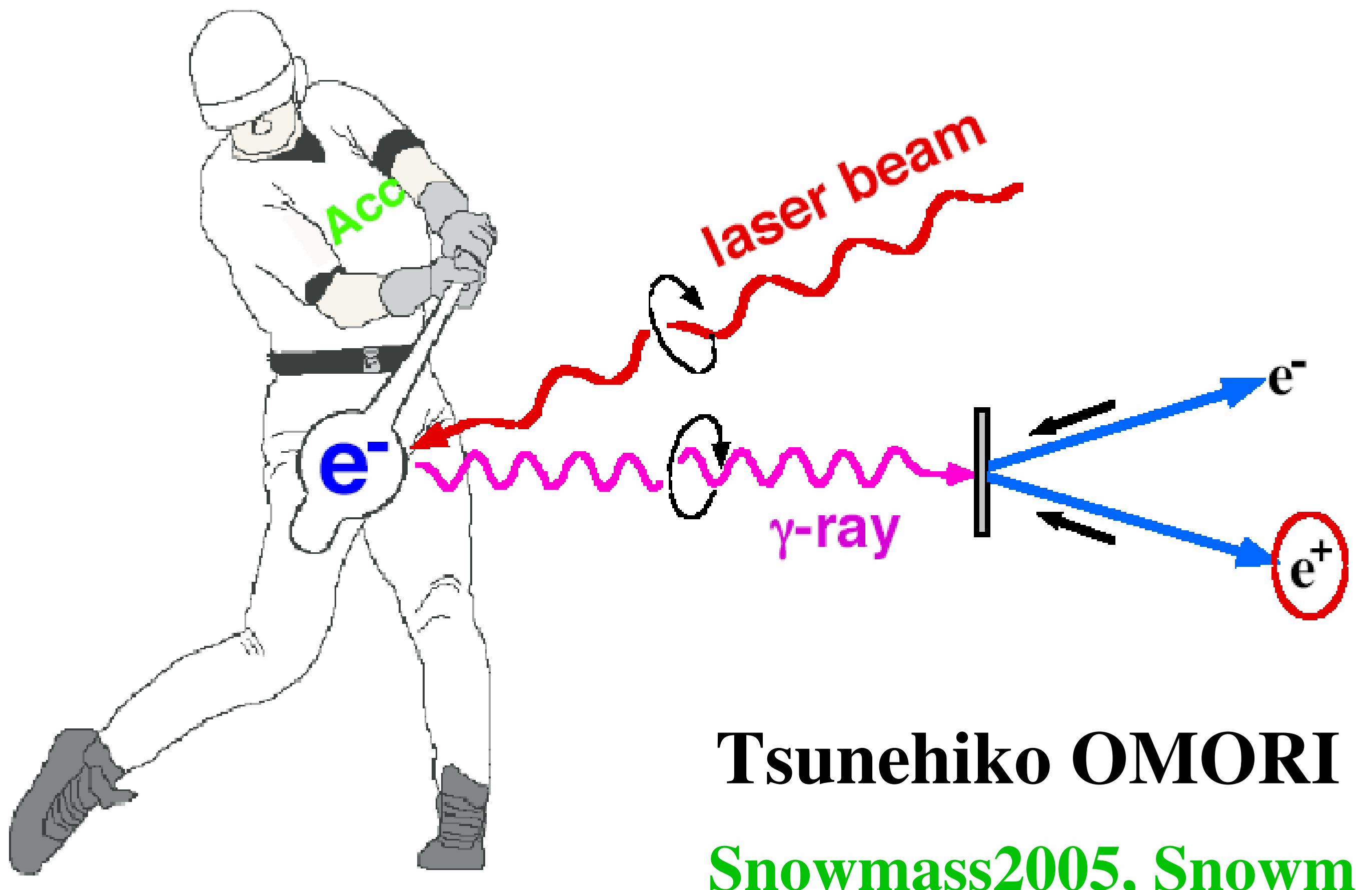
Compton Scheme Overview
Polarized e^+ Source for ILC



Tsunehiko OMORI (KEK)

Snowmass2005, Snowmass Colorado

18/Aug/2005

Why Compton Scheme?

i) Positron Polarization.

ii) Full energy/intensity e^- beam is NOT necessary to produce positrons. Therefore, Electron and positron systems remain independent. Easier development, easier commissioning, easier operation.

iii) No problem of low energy operation of the collider (GigaZ).

Today's talk

1. Experiment at KEK-ATF

   proof-of-principle

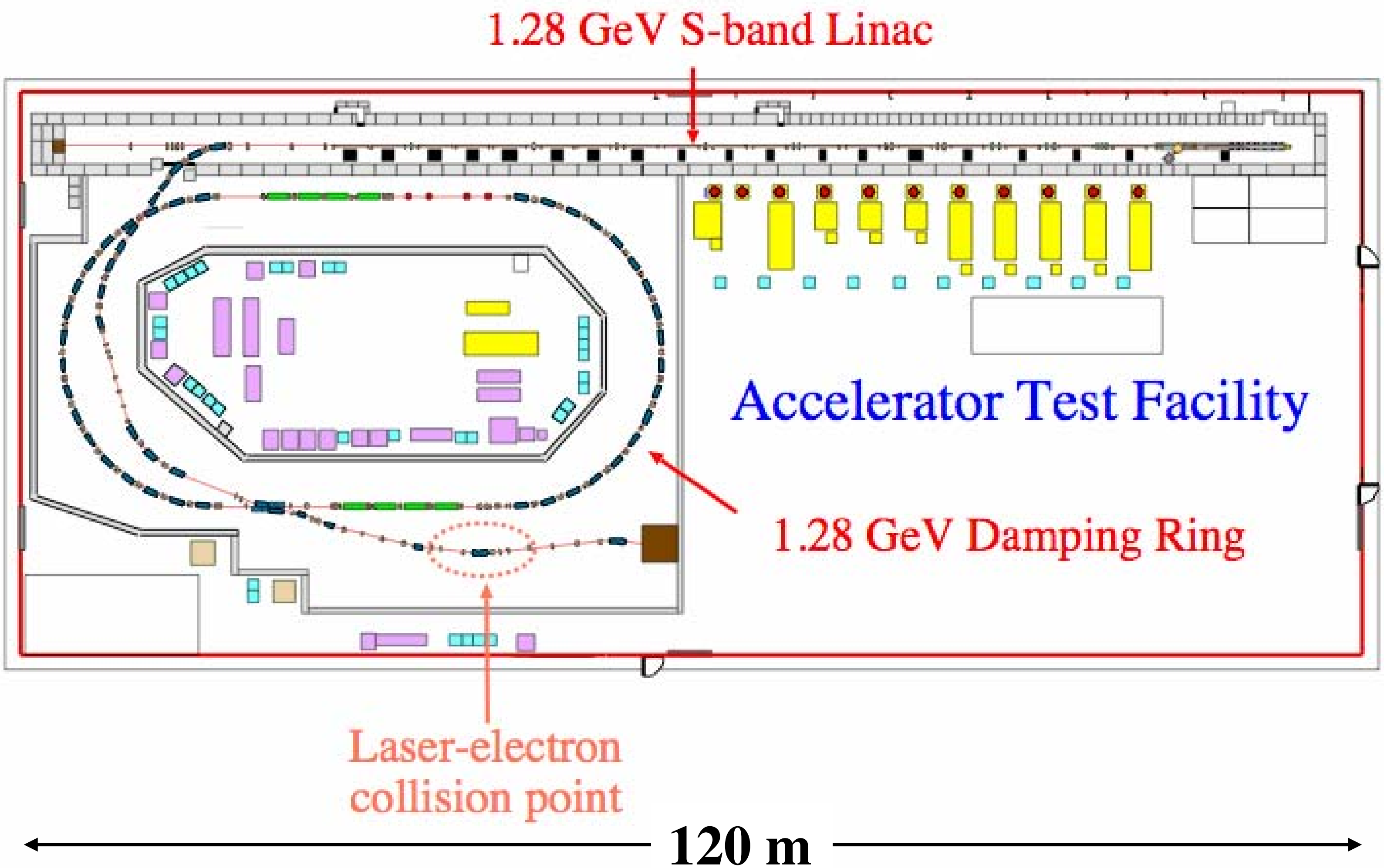
2. Concept of Compton Polarized e^+ Source for ILC

Experiment at KEK-ATF

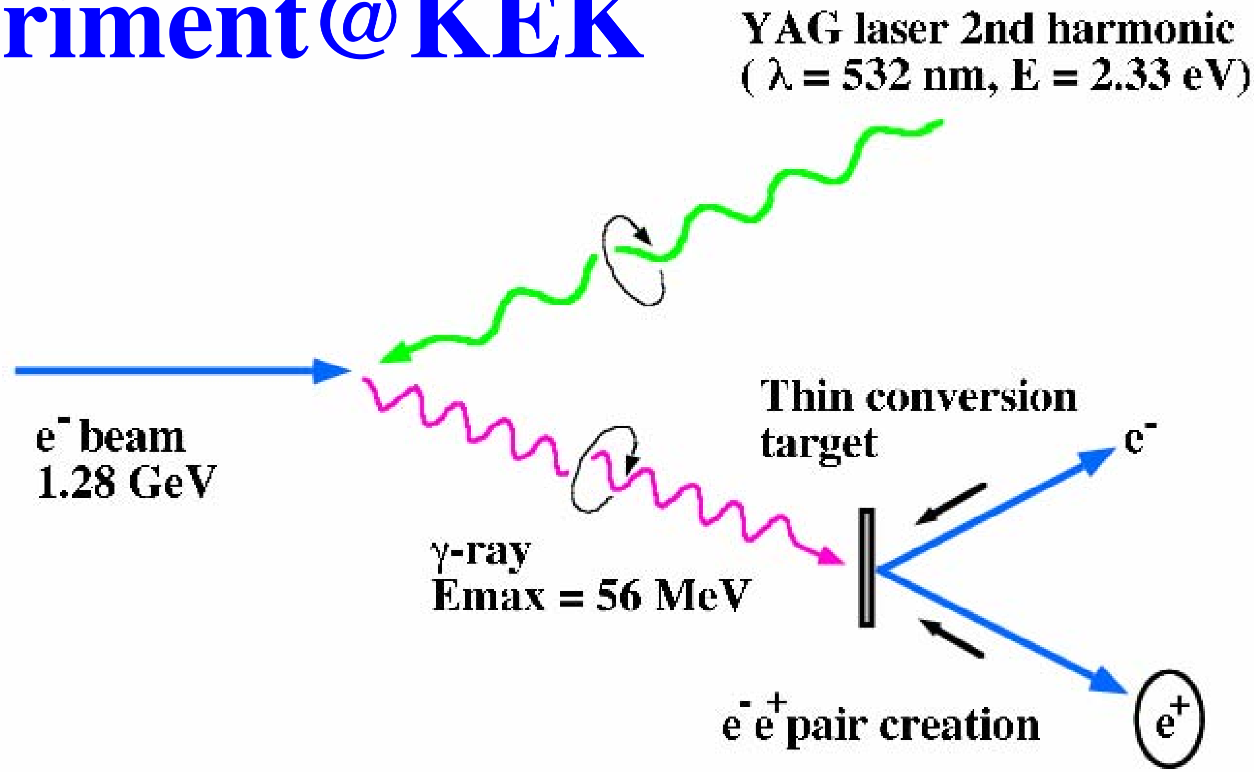
ATF: Accelerator Test Facility for ILC built at KEK

Collaborating institute: Waseda, TMU, KEK, NIRS, and AIST

T. Omori, M. Fukuda, T. Hirose, Y. Kurihara, R. Kuroda, M. Nomura, A. Ohashi, T. Okugi, K. Sakaue, T. Saito, J. Urakawa, M. Washio, and I . Yamazaki



