Low Emittance Rings LER 2010 workshop

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Optimization Algorithms and the ALS Lattice Upgrade

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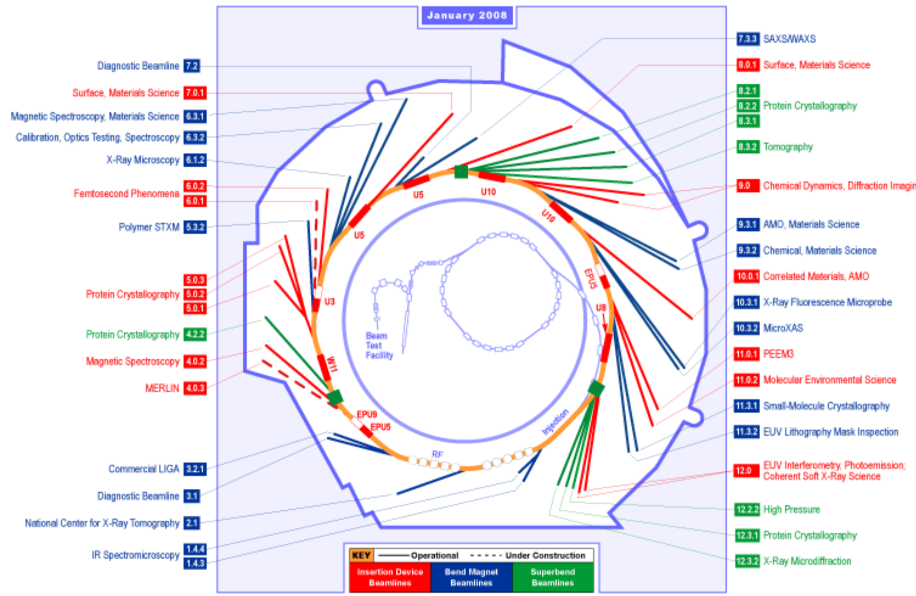
Outline

- Introduction
  - The ALS
  - Lattice Upgrade Project
- Optimization Algorithms
  - GLASS (global analysis …)
  - MOGA (genetic)
  - Frequency Maps (quantitative)
  - Further Developments
- Performance of upgraded ALS
- Summary

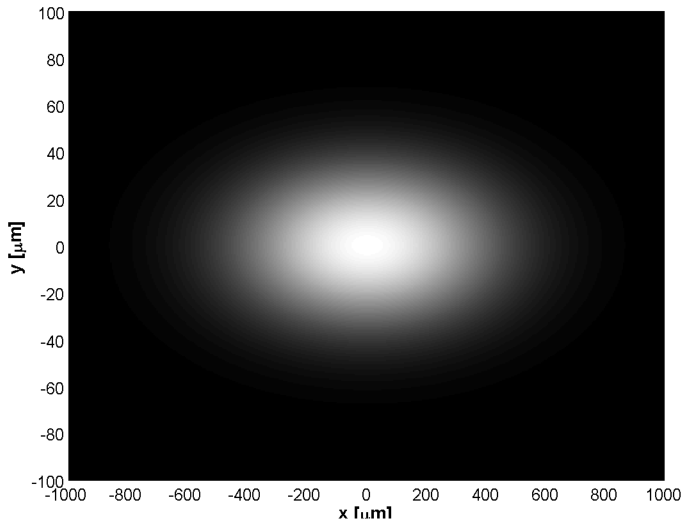
ALS Parameters and Beamlines

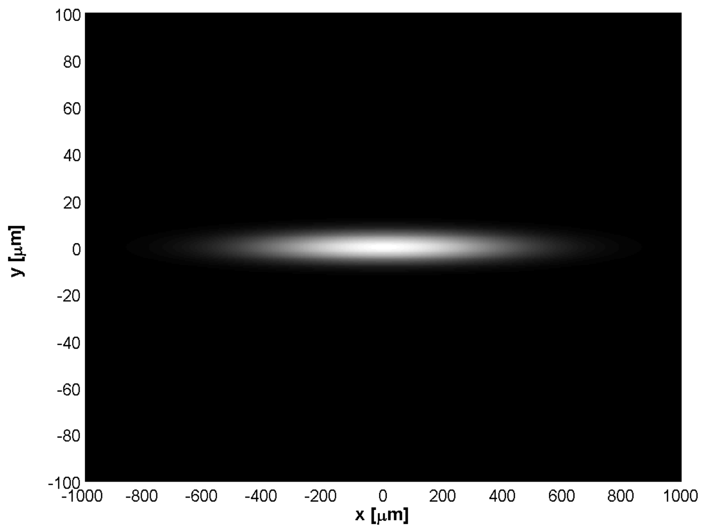
Nominal Energy	1.5-1.9 GeV
Circumference	196.8 m
RF frequency	499.642 MHz
Harmonic number	328
Beam current	500 mA multibunch 35-50 mA two-bunch
Nat. emittance	6.3 nm (future 2.2) at 1.9 GeV
Vert. Emittance	30 – 50 pm (user ops), 4-5 pm (dedicated AP)
Nat. energy spread	0.097%
Refill period	Top-off every 30-60 s (current stability 0.3%)
User Beamlines	>40 simultaneous (11 insertion devices)



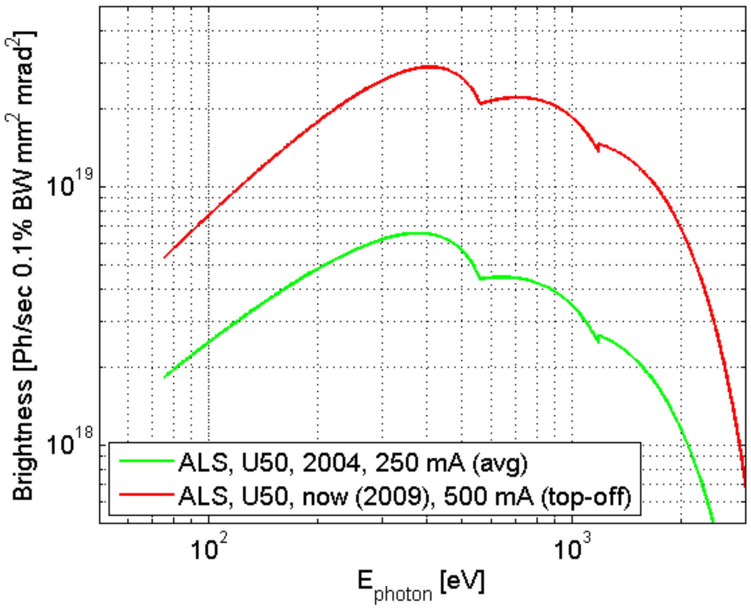
Vertical Emittance Reduction

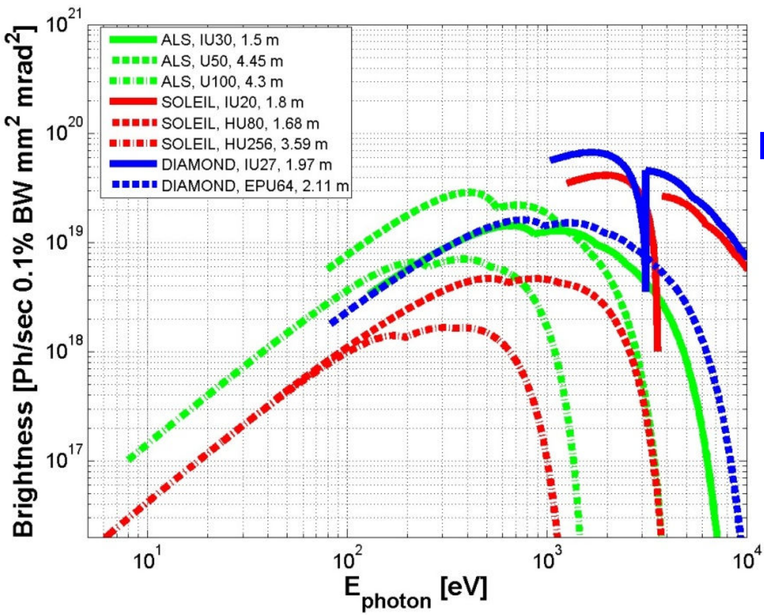
- Successfully demonstrated vertical emittances much smaller current nominal parameters in 2003
- Using LOCO and 24 skew quadrupoles we achieved an emittance reduction to below 5 pm
- For routine top-off operation we only use 30 -50 pm – i.e. 'diffraction limited' at 2.5 keV
  - Benefit beyond only for very few hard x-ray beamlines
  - Challenges at even smaller emittances would be lifetime and beamsize stabilty (low beam energy -> Touschek and big ID influence on beamsize)





ALS Brightness

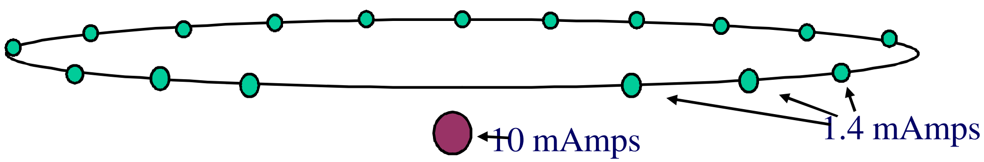




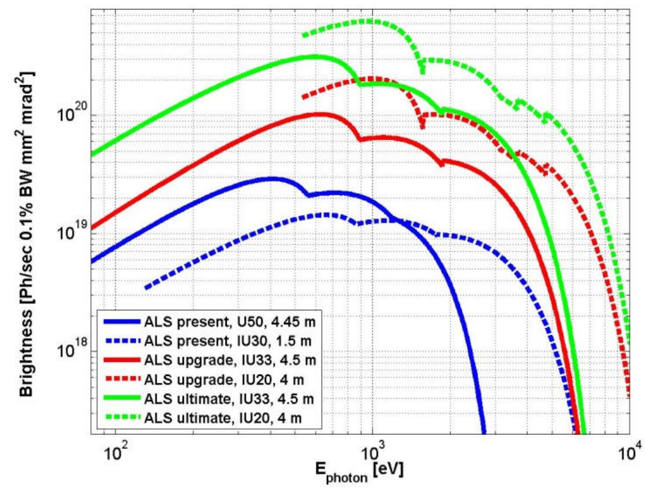
- **Recent Top-off upgrade provided factor of 3-10 improvement in brightness for undulator and (super-) bend users**
- **Now, the ALS compares favorably with the newest light sources below 1 keV photon energy**

