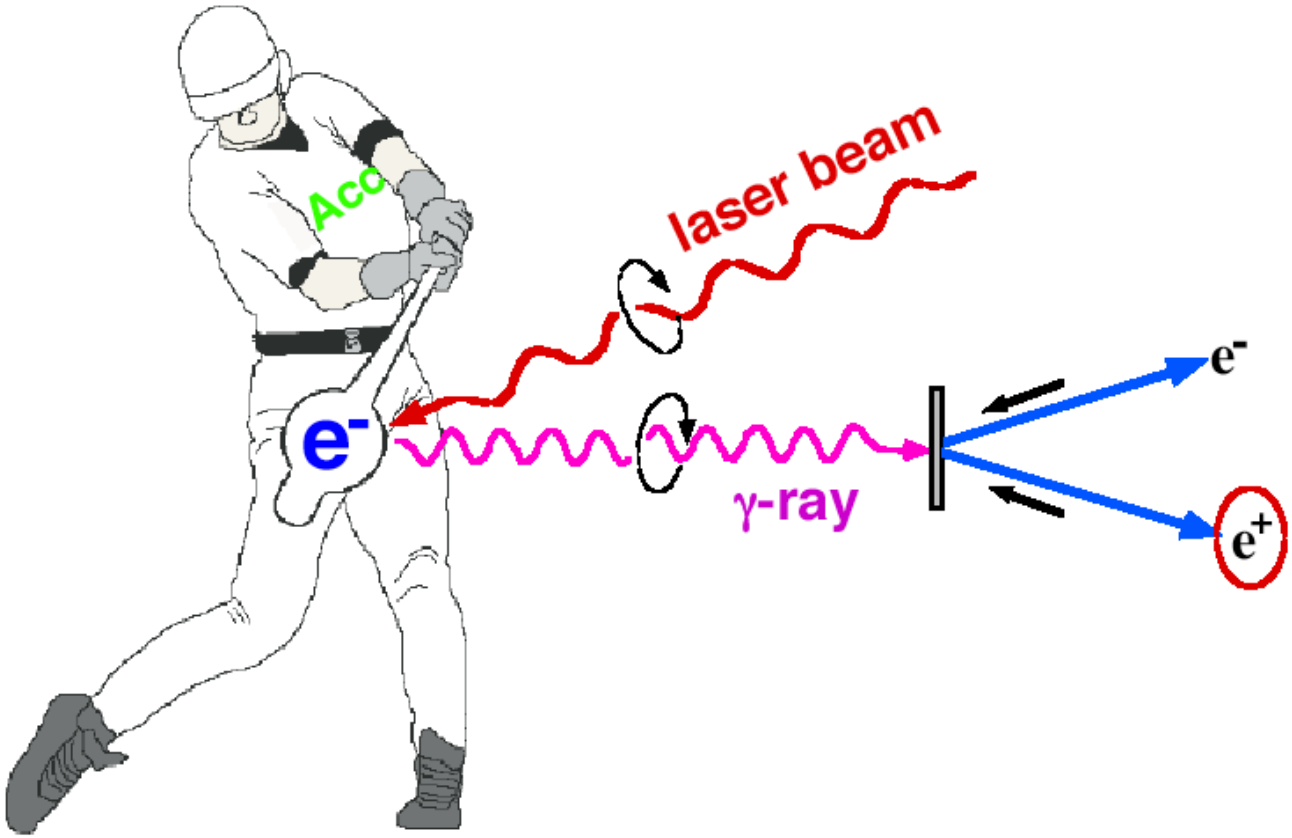
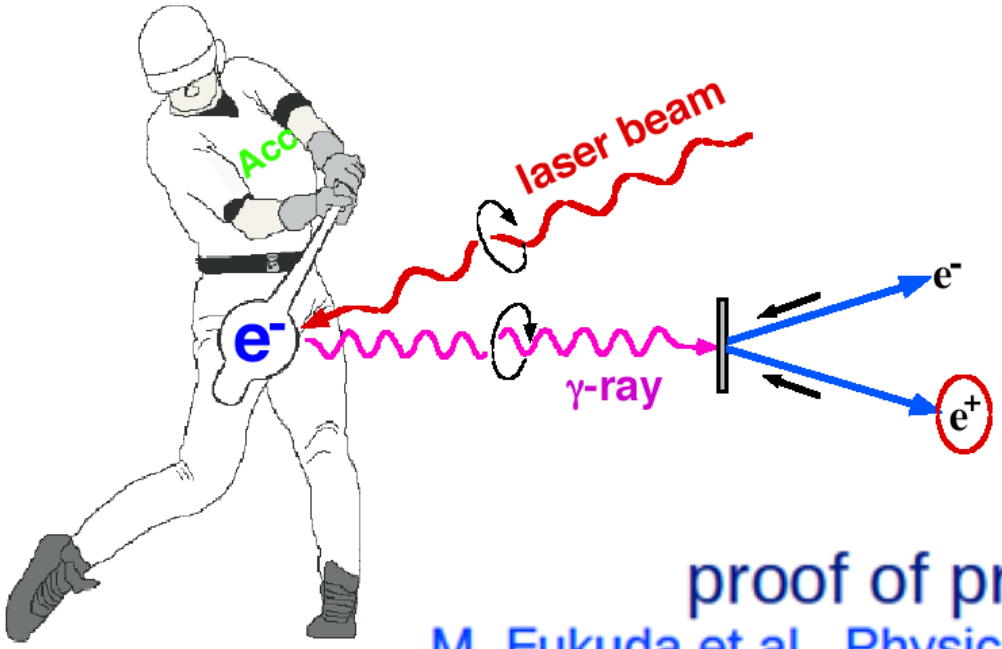
Compton for ILC



LCWS2012, UT at Arlington, USA
T. Omori (KEK)

Introduction

- Polarized e+ by laser Compton Scheme



Ee~1GeV for 10MeV gammas

easy to control polarization
independent source

proof of principle experiment

M. Fukuda et al., Physical Review Letters 91, 164801 (2003)
T.Omori *et* al., Physical Review Letters 96, 114801(2006)

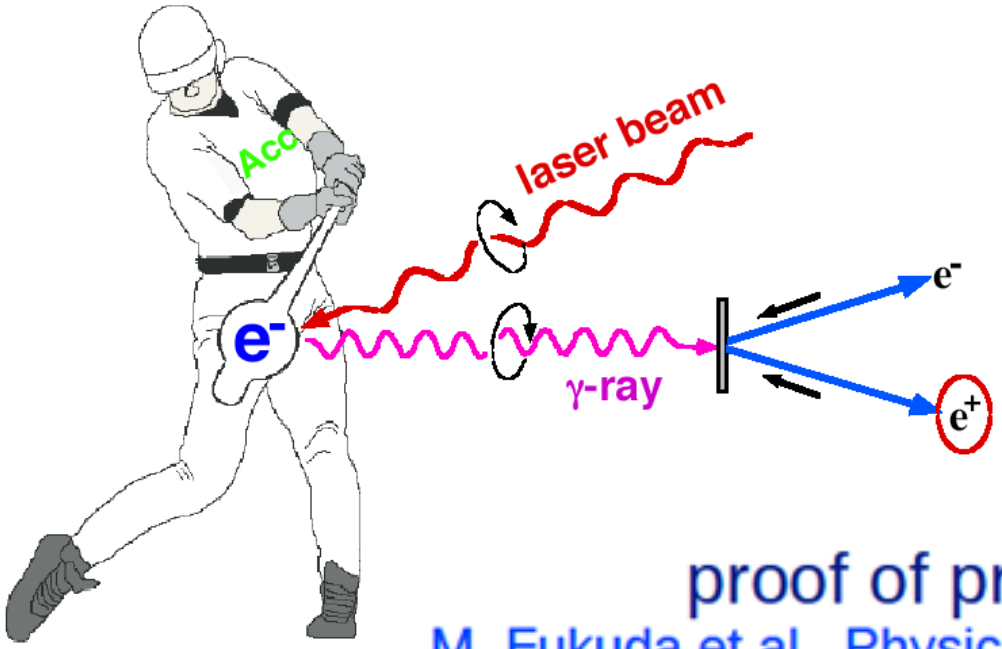
Toward the positron sources

(1) Design Study : upgrade from 300 Hz Conventional

(2) R/D : Optical cavity at ATF

Introduction

- Polarized e+ by laser Compton Scheme



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Toward the positron sources

(1) Design Study : upgrade from 300 Hz Conventional

(2) R/D : Optical cavity at ATF

Design Study

Upgrade from
300 Hz Conventional e+ source
to
Compton pol e+ source.

Laser Compton e^+ Source for ILC

Reminder: We have 3 schemes.

1. Linac Base Laser Compton

   Linac + non-stacking Laser Cavity (λ=10μm),
   and No stacking in DR

   Proposal V. Yakimenko and I. Pogorersky

   T. Omori et al., Nucl. Instr. and Meth. in Phys. Res., A500 (2003) pp 232-252

2. Ring Base Laser Compton

   Storage Ring + Laser Stacking Cavity (λ=1μm),
   and e+ stacking in DR

   S. Araki et al., physics/0509016

3. ERL Base Laser Compton

   ERL + Laser Stacking Cavity (λ=1μm),
   and e+ stacking in DR

Laser Compton e^+ Source for ILC

Reminder: We have 3 schemes. (Here we show old designs)

1. Linac Base Laser Compton

   Linac + non-stacking Laser Cavity (λ=10μm),
   and No stacking in DR

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3. ERL Base Laser Compton

   ERL + Laser Stacking Cavity (λ=1μm),
   and e+ stacking in DR

Conventional e+ Source for ILC

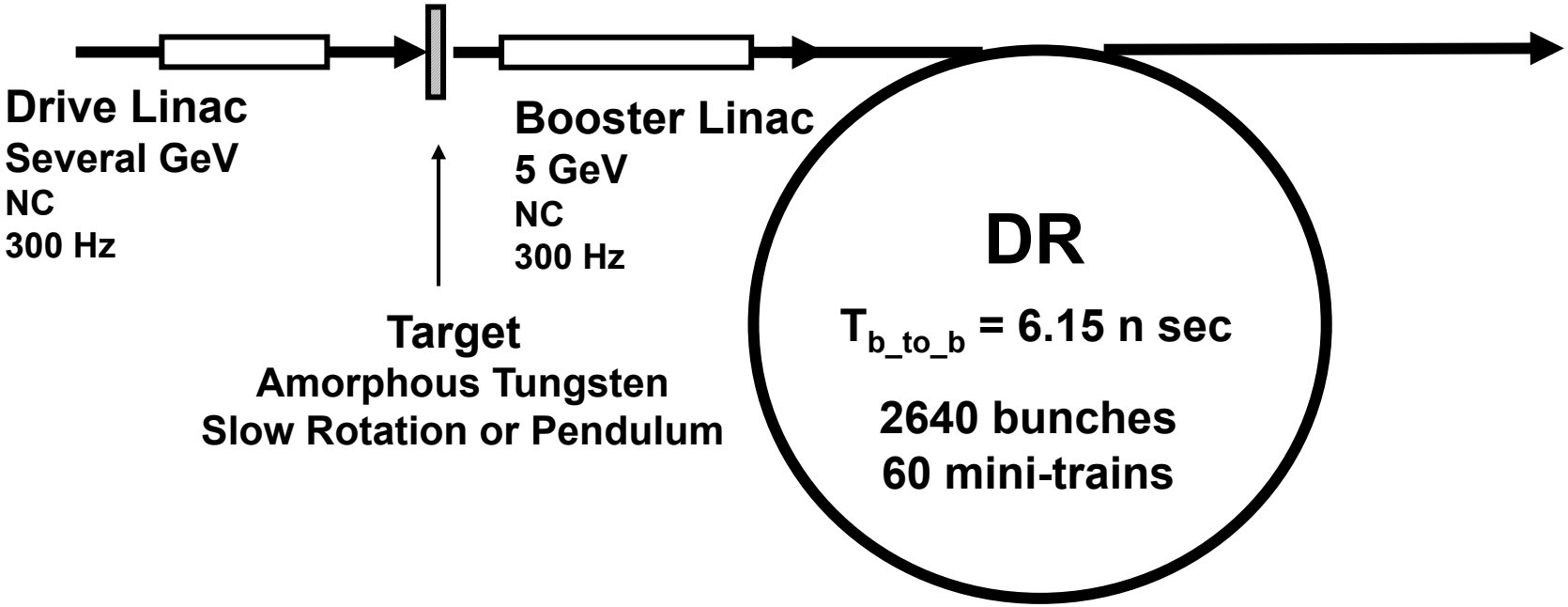
Normal Conducting Drive and Booster Linacs in 300 Hz operation

e+ creation

20 triplets, rep. = 300 Hz, pulse length ~ 1μs
- **triplet = 3 mini-trains with gaps**
- **44 bunches/mini-train, $T_{b\_to\_b}$ = 6.15 n sec**

go to main linac

2640 bunches/train, rep. = 5 Hz
- **$T_{b\_to\_b}$ = 369 n sec**



Time remaining for damping = 137 m sec

We create 2640 bunches in 63 m sec

Conventional e+ Source for ILC

Normal Conducting Drive and Booster Linacs in 300 Hz operation

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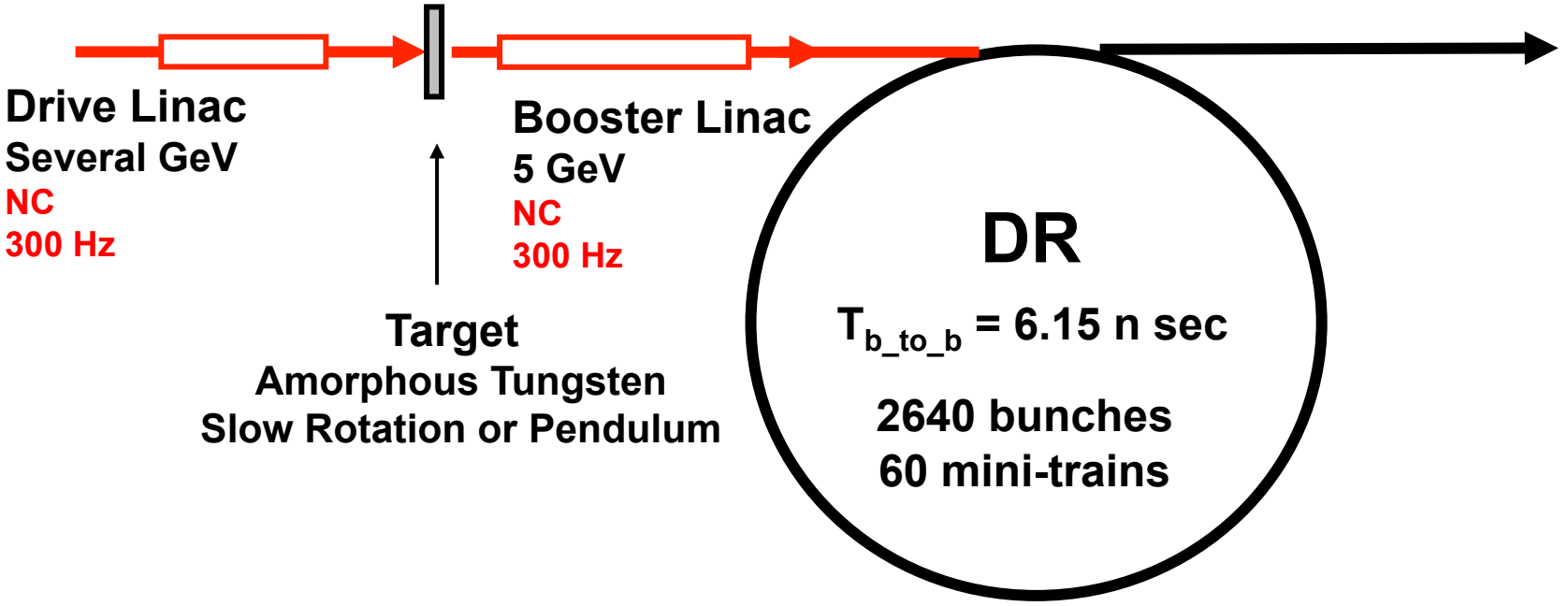
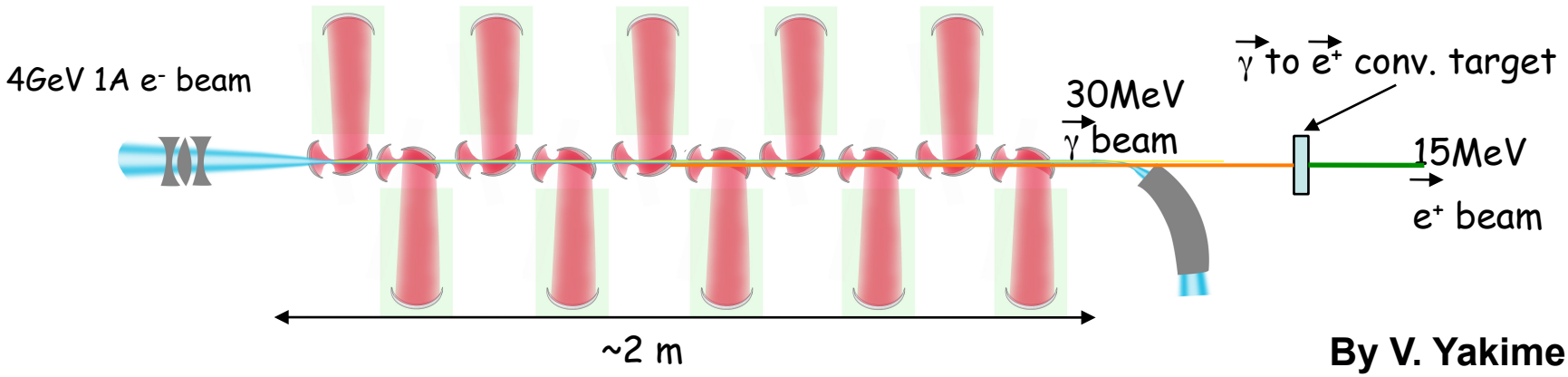


Time remaining for damping = 137 m sec

We create 2640 bunches
in 63 m sec

Linac Scheme (Old design)

- CO_2 laser beam and 4 GeV e-beam produced by linac.
  - **4GeV 15nC e- beam with 12 ns spacing.**
  - **10 CPs, which stores 10 J CO_2 laser pulse repeated by 83 Mhz cycle.**
- 5E+11 γ-ray -> 2E+10 e+ (2% conversion)
- 1.2μs pulse, which contains 100 bunches, are repeated by 150 Hz to generated 3000 bunches within 200ms.
  - Laser system relies on the commercially available lasers but need R&D for high repetition operation.
  - Ring cavity with laser amplifier realizes the C02 laser pulse train.



By V. Yakimenko

Conventional e+ Source for ILC

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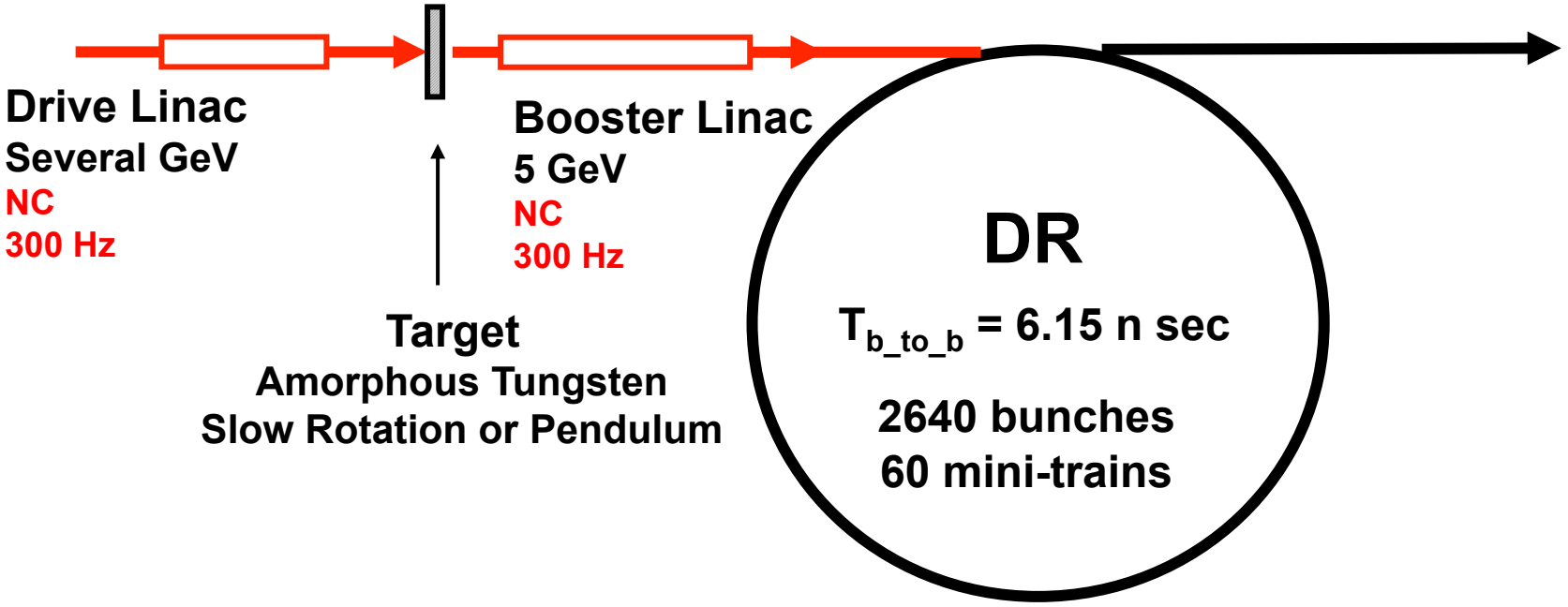

Time remaining for damping = 137 m sec

We create 2640 bunches
in 63 m sec

Linac Compton (NO big change)

