Breakout Session 1 – 4GSR Accelerators

Close-out Summary

Accelerator Physics – R. Hettel (SLAC) chair

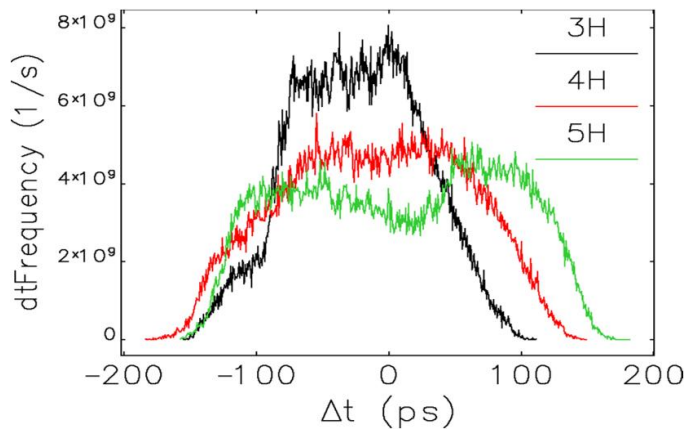
Accelerator Implementation – S. Leemann (MAX IV) chair

Beam Dynamics Modeling of a Passive Bunch-Lengthening Cavity for the APS MBA Lattice - M. Borland, APS

- Bunch lengthening is required to increase Touschek lifetime and to reduce IBS and chamber heating.
- Effects of passive bunch lengthening cavity (HHC) for APS-U studied in simulations.
- elegant code enhanced to more efficiently simulate multibunch beams with parallel computing.

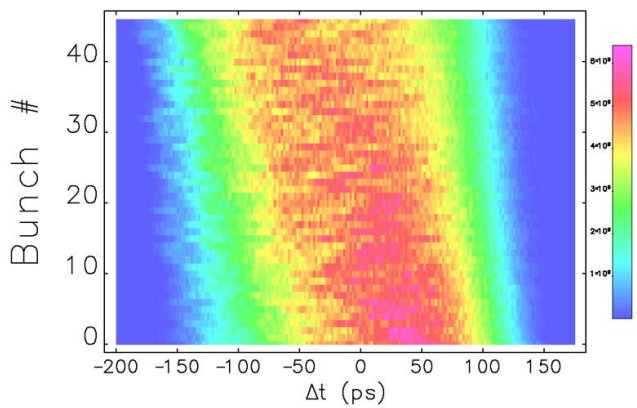
Conclusions:

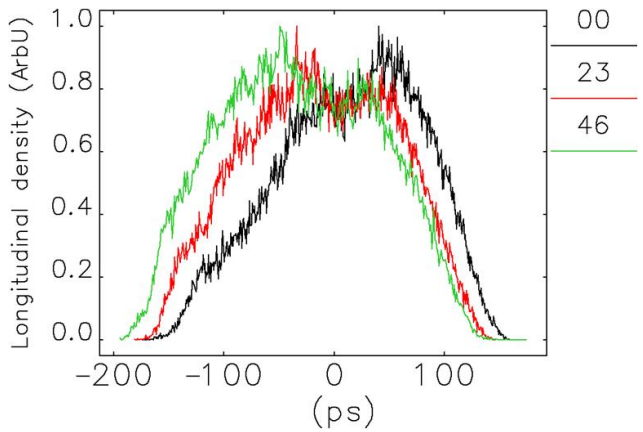
- Lengthening from 12 ps (0 current) to ~75 ps rms for 200 mA/48 bunches looks possible, aided by microwave instability and potential well distortion.
- Optimum cavity detuning and loaded Q don't completely agree with analytical predictions. Trying to understand discrepancies between analytical and simulation results for this and other effects.
- Impact of small variations in bunch population is negligible.
- 3rd, 4th and 5th harmonic cavities investigated.



bunch lengthening with 3rd, 4th and 5th harmonic cavities

- Impact of missing bunch in a symmetric fill pattern appears to be manageable but needs discussion. Users may not appreciate resulting ~40 ps timing centroid shifts over bunch train.



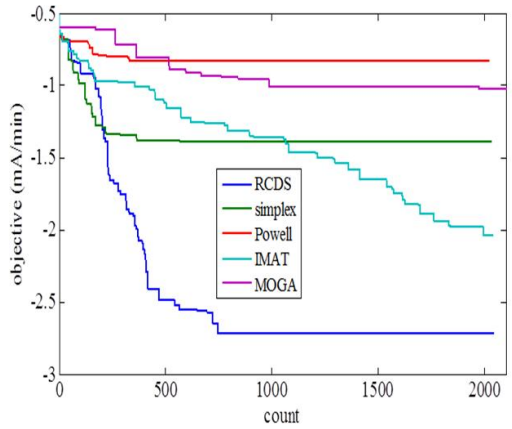


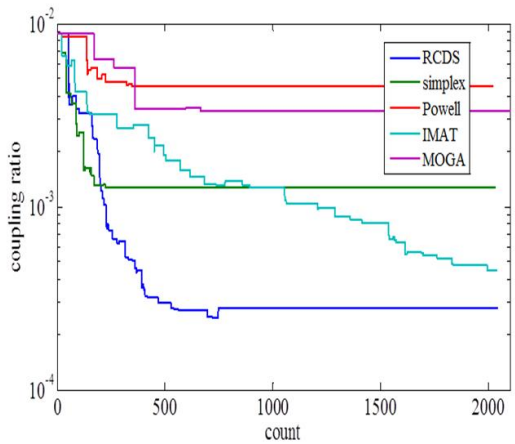
shift in bunch time-of-arrival caused by HHC when a bunch is missing bunch in symmetric fill pattern

- Improvements in lifetime are significant for both 48 and 324 bunches.
- Question: What is performance with active HHC? (may be needed at low current)
- Additional HHC implementation modes are possible and will be investigated.
- Several “next steps” to extend simulation.

Online Optimization of Nonlinear Dynamics for DLSRs – X. Huang, SLAC

- Nonlinear dynamics challenges in DLSRs (4GSRs) make online lattice optimization and automatic tuning, based on beam measurements, desirable
- Many optimization algorithms considered. Robust Conjugate Direction Search (RCDS) method selected for speed of convergence.
- Beam-based RCDS correction of coupling and improvement of injection efficiency by nonlinear lattice optimization conducted on SPEAR. Coupling reduced to ~2 x 10^{-4}; dynamic aperture increased from 15 mm to ~18 mm.





Conclusions:

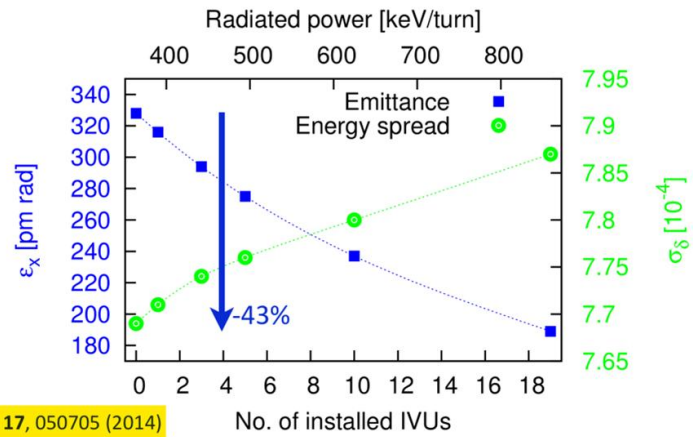
- Online optimization provides an alternative to having an accurate simulation model.
- Having an accurate nonlinear model would benefit 4GSR operation.
- Having nonlinear optics monitors and a beam- based nonlinear optics calibration tool (nonLOCO) for 4GSRs would be useful.

Interplay of Touschek Scattering, Intrabeam Scattering, and RF Cavites in Ultralow-Emittance Storage Rings – S. Leemann, MAX IV

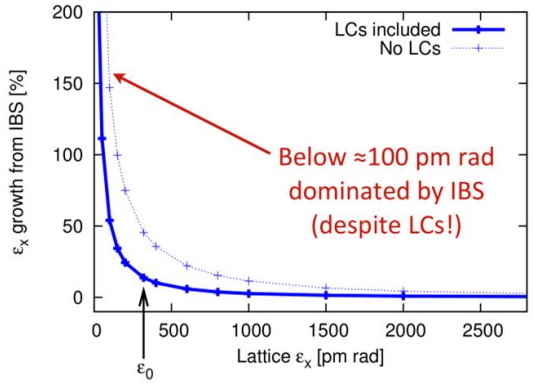
- Ultralow-emittance rings using MBA lattices have weak dipoles: damping wigglers and/or IDs can have large impact on radiated power, emittance, energy spread.
- IBS leads to emittance blowup in all three planes.
- Transverse and longitudinal beam properties linked through IBS.
- All parameters vary with ID changes during user run.
- Studied dependence of emittance on IBS and bunch current, dependence of Touschek lifetime on emittance and IBS and RF acceptance.
- Touschek lifetime increases as emittance reduced below a critical value.

Conclusions:

- Bunch lengthening cavity should allow minimal emittance and maximal lifetime at high current by mitigating IBS.
- Round beams reduce IBS effects.
- 4GSRs require sufficient momentum aperture so that Touschek lifetime remains satisfactory despite ultralow emittance and high bunch charge.
- Question: Should a “tuning wiggler” be added to compensate for varying IDs? Other mitigating options may be possible.



