High Power Picosecond Laser Pulse Recirculation

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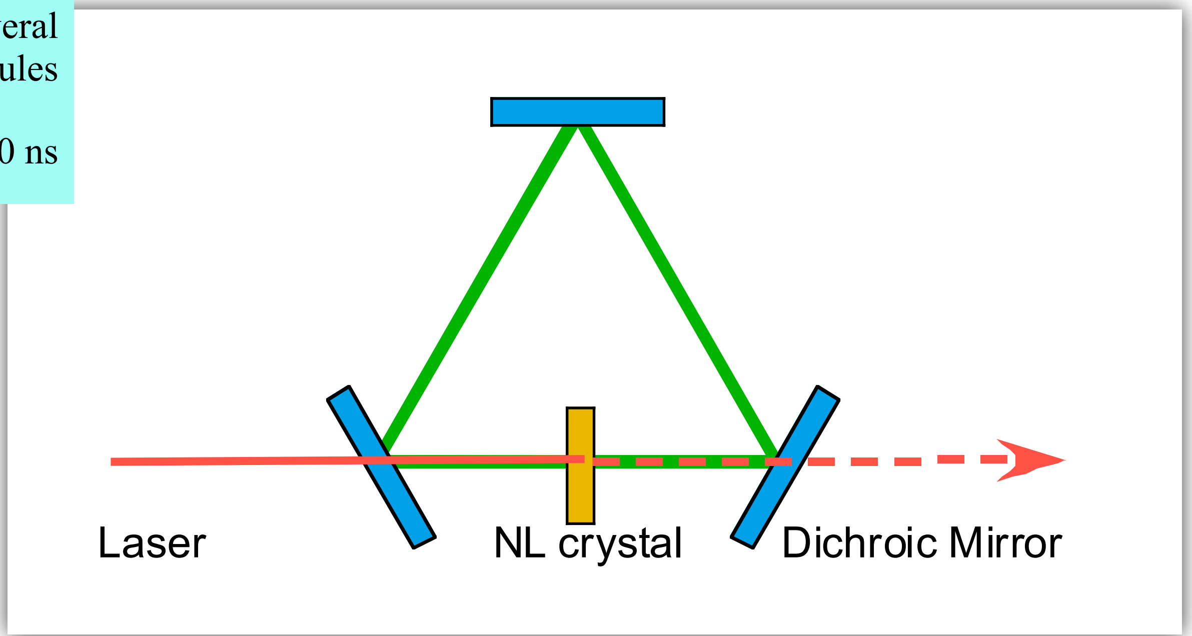
Outline

- High brightness, narrowband gamma-ray generation at LLNL
- Recirculation Injection by Nonlinear Gating (RING) concept
  - Experimental results
  - Current design
  - Application to polarized positron generation

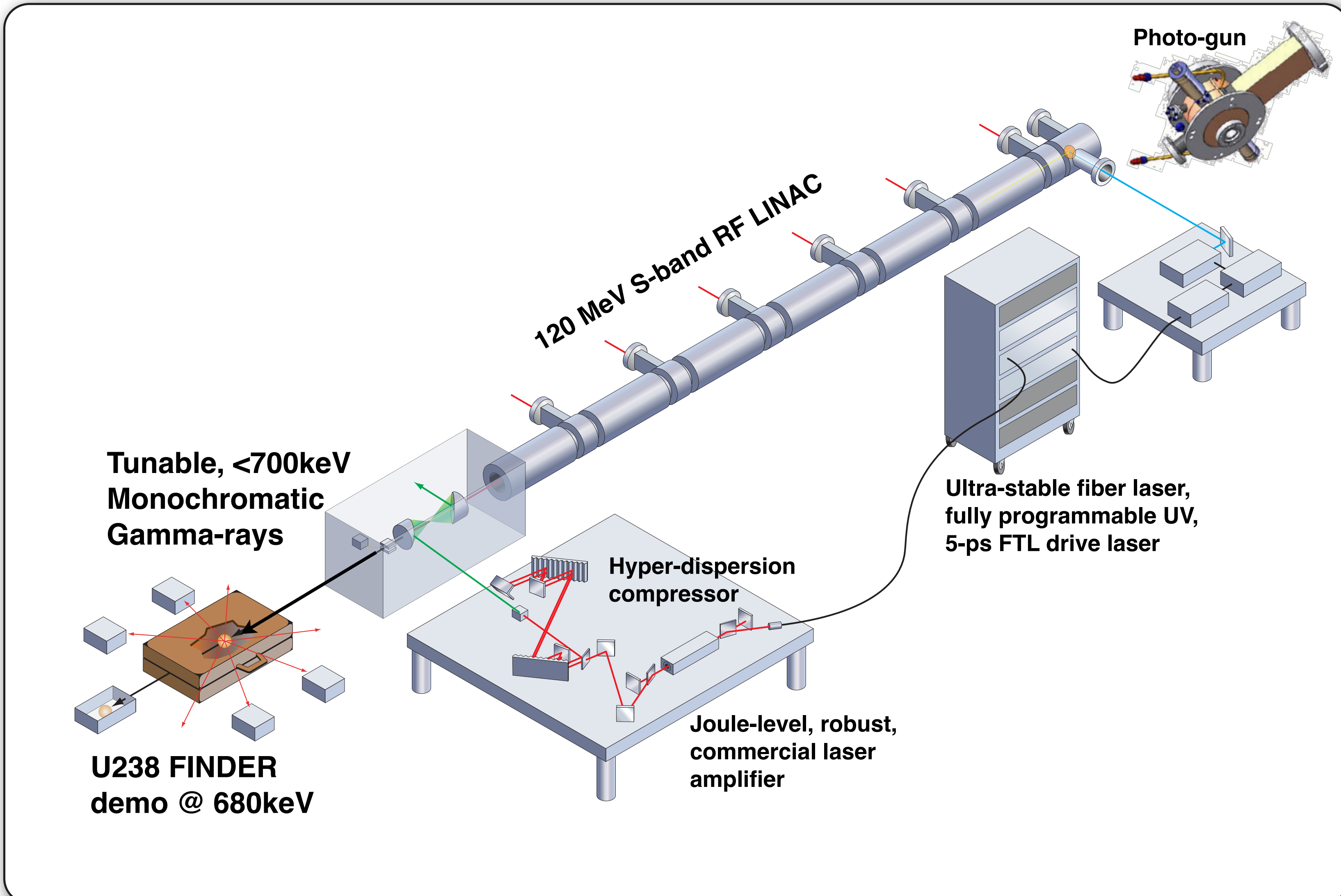
We describe a novel technology for storage and recirculation of high peak power, short laser pulses

Effective Average Power Enhancement	up to 20x
Pulse Energy	up to several Joules
Pulse Duration	100 fs - 10 ns



- Recirculation Injection by Nonlinear Gating (RING) is based on nonlinear frequency conversion of the incident laser pulse inside an optical cavity.
- The residual fundamental frequency is transmitted through the mirrors.
- The frequency doubled beam becomes trapped.

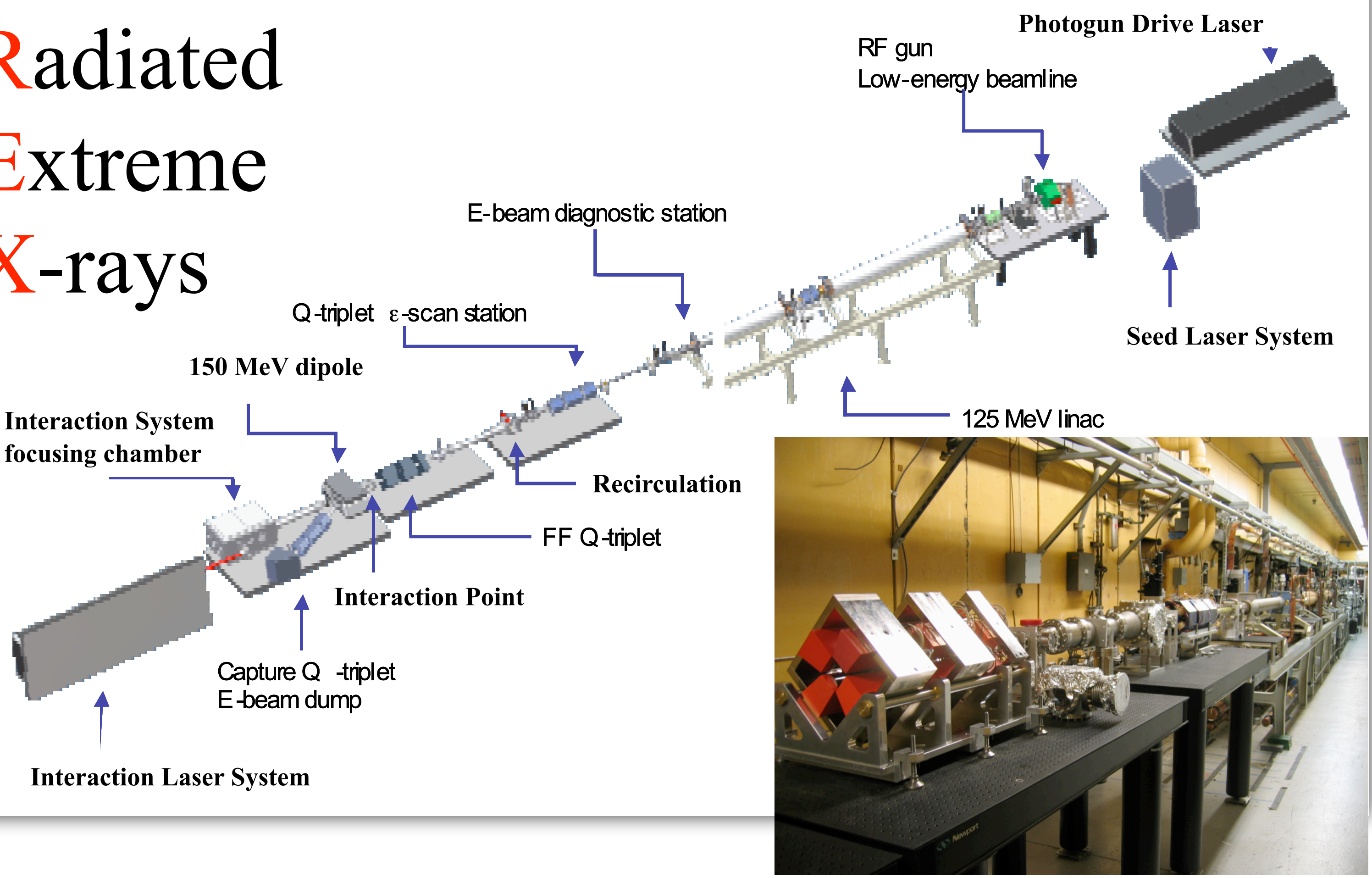
RING would increase the efficiency of Compton-scattering generated X-rays by more than 20 times



