CLIC polarized e+ source based on laser Compton scattering

Frank Zimmermann
CLIC Meeting, 16. December 2005

Thanks to Eugene Bulyak,
Masao Kuriki, Klaus Moenig,
Tsunehiko Omori, Junji Urakawa,
Alessandro Variola

outline

- introduction
- ILC scheme
- differences ILC - CLIC
- CLIC scheme
- Compton ring dynamics
- laser system
- optical cavities
- ATF R&D
- LAL studies
- stacking in DR or pre-DR
- Compton Workshop 2006

Introduction

- polarized e+ source based on laser Compton scattering for the ILC was proposed at Snowmass 2005

- experimental tests at the ATF have demonstrated the production of 10^4 polarized e+ per bunch with 77 +/- 10% polarization

- stacking in the damping ring is a new feature proposed for the ILC

References

1) S. Araki et al, *“Conceptual Design of a Polarized Positron Source Based on Laser Compton Scattering – A Proposal Submitted to Snowmass 2005*”, KEK-Preprint 2005-60, CLIC Note 639, LAL 05-94 (2005)
2) T. Omori et al, *“Efficient Propagation of the Polarization from Laser Photons to Positrons Through Compton Scattering and Electron-Positron Pair Creation*”, Phys. Rev. Letters (2005)
3) E. Bulyak, P. Gladkikh, V. Skomorokhov, *“Synchrotron Dynamics in Compton X-Ray Ring with Nonlinear Compaction*”, in arXiv p. 5 physics/0505204v1 (2005)

CLIC Note 639

physics/0509016
CARE/ELAN Document-2005-013
CLIC Note 639
KEK Preprint 2005-60
LAL 05-94
September 2, 2005

Conceptual Design of a Polarised Positron Source Based on Laser Compton Scattering

— *A Proposal Submitted to Snowmass 2005* —

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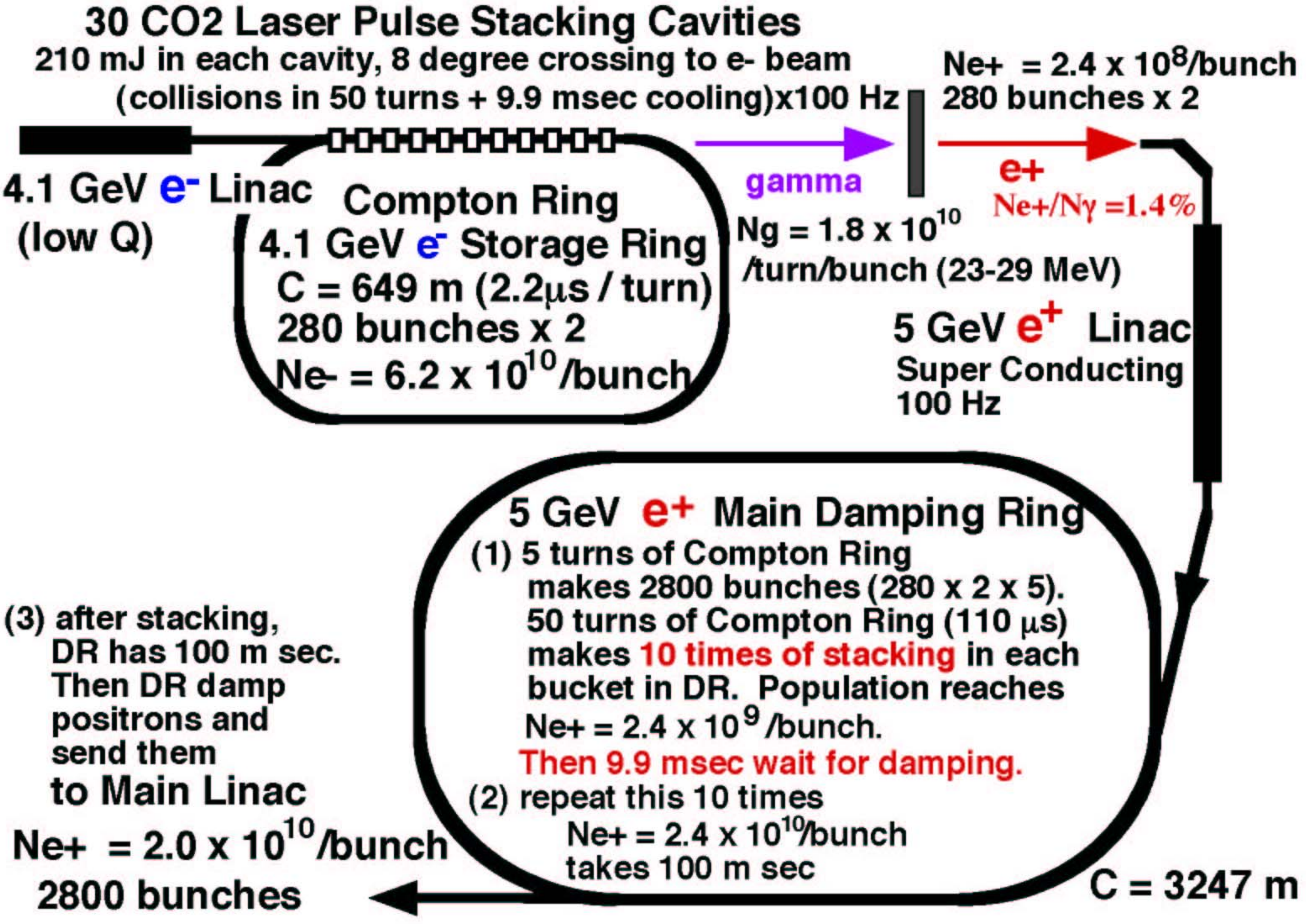
proposal of a polarized e+ source based on laser Compton scattering for the ILC was presented at Snowmass 2005;
the same scheme can be adapted to CLIC

"POSIPOL collaboration"

ILC source

- either YAG or CO2 laser (→differing parameters)
- 1.3 or 4.1 GeV linac injecting into 1.3 or 4.1 GeV Compton storage ring with 280 (or 2x280) bunches and C=277 (649) m
- ILC Compton ring contains 30 coupled optical cavities with laser-beam interaction points producting 1.36 (1.8)x10^{10} polarized photons per bunch and turn
- after conversion on a target with yield 1.4% this results in 1.9 (2.4) x10^{8} polarized e+
- 100 (50) turns in Compton ring result in 10x2800 bunches of polarized e+ which are accelerated in a 5 GV pulsed s.c. linac operating at 100 Hz
- bunches are stacked 10 times in each bucket of the DR and the whole process is repeated ten times with a time separation of 10 ms for damping
- after 90 ms accumulation is completed; the damping ring stores e+ bunches for 100 further ms before extraction

ILC polarized positron source w. CO2 laser



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

N_{e+} = 2.4 x 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
N_{e-} = 6.2 x 10^{10}/bunch

gamma

Ng = 1.8 x 10^{10}
/turn/bunch (23-29 MeV)

e+
N_{e+}/N_γ =1.4%

5 GeV e+ Linac
Super Conducting
100 Hz

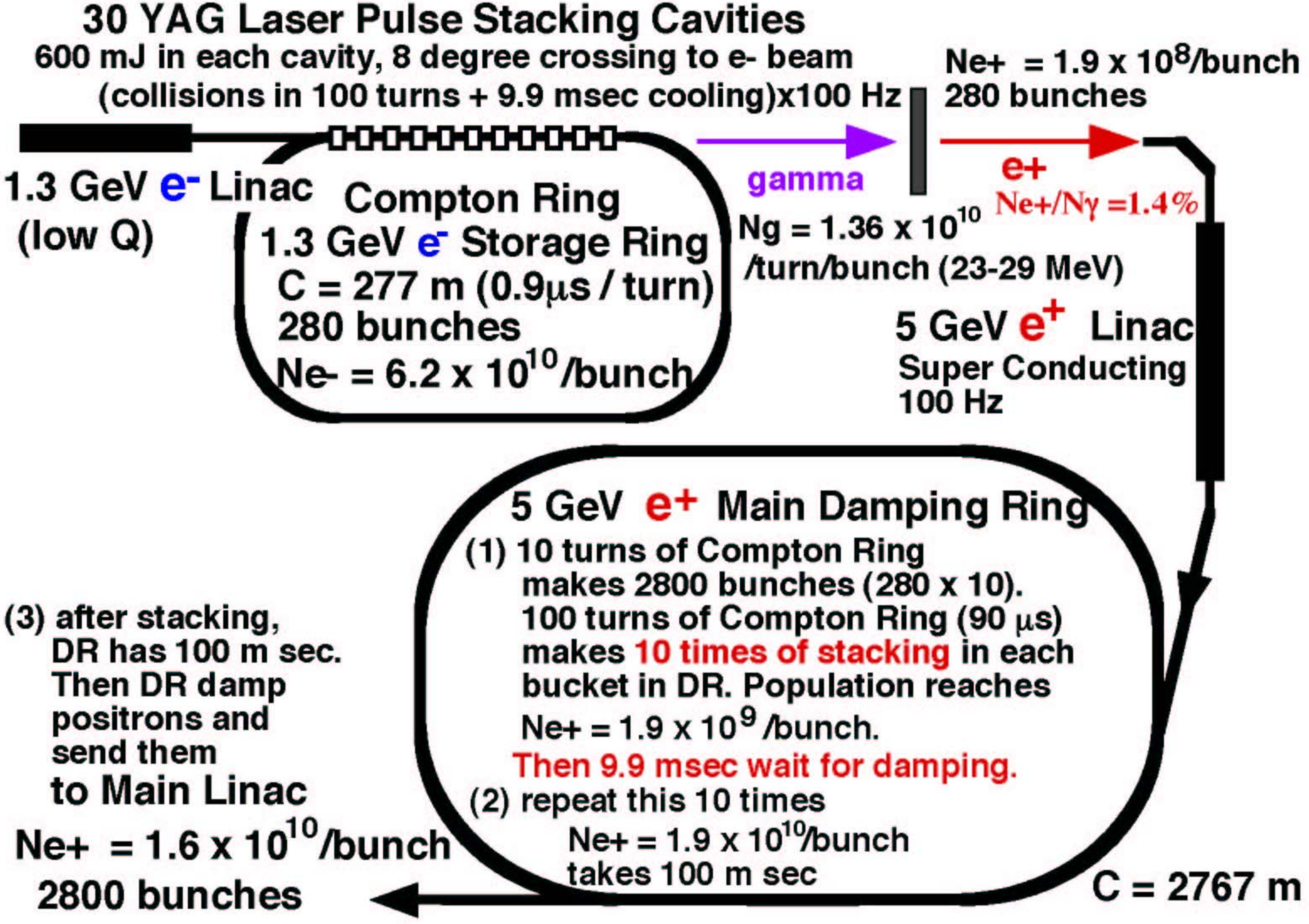
5 GeV e+ Main Damping Ring
(1) 5 turns of Compton Ring
makes 2800 bunches (280 x 2 x 5).
50 turns of Compton Ring (110 μs)
makes 10 times of stacking in each
bucket in DR. Population reaches
N_{e+} = 2.4 x 10^9 /bunch.
Then 9.9 msec wait for damping.
(2) repeat this 10 times
N_{e+} = 2.4 x 10^{10}/bunch
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

