Optical Stochastic Cooling: Gold beams in RHIC & HALO applications

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Basic idea

Stochastic Cooling

$$n_d^{ideal} \approx 2N_s \qquad N_s = \frac{\lambda}{3\Gamma}\frac{N_i}{\sigma_l}$$

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

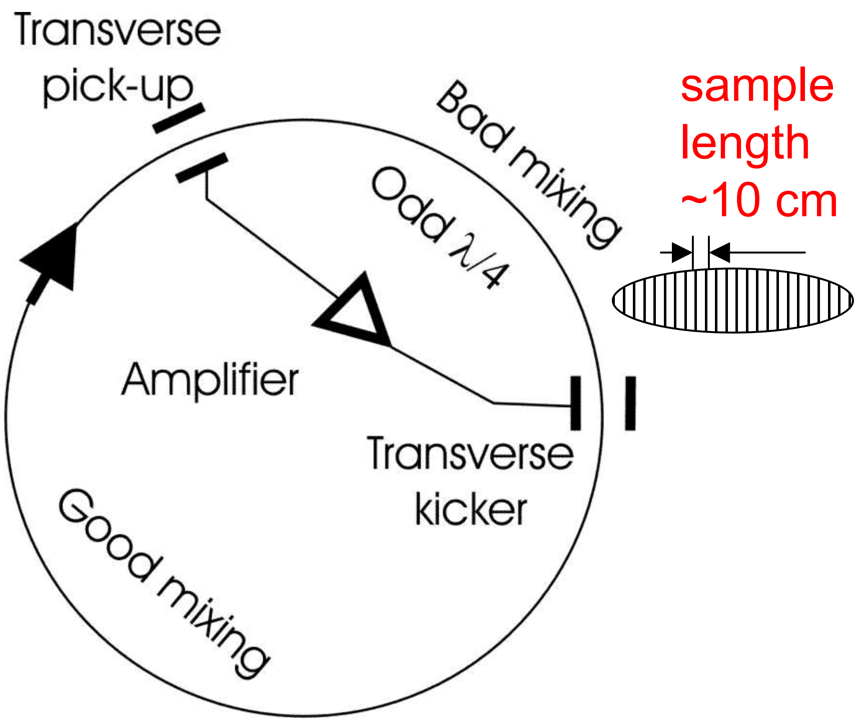
λ~ 5 cm => bandwidth limited cooling time τ~10 hrs.

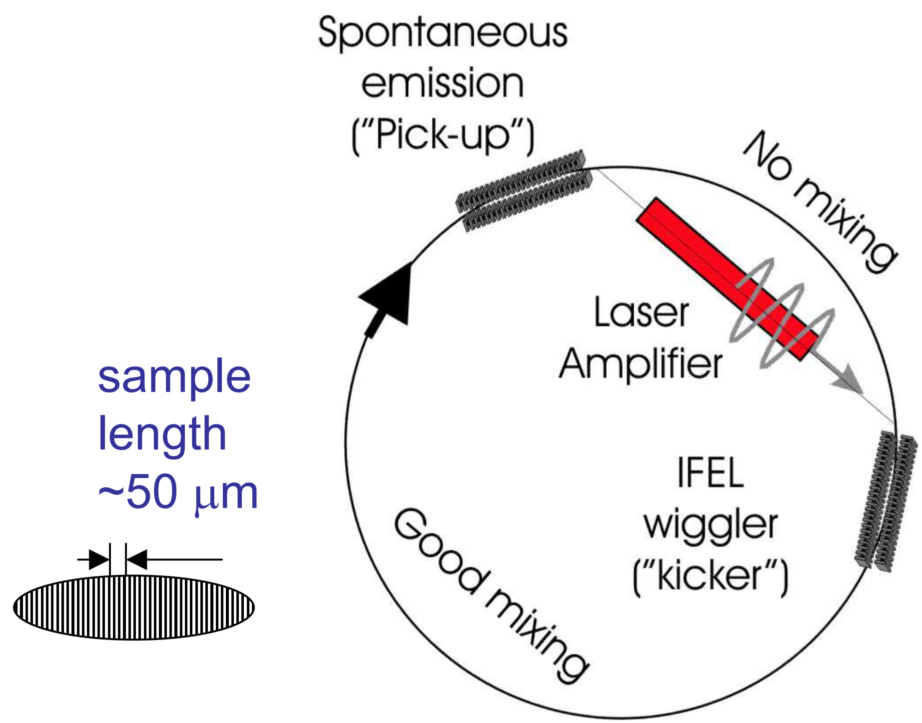
Optical Stochastic Cooling

$$n_d \approx 2eN_s$$

In practice time is amplifier limited

λ~ 12 μm => power limited cooling time
τ~1 hr with 16 W; bandwidth limited **τ~9 sec!**





