Fast Distribution of Pulses in Multiple Beam Line Facilities

Thanks to
Vladimir Balandin, Nina Golubeva
and Frank Obier

Winfried Decking
Fast Distribution of Pulses in Multiple
Beam Line Facilities
FEL2010, Malmö, 25.7.2010

From the welcome of our conference chairs,
Nils Mårtensson and Sverker Werin:

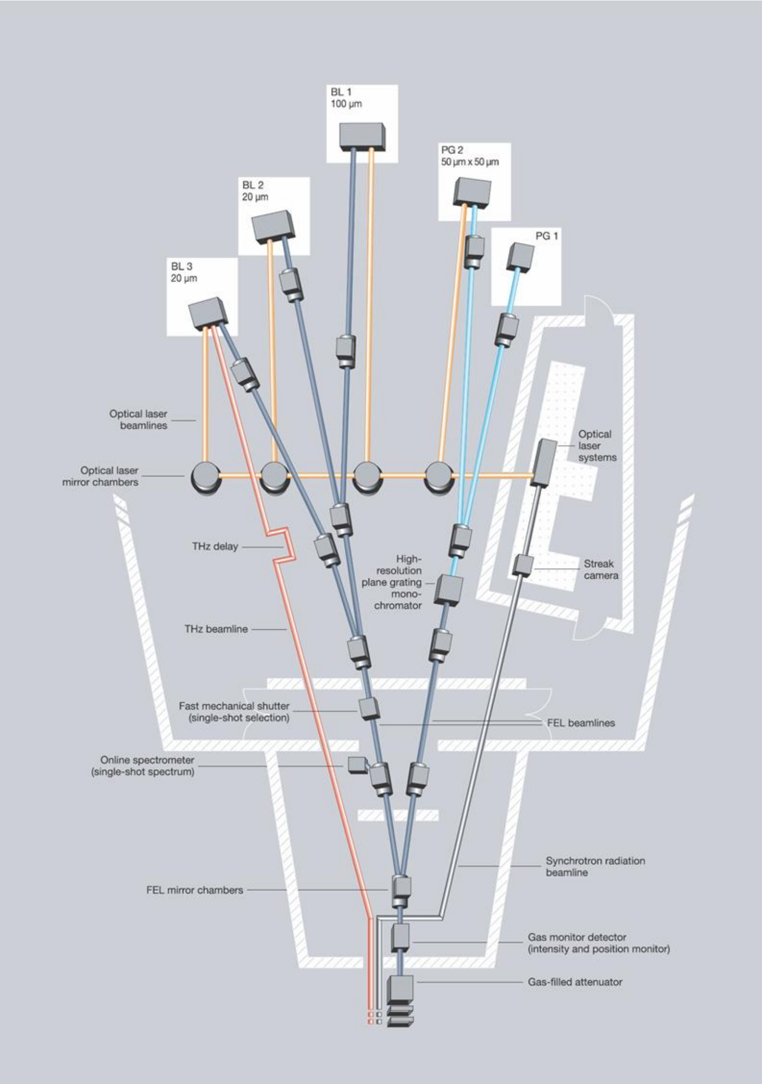
“The FEL conference is an important step-stone for FEL interest in Sweden, but more so all around the world we are moving into the era of user facilities. We believe that during FEL2010 we will see several important steps in the FELs maturing, growing and prospering.”

But we do have a problem:

Serving many users with an FEL

- Storage rings have 30+ beam lines with >MHz pulse repetition rates
- FELs serve one user at a time with the driver linac repetition (or pulse) rate
(exception: use spent beam to drive another FEL, usually only possible for soft x-rays with less demanding beam quality requirements, example European XFEL)
- Nevertheless many user stations are desirable
  - to allow for experiment set-up
  - to make efficient use of many pulse linacs

Photon Pulse Distribution

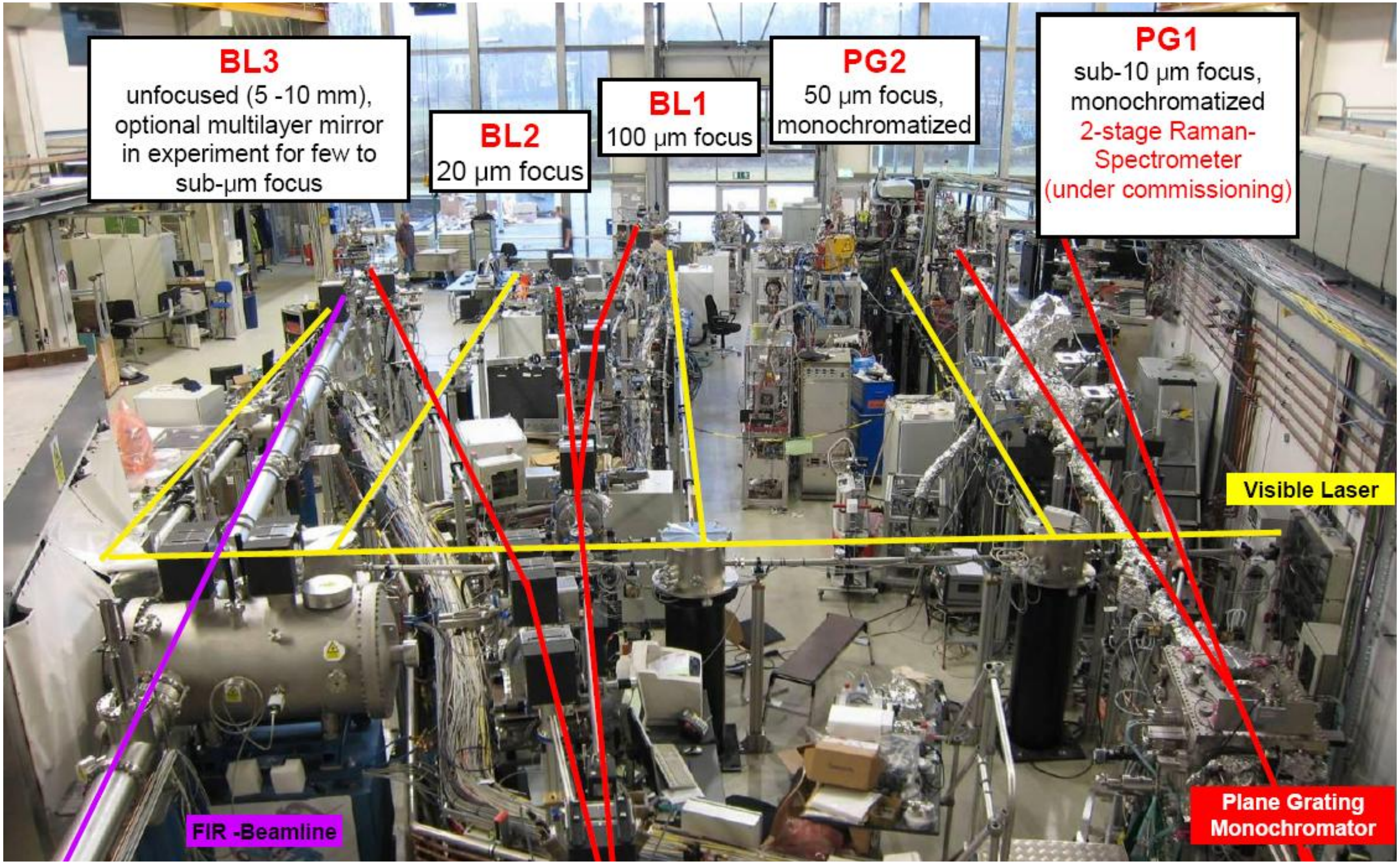


Moveable mirrors steer the beam to several experimental stations

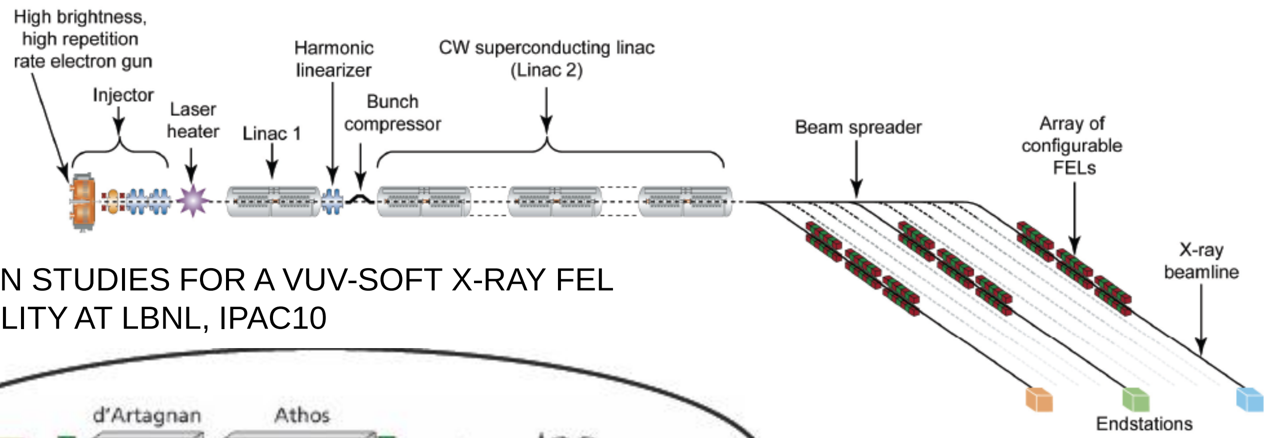
- mechanical motion, slow
- typical switching frequency in the order of hours

Tiedtke et.al.,The soft x-ray free-electron laser FLASH at DESY: beamlines, diagnostics and end-stations, New Journal of Physics 11 (2009)

