NEW DEVELOPMENTS IN LIGHT SOURCE MAGNET DESIGN

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Outline

- Introduction
- Magnet system developments
  - Combined function magnets
  - Superbends
  - Permanent magnet systems
    - Chicane
- Insertion device developments
  - Cryogenic in-vacuum
  - Superconducting devices

Introduction

- Developments in light source magnet design are occurring on a number of fronts:
  - Lattice magnets
    - Combined function designs
    - Permanent magnet systems
    - Superconducting magnet systems
  - Kicker magnets (single-bunch….)
  - Insertion devices
    - Novel spectral characteristics
    - Dynamic multipole compensation
    - Cryogenic permanent magnet
    - Superconducting (planar and variable polarization)

Some discussion here…

And more discussion here…

Lattice magnet developments

- Trend is to optimally combine magnet functions:
  - reduce space requirements of lattice magnets
  - Improve overall efficiency
  - Minimize overall magnet cost
- Industry has provided cost effective solutions:
  - Examples – Soleil (Paris), Canadian Light Source, Australian Light Source, etc
  - Improvements in machining and fabrication tolerances, measurement and quality control capabilities

ALS Superbends

- Stronger field, shorter length:
  - Higher critical photon energy – key for hard x-ray research
- Three-fold symmetry at ALS
- First operation of superconducting lattice magnet on a 3^{rd} generation ring
- Operating since 2001
  - Excellent operational record

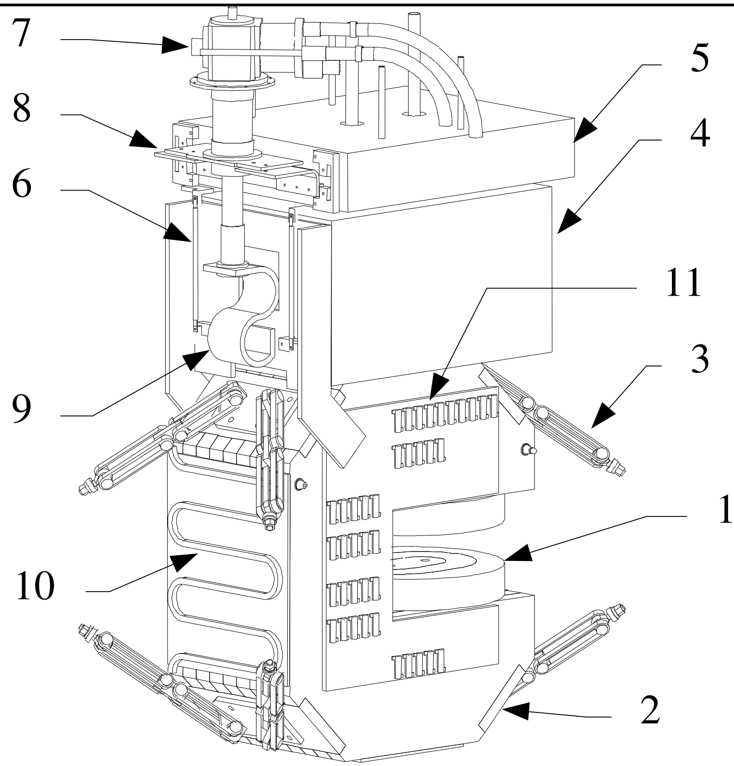


Fig. 1. Superbend cold mass assembly: 1 – superconducting coils with steel poles, 2 – laminated steel yoke, 3 – suspension straps, 4 – LHe vessel, 5 – LN_2 vessel, 6 – HTS leads, 7 – cryocooler, 8 – 50 K thermal connection, 9 – 4 K thermal connection, 10- cooldown tube, 11 – warmup heater.

J. Zbasnik, et al., "ALS Superbend Magnet System", IEEE Transactions on Applied Superconductivity, vol. 11, No. 1, pp 2531-2534, March 2001.

Example of combined function magnet

- ALS sextupole
  - “Traditional” sextupole with additional capabilities:
    - Vertical steering
    - Horizontal steering
    - Skew quadrupole
  - Designed using Halbach perturbation theory
- Similar concept used in Soleil sextupoles
- MaxLab proposes combined multipole magnets for the MAX IV lattice (**quadrupoles** with **sextupole** and possibly **octupole** content)
  - May serve as a template for future light source lattice designs

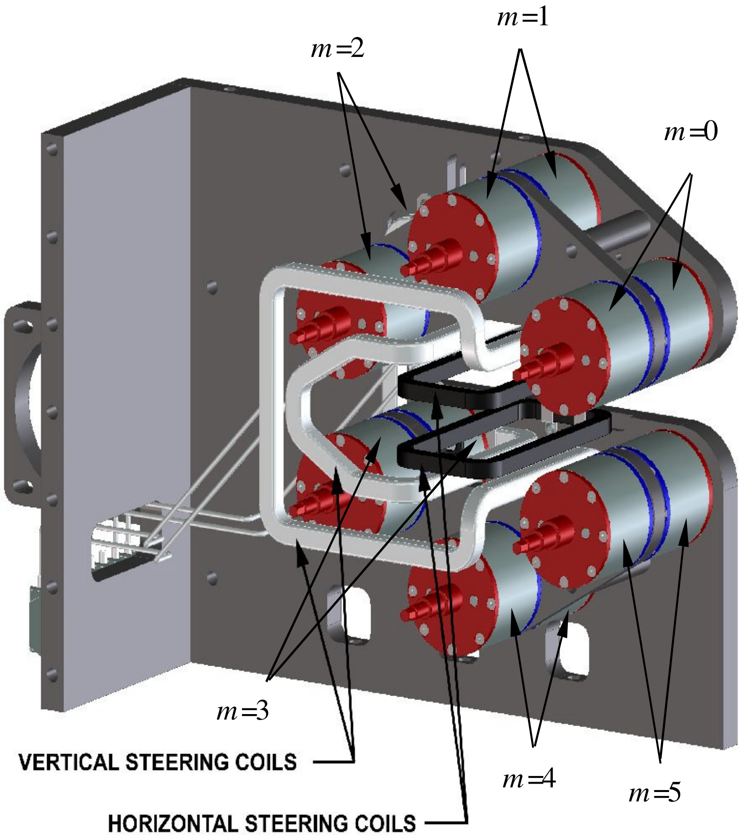
S. Marks, “Magnetic Design of Trim Excitations for the Advanced Light Source Storage Ring Sextupole”, IEEE Transaction on Magnetics, Vol. 32, No. 4.

