

# Injection/extraction systems and methods for ultra-low emittance rings (Developments in light sources)

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Nano Beam Technologies  
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# Introduction

- Synergy among collider, damping ring and light source communities
  - We meet at Low Emittance Ring Workshops supported by TIARA, EuCARD-2 and ARIES → IFAST
  - Damping ring and light source are quite similar machines
  - Developments for the present and new generation light source would be useful for the other communities as well

# CLIC damping ring, SLS and SLS2

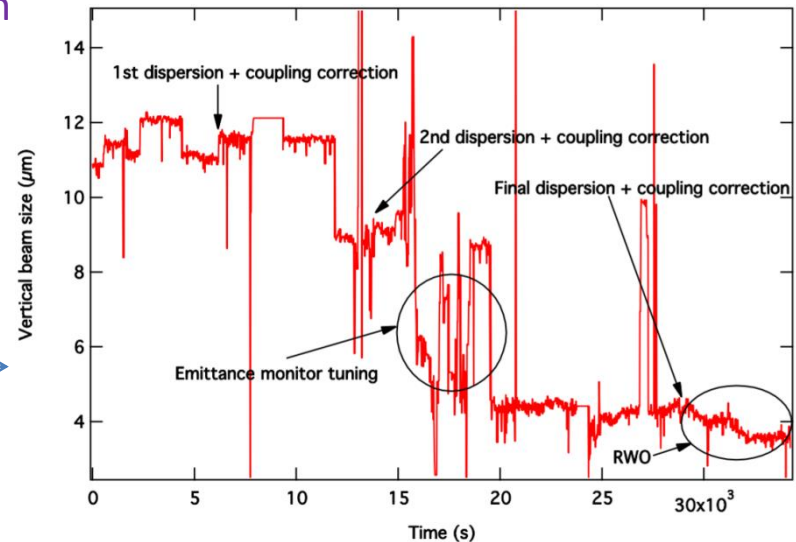
| Parameters                  | CLIC DR     | SLS         | SLS2        |
|-----------------------------|-------------|-------------|-------------|
| Beam energy (GeV)           | 2.86        | 2.41        | 2.7         |
| Circumference (m)           | 427.5       | 288         | 288         |
| Bunch population ( $10^9$ ) | 4.1         | 6.1         | 5.2         |
| Lattice structure           | TME/FODO    | TBA         | 7BA /LGB-RB |
| Betatron tune, H/V          | 48.35/10.40 | 20.43/8.74  | 39.37/15.23 |
| Uncorr. Chromaticity, H/V   | -115/-85    | -67.3/-22.2 | -99/-33.4   |
| Norm. emittance, H/V (nm)   | 456/4.8     | 26000/47    | 708/53      |
| Energy loss per turn (MeV)  | 4           | 0.55        | 0.89        |
| Damping time, H/V/L (ms)    | 2/2/1       | 8.7/8.7/4.3 | 3.6/5.8/4.3 |
| Momentum compaction         | 1.30E-04    | 6.04E-04    | 1.04E-04    |
| Energy spread ( $10^{-3}$ ) | 1           | 0.88        | 1.04        |
| Rf frequency (GHz)          | 1 or 2      | 0.5         | 0.5         |

- Emittance lowered by damping wigglers in CLIC DR while by MBA in SLS2
- However, most parameters are on the same order of magnitude
- SLS vertical emittance is set to 10 pm (geometrical) during operation and can be tuned down to 1 pm (!)

# Vertical emittance tuning at SLS

- Tuning in 2011, achieving  $\sim 1$  pm (the requirement for damping rings and the collider, e.g., FCC-ee)
  - Analysis of the latest survey data
    - 30  $\mu\text{m}$  rms elem.-to-elem.
  - Beam Assisted Girder Alignment
    - 50  $\mu\text{m}$  rms girder-to-girder initially  $\rightarrow$  Some vertical correctors strongly excited
    - Remote girder alignment with stored beam and fast orbit feedback running  $\rightarrow$  Immediate online confirmation
  - Systematic correction based on LOCO approach
  - Empirical tuning, e.g., random optimization

Measured vertical beam size during the tuning



Emittance ratio of  $\sim 0.0002$  is achieved!



