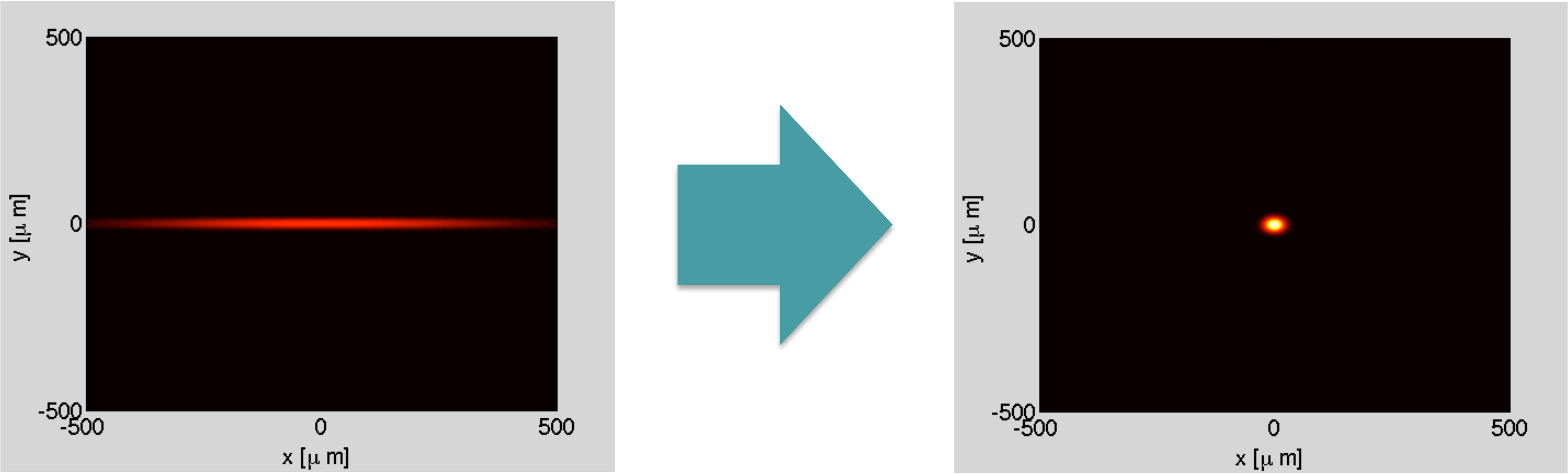
Overview of AP issues facing DLSR lattice and component design

David Robin

Workshop on Diffraction Limited Storage Rings, SLAC

with input from

C. Steier, H. Tarawneh, B. Hettel, M. Borland, L. Nadolski. ESRF



Outline

- Enabling technologies and challenges
- Lattice optimization
- Intrabeam scattering
- Injection – Swap-out or Accumulation
- Collective Effects
- New facilities versus upgrades

Overview of enabling technologies for DLSRs

- Lattice design evolution (MBA)
- Improved accelerator simulation tools
- Compact magnet technology
- Compact vacuum (NeG) technology
- Faster injection kickers
- In-situ magnet measurement and alignment methods
- Mode damped RF cavities and highly stable power sources
- High performance X-ray optics
- High performance IDs (superconducting, Delta, etc.)
- more …

Fundamental challenges of low emittance DLSR

from M. Borland,
GRC 8/13

- **Inescapable fact**
  - To reduce the amplitude of dispersive orbits, must focus more frequently and more strongly
- **Focusing (quadrupole) elements have chromatic aberrations**
  - Sextupole magnets added to correct these
  - Introduces higher order chromatic and geometric aberrations
  - More sextupoles or octupoles added to correct these...
- **Stronger focusing leads to difficult non-linear dynamics**
  - Poor “momentum aperture” ⇒ reduced lifetime ⇒ frequent injection
  - Poor “dynamic aperture” ⇒ greater difficulty injecting ⇒ on-axis injection?

1: M. Borland, IPAC12, 1013-1017.
2: M. Borland, “Can APS Compete with the Next Generation,” 2002; L. Emery et al., PAC03, 256.

Fundamental challenges of DLSR – cont.

- **Intra-beam scattering (IBS)**
  - Multiple electron-electron scattering in a bunch
  - Leads to increased emittance and energy spread
  - **Possible mitigations:**
    - Many low-intensity bunches
    - Round beams
    - Bunch lengthening system
    - Damping wigglers
- **Beam instabilities**
  - **Transverse:** resistive wall, ion trapping in multi-bunch mode, single bunch TMCI
    - **Beam blow-up ⇒ brilliance reduction**
    - **transverse beam oscillations ⇒ beam losses**
  - **Longitudinal:** primarily from cavity HOMs
  - **Possible mitigations**: mode-damped cavities, smooth chamber transitions, low-Z chamber material, low charge/bunch, longer bunches, feedback
- **X-ray optics**
  - Advances in optics needed to preserve coherence, handle high power densities

Start with lattice optimization

from M. Borland,
GRC 8/13

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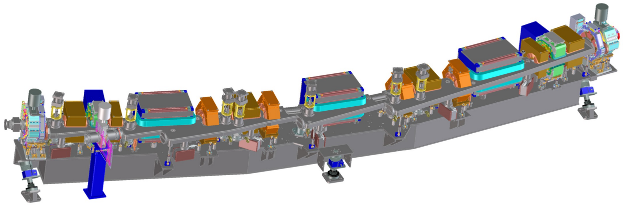
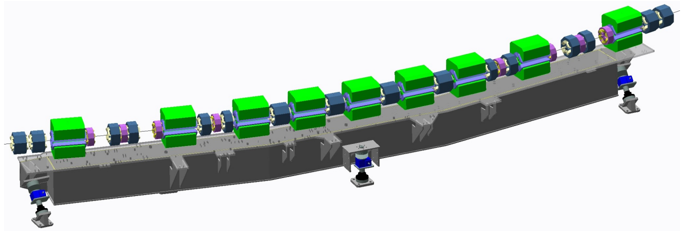
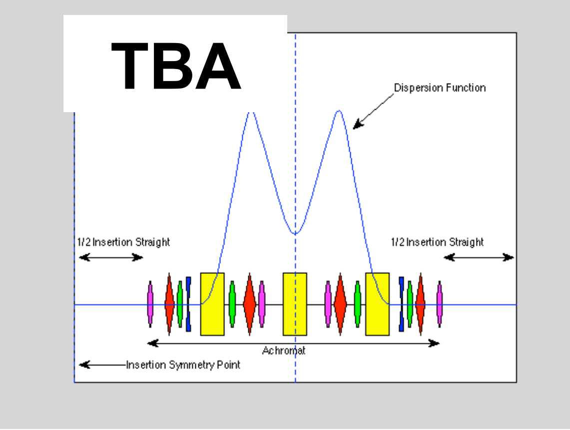
Multi-bend achromats pave way to the diffraction limit

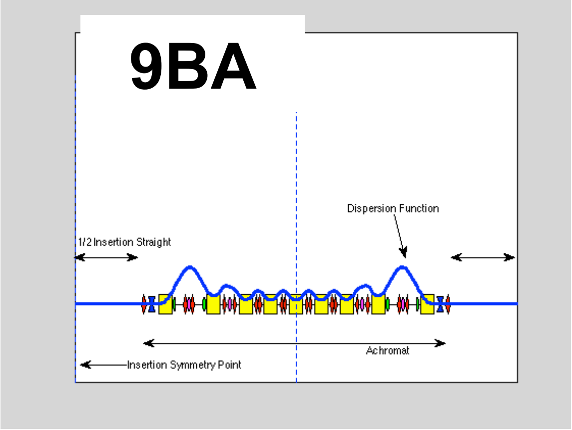
Lattice design of ALS evolved from a triple-bend achromats (TBA) to a multi-bend (9BA) achromat for ALS-II. Result is a large reduction in emittance, $\varepsilon_x = \sigma_x \sigma'_x$







$$\varepsilon_x = \boxed{2000\ \text{pm}} @\ 1.9GeV$$



$$\varepsilon_x = \boxed{52\ \text{pm}} @\ 2.0GeV$$

MBA: Strong Focusing and Low Dispersion

D. Einfeld *et al*., Proc. PAC 95, Dallas TX

First used for MAX-IV.

$$\varepsilon_x = C_L \frac{E^2}{\boxed{N_D^3}}, \qquad \varepsilon_x \propto \frac{E^2}{C^3}$$

C_L = lattice constant
N_D = # dipoles
C = Circumference

Development of accelerator simulation tools

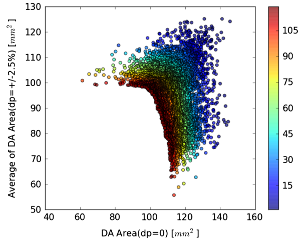


FIG. 1. The last generation of objective functions: DA of on-momentum (horizontal axis) and off-momentum (vertical axis) particles. Points are colored according to their rank.

