Sources + Injector

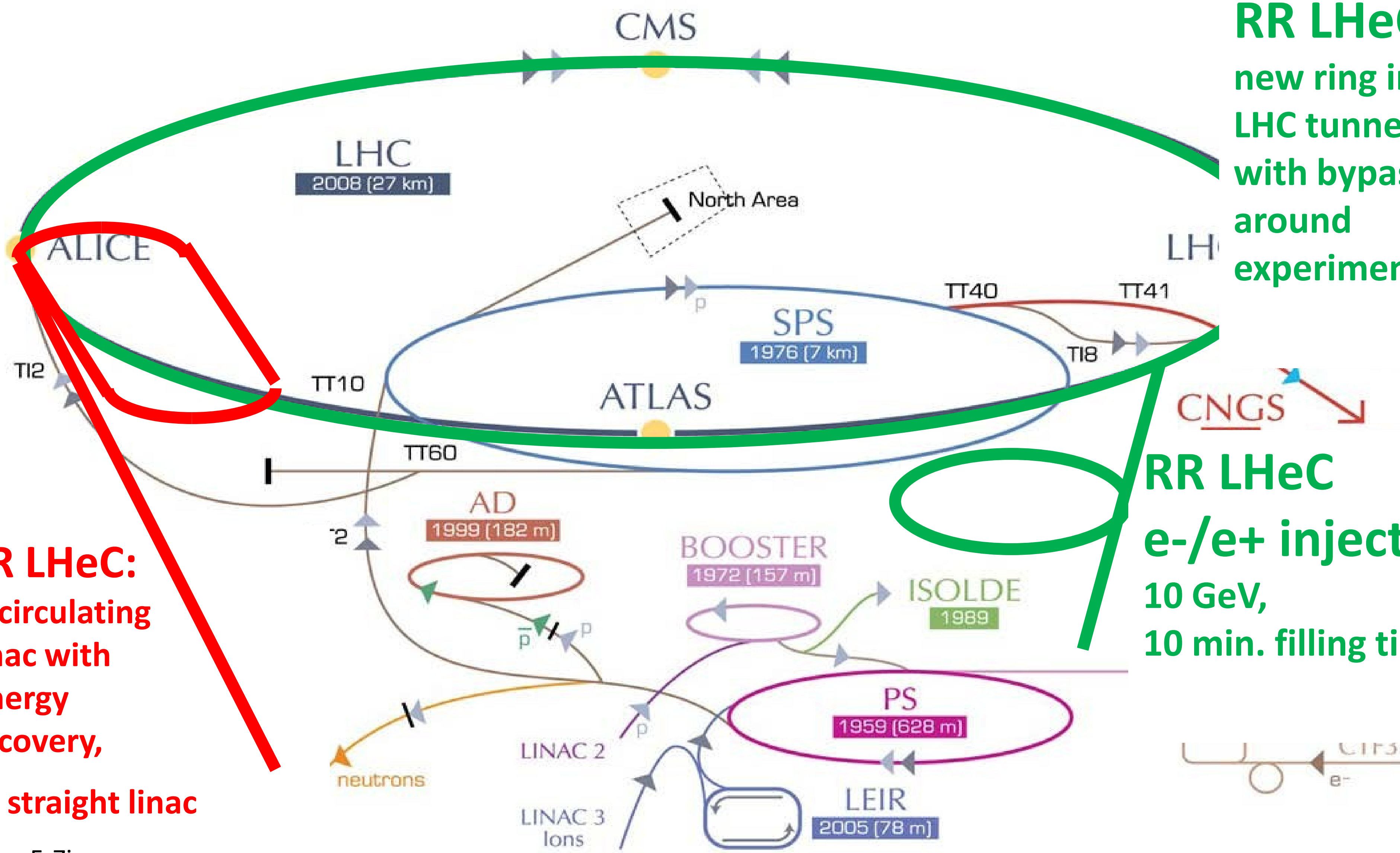
L. Rinolfi

Thanks, for useful discussions, to:

O. Brüning, H. Burkhardt, O. Dadoun, T. Omori, M. Petrarca, M. Poelker, D. Schulte, A. Vivoli, V. Yakimenko, F. Zimmermann

LHeC – the two options

LR= Linac-Ring RR= Ring-Ring



RR LHeC:
new ring in LHC tunnel, with bypasses around experiments

RR LHeC e-/e+ injector
10 GeV,
10 min. filling time

LR LHeC:
recirculating linac with energy recovery,

or straight linac

F. Zimmermann

Linac – Ring option

Polarized (e^-)

LHeC parameters

Table 4: Lepton Beam Parameters and Luminosity

	p-60	erl	p-140
e^- energy at IP [GeV]	60	60	140
luminosity [10^{32} cm^{-2}s^{-1}]	1.1	10.1	0.4
polarization [%]	90	90	90
bunch population [10^9]	4.5	2.0	1.6
e^- bunch length [μm]	300	300	300
bunch interval [ns]	50	50	50
transv. emit. $\gamma\epsilon_{x,y}$ [μm]	50	50	100
rms IP beam size [μm]	7	7	7
hourglass reduction H_{hg}	0.91	0.91	0.94
crossing angle θ_c	0	0	0
repetition rate [Hz]	10	CW	10
bunches/pulse [10^5]	1	N/A	1
pulse current [mA]	14.8	6.6	5.4
beam pulse length [ms]	5	N/A	5
ER efficiency η	0	94%	0
total wall plug power [MW]	100	100	100