ALS Upgrades Beyond Top-off

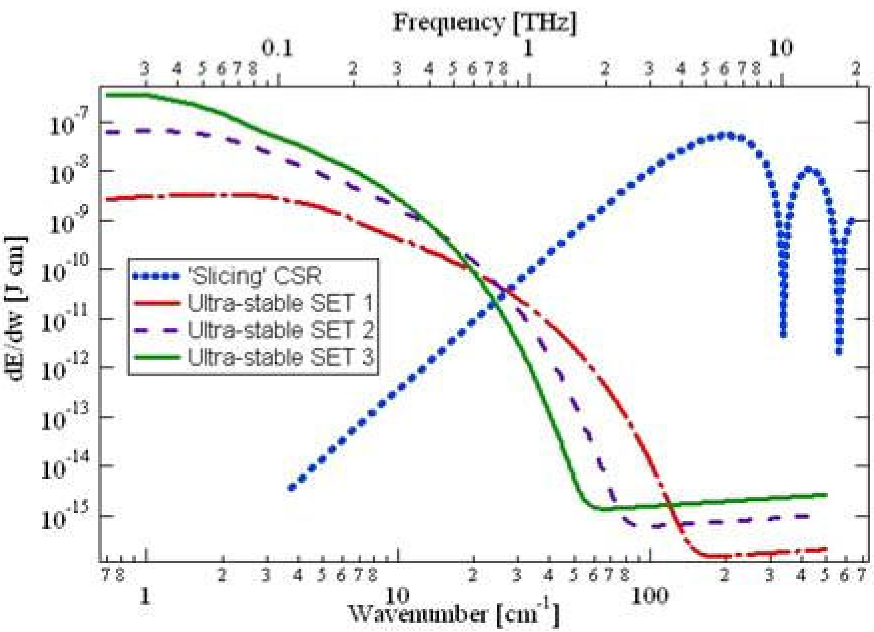
Tailored Bunch Operation

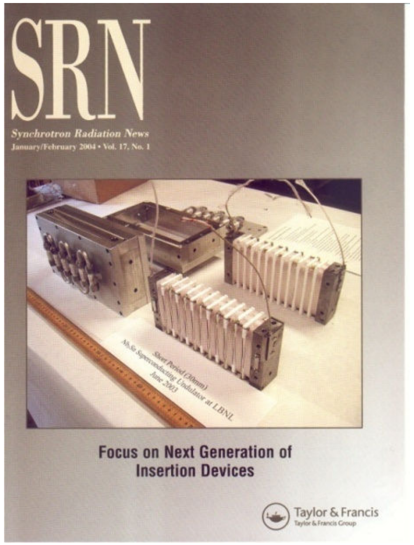


High Brightness



Terahertz

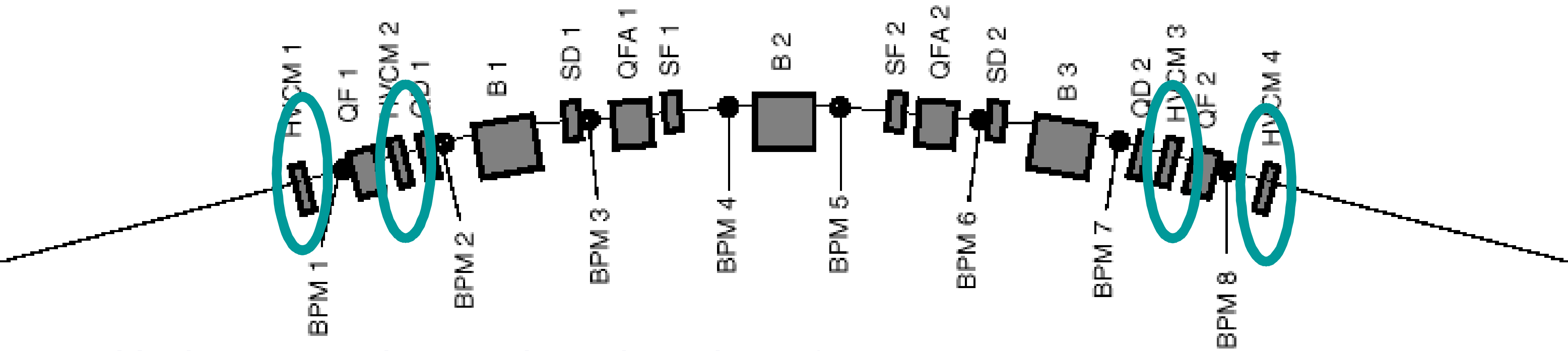




Advanced Insertion Devices

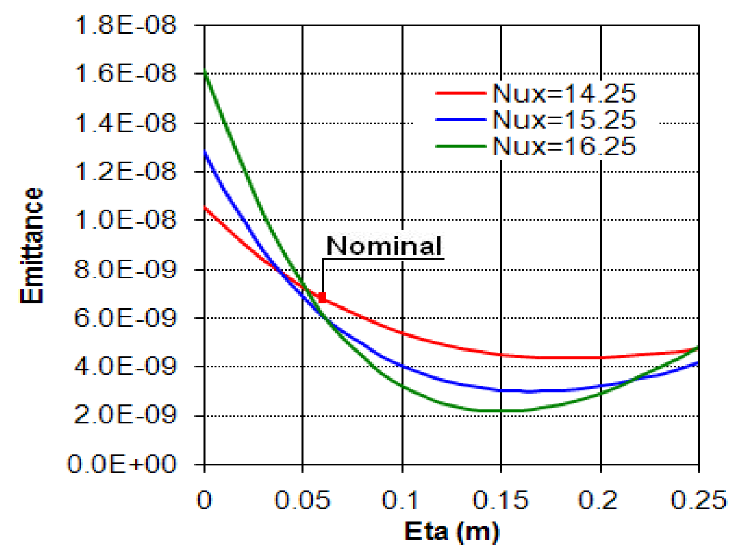
ALS Lattice Upgrade Project

Install New Sextupoles



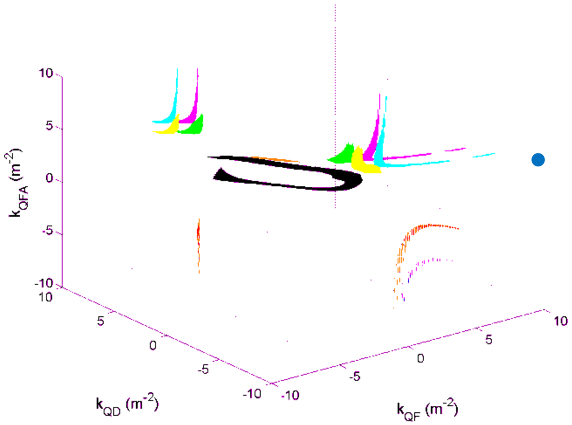
- Horizontal emittance is reduced to 1/3 from 6.3 nm rad to 2.2 nm rad
- Brightness is inversely proportional to emittance
- Idea in 2004, on backburner during top-off upgrade, funding in 2009, completion in 2012

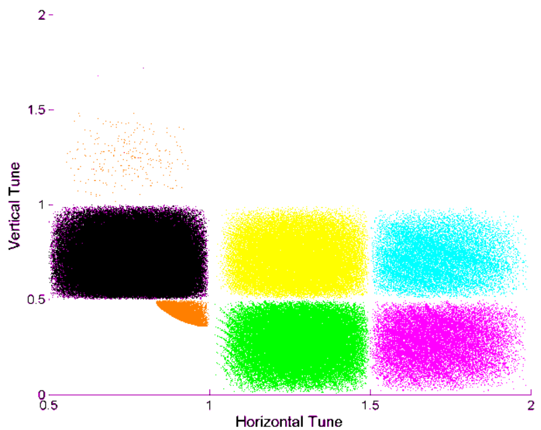
Of existing light sources, only PETRA-III has a lower emittance



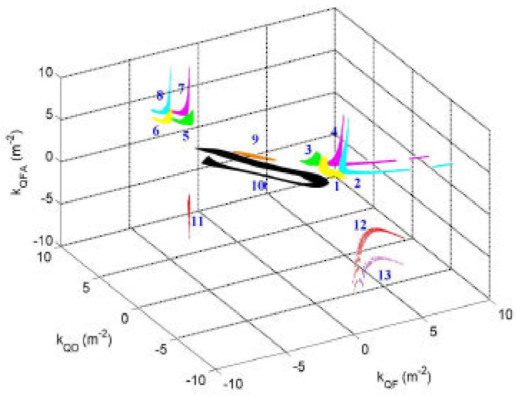
Lattice optimization

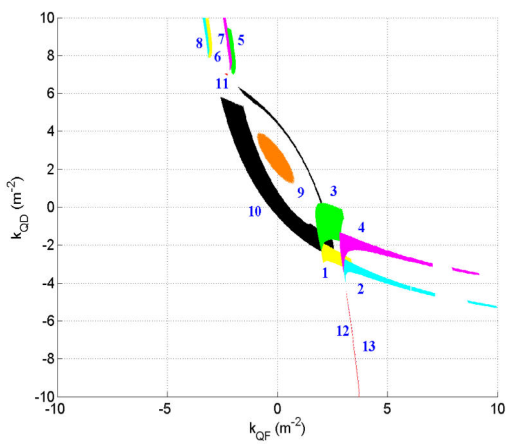
- **GLASS – Global Analysis of All Stable Solutions**
  - **Tool to look for optimum lattice solution for highly periodic lattices (few parameters)**
- **MOGA – Multi Objective Genetic Algorithms**
  - **Usefulness for accelerators first demonstrated for photo injectors (Bazarov et al./Cornell)**
  - **Optimum solution with moderate computation time for larger dimensional parameter spaces**
  - **Integrated optimization of linear+nonlinear lattice possible**
- **Frequency Maps (quantitative diffusion rates)**
  - **In use for years for studies of global dynamics (simulation and measurement).**
  - **Can also be used as merit function (e.g. for MOGA)**



