Accelerator Physics Issues for the ALS with Superbends

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- Introduction
- Baseline Measurements
- Orbit Stability/Vibration
- Injection Efficiency/Lifetime
- Summary

Introduction

Smooth transition to Superbends ⇒ some guiding principles:

- Install all systems that can be installed ahead of the main Superbend shutdown early:
  - → Power supplies (QFA, QDA), Control system (Gradient, QFA, QDA)
  - → New (ID)BPMs, EEBI system, ...
- Precommission all new hardware with beam (and use it if possible to improve user operation):
  - → Last years startup, ...
- Evaluate and test accelerator physics issues before actual commissioning, in simulations and experiments (with ’simulated’ Superbends)
  - → Baseline measurements, ...
  - → Orbit stability/Vibration
  - → Nonlinear Dynamics (Injection efficiency/Lifetime)

Planned Work (as presented at last review)

- Extend beam based alignment further: QFA horizontal plane (C-shaped magnets; hysteresis; shunts) $\rightarrow$ hardware problem (not necessary for SB); QDAs (second sextupole family; superbends) $\rightarrow$ software tested, works
- Tune feed forward for insertion devices $\rightarrow$ done
- Studies of beam dynamics with broken symmetry (simulating effect of superbends) $\rightarrow$ done, expanded to off-energy!
- BPMs for errant photon beam interlock and orbit feedback $\rightarrow$ mostly done, tested with beam
- Vibration measurements $\rightarrow$ done
- Extend bend magnet integrated field measurements (hysteresis; SSRL + resonant depolarization) $\rightarrow$ done

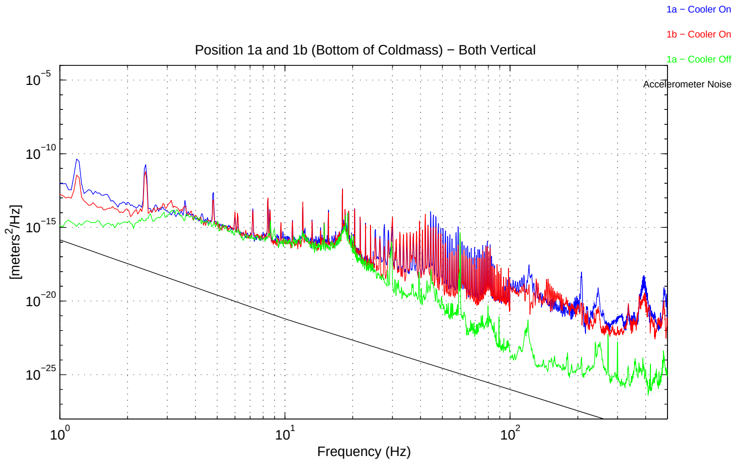
Baseline Measurements

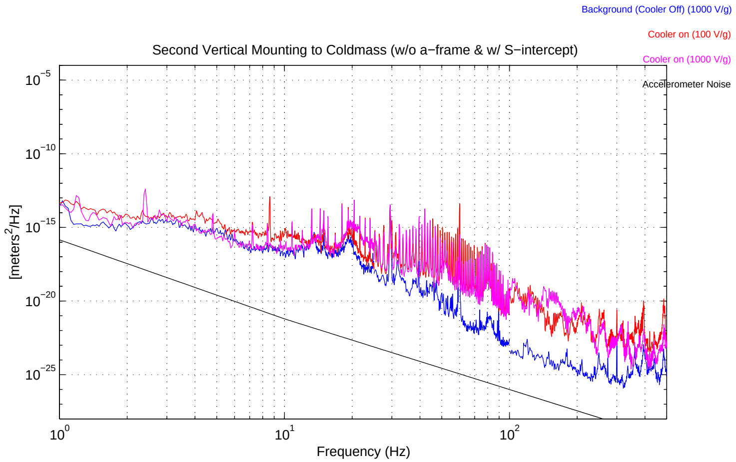
- Conducted complete set of baseline measurements before Superbend shutdown (for comparison during startup and commissioning)
  - → Hardware properties (e.g. power supply ripple, scaling factors, power supply transfer functions, ramp performance, gradient magnet transfer function)
  - → Beam properties (absolute orbit, injection trajectories, response matrices)
  - → Derived quantities (e.g. complete lattice model)
  - → Control system performance