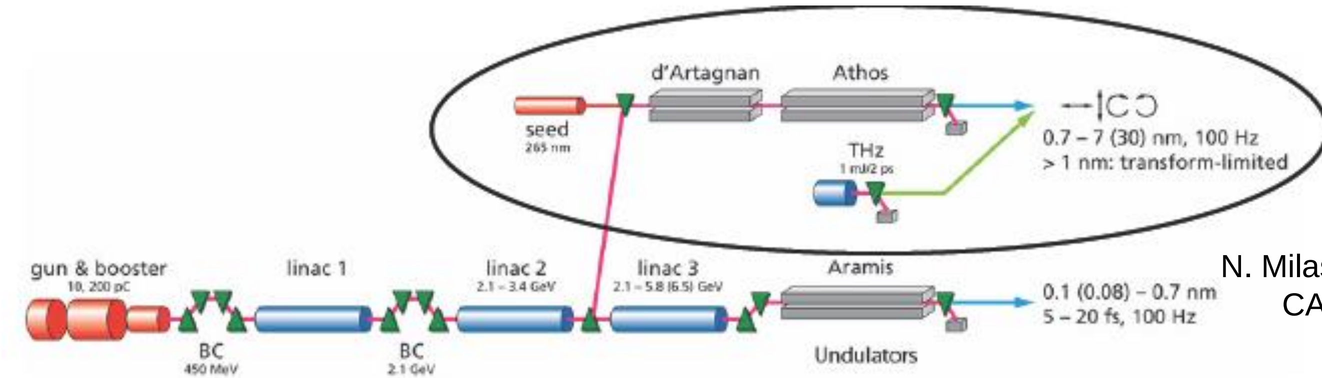
Example: FLASH Experimental Hall



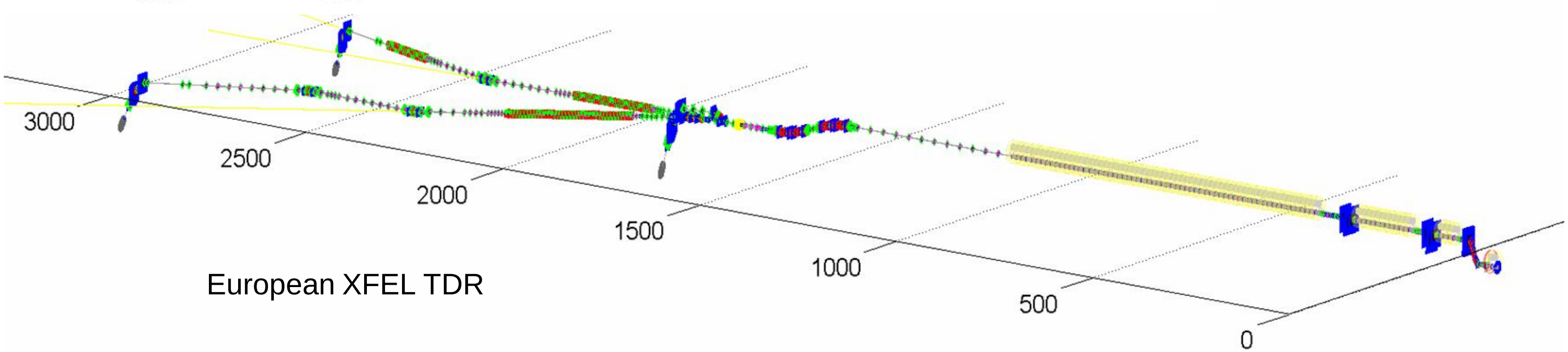
This talk: Electron beam distribution



J.N. Corlett et.al., DESIGN STUDIES FOR A VUV-SOFT X-RAY FEL FACILITY AT LBNL, IPAC10

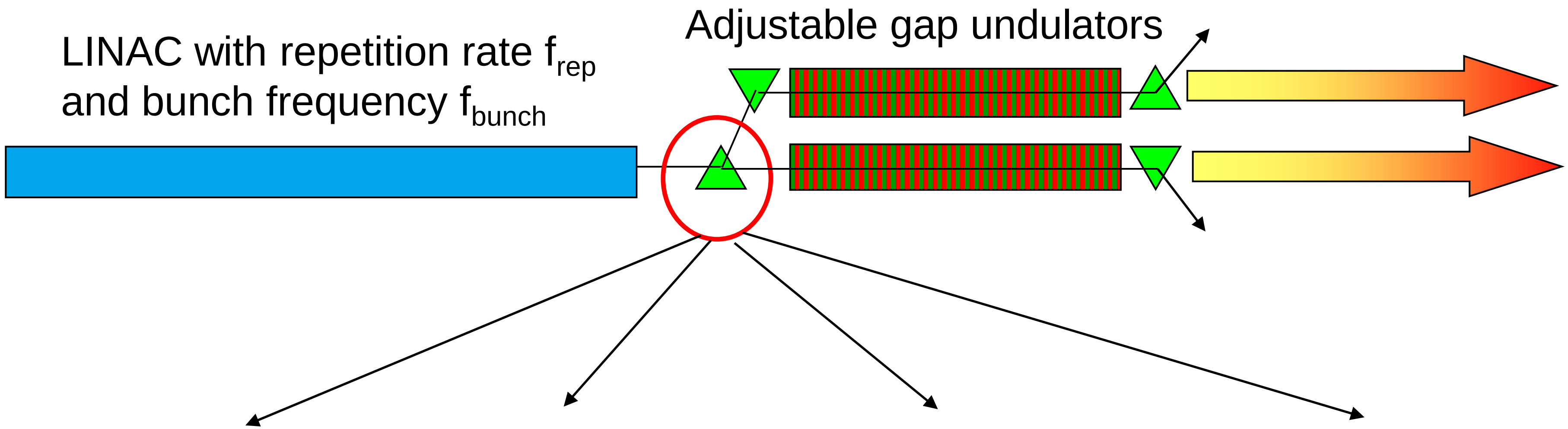


N. Milas, Switch yard design for SwissFEL, CANDLE-DESY-PSI Collaboration Workshop



European XFEL TDR

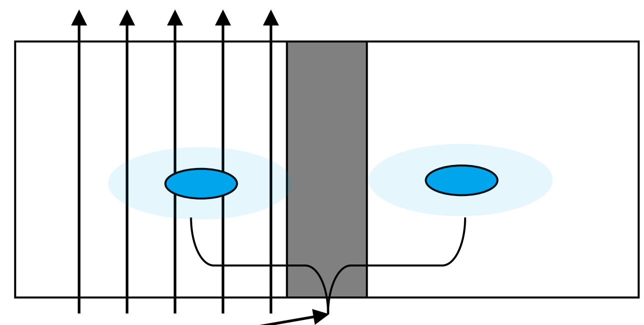
Electron Beam Switch Options



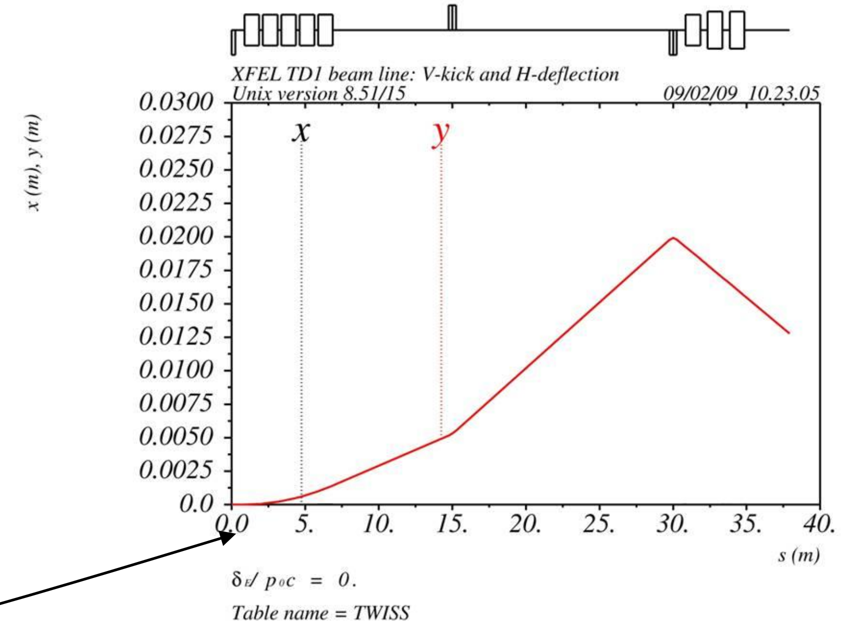
DC Magnet	‚Slow' switch with f_{rep}	High Q Resonator with f_{bunch}/n	Programmable fast kicker with f_{bunch}
One beam line only Easy	Duty cycle reduced by # beamlines Relatively easy	Fixed bunch pattern Full duty cycle	Most Flexible

Kicker-Septum Scheme to reduce kicker strength

Use fast deflector to deflect beam far enough to employ septum magnet with field free region for straight beam and large field for deflected beam



$$\Delta = x_{septum} + 2m_{collimation}\sigma_{x,septum}$$
$$= \Theta_{kick} R_{12}(kicker,septum)$$



Kicker-Septum Scheme -> Stability

Stability goal at undulator < 1/10 σ

$$\frac{\Delta\Theta}{\Theta} = n_{jitter} \Big/ \left(2m_{collimation} + \frac{x_{septum}}{\sigma_{x,septum}}\right)$$