PRST-AB **17**, 050705 (2014)

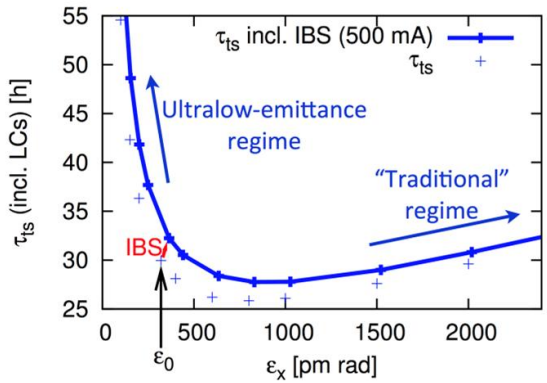


I = 500 mA
δ_{RF} = 4.5%
$\sigma_\delta \approx$ const
ε_y = 8 pm rad

For MAX IV 3 GeV SR (bare lattice):

- IBS blows up emittance by 45%
- LCs ($\sigma_s \rightarrow \approx 5\sigma_s$) can reduce to 13%

PRST-AB **17**, 050705 (2014)



I = 500 mA
δ_{acc} = 4.5%
σ_δ = const
ε_y = 8 pm rad

PRST-AB **17**, 05

Breakout Session Discussion Comments

- Targeted, focused workshops on various topics are needed.
- Future 4GSR workshops should be coordinated internationally.

Accelerator Implementation

- BAPS Design and R&D
  Qing Qin, IHEP

- Progress on the Injection/Extraction Kicker for the ALS-U
  Stefano De Santis, LBNL

- ESRF II Engineering Challenges
  Jean-Claude Biasci, ESRF

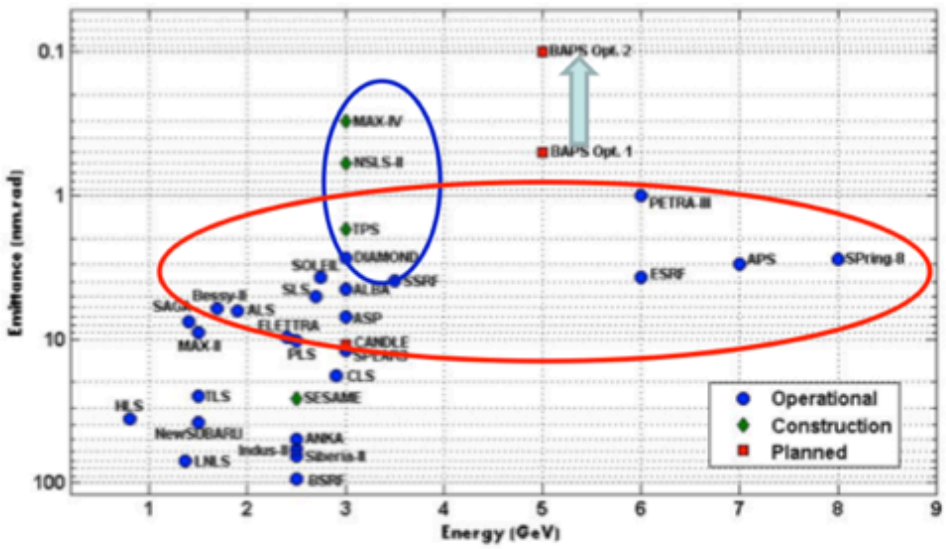
- Magnet Alignment Challenges for an MBA Storage Ring
  Animesh Jain, BNL

BAPS Design and R&D

- Staged approach: 5-6 GeV, 0.5 nm rad → 0.05 nm rad
- Investigating types of 7BA: MAX IV vs. HMBA
- Technical systems R&D while awaiting funding decision

BAPS Design and R&D

Beijing Advanced Photon Source (BAPS)

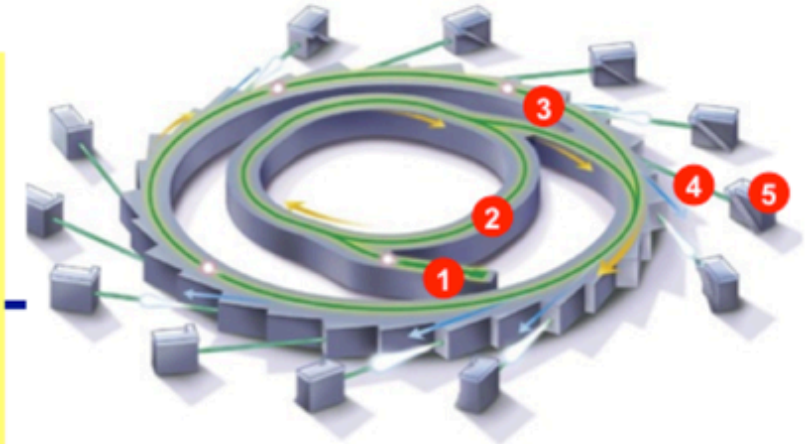


5 – 6 GeV, ~1300 m,
~ 0.46 nm.rad, 0.15 nm.rad w/DW
200 ~ 300 mA,
Brightness: > 10^{21} /s/mm^2/mrad^2/0.1%BW
Feasible upgrade to ERL or USR

1 – Linac
2 – Booster
3 – Storage ring
4 – Beam lines
5 – Experimental stations

Lattice evolution:

- 48 DBA, 1200 m, 1.5 nm.rad, 0.5 nm.rad w/DW
- 36 7BA, 1370 m, 51 pm.rad, 10 pm.rad w/DW + round beam production
- 40 TBA, 1280 m, 0.46 nm.rad, 0.15 nm.rad w/ID and DW
- 7BA, ~1300 m, 0.088 – 0.048 nm.rad



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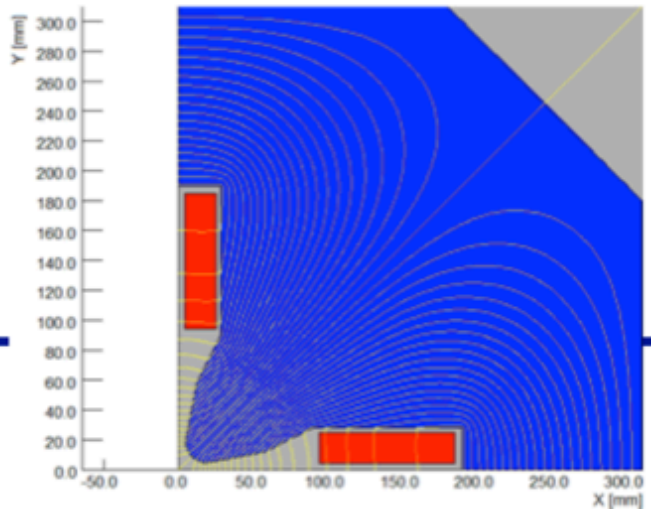
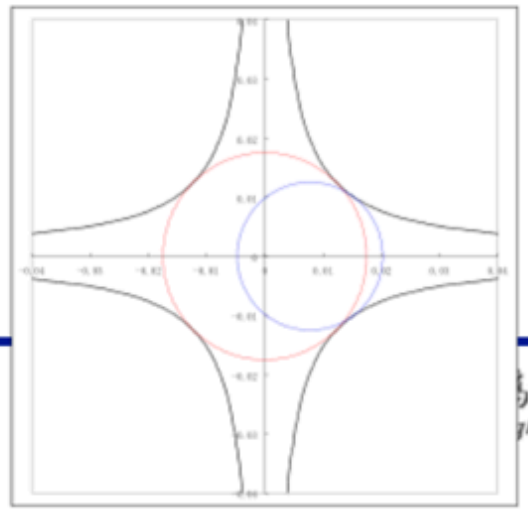
BAPS Design and R&D

- **Magnet**

- **High gradient quad and high gradient dipole/quad combined function magnet**
  - **2D design finished**
  - **Pure iron is used as the yoke and pole material.**
  - **FeCo or FeCoV alloy will be considered to reduce the power consumption.**

