A Review on Injection Schemes

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Introduction

- Top-up operation mode has become standard for the third generation light source (3GLS)
- Challenges in 4GLS/MBA storage ring
  - Smaller physical/dynamic aperture
  - Smaller beam size (Transparency)
- New injection schemes and many variants have been studied and developed
- Top-up injection in 4GLS and the future machine?

Prerequisite for successful injection (1)

- Quality injection beam
  - Low emittance booster, or ideally a full-energy linac if affordable
  - Emittance manipulations [1] in the booster; no cost!
  - RF gymnastics to shorten the bunch?

Emittance equalization in ESRF booster [2]

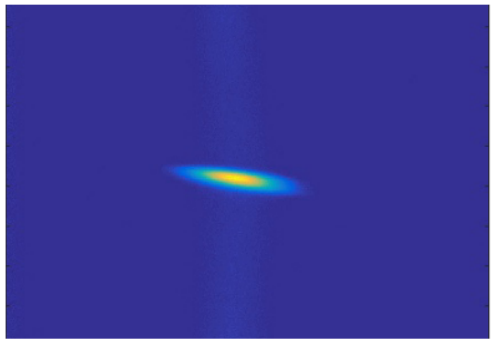


Figure 7: Beam size image with nominal booster setting (setting 1).

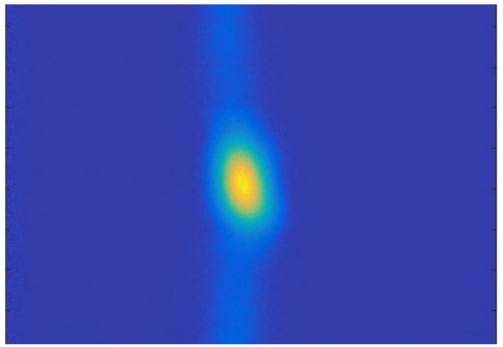
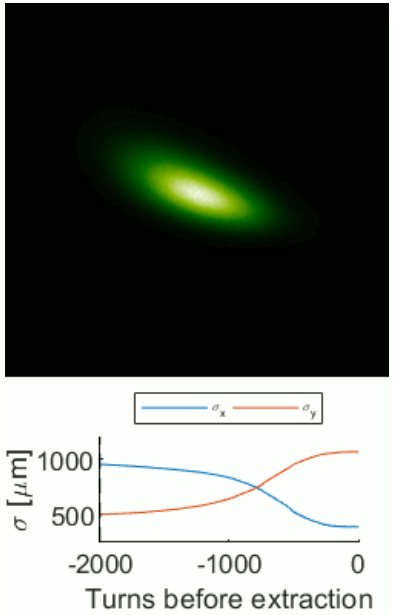


Figure 8: Beam size image with maximum emittance reduction (setting 4).

Emittance exchange in SLS booster [3]



[1] P. Kuske and F. Kramer, IPAC'16
[2] N. Carmignani et al., IPAC'18
[3] J. Kallestrup and M. Aiba, PRAB **23**, 020701

Prerequisite for successful injection (2)

- Thin septum
  - Two stage septum, “thick and thin”, pioneered by ALS (and proton machines), is becoming a standard design for the new machine