Permanent magnets for lattice functions

- The trend in Light Sources is towards full-energy injection and in many cases top-off injection
  - Can consider "unconventional" approaches
    - Permanent magnets for the lattice!?
      - Idea not new:
        - "Workshop on Permanent Magnet Storage Rings", LBL, 1994
        - Used for antiproton storage rings (Fermilab recycler)
    - Advantages
      - Significant reduction in infrastructure (water, power,…)
      - Stable operation – no beam loss due to power outage (motivation for e^+ ring)
      - May provide enhanced performance if apertures can be made small
    - Issues:
      - Radiation damage mitigation
      - Field control (perturbation level)
      - Field error mitigation

ALS Permanent magnet chicane

- The ALS now uses a pure permanent magnet for the chicanes
  - No hysteresis
  - Control of multipoles – excellent combined-function capabilities
  - Scalable strength, built-in capability for fabrication and installation error compensation



Concept proposed in: *R. Schlueter et al, NIM Phys Res. A, Vol 395, 1997*

Insertion device developments

- Excellent review by J. Chavanne and P. Elleaume, EPAC 2006
- Recent workshop on ID developments, sponsored by B. Diviacco, ELETTRA (Nov. 2006)
  - Progress on devices with novel spectral properties
  - Dynamic multipole compensation
  - Research on FEL application-specific issues
  - New results in cryogenic in-vacuum permanent magnet development
  - New results in superconducting insertion devices – planar and variable polarization

Devices with novel spectral properties

- Variable polarization devices are becoming the ID of choice for soft x-ray applications
  - Also becoming more common on high-energy rings
  - Some companies developing fabrication expertise
- Quasi-periodic capabilities are intriguing
  - Reduced perturbation of energy states by harmonics transmitted through the monochrometer
  - Can be implemented on variable polarization devices as well

-S. Hashimoto and S. Sasaki, JAERI-M Report 94-055 (1994).

-S. Sasaki, S. Hashimoto, H. Kobayashi, M. Takao and Y. Miyahara, in Proc. of Inter. Conf. of Synchrotron Radiation Instrumentation ’94, New York, U.S.A., 1994.

Quasi-periodicity

- Idea: Interlace two periodic devices
  - Modification: interlace two devices with same period, different field strength

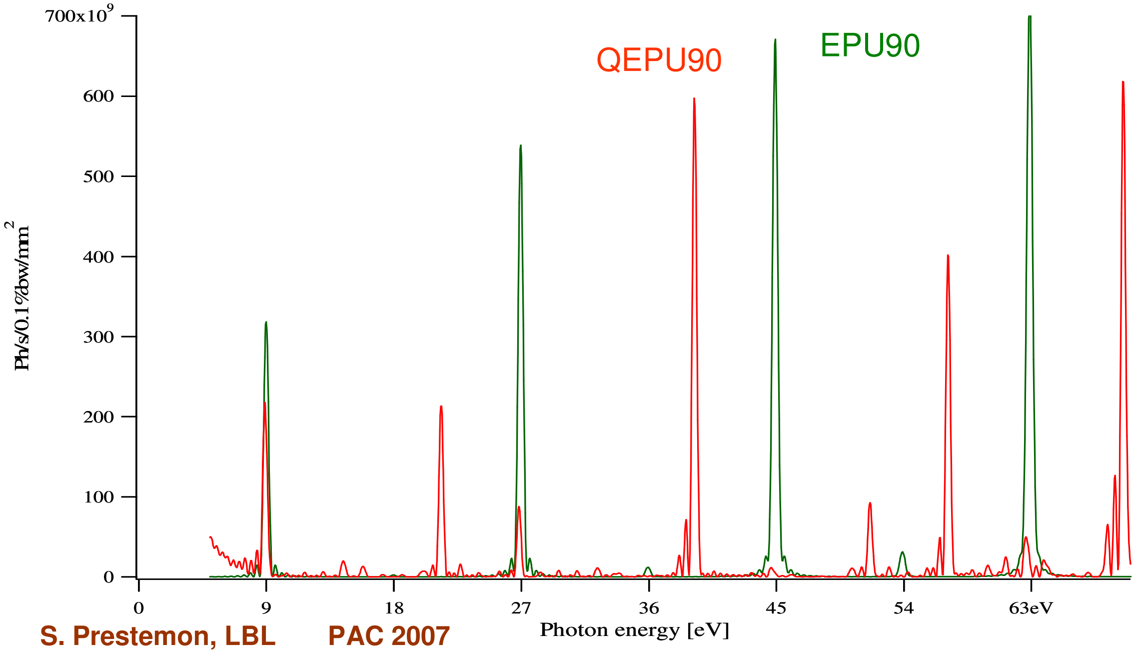
Planar:

-B. Diviacco et al, EPAC 1998;

