Optical Stochastic Cooling Proof of Principle Experiment

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for the OSC@Bates Collaboration

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OSC@Bates Collaboration

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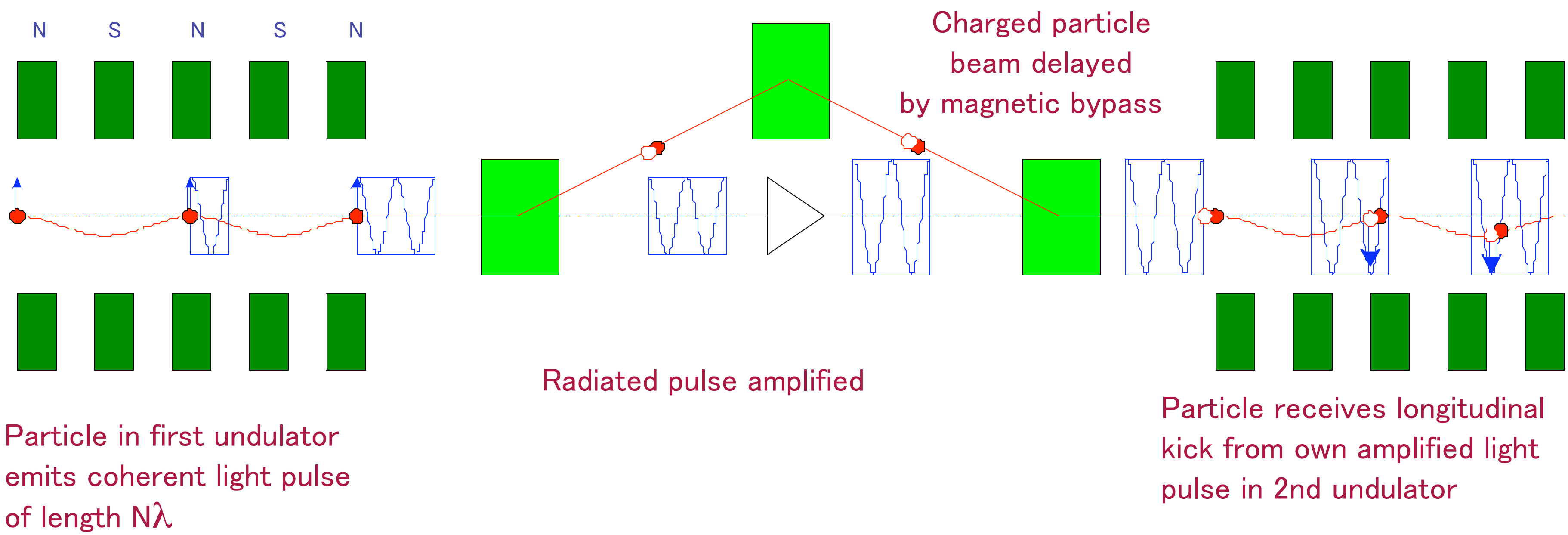
Motivation

- Beam cooling essential for maximizing luminosity in colliders
  - Raise peak luminosity by lowering σ^*
  - Integrated luminosity by damping emittance growth
- Need to cool beams of high energy and high brightness
- Stochastic cooling
  - Cooling of antiprotons, ions
  - Cooling time limited by bandwidth of feed-forward system
  - Seek to divide bunches into smaller samples more readily cooled
- Optical stochastic cooling
  - Feed-forward system based on optical photons
  - Large increase in bandwidth ($>10^4$) should yield corresponding decrease in cooling time
  - Promising for high energy hadrons, ions, muons

Transit Time OSC

M. Zolotorev & A. Zholents, Phys. Rev. E 50, 3087 (1994)

- Analogous to stochastic cooling with undulators as pick-up and kicker
- Works to lower momentum spread, transverse cooling through dispersion



