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# DEVELOPMENT OF HIGH AVERAGE POWER LASERS FOR THE PHOTON COLLIDER*

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*Abstract*

The laser and optics system for the photon collider [1] seeks to minimize the required laser power by using an optical stacking cavity [2, 3] to recirculate the laser light. An enhancement of between 300 to 400 is desired. In order to achieve this the laser pulses which drive the cavity must precisely match the phase of the pulse circulating within the cavity. We report on simulations of the performance of a stacking cavity to various variations of the drive laser in order to specify the required tolerances of the laser system.

## INTRODUCTION

We look at the behavior of a simple four mirror cavity as shown in Fig. 1. As a unit input pulse is applied to the coupling mirror a pulse begins to build up in the interior of the cavity. If the drive pulses and the interior pulse arrive at the coupling mirror in phase the interior pulse will build up to a larger value. The achievable enhancement is a strong function of the reflectivity of the cavities. The best performance if attained when the reflectivities of the input coupler is matched to the internal refectivities of the cavity. In Fig. 2 we show the build up of the internal pulse after a certain number of drive pulses, assuming the input coupler has a reflectivity of 0.996 and the interior mirrors have 0.998 reflectivity. With these parameters the cavity will reach an enhancement factor of 450. Reducing the coupler reflectivity gives a faster cavity loading rate but with a reduced enhancement of the internal pulse. The enhancement as a function of coupler reflectivity and total internal cavity reflectivity is shown in Fig. 3. The best enhancement is achieved when the coupling mirror is matched to the reflectivity of the cavity. A coupler reflectivity just below the internal cavity reflectivity minimizes the required laser power.

## VARYING THE PARAMETERS

The enhancement factor calculated above assumes everything associated with the laser and resonant cavity is perfect. There are numerous parameters which will degrade the cavity enhancement.

- Dispersion in the cavity
- Phase Noise

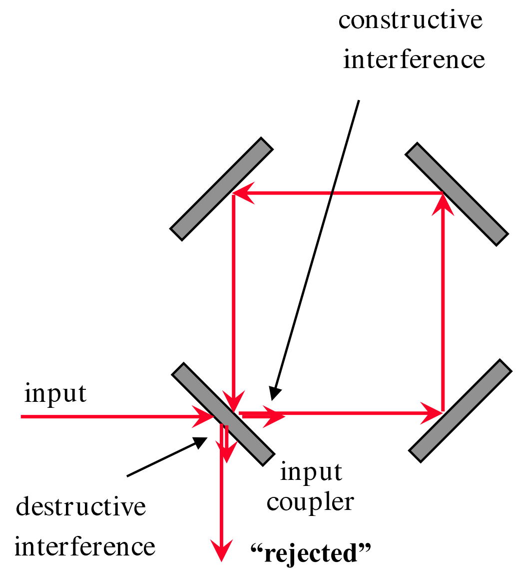


Figure 1: Arrangement of mirrors.

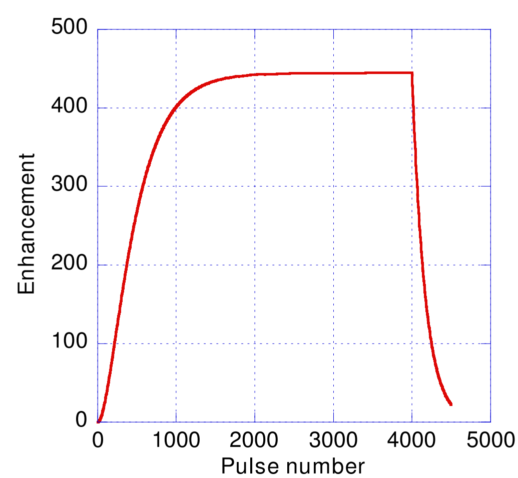


Figure 2: Ratio of the interior pulse size to the drive beam pulse size as a function of pulse number.