LHeC Linac-Ring Design Status

by F. Zimmermann

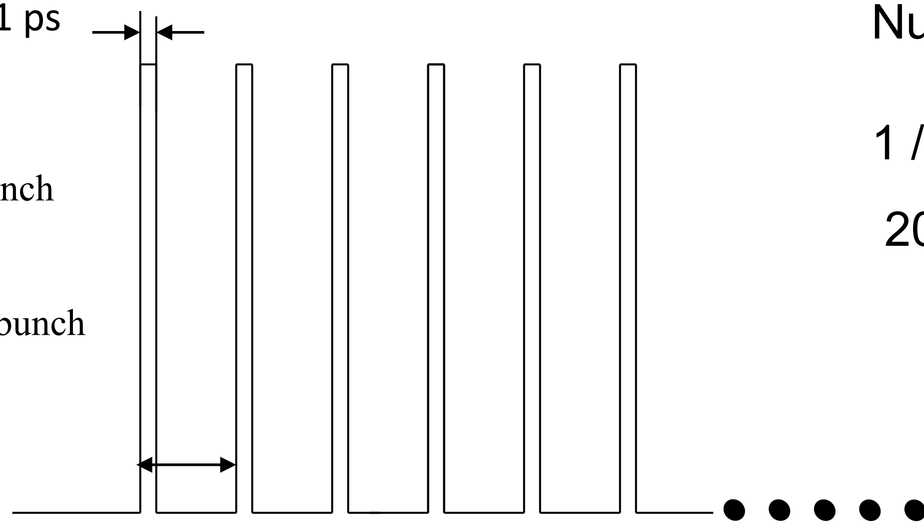
LHeC meeting

20th May 2010

The 60-GeV "erl" scenario, with a possible extension to 70 GeV, has been chosen as baseline for the linac-ring LHeC design.

LHeC-RL (60 GeV-ERL) beam structure at IP for e^- and e^+

1 ps



0.33 nC / bunch

2.06×10^9 e^-/bunch

50 ns,

20 MHz

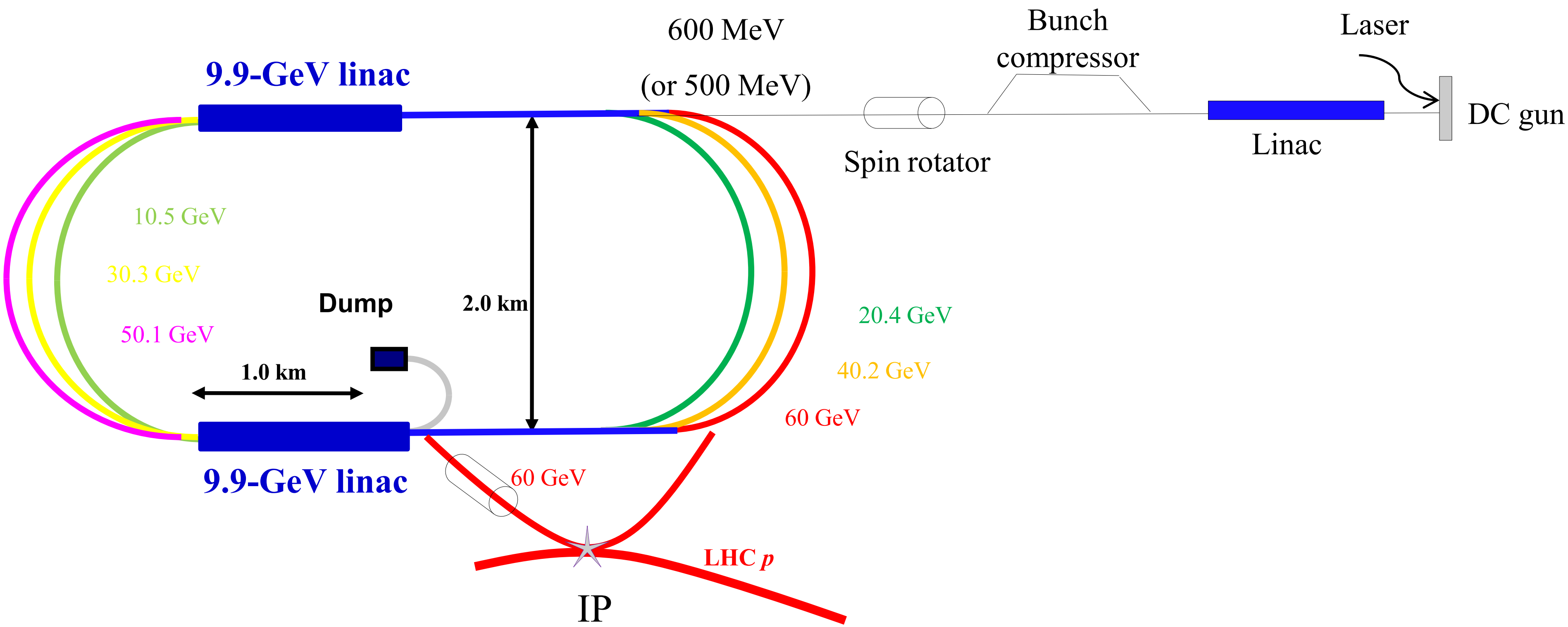
<I> = 6.6 mA

Number of bunches per second

$1 / 50 \times 10^{-9}$ s = 20×10^6 b/s

20×10^6 b/s x 0.33×10^{-9} C/b = 6.6 mA

Injector for ERL



e^- source parameters

Parameters	**LHeC 60 GeV "erl"**
Electrons/bunch (N_{e-})	2.2×10^9 (*)
Charge / bunch (q_e)	0.35 nC
Number of bunches / s (n_b)	20×10^6
Width of bunch (t_p)	10 - 100 ps (**)
Time between bunches (Δt_b)	50 ns
Pulse repetition rate	CW
Average current	6.6 mA
Peak current of bunch (I_{peak})	3.5 - 350 A
Current density (1 cm radius)	1.1 - 110 A/cm^2
Polarization	> 90%

(*) Assumed 90% efficiency

(**) Microbunch width $(t_p)_{LHeC}$ between 10 and 100 ps (depends on the photocathode and laser)

cw laser parameters for LHeC e^- source

$$E_L = \frac{hc}{q} \frac{Q}{\lambda \times QE}$$

$$E_L(J) = 1.24 \times 10^{-6} \frac{Q(nC)}{\lambda(nm) \times QE}$$

$\lambda \approx$ 775 - 780 nm for GaAs photocathodes

QE ≈ 0.2 %

Parameters	Units	LHeC 60 GeV
Laser energy on photocathode (E_L) per pulse	J	0.28 x10^{-6}
Peak power ($P_p = E_L / t_b$)	W	2.8 - 280 kW
Average power ($P_a = E_L$ x f_{las})	W	5.6 W