Kick strength approx. 100-300 σ

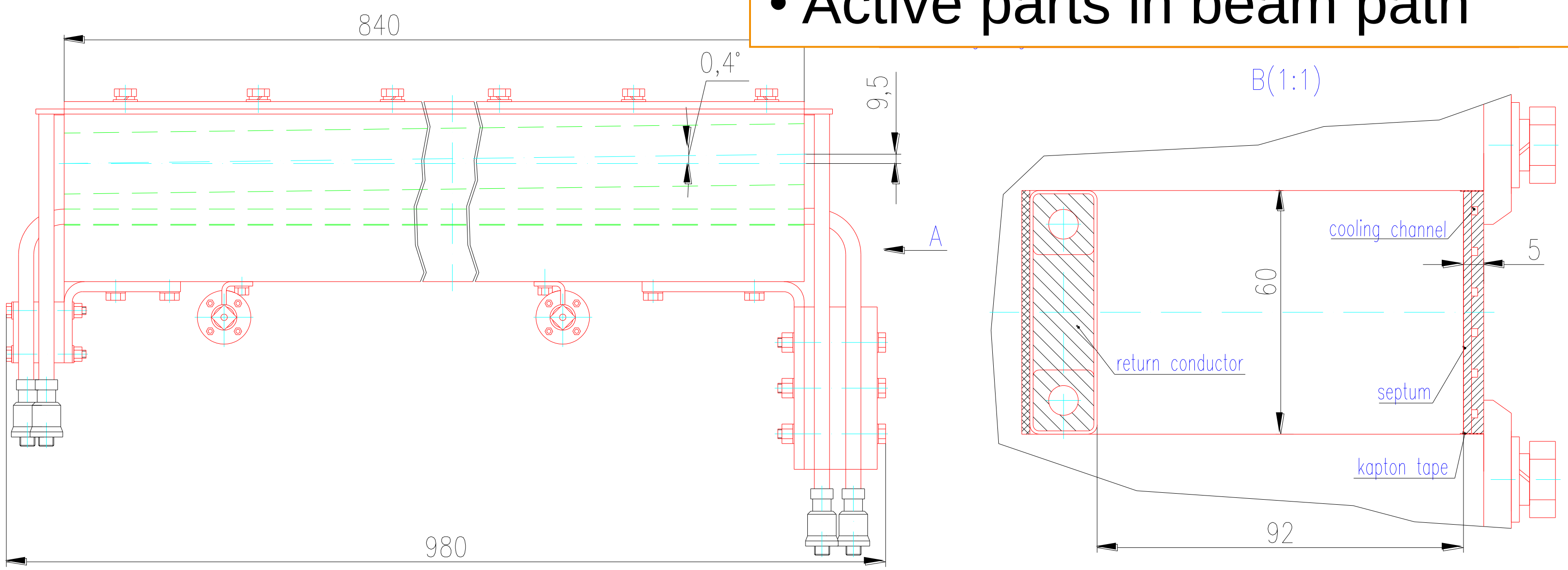
=> rel. amplitude stability < 1e-3 to 1e-4

Septum deflection approx. several 1000 σ

=> rel. amplitude stability < 1e-5

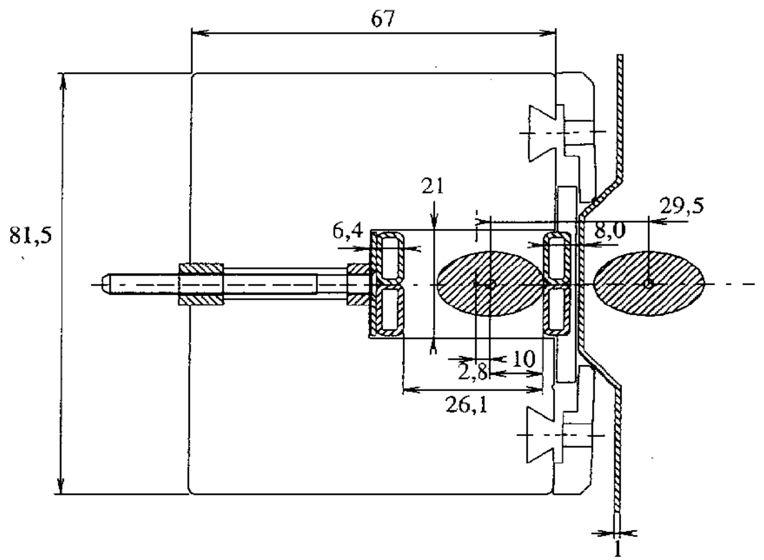
Options for Septa - Current Sheet DC Septum

- High current density in septum blade
- High power consumption
- Active parts in beam path

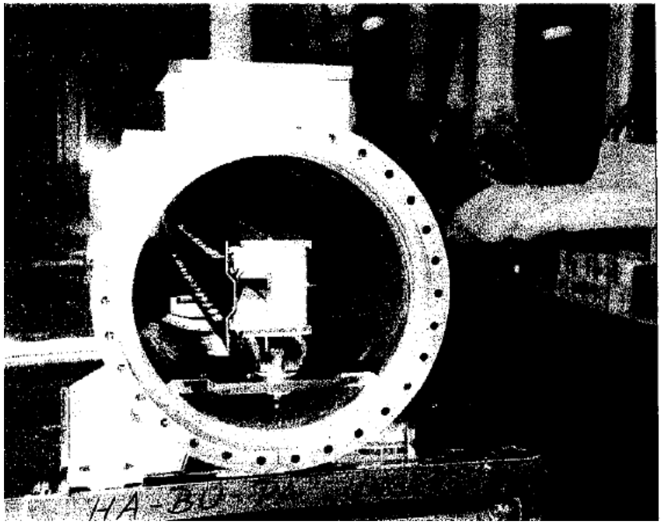


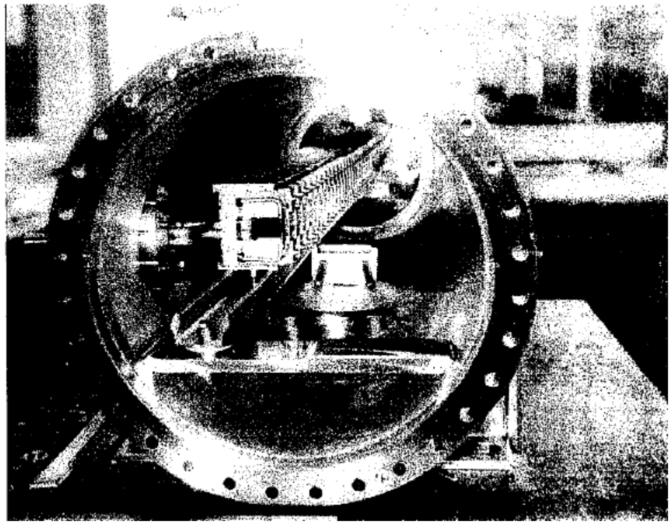
Efremov Institute, Design Study for European XFEL

Options for Septa - Current Sheet AC Septum



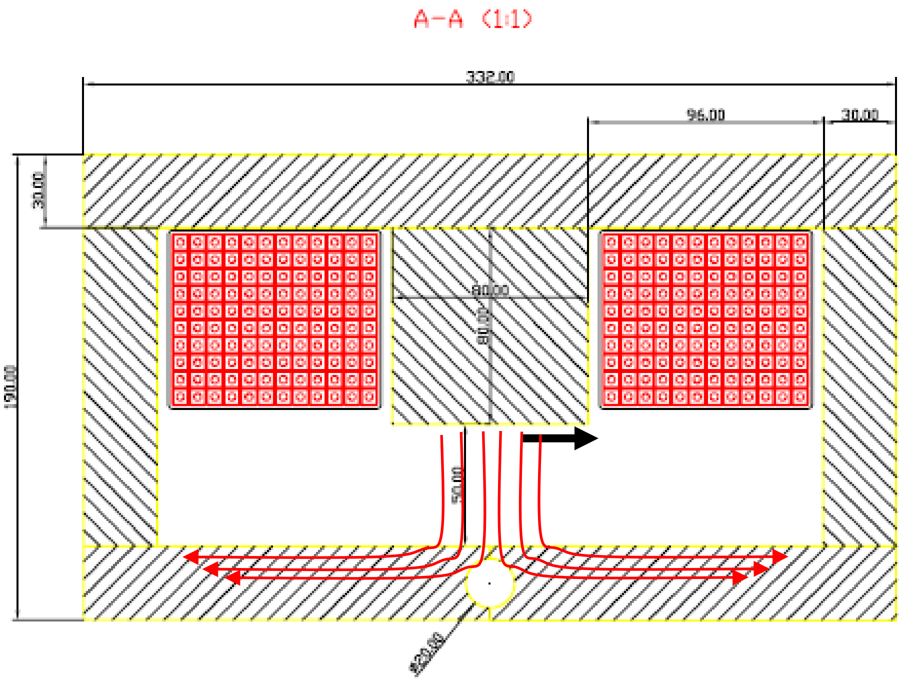
- Pulsed operation
- Low average power
- Active parts in beam path
- Stability issues