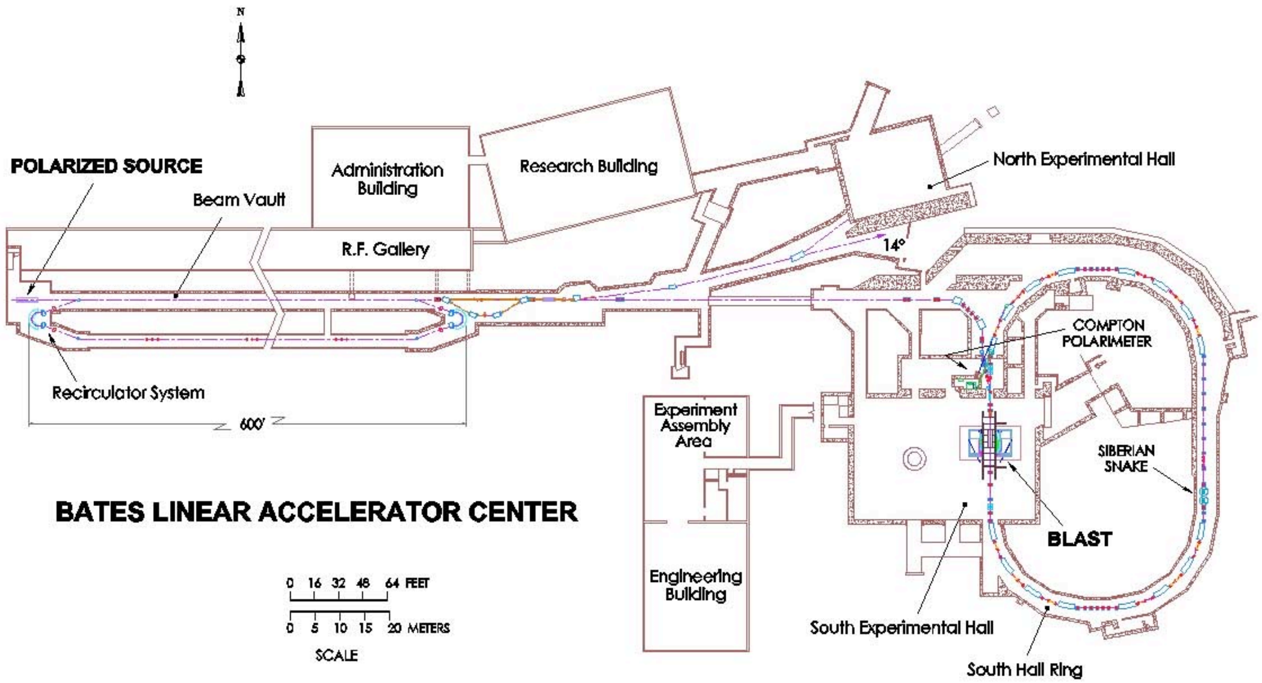
- Momentum kick based on phase shift due to transit time difference
- Bypass optics for central orbit to sit on zero crossing of field in U2