Expected performance for the LHeC e^- source

Parameters	Units	LHeC
Gun high voltage	kV	140
Initial charge at the gun	nC	0.35
Initial bunch length at the cathode	ps	10 - 100
Injector energy	MeV	500
Bunch length after the Bunch Compressor	ps	1
Energy spread	%	< 1
Normalized rms emittance	mm.mrad	< 50
Polarization	%	> 90

Production of ultra-short pulse beam with high charge (< 10 ps, @1 nC/bunch) and low emittance (< 1 π.mm.mrad, @1 nC/bunch) is not yet obtained but achievable

Today status for photocathodes

Electron Spin Polarization >80 % and 0.2%<QE<1% has been obtained

Nagoya, KEK, JLAB, SLAC, …..

Surface Charge Limit for 0.4nC/bunch and 2.8ns bunch separation is ok

KEK

Peak Current ~10A with ~ 4ns laser has been produced

SLAC

Assuming 10 A peak current possible, the LHeC charge (350 pC/bunch) => laser pulse = 35 ps

Project for ~ 1 mA with ~ 1 nC/bunch at XFEL based on concept of SRF hybrid Nb/Pb gun

ERL project ~10 mA with 77 pC/bunch at JAEA (Japan).

Today the production of the 7 mA average current with reasonable life time (> 1 week) seems doable from photocathodes but remains to be demonstrated !

Today status for the gun and laser

Gun:

Load locked gun with high voltage 100 kV - 200 kV, tunable gap, vacuum <10^{-10} Pa

JLAB

DC gun 380 kV without beam, vacuum 10^{-9} Pa; tested for 8h at 500 kV

JAERI

Laser:

Output laser pulse energy of E_L~1μJ is required in order to obtain ~ 0.3μJ on the cathode.

Oscillator technology with repetition rate > 20 MHz is available in solid state and fiber oscillator.

Laser with required energy (1MHz and 500 ps) is available on the market for a fiber laser system.

With a strong R&D, upgrading to 20MHz is probably feasible nowadays

R&D issues for the LHeC polarized source

- Operation with high average current (7 mA)
- Very good vacuum required for good lifetime
- Emittance growth due to space charge
- Space charge limit and Surface charge limit
- Field emission issue with very high voltage (>> 100kV)
- Laser performance issue
- Cathode/anode design for 100% transport
- Higher QE (Quantum Efficiency)

R&D is required in order to get the expected performance

Summary for LHeC e^- Injector

For the source (photocathode, DC gun and laser) , experimental test facility required => R&D.

A conventional Injector Linac accelerates beam up to 500 MeV before injection in the ERL.

One (or several) stage of bunch compressor required to reach the 1 ps bunch length (compensation of longer initial laser pulse and space charge effects inducing bunch lengthening).

Implementation of spin rotators.

Beam instrumentation to measure the 90% polarization.

Ring – Ring option

Unpolarized (e^- and e^+)

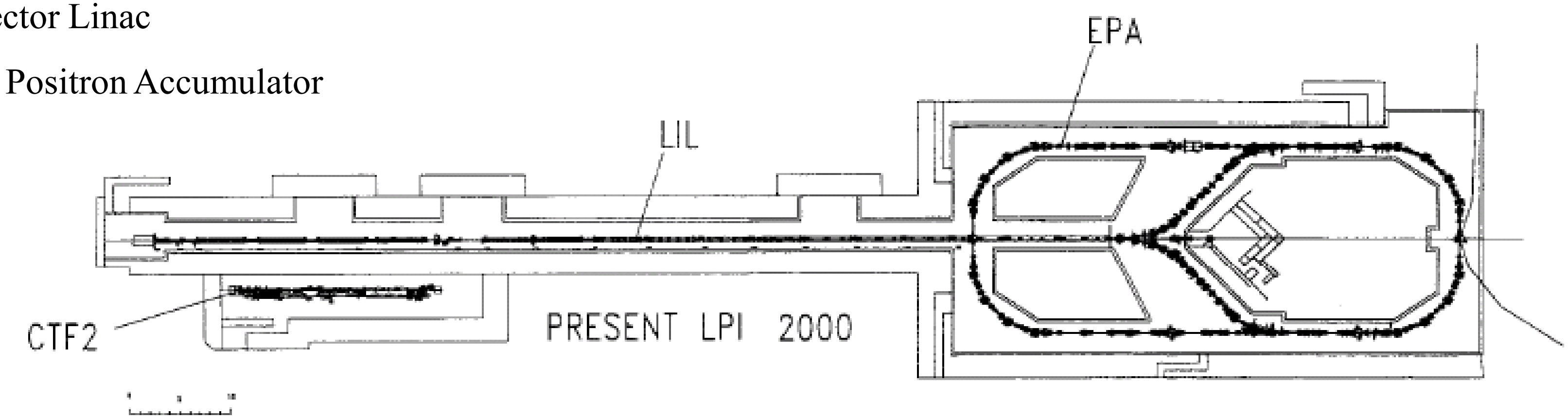
The LPI* as an e^- and e^+ sources

(*) LPI = LEP Pre-Injector

See H. Burkhardt talk

LIL = LEP Injector Linac

EPA = Electron Positron Accumulator



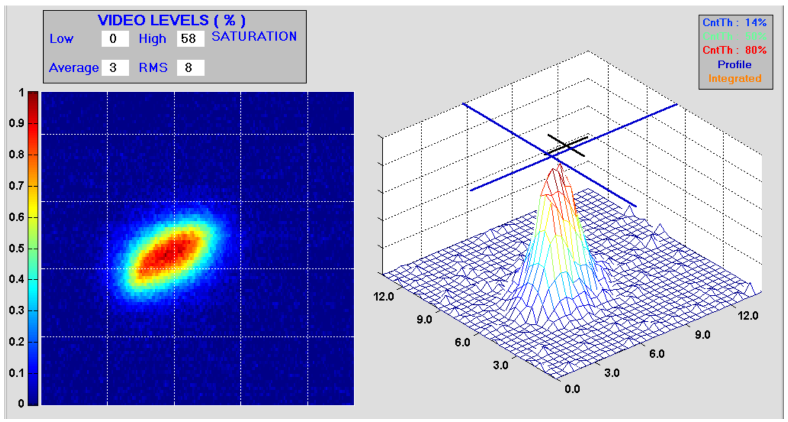
LIL Beam Characteristics

Energy : 200 to 700 MeV

Intensity : 5×10^8 to 2×10^{10} e^- / pulse
Pulse length 10 to 35 ns (FWHM)

