Compton based Polarized Positrons Source for ILC

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On behalf of

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Outline

- Review
  - Requirements (positron beam)for International Linear Collider
  - Proposal by Omori,et al
- ATF(BNL,NY) proposal
  - Introduce the proposal
  - Discuss parameter choice
  - Ring vs. Linac and stacking vs.no-stacking
- Laser System
- Experiment

  ATF,BNL

  KEK,Japan
- Conclusions

ILC Source Requirements

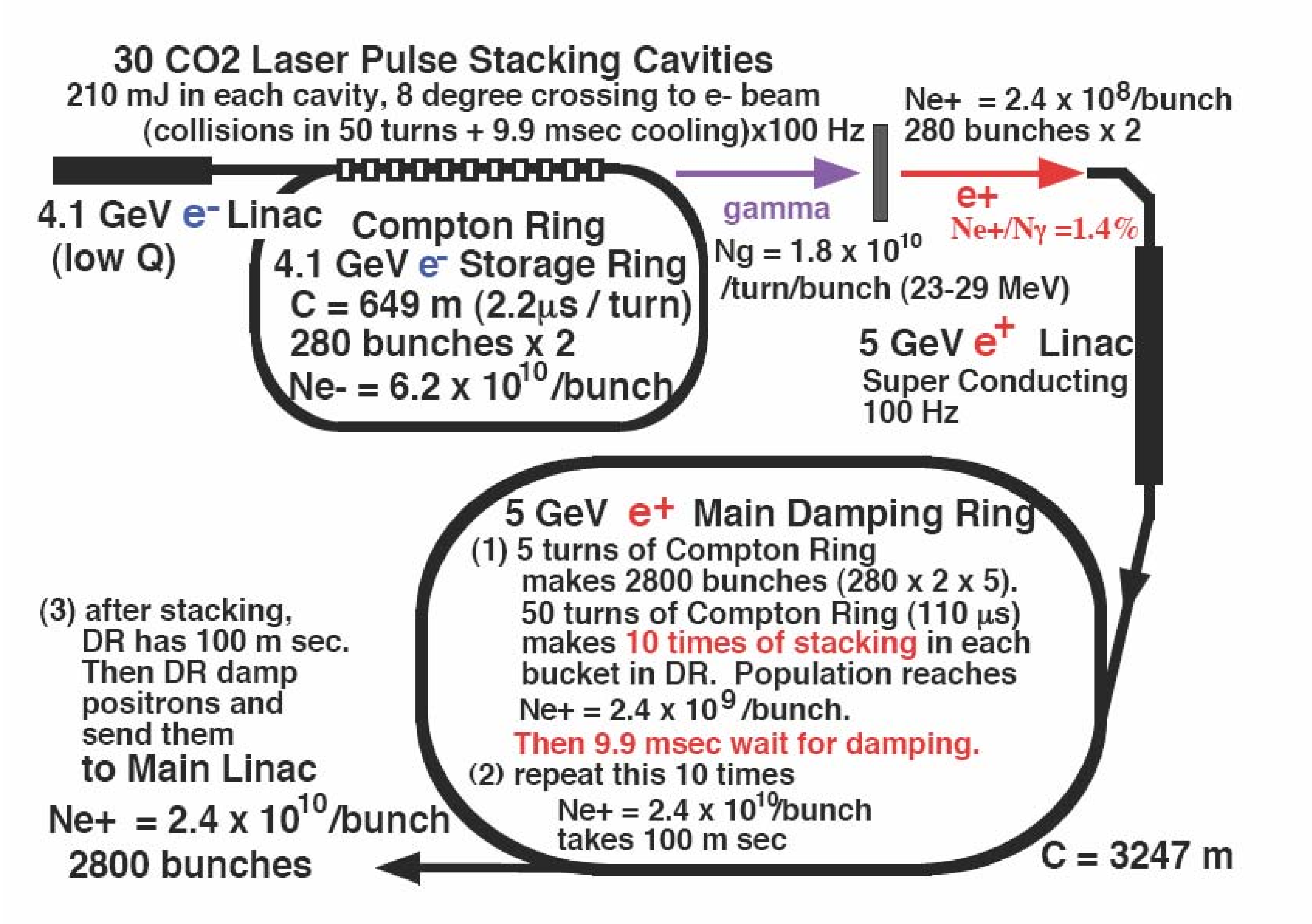
Parameter	**Symbol**	**Value**	**Unit**
Positrons per bunch	n_p	2×10^{10}	e^+
Bunches per pulse	N_b	2820	
Bunch Spacing*	t_b	~300	ns
Pulse rep. rate	f_{rep}	5	Hz
Energy	E_0	5	GeV
Positron Polarization**	P_p	~60	%

