BEAM INJECTION WITH A PULSED MULTIPOLE KICKER MAGNET FOR THE STORAGE RING OF HIGH BRILLIANCE SYNCHROTRON RADIATON SOURCE

Saroj Kumar Jena

A A Fakhri, A D Ghodke

RRCAT, Indore, India

Asian Forum for Accelerators and Detectors
16-18 March 2021

Outline

- Beam injection schemes into a high brightness synchrotron radiation source (HBSRS) of energy 6 GeV and emittance 150 pm. rad
- Description of pulsed multipole injection scheme
- Simulation study using ELEGANT
- Tolerance estimation
- Summary

Beam injection schemes

- Conventional injection (CI)
- Pulsed multipole injection (PMI)

Off –axis injection

- Longitudinal injection (LI)
- Swap out injection (SI)

On –axis injection

Drawbacks of conventional

Difficulty in perfectly closing the local orbit bump

During top-up injection, stored beam perturbs and photon beam intensity modulates

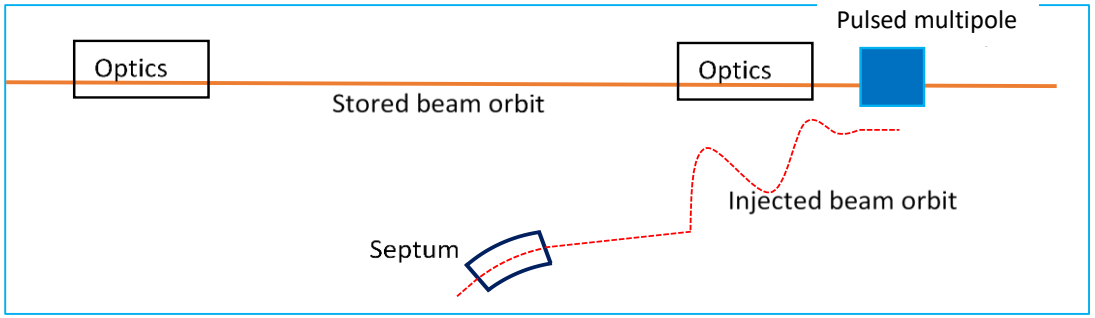
Constraints in MBA type lattice

- ❖ Reduced dynamic aperture
- ❖ Essential top-up injection

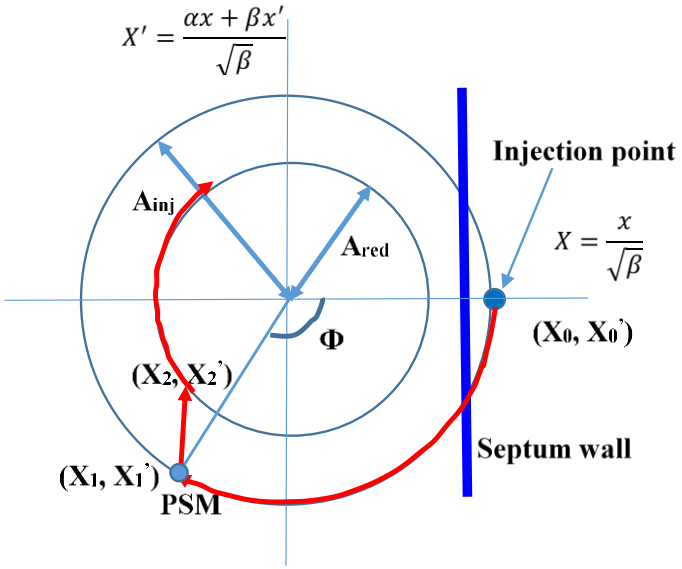
→ PMI, LI and SI are best suitable injection schemes

Pulsed multipole injection

The injected bunch passes through a pulsed sextupole magnet (PSM) or non linear kicker (NLK), with an offset from its center while the circulating bunch pass through the center.



B_y=0 at x=0 , does not kick the stored beam



H. Takaki, et al., PRST AB, 13, (2010)

The location of PSM is crucial in this injection scheme and optimized using simulation code to achieve minimum kicker strength and good capture of injected beam.