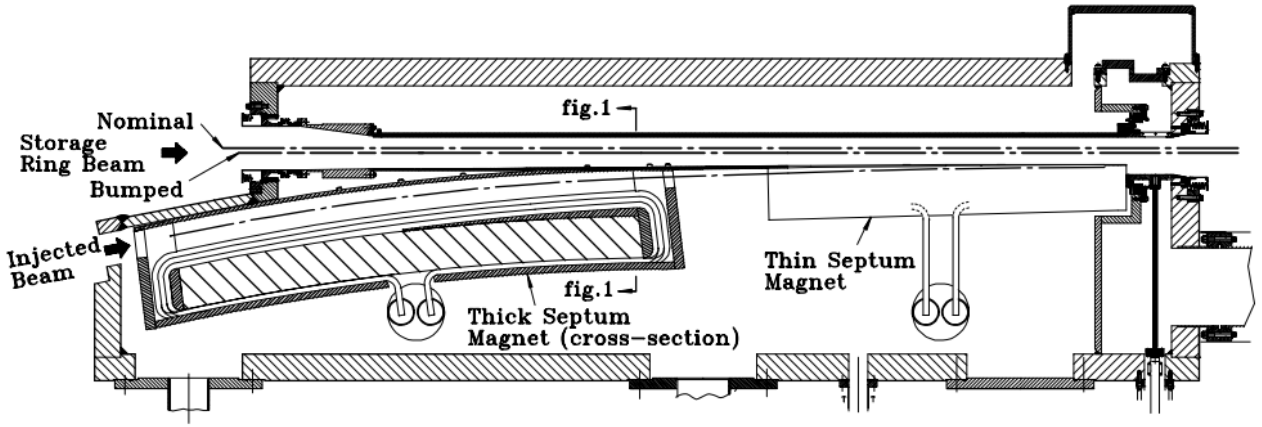


Figure 2: Injection Septum Magnet Layout, Top View

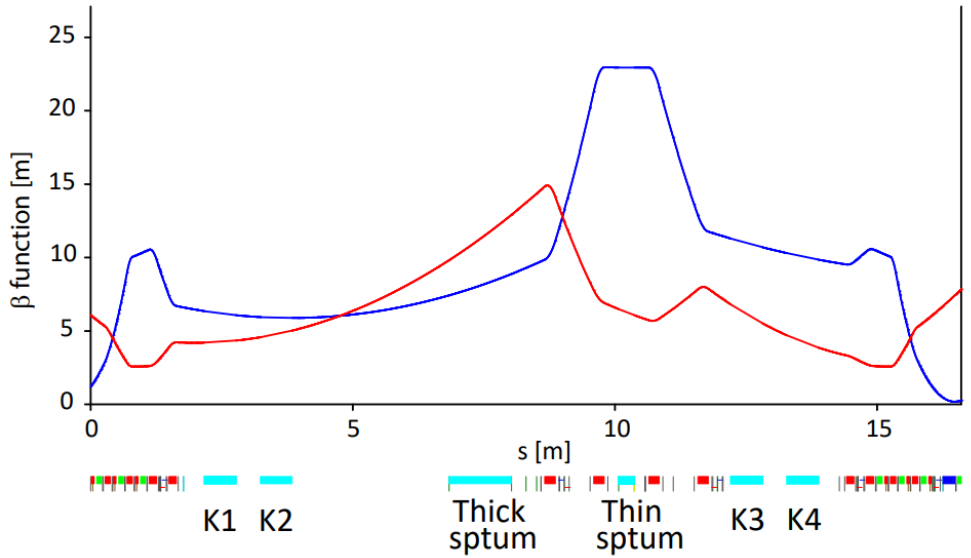
Ref. D. Shuman et al., IPAC’2005

Prerequisite for successful injection (3)

- Twiss parameter at the septum
  - Larger beta function magnifies the dynamic aperture and makes the effective septum thickness thinner

