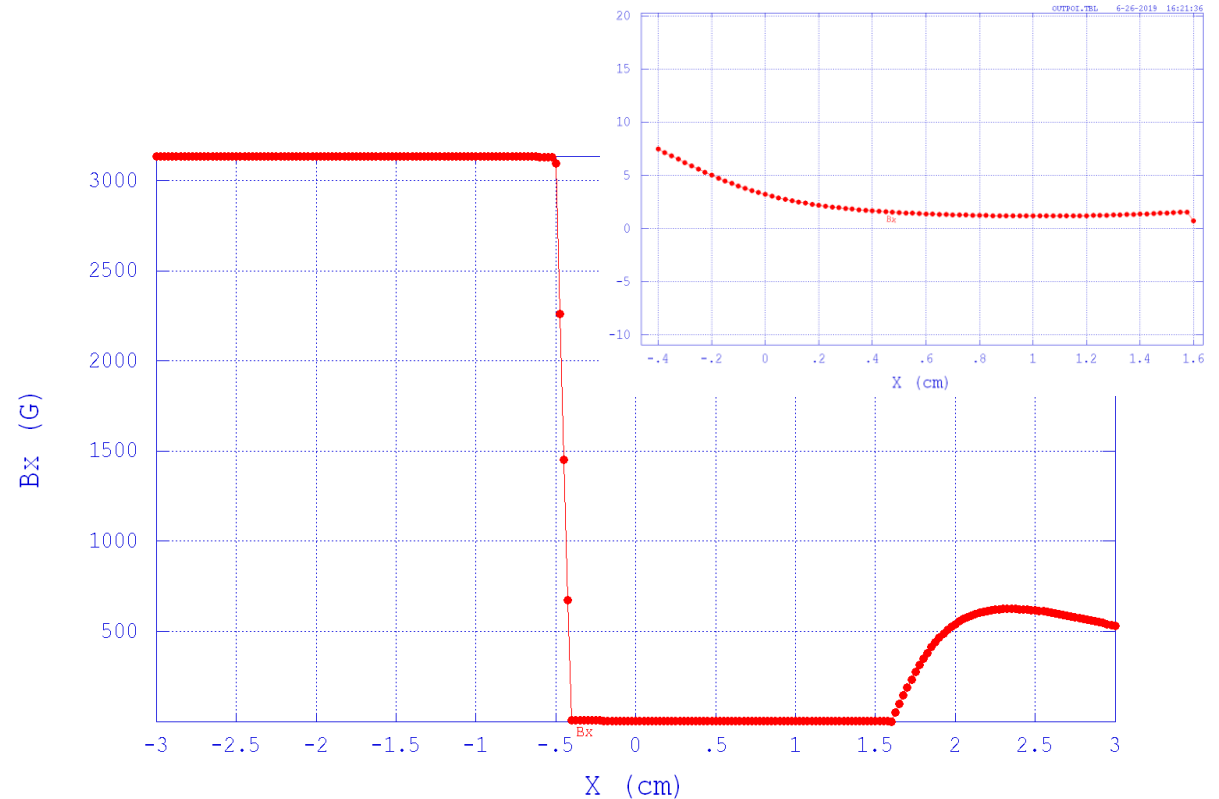