N_{e+} = 2.0 x 10^{10}/bunch
2800 bunches

ILC polarized positron source w. YAG laser



30 YAG Laser Pulse Stacking Cavities
600 mJ in each cavity, 8 degree crossing to e- beam
(collisions in 100 turns + 9.9 msec cooling)x100 Hz

1.3 GeV e- Linac
(low Q)

Compton Ring
1.3 GeV e- Storage Ring
C = 277 m (0.9μs / turn)
280 bunches
Ne- = 6.2 x 10^{10}/bunch

gamma
Ng = 1.36 x 10^{10}
/turn/bunch (23-29 MeV)

Ne+ = 1.9 x 10^{8}/bunch
280 bunches

e+
Ne+/Nγ =1.4%

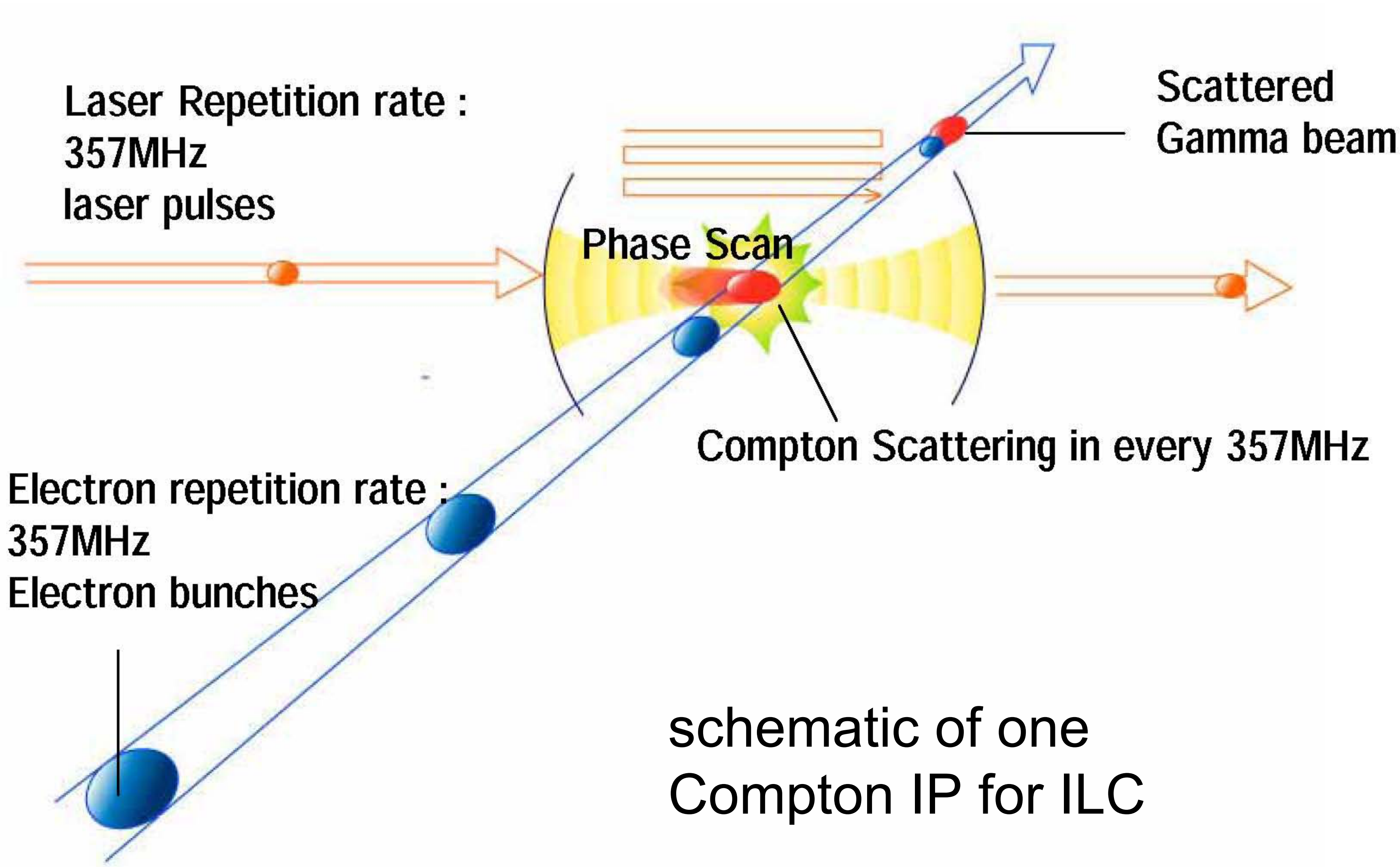
5 GeV e+ Linac
Super Conducting
100 Hz

5 GeV e+ Main Damping Ring
(1) 10 turns of Compton Ring
makes 2800 bunches (280 x 10).
100 turns of Compton Ring (90 μs)
makes 10 times of stacking in each
bucket in DR. Population reaches
Ne+ = 1.9 x 10^{9} /bunch.
Then 9.9 msec wait for damping.
(2) repeat this 10 times
Ne+ = 1.9 x 10^{10}/bunch
takes 100 m sec

C = 2767 m

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

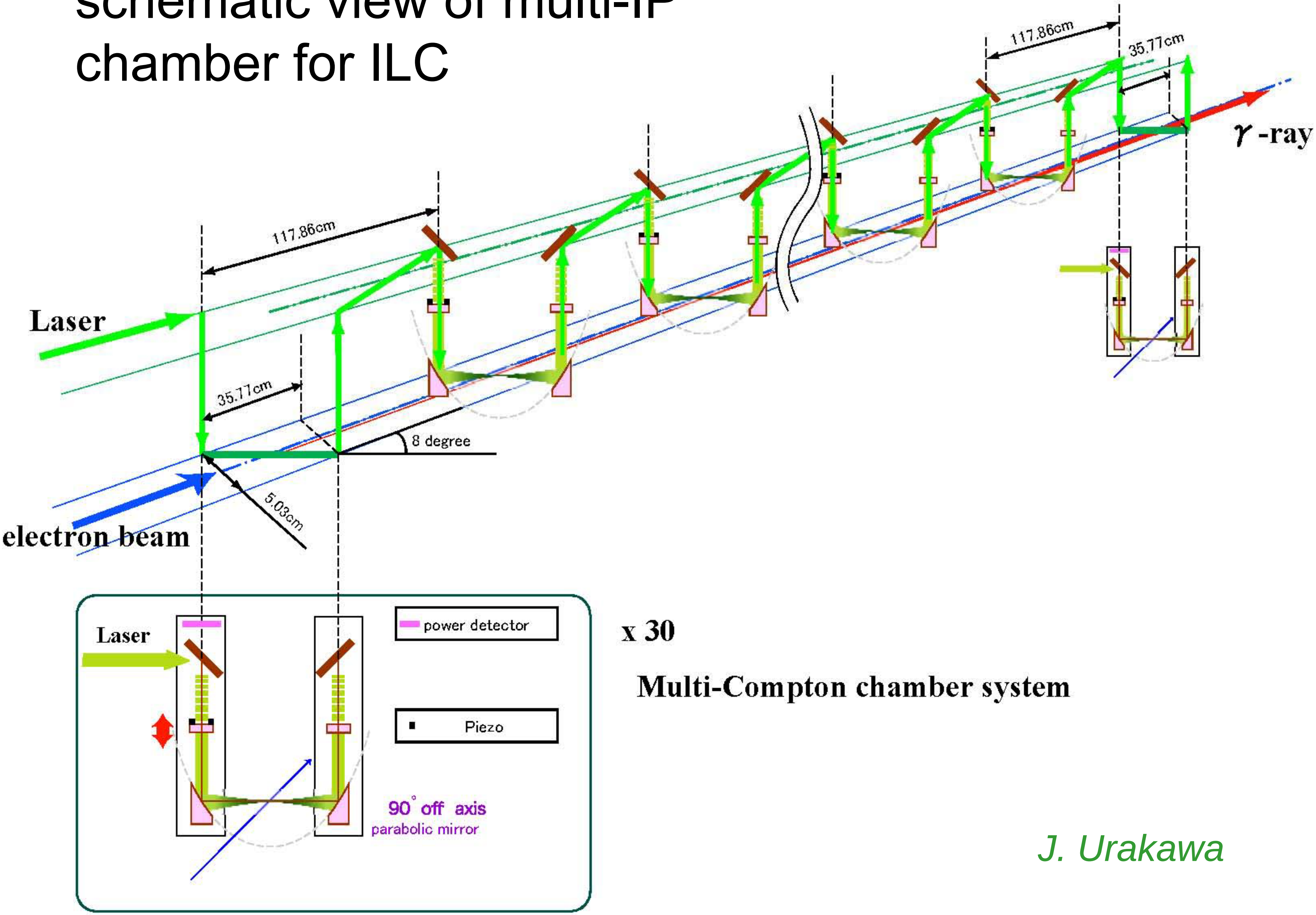
Ne+ = 1.6 x 10^{10}/bunch
2800 bunches



schematic of one
Compton IP for ILC

J. Urakawa

schematic view of multi-IP chamber for ILC



x 30

Multi-Compton chamber system

J. Urakawa

Compton-based e+ source for CLIC

why?

- either ILC or CLIC could be realized depending on physics case and cost
- CLIC differs from ILC in beam parameters, damping ring, bunch spacing, and repetition rate → some aspects of e+ source become easier
- recommendation by Yokoya san to use a polarized e+ source at CLIC and not at ILC

for simplicity consider only YAG laser case, since it puts less demand on injection linac and Compton ring *four main differences* between ILC and CLIC

- beam structure: CLIC has a smaller bunch charge (about 10x less) and less bunches per pulse (about 20x less) → relaxed laser parameters

- bunch spacing in DR: 0.533 ns instead of 2.8 ns
  → layout of optical cavities more challenging
  → multiple pulses stored in one cavity?