SLS 2.0 injection straight

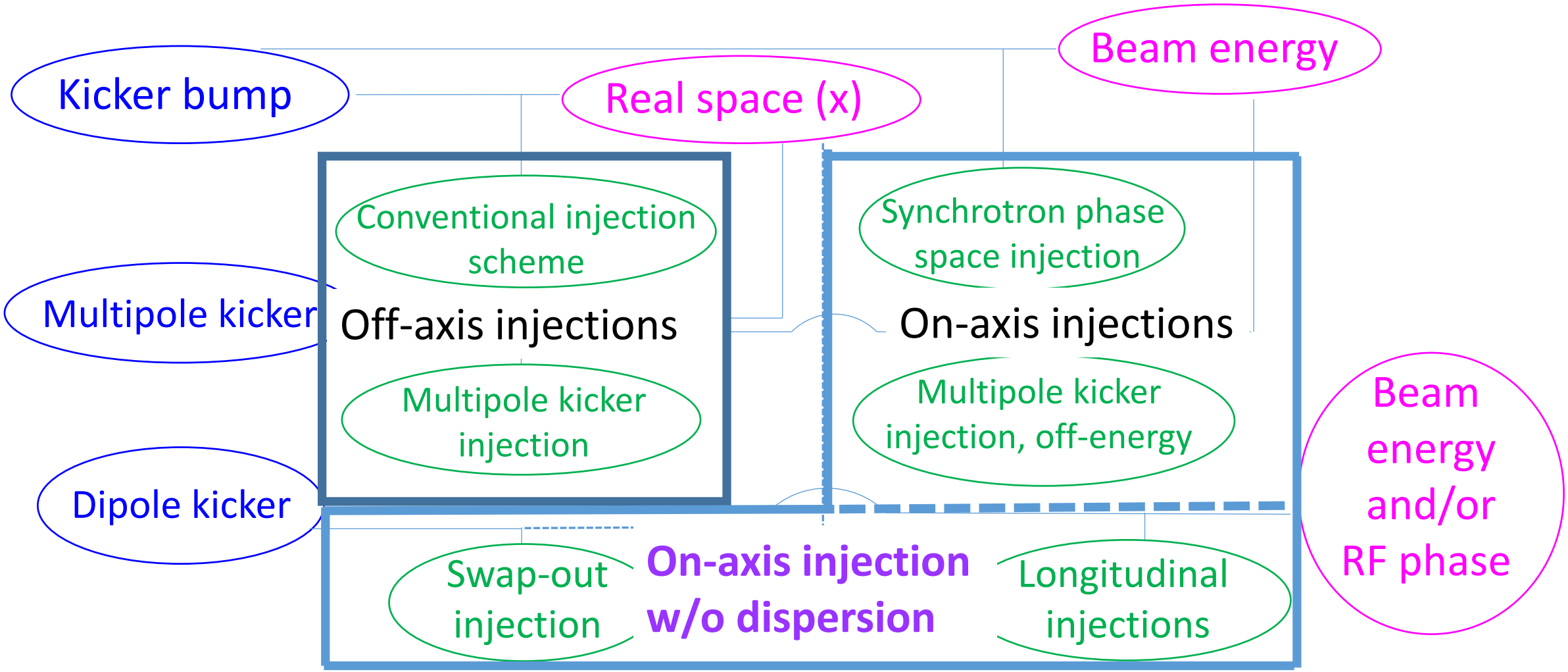
- "Pseudosymmetry" to push the on-energy superperiodicity to the number of arcs
- Beta function at the septum is increased while the phase advances along the straight are adjusted to the values that are common to all straights



A variety of injection schemes (1)

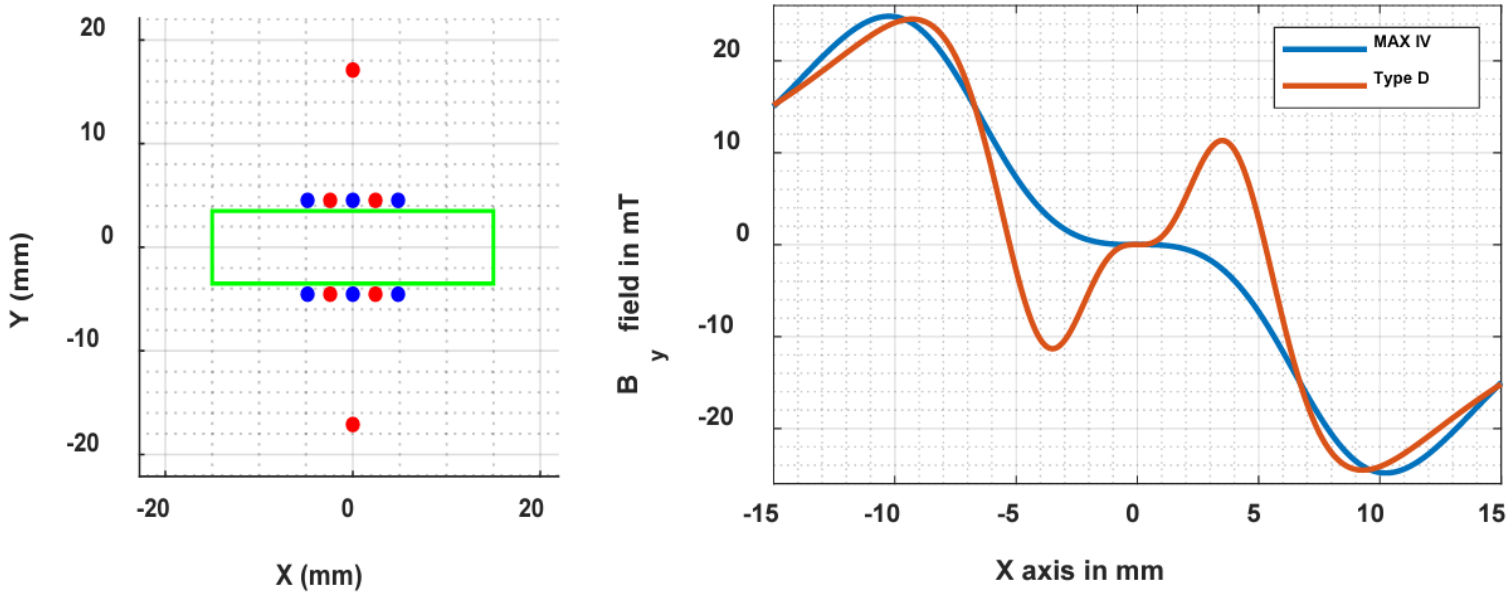
- Top-up injection scheme = Beam separation × Type of kicker
  - Example: Kicker-bump injection = Separation in real space × Dipole kickers
  - Injection beam has to be separated from the stored beam, at least, in one of 6 coordinates [x, x’, y, y’, t, p] at the time of injection (Liouville’s theorem)
  - Various types of kicker are available (dipole, quadrupole, multipole, cavity, etc.)

