LHeC Sources

L. Rinolfi

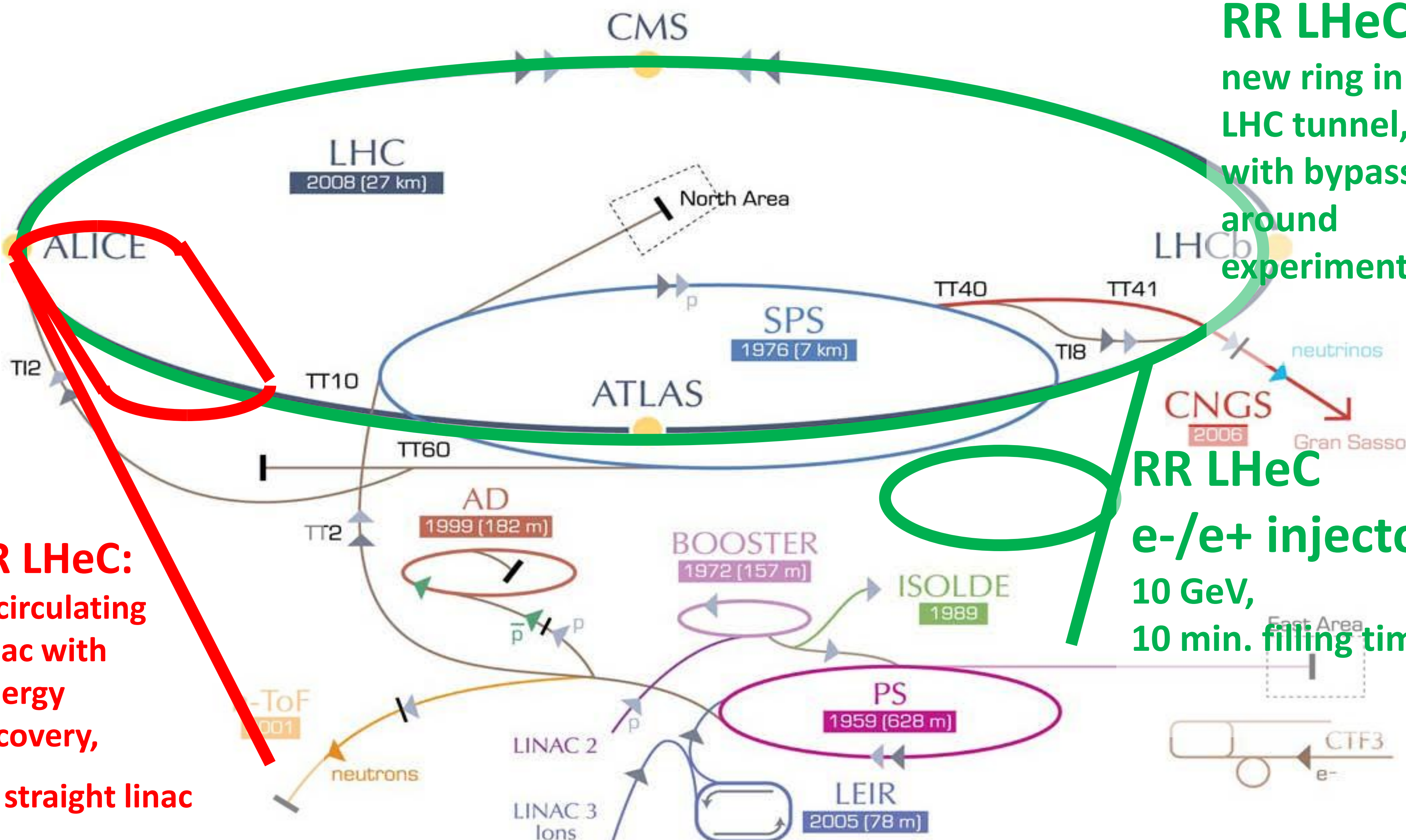
CERN

Thanks to:

I. Bailey, H. Braun, O. Brüning, E. Bulyak, R. Chehab, O. Dadoun, P. Gladkikh, M. Klein,
T. Omori, P. Sievers, D. Schulte, A. Variola, 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

Performance targets

* e^- energy ≥60 GeV
* luminosity ~10^{33} $cm^{-2}s^{-1}$
* total electrical power for e^-: ≤100 MW
* e^+p collisions with similar luminosity
* simultaneous with LHC *pp* physics
* e^-/e^+ polarization

LHeC design parameters

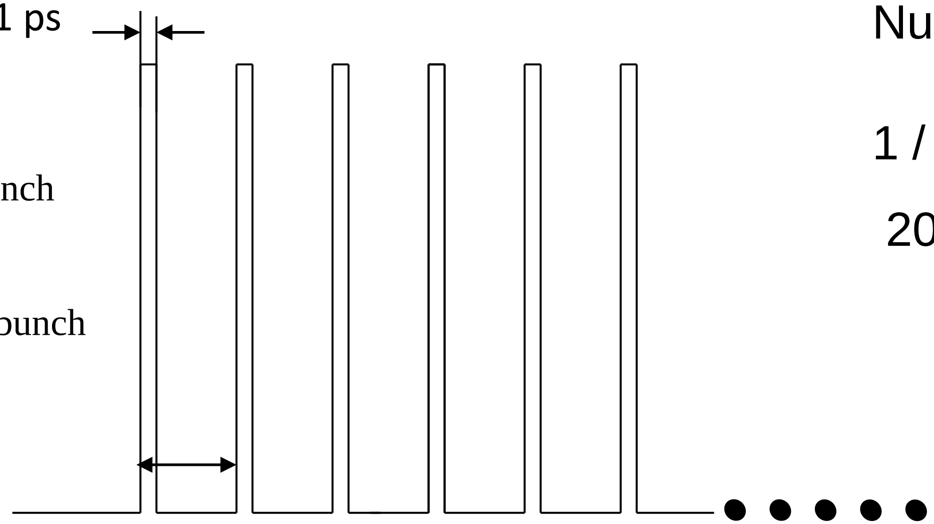
options	RR	LR	LR*
e- energy at IP[GeV]	60	60	140
ep luminosity [10^{32} $cm^{-2}s^{-1}$]	8	10	0.4
eN luminosity [10^{32} $cm^{-2}s^{-1}$]	0.45	1	0.04
polarization for e^- (e^+) [%]	40 (40)	90 (0)	90 (0)
bunch population [10^9]	20	2 (or 1.0)	0.8
e- bunch length [mm]	6	0.3	0.3
bunch interval [ns]	25	50 (or 25)	25
transv. emit. $\gamma\varepsilon_{x,y}$ [mm]	0.59, 0.29	0.05	0.1
rms IP beam size $\sigma_{x,y}$ [μm]	45, 22	7	7
e- IP beta funct. $\beta^*_{x,y}$ [m]	0.4, 0.2	0.12	0.14
full crossing angle [mrad]	0.93	0	0
repetition rate [Hz]	N/A	N/A	10
beam pulse length [ms]	N/A	N/A	5
ER efficiency	N/A	94%	N/A
average current [mA]	100	6.4	5.4
tot. wall plug power[MW]	100	100	100