Ultra low vertical emittance at SLS through systematic and random optimization<sup>2</sup>

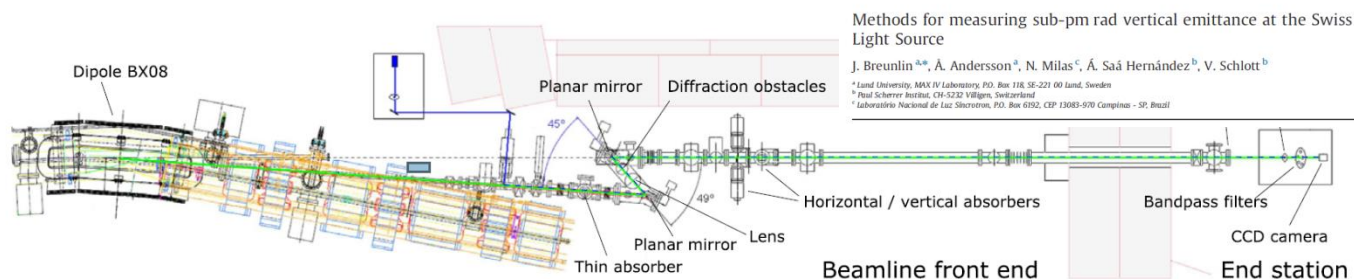
M. Aiba\*, M. Böge, N. Milas, A. Streun  
Paul Scherrer Institut, CH-5232, Villigen, Switzerland

# Vertical beam size diagnostics

- Beam size monitor to verify 1-pm emittance (a few  $\mu\text{m}$  beam size)
  - Using  $\pi$ -polarized synchrotron radiation
  - Using interferometric methods



Contents lists available at ScienceDirect  
Nuclear Instruments and Methods in  
Physics Research A  
journal homepage: [www.elsevier.com/locate/nima](http://www.elsevier.com/locate/nima)



Methods for measuring sub-pm rad vertical emittance at the Swiss Light Source

J. Breunlin<sup>a,\*</sup>, Å. Andersson<sup>a</sup>, N. Milas<sup>c</sup>, Á. Saá Hernández<sup>b</sup>, V. Schlott<sup>b</sup>

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- Novel monitor using vertical undulator is developed at Australian Synchrotron

PRL **109**, 194801 (2012)

PHYSICAL REVIEW LETTERS

week ending  
9 NOVEMBER 2012

## Observation of Picometer Vertical Emittance with a Vertical Undulator

K. P. Wootton,<sup>1,\*</sup> M. J. Boland,<sup>1,2</sup> R. Dowd,<sup>2</sup> Y.-R. E. Tan,<sup>2</sup> B. C. C. Cowie,<sup>2</sup> Y. Papaphilippou,<sup>3</sup>  
G. N. Taylor,<sup>1</sup> and R. P. Rassool<sup>1</sup>

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<sup>3</sup>European Organization for Nuclear Research (CERN), BE Department, 1211 Geneva 23, Switzerland

(Received 11 July 2012; published 8 November 2012)

- At higher energy, X-ray pinhole camera may be used

# Lattice development

**1989:** J.P. Delahaye, J.P. Potier, PAC'89  
'**Reverse bending** magnets in a combined-function lattice for the CLIC damping ring'

**1992:** A.F. Wrulich, Fourth Generation Light Sources workshop at SLAC  
'Overview of 3rd generation light sources'  
**Longitudinal Gradient Bend**

