parameters of LHeC in the 80-km tunnel

"*TLHeC*" and "*VHE-TLHeC*"

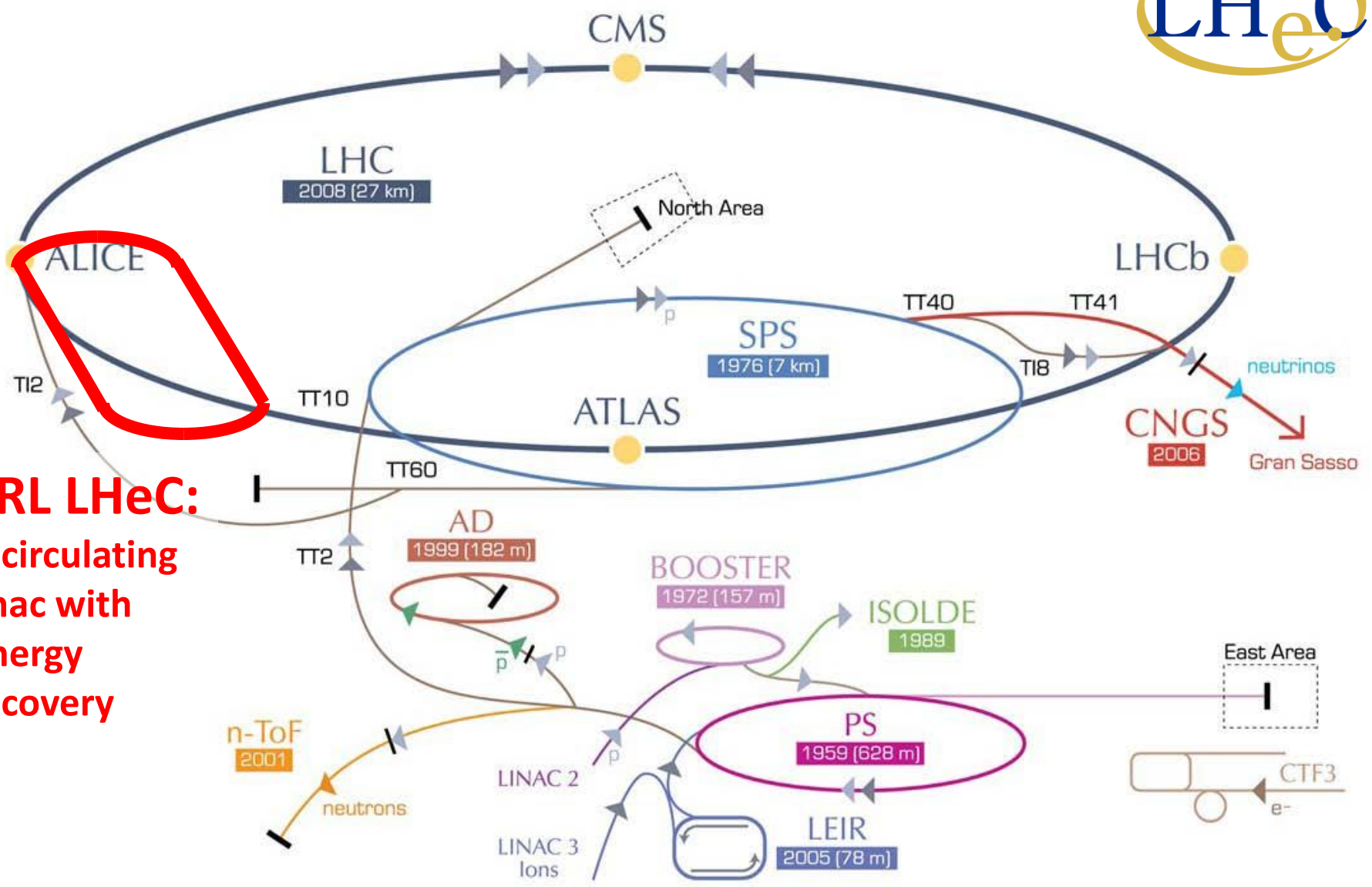
Frank Zimmermann

Joint Snowmass-EuCARD/AccNet-HiLumi LHC meeting
'Frontier Capabilities for Hadron Colliders 2013'