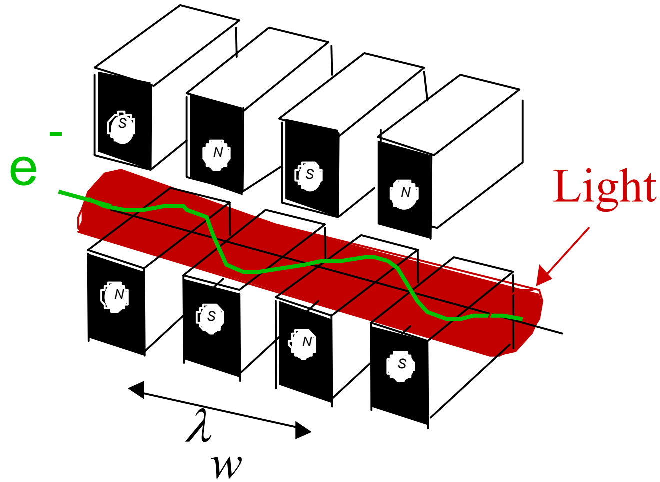
OSC VS. Electron cooling

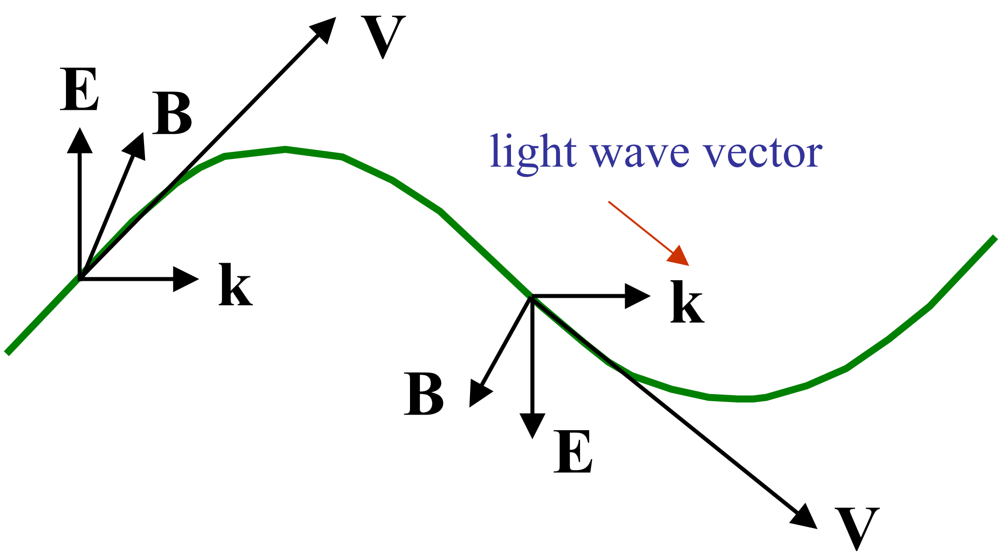
- OSC favorites the beam tails (time transient method): $^{dA}/_{dt} \sim \sin(k\,A)$
- Usually limited by the power of the optical amplifier.
- Low signal with low γ beams
- Match of the high field wiggler period and laser wavelength is required.
- ***Efficient against HALO.***

- Electron cooling is efficient on beam core $^{dA}/_{dt} \sim A^{3/2}$
- Limited by electron current/ recombination compromise.
- Cooling time slows with beam energy but same way as IBS.
- ***Efficient against IBS.***

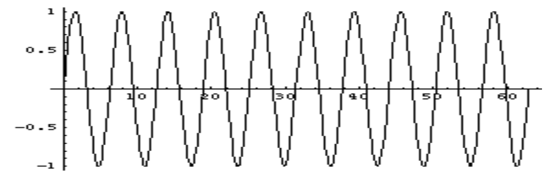
Undulator can be used as the Pick up and Kicker