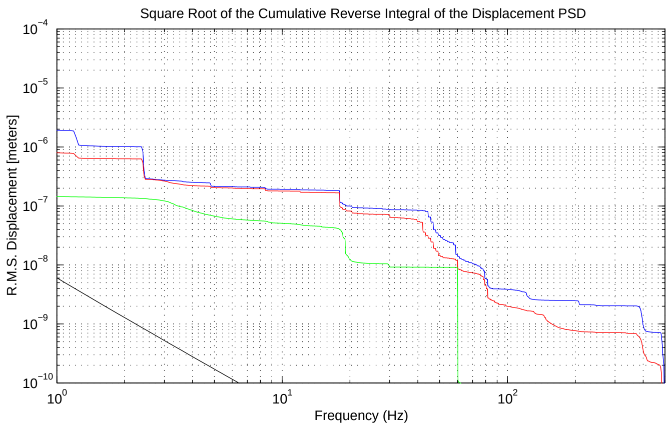
Vibration Studies

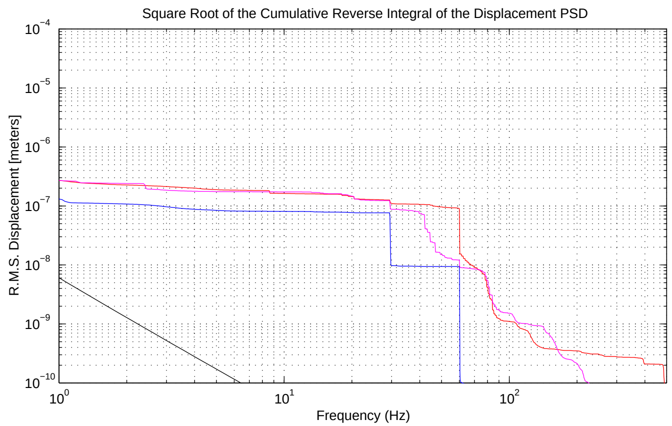
- Extensive study of vibrations induced by cryocooler.
- Measurements with accelerometers and with beam (mockup cryocooler installation on normal center bending magnet).
- Difficult experiments (environmental noise, accelerometers not well suited for delta pulse excitation, ...).
- Cold mass vibration was initially just above tolerance ($\leq$5 μm, $\leq$2 μrad) $\Rightarrow$ modified. S-link between cold head and magnet cold mass $\Rightarrow$ improvement by more than one order of magnitude.
- Studies with beam (IDBPMs) showed no effect due to vibration transmitted to other magnets; Infrared beamline saw no effect, either.

Vibration Studies (on Superbend yoke)

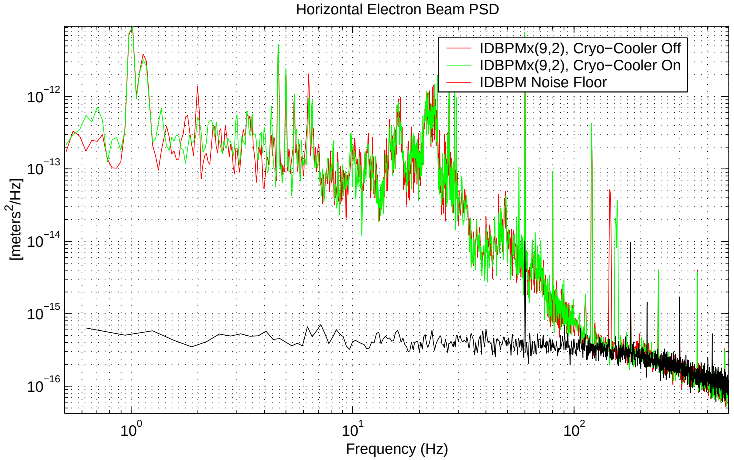


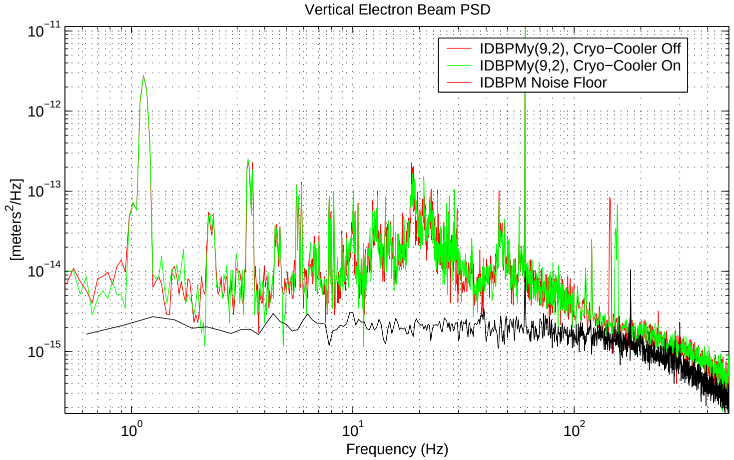


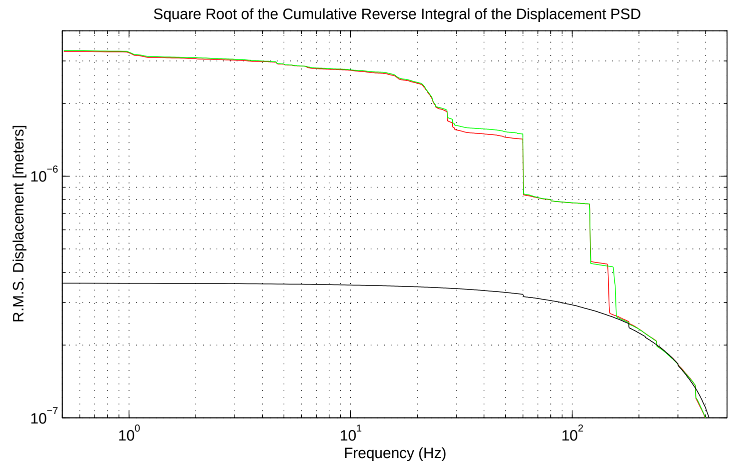


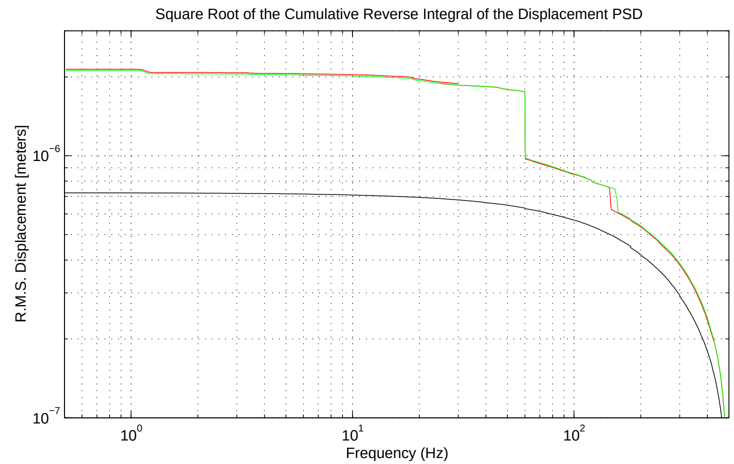


Vibration Studies (with beam)