- damping ring; CLIC damping ring needs to produce beam with extremely small emittance, limited dynamic aperture; →pre-damping ring is required; we can use and optimize pre-damping ring for stacking polarized e+ from Compton source

- CLIC repetition rate is 150 Hz instead of 5 Hz for ILC

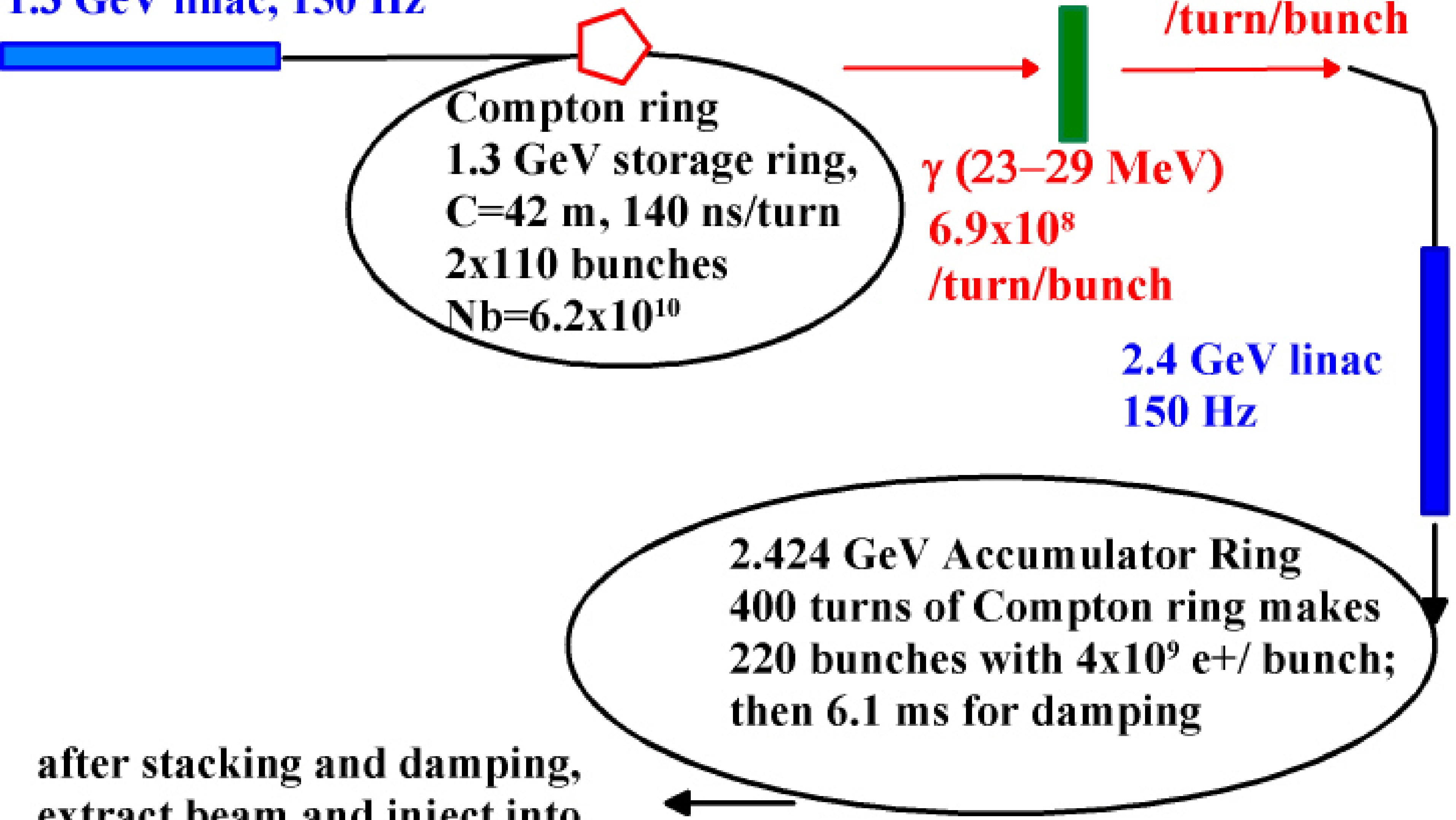
CLIC and ILC Damping Ring Parameters

parameter	CLIC	ILC (OTW/PPA)
energy	2.424 GeV	5 GeV
circumference	360 m	3230 m (or >)
bunch population	2.56×10^{9}	2×10^{10}
bunches/train	110	280
Intertrain gap	flexible	80 missing bunches
# trains/pulse	2	10
bunch spacing	0.533 ns	3.077 ns
hor.norm.emittance	600 nm	3 μm (?)
rf frequency	~1.875 GHz	650 MHz
vert.norm. emittance	5-10 nm	~10 nm (?)
rms bunch length	1.54 mm	6 mm
rms energy spread	0.126%	0.14%
repetition rate	150 Hz	5 Hz

as a consequence of these differences, we expect that *we can significantly reduce the number of laser cavities in the CLIC Compton ring*, ideally *to one* (a case which was already demonstrated at ATF)

this may considerably *simplify design of Compton ring, laser hardware, and operation*

schematic of total system for CLIC



1.3 GeV linac, 150 Hz

1 YAG Laser Pulse
Stacking Cavity, 590 mJ

$9.8\text{x}10^6$ pol. e+
/turn/bunch

Compton ring
1.3 GeV storage ring,
C=42 m, 140 ns/turn
2x110 bunches
Nb=$6.2\text{x}10^{10}$

γ (23–29 MeV)
$6.9\text{x}10^8$
/turn/bunch

2.4 GeV linac
150 Hz

2.424 GeV Accumulator Ring
400 turns of Compton ring makes
220 bunches with $4\text{x}10^9$ e+/ bunch;
then 6.1 ms for damping

after stacking and damping,
extract beam and inject into
damping ring, 220 bunches

tentative polarized e+ source parameters for CLIC & ILC

parameter	CLIC	ILC
energy	1.3 GeV	1.3 GeV
circumference	42 m	277 m
rf frequency	1.875 GHz	650 MHz
bunch spacing	0.16 m	0.923 m
# bunches stored	220	280
bunch population	$6.2x10^{10}$	$6.2x10^{10}$
#optical cavities	1	30
photons/bunch/turn	$2.8x10^{9}$	$5.8x10^{10}$
photons 23.2 MeV-29 MeV	$6.9x10^{8}$	$1.36x10^{10}$
pol. e+ /bunch/turn	$9.8x10^{6}$	$1.9x10^{8}$
#injections/bunch	400	100
total # e+/pulse	$5.6x10^{11}$	$5.3x10^{13}$
total # e+/second	$8.4x10^{13}$	$2.7x10^{14}$

tentative YAG laser parameters for CLIC & ILC

parameter	CLIC	ILC
laser pulse duration	57 μs	90 μs
rest between Compton cycles	6.1 ms	9.9 ms

tentative Compton IP parameters for CLIC

e- bunch length at C-IP	5 mm?
e- rms hor./vert. beam size	25, 5 μm
e- beam energy	1.3 GeV
e- bunch charge	10 nC
laser photon energy	1.164 eV
rms laser radius	5 μm
rms laser pulse width	0.9 mm
laser pulse energy	592 mJ
no. of laser cavities	1
crossing angle	~10 degrees
photons in cavity pulse	3.2×10^{18}
polarized γs per bunch & turn	6.9×10^{8}
positron yield e+/γ	0.014

Compton parameters

$x=0.023$, $E_{\gamma,max}=30$ MeV

$$\sigma_C \approx \sigma_T = \frac{8\pi}{3} r_e^2$$

→ laser-photon scattering probability
in 1 collision < 10^{-8}

→ *pulse depletion from scattering negligible*

$$\xi^2 = \frac{2 n_\gamma r_e^2 \lambda}{\alpha} \approx 0.02 << 1$$

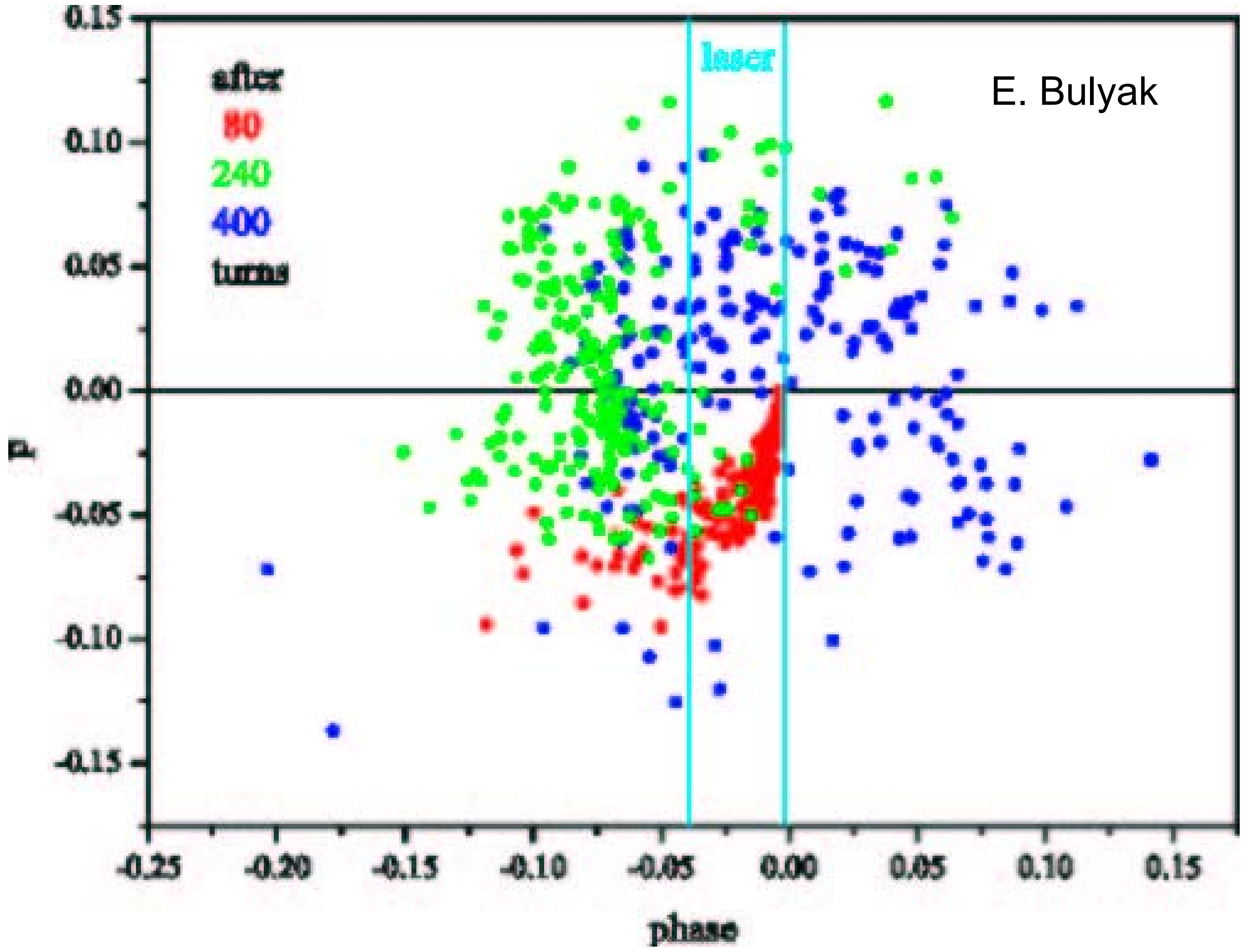
→ *nonlinear Compton effect not important*