A. Mueller,
DESY 3 Septum

Options for Septa - Lambertson DC Septum

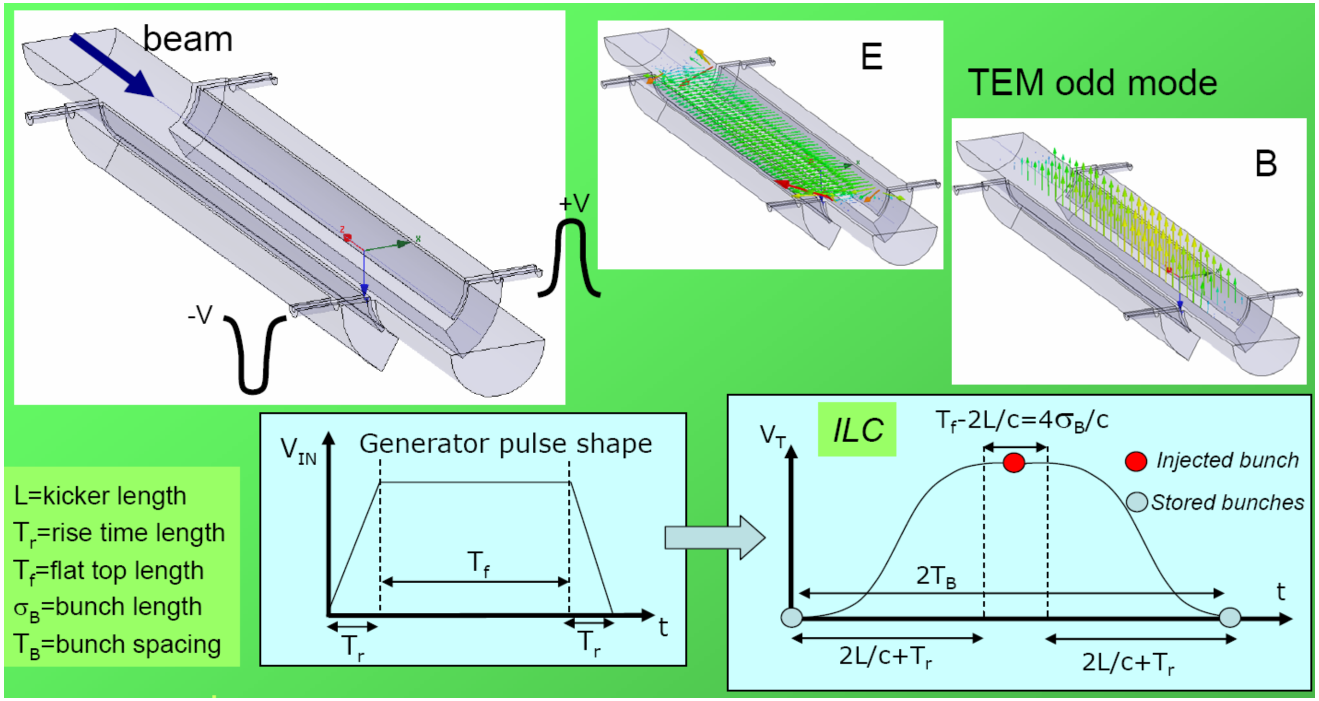


Efremov Institute, Design Study for European XFEL

- ‘Classical’ electro-magnet
- Low power, no active components in beam bath
- Needs orthogonal kick

Options for Kicker - Stripline

- Developments for ILC pave(d) the way

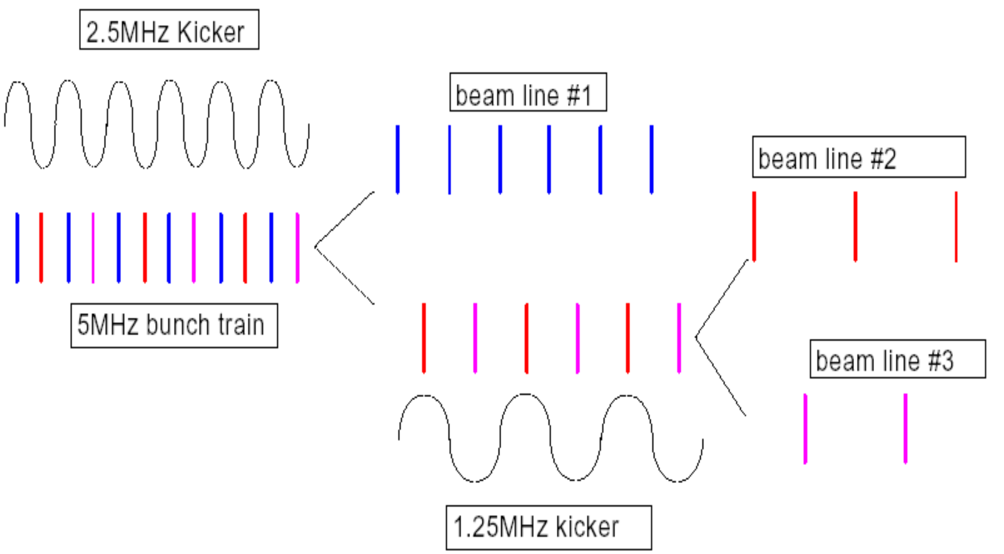


D. Alesini,
FAST RF KICKER DESIGN
ICFA Mini-Workshop on
Deflecting/Crabbing Cavity
Applications in Accelerators,
Shanghai, April 23-25, 2008

- Striplines optimized for 50 Ω impedance
- Optimize stripline geometry (length, gap, shape, coverage angle) to maximize shunt impedance
- Minimize wakefield impact on beam

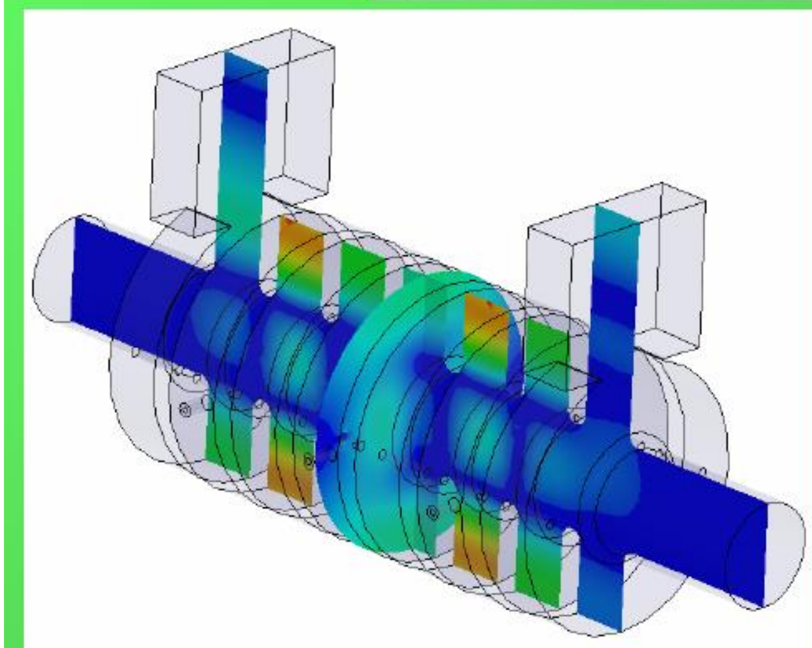
Options for Kicker – RF Deflectors

- Higher efficiency
- Oscillating system
- Frequency is fixed



High Q Resonator with f_{bunch}/n

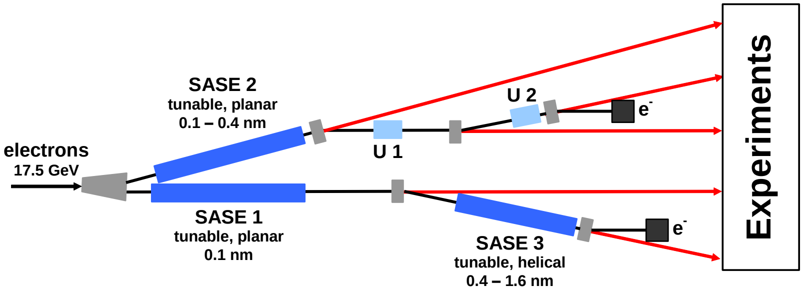
Example:
Traveling Wave RF Deflector for the CLIC combiner ring

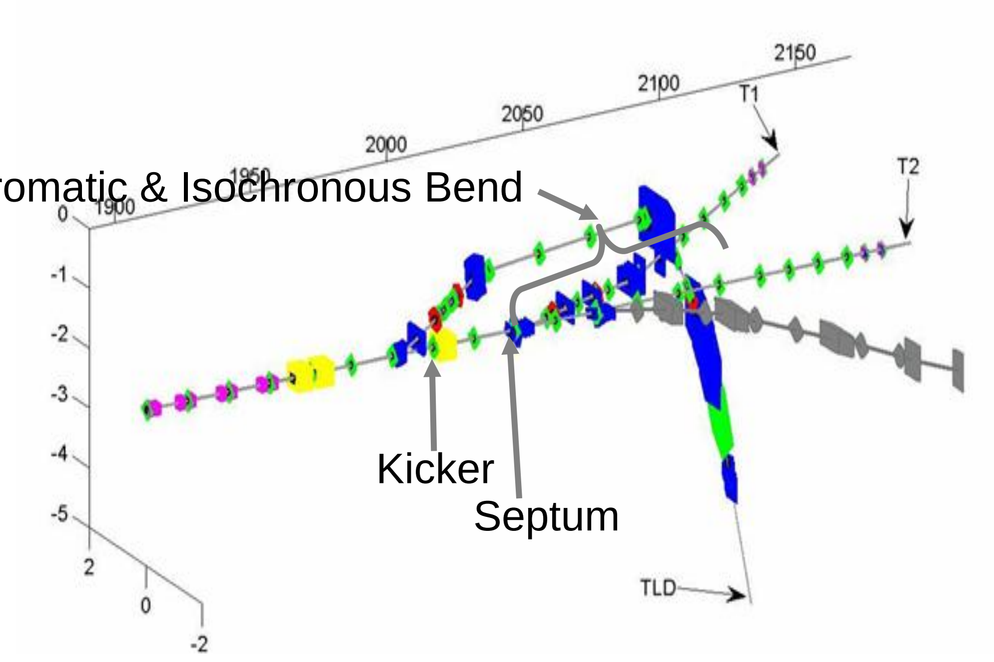


D. Alesini, FAST RF KICKER DESIGN
ICFA Mini-Workshop on Deflecting/Crabbing Cavity Applications in Accelerators, Shanghai, April 23-25, 2008

