Compton based Polarized Positrons Source for ILC

V. Yakimenko[1], D. Cline[2], Ya. Fukui[2], V. Litvinenko[1],
I. Pogorelsky[1], S. Roychowdhury[3]

[1]BNL, [2]UCLA, [3]Duke Univ.

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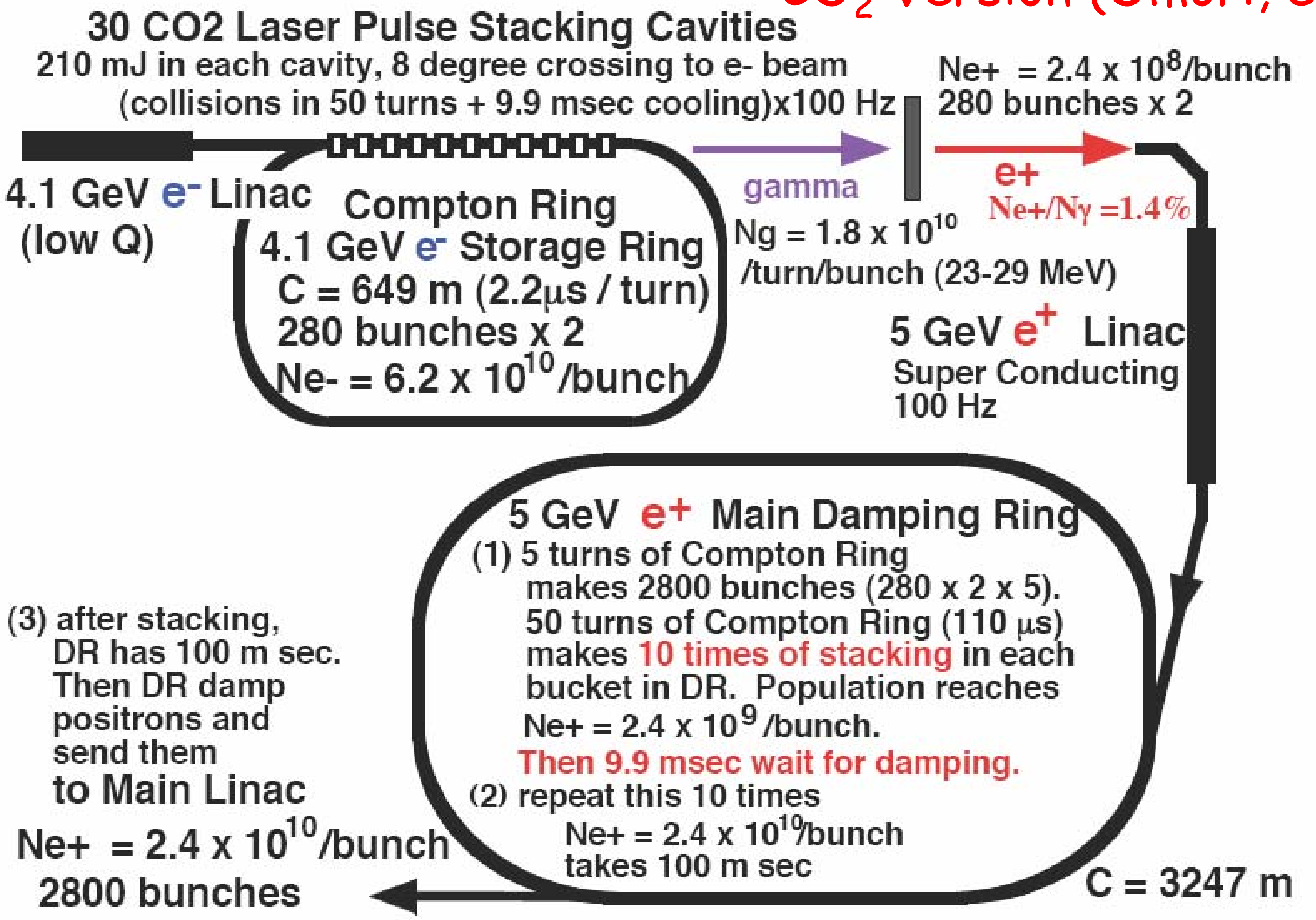
ILC Source requirements

Parameter	**Symbol**	**Value**	**Unit**
Positrons per bunch	n_p	2×10^{10}	e^+
Bunches per pulse	N_b	2820	
Bunch Spacing*	τ_b	~300	ns
Pulse rep. rate	f_{rep}	5	Hz
Energy	E_0	5	GeV
Positron Polarization**	P_p	~60	%

* The length of the bunch train in ILC is 2820x300ns = 0.85 ms or 250 km. Bunch spacing has to be reduced in the dumping ring.