Frequency: 1 to 100 Hz

Beam sizes: $\sigma_x = \sigma_y = 3$ mm



EPA ring

EPA	Range
Energy	200 to 600 MeV
Charge	up to 4.5 x 10^{11}
Intensity	up to 0.172 A
Nb buckets	1 to 8
Emittance	0.1 mm.mrad
Tune	Q_x = 4.537; Q_y = 4.298
Vacuum	10^{-8} Pa

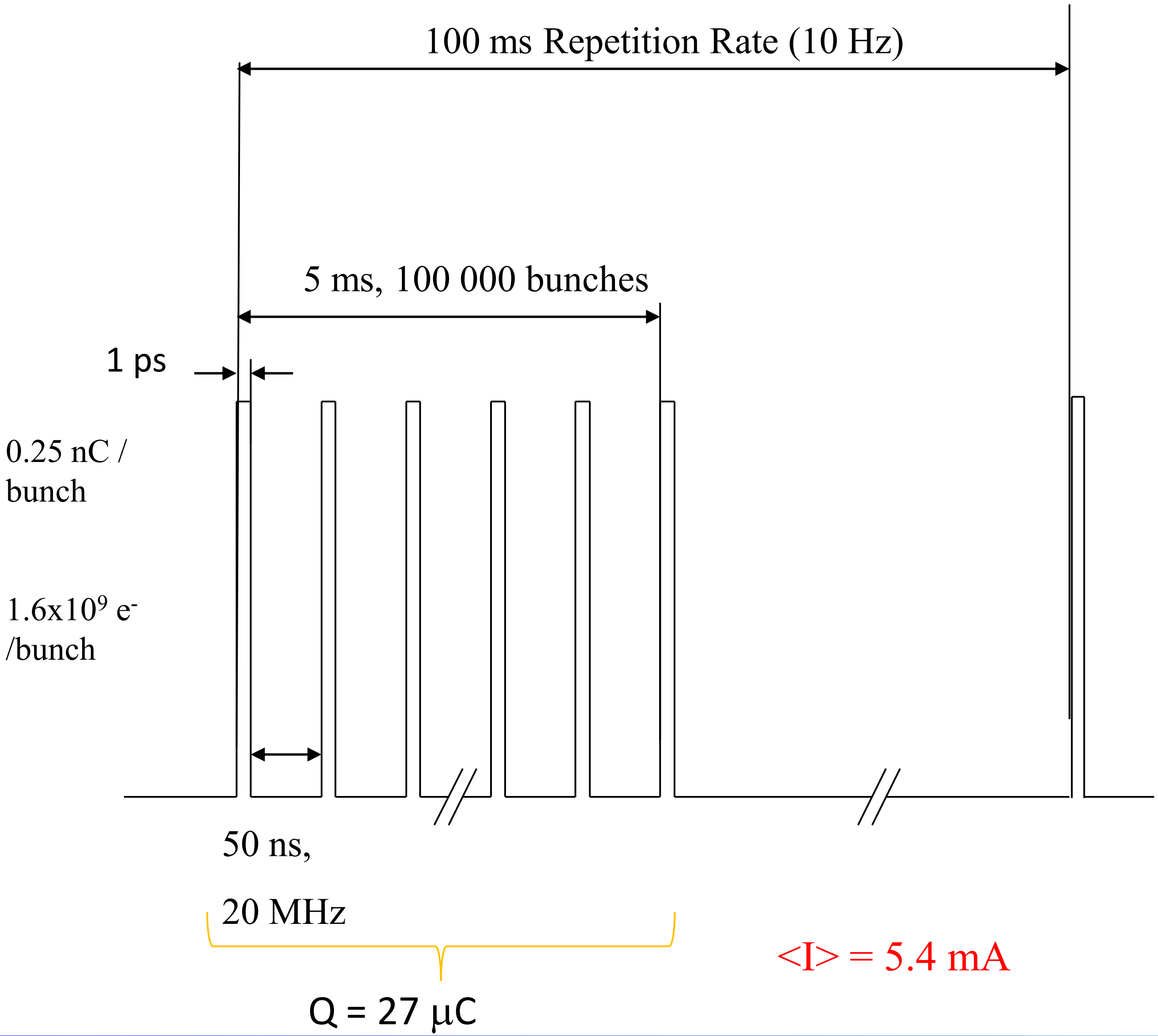
Linac – Ring option

Unpolarized (e^+)