The phase advance of the PSM from the injection point (IP) and horizontal beta function plays the crucial role in deciding the PSM location.

Implemented in KEK-PF and MAX-IV and planned in several storage rings

Assumed operation Scheme of HBSRS

200 MeV Linac

↓

Booster Synchrotron

Ramping from 200 MeV to 6 GeV
Rep. rate: 1 -2 Hz
Emittance: 5 nm rad

6 GeV Storage Ring

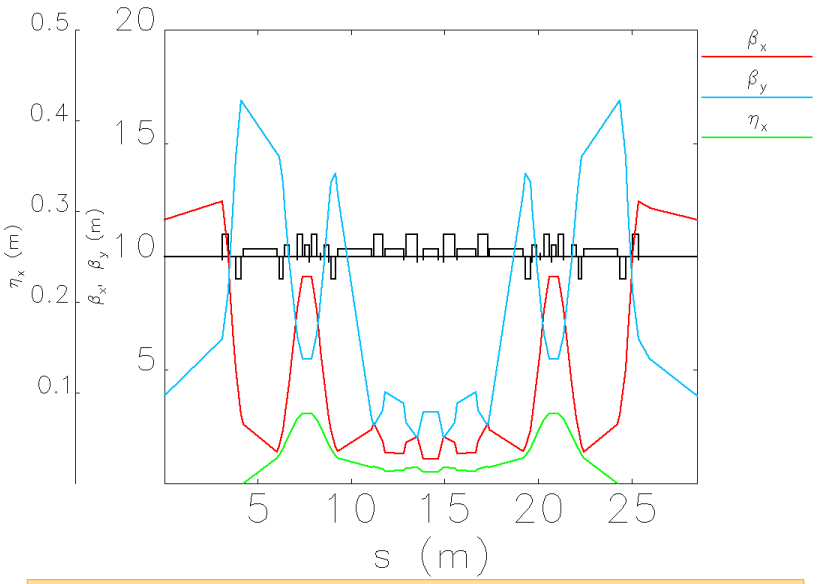
Emittance:150 pm rad
Lattice structure: 7 BA
Top-Up Injection
Filling pattern (h=1520)

High resolution mode (single bunch & 10 bunches)
High brightness mode (1000 bunches)

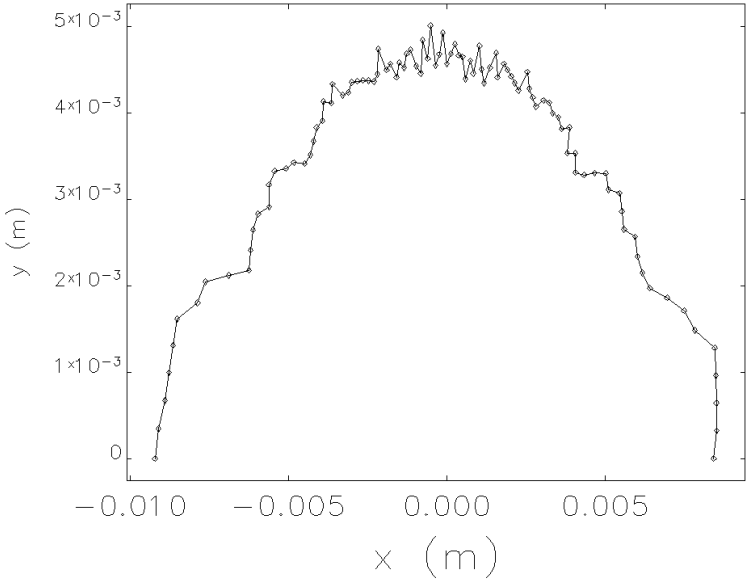
The lattice of Storage ring of HBSRS

Beam Energy	6.0 GeV
RF frequency	500 MHz
Circulating beam current	200 mA
Circumference	911.8 m
Number of straight sections	32
Length of straight section	6.0 m
Betatron tunes (horizontal / vertical)	74.147 / 24.212
Horizontal emittance	150 pm-rad

A. D. Ghodke, et al., InPAC 2019



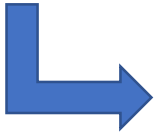
The lattice layout and twiss function for a unit cell of the storage ring of HBSRS.