-J. Chavanne et al, EPAC 1998

EPU:

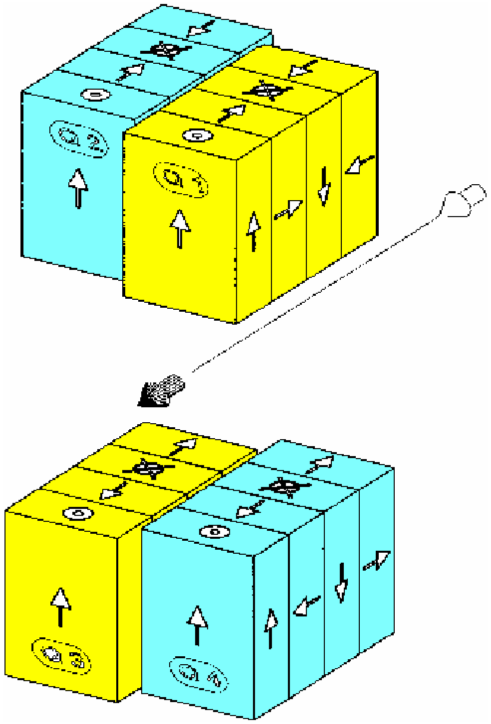
B. Diviacco, APS Workshop, 2002



EPU accelerator issue: Dynamic multipoles

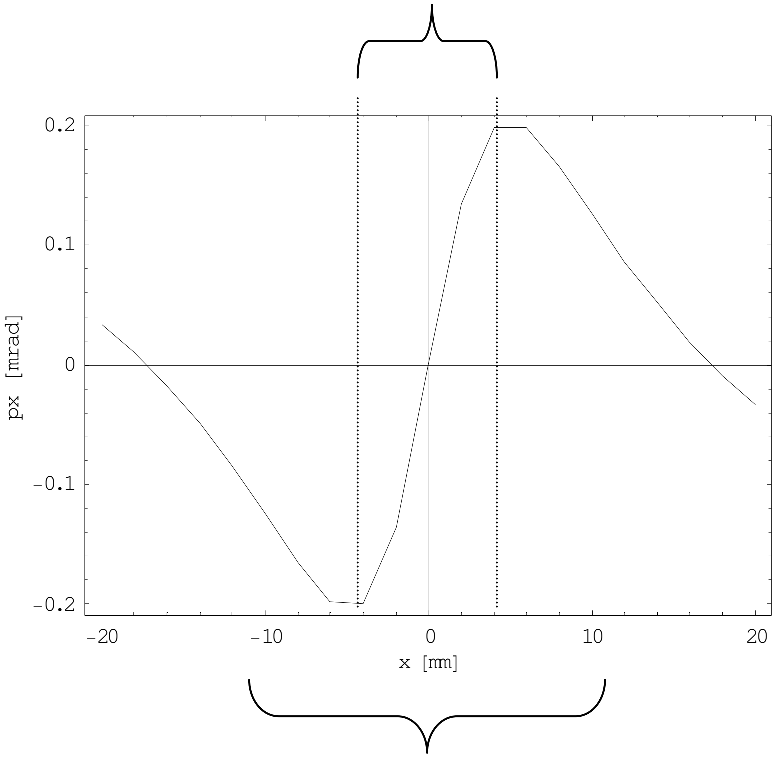
- Vertical focusing of planar insertion devices is well-known
  - Emanates from $f_z \sim v_x B_z$ off-axis
  - Can be compensated using lattice and/or corrector quadrupoles

- For EPU’s:
  - varying field configurations result in focusing properties that vary with phase shift (i.e. polarization mode)
  - fast field roll-off results in nonlinear focus/defocus properties
  - Noted and evaluated by P. Elleaume et al; detailed solution tested/implemented by J. Bahrdt et al., I. Blomquist, B. Diviacco,…



Example: ALS EPU's

- ALS has three 50mm period APPLE II's
- One 90mm device will soon be installed (MERLIN)
- Top-Off will require dynamic multipole correction for reasonable injection efficiency



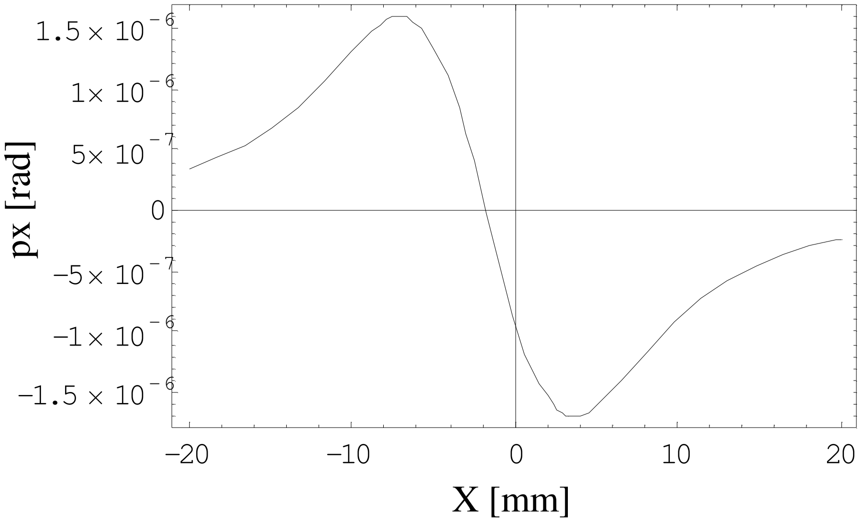
Uncorrected EPU90
Linear defocusing region limited