*Length of bunch train=2820x300(ns)=0.85ms~250km

**Conversion/capture efficiency for polarized gamma ←→ polarized e^+

60% ←→ 1.5%

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



Polarized Positrons Source (PPS for ILC)

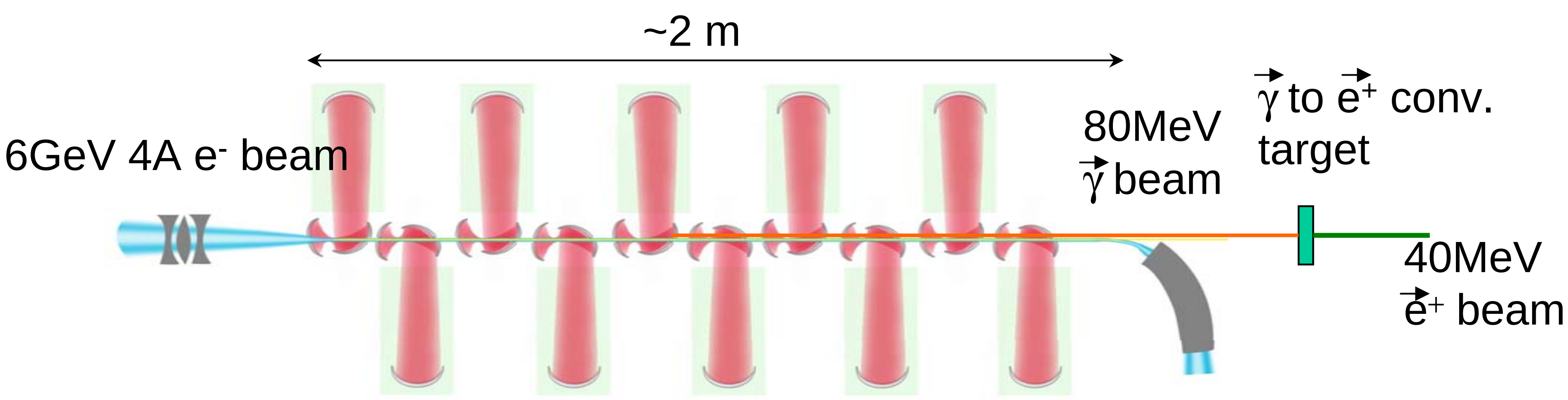
ATF,BNL Proposal

❑Polarized Gamma Ray Generated By

- Compton scattering inside optical cavity of CO_2 laser *with*
- 6 GeV electron beam produced by Linac
- Expected Efficiency $N\gamma/Ne^- \sim 10$

❑Polarized Positron Beam Generated By

- Scattering 80 MeV γ ray on a thin target
- Capture Efficiency $Ne^+ / N\gamma \sim 1.5\%$



Merits of the Proposal

- Required intensities of polarized positrons obtained because
  - e-beam charge is sufficiently high(10 times compared to conventional non polarized source)
  - complex CO_2 laser system
- L-band type photo injector and linac for acceleration
  - No R&D required
- Laser system
  - commercially available lasers
  - R&D for the new mode of operation (described later)

Choice of Parameters

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

Ne # of electrons, N_ϕ # of laser photons
Nγ # of gamma rays, S area of interacting beams
σ_c Compton cross section

