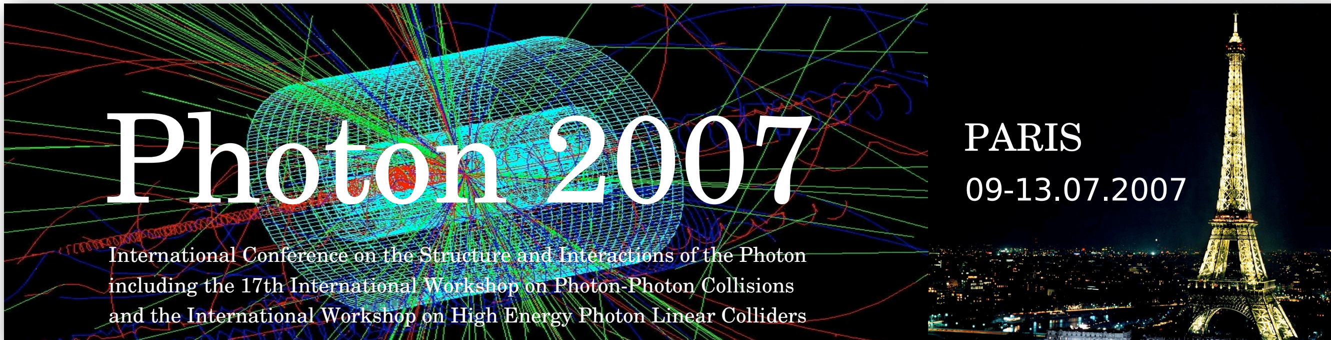


High-Power Picosecond Pulse Recirculation for Inverse Compton Scattering

I. Jovanovic, M. Shverdin, D. Gibson, C. Brown, and J. Gronberg

Physics and Advanced Technologies

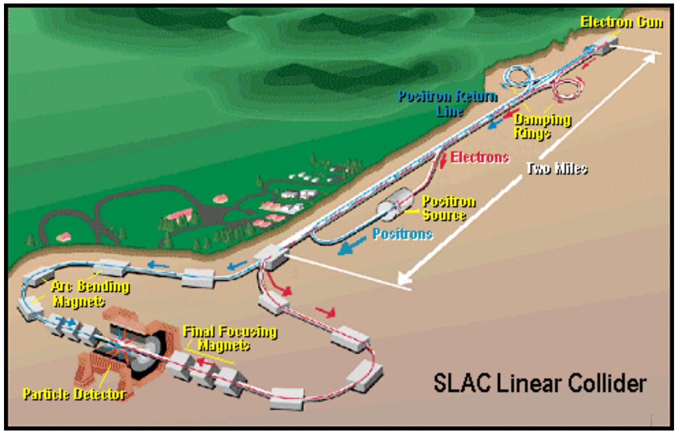
Lawrence Livermore National Laboratory

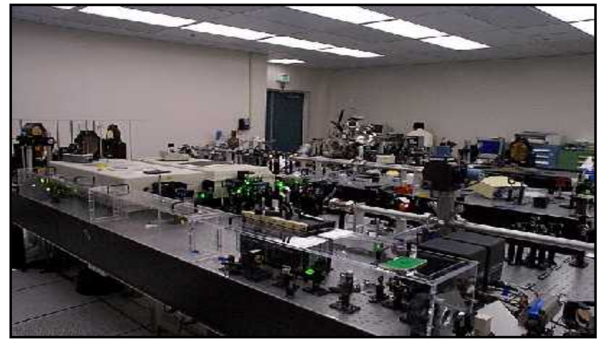
This work was performed under the auspices of the US Department of Energy by the University of California, Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.

Outline

- Motivation and prior work
- Recirculation Injection by Nonlinear Gating (RING)
- Experimental results
- Modeling / Scaling
- Applications: ILC and others

Motivation: repetition rates of LINACs vs high-energy lasers

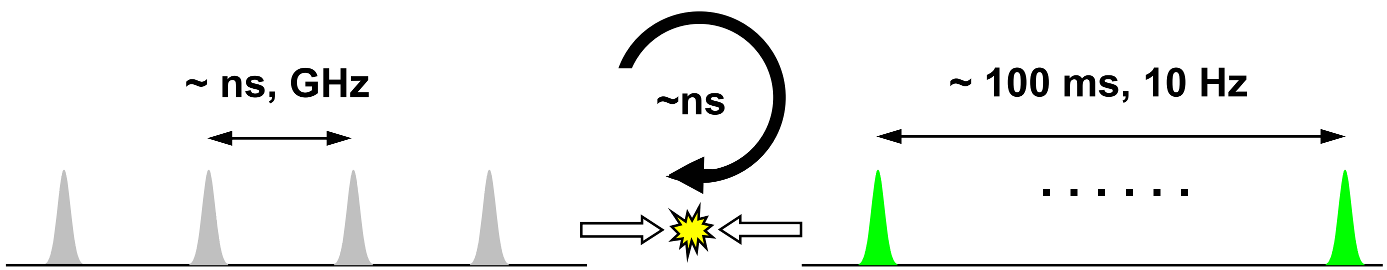




f_{LINAC}~1 GHz

f_{Laser}~10 Hz

$f_{LINAC}/f_{Laser} \sim 10^8$



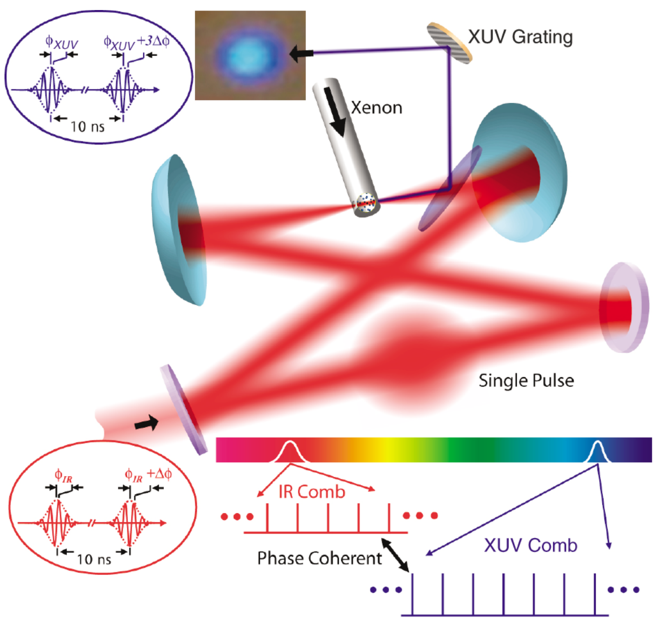
$\sigma = 0.665 \times 10^{-24}$ cm^2, $\eta < 10^{-8}$-10^{-10}

Prior work: resonant cavity enhancement of mode-locked lasers

PRL 94, 193201 (2005) PHYSICAL REVIEW LETTERS week ending 20 MAY 2005

Phase-Coherent Frequency Combs in the Vacuum Ultraviolet via High-Harmonic Generation inside a Femtosecond Enhancement Cavity

R. Jason Jones,* Kevin D. Moll, Michael J. Thorpe, and Jun Ye†
JILA, National Institute of Standards and Technology and University of Colorado, Boulder, Colorado 80309-0440, USA
(Received 7 April 2005; published 20 May 2005)

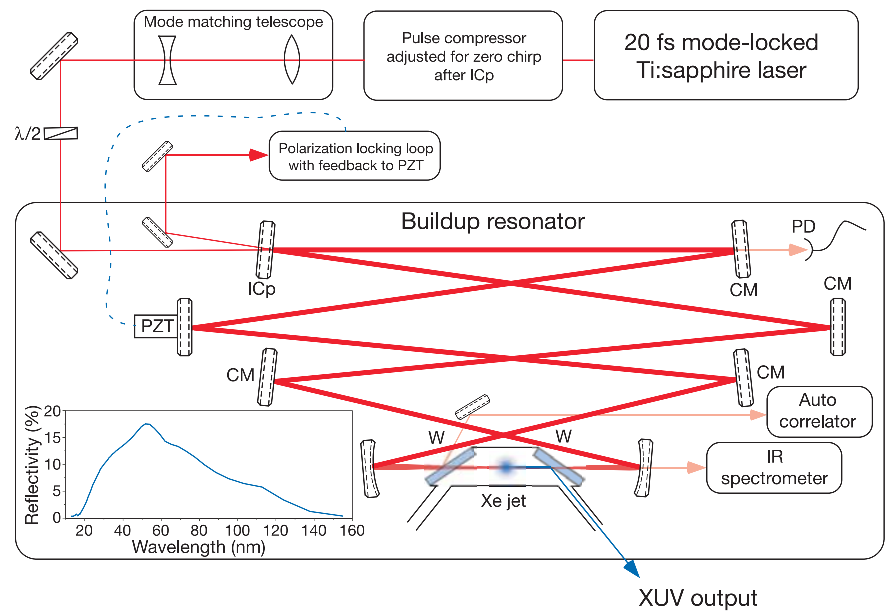


nature Vol 436|14 July 2005|doi:10.1038/nature03851

LETTERS

A frequency comb in the extreme ultraviolet

Christoph Gohle[1], Thomas Udem[1], Maximilian Herrmann[1], Jens Rauschenberger[1], Ronald Holzwarth[1], Hans A. Schuessler[1], Ferenc Krausz[1,2] & Theodor W. Hänsch[1,2]



Resonant cavity coupling applied to ILC

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Nuclear Instruments and Methods in Physics Research A 564 (2006) 212–224

