First Experimental Demonstration of Optical Stochastic Cooling with the MIT-Bates South Hall Ring

W. Barletta, P. Demos, K. Dow, J. Hays-Wehle, E. Ihloff,
J. Kelsey, B. McAllister, R. Milner, R. Redwine (P.I.), S. Steadman,
C. Tschalär, E. Tsentalovich, and F. Wang,
Bates R&E/Accelerator Center and
Laboratory for Nuclear Science, MIT
F. Kärtner, J. Moses, and A. Siddiqui
Research Laboratory of Electronics, MIT
M. Babzien, M. Bai, M. Blaskiewicz, M. Brennan, W. Fischer,
V. Litvinenko, T. Roser and V. Yakimenko
Brookhaven National Laboratory
S.Y. Lee
Indiana University Cyclotron Facility
W. Wan, A. Zholents and M. Zolotorev
Lawrence Berkeley National Laboratory

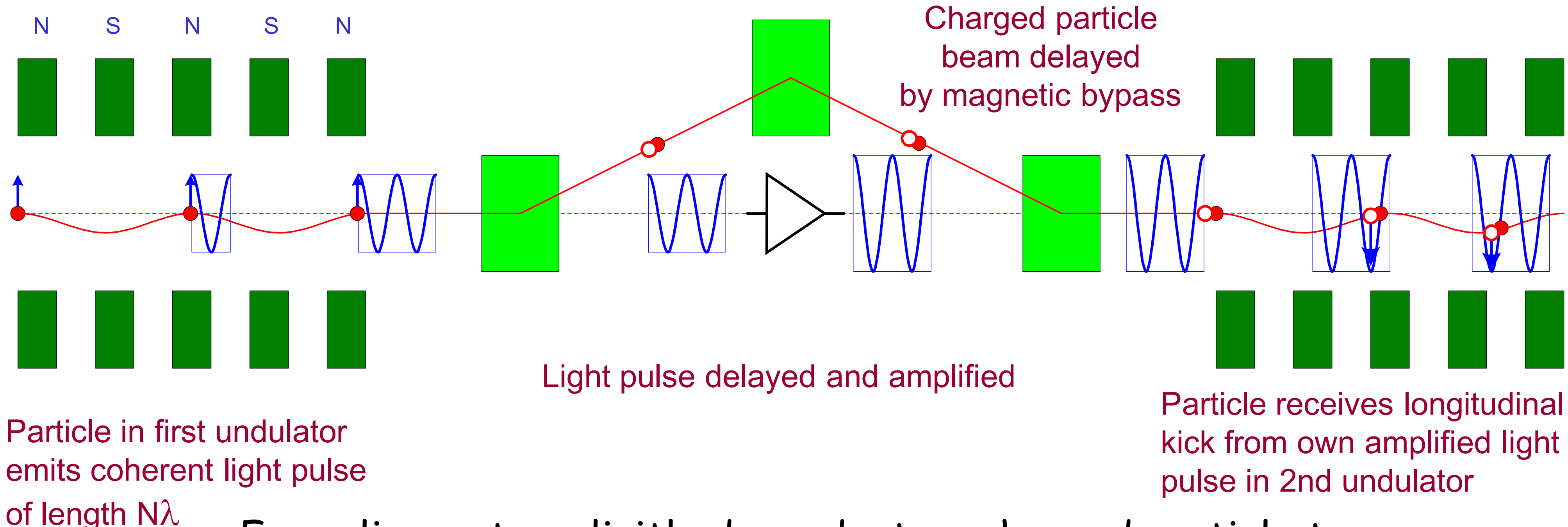
Reference: M.S. Zolotorev and A.A. Zholents, Phys. Rev. E 50, 3087 (1994)

Why Optical Stochastic Cooling?

- Beam cooling essential for maximizing luminosity in modern colliders
- Existing techniques diminish in effectiveness for beams at high energy and high brightness
- Optical stochastic cooling holds promise for this regime
- Relevant to RHIC, EIC/eRHIC, LHC, muon collider etc.
- Potential application to high brightness beams
- Involves delicate manipulation of beams with light
- Bates experiment seeks to demonstrate this new technique for the first time

Introduction to OSC

- Transit-time method of optical stochastic cooling:
  - Reduce momentum spread; transverse cooling through dispersion
- Analogous to stochastic cooling using undulator radiation
- Increase of system bandwidth by 4 orders of magnitude compared with microwave stochastic cooling reduces cooling time