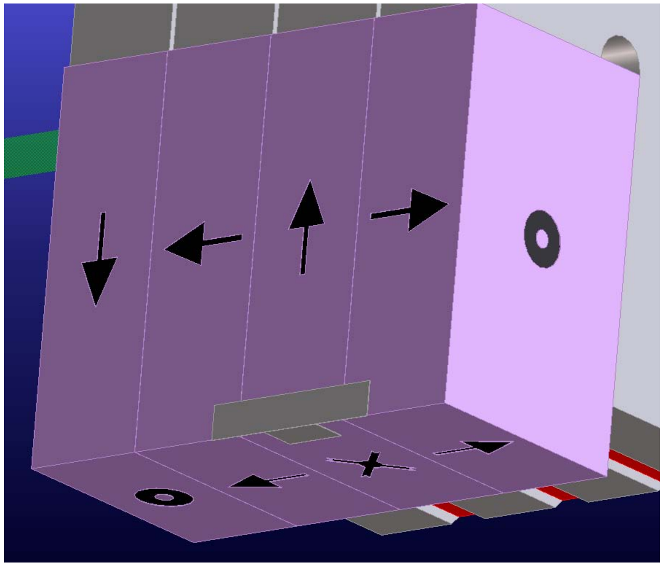
Dynamic aperture needed for top-off at the ALS

Solution: addition of magnetic correctors

- Magnetic material, correctly dimensioned and located on the different quadrants, can partially compensate the nonlinear effect

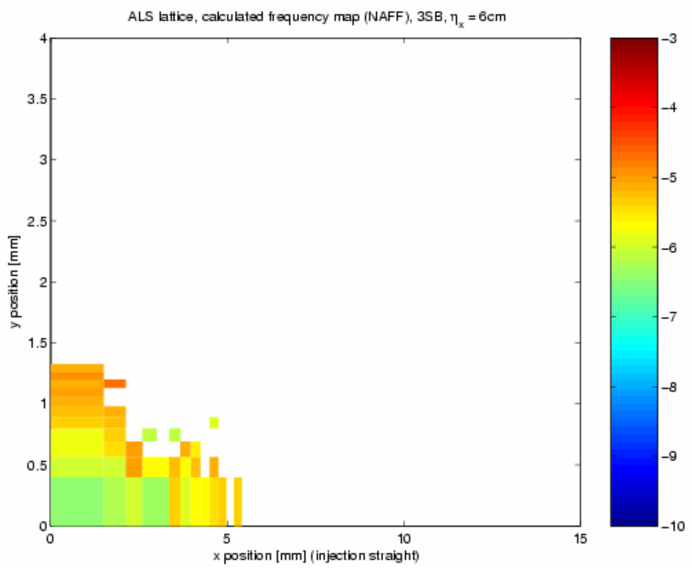
Idea originally proposed by J. Chavanne and P. Elleaume

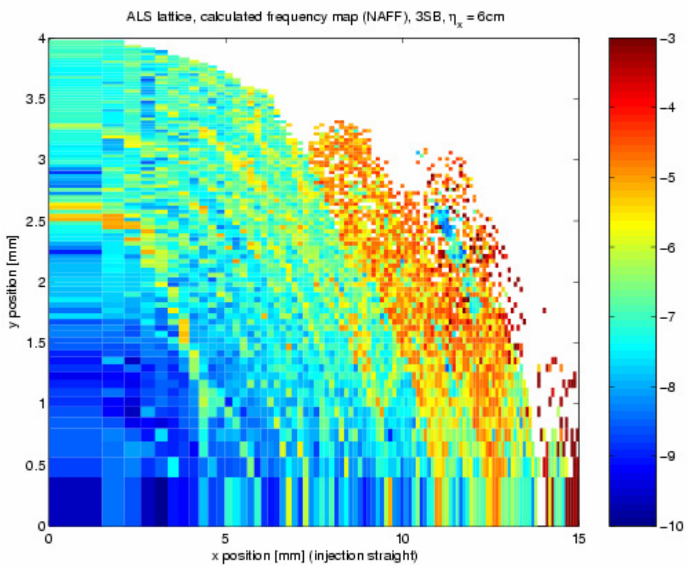




Impact of magnetic corrections

- Calculations suggest dynamic aperture is recovered in most polarization modes for the ALS (C. *Steier et al., EPAC 2006*)





Developments in novel insertion devices

- CIVID developments
- Superconducting undulators
  - Planar
  - Variable polarization