**2017:** SLS2 CDR  
**LGB-RB cell** by A. Streun

*~4 times lower emittance*

**Hybrid LGB-RB lattice** is considered in some light source upgrade projects

**90's:** D. Einfeld et. al.,  
**Multi-bend achromat**

**2013:** L. Farvacque et. al., IPAC'13  
'A low emittance lattice for ESRF'  
**Hybrid lattice** (Originally developed for Super-B, P. Raimondi et. al., ~2006)

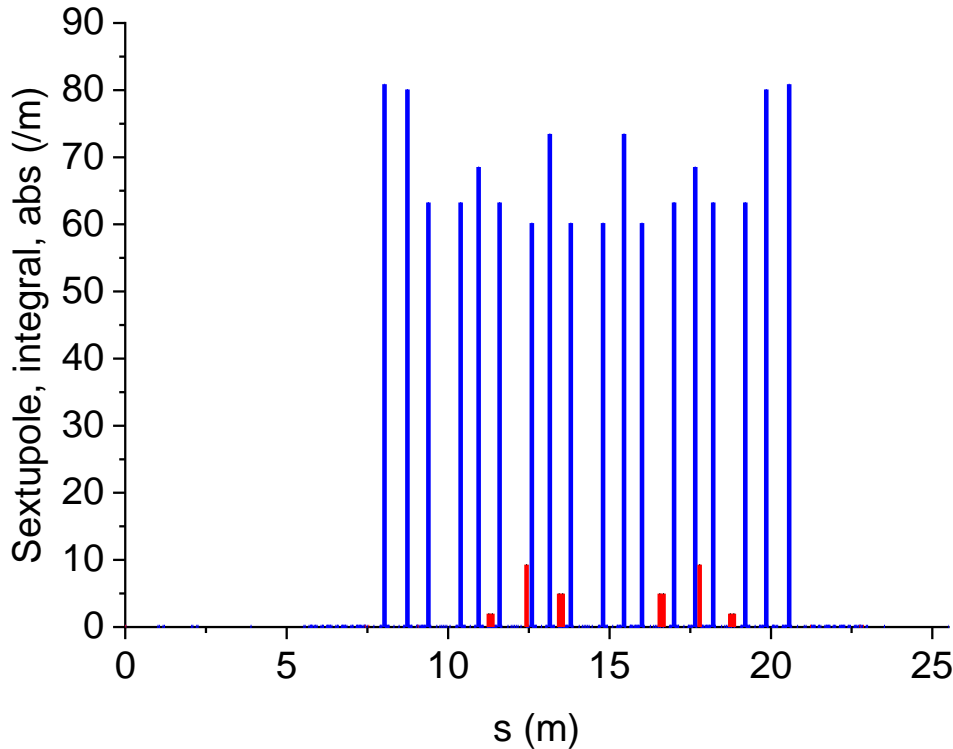
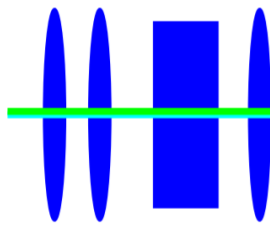
*Lattice nonlinearity mitigated*

Low emittance lattice evolution is driven by technology advance

- Permanent magnet
- NEG coating

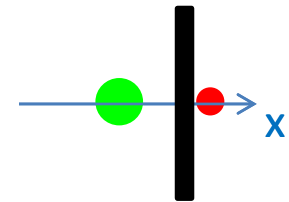
# Injection

- For the next generation light source injection is quite challenging due to
- Various developments
  - For injection
  - Kickers
  - Cor