CLIC Compton ring dynamics and e+ yield

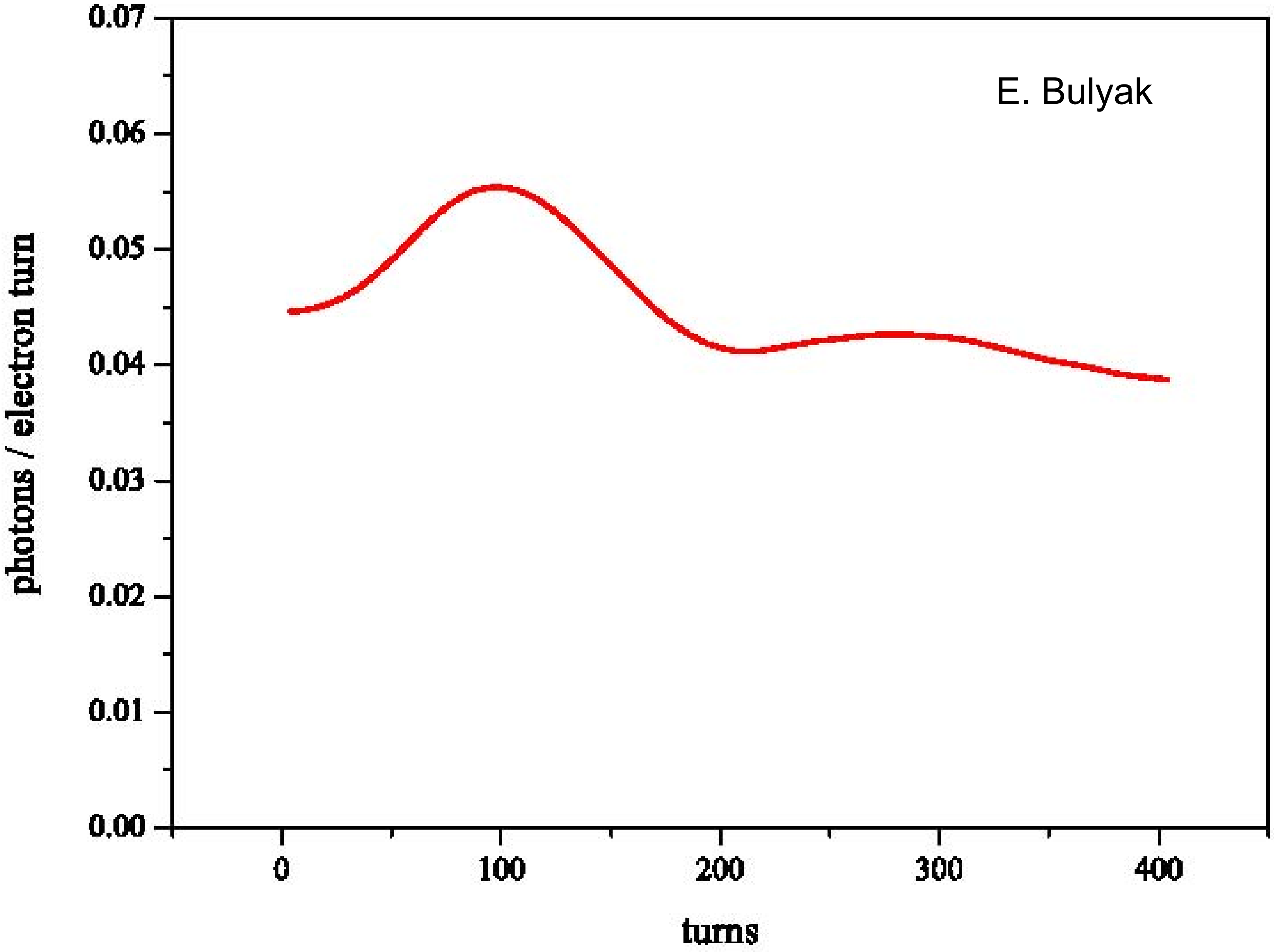
simulation of CLIC Compton ring dynamics and e+ yield was performed by E. Bulyak with code modeling longitudinal dynamics with nonlinear momentum compaction;
Eugene considered Compton ring with circumference 42 m, rf frequency 1.875 GHz, and 1 YAG laser cavity with 590 mJ ;
all other parameters were taken as for ILC nonlinear lattice

e^+yield per Compton-ring laser-bunch collision:
e^+yield/bunch = (bunch population) x (gamma yield) x (energy collimation) x (positron yield)
e^+yield/bunch = $6.2\text{x}10^{10}$ x $4.4645\text{x}10^{-2}$ x 0.248 x 1/70 = $9.8\text{x}10^{6}$

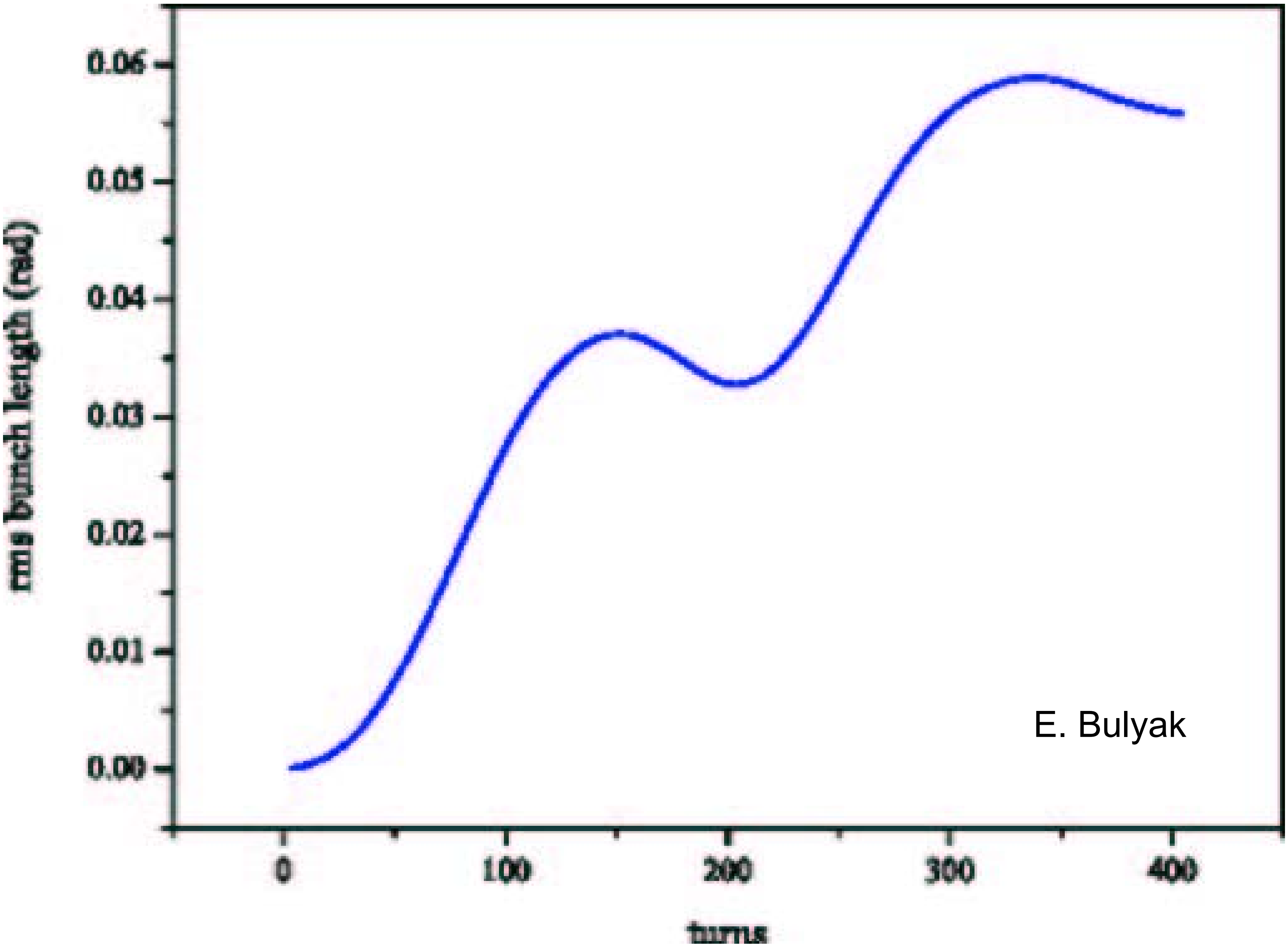
CLIC Compton ring can operate in steady state without losses; no cooling interval is required and e+ train length limited only by the length of the laser pulse; average photon production efficiency is rather high, namely ~64% of maximum theoretical (=initial) value for pointlike bunch matched to laser



Compton-ring particle phase-space distribution after 80, 240 and 400 turns; blue vertical lines indicate the rms laser splash size; the initial distribution of 200 test particles was pointlike; total duration of laser pulse is 400 turns



simulated photon yield as a function of turn number for continuous interaction with the laser over 400 turns



simulated rms bunch length as a function of turn number for continuous interaction with the laser over 400 turns

E. Bulyak & P. Gladkikh
(Kharkov institute / Ukraine)

many ideas & simulations for Compton rings
especially for difficult ILC conditions

- rf phase manipulation
- low & nonlinear momentum compaction
- wigglers
- pulsed momentum compaction lattice
- lattice design
- Compton simulation