Example: European XFEL Beam Switchyard - 1

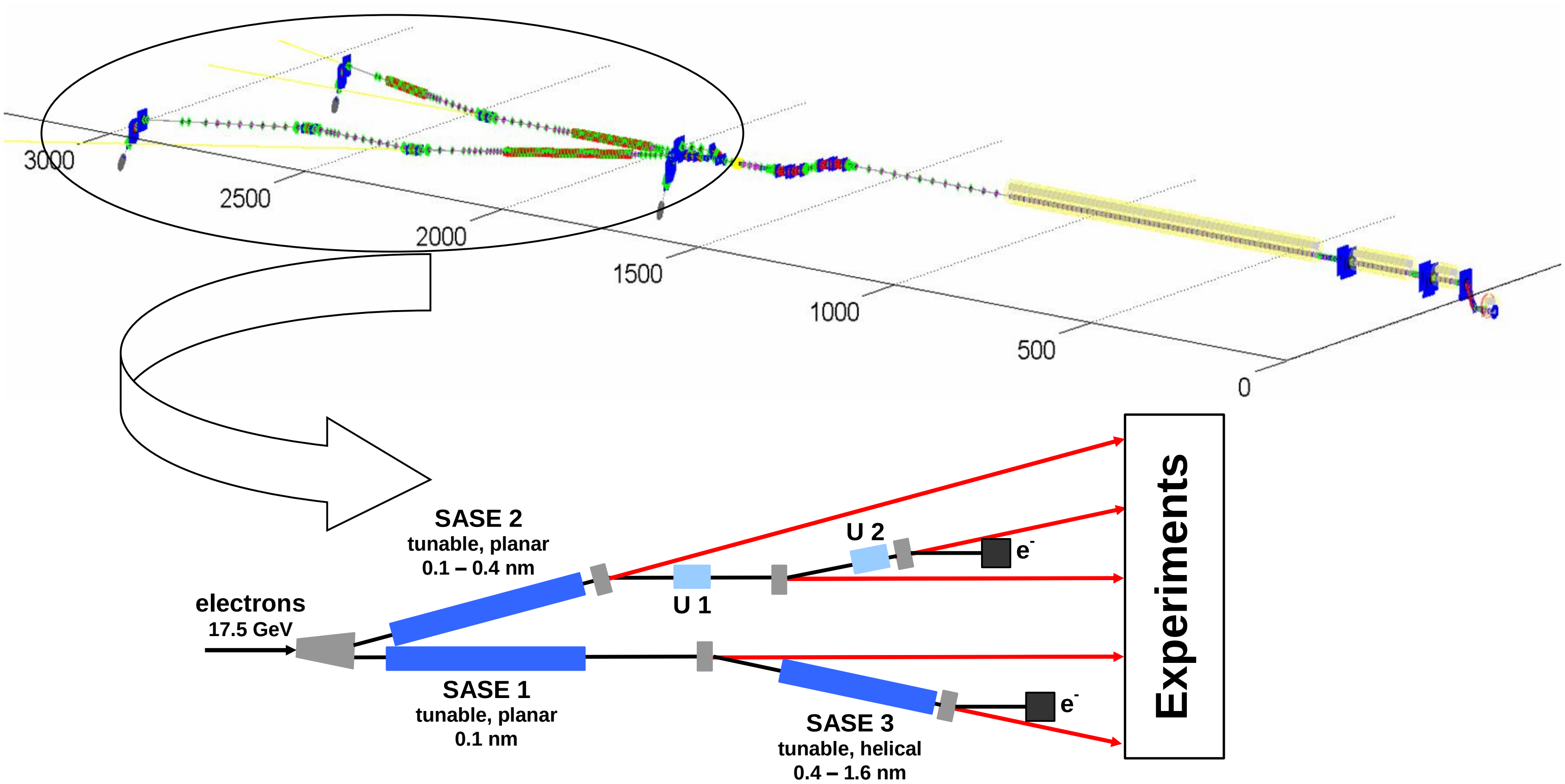
- Kicker-Septum (Lambertson) Scheme
- Stable flat-top kicker distributes between beam lines
- Fast burst kicker deflects into dump for arbitrary bunch pattern and emergency beam abort
- Linac operates with constant beam loading





Example: European XFEL Beam Switchyard - 1

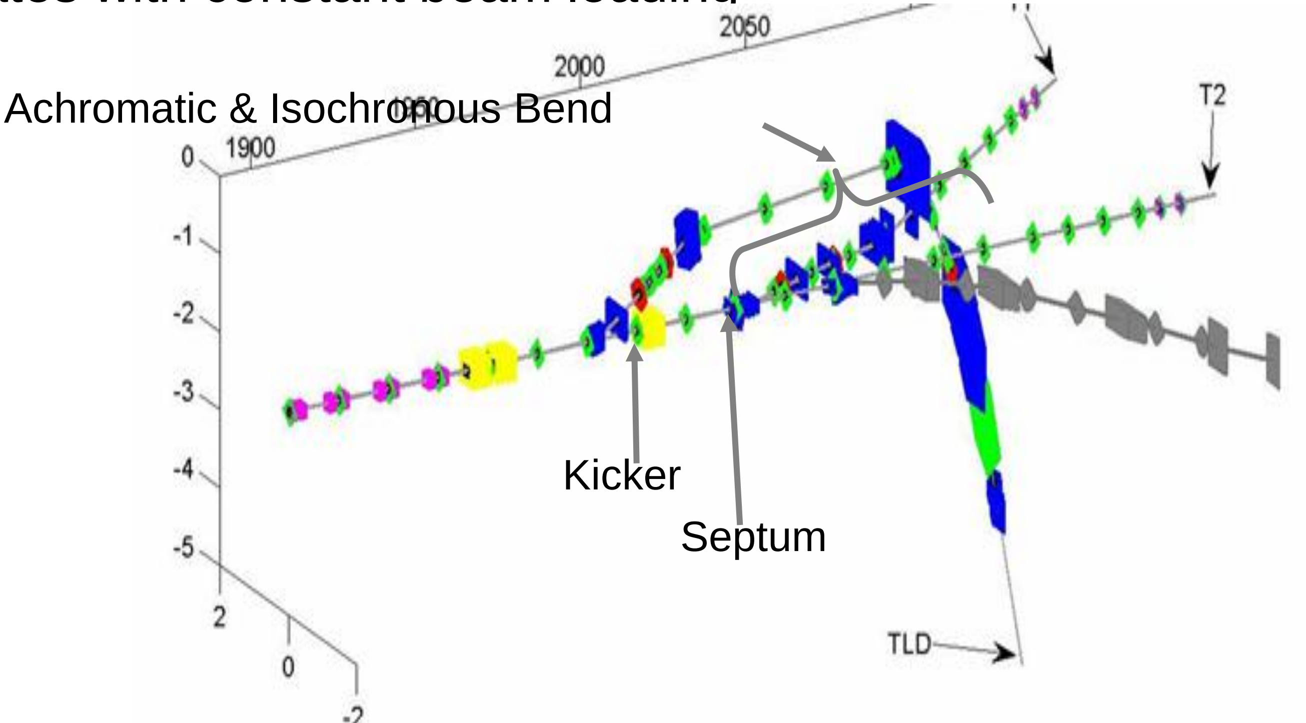
- 14 GeV drive linac in burst mode with 10 Hz f_{rep} and 4.5 MHz f_{bunch}
- Beam Distribution in two (up to four) independent electron beamlines



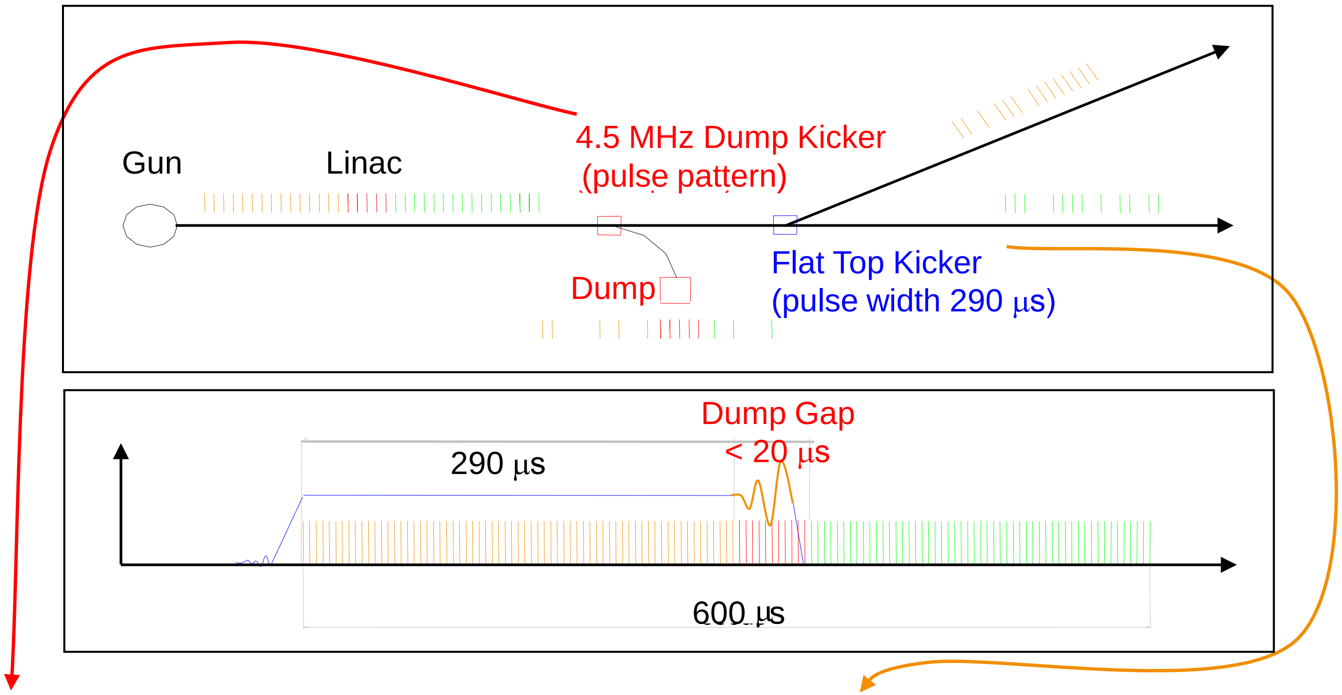
DESY

Example: European XFEL Beam Switchyard - 2

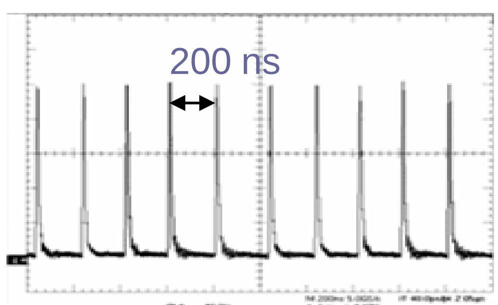
- Kicker-Septum (Lambertson) Scheme
- Stable flat-top kicker distributes between beam lines
- Fast burst kicker deflects into dump for arbitrary bunch pattern and emergency beam abort
- Linac operates with constant beam loading