RR= Ring – Ring

LR =Linac –Ring

***) pulsed**

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



<I> = 6.6 mA

Number of bunches per second

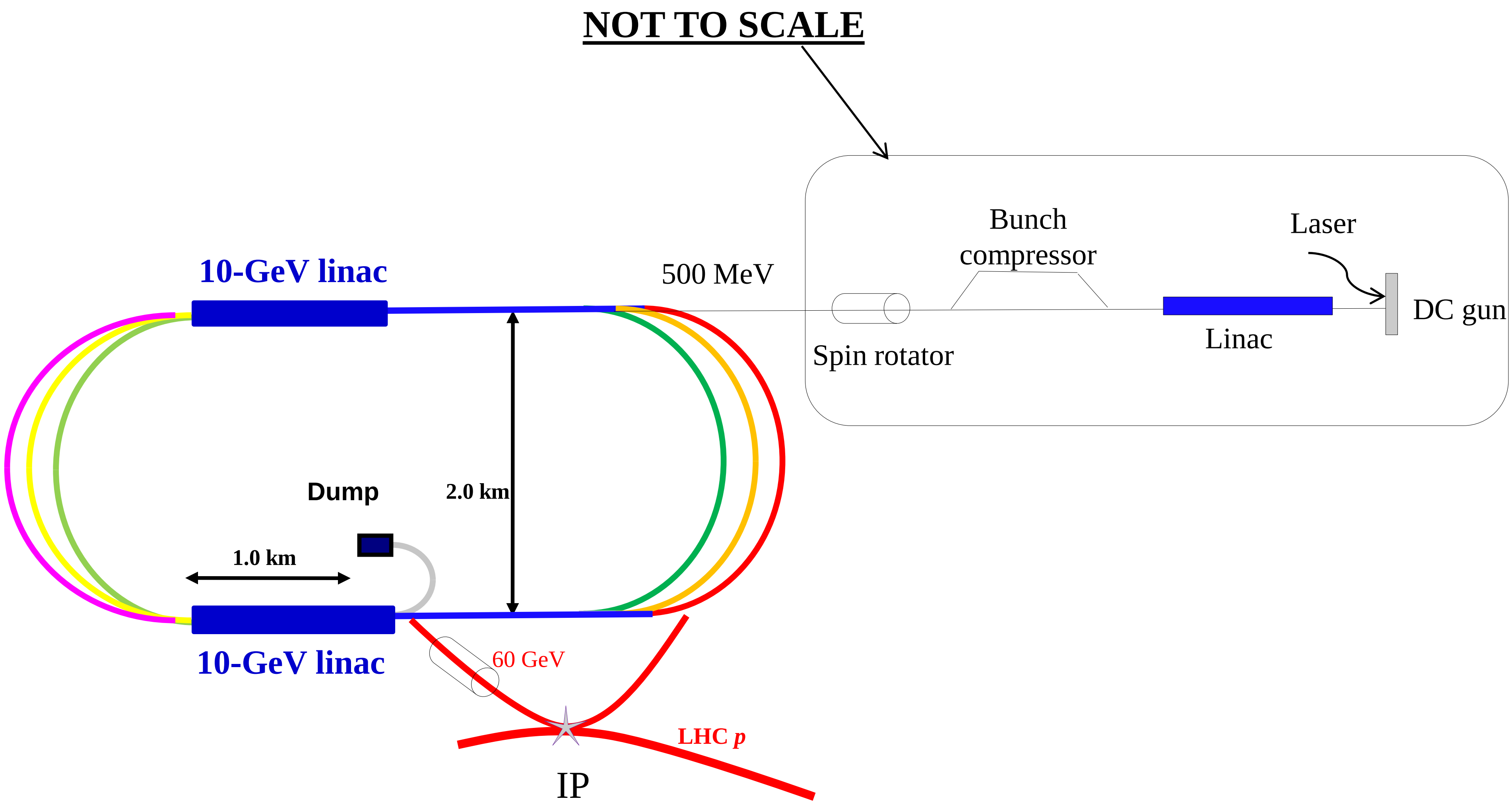
$1 / 50\times10^{-9}$ s = 20×10^{6} b/s

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

Study 3 cases

1) Polarized e^-
2) Unpolarized e^+
3) Polarized e^+

Electron injector for ERL

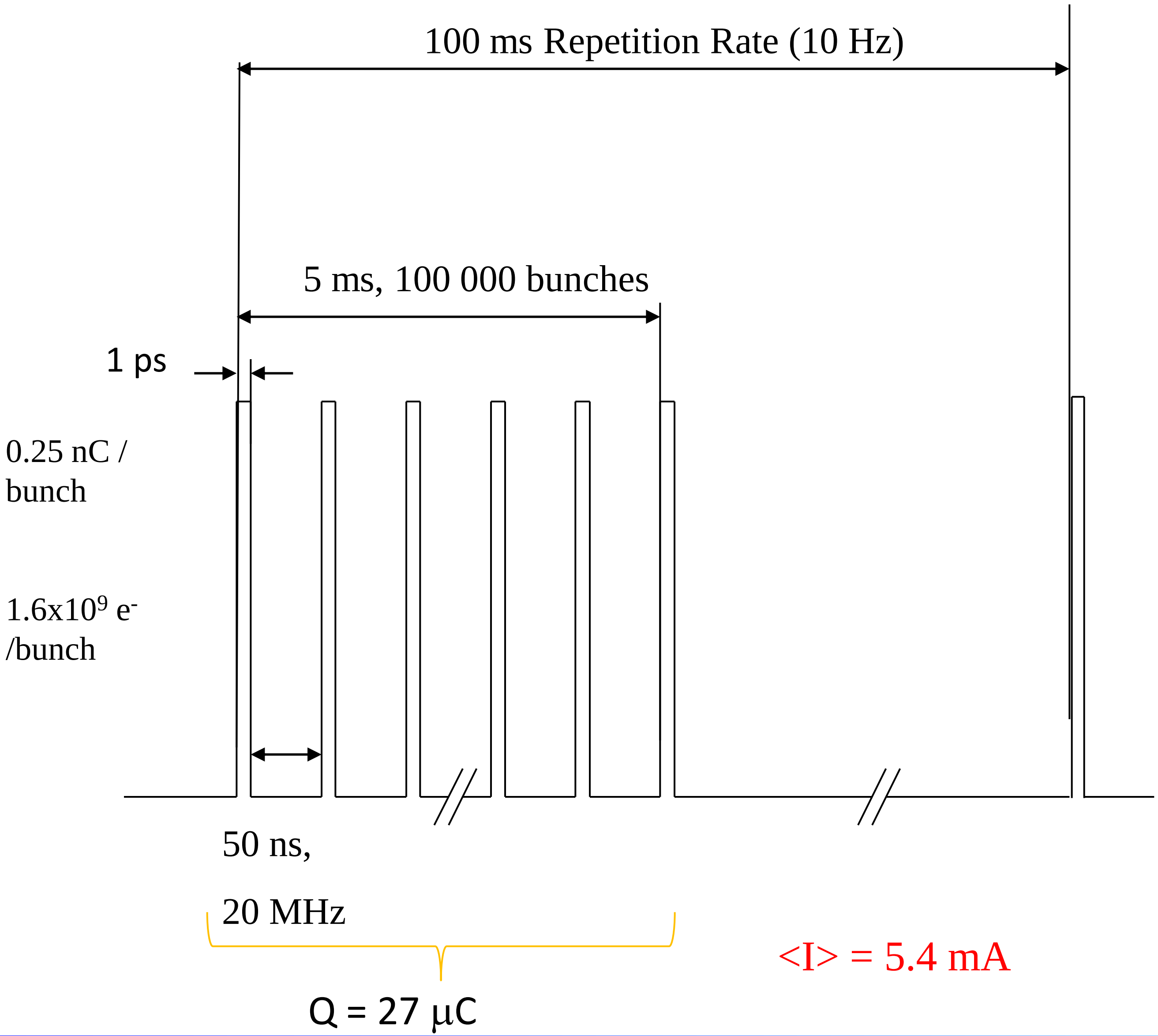


Flux of e^+