The dynamic aperture (DA) of bare lattice for on momentum particle at the IP of storage ring. This promises off-axis injection.

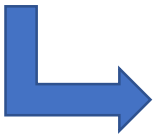
Location of PSM kicker

Option 1: Septum and PSM placed in injection straight



Difficult to place, because of insufficient phase advance between IP and PSM

Option 2: Septum and PSM placed in different straight section



PSM is placed at beginning of 2^{nd} straight section, (25.6 m away from IP). This provides proper horizontal phase advance (odd integer multiple of $\pi/4$).

Injection process using PSM

Injected beam is assumed from a booster of emittance 5 nm-rad and energy spread of 0.125 %.

The separation between injected beam and stored beam is decided by

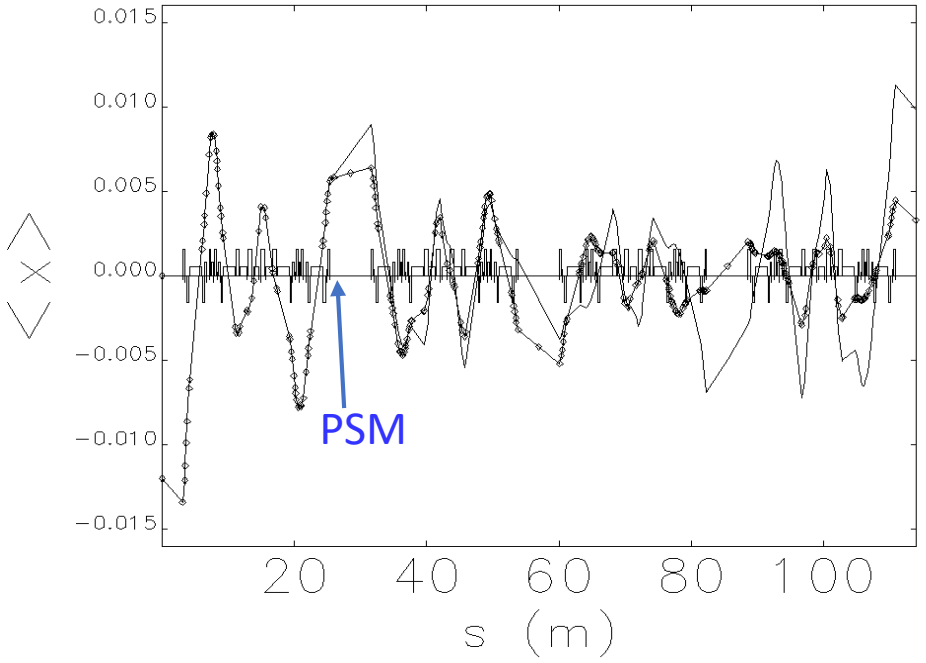
$$\Delta x_{sep} = 3\sigma_{inj} + s_a + x_{cod} + th_{sep}$$

- $3\sigma_{inj}$: Injected beam size
- s_a: Aperture required for stored beam
- x_{cod}: COD error
- th_{sep}: Septum thickness

The angle of injected beam is optimized as -0.45 mrad.

Thus the beam is injected into storage ring at IP with (x, x')=(-12 mm, -0.45 mrad)