European XFEL Beam Switchyard - 3

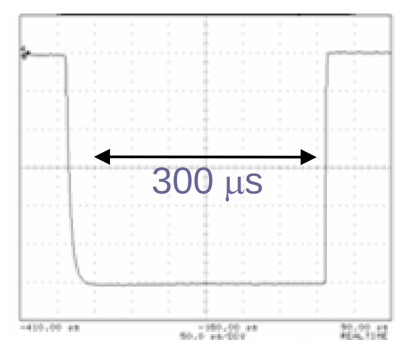


- low accuracy (>1 %)
- 4.5 MHz burst operation



example:
pulser prototype measurement

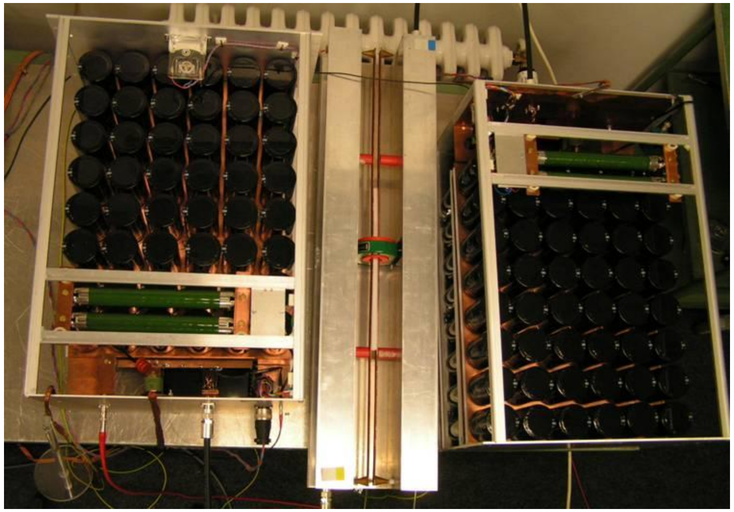
- high accuracy (< 0.01 %)
- 10 Hz operation

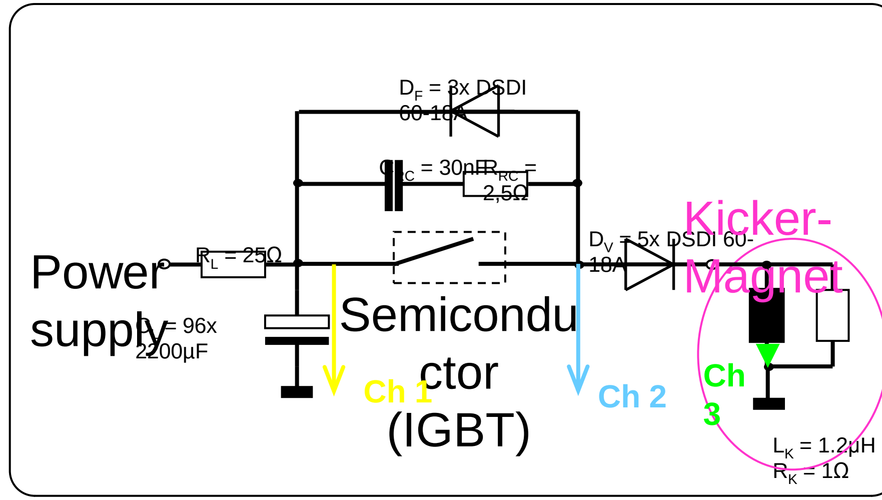


example:
pulser prototype measurement

FLAT Top Pulser

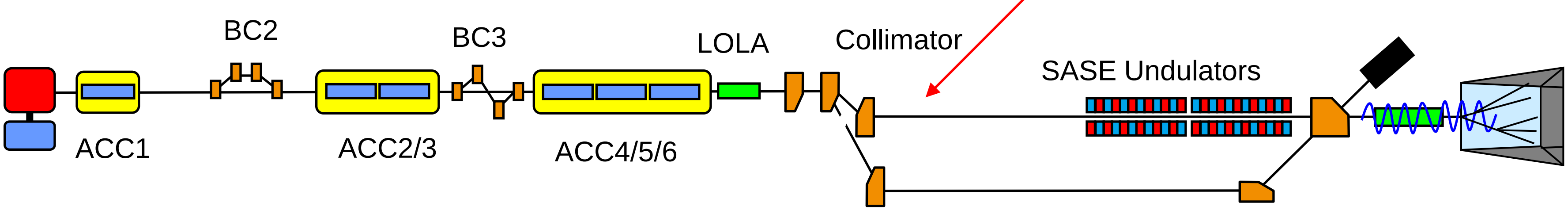
In-house development





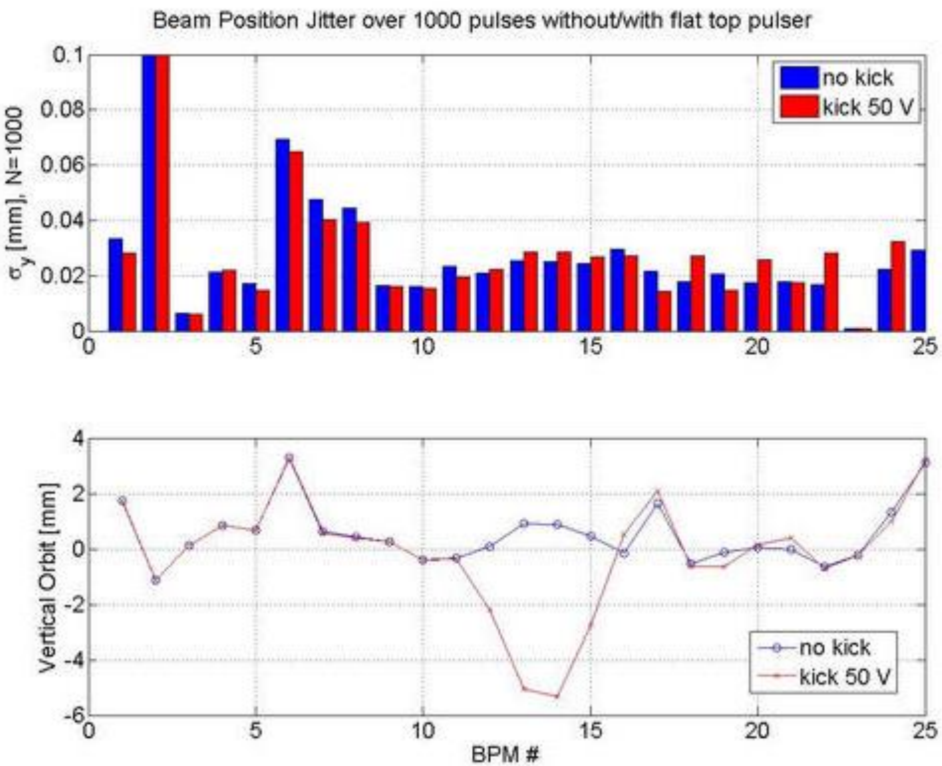
FLASH Measurement

installed on one of the FB kickers
closed bump with 2 downstream VSTEERERS



FLAT Top Pulser – Kick Stability

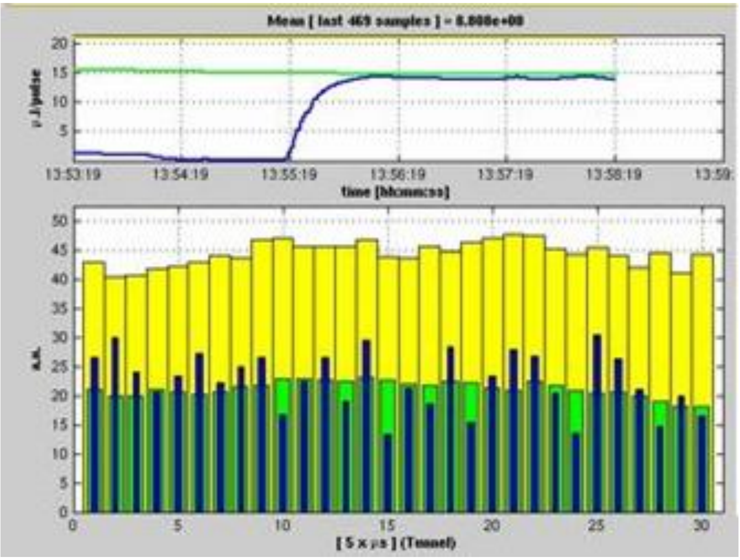
RMS stability with beam: < 4e-3
(resolution limited)