Nice review of progress can be found at http://www.elettra.trieste.it/UM14/

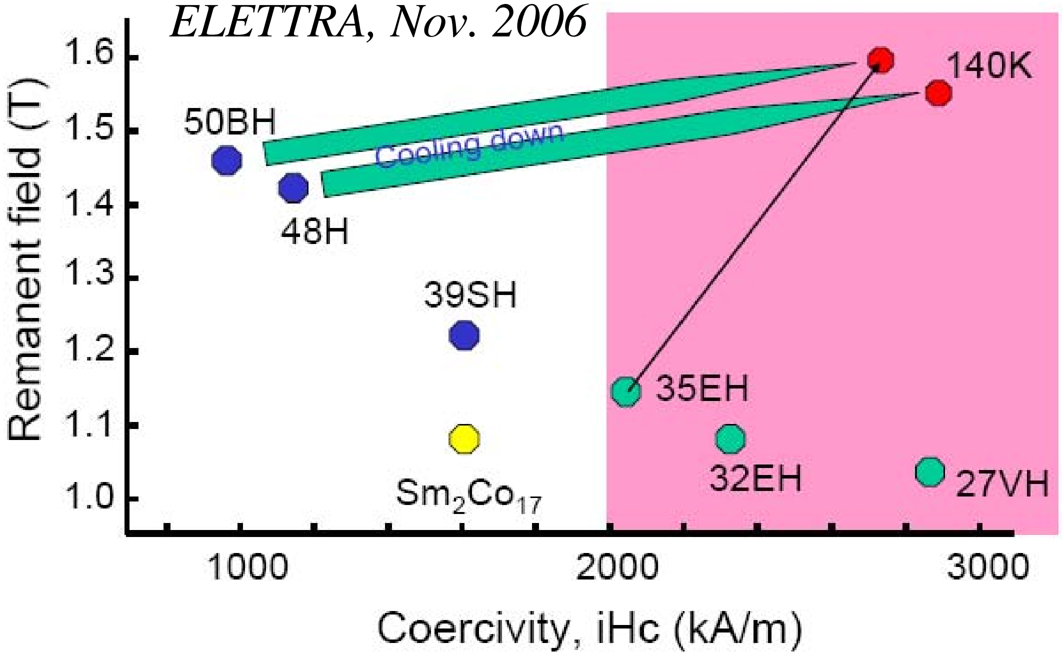
Cryogenic permanent magnet R&D

- Main groups: SPring8, ESRF, Brookhaven
  - Some industrial efforts (e.g. ADC)
  - Prototypes have been built and tested
  - No prototypes have used higher remanance material

- Motivation:
  - Increase in Remanance by as much as ~12%
  - Increase in Coercivity allows use of higher remanance material

=>Theoretical increase of ~30% - motivates research

T. Tanaka, New Frontiers in ID's, ELETTRA, Nov. 2006



CIVID Issues

- Key concerns:
  - Phase error correction: does room temperature correction apply at cryogenic temperatures?
    - Tentative data from SPring-8: ***yes***
    - Awaiting ESRF confirmation measurements
  - Can enhanced coercivity be leveraged?
    - Cannot bake-out devices! Will devices "Cryopump" at 150K? Can sufficient pumping be provided without baking?
- Note: enhanced coercivity may nevertheless be useful for applications where demagnetization due to thermal / radiation loads is a concern

Superconducting insertion devices

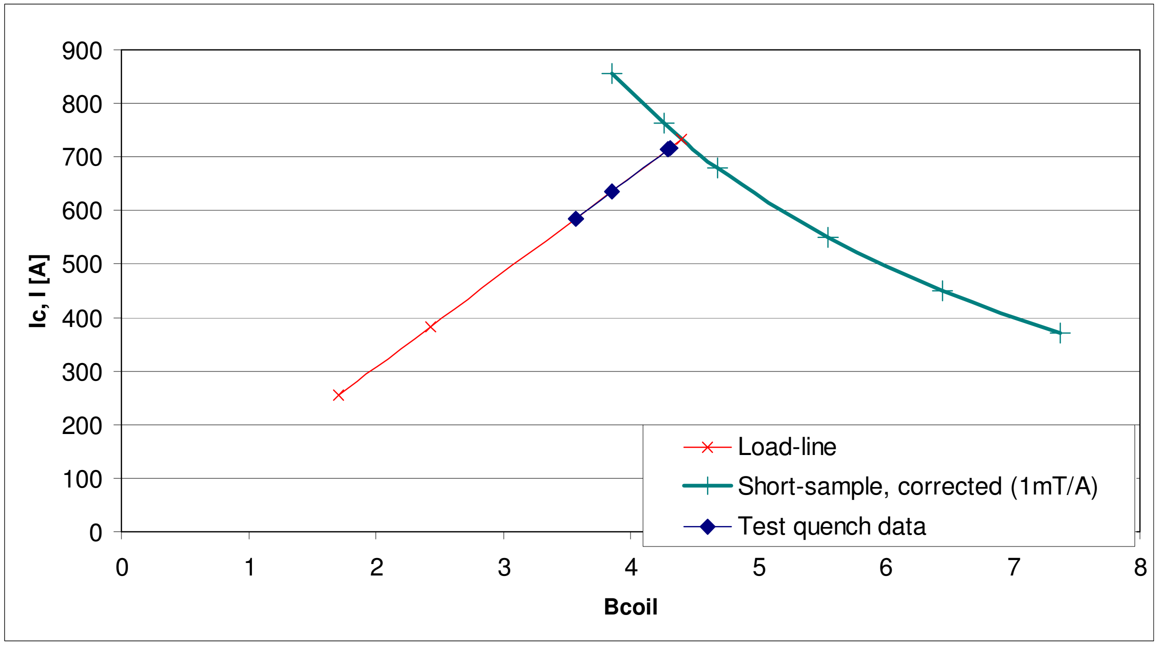
- Many superconducting wigglers are being installed (Canadian Light Source, Brazilian Light Source,…; ALBA planning SC wiggler)
- ANKA has detailed performance data for first NbTi undulator
  - First spectral data (Rossmanith, ASC 2006)
  - Thermal load measurements
- EU funded collaboration (ANKA, MAXLAB, ESRF, ELETTRA) (*Rossmanith, New Frontiers in ID's, ELETTRA, Nov. 2006)*
  - Cryogenic systems
  - Magnet measurements
- ANKA proceeding with procurement of a second superconducting undulator; considering Nb_3Sn long-term
- LBL: successful test of a Nb_3Sn prototype
- APS: continuing Nb_3Sn research following collaboration with LBL