- To produce 10^{12} positrons per bunch ←→ ~10 nc electron bunches
- Pulse train structure(2820) is set by main linac.
- Bunch spacing(~300 ns) is to be changed in the damping ring(any design)
  - ~3ns spacing matches inversion life time of laser (3ns*2820=8.5microsec)
- Laser Energy limited to ~1J
  - Non linear effects in Compton scattering
- Laser Focus @40μm
  - Practical consideration of e and laser beam focusing
  - 5 ps long laser
- Reducing charge in bunches(positron stacking) leads to
  - increase in average laser power
- Gamma beam size is smaller(compared to other designs)
  - compact design of Compton backscattering region
- Conversion Efficiency (polarized gamma to captured polarized positron)
  - assumed ~1.5%
  - subject to optimization

Polarized Gamma Beam Generation   Summary

Parameter	Symbol	Single Shot Injection	Stacking mode	Unit
Rep rate	f_{rep}	5	150	*Hz*
e^- per bunch	n_p	8×10^{10}	8×10^{9}	
Bunches per pulse	N_b	2820	2820	
Bunch Spacing	τ_b	3	3	*ns*
Beam current (ave./pulse)	I_{beam}	0.2 / 4	0.6 / 0.4	mA / A
Average beam power	P_{beam}	1	3	*MW*
Number of lasers	N_{laser}	15	5	
Laser pulse length	τ_{laser}	5	5	*ps*
Intra cavity energy	E_{laser}	8 x 0.8	8 x 0.8	*J*
Size at focus	σ_{laser}	40	40	μm
Efficiency per laser IP	$N\gamma / Ne^-$	1	1	
Number of γ per bunch	$N\gamma$	1.5×10^{12}	1.5×10^{12}	

Ring Or Linac?

- ❑ 6 GeV Compton Ring
  - rms energy spread ~ 2%
    - CO_2 laser interaction with 4MW synchrotron radiation.
  - Dificult ring design
  - Very difficult laser design
    - high repition rate
    - high average power
    - cavity stacking
- ❑ Aperture Requirements of Ring Design
  - small angle Compton back scattering
    - less efficient

- ❑ Linac Design
  - Head On Compton back scattering

Stacking or No Stacking?