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

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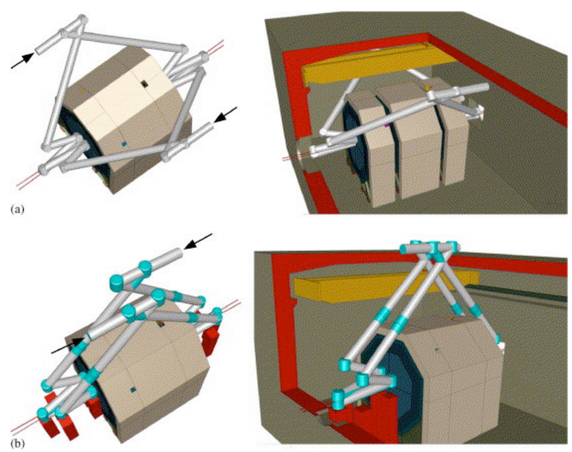
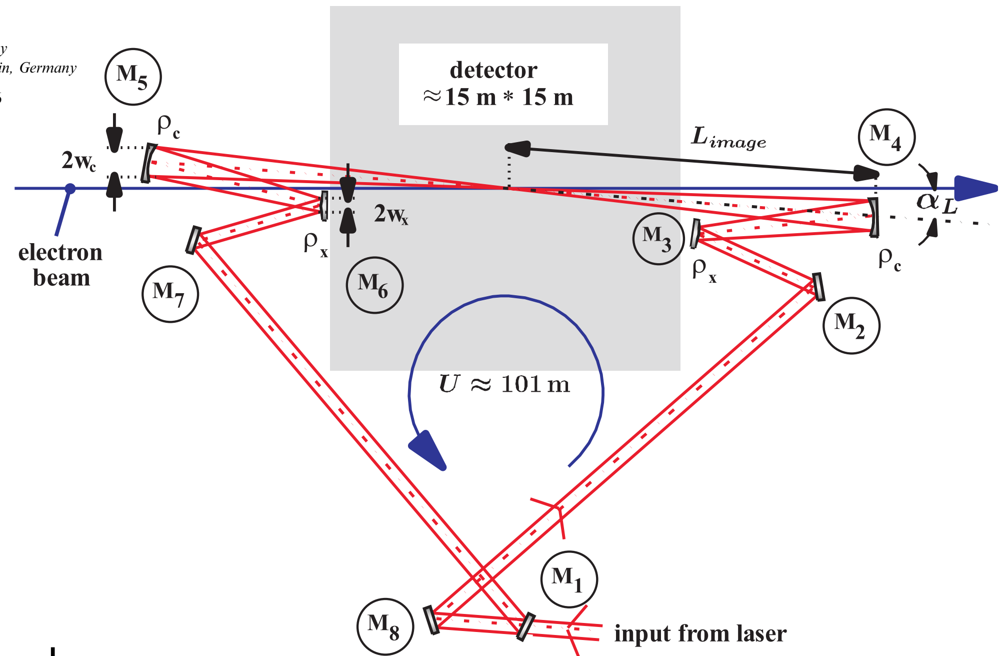
Design study of an optical cavity for a future photon collider at ILC

G. Klemz[a,b,*], K. Mönig[a], I. Will[b]

[a]Deutsches Elektronen-Synchrotron, DESY-Zeuthen, Platanenallee 6, 15738 Zeuthen, Germany
[b]Max-Born-Institute for Nonlinear Optics and Short Pulse Spectroscopy, Max-Born Str. 2A, 12489 Berlin, Germany

Received 11 July 2005; received in revised form 23 February 2006; accepted 15 March 2006
Available online 18 April 2006





Interferometric alignment accuracy is required
Laser requirements are stringent

High-power pulse injection by electro-optical switching

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Optics Communications 214 (2002) 291–295
Optics Communications
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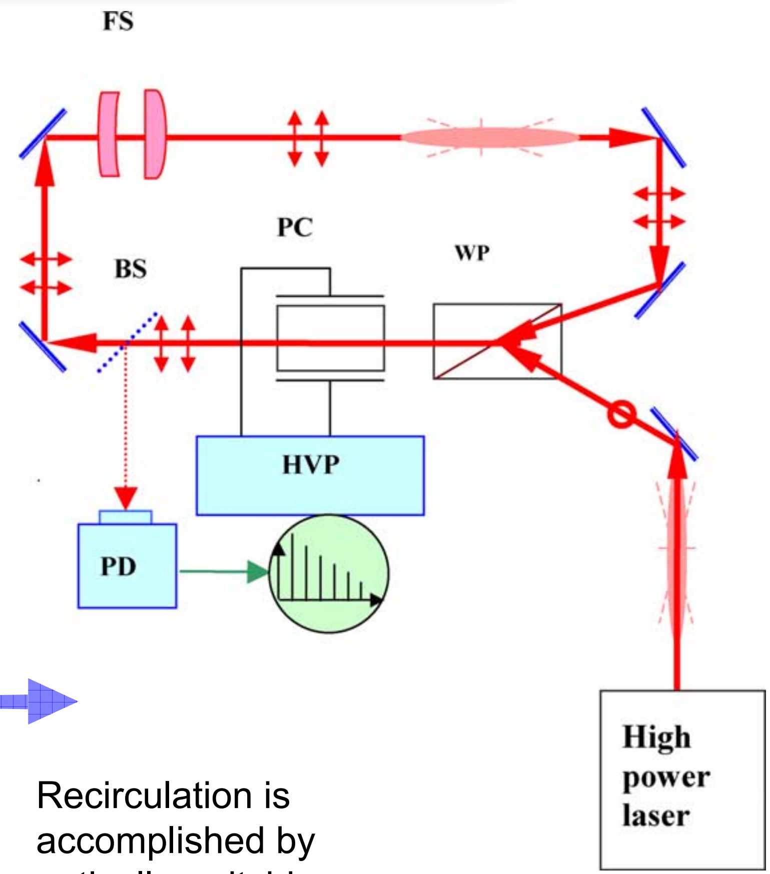
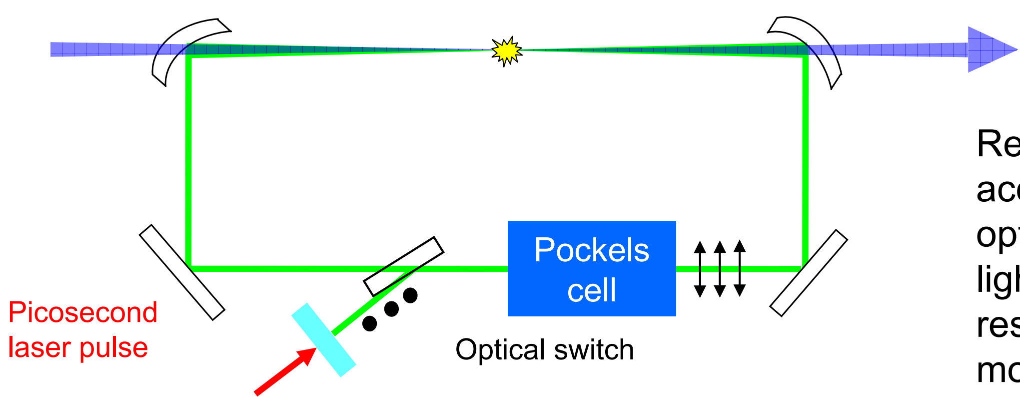
Development of an electro-optical device for storage of high power laser pulses

Tarek Mohamed[a,1], Guillermo Andler[b], Reinhold Schuch[a,*]

[a] Stockholm Center for Physics, Astronomy and Biotechnology (SCFAB), Fysikum, S-10691 Stockholm, Sweden
[b] Manne Siegbahn Laboratory, Frescativägen 24, S-10405 Stockholm, Sweden

Received 27 May 2002; accepted 28 October 2002





Recirculation is accomplished by optically switching light into a cavity, resulting in “burst-mode” operation.

Active optical storage ring

Appl. Phys. B 79, 817–821 (2004)
DOI: 10.1007/s00340-004-1621-4

Applied Physics B
Lasers and Optics

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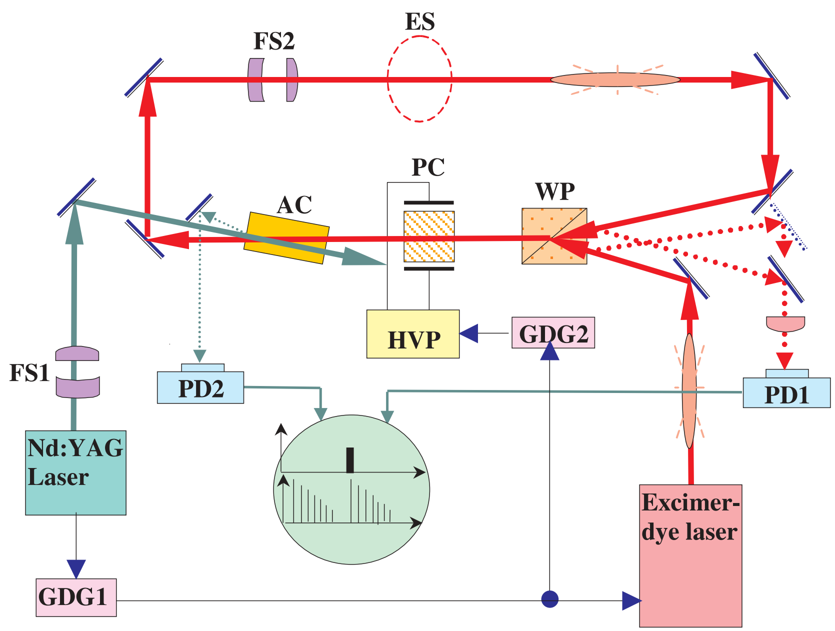
G. ANDLER[2,✉]
R. SCHUCH[1]

Active optical storage ring for high-power laser pulses

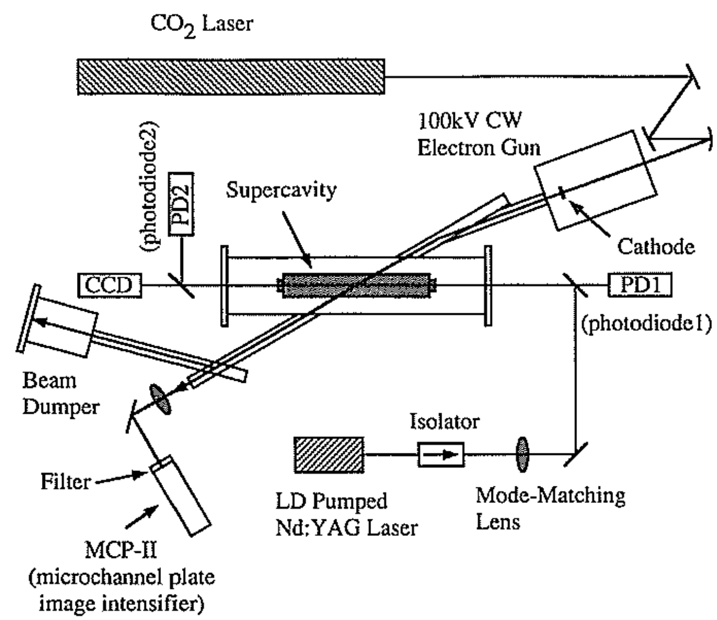
[1] Atomic Physics, Fysikum, Stockholm University, 10691 Stockholm, Sweden
[2] Manne Siegbahn Laboratory, Frescativägen 24, 10405 Stockholm, Sweden