OSC Demo With Electrons

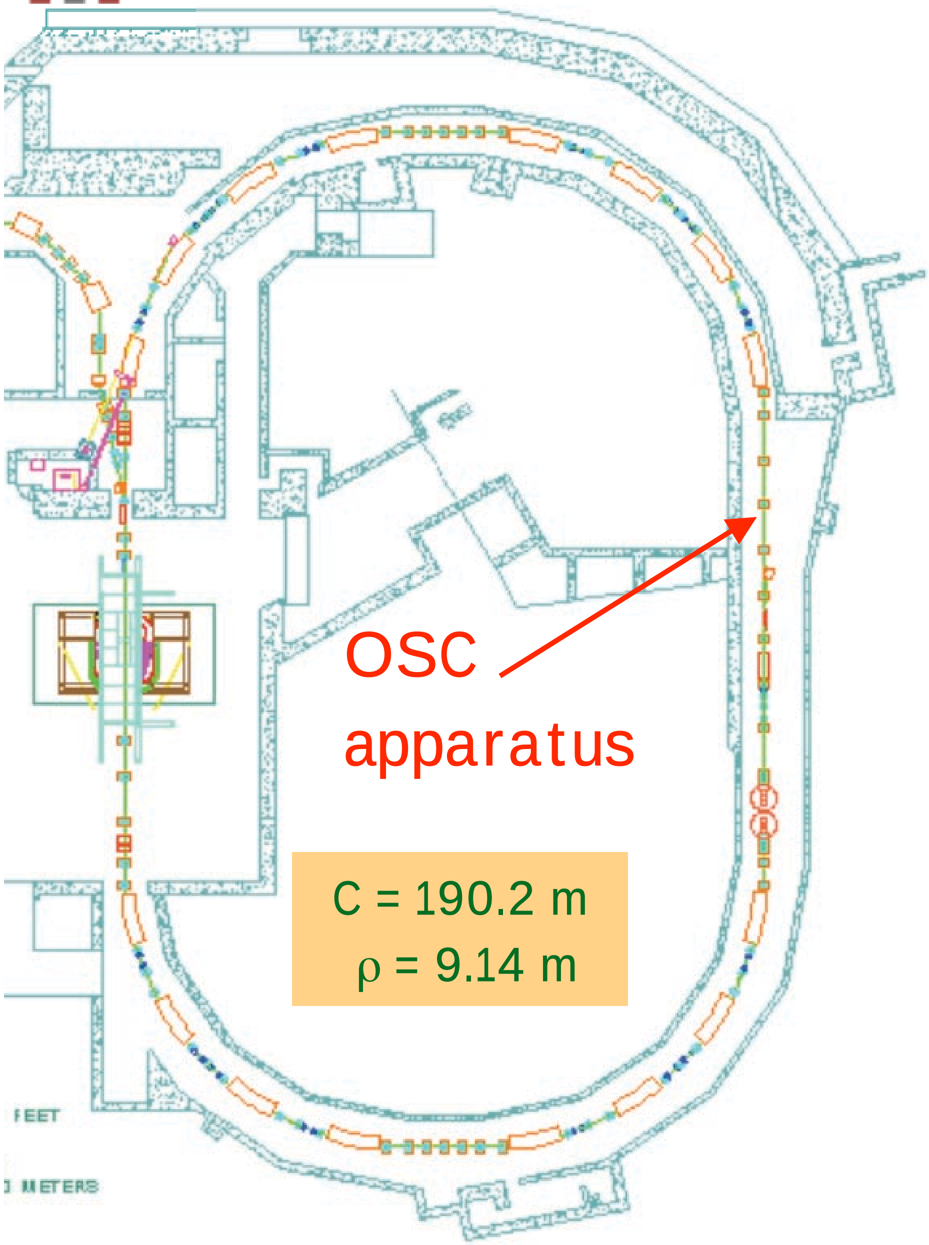
- OSC considered for p, ions at several facilities, still unproven
  - Counteracts heating due to IBS, beam-beam (cooling of tails)
  - OSC rates, luminosity gain strongly depend on achievable parameters
- Technical requirements for cooling of heavy particles are severe ($$$)
  - Optics of particles in bypass controlled to fraction of λ
  - Very strong wiggler fields
  - Amplifier saturates far below optimal gain
  - Diagnostics predictive of OSC required (cooling time of order hours)
- Demonstration of OSC with e^- would point way to cooling at very high E, N
  - OSC of electrons much faster (~1 sec)
  - Modest technical requirements (wiggler, amplifier, chicane)
  - Develop techniques to achieve OSC, study physics for scaling to high E, N
  - Proposed at several facilities but not carried out

MIT-Bates Accelerator Complex

- MIT-Bates accelerator ideally suited for dedicated OSC study
  - Accelerate electrons with versatile bunch structure with S-band Linac
  - Beam injected into South Hall Ring for long-lived storage
- Status
  - Operated as DOE nuclear physics user facility through 2005
  - Transition completed to MIT-owned facility with accelerator intact
  - Viability of complete accelerator verified (OSC beam study, April 2007)



MIT-Bates South Hall Ring



- Distinguish OSC from damping due to synchrotron radiation
  - Low energy electrons
  - Large dipole bend radius
  - Established stored beam at 325 MeV during 2007 run
- South Hall Ring geometry
  - 2 Long straight sections
  - OSC in east straight
  - Access area in northern arc
- Goal: 1st OSC demonstration
  - Design tolerances consistent with existing technology
  - Existing diagnostics, RF system accommodate OSC experiment

