The Large Hadron electron Collider (LHeC) at the LHC

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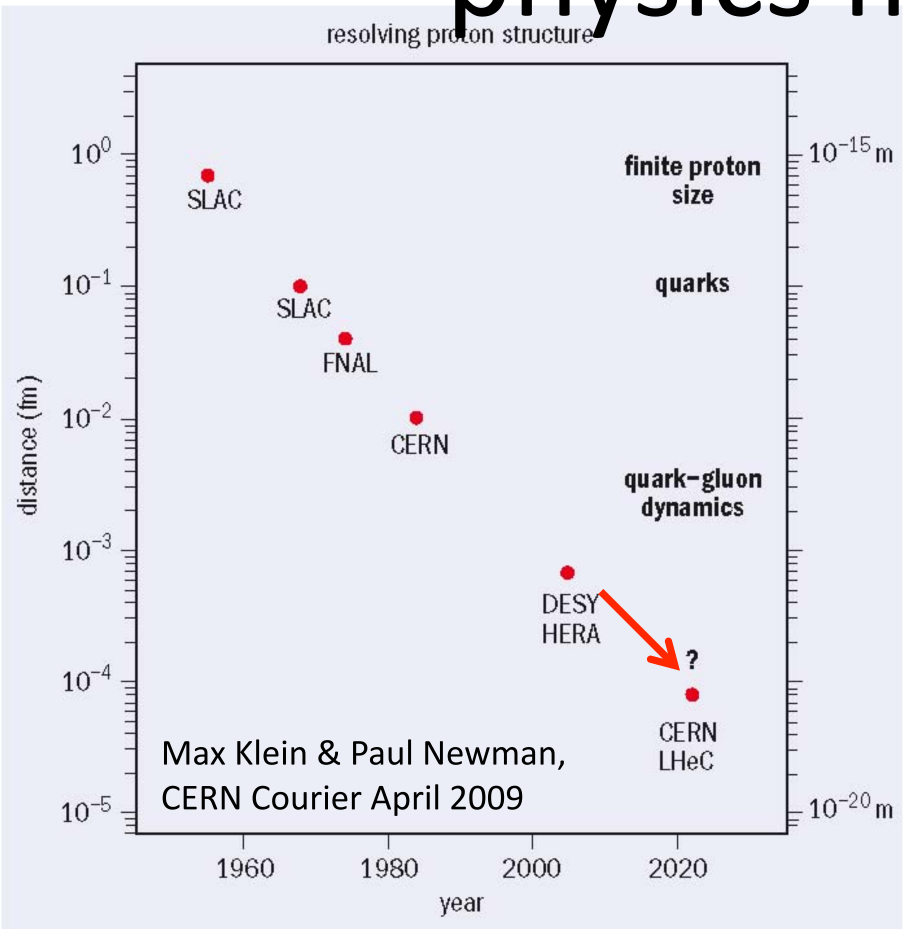
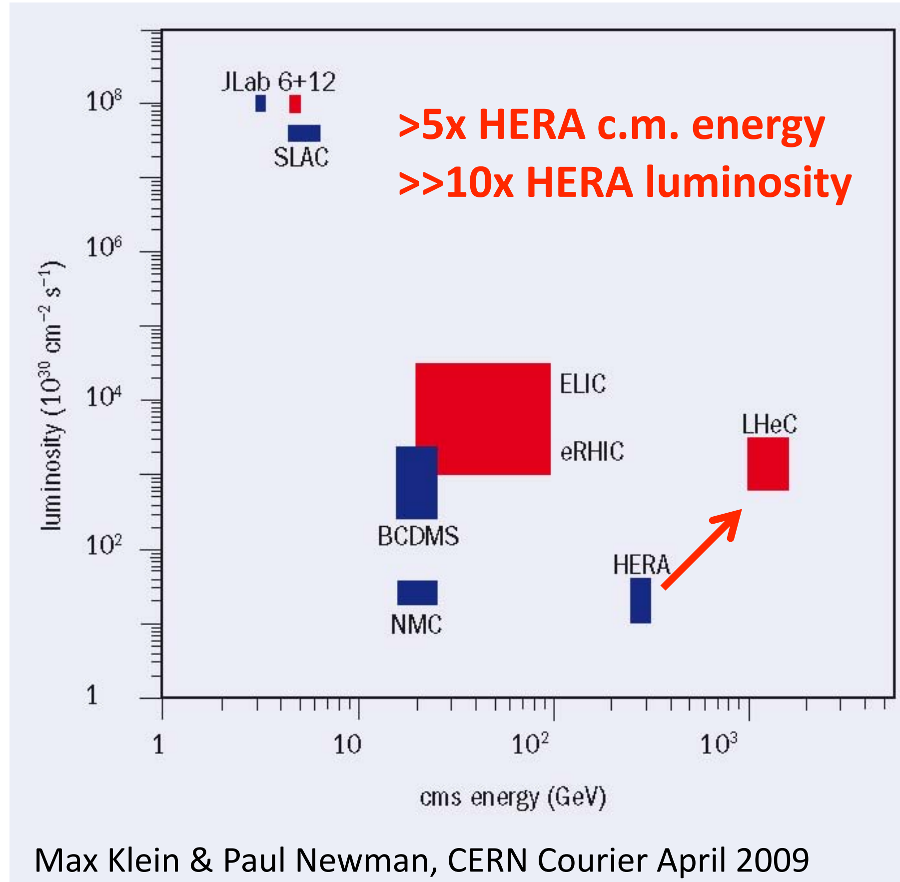
physics motivation



