

# Optical Stochastic Cooling for RHIC

### Basic idea

#### Stochastic Cooling

$N_s = \frac{\lambda}{3\Gamma} \frac{N_i}{\sigma_i}$

In practice  $n_d = 20 n_d^{ideal}$

$\lambda \sim 5 \text{ cm} \Rightarrow$  ideal bandwidth limited cooling time  $\tau \sim 2.5 \text{ hrs.}$

Transverse pick-up

#### Optical Stochastic Cooling

$n_d \approx 2e N_s$

In practice time is amplifier limited

$\lambda \sim 12 \mu\text{m} \Rightarrow$  power limited cooling time  $\tau \sim 1 \text{ hr.}$  with 16 W; bandwidth limited  $\tau \sim 11 \text{ sec!}$

Spontaneous emission ("Pick-up")

### 5 main components of OSC

- Optical amplifier (Optical Parametric Amplifier (OPA) : 3 cm long CdGeAs<sub>2</sub> crystal, cooled to 77K for better thermal conductivity and transparency) (experimental tests within 1 year)
- Pump source for OPA (mode locked CO or CO-2 laser operating at 10 MHz with 200W output at 5.3 micron) (forgotten technology, design with 1 year)
- RHIC lattice modification design (exist only understanding what needs to be done)
- Diagnostics (needs to be developed)
- Pair (per ring) of 10T 3 meter long wiggler and modified RHIC bending magnets (to allow wiggler light extraction) (existing technology, need cost estimate)

### Undulator can be used as the Pick up and Kicker

Electron trajectory through undulator

Light wave vector

### Transient Time Method of OSC

A pick-up and a kicker should be installed in a position with a nonzero dispersion function for a simultaneous cooling of energy and transverse coordinates (similar to the Palmer's method of the momentum cooling).

before kick  $\Delta x = \eta \frac{\Delta E}{E}$

after kick

transverse kick  $\Delta x = x_\beta^{(e)} - x_\beta = -\eta \frac{\Delta E}{E}$

energy kick

Coupling is used to share dumping between horizontal and vertical coordinates

### Parametric Amplifier

ion beam

Nonlinear crystal CdGeAs<sub>2</sub>

$d_{36} = 236 \text{ pm/V}$

$\omega_i = \omega_p - \omega_s$   
 $k_p = k_s + k_i$

Amplified signal

Pump laser

$\lambda_{\text{pump}} = 5.3 \mu\text{m}$  (Doubled frequency CO<sub>2</sub> laser)  
 $\lambda_{\text{signal}} = 12 \mu\text{m}$   
 $P_L = 20 \text{ MW/cm}^2$  (damage threshold, conservative)  
 $l = 4 \text{ mm}$  ( $e$  times gain length)  
3 cm length crystal  $\Rightarrow$  intensity gain  $3 \cdot 10^5$

### CdGeAs<sub>2</sub> has long been known as a promising nonlinear optical material for IR frequency conversion

Advantages

- Highest Nonlinear Coefficient of any known compound ( $d = 236 \text{ pm/V}$ )
- Long Wavelength IR Cut-off (17 microns)
- Large Birefringence allows for Broad Phase-Matching range
- Adequate Thermal Conductivity (.042 W/cmK) for high power applications

Disadvantages

- Anisotropic Thermal Expansion (a-axis  $15 \times$  c-axis), cracking
- Defect-related Absorption Loss

### Bypass for RHIC

RHIC parameters

Ions  $^{197}\text{Au}^{79+}$   $N_{\text{ions}} = 120 \times 1.2 \cdot 10^9$   
 $E = 100 \text{ GeV/per nucleon}$   
 $\varepsilon = 0.65 \cdot 10^{-9} \text{ m}$   $\sigma_\beta = 4 \cdot 10^{-4}$   
Perimeter = 3834 m.

Amplifier parameters

For 1 hour cooling time  
 $\lambda = 12 \mu\text{m}$  required light power is  $P = 16 \text{ W}$

Preliminary schematic of bypass

### Making sense of the different cooling techniques

Stochastic Cooling: beam error signal is measured by a pickup, amplified by RF amplifier and corrected in the kicker

- Experiment on RHIC-Spring 2004
- Works over wide range of ion beam energies
- Limited by amplifier bandwidth  $\sim 5 \text{ GHz}$
- Requires expensive RF amplifier
- Possibly can cool only trails of the RHIC beam

Electron cooling: ion beam "heat" transferred to "cold" electron beam

- Limited by electron beam current
- Works over wide range of the ion beam energies
- Effective for the beam core and against IBS (faster cooling for the colder beam)
- Complimentary with OSC as it effective against IBS (main growth in RHIC)

Requires expensive and challenging ERL and long solenoid

EC was not demonstrated at high energies

Neither cooling was demonstrated for the bunched beam

Optical SC: Same as SC, but at optical wavelength

- Not limited by amplifier bandwidth  $\sim 3 \text{ THz}$
- Can cool whole RHIC beam in one hour with 16W of optical power
- Experiment on RHIC-Spring 2004
- Favors large amplitudes, can be adjusted for the different beam amplitudes
- Greatly reduces requirements on electron current if used with EC
- Works over limited  $\sim 5-10\%$  range of the ion beam energies
- Requires challenging RHIC lattice modifications
- No experimental demonstration - period.

(Colors: Good, Bad)