Normal Conducting Drive and Booster Linacs <-- Reuse

e+ creation

20 triplets, rep. = 300 Hz
- triplet = 3 mini-trains with gaps
- 44 bunches/mini-train, $T_{b\_to\_b}$ = 6.15 n sec

go to main linac

2640 bunches/train, rep. = 5 Hz
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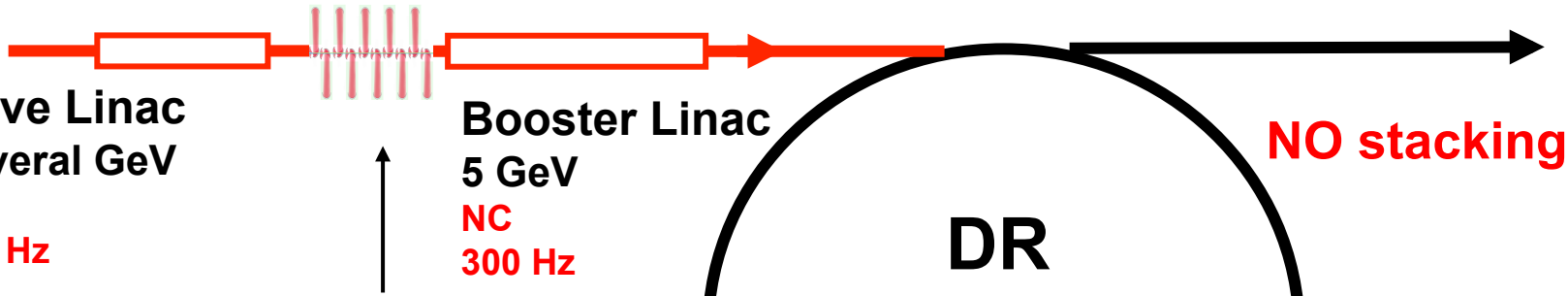


Drive Linac
Several GeV
NC
300 Hz

Booster Linac
5 GeV
NC
300 Hz

Target
CO2 Laser Cavities

Replace target
Single Tungsten Target --> CO2 Laser Cavies

DR
$T_{b\_to\_b}$ = 6.15 n sec
2640 bunches
60 mini-trains

NO stacking in DR

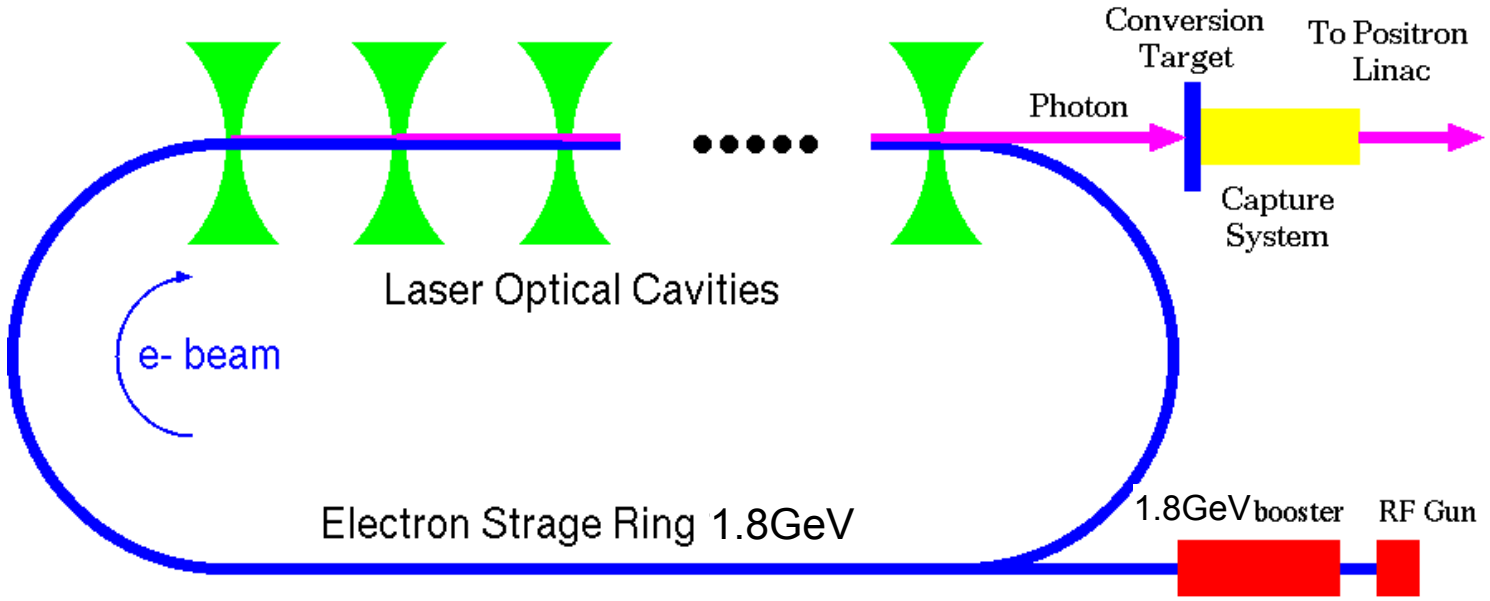
Time remaining for damping = 137 m sec

We create 2640 bunches
in 63 m sec

Compton Ring (Old Design)

- Electron driver:5.3nC, 6.2ns, 1ps, 1.8GeV
- Laser : 0.6Jx5 CP (optical cavities).
- By one collision, positron bunch with Ne+:2.0E+8 is generated.
- 10 bunches are stacked on a same bucket in DR. This process is repeated 10 times with 10ms interval .
- Finally, Ne+:2E+10 is obtained.

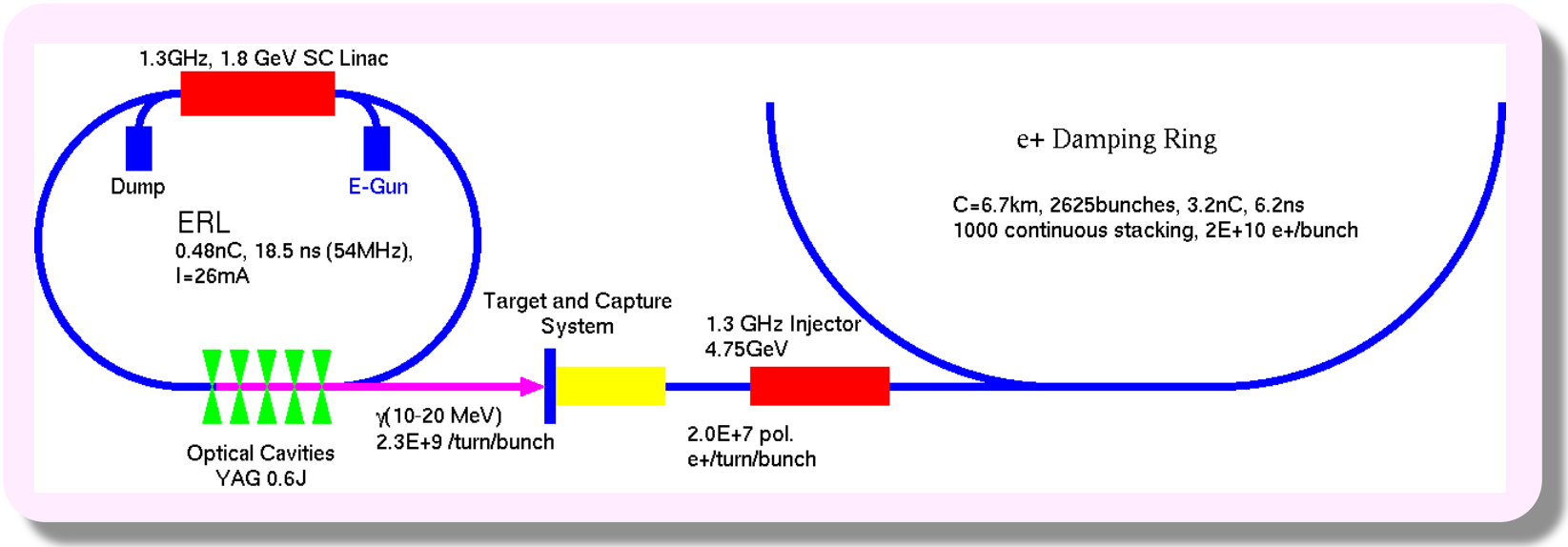
90 ms (10 ms x 9)



ERL scheme (Old Design)

- Electron is provided by ERL (Energy Recovery Linac).
- Both advantages (high yield at Linac and high repetition at CR) are compatible in the ERL solution.
- Continuous stacking the e+ bunches on a same bucket in DR during 100ms, the final intensity is 2E+10 e^+.
- Another 100ms is used for damping.

100 ms



Ring/ERL Compton

Normal Conducting Drive < -- Throw away, Booster Linac <-- Reuse

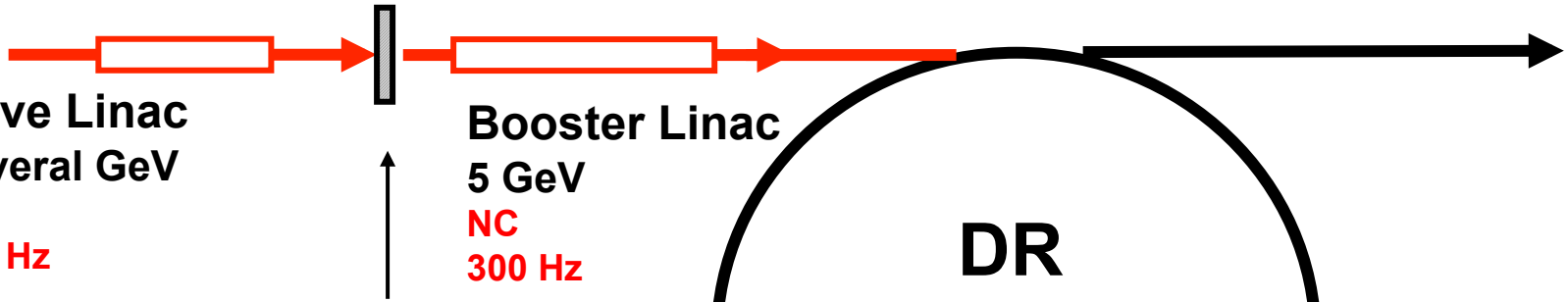
300 Hz Conventional

e+ creation

20 triplets, rep. = 300 Hz
- **triplet = 3 mini-trains with gaps**
- **44 bunches/mini-train, $T_{b\_to\_b}$ = 6.15 n sec**

go to main linac

2640 bunches/train, rep. = 5 Hz
- **$T_{b\_to\_b}$ = 369 n sec**



Drive Linac
Several GeV
NC
300 Hz

Booster Linac
5 GeV
NC
300 Hz

Target
Amorphous Tungsten
Slow Rotation or Pendulum

DR

$T_{b\_to\_b}$ = 6.15 n sec

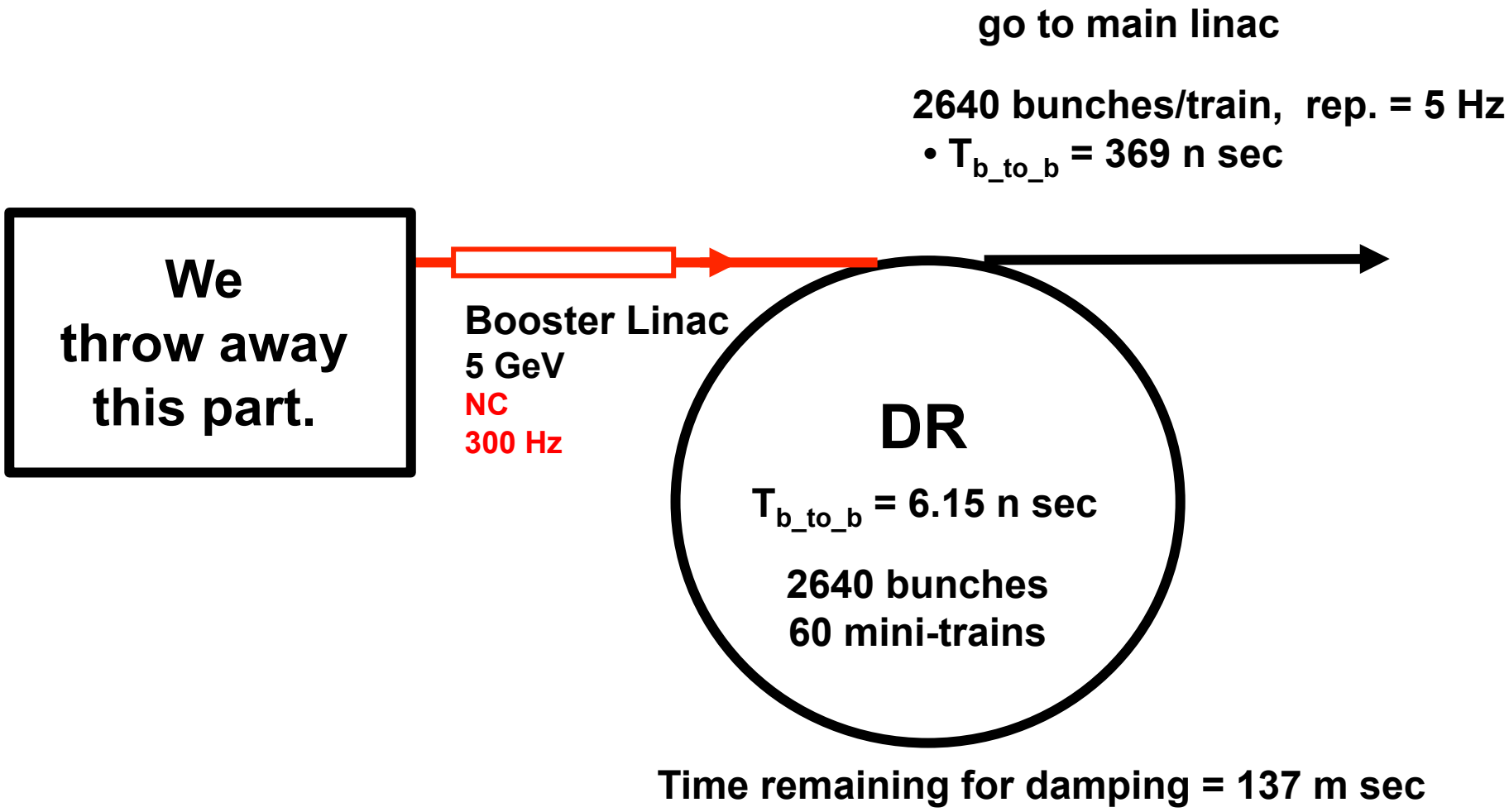
2640 bunches
60 mini-trains

Time remaining for damping = 137 m sec

We create 2640 bunches in 63 m sec

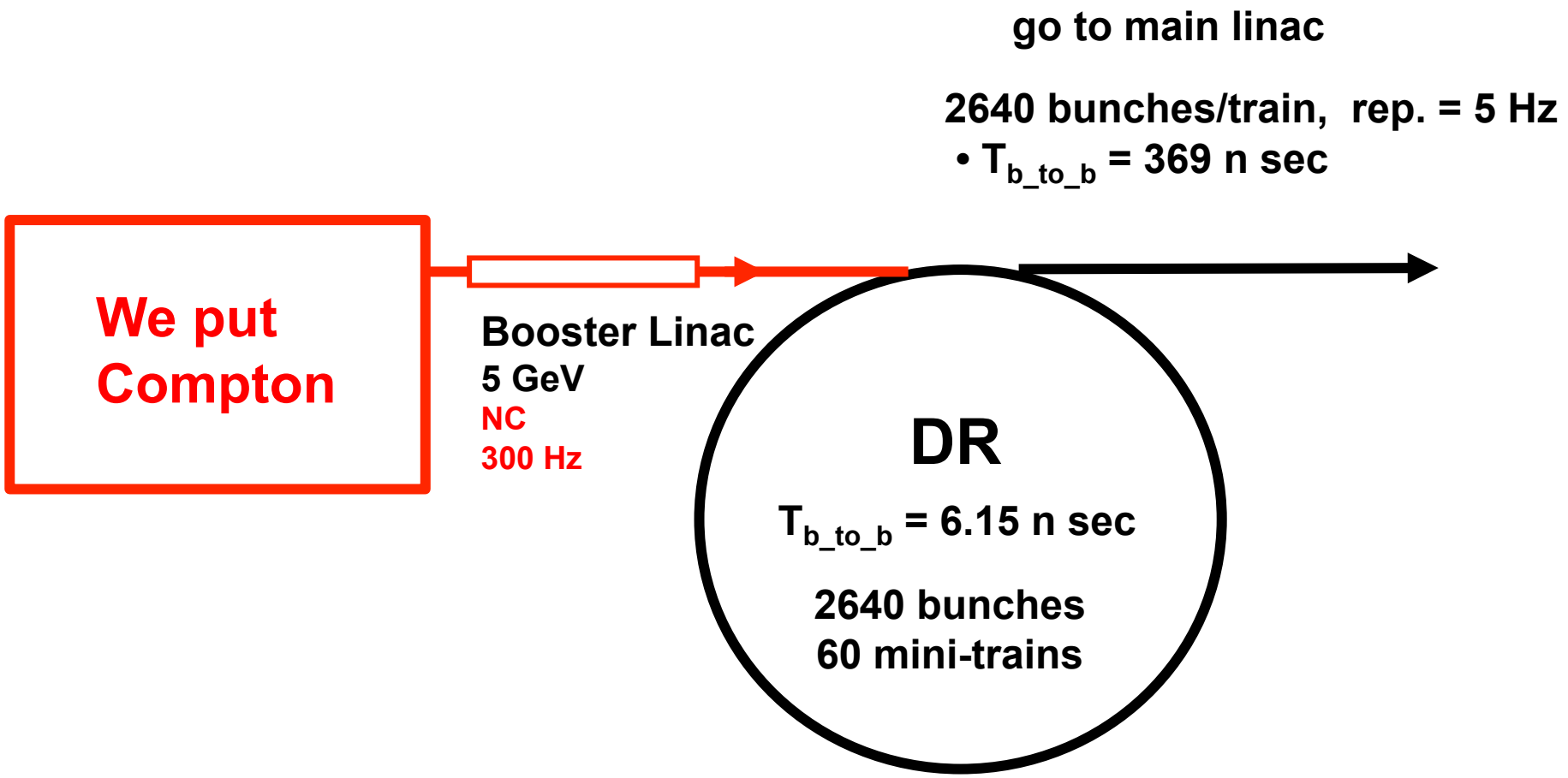
Ring/ERL Compton

Normal Conducting Drive < -- Throw away, Booster Linac <-- Reuse



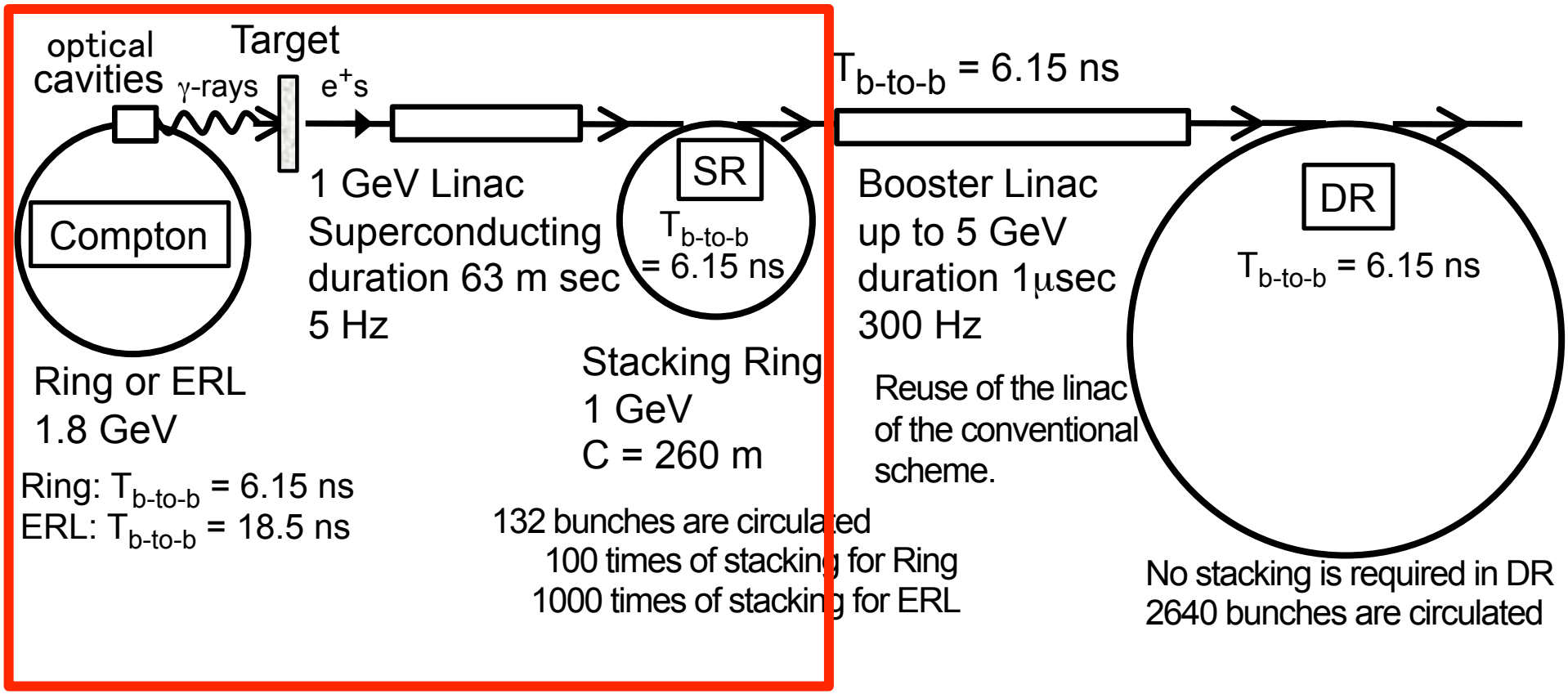
Ring/ERL Compton

Normal Conducting Drive < -- Throw away, Booster Linac <-- Reuse



Ring/ERL Compton

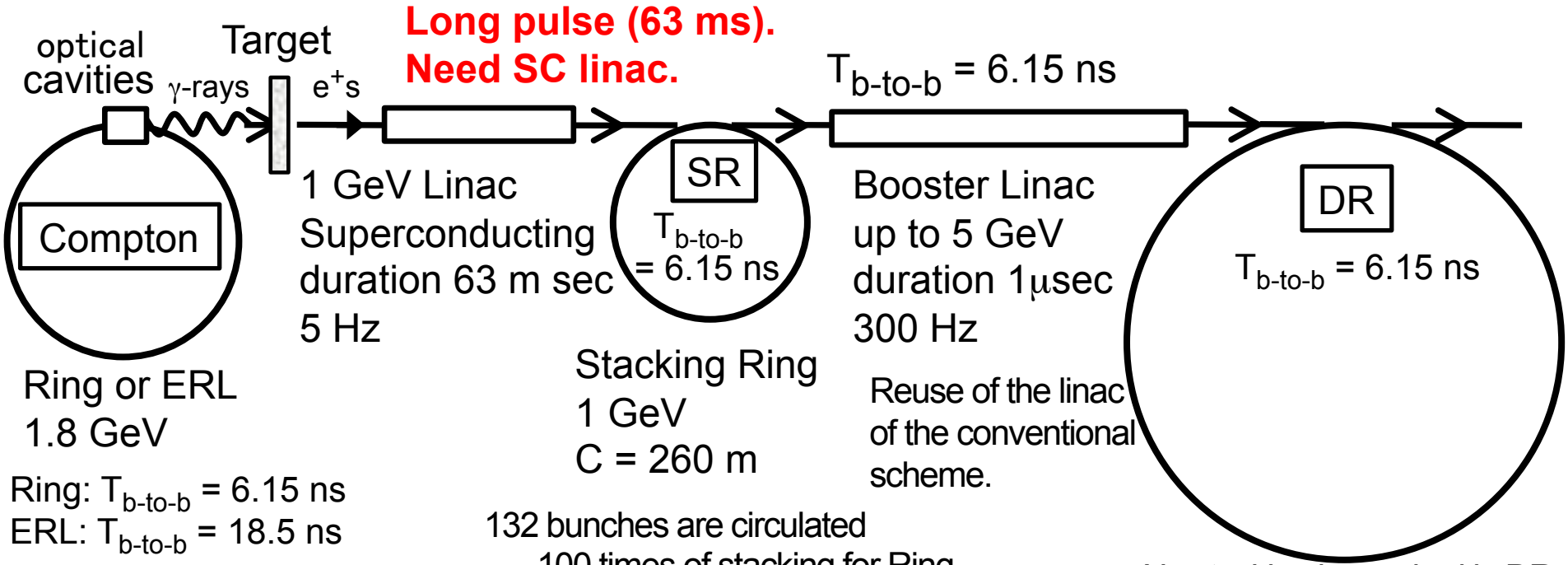
Normal Conducting Drive < -- Throw away, Booster Linac <-- Reuse



Compton

Ring/ERL Compton

Normal Conducting Drive < -- Throw away, Booster Linac <-- Reuse



We create 2640 bunches in 63 m sec.
We make stacking in the SR.