Low Thomson cross-section ($\sigma=0.67\times10^{-24}$ cm^2) results in laser to X-ray conversion efficiency, $\eta\sim10^{-8}$-10^{-10}

High peak brightness MeV-class narrowband gamma ray source is being built at LLNL

Thomson
Radiated
Extreme
X-rays



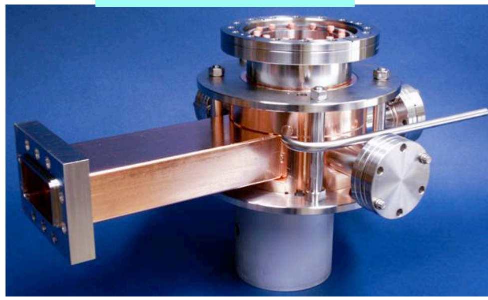
T-REX incorporates major advances in laser and electron beam technology

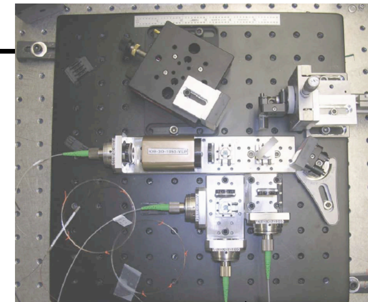
Photogun

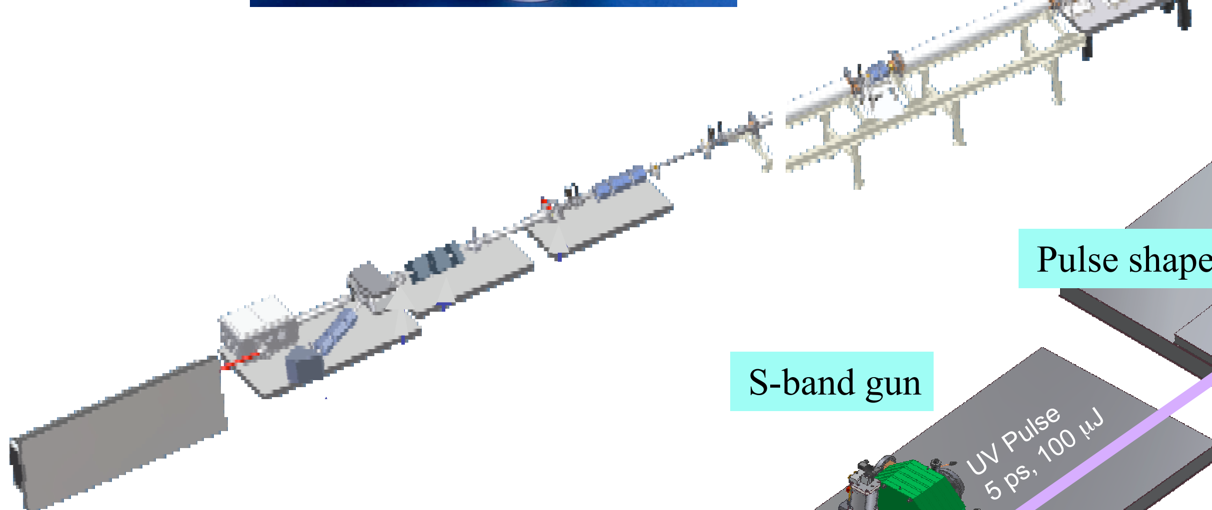
Mg cathode

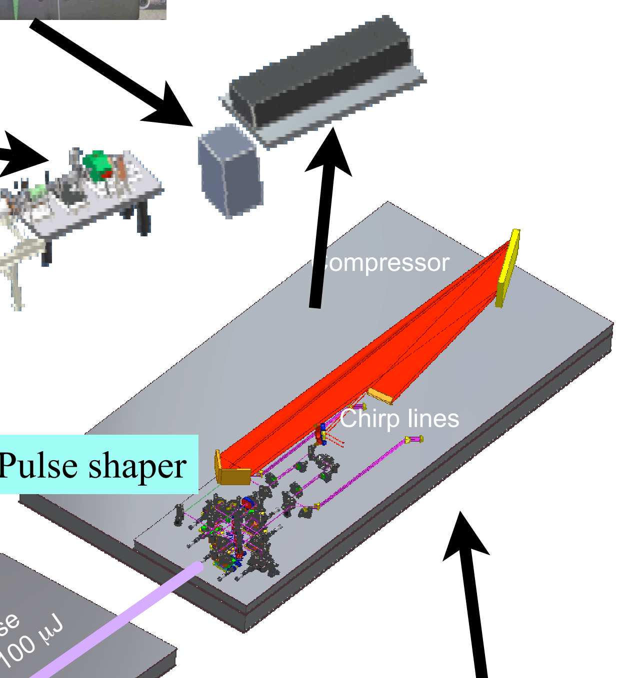
Gradient	120 MV/m
emittance	0.7 mm.mrad
charge	1nC
Energy	6 MeV

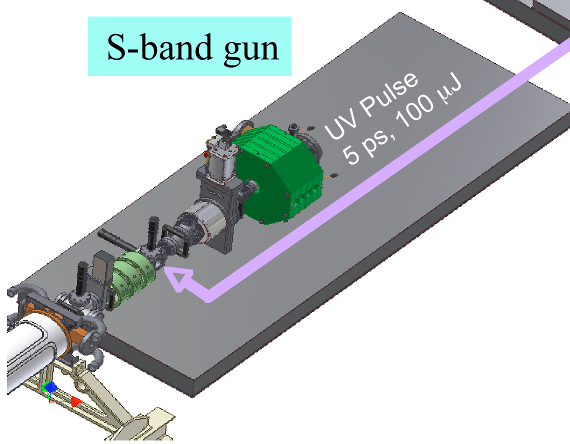
S-band RF gun

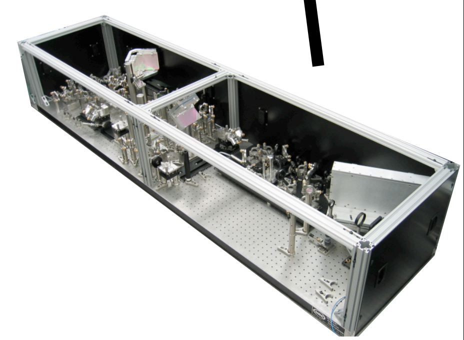








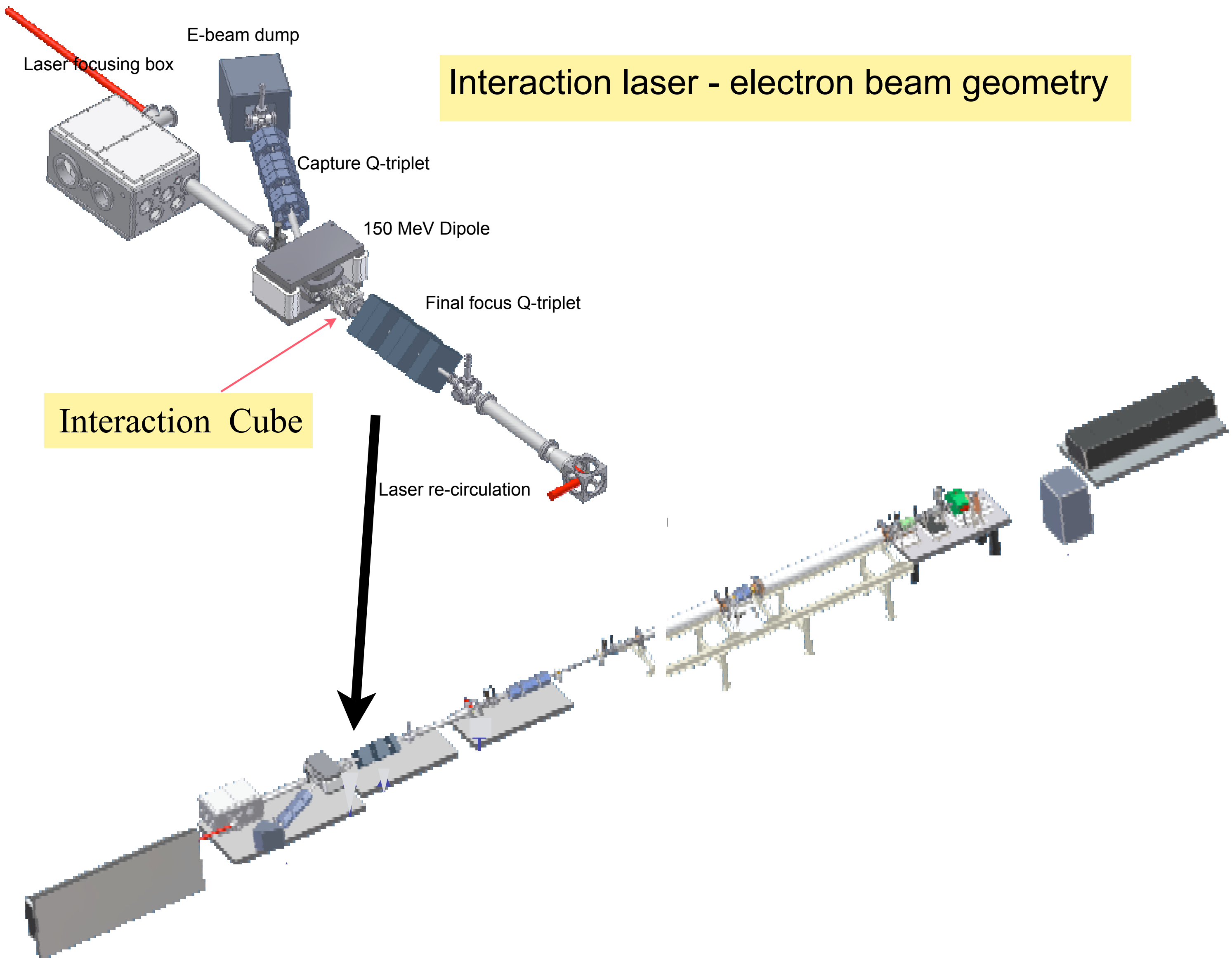




Photogun laser

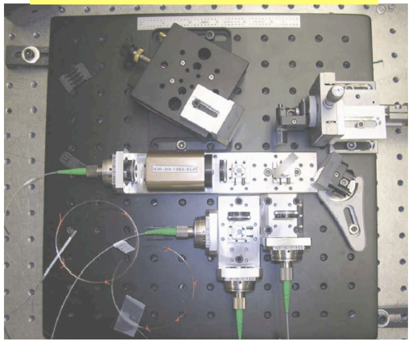
- Highly compact fiber based oscillator and amplifier design (500 μJ, 200 fs)
- High throughput MLD grating compressor
- Temporal shaping of the UV pulse to a "beer-can" format