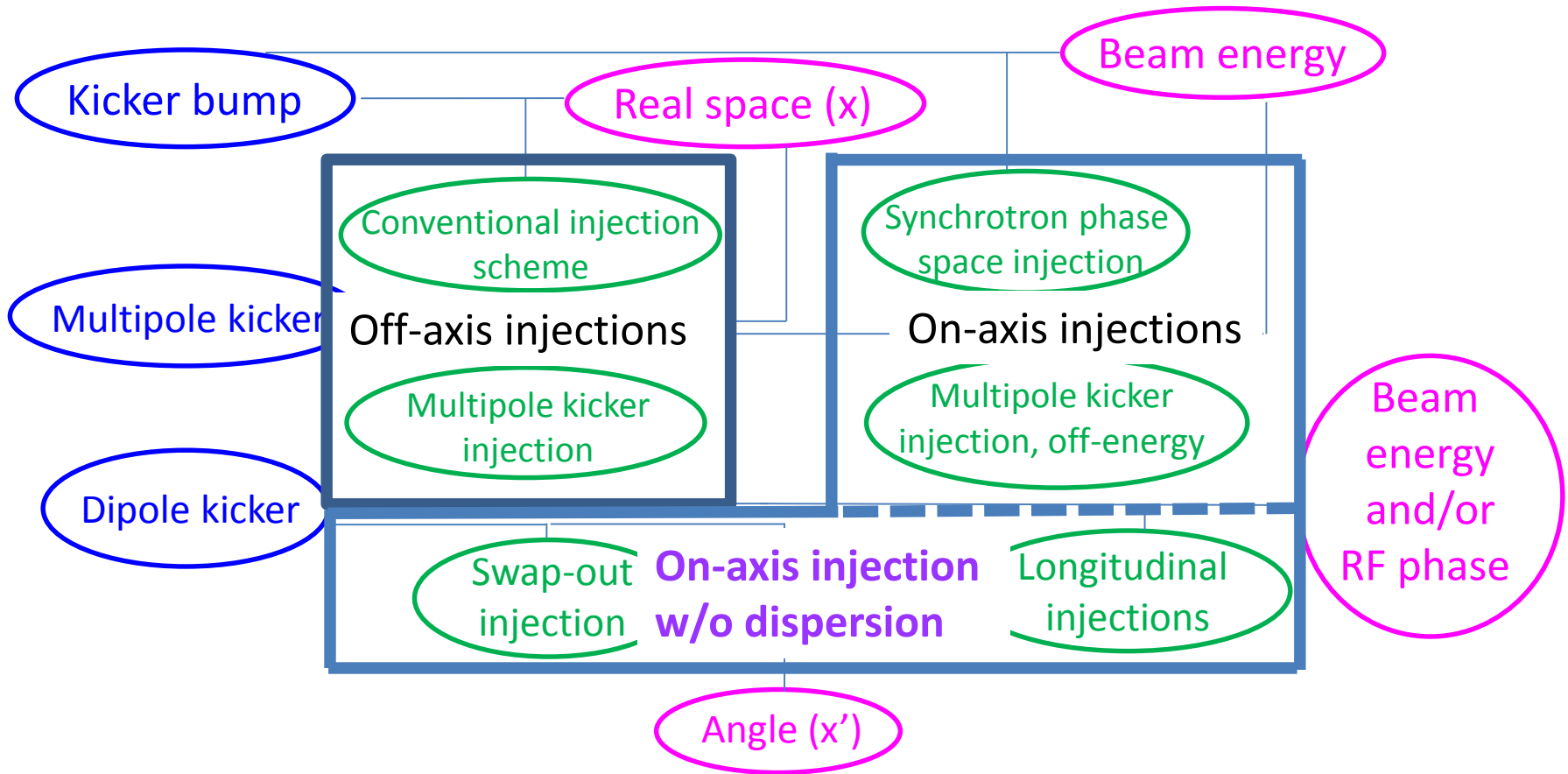


Injection kickers      Ring lattice

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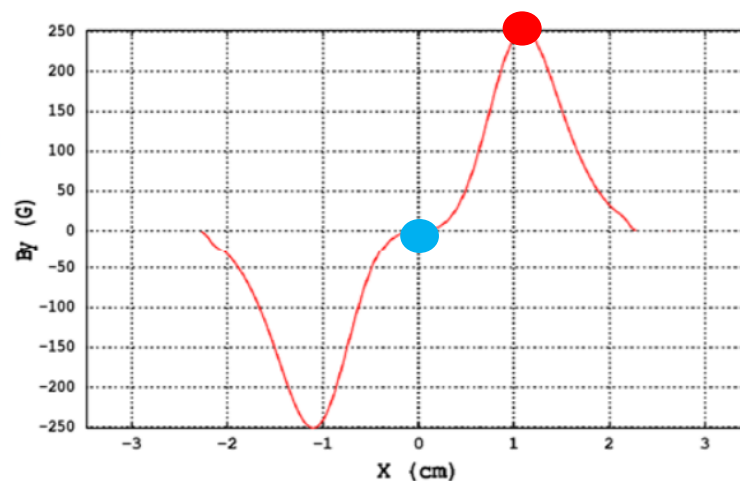
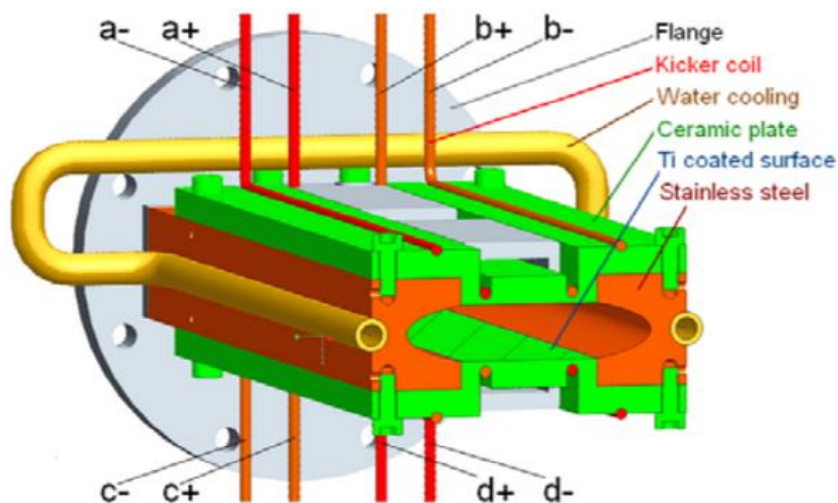