RMS stability in lab: 2e-4
(compared 2 pulsers to each other)

… and maintains SASE

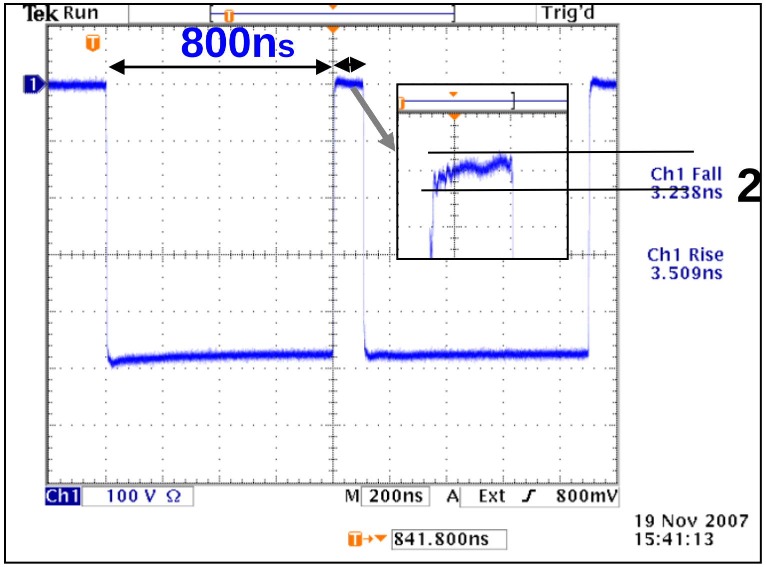
Time dependent SASE power
Blue line: kicker and correctors on
Green line: kicker and correctors off



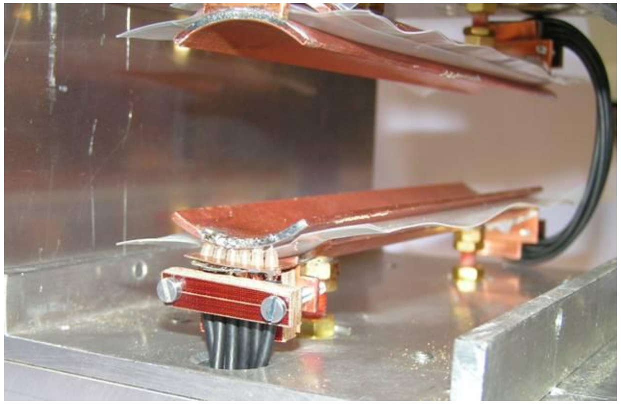
Actual SASE power over 30 bunches in RF pulse (blue, green average, yellow maximum)

FAST Pulser

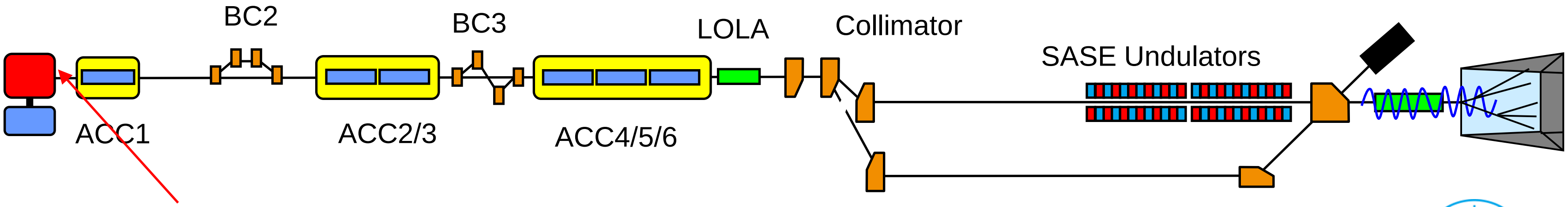
Company built pulser and in-house kicker



2.5V = 0.5%



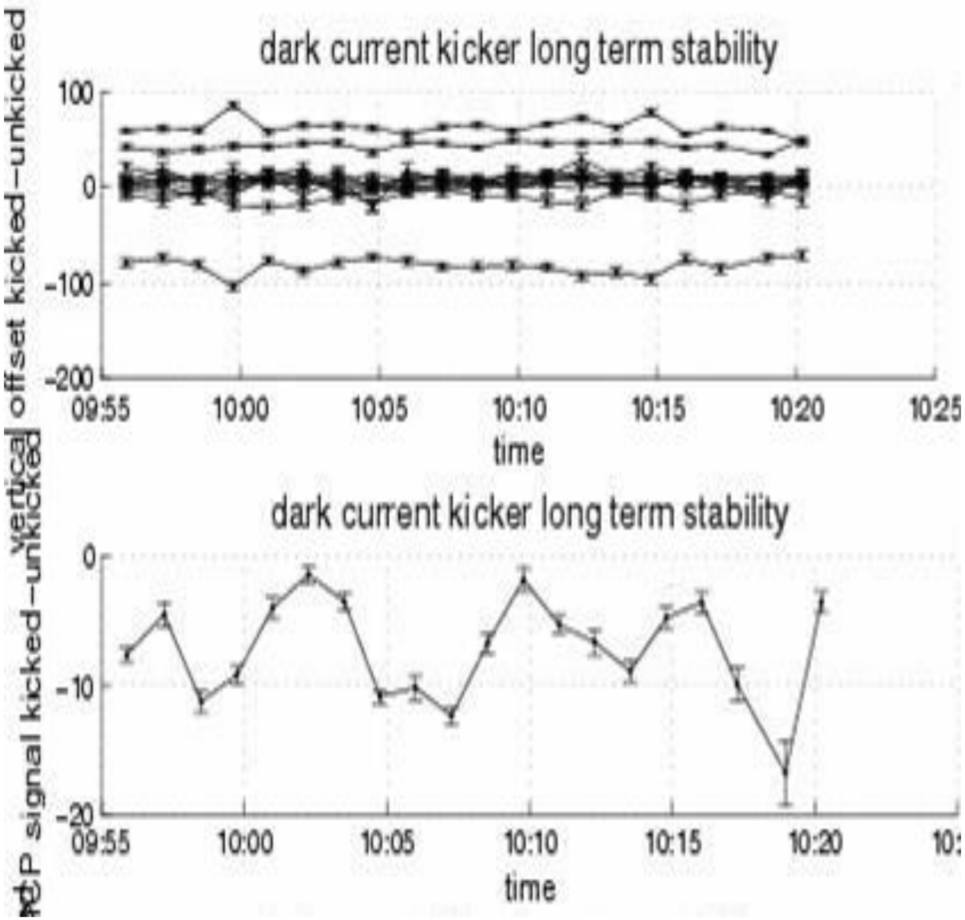
FLASH Measurement



installed after the gun to be used as dark current kicker

Fast Pulser – Pulse Stability

difference trajectory kicked-not kicked



difference SASE power kicked-not kicked [%]

- estimated stability about 1%, but measurement hampered by large residual kick in flat bottom
- SASE drops only by about 5% (with little tuning)

Bending Systems: Requirements - 1

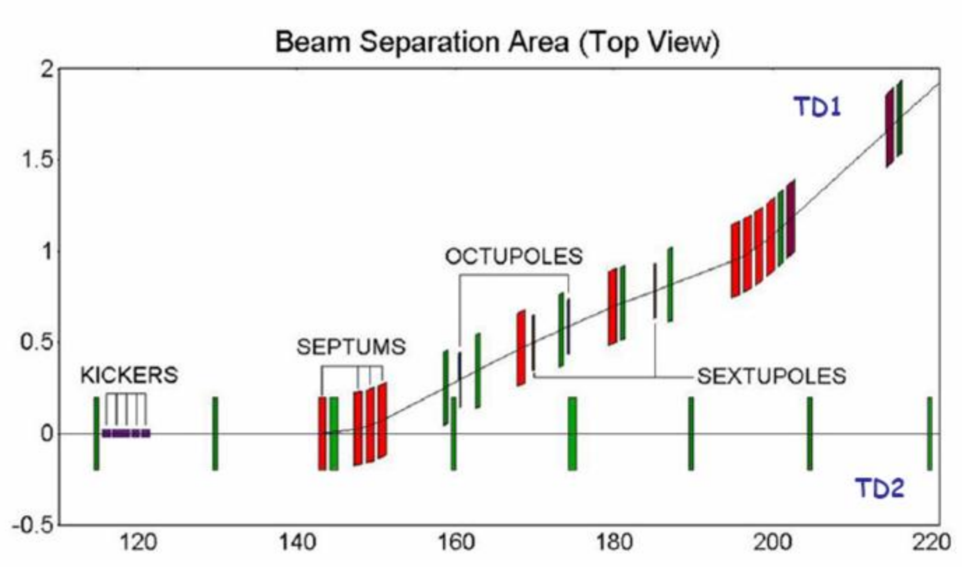
- Beam transport for large energy spread/chirp or energy variations along bunch train => achromatic (R_{16} ,R_{26} etc. =0)
- Maintain (or even fine tune) compression for energy chirped bunches (left over from previous compression, longitudinal space charge, wakes) => isochronous, or tunable R_{56}
- Minimize CSR induced energy spread increase => minimize total bending angle
- Minimize CSR induced transverse emittance growth => optimize beam optics in and in between bends
- Prevent additional micro-bunching instability gain => isochronous, or tunable R_{56},optimize beam optics

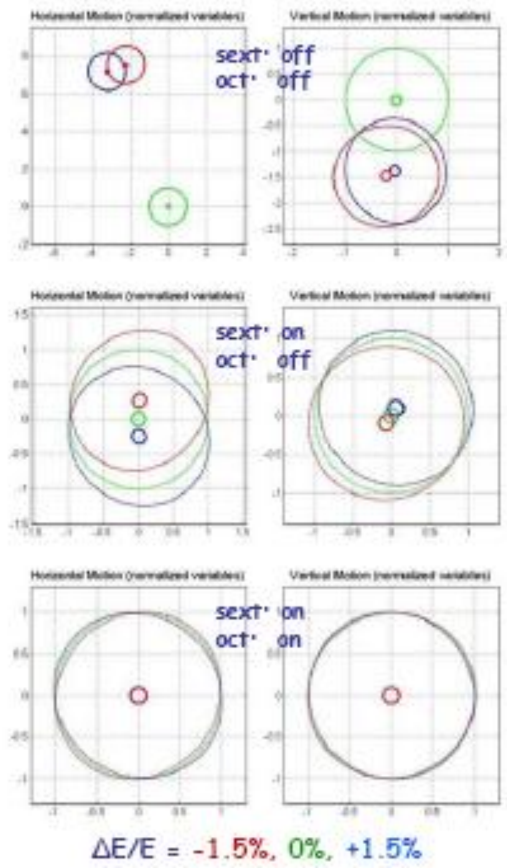
Bending Systems: Requirements - 2

- Energy collimation => decouple dispersion and beta function, provide large dispersion to maximize collimation apertures
- Match all geometric and engineering constraints
- ….

