Beam-based Diagnostics USPAS Knoxville, TN, January 2019

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Motivation

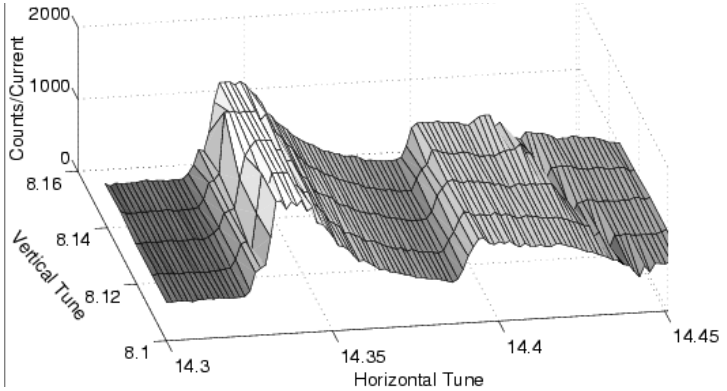
- Storage rings are used for many science and technology applications
  - synchrotron radiation light sources for biology, chemistry, and materials science
  - colliders for high-energy physics
  - damping rings to reduce the emittance for linear colliders.

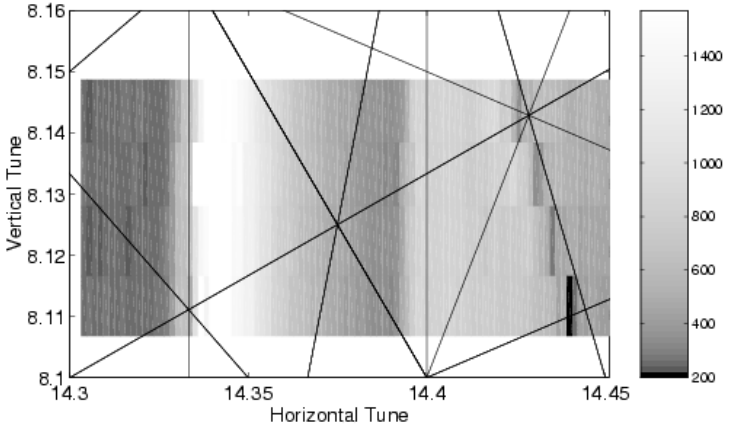
- Small equilibrium emittances to maximize brightness or luminosity require
  - strong quadrupoles resulting in large chromatic aberrations
  - correction requires strong sextupoles creating non-linearities
  - Nonlinearities can cause motion at large amplitudes to become unstable (dynamic aperture).

- The dynamic aperture limits the performance in many current accelerators.
  - To optimize the performance a good knowledge of the machine model is required.
    - To achieve the required accuracy of the machine model, beam based measurements have proven to be essential. Alternative approach: beam-based model independent optimization and machine learning
  - In high performance linear accelerators (like FELs) similar considerations apply and variations of the techniques in this class are used

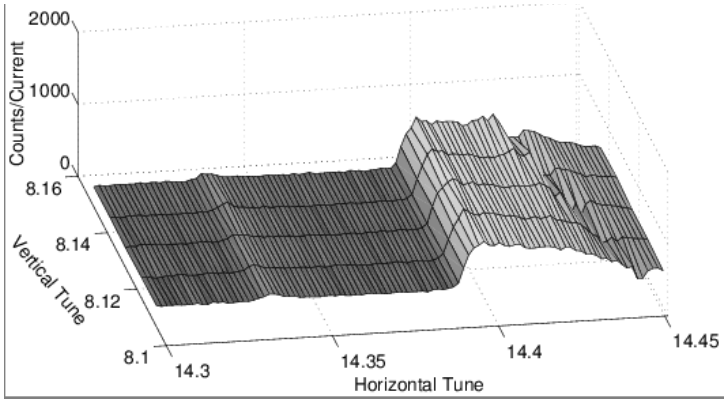
Example: Tune scans (with and without beam based correction for symmetry)