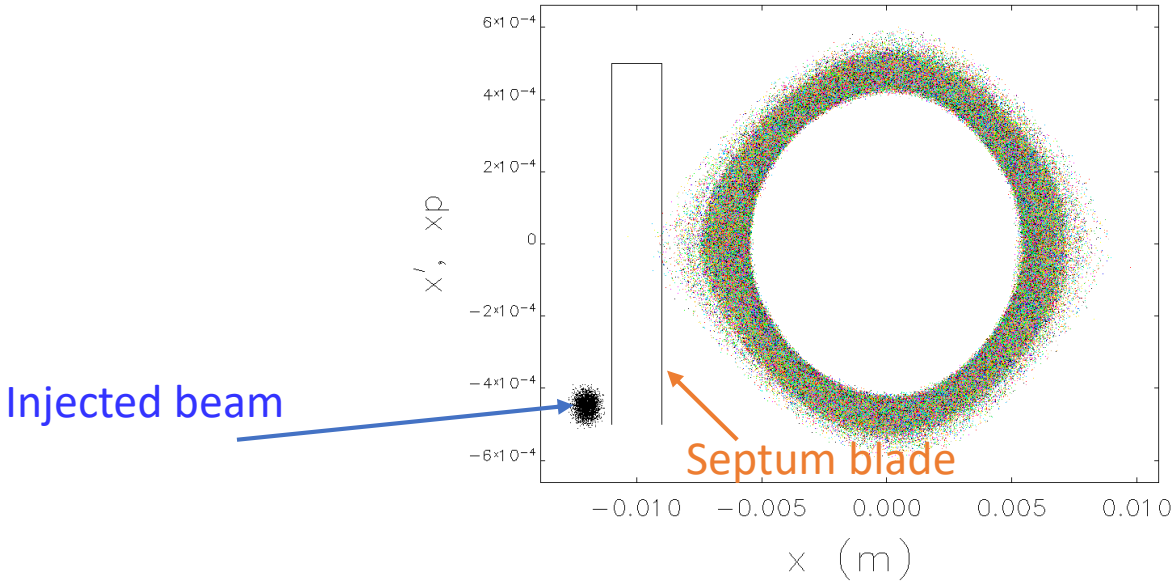
The optimized strength of the PSM is estimated as 75 m^{-2} and this corresponds to sextupole gradient of 3000 T/m^2. This required gradient is less than the strongest sextupole found in the storage ring lattice



The centroid of injected beam trajectory with PSM OFF (solid line) and ON (solid line + symbol)

Multiparticle tracking simulation using ELEGANT

An ensemble of 3000 particles were generated with injected beam parameters and tracked for 212 turn (1 synchrotron oscillation period) including SR effects (radiation damping & quantum excitation).