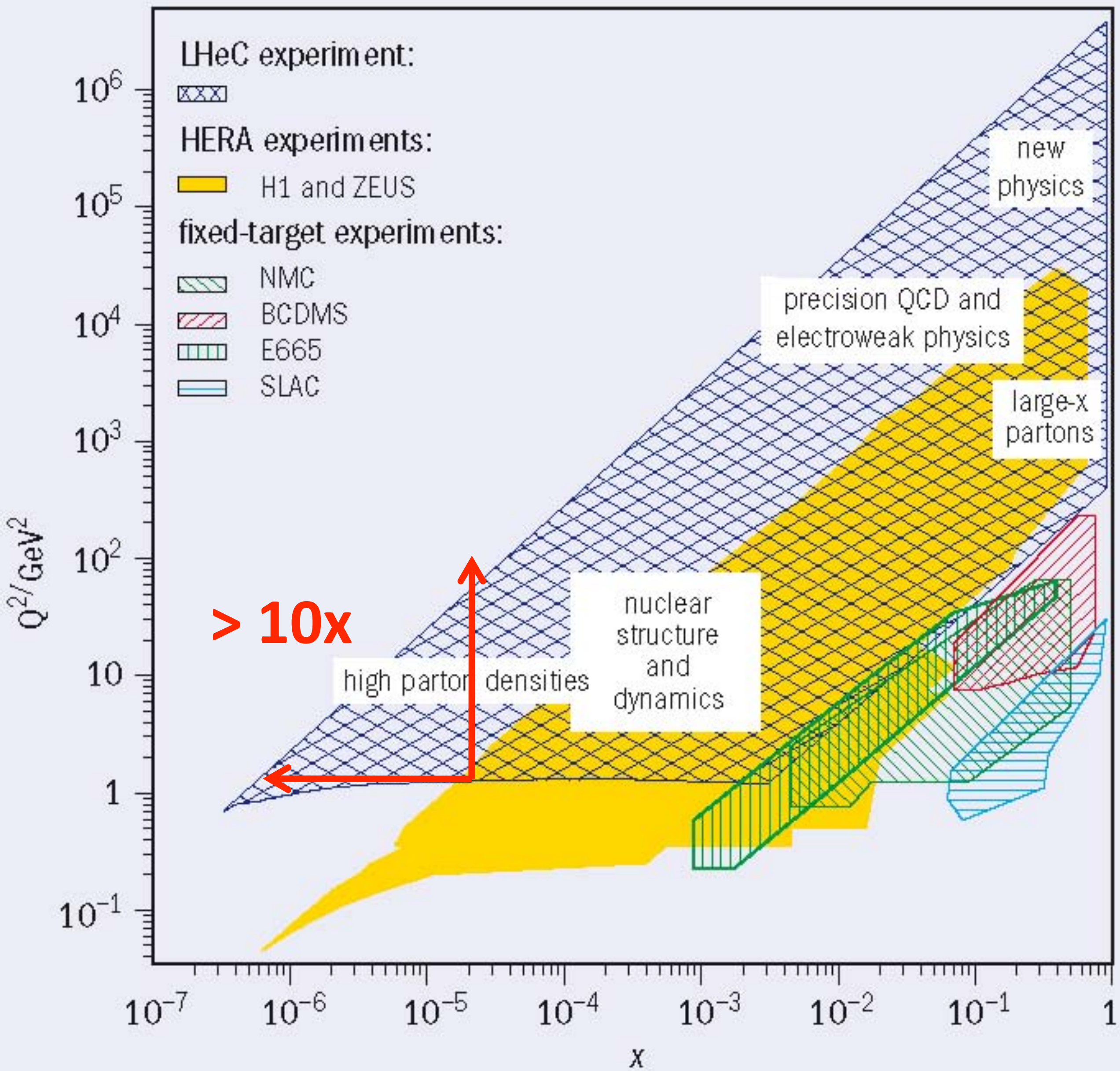
distance scales resolved in lepton-hadron scattering experiments since 1950s, and some of the new physics revealed