** Polarization level defines conversion/capture efficiency of polarized γ rays into polarized positrons. 60% level corresponds to ~1.5% efficiency.

Polarized Positron Production: Compton Ring Scheme: CO_2 Version (Omori, et al.)



30 CO2 Laser Pulse Stacking Cavities

210 mJ in each cavity, 8 degree crossing to e- beam

(collisions in 50 turns + 9.9 msec cooling)x100 Hz

$Ne+ = 2.4 \times 10^8$/bunch

280 bunches x 2

4.1 GeV e^- Linac

(low Q)

Compton Ring

4.1 GeV e^- Storage Ring

C = 649 m (2.2μs / turn)

280 bunches x 2

$Ne- = 6.2 \times 10^{10}$/bunch

gamma

$Ng = 1.8 \times 10^{10}$

/turn/bunch (23-29 MeV)

e+

$Ne+/N\gamma = 1.4\%$

5 GeV e^+ Linac

Super Conducting

100 Hz

5 GeV e^+ Main Damping Ring

(1) 5 turns of Compton Ring
makes 2800 bunches (280 x 2 x 5).
50 turns of Compton Ring (110 μs)
makes 10 times of stacking in each
bucket in DR. Population reaches
$Ne+ = 2.4 \times 10^9$ /bunch.
Then 9.9 msec wait for damping.

(2) repeat this 10 times
$Ne+ = 2.4 \times 10^{10}$/bunch
takes 100 m sec

C = 3247 m

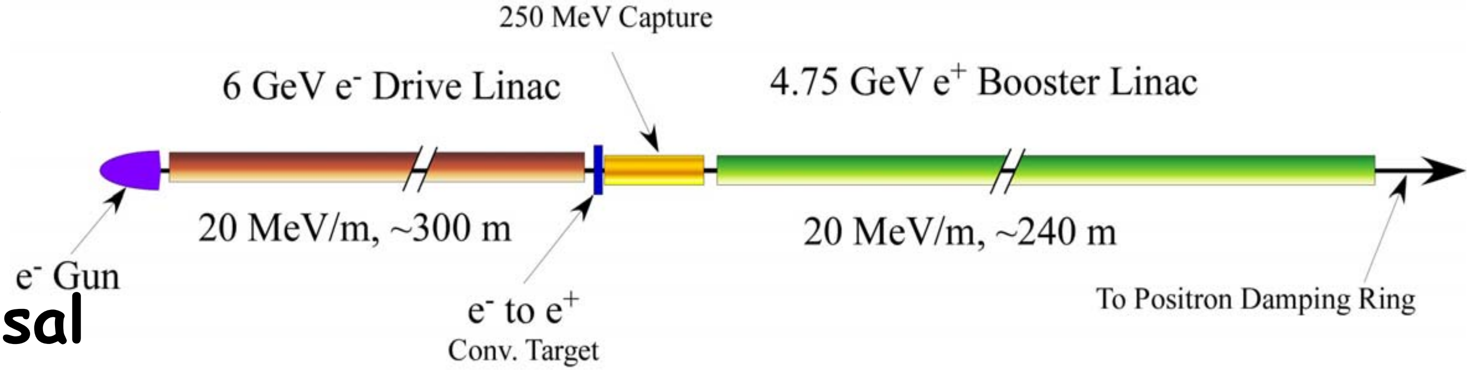
(3) after stacking,
DR has 100 m sec.
Then DR damp
positrons and
send them
to Main Linac