Electron trajectory through undulator





magnetic field in the undulator



$$B = B_o \, \mathrm{Sin}\,(k_u z)$$

Resonance condition

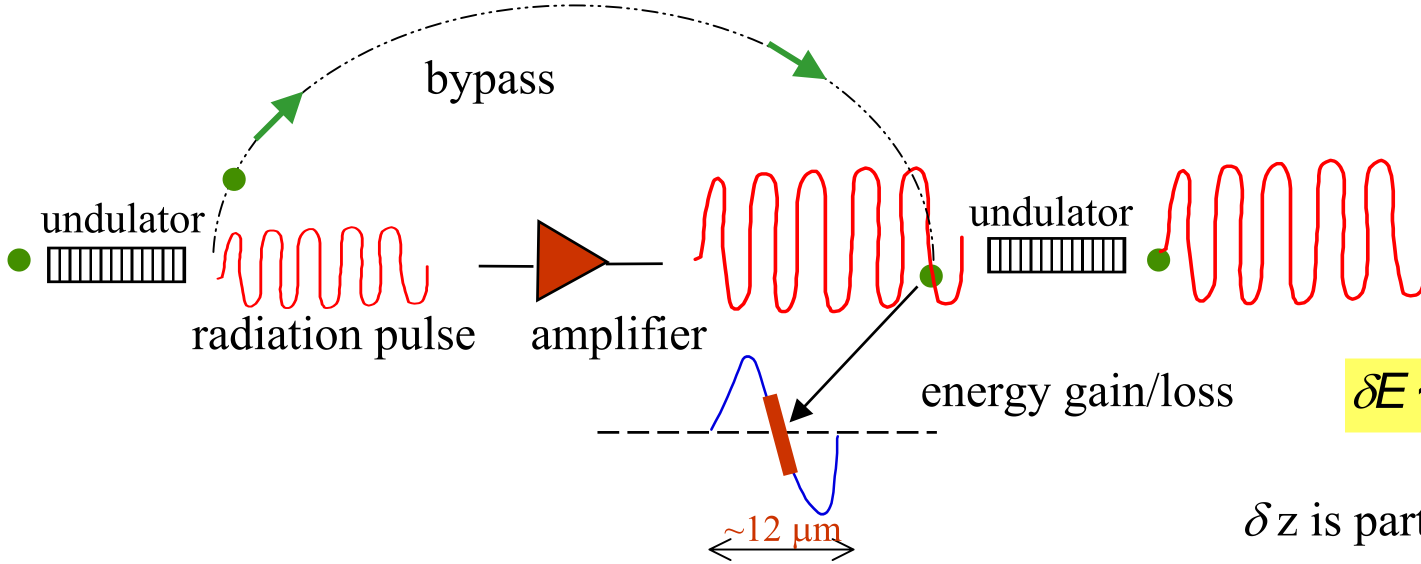
$$k = k_u \, 2\gamma^2/(1+K^2/2)$$

$$K = Z\, e\, B_o/(k_u M c^2)$$

Undulator parameter:

K<<1 for heavy ions

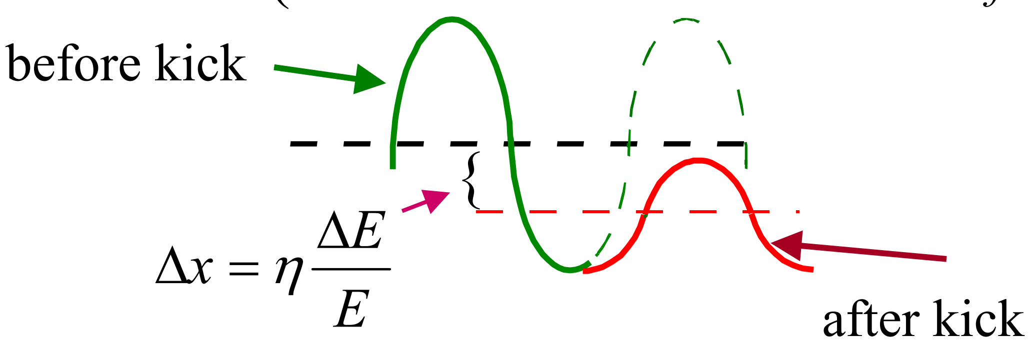
Transient Time Method of OSC



$\delta E \sim \sin(k\,\delta z)$

δz is particle delay

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*).