energies and luminosities of existing and proposed future lepton-proton scattering facilities

e- energy ~60-140 GeV

luminosity ~10^{33} cm^{-2}s^{-1}

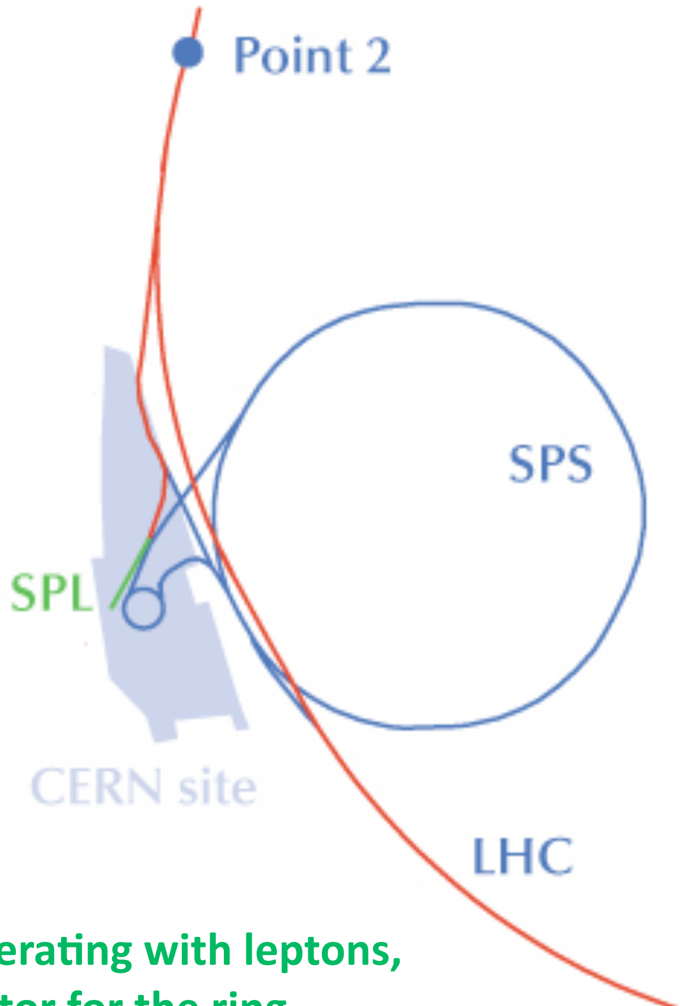


Max Klein & Paul Newman, CERN Courier April 2009

kinematic plane in Bjorken-x and resolving power Q^2, showing the coverage of fixed target experiments, ***HERA*** and ***LHeC***