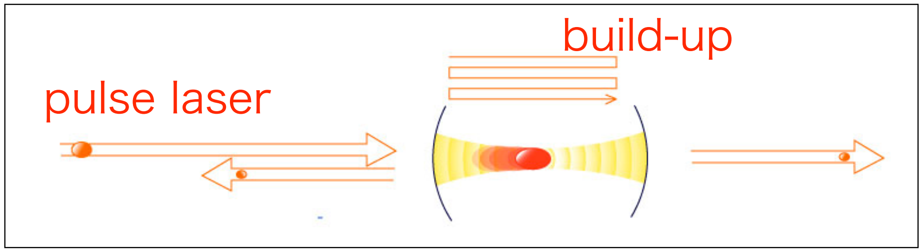
Jpn. J. Appl. Phys. Vol. 36 (1997) pp. L 1446–L 1448
Part 2, No. 11A, 1 November 1997

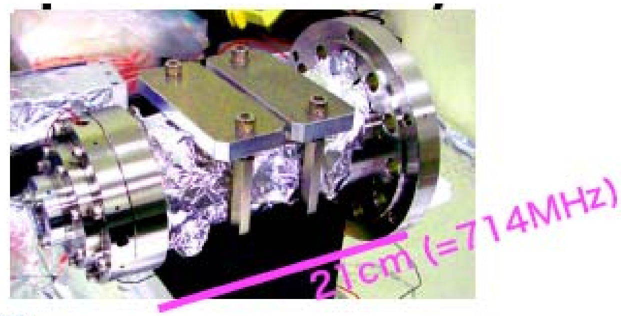
Proof of Principle Experiments for Compton Scattering of a Stored Photon in a Supercavity

Ahsa MOON, Masayuki FUJITA[1], Eiji YASUDA[2], Hidehiro TANAKA[2], Prabir Kumar ROY, Masato DAICHO[3], Koichi OHKUBO, Naoya NAKAO, Takeshi WATANABE[2], Takayuki ISHIDA[2], Kazuo IMASAKI[1], Nobuhisa OHIGASHI[2], Yoshiaki TSUNAWAKI[3], Kunioki MIMA, Sadao NAKAI and Chiyoe YAMANAKA[1]
Institute of Laser Engineering, Osaka University, 2-6 Yamada-oka, Suita, Osaka 565, Japan
[1] *Institute for Laser Technology, 2-6 Yamada-oka, Suita, Osaka 565, Japan*
[2] *Kansai University, Suita, Osaka 564, Japan*
[3] *Osaka Sangyo University, 3-1-1 Daito, Osaka 574, Japan*

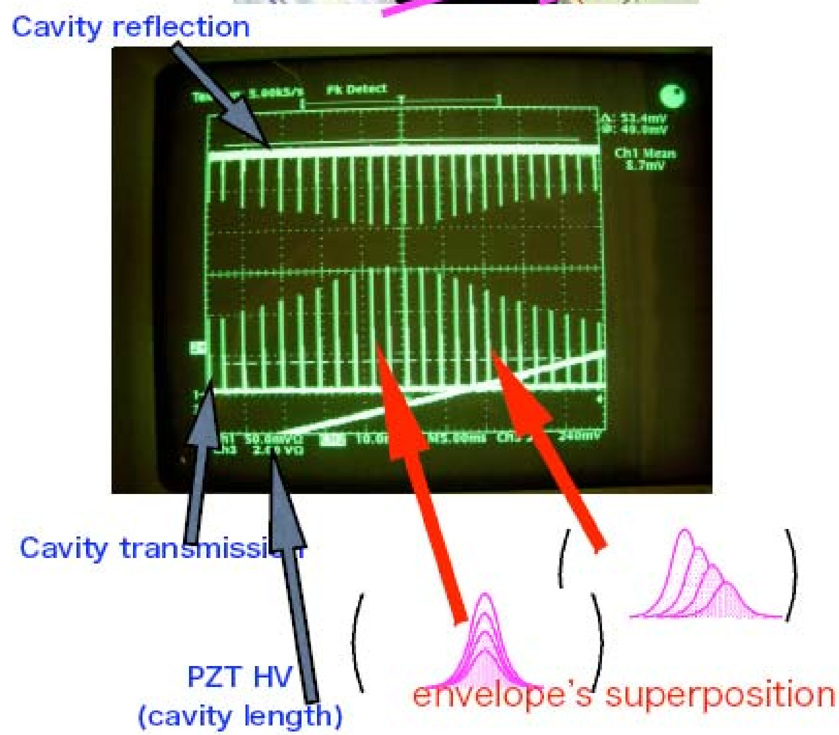


Short pulse stacking for laser wire beam monitor





Y. Honda, et al (KEK)



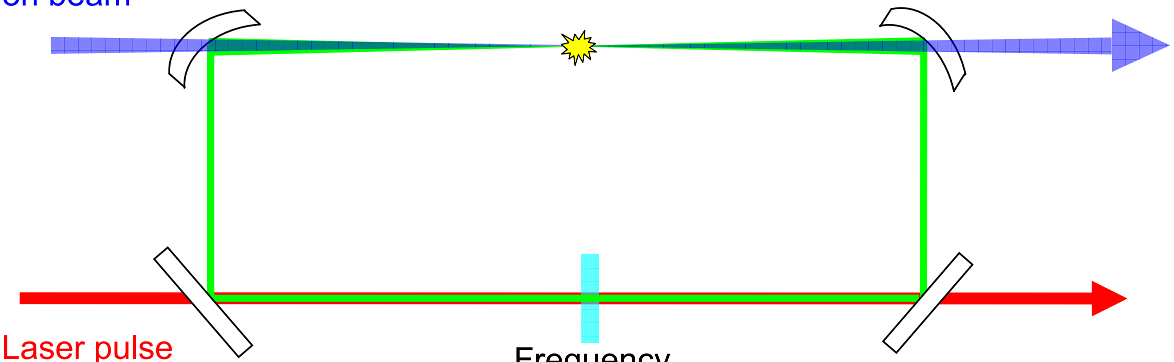
Y. Honda

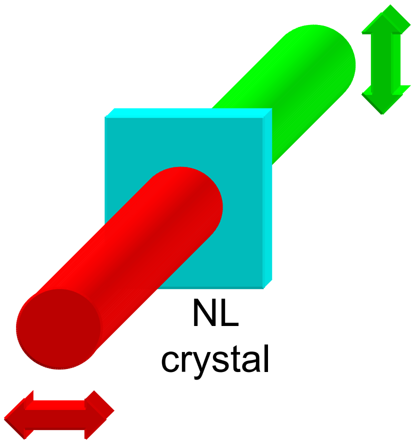
What are the problems associated with the previously proposed schemes?

Pulse stacking	Electro-optical switching	Intra-cavity operation
• Requires interferometric alignment accuracy • High repetition rate incompatible with high pulse enegy • Only a fraction of the incident laser energy is used • Limited in average power	• Susceptible to B-integral • Limited in average power due to optical switch limitations • High intracavity loss	• Low peak power - few photons overlapped with the electron bunch

A solution is desired that would be robust, based on the available laser technology, and compatible with the required pulse and beam format in ILC.

We introduce a novel method for recirculation of an intense laser pulse



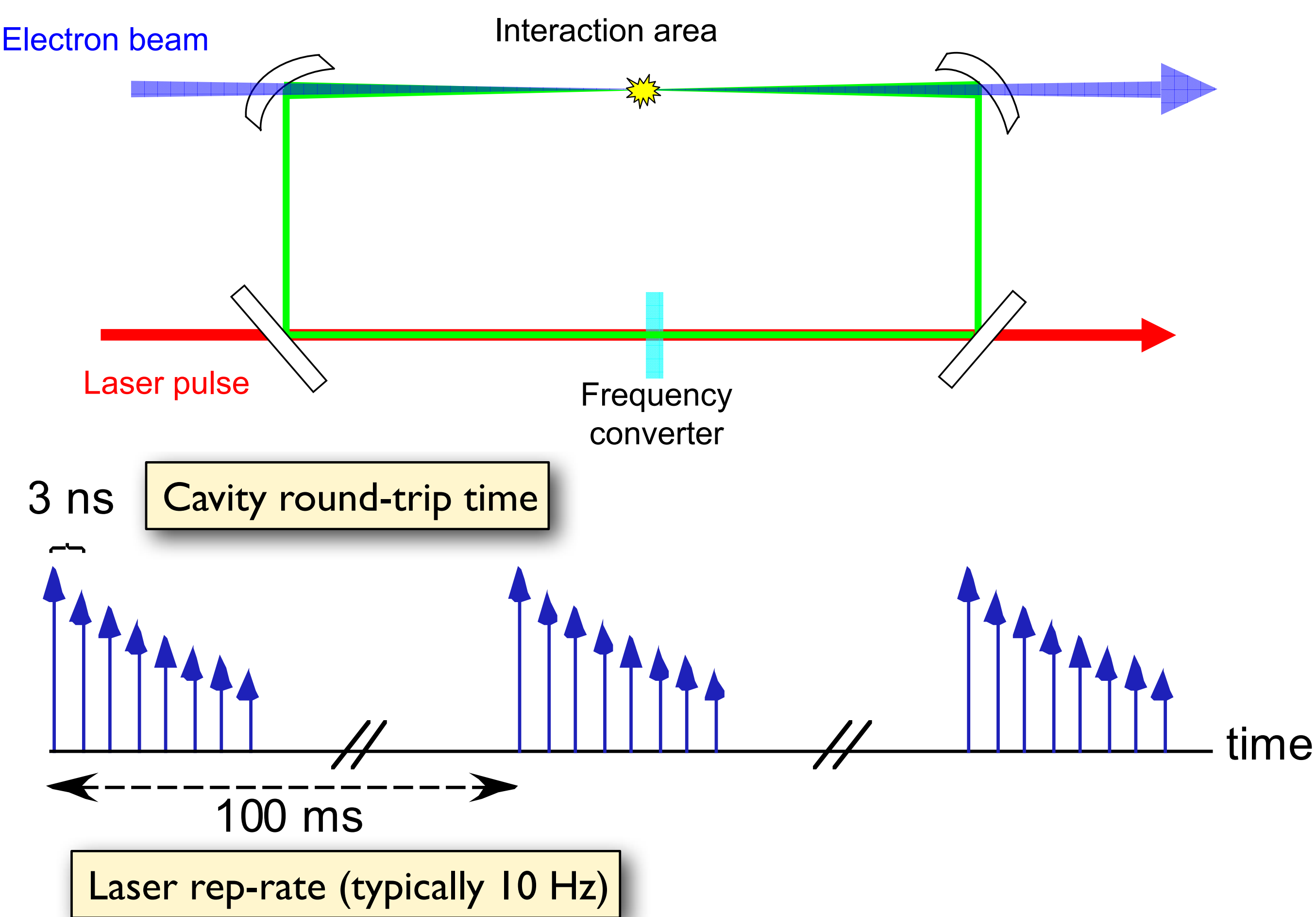


Nonlinear crystal acts as an exceptional optical switch: it modifies frequency and polarization

For picosecond pulses the crystal is **thin** and does not produce appreciable dispersion, self-phase modulation, and self-focusing. Thermal effects are also much reduced.