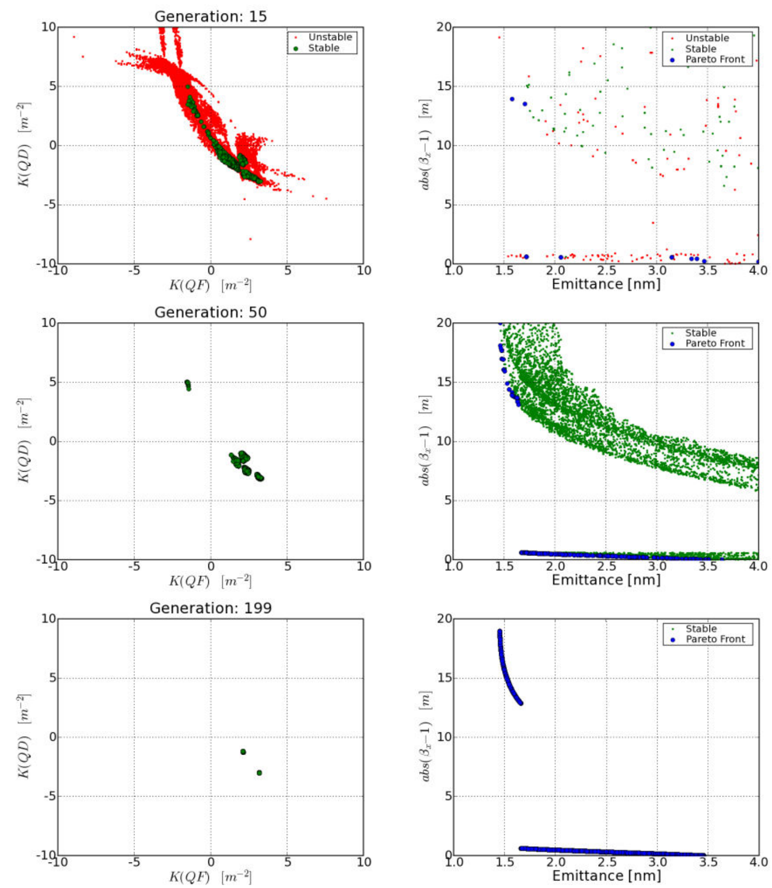


GLASS and MOGA

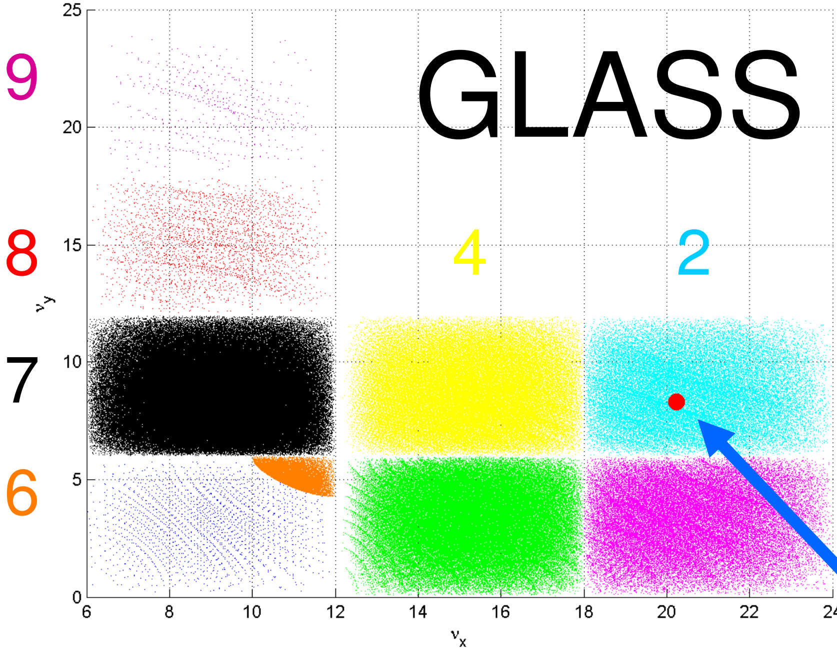


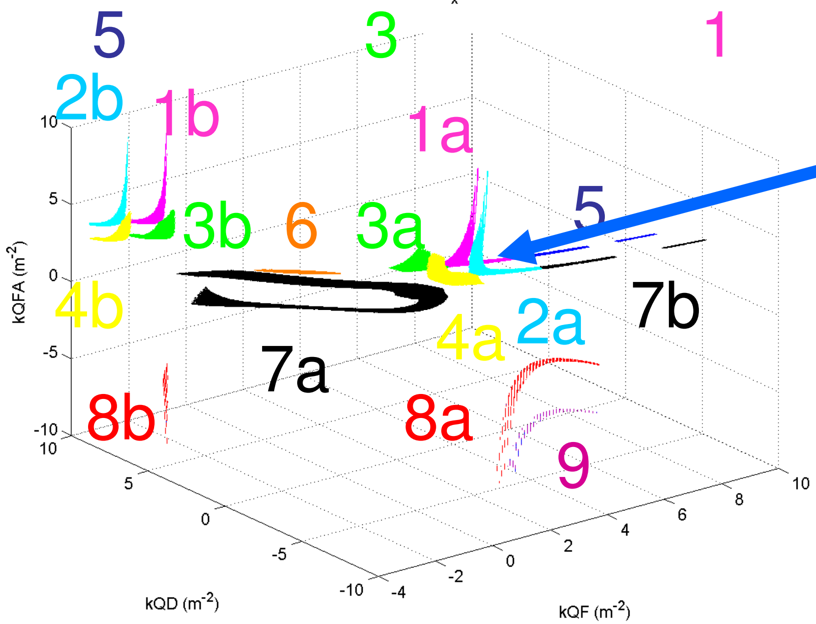


D. Robin, et al., Physical Review Special Topics 024002 (2008)

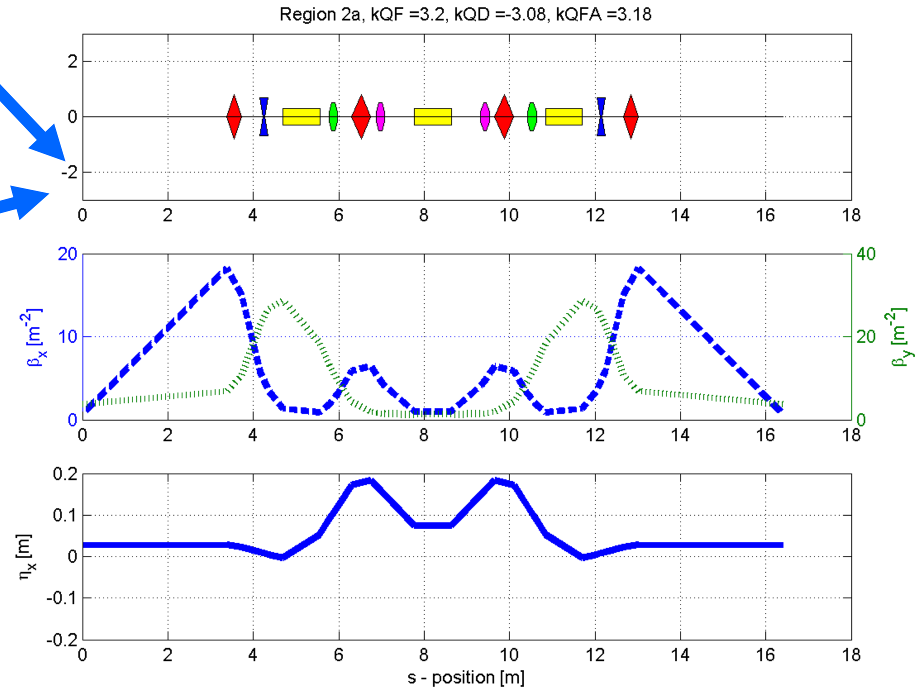


L. Yang et. al “Global optimization of the magnetic lattice using multiobjective genetic algorithms”, Nuclear Instruments and Methods in Physics Research A 609 (2009) 50–57





- *Low emittance*
- *Low momentum compaction*
- *Small beta functions in center bend*
- *Small horizontal beta in straights*



Genetic Algorithm (GA)