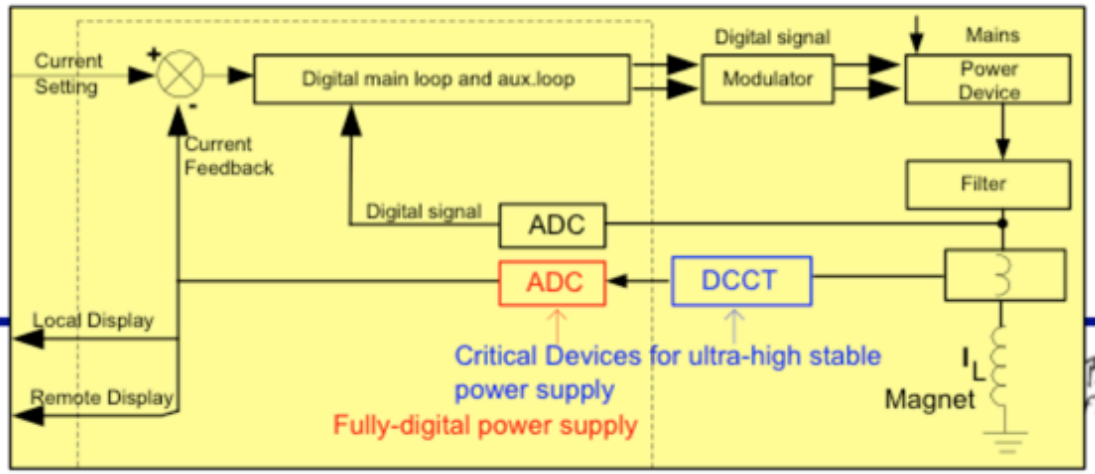




BAPS Design and R&D

- **Power supply**

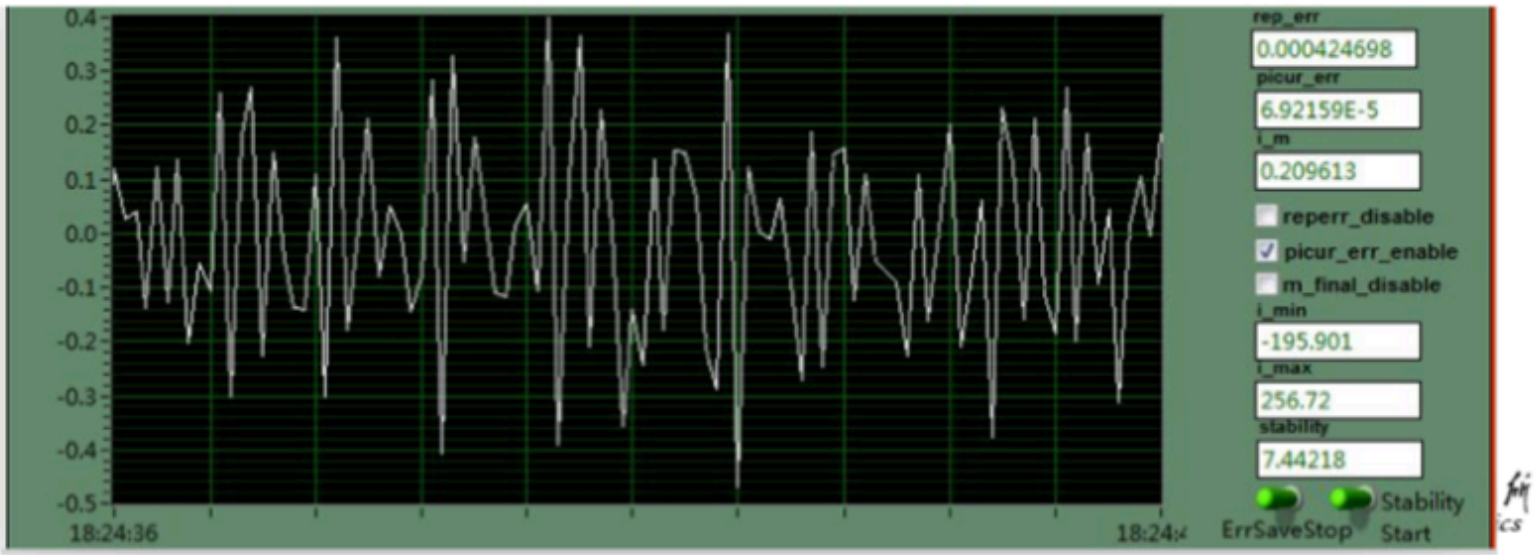
- **10ppm ultra-high stable power supply**
  - Stability requirements: an order of magnitude higher than BEPCII power supplies.
  - For fully-digital power supply, application of highly precious and stable ADC is most important.
  - Research on the water-cooling, air-cooling and power room temperature control to ensure 10ppm stability.



BAPS Design and R&D

2Hz dynamic output power supply

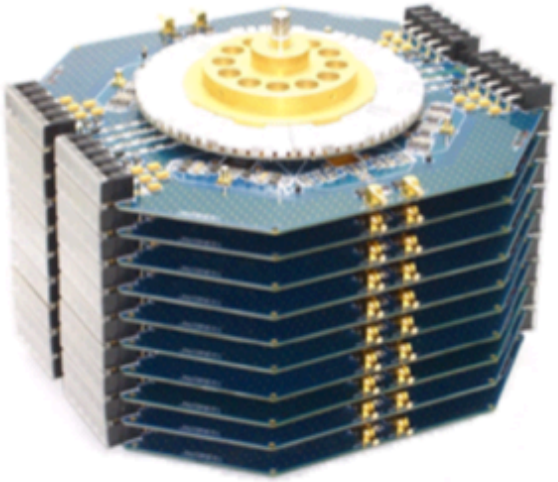
- **A prototype: 180A/30V**
  - With the self-designed digital controller
  - Adding the repetitive controller:
    - 100 + 50 sin(wt)
    - output shows: tracking error better than 0.5 ‰

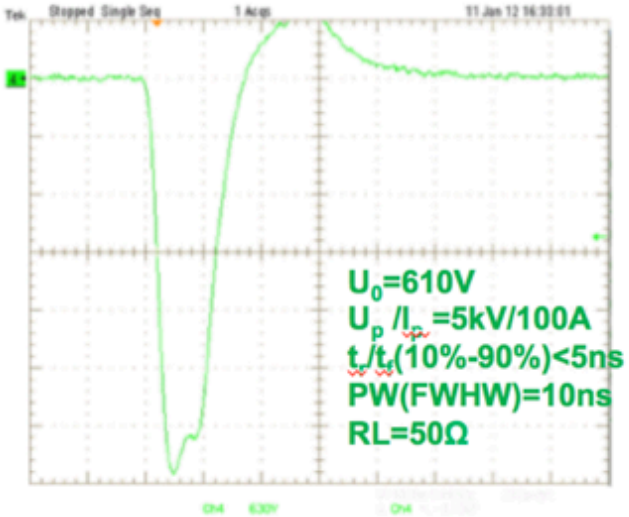


BAPS Design and R&D

Inductive Adder R&D experience

The prototype was special designed for ILC DR strip-line kicker in IHEP, 2011.





10-stage inductive adder assembly and test result

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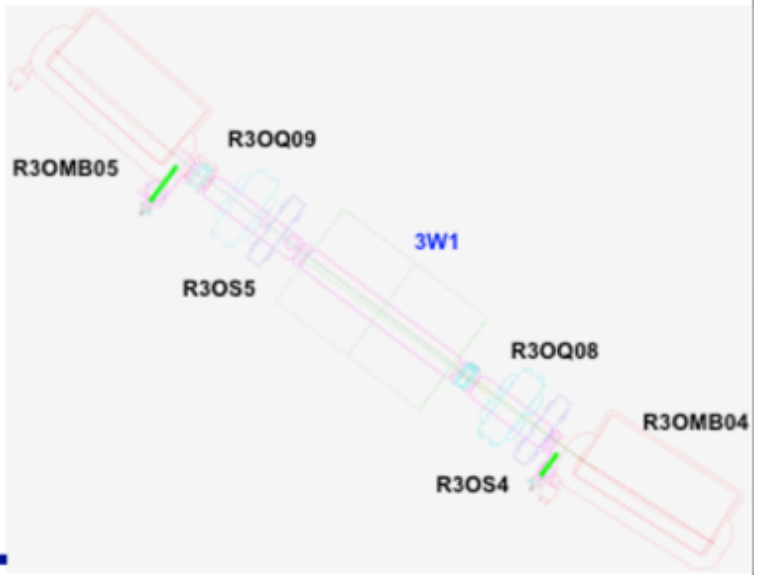
Institute of High Energy Physics

BAPS Design and R&D

- **Superconducting wiggler SC-3W1**
  - A superconducting wiggler is designed to verify some beam line technologies used for BAPS
  - The wiggler will be installed on the BEPCII storage ring to replace the original permanent magnet wiggler 3W1
  - Design parameters
    - Vertical beam stay clear
      - 39mm (for collider mode)
    - Good field region
      - Horizontal: ±23mm
      - Vertical: ±10mm
    - Field quality
      - First order integral: 500Gs•cm
      - Second order integral: 50000Gs•cm^2



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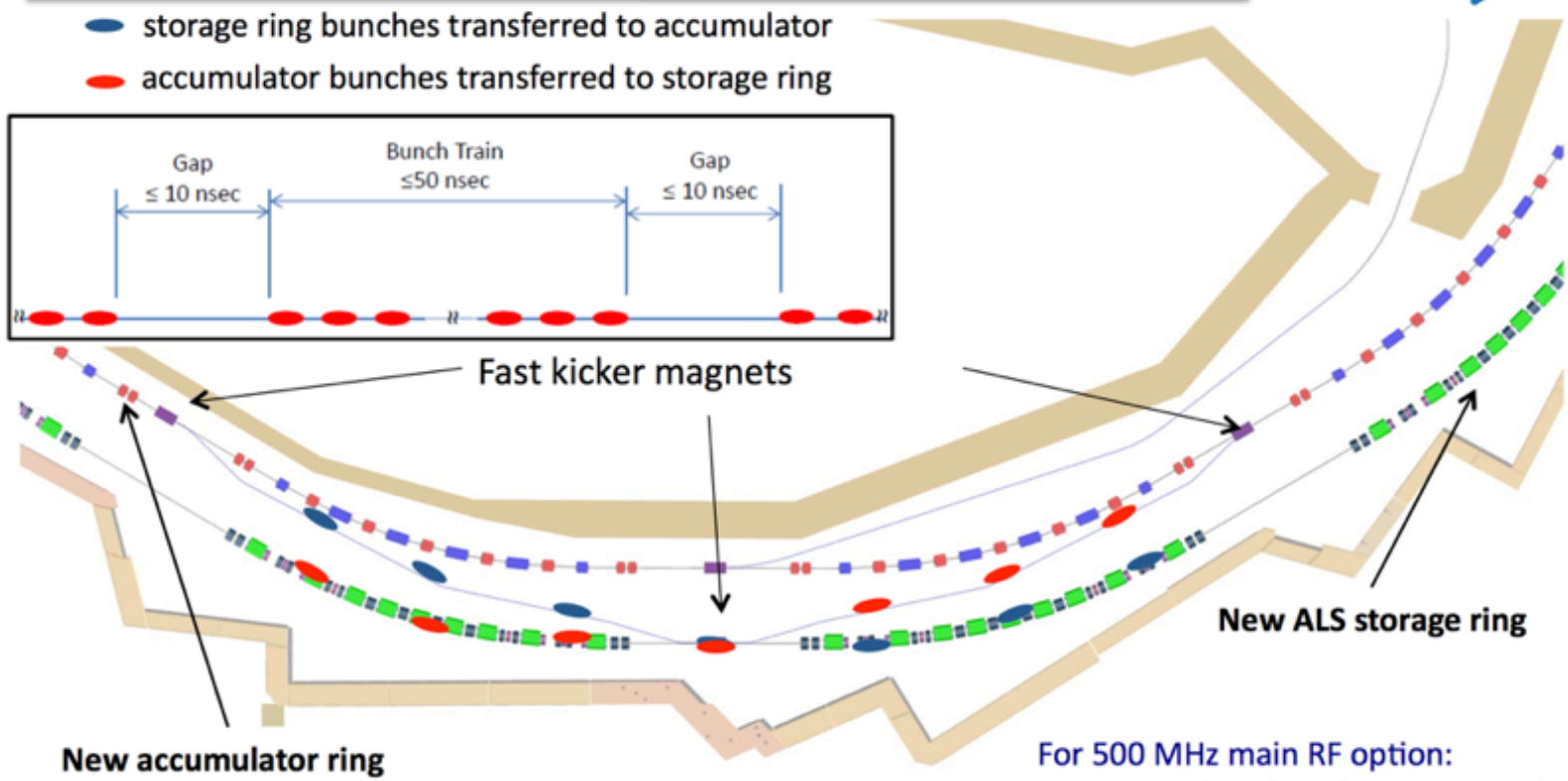
Progress on the Injection/Extraction Kicker for the ALS-U