$Ne+ = 2.4 \times 10^{10}$/bunch

2800 bunches

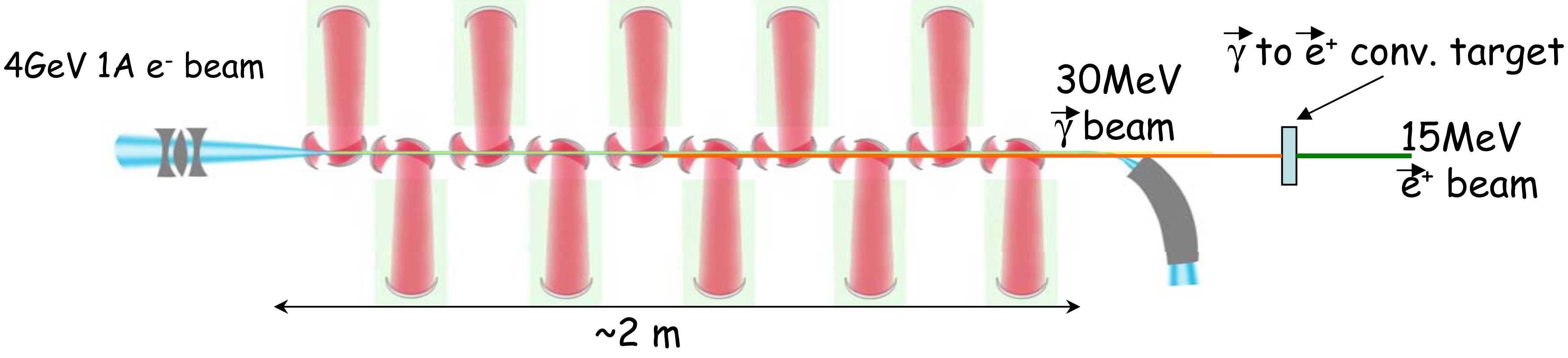
Polarized Positrons Source (PPS for ILC)

Conventional Non-Polarized Positrons:



In our proposal

- polarized γ-ray beam is generated in the Compton back scattering inside optical cavity of CO_2 laser beam and 4 GeV e-beam produced by linac.
- The required intensities of polarized positrons are obtained due to 10 times increase of the e-beam charge (compared to non polarized case) and 5 to 10 CO_2 laser system IPs.
- Laser system relies on the commercially available lasers but need R&D for the new mode of operation
- 5ps 10J@0.05 Hz CO_2 laser is operated at ATF



Choice of parameters

$$N_{\vec{\gamma}} = \frac{N_e N_{\vec{\varphi}}}{S} \sigma_C$$

N_γ, N_e and N_ϕ are the numbers of γ-rays, electrons and laser photons, S is the area of the interacting beams and σ_C is the Compton cross sections

- ~40 μm laser focus is set by practical considerations of electron and laser beams focusing and requires ~5 ps long laser pulses
- Nonlinear effects in Compton back scattering limit laser energy at ~1J
- Pulse train structure of 2820 bunches is set by main linac.
- ~300ns bunch spacing in the main linac will be changed in the dumping ring in any design. 12 ns bunch spacing is selected to optimize linac acceleration gradient.
- Train of ~10 nC electron bunches is required to produce 10^{12} polarized gammas per bunch. (~1 γ-ray per 1 electron per laser IP)
- Reduction of charge in the bunches (stacking of the positrons) leads to increase in the average power of the laser and electron beams
- Conversion efficiency of polarized gammas into captured polarized positrons is assumed at ~1.5% and is subject of optimization.
- The size of the gamma beam on the conversion target is expected to be much smaller when compared to other schemes due to the compact design of the Compton backscattering region.
- Laser and drive linac are operated at 150Hz to optimize its performance. Train of 100 bunches is generated with 150Hz. 30 pulses are needed to form ~3000 bunches of ILC beam, stored in the dumping ring.