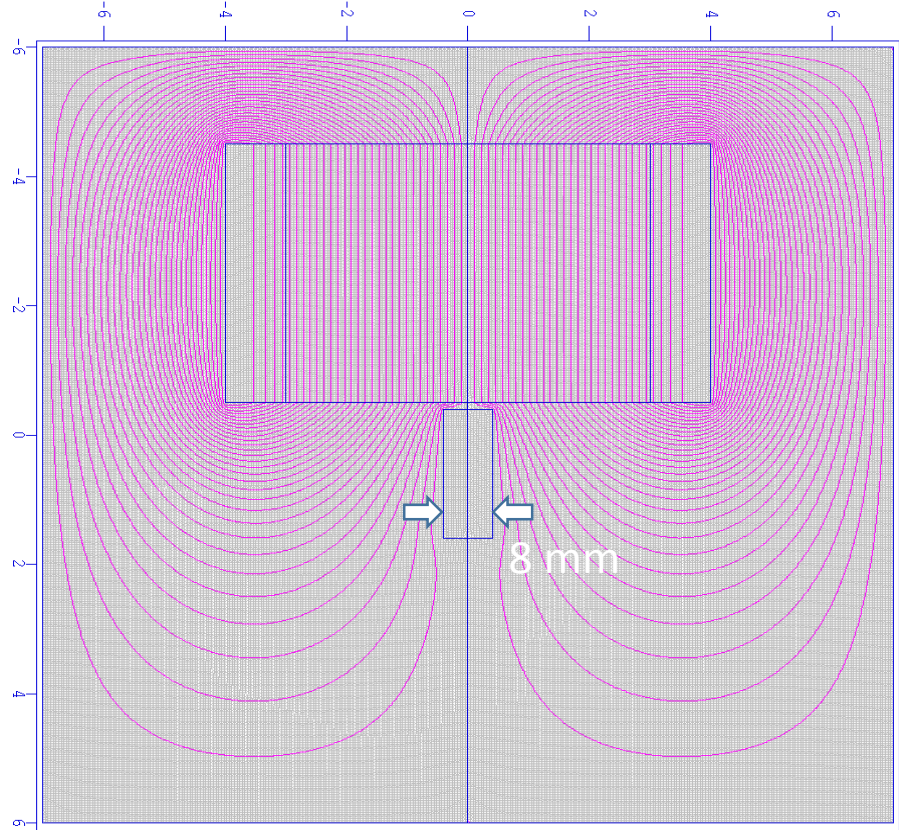
- Lamberton magnet