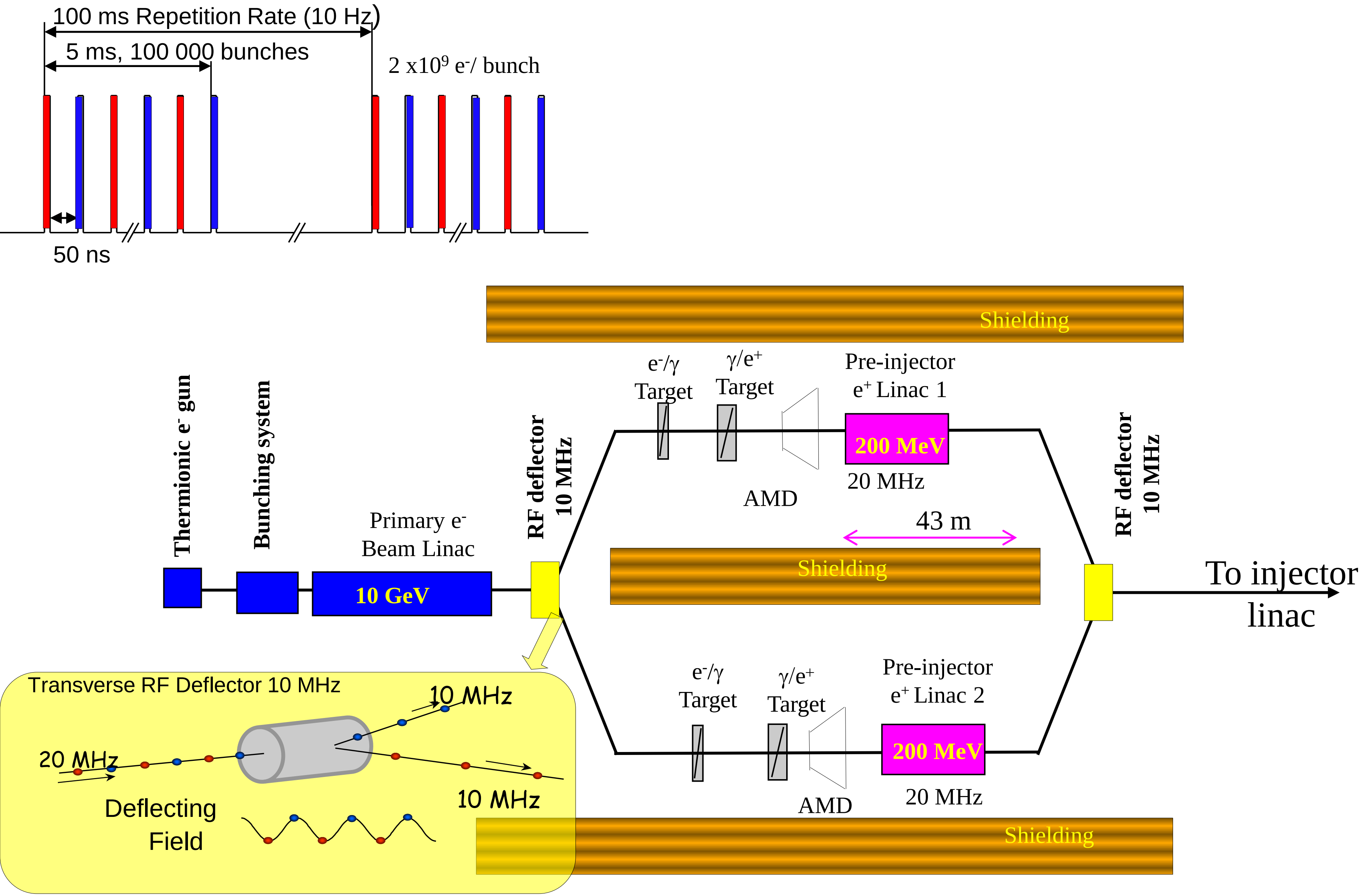
	SLC	CLIC (3 TeV)	ILC (RDR)	LHeC p-140	LHeC ERL
Energy	1.19 GeV	2.86 GeV	5 GeV	140 GeV	60 GeV
e^+/ bunch at IP	40×10^9	3.72×10^9	20×10^9	1.6×10^9	2×10^9
e^+/ bunch after capture	50×10^9	7.6×10^9	30×10^9	1.8×10^9	2.2×10^9
Bunches / macropulse	1	312	2625	10^5	NA
Macropulse repet. rate	120	50	5	10	CW
Bunches / second	120	15600	13125	10^6	20×10^6
e^+ / second **($\times 10^{14}$)**	**0.06**	**1.1**	**3.9**	**18**	**440**