Polarized γ beam generation

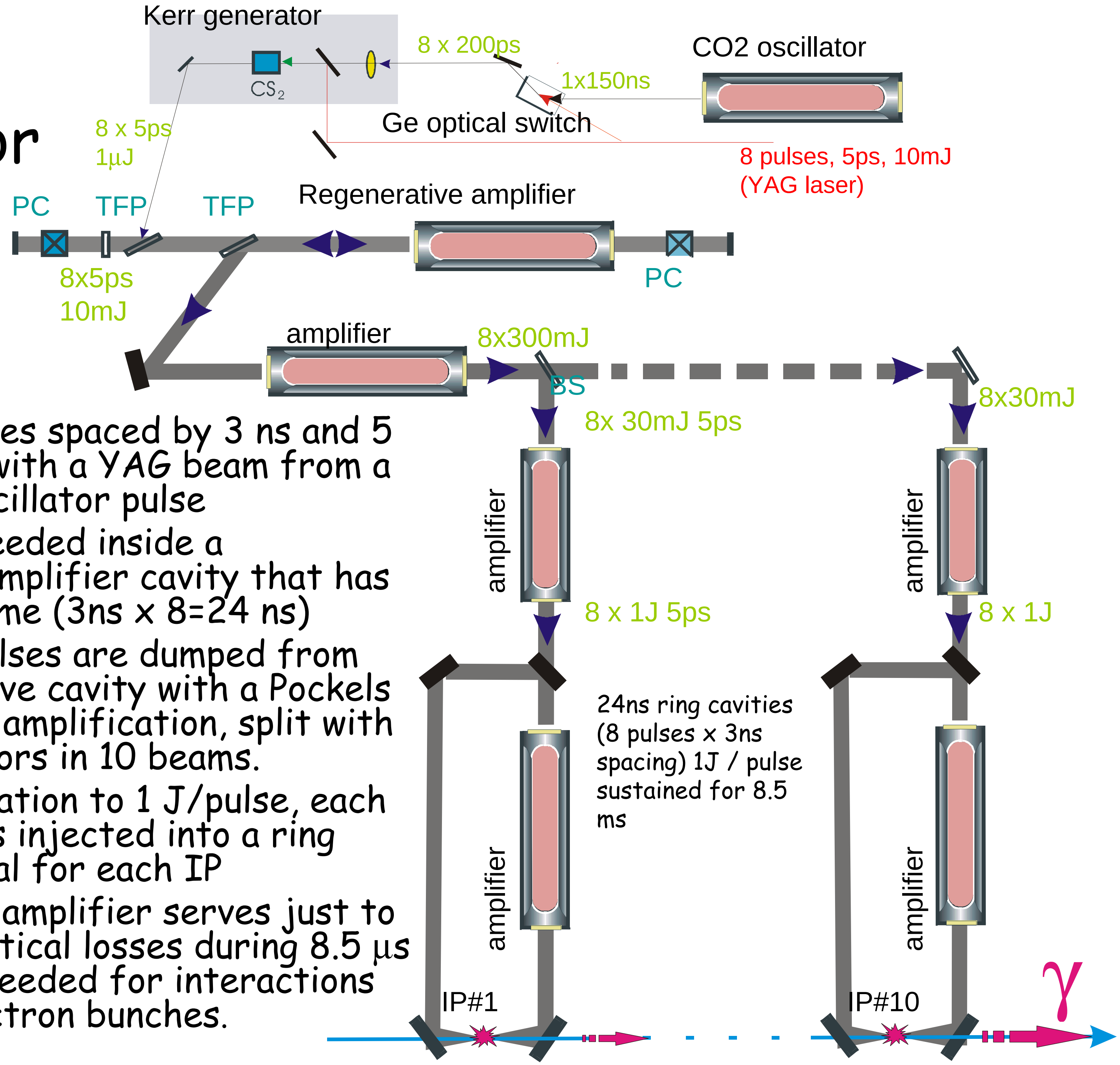
Parameter	**Symbol**	**Single Shot Injection**		Storage mode	**Unit**
Rep rate	f_{rep}	5		150	*Hz*
e^- per bunch	n_e	8×10^{10}		8×10^{10}	
Bunches per pulse	N_b	2820		*100*	
Bunch Spacing	τ_b	6	3	12	ns
Beam current (ave./pulse)	I_{beam}	0.2/2	0.2/4	0.2/1	m*A/A*
Average e-beam power	P_{beam}	1		1	*MW*
Number of laser IPs	N_{laser}	30	15	5	
Laser pulse length	τ_{laser}	5			*ps*
Intra cavity energy	E_{laser}	4 x 0.8	8x0.8	2x0.8	
Ave. laser power (5% losses)	P_{laser}	30x0.4	15x0.7	5x0.7	*kW*
Size at focus	σ_{laser}	40			*μm*
Efficiency per laser IP	$N\gamma/Ne^-$	~1			
Number of γ	$N\gamma$	1.5×10^{12}			

Ring or Linac?
Stacking or No-stacking?