1-mm blade results in a significant leak field...

# Septum with 1-mm thick blade (3)

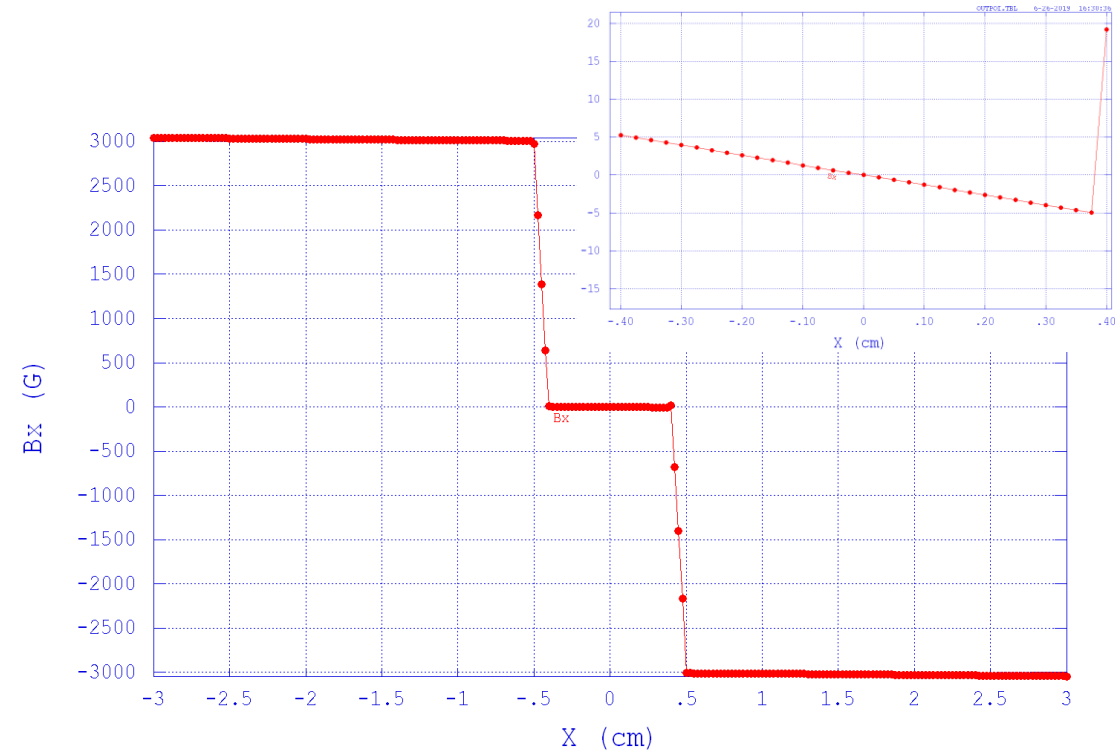
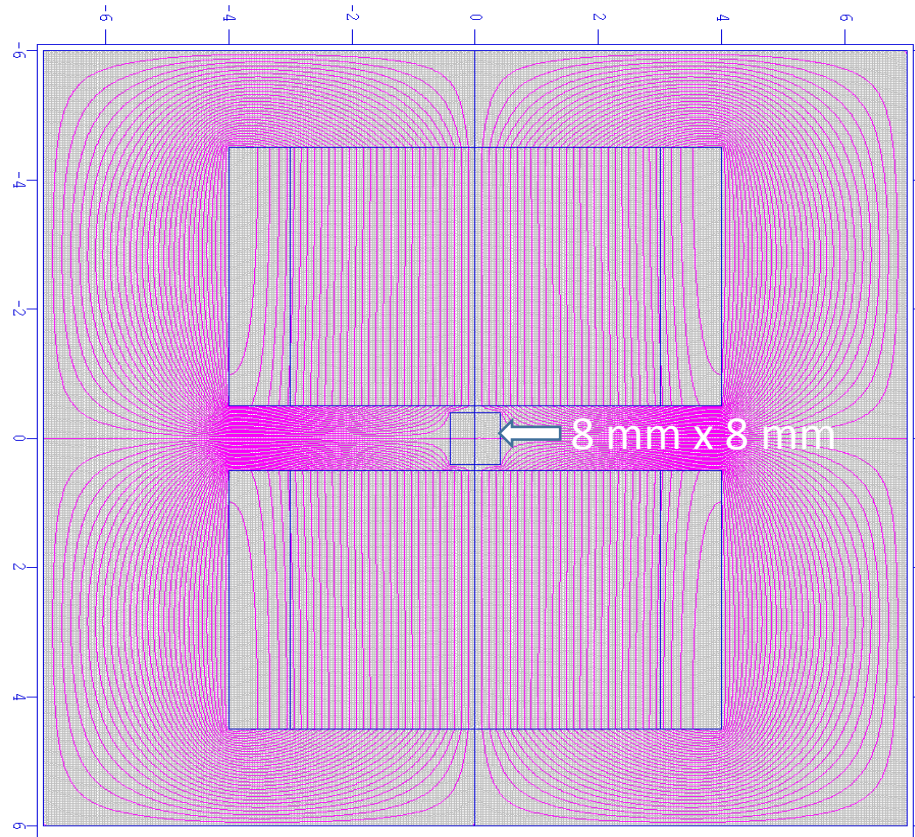
- Lambertson magnet



Leak field can be nicely suppressed by reducing the width of the hole

# Septum with 1-mm thick blade (3)

- Lambertson magnet



Leak field can be symmetrised/linearised:

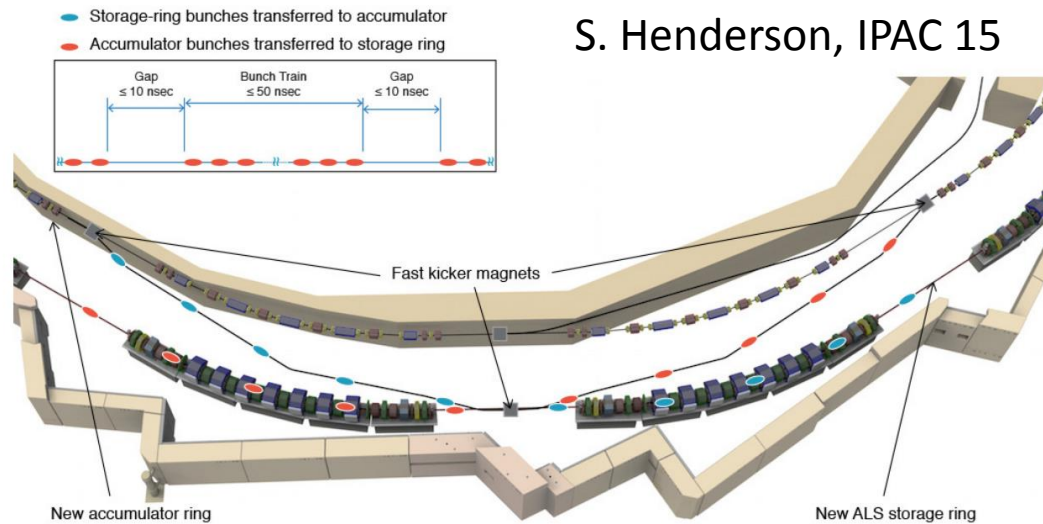
$B \sim 0.3$  T for injection beam

$B' \sim 0.1$  T/m for stored beam (cf. Lattice quads  $\sim 90$  T/m)

# On-axis injection (1)

- Swap-out injection

- Fully minimize the dynamic aperture required for the injection
- Plan of ALS-U, bunch-train swap-out injection, with an accumulator:



Long-pulse flat-top kicker

- APS-U plans a bunch-by-bunch swap-out injection



Short-pulse kicker  
(twice bunch spacing)

# On-axis injection (2)

- Longitudinal injection

- Injection *between* stored bunches
- Lattice acceptance requirement comparable to the one for Touschek lifetime

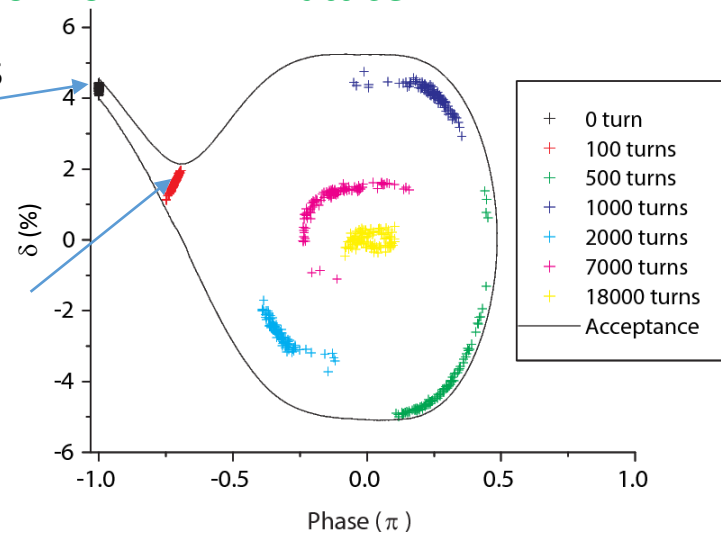


Very short-pulse kicker  
(>bunch spacing)

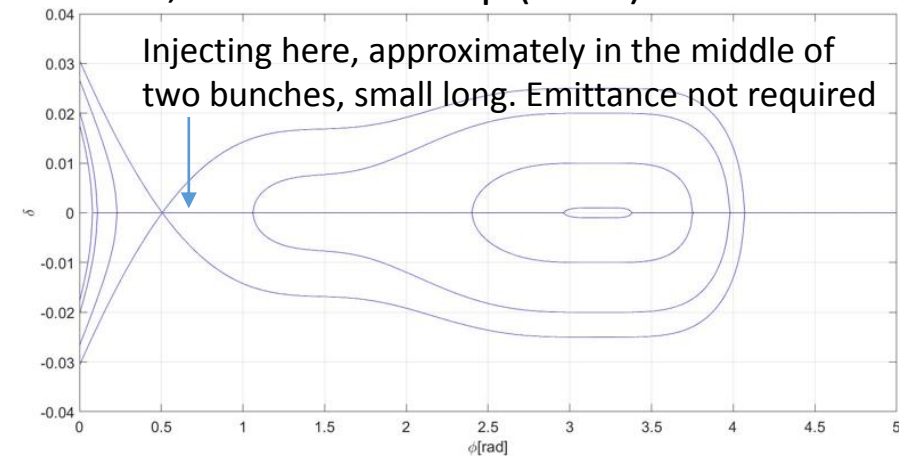
Simulation for MAX IV lattice

Injecting here requires small long. emittance

Injecting here requires a faster kicker fall time



RF bucket lengthening with 1st+2nd+3rd HC  
G. Xu, TWIIS workshop (2017)



Good also for lifetime!