x 20 x 300 x 7000

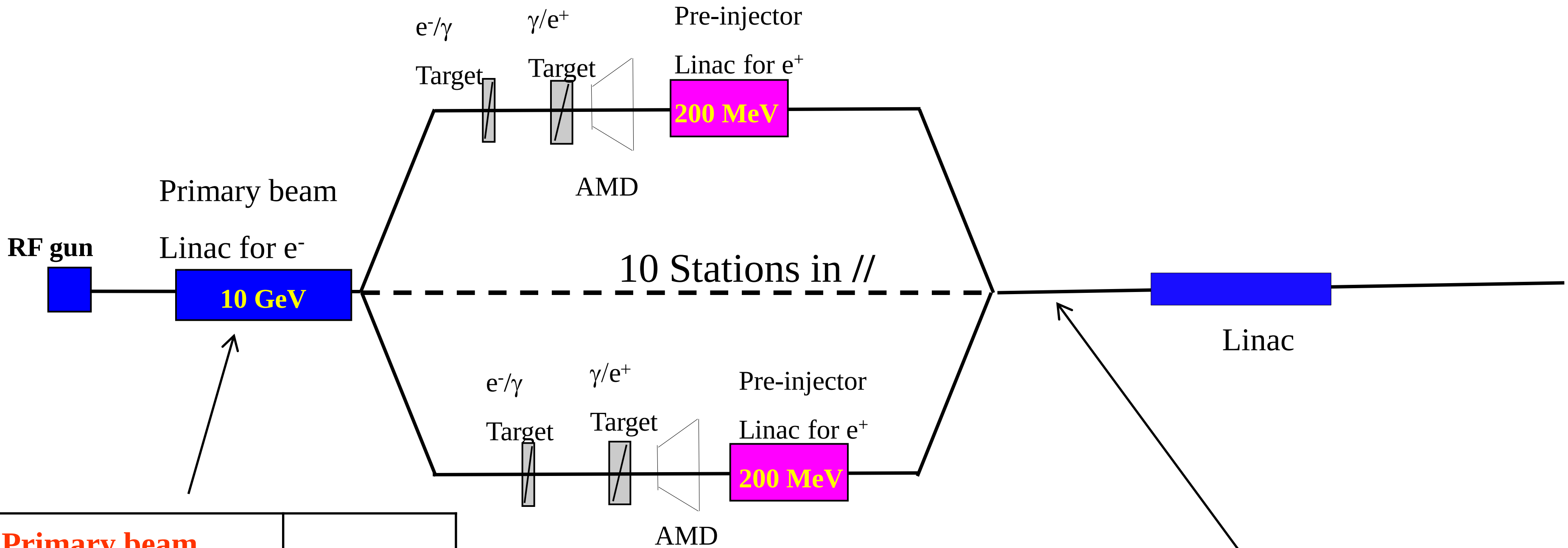
LHeC-LR beam structure for p-140 GeV



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

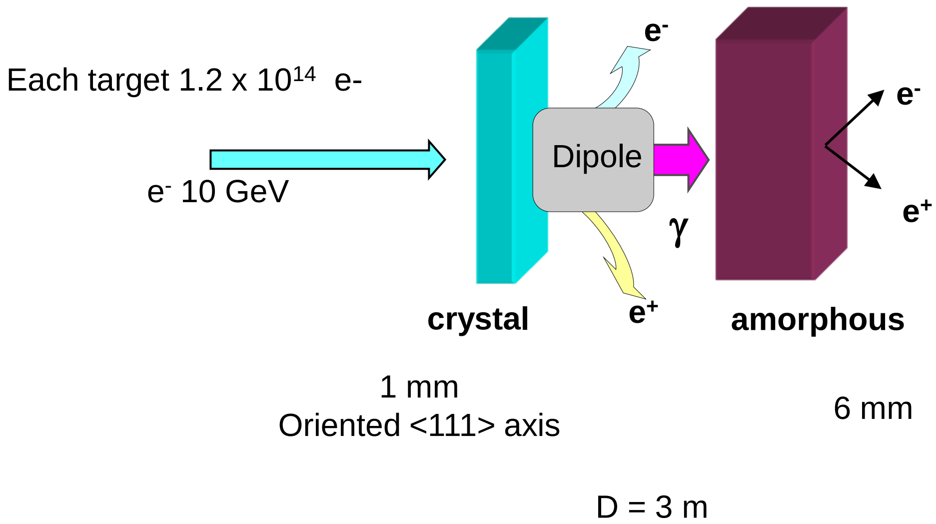
Target @ 1 station	
Yield (e^+ / e^-)	1.5
Beam power	190 kW
Deposited power / target	5.6 kW
PEDD	30 J/g
Nb e^+ / bunch	1.8 x 10^9
Nb bunches / pulse	10 000
Nb e^+ / pulse	1.8 x 10^{13}

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

Concept Hybrid targets:

R. Chehab, V. Strakhovenko, A. Variola



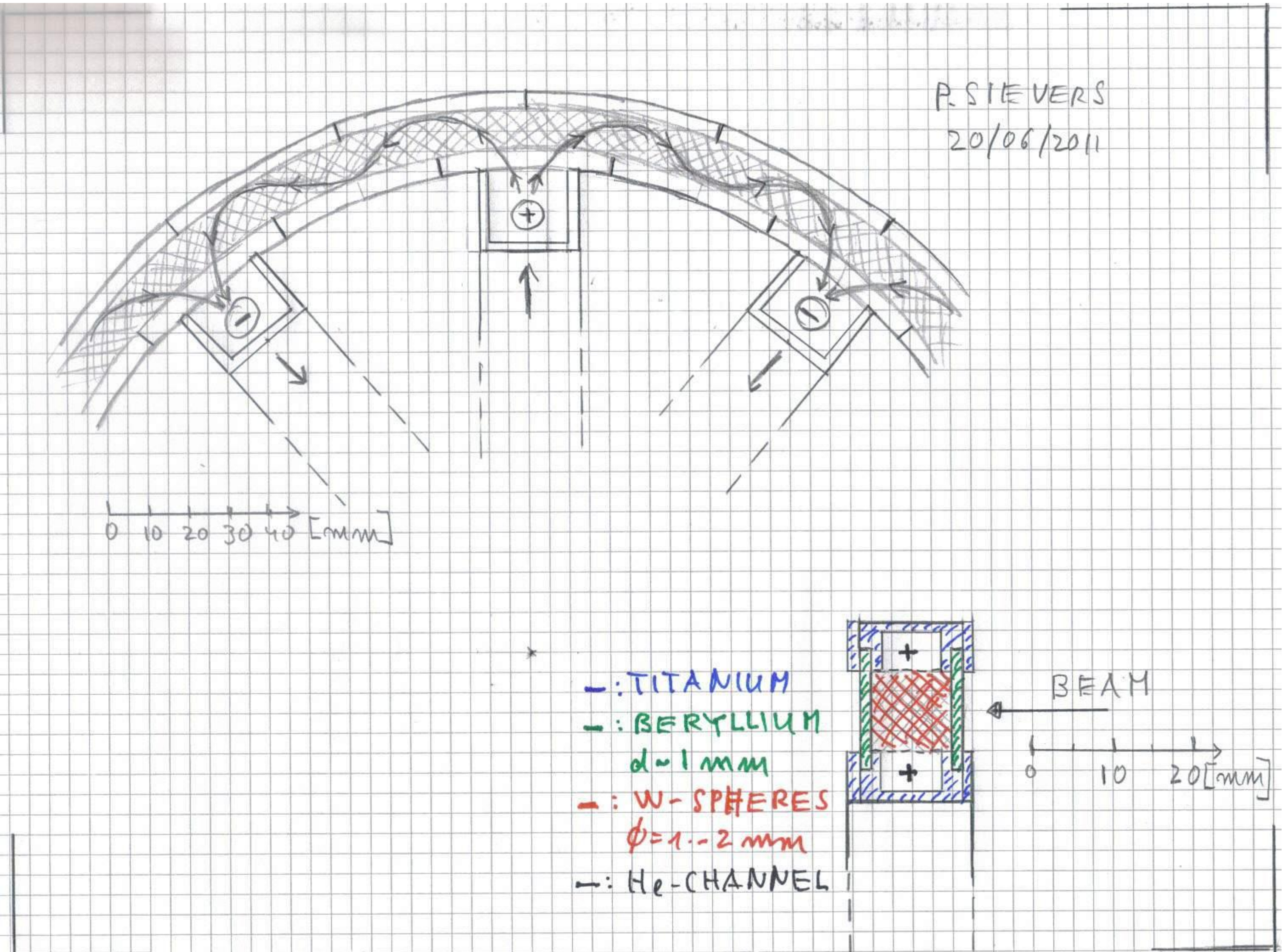
<u>For each e^+ target:</u>

- Peak Energy Deposition Density (PEDD) is maybe ok (?) < expected breakdown limit of 35 J/g
- Relaxation time in the target (shock wave) is maybe ok (?) below the expected limit of 10 μs
- Total beam power deposition is probably an issue (5.6 kW / target)