Flux of e^+

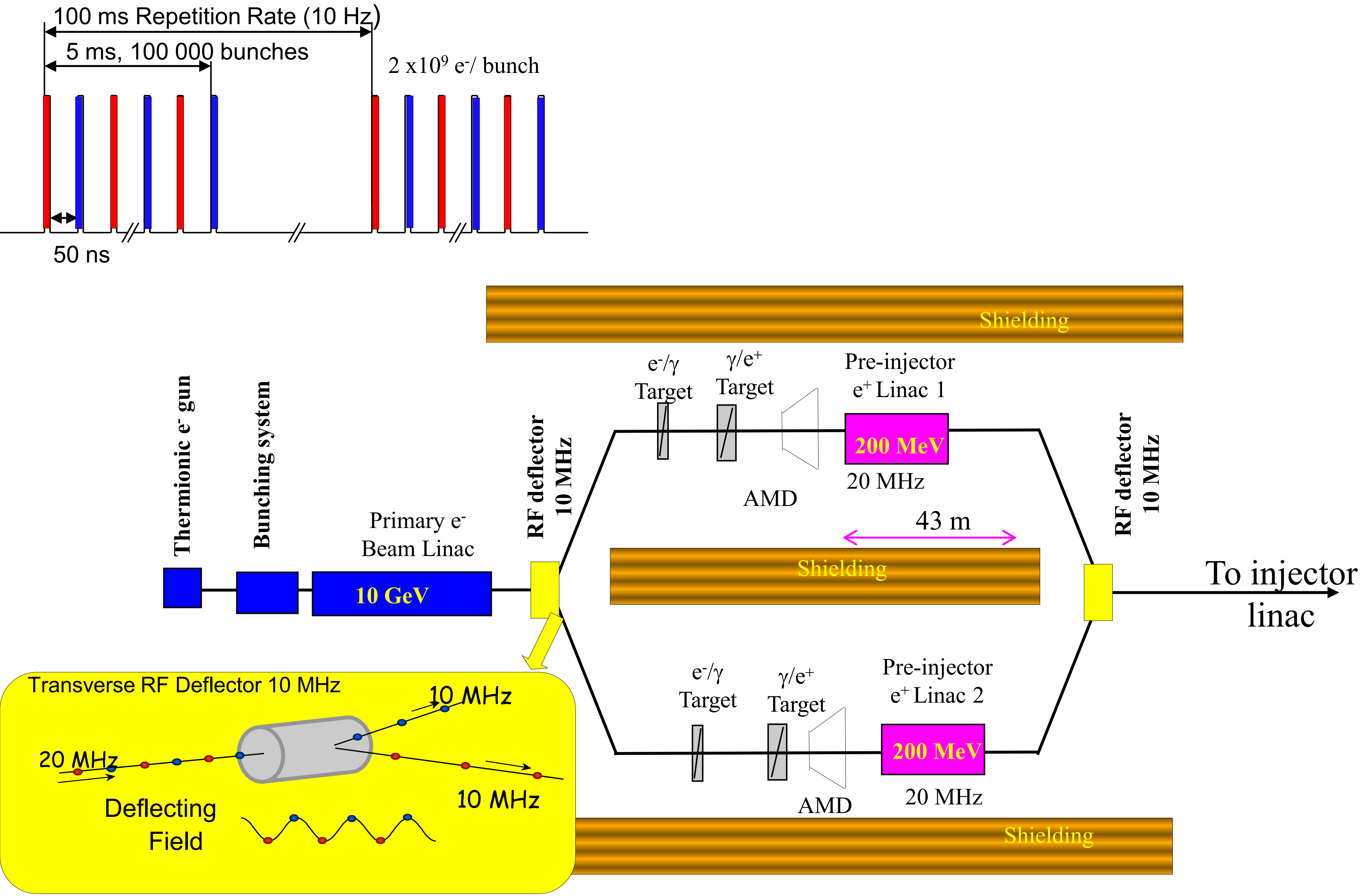
	SLC	CLIC (3 TeV)	LHeC p-140	LHeC ERL
Energy	1.19 GeV	2.86 GeV	140 GeV	60 GeV
e^+/ bunch at IP	40×10^9	3.72×10^9	1.6×10^9	2×10^9
e^+/ bunch after capture	50×10^9	7.6×10^9	1.8×10^9	2.2×10^9
Bunches / macropulse	1	312	10^5	NA
Macropulse repet. rate	120	50	10	CW
Bunches / second	120	15600	10^6	20×10^6
e^+ / second	**0.06×10^{14}**	**1.1×10^{14}**	**18×10^{14}**	**440×10^{14}**