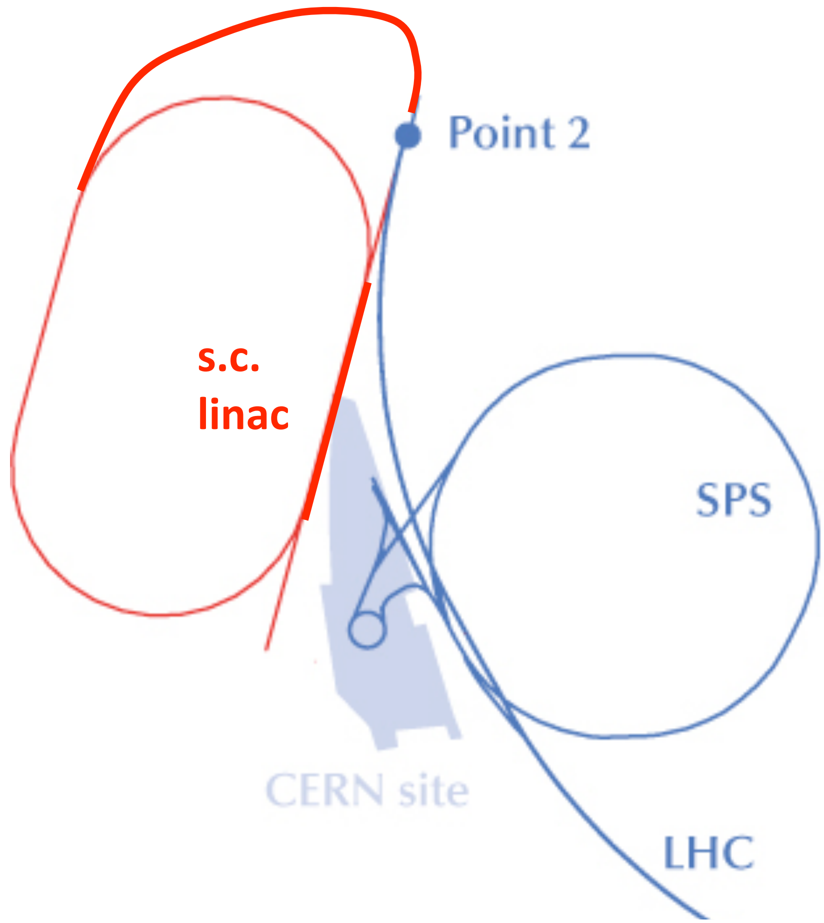
particle physicists request both e^-p &e^+p collisions; lepton polarization is also "very much desired"

option 1: “ring-ring” (RR)
e-/e+ ring in LHC tunnel



SPL, operating with leptons, as injector for the ring, possibly with recirculation

option 2: “ring-linac” (RL)



up to 70 GeV: option for cw operation and recirculation with energy recovery; > 70 GeV: pulsed operation at higher gradient ; γ-hadron option

tentative SC linac parameters for RL

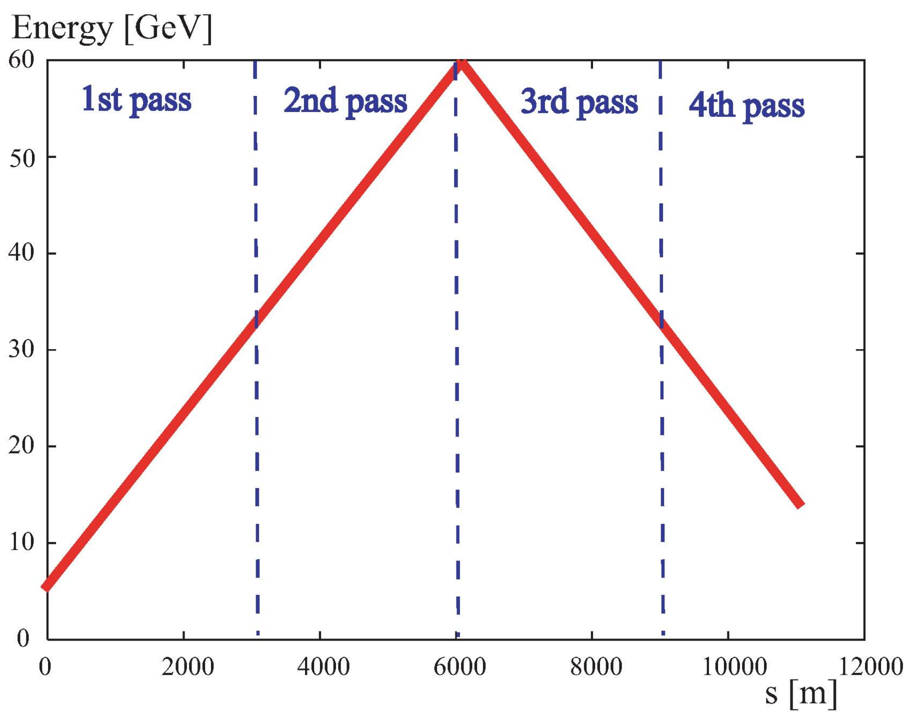
LHeC-RL scenario	lumi	baseline	energy
final energy [GeV]	60	100	140
cell length [m]	24	24	24
cavity fill factor	0.7	0.7	0.7
tot. linac length [m]	3000	2712	3024
cav. gradient [MV/m]	13	25	32
operation mode	CW (ERL)	pulsed	pulsed