NO stacking in DR.

Ring/ERL Compton

Details (All parameters are tentative and still premature)

Ring/ERL Common Details

Positrons produced by the polarized gamma-rays are accelerated upto 1 GeV by the superconducting linac then injected into the 1 GeV stacking ring. The linac operates at 5 Hz and has a long duration of 63 m sec. Then the 1 GeV stacking ring with about 260m circumference is employed. In the stacking ring, 132 bunchs are stored with 6.15 ns bunch spacing. The 132 bunches are sent to the booster linac at once by a kicker which pulse length is 1 micro seconds. The booster linac is normal conducting. It has heavy beam loading ($3x10^{10}$ positrons/bunch) and operated with about 1 μ sec pulse duration at 300 Hz. 20 times beam extraction from the stacking.

Ring-Compton Details

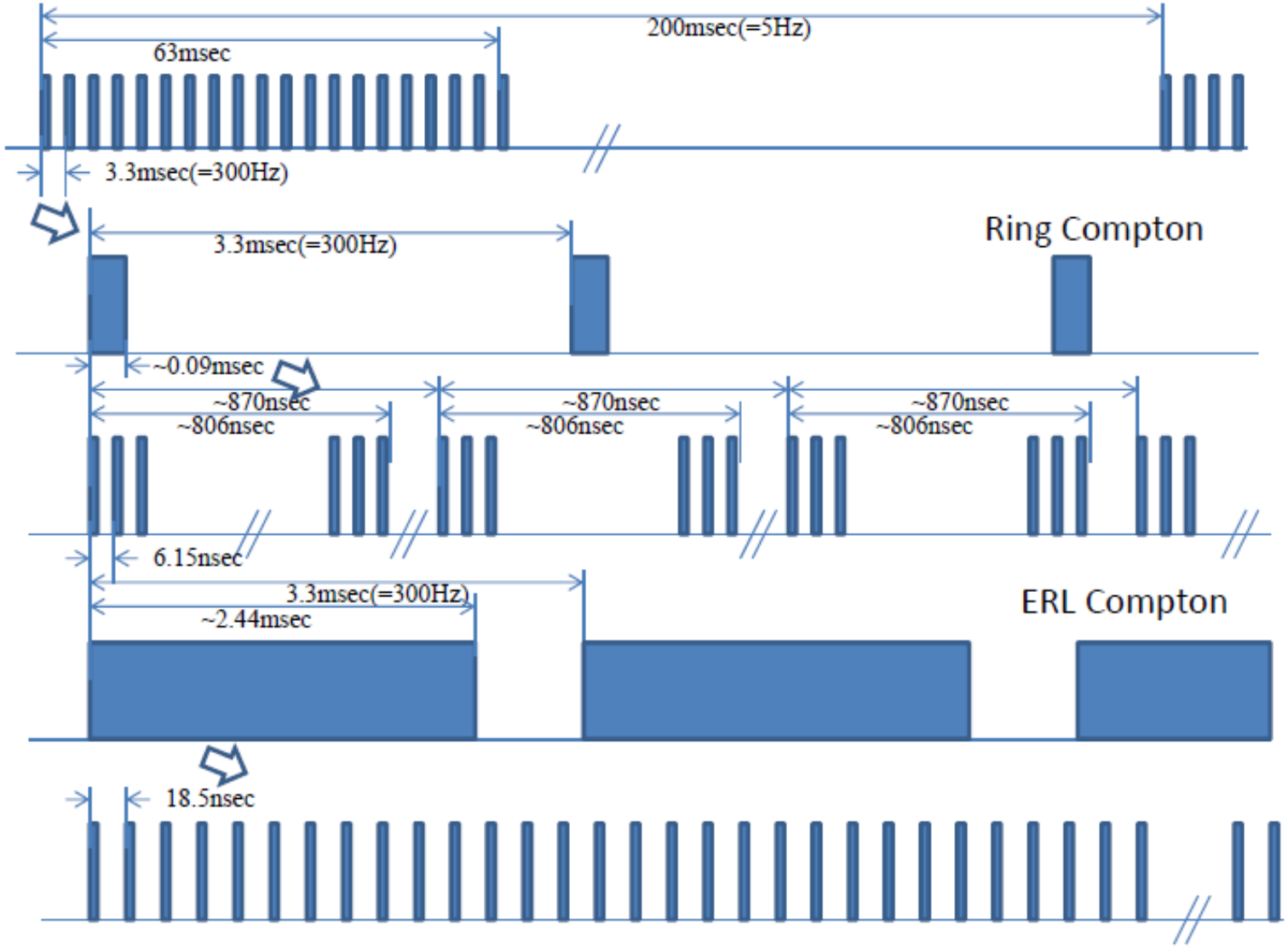
We need 100 times positron bunch stacking in the same bunch in the staking ring. Since the bunch spacing in the Compton ring and in the staking ring is the same, 100 times of stacking need 100 turns in the sacking ring. It takes about 87μs, because the circumference of the ring is 260 m. We take cooling period of 3.2ms after stacking for stable operation of the Compton ring and the stacking ring. Total period of one cycle is 3.3 m sec (300 Hz). 20 times beam extraction takes 63ms.

ERL-Compton Details

We need 1000 times of the stacking in the same bunch in the stacking ring. The bunch separation in ERL is 18.5 n sec. Therefore, the period of 1000 times positron bunch stacking is about 2.4ms. In a turn of the stacking ring, stacking is performed with three bunch intervals. In the next turn, stacking is not performed in the same bunch, but it is performed in the adjacent bunch which has 6.15-n-sec separation. This means stacking on the same bunch is performed with three turn intervals. The interval makes the stacking easier. Also through the process of the stacking, bunch spacing is changed from 18.5 ns to 6.15 ns. Since stacking takes long time, 2.4 m sec, cooling in the stacking ring is on going simultaneously. Remaining 0.9 m sec is used for additional cooling.

Ring/ERL Compton

Timing Chart (All parameters are tentative and still premature)



R/D

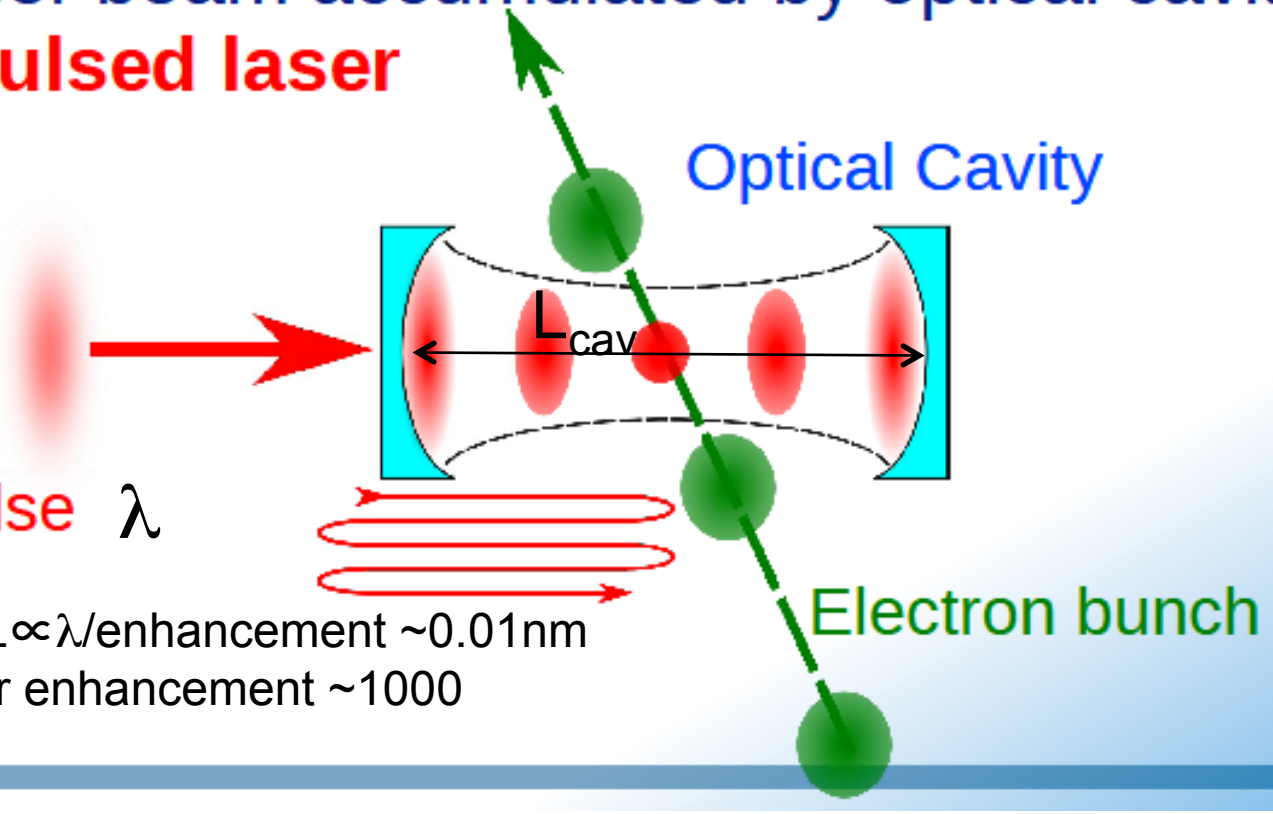
Optical Cavity for Ring/ERL Compton

Staking Laser Pulses in Optical Cavity

Miyoshi PosiPol2010

Increase power of laser beam at interaction point for increasing gamma yield.

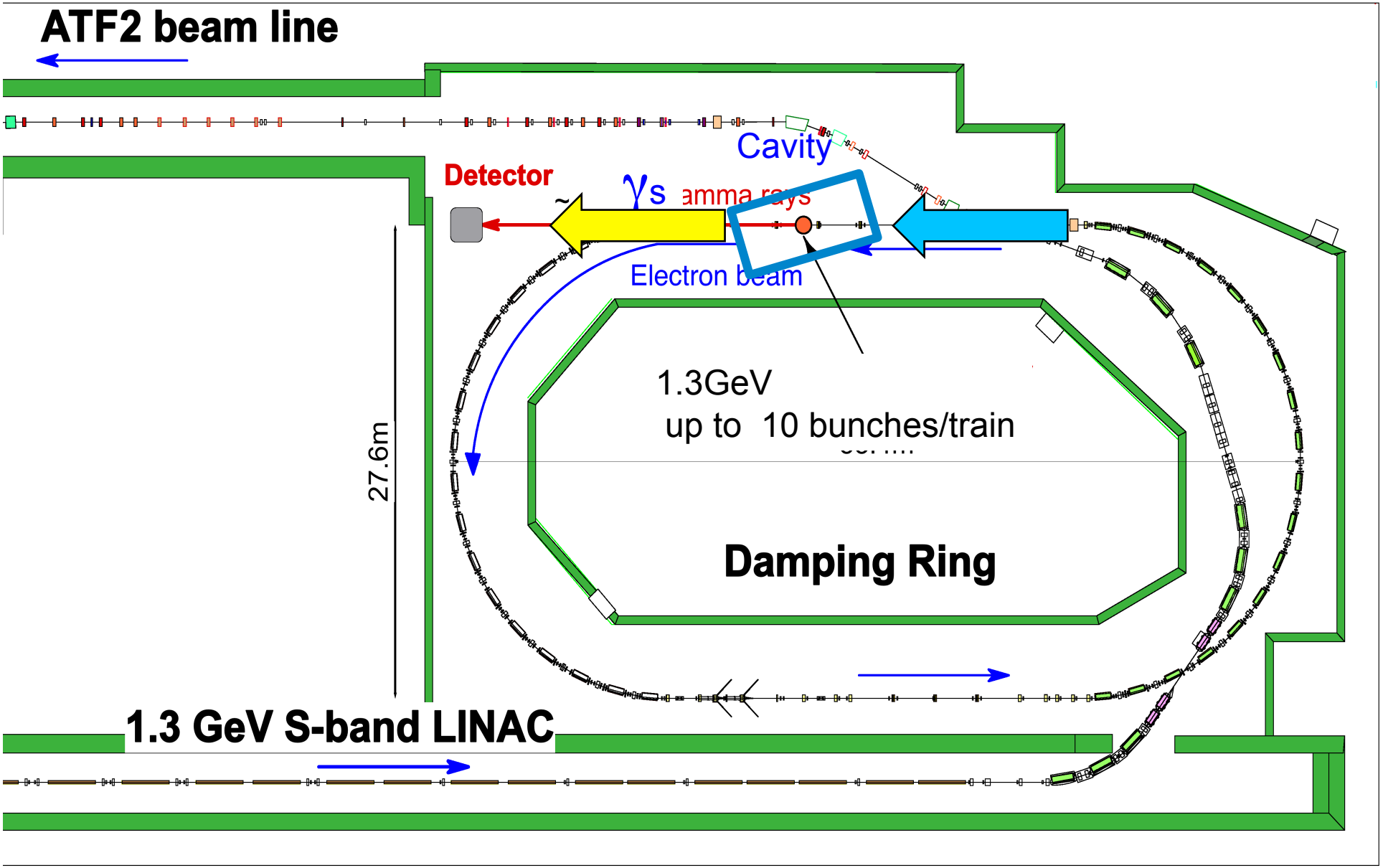
- **enhancement with optical cavity**
  - Laser beam accumulated by optical cavity
- **use pulsed laser**



$$L_{cav} = m\frac{\lambda}{2}$$

dL∝λ/enhancement ~0.01nm
for enhancement ~1000

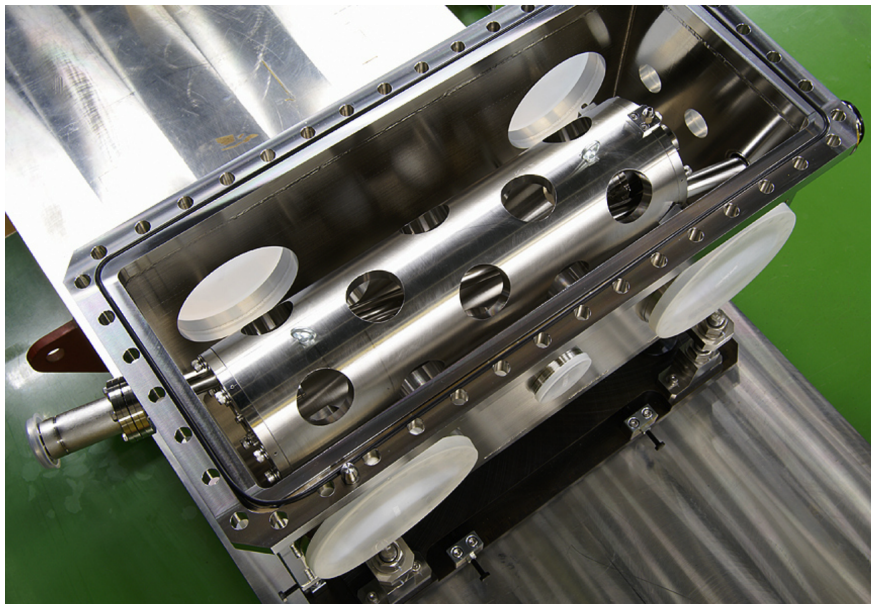
Experiments at the KEK ATF



Two Prototype Cavities

2-mirror cavity

(Hiroshima / Weseda / Kyoto / IHEP / KEK)

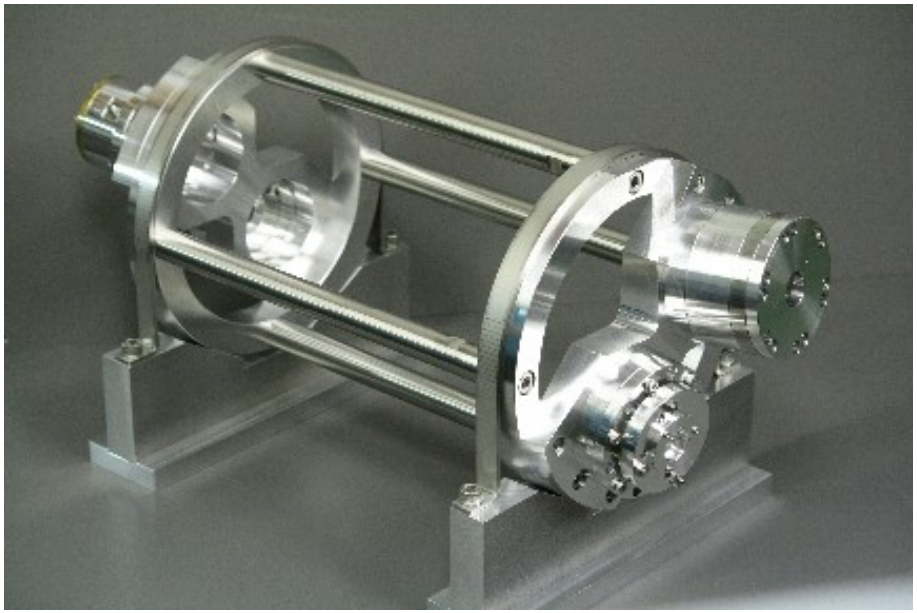


moderate enhancement
moderate spot size
simple control

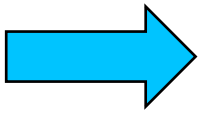
demonstration of γ ray gen.
accum. exp. w/ cavity and acc.