Gamma rays will be produced during head-on collision of 120 MeV electrons and a few Joule 10 ps laser pulse

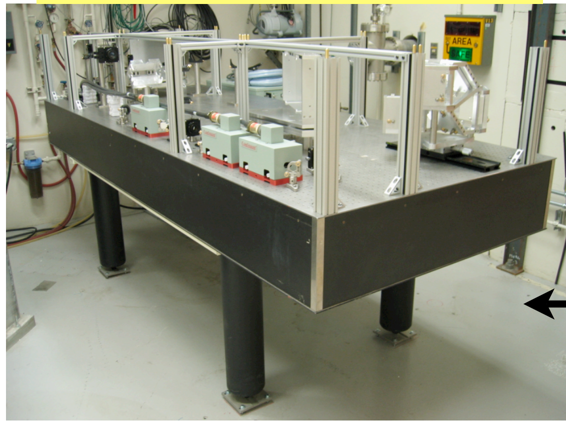


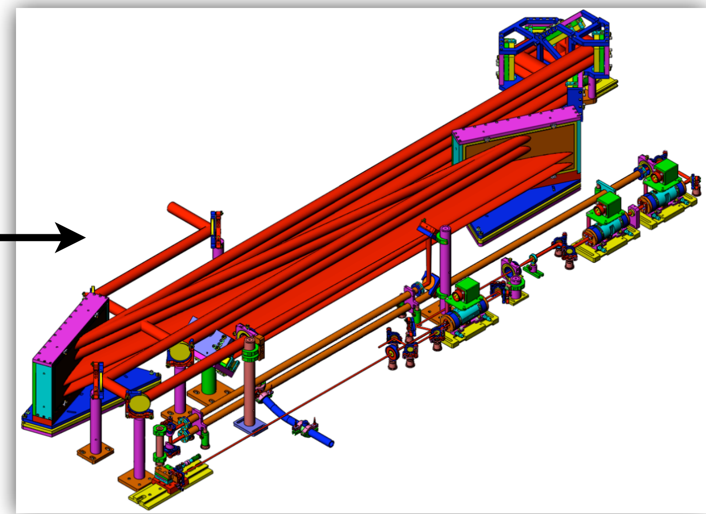
Interaction laser will produce up to 3J of IR at 10 ps

Fiber Laser Front End



Multi-pass amplifier + Compressor

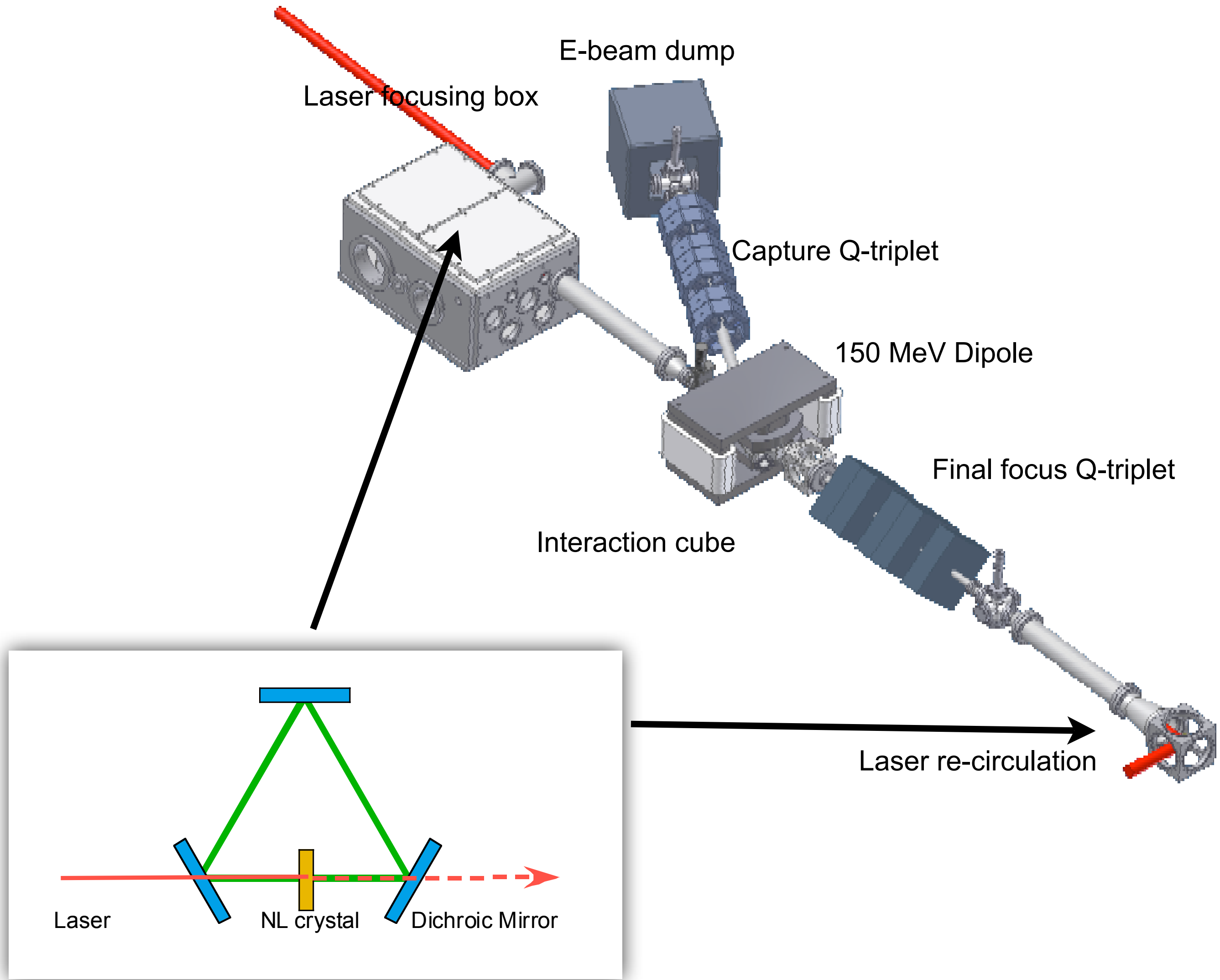




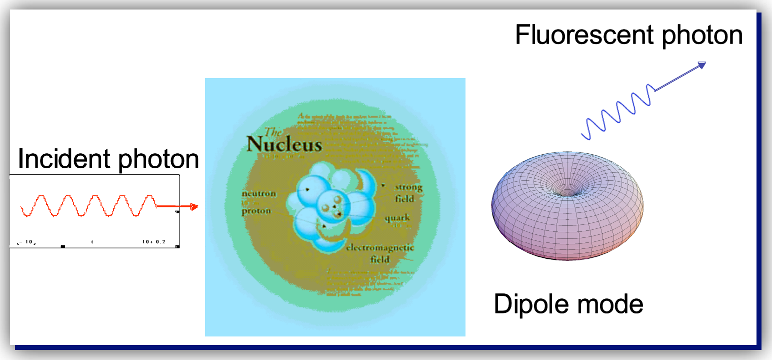
Chirped pulse amplification at 10 ps

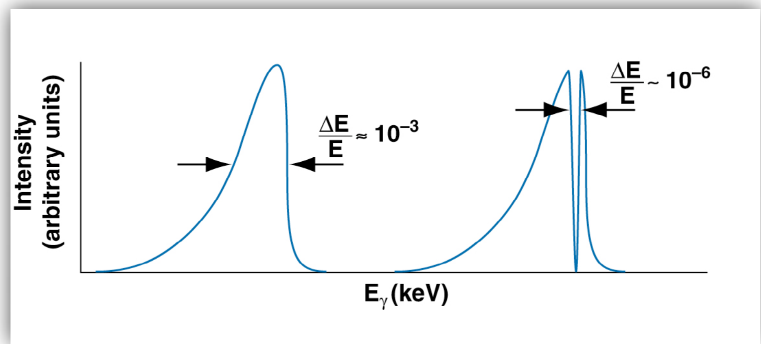
- State of the art interaction laser
    - Fiber Front end (500 µJ, 200 fs transform limit)
    - Chirped Fiber Bragg grating stretches the pulse to 6 ns prior to amplification
    - Commercial Nd:YAG power amplifier
    - Hyper-dispersion compressor (3m x 1m footprint)
        - **Standard compressor required for our narrowband pulse would be 34 m long**

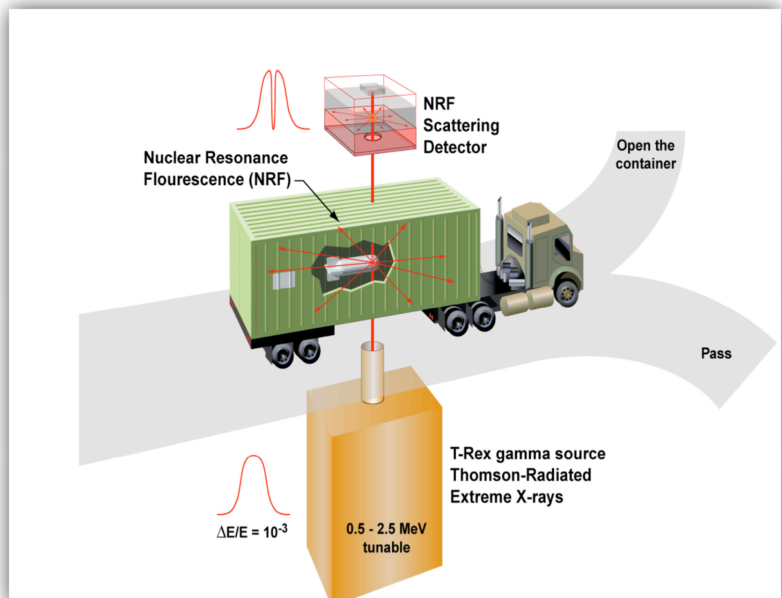
RING cavity would be integrated with the T-REX system