Symplectic Tracking based methods

DA, MA separated

DA, MA together

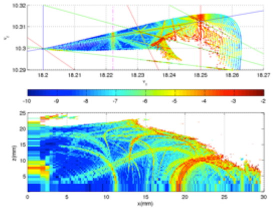
from L. Nadolski, ICFA LowEring, Oxford 7/13

Direct tracking based optimization

GLASS

Analytical based method

Genetic Algorithm
MOGA



Lie Algebra/Differential Algebra

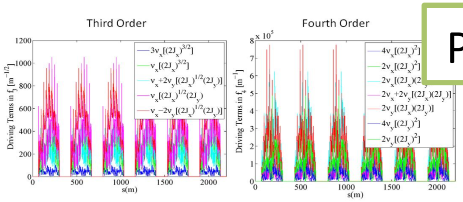
Frequency Maps
FMA
Diffusion factor

Nonlinear
“LOCO”

Resonance Driving Terms
RDT minimization

Amplitude Tuneshift
minimization

Canceling
Sextupole
Resonances



K.L. Brown & R.V. Servranckx
Nucl. Inst. Meth., A258:480–502, 1987

There are still three tune shift terms.

Yunhai Cai
Nucl. Inst. Meth., A645:168–174, 2011.

Phase advances

Interleaved
sextupoles

Resonance identification

Robustness to magnetic, alignment errors

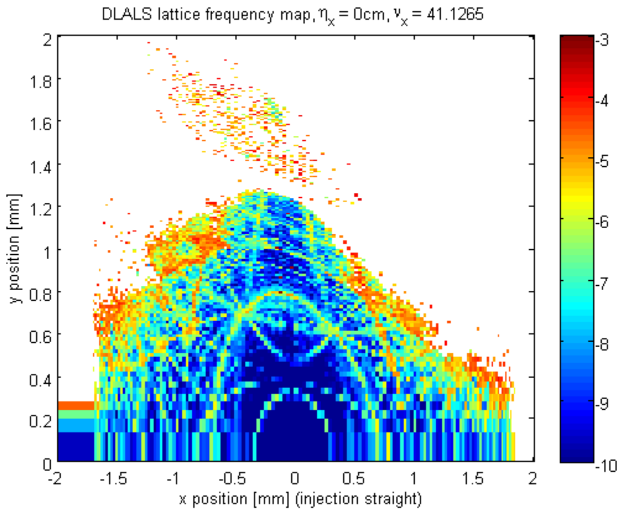
Robustness ID configurations

Tracking codes: **PTC MADX TRACY AT LEGO OPA ELEGANT**

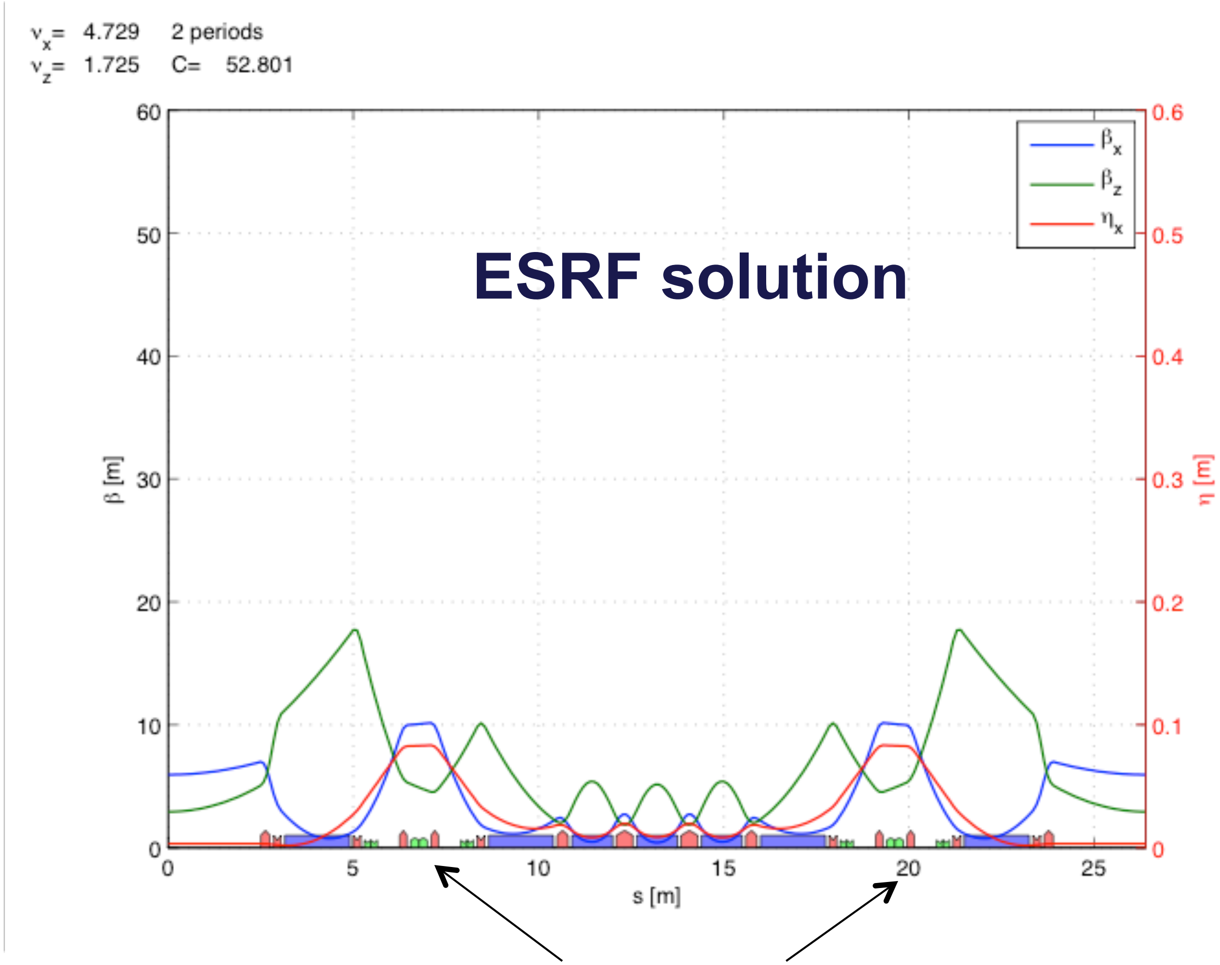
Strategies for optimizing the lattice

Goal of obtaining desired emittance and betas with acceptable dynamic and momentum apertures

- **Lots of different and powerful techniques**
  - **Simultaneous optimization of linear and nonlinear design**
- **Also enhanced computing power is allowing**
  - **Exploration of larger number of parameters**
- **Decide on whether swap-out is acceptable**
  - **Allows to push the parameters further**
  - **Other possible advantages**
  - **Kicker technology could limit the fill patterns -> timing modes**