4-mirror cavity

(Inspired by French Activity)

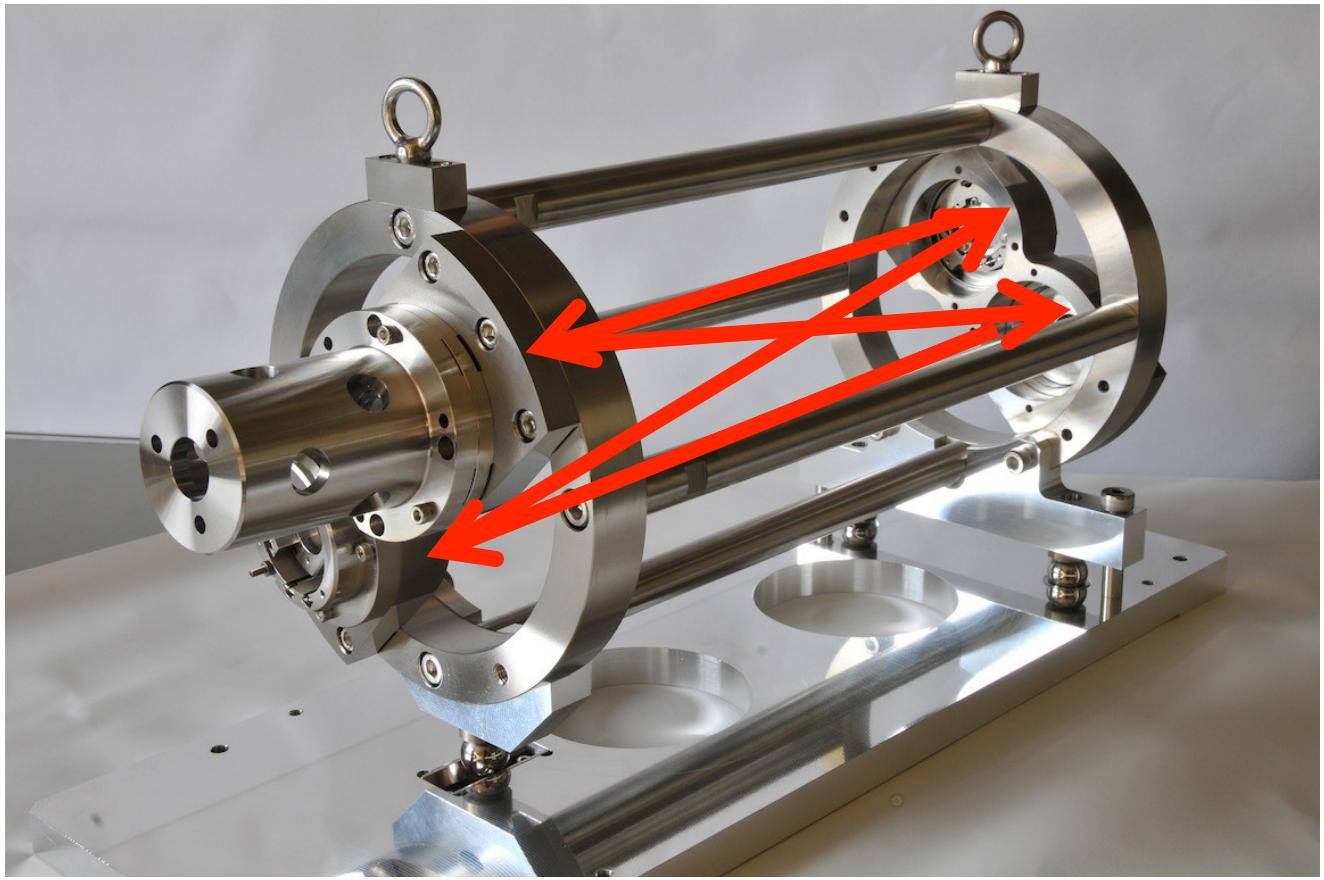


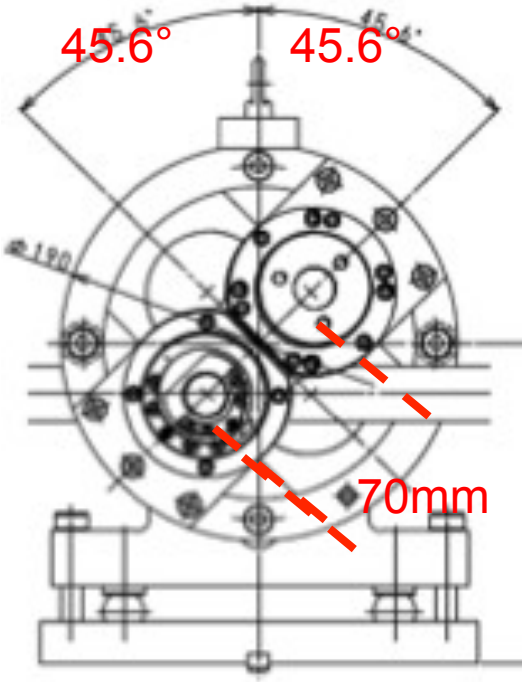
high enhancement
small spot size
complicated control



intense γ ray generation

New cavity
Installed into the ATF





R1 = 99.9% (input), R2 = R3 = R4 = 99.99%

Two 4 mirror cavities are at the ATF

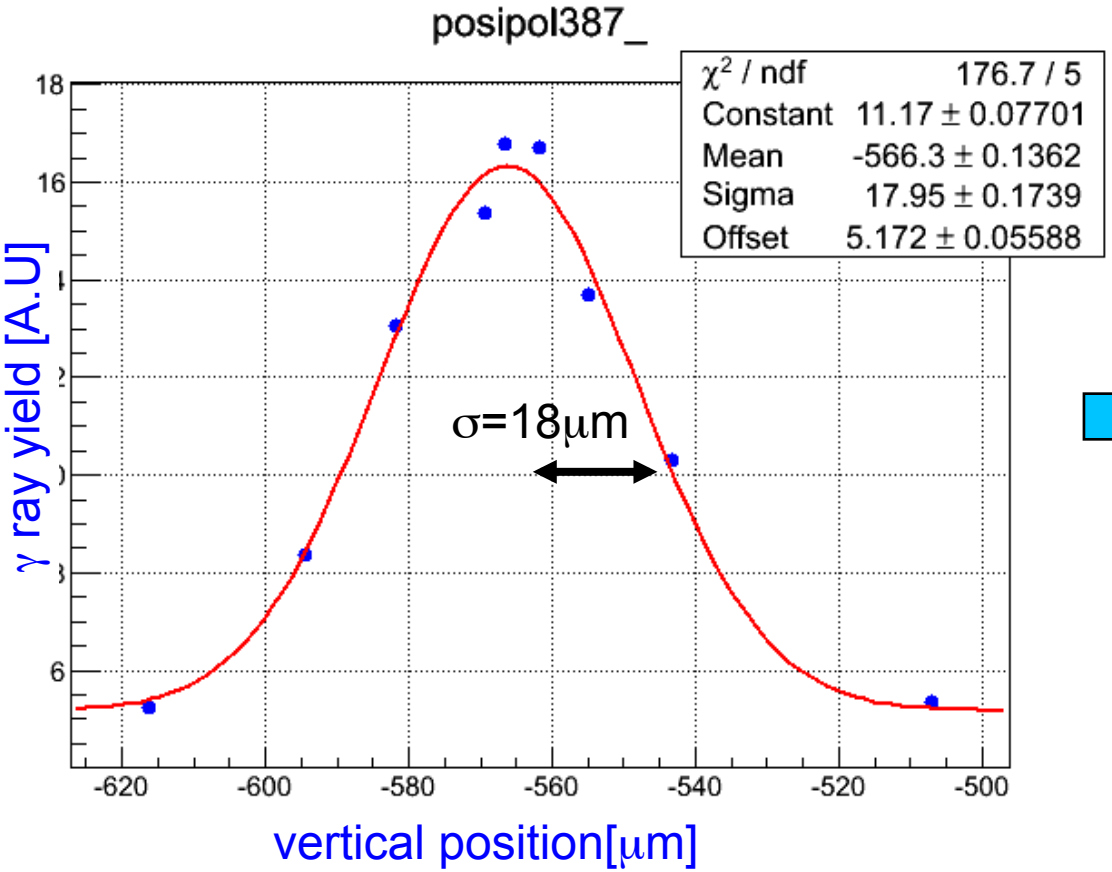
KEK-Hiroshima
installed 2011

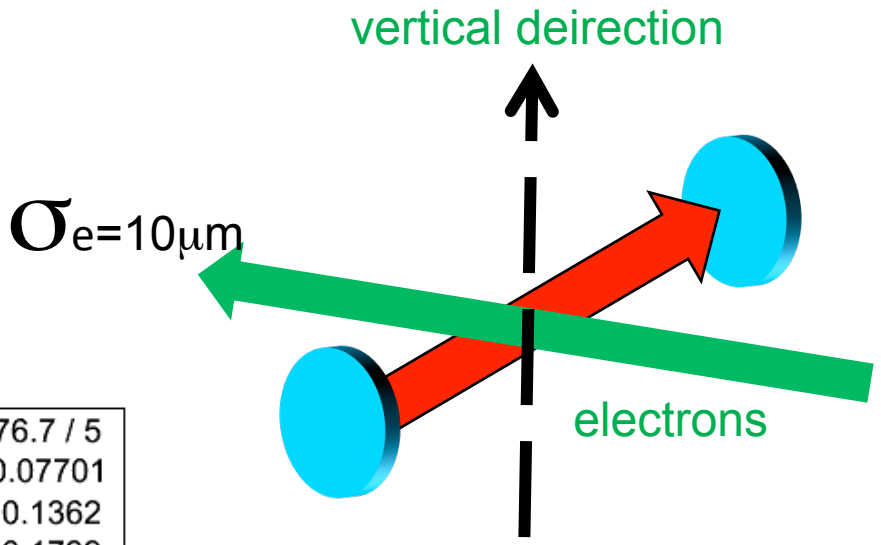
relatively simple control system
employs new feed back scheme

LAL-Orsay
installed summer 2010

sophisticated control
digital PDH feedback

Laser spot size
15μm achieved

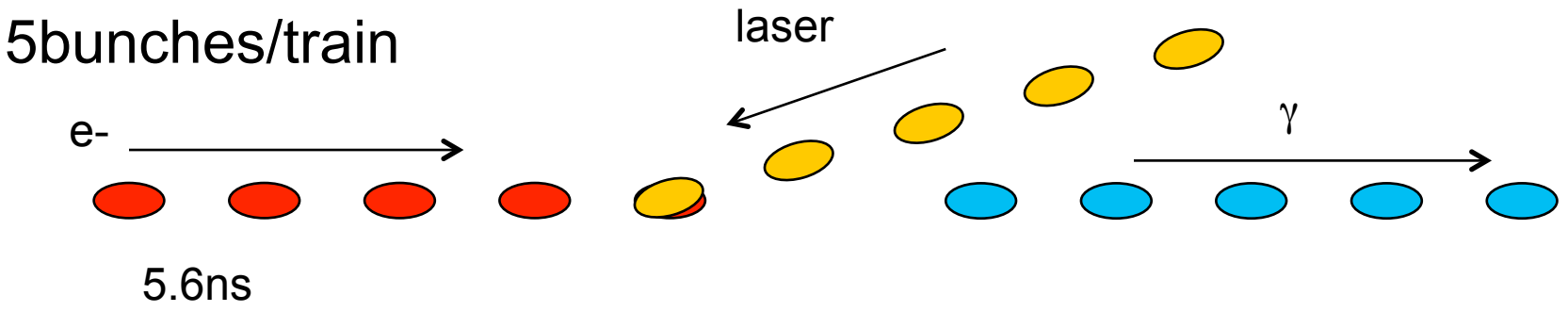




σ_L=15μm

it was 30μm w/ 2 M cavity

γ ray Generation / electron

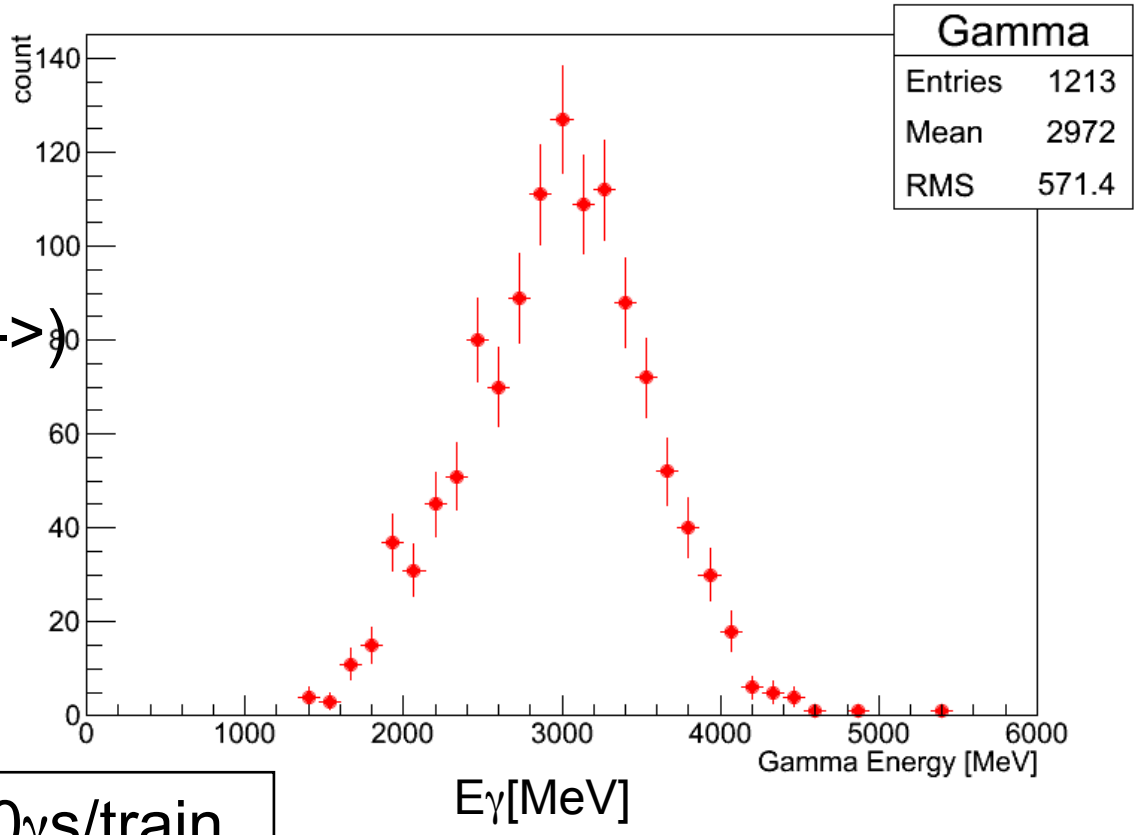


2970±20 MeV (the plot ->)

⇒ ~120γs/train

ATF 2.16MHz

~2.6×10^{8}/sec

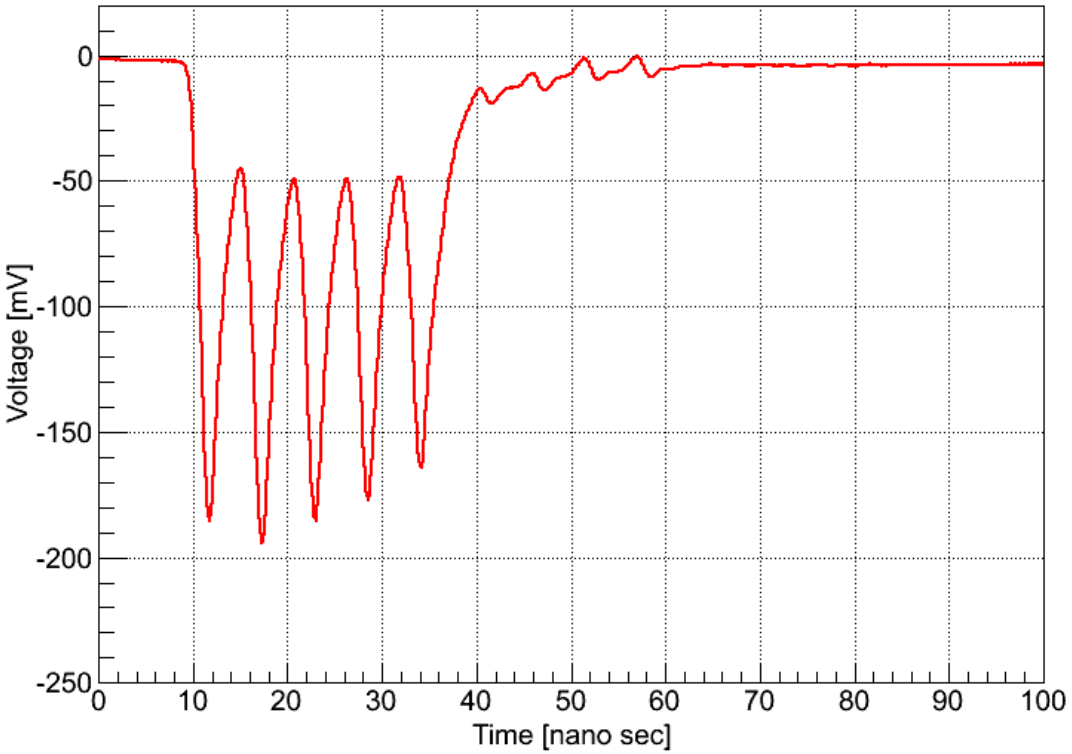


Eγ[MeV]

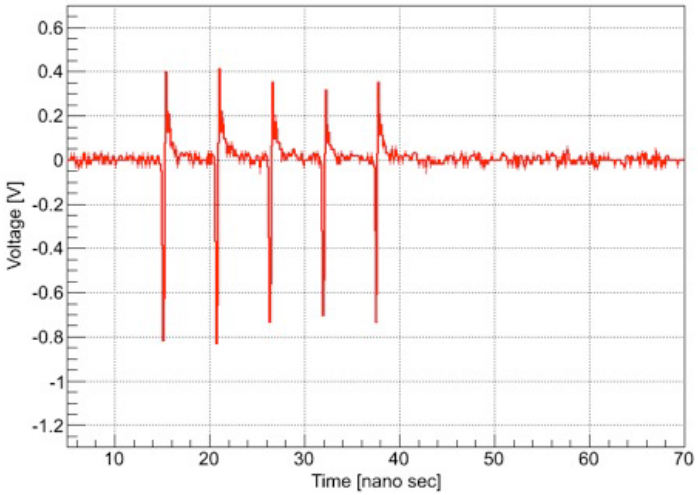
best record so far ~150γs/train

bunch/bunch measurement

wave form from detector



e- bunch monitor



◆～117/train ⇒ consistent w/ calorimeter measurement

◆no bunch dependence (yield is proportional to e- current)

New Issue Found

Loss at Mirror

0.25 Watts Loss / Mirror (Very Rough Estimate)

→ 100 PPM

Spec. of the Mirror 5 PPM

Wrong Fabrication? or We polluted the surface?

Status and plan of KEK-Hiroshima cavity

- **2.6KW stored as of 25 May 2012**
  - **30 γs / bunch (old 2M- Cavity) -> 150 γs /train**
  - **correspond to 3.3 × 10^8 γ/s**
- **BaF2 detector was employed to observe bunch by bunch generation**
  - **Planed to be replaced w/ a Lead glass counter**
    - **used in TOPAZ barrel cal. at TRISTAN!**
- **New Issue Found: Loss at Mirror**
- **Plan**
  - **more power enhancement**
    - **16600 enhancement (finesse 48,000)**
  - **digital feedback**

Summary

Summary

1. Design Study:

Ways from 300 Hz conventional e^+ source to Compton pol e^+ source are presented.

(1) Linac Compton :

Small modification. Just replace tungsten target by CO2 laser cavities.

(2) Ring/ERL Compton :

Large modification is required. We add a 1 GeV SC linac (63 ms pulse), a 1 GeV stacking ring, and a Ring/ERL as a driver.

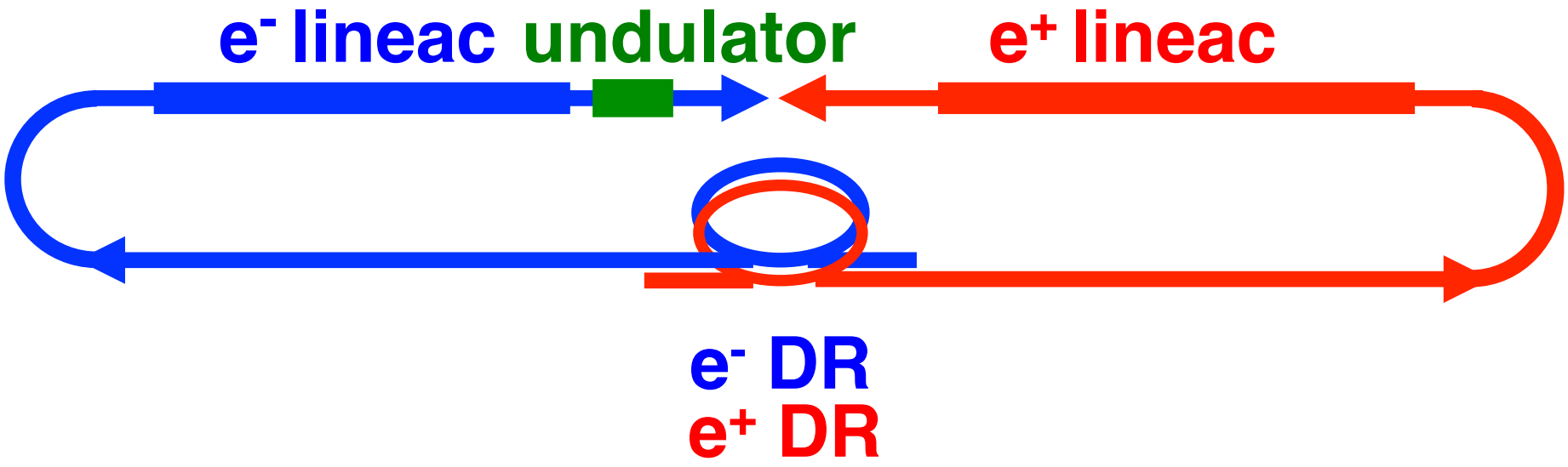
2. R/D:

Development of the 4-mirror cavity is on going at KEK for Ring/ERL Compton.