LHeC-LR beam structure for p-140 GeV

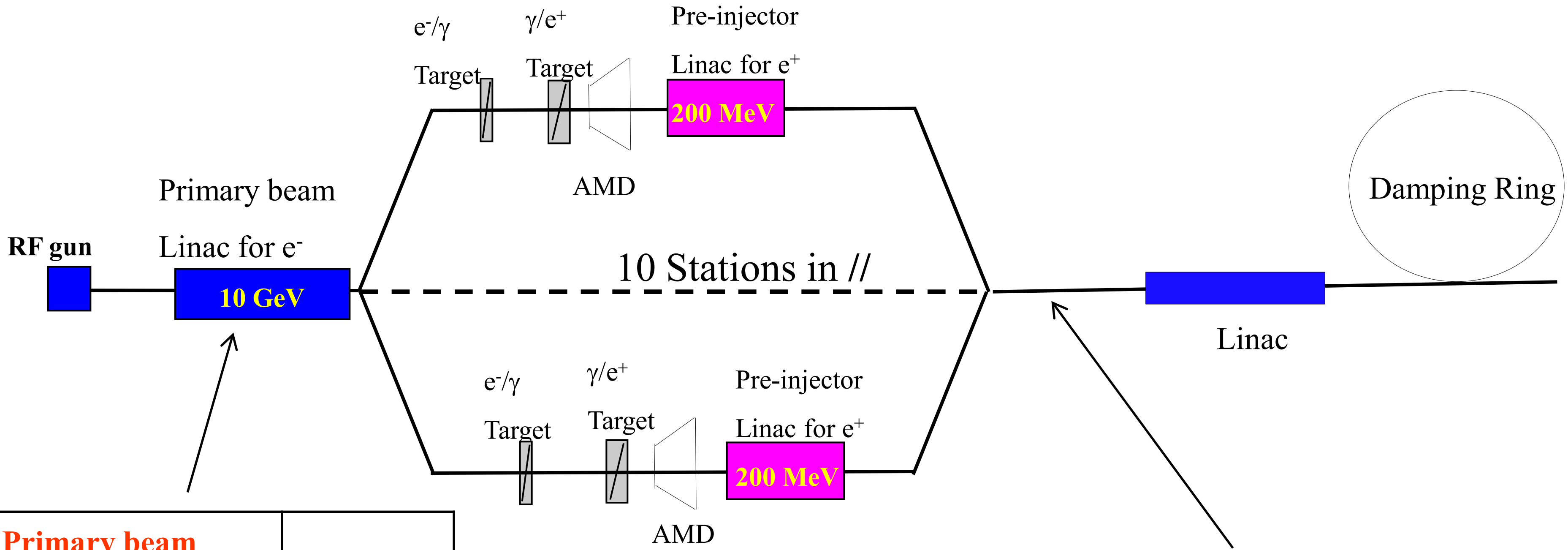


<I> = 5.4 mA

Concept of 2 parallel target stations



A possibility for unpolarized e^+ at LHeC

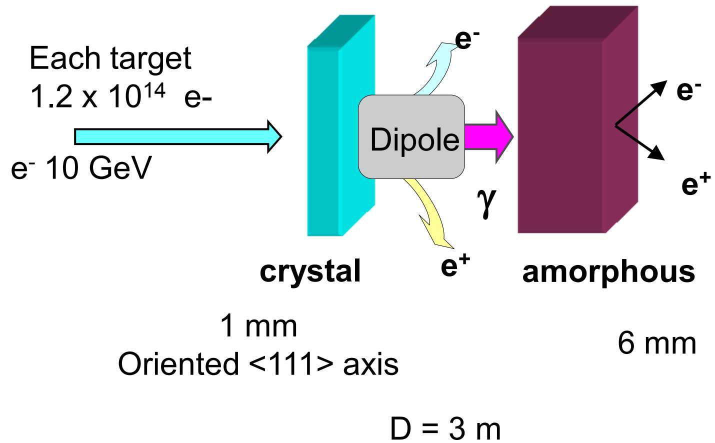


Primary beam	
Primary beam energy	10 GeV
Nb e^- / bunch	1.2 x 10^9
Nb bunches / pulse	100 000
Nb e^- / pulse	1.2 x 10^{14}
Pulse length	5 ms
Beam power	1900 kW
Bunch length	1 ps

Target @ 1 station	
Yield (e^+ / e^-)	1.5
Beam power	190 kW
Deposited power / target	5.6 kW
PEDD	0.3 J/g
Nb e^+ / bunch	1.8 x 10^9
Nb bunches / pulse	10 000
Nb e^+ / pulse	1.8 x 10^{13}

e^+ @ 10 stations	
Beam energy	200 MeV
Nb e^+ / bunch	1.8 x 10^9
Nb bunches / pulse	100 000
Nb e^+ / pulse	1.8 x 10^{14}
Bunch spacing	50 ns
Rep. rate	10 Hz

Issues for e^+ targets



<u>For each e^+ target:</u>

- Peak Energy Deposition Density (PEDD) is ok => below the breakdown limit of 35 J/g
- Relaxation time in the target (shock wave) is ok => below the expected limit of 10 µs
- Total beam power deposition is the main issue (5.6 kW / target) => need tests

Summary for LHeC e^+ Injector (p-140 GeV)

1) A conventional linac, with its injector, is required to accelerate e^- beam up to 10 GeV

2) Two RF deflectors are required to split e^- beam and recombine e^+ beams:

- Experience exits for 3 GHz and 2 lines in parallel
- Design and tests are necessary for 2 MHz, and10 lines in parallel

3) Ten e^+ target stations in parallel (radiation issues, shielding, etc…):

- See previous slides

4) Pre-Injector Linacs (200 MeV):

- Bunch length (20 to 100 ps) => bunch compressor
- Normalized rms emittances (6000 to 10000 mm.mrad) => Damping Ring

5) Linac and Damping Ring:

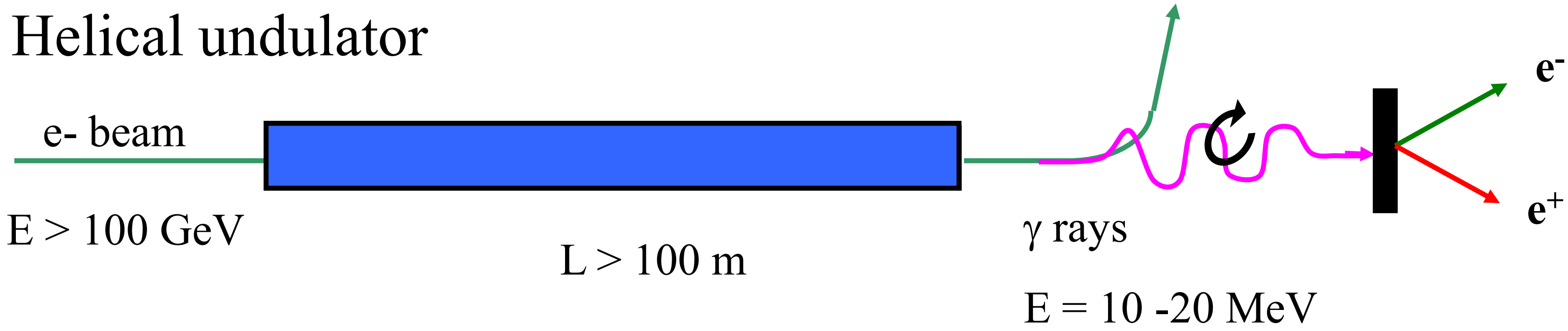
- Optimal energy needs to be defined
- Issues related to the long train (5 ms)