- RMS energy spread in 6 GeV Compton ring ~2% for CO_2 laser interaction with 4MW in synchrotron radiation. Difficult ring and very difficult laser (high repetition rate, average power, cavity stacking).
- Head on Compton back scattering will be realized in the Linac design (electron beam will pass through small halls in the mirrors.)
- Aperture requirements for the ring design dictate less efficient small angle Compton back scattering scheme.
- For scheme without accumulation the main issue is high current ~4A in macro pulse (requires short accelerator sections, more klystrons and longer linac or a ring to change bunch spacing from ~12ns to 3ns).
- The average beam power is increased with higher repetition rate required for the scheme with accumulation. It is 3MW for 150Hz. SC and NC linac structures can be used. Very difficult laser
- Simpler damping ring and laser system at 5Hz for the scheme without accumulation might offset linac complexity.

Laser system for PPS

- Train of 8 pulses spaced by 3 ns and 5 ps long sliced with a YAG beam from a 150 ns CO2 oscillator pulse
- This train is seeded inside a regenerative amplifier cavity that has a round-trip time (3ns x 8=24 ns)
- Amplified 8 pulses are dumped from the regenerative cavity with a Pockels cell and, after amplification, split with partial reflectors in 10 beams.
- After amplification to 1 J/pulse, each 8-pulse train is injected into a ring cavity individual for each IP
- An intracavity amplifier serves just to compensate optical losses during 8.5 µs time interval needed for interactions with 2820 electron bunches.



24ns ring cavities (8 pulses x 3ns spacing) 1J / pulse sustained for 8.5 ms

Laser system for PPS

- Optical slicing and amplification of 5 ps CO_2 pulses has been demonstrated and utilized in routine ATF operation for user experiments.
- CO_2 oscillator and initial amplifiers are commercially available lasers from SDI and operate at rep. rate up to 500Hz.
- Final intracavity amplifiers shall operate at average power ~0.75 kW in non standard mode of operation.
- Another issue to be addressed by industry is fabrication of optical elements to withstand high intracavity laser power.