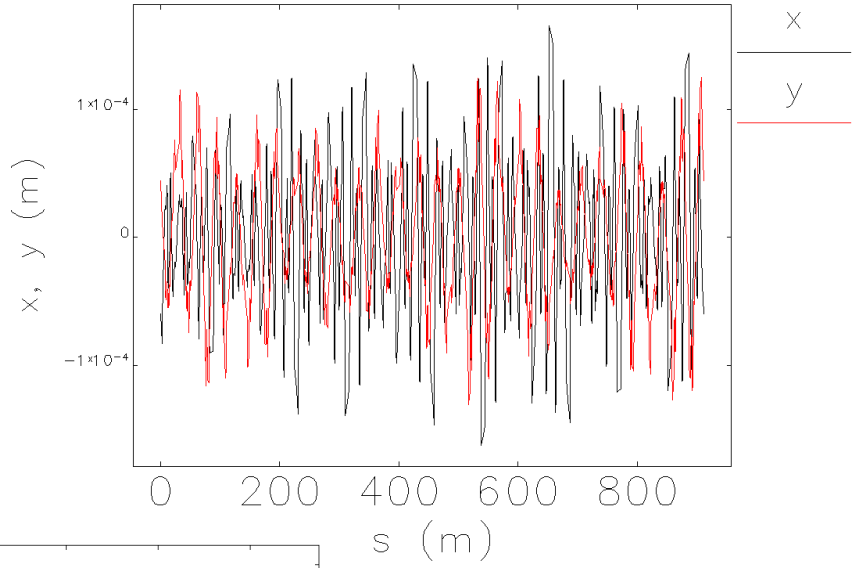


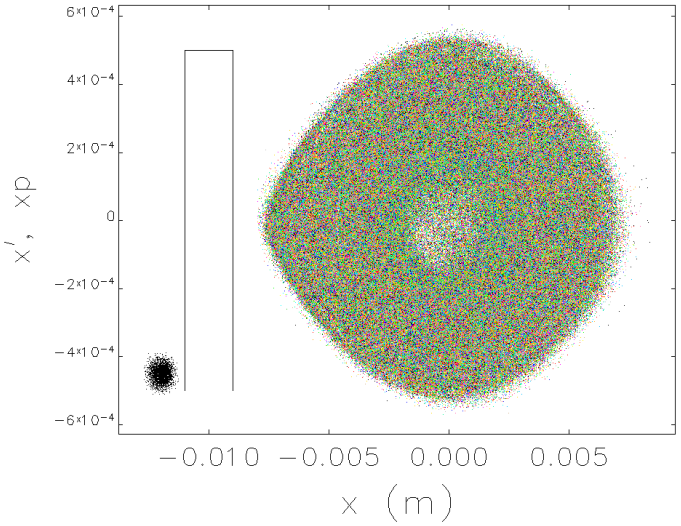
Injection process for the first 212 turns and capture of injected beam in storage ring acceptance

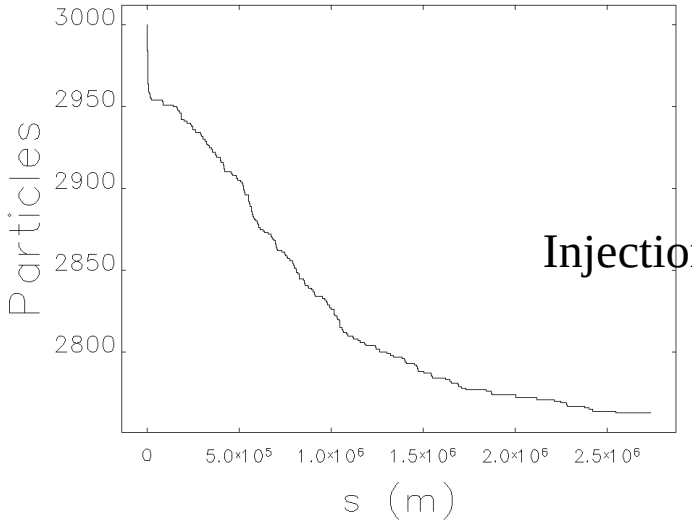
Injection tracking with errors in the ring

Misalignment and magnetic field errors are introduced in all dipoles, quadrupoles, and sextupoles magnets such that, the generated COD is ~ ± 100 μm. This also produces residual beta-beating of 1 % RMS.

With this, particles were tracked for 3000 turns (~ 1 damping time).