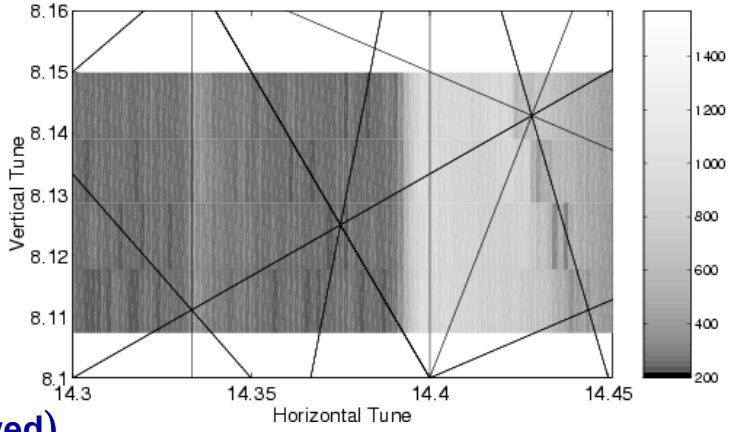
Uncorrected lattice





Corrected lattice





Three resonances:

$5\nu_x = 72$ **(allowed)**

$3\nu_x = 43$ **(unallowed)**

$2\nu_x - \nu_y = 37$ **(unallowed)**

Shown are loss maps measured in ALS

USPAS Knoxville Class Schedule*

- Class meets from 9-12 and 14-17 daily
- Computer labs
  - Mo-Thu 14-15:30
- Not all time in class-room will be lectures, (hopefully) some time will be available for discussion, further tutorials, …
- Lecturers will at least be available from 21:00-22:00 in computer room and/or study room

*Friday all USPAS classes end at noon

Problem sets

- Distributed in the afternoon (website download/email?): Monday-Thursday
  - Mostly computer homework
- Due following day: Tuesday-Friday
  - Computer homework can be handed in late if computer room availability should be insufficient

Grades

- Based on problem sets, class participation, computer class, (and final exam).

Draft Lecture Schedule*

- **Monday (Accelerator Physics Fundamentals, Basic Measurements):**
  - Course Introduction/Organization/Outline (Christoph, James, Xiaobiao)
  - Review of basic measurements (James Safranek)
  - Introduction to the Matlab Middle Layer and computer class (Xiaobiao Huang)
  - Introduction to main concepts of accelerator physics (Christoph Steier)
- **Tuesday (Linear Lattice):**
  - Phase Advance Measurements / Model Independent Analysis (Xiaobiao Huang)
  - Orbit Response Matrix Analysis - LOCO (James Safranek)
  - Orbit Stability, Orbit Correction, Feedback (Christoph Steier)
- **Wednesday (Beamsize, Coupling, Nonlinear Dynamics):**
  - Beamsize/Emittance measurements (James Safranek)
  - Coupling (global/local), Vertical Dispersion, Measurement and Correction (Christoph Steier)
  - Nonlinear Dynamics, Dynamic Aperture, Lifetime, Frequency Maps (Christoph Steier)
- **Thursday (Beam Based Optimization, Collective Effects):**
  - Beam Based Optimization (Xiaobiao Huang)
  - Automated Beam based Storage Ring Commissioning (Christoph Steier)
  - Instabilities, Higher Order Modes - Beam Based Measurements (Christoph Steier)
- **Friday (Undulators/Wigglers, Energy Calibration):**
  - Insertion Devices (nonlinear dynamics of wigglers/undulators) (James Safranek)
  - Spin Dynamics, Energy Calibration (Christoph Steier)