Compton ring longitudinal dynamics for ILC

(with 30 laser-beam IPs)

circulating e- having interacted with laser avoid further interaction due to energy loss and synchrotron motion

→ train much shorter than synchrotron period enhances γ rate

→ pulsed mode of operation

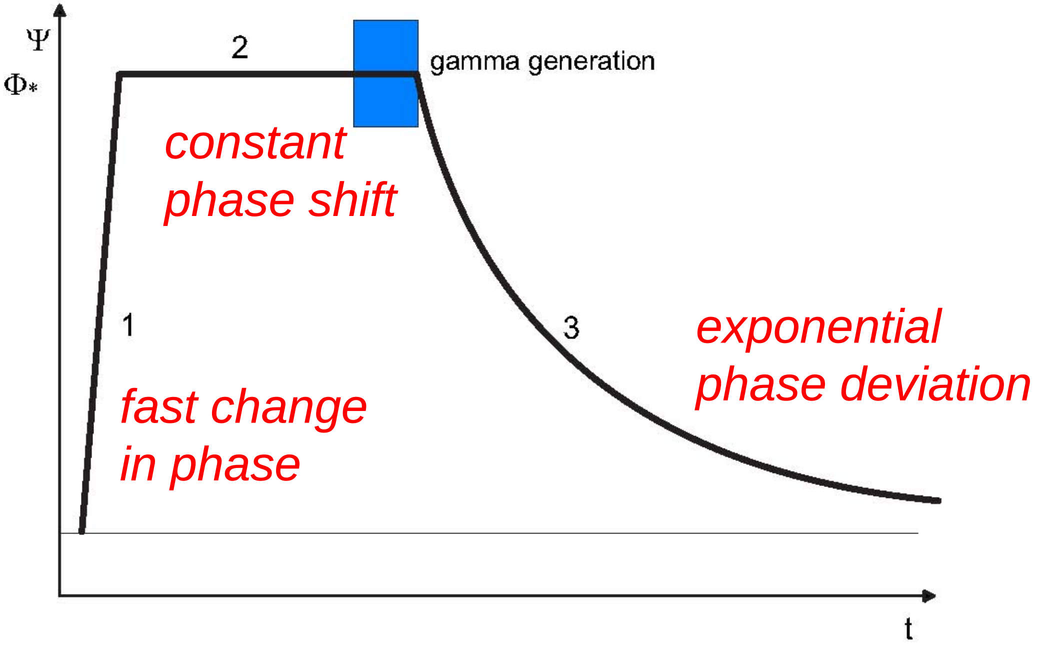
→ initial bunch position is chosen so that trajectory tangent is parallel to *p* axis

→ zero quadratic and proper 3rd order momentum compaction can reduce trajectory curvature at the initial bunch point

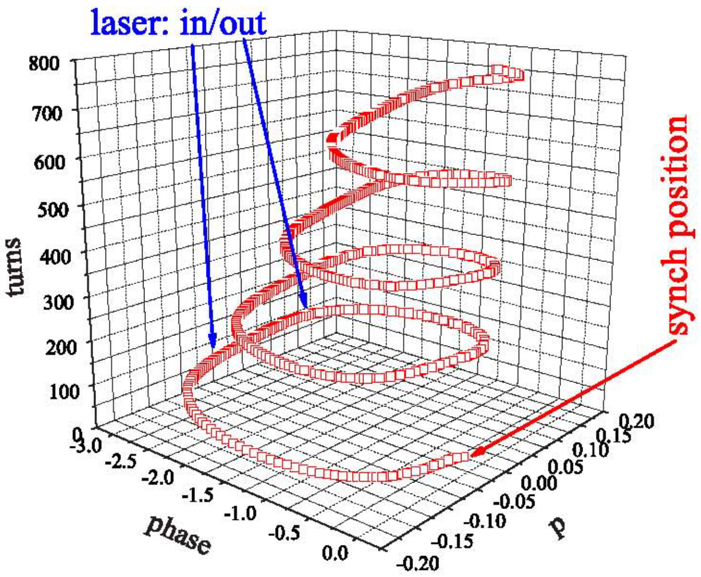
→ periodical transport to optimal position

→ rf phase manipulation (RFPM)

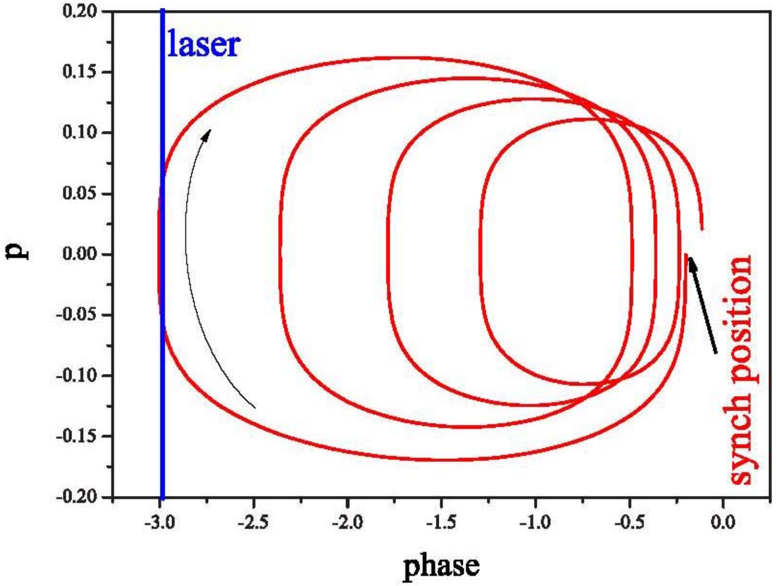
E. Bulyak & P. Gladkikh



rf phase manipulation



bunch trajectory under rf phase manipulation



rf phase manipulation scheme for ILC

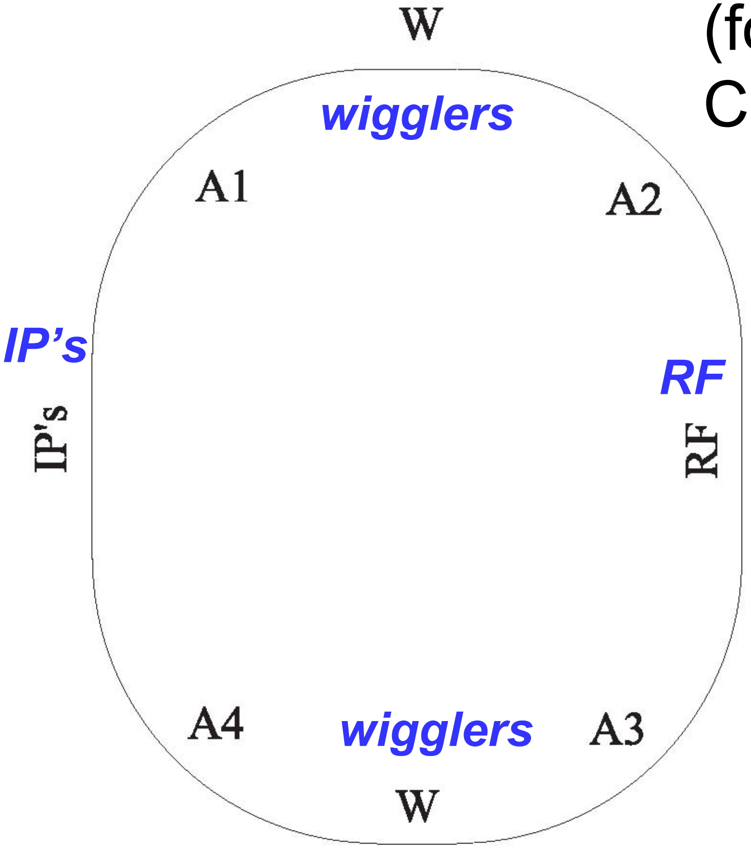
RFPM enhances γ intensity by factor 4; yield then equals 0.4 x theoretical maximum [YAG laser case]

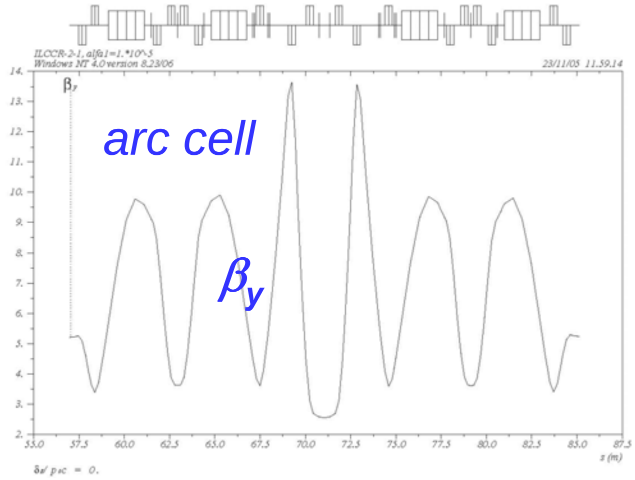
(CLIC: 0.64 w/o RFPM!)