- ALS-U injection/extraction requirements
- Kicker requirements & implementation
- Pulser design & development of inductive adder

Progress on the Injection/Extraction Kicker for the ALS-U

Swap-out Injection Scheme

ALS-U DIFFRACTION-LIMITED LIGHT SOURCE



For 500 MHz main RF option:
11 trains of 26 bunches separated by 4-bucket gaps
For the 100 MHz option:
66 bunches with a 10 ns separation

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

S. De Santis – DLSR'14 Workshop, November 19th

5

Progress on the Injection/Extraction Kicker for the ALS-U

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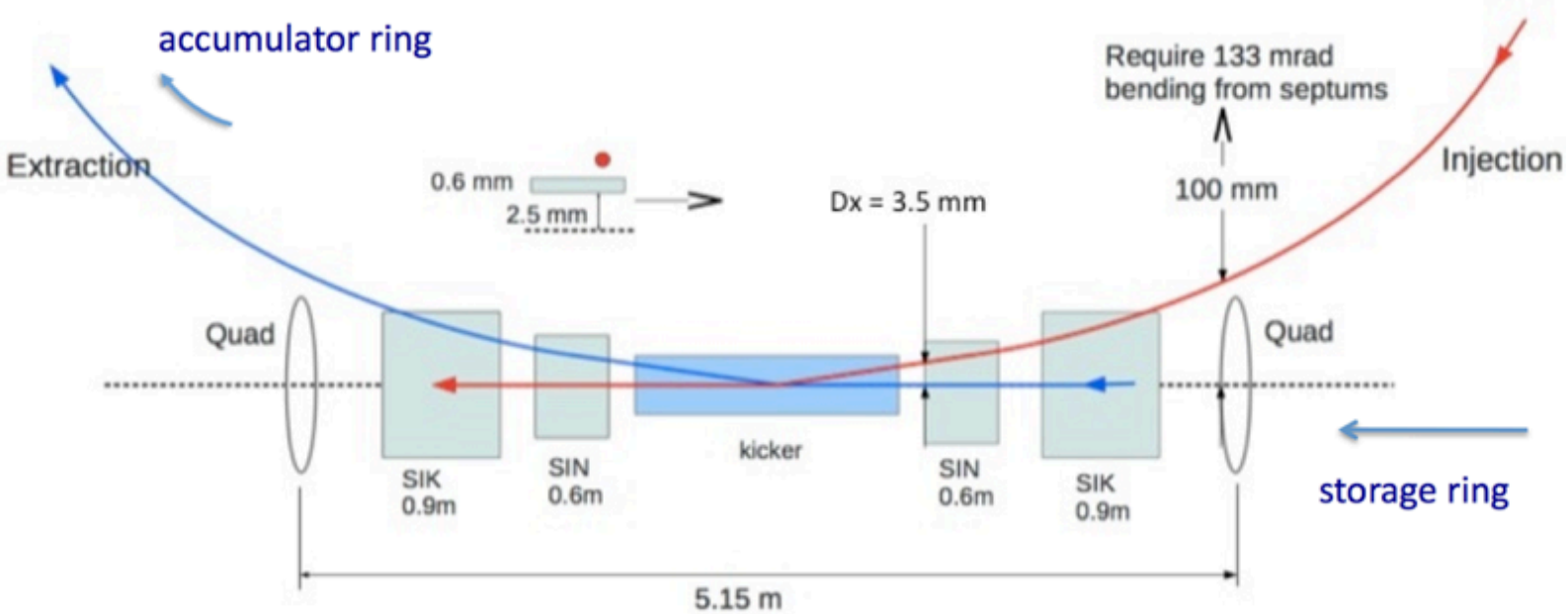
Progress on the Injection/Extraction Kicker for the ALS-U

Kicker Requirements



Beam Energy: 2 GeV
Bend Angle: 3.5 mrad
Total Kicker Length: 2 m

Rise/Fall Time: ≤ 10 ns
Max. Pulse Length: 50 ns
Repetition Rate: ≈ 30 s

Beam Stay Clear: 2.5 mm

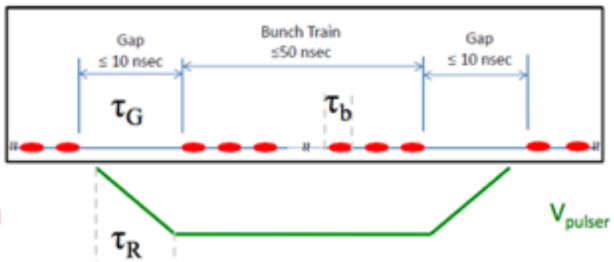
Progress on the Injection/Extraction Kicker for the ALS-U

Shunt Impedance

6 ns 0.4 ns

$$L_{mod} \le \frac{\tau_G - \tau_R - \tau_b}{2} c$$

maximum length of a stripline module: 50 cm



6 mm

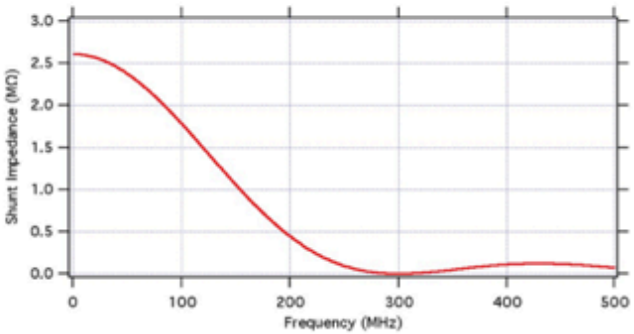
$$\pm V_0 = \frac{\Theta E_b h}{4 L_{tot}} = 5.25 \text{ kV}$$

Stripline voltage for 3.5 mrad deflection over 2 meters (4 modules)

$$Z_s(\omega) = \frac{(V_\perp / N_{mod})^2}{2P_{mod}} =$$

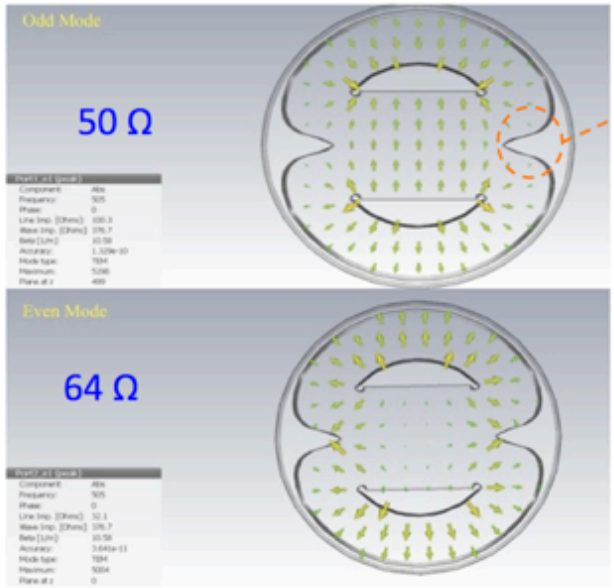
$$= 2Z_0 \left(\frac{L_{mod}\, g_\perp}{h/2} \right)^2 \left(\frac{\sin(\omega L_{mod}/c)}{\omega L_{mod}/c} \right)^2$$

Shunt impedance



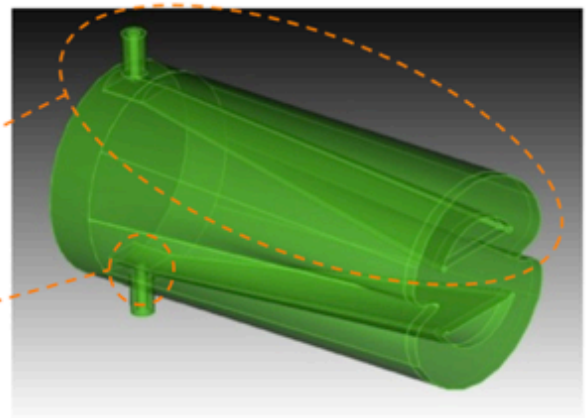
Progress on the Injection/Extraction Kicker for the ALS-U

Physical Implementation



Transverse plane fenders, to lower the even mode characteristic impedance from 77 to 64 Ω

Longitudinal tapers to reduce beam coupling impedance at high frequency and improve the feedthrough-to-stripline 50 Ω matching