transverse kick

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

energy kick

Coupling is used to share dumping between horizontal and vertical coordinates

Cooling of Heavy Ions at RHIC

RHIC parameters

Ions $^{+79}Au^{197}$ N_{ions}=120 x $1.2\cdot10^{9}$

E = 100 GeV/per nucleon

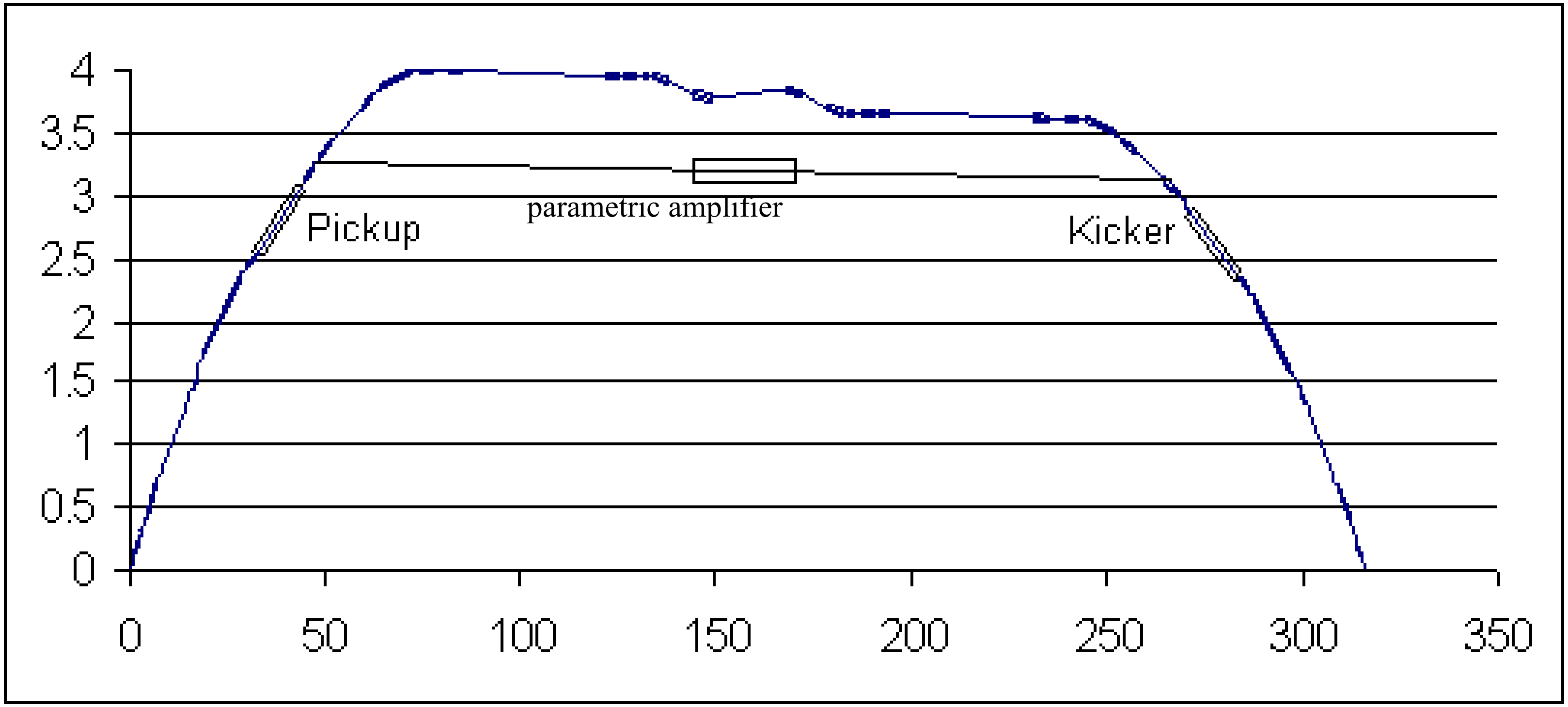
$\varepsilon = 0.65\cdot10^{-9}$ m $\sigma_\delta = 4\cdot10^{-4}$

Perimeter = 3834 m.

Amplifier parameters

For 1 hour cooling time λ= 12 μm required light power is P = 16 W

Preliminary schematic of bypass



Studies of the performance of the model bypass lattice

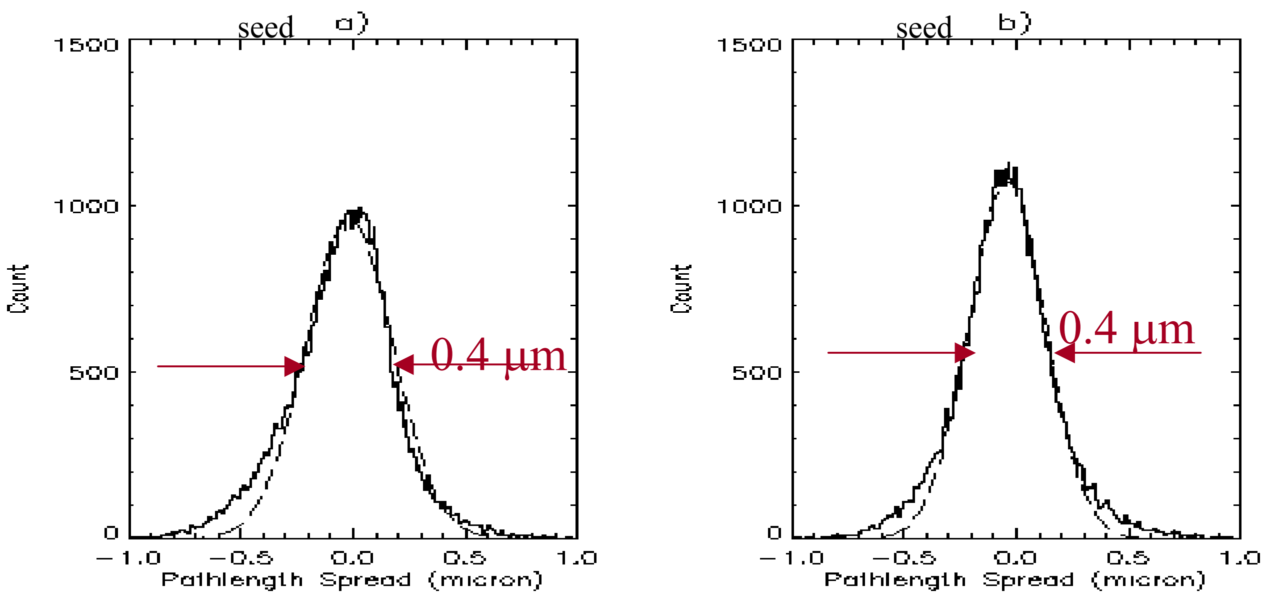
(Concern: requirement for isochronicity $\lambda_s/2\pi = 1.9\ \mu m$ @ $12\ \mu m$)