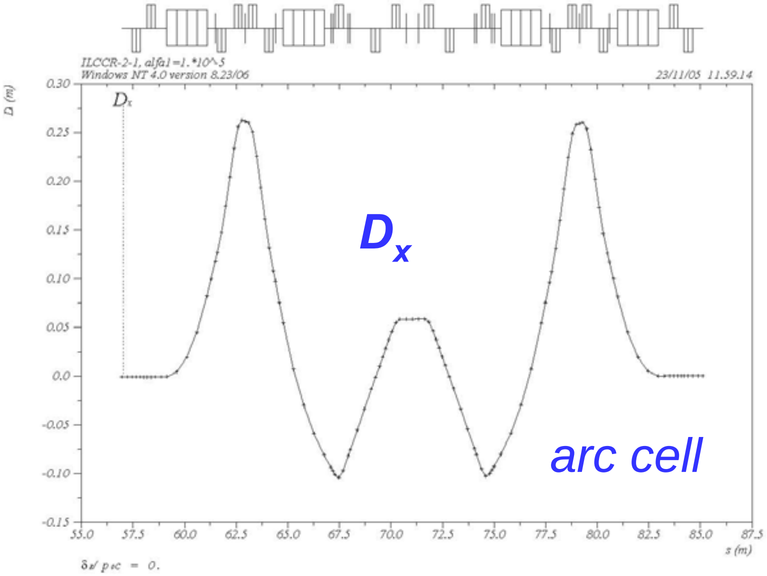
E. Bulyak & P. Gladkikh

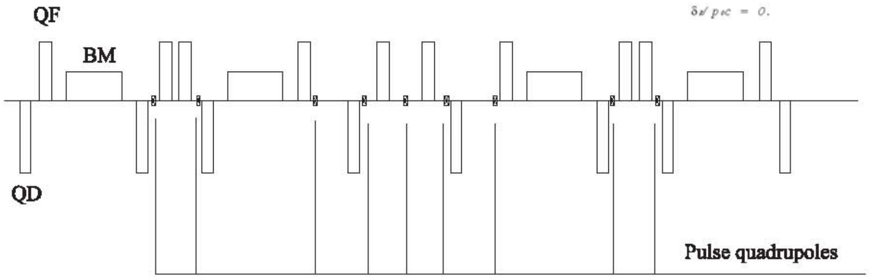
Compton ring lattice design

(for ILC, CO_2 laser)





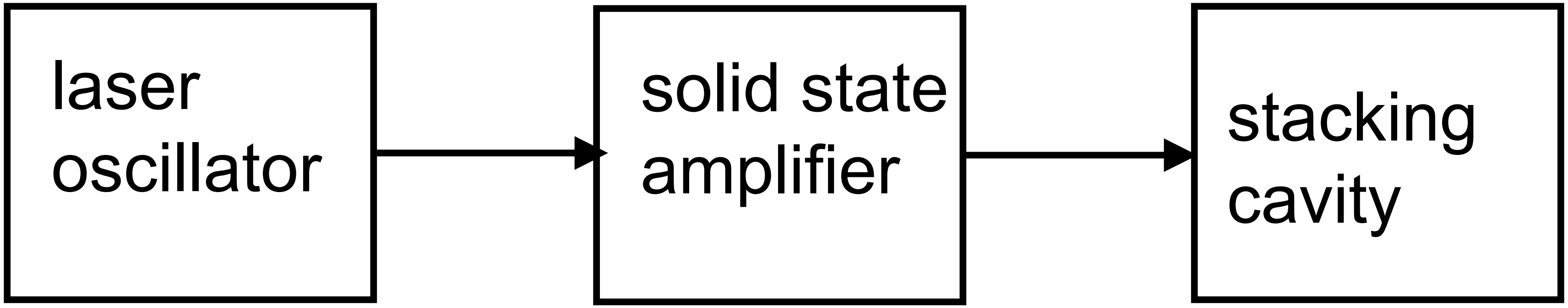




E. Bulyak &
P. Gladkikh

pulsed quadrupoles switched on just before laser system → pulsed α_c

schematic of laser system for CLIC or ILC



laser oscillator

solid state amplifier

stacking cavity

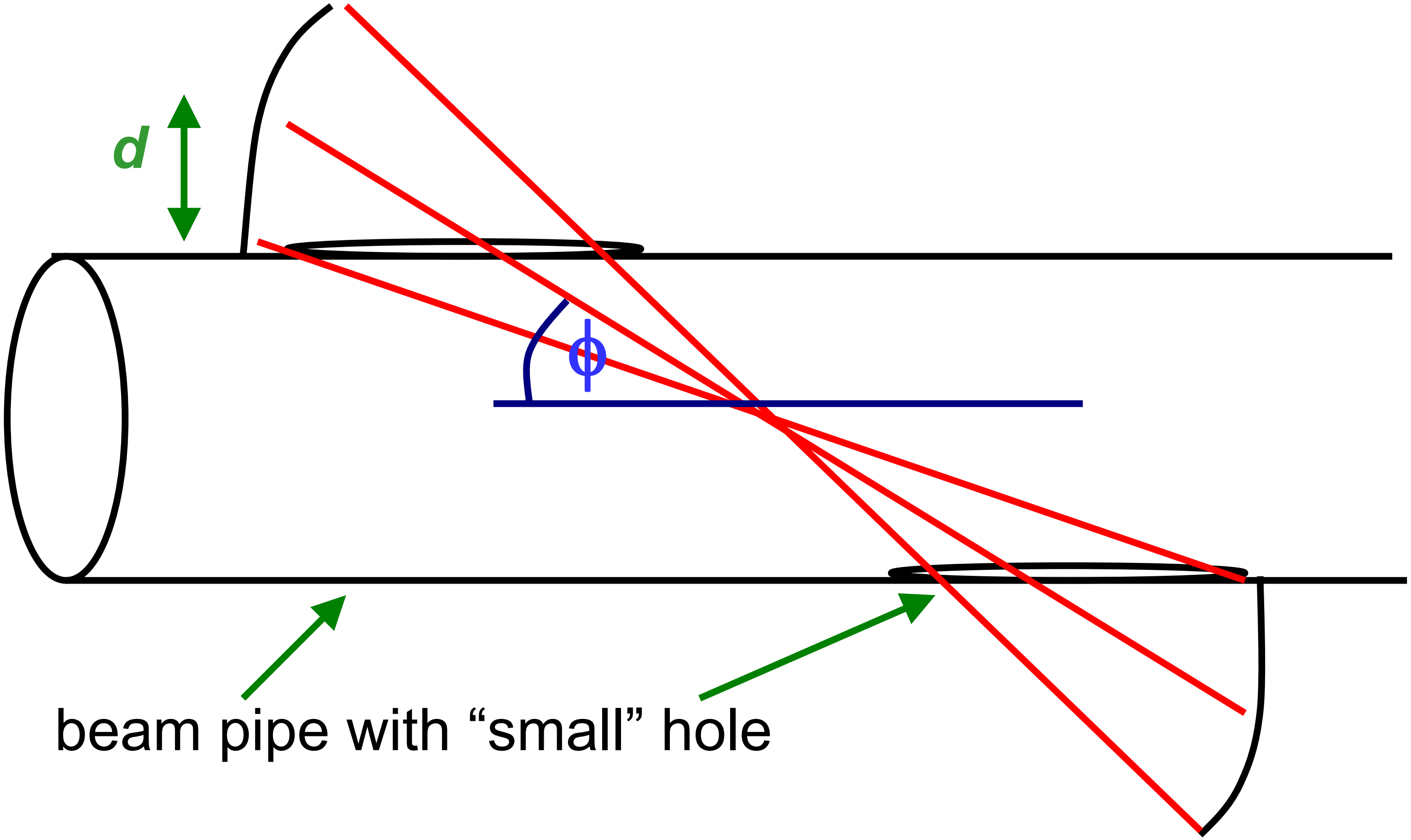
170 nJ
10 ps FW
117 MHz
20 W

600 μJ,
gain 3500,
ATF: 10^4
(ATF rf gun)
CPMA

600 mJ,
factor 1000 enhancement,
ATF: 300 (pulsed laser wire)
ATF: 1000 (cw laser wire),
e.g., 16 pulses in 1.3-m cavity

J. Urakawa
KEK scheme

schematic of optical cavity

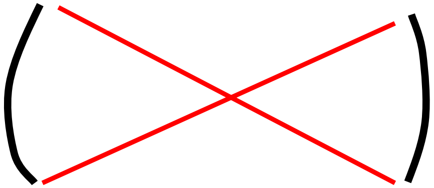


beam pipe with “small” hole

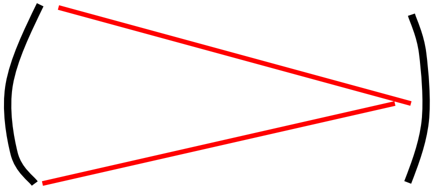
cavity length $l \sim d/\phi$
$d \sim 25$ mm, $\phi \sim 10^{o} \rightarrow l \sim 28$ cm
(3-4 pulses)

J. Urakawa
KEK/ATF scheme

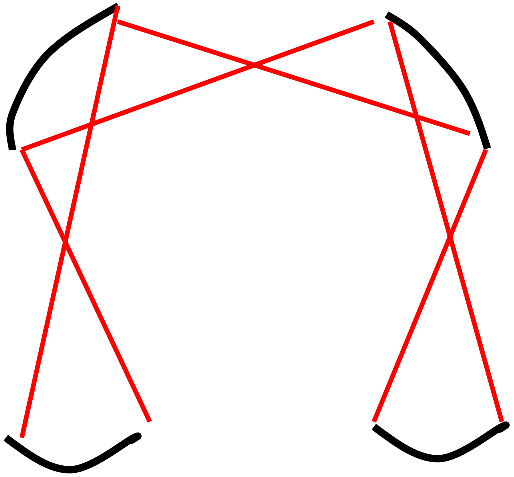
cavity configurations



unstable 2 mirror configuration



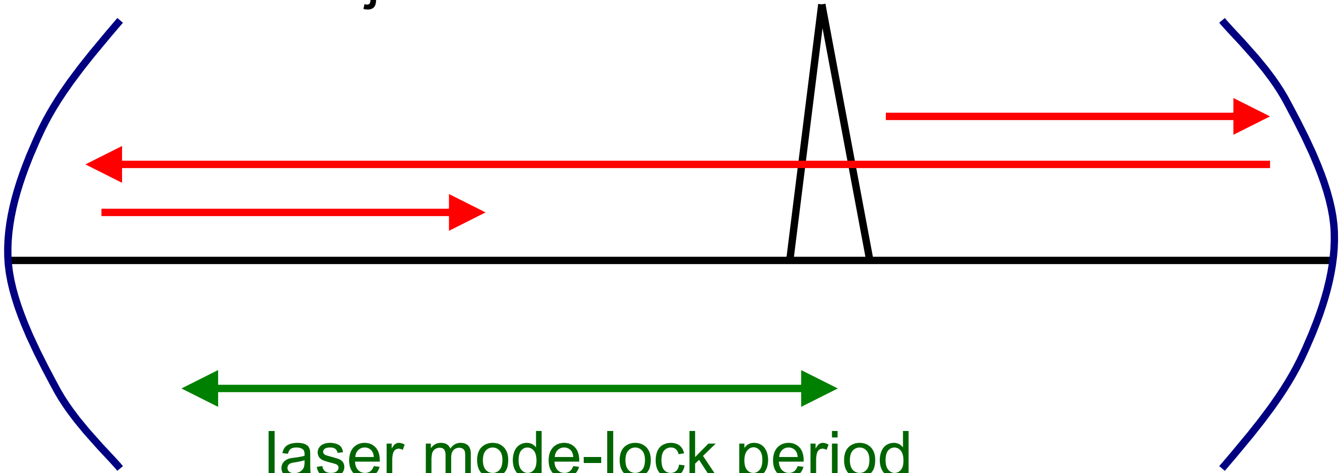
stable 2 mirror configuration
larger spot size in the center