- Cavity length/laser repetition length
- Amplitude noise
- Thermal changes to refractive index of the amplifiers
- Pointing Stability

Group velocity dispersion (GVD) in the resonant cavity mirrors will cause the different frequencies of the ps pulse to propagate at different velocities and eventually the

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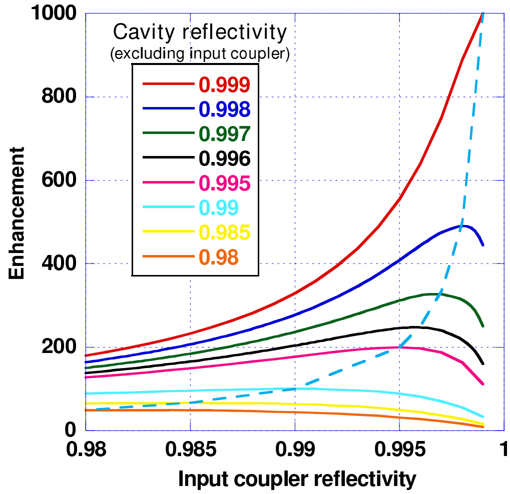


Figure 3: Enhancement as a function of input coupler reflectivity for various values of the total reflectivity of the internal cavity mirrors.

structure of the circulating pulse will not match the input pulses. Figure 4 shows that the total cavity GVD should be less than 100 $fs^2$.

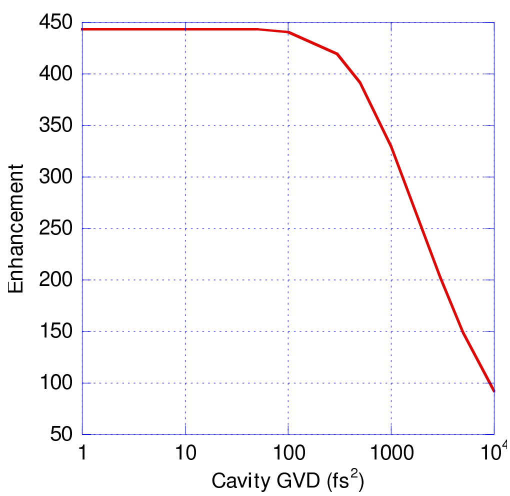


Figure 4: Cavity enhancement as a function of group velocity dispersion.

Random phase noise will be imparted on the output pulses due to mechanical, environmental, and amplifier instabilities. Figure 5 shows that anything above 0.02 waves (125 mrad) rms will severely degrade the cavity enhancement factor. Femtolasers [1] is currently selling a 5 mJ - 1 KHz - 30 fs system with 50 mrad rms phase noise. The same noise minimization and control techniques will need to be applied here.

When propagating through a nonlinear medium at high intensity, pulse energy jitter is converted to phase jitter. Typical short-pulse laser systems run with a B-integral of 1-2 rad, where the B-integral is a measure of the accumulated nonlinear phase. In this regime, Fig. 6 shows that we must keep that pulse energy jitter below a couple of percent to avoid degradation of the cavity enhancement.

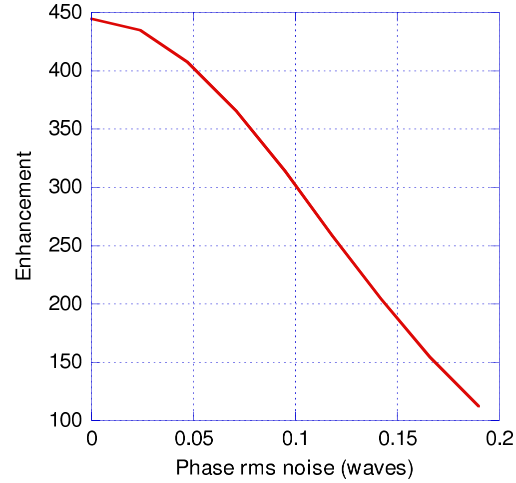


Figure 5: Cavity enhancement as a function of random phase noise in the system.

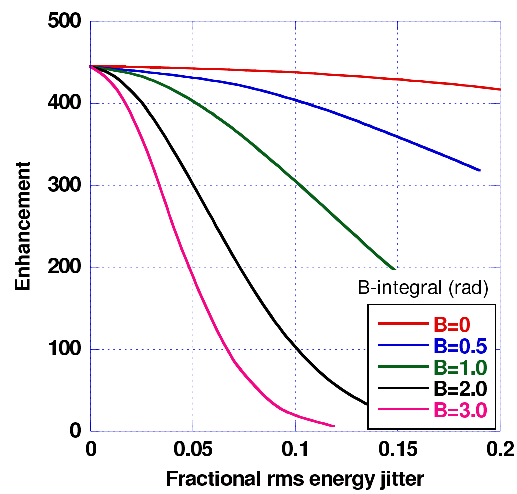


Figure 6: Cavity enhancement as a function of pulse energy jitter.