Bypass lattice errors:

Quadrupole gradient :	$\Delta G/G=1x10^{-3}$
Bending field:	$\Delta B/B=1x10^{-3}$
Sextupole gradient:	$\Delta S/S=1x10^{-3}$
Tilt angle:	0.2 mrad
Misalignment:	150 μm
Multipoles:	$\Delta G/G=1x10^{-4}$ at r=3cm
	$\Delta B/B=1x10^{-4}$ at r=3cm
Power supply ripple:	$1x10^{-4}$

Histograms showing a spread of the path lengths due high order aberrations in the lattice and all kind of errors

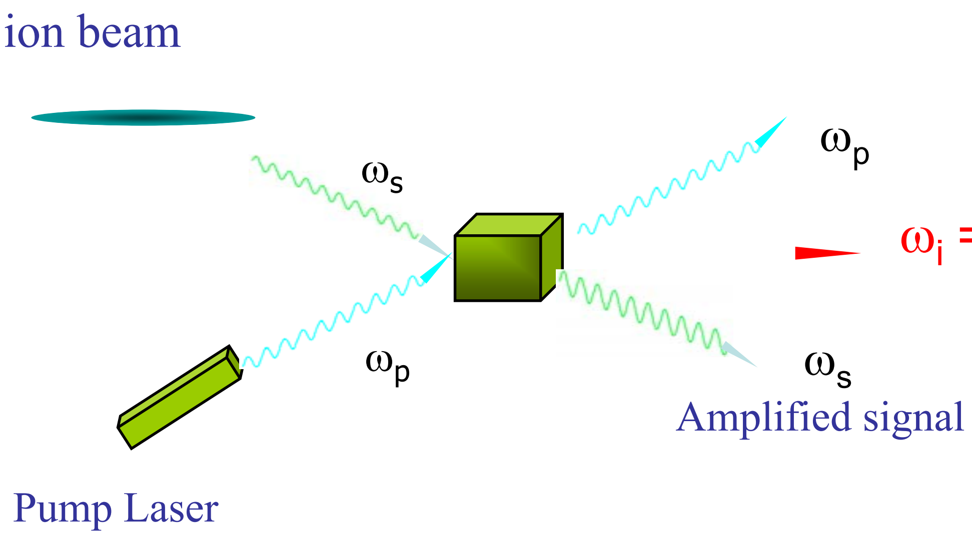
Examples of particle tracking for a model bypass lattice



MINI-Workshop in October 2002 (optical amplifier candidates)

- Low pressure CO_2 laser would not work as amplifier due to gain spectrum.
- High pressure CO_2 laser solution is extremely energy inefficient.
- Parametric crystal amplifier offers high energy efficiency and bandwidth.
- Series of experiments are required to test crystal performance.

Parametric Amplifier



Nonlinear crystal $CdGeAs_2$

$d_{36} = 236$ pm/V

$\omega_i = \omega_p - \omega_s$;

$k_p = k_s + k_i$

$\lambda_{pump} = 5.3\ \mu m$ (Doubled frequency CO_2 laser)