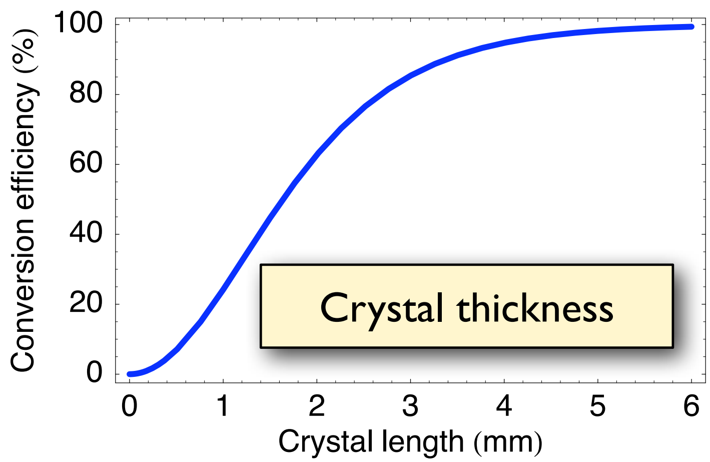
When used as a frequency doubler or tripler, this switch increases the photon energy by 2 or 3! (reduced LINAC size and cost).

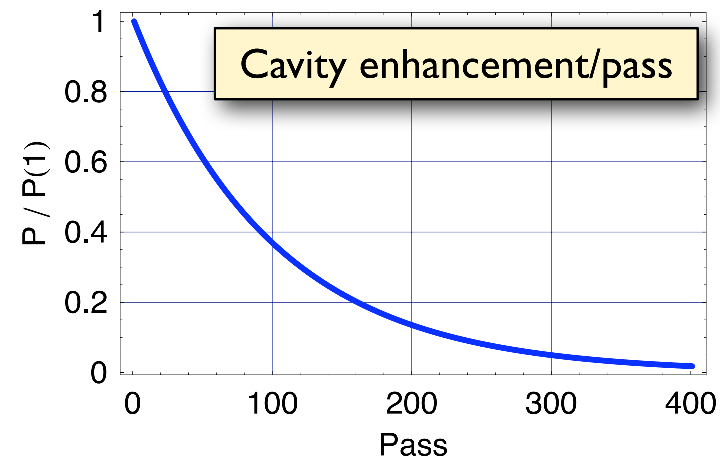
RING operates in a burst-mode

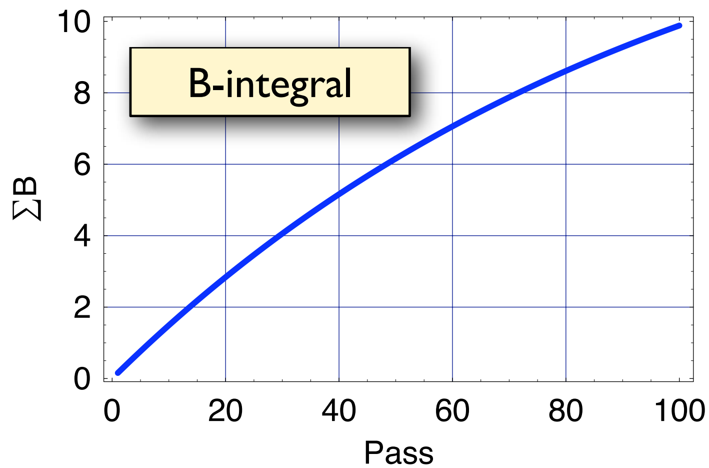


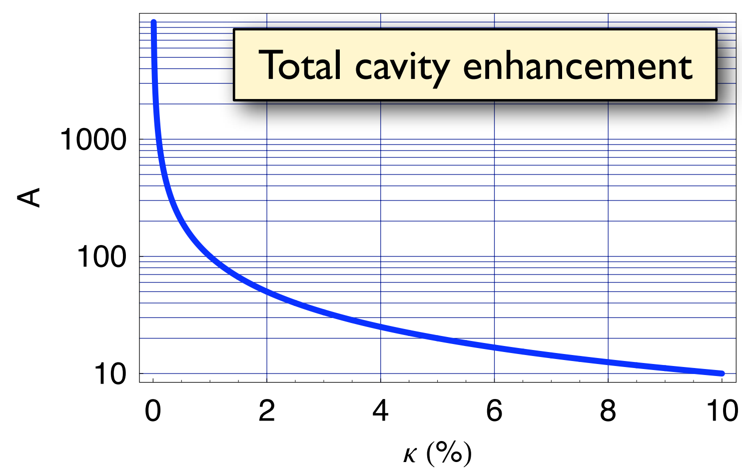
Electron beam format must match the laser pulse format

The required crystal switch thickness is short; the resulting B-integral is small