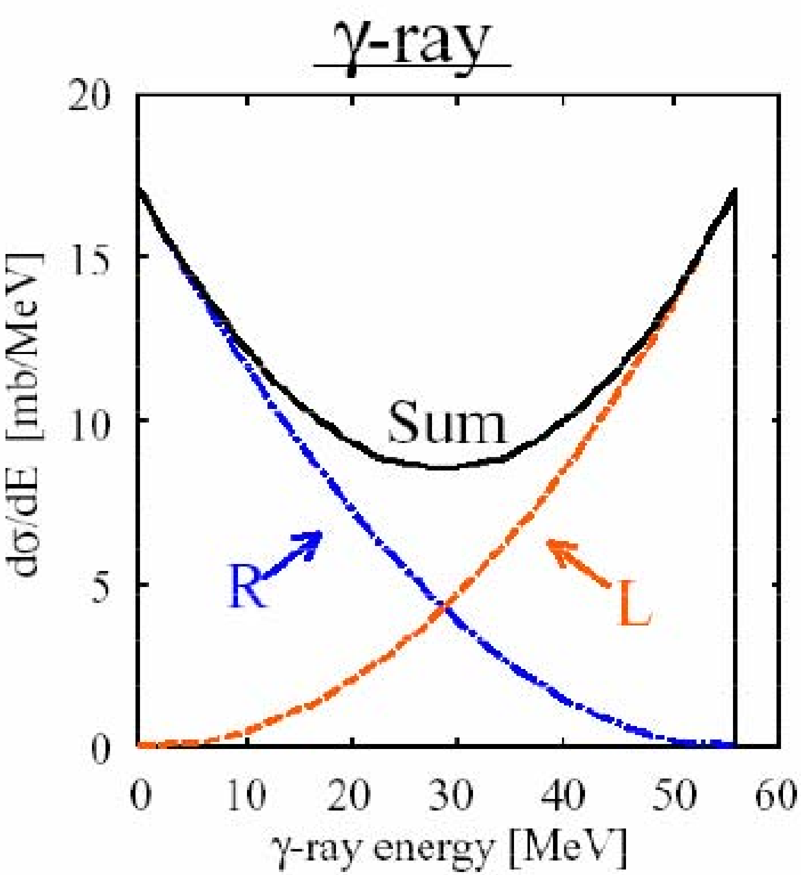
Experiment@KEK

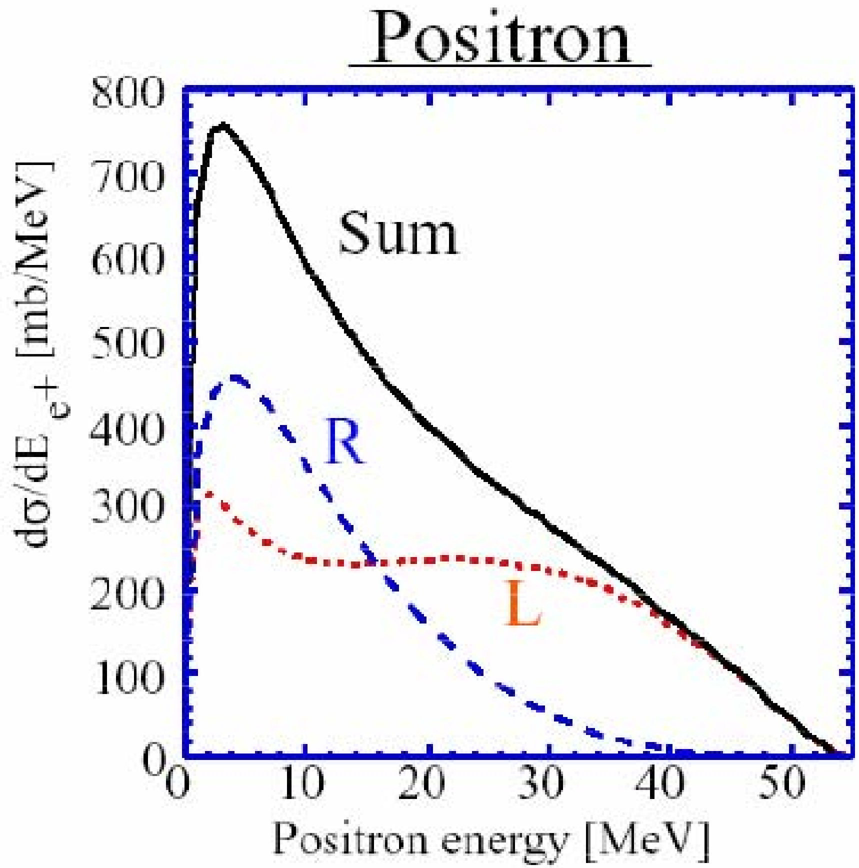


i) proof-of-principle demonstration

ii) accumulate technical informations:
polarimetry, beam diagnosis, …

Cross section (calculation)

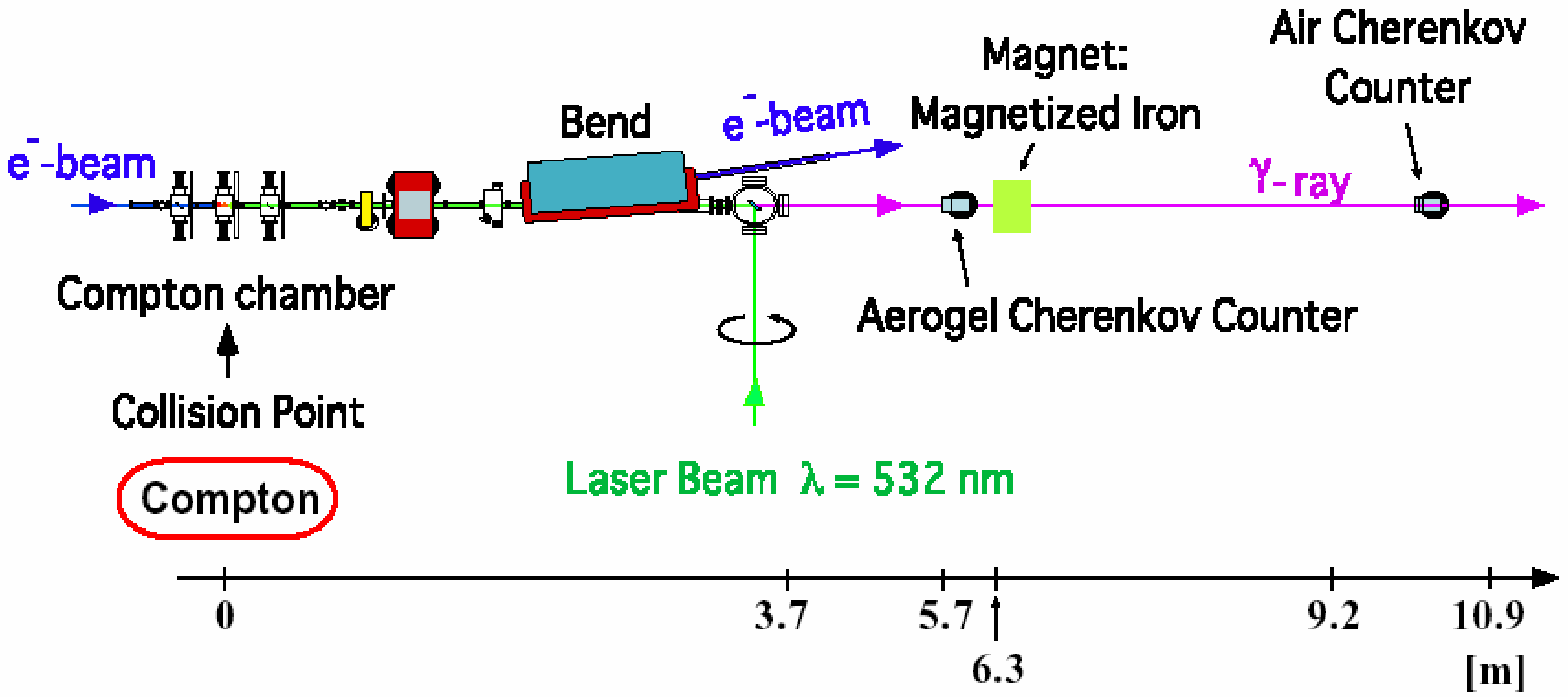




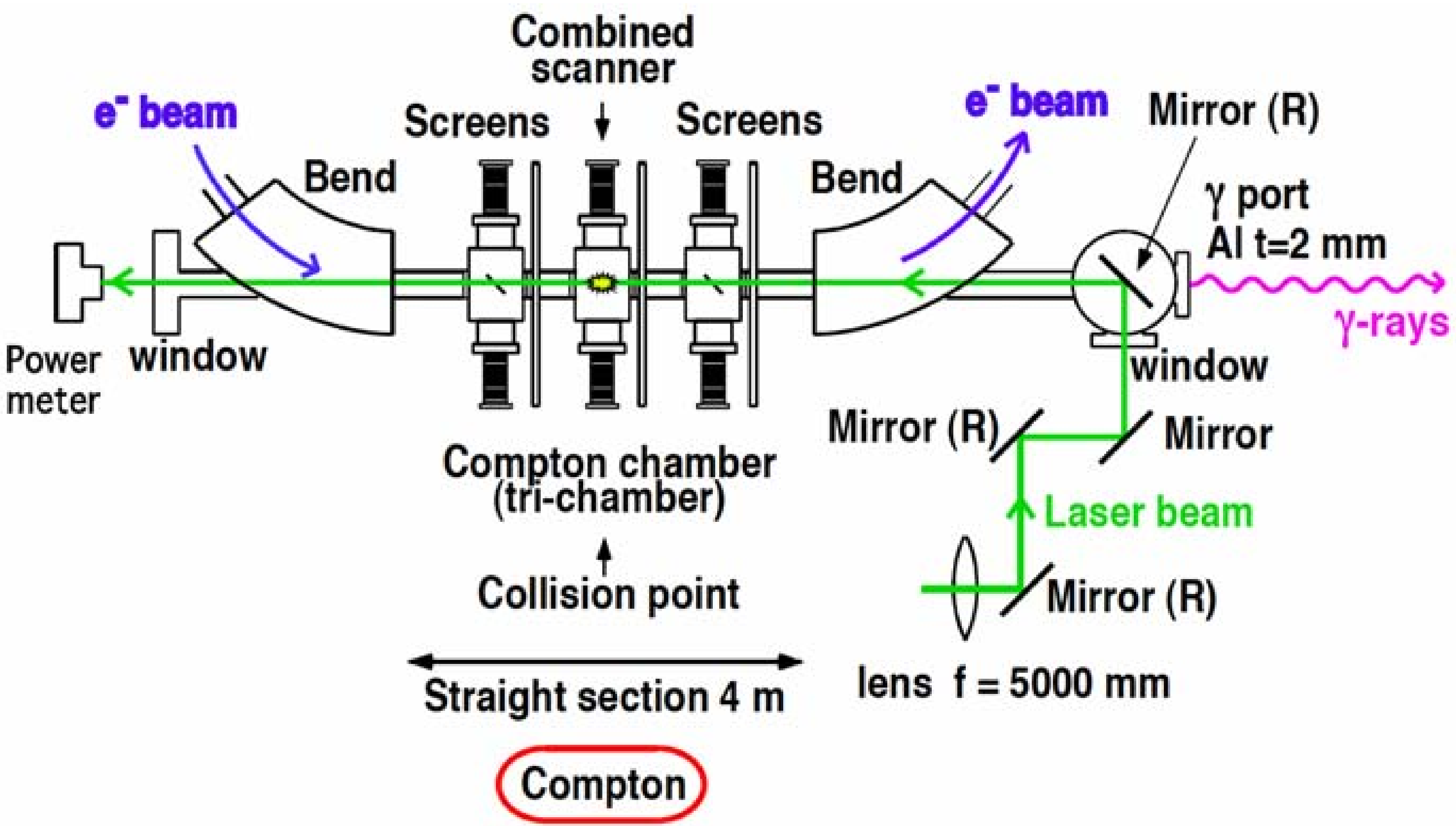
γ & e^+ : short bunch length 31 psec

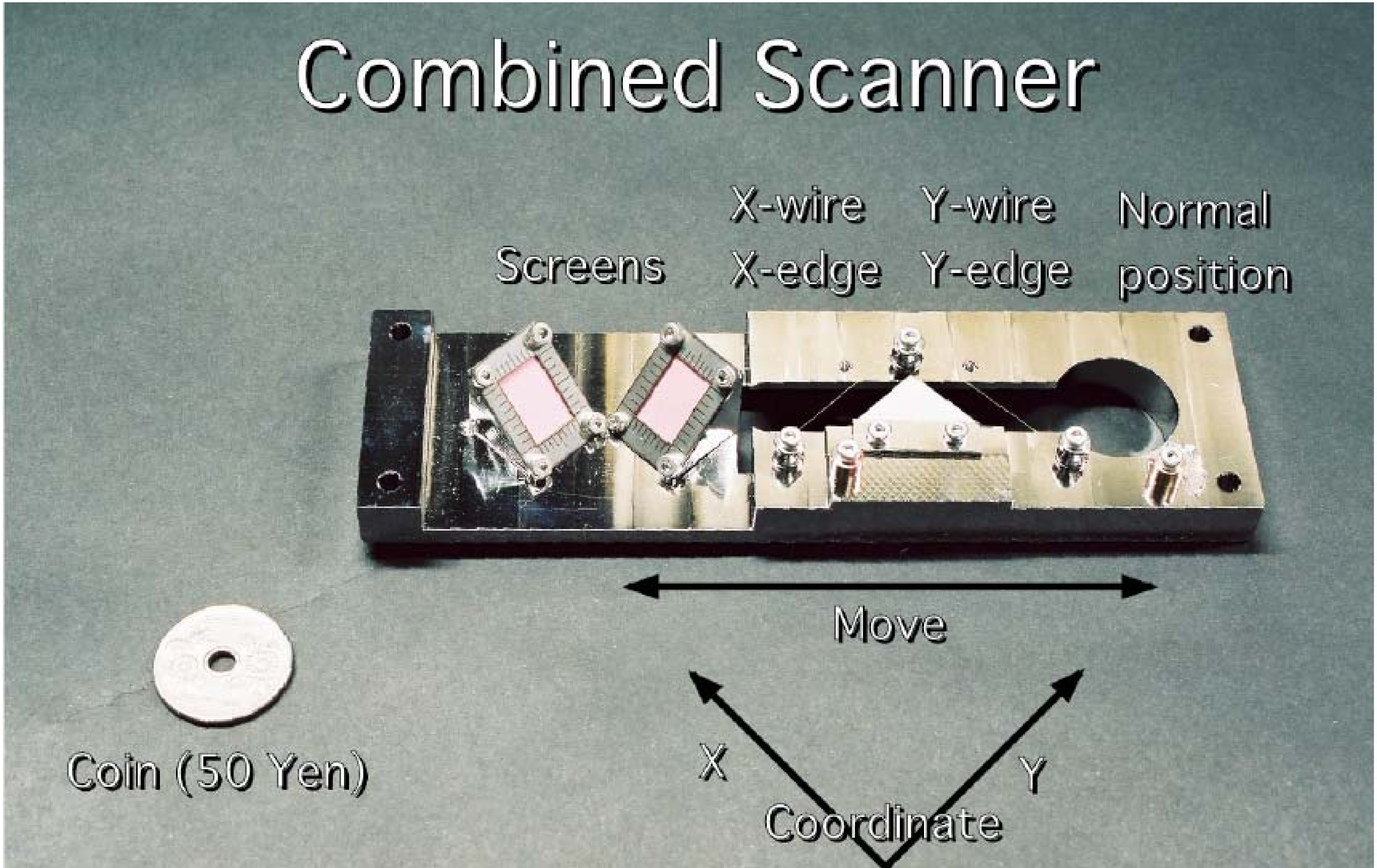
γ-ray: production, detection, and polarimetry