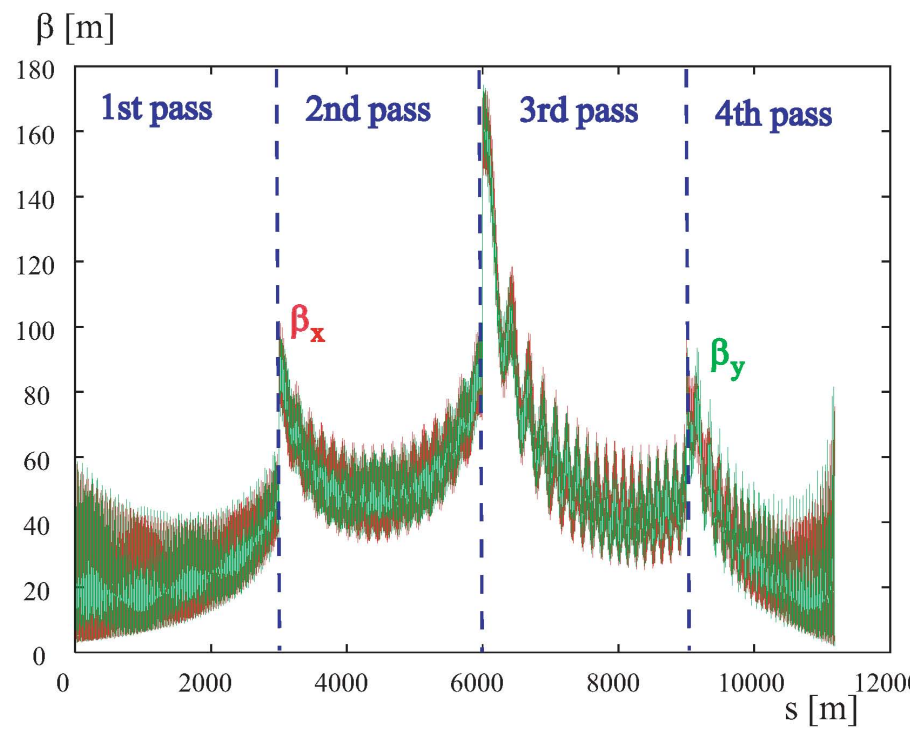
RF frequency: ~700 MHz

4 passes **2 passes**

Anders Eide

example linac optics for 4-pass ERL option





Anders Eide

luminosity constraints

LHC 7-TeV *p* beam parameters

	$N_{b,p}$	T_{sep}	$\varepsilon_p \gamma_p$	$\beta^*_{p,min}$
LHC phase-I upgrade	**$1.7\text{x}10^{11}$**	**25 ns**	**3.75 μm**	**0.25 m**
LHC phase-II upgrade (“LPA”)	**$5\text{x}10^{11}$**	**50 ns**	**3.75 μm**	**0.10 m**