Nonlinear Dynamics ⇒ Injection/Lifetime

Winfried Decking (DESY); Jacques Laskar, Laurent Nadolski (IMC-CNRS);
David Robin, Christoph Steier, Ying Wu (LBNL)

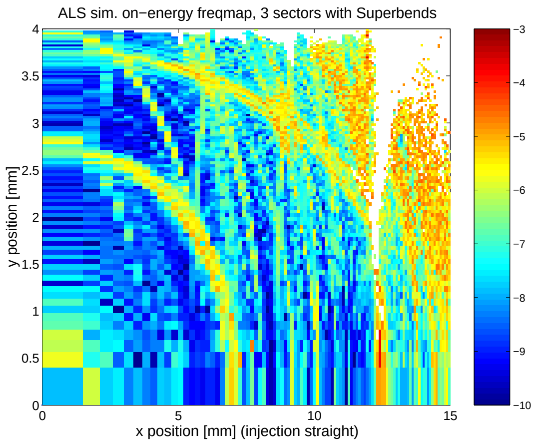
- Sufficient injection efficiency is necessary to operate any machine.
- Injection efficiency at ALS is dominated by on-energy dynamic aperture.
- Lifetime is a crucial performance parameter for all light sources ⇒ for 3rd generation light sources lifetime dominated by Touschek effect ⇒ Touschek lifetime strong function of momentum acceptance ε

$$\tau_{\rm tou} \propto E^3 \frac{V_{\rm bunch}\sigma'_x}{I_{\rm bunch}} \varepsilon^2 f\left(\varepsilon, \sigma'_x, E\right)$$

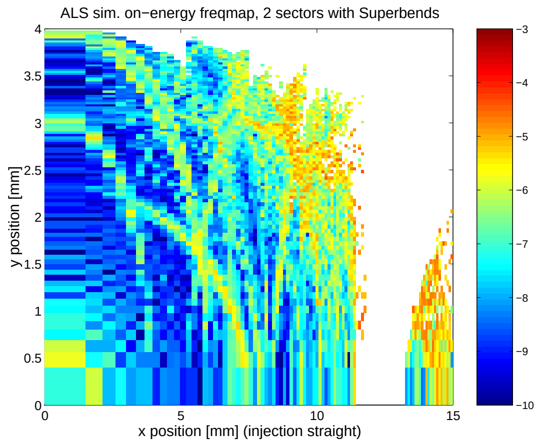
  ⇒ Momentum acceptance ε influenced/limited by single particle dynamics
- Design momentum acceptance for current light sources: $\geq$3%; achieved: about $\geq$2% ⇒ Need to understand current limitations