at ATF Extraction line



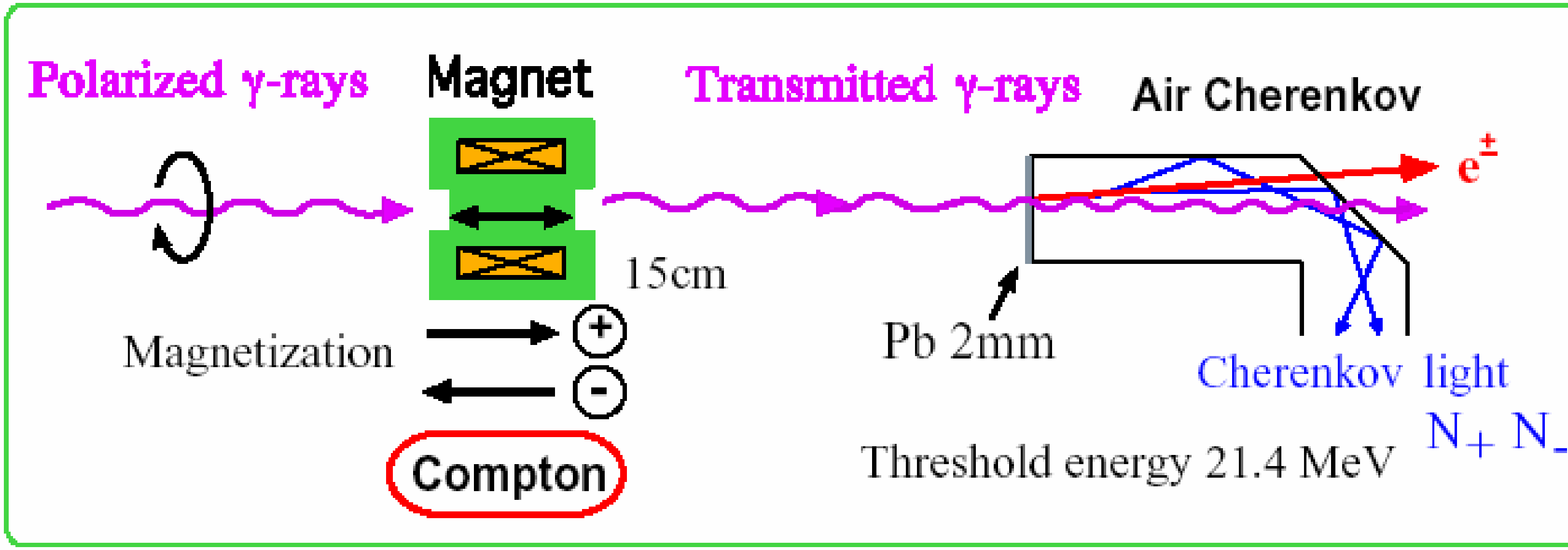
Compton Chamber




Combined Scanner
Screens
X-wire
X-edge
Y-wire
Y-edge
Normal
position
Move
Coin (50 Yen)
X
Y
Coordinate

Measure Asymmetry

ΔT=31 psec → can NOT measure each γ-ray



Cross section of Compton scattering

$$\sigma(\uparrow\uparrow) < \sigma(\uparrow\downarrow)$$

⇓

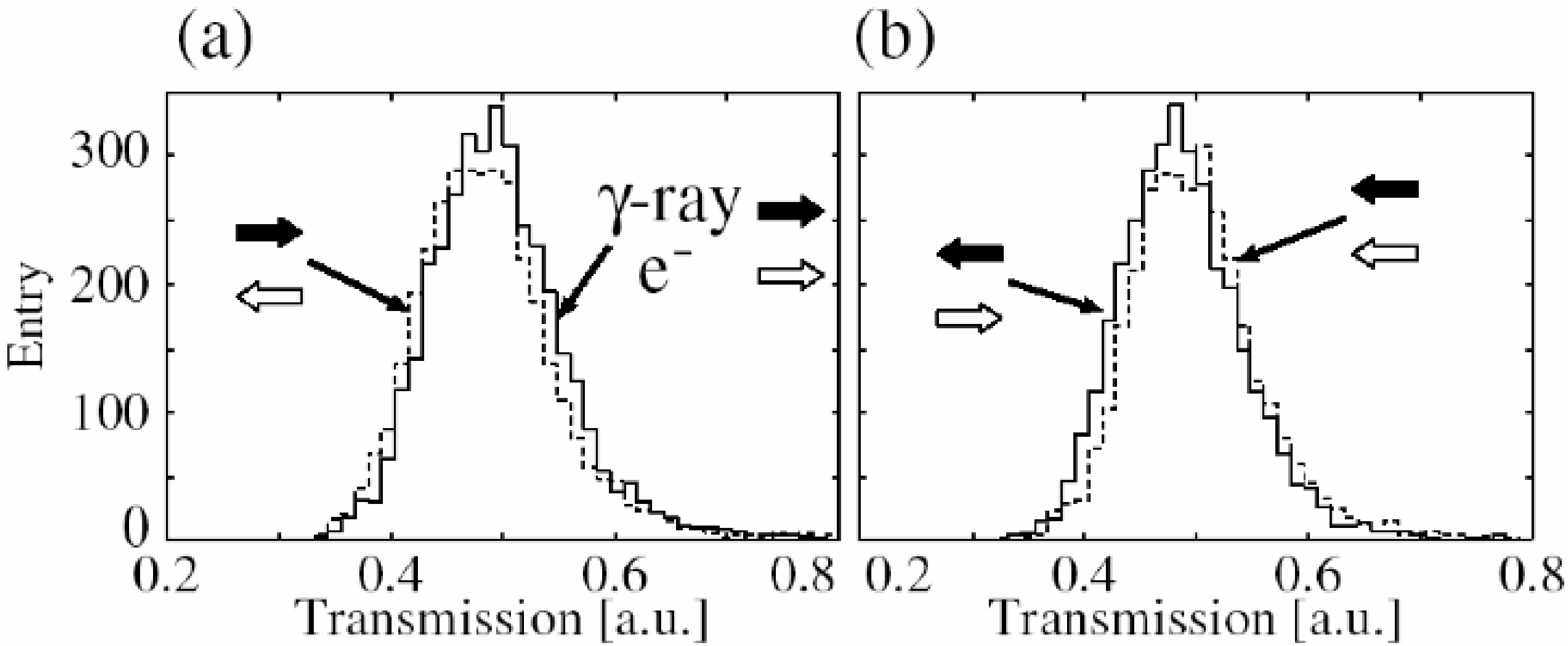
Transmission depends on the direction of the magnetization

Expected asymmetry

$$A = \frac{N_+ - N_-}{N_+ + N_-}$$

A = 1.3 % (Pol.=88%)
(E_{th} = 21.4MeV)

-ray Measured Asymmetry (3 years ago)

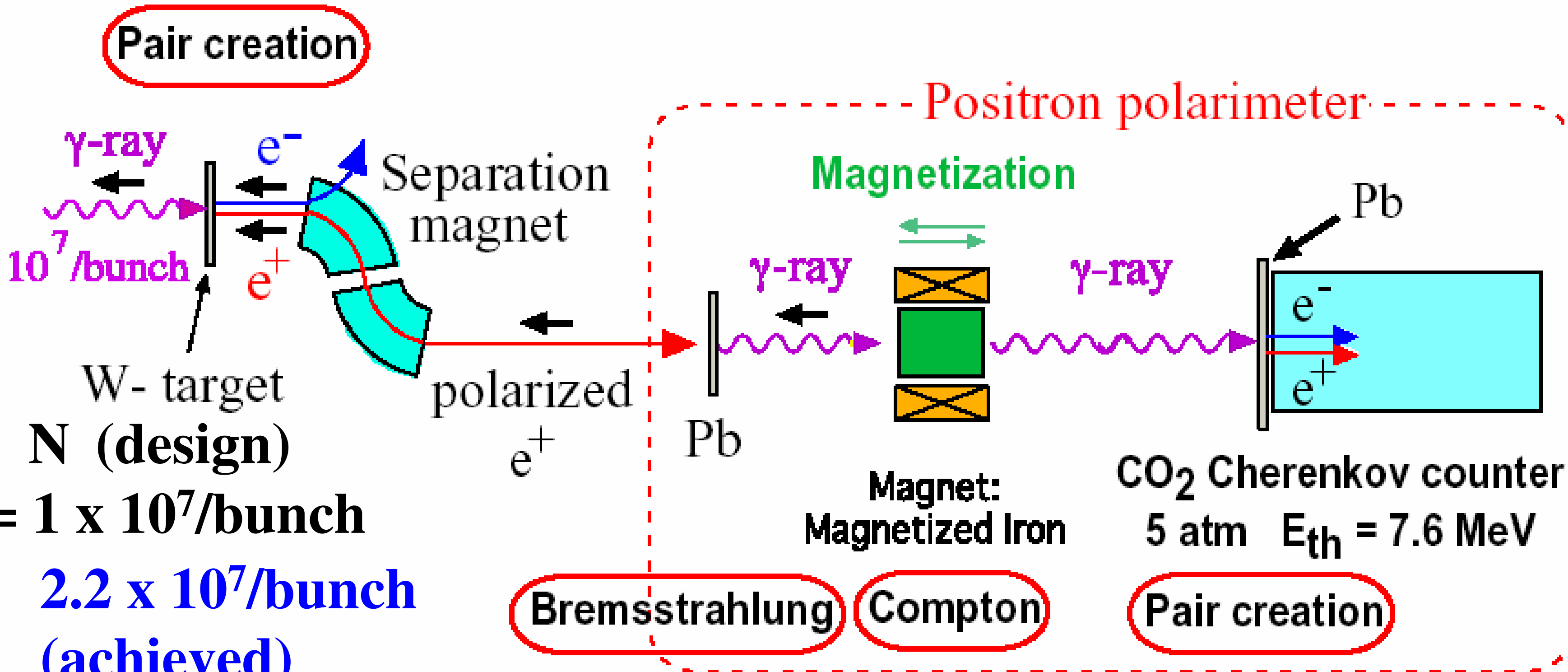


A= -0.93± 0.15 % | **A= 1.18± 0.15 %**

laser pol. = - 79 % | laser pol. = + 79 %

M. Fukuda et al., PRL 91(2003)164801

Positron: production, selection, and polarimetry



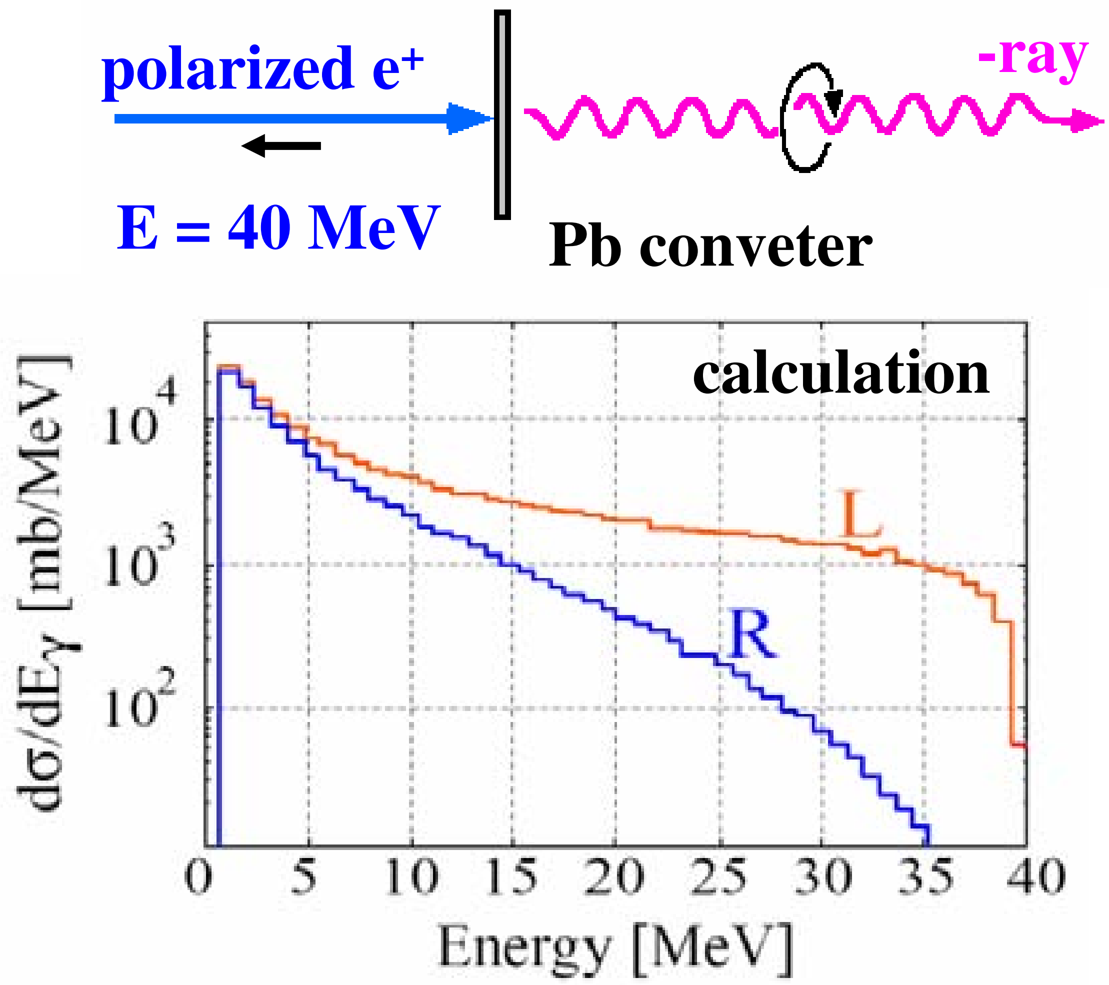
N (design)
= 1 x 10^7/bunch

2.2 x 10^7/bunch (achieved)