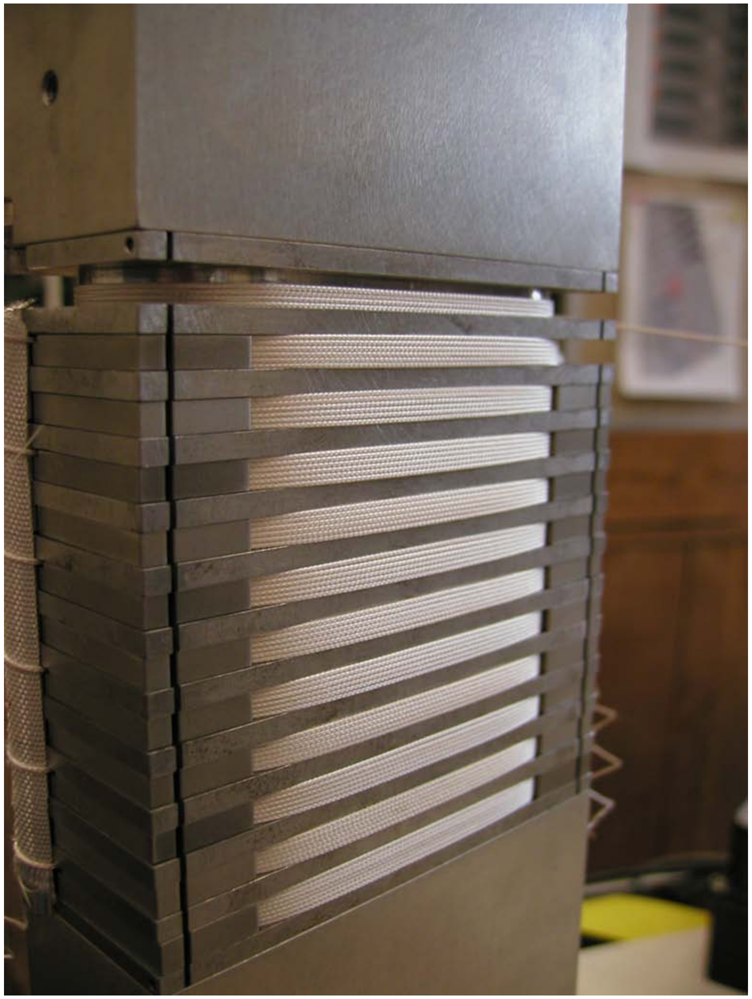
R&D issues: 1) Phase error correction
2) Magnetic measurements of cold device
2) Calorimetry for beam-based heating

Excellent case for multi-facility collaborative project!!

LBL Superconducting undulator prototype

- Third LBL prototype – reached "short sample"
  - J_{eng}=1760A/mm^2
  - 14.5mm period; would yield B~1.6T for a magnetic gap of 6mm





Variable polarization superconducting undulators

- Multiple design concepts have been proposed
- Typically do not provide significant field enhancement over permanent magnet devices
- Advantages
  - No moving parts
  - Possibly enhanced spectral control
  - Possible enhanced spectral range (period doubling/halving)
- Disadvantages
  - Superconductors not well-suited for rapid field (polarization) change
  - Phase-error correction and field measurement needs to be addressed

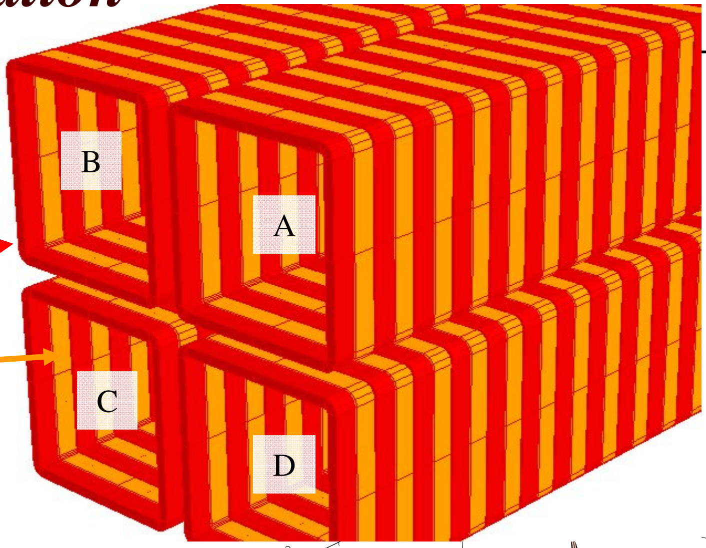
Polarization control: LBL SC-EPU concept

Generating variable elliptic polarization

- Add a second 4-quadrant array of such coil-series, offset in z by λ/4 (coil series α and β)
- With the following constraints the eight currents are reduced to four independent degrees of freedom:

$$I_C^{\alpha} = -I_A^{\alpha}, \quad I_D^{\alpha} = -I_B^{\alpha}$$

$$I_C^{\beta} = -I_A^{\beta}, \quad I_D^{\beta} = -I_B^{\beta}$$

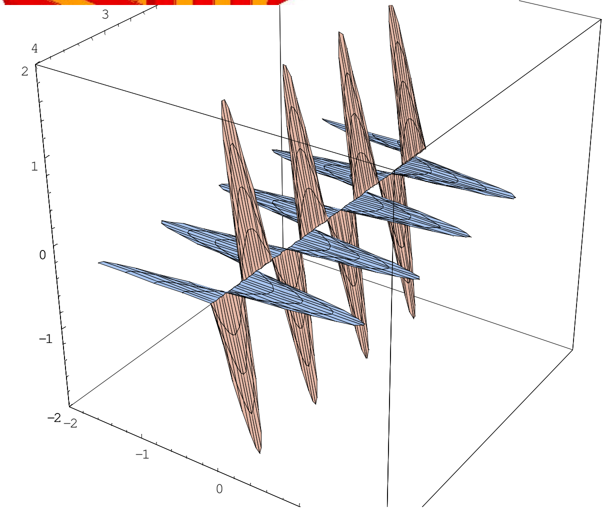


- The α and β fields are 90° phase shifted, providing full elliptic polarization control via