Progress on the Injection/Extraction Kicker for the ALS-U

- ALS-U injection/extraction requirements
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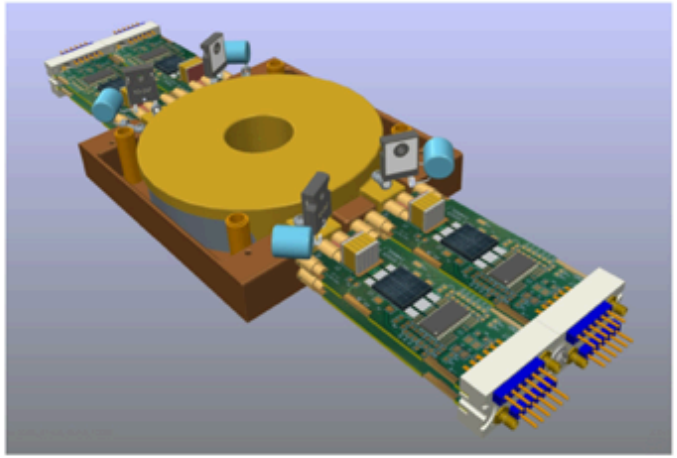
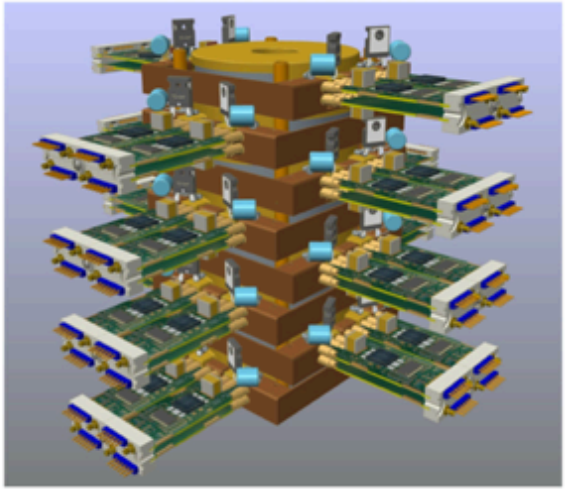
Progress on the Injection/Extraction Kicker for the ALS-U

Inductive Adder – Prototype

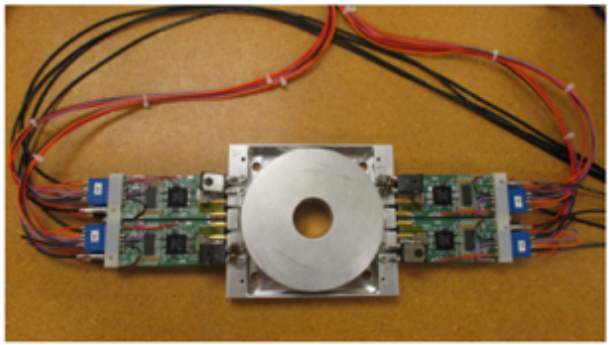
SINGLE STAGE



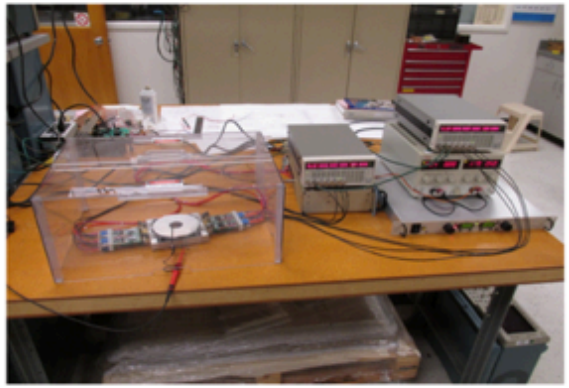
8-STAGE FULL MODULE



"REAL" SINGLE STAGE...

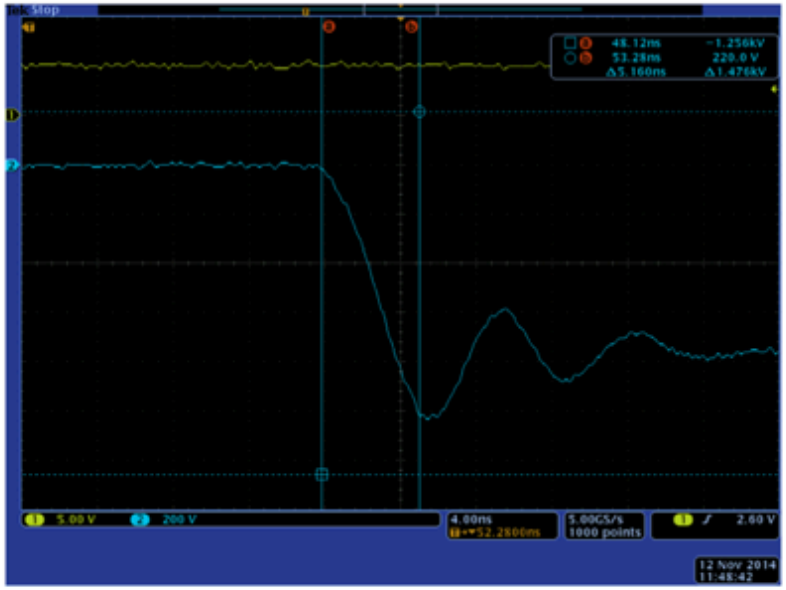


...BEING TESTED

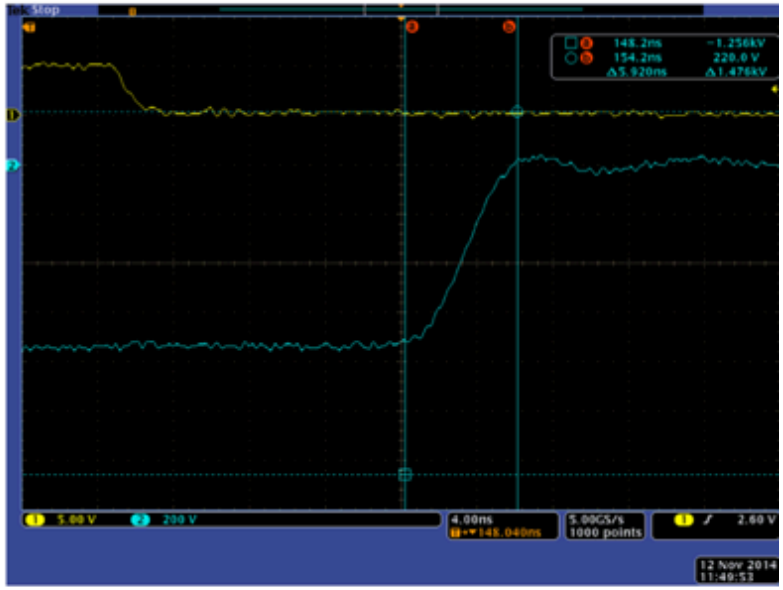


Progress on the Injection/Extraction Kicker for the ALS-U

Inductive Adder – Rise/Fall Time



0-100% rise ~ 5.2 ns



0-100% fall ~ 5.9 ns

Voltage overshoot and ringing needs to be understood and reduced

- Clamping diode capacitance ?
- HV probe ?
- Core housing capacitance ?
- PC board details ?

ESRF II Engineering Challenges

- Space
- Vacuum chambers & absorbers
- Girders
- Magnet design

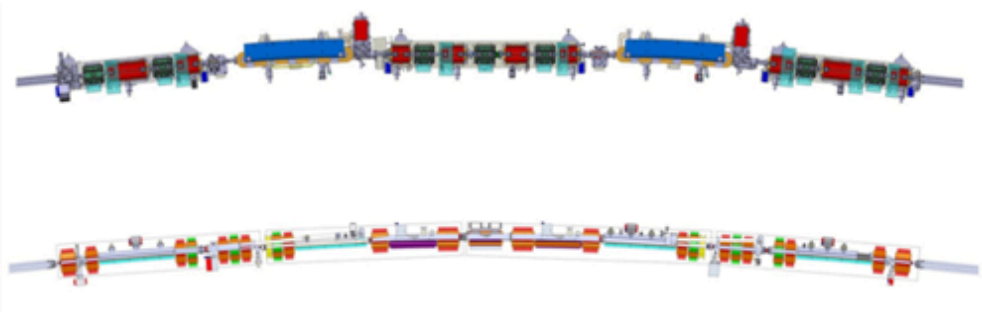
ESRF II Engineering Challenges

Lattice contraints - Free space

A Light for Science

Present ESRF Double Bend Achromat:

- 2 dipoles + 15 quad., Sext.) per cell
- ID length : 5m, 6m, 7m



ESRF Storage Ring = 32 cells
each cell = 26.4m long

ESRF II Hybrid 7 Bend Achromat:

- 4 dipoles + 3 dipoles-quad + 24 quad., sext., oct) per cell
- ID length : 5m

Free space between magnets (total for one cell): 3.4m instead of 8m today

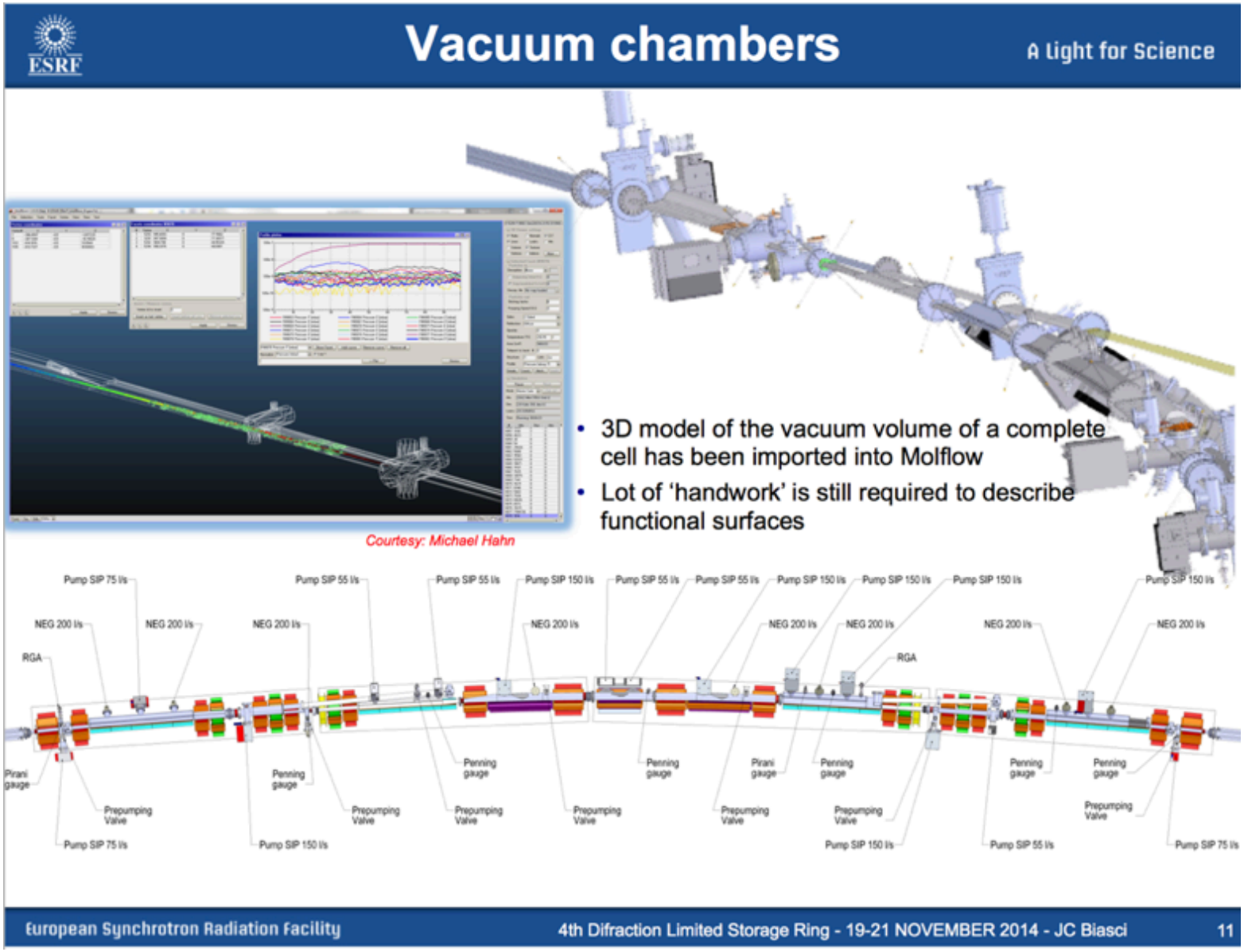
Main engineering challenge:

- Lack of space

ESRF II Engineering Challenges

- Space
- Vacuum chambers & absorbers
- Girders
- Magnet design

ESRF II Engineering Challenges



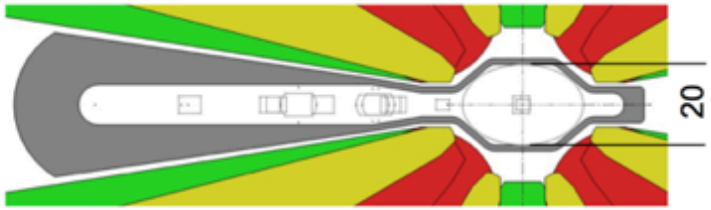
ESRF II Engineering Challenges

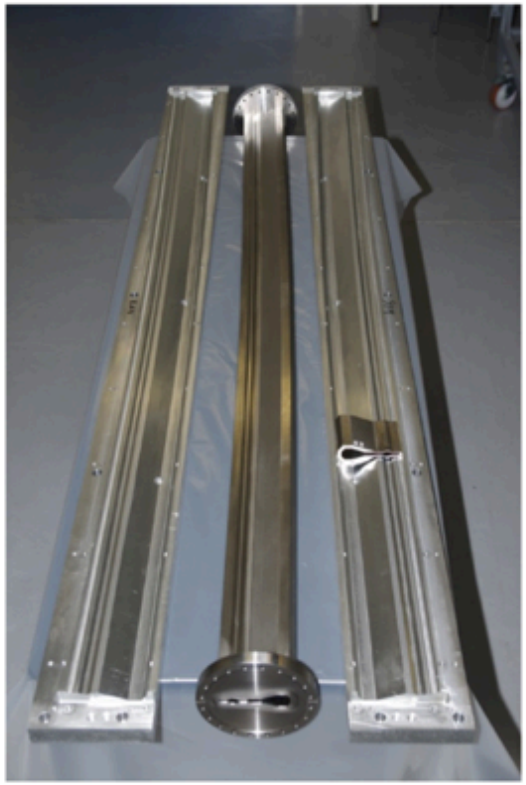
Vacuum chambers

A Light for Science

Technical issues:

- Beam stay clear
- Bakeout material
- Profiles, manufacturing process
- Raw material
- Absorbers, ray tracing
- RF fingers, transitions, FE, impedance…
- Vacuum performance
- NEG coating (Chambers & & 12)



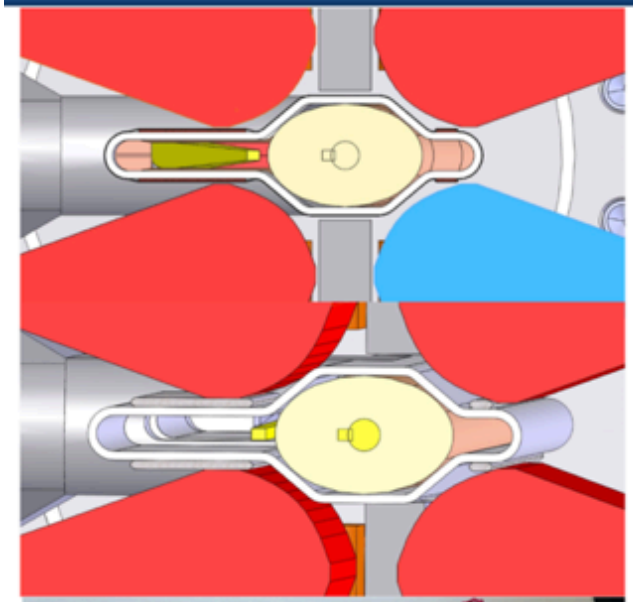


Central part: Stainless steel
Vacuum chamber prototype

ESRF II Engineering Challenges

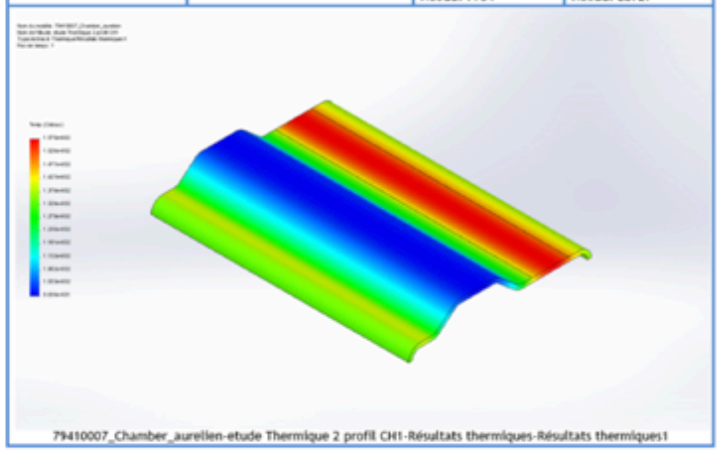
Vacuum chambers bakeout

A Light for Science



- Different configurations of heating element arrangement are under study
- Thermal simulation is being carried out by means of FE module of Solid Works
- Radiation resistance tests are on the way on the existing machine

Nom	Type	Min	Max
Résultats thermiques1	TEMP: Température	98.3935 Celsius Noeud: 7734	157.503 Celsius Noeud: 28727



Courtesy: Michael Hahn

ESRF II Engineering Challenges

- Space
- Vacuum chambers & absorbers
- Girders
- Magnet design

ESRF II Engineering Challenges

Girders

A Light for Science

INPUT DATA

- Girder length = 5.2m, magnets weight = 6 000kg
  - Static positioning required

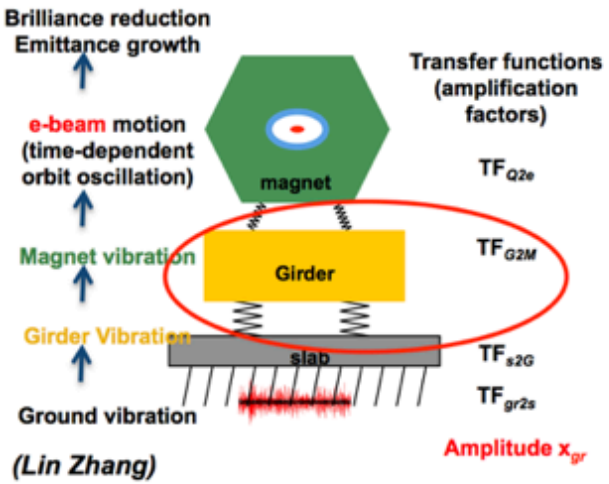
	HORIZONTAL (Y)	VERTICAL (Z)
Girder to girder	50 μm	50 μm

- ESRF site and slabs large displacements
  - Static = 150 μm / 6 months
- Vibration level = high compared to other sites

GIRDER PROJECT SPECIFICATION

- Motorized Z adjustment resolution 5μm
- Manual Y adjustment resolution 5μm
- 1st natural frequency = 50Hz (design criteria)
  35Hz (measured target)

Vibration amplification ground to beam



Challenges
- High precision positioning requirements, motorization
- High stability requirements
- Lack of space
- Budget limits

} Difficult to match

Courtesy: Filippo Cianciosi

ESRF II Engineering Challenges

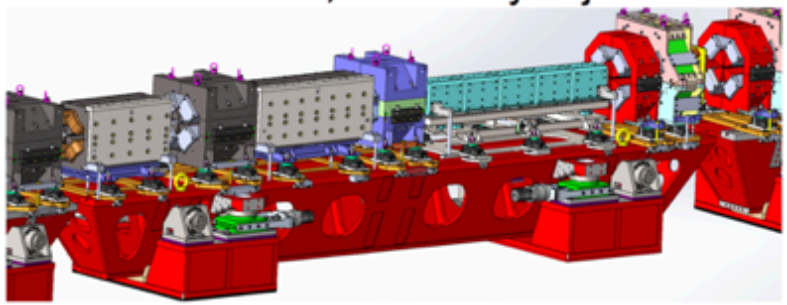
ESRF

Girders

A Light for Science

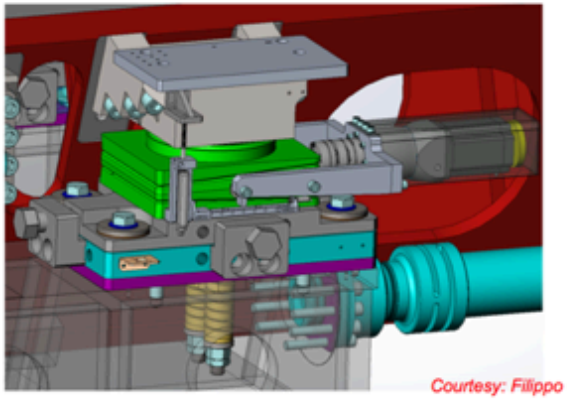
Girder design, the orthogonal heptapod

- 4 motorized adjustable supports in Z direction
- 3 manual horizontal jacks (one in X, two in Y)
- There is 1 degree of hyperstaticity in the vertical direction, a carefully adj of the 4 feets is required
- Technology:
- Girder material: carbon steel
- Typical tickness: 30mm (20-50)
- Piece junction:
- full penetration and continous welding