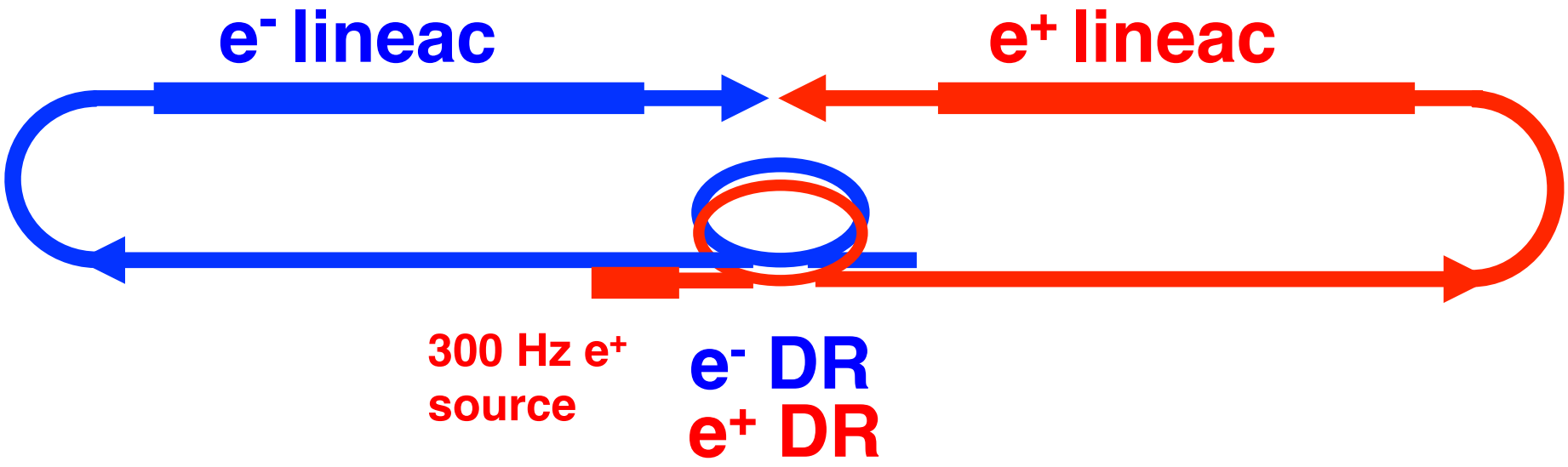
Appendix

Upgrade from
300 Hz Conventional e+ source
to
Undulator pol. e+ source

Undulator e+ source

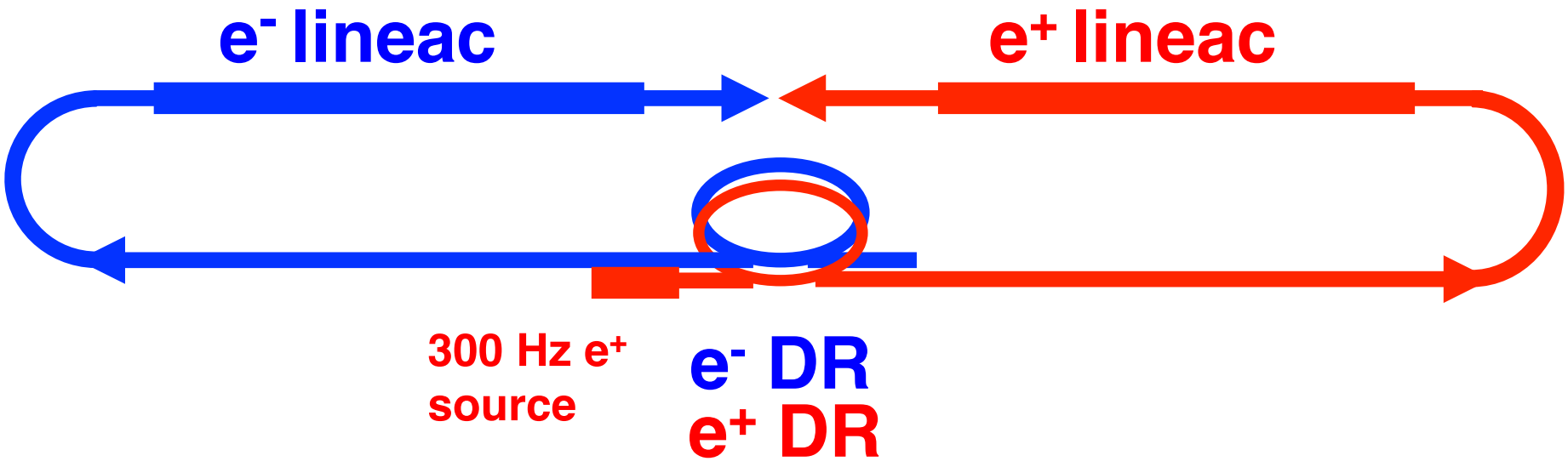


300 Hz Conventional e+



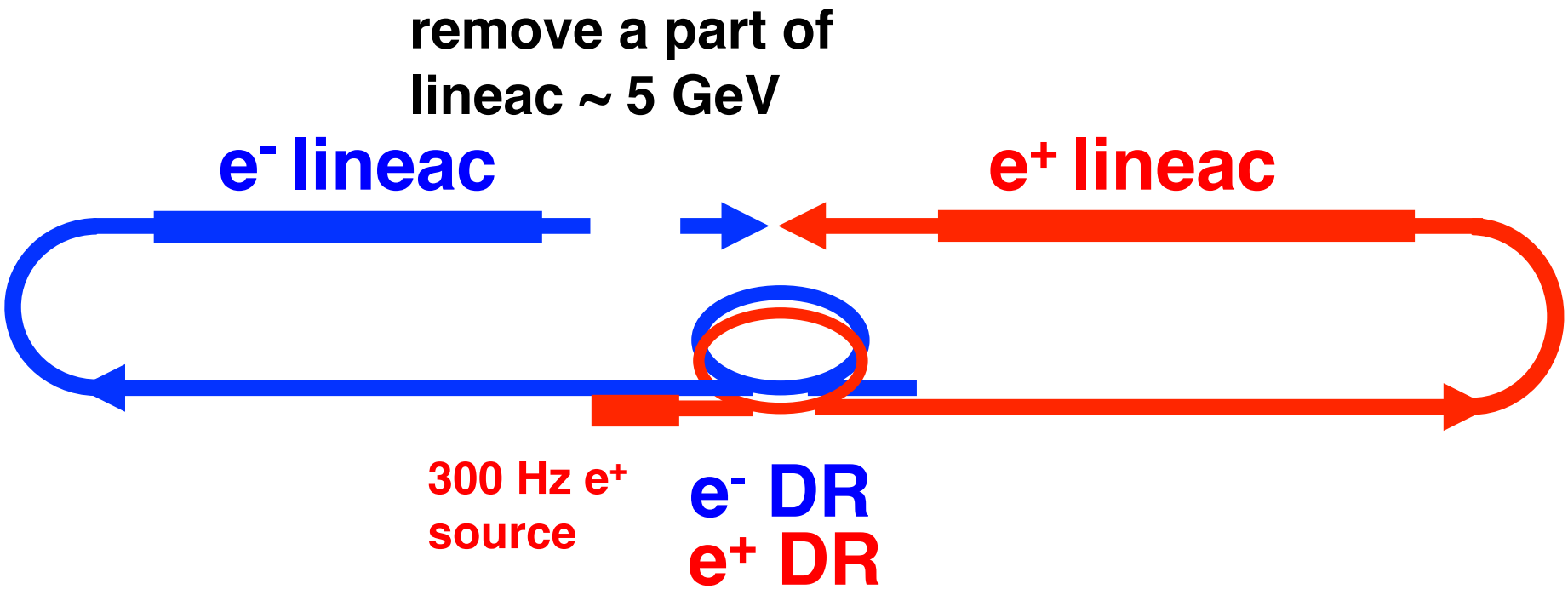
300 Hz Conventional e+

→ Undulator pol. e+ source



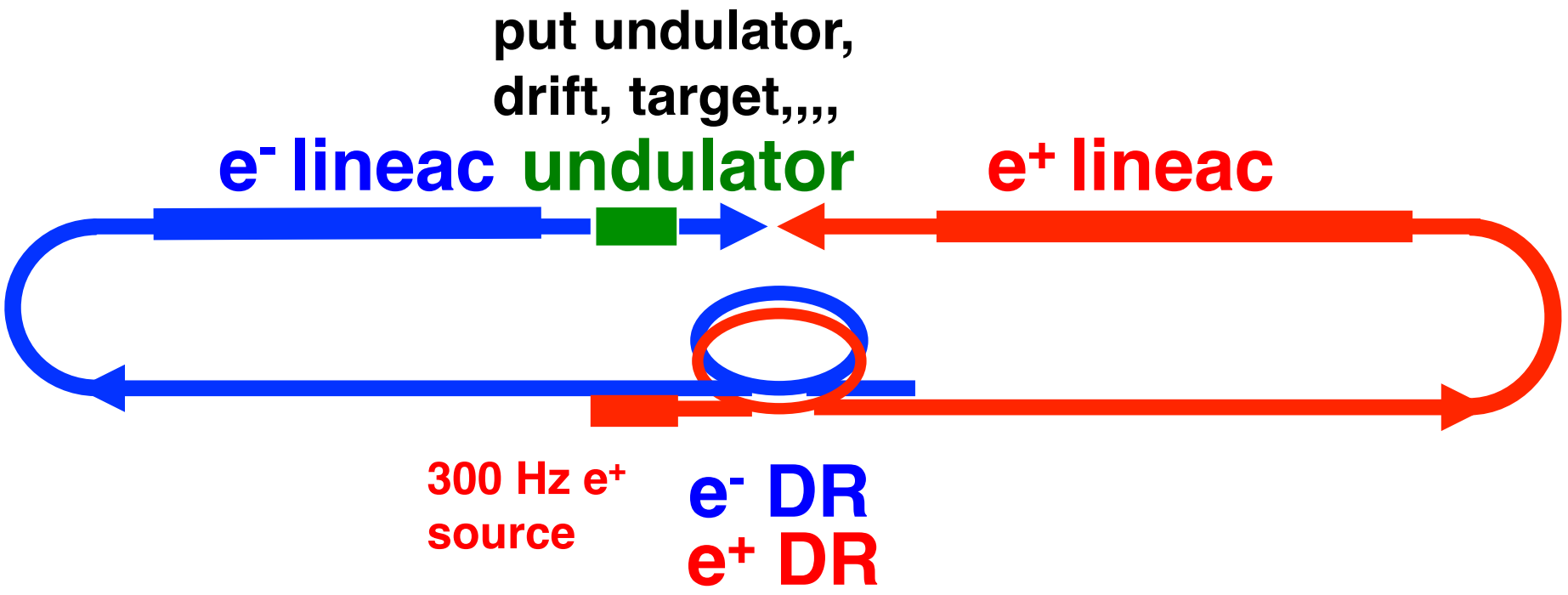
300 Hz Conventional e+

→ Undulator pol. e+ source



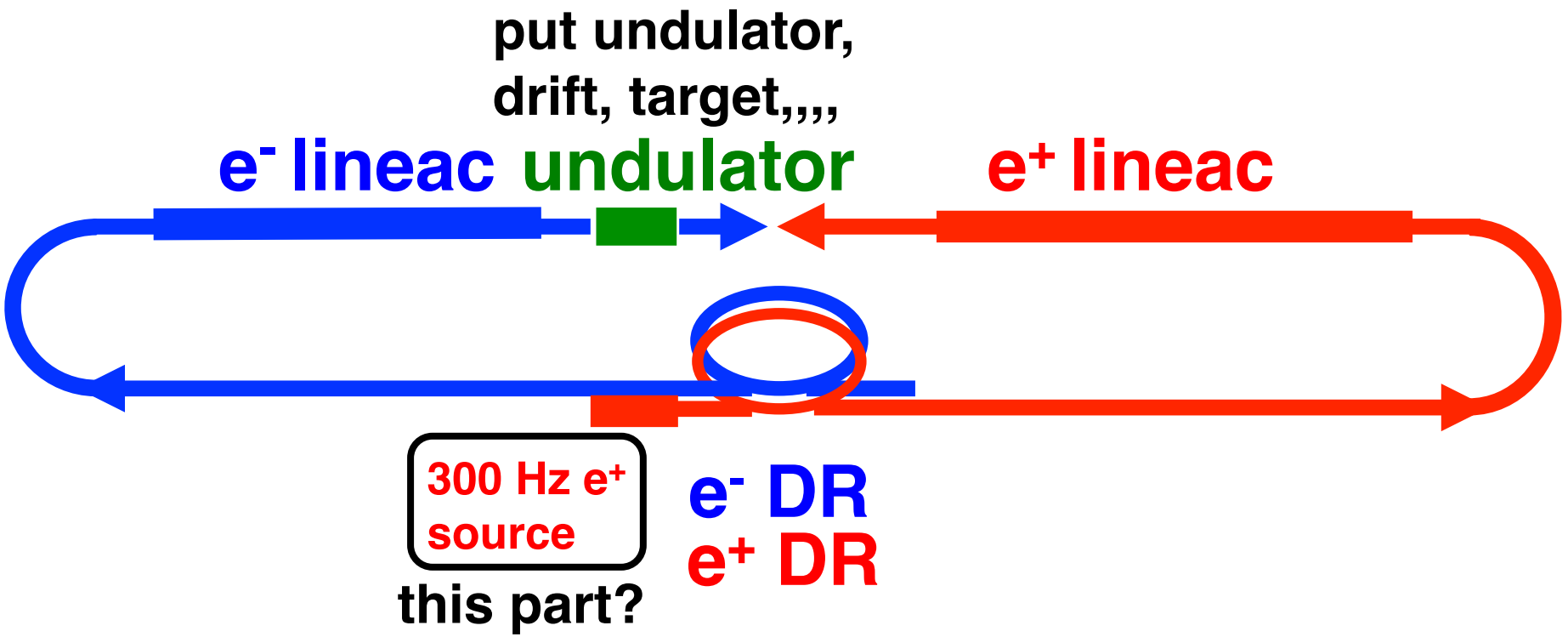
300 Hz Conventional e+

→ Undulator pol. e+ source

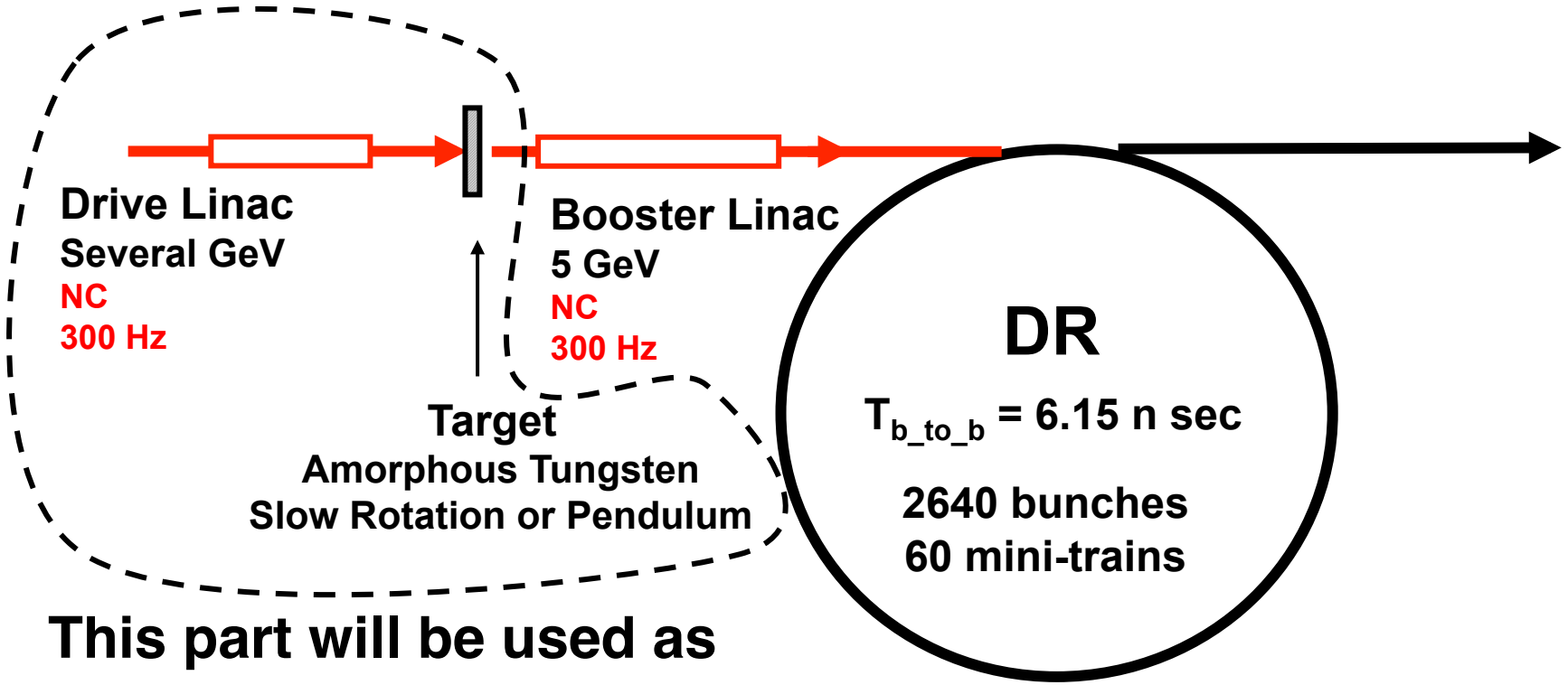


300 Hz Conventional e+

→ Undulator pol. e+ source



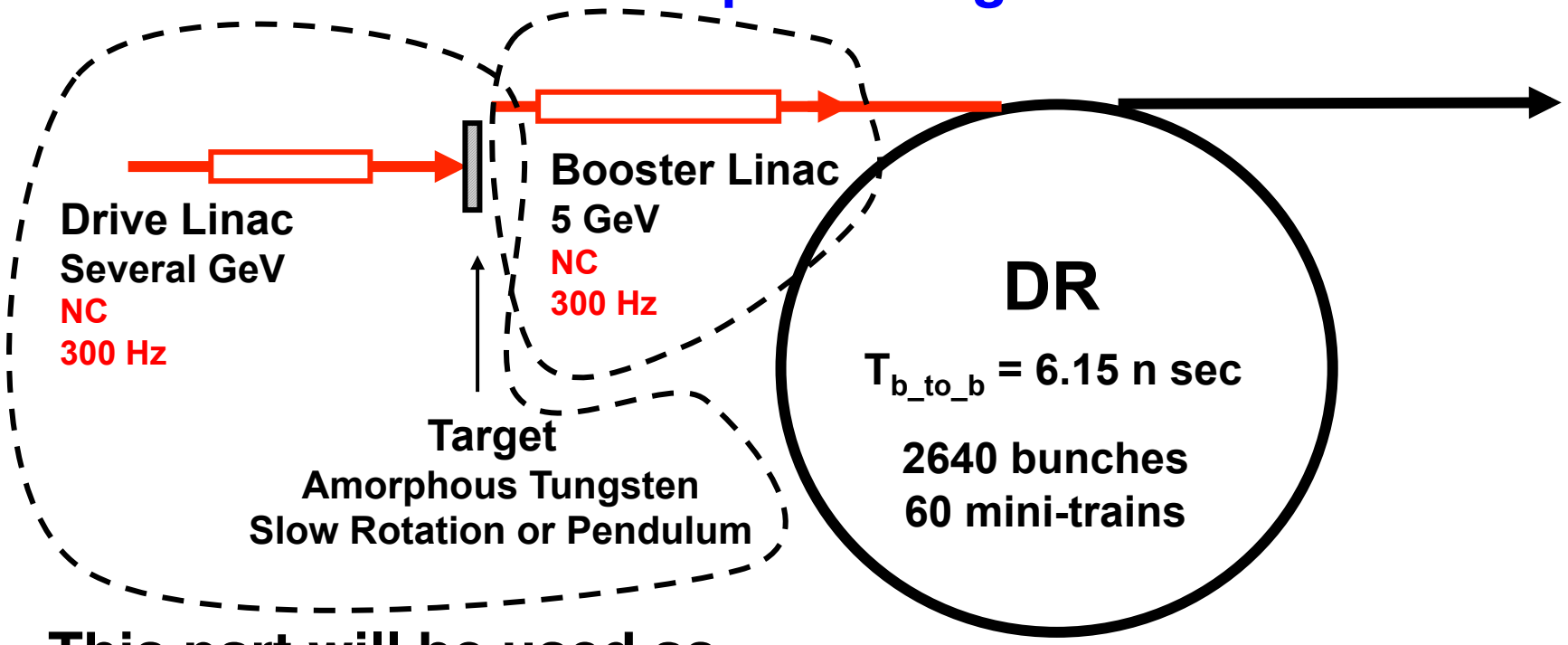
300 Hz Conventional e+
→ Undulator pol. e+ source



This part will be used as a single-bunch full-charge Keep Alive Source

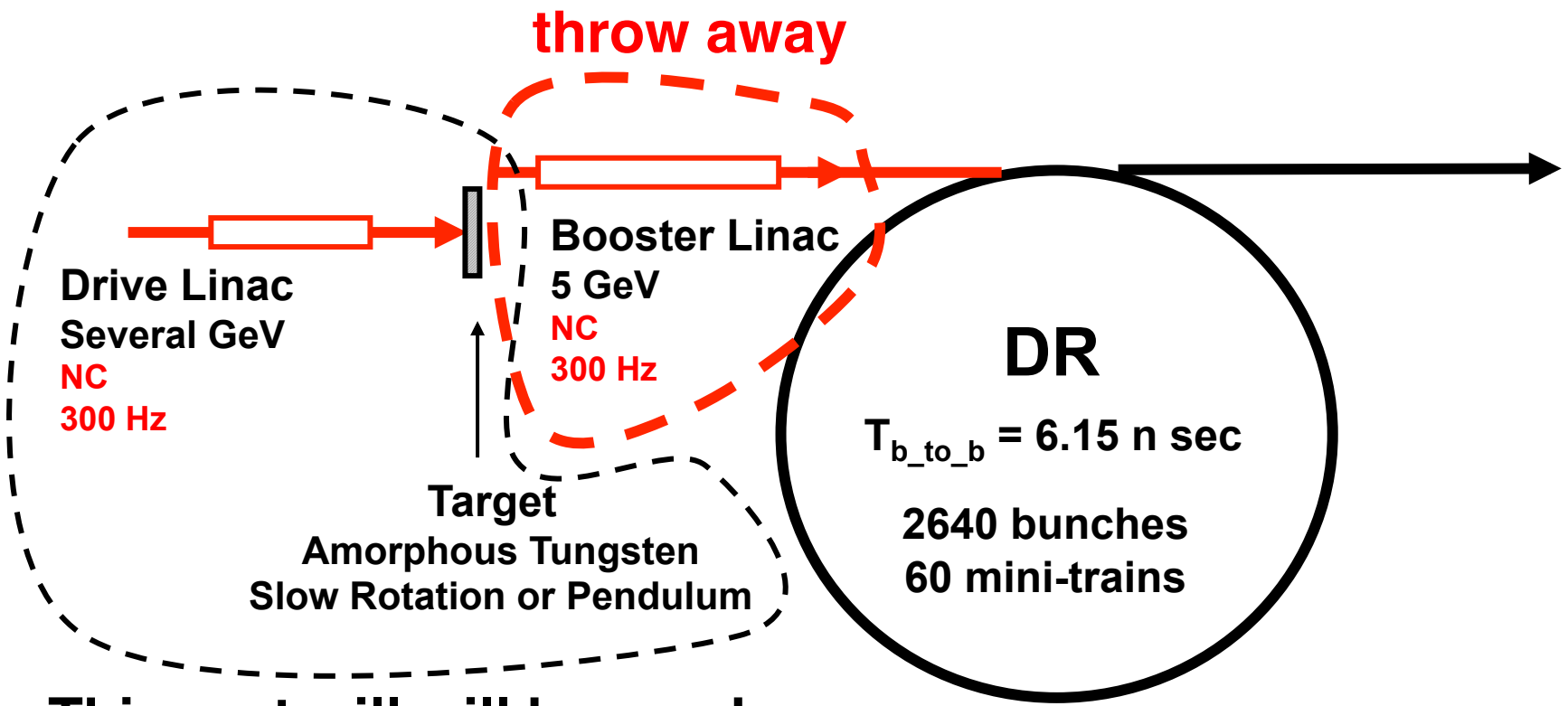
300 Hz Conventional e+
→ Undulator pol. e+ source

We need the booster linac which has 1 ms pulse length. → We need a SC booster linac.