p and *e* beams matched at collision point

ring emittance >> linac emittance

ring has larger IP beam divergence

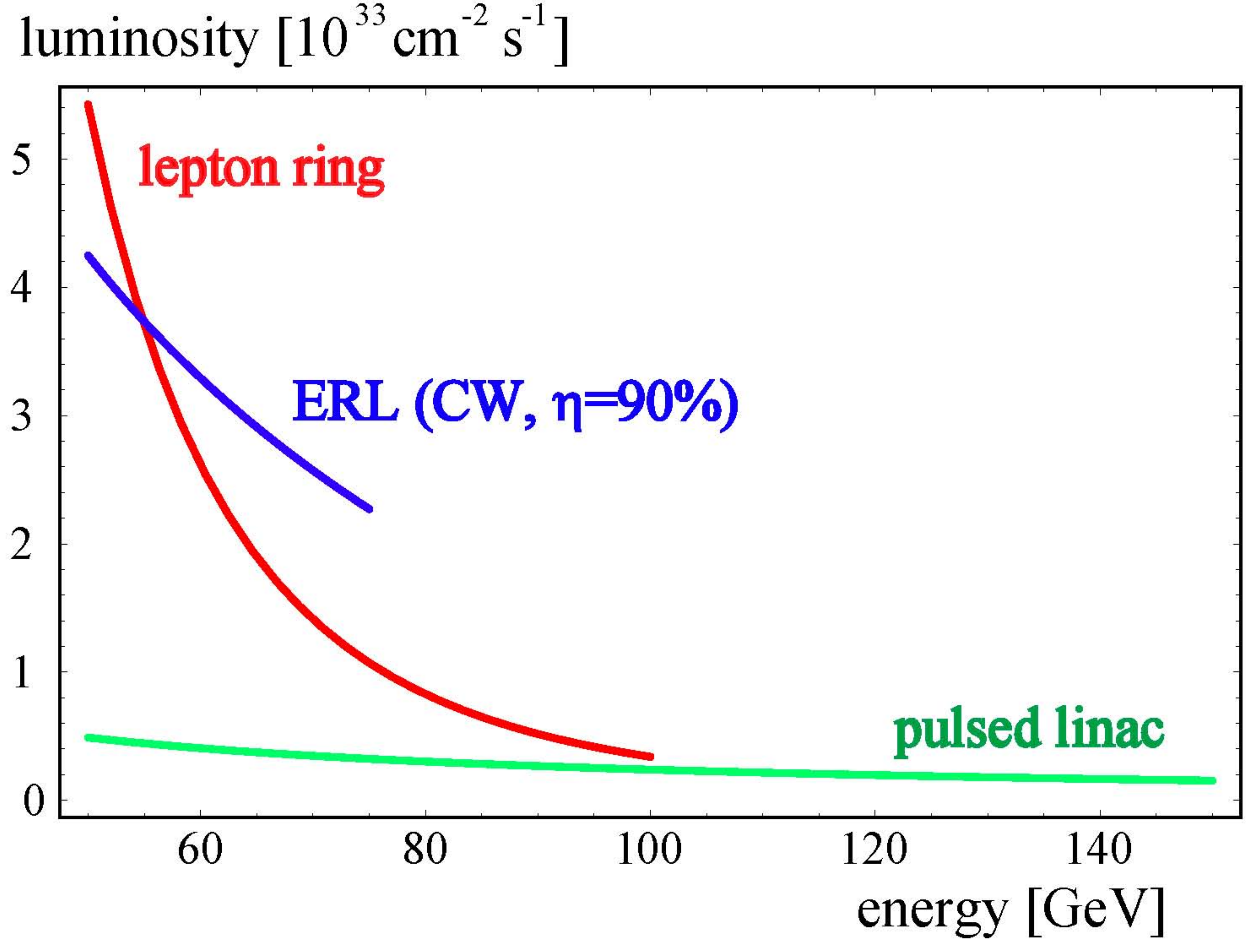
+ hourglass effect (→ larger β* for ring)

ring SR power = linac beam power & cryo power

= 100 MW

linac has much lower current

luminosity vs energy



example parameters

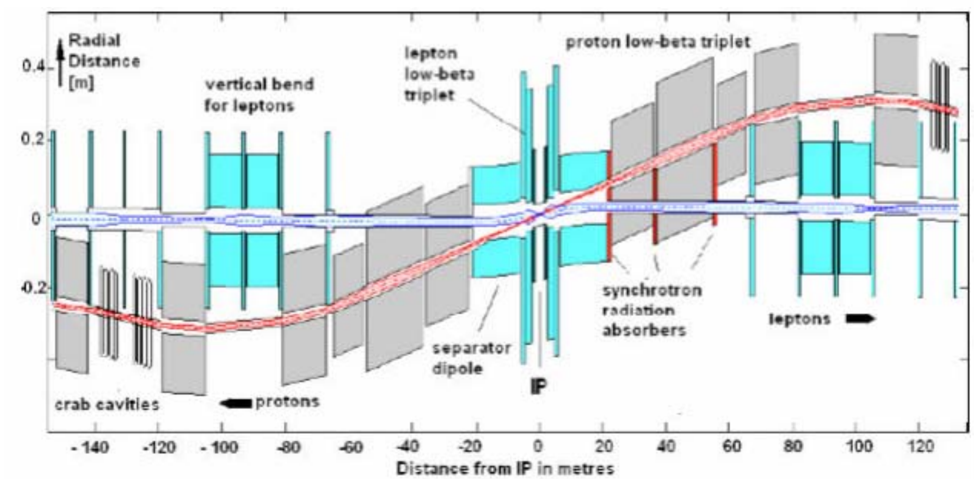
	LHeC-RR	LHeC-RL high lumi	LHeC-RL 100 GeV	LHeC-RL high energy	ILC	XFEL
e^- energy at IP [GeV]	60	60	100	140	(2×)250	20
luminosity [10^{32} cm^{-2}s^{-1}]	29	29† (2.9‡)	2.2	1.5	200	N/A
bunch population [10^{10}]	5.6	0.19† (0.02‡)	0.3 (1.5)	0.2 (1.0)	2	0.6
e^- bunch length [μm]	~10,000	300	300	300	300	24
bunch interval [ns]	50	50	50 (250)	50 (250)	369	200
norm. hor.&vert. emittance [μm]	4000, 2500	50	50	50	10, 0.04	1.4
average current [mA]	135	7† (0.7‡)	0.5	0.5	0.04	0.03
rms IP beam size [μm]	44, 27	7	7	7	0.64, 0.006	N/A
repetition rate [Hz]	CW	CW	10 [5% d.f.]	10 [5% d.f.]	5	10
bunches/pulse	N/A	N/A	71430	14286	2625	3250
pulse current [mA]	N/A	N/A	10	10	9	25
beam pulse length [ms]	N/A	N/A	5	5	1	0.65
cryo power [MW]	0.5	20	4	6	34	3.6
total wall plug power [MW]	100	100	100	100	230	19