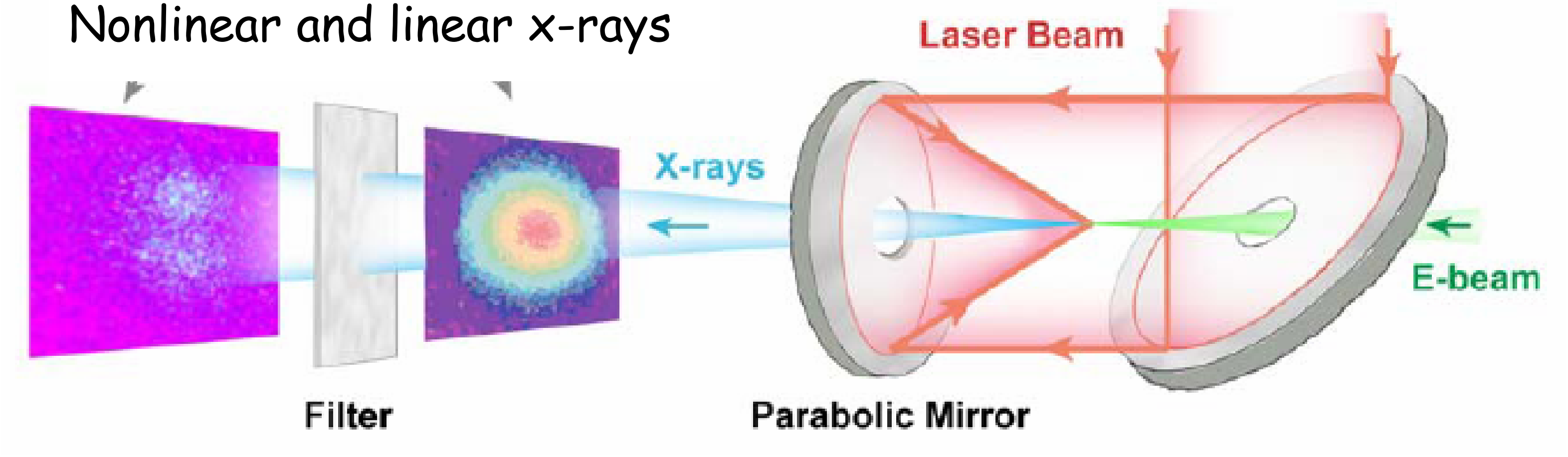
Lasers from SDI

http://www.lightmachinery.com/SDI-CO2-lasers.html

	WH20	WH100	WH350	WH500
Wavelength		9 – 11μm, Line Tunable		
Continuous Repetition Rate	20 Hz	100 Hz	350 Hz	500 Hz
Pulse Energy		1.5 J		
Mode Type		Multimode		
Optional:	TEMoo, custom beam shapes, SLM			
Beam Size		13 x 13 mm^2		
Average Power	30 W	150 W	525 W	750 W
Power Stability		< 7 %		

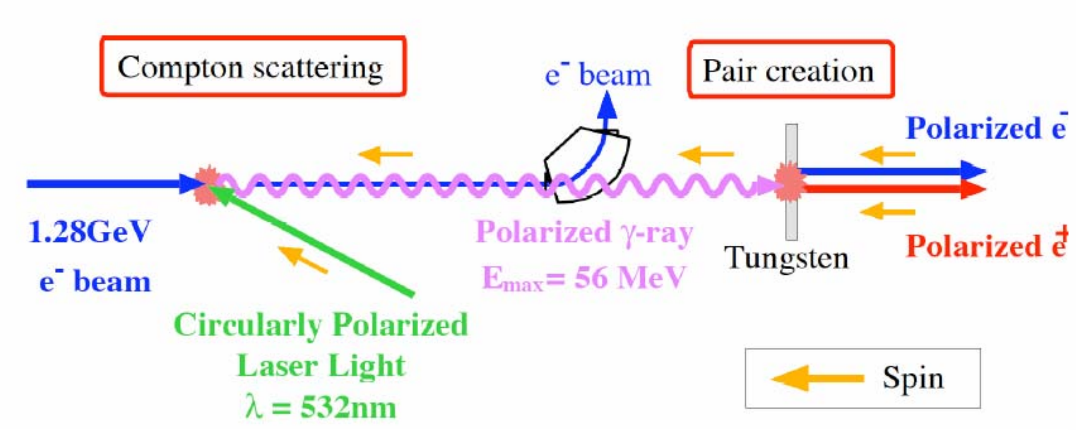
Compton Experiment at Brookhaven ATF (record number of X-rays with 10 μm laser)

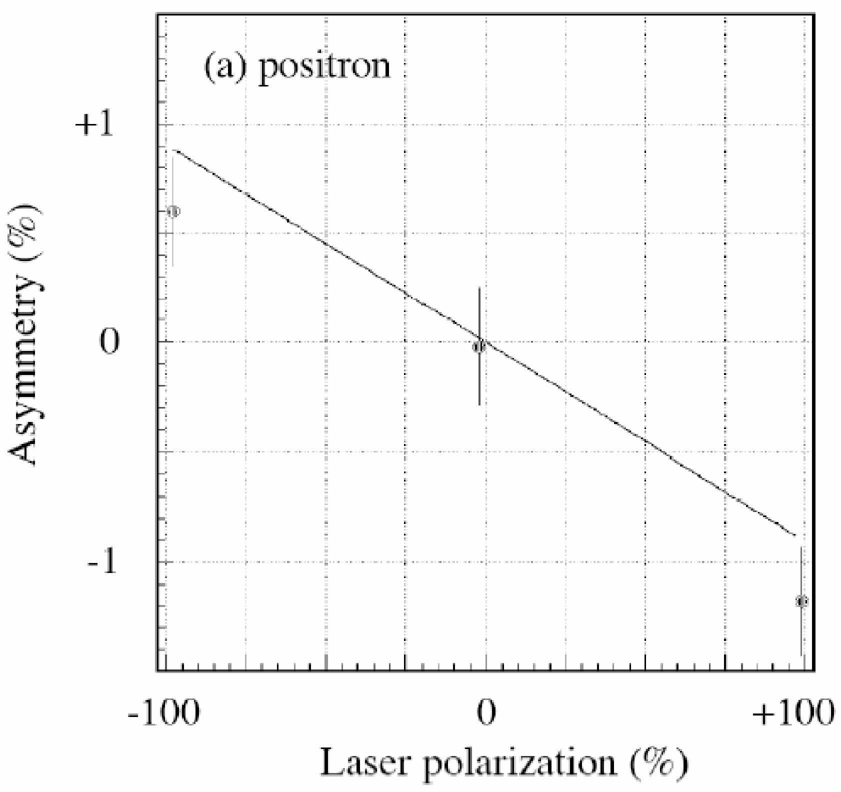
- More then 10^8 of x-rays were generated in the experiment PR ST 2000. N_X/N_{e-} ~0.1.
- (0.35 as of April 2006- limited by laser/electron beams diagnostics)
- Interaction point with high power laser focus of ~30μm was tested.
- Nonlinear limit (more then one laser photon scattered from electron) was verified. PRL 2005.