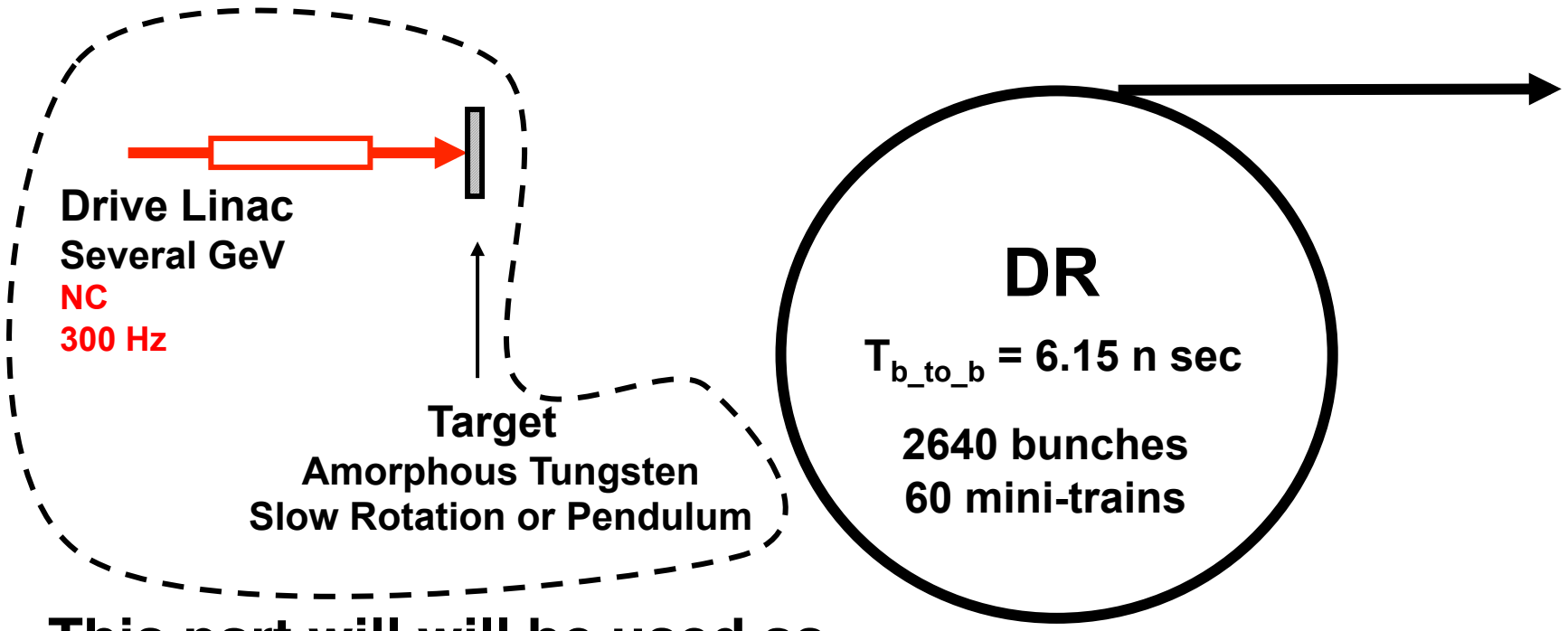
This part will be used as a single-bunch full-charge Keep Alive Source

300 Hz Conventional e+
→ Undulator pol. e+ source



This part will will be used as a single-bunch full-charge Keep Alive Source

300 Hz Conventional e+
→ Undulator pol. e+ source

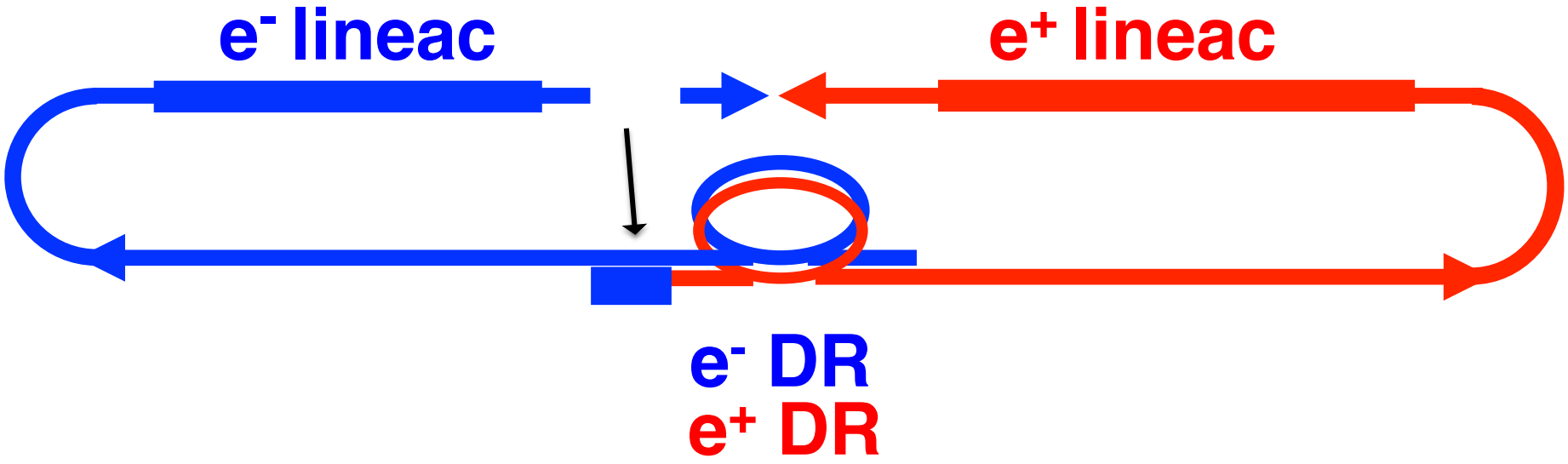


This part will will be used as a single-bunch full-charge Keep Alive Source

300 Hz Conventional e+

→ Undulator pol. e+ source

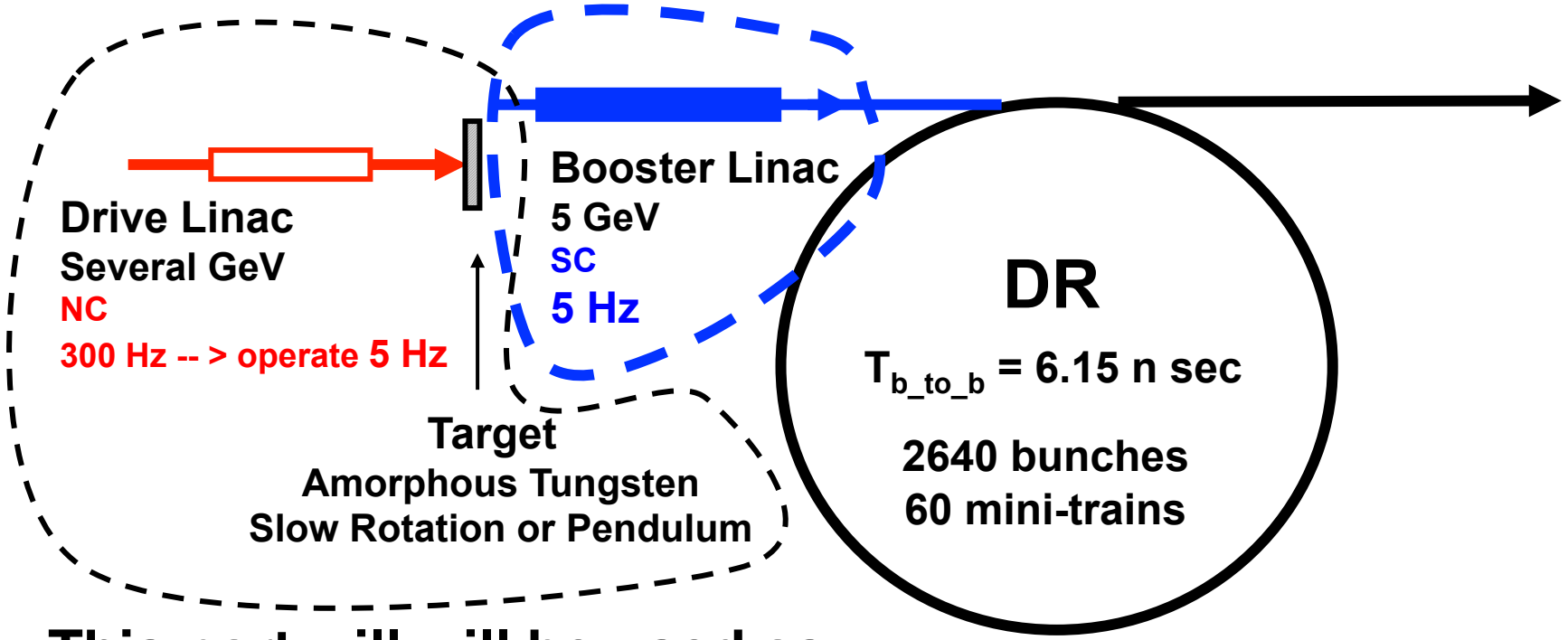
a part of lineac ~5 GeV
becomes the booster



300 Hz Conventional e+

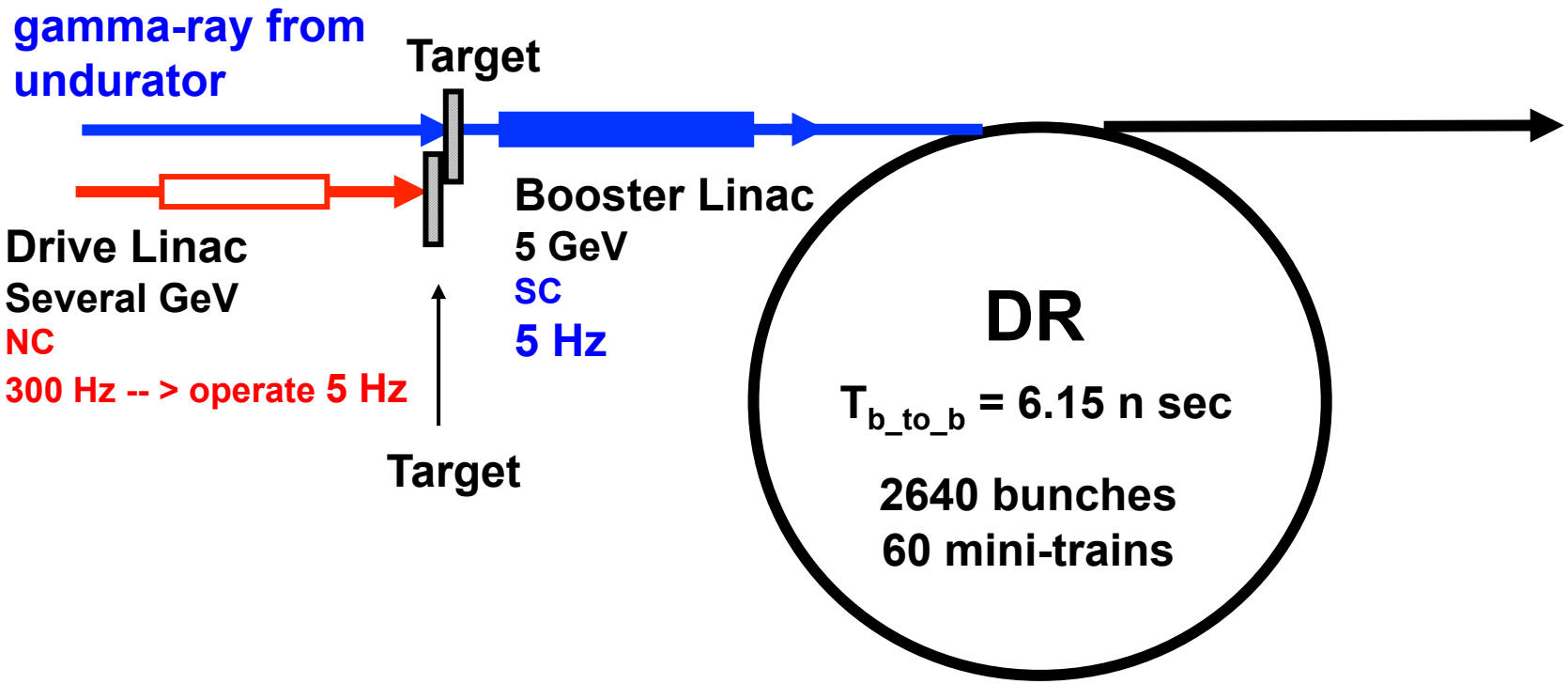
→ Undulator pol. e+ source

put a 5 GeV SC linac which comes from the end of the main linac



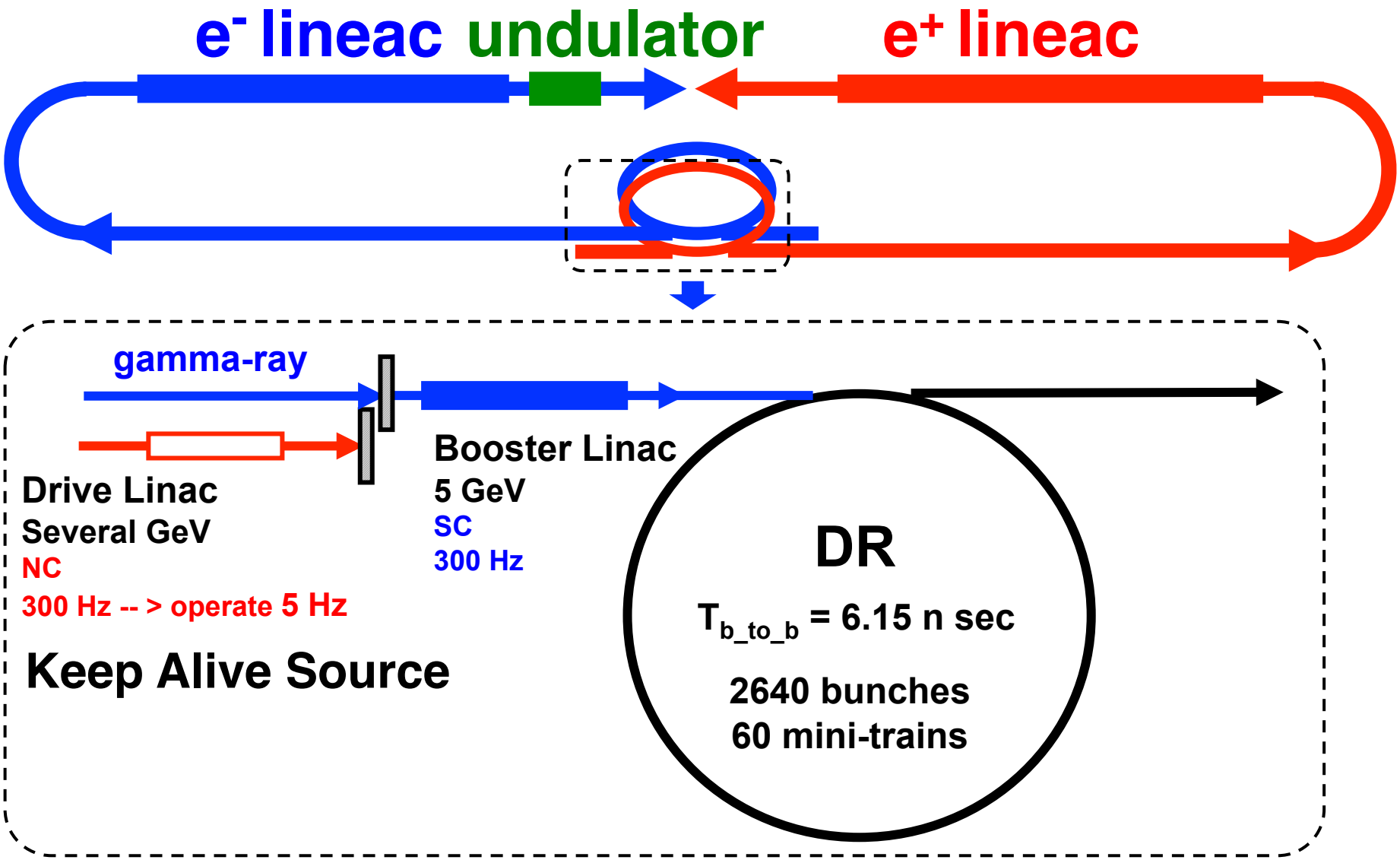
This part will will be used as a single-bunch full-charge Keep Alive Source

300 Hz Conventional e+
→ Undulator pol. e+ source



300 Hz Conventional e+

→ Undulator pol. e+ source



300 Hz Conventional e+
→ Undulator pol. e+ source

Pros.

No big additional investment.

We can reuse removed e- linac for the e+ booster.

Cons.

Decrease E_{cm}

dE(e-) = - 5 GeV (remove e- linac) - 3 GeV (undulator)

dE_{cm} = - 16 GeV (We don't want asymmetric collision)

Summary

Summary

1. Design Study:

Ways from 300 Hz conventional e^+ source to Compton pol e^+ source are presented.

(1) Linac Compton :

Small modification. Just replace tungsten target by CO2 laser cavities.

(2) Ring/ERL Compton :

Large modification is required. We add a 1 GeV SC linac (63 ms pulse), a 1 GeV stacking ring, and a Ring/ERL as a driver.

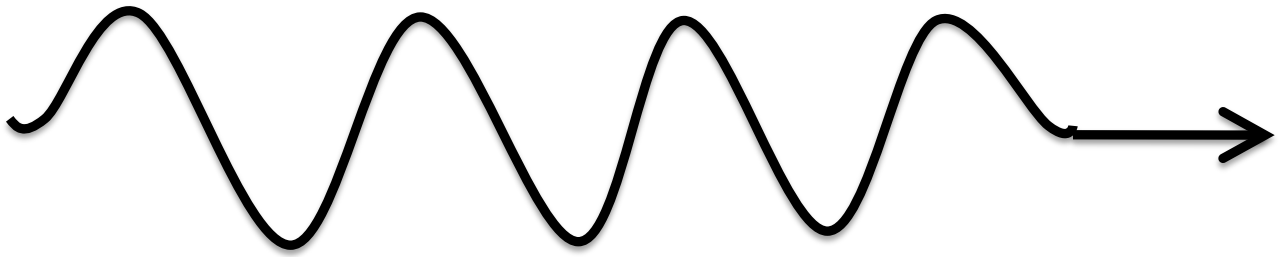
2. R/D:

Development of the 4-mirror cavity is on going at KEK for Ring/ERL Compton.

3. Appendix:

A way from 300 Hz conventional e^+ source to undulator pol e^+ source is presented.

Backup Slides



(For ERL, in each turn stacking are performed with three bunch intervals. This makes the stacking easier and changes bunch spacing from 18.5 ns to 6.15 ns.)

Laser Compton e^+ Source for ILC

We have 3 schemes.