Obtaining small emittance with sufficiently large dynamic aperture

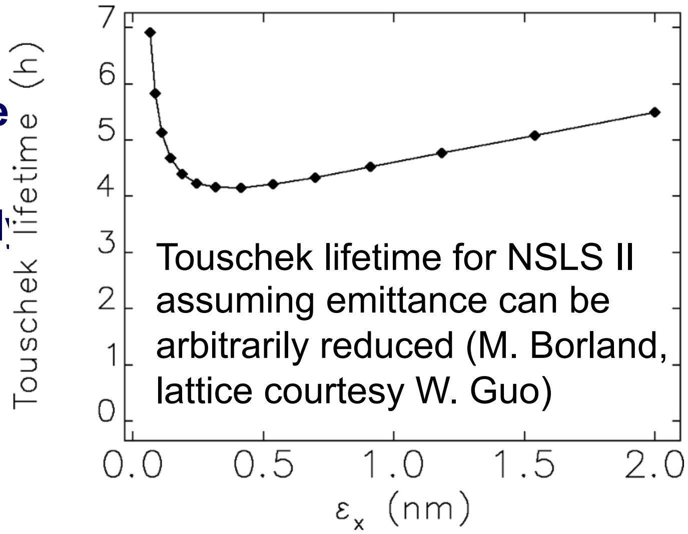


ESRF solution

Sexupoles in higher dispersion region

Beam lifetime

- **Need sufficient lifetime to maintain high average current**
- **Vacuum Lifetime**
    - **Small apertures (dynamic and momentum) require low vacuum for sufficient lifetime**
- **Touschek lifetime**
    - **Small momentum apertures and dense bunche will decrease lifetime**
    - **However very small emittances with sufficientl large momentum apertures may result in an increase in lifetime.**
        - **Are we getting into this regime?**

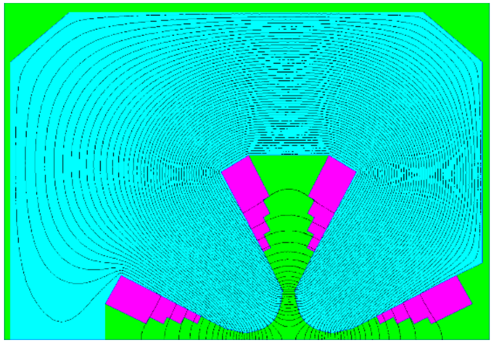


Touschek lifetime for NSLS II assuming emittance can be arbitrarily reduced (M. Borland, lattice courtesy W. Guo)

Adjustability of the lattice

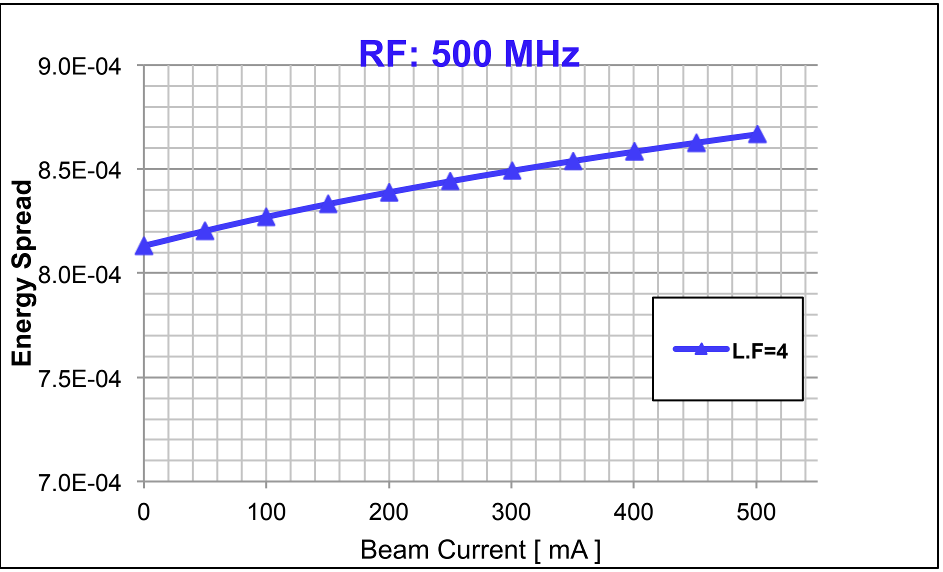
- **Require stong combined function magnets**
- **Couple dipole and quadrupole**
- **Reduces the flexibility of the operating condition**
- **Gain flexibility may require backleg or moving magnets**

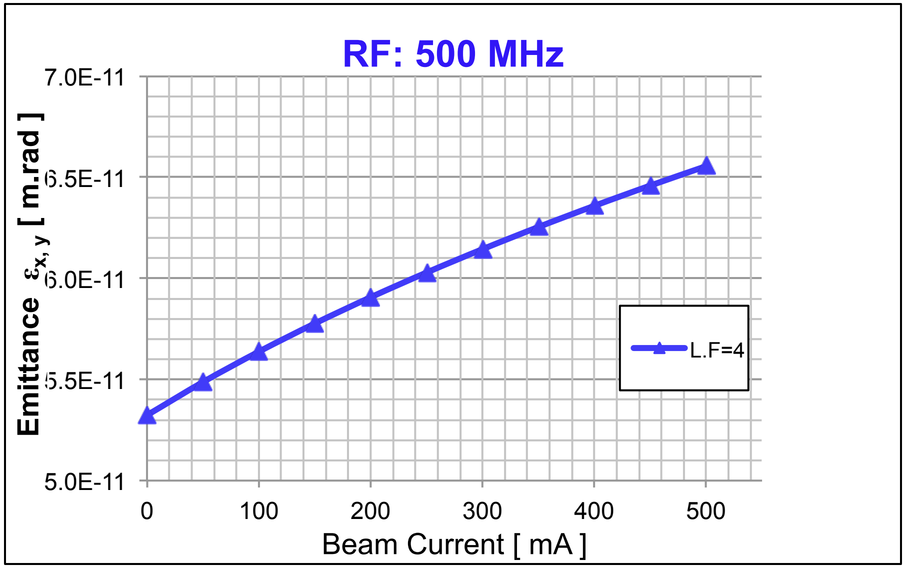
Combined Function Magnets



Fundamental challenges of DLSR – cont.

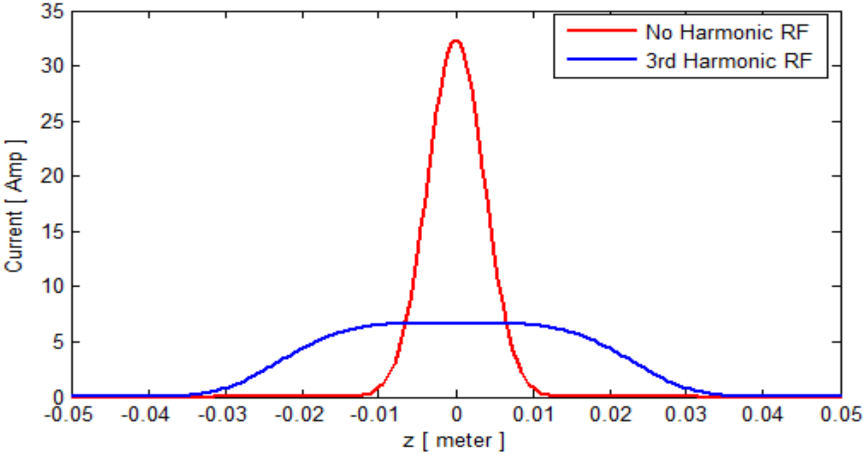
- **Intra-beam scattering (IBS)**
  - Multiple electron-electron scattering in a bunch
  - Leads to increased emittance and energy spread
  - **Possible mitigations:**
    - Many low-intensity bunches
    - Round beams
    - Bunch lengthening system
    - Damping wigglers