stable 4 mirror configuration
(LAL) *with small spot size*

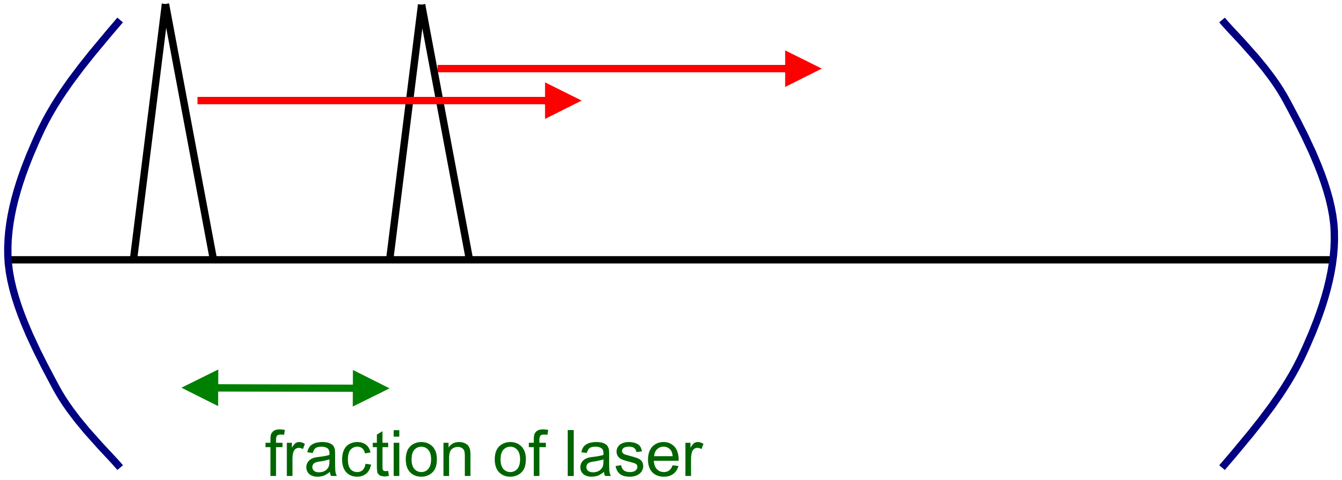
A. Variola
LAL scheme

laser frequency multiplication



1st laser bunch injected

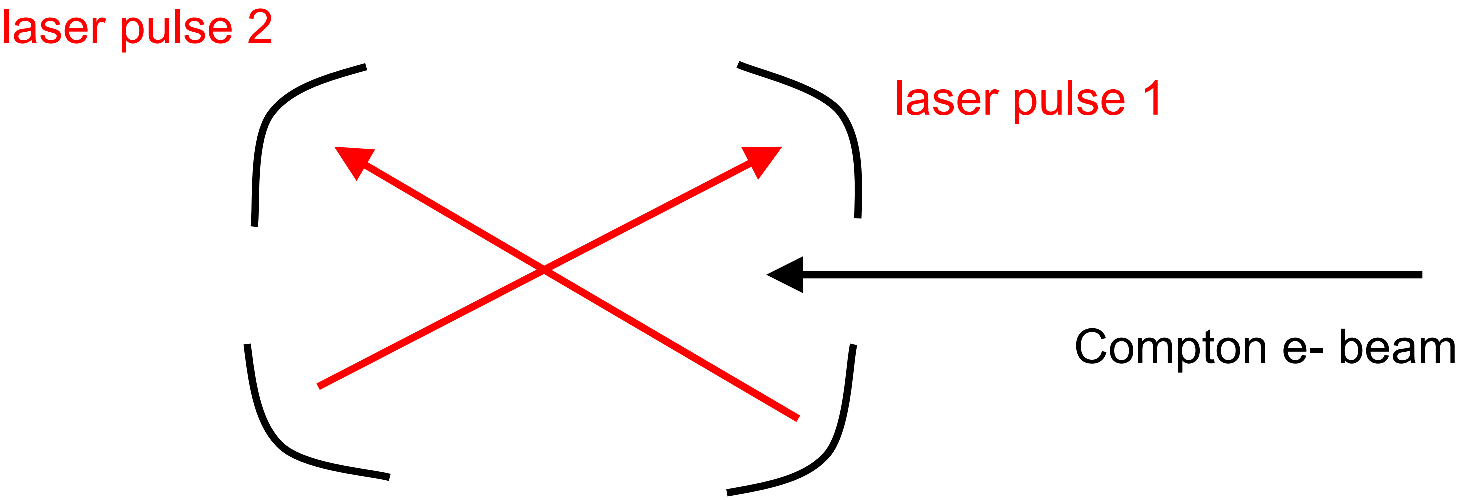
laser mode-lock period



nth laser bunch injected

fraction of laser
mode-lock period
~0.533 ns

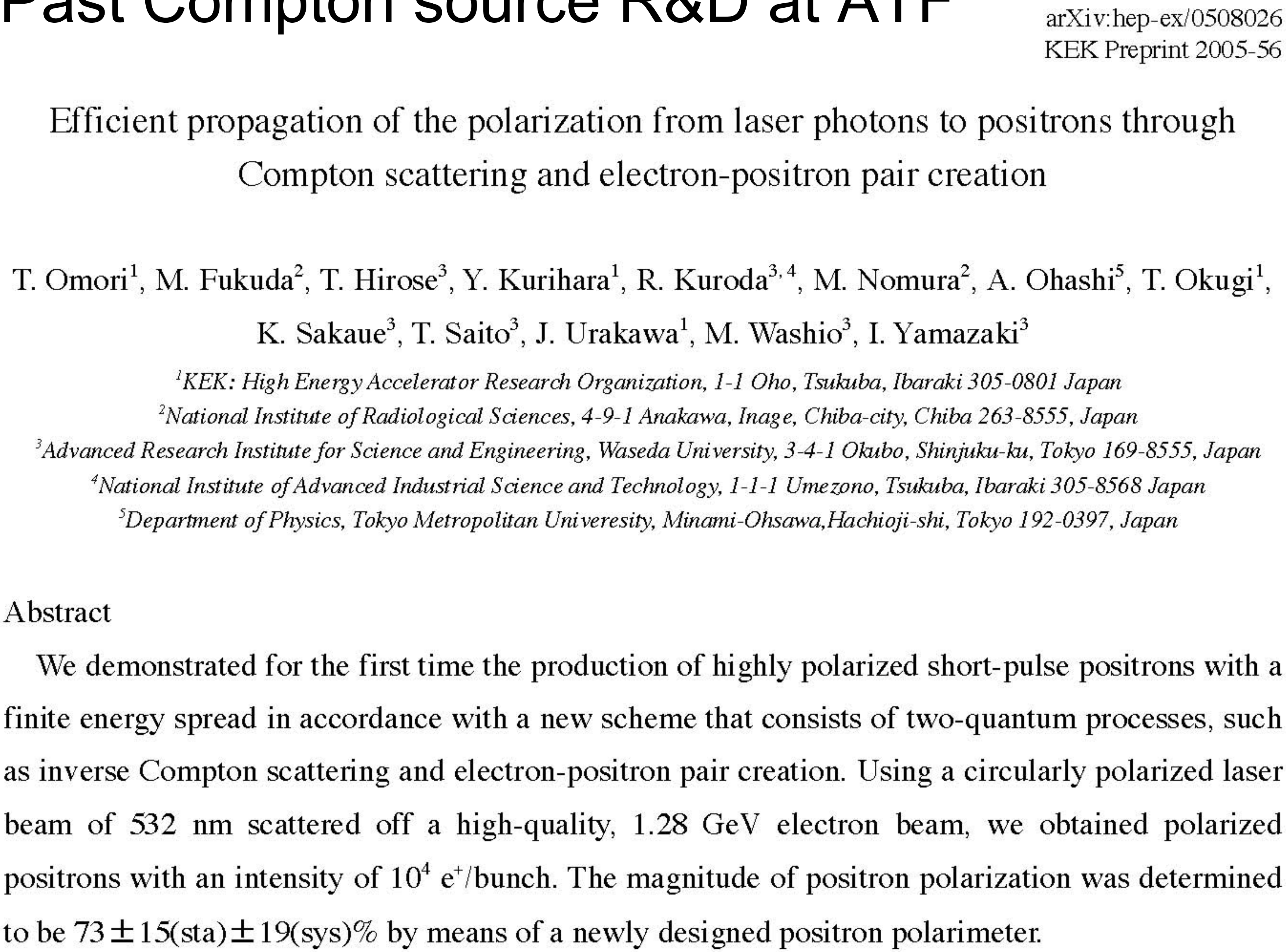
another method for short bunch spacing



higher collision frequency with independent laser pulses in several larger optical cavities

A. Variola, LAL

Past Compton source R&D at ATF



arXiv:hep-ex/0508026
KEK Preprint 2005-56

Efficient propagation of the polarization from laser photons to positrons through Compton scattering and electron-positron pair creation

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Abstract

We demonstrated for the first time the production of highly polarized short-pulse positrons with a finite energy spread in accordance with a new scheme that consists of two-quantum processes, such as inverse Compton scattering and electron-positron pair creation. Using a circularly polarized laser beam of 532 nm scattered off a high-quality, 1.28 GeV electron beam, we obtained polarized positrons with an intensity of 10^4 e^+/bunch. The magnitude of positron polarization was determined to be 73±15(sta)±19(sys)% by means of a newly designed positron polarimeter.