=> All these issues needs experimental tests

Another possibility for e^+ target

See P. Sievers talk



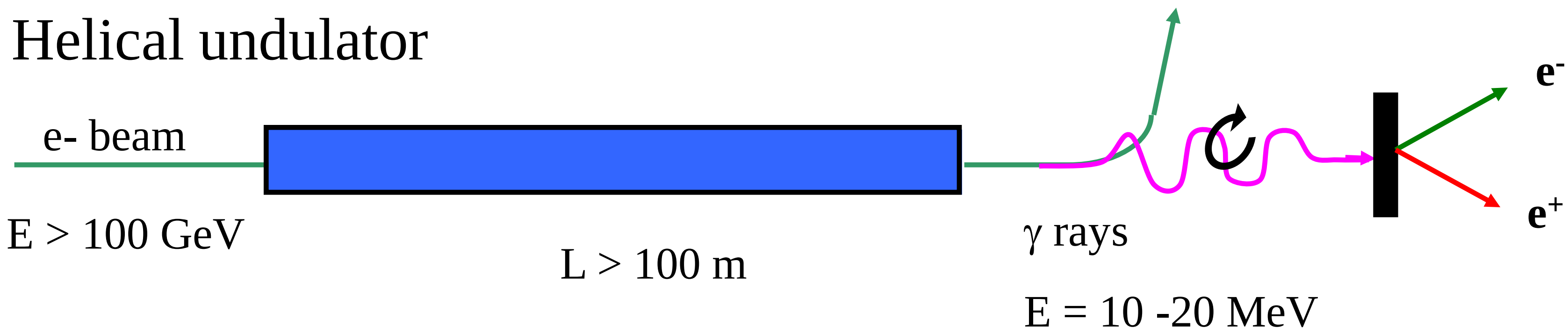
Densely packed W spheres

Rotating rim = 20 m/s

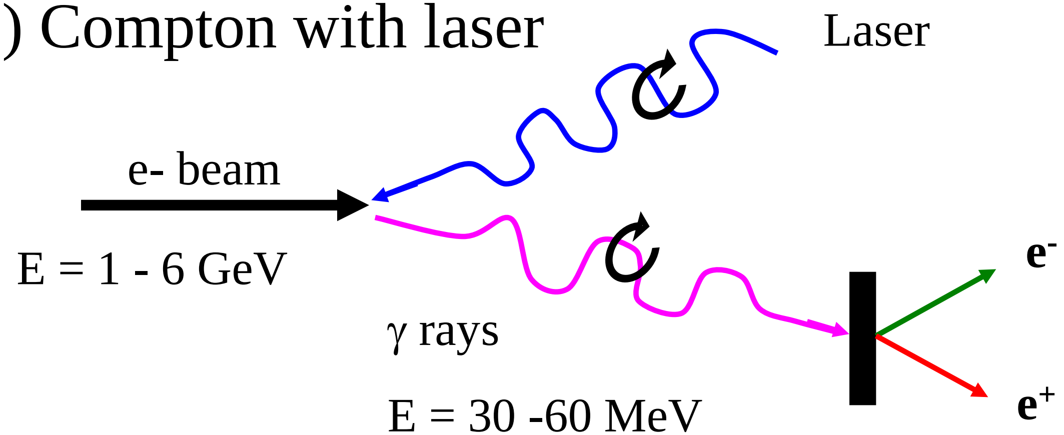
Rep. rate = 1000 rpm

Two methods to produce polarized e$^+$

1) Helical undulator

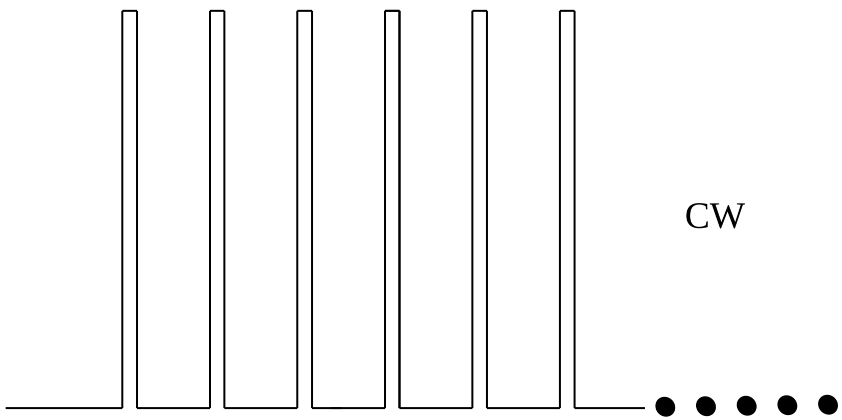


2) Compton with laser



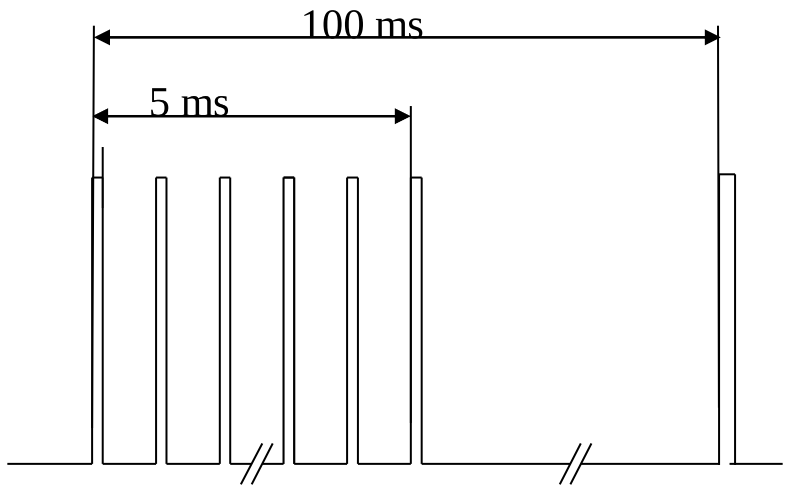
Investigations to produce polarized e^+

ERL – 60 GeV



1) Compton Linac
2) Several Compton Rings

p – 140 GeV

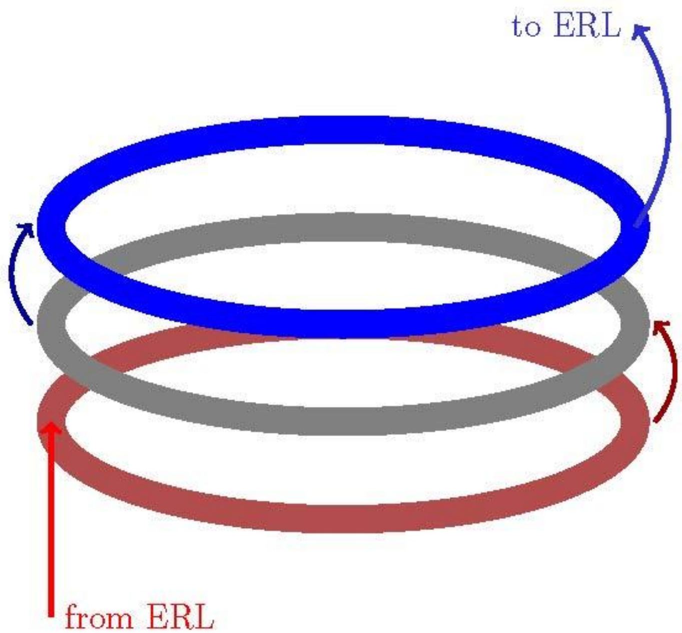


1) Undulator using spent beam
2) Compton Linac
3) Compton Ring

Three rings transformer for e^+ source option

See E. Bulyak and

P. Gladkikh talks



extraction ring (*N* turns)

fast cooling ring (*N* turns)

accumulator ring (*N* turns)

E. Bulyak "Performance of Compton Sources of Polarised Positrons"

at Positron for LHeC - Brainstorming workshop - May 2011 (Ref slide 18)

Summary

LHeC

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.

Some references for the LHeC sources

3rd CERN-ECFA-NuPecc workshop on the LHeC - November 2010
http://indico.cern.ch/conferenceDisplay.py?confId=105142

Positron for LHeC - Brainstorming workshop - May 2011
http://indico.cern.ch/conferenceDisplay.py?confId=140044

CERN-ECFA-NuPecc workshop on the LHeC - June 2012
http://indico.cern.ch/conferenceDisplay.py?confId=183282