Ne+(design) = 3 x 10^4/bunch

Pol(expected) = 80%   Asym (expected) = 0.95%

Measure e^+ polarization :
use Bremsstrahlung -ray



Measurement and Cross-Check

Measurement

e^+ beam pol. (laser pol)		e^- spin in iron (magnet pol.)			expected value (MC)
R			Calculate A	A(R) :	A(R) ~ + 0.95 %
L			Calculate A	A(L) :	A(L) ~ - 0.95 %
0	non (Liner)		Calculate A	A(0) :	A(0) = 0

Cross-Check

e^+ beam pol.	magnet pol.			
	P	Calculate A	A(P) :	A(P) ~ + 0.95 %
	N	Calculate A	A(N) :	A(N) ~ - 0.95 %

Zero magnet current Not Equal No-polarization,
due to residual magnetism

e^+ polarization (e^+ run): results

Measurement

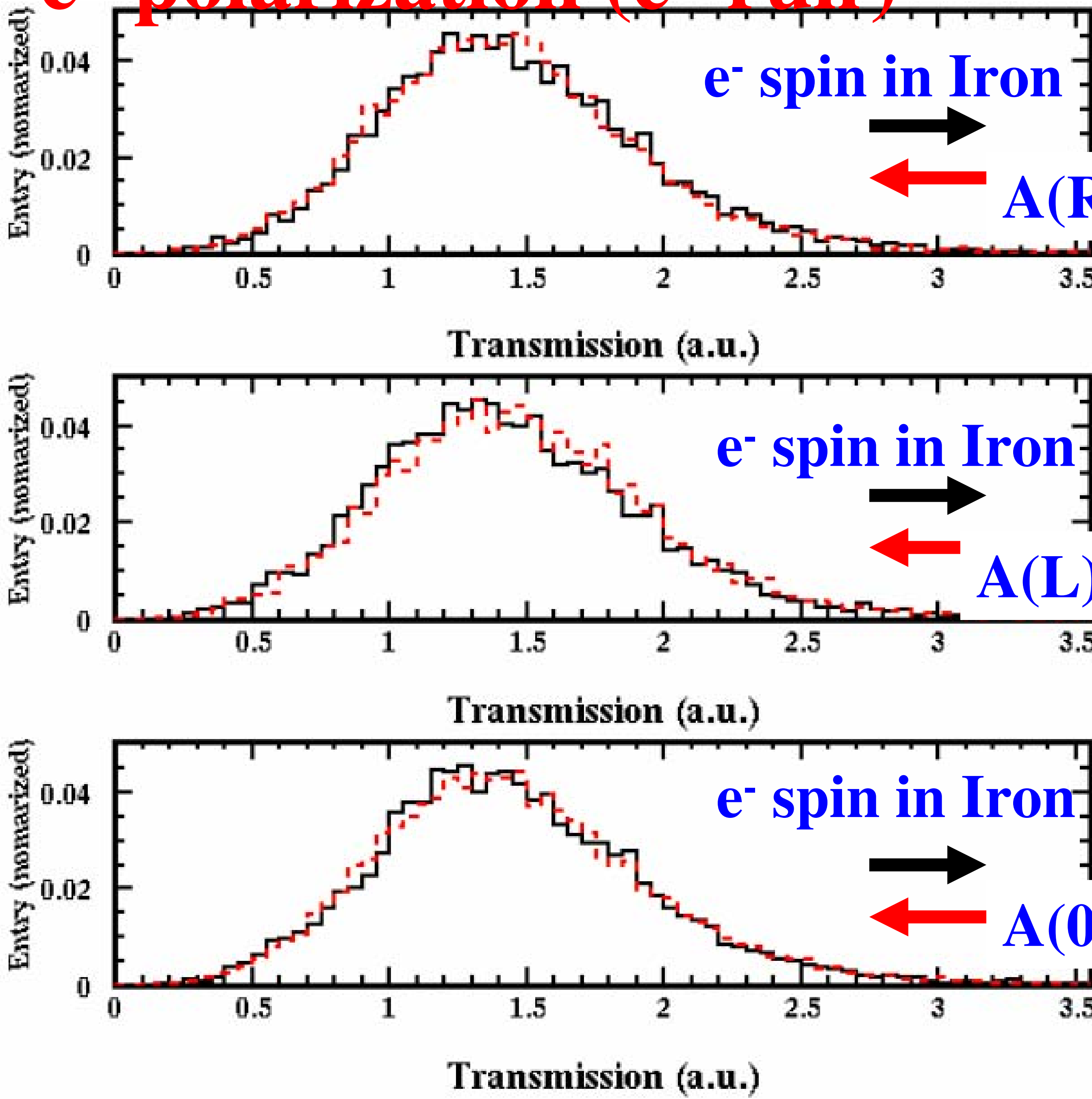
e^+ beam pol. (laser pol)	e^- spin in iron (magnet pol.)	
R → (green)	→ (black) / ← (red)	A(R)= +0.60 ± 0.25%
L ← (green)	→ (black) / ← (red)	A(L)= -1.18 ± 0.27%
0 non (Liner)	→ (black) / ← (red)	A(0)= -0.02 ± 0.25%

Cross-Check

e^+ beam pol.	magnet pol.	
→ / ← (green)	P → (black)	A(P)= +0.81 ± 0.26%
→ / ← (green)	N ← (red)	A(N)= -0.97 ± 0.26%

e^+ polarization (e^+ run)

T. Omori et al., arXiv:hep-ex/0508026
KEK Preprint 2005-56



e^- spin in Iron

e^+ beam spin

A(R)= +0.60 ± 0.25%

e^- spin in Iron

e^+ beam spin

A(L)= -1.18 ± 0.27%

e^- spin in Iron

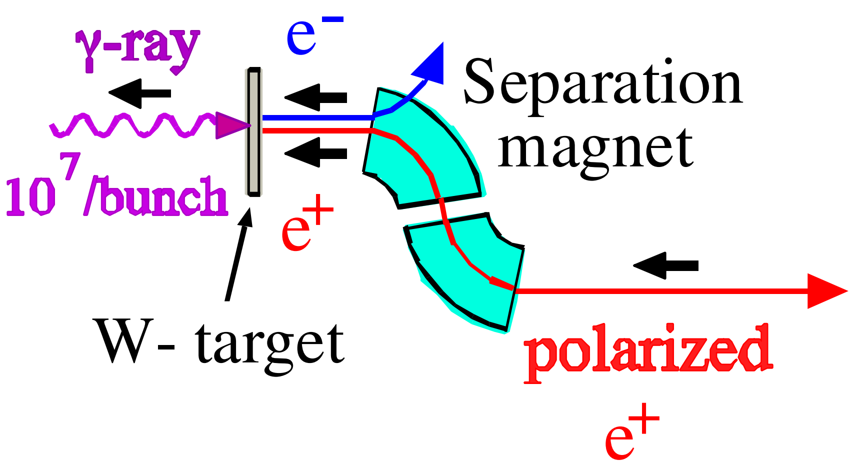
e^+ beam spin

non

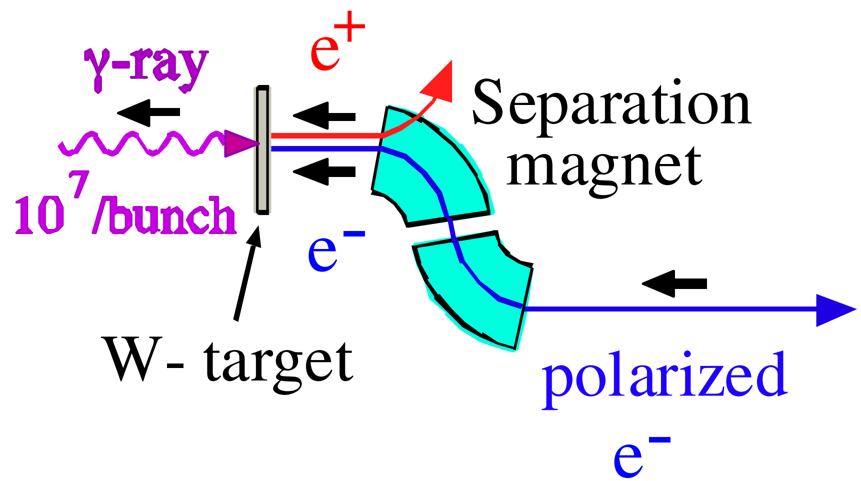
A(0)= -0.02 ± 0.25%

We did e⁻ run, also.

e^+ run



e^- run



e^- polarization (e^- run): results

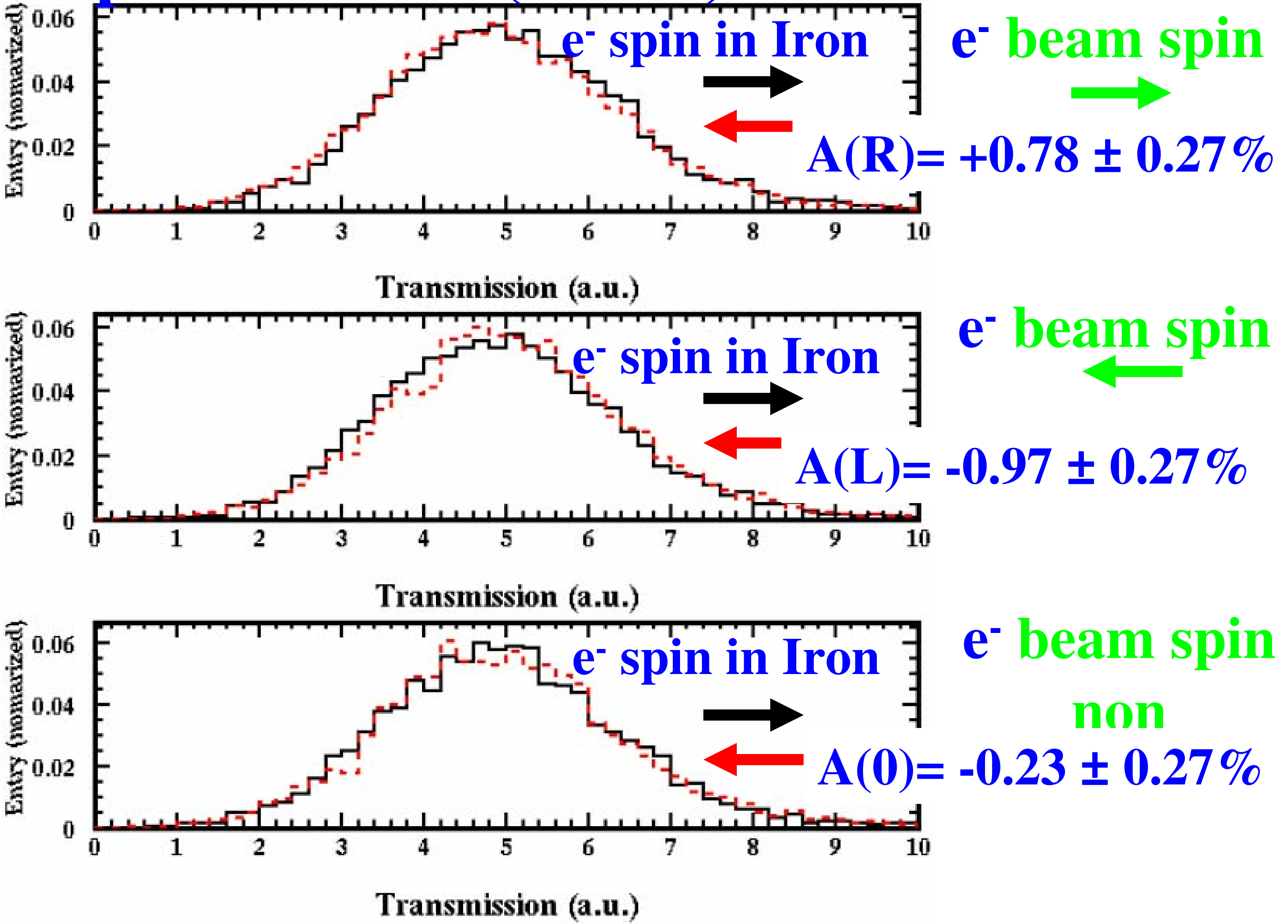
Measurement

e^- beam pol. (laser pol)		e^- spin in iron (magnet pol.)	
R	→	⇄)	A(R)= +0.78 ± 0.27%
L	←	⇄)	A(L)= -0.97 ± 0.27%
0	non (Liner)	⇄)	A(0)= -0.23 ± 0.27%

Cross-Check

e^- beam pol.	magnet pol.		
⇄)	P	→	A(P)= +0.72 ± 0.27%
⇄)	N	←	A(N)= -1.03 ± 0.27%

e⁻ polarization (e⁻ run)



Summary of Experiment

1) The experiment was successful.
   High intensity short pulse polarized e^+ beam was firstly produced.
   Pol. ~ 80%
2) We confirmed propagation of the polarization from laser photons -> -rays -> and pair created e^+s & e^-s.
3) We established polarimetry of short pulse & high intensity -rays, positrons, and electrons.