Support & adjustment

- Wedge Airloc 414-KSKC (modified) with integrated spherical socket
- Limit switches & encoder
- Sliding surface, skid made with bronze with coating



Courtesy: Filippo Cianciosi

ESRF II Engineering Challenges

- Space
- Vacuum chambers & absorbers
- Girders
- Magnet design

ESRF II Engineering Challenges

Magnets design

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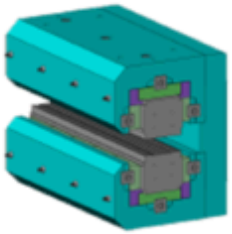
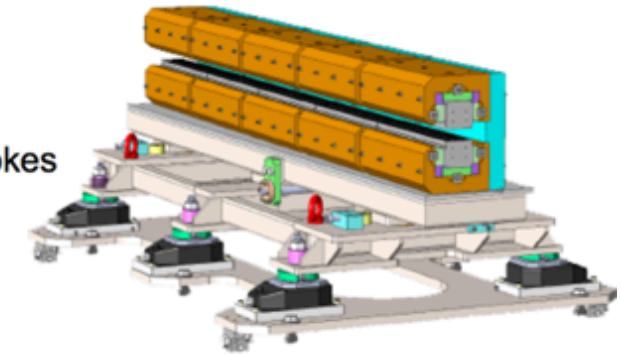
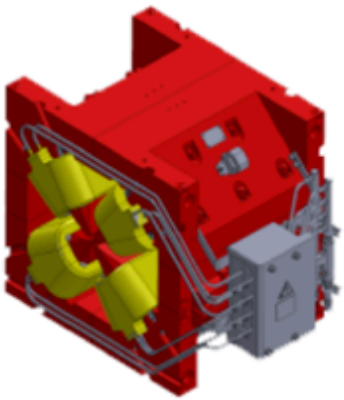


DL

- Permanent magnets with machined yokes
- Prototypes are being characterised
- No major technical issue



- Support allowing to remove DL during bakeout



Quadrupoles

- Quarter yokes machined independently
- +/- 20 µm tolerance expected after assembly
- Quarter yoke assembly: solutions to be tested (accuracy, repeatability)
- Technical issues
  - Raw material cost & procurement
  - Machining tolerances

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ESRF II Engineering Challenges

Magnets design

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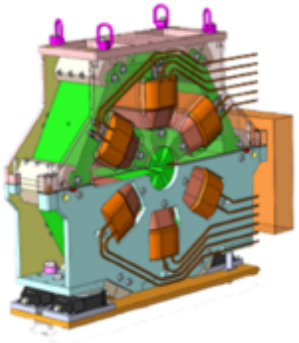
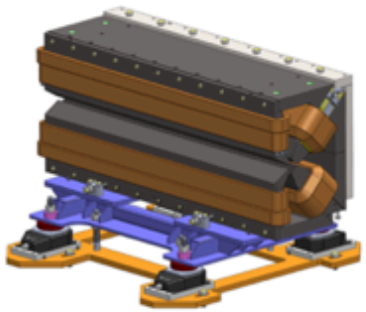


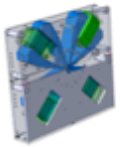
Sextupoles

- Laminated magnet
- 1st Engineering design completed in May 2014
- "Heavy" mechanical design: stainless steel frame, large clamps, …
- Simplified design in progress
- No major technical issues
  - Girder fixation not easy due to small length

DQ Dipole Quadrupoles

- 3D model complete
- Engineering design in progress
- Mechanical prototype to be ordered end 2014
  - technical issues:
    - Machining tolerances





Octupoles & Correctors

- no major technical issues
  - Octupole prototype received

Magnet Alignment Challenges for an MBA Storage Ring

- Alignment: survey vs. direct magnetic measurement
- Mechanical vs. magnetic axes
- Direct magnetic measurement
- Specific MBA challenge

Magnet Alignment Challenges for an MBA Storage Ring

Outline

- Definition of "alignment" in the context of this talk:
  - The process of positioning multiple (>2) *physically disjointed* objects such that their magnetic centers lie on a desired curve.
- Alignment methods involving survey and/or mechanical precision, with or without the use of magnetic measurements:
  - Magnetic measurements to *fiducialize*, then survey to install
  - Magnetic measurements to *characterize*, then shim (?) to install
  - Alignment using manufacturing tolerances alone
- Direct alignment using magnetic measurements
- Special requirements for multi-bend acromat (MBA) storage rings.

Magnet Alignment Challenges for an MBA Storage Ring

Summary: Mechanical/Survey based Alignment

- Alignment using survey:
  - Does not require special precision machined reference surfaces.
  - Requires the magnet fiducials to be related to the magnet center (either magnetic or mechanical).
  - Alignment at ~30 μm level of several elements on a common support spanning several meters may be possible, but not easy.
- Alignment using precision reference surfaces:
  - Aligning several elements on a common support is straightforward.
  - Requires precision machining of each magnet element as well as of long, massive support structures that should not deform easily.
  - Magnetic and mechanical axes must show good agreement.

Magnet Alignment Challenges for an MBA Storage Ring

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Magnet Alignment Challenges for an MBA Storage Ring

Mechanical Vs. Magnetic Axes

- While the definition of magnetic axis is less ambiguous, there is no unique definition of the mechanical axis of an as-built magnet
  - Option 1: Define as a fixed offset from reference surfaces
    - Easy to use; no ambiguity; but really only pole positions matter
  - Option 2: Define somehow based on survey of individual poles
    - Tedious; complex pole profiles not very suitable to work with; subject to data analysis procedures; not too useful for aligning.
- While good agreement between mechanical and magnetic axes is reported in some cases (e.g. SLS), counter examples exist.
- It may be prudent to confirm the validity of this agreement in a specific production before deciding on a purely mechanical alignment, specially if tight alignment tolerances are needed.

Magnet Alignment Challenges for an MBA Storage Ring

- Alignment: survey vs. direct magnetic measurement
- Mechanical vs. magnetic axes
- Direct magnetic measurement
- Specific MBA challenge

Magnet Alignment Challenges for an MBA Storage Ring

Direct Magnetic Alignment

- Magnets may be aligned directly to each other using magnetic measurements. This offers some advantages:
  - No need to fiducialize magnets, no stack up of errors
  - No need for precision reference surfaces
  - Support structure requires no precision manufacturing (cheap)
  - Mechanical vs. magnetic axes is irrelevant (less R&D & monitoring)
- Requires a wire based measurement technique, and is thus most suitable for straight assemblies up to ~5 m long.
- Requires temporary fixtures to move and secure magnets.
- Most frequently voiced concern is that it is too expensive, or too time consuming (not necessarily well founded!)