# An overview of top-up injection schemes





# Nonlinear kicker

- Development at BESSY, Soleil and MAX-IV



THPO024

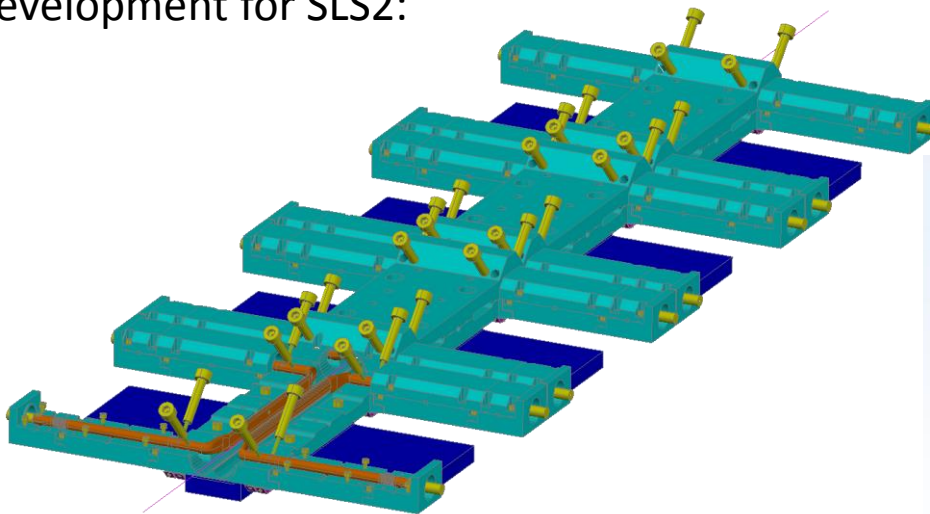
Proceedings of IPAC2011, San Sebastián, Spain