Formalism not explicitly dependent on charged particle type

OSC in RHIC/eRHIC

- **Estimates of OSC made for RHIC** {M. Babzien *et al*, Phys Rev STAB 7, 012801 (2004)}
  - Increased beam lifetime and time-averaged luminosity for p and Au ions by counteracting the beam spreading from IBS and beam-beam interactions
  - Reduces tails and detector background
  - IP10 could accommodate OSC apparatus
  - Preliminary estimates indicate that a factor of 2 increase in proton-proton collision luminosity seems possible, but this estimate depends strongly on achievable experimental parameters.
  - 16 W of amplifier power assumed

- ***OSC for eRHIC***
  - In linac-ring eRHIC design, it is strongly advantageous to cool the proton beam for increased luminosity.
  - With laser development, amplifier powers of ~ 1000 W may be realizable.
  - Strong motivation for OSC demonstration experiment.

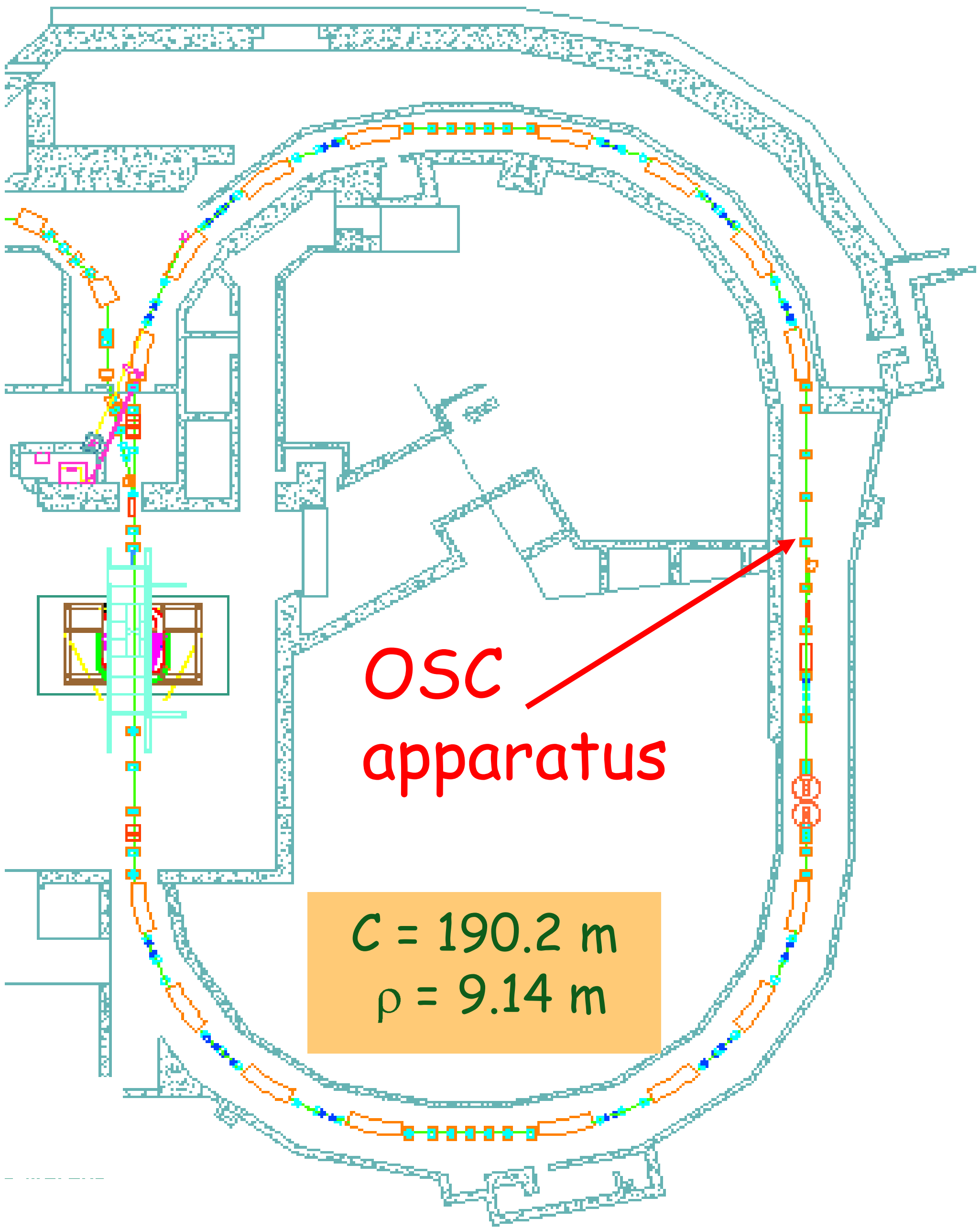
OSC Demonstration with Electrons

- OSC never demonstrated in practice

- Technical requirements for cooling of heavy particles are very severe