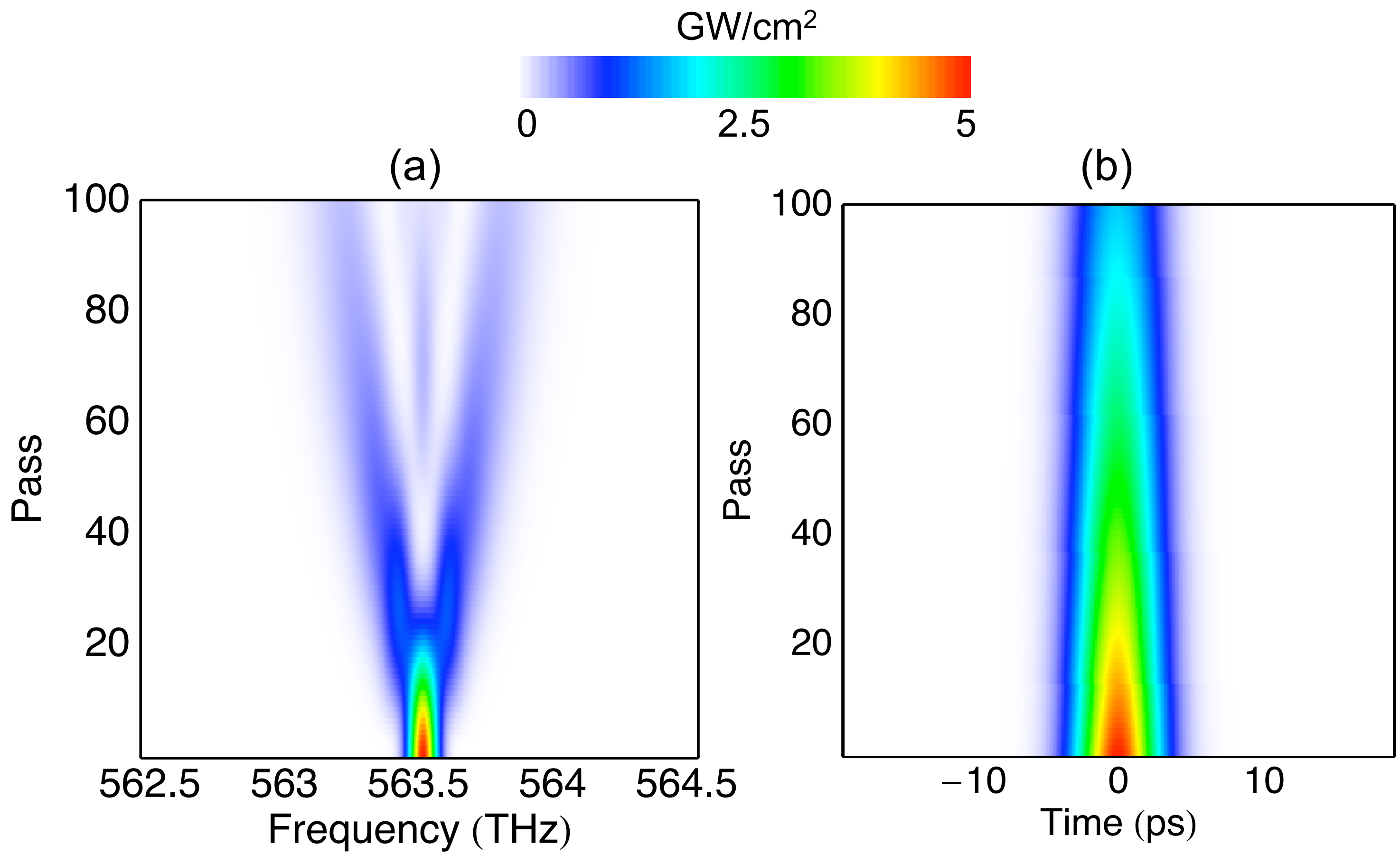






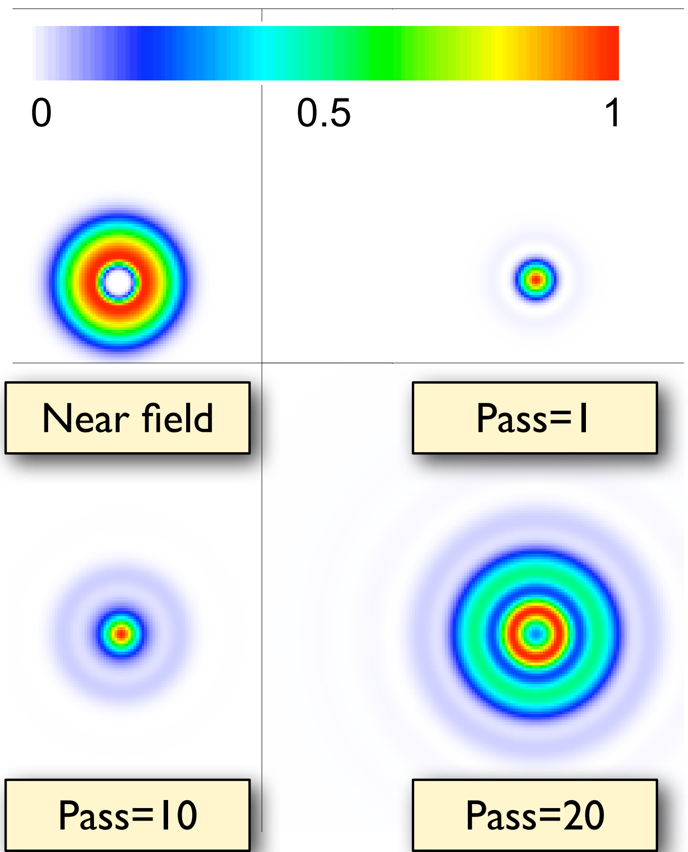


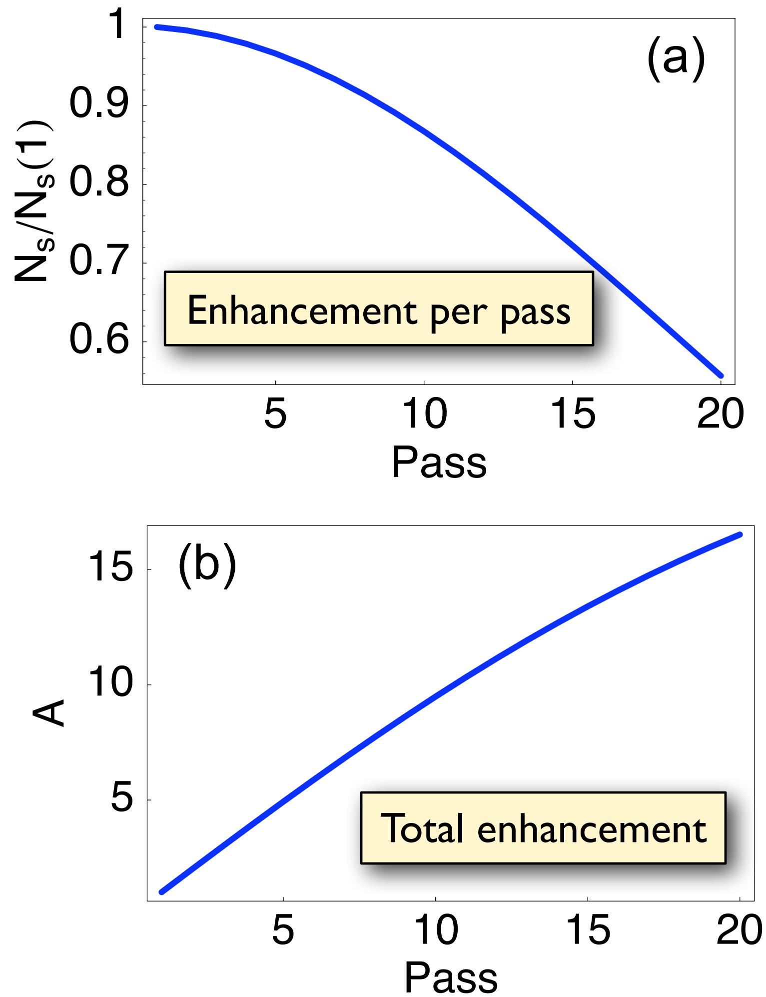
Effect of the recirculation in RING on pulse spectrum and pulse duration



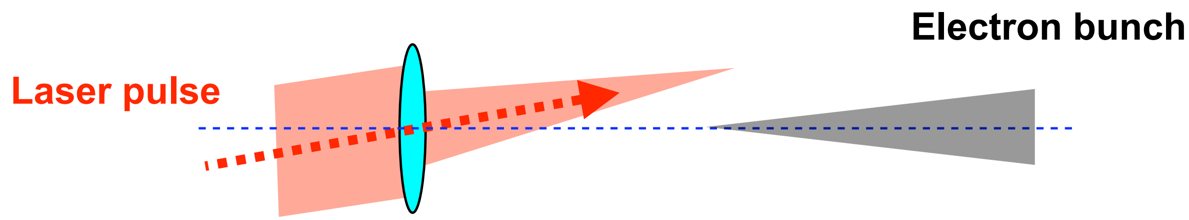
For a chosen 5-ps transform-limited pulse, the increase in pulse duration is marginal.

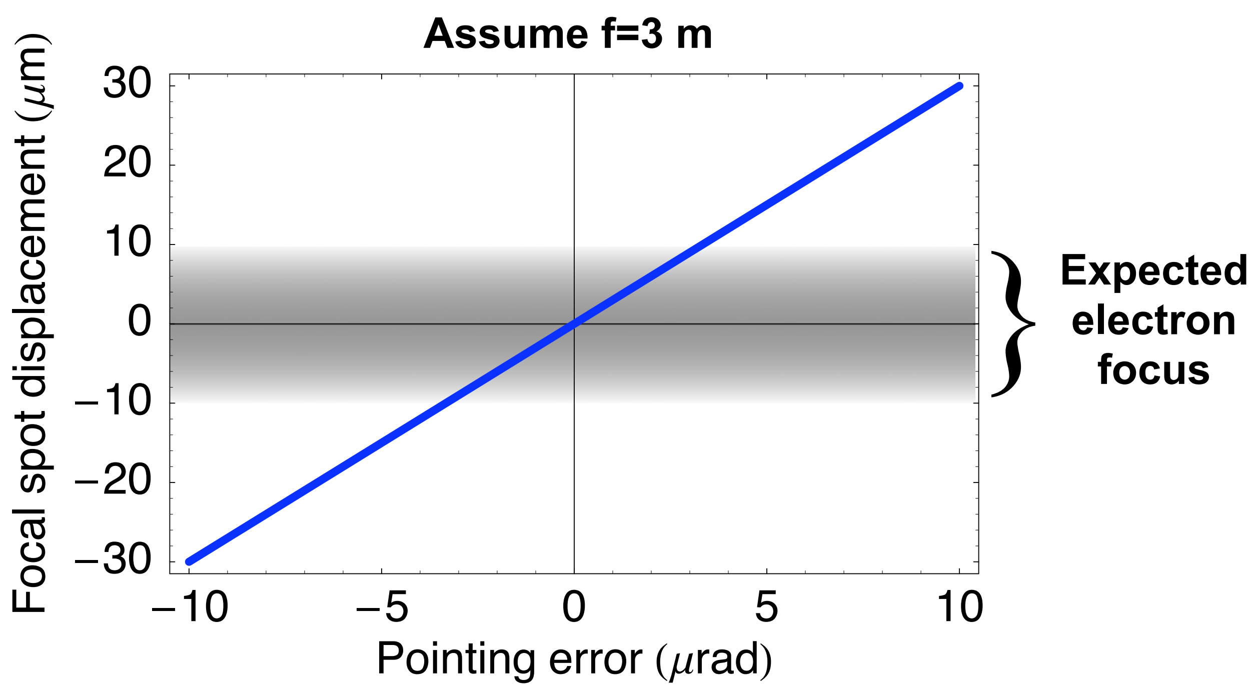
The accumulated nonlinear phase can impact the focal spot size and shape



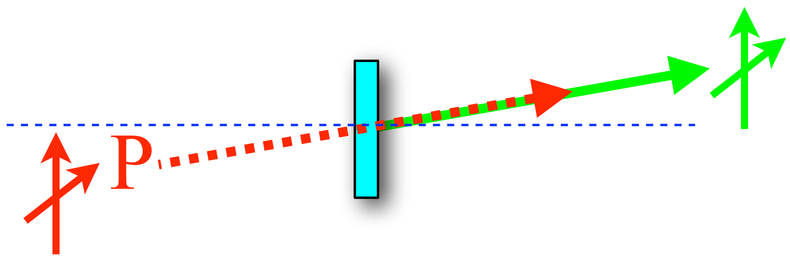


Focal region can be very sensitive to pointing error on the input

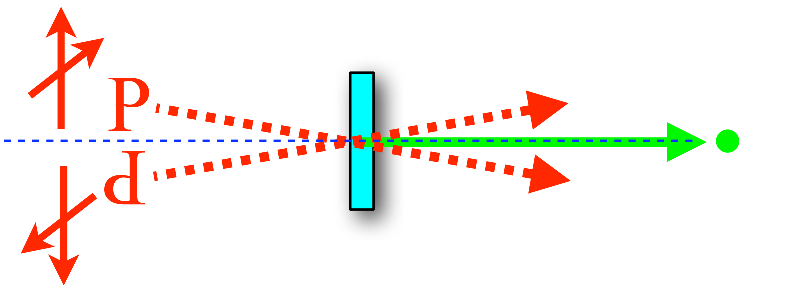




Pointing instability can be eliminated by image rotation followed by frequency mixing

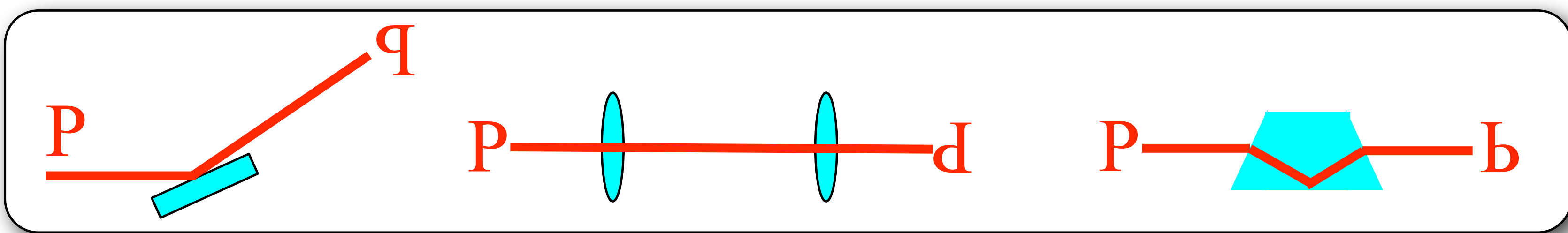


Single beam: pointing instability can lead to a difference in pointing of the injected beam