Linac – Ring option

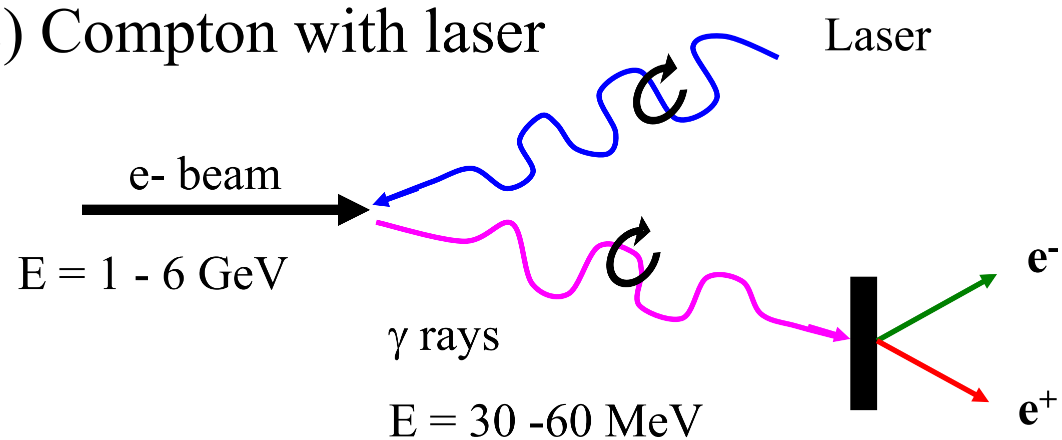
Polarized (e^+)

Two methods to produce polarized e^+

1) Helical undulator

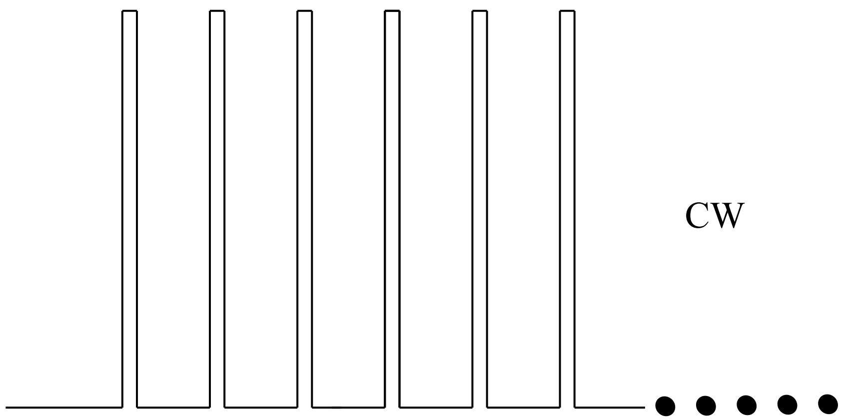


2) Compton with laser



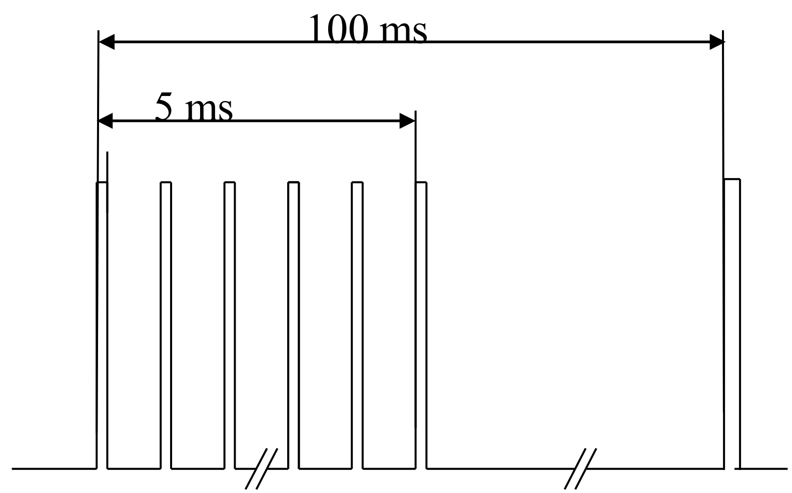
Possible investigations to produce polarized e^+