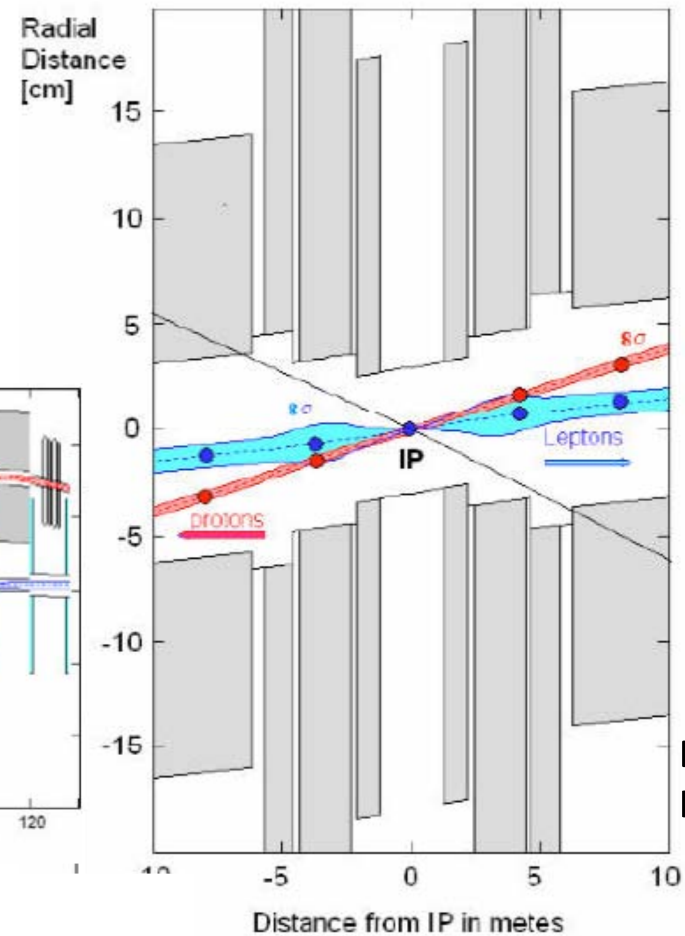
Example LHeC-RR and RL parameters. Numbers for LHeC-RL high-luminosity option marked by `†' assume energy recovery with $\eta_{ER}$=90%; those with `‡' refer to η_{ER}=0%. ILC and XFEL numbers are included for comparison. Note that optimization of the RR luminosity for different LHC beam assumptions leads to similar luminosity values of about 10^{33}cm^{-2}s^{-1}

IR layout & crab crossing (for RR)

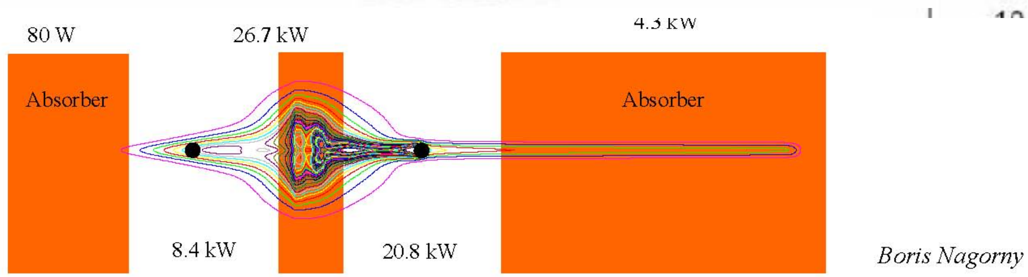
crossing angle to support early separation: 1-2 mrad

proton crab cavities:
15-30 MV at 800 MHz)