$$\vec{B}^{\alpha}(I_A^{\alpha}, I_B^{\alpha}; z), \quad \vec{B}^{\beta}(I_A^{\beta}, I_B^{\beta}; z):$$

$$\begin{pmatrix} B_x^{\alpha} \\ B_y^{\alpha} \end{pmatrix} = \eta \left\{ \begin{pmatrix} \mathrm{Cos}(\psi) & -\mathrm{Cos}(\psi) \\ \mathrm{Sin}(\psi) & \mathrm{Sin}(\psi) \end{pmatrix} \begin{pmatrix} I_A^{\alpha} \\ I_B^{\alpha} \end{pmatrix} \right\} \mathrm{Sin}\left(\frac{2\pi z}{\lambda} \right)$$

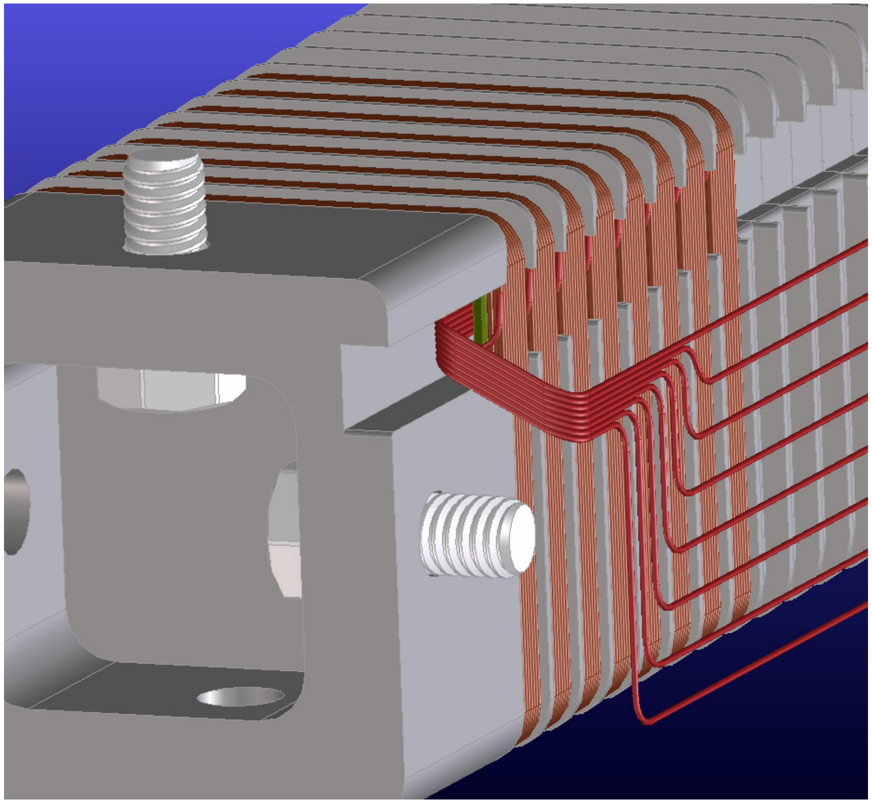
$$\begin{pmatrix} B_x^{\beta} \\ B_y^{\beta} \end{pmatrix} = \eta \left\{ \begin{pmatrix} \mathrm{Cos}(\psi) & -\mathrm{Cos}(\psi) \\ \mathrm{Sin}(\psi) & \mathrm{Sin}(\psi) \end{pmatrix} \begin{pmatrix} I_A^{\alpha} \\ I_B^{\alpha} \end{pmatrix} \right\} \mathrm{Sin}\left(\frac{2\pi z}{\lambda} - \frac{\pi}{2} \right)$$