ERL – 60 GeV



1) Compton Linac

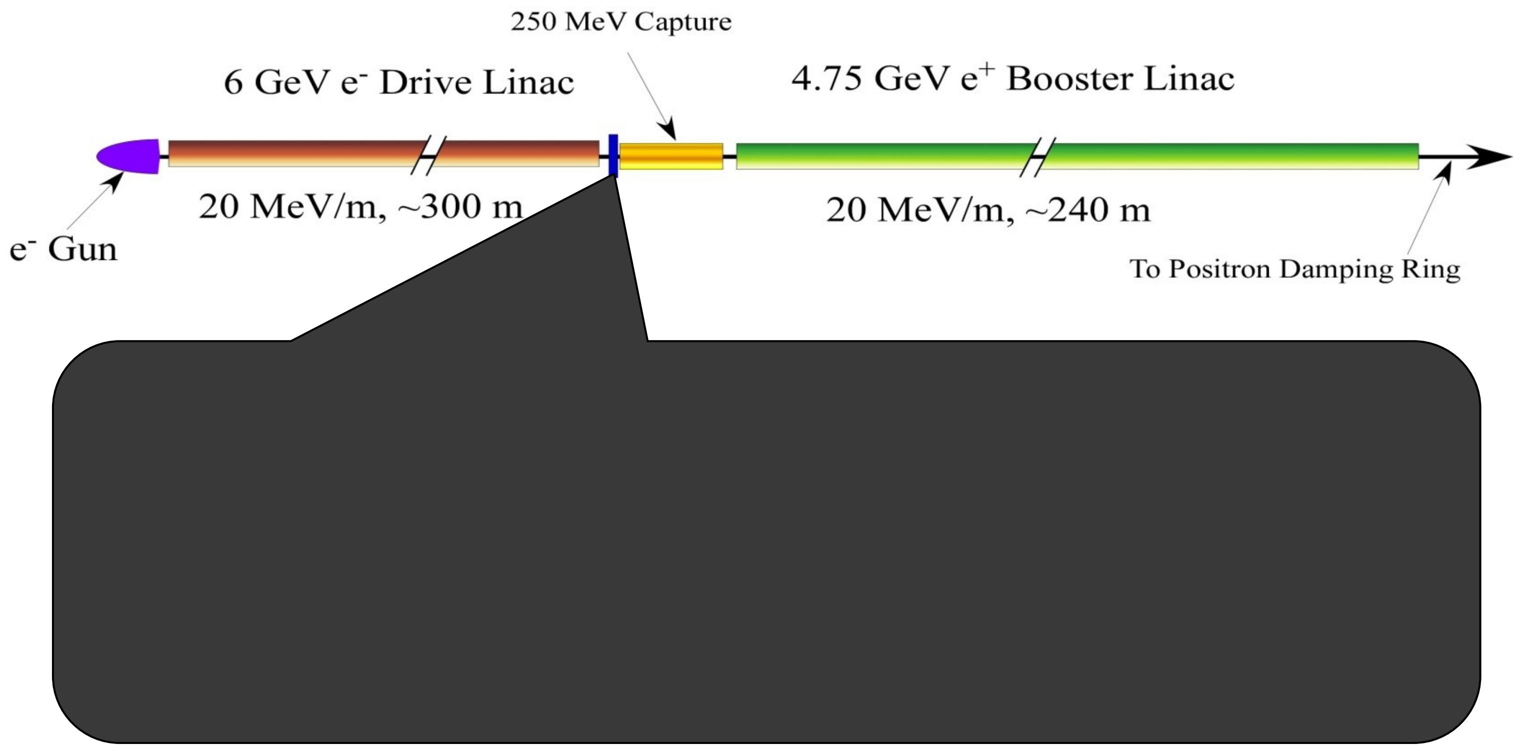
p – 140 GeV



1) Undulator using spent beam
2) Compton Linac
3) Compton Ring

Polarized Positrons from Compton Linac

V. Yakimenko



Polarized γ-ray beam is generated in the Compton back scattering inside optical cavity of CO2 laser beam and 6 GeV e-beam produced by linac.

Simple estimations for Compton Linac

$N_{\gamma} / N_{e-} = 1$ (demonstrated at BNL)

$N_{e+} / N_{\gamma} = 0.02$ (expected)

i.e. ≈ 50 gammas to generate 1 e^+

Data for CLIC:

$N_{e+} = 6.4 \times 10^9$ / bunch ~ 1 nC

$N_{e-} = 0.32 \times 10^{12}$ / bunch ~ 50 nC

Therefore with 5 nC / e^- bunch and 10 Compton IP's

=> 1 nC / e^+ bunch

Data for LHeC:

$N_{e+} = 2.2 \times 10^9$ / bunch ~ 0.35 nC

$N_{e-} = 0.11 \times 10^{12}$ / bunch ~ 18 nC

Therefore with 1.8 nC / e^- bunch and 10 Compton IP's

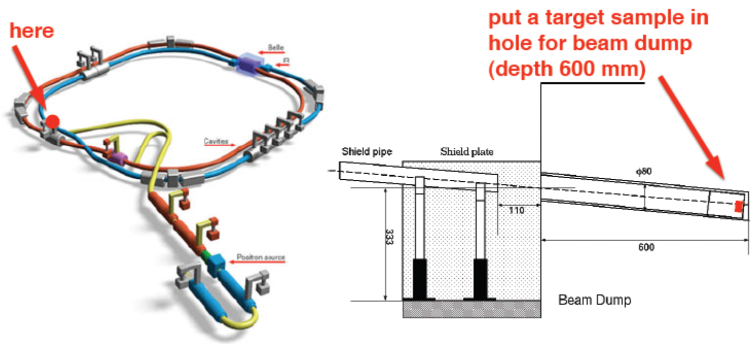
=> 0.35 nC / e^+ bunch

BUT many issues:

Laser cavities need strong R&D, emittances, huge power on the target, liquid targets ?, etc, …

Shock wave tests on BN window

T. Omori



- KEKB-HER: 8GeV, 10nC (Max), 1600 bunches (1600mA)
- The beam is deflected by the abort kicker as shown when it is dumped.

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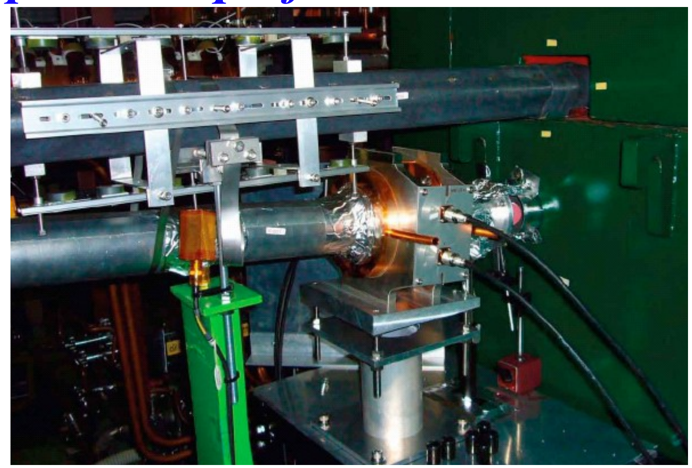
Experiment performed at KEKB



Total Energy of the Beam

8 GeV, 5 nC/bunch (= 800 mA), 1600 bunches --> 64 kJ

Energy deposit of the target (~12 % of Energy of the beam)

~ 7.7 kJ

Target Destruction

Plan of New Experiment

1. **We will use material (metal) which melting point is higher than that of lead.**
2. **We consider several metals.**
   Ti, Fe, Cu, W

Summary

Ring-Ring option

e^- and e^+ injectors:

1) No need of polarized beams (polarization obtained in the ring)
2) Former and existing machines have already demonstrated the requested performance
3) Detailed design would improve the results.

Linac-Ring option

Polarized e^- beam injector

The injector, with expected performance, is feasible but requires an important R&D.

Unpolarized e^+ beam injector

A preliminary design has been proposed (for p-140 GeV). It is challenging, needs further studies and requires a strong R&D.

Polarized e^+ beam injector

The design is extremely demanding and requires more studies and investigations with a very strong R&D.