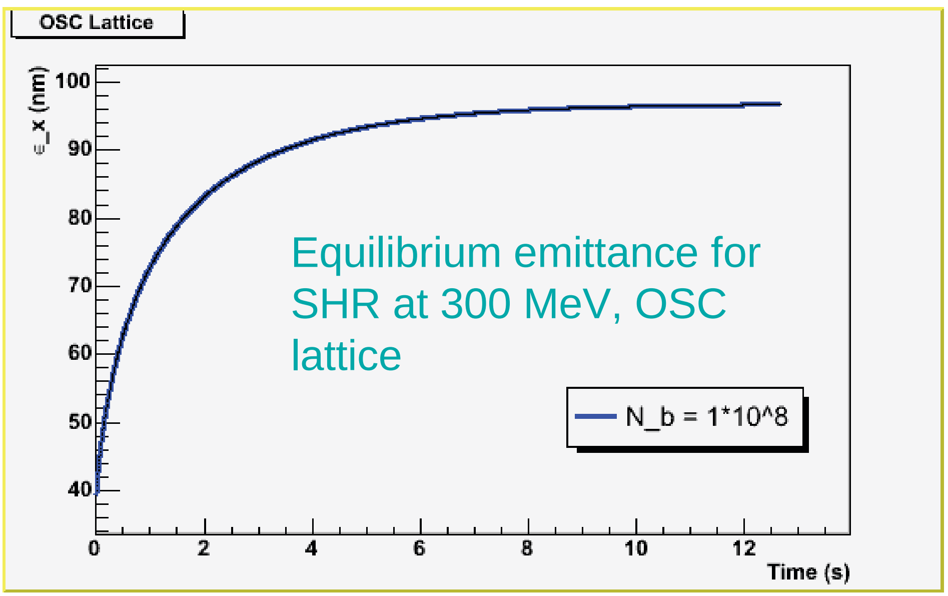
OSC Beam Parameters

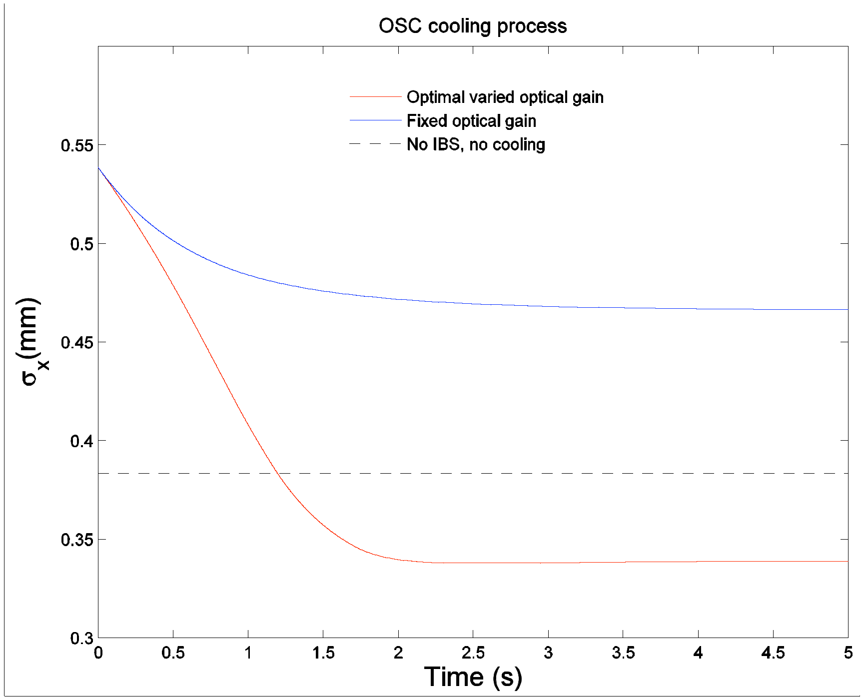
Parameter	Symbol	Design Value
Beam Energy	E	300 MeV
SR transverse damping time (sec.)	τ_x	4.83 s
Particles/bunch	N_b	$1.0 * 10^8$
SHR bunch frequency	f_b	18.9 MHz
SHR average current	I	0.3 mA
SHR horizontal emittance	ε_x	98π nm rad
SHR relative momentum spread	σ_p	$1.67 * 10^{-4}$