CDR for the LHeC published

CERN-OPEN-2012-015
LHeC-Note-2012-001 GEN
Geneva, June 14, 2012

About 150 Experimentalists and Theorists from 50 Institutes

arXiv:1206.2913v1 [physics.acc-ph] 13 Jun 2012

A Large Hadron Electron Collider at CERN

Report on the Physics and Design
Concepts for Machine and Detector

LHeC Study Group

Submitted to J.Phys. G

LHeC Study Group

J.L.Abelleira Fernandez[16,23], C.Adolphsen[57], A.N.Akay[03], H.Aksakal[39], J.L.Albacete[52], S.Alekhin[17,54], P.Allport[24], V.Andreev[34], R.B.Appleby[14,30], E.Arikan[39], N.Armesto[53,a], G.Azuelos[33,64], M.Bai[37], D.Barber[14,17,24], J.Bartels[18], O.Behnke[17], J.Behr[17], A.S.Belyaev[15,56], I.Ben-Zvi[37], N.Bernard[25], S.Bertolucci[16], S.Bettoni[16], S.Biswal[41], J.Blümlein[17], H.Böttcher[17], A.Bogacz[36], C.Bracco[16], G.Brandt[44], H.Braun[65], S.Brodsky[57,b], O.Brüning[16], E.Bulyak[12], A.Buniatyan[17], H.Burkhardt[16], I.T.Cakir[02], O.Cakir[01], R.Calaga[16], V.Cetinkaya[01], E.Ciapala[16], R.Ciftci[01], A.K.Ciftci[01], B.A.Cole[38], J.C.Collins[48], O.Dadoun[42], J.Dainton[24], A.De.Roeck[16], D.d'Enterria[16], A.Dudarev[16], A.Eide[60], R.Enberg[63], E.Eroglu[62], K.J.Eskola[21], L.Favart[08], M.Fitterer[16], S.Forte[32], A.Gaddi[16], P.Gambino[59], H.García Morales[16], T.Gehrmann[69], P.Gladkikh[12], C.Glasman[28], R.Godbole[35], B.Goddard[16], T.Greenshaw[24], A.Guffanti[13], V.Guzey[19,36], C.Gwenlan[44], T.Han[50], Y.Hao[37], F.Haug[16], W.Herr[16], A.Hervé[27], B.J.Holzer[16], M.Ishitsuka[58], M.Jacquet[42], B.Jeanneret[16], J.M.Jimenez[16], J.M.Jowett[16], H.Jung[17], H.Karadeniz[02], D.Kayran[37], A.Kilic[62], K.Kimura[58], M.Klein[24], U.Klein[24], T.Kluge[24], F.Kocak[62], M.Korostelev[24], A.Kosmicki[16], P.Kostka[17], H.Kowalski[17], G.Kramer[18], D.Kuchler[16], M.Kuze[58], T.Lappi[21,c], P.Laycock[24], E.Levichev[40], S.Levonian[17], V.N.Litvinenko[37], A.Lombardi[16], J.Maeda[58], C.Marquet[16], B.Mellado[27], K.H.Mess[16], A.Milanese[16], S.Moch[17], I.I.Morozov[40], Y.Muttoni[16], S.Myers[16], S.Nandi[55], Z.Nergiz[39], P.R.Newman[06], T.Omori[61], J.Osborne[16], E.Paoloni[49], Y.Papaphilippou[16], C.Pascaud[42], H.Paukkunen[53], E.Perez[16], T.Pieloni[23], E.Pilicer[62], B.Pire[45], R.Placakyte[17], A.Polini[07], V.Ptitsyn[37], Y.Pupkov[40], V.Radescu[17], S.Raychaudhuri[35], L.Rinolfi[16], R.Rohini[35], J.Rojo[16,31], S.Russenschuck[16], M.Sahin[03], C.A.Salgado[53,a], K.Sampei[58], R.Sassot[09], E.Sauvan[04], U.Schneekloth[17], T.Schörner-Sadenius[17], D.Schulte[16], A.Senol[22], A.Seryi[44], P.Sievers[16], A.N.Skrinsky[40], W.Smith[27], H.Spiesberger[29], A.M.Stasto[48,d], M.Strikman[48], M.Sullivan[57], S.Sultansoy[03,e], Y.P.Sun[57], B.Surrow[11], L.Szymanowski[66,f], P.Taels[05], I.Tapan[62], T.Tasci[22], E.Tassi[10], H.Ten.Kate[16], J.Terron[28], H.Thiesen[16], L.Thompson[14,30], K.Tokushuku[61], R.Tomás García[16], D.Tommasini[16], D.Trbojevic[37], N.Tsoupas[37], J.Tuckmantel[16], S.Turkoz[01], T.N.Trinh[47], K.Tywoniuk[26], G.Unel[20], J.Urakawa[61], P.VanMechelen[05], A.Variola[52], R.Veness[16], A.Vivoli[16], P.Vobly[40], J.Wagner[66], R.Wallny[68], S.Wallon[43,46,f], G.Watt[16], C.Weiss[36], U.A.Wiedemann[16], U.Wienands[57], F.Willeke[37], B.-W.Xiao[48], V.Yakimenko[37], A.F.Zarnecki[67], Z.Zhang[42], F.Zimmermann[16], R.Zlebcik[51], F.Zomer[42]

LHeC CDR completed (~630 pages)

SPARES

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

LHeC

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

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

$\lambda \approx$ 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 ($P_a = E_L \times f_{las}$)	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

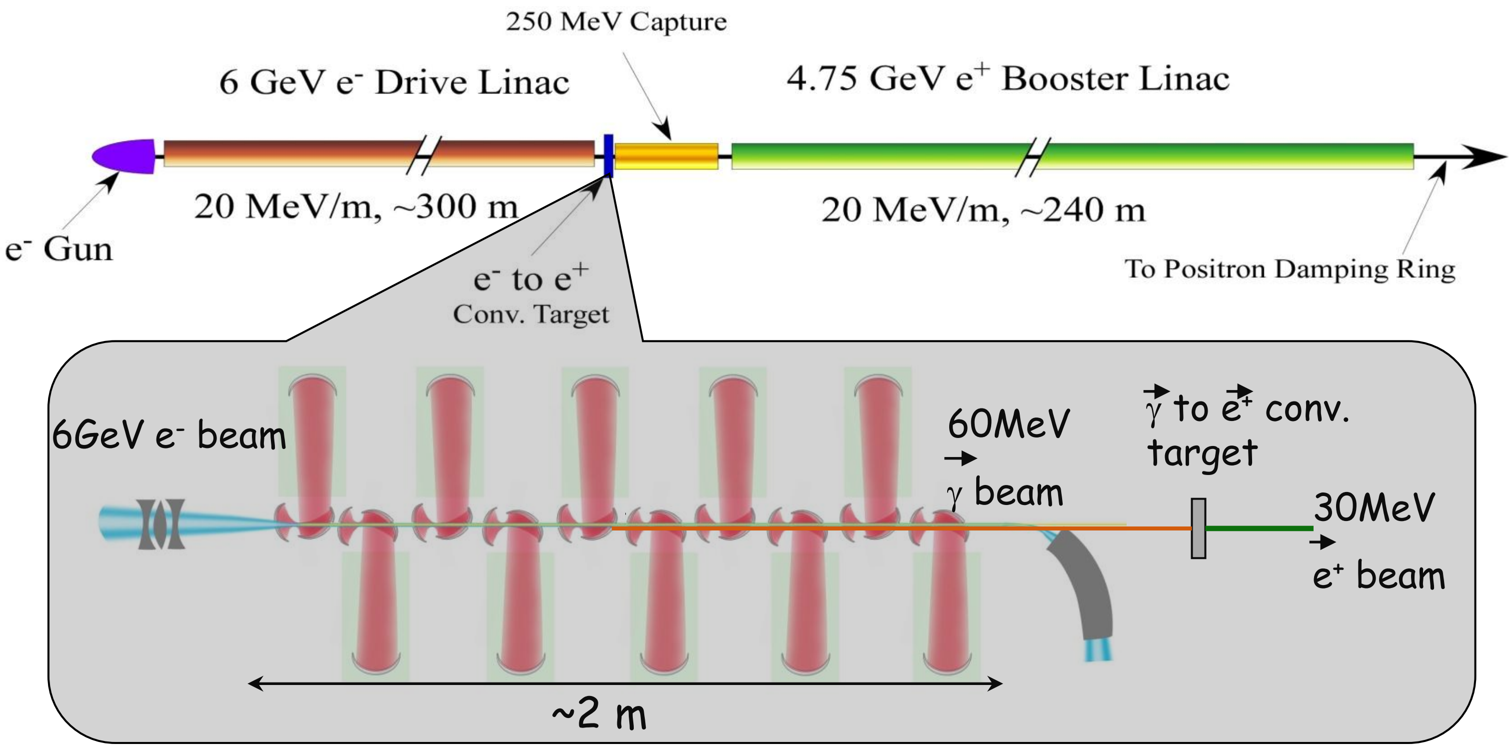
R&D issues for the LHeC polarized source