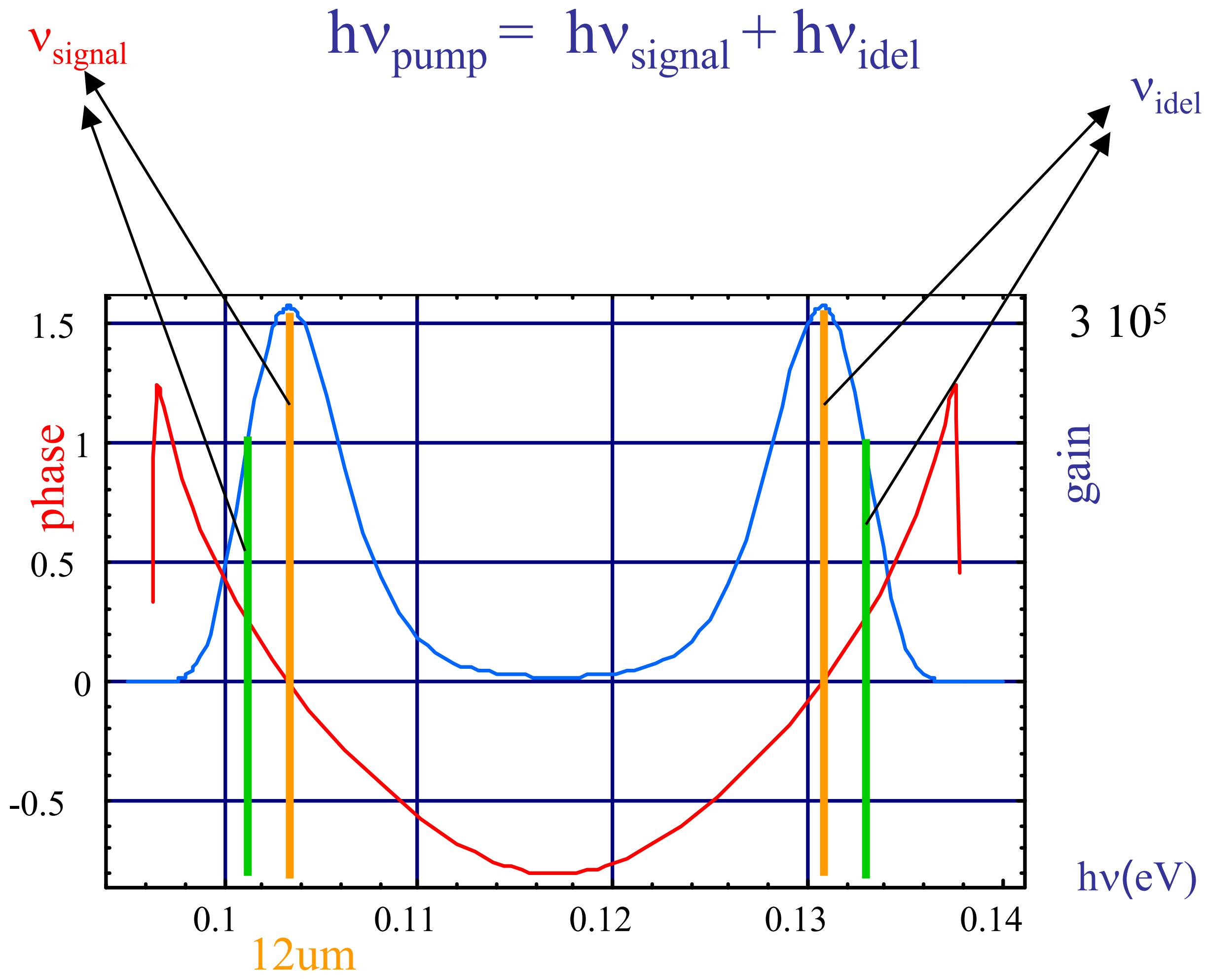
$\lambda_{signal} = 12\ \mu m$

$P_L = 20$ MW/cm^2 (damage threshold, conservative)

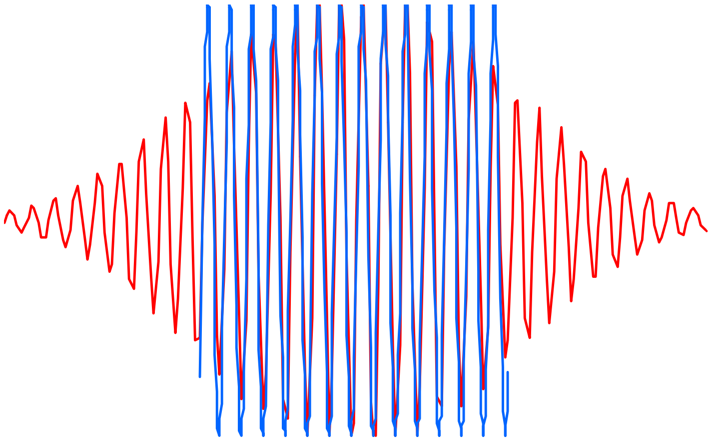
$l = 4$ mm (*e* times gain length)

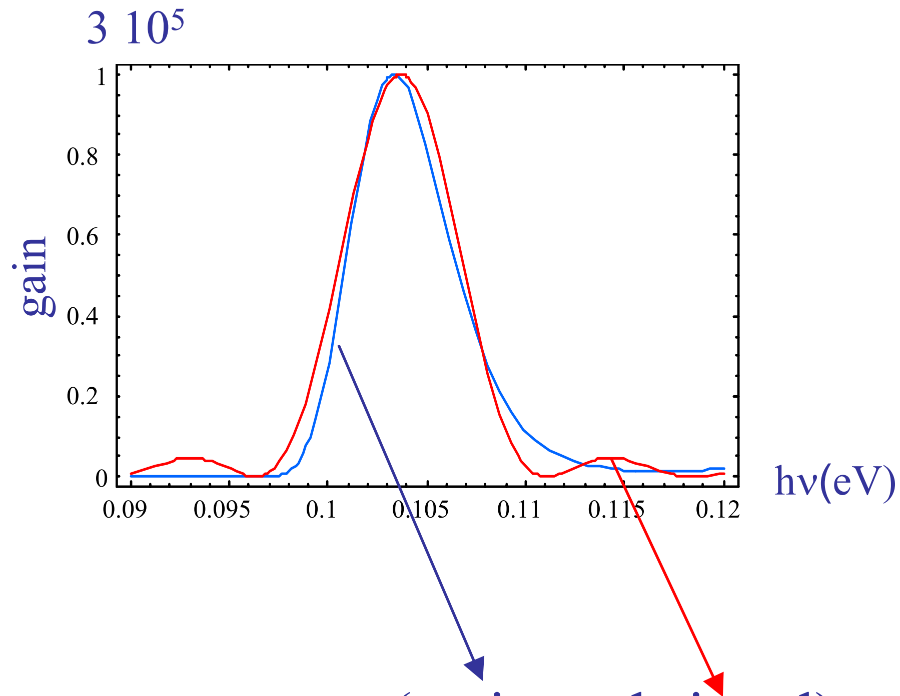
3 cm length crystal → intensity gain $3\ 10^5$