A Typical GA with Nondomination Concept

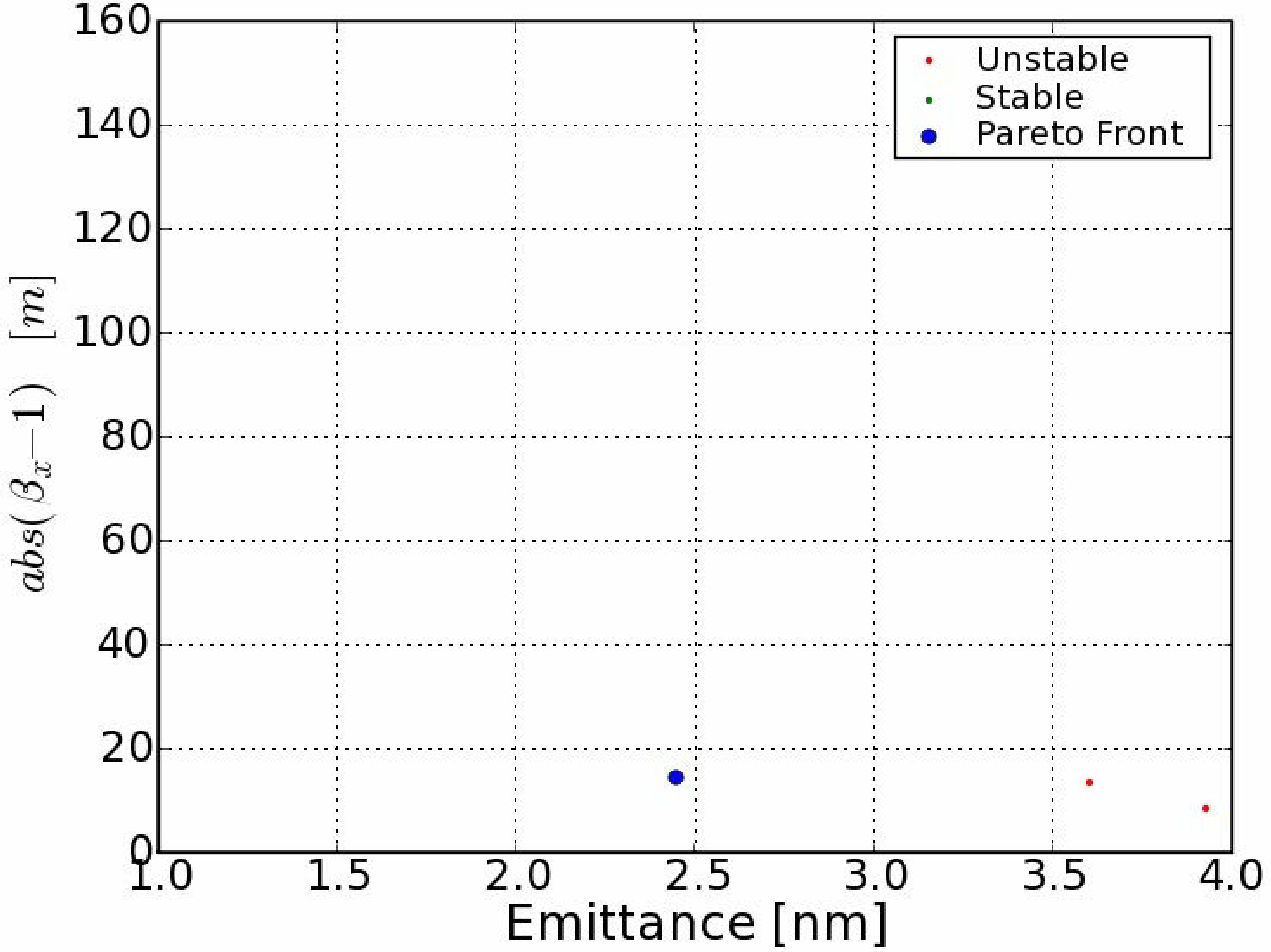
Non-dominated Sorting Genetic Algorithm (NSGA-II):

MOEA (Multi-Objective Evolutionary Algorithm)

```
Initialize population (first generation)
repeat
    select parent to child (select+cross)
    mutation(child)
    evaluate(child)
    merge(parent, child) if preserve the elite solutions.
    nondominated sort()
until reach maximum generation
```

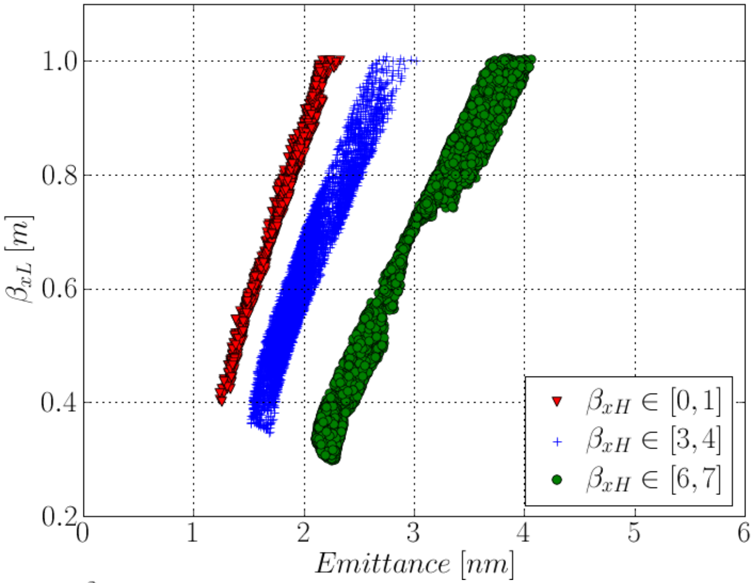
- **Elite-preserving operator**: preserve and use previously found best solutions in subsequent generations.

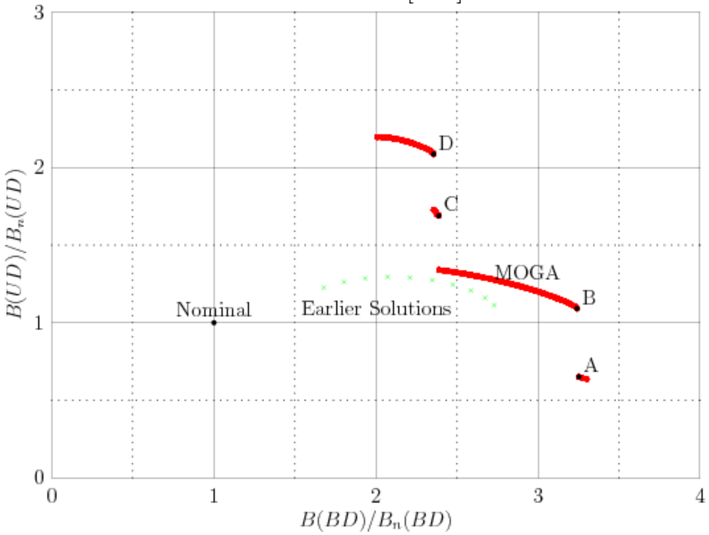
Movie of Convergence



Results of MOGA and future Plans

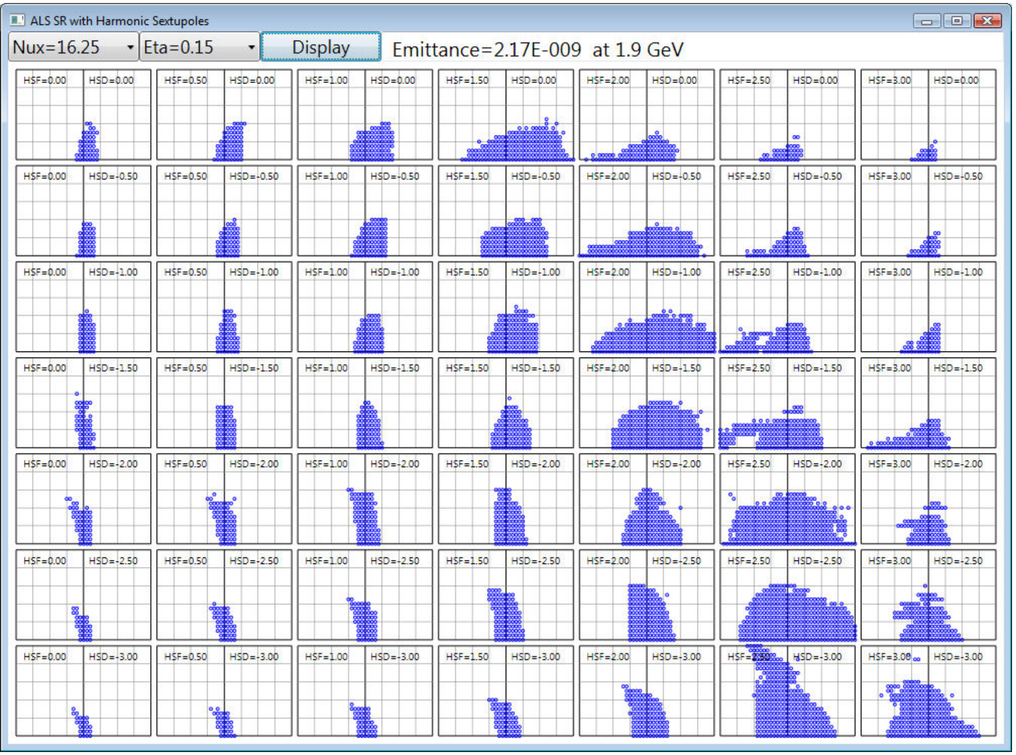
- Studied lattices with more parameters (6-10)
  - low beta functions in both planes in ½ or most of the straights (optimize diffraction match)
  - Withy sufficient beta function in injection straight to allow injection
- Did not find lattice with emittances significantly below 2 nm baseline
- Starting with simultaneous optimization of linear and nonlinear dynamics
  - Lingyun is just getting first results for NSLS-II (like Michael at APS)