No Stacking

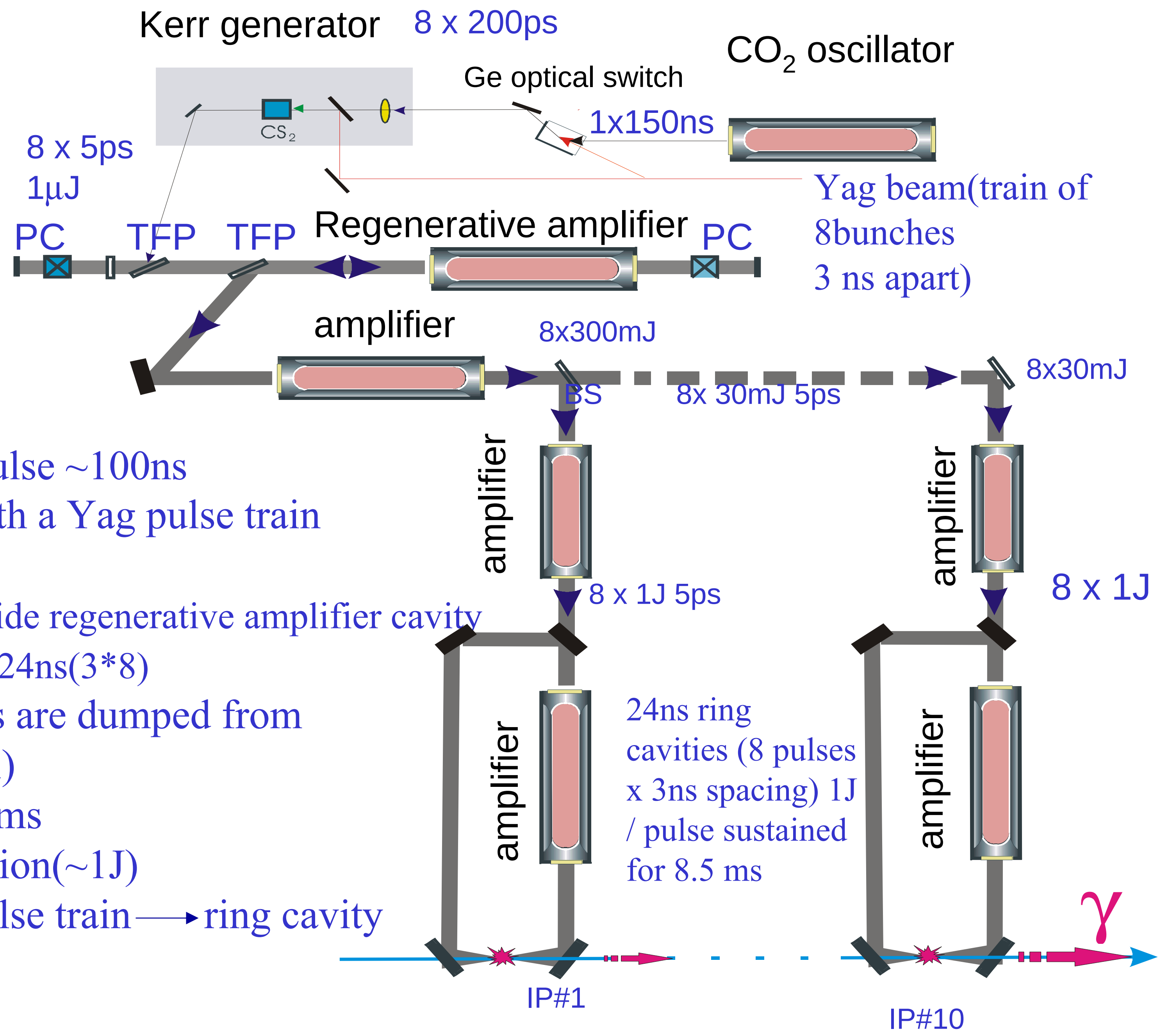
- High current in macro-pulse(~ 4 A)
  - short accelerator sections,
  - more klystrons
  - longer linac

Stacking

- High repitition
  - average beam power inc
  - 3MW for 150Hz.
- Linac
  - SuperConducting
  - NormalConducting

•Simpler damping ring and laser system at 5Hz for the scheme without accumulation may offset linac complexity.

Laser System



1. CO_2 oscillator pulse ~100ns
   Sliced with a Yag pulse train
2. CO_2 laser train
   seeded inside regenerative amplifier cavity
   round trip 24ns(3*8)
3. Amplified pulses are dumped from cavity(pockels cell)
4. Split into 10 beams
5. After Amplification(~1J)
   each 8 pulse train ⟶ ring cavity

Status Of Laser System For Polarized Positron Source

✓Optical slicing and amplification
- demonstrated at ATF
- routine for user experiments*

✓CO_2 oscillator and amplifier
- commercially available from SDI
- rep rate up to 500Hz

❖Final Intra-cavity amplifiers
- average power 10-20 Kw(150Hz)
- Needs R&D

❖Optical elements
- need to withstand high intra-cavity power
- to be addressed by industry