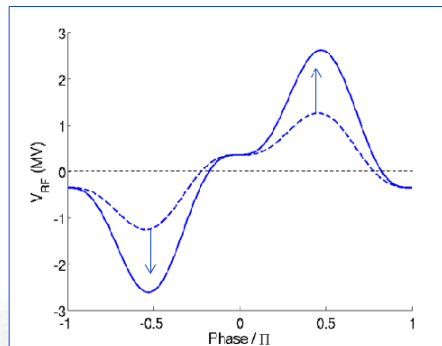
# On-axis injection (3)

## III. Longitudinal injection: new scheme

### ❑ Create a “longitudinal NLK”

= Additional RF pulse that will:

- Reduce the injected off-momentum deviation as quickly as possible and let enter the particles into the longitudinal bucket
- Keep the stored beam unaffected, in terms of centroid position and bunch length.



In practice, stored beam will be lengthened with the 3<sup>rd</sup> harmonic, which suggests that 3 HC already exists and can be also used for NLK scheme.

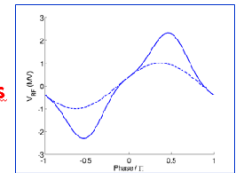
New total RF pulse

## III. Longitudinal injection: new scheme

### ❑ Effect of the “longitudinal NLK”

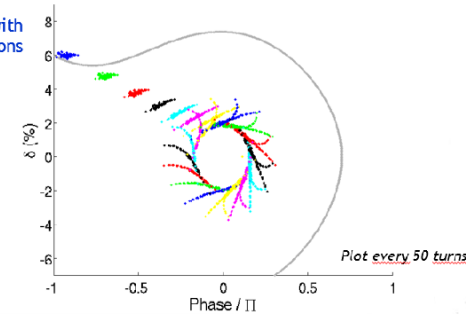
Simulate realistic injected beam from Booster:

Considering a basic MBA lattice for Booster with  $\varepsilon_x = \varepsilon_z = 10 \text{ nm}\cdot\text{rad}$ ,  $\sigma_s = 35 \text{ ps}$



- Switch on  $V_{RF \text{ add}} = 1 \text{ MV}$ ,
- Switch off when “mean phase” =  $\varphi_s$

Injected beam with adapted  $\beta$  functions



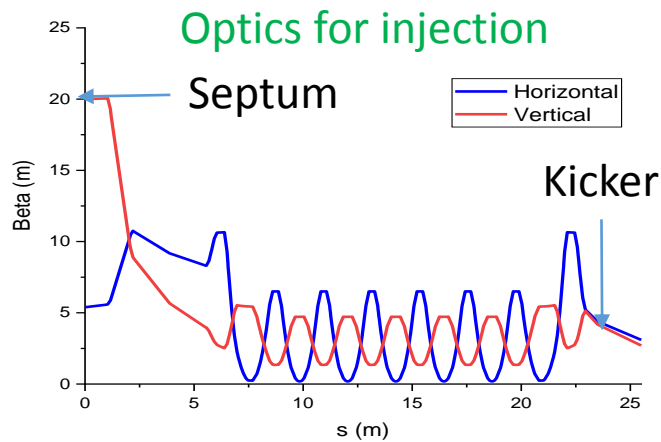
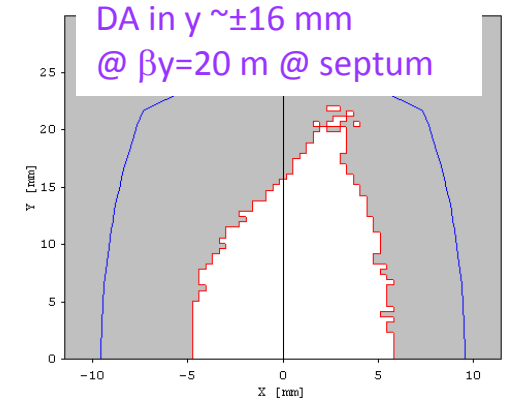
RF system enabling such gymnastics precisely