## DEVELOPMENT OF A NON-LINEAR KICKER SYSTEM TO FACILITATE A NEW INJECTION SCHEME FOR THE BESSY II STORAGE RING

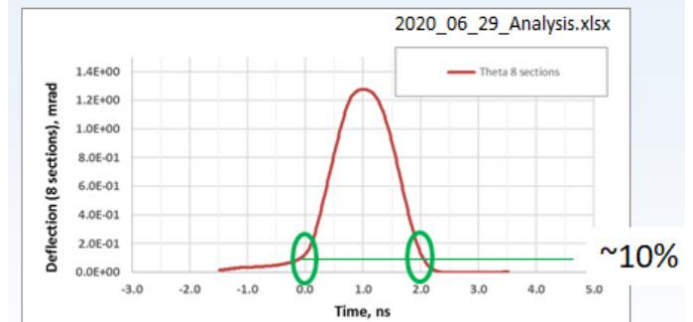
T. Atkinson, M. Dirsat, O. Dressler, P. Kuske, Helmholtz-Zentrum Berlin, 14109 Berlin, Germany;  
H. Rast, TU Dortmund University, 44227 Dortmund, Germany

# Ultra short pulse kicker

- Swap-out and longitudinal injections require a kicker with short pulse, ns regime
- Many developments in the past and present, e.g.,
  - T. Naito et al., “Multi-Bunch Beam Extraction Using Strip-line Kicker at ATF”, Nucl. Instrum. and Methods in Phys. Research Section A, Vol. 571, pp. 599--607, 2007
  - M. J. Barnes, T. Fowler, G. Ravida and A. Ueda, “Design of the Modulator for the CTF3 Tail Clipper Kicker”, Proc. Particle Accelerator Conference, (PAC’07), pp. 2185–2187.
  - D. Alesini et al., “Design, Test, and Operation of New Tapered Stripline Injection Kickers for the e +e – Collider DAΦNE”, Phys. Rev. ST Accel. Beams, vol. 13, p. 111002, 2010.
  - F. Lenkszus et al., “Fast Injection System R&D for the APS Upgrade”, in Proc. 6th Int. Particle Accelerator Conf. (IPAC’15), pp. 1797–1799.
- Development for SLS2:



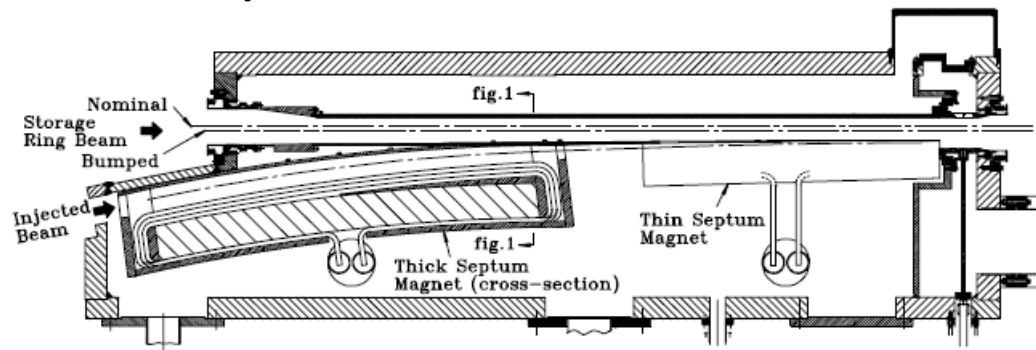
Figures: courtesy of M. Paraliiev



Expected deflection from 8 sections\*

# Thin septum

- In proton machines, a series of septa with different thicknesses is widely used
- This approach also eases the injection of electron/positron machines
- ALS injection septa:



Proceedings of 2005 Particle Accelerator Conference, Knoxville, Tennessee

## STRAY FIELD REDUCTION OF ALS EDDY CURRENT SEPTUM MAGNETS\*

D. Shuman\*, W. Barry, S. Prestemon, R. Schlueter, C. Steier, G. Stover, LBNL, Berkeley, CA, USA

# Extraction

- Extraction has not been an important topic for light sources
- However, swap-out injection involves beam extraction, and it is important to extract/dump very low emittance beam safely
- Nevertheless, the requirements on stability/precision are not as tight as the extraction from damping ring

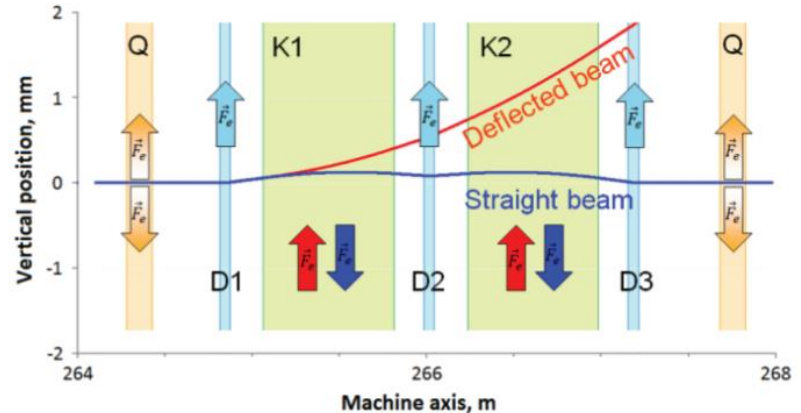
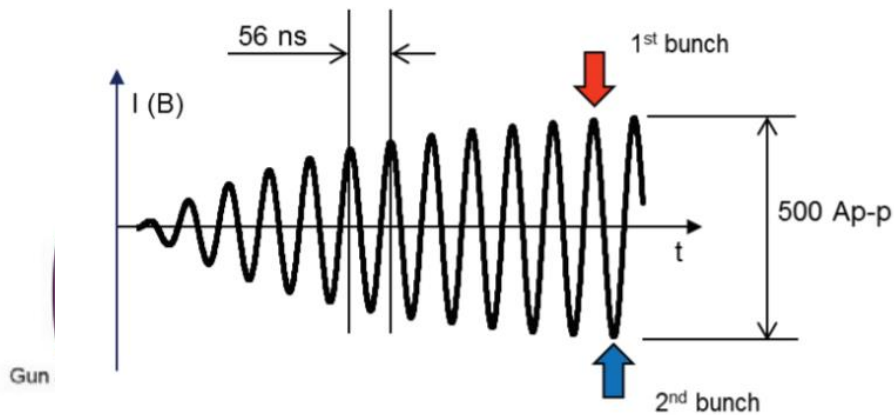
# “Beam extraction” at SwissFEL

Proceedings of FEL2014, Basel, Switzerland

MOP039

## HIGH STABILITY RESONANT KICKER DEVELOPMENT FOR THE SwissFEL SWITCH YARD

M. Paraliiev<sup>#</sup>, C. Gough, S. Dordevic, H. Braun,  
Paul Scherrer Institut, Villigen PSI, Switzerland



High stability, 3~4 ppm amplitude jitter, is achieved through LC resonator including the kicker magnet itself

# Summary

- Horizontal emittance
  - Low emittance ring lattice and related technologies are still advancing, largely driven by new generation light source developments
  - Permanent magnet dipole has become “standard”
- Ultralow vertical emittance
  - The goal of the damping ring is definitely achievable
  - The goal of FCC-ee ( $\varepsilon$  ratio  $\sim 0.002$ ) may be still challenge
- Injection/Extraction
  - A lot of developments are under going for new generation light source
  - New kickers may be useful for damping rings and colliders
- Several topics (vacuum and magnet technologies, instabilities, insertion device development, feedbacks, etc.) are not covered in this talk but important!

Synergy continues!