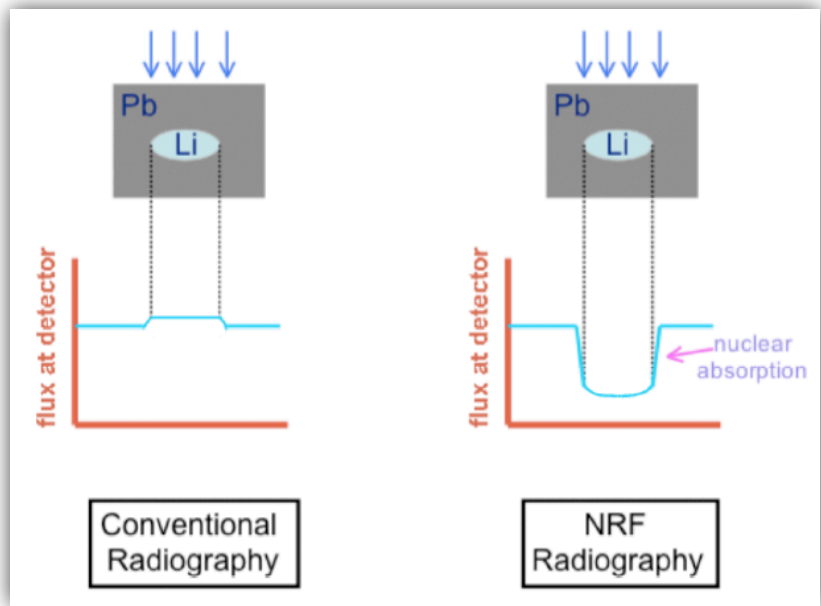


T-REX system will be commissioned for NRF detection and radiography applications



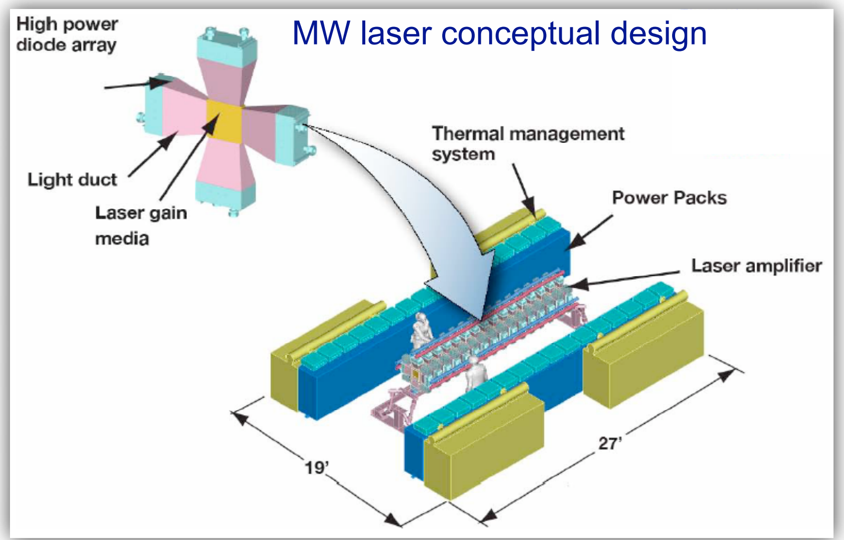


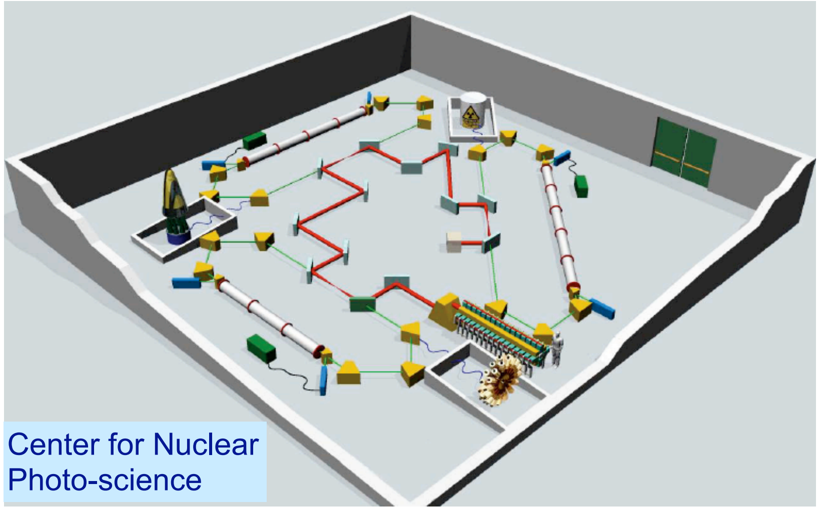




We envision T-REX growing into a center for nuclear photo-science

Energy-recovery linacs
Superconducting linacs
Superconducting rf guns
Tailor-aperture ceramic lasers
Nonlinear trapping

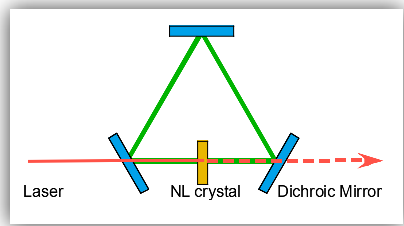


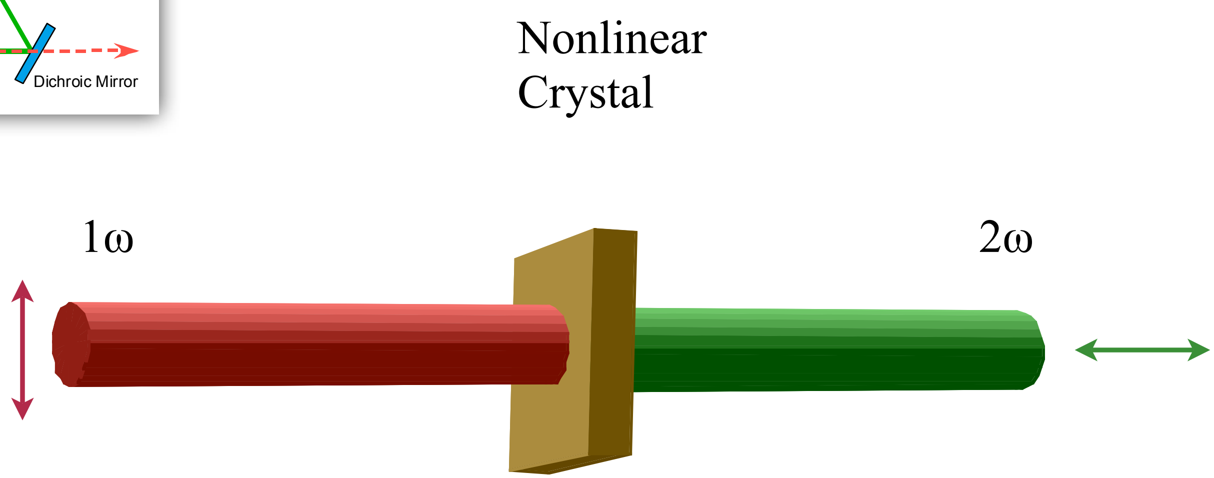


kW-average gamma-ray flux
Isotopic imaging
Inverse density radiography
gamma-induced fission
Parity measurements

Details of RING Cavity

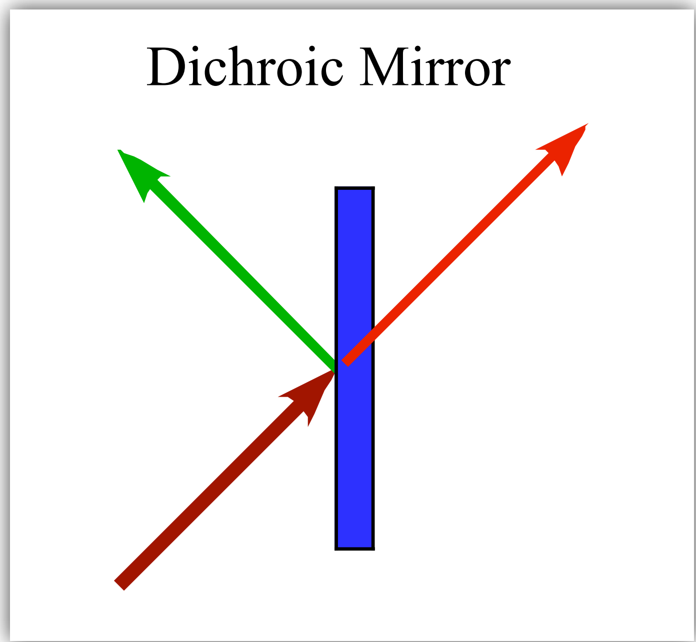
Nonlinear frequency mixing acts as a switch inside the cavity





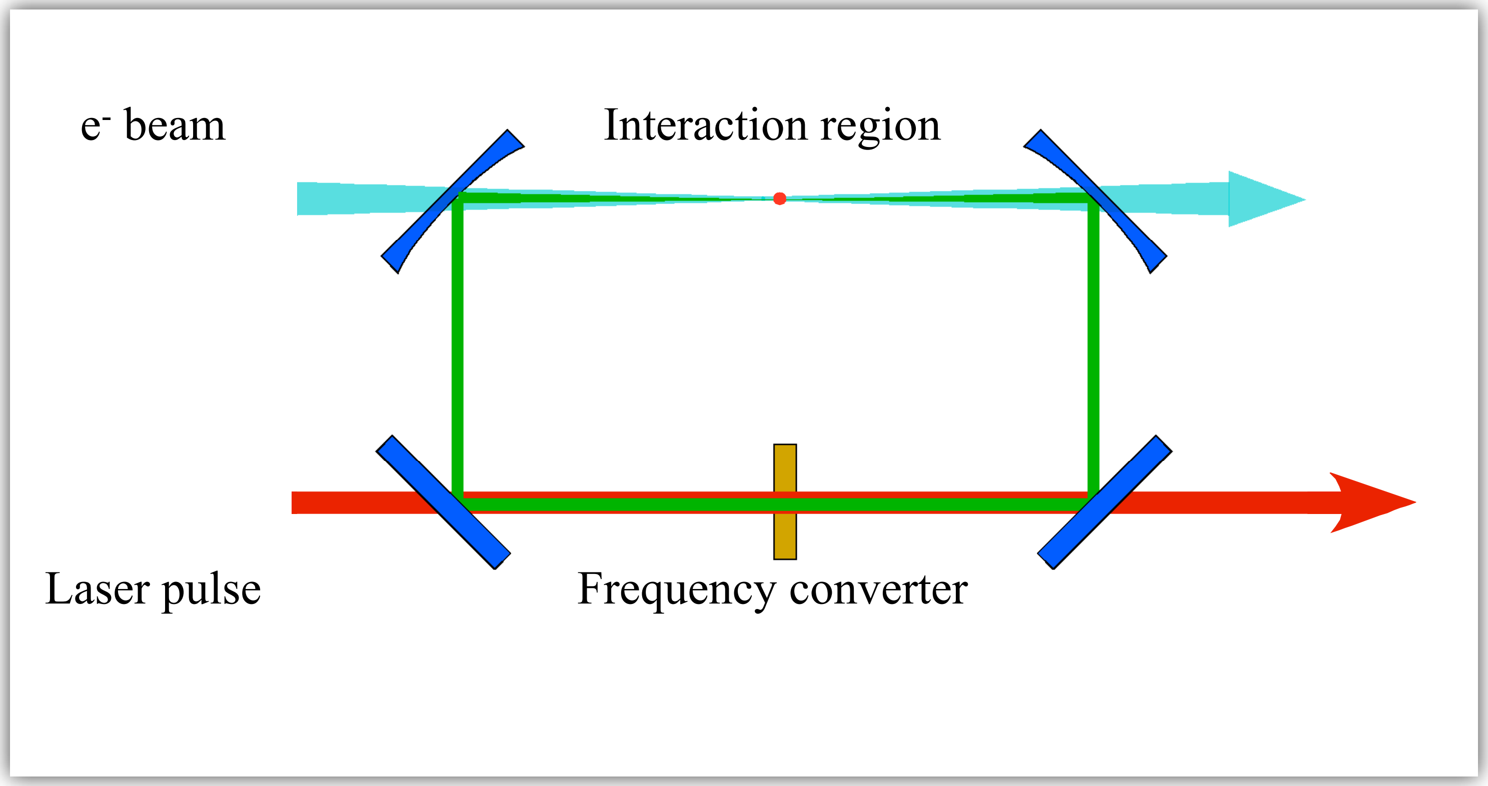
- Conversion efficiency from the fundamental to the 2nd harmonic can be up to 80%.
  - Photon energy is increased
- For short high peak power pulses, crystal thickness is ~1mm
  - Nonlinear effects and pulse dispersion are minimized
- Minimal absorption and reflection losses
- Nonlinear process also modifies beam polarization