  - Bypass optics must be synchronized with amplified light within 1 μm (fraction of λ)
  - Very strong wiggler fields needed for bending heavy particles (~10 T peak)
  - Amplifier output saturates far below optimal gain
  - Diagnostics capable of detecting OSC required (cooling time ~ hours)

- Demonstration of OSC with electrons can point way to cooling beams at very high energy and high bunch population
  - OSC of electrons much faster (seconds) than for hadron beams (hours)
  - Modest technical requirements (wiggler, amplifier, bypass chicane)
  - Develop techniques and diagnostics needed to achieve OSC in practice
  - Evaluate prospects for OSC in high-energy, high-brightness regimes

MIT-Bates South Hall Ring

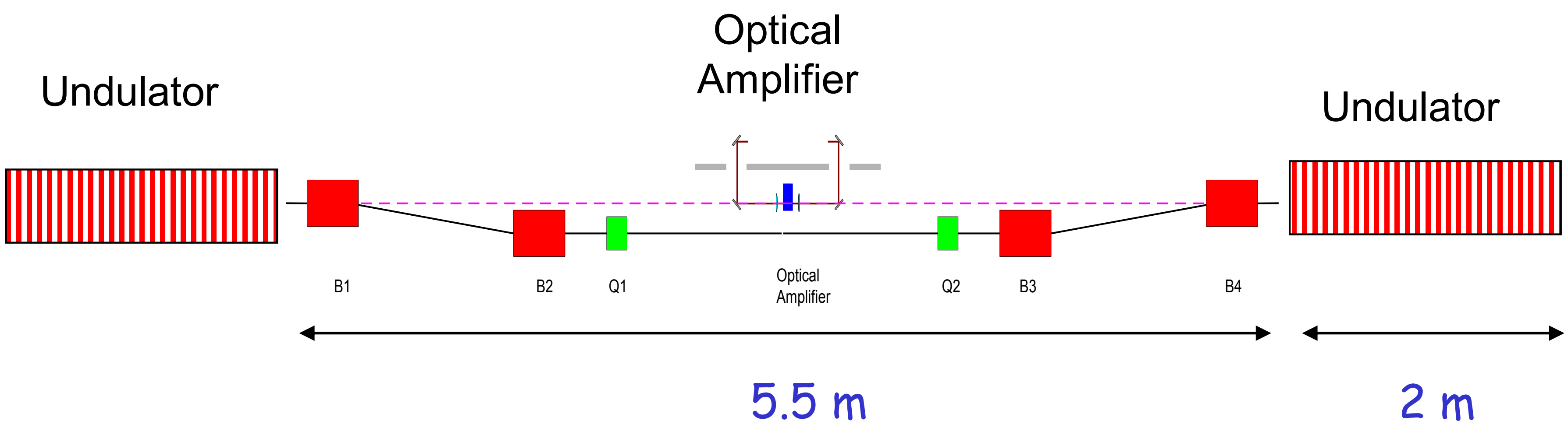


- Distinguish OSC from damping due to synchrotron radiation
  - Low energy electrons
  - Large dipole bend radius
- Long straight sections desirable for OSC apparatus
- South Hall Ring, e^- storage ring
  - Full energy injection at 300 MeV
- Dedicated use of South Hall Ring for first OSC demonstration
  - Design tolerances consistent with existing technology
  - Optimize for SHR environment