Mitigating the effects of intrabeam scattering

- **Reducing the beam density**
  - **Fill as many bunches as possible**
    - **Limited by the injection scheme, ions, or desired timing modes**
    - **Push towards DC has benefits for certain techniques such as ARPES and XPCS.**
  - **Lengthening the bunches using harmonic cavities**
    - **Limited by fill patterns / phase transients**
  - **Operate with rounder beams**
    - **Increasing the vertical beamsizes by coupling or dispersion or …**
    - **What is the impact on the dynamics?**



3^{rd} Harmonic Cavities (see J. Byrd's talk)

- **Need aggressive bunch lengthening (factor >=4)**
  - **To keep IBS emittance growth in check**
  - **Increase instability thresholds**
- **Difficult because of amplitude/ phase transients**
- **Mitigation:**
  - **s/c?, low frequency?, many bunch trains, small gaps, …**
- **Background:**
  - **Max-IV think they can achieve this**
  - **s/c 3HC in use at several European facilities**

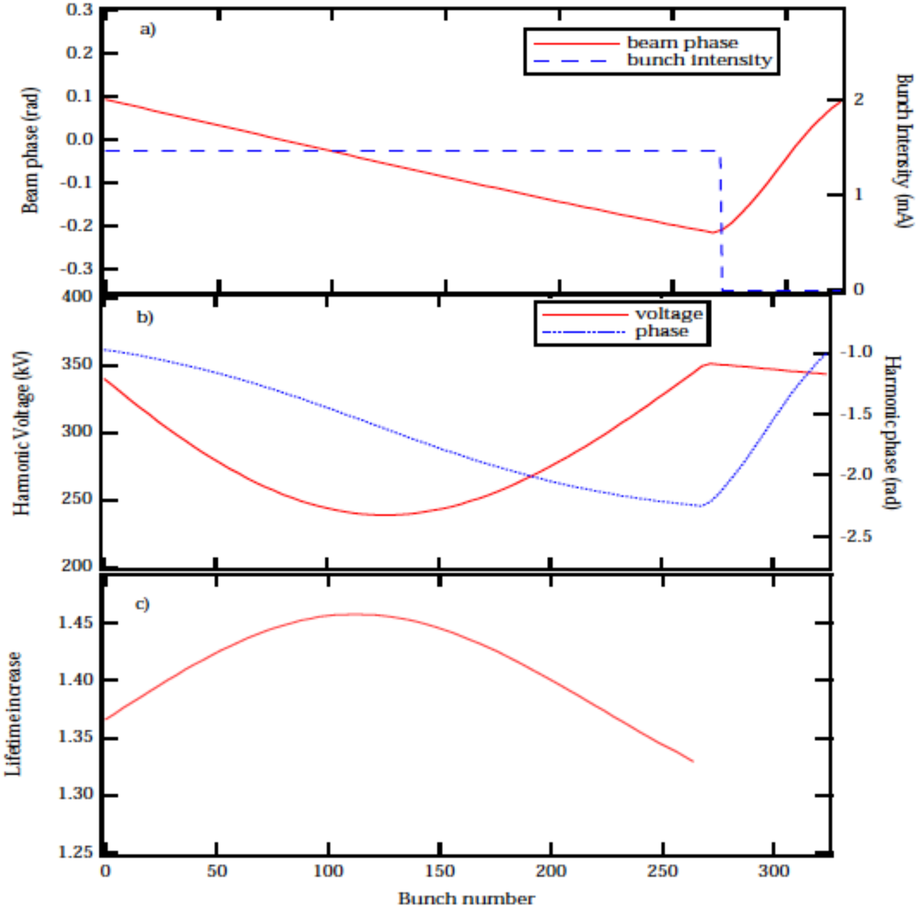


Figure 8. Simulation results for ALS conditions with 17% gap in the fill pattern.

Injection – Accumulation or on-axis Swap-out

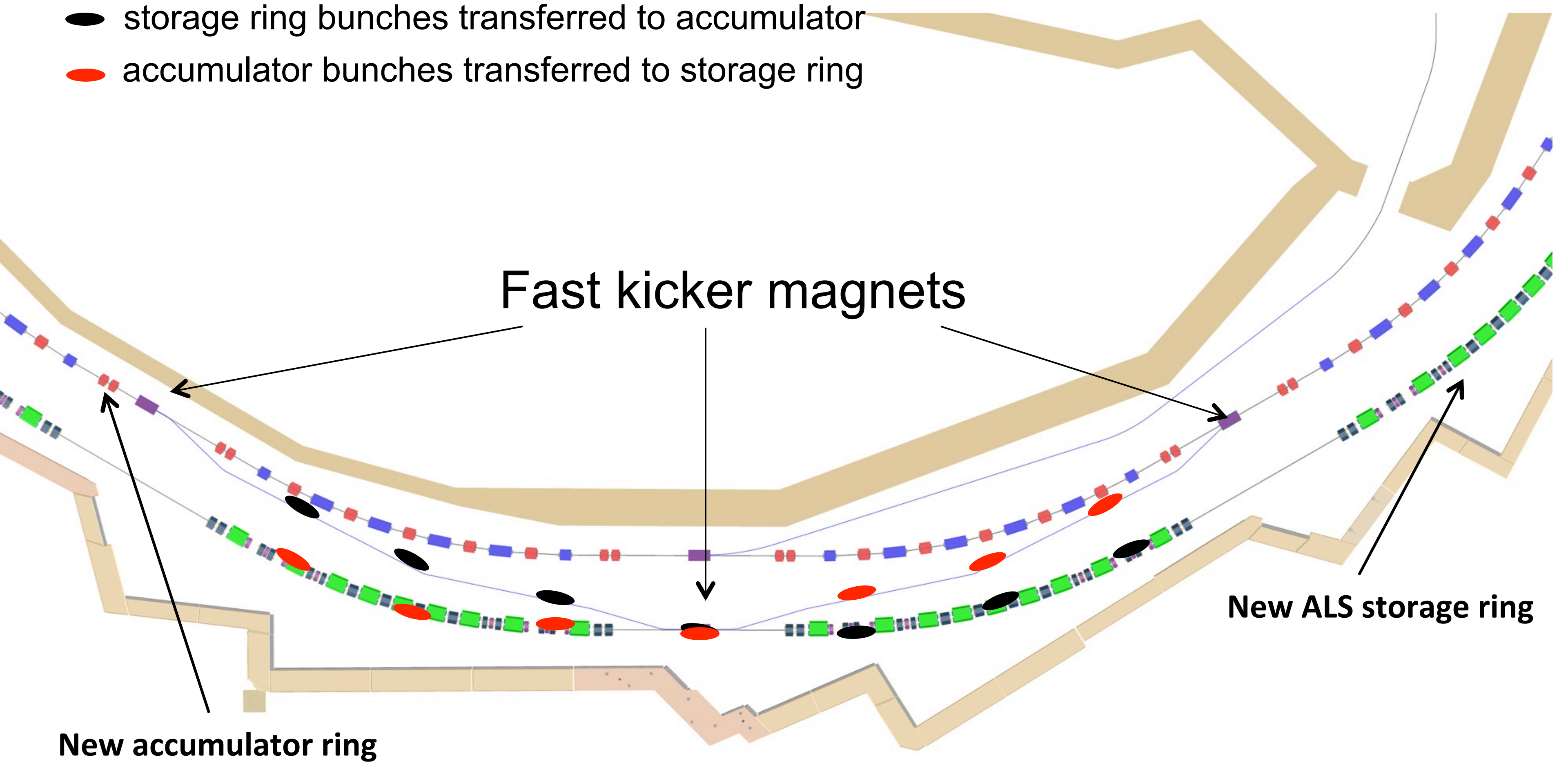
- Accumulation
  - Traditional injection scheme
  - Requires sufficiently large dynamic aperture