Amplifier bandwidth with $CdGeAs_2$ crystal



Limited bandwidth effect

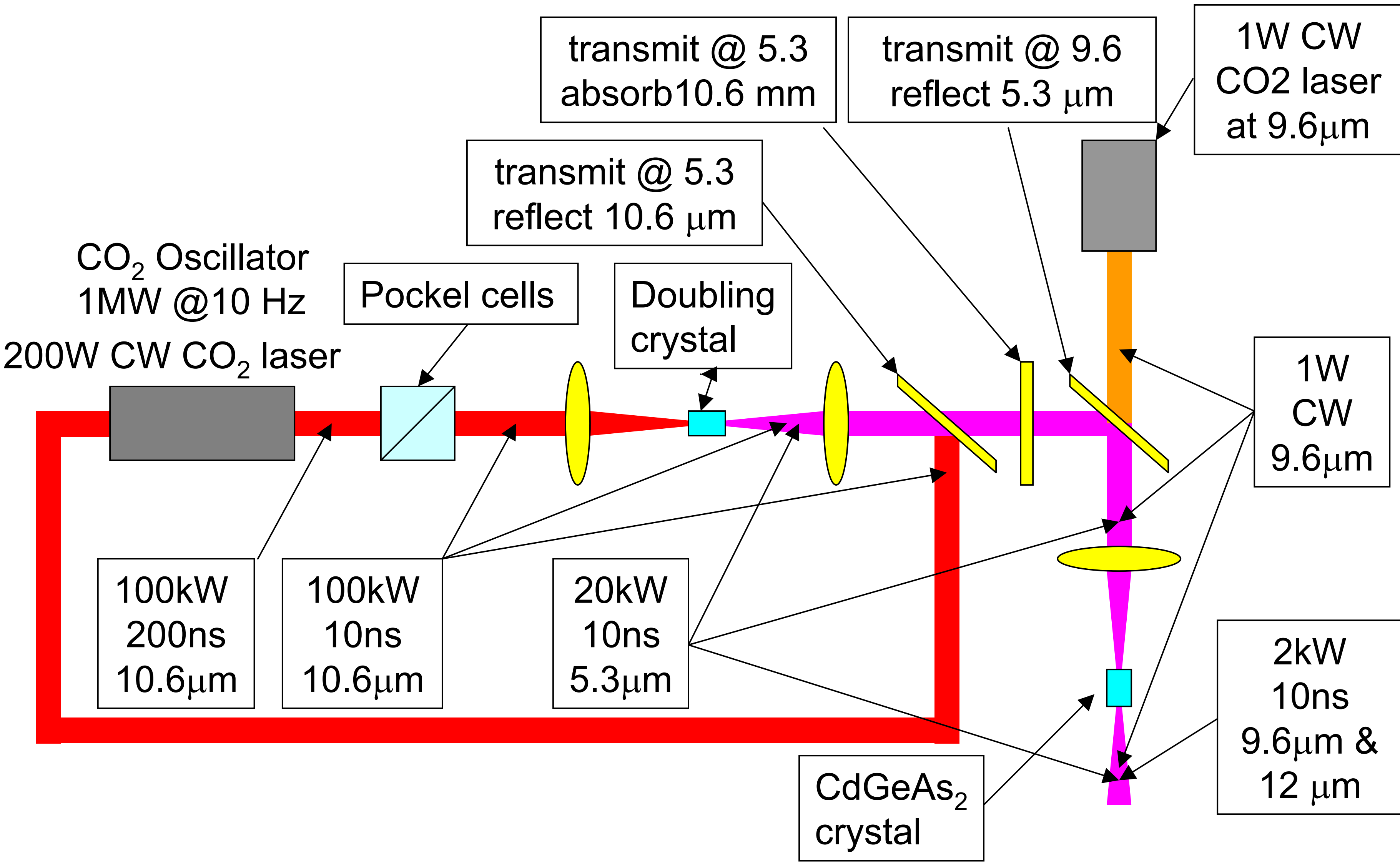




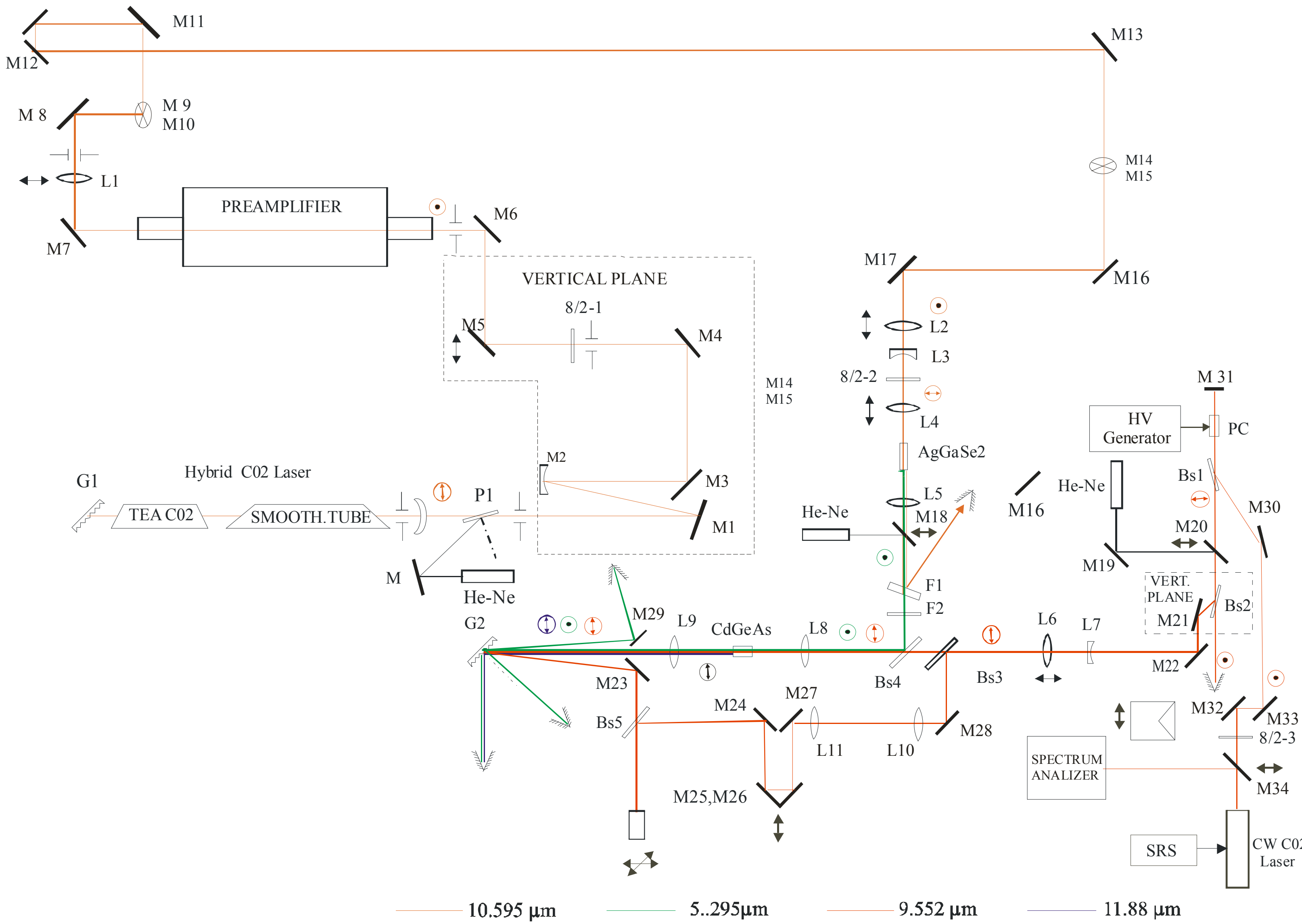
Time domain 14 wiggles
before & after amplifier

(gain and signal)
Frequency domain

Crystal based amplifier



Detailed plan is more complex



Noise of the optical amplifier

Not a problem!

The amplifier <u>is not</u> affected by a thermal noise. Practically, there are no thermal photons with the energy of signal photons because: $h\nu >> kT$; $n_{ph} \sim e^{-h\nu/kT}$

Noise of the amplifier is due to the <u>spontaneous emission</u>.

The equivalent noise of the spontaneous emission at the amplifier front end is one photon per mode. It is like "having extra ~1/2α particles" in a sample.

For undulator radiation: $n_{ph} = 4.12\ \alpha\ K^2/(1+K^2)$

$\alpha \sim Z^2/137$, where Z is the particle charge

Conclusion

- Optical parametric amplifiers with wide bandwidth operating in the infrared region (10-20 μm) open up possibility of cooling heavy ions at RHIC.
- For one hour cooling time at RHIC this requires <u>16 W</u> of amplifier power
- Cooling can be applied to the tails by adjusting timing of the pump laser. Cooling time would be seconds due to small number of ions in the sample
- Optical manipulations of beams is an emerging technology which will keep progressing along with the laser and accelerator technology

Goals

- Test of the amplification in the crystal with pumping by second harmonic of CO_2. (summer of 2003)
- Verifying crystal property (improvements in absorption after liquid N_2 cooling and irradiating crystal). (2004)
- Design of the mode-locked low pressure CO_2 laser. (2004)
- Staged operation of the crystal amplifier in order to improve bandwidth.