Successful beam development Run in April-May 2007

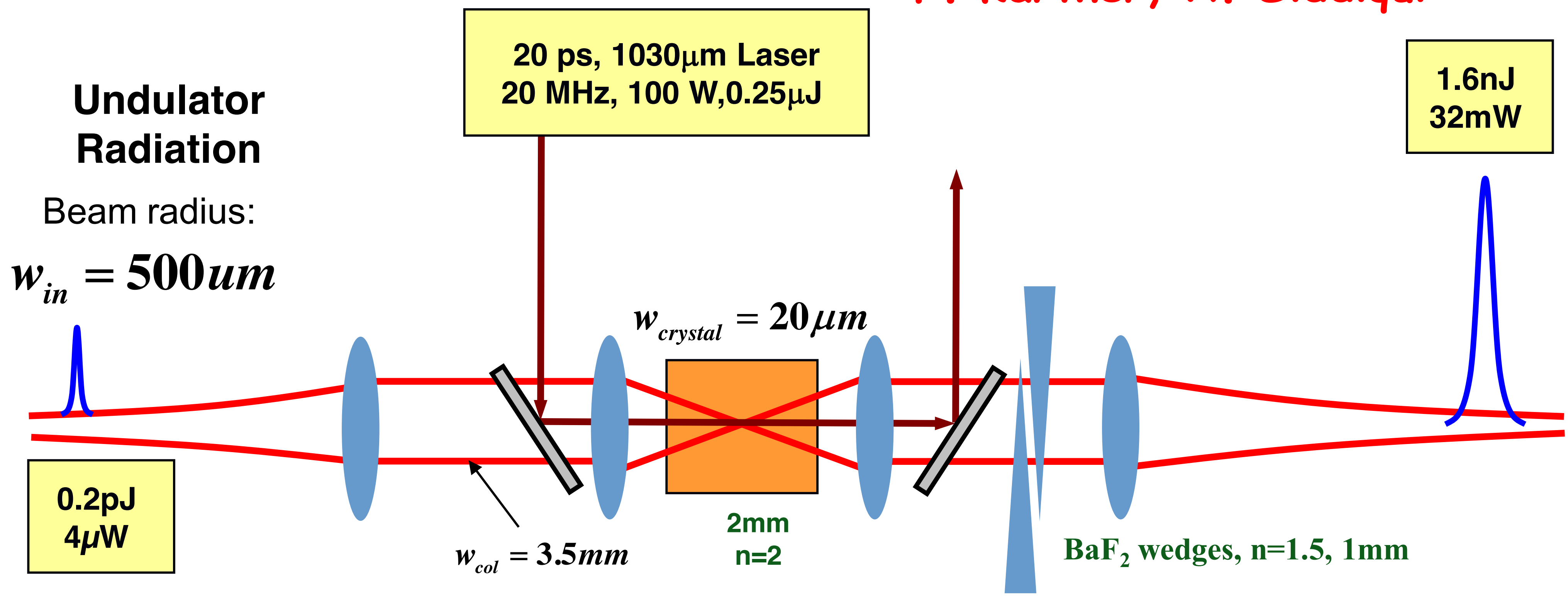
OSC Apparatus Overview

- Broadband optical parametric amplifier (developed by MIT-RLE)
  - Large dispersion-free linear amplification in short medium
  - Total delay ~20 ps with control to a fraction of an optical cycle
- Small angle (65 mrad) OSC bypass with 6 mm path length change makes the setup robust
  - Fixed optics with achievable magnet tolerances
  - Minimize effects of synchrotron radiation and required changes to SHR RF
- Undulators matched to amplifier wavelength (2 μm), bandwidth (~10%)
- All readily integrated within 10 m of SHR east straight section