Concept of Compton polarized e^+ source for ILC

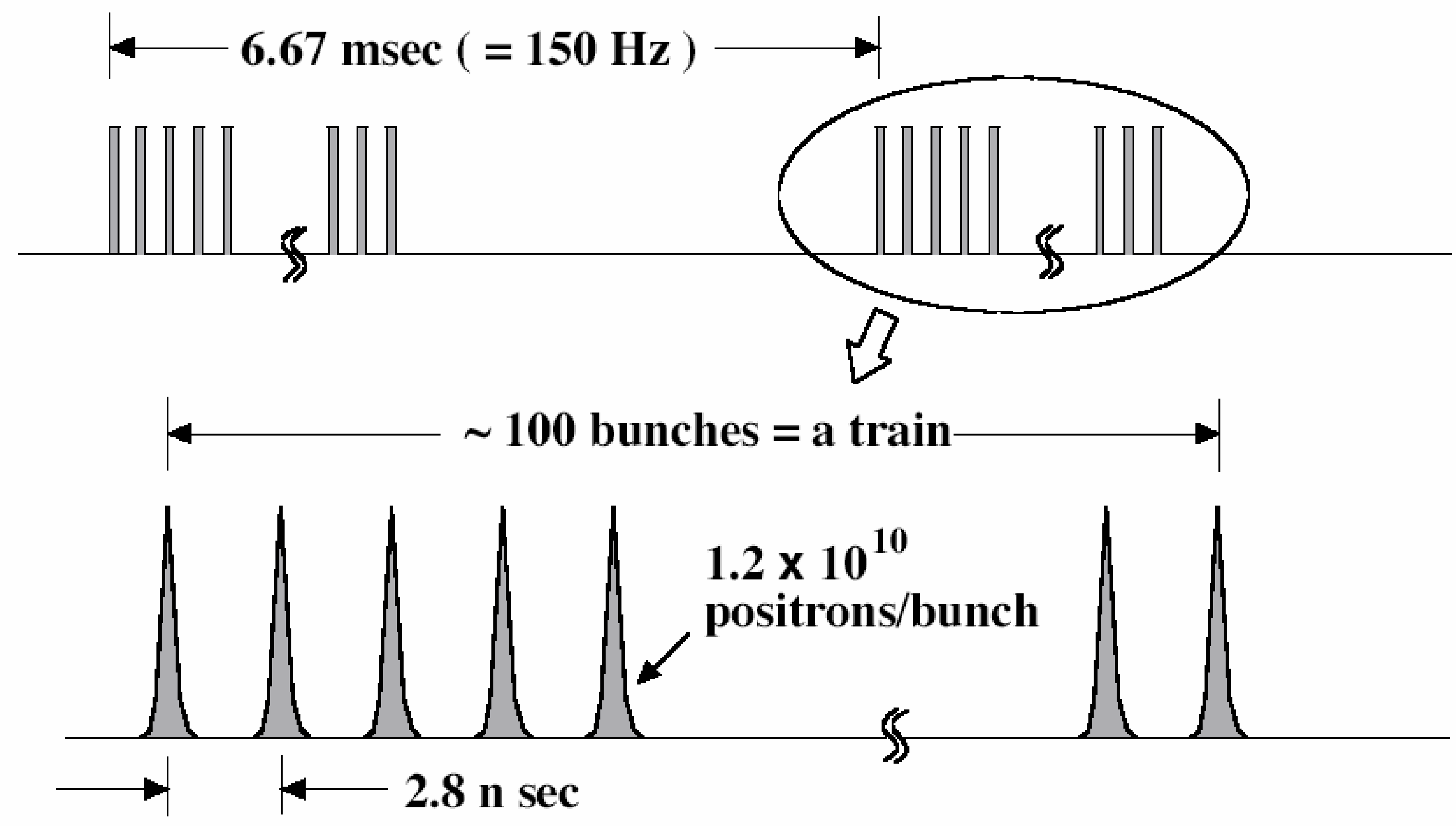
Collaborating Institutes:
BINP, CERN, DESY, Hiroshima, IHEP, IPN, KEK, Kyoto, LAL, NIRS, NSC-KIPT, SHI, and Waseda

Sakae Araki Yasuo Higashi Yousuke Honda Masao Kuriki Toshiyuki Okugi Tsunehiko Omori Takashi Taniguchi Nobuhiro Terunuma, Junji Urakawa X Artru M Chevallier, V Strakhovenko, Eugene Bulyak Peter Gladkikh Klaus Meonig, Robert Chehab Alessandro Variola Fabian Zomer Frank Zimmermann, Kazuyuki Sakaue Tachishige Hirose Masakazu Washio Noboru Sasao Hirokazu Yokoyama Masafumi Fukuda Koichiro Hirano Mikio Takano Tohru Takahashi Hiroki Sato Akira Tsunemi and Jie Gao

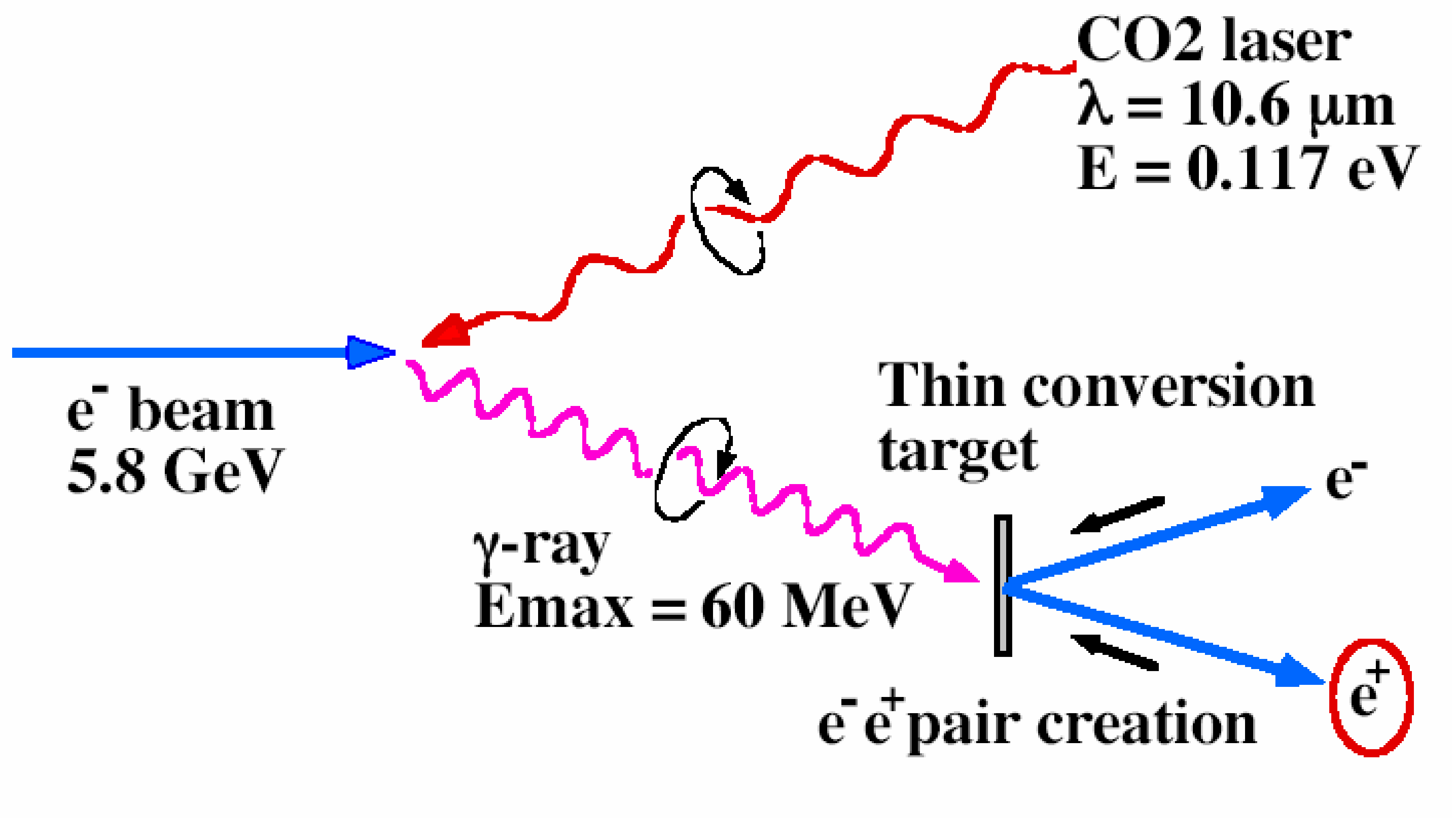
We had a conceptual design for a warm LC.

~ 100 bunches in ~ 300 nsec,
bunch to bunch : ~2.8 nsec,
1.2x10^{10} positrons/bunch,
pol. ~ 54%.

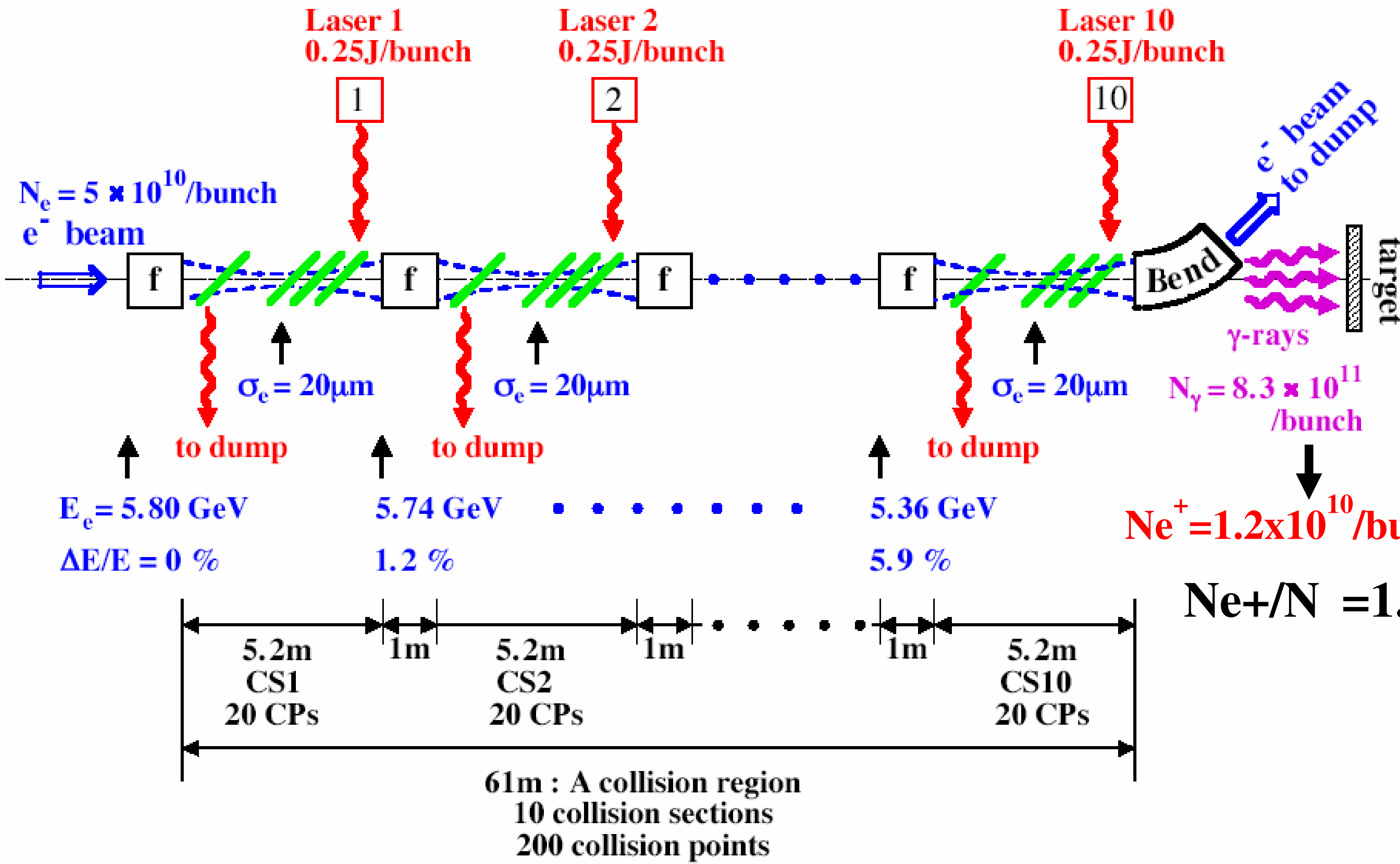
T. Omori et al.,
NIM A500 (2003)
232-252



Conceptual Design (warm LC)



Conceptual Design for warm LC



$Ne^+ = 1.2 \times 10^{10}$/bunch

Ne+/N =1.4%

T. Omori et al., NIM A500 (2003) 232-252

Is Compton applicable to a cold LC?

↓

Yes !

With New and Improved design

↓

Full use of slow repetition rate (5Hz)

ILC requirements

2x10^{10} e$^+$/bunch (hard)

2800 bunches/train (hard)

5 Hz (we have time to store e$^+$s)

Strategy

Old: Design for warm LC

make positrons at once.

both electron & laser beams : single path

T. Omori et al.,
NIM A500 (2003)
232-252

New: Design for cold LC (ILC)

make positrons in 100 m sec.