On-energy Frequency Map – Different Number of Superbends

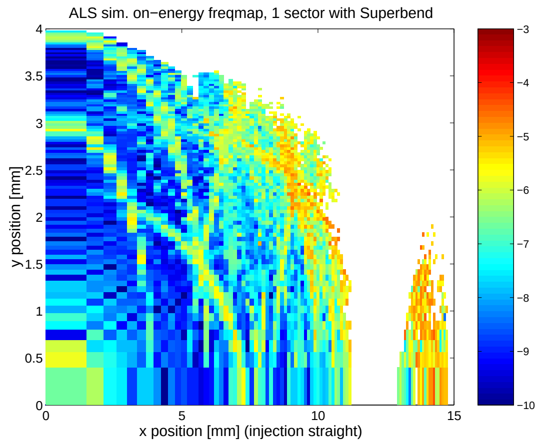
3 Superbends



2 Superbends



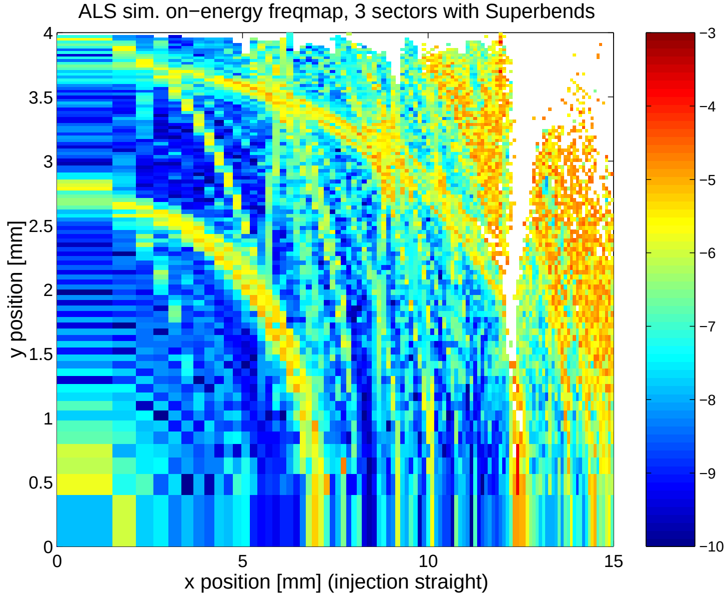
1 Superbend



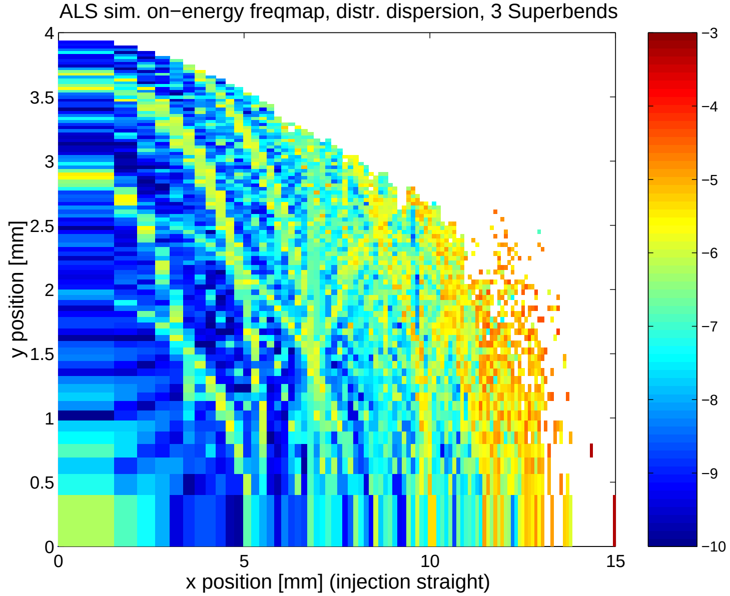
- With decreasing number of Superbends, chaotic regions in the diffusion map extend to lower amplitudes and stable areas shrink
- In all cases, the remaining stable area is large enough for injection (needed are about 8 mm).