Undulator Radiation

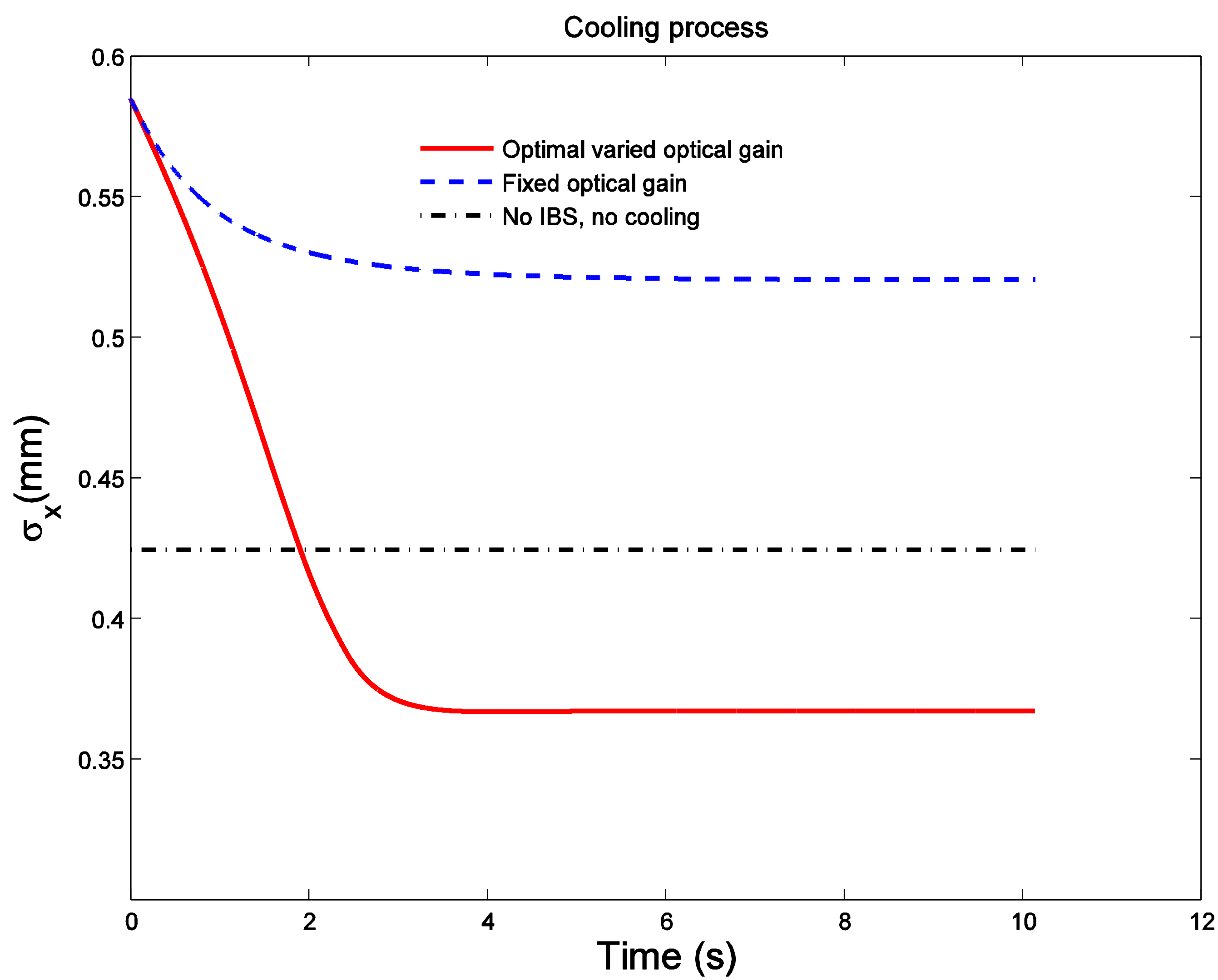
F. Kärtner, A. Siddiqui



- Amplification in periodically poled lithium niobate crystal (PPLN)
- Pump laser controls gain; phase-locked to stored electron beam
- Optics internal to SHR vacuum system; remotely actuated
- Fine phase control allows interferometry in 2nd undulator for achieving OSC

OSC Numerical Modeling

observation of beam transverse size changes during cooling process



OSC Experiment at Bates

- Applied for funding to build apparatus, run experiment
  - Rated as `Compelling' by Accelerator Physics Review Panel
  - MIT funded beam study in April-May 2007
  - Proposal submitted to DOE-NP December 2008
  - Envision joint NP-HEP funding
- Realization plan over 4 years
  - Develop beam tune for OSC enhancement (OSC Lattice)
  - Develop and install OSC chicane
  - Install wigglers and amplifier
  - Initiate cooling experiments
- Experimental program to study OSC of damped electron beam
  - Measure OSC as function of bunch intensity, lattice, and amplifier parameters
  - Develop new diagnostics for OSC optimization

Four year plan

- **Year 1**
  - optical amplifier development
  - design of the bypass chicane
  - design of the undulators

  $ 1.33 M

- **Year 2**
  - wigglers and full OPA installed
  - beam diagnostics operational
  - two month run of accelerator complex

  $ 2.42 M

- **Year 3**
  - full optical feedback system
  - commissioning run

  $ 1.77 M

- **Year 4**
  - OSC experiments commence

  $ 1.38 M

Summary

- Cooling of high energy hadron beams holds major promise for increasing the collision luminosity of EIC
- OSC is a promising cooling technique which has never been demonstrated
- The proposed Bates experiment utilizes an existing and available accelerator complex
- The collaboration contains the necessary expertise to carry out the experiment and to subsequently deploy it at RHIC
- DOE proposal under review
- Endorsement of EICAC would be important and welcome