  May not be possible for those lattices with small dynamic apertures

- On-Axis Swap-out
  - Bunch is replaced with a fresh bunch or bunch train
  - Recover or dump replaced bunches
    - Added complexity versus stress on the injection system
  - Requires fast kickers to minimize gaps in fill pattern
    - May impact the range of fill patterns

Swap-out injection was first proposed by M. Borland for possible APS upgrades

Swapping beam accumulator and storage ring bunch trains



● storage ring bunches transferred to accumulator

🔴 accumulator bunches transferred to storage ring

Fast kicker magnets

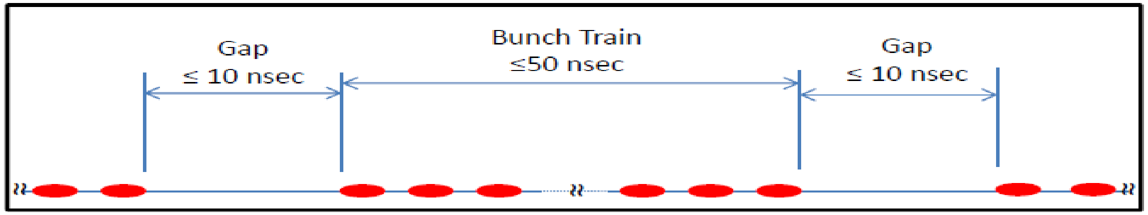
New ALS storage ring

New accumulator ring

Swap-out choices

Choose to swap-out

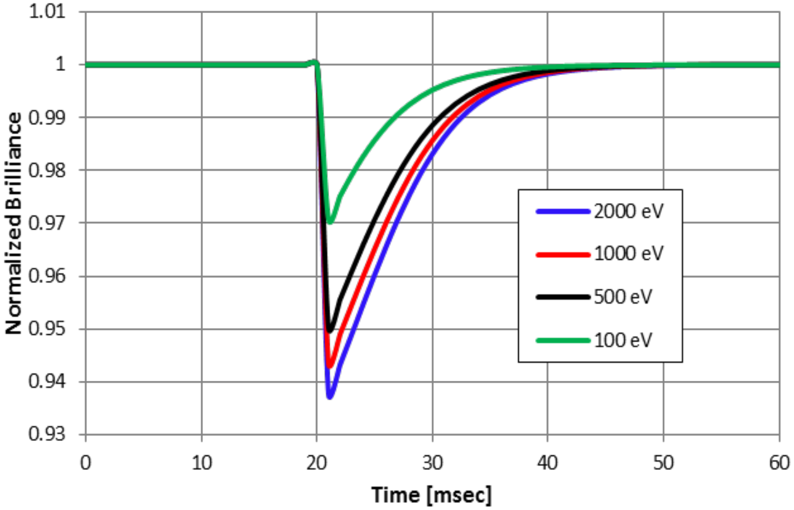
- Single bunch
- Bunch train
- Full beam



Impacts

- Kicker parameters (rise time, flat top)
- Stress on the injector
- Current in the accumulator
- Possible fill patterns
- Transparency of injection

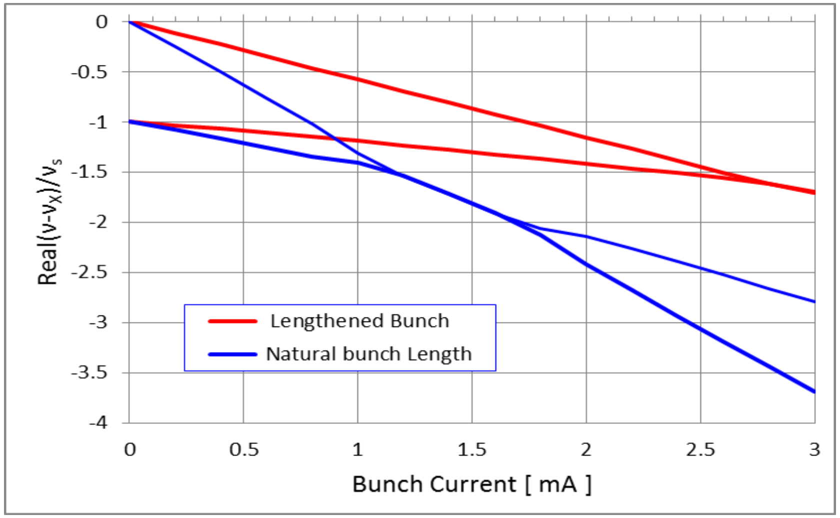
Brightness evolution: inject $0.1{*}I_{beam}$



TMCI vs. Bunch Lengthening & Chromaticity

- ☐ Because of the small momentum compaction factor and the small synchrotron tunes, the single bunch instabilities could present a problem

- ☐ Distributed vacuum pumping by NEG is foreseen with high transverse impedance in the high frequency range.



- ☐ What are the required single bunch currents for a given ring?

Heat loading on beam optics is an important issue

- Maximize brightness will increase the angular power density

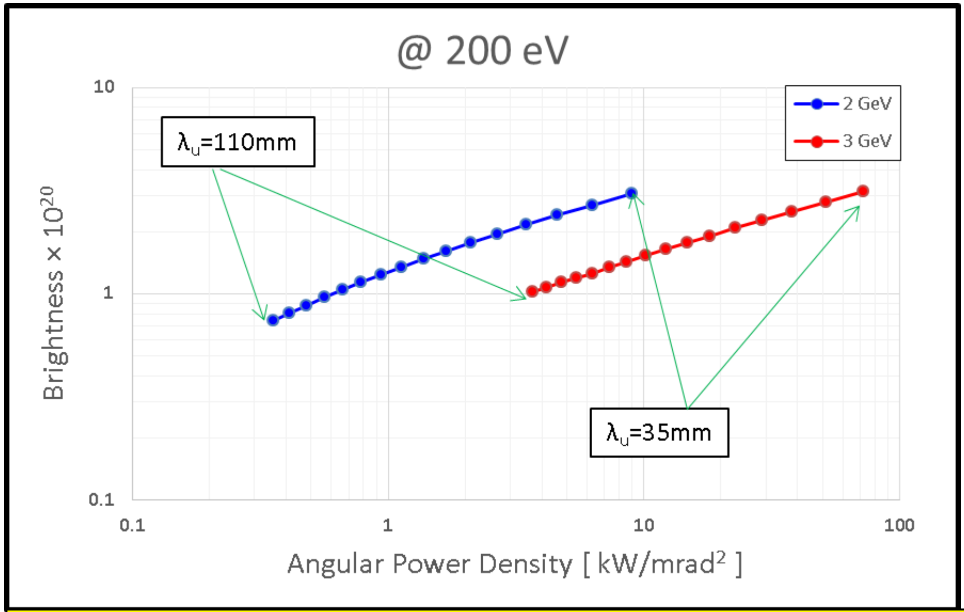
- Need to preserve the brightness in both planes.