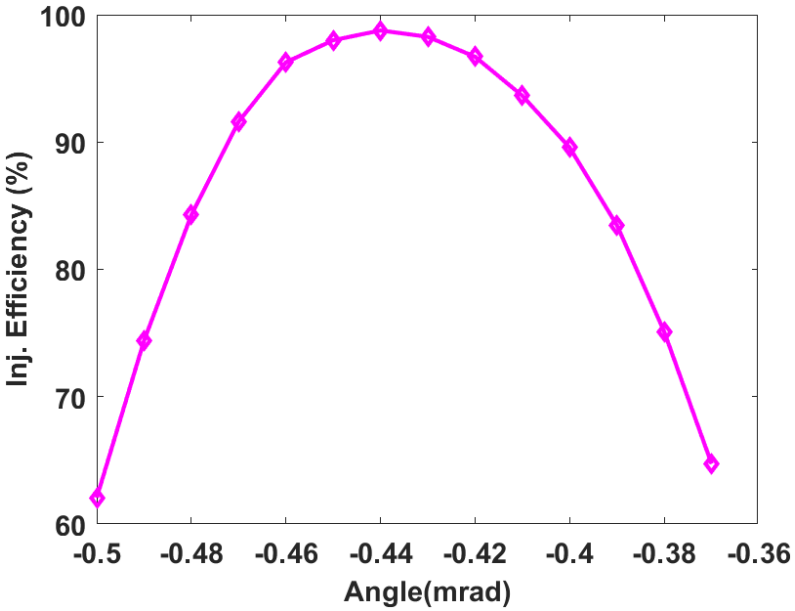




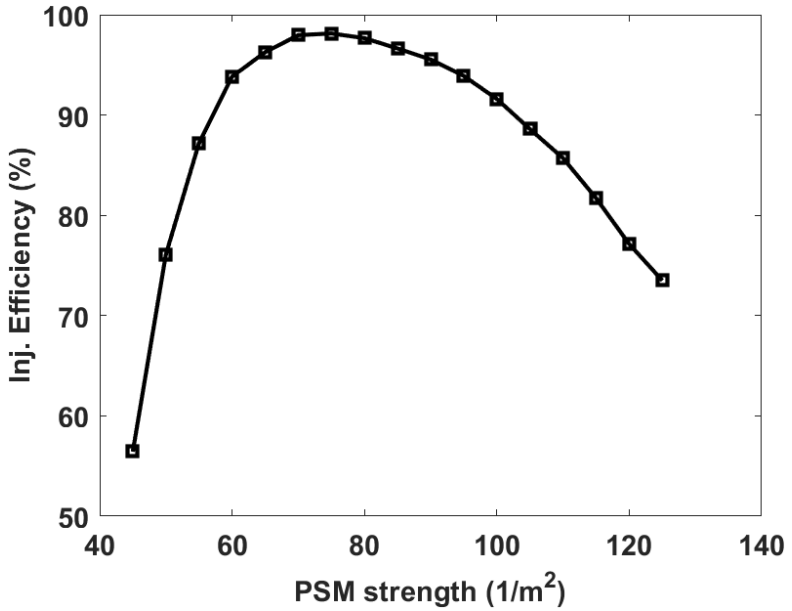
Injection efficiency : ~ 92%

Tolerance estimation

Injected beam angle Vs. inj. efficiency



PSM strength Vs. inj. efficiency



Injection angle plays a crucial role and for a narrow tolerable angle of ≤ 0.03 mrad, injection efficiency above 90 % can be achieved.

For a wide range of PSM strength between 70-95 m^{-2}, the injection efficiency of more than 90 % can be achieved.

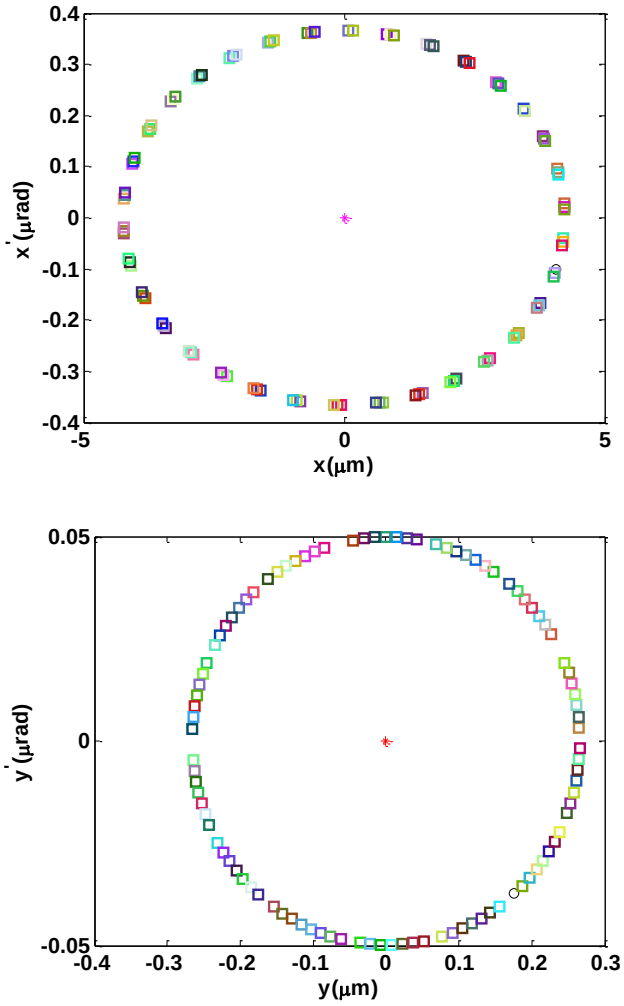
Increase of the injected beam emittance reduces the injection efficiency due to nonlinearity of the kick at the injected beam location

Influence of PSM on stored beam

The stored beam has a finite beam size [41 μm (H) X 3 μm (V)]. In case of PSM center is not perfectly aligned to the design orbit, stored beam will receive some kicks from the PSM and lead to perturbation.