Laser From SDI

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

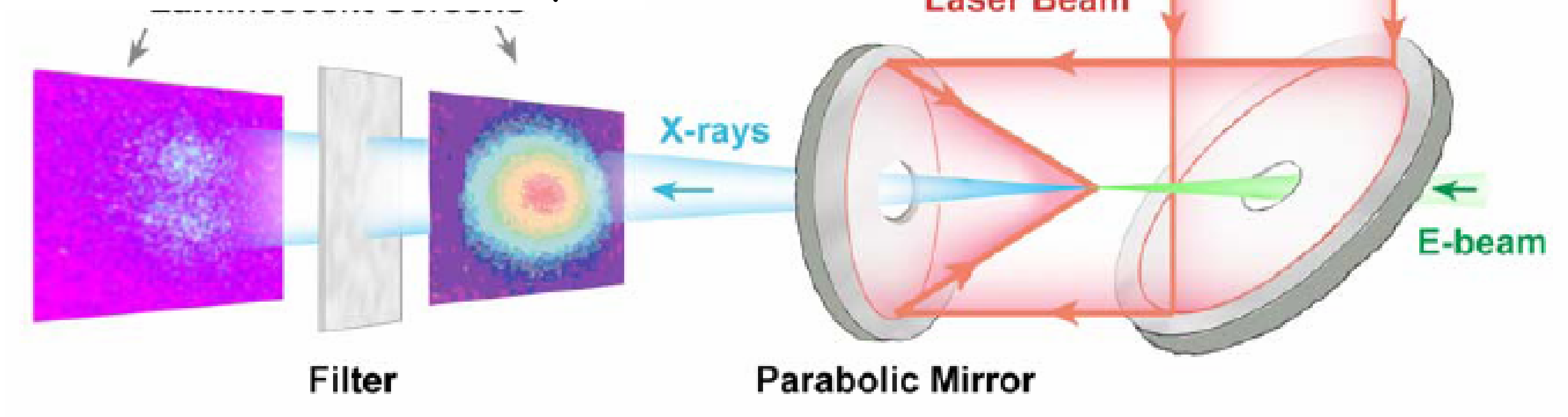
Wavelength (continous)	**9 – 11µm, Line Tunable**
Repetition Rate	**20 Hz 100 Hz 350 Hz 500 Hz**
Pulse Energy	**1.5 J**
Mode Type optional	**Multimode** **TEMoo, custom beam shapes, SLM**
Beam Size	**13 x 13 mm^2**
Average Power	**30 W 150 W 525 W 750 W**
Power Stability	< 7 %

WH10

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

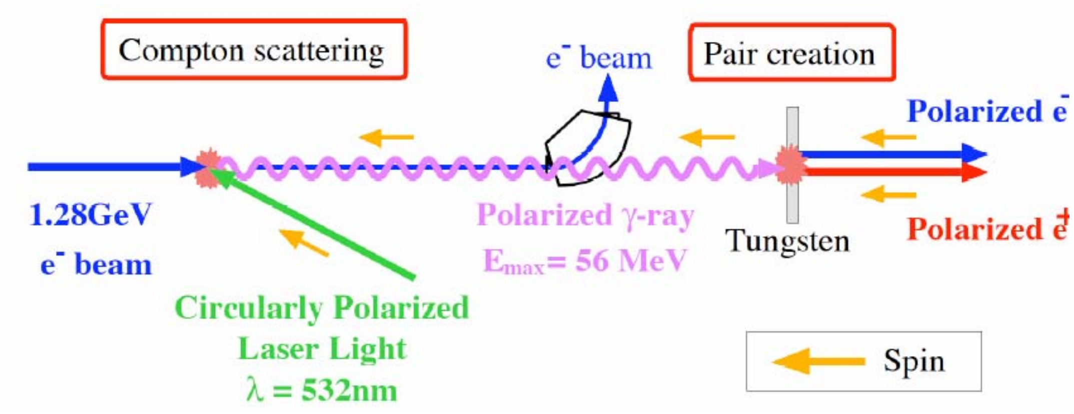
- X rays generated > ~10^8 PR ST 2000
- N_x/N_e ~0.1
- Interaction point with high power laser focus of ~30μm was tested.
- Nonlinear limit (more then one laser photon scattered from electron) was verified. **PRL 2005.**