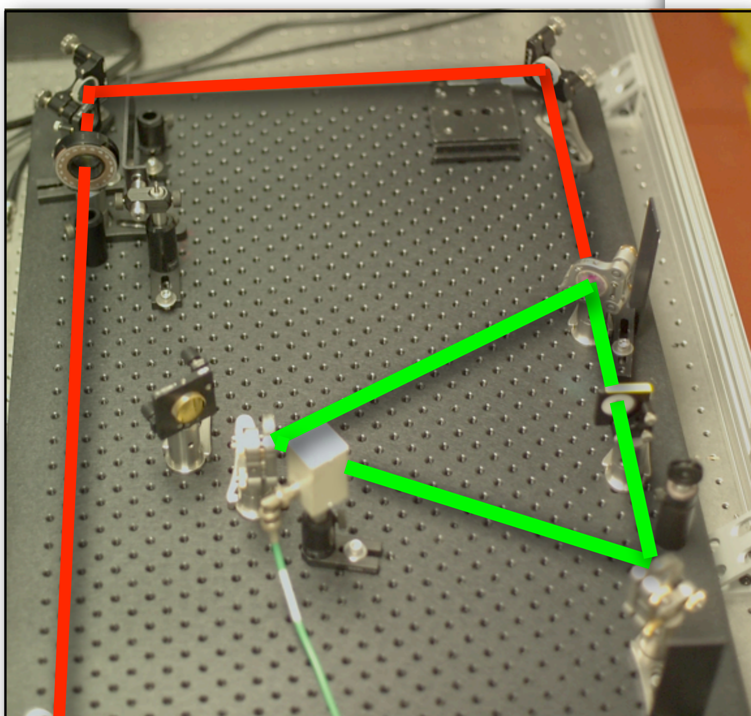


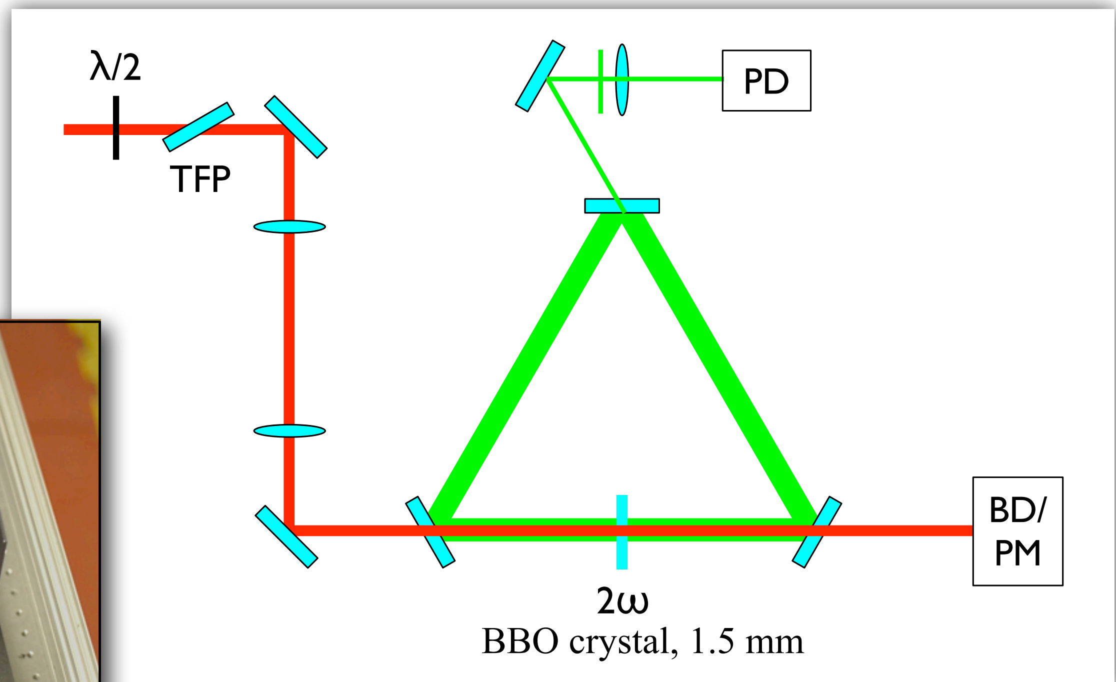
Two beams with image rotation: pointing instability is eliminated after frequency mixing

Simple methods for image rotation

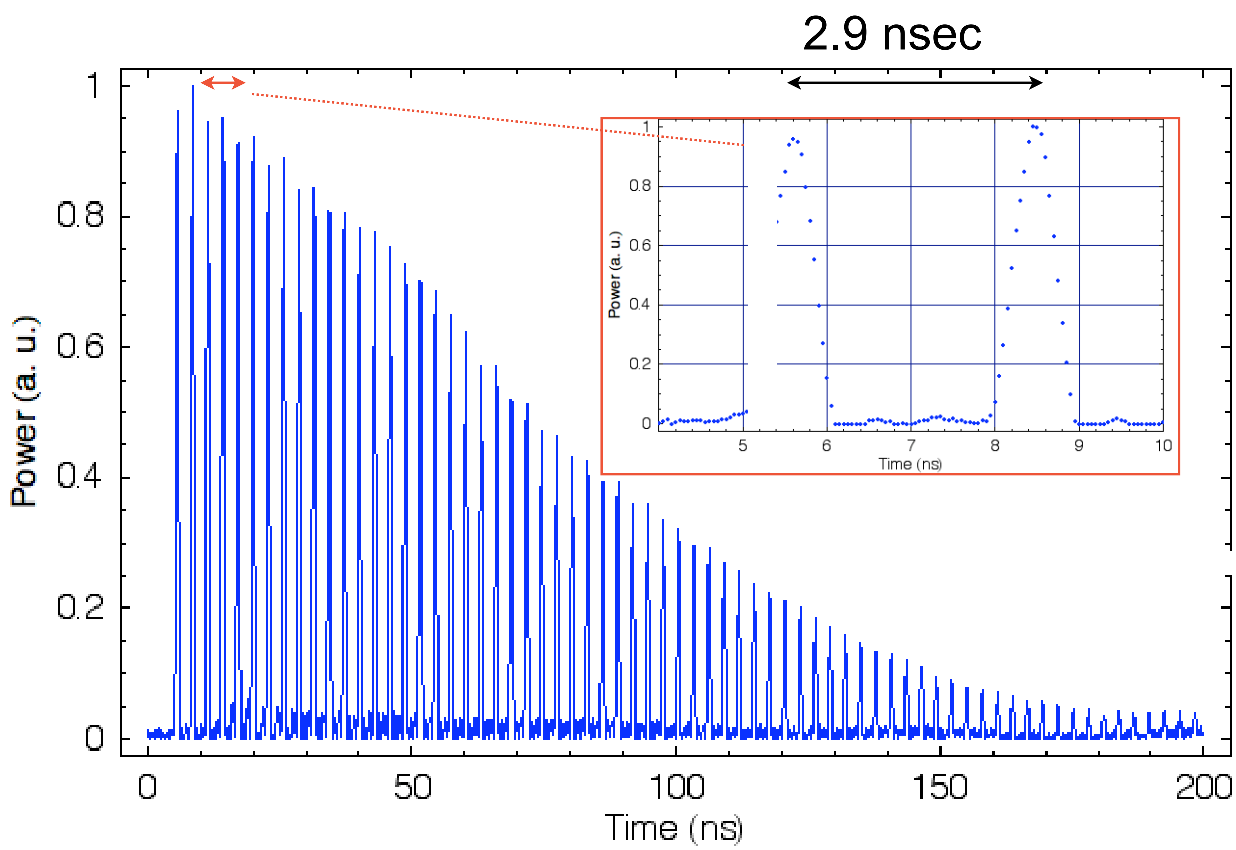


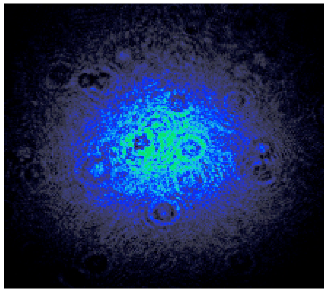
We have experimentally demonstrated the viability of the RING technique





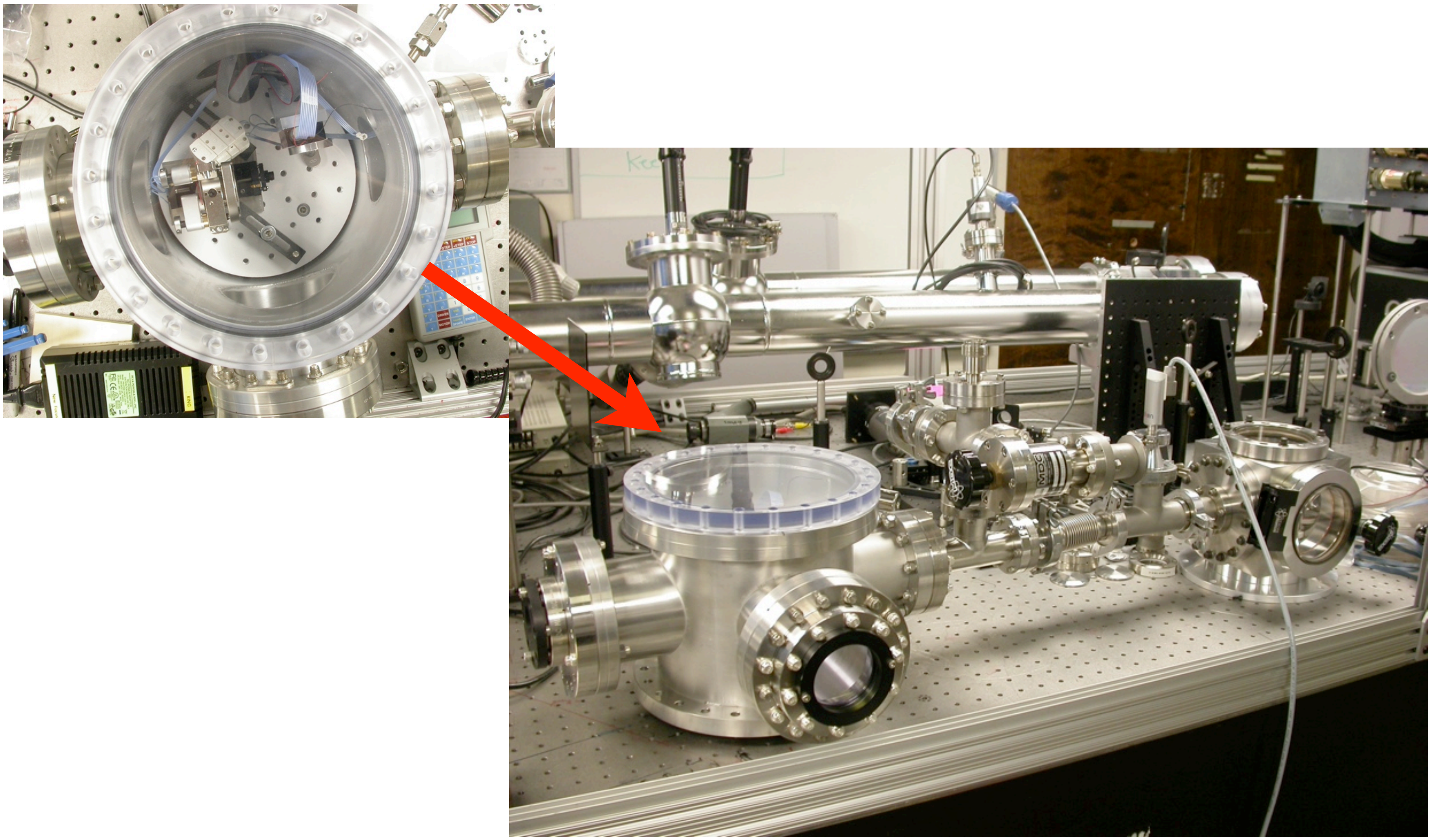
RING preliminary experimental results: cavity enhancement of 28.5x





- 80 μJ of green at pulse duration of 10 ps and ~3 mm FWHM
  - ➡ We achieved recirculation of up to 500μJ @ 1 ps, corresponding to 7 GW/cm² in the green.