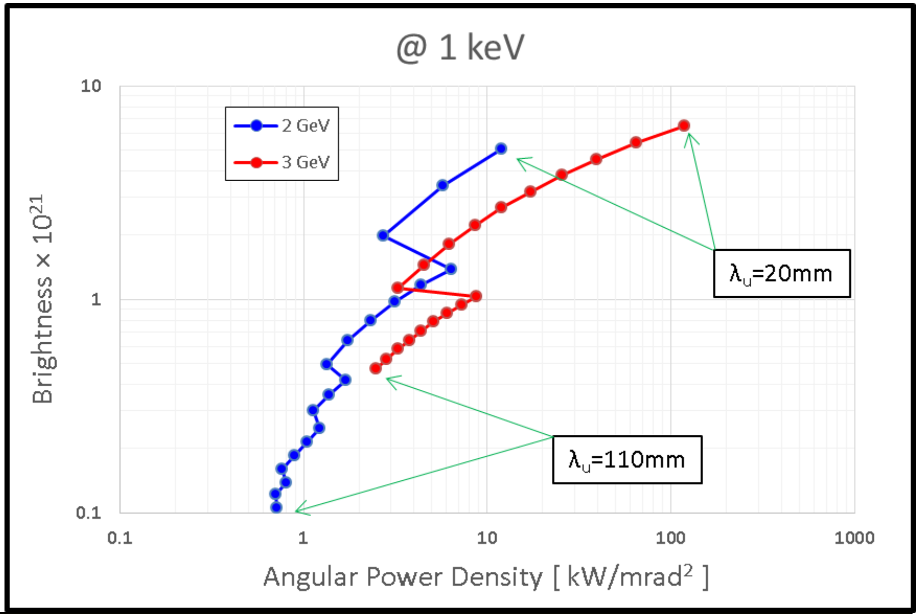
- The first optic (that has the highest heat load) is particularly important

- Situation becomes worse when going to larger K values to access lower photon energies

Angular Power Density vs. Brightness

The power density is an important issue for the low photon energies. The performance and the cost effectiveness are a trade-off between **Brightness**, **Power density** & **Slope error.**

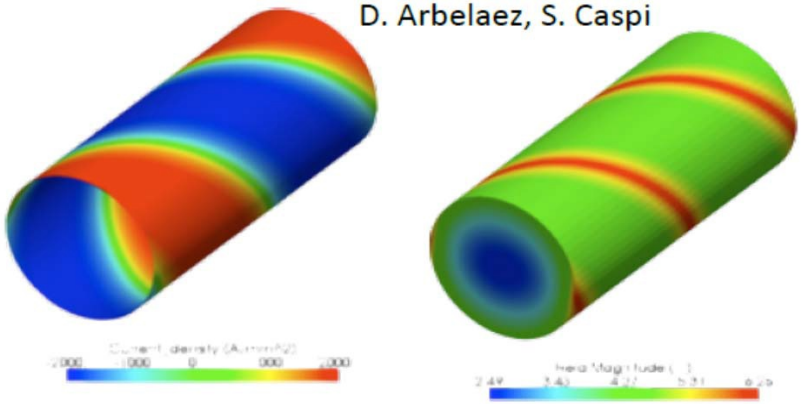




Parameters @ 2 GeV & 3 GeV:$\varepsilon_{x,y}$=50 pm.rad, $\beta_{x,y}$ =1 m, L_{ID} = 4m and I = 500 mA

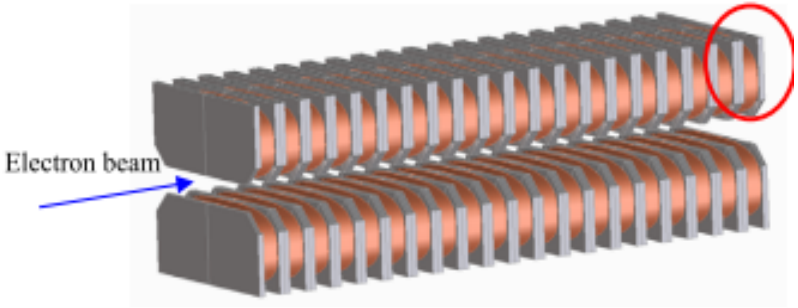
Insertion device

- **Higher performance insertion devices will allow increased performance**
  - Superconducting, Delta, etc.

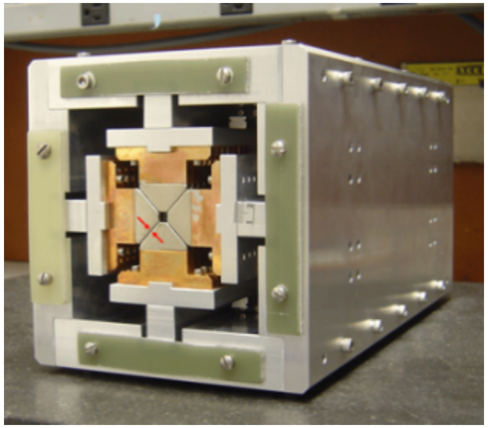


D. Arbelaez, S. Caspi

Bifilar Helical Undulator



SC undulator development at APS (E. Gluskin et al.), LBNL (S. Prestemon et al.), and elsewhere



Delta undulator prototype

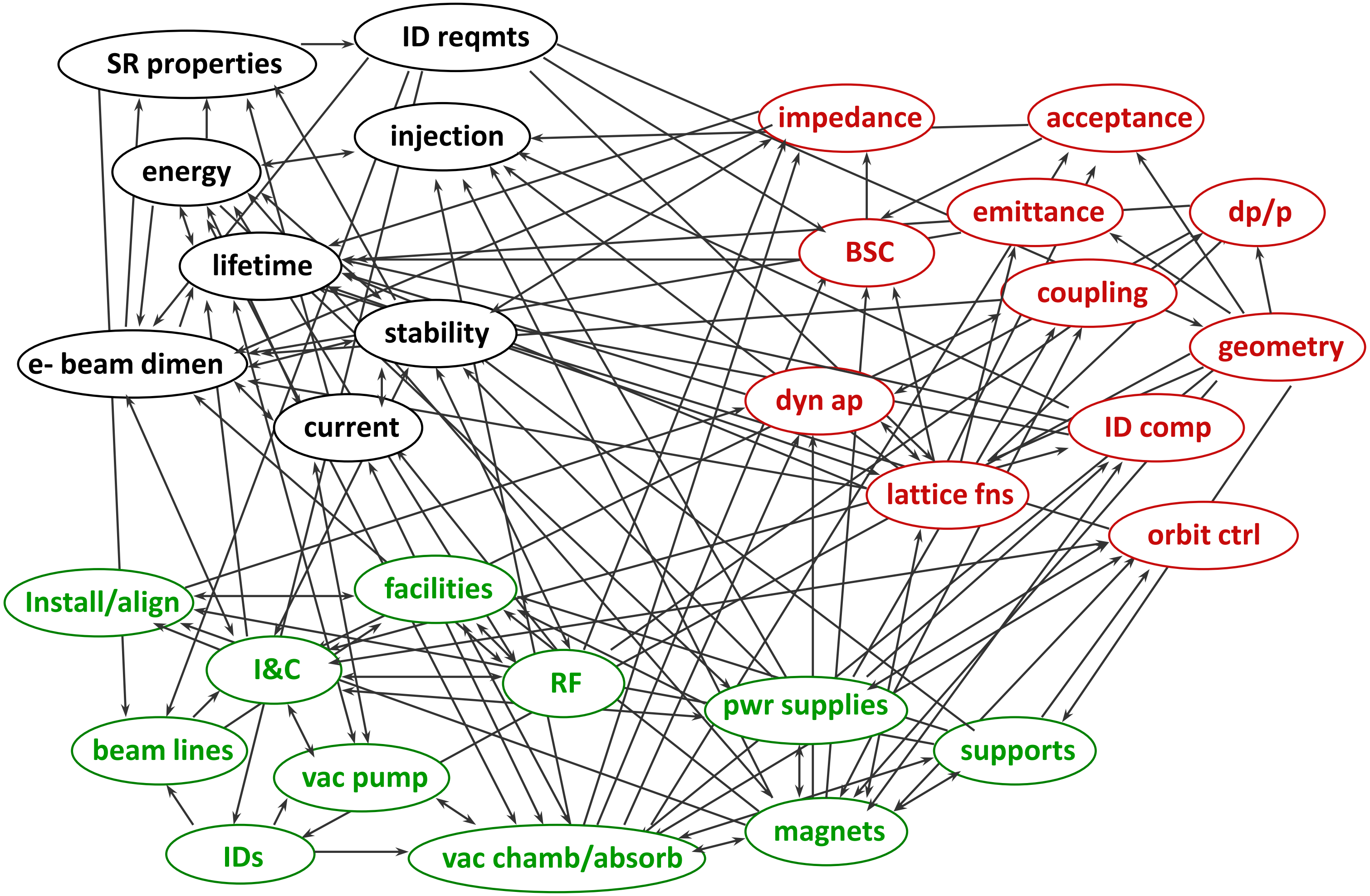
- A. Temnykh

Other issues

- Timing modes and short pulse
  - What timing modes are desirable
  - What pulse lengths
  - What fill patterns
  - Capatible with crabbing or other techniques