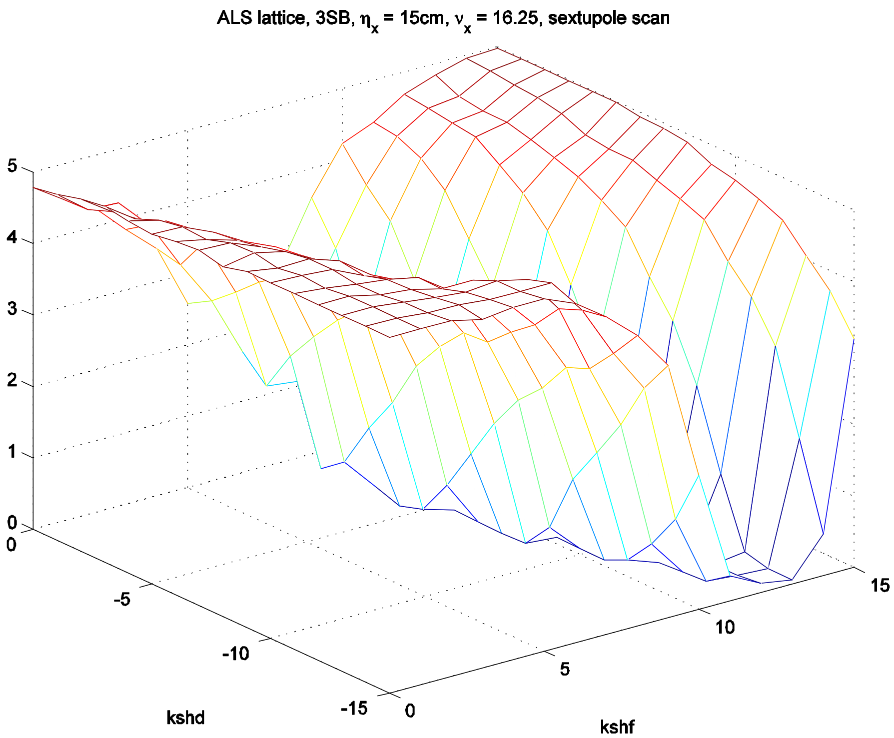




Nonlinear Lattice Optimization

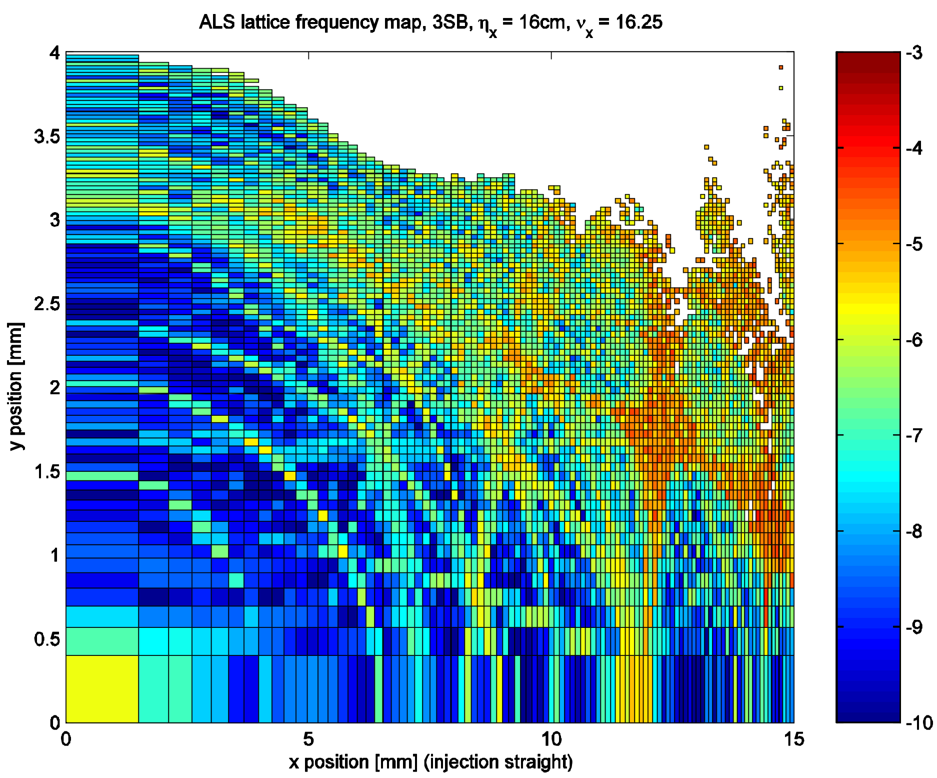
- In past we usually restricted ourselves to two parameter scans (harmonic sextupoles, tunes, …) and iterate – future: MOGA
- Either use 'quick and dirty' dynamic aperture calculation (left) to skim through large number of possible lattices
- Frequency map analysis (right) is slower but more accurate

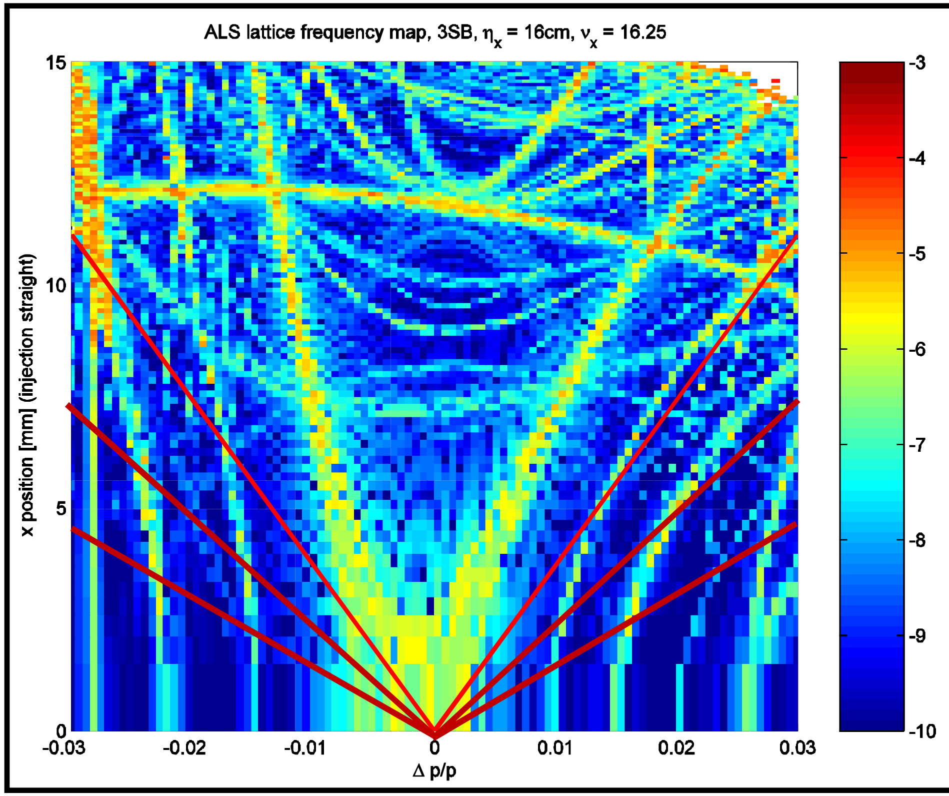




Merit Function for Lattice Optimization

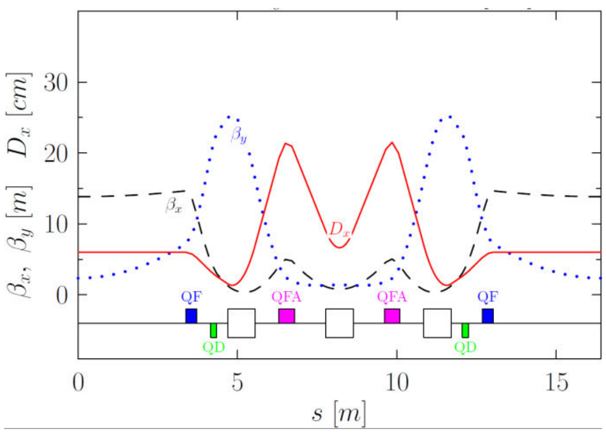
- Sum of all diffusion rates over predefined ‘area of interest’
- Do not optimize sextupoles/tunes/… to minimize footprint/detuning/… but rather to optimize global dynamics