Dichroic mirrors allow wavelength selective transmission and reflection



- Generated 2nd harmonic reflects off the mirror
- Residual fundamental beam is transmitted through the mirror out of the cavity
- Reflectivities better than 99.9% can be achieved
- Polarization difference can further increase the performance of the coating

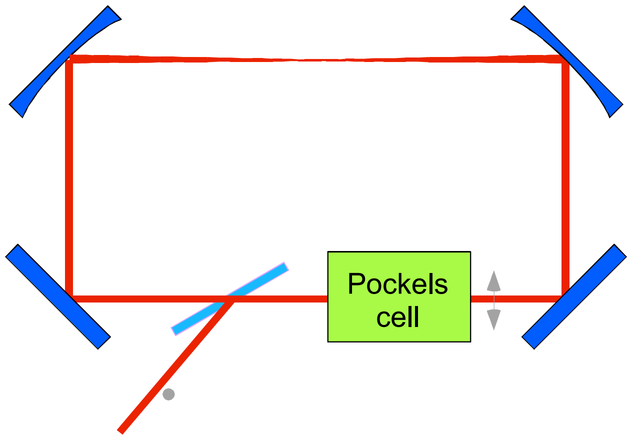
RING cavity for enhancing photon-electron interactions allows recirculation of Joule-class, few picosecond pulses



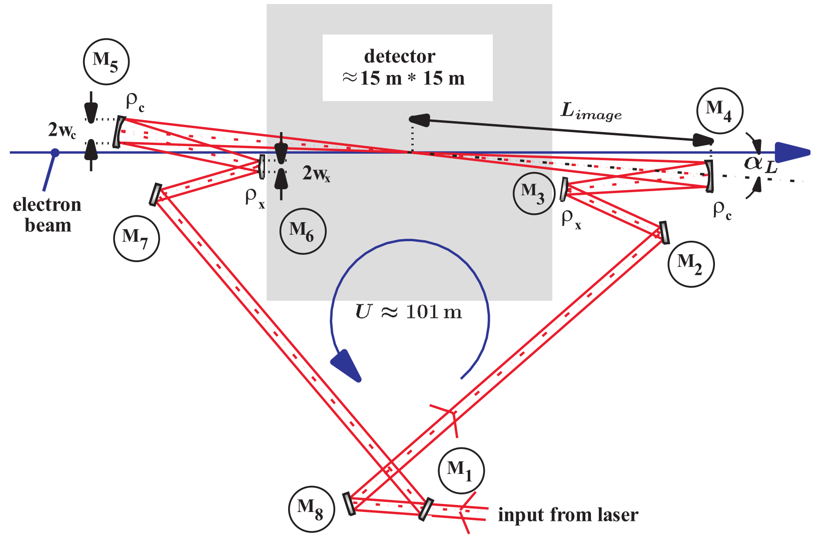
Laser-electron interaction occurs at the overlapping focus inside the cavity.

Alternative schemes for pulse recirculation include resonant cavity coupling and active pulse switching out of the cavity

Electro-optic pulse switching



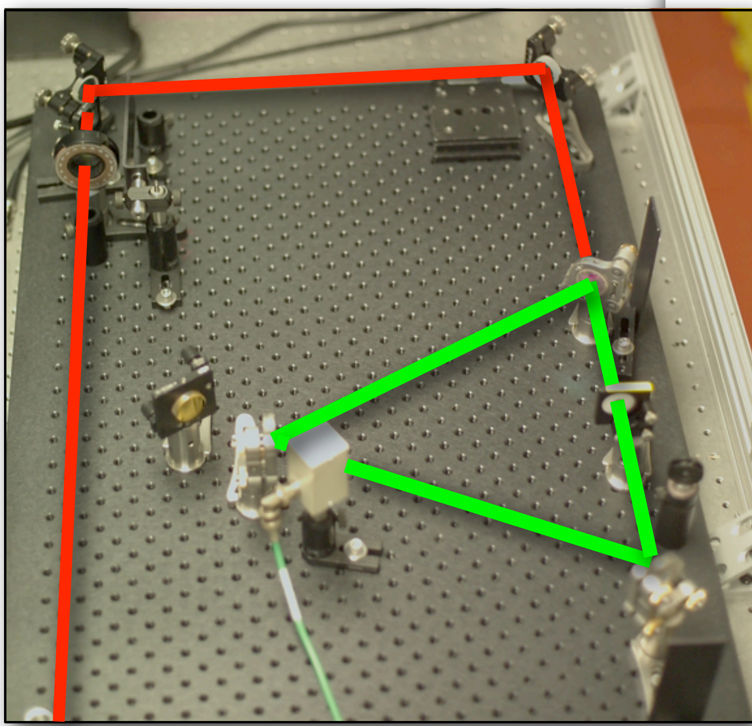
Resonant cavity loading (TESLA design)

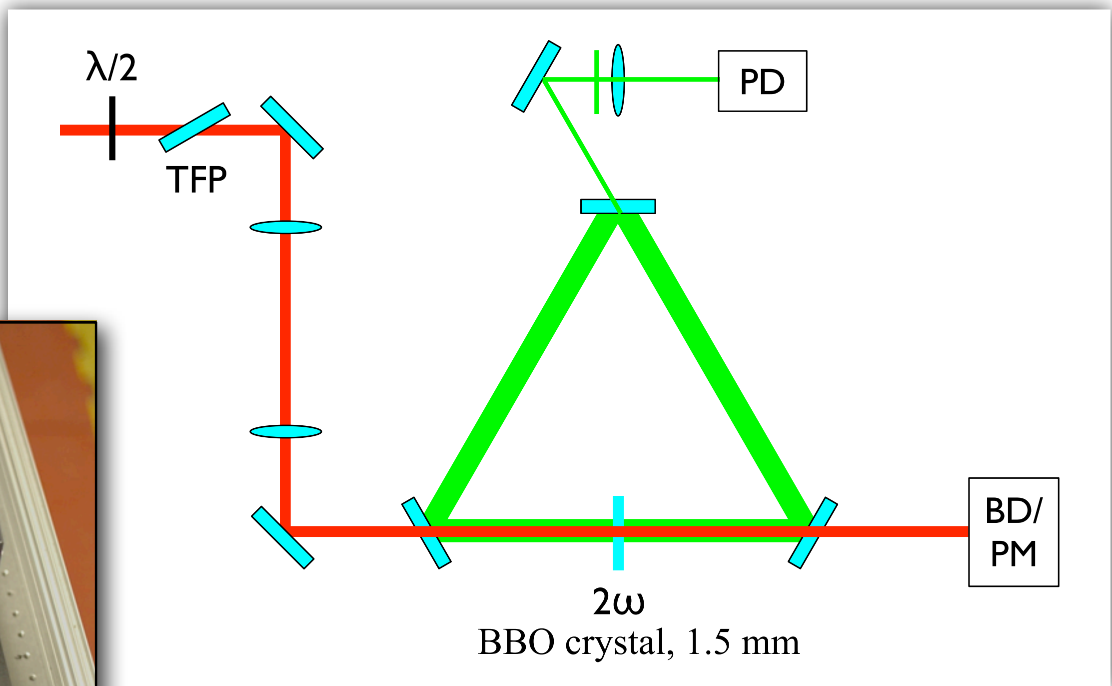


- Resonant cavity loading has been successfully demonstrated with nano-joule scale pulses with Q-factor up to 200.
- Cavity injection works well with longer pulses (100s of picoseconds and longer).
  - For picosecond pulses, nonlinear phase accumulation rapidly destroys the beam quality