21 February 2013

work supported by the European Commission under the FP7 Research Infrastructures project EuCARD, grant agreement no. 227579

Large Hadron electron Collider (LHeC)
baseline design



ERL LHeC:
recirculating linac with energy recovery

LHeC Conceptual Design Report

DRAFT 1.0
Geneva, September 3, 2011
CERN report
ECFA report
NuPECC report
LHeC-Note-2011-003 GEN

A Large Hadron Electron Collider at CERN

Report on the Physics and Design
Concepts for Machine and Detector

LHeC Study Group
THIS IS THE VERSION FOR REFEREEING, NOT FOR DISTRIBUTION

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http://cern.ch/lhec

LHeC Study Group

J. Abelleira Fernandez[10,15], C.Adolphsen[39], S.Alekhin[40,11], A.N.Akai[01], H.Aksakal[30], P.Allport[17], J.L.Albacete[37], V.Andreev[25], R.B.Appleby[23], N.Armesto[38], G.Azuelos[26], M.Bai[47], D.Barber[11], J.Bartels[12], J.Behr[11], O.Behnke[11], S.Belyaev[10], I.BenZvi[47], N.Bernard[16], S.Bertolucci[10], S.Bettoni[10], S.Biswal[32], J.Bluemlein[11], H.Boettcher[11], H.Braun[48], S.Brodsky[39], A.Bogacz[28], C.Bracco[10], O.Bruening[10], E.Bulyak[08], A.Bunyatian[11], H.Burkhardt[10], I.T.Cakir[54], O.Cakir[53], R.Calaga[47], E.Ciapala[10], R.Ciftci[01], A.K.Ciftci[01], B.A.Cole[29], J.C.Collins[46], J.Dainton[17], A.De.Roeck[10], D.d'Enterria[10], A.Dudarev[10], A.Eide[43], E.Eroglu[45], K.J.Eskola[14], L.Favart[06], M.Fitterer[10], S.Forte[24], P.Gambino[42], T.Gehrmann[50], C.Glasman[22], R.Godbole[27], B.Goddard[10], T.Greenshaw[17], A.Guffanti[09], V. Guzey[28], C.Gwenlan[34], T.Han[36], Y.Hao[47], F.Haug[10], W.Herr[10], B.Holzer[10], M.Ishitsuka[41], M.Jacquet[33], B.Jeanneret[10], J.M.Jimenez[10], H.Jung[11], J.M.Jowett[10], H.Karadeniz[54], D.Kayran[47], F.Kocac[45], A.Kilic[45], K.Kimura[41], M.Klein[17], U.Klein[17], T.Kluge[17], G.Kramer[12], M.Korostelev[23], A.Kosmicki[10], P.Kostka[11], H.Kowalski[11], D.Kuchler[10], M.Kuze[41], T.Lappi[14], P.Laycock[17], E.Levichev[31], S.Levonian[11], V.N.Litvinenko[47], A.Lombardi[10], C.Marquet[10], B.Mellado[07], K.H.Mess[10], S.Moch[11], I.I.Morozov[31], Y.Muttoni[10], S.Myers[10], S.Nandi[26], P.R.Newman[03], T.Omori[44], J.Osborne[10], Y.Papaphilippou[10], E.Paoloni[35], C.Pascaud[33], H.Paukkunen[38], E.Perez[10], T.Pieloni[15], E.Pilicer[45], A.Polini[04], V.Ptitsyn[47], Y.Pupkov[31], V.Radescu[13], S.Raychaudhuri[27], L.Rinolfi[10], R.Rohini[27], J.Rojo[24], S.Russenschuck[10], C.A.Salgado[38], K.Sampei[41], E.Sauvan[19], M.Sahin[01], U.Schneekloth[11], A.N.Skrinsky[31], T.Schoerner Sadenius[11], D.Schulte[10], H.Spiesberger[21], A.M.Stasto[46], M.Strikman[46], M.Sullivan[39], B.Surrow[05], S.Sultansoy[01], Y.P.Sun[39], W.Smith[20], I.Tapan[45], P.Taels[02], E.Tassi[52], H.Ten.Kate[10], J.Terron[22], H.Thiesen[10], L.Thompson[23], K.Tokushuku[44], R.Tomas.Garcia[10], D.Tommasini[10], D.Trbojevic[47], N.Tsoupas[47], J.Tuckmantel[10], S.Turkoz[53], K.Tywoniuk[18], G.Unel[10], J.Urakawa[44], P.VanMechelen[02], A.Variola[37], R.Veness[10], A.Vivoli[10], P.Vobly[31], R.Wallny[51], G.Watt[10], G.Weiglein[12], C.Weiss[28], U.A.Wiedemann[10], U.Wienands[39], F.Willeke[47], V.Yakimenko[47], A.F.Zarnecki[49], F.Zimmermann[10], F.Zomer[33]