Bernhard Holzer



SC half quadrupoles synchrotron radiation

positrons

ring

a rebuilt conventional e^+ source would suffice

linac

true challenge: **10x more e^+ than ILC!**

large # bunches → damping ring difficult

candidate e^+ sources under study (*POSIPOL* coll.):

- **ERL Compton** source for CW operation

  e.g. 100 mA ERL w. 10 optical cavities

- **undulator source using spent e- beam**

- **linac-Compton** source for pulsed operation

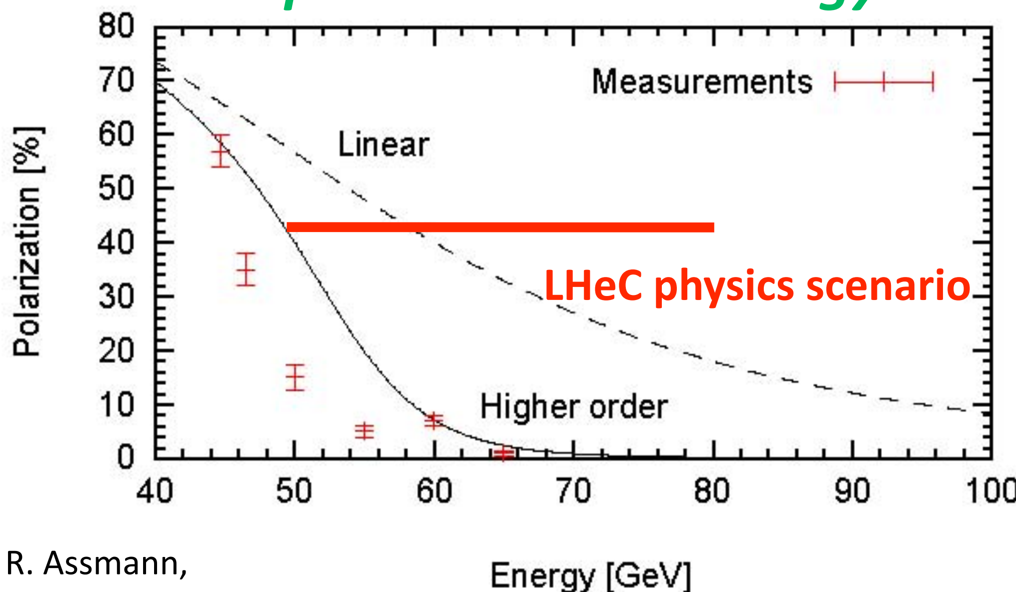
complementary options: collimate to shrink emittance, extremely fast damping in laser cooling ring?, recycle e+ together with recovering their energy?

T. Omori, J. Urakawa *et al*

polarization

ring

LEP polarization vs. energy



R. Assmann, Chamonix 1999, & Spin2000

Sokolov-Ternov polarization time decreases from 5 hr at 46 GeV to ½ hr at 70 GeV

but depolarizing rate increases even faster

"very very difficult, but polarization cannot be fully excluded w/o study"

R. Assmann, D. Barber

linac

e- : from polarized dc gun with ~90% polarization, 10-100 μm normalized emittance

e+: up to ~60% from undulator or Compton-based source

conclusions

LHeC could provide **high-energy high-luminosity**
$e^{\pm}p$ & $e^{\pm}A$ collisions

two major designs under study:

✓**ring-ring option** with **$10^{33}cm^{-2}s^{-1}$ up to 80 GeV**

✓**linac-ring option with similar luminosity using**
$\pm$
energy recovery, possible **extension to 140 GeV**

ring injection may be provided by **operating the SPL as an e^{-}/e^{+} accelerator**, possibly w. recirculation

some **intriguing accelerator-physics** issues:
e^{+} production (L), energy recovery (L),
crab cavities (R), polarization (R),….

more information

LHeC web site
www.lhec.org.uk

second ECFA-CERN workshop on the LHeC in September 2009