On-energy Frequency Map – Different Dispersion

3 Superbends, no dispersion

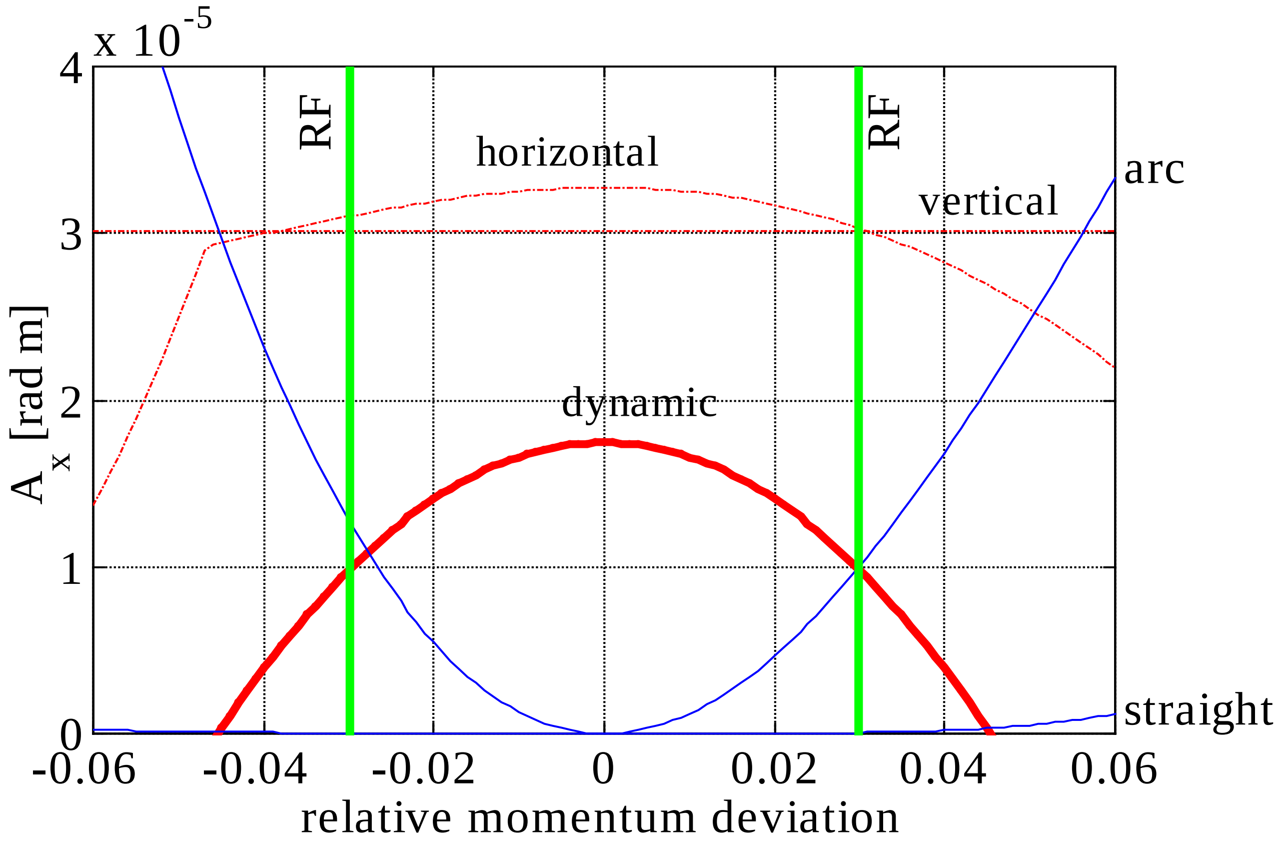


3 Superbends, distributed dispersion



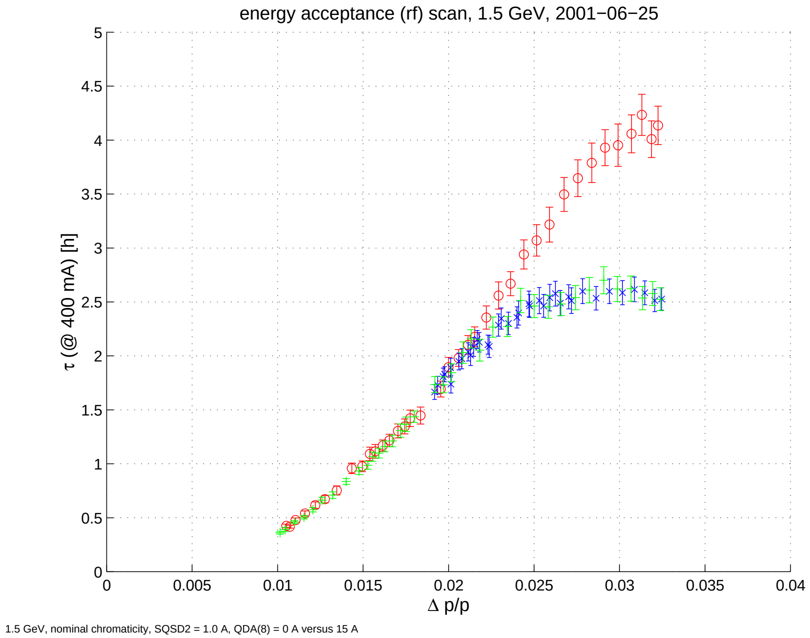
- Introducing distributed dispersion to lower the natural emittance down to about 7 nm reduces stable areas significantly (stronger sextupoles)
- The remaining stable area with 3 Superbends is large enough for injection (needed are about 8 mm).

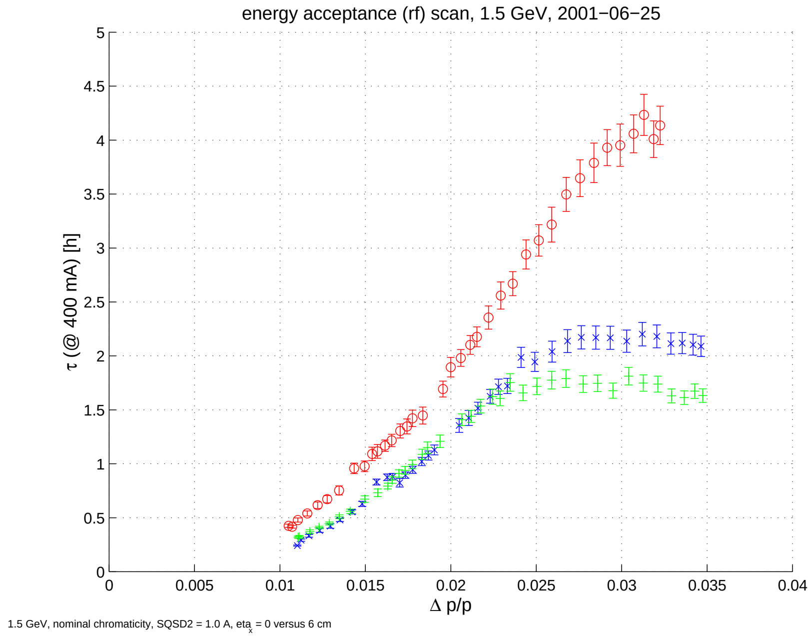
What Determines Momentum Acceptance ?



⇒ Possibility to study momentum acceptance by scanning rf-voltage

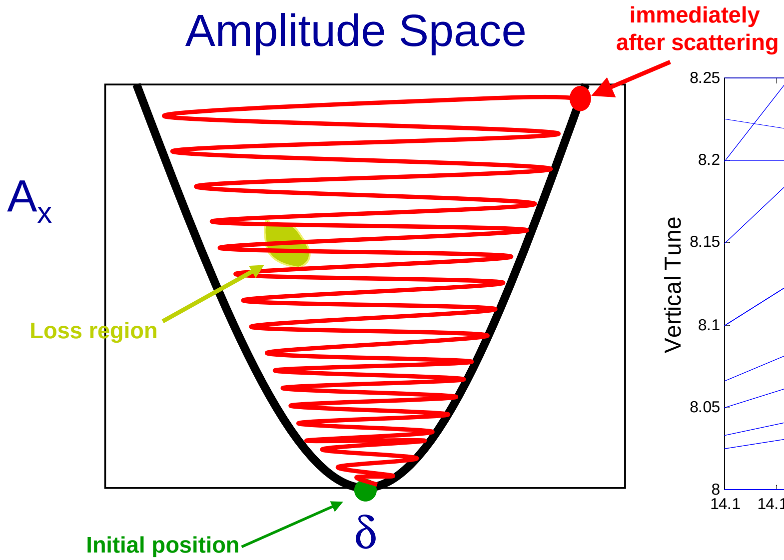
ALS: RF-amplitude scan

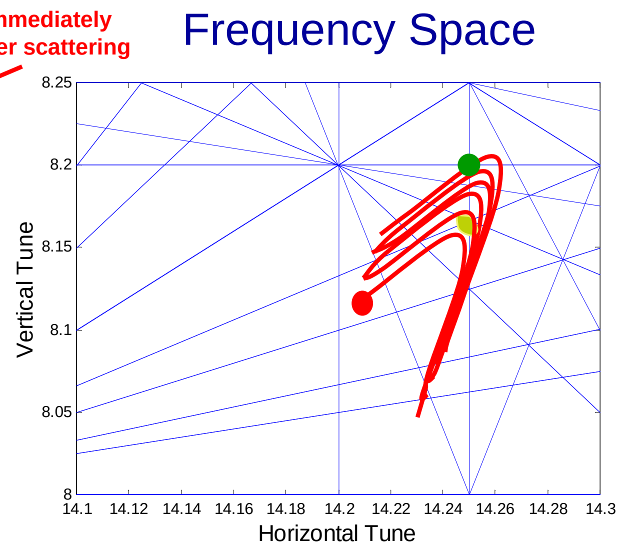




- Momentum acceptance in ALS is clearly impacted by dynamics
- Reduction with three Superbends and distributed dispersion small, with 1 Superbend below 50% and probably around 10–20% (1.9 GeV).