Real CCD images
Nonlinear and linear x-rays

Compton Experiment at KEK ATF (polarized positrons with 532 nm laser)

- Experiment demonstrated beam of 10^6 polarized γ-rays (PRL 91/16, 2003)
- Experiment demonstrated 10^4 positron beam with 79% polarization level (KEK Preprint 2005-56, PRL 2005)





Laser R&D

- 1st year: (2 Post Doc + $250K equipment)
  - Demonstrate slicing of a train of eight 5-ps CO2 pulses (based on existing ATF laser systems)
  - Simulations of the ILC laser system.
  - Design and purchase of custom CO2 amplifier ~5J/pulse, 150 Hz
  - Design of photocathode/slicing laser
- 2nd year: (2 Post Doc + $700K equipment + room)
  - Dedicated YAG oscillator and amplifiers
  - Purchase of standard CO2 oscillator and amplifier @150 Hz
  - 8-pulse train amplification to 1J/pulse.
  - Delivery of custom CO2 amplifier ~5J/pulse, 150 Hz, 10 atm
- 3rd year (2 Post Doc + $500K equipment)
  - Injection of 2-pulse train into interaction cavity and maintaining 100 intra cavity passes (total 200 pulses @ 1J/pulse, 150 Hz).
  - Intracavity laser/e-beam (60 MeV) interaction with production of trains of 100 6.5 keV x-ray pulses @ 6 Hz between trains with efficiency N_γ/N_{e-} ~1.

- At the end of 3 year program we will have full scale prototype with one (out of five) interaction cavity @150Hz. The laser injection part will be fully functional.

- The accelerator part of PPS proposal is based on the existing technologies and design can be completed in about 1 year.
- 2nd and 3rd years of R&D will be focused on risk reduction

Cost speculation
to prioritize R&D areas

• @5Hz, 3 ns (no storage , 2820 per pulse)	
– CO2 Laser system @5Hz	~10M$
– 4Gev, 4A 5 Hz linac 10MV/m	~300M$
– Damping ring (2.5 km)	~200M$
• @5Hz, 6ns (no storage, 2820 per pulse)	
– CO2 Laser system @5Hz	~15M$
– 4Gev, 2A 5 Hz linac 15MV/m	~150M$
– Damping ring (5 km)	~300M$
• @150Hz (beam storage: 30 pulses 100 bunches each)	
– CO2 Laser system @150Hz	5-10M
– 4GeV, 0.8A 150Hz linac 20MV/m	~100M$
– Damping ring (2.5 km)	~200M$

- Optimization is needed !

Conclusion

- We propose Polarized Positron Source based on Compton back scattering inside optical cavity of CO_2 laser beam and 4 GeV e-beam produced by linac.
- The proposal requires high power picosecond CO2 laser mode of operation tested at ATF to generate **1 gamma per 1 electron per 1 laser IP**.
- The proposal utilizes commercially available units for laser and accelerator systems.
- 3 year laser R&D is needed to verify laser operation in the non standard regime.
- CLIC beam needs are easily satisfied due to lower beam intensity requirement and same rep. rate.