*Might adjust schedule based on interest/progress

Website

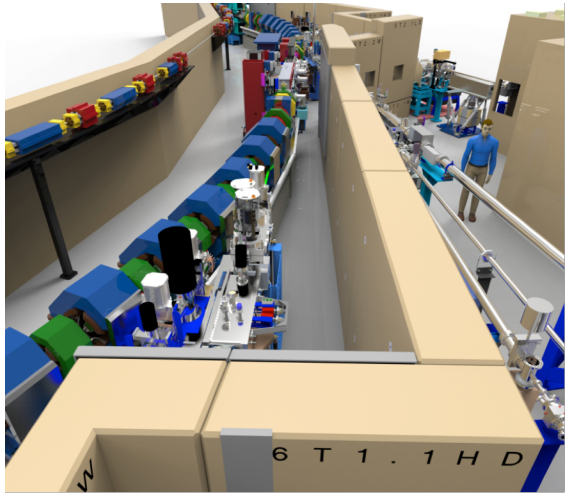
- There is a website for this class
  - http://www2.als.lbl.gov/als_physics/csteier/uspas19/
  - Will be updated as we go along
- Do not plan to hand out paper copies of talks – but will post ahead of actual lecture
- If you are curious and want to read further ahead: there also are earlier versions of this class (…/uspas15/). We will change and update several aspects but keep many things.

Class / Lecturer Introduction

- *Round table with short statement of background and interest in topic*

About Christoph

- Studied at Bonn University (Germany)
  - Diploma on mitigation of ion induced instabilities
  - PhD on acceleration of polarized electrons
  - Worked on electron cooling for HERA
- Since 1999 at LBNL
  - Nonlinear Dynamics, Lattice Design, Stability, Operations, Projects, …
    - Advanced Light Source
    - ALS-U – Accelerator Lead
  - Many other projects
    - PEP-II, Spear-3, NGLS, LCLS-II, NLC, ILC, …



Parameter	Units	ALS	ALS-U
Electron energy	GeV	1.9	2.0
Horiz. emittance	pm	2000	~70
Vert. emittance	pm	30	~70
Beamsize @ ID center (σ_x/σ_y)	mm	251 / 9	12/ 14
Beamsize @ bend (σ_x/σ_y)	mm	40 / 7	7/ 10
bunch length (FWHM)	ps	60-70 (harmonic cavity)	100-120 (harmonic cavity)
RF frequency	MHz	500	500
Circumference	m	196.8	~196.5

About James

- Undergraduate at UC Berkeley
- Graduate student with H. Wiedemann at Stanford/SSRL
- 6 years at NSLS in New York
- 1 year at SLAC's PEP-II collider
- Many years back at SSRL's Accelerator Division at SLAC, where I am presently director.

About Xiabiao

- Studied at Tsinghua University in Beijing
- PhD at Indiana University – thesis work mostly at Fermilab
- Head of SSRL Accelerator Physics

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Introduction (ctd).