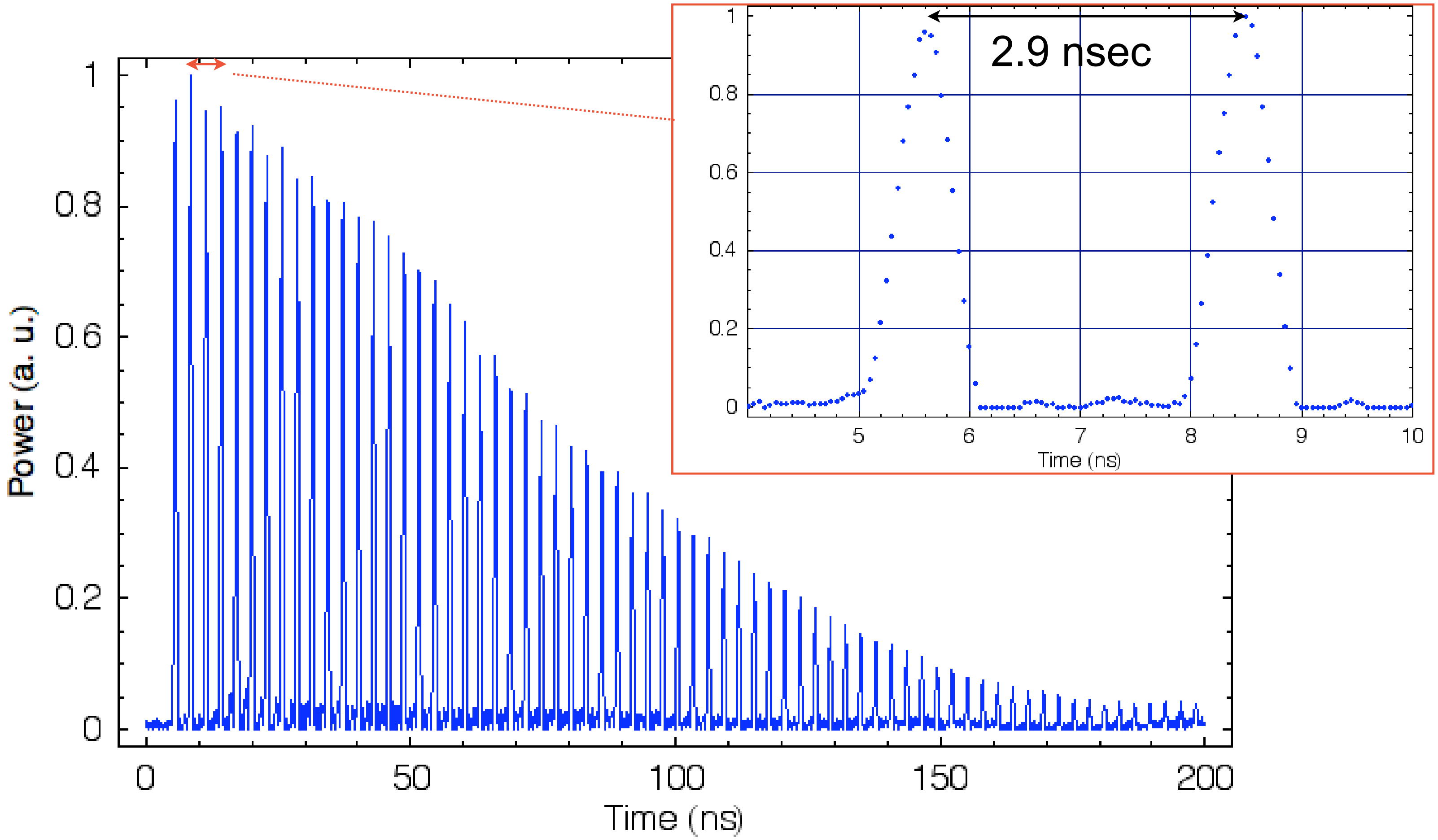
RING proof-of-principle experiment

We have experimentally demonstrated the viability of the RING technique





Measured cavity enhancement was 28.5x

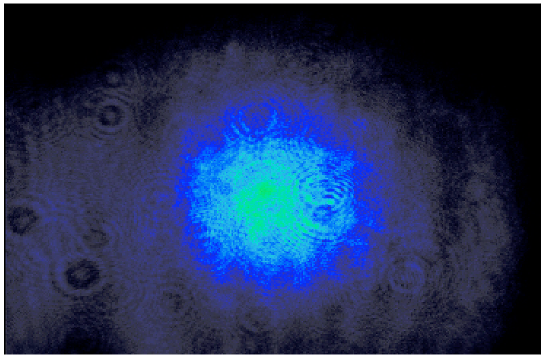


- Green signal measured on the photodiode after the RING cavity.
- Repetition rate is equal to the cavity roundtrip time
- 80 μJ of green at pulse duration of 10 ps and ~3 mm FWHM

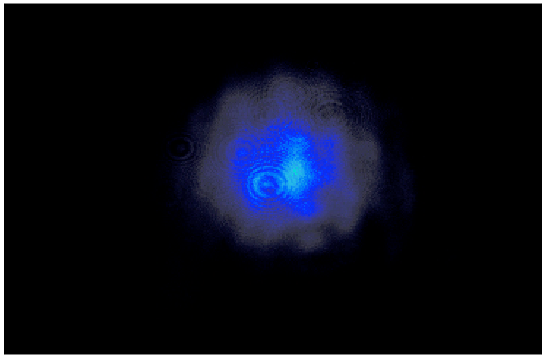
  ➡ We achieved recirculation of up to 500μJ @ 1 ps, corresponding to 7 GW/cm^2 in the green.

RING performance was primarily limited by beam diffraction and Fresnel losses

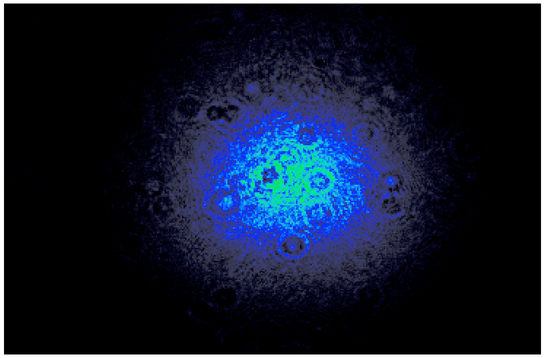
Fundamental



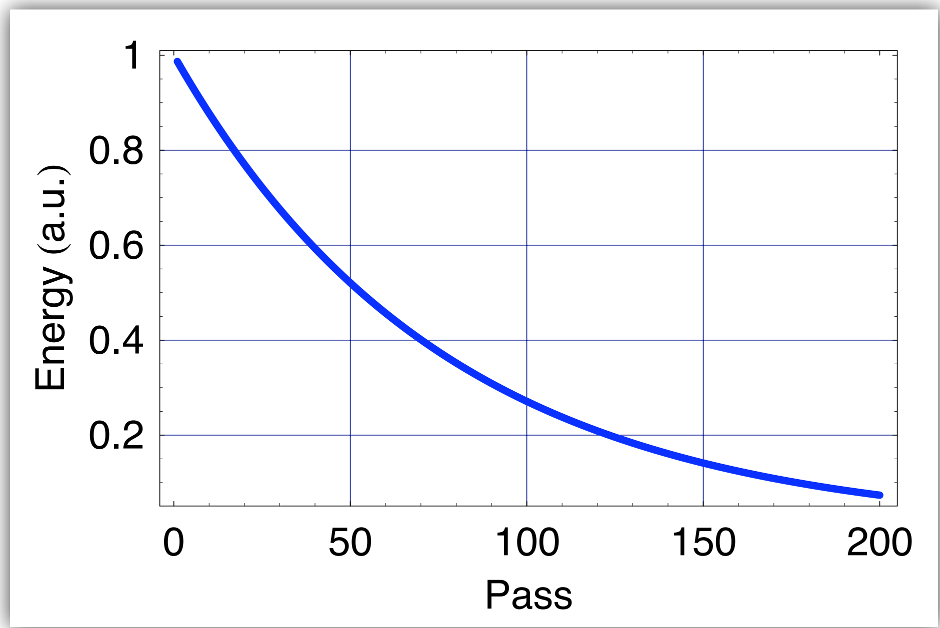
2nd harmonic



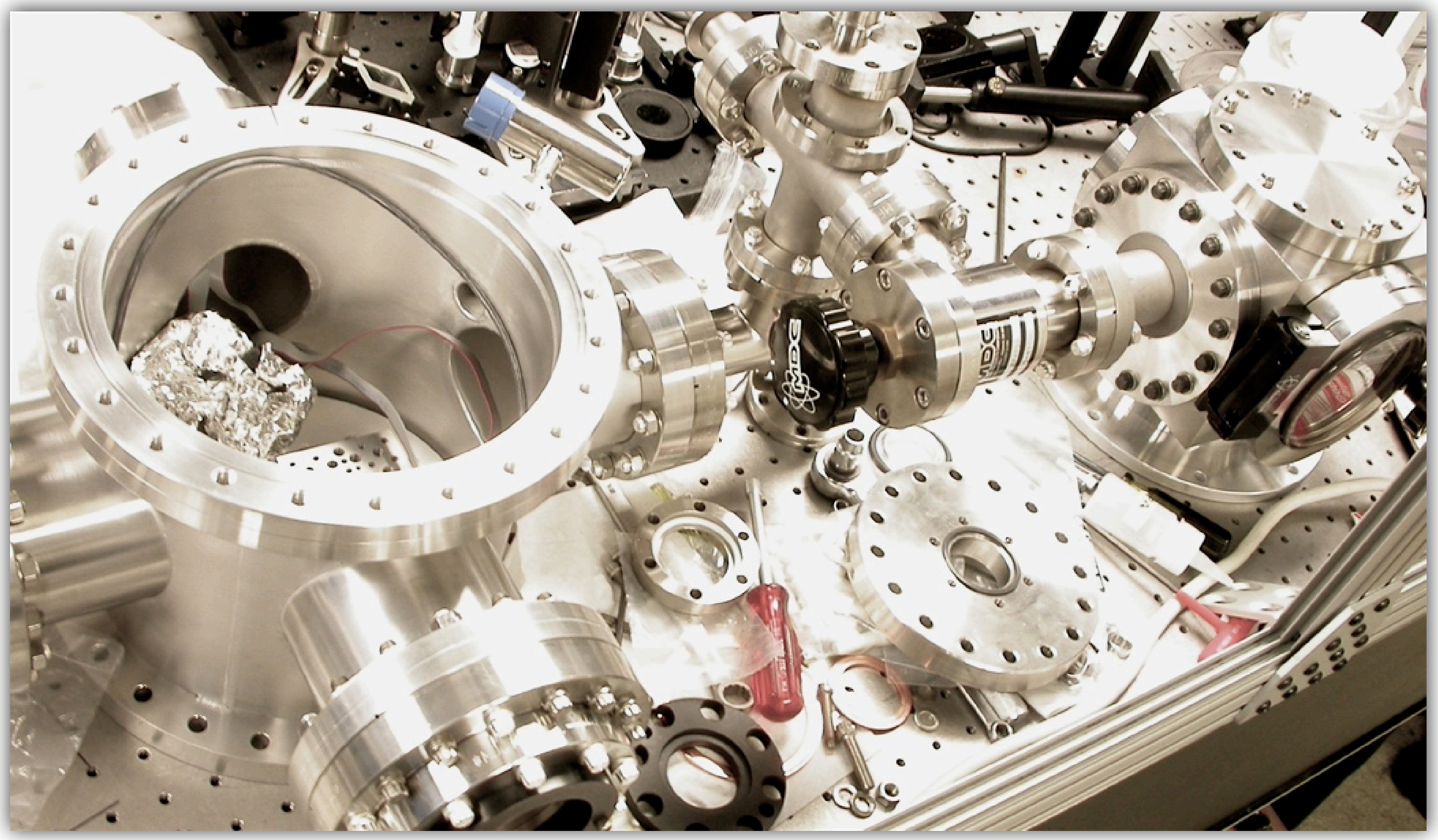
2nd harmonic after cavity



Predicted RING cavity enhancement for gaussian beams and Fresnel losses of 1% per roundtrip is 77x