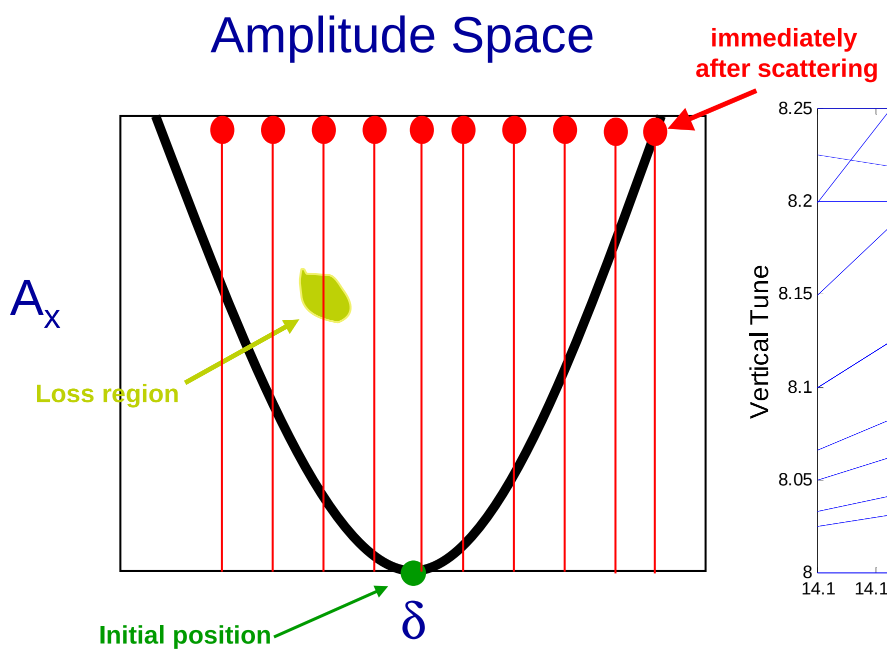
Touschek Scattering → Tuneshift → Particle Loss

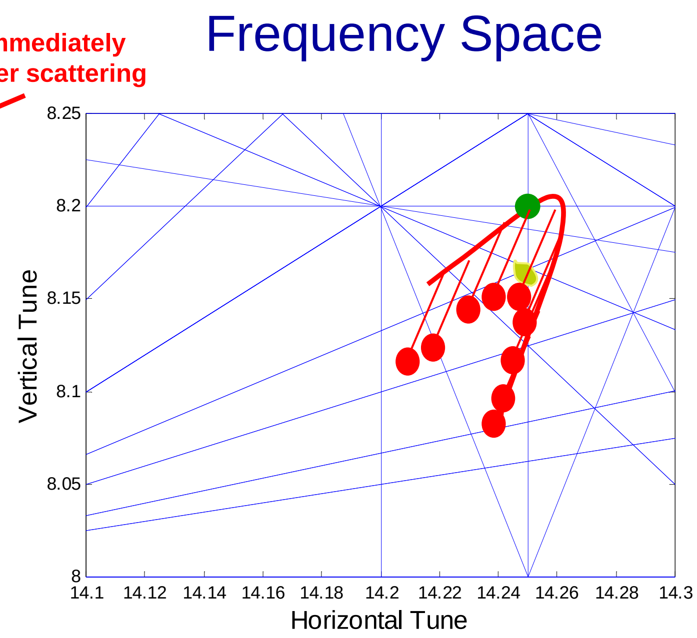




- Particle loosing/gaining energy → hor. (dispersion/H-function) + long. oscillation
- Change in particle's betatron tune due to
  - Synchrotron oscillation (change in Δp, chromaticity)
  - Radiation damping ($\Delta p/p$ and A_x, chromaticity, detuning with amplitude)
  - Particle can get into regions of tune space where the motion gets chaotic or resonantly excited

Measurement Principle

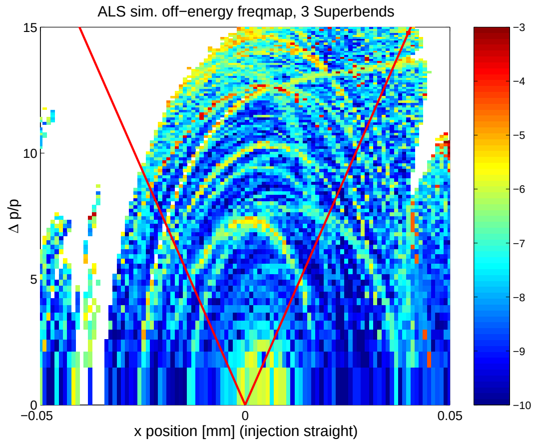




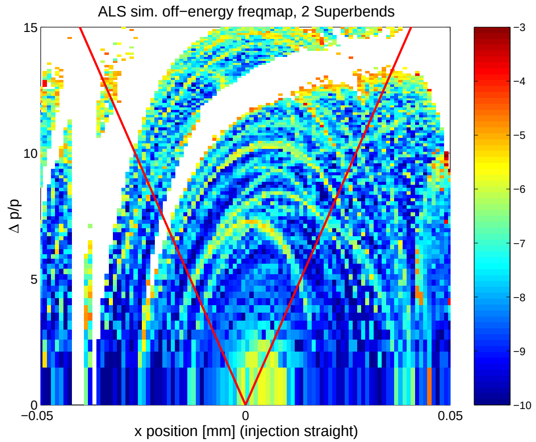
- Experimentally very difficult to apply simultaneous transverse and longitudinal kick
- Still possible to locate loss regions when scanning only transverse amplitude while keeping energy offset constant