- Choose lowest viable energy for OSC demonstration experiment
- OSC Lattice with large emittance for enhanced cooling
  - Modeling of IBS and Touschek lifetime (F. Wang, FRPM088)
  - Produces high dispersion (η =6 m) in straight for transverse OSC
- f_b to match amplifier rate (mode-locked photoinjector laser sets timing)

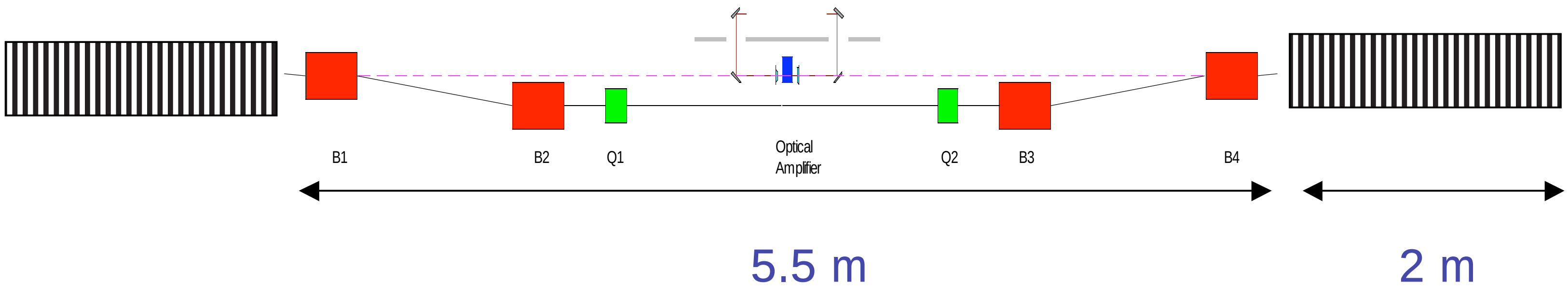
Experiment Approach

- Allow beam to reach equilibrium condition after injection
  - Equilibrium when IBS growth rate matches synchrotron damping
  - Other effects at lower level (residual gas, quantum excitation)
- Optically cool beam from its initial equilibrium
  - Expect strong OSC effects on transverse beam size
  - Study as function of bunch intensity, amplifier parameters