Future Compton source R&D at ATF

Kharkov colleagues study 42-cm cavity for 2 pulses;
such cavity will be installed at ATF in January 2006;
new ATF laser system was ordered for March 2006

2 studies will be performed in 2006:
(1) stacking of multiple pulses in single cavity
(2) two coupled cavities with feedback control

J. Urakawa

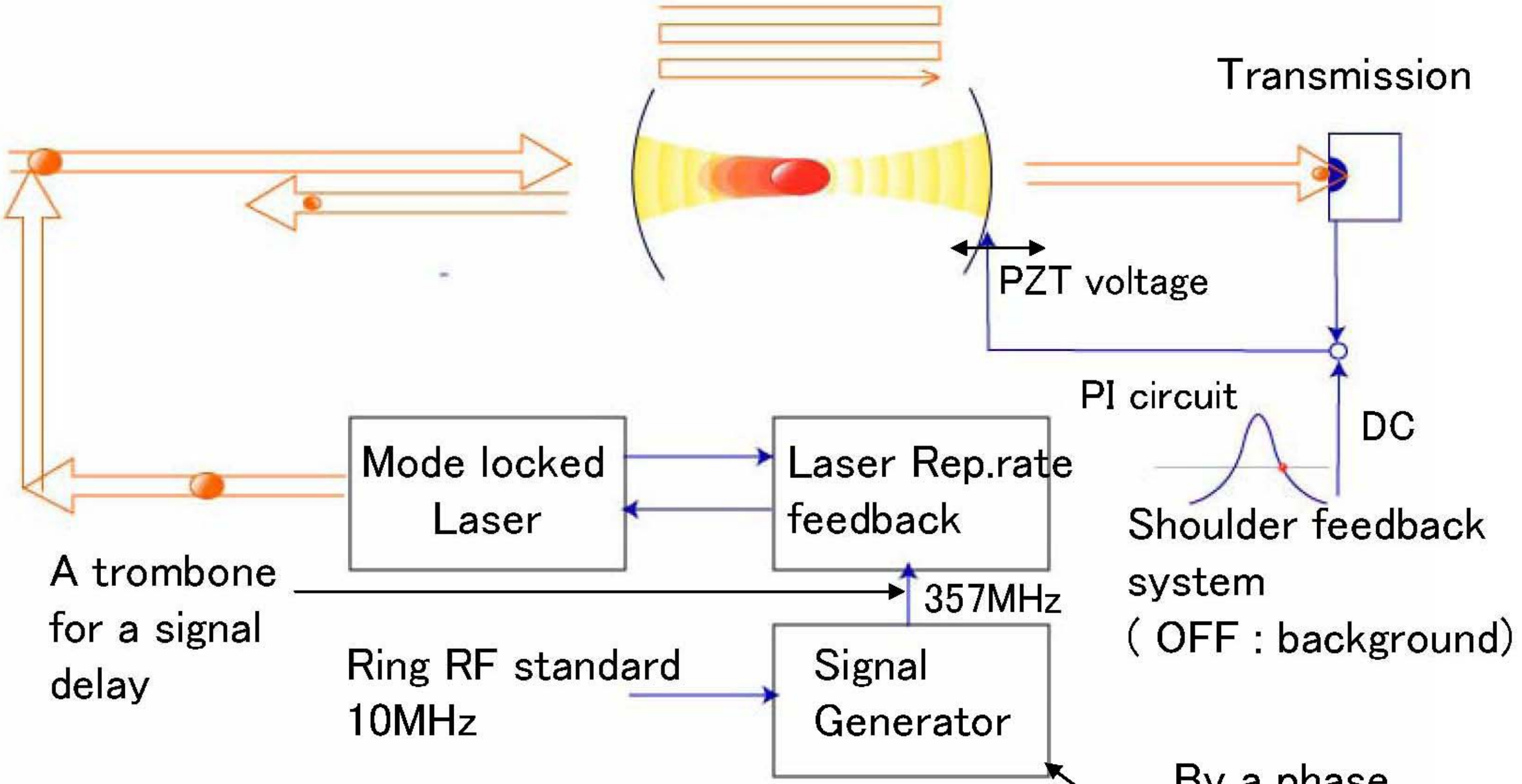
Compton source studies at LAL (K. Moenig, A. Variola, F. Zomer)

A. Variola

different concept:

- laser operates in continuous mode at 40-80 MHz (1 μJ per pulse available now, assume 10 μJ is possible)
- consider quality factor of optical cavity equal to 10^4 or 10^5 in continuous mode
- laser pulse energy of ~100 mJ in optical cavity or ~6 times less than in pulsed laser scheme;
- produce more e+ bunchlets to accumulate full charge
- use all 3 ILC damping rings for intermediate storage and accumulation during 150 ms
- then apply rf gymnastics to generate final bunches and store in 1 or 2 rings for 50–ms damping (Raimondi scheme)
- LAL feedback acts on laser (laser-cavity amplifier & frequency), - KEK feedback acts on optical cavity

OPTICAL CAVITY : feedback circuit



Transmission

PZT voltage

PI circuit

DC

Mode locked Laser

Laser Rep.rate feedback

Shoulder feedback system
(OFF : background)

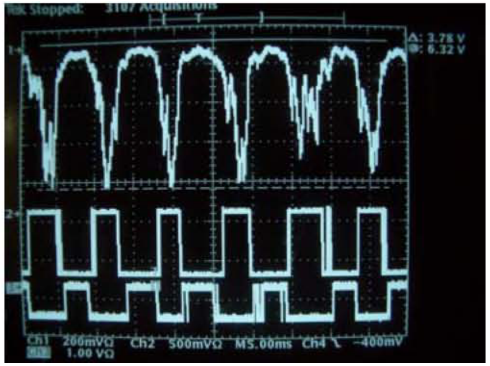
A trombone for a signal delay

357MHz

Ring RF standard 10MHz

Signal Generator

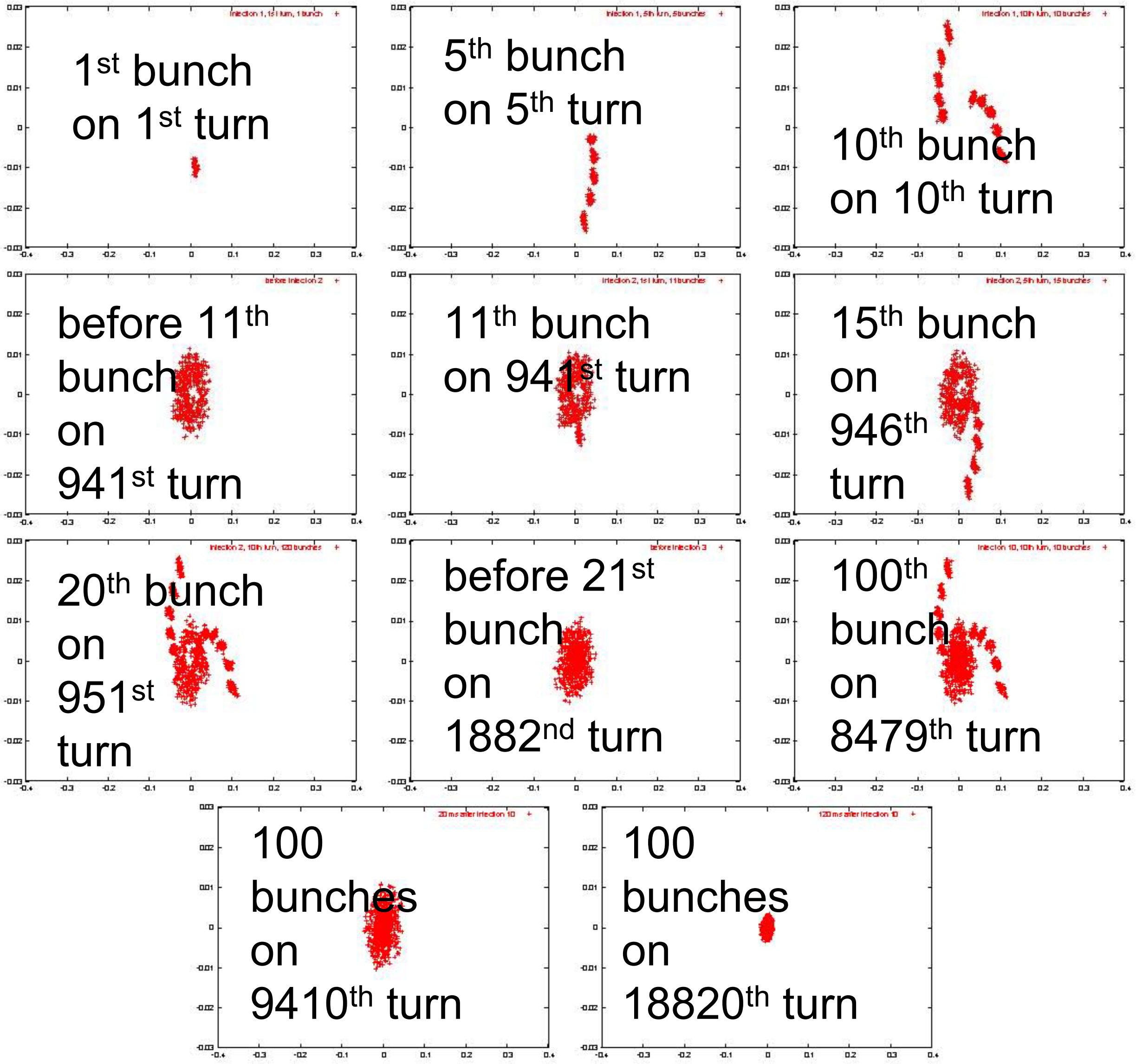
By a phase detector, the signal is synchronized with Ring RF.



← Feedback ON/OFF

J. Urakawa KEK/ATF scheme

e+ stacking



stacking in ILC – longitudinal phase space

ILC scheme:
10 turn injection
into the same bucket
of main DR
(at different δ);
followed by
10 ms damping,
this is repeated
10 times!

CLIC:
250-400 turn injection
into the same bucket,
no repetition

CLIC uses
pre-damping ring
optimized for e+
accumulation

Proposal for a workshop on Compton-based polarized positron source

Place: CERN?
Time: End of April 2006?
Duration: 2 or 2.5 days
Initiative: LAL (A. Variola)

interested parties

KEK (Japan), IPN Lyon (France), LAL Orsay (France), INFN Frascati (Italy), CERN (Switzerland), BINP (Russia), NSC KIPT (Ukraine), DESY-Zeuthen (Germany), Waseda U., Kyoto U., NIRS, Hiroshima U., Sumitomo HI (all Japan), IHEP (China), IHEP (Russia), Munich U. (Germany), SLAC (USA), European laser industry (e.g., TimeBandwidth / Switzerland),…

addressing several open questions

- design & dynamics of Compton ring
- laser system
- optical cavities & feedback
- e+ production & capture system
- e+ stacking in accumulator or damping ring
- experimental program (KEK/ATF, LAL, Frascati, various light sources,…)

it seems time to bring the dispersed community together to arrive at a consistent overall design

ELAN workshop?

- focused topical workshop to address critical issues, find solutions for this type of e+ source & finalize conceptual design
- ELAN support would help for travel
- in particular might allow travel subsistence for a few Ukrainian and/or Russian colleagues
- ELAN steering group suggested combination with mini-workshops on lasers for accelerators (G. Blair) & on advanced acceleration (B. Cros)
- Louis Rinolfi will co-organize the workshop

thank you

merry Christmas
& a happy 2006!