- Smooth transition for existing facilities
  - Preserving / Upgrading beamlines
  - Minimizing downtime

DLSR design optimization



R. Hettel
SPEAR 3 Design
Jan. 17 2003

Draft
rev 1

Concluding remarks

- Lot of challenges some but not all mentioned in this talk
- None appear to be showstoppers
- Plenty of opportunity for optmization
- Many are challenges are common
- Large and growing community

Great opportunity for collaboration

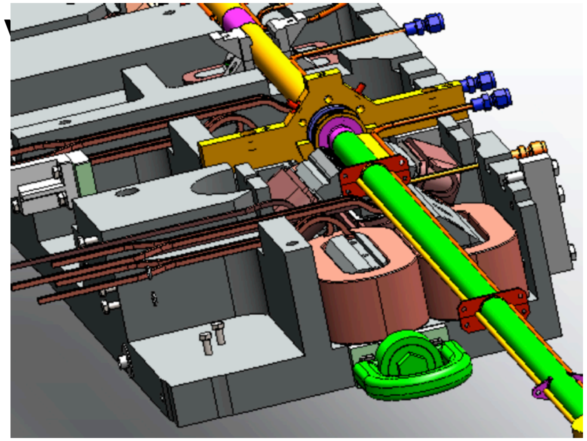
DLSRs: why now? – cont.

Compact magnet and vacuum technology

- NEG-coated vacuum chambers enable small apertures to enable high magnet gradients

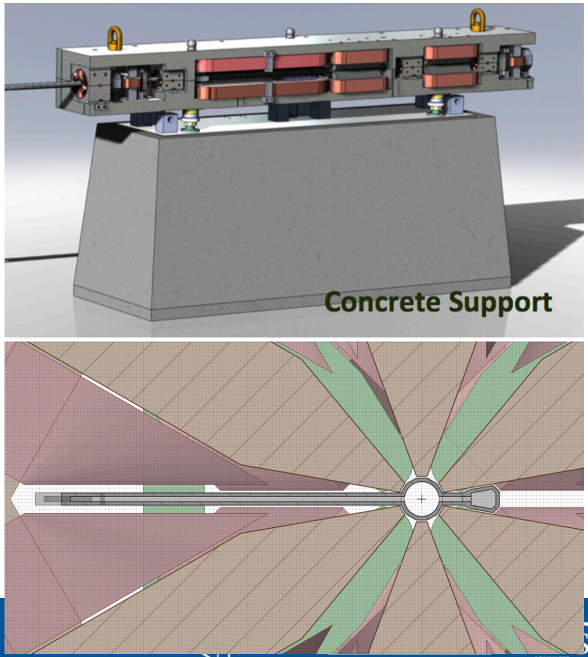
  Pioneered at CERN, used extensively at Soleil, and adopted for MAX-IV and Sirius MBA lattices

- Precision magnet pole machining for small aperture magnets, combined function magnets, tolerance for magnet crosstalk si



MAX-IV

Courtesy S. Leemans



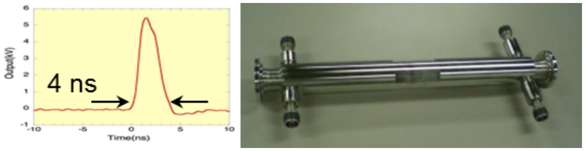
SPring-8 concept

K. Soutome

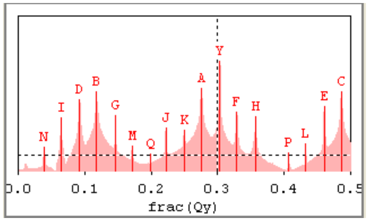
DLSRs: why now? – cont.

Other advances in accelerator and light source technology

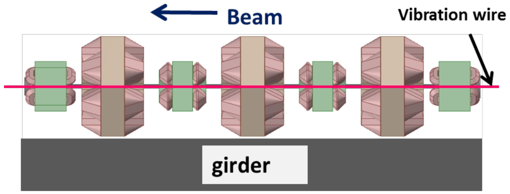
- Fast kickers for swap-out injection
- Sub-micron e- BPMs and orbit feedback
- Accelerator and beam line component mechanical stabilizing systems
- Micron resolution single pass BPMs (non-linear lattice tuning)
    - "In-situ" magnet measurement and alignment methods (e.g. NSLS-II)
- Mode-damped RF cavities (fundamental and harmonic)
- Highly stable solid state RF power sources
- High performance IDs (superconductin Delta, etc.)



Fast kickers – KEK ATF

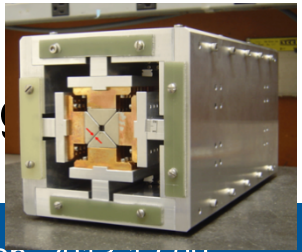


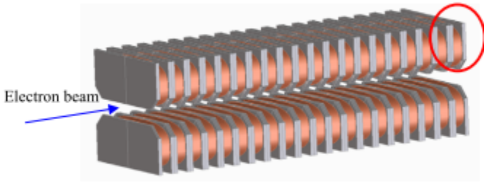
Higher order resonances detected by turn-turn BPMs (A. Franchi)



SPring-8 concept based on NSLS-II vibrating wire method - K. Soutome

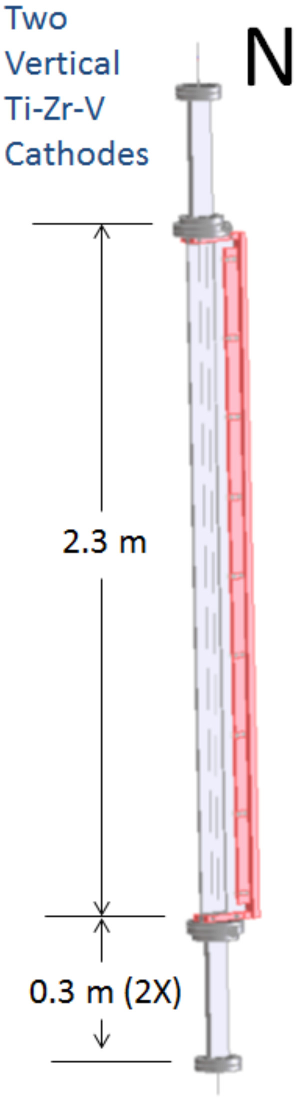
Delta undulator prototype - A. Temnykh





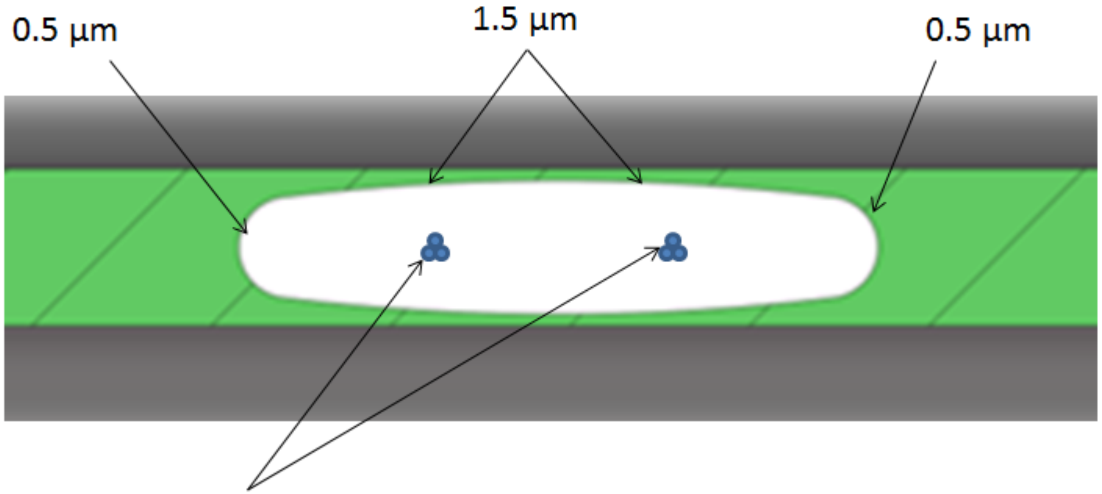
SC undulator development at LBNL (S. Prestemon et al.), APS (E. Gluskin et al.) and elsewhere