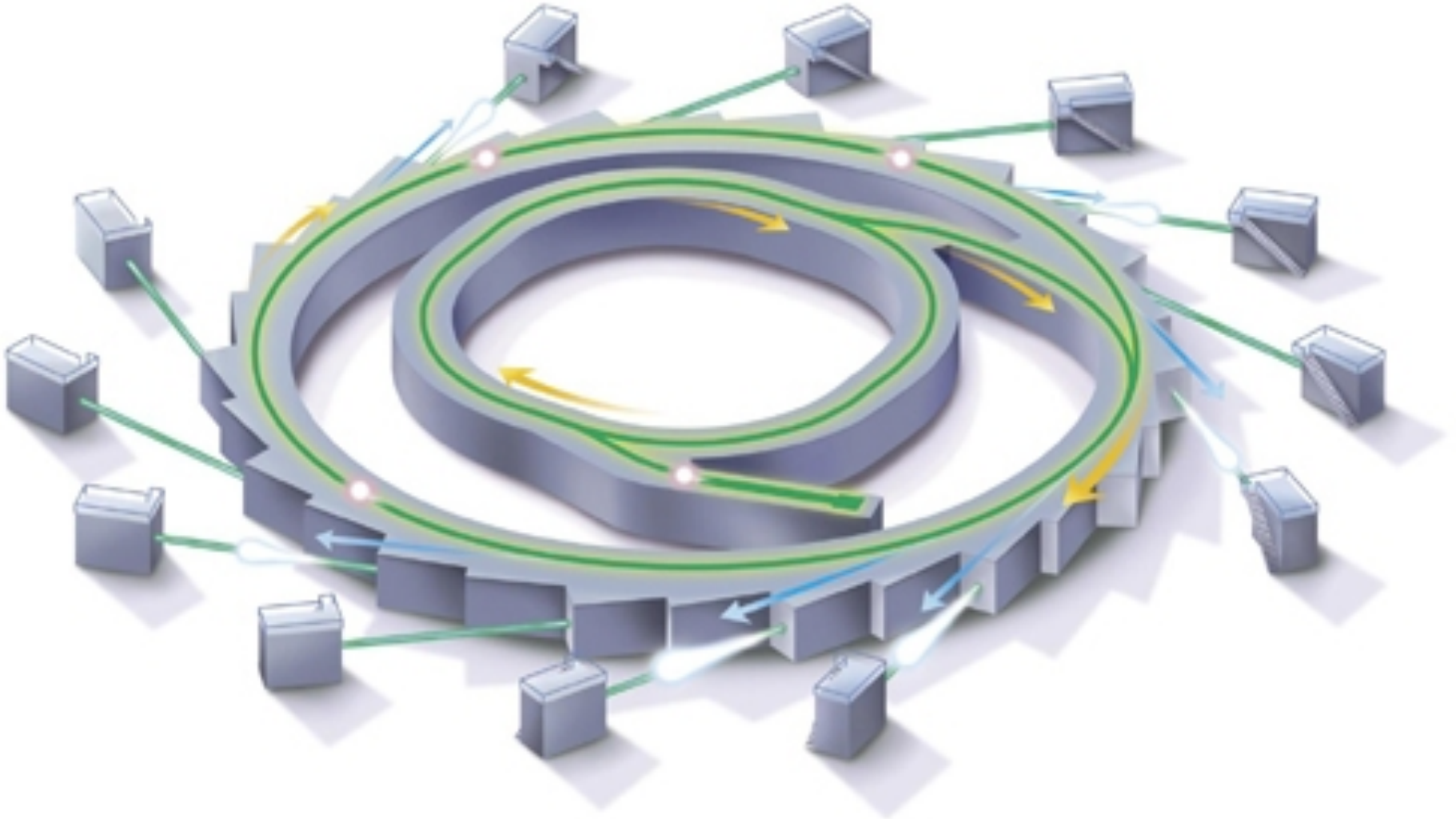
- This course will deal in detail with measurements involving many areas of transverse (and longitudinal) single (and multiple) particle dynamics
  - Most (but not all) of you already have learned all fundamentals
- This afternoon we will have a compact lecture to remind you of all concepts, to get all to somewhat consistent starting point for class
  - For transverse dynamics will introduce lattice functions in two different ways (including the one usually used in lattice codes, which you might not have learned, yet).
  - *The remainder of the week will be much more practical – and does not require that you completely understand everything in this recap*

- *Disclaimer: Our class is storage ring biased. Basic concepts and measurements are applicable to transfer lines and linacs, but details are different. If you have questions regarding lines, linacs, protons: You are welcome to ask at any time.*