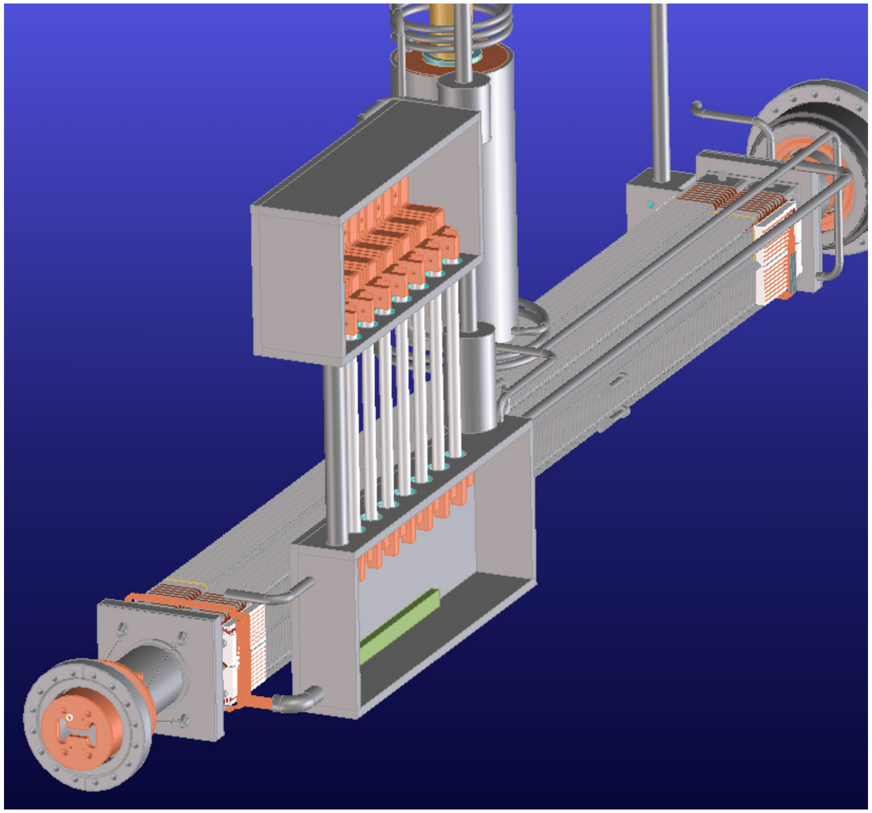


Note: $B_{x,y}^{\alpha} = \sum_n a_{n;x,y} \sin\left(\frac{2\pi n x}{\lambda} \right)$; typically $\frac{a_3}{a_1} < 2\%$

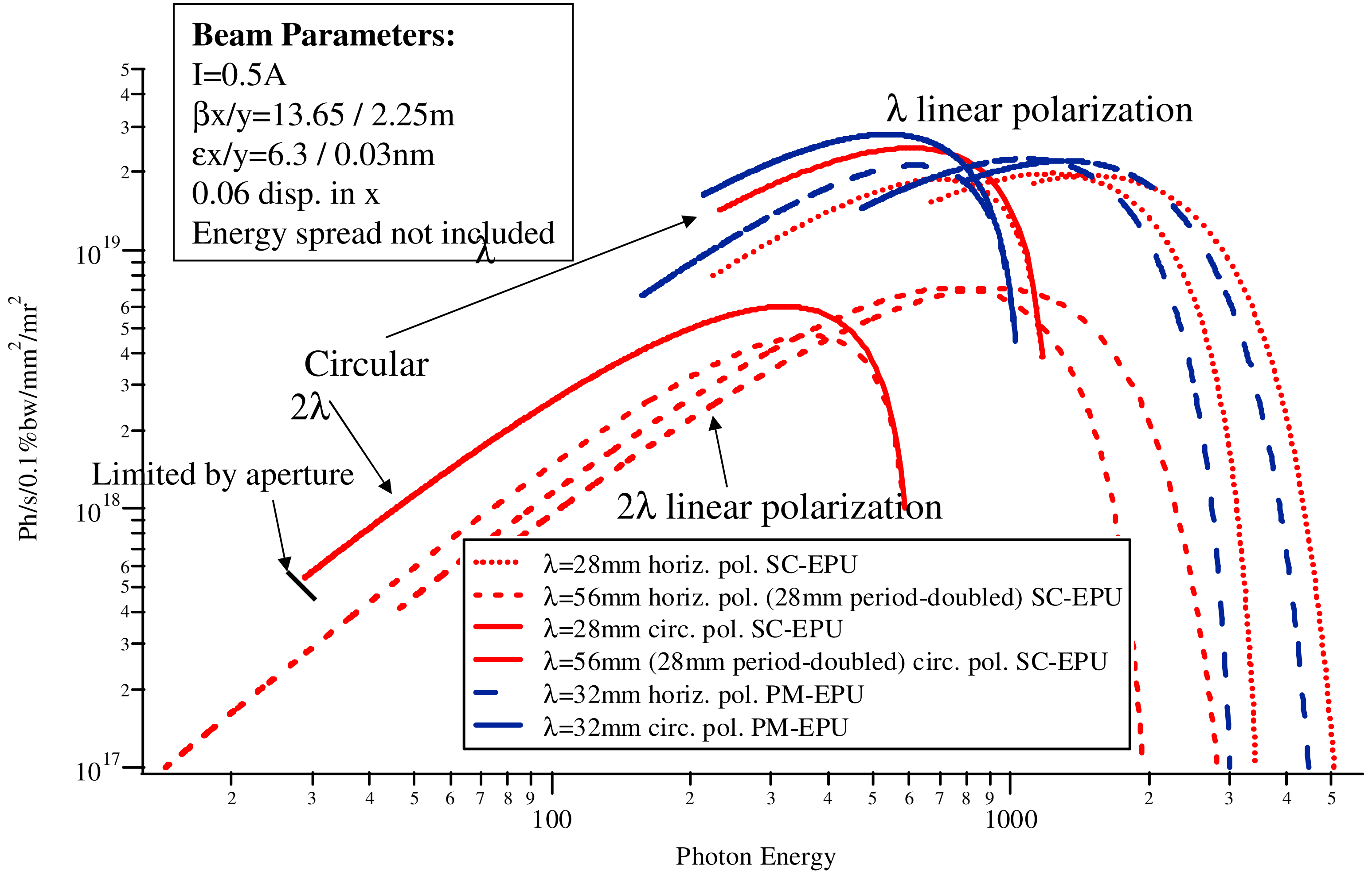
A conceptual design for the SC-EPU

- Four-quadrant, iron-free design
- Performance limited by AC losses (dB/dt-induced heating) of coil
- Period halving/doubling requires “switchyard” – superconducting switch needs to be demonstrated





Spectral range and Brightness of example SC-EPU λ=28mm device and PM-EPU λ=32mm



Beam Parameters:
I=0.5A
βx/y=13.65 / 2.25m
εx/y=6.3 / 0.03nm
0.06 disp. in x
Energy spread not included

Summary

- There are a wide variety of magnetic systems in light sources – here we only discussed a small subset
- There are "new" ideas being researched
  - often new opportunities for "old" ideas, with renewed interest stemming from developments in neighboring fields
- We can expect more diverse systems in the future – superconducting, permanent magnet, and "traditional" electromagnets designed to optimally address target applications