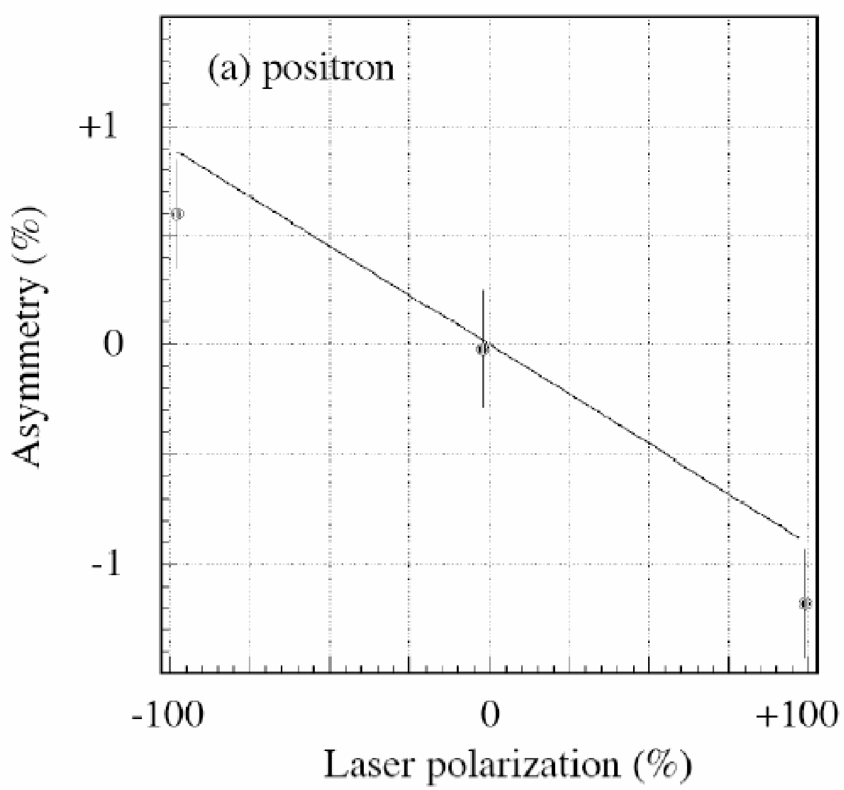
Real CCD images
Nonlinear and linear x-rays



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

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





Conclusion

- We propose a Polarized Positron Source.
  - based on Compton back scattering inside optical cavity of CO_2 laser beam and 6 GeV e-beam produced by linac.
- The proposal utilizes commercially available units for laser and accelerator systems.
- The proposal requires high power picosecond CO2 laser mode of operation developed at ATF
- 3 year laser R&D is needed to verify laser operation in the non standard regime.