1. **Ring Base Laser Compton**

   Storage Ring + Laser Stacking Cavity (λ=1μm), and e+ stacking in DR

   S. Araki et al., physics/0509016

2. **ERL Base Laser Compton**

   ERL + Laser Stacking Cavity (λ=1μm), and e+ stacking in DR

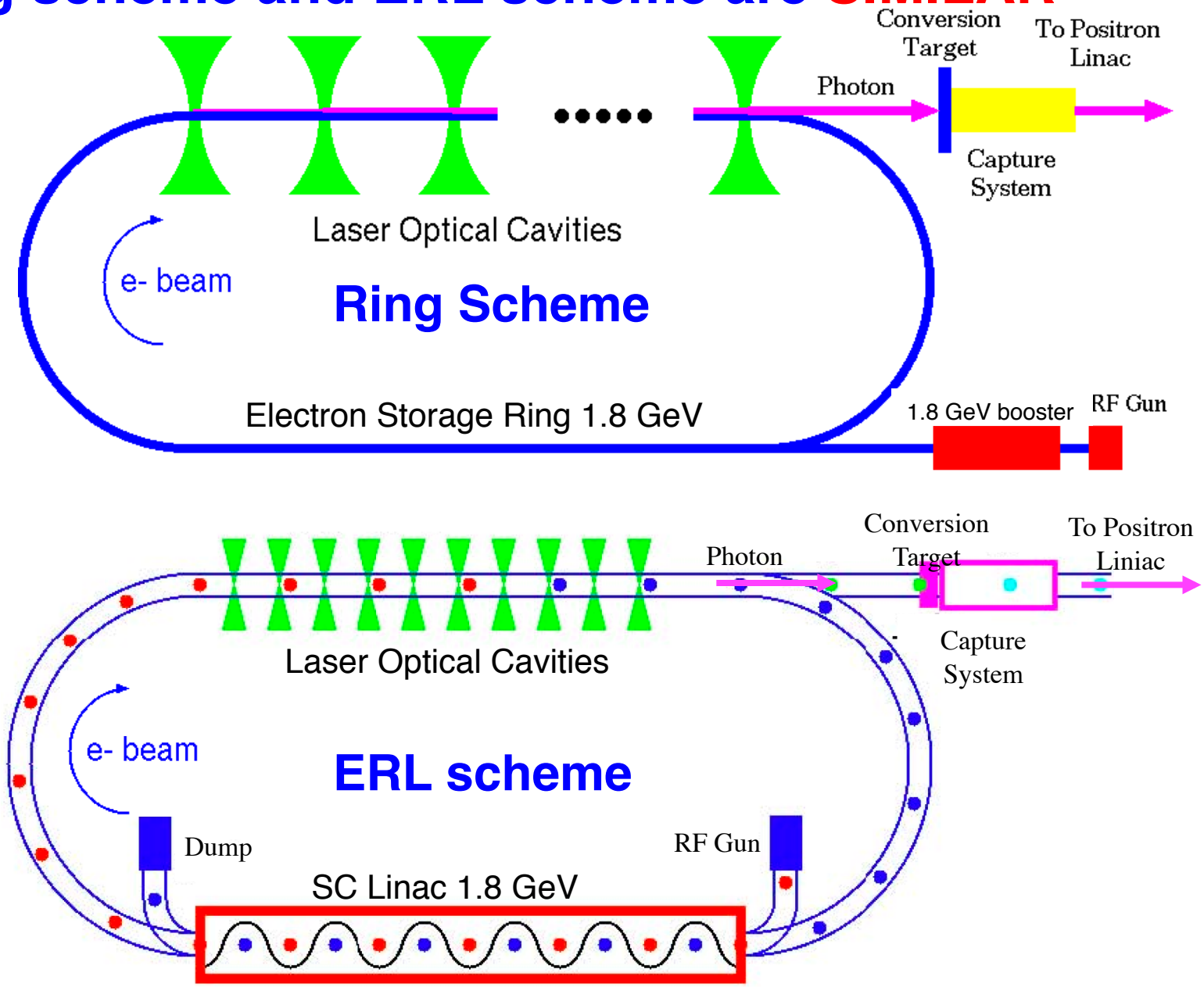
3. **Linac Base Laser Compton**

   Linac + non-stacking Laser Cavity (λ=10μm), and No stacking in DR

   Proposal V. Yakimenko and I. Pogorersky

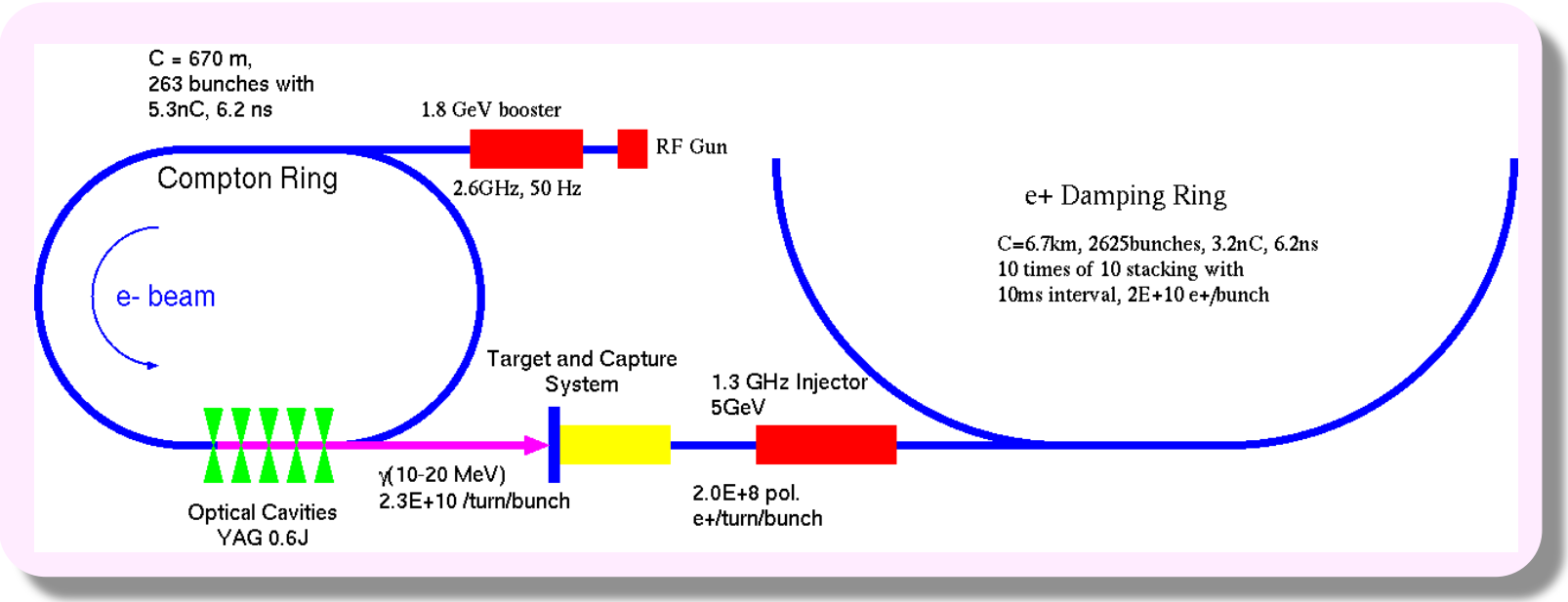
   T. Omori et al., Nucl. Instr. and Meth. in Phys. Res., A500 (2003) pp 232-252

Ring scheme and ERL scheme are SIMILAR

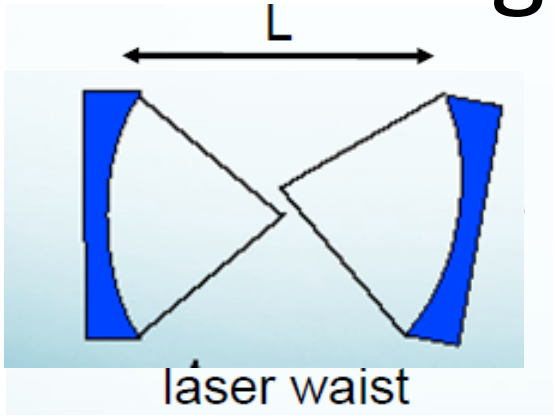


Compton Ring (1)

- Inverse Compton scattering between electron stored in a ring (CR) and laser light stored in optical cavities.
- Energy spread of the electron beam is increased by the scattering. 10 ms interval for the beam cooling.
- 100 times stacking in a same bucket of DR makes the required bunch intensity.

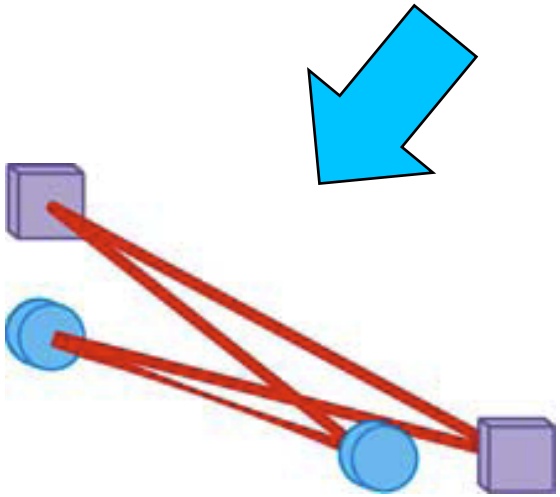


We should go to 3D 4 mirror ring cavity to get small sport size



2 mirrors is not stable
for small spot size

2d 4M has astigmatism

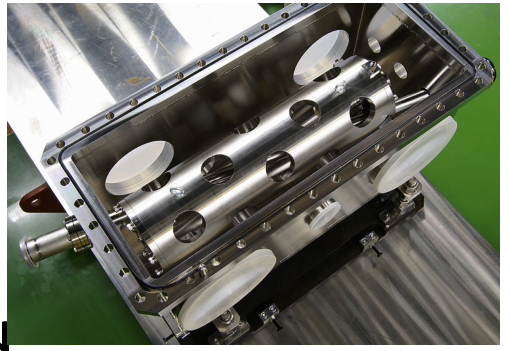


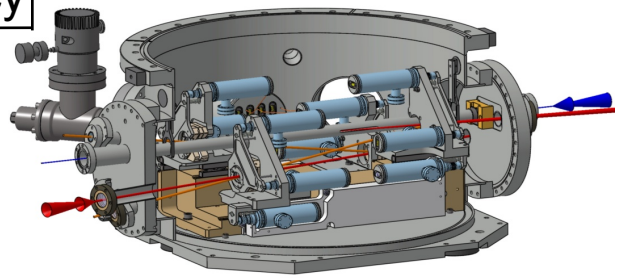
3D (or twisted)
4M ring cavity

Brief History

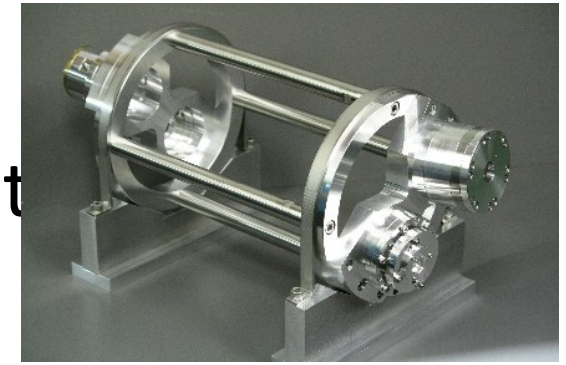
- 2007　2 Mirror cavities installed
  - 2.5kW　γ rays generate
- 2010 French 4 Mirror cavity installed

Reported FJPPL2010 Annecy

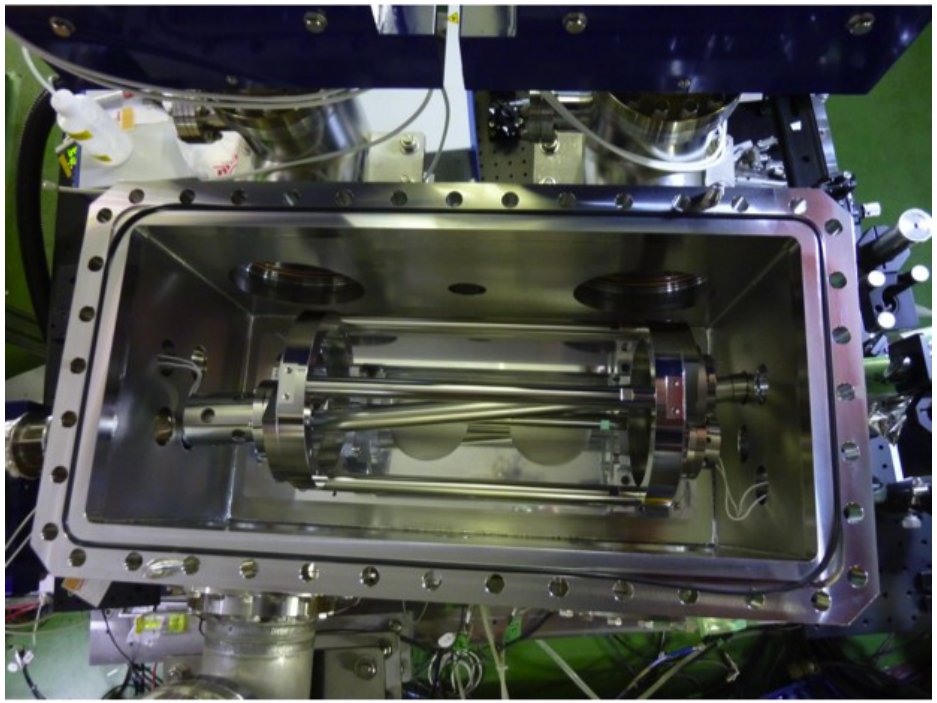




  - γ rays confirmed
- 2011　earthquake
  - No major damage to our equipment.
  - beam back in June 2011
- 2011　KEK-Hiroshima 4 mirror cavit installed
  - γ rays confirmed

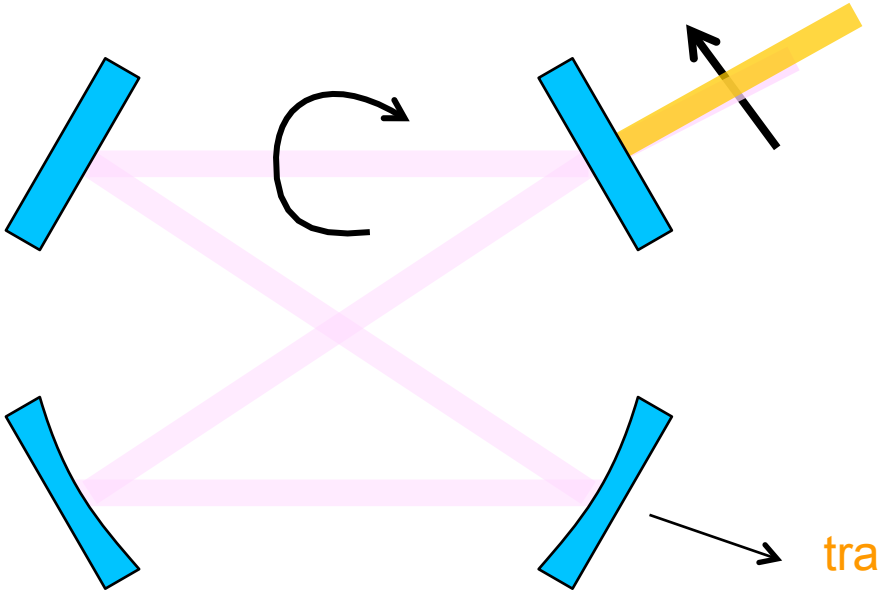


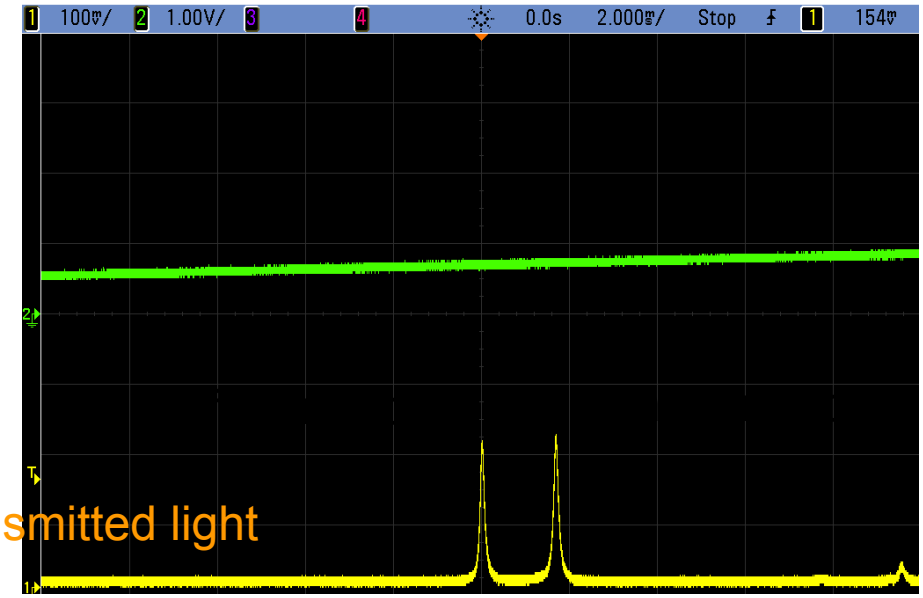
Installation of KEK-Hiroshima 4M-cavity



3 Dimensional 4 Mirror Cavity

- Resonates only for circular polarization
  - geometric phase due to twisted pass
  - cavity only resonates with circular polarization
  - usable for pol. switching

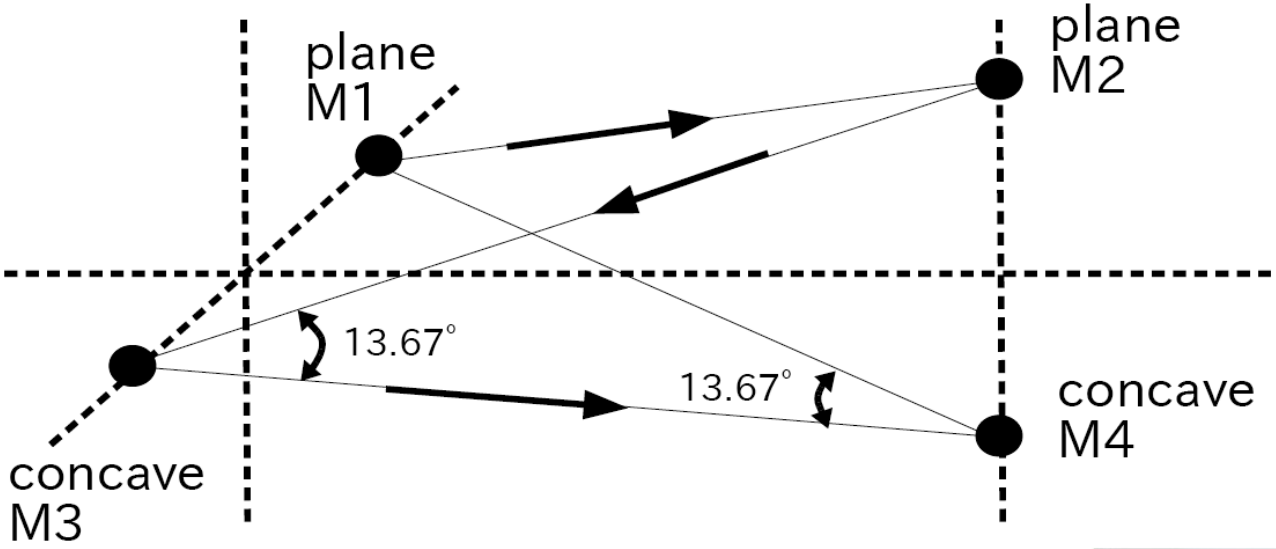




transmitted light

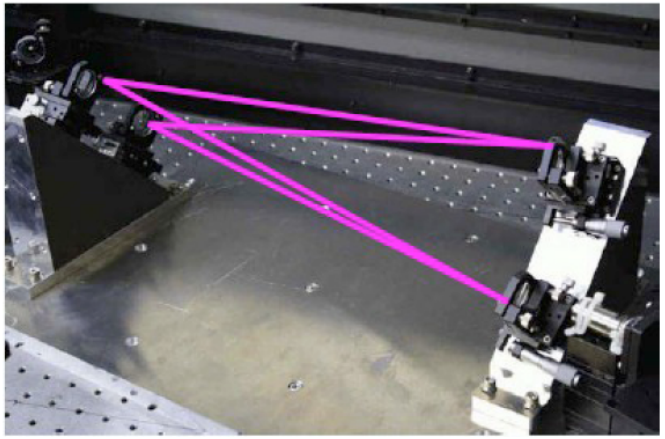
circumference of the cavity

Configration of test bed

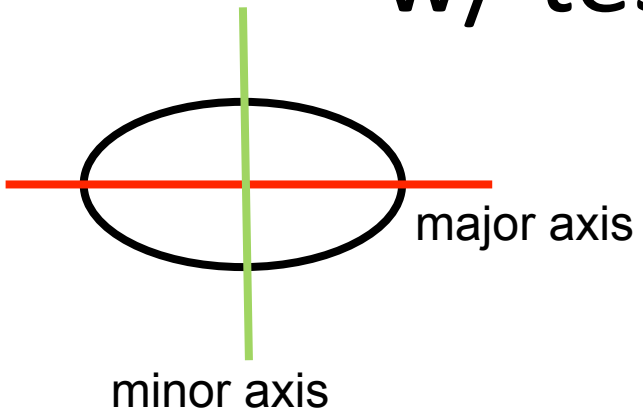


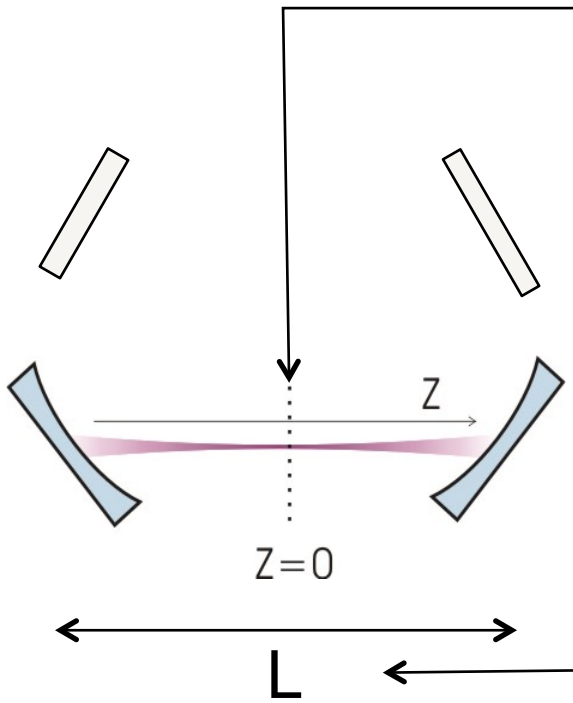
L1=M1-M2=420mm
L2=M2-M3=420mm
L3=M3-M4=420mm
L4=M4-M1=420mm