Transverse Beam-dynamics: Terminology

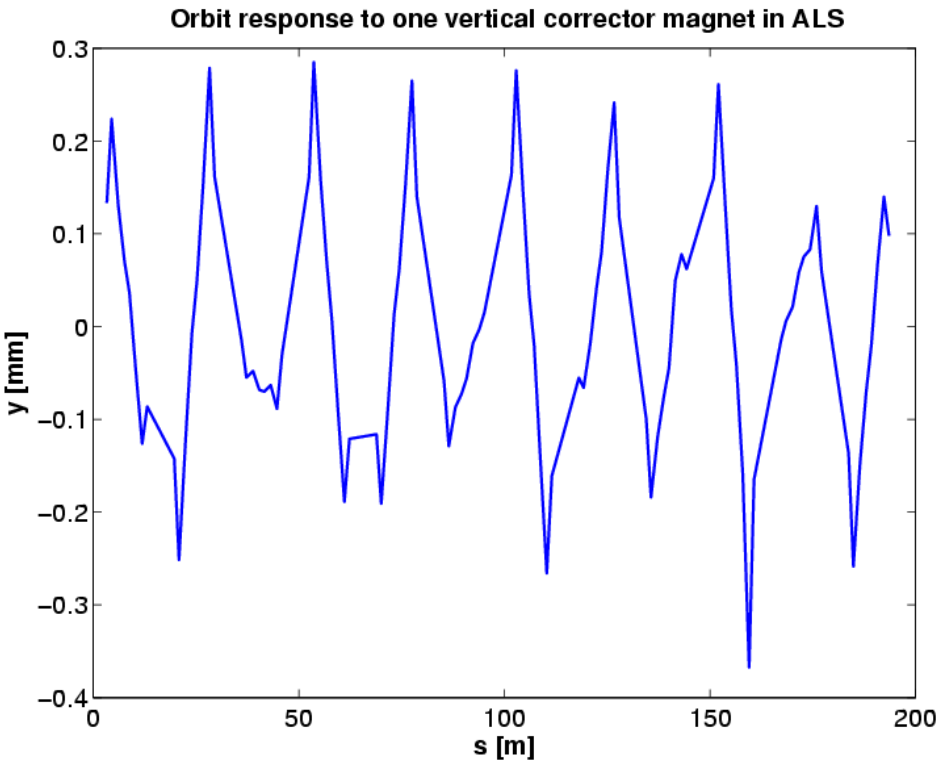
- Linear beamdynamics (Today) determined by:
  - Dipoles
  - Quadrupoles (lenses)
  - Solenoids
  - RF-resonators
  - (synchrotron radiation)
- Nonlinear (Wednesday/Thursday):
  - Sextupoles, higher multipoles, errors, insertion devices (undulators/wigglers), stochastic nature of SR, …
- Trajectory/Orbit – (more on closed orbit Tomorrow)
  - Closed orbit: closed, periodic trajectory around a ring (closes after one turn in position and angle).
  - Particles that deviate from the closed orbit will oscillate about it (transverse: Betatron oscillations, longitudinal: Synchrotron Oscillations)

Main ‘ingredients’ of an Accelerator



Closed Orbit: 'Definition'

- Closed orbit is (periodic) trajectory which closes after one turn around (in position and angle)
  - i.e. the fixed point in 4 (6) dimensional space for the one-turn map.
- Practically, it is the center of the particle distribution that one can measure at any point
- The ideal orbit is the orbit through the centers of all (perfectly) aligned magnetic elements.
- Particles close to the closed orbit will oscillate around it.
  - Transverse: Betatron Oscillation, Longitudinal: Synchrotron Oscillation
  - There is an equivalent for a transfer line, where particles launched off axis will oscillate around average trajectory



Schedule for Today

- **Monday (Accelerator Physics Fundamentals, Basic Measurements, Simulation Codes):**
  - Course Introduction/Organization/Outline (Christoph, James, Xiaobiao)
  - Review of basic measurements (James Safranek)
  - Introduction to Matlab Middle Layer and computer class (Xiaobiao Huang)
  - Lunch break
  - Computer Class
  - Introduction to main concepts of accelerator physics (Christoph Steier)
- **Tuesday (Linear Lattice):**
  - Phase Advance Measurements / Model Independent Analysis (Xiaobiao Huang)
  - Orbit Response Matrix Analysis - LOCO (James Safranek)
  - Orbit Stability, Orbit Correction, Feedback (Christoph Steier)