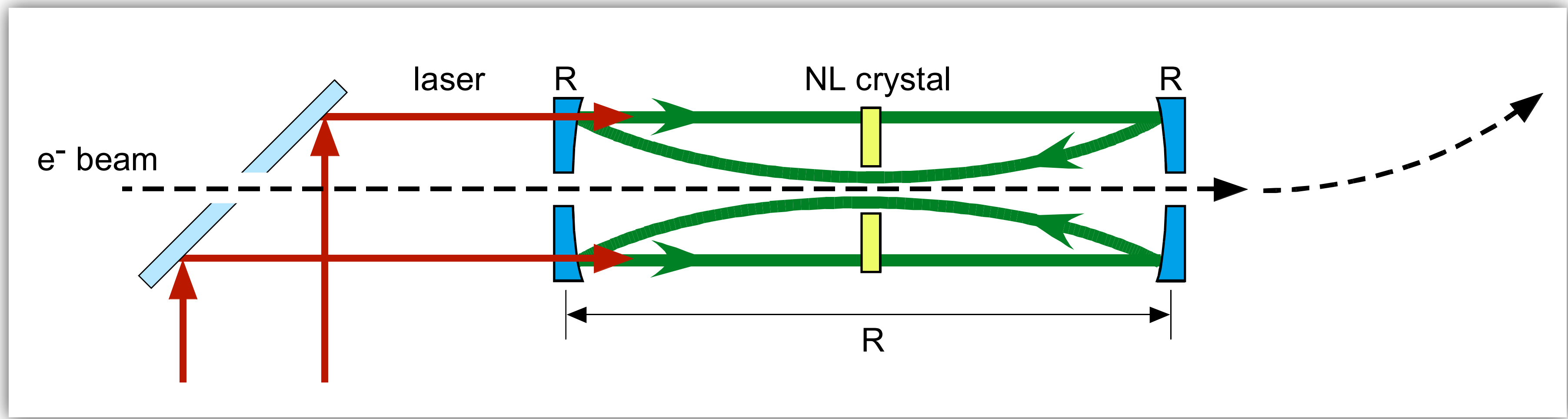


Internal focus RING cavity designs

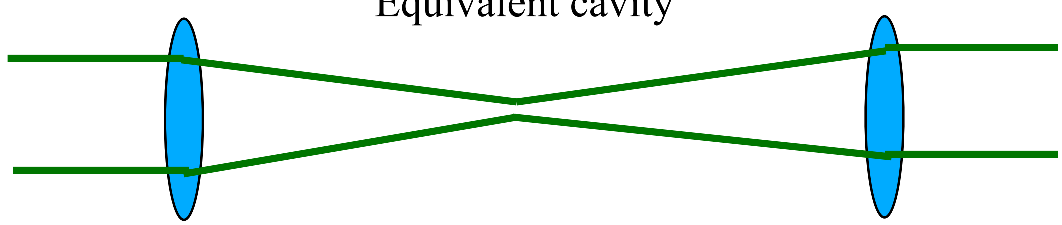


... experimental work on 1mJ recirculation is in progress

RING design is self-imaging and has an internal focus

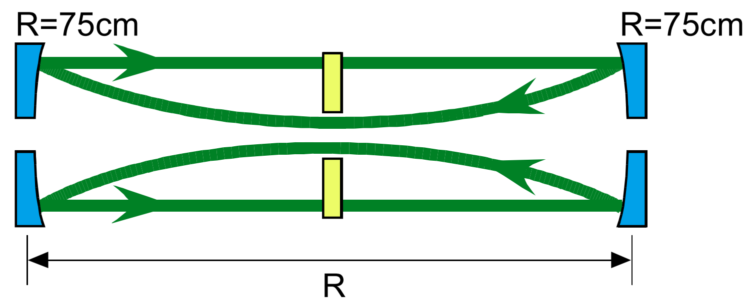


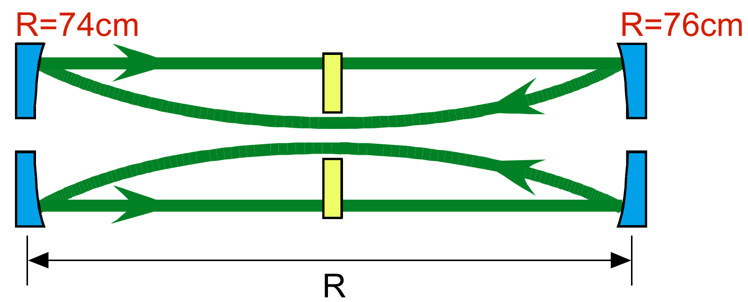
Equivalent cavity

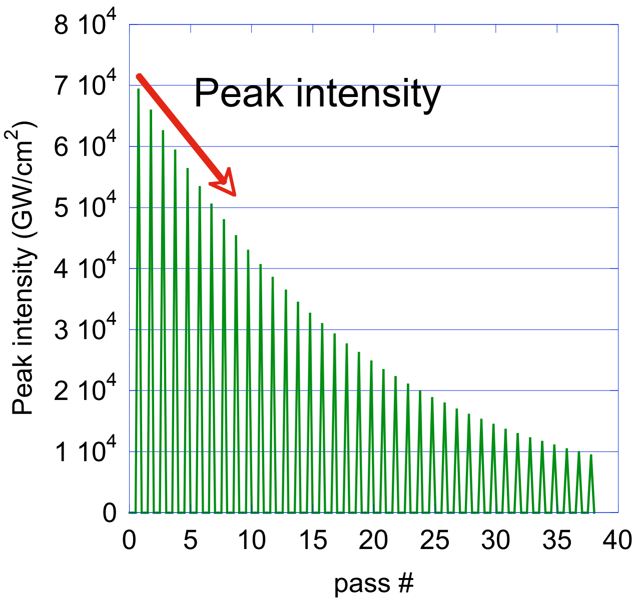


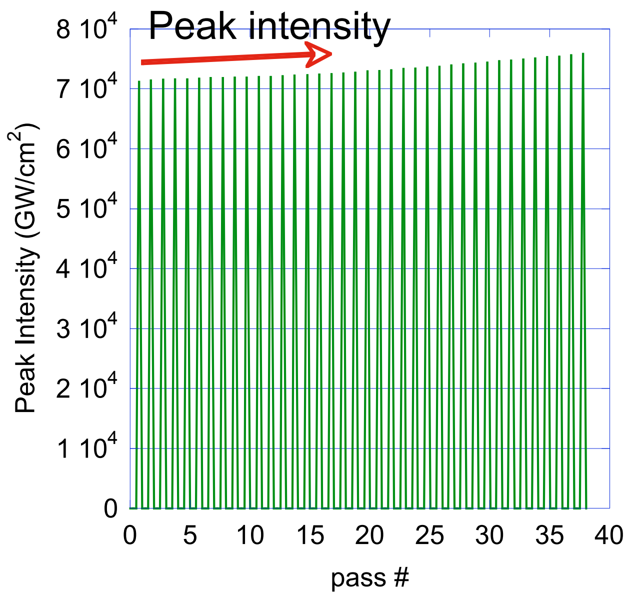
- The RING cavity consists of a confocal resonator formed by two dichroic mirrors and a nonlinear crystal.
- The green beam is collimated travelling from left to right and focuses travelling from right to left. Holes in the crystal and mirrors allow the electron beam to pass through the cavity.
- B-integral accumulation is reduced by 50%
- Imaging design supports recirculation of beams with complex spatial mode structure

Drop in the peak intensity can be compensated by a magnifying cavity configuration