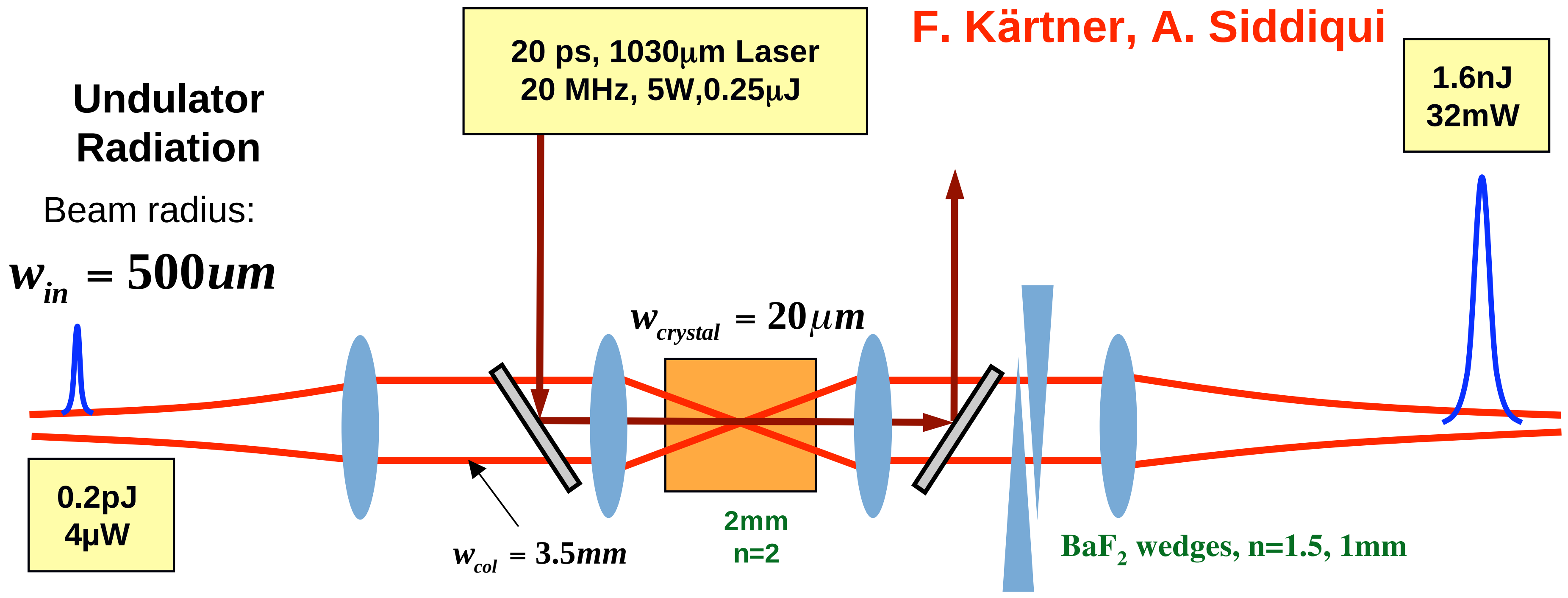
OSC Apparatus Overview



Compact apparatus readily integrated into SHR East Straight

- Broadband optical parametric amplifier (PPLN) in low conversion limit
  - Large dispersion-free amplification with great signal to noise
  - Very short medium required, total delay ~20 ps
- Allows small angle (65 mrad) OSC bypass with 6 mm path length change
  - Fixed optics with achievable magnet tolerances
  - Minimize additional synchrotron radiation and changes to SHR RF
- 2 planar undulators tuned to amp wavelength (2 μm), bandwidth (~10%)

Undulator Radiation



- Amplifier, optics internal to SHR vacuum system, remotely actuated
- Pump laser sets gain, optimize as beam cools
- Fine phase control allows interferometry in U2 for achieving OSC
    - Synchronize amplified radiation and e^- beam at U2 to fraction of λ
    - Best at low gain, explore use in feedback as A2 >> A1

OSC Chicane

- Chicane optics control path length difference between electrons and light
  - Straightforward linear optics for small symmetric chicane
  - COSY simulation shows small effects from nonlinear terms

	X mm	x' mrad	y mm	y' mrad	l mm	$\Delta p/p$ %
X	1.02632	6.07987	0.00000	0.00000	0.00000	-0.02580
x'	0.00877	1.02632	0.00000	0.00000	0.00000	-0.00860
Y	0.00000	0.00000	0.84246	5.72468	0.00000	0.00000
y'	0.00000	0.00000	-0.05070	0.84246	0.00000	0.00000
l	**0.00086**	**0.00258**	0.00000	0.00000	1.00000	**-0.01200**
$\Delta p/p$	0.00000	0.00000	0.00000	0.00000	0.00000	1.00000

- Absolute tolerances for achieving OSC modest with small chicane
- Stability requirements, variation for central orbit length ≤ 0.1 μm (20° phase)
  - Current stability for power supplies {10^{-5}}
  - Position stability of devices {50 μm}

Summary

- Optical Stochastic Cooling is a technique with a large role to play in rapid of cooling beams with high energy and high brightness
  - Significant cost and time savings in designing OSC into machine
  - Initial demonstration of OSC with low energy electrons is essential to probe the physics and address key technical questions
  - Rated "Compelling" by RHIC Accelerator Physics Review Panel (2007)
- Realization plan for OSC demonstration with electrons over 3 years
  - Complete beam studies for OSC Lattice
  - Install and commission OSC chicane, wigglers
  - Integration of amplifier into SHR
- Experimental program to study OSC of damped electron beam
  - Measure OSC as function of bunch intensity, lattice parameters
  - Investigate diagnostics for OSC achievement and optimization
  - Many extensions (energy, tunable chicane) possible
- Experiment is ready to proceed, awaiting full funding