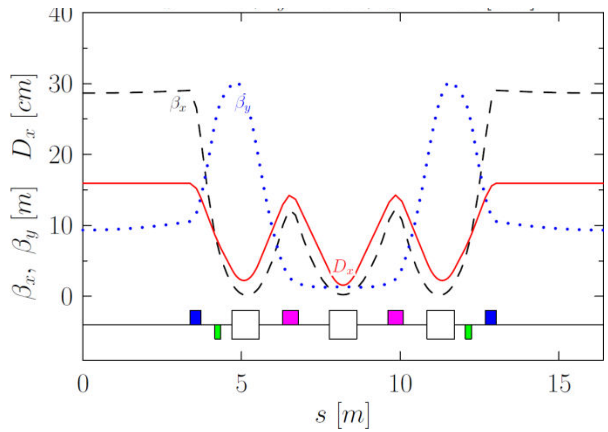


Back to ALS upgrade

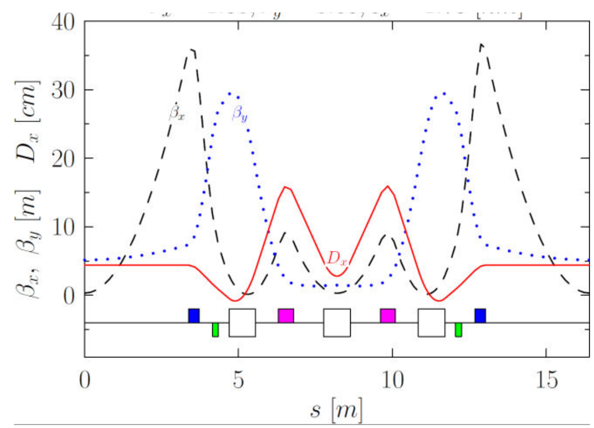
Current Lattice



New Large β_x Lattice



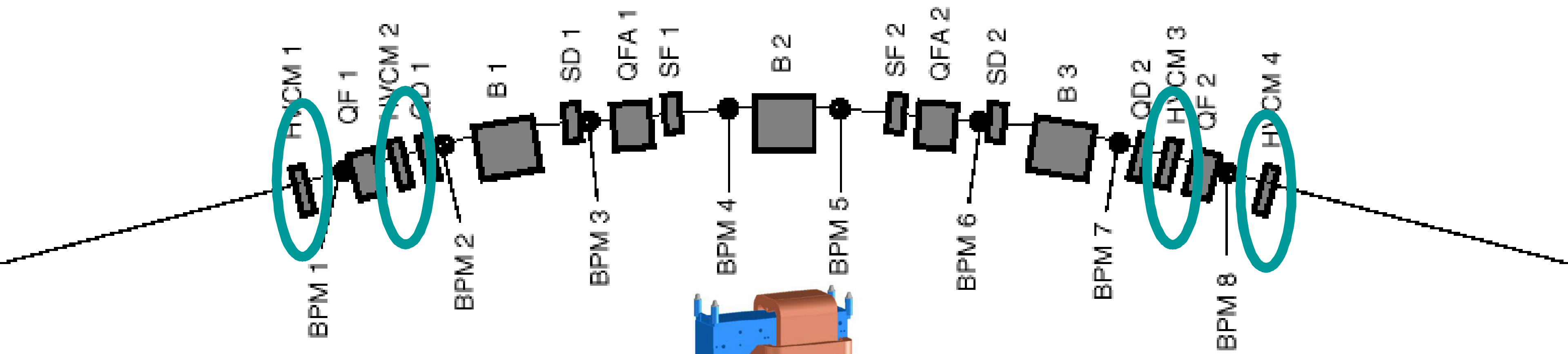
New Small β_x Lattice



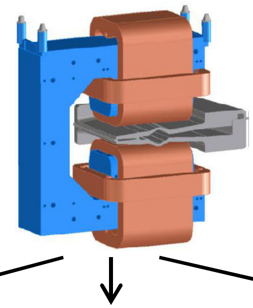
- Several possible lattices with ~2 nm rad emittance
  - 3x smaller than the nominal ALS (~6.3 nmrad)
- Large β_x lattice optimizes brightness in the central bends
- Small β_x lattice optimizes brightness in the insertion devices

Hardware Changes

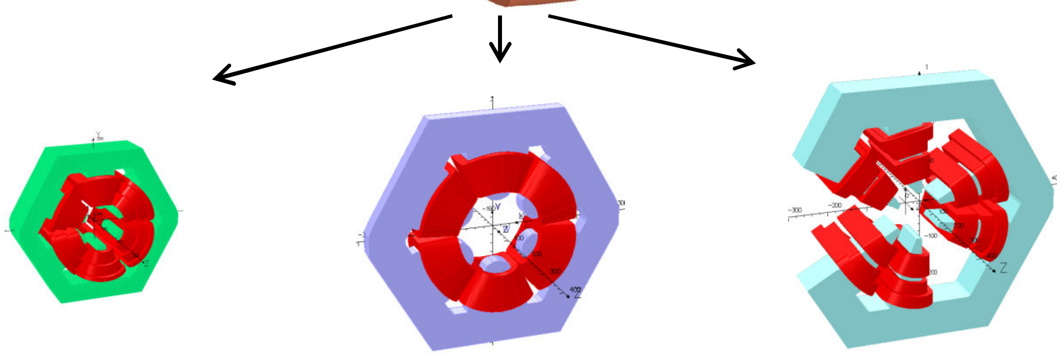
Install New Sextupoles



Existing Correctors



Sextupole / Corrector Multimagnet



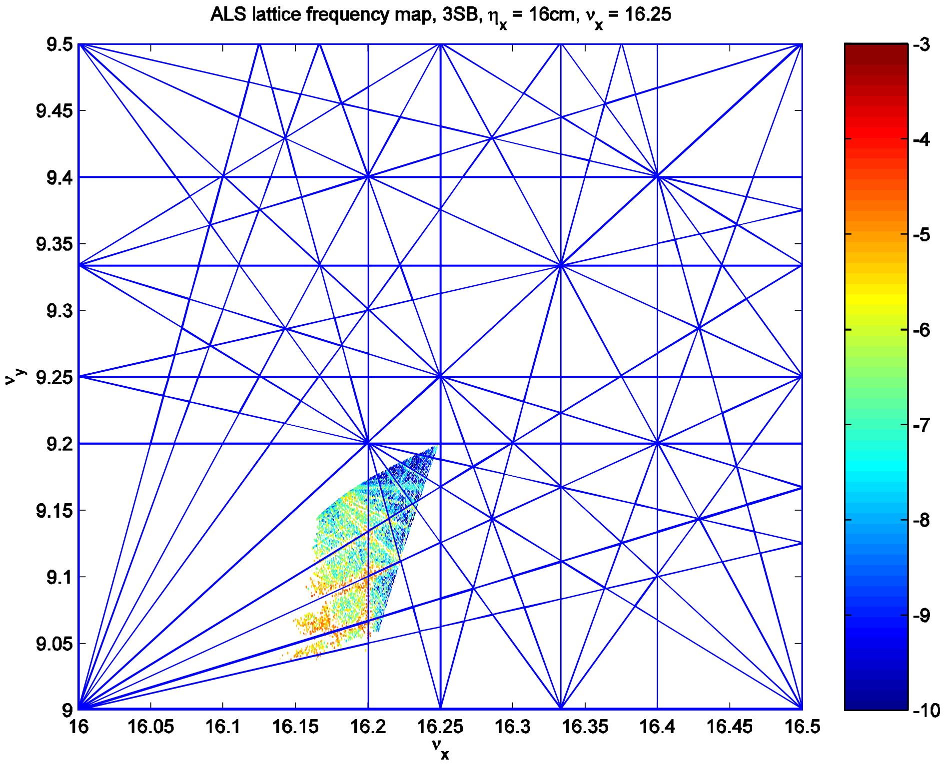
H. Nishimura, S. Marks, D. S. Robin, R. D. Schlueter, C. A. Steier, W. Wan – Proceedings of the 2007 PAC Conf

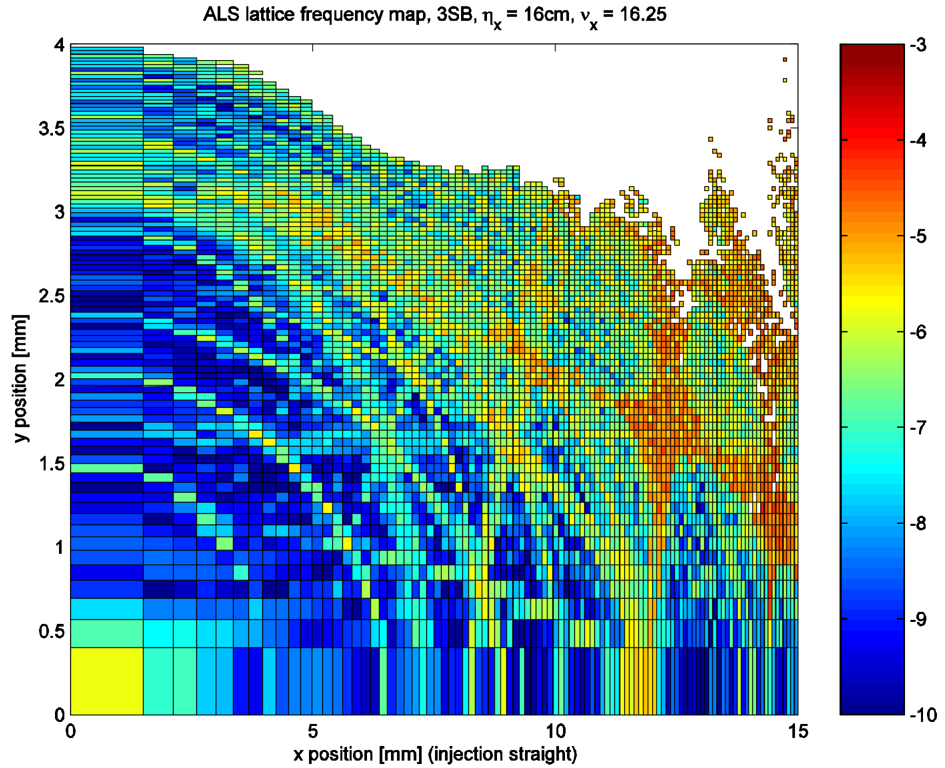
Baseline of Upgrade

- Baseline Lattice is the high beta lattice (ν_x=16.25, ν_y = 9.2, η_x=15cm)
- 48 new Sextupoles – 3 types
  - 2 in injection straight, sextupole only
  - 22 inner ones in other 11 straights (sextupole, HCM+VCM+skew) – symmetric
  - 24 outer ones in all straights (sextupole+HCM+VCM, possibility for skew) – C-shaped
- New power supplies for sextupoles (48) and skews (24)
- Controls for new power supplies (and FF integration of skews)
- Magnetic Measurements, Fiducialization, Installation of magnets, cables, EPS, power supplies, controls
- Basic Commissioning