The estimated misalignment tolerance of PSM is found to be 80 μm in horizontal plane and 10 μm in vertical plane to restrict the stored beam oscillation within limit of 10% of beam size.

Thus, it is important to align the PSM exactly to the stored beam to avoid disturbance of stored beam while pulsing the PSM. ***Beam based alignment*** of PSM is essential to make this beam injection scheme transparent to users.



Stored beam motion in horizontal and vertical phase space with PSM misaligned

Plan for improving injection efficiency

Position and angle stability of injected beam at IP by measuring both of them using 16 button electrode BPM in injection straight

Beam collimation (if required) in transport line

Improvement of dynamic aperture

Beta beat correction

Advantages of PMI

Much simpler to operate with only one kicker

Less required space

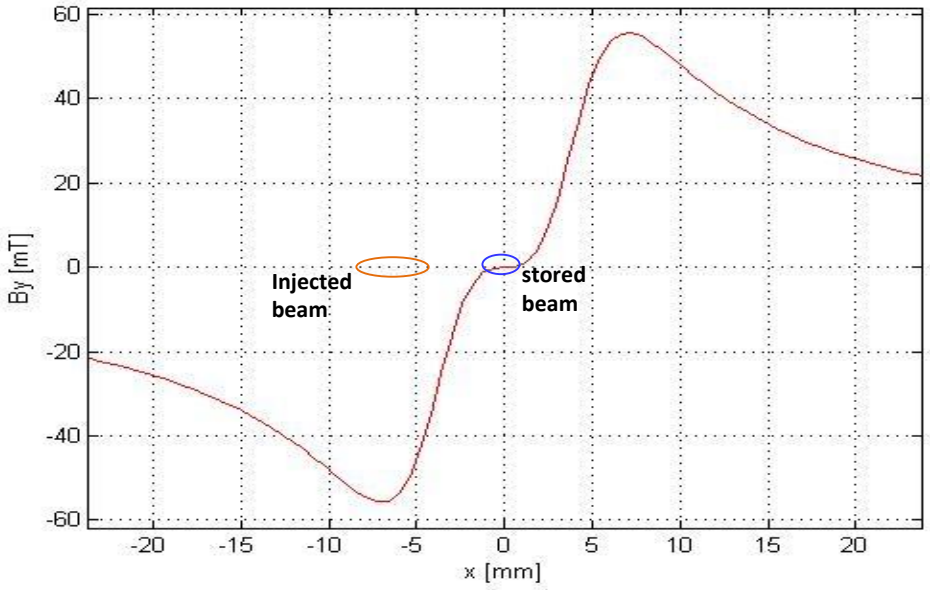
Very small perturbation to the stored beam

But

For high injection efficiency, small injected beam emittance is required. To cater this, non linear kicker (NLK) has been conceptualized and proposed in several light sources.

Non Linear kicker (NLK)

NLK provides flat zero field at center and flat maximum field at the injected beam location



NLK kicks the injected beam off-axis inside the dynamic aperture of the storage ring, while providing minimal perturbation to the stored beam

MAX-IV and SIRIUS has deployed and planned in several light sources to be upgraded

Patrick Alexandre, et al., NIM A (2021)
L. Liu, et al., IPAC 2016

The location of NLK will be the same as in PSM in the storage ring

Summary and outlook

Simulation studies of beam injection using PSM shows promising results.

This scheme demands tight tolerance on injected beam angle

This requires alignment of the PSM with high precision (BBA).

Further studies will be carried out using NLK

Alternative injection schemes are under study

Thanks for kind attention