CO_2 Laser @ ATF

❑Oscillator

•Single longitudinal,zero transverse mode TEA

•Source of a 10micron beam

•1atm discharge cell is the high power element

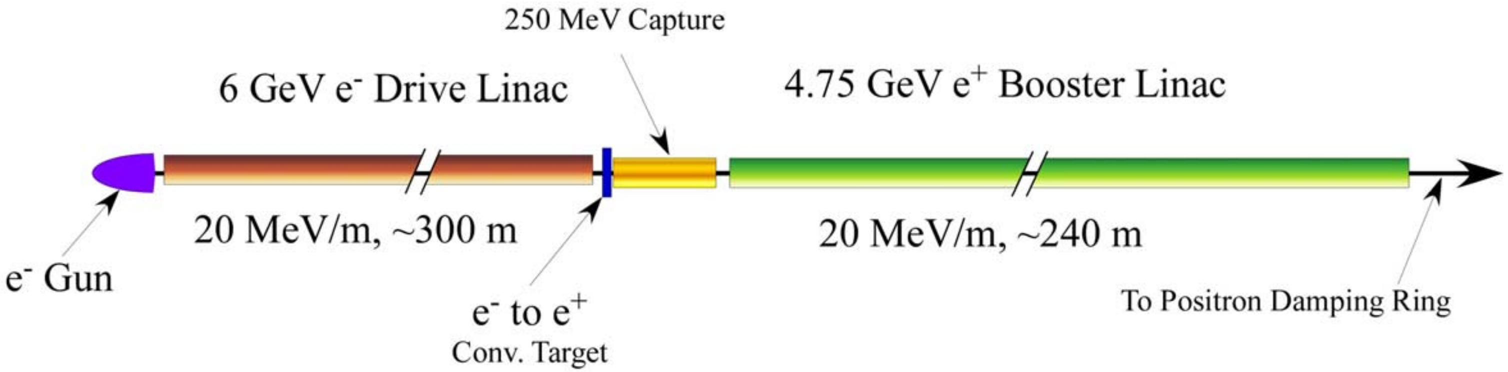
•low pressure discharge cell as well

•Pulses

- •100 nano sec
- •1 MW power(20 Hz)

❑Amplifier

- •3 Atm CO_2
- •Regenerative cavity
  - •extracted after the controlled number of double passes (normally five).
  - •output energy is limited by the damage threshold of the Pockels crystal to ~100 mJ.
- •Multi-pass
  - •The four extra passes through the amplifier
  - •output laser energy of 1 J
  - •peak power is 10 GW



do we need this,necassarily?

Compton Experiment Details1

- Electron beam
  - Bunch Charge 0.5 –1 nC
  - Energy Spread 0.15%
  - Normalized emittance 2-4 mm-mrad
  - Spot size 32µm
- Laser Beam(CO2)
  - 0.6 GW
  - 180 ps
  - Tight Focus
    - Cu Parabolic mirror(5 mm diameter hole)
- Laser Lossed Avoided
  - Quasi Gaussian Laser beam-Annular Shape(ZnSe axicon lenses)

Compton Measurement Details2

- Thomson signal
  - Diverging cone of $\theta = 1/\gamma = 8$ mm-mrad
  - Detected by 20 mm Si aperture
  - 140 cm from the interaction point
    - 120 cm inside vacuum
    - 250 micromts Be
    - 20 cms in air
  - separated from e beam by bending dipole magnet
  - Detected signal higher than 60 MeV Bremsstrahlung
    - SNR 100
    - max 6.5 KeV(1.8Angstrom)
    - min 5 KeV

180 degree geometry

- For shorter x ray pulses
  - In 180 deg geometry x ray pulse duration

$$\tau_{xray} = \tau_{electron\ bunch\ length} + (\tau_{laser\ pulse\ length}/4\,\gamma^2)$$

- Higher Number of Photons

Time Interval for interaction

focussed laser and e-beam is

$\pi\, r_L/\lambda$

r_L is laser beam radius

r_L is longer in 180 deg geometry

Ref I.V. Pogorelsky et alPRST-Vol3,090702,2000

CO_2 vs Yag

$$B = \frac{N_x \gamma^2}{4(\pi\sigma_b)^2 \tau_b}$$

B is Brightness

N_x *is* number of x ray photons per pulse

σ_b is focus spot size

τ_b *is* electron bunch length

$$N_x \propto \frac{E_L Q \lambda}{\sigma_L^2 (1 + a^2/2)}$$

E_L is portion of laser energy within time interval $4z_o / c$ that participates in interaction with electron bunch

Q is electron bunch charge

$$\lambda_x = \frac{\lambda(1 + a^2/2)}{4\gamma^2}$$

→ this is invariant

Choose γ and λ as high aspossible

CO2 has ten times λ

- needs sqrt(10) times energetic e-beam (higher γ)
- improves angular divergence
- back scattered x ray ~10 times Nx

Ref I.V. Pogorelsky et alPRST-Vol3,090702,2000

Yag has shorter λ

can be focussed to smaller spot

needs tighter e beam focus

coalignment problems?

space charge effects

Undulator vs. Compton Scheme

- **Undulator**
  - Additionl energy spread of about 0.15%
  - Issues with
    - vacuum in undulator
    - radiation in the beampipe

- **Compton**
  - High Current electr beam
  - complicated high power laser system
  - laser polarisation can be switched easily hence
    - switching positron polarisation
  - higher reachable degree of polarisation
  - Independent of the elctron linac