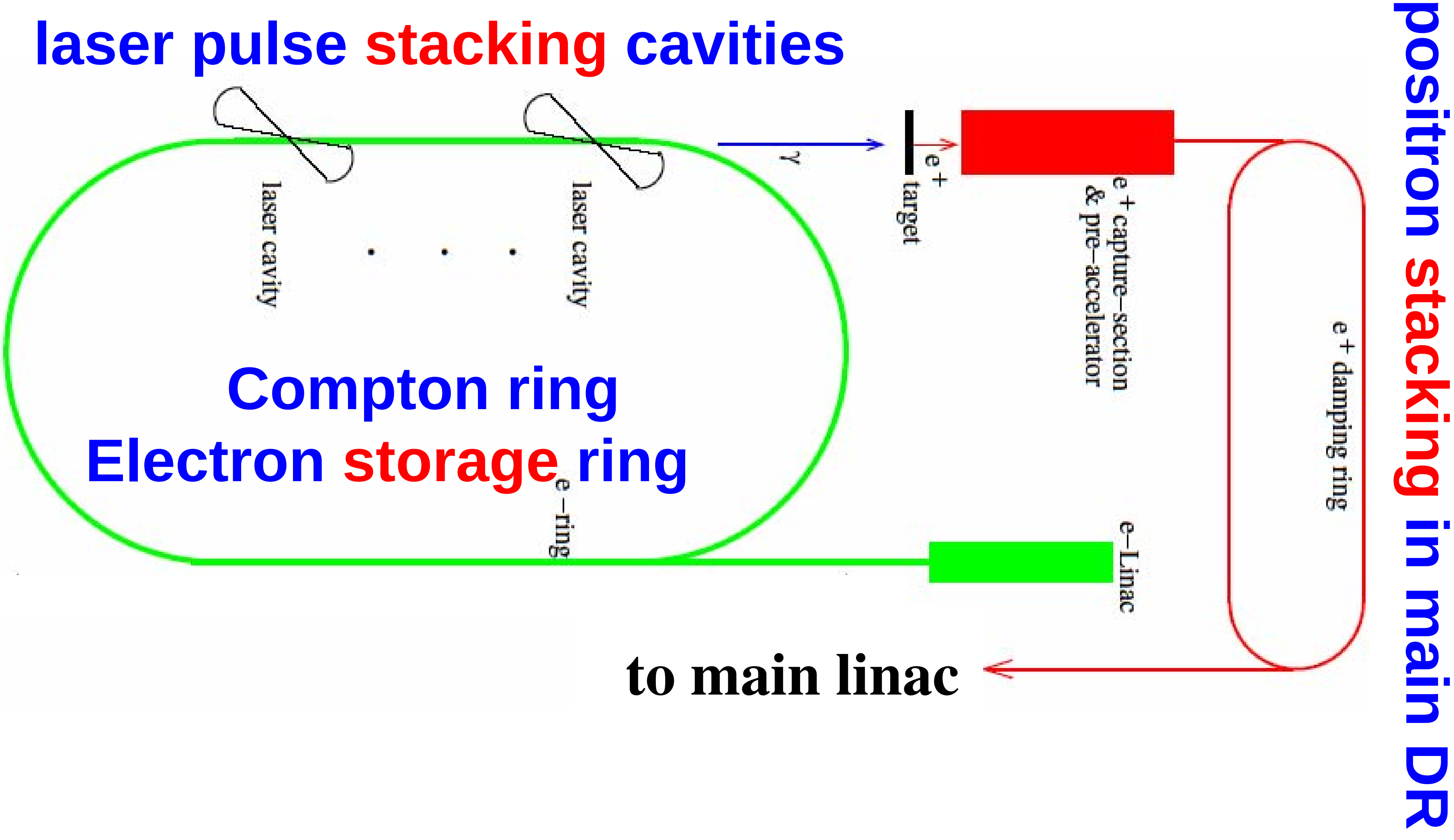
Electron storage ring,

laser pulse stacking cavity : Re-use !!!

positron stacking in DR.

Basic Idea:
K. Moenig
P. Rainer

Re-use Concept



Two versions

	CO_2	YAG
Electron Beam (Compton Ring)		
Electron Energy (GeV)	4.1	1.3
Ne-/bunch	6.3×10^{10}	6.3×10^{10}
Spot Size at CP (micron)	5(h)x25(v)	5(h)x25(v)
Circumferences (m)	649.4	276.7
Number of Bunches	280x2	280
Number of Trains	2	1
Laser Beam		
Photon Energy (eV)	0.117	1.16
Pulse Energy/bunch(mJ)	210	590
Spot Size at CP (micron)	25(h)x25(v)	5(h)x5(v)
Gamma-rays		
Energy(MeV)	23-29	23-29

Two versions

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Electron Beam (Compton Ring)		
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Gamma-rays		
Energy(MeV)	23-29	23-29

CO2

Pros:

- large N_{photon} ($N_{photon} = E_{laser}/E_{photon}$)
- Larger tolerance

Cons:

- Higher e- beam energy --> More Cost
- No experience of laser pulse stacking of CO_2

YAG

Pros:

- Low e- beam energy --> Less Cost
- Experience of laser pulse stacking of YAG

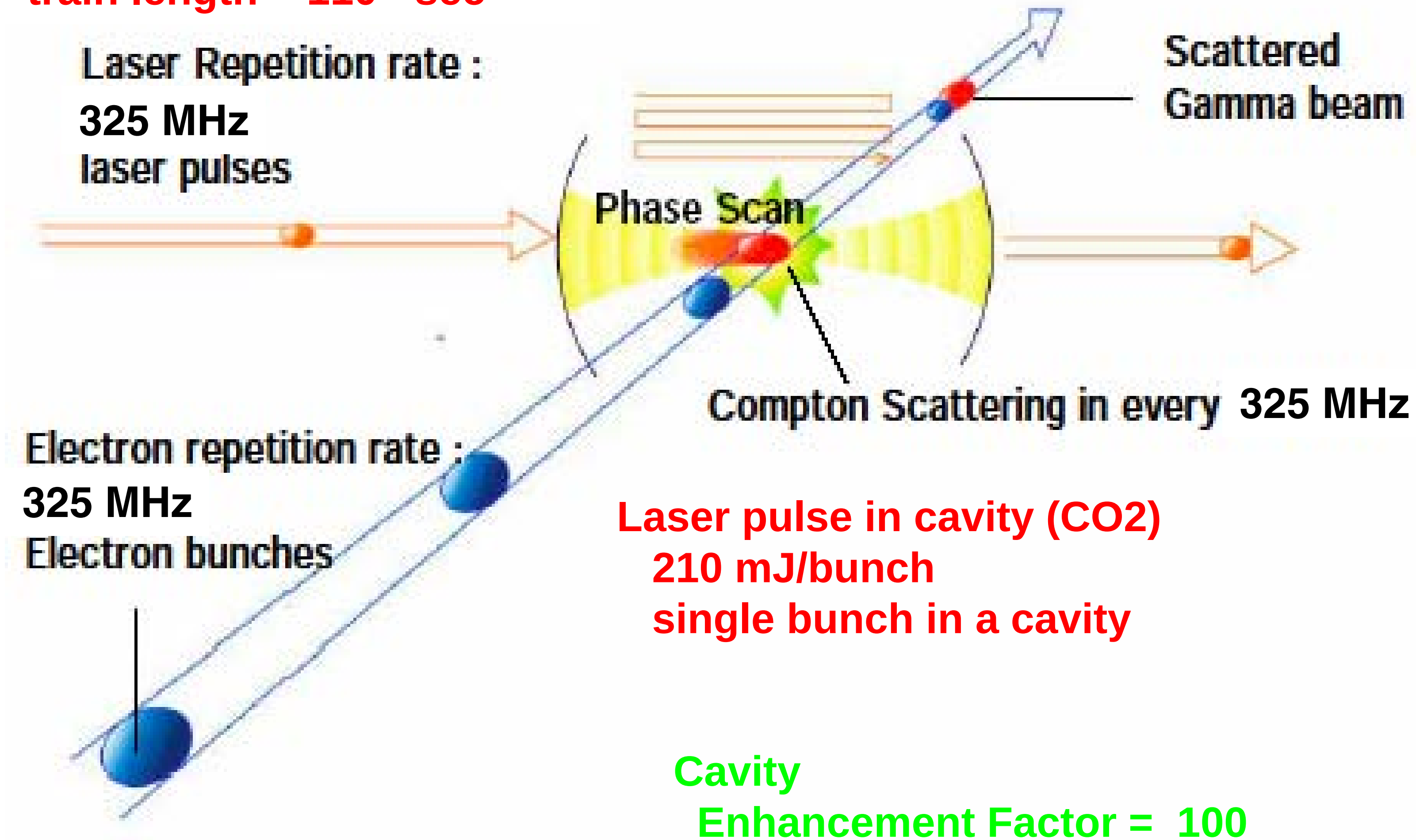
Cons:

- Smaller N_{photon} ($N_{photon} = E_{laser}/E_{photon}$)
- Small tolerance

Laser Pulse Stacking Cavity

Input laser (CO_2 laser)
- **Energy 2.1 mJ/bunch**
- **3.077 nsec bunch spacing**
- **train length = 110 sec**

Laser-electron
8 degree crossing



Laser pulse in cavity (CO_2)
- **210 mJ/bunch**
- **single bunch in a cavity**

Cavity
Enhancement Factor = 100

Compton Ring (e^- storage Ring)

Loss of Electrons by collision

Negligible

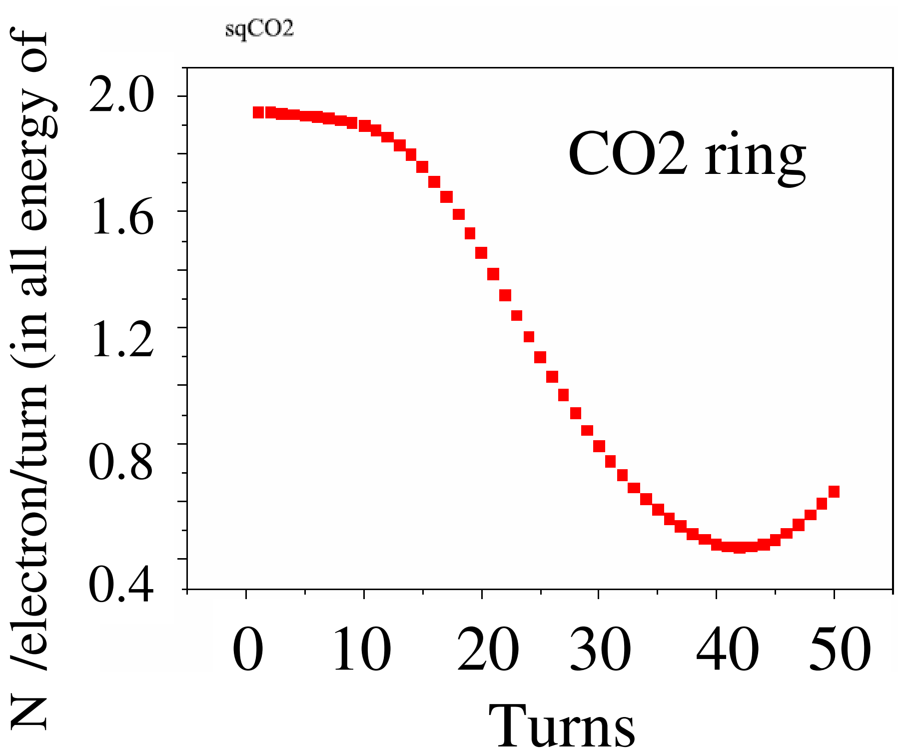
N /collision decrease due to bunch lengthening

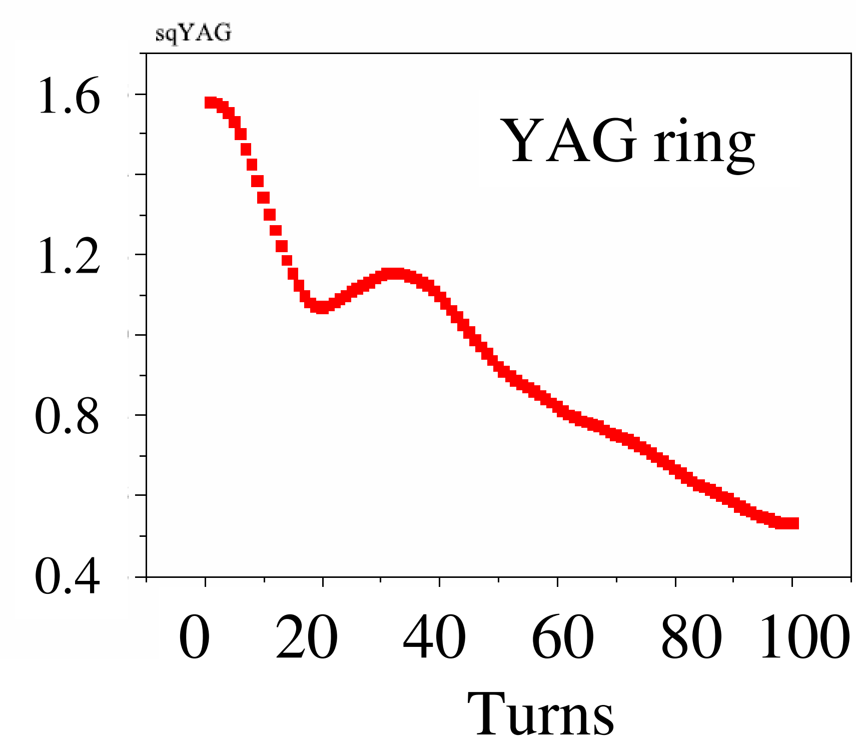
Pulsed mode operation

Laser on ~ 100 micro sec
Laser off ~ 9.9 m sec (for cooling)

Repeat 100 Hz

Compton Ring (e- storage Ring)