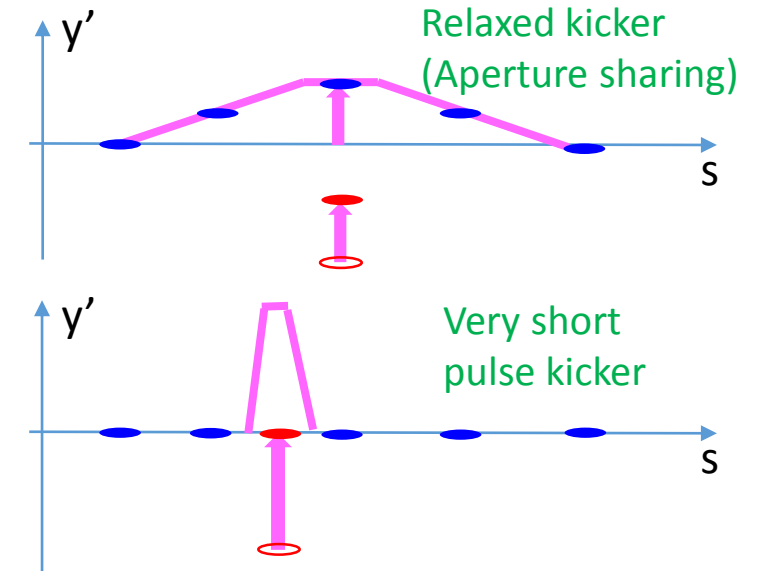
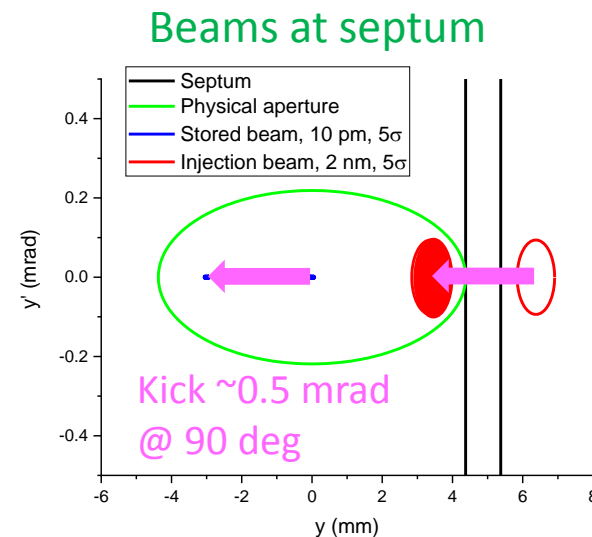
# Quasi-transparent, quasi-on-axis injection

- Ingredients

- Thin septum + Short pulse kicker, and no kicker bump!
- Injection in the vertical plane within the mini-gap horizontal undulators → Sufficient DA
- High-beta at septum and low-beta at IDs ← Pseudo-symmetry
- Aperture sharing
  - Rather weak kicker just to pull out the injection beam over the thin septum
  - Kicker pulse length can be significantly relaxed by allowing a minor disturbance to a few bunches
  - Kicker can be replaced by very short kicker when ready, realizing a fully transparent longitudinal injection




Septum: Thin Lambertson + Thick horizontal septum  
or Thin vertical septum + Thick Lambertson



## A few more R&D items

- Active harmonic cavity / Beam loading compensation cavity
  - To increase the effective bunch lengthening and the lifetime (not needed for a uniform filling)
- Compact undulator
  - (Quasi-)on-axis injection minimizes the injection beam oscillation, relaxing the good field region requirement
- Strong sextupoles and octupoles
  - Permanent magnet?

# Summary

- Injection into small aperture rings includes several difficulties
- They can be overcome by means of
  - Sophisticated linear and nonlinear optics
  - Very thin septum
  - Vertical off-axis injection
  - On-axis injections
- Several hardware R&Ds are suggested 

Thank you for your attention!

Acknowledgement:

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