A variety of injection schemes (2)



Recent kicker development (1)

- In-vacuum nonlinear kicker at Soleil
  - Field peak close to the closed orbit (≈3.5 mm)



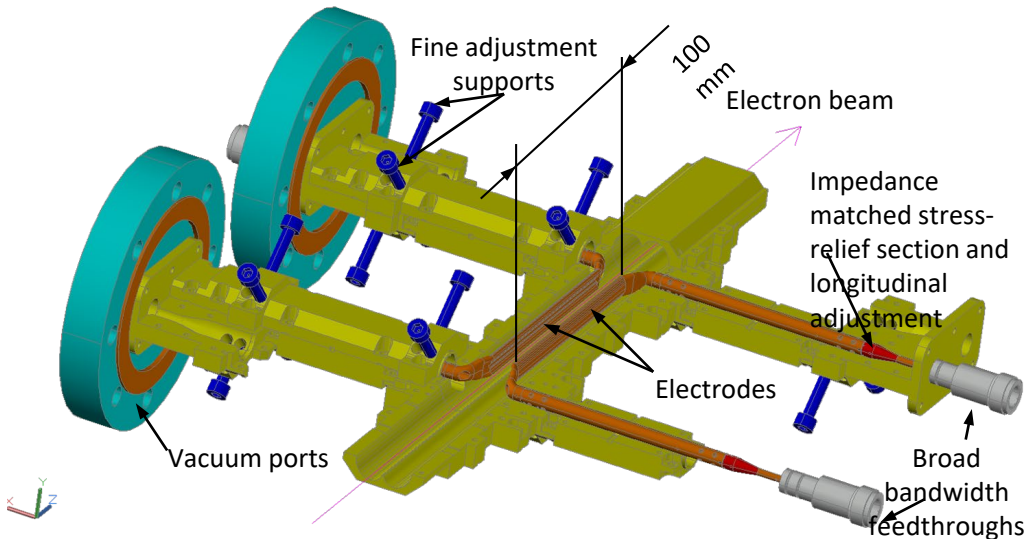
Ref: P. Alexandre, IPAC'23

Recent kicker development (2)

- Nano-second kicker
  - Low pulser voltage design for reliability

Table 2: Derived and Chosen Kicker System Parameters

Parameter	Fast	Super-fast
Deflection type	Electromagnetic (TEM)	
Kicker type	Stripline (vacuum)	
Kicker section length	100 mm	
Number of sections	8	
Maximum deflection	0.5 mrad	1.0 mrad
Magnetic field	2.8 mT	5.7 mT
Electric field	0.9 MV/m	1.7 MV/m
Electrode voltage	±4.3 kV	±8.5 kV
Electrode current	±85 A	±170 A
Excitation pulse length	<30 ns	~1 ns
Odd / Even el. impedance	2x 50.0 Ω / 2x 56.0 Ω	