Off-energy Acceptance – Different Number of Superbends

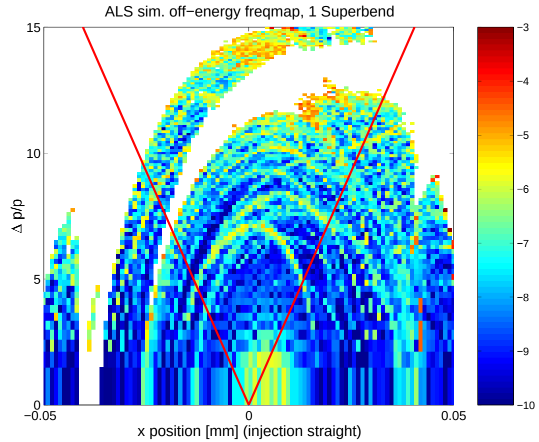
3 Superbends



2 Superbends



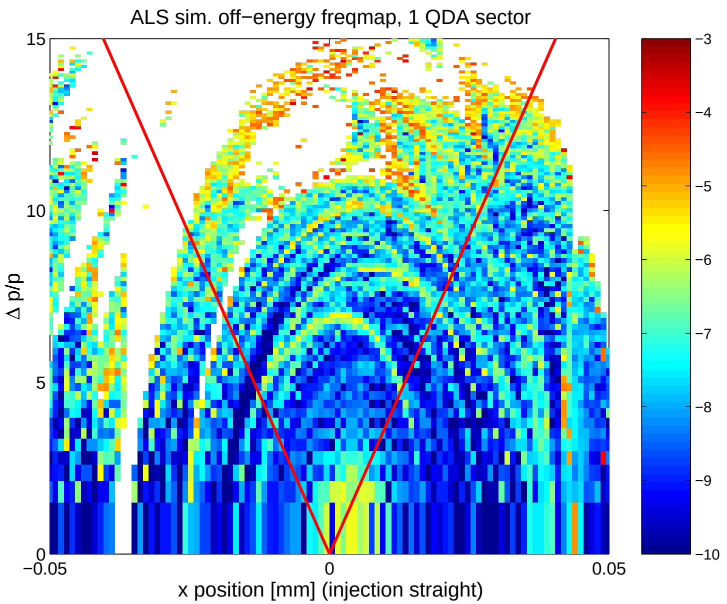
1 Superbend



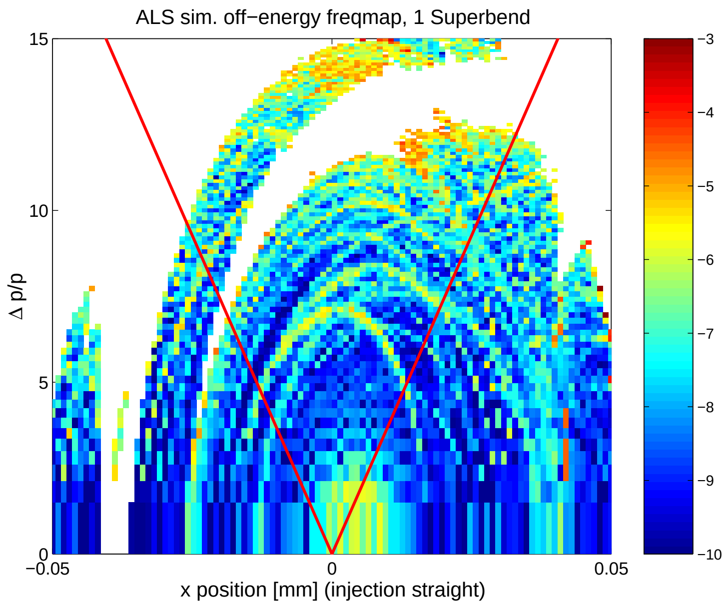
- Lower symmetry clearly excites additional resonances, leading to smaller stable areas (smaller dynamic momentum acceptance)
- However, the impact on the lifetime at 1.9 GeV is predicted to be small, because the rf-acceptance is only about 2.5%, anyhow.