Magnet Alignment Challenges for an MBA Storage Ring

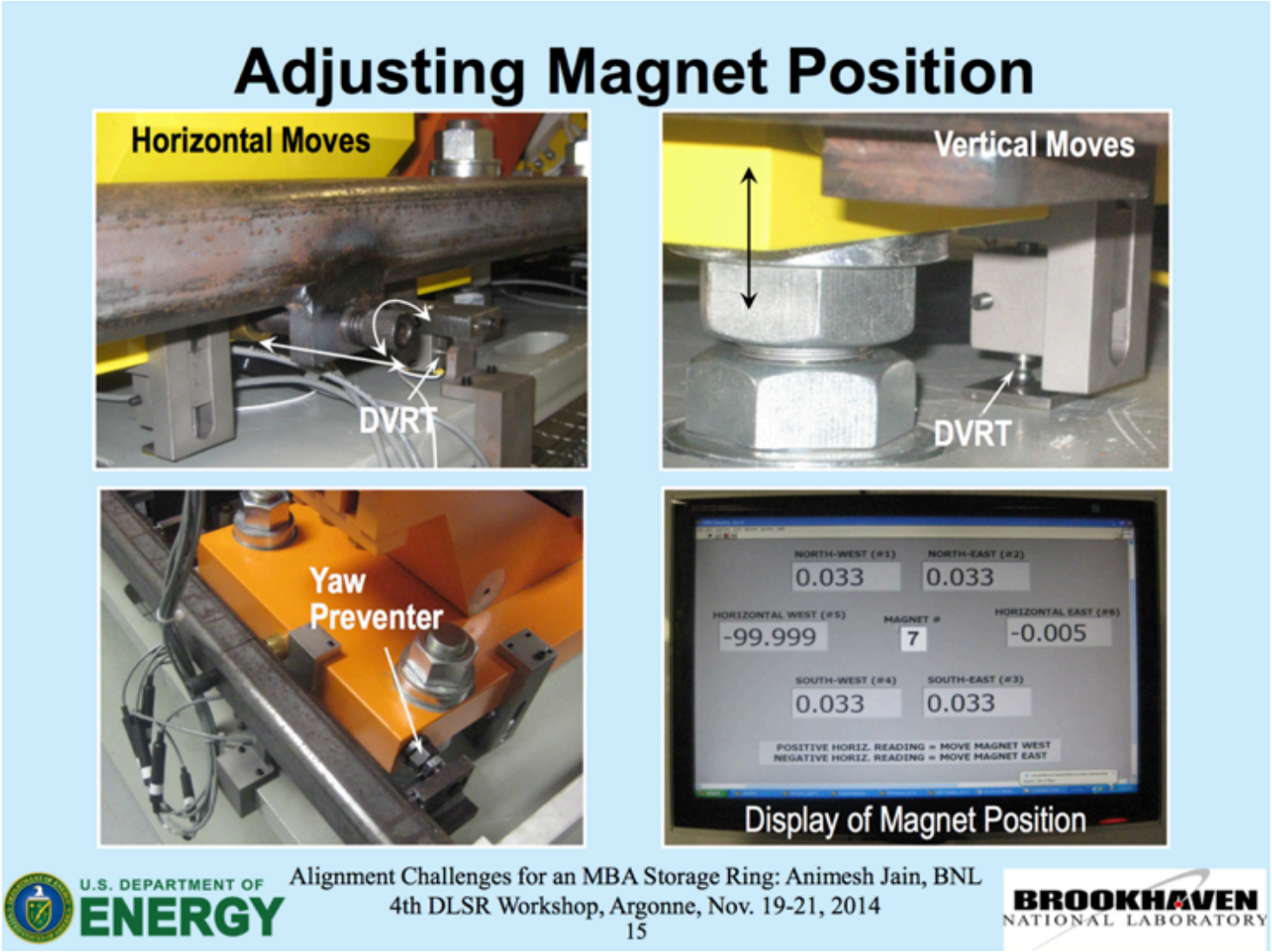
Wire Based Measurement Techniques

- Stretched Wire
  - The wire is moved across the aperture and the change in flux is measured. The axis is derived from a set of measurements with different wire motion paths. (Accuracy ~2-5 μm; time ~ ½ hr)
- Vibrating wire
  - An AC current of a frequency matching a resonant mode of the wire is passed through the wire. This causes the wire to vibrate with an amplitude proportional to the field strength.
  - Vibration amplitudes are analyzed as a function of wire position to derive the magnetic axis. (Accuracy ~2-5 μm; time ~ ½ to ¾ hr)
- Rotating wire (not yet well established, but promising)
  - A single wire is used as a rotating coil. (Accuracy ?; time ~ ¼ hr)

Magnet Alignment Challenges for an MBA Storage Ring

A NSLS-II Girder Undergoing Alignment

Magnet Alignment Challenges for an MBA Storage Ring



Magnet Alignment Challenges for an MBA Storage Ring

- Alignment: survey vs. direct magnetic measurement
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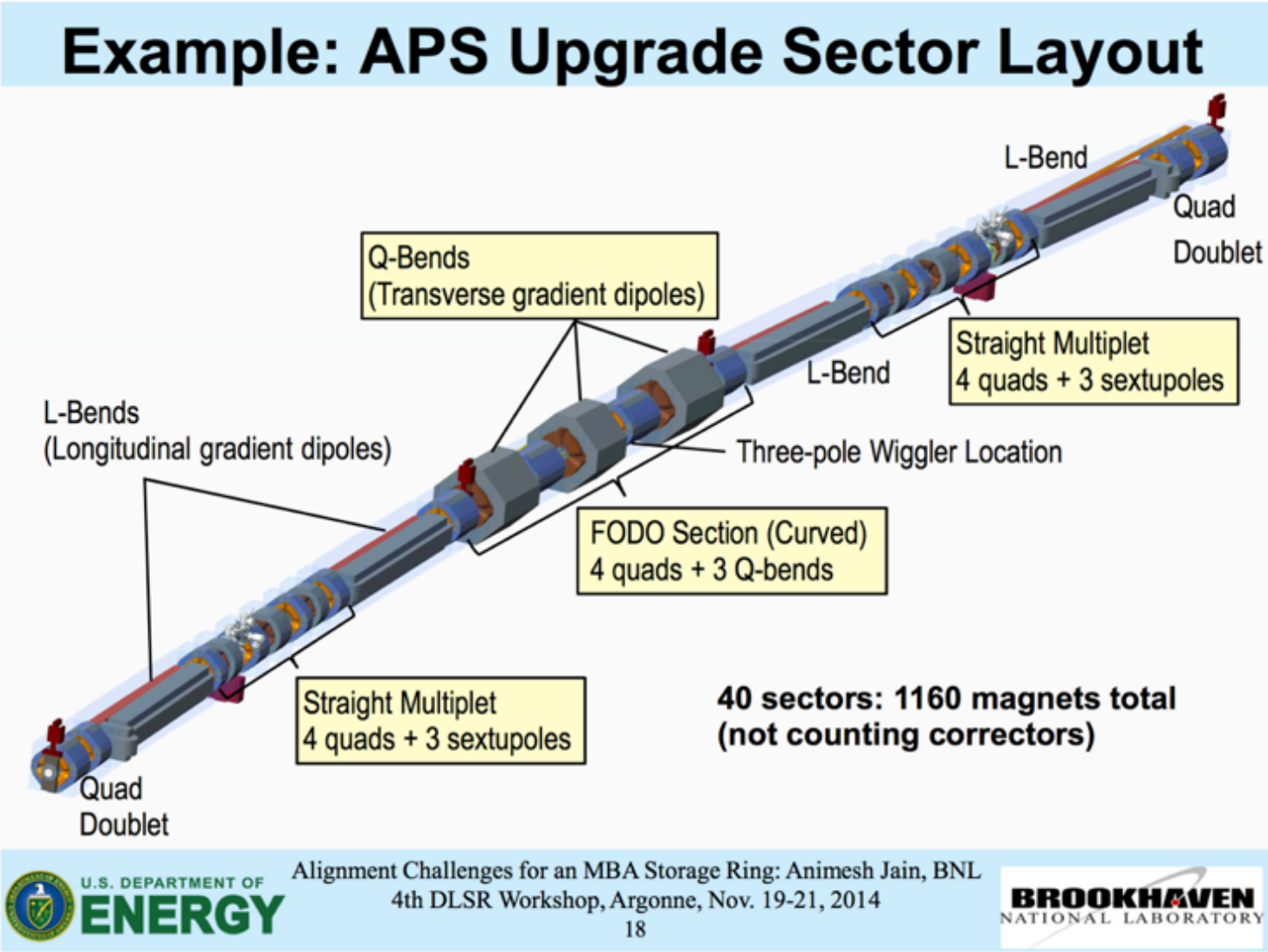
Magnet Alignment Challenges for an MBA Storage Ring



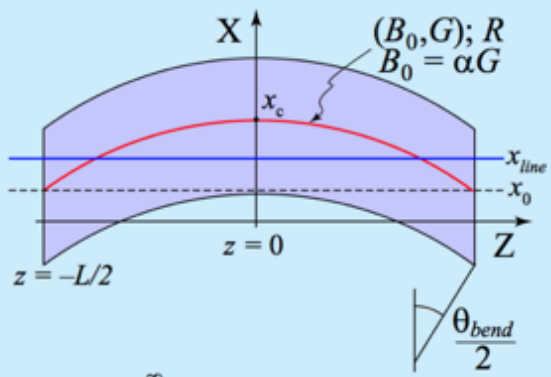
Magnet Alignment Challenges for an MBA Storage Ring

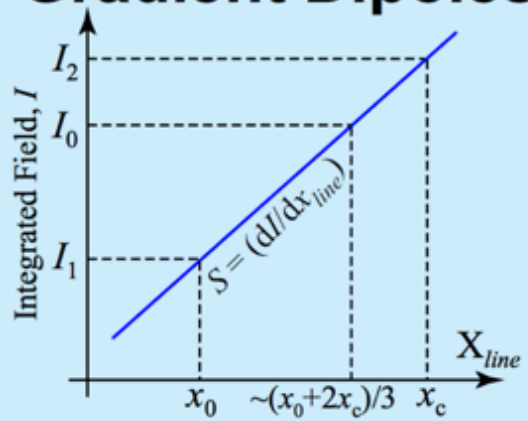
Options for Curved Sections

- Standard technique applicable to measurement of curved sections is to use a Hall probe system with precision stages.
- Hall probe element can be located in the stage coordinate system using a magnetic pin, for example. But this involves accurate knowledge (survey) of the pin location.
- The magnet can be mapped using Hall probe, and the axis derived, provided there is easy access for the Hall probe holder.
  - Easier to do with an open side design (e.g. ESRF design)
  - Achievable accuracy may not be sufficient; also time consuming.
- Another option is to measure along straight lines using a wire, and apply appropriate offset (to be developed, ESRF inspired).

Magnet Alignment Challenges for an MBA Storage Ring

Straight Line Integration in Gradient Dipoles





$$I(x_{line}) = \int_{-\infty}^{\infty} B_y(x_{line}, z) \cdot dz$$

$$I = S\left[x_{line} - x_0 + \alpha + R\left\{\cos\left(\frac{\theta_{bend}}{2}\right) - \frac{\theta_{bend} + \sin\theta_{bend}}{4\sin(\theta_{bend}/2)}\right\}\right]$$

$$I_1 = S\left[\alpha + R\left\{\cos\left(\frac{\theta_{bend}}{2}\right) - \frac{\theta_{bend} + \sin\theta_{bend}}{4\sin(\theta_{bend}/2)}\right\}\right] \approx S\left[\alpha - \frac{R\theta_{bend}^2}{12}\right]$$

$$I_2 = S\left[\alpha + R\left\{1 - \frac{\theta_{bend} + \sin\theta_{bend}}{4\sin(\theta_{bend}/2)}\right\}\right] \approx S\left[\alpha + \frac{R\theta_{bend}^2}{24}\right]$$

Integral along curved trajectory:

$$I_0 = S\frac{\alpha\theta_{bend}}{2\sin(\theta_{bend}/2)}$$

$$\approx (S\alpha)\left[1 + \frac{\theta_{bend}^2}{24}\right]$$