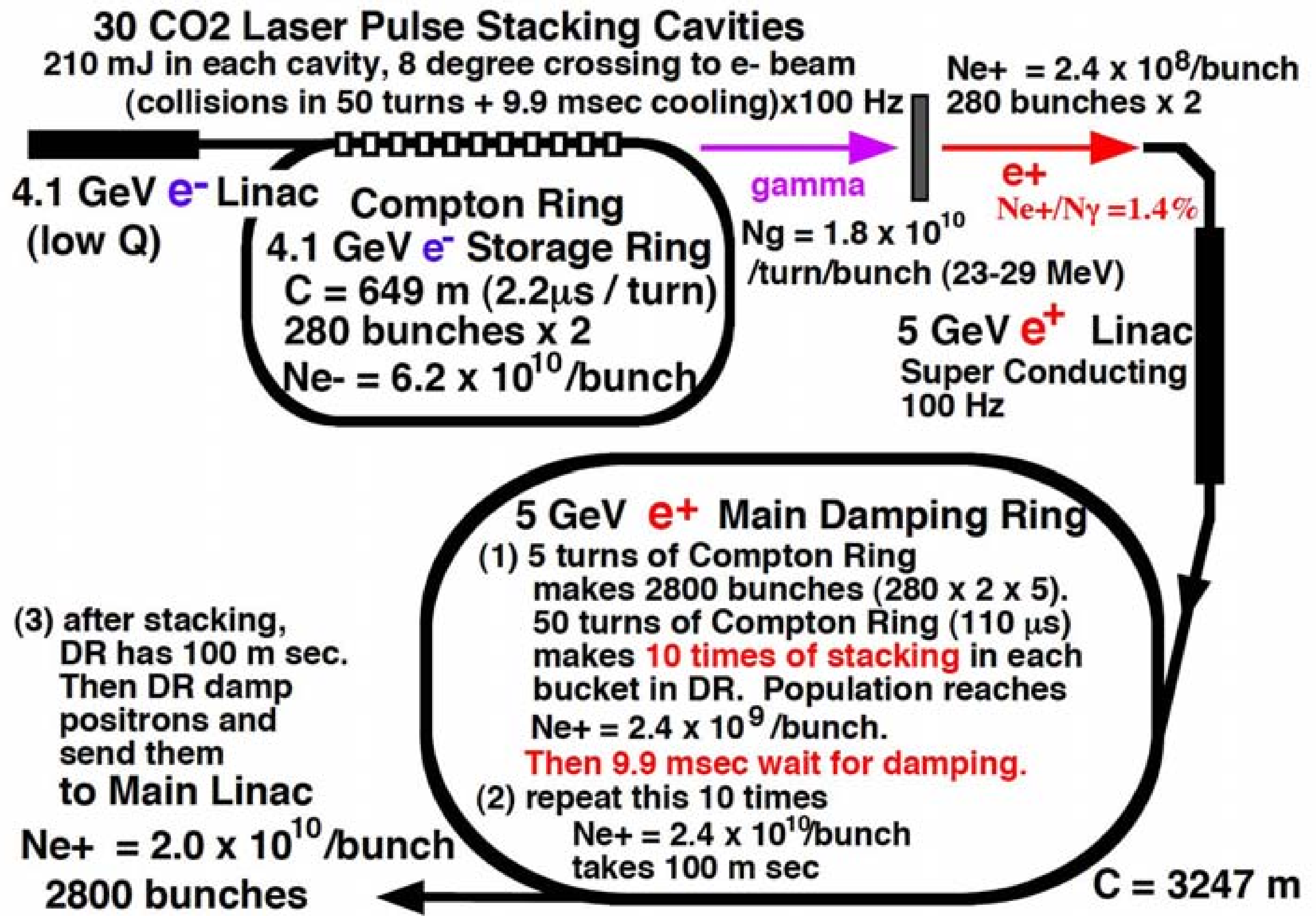


Average N /turn (in 23-29 MeV)

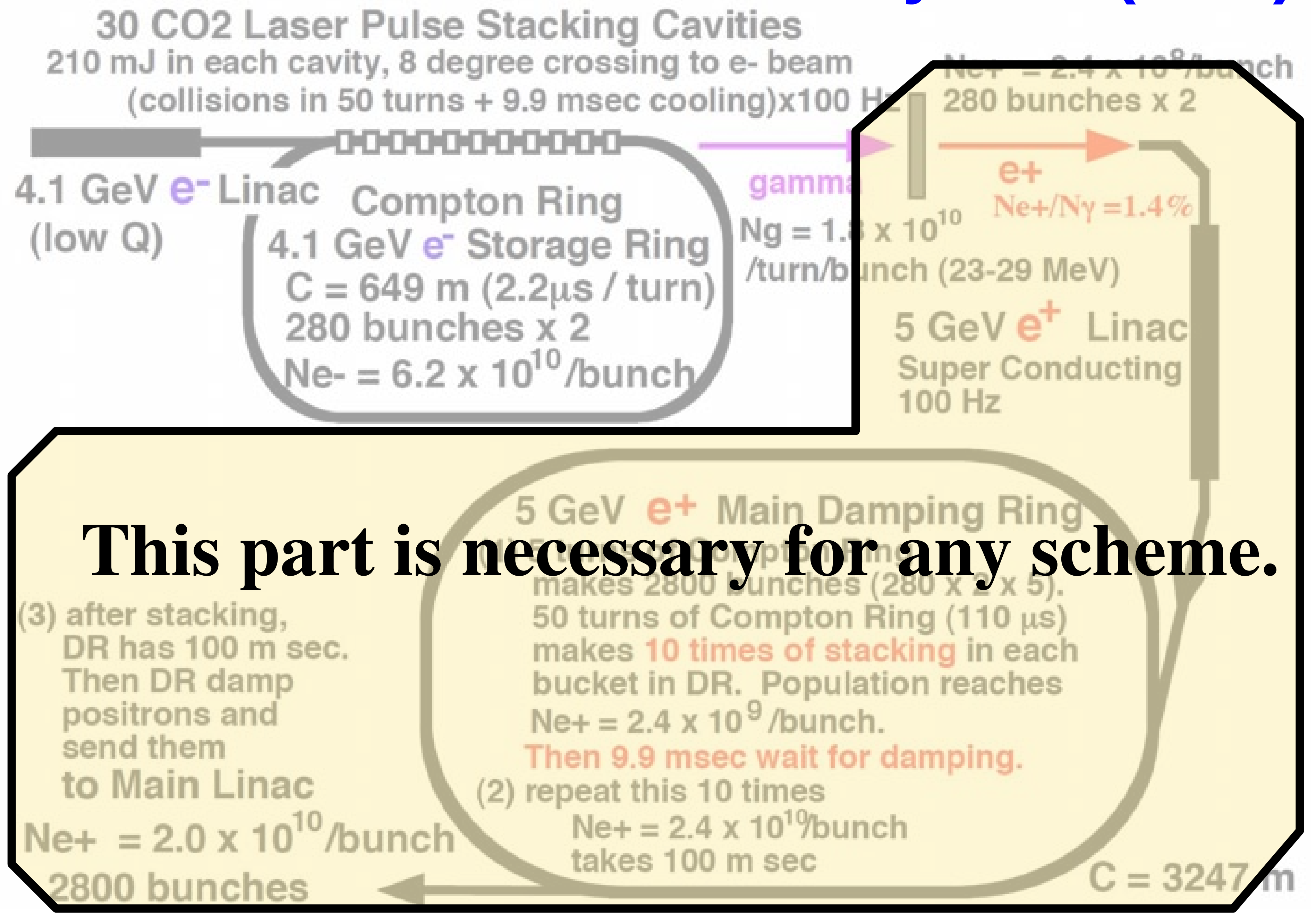
CO2 : 1.78x10^{10} /turn
(average in 50 turns)

YAG : 1.36x10^{10} /turn
(average in 100 turns)

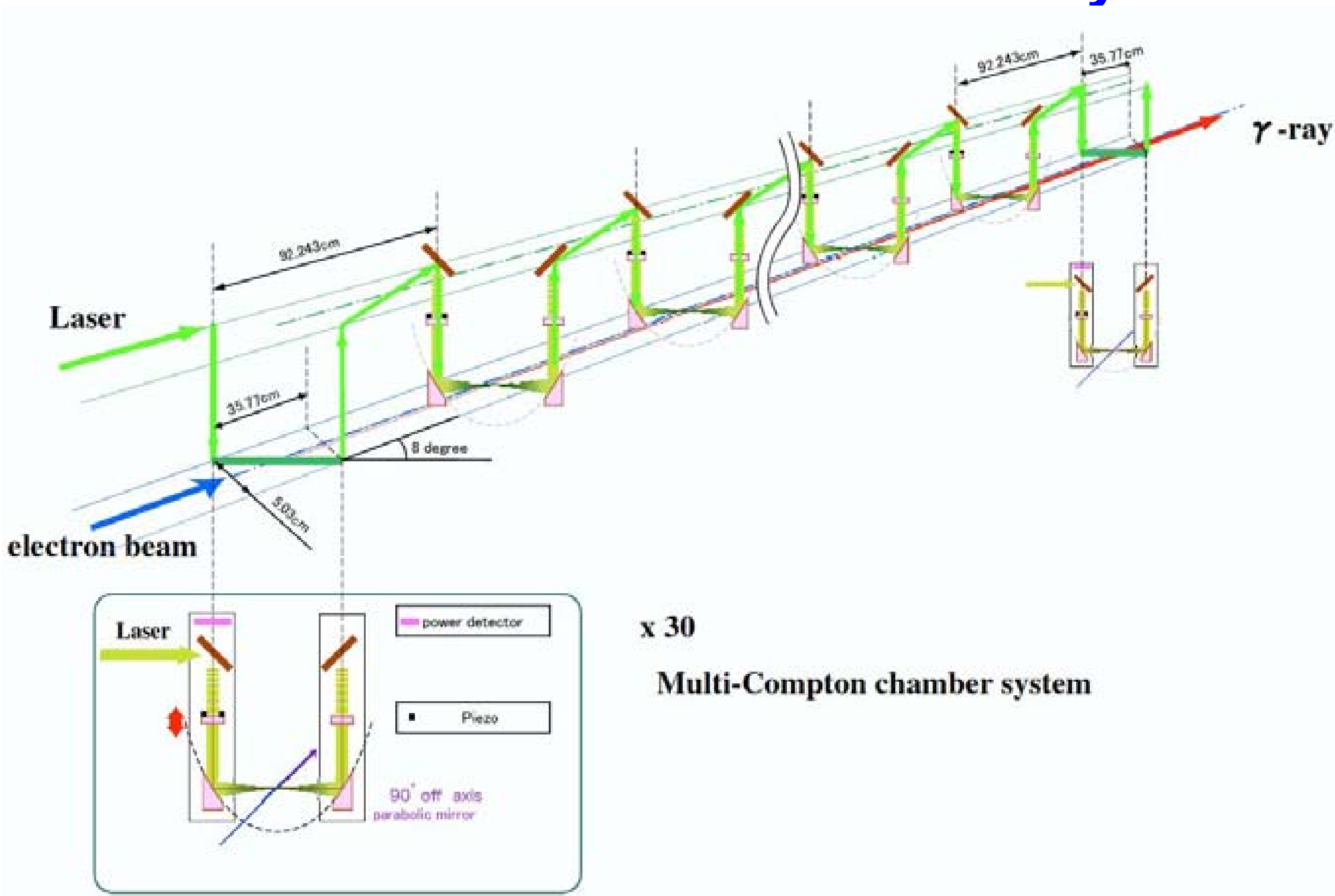
Schematic View of Whole System (CO2)



Schematic View of Whole System (CO2)



One laser feeds 30 cavities in daisy chain



Positron Acceleration to DR

Pre Positron Accelerator (PPA)

Accelerate up to 287 MeV
Normal conducting L-band linac pulse~100 sec, rep. = 100Hz

Main Positron Accelerator (MPA)

Accelerate up to 5 GeV
Two versions are now under considerration

i) SC linac L ~ 270 m (rep. = 100Hz)
almost identical to main linac
need more cooling power/module (x4 of main linac)

ii) Normal conducting linac L ~ 620 m (rep. = 100Hz)
identical to the latter part of PPA