Single section kicker geometry
3D CAD model (Prototype)

Ref: M. Paraliev et al., IPAC'21

Additional kicker

- Additional kickers to compensate for a bump non-closure at SPring-8 [1]
- In general, a second kicker at the right betatron phase could compensate for the disturbance due to the injection kicker

Transverse deflecting cavities, an injection kicker + an additional kicker [2]

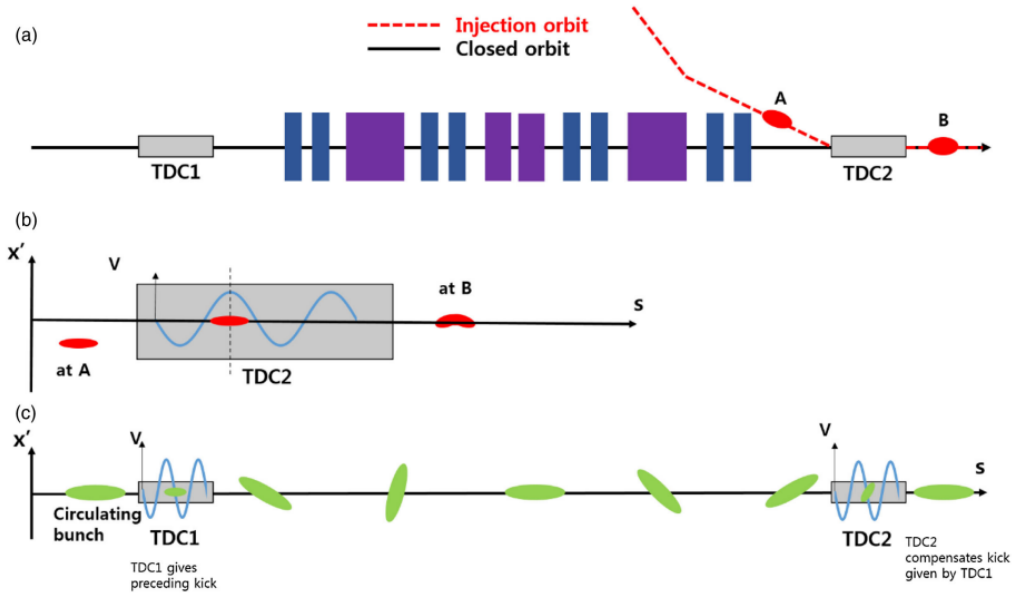


FIG. 2. Schematics for the working principle of on-axis injection with two deflecting cavities. (a)-(b) The second TDC kicks the injected beam on-axis. (c) The two TDCs crab and uncrab the stored beam (circulating bunch).

[1] C. Mitsuda, TWIIS workshop 2017

[2] J. Kim et al., PRAB 22 011601

Where are we going?

Kicker-bump injection

Most 3GLS
ESRF-EBS
ELETTRA II
etc.

Multipole/Nonlinear kicker

MAX IV
Sirius
Soleil II
etc.

Swap-out

ALS-U
APS-U
HEPS
etc.

Short pulse kicker
(Aperture sharing, Long. Inj.)

SLS 2.0
Diamond II
PETRA IV
etc.

The optimum injection scheme may depend on each storage ring as well as the demands of the beamline users

* Free images from pixabay.com

Collective effect during injection

- High bunch current operation modes
  - Even though the instability itself is stable, transient effects can lead to a beam loss