- 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

Polarized Positrons from Compton Linac

V. Yakimenko



Polarized γ-ray beam is generated in the Compton back scattering inside optical cavity of CO_2 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 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

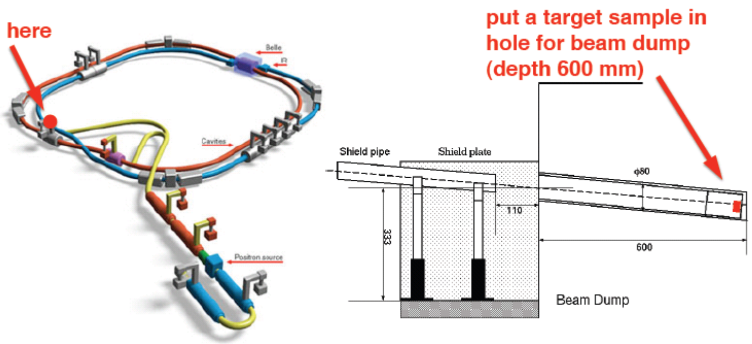
=> 0.35 nC / e^+ bunch

BUT many issues:

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

Shock wave tests on BN window

LHeC
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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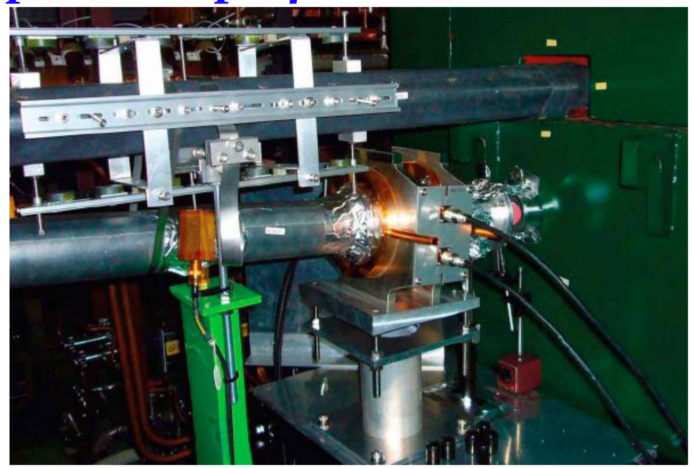
Experiment performed at KEKB



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)

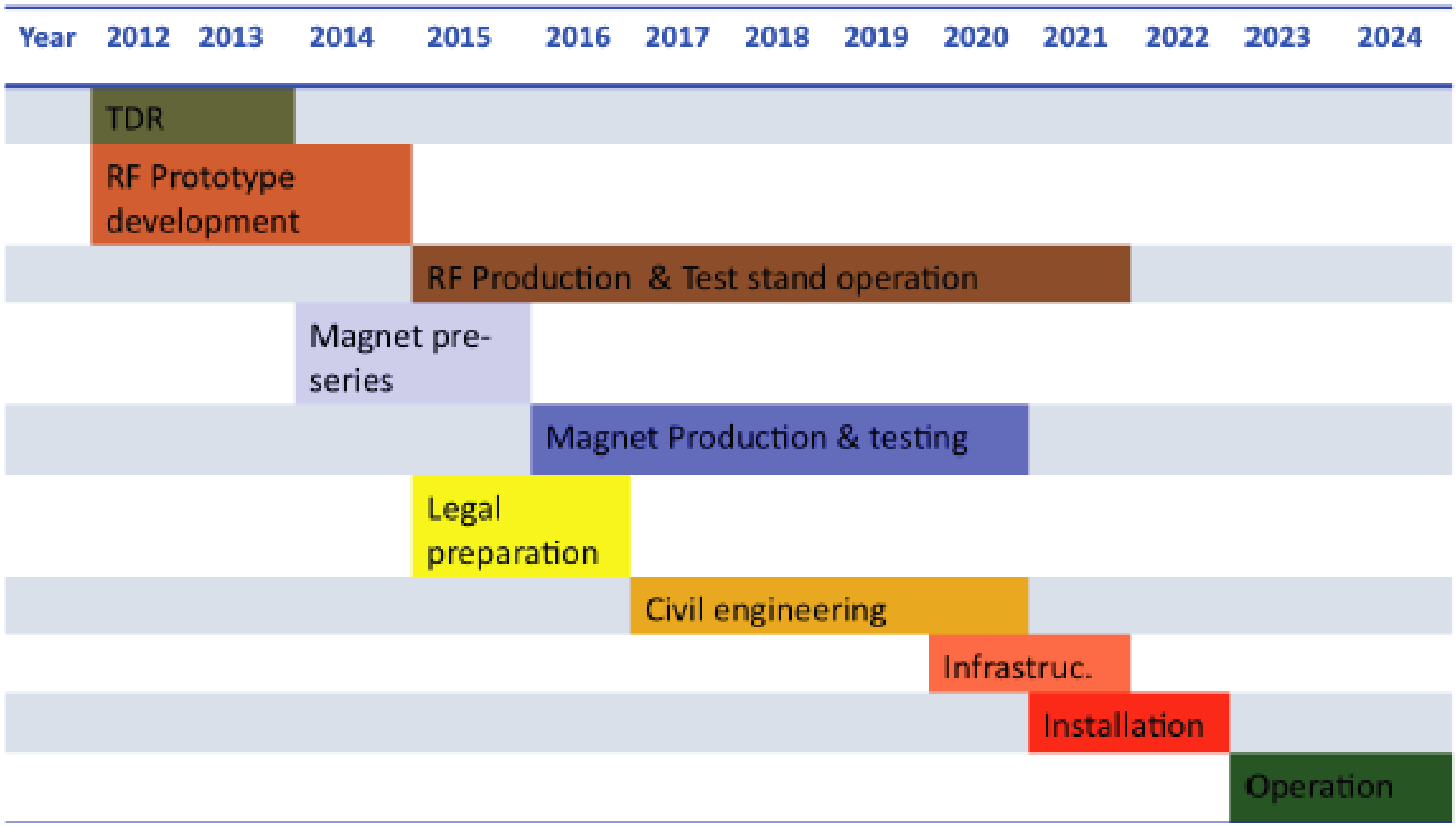
~ 7.7 kJ

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

Draft LHeC time schedule



-Only 2 long shutdowns planned before 2022

-Only 10 years for the LHeC from CDR to project start.

LS3 --- HL LHC

O. Brüning, ECFA meeting, 25 November 2011