e^+ stacking in Damping Ring

Main DR itself is the ideal choice of stacking ring

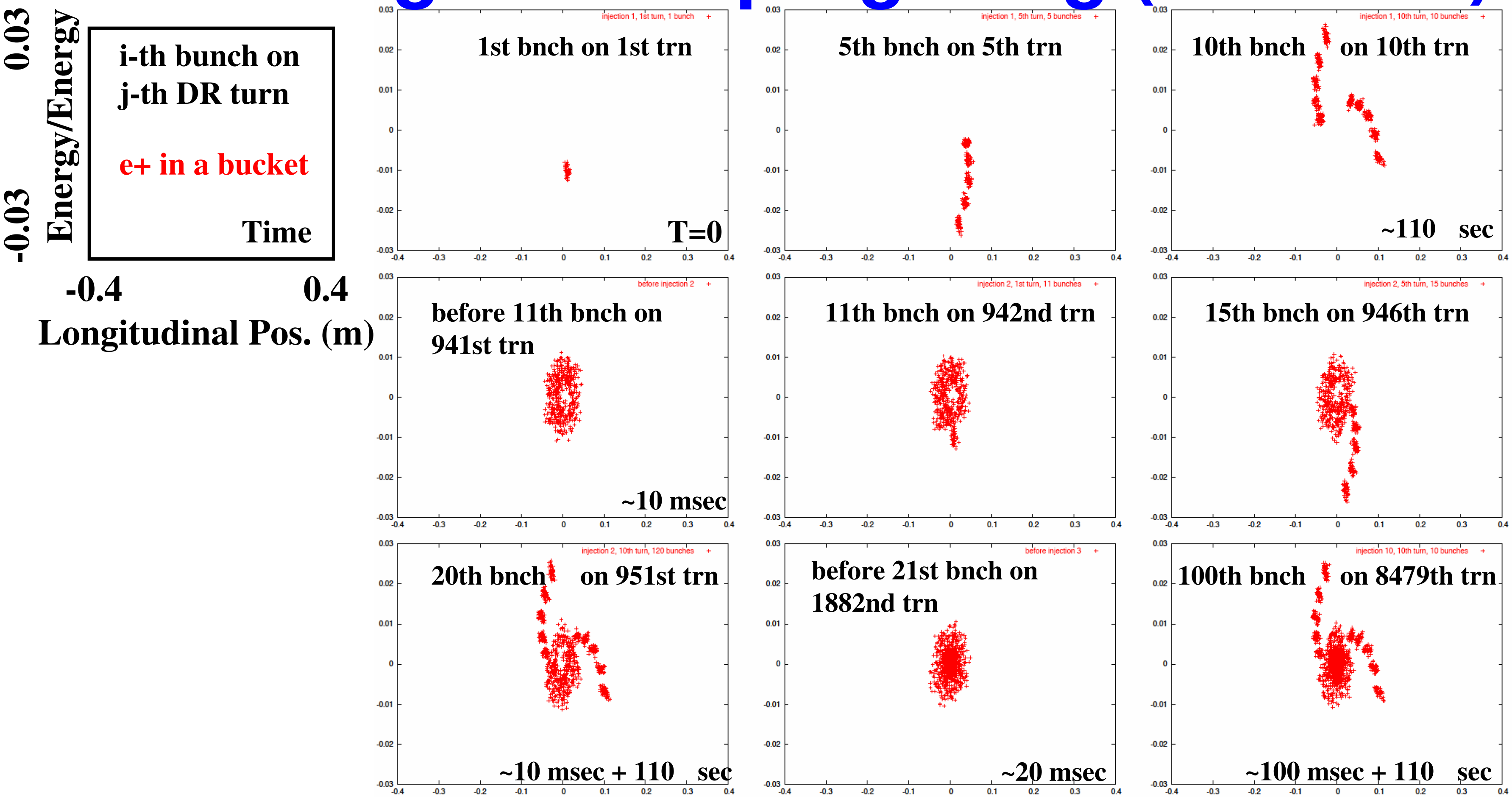
- Can store full number of e^+ bunches
- Have short damping time of ~10 m sec
- Have large longitudinal bucket area ~ 450 mm
  - ~10 x injected beam size : ~ 5mm(rms)x10(edge)
- Stack in longitudinal phase space

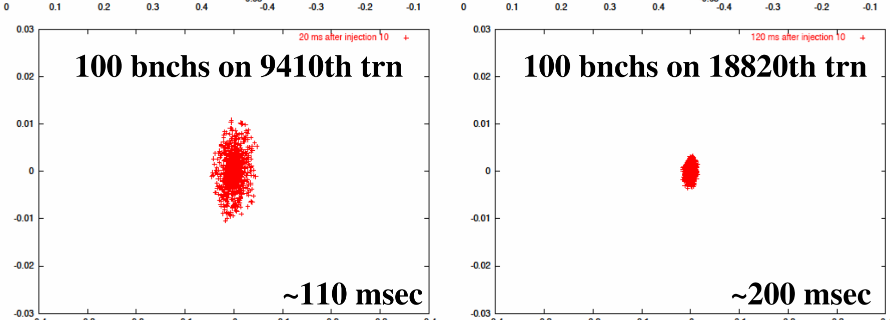
We assume

- Circumference ~3.3 km.
- RF = 650 MHz (3.077 n sec of bunch-to-bunch)
- 2800 bunches in a ring (280 bunches/train x 10 trains)
- (10 turn injection in 110 sec + 9.9 m sec damping)x10
  - --> 100 times of stacking in a bucket in total

10 turns of DR <--> 50 turns Compton ring (CO2)

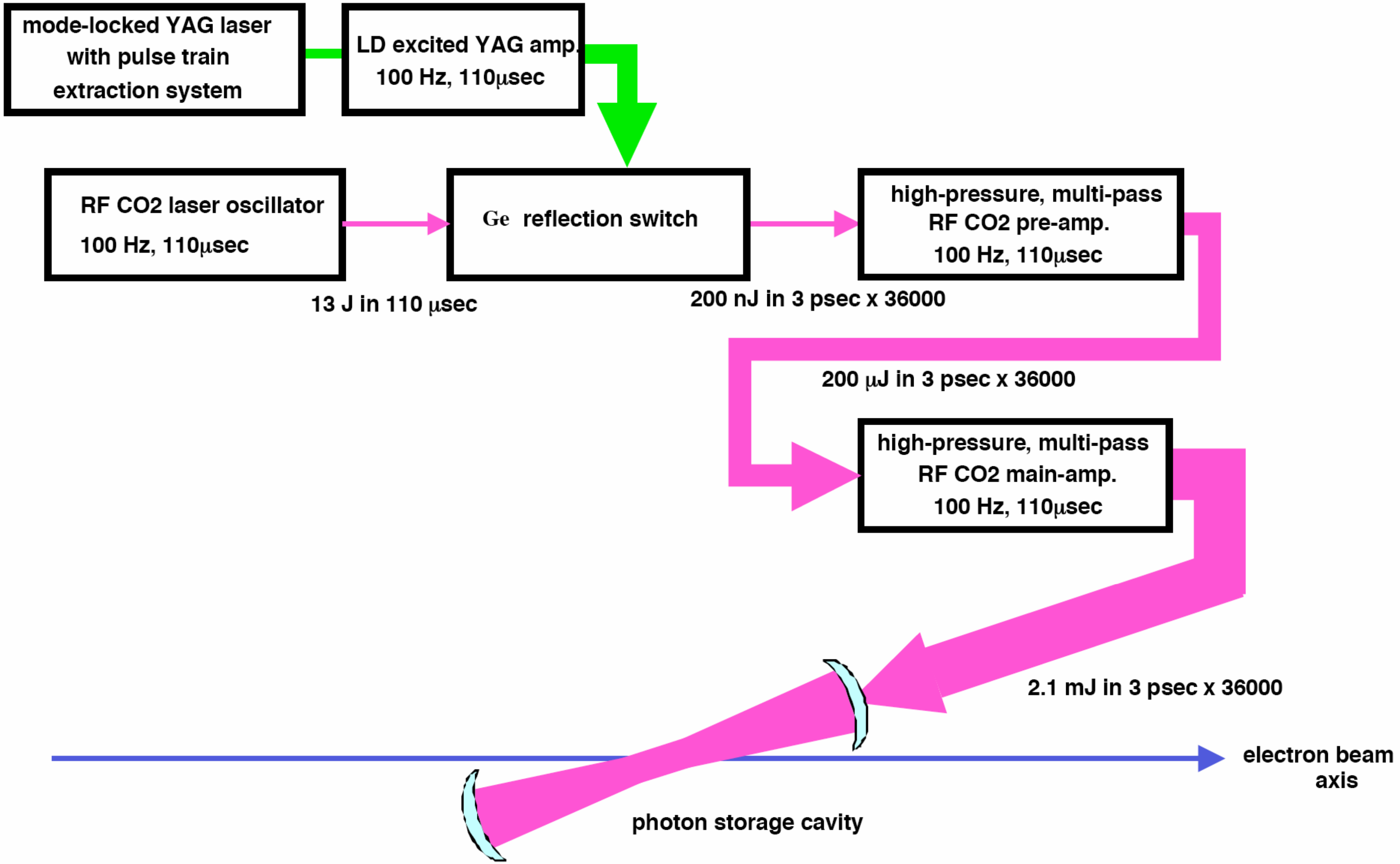
e^+ stacking in Damping Ring (simulation)



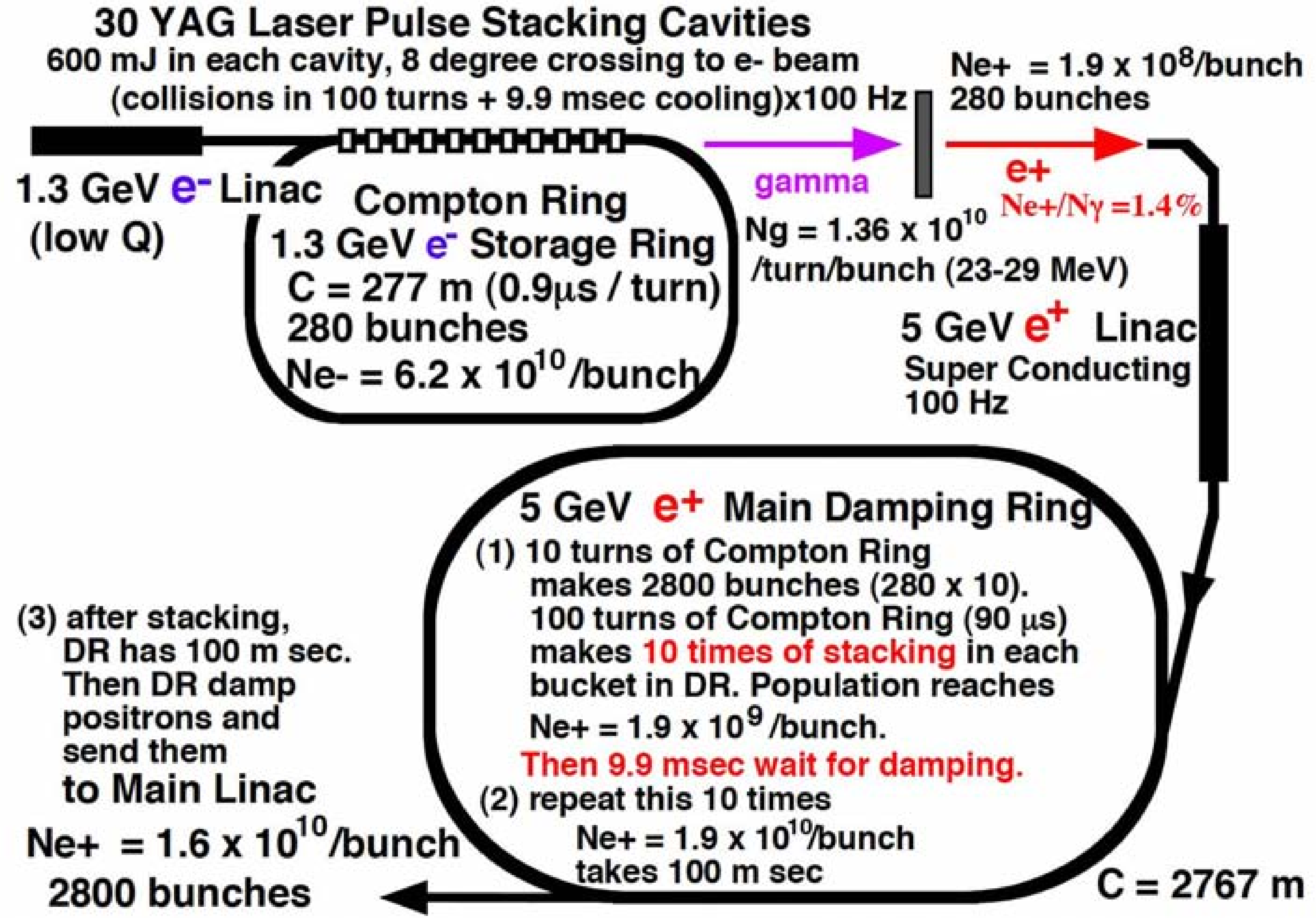


stacking loss = 18%
in total

Laser System (CO_2 version)



Schematic View of Whole System (YAG)



Note

DR circumference in this design (~ 3 km) is an example. If DR-people choose other circumference, Compton scheme can be changed to meet it.

If ILC choose 5600-bunch, Compton scheme can be changed to meet it.

Optimization is still on going. We think that Ne^{+} can exceeds $2x10^{10}$ in both CO2 and YAG versions.

Optimization is still on going. We think that stacking loss can be made much smaller.

We are trying to make revised design of CO_2 Compton ring, C ~ 600 m --> C ~ 300 m, in order to reduce cost.

Summary of ILC source design

Compton scheme is a good candidate of ILC polarized e^+ source.

We have new Idea

make positrons in 100 m sec.

- **Electron storage ring**
- **laser pulse stacking cavity**
- **positron stacking in main DR**

2.0×10^{10} e^+/bunch x 2800 bunches @ 5Hz
with high polarization (~ 60%)
(1.6×10^{10} e^+/bunch in YAG version)

Some values are extrapolation from old design.
We need detailed simulation.

Summary of Summaries

Why Compton scheme?

Independent:

in operation, in energy, in commissioning,
in electron-positron arms, and in development.

How R/D is going on?

Very healthy in three aspects.

i) Proof of principle (experiment): finished

Good results of polarization.
Establish method of pol. measurement
and beam diagnosis.

ii) Conceptual Design (simulation)

Promising. 5 Hz is suitable for Compton

iii) Component R/D (experiment)

Next speaker (J. Urakawa).

Slides to Use Answering Questions

Table 1: Example parameters of damping ring employed for positron stacking.

energy	5 GeV
circumference	3323 m
particles per extracted bunch	2.4×10^{10}
rf frequency	650 MHz
number of trains	10
number of bunches per train	280
gap between trains (no. of missing bunches)	80
particles per injected bunch	2.4×10^{8}
injections per bucket on successive turns	10
injection repetition rate during 100 ms	100 Hz
total number of injections	100
store time after 100 injections	100 ms
energy loss per turn	5.5 MeV
damping time	10 ms
transverse emittance at injection	0.005 rad-m
rms bunch length at injection	3 mm
rms energy spread at injection	0.14%
final rms bunch length	6 mm
final rms energy spread	0.14%
longitudinal “edge” emittance at injection	0.7 meV-s
rf voltage	20 MV
momentum compaction	3×10^{-4}
2nd order momentum compaction	1.3×10^{-3}
synchrotron tune	0.0365
bucket area	292 meV-s
synchronous phase	15.58°
separatrix phases 1 & 2	164.42°, −159.19°
maximum momentum acceptance	±2.7%