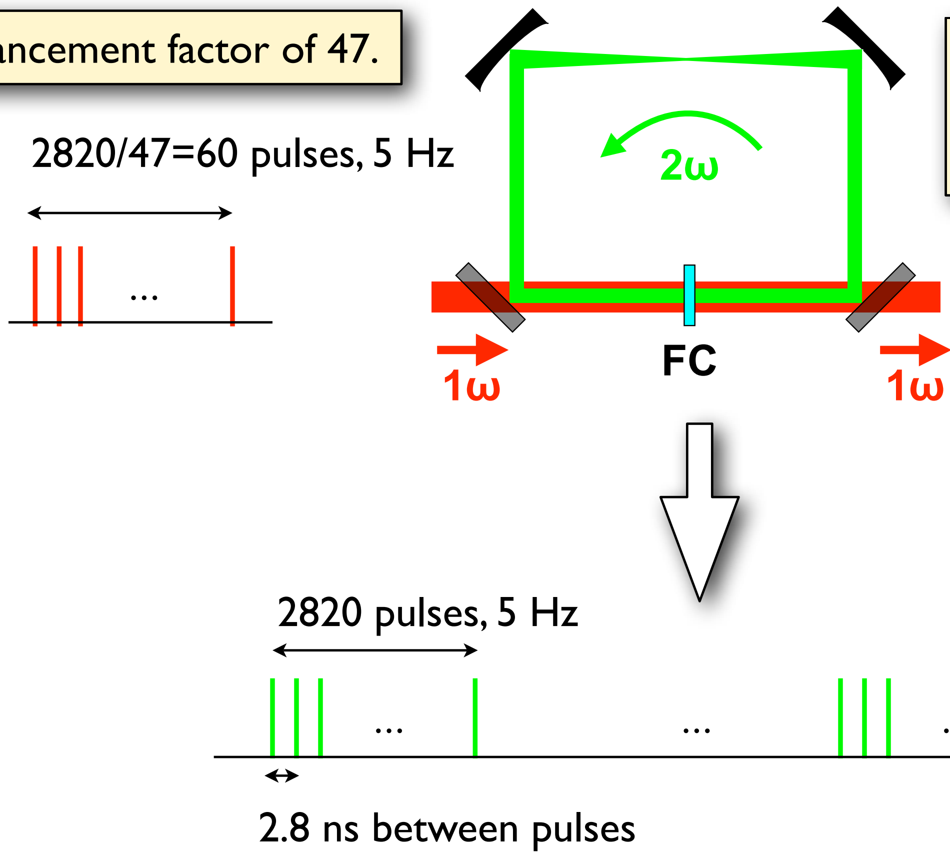
We are constructing a vacuum RING cavity



RING in cold accelerator technology (ILC)

Assume enhancement factor of 47.

Cavity length is the length of the incident laser pulse train.

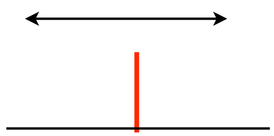


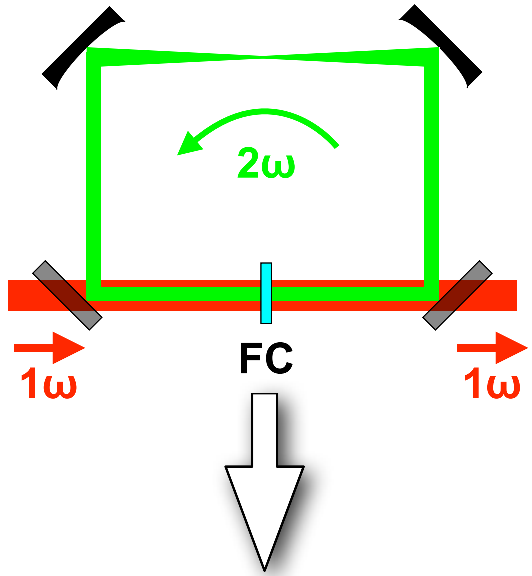
Cavity length: 60 x 2.8 ns = 168 ns

RING in warm accelerator technology (NLC)

Assume enhancement factor of 95.

1 pulse, 120 Hz





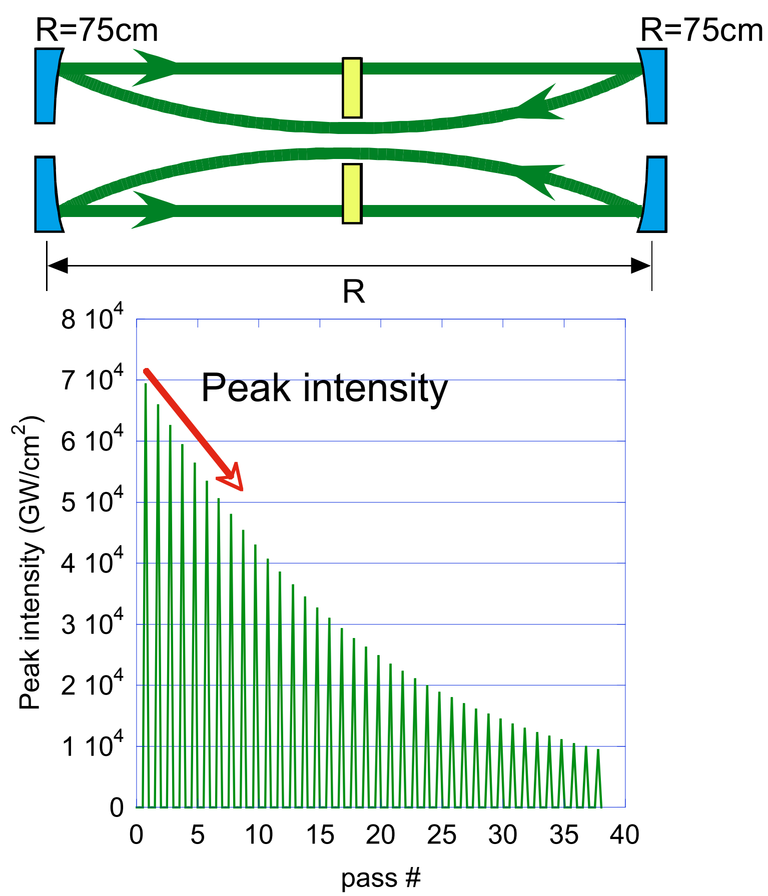
Cavity length is the resulting inter-pulse delay = 337 ns

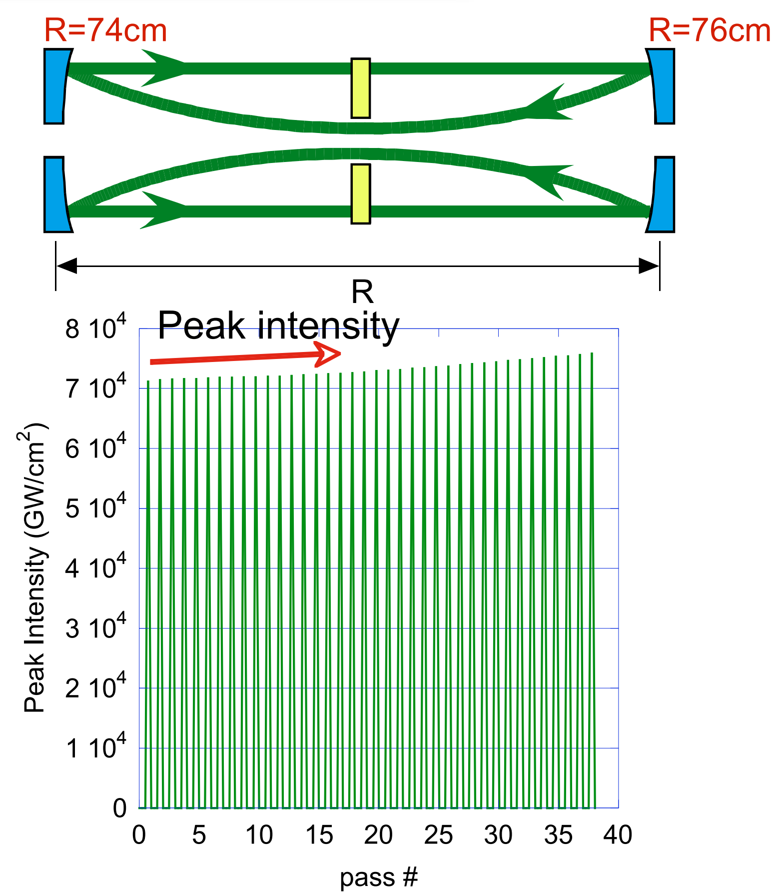
95 pulses, 120 Hz

337 ns between pulses

RING reduces the requirement on the pump laser average power by the enhancement factor.