Baseline Lattice: Dynamic Aperture

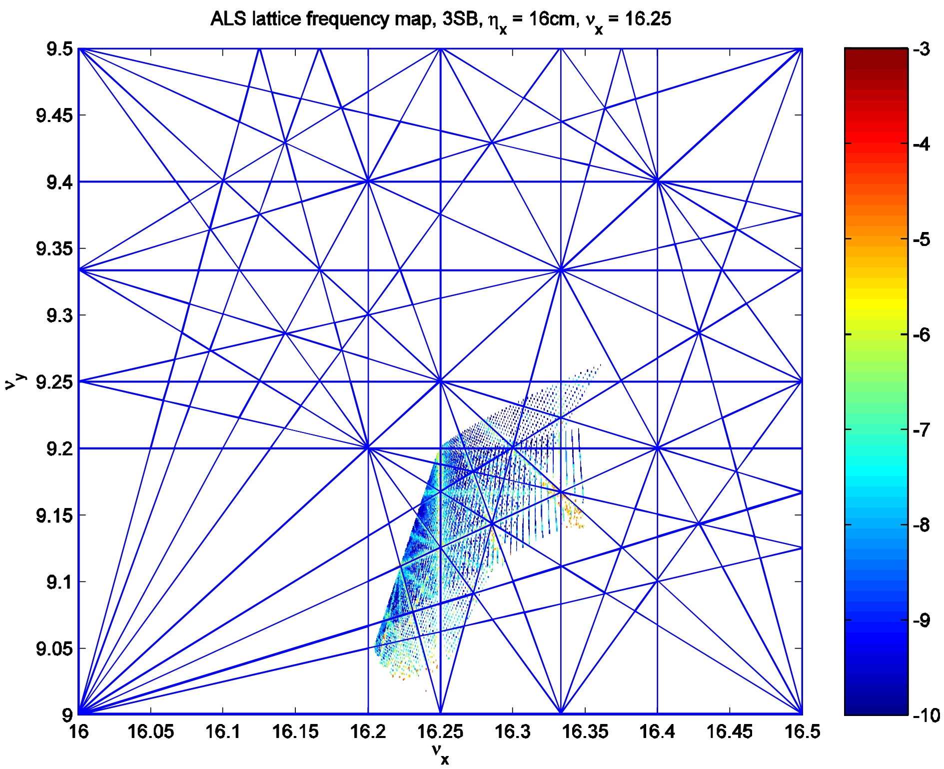
- Dynamic aperture is fairly large (larger than current lattice – however, beta function is larger)

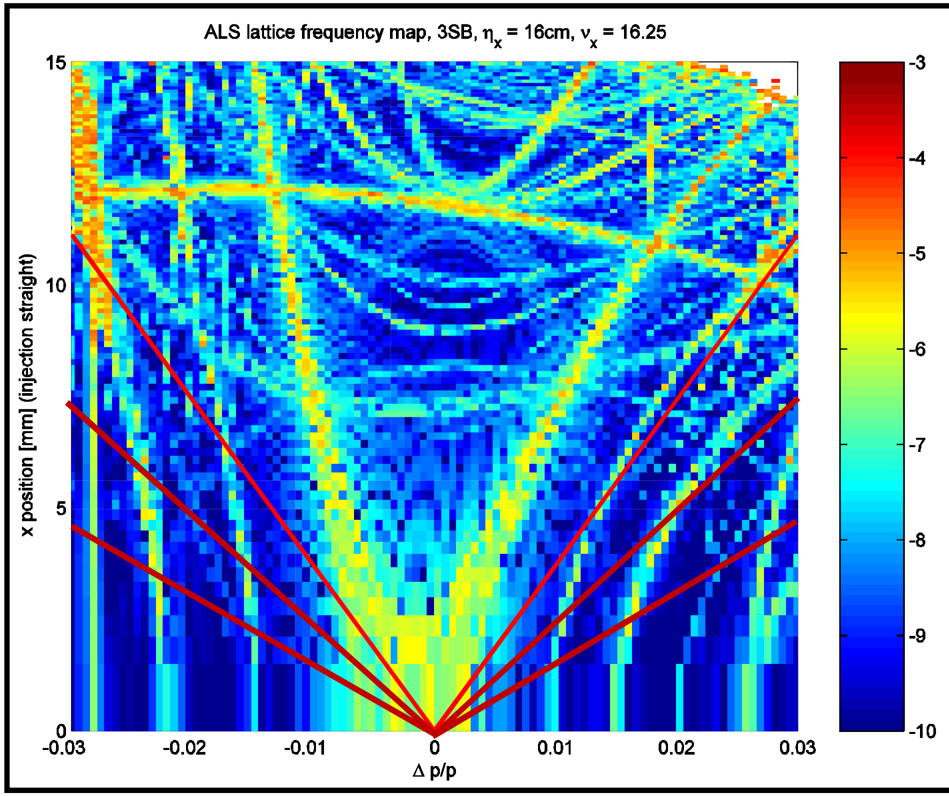




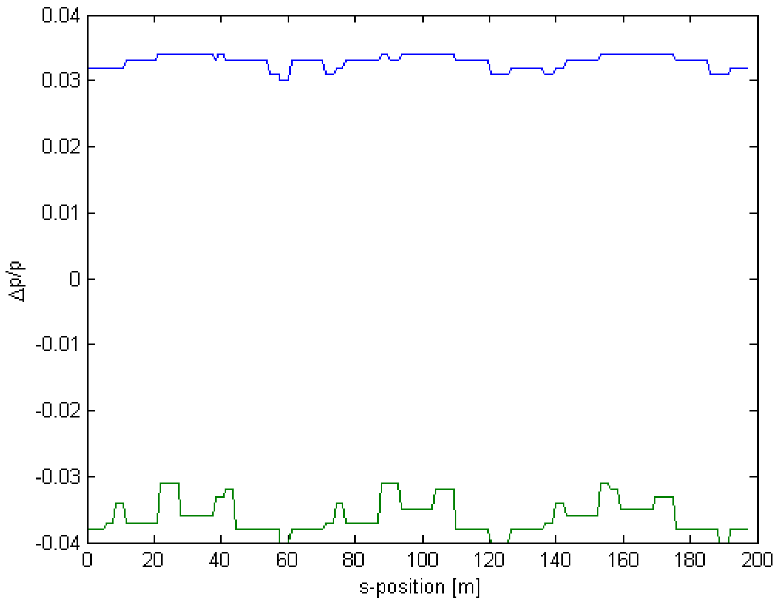
Baseline Lattice: Momentum Aperture

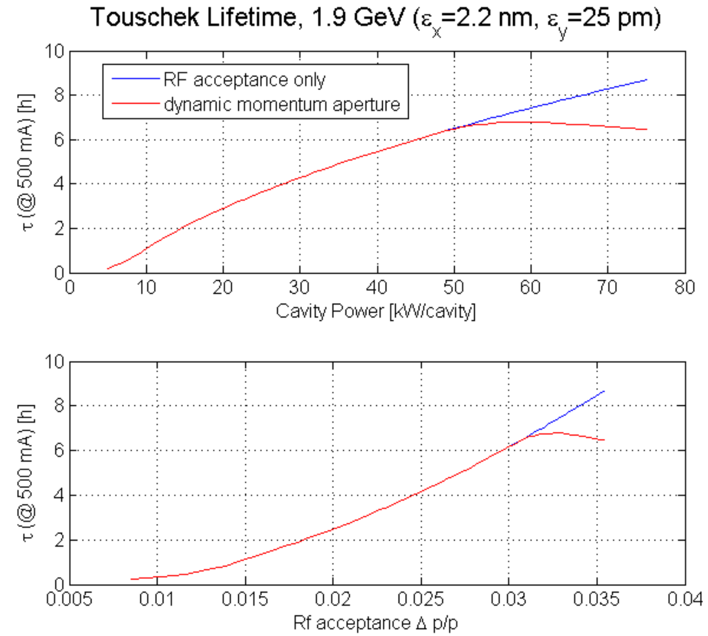
- Smaller H function in the arc results in larger momentum acceptance
- H function in the straight still smaller than in the arc: wiggler and other IDs reduce emittance further (or more importantly do not increase it)



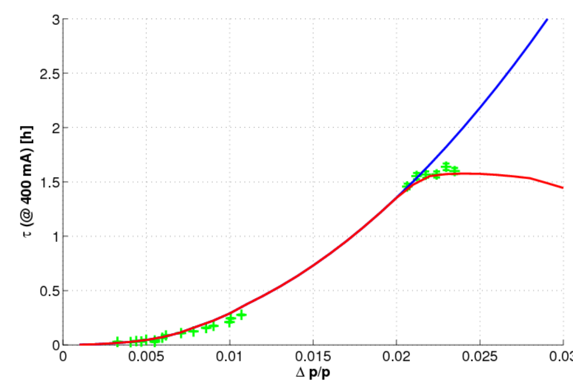


Touschek Lifetime of Upgrade

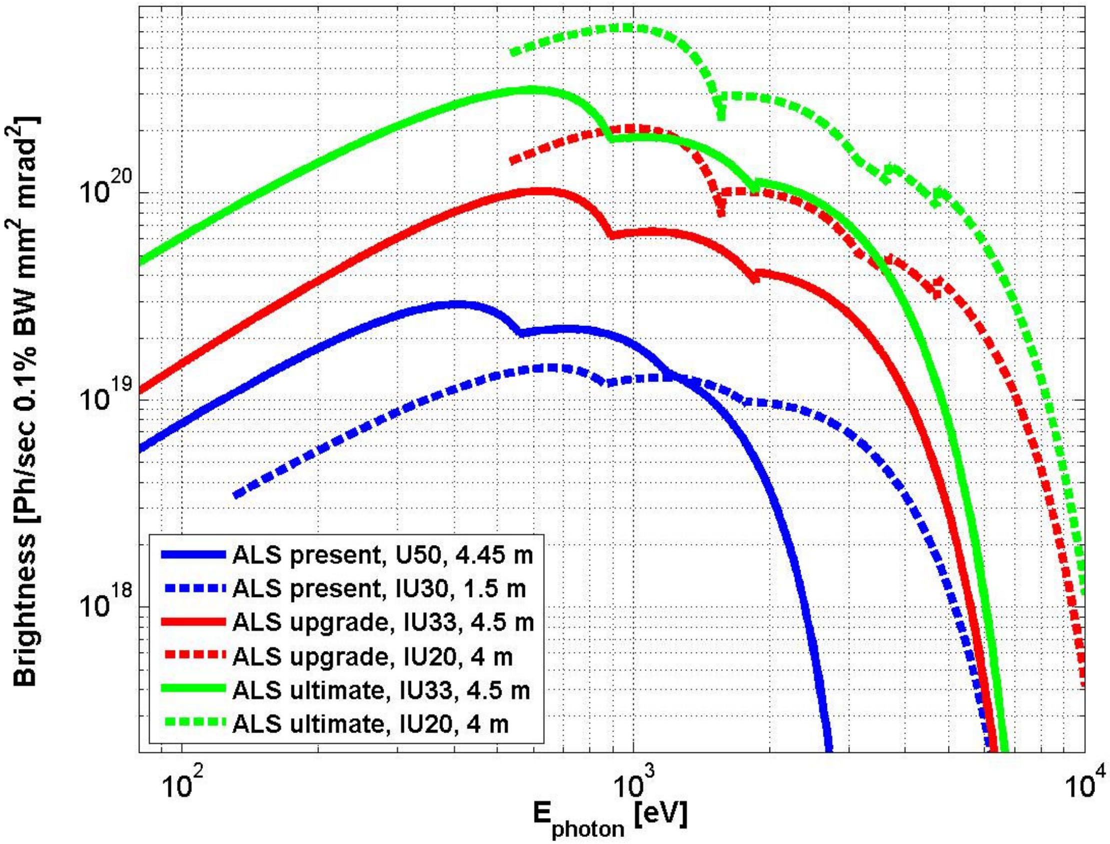




- Dynamic Momentum Aperture larger
- Touschek Lifetime longer than present lattice
  - Beyond minimum of Touschek function