Simulation for APS-U

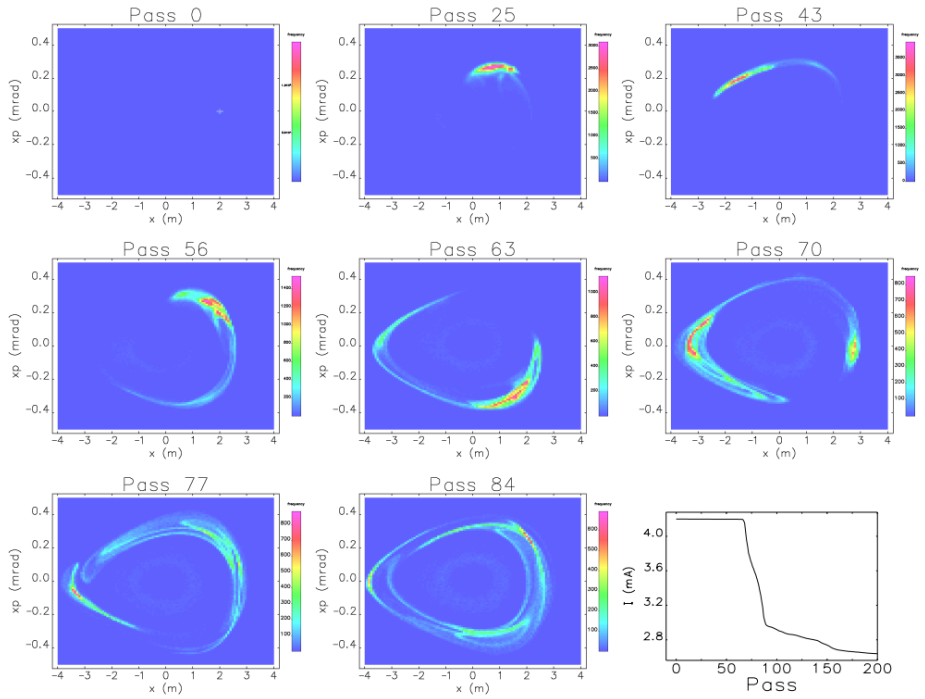


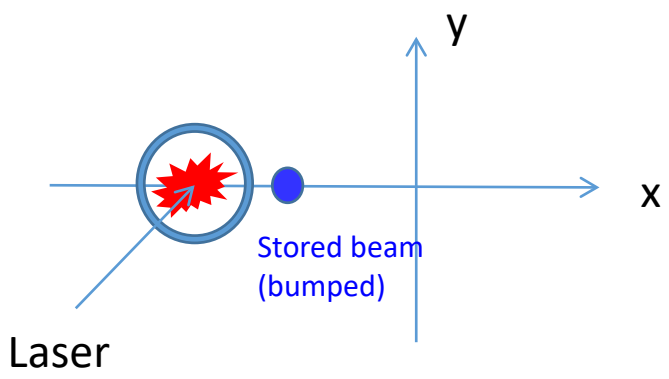
Figure 1: Horizontal phase space plots of the stored bunch after a top-up shot at Pass 0.

R. Lindberg, M. Borland and A. Blednykh, NAPAC'2016

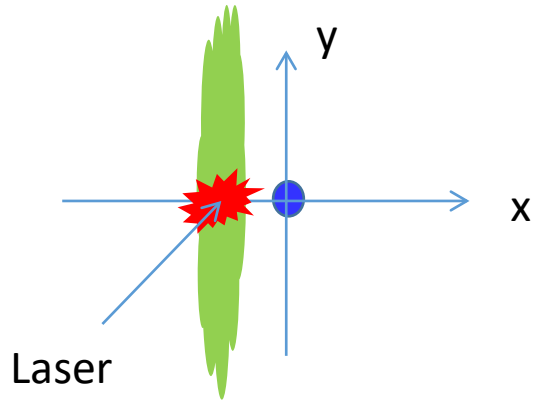
Direct generation??

- Electron beam can be generated within the storage ring with the laser wake plasma?
  - The beam parameters are almost compatible with the storage ring acceptance; transverse emittance of a few mm.mrad and energy spread of several %
  - Beam charge reproduciability is not very important

In-vacuum capillary + Kicker-bump



Gas jet at the vicinity of the closed orbit?



Totally unfeasible or our future option?

Summary

- New injection schemes and many variants have been studied and developed in the scope of 4GLS
- Technology is (getting) ready for new schemes
  - One can select “optimum scheme”, which is compatible with the designed storage ring and the demands of the users
  - Multiple implementation may be considered

    (e.g. SLS 2.0 Kicker bump and Aperture sharing)
- Not all possibilities have yet been explored