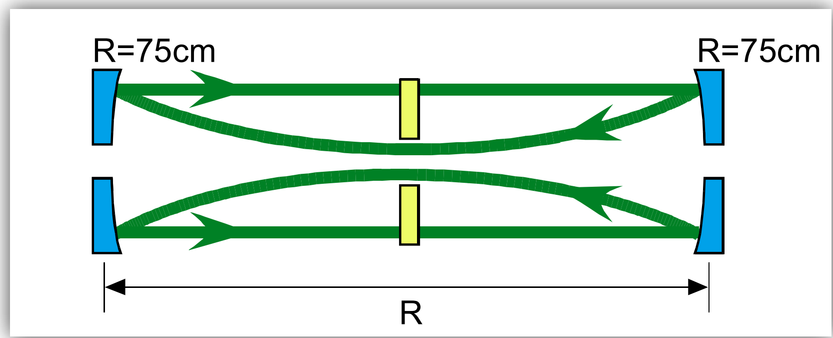


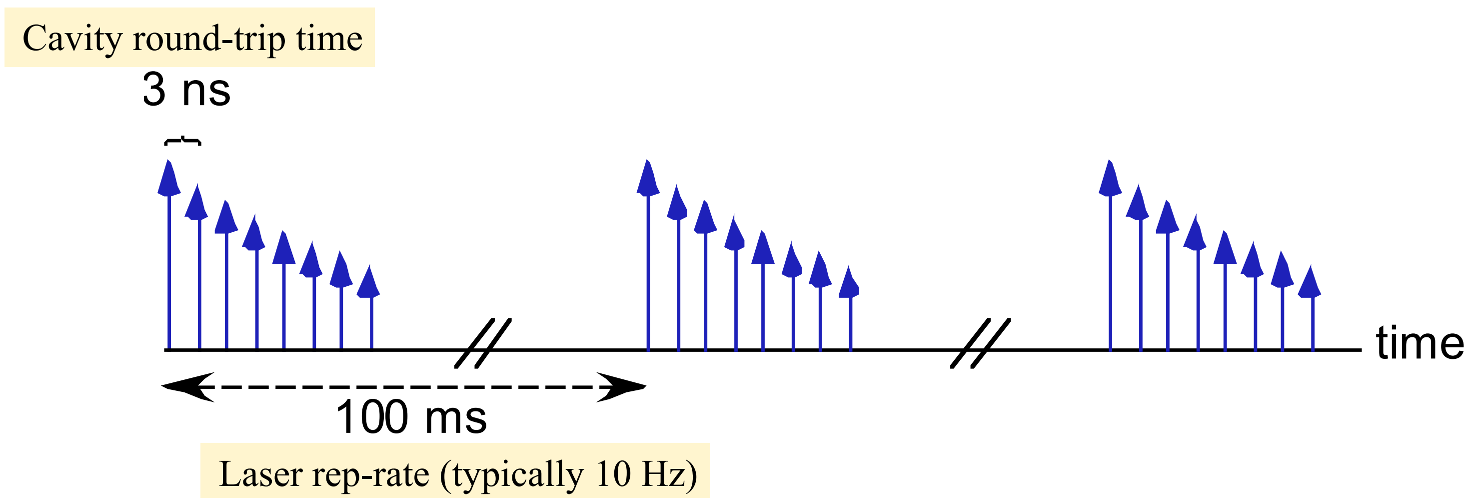






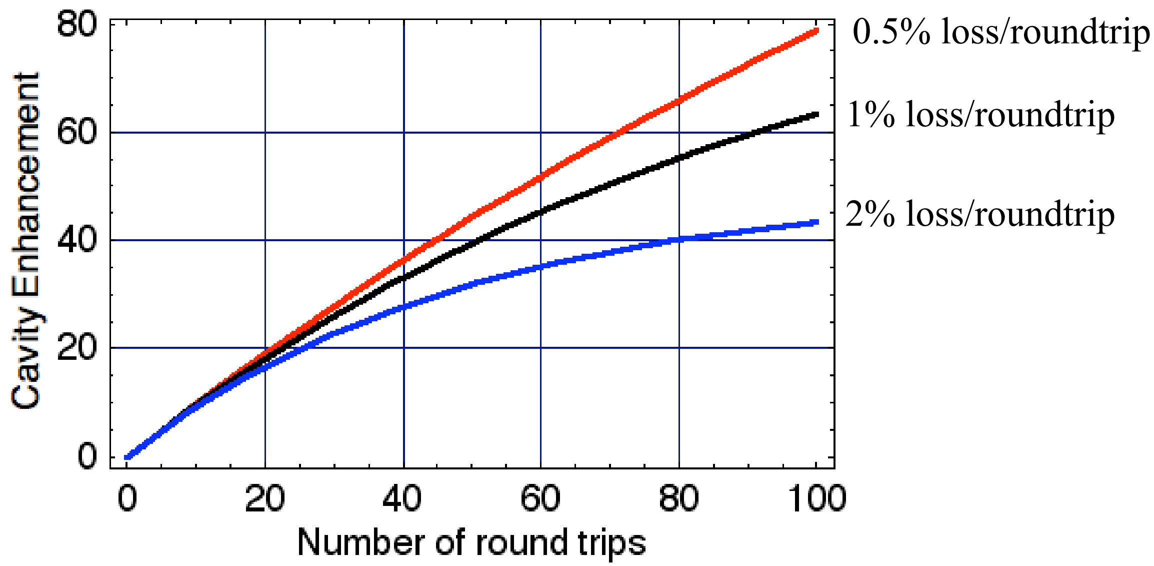
RING operates in burst-mode

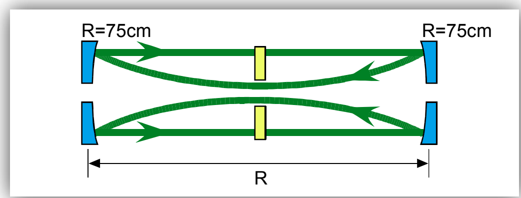




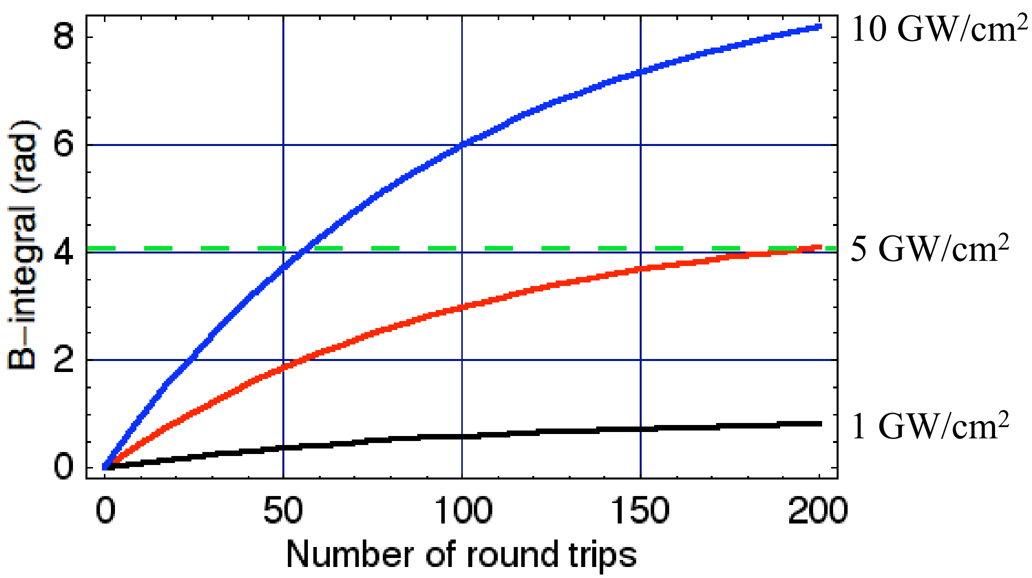
Electron beam format must match the laser pulse format

Cavity enhancement is limited by optical losses and nonlinear phase accumulation.





1mm nonlinear crystal (BBO) thickness

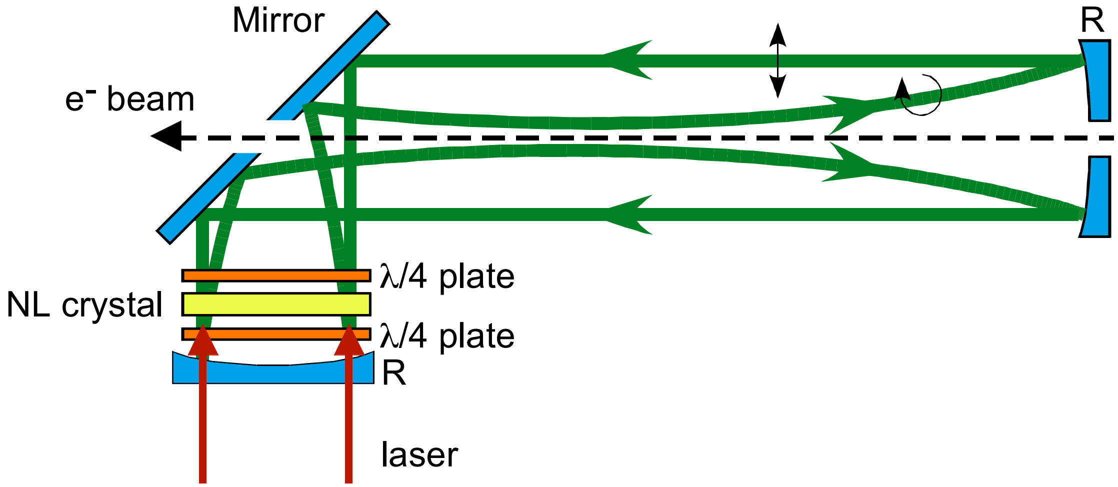


When B > 4, accumulated nonlinear phase leads to beam break-up

Need sufficiently low intensity to eliminate B-integral limitation.

RING cavity for polarized positron generation

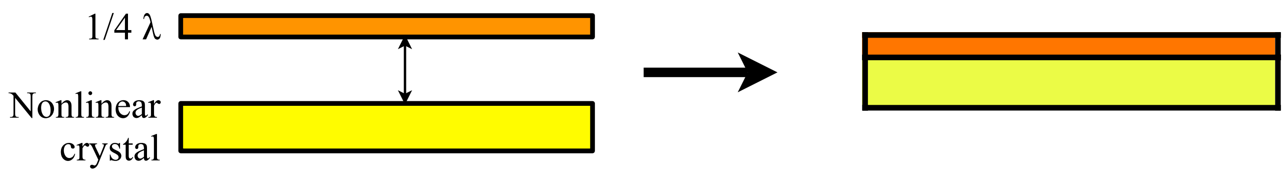
A modified RING cavity can produce circularly polarized photons at the laser-electron focus

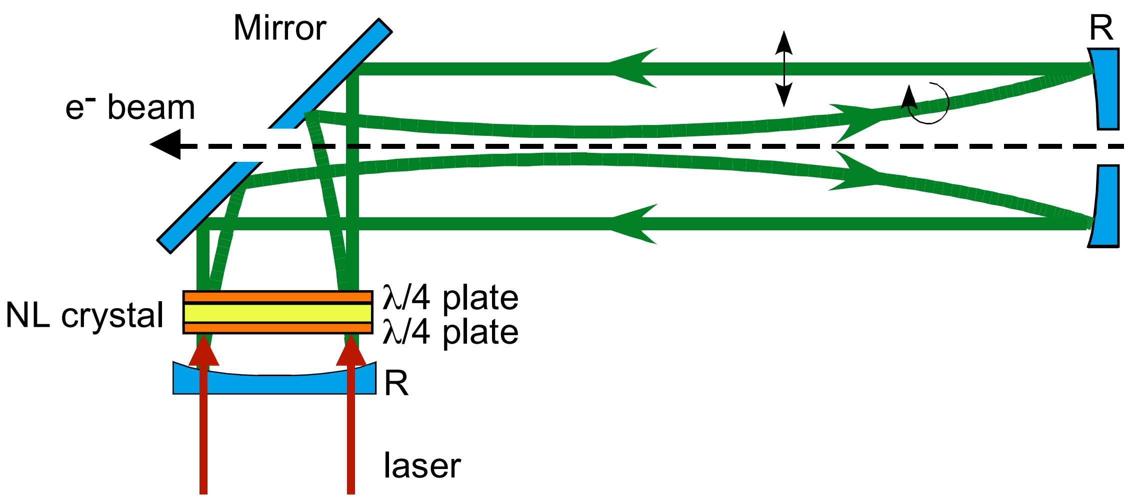


- A quarter-waveplate after the nonlinear crystal will convert linear to circular polarization.
- A second quarter-waveplate will keep the same handedness of the polarization at the focus after each roundtrip.
- The crystal and the waveplates are out of the electron path
  - Compatible with GeV and TeV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

Waveplate can be attached to the crystal to eliminate additional Fresnel losses

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

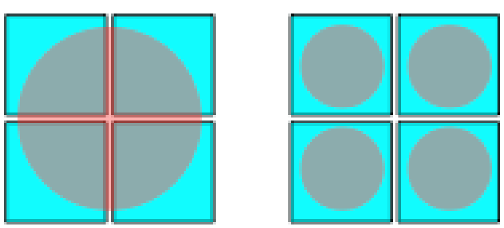
Scaling to full energy recirculation

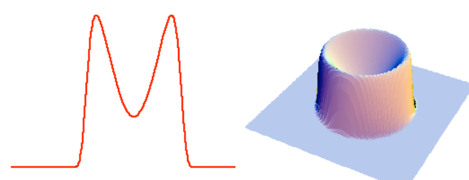
Laser energy ~ 1J

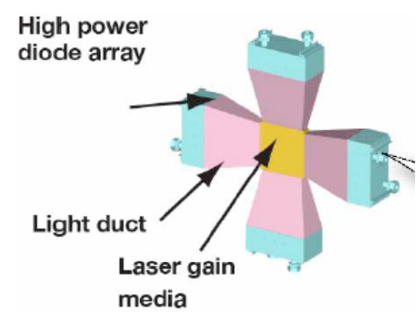
Pulse duration ~ 10 ps

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







Conclusions

- RING cavity can increase the effective average power of the laser system by up 20x
- 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
- RING cavity will be integrated with T-REX inverse compton-scattering based gamma-ray generating apparatus that is currently being built at LLNL.