NEG coated chamber (Cosmic) example



NEG Coating Process (SAES)

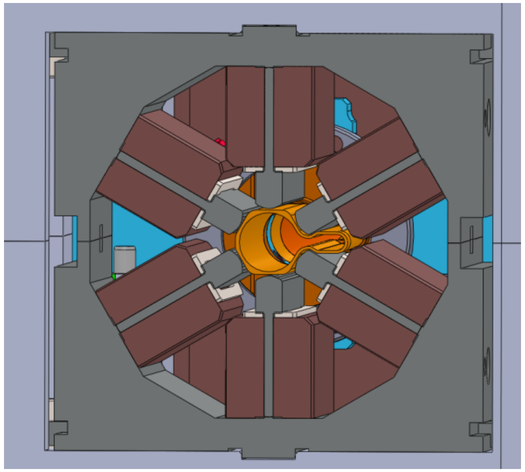
- Magnetron sputtering process inside vertical chamber
- Magnet ID = 40 cm
- Coating length inside magnet = 1.6 meters
- 2.3 Meter chamber will be coated in two steps
- Room temperature process
- Coating thickness will be 1 micron (+/- 0.5 µm)

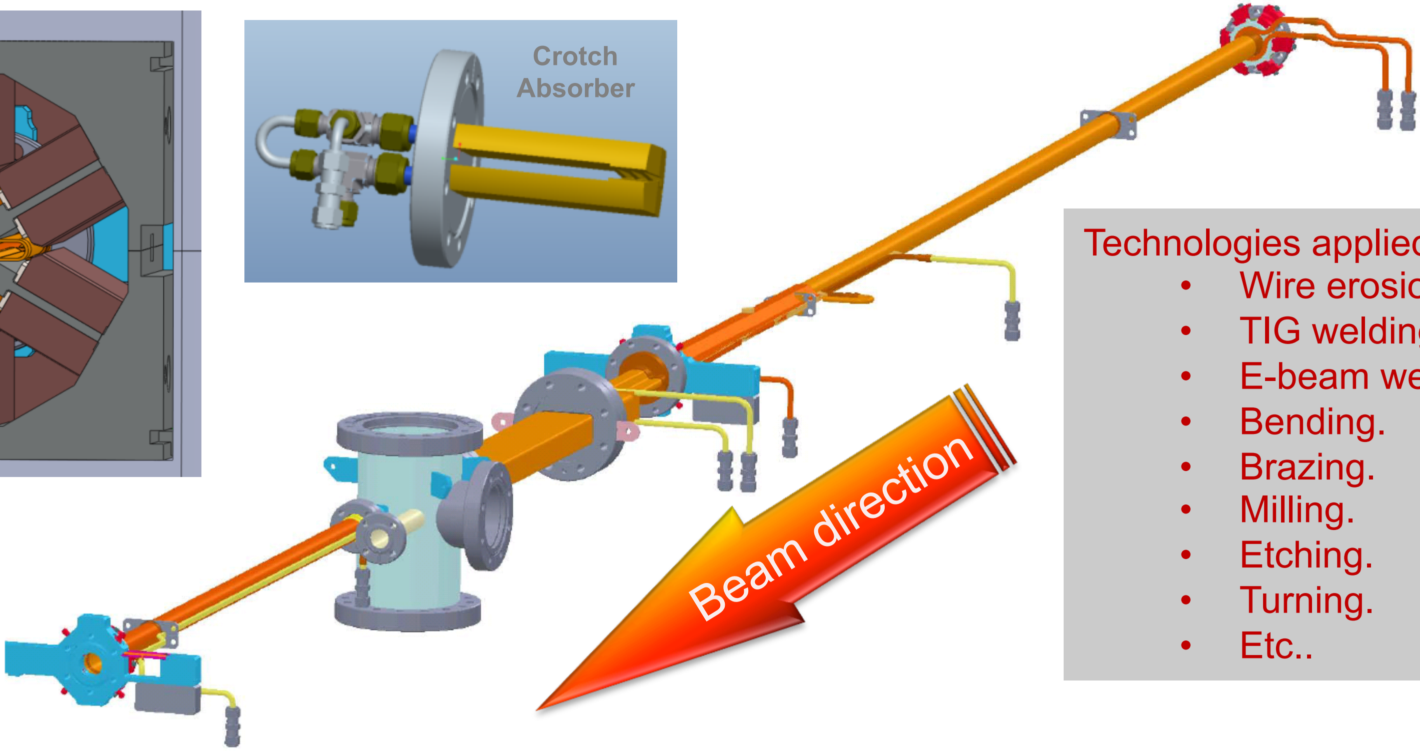


Ti-Zr-V Cathodes are formed by a wire triplets. Dia. Wire ~ 1 mm.

Max-IV Vacuum chamber for beam extraction

E. Al-Dmour

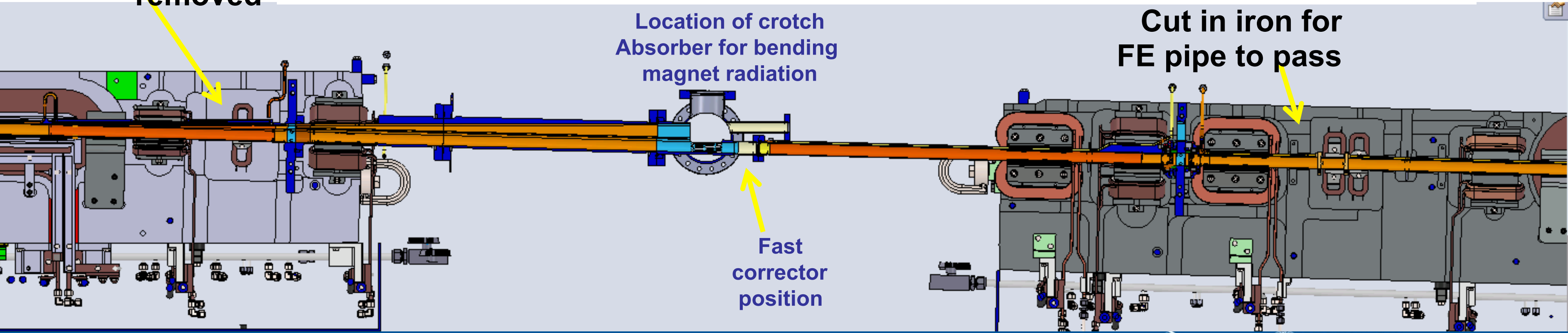




Technologies applied:

- Wire erosion.
- TIG welding.
- E-beam welding
- Bending.
- Brazing.
- Milling.
- Etching.
- Turning.
- Etc..

One vertical corrector removed



Location of crotch Absorber for bending magnet radiation

Fast corrector position

Cut in iron for FE pipe to pass