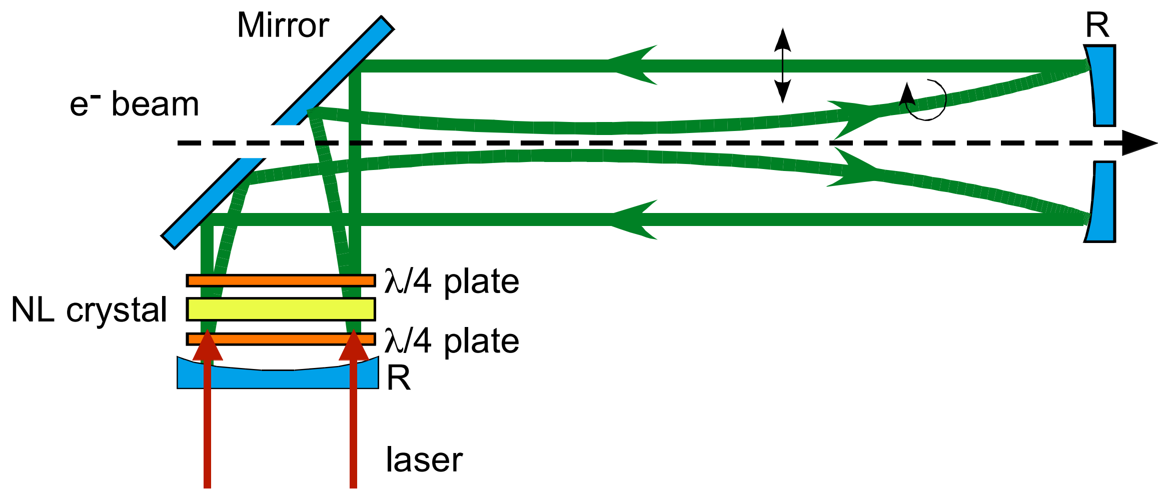
RING can operate without loss in intensity if a magnifying cavity is used





Magnification of the beam on cavity mirrors on each pass can compensate for the loss of intensity due to optical losses or beam quality degradation.

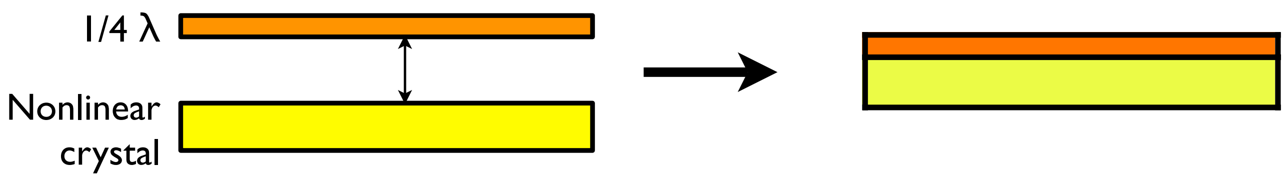
RING can be used to produce a circularly polarized beam

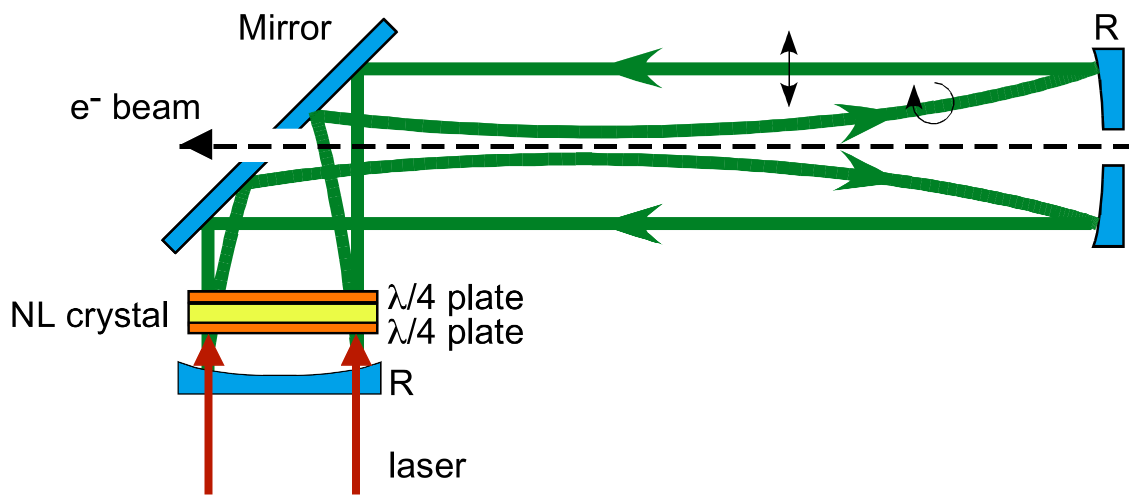


- A quarter-waveplate after the nonlinear crystal will convert linear to circular polarization.
- A second quarter-waveplate will keep the same handedness of the polarization at the focus after each roundtrip.
- The crystal and the waveplates are out of the electron path
  - Compatible with GeV and TeV electron beams

Fresnel losses can be minimized by attaching the waveplate to the crystal

Waveplate grown from the same crystal substrate could be diffusion bonded to the crystal



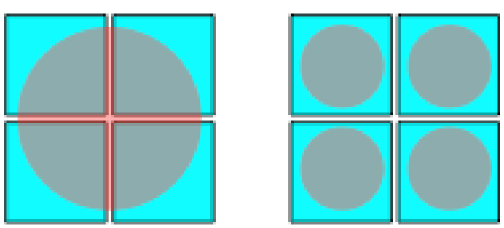


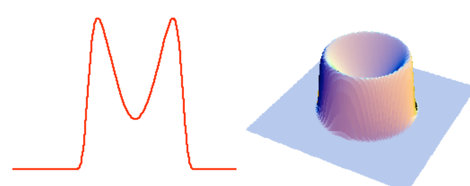
- Waveplate thickness adds 10s of microns to the total crystal thickness (~1%)
- Optical quality can be as good as the crystal finish

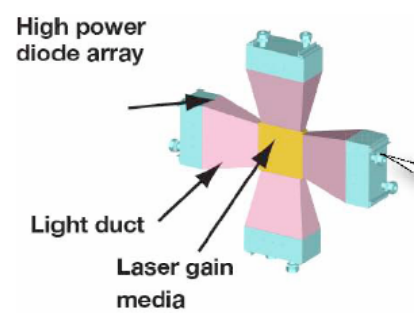
Scaling of the RING cavity to high power

Laser energy ~ 1J; Pulse duration ~ 10 ps; Rep-rate ~ 1.4 kHz

High peak intensity	High thermal gradient in the NL crystal	High average power
increase beam size spatially and temporally multiplex the laser beam	Spatial format of the laser beam can compensate for the thermal gradient Other ideas/technologies are needed!	Ceramic laser technology holds promise for high average power short pulse operation

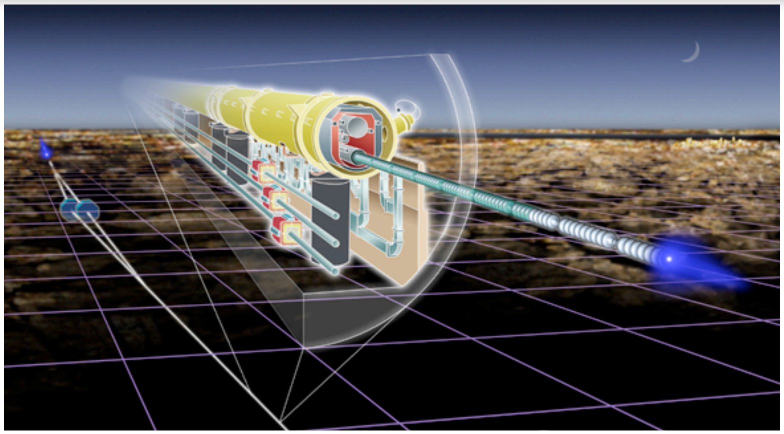




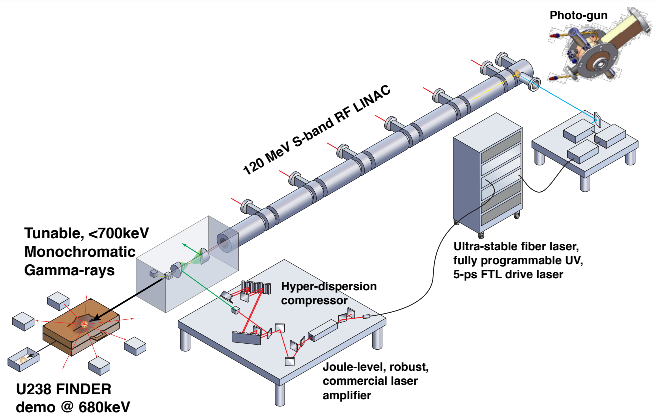


Sample applications

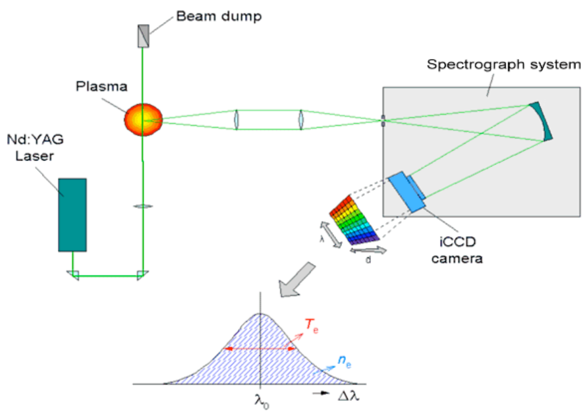
Gamma-gamma collider



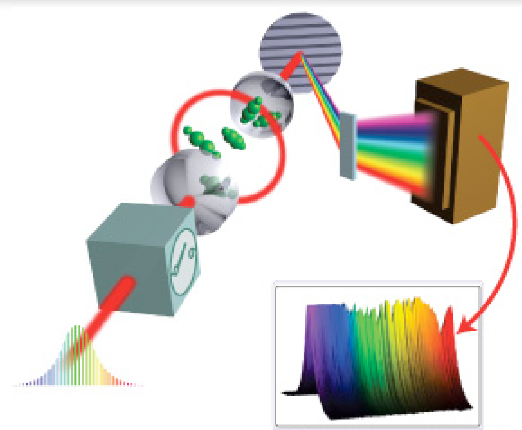
Nuclear spectroscopy



Plasma diagnostics



Cavity ring-down spectroscopy



Conclusions

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Nuclear Instruments and Methods in Physics Research A 578 (2007) 160–171

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

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High-power laser pulse recirculation for inverse Compton scattering-produced γ-rays

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Received 24 April 2007; accepted 24 April 2007
Available online 8 May 2007

- RING cavity can increase the effective average power of the laser system by up to 100x
- RING cavity architecture is compatible with recirculation of high energy short laser pulses
- Compared to other "photon trapping" designs, RING cavity has 10x lower B-integral accumulation
- Compared to resonant enhancement schemes, RING cavity does not require interferometric stabilization
- Experimental work is underway to demonstrate recirculation of joule-scale pulses