European XFEL Bend System

- Simultaneous horizontal and vertical dispersion
- Tilted Lambertson septum compensates common downstream quad
- Tilted sextupoles and octupoles control chromatic aberrations ($\Delta E/E=3\%$)
- Reverse bends for first order isochronicity
- Collimation provided upstream

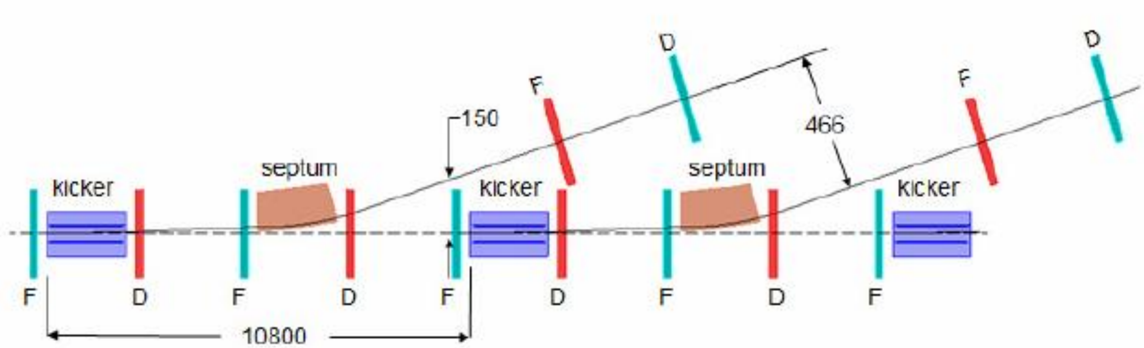


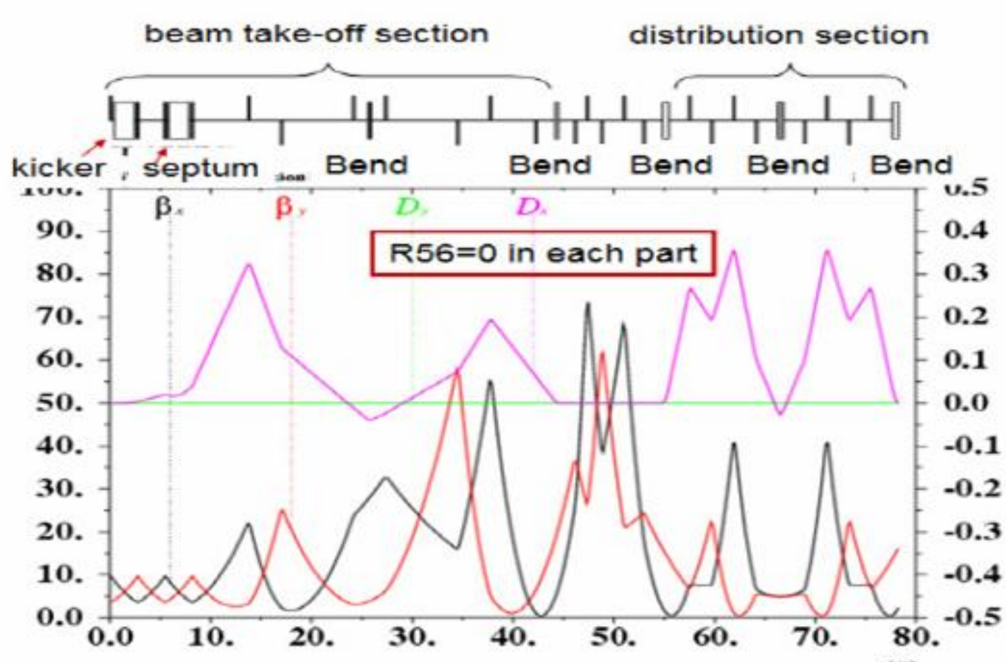


V.Balandin, W.Decking, N.Golubeva, IPAC'10, Kyoto, Japan

LBNL study for Soft X-ray FEL

- Kicker & Septum embedded in 90 deg FODO (as E-XFEL)
- 1 MHz rep. rate
- Each section isochronous (minimizes microbunching instability gain)
- Total angles 0.5 to 8 deg
- Collimation upstream

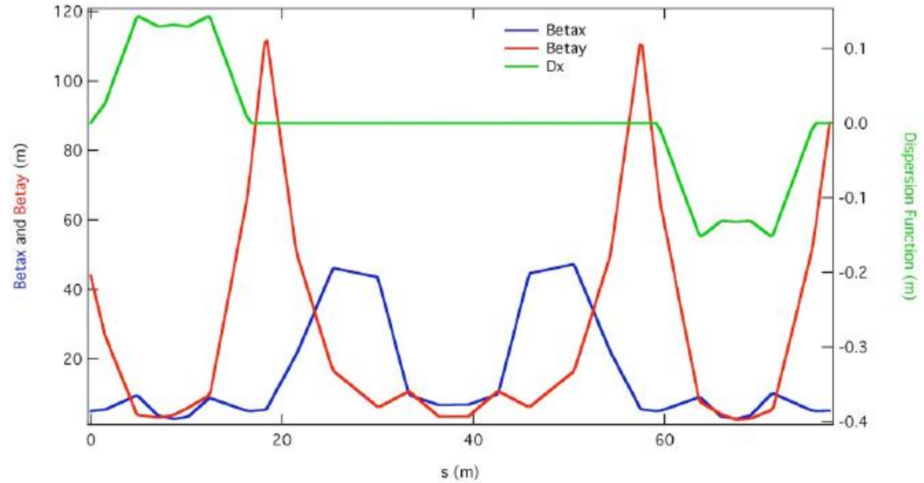


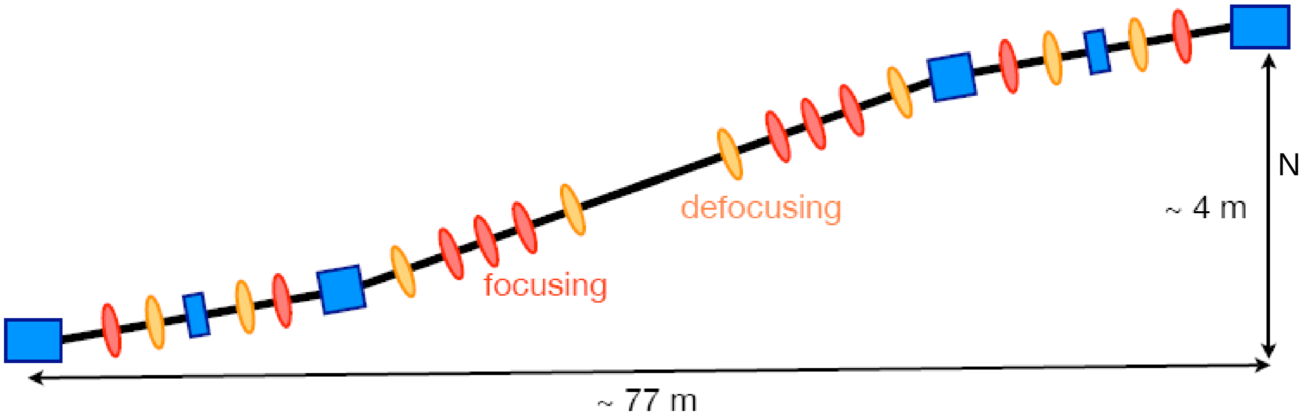


A. Zholents et.al., LINAC DESIGN FOR AN ARRAY OF SOFT X-RAY FREE ELECTRON LASERS, LINAC08
Kur et.al., Accelerator Design Study for a Soft X-Ray Free Electron Laser at the Lawrence Berkeley National Laboratory, LBNL 2670E

SwissFEL Switch Yard

- Resonant Kicker & Septum scheme (100Hz, 50 ns bunch distance)
- Emittance growth compensation through phase advance adjustment in between achromats
- R_{56} tuneable
- Small betas in large angle dipoles
- Space for sextupoles
- Collimation included





N. Milas et.al., Switch yard design for SwissFEL, this conference

Summary

- Electron beam distribution enables true multi-user facility
- Stripline Kicker & Septum Scheme commonly used thanks to recent availability of fast pulsers and linear collider R&D
- Most challenging issue is stability and reproducibility of the pulsed system

- Bend systems have to fulfill many opposing requirements
- Isochronous achromats in all designs (length 70 to 100 m)
- Inclusion in beam dynamics studies essential to simulate overall performance of the beam