There are also several factors that will cause a slow change in phase throughout the 1 ms train. These include optic movement, pointing instability, and thermal effects in the amplifiers. Figure 7 shows the loss in cavity enhancement if a linear phase ramp is applied during the 4000-pulse train. We would like to keep the phase variation to less than 0.5 waves to maintain high enhancement. This corresponds to a cavity length change of less than 0.5 micron during the train or a temperature change of less than 0.1 °C over a 10 cm length of a typical amplifier crystal.

## FINAL AMPLIFIER DESIGN

The final amplifier must balance gain energetics with temperature uniformity and heat removal. This amplifier

[1] http://www.femtolasers.com

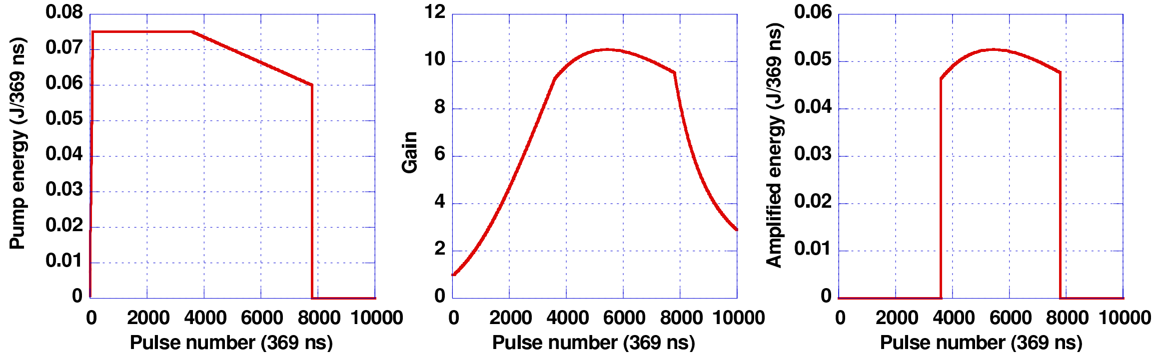


Figure 8: The amplifier pump pulse, gain and extraction over the pulse train.

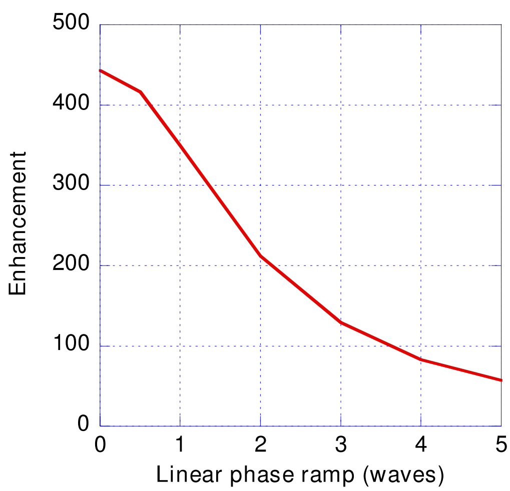


Figure 7: Cavity enhancement as a function of linear phase ramp.

will be pumped by pulsed diodes with approximately 200 J of heat deposited at 5 Hz. Depending on the geometry, the temperature rise during the diode-pumping will be 10-100 °C. If we can produce and maintain a uniform spatial temperature distribution (or one that averages out over the propagation path) the overall phase change can be taken out with a phase modulator in the beginning of the system. The final amplifier will need to have a gain of 10 with a bandwidth that will support picosecond pulse durations. Our initial designs are centered around thin (mm) slabs of Yb:YAG. The results of a simple model for pumping and extracting a pulse train from a Yb:YAG amplifier are shown in Fig. 8.

## FUTURE WORK

Future work will include developing a more detailed model of the quasi-three-level gain energetics in Yb:YAG and other Yb-doped materials. From this, we will get a better idea of the heat load to feed into the finite-element model of the time-dependent phase distortions. In the end, we plan to produce a conceptual design of a laser system that meets all the requirements for pumping the resonant enhancement cavity with an energy gain of 300-400.

Recirculating cavities are currently being developed for photon generation by laser-Compton scattering [4, 5] for a variety of applications including photon beam generation for polarized positron sources. These efforts on cavity development and the work described in this paper are synergistic as both will be needed to achieve high conversion efficiency of electrons beams to photon beams.

## REFERENCES


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