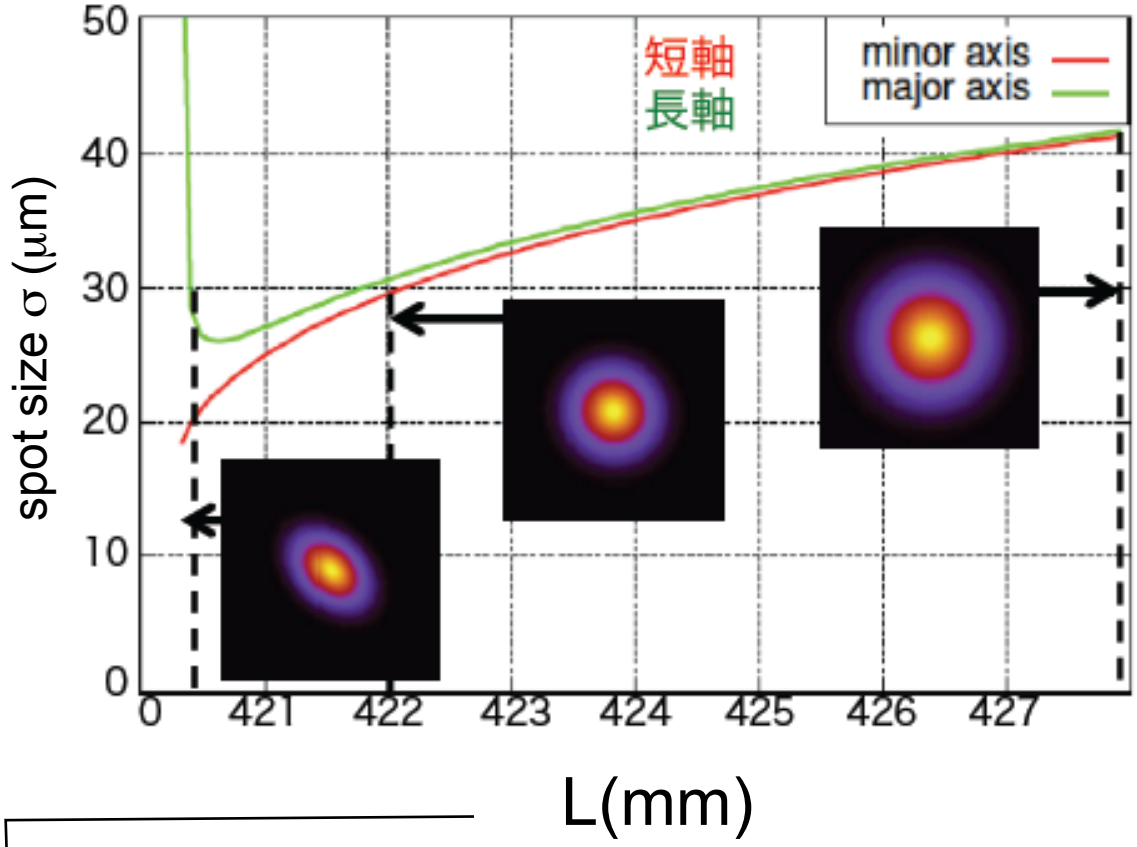
M2-M4=100mm
M1-M3=100mm



calculation of spot size w/ test bench geometry

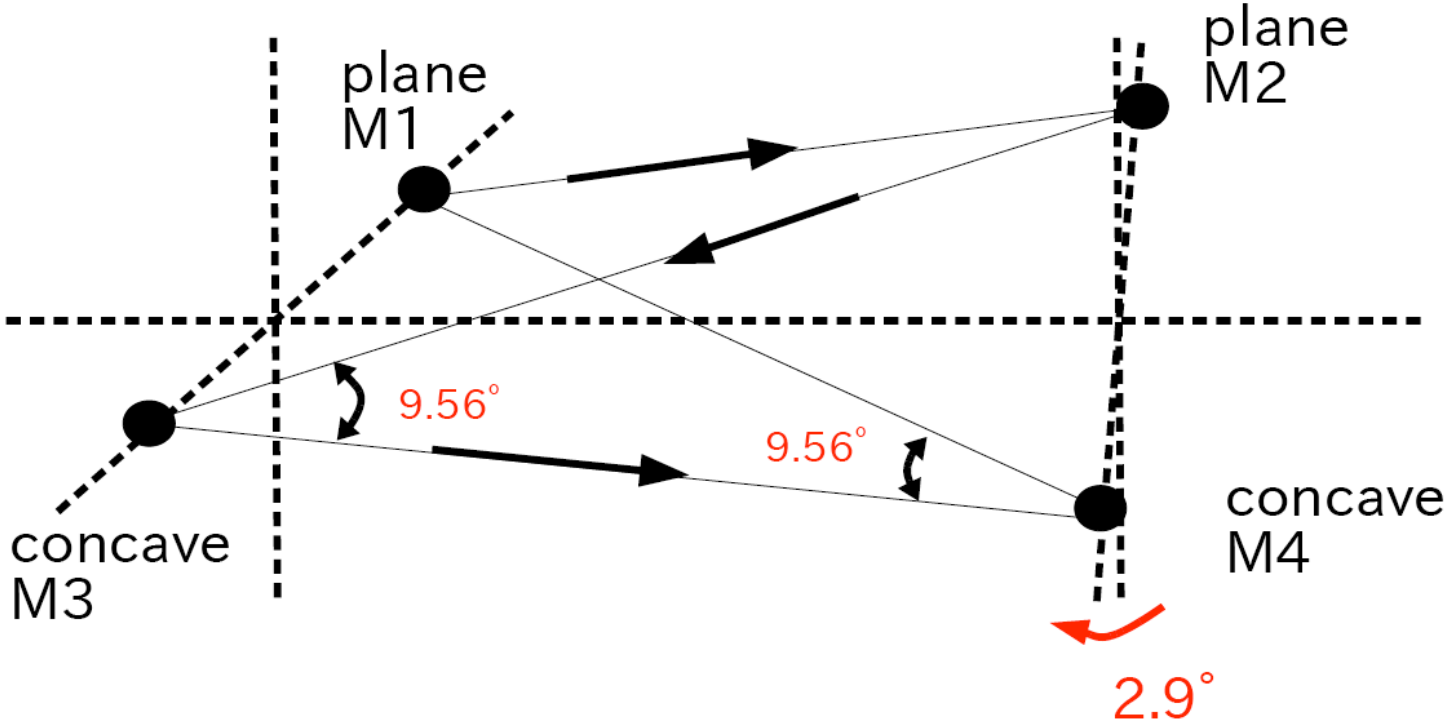






spot size is not sufficiently small with test bench geometry

new geometry

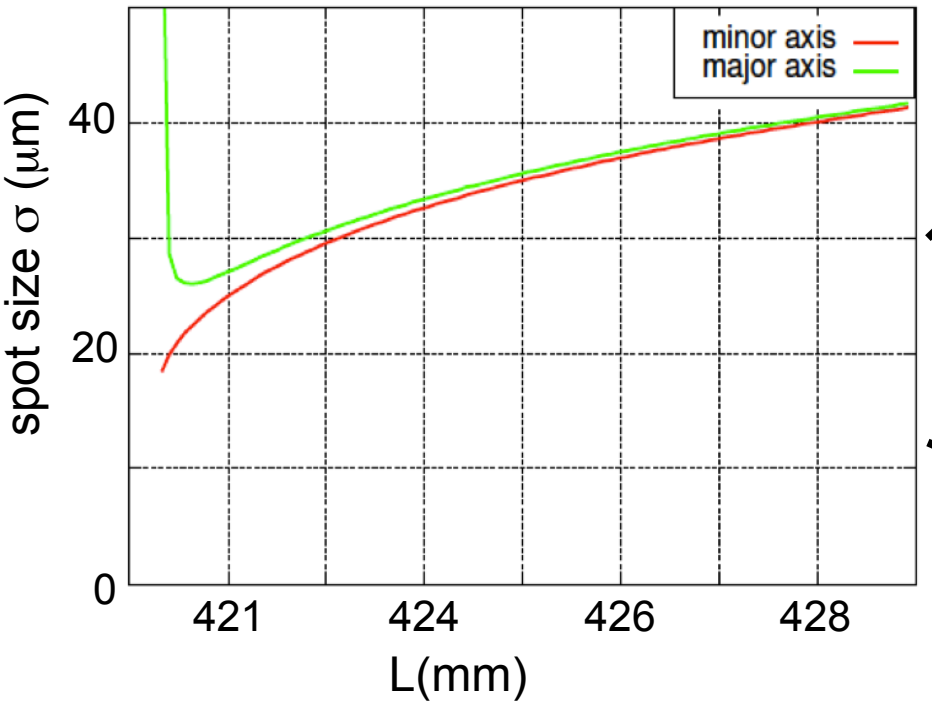


L1=M1-M2=420mm
L2=M2-M3=420mm
L3=M3-M4=420mm
L4=M4-M1=420mm

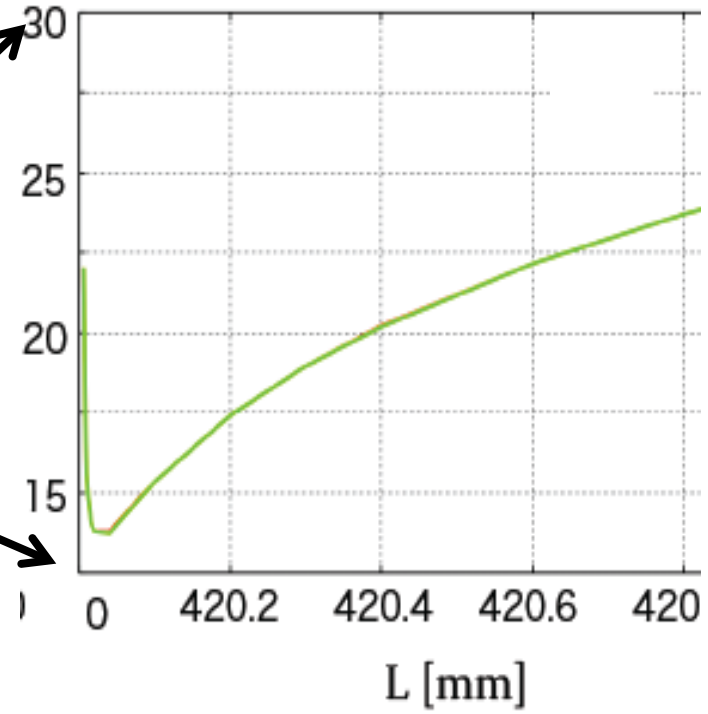
M2-M4=70mm
M1-M3=70mm

expected spot size w/ new geometry

Before optimization



After optimization



laser spot size of 15 μm is expected with new geometry

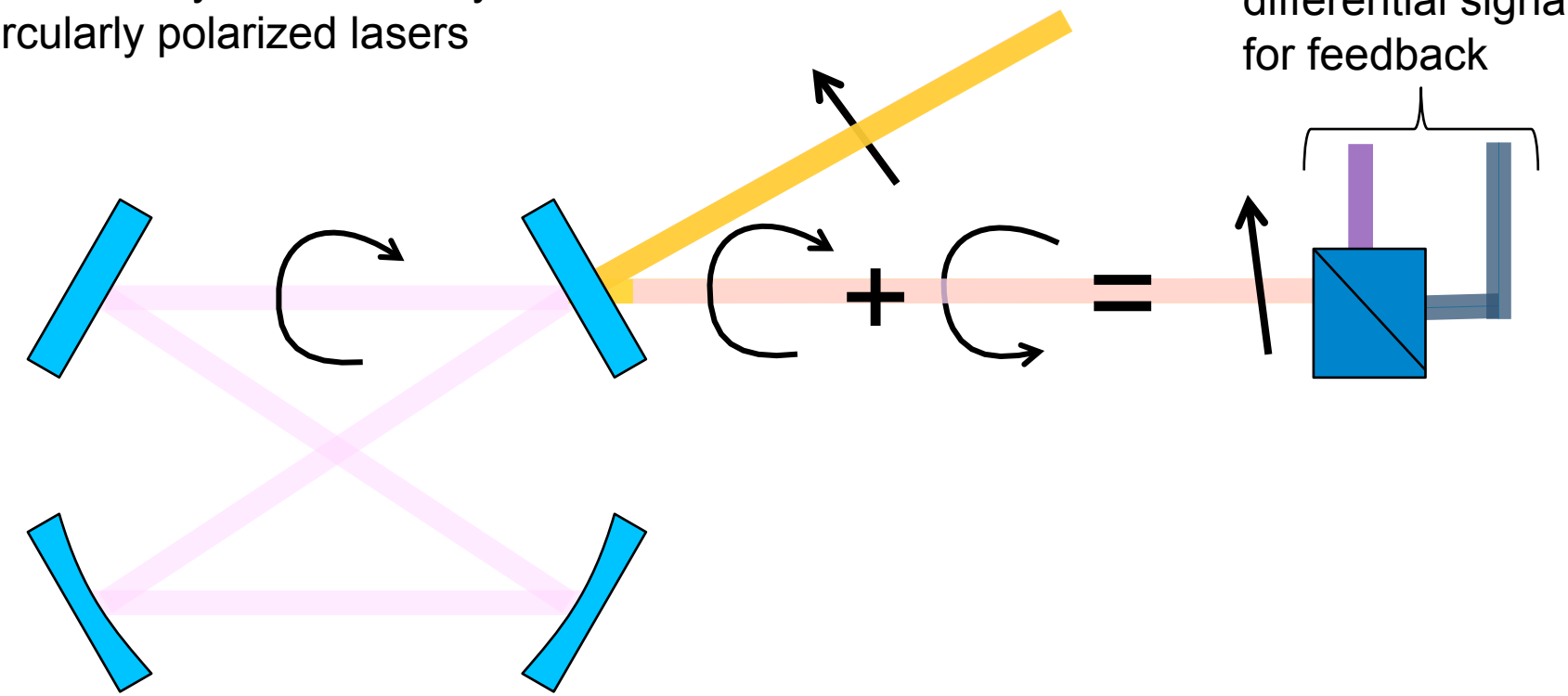
Cavity length feedback with 3D feature

cavity length must be L = nλ/2 with very high precision

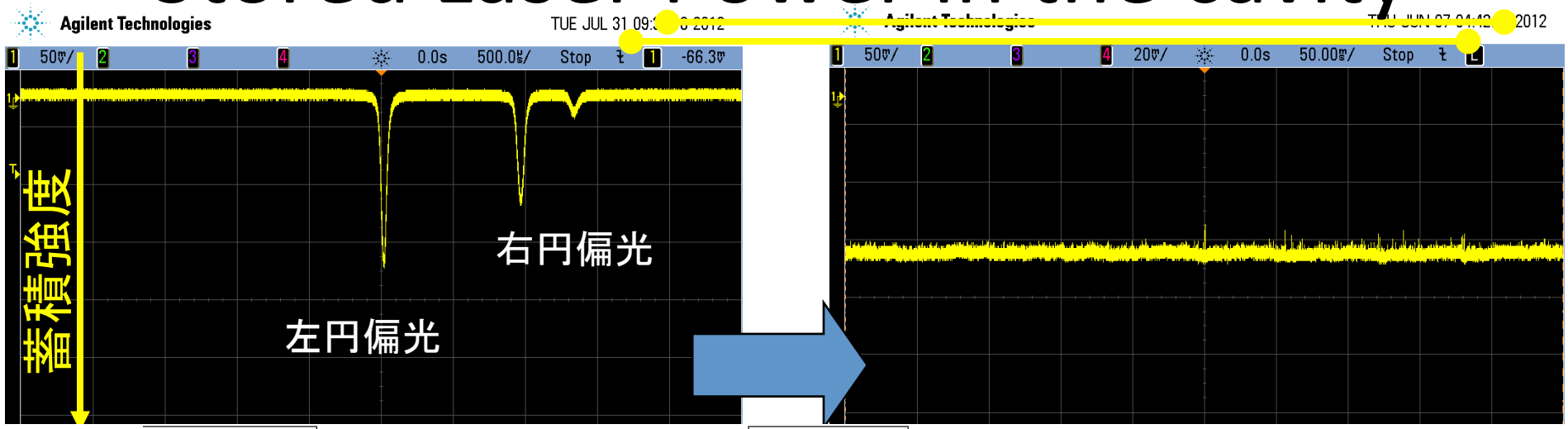
(for enhancement of 1900 dL<< 87pm while L = 1.64m)

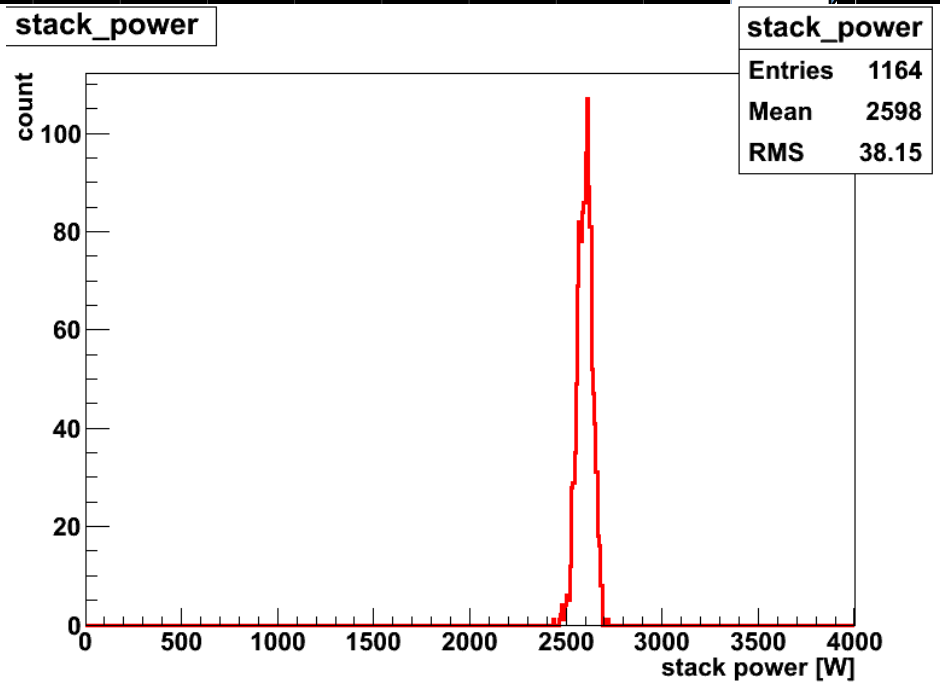
3D4M cavity resonate only with circularly polarized lasers

differential signal for feedback



Stored Laser Power in the cavity

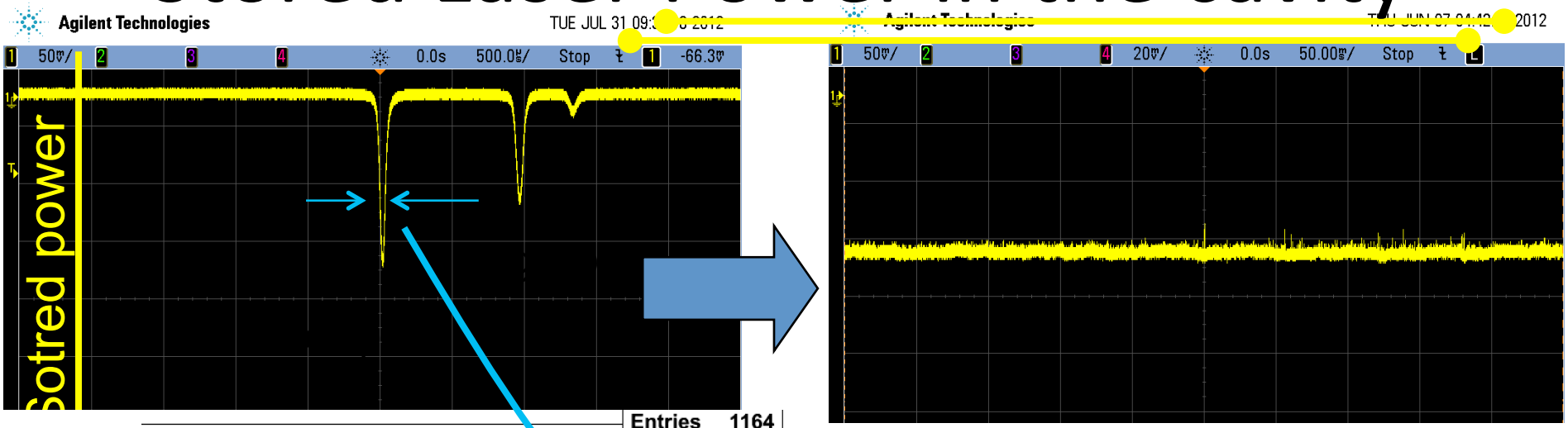


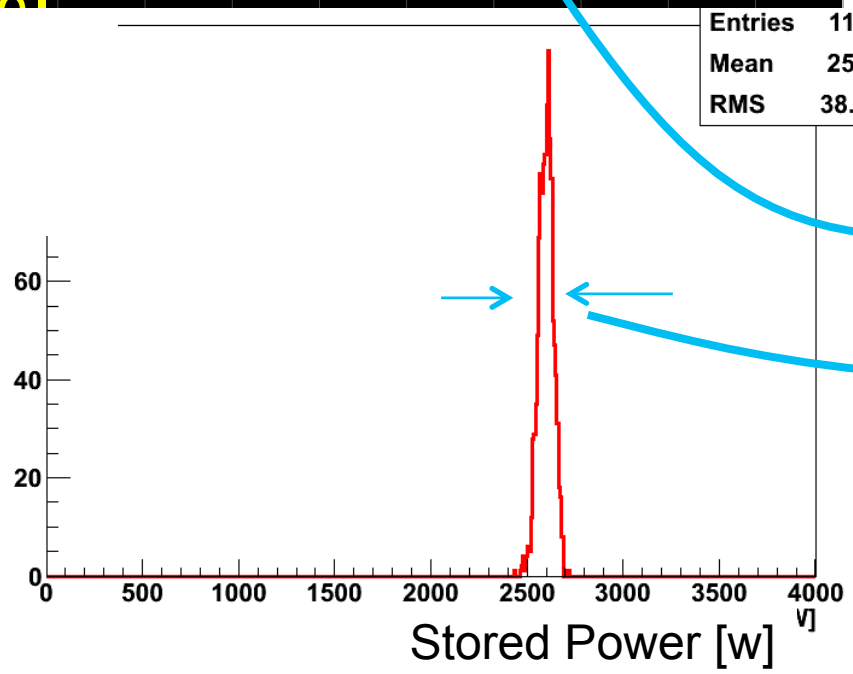


stack_power	
Entries	1164
Mean	2598
RMS	38.15

Laser Power 2.6kW
Time Jitter＝8.0ps

Stored Laser Power in the cavity





FWHM: 110pm

4pm

Laser Power 2.6kW
(1850 enhancement)
Time Jitter＝8.0ps