Comparison QDA - Superbend

1 sector with QDA magnets



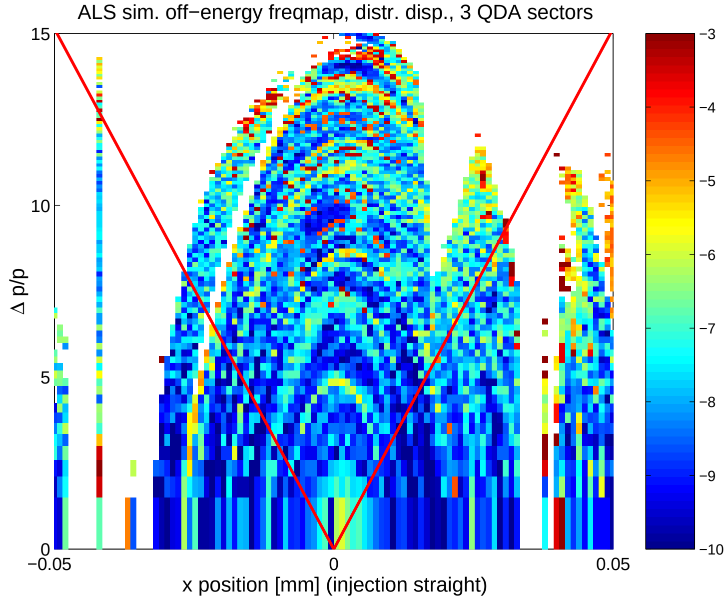
1 Superbend sector



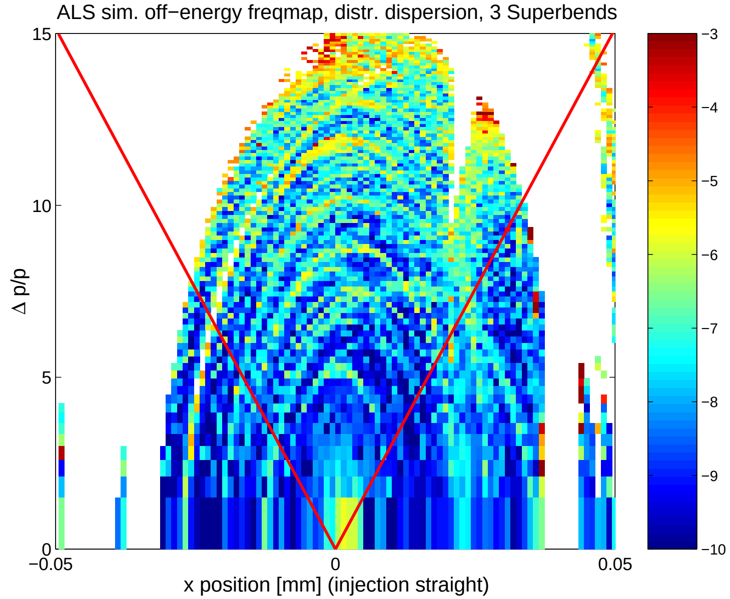
- Simulate symmetry breaking using QDA magnets next to location of Superbends. Does not simulate sextupole component of Superbend field.
- Simulated off-energy diffusion maps look very similar for case of one Superbend sector or one QDA sector.

Comparison QDA - Superbend

3 QDA sectors, distibuted dispersion



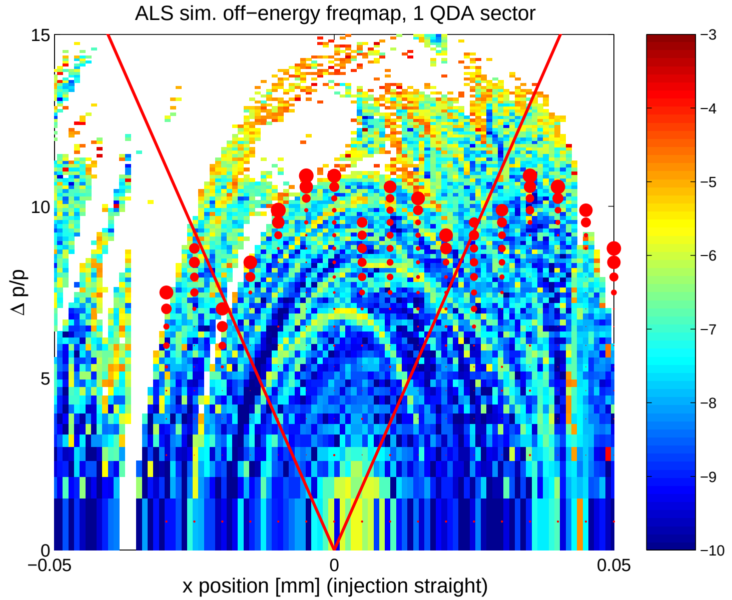
3 Superbends, distributed dispersion



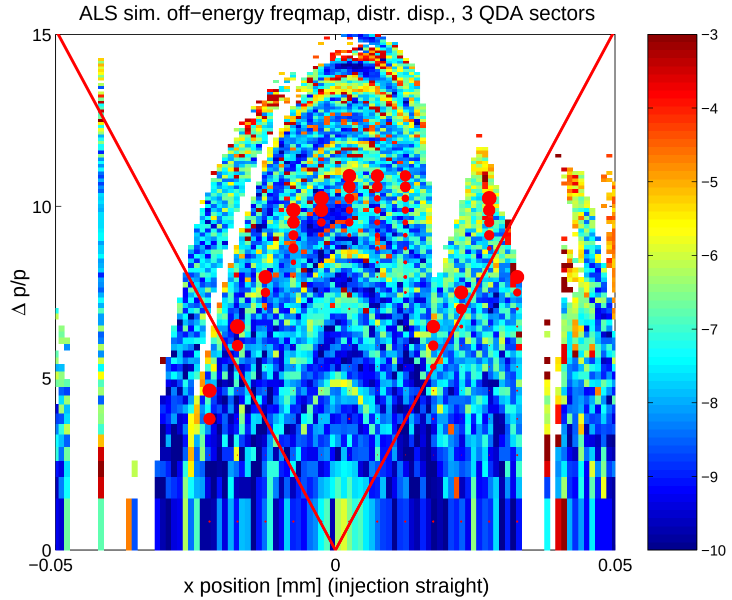
- Simulated off-energy diffusion maps look very similar as well for case of distributed dispersion and either 3 Superbend sectors or 3 QDA sectors.

Comparison Simulation - Experiment

1 QDA sector, no dispersion



3 QDA sectors, distributed dispersion



- Agreement with simulations is very good $\Rightarrow$ great confidence in predictions of impact of Superbends

Summary

- Baseline measurements were taken, tools for commissiong of Superbends are tested.
- Vibration measurements ⇒ improved design of S-link
- Studied on-energy and off-energy nonlinear dynamics with Superbends, both in simulations and experiments.
- On-energy dynamics present no problem (good injection efficiency).
- Off-energy dynamics will be impacted, depending on lattice and number of Superbends.
- For rf-acceptance of 2.5% (like at the moment at 1.9 GeV), impact of 3 Superbends will be small (even with distributed dispersion). Lifetime reduction with 1 (or 2) Superbend(s) is probably around 10-20% and certainly below 50%.