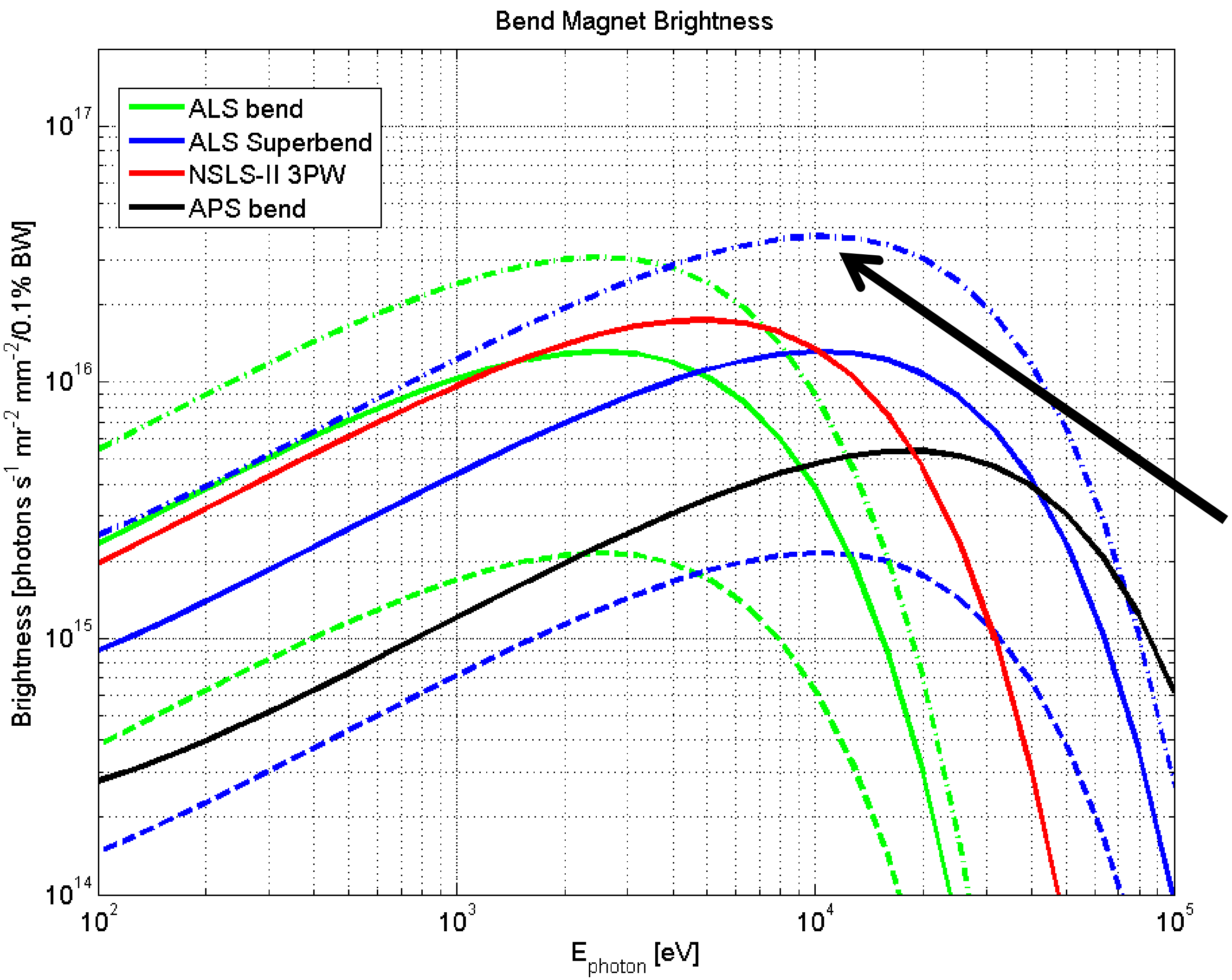
Comparison of insertion device brightness



ALS ultimate case requires further upgrades beyond the baseline of this project (injection system) and physics studies are incomplete – not sure, yet, whether fully feasible.

Existing lattice with existing insertion devices
Large β_x lattice with conventional long insertion devices
Small β_x lattice with conventional long insertion devices

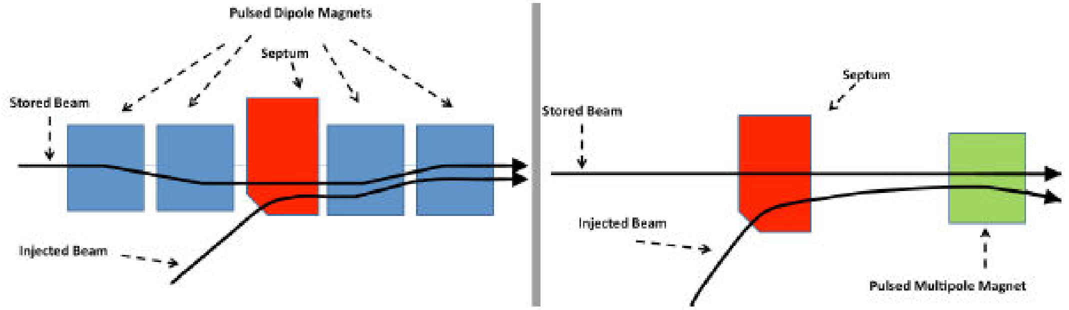
Bend Magnet Brightness



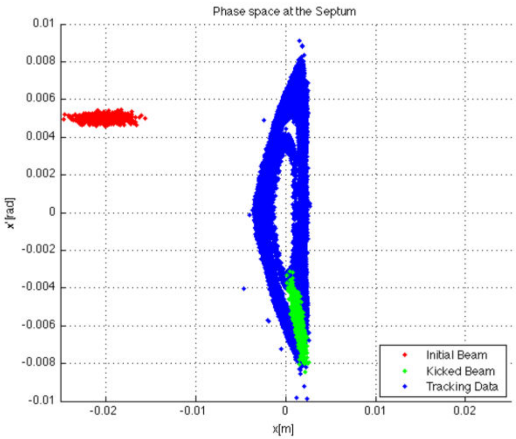
Because of simultaneously small beta function in both planes in center bend magnet (TBA), (super)bend source points will provide higher brightness than other sources – match to diffraction ellipse.

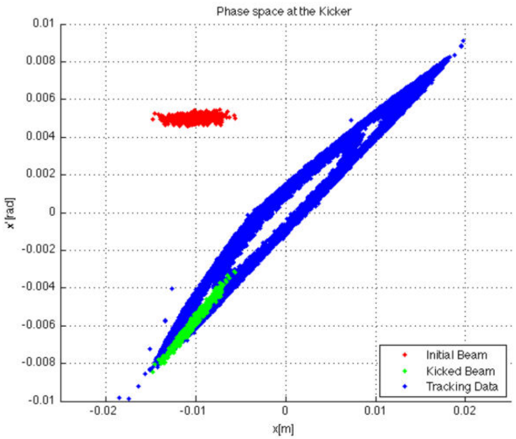
Low Beta Option – Initial Studies

- Injection using
  - 'Multipole' Injection Kicker
- Might allow injection despite very small dynamic aperture (very small beta function at septum)



To hopefully enable this further upgrade, many additional studies are necessary. Not sure whether fully feasible.





	Present (ALS Storage Ring)	Low-β Lattice (Simulation)
ν_x	14.241	21.675
ν_y	9.182	8.699
$\nu_{x'}$	0.5	0
$\nu_{y'}$	1.5	0
β_x^*	13.6 m	0.5 m
$\hat{\beta}_x$	18.1 m	36.0 m
QF	2.237 m^{-2}	3.205 m^{-2}
QD	-2.511 m^{-2}	-3.189 m^{-2}
QFA	2.954 m^{-2}	3.427 m^{-2}
QDA	-1.779 m^{-2}	N/A (no superbend)
SF·ℓ	15.235 m^{-2}	31.117 m^{-2}
SD·ℓ	-10.563 m^{-2}	-14.911 m^{-2}
HSF·ℓ	N/A	3.045 m^{-2}
HSD·ℓ	N/A	-2.436 m^{-2}

Summary

- ALS performance continues to evolve
- Presented three new lattice optimization techniques (which we pushed forward or collaborated on)
  - GLASS
  - MOGA
  - Frequency map diffusion rates
- Results were used to improve lattice upgrade
  - Will provide big brightness increases for users in cost effective way