About 150 Experimentalists and Theorists from 50 Institutes
Tentative list

Thanks to all and to
CERN, ECFA, NuPECC

~600 pages

LHeC Higgs physics

- precision coupling measurements

  ($Hb\bar{b}$, $H\gamma\gamma$, $H4l$,…)
- reduction of theoretical QCD-related uncertainties in *pp* Higgs physics
- potential to find new physics at the cleanly accessible *WWH* (and *ZZH*) vertices

L-R LHeC road map to ≥10^{33} $cm^{-2}s^{-1}$

luminosity of LR collider:

(round beams)

H_D~1.3

D. Schulte
LHeC2010

$$L = \frac{1}{4\pi e}\frac{N_{b,p}}{\varepsilon_p}\frac{1}{\beta^*_p} I_e H_{hg} H_D$$

highest proton
beam brightness "permitted"
(ultimate LHC values)

$\gamma\varepsilon$=3.75 μm

N_b=1.7x10^{11}

bunch spacing
25 or 50 ns

smallest conceivable
proton β* function:
- reduced *l** (23 m → 10 m)
- squeeze only one *p* beam
- new magnet technology Nb_3Sn

β^*_p=0.1 m

average e^-
current
limited by
energy
recovery
efficiency

I_e=6.4 mA

maximize geometric
overlap factor
- head-on collision
- small e- emittance

θ_c=0

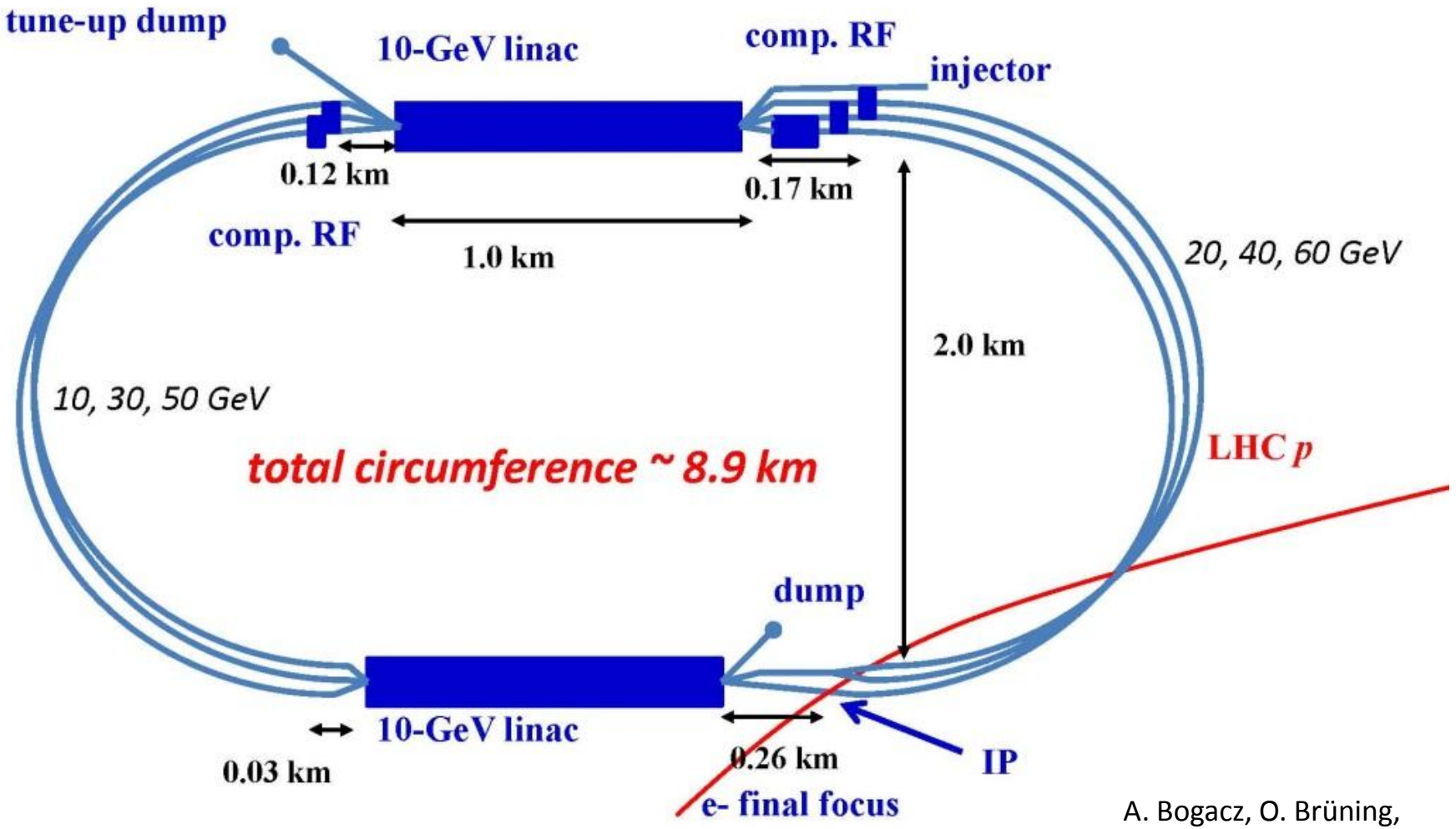
H_{hg}≥0.9

parameter [unit]	LHeC	
species	$e^{\pm}$	p, $^{208}Pb^{82+}$
beam energy (/nucleon) [GeV]	60	7000, 2760
bunch spacing [ns]	25, 100	25, 100
bunch intensity (nucleon) [10^{10}]	0.1 (0.2), 0.4	17 (22), 2.5
beam current [mA]	6.4 (12.8)	860 (1110), 6
rms bunch length [mm]	0.6	75.5
polarization [%]	90 (e^+ none)	none, none
normalized rms emittance [μm]	50	3.75 (2.0), 1.5
geometric rms emittance [nm]	0.43	0.50 (0.31)
IP beta function $\beta^*_{x,y}$ [m]	0.12 (0.032)	0.1 (0.05)
IP rms spot size [μm]	**7.2 (3.7)**	**7.2 (3.7)**
synchrotron tune	-	0.0019
hadron beam-beam parameter	0.0001 (0.0002)	
lepton disruption parameter D	6 (30)	
hourglass reduction factor H_{hg}	0.91 (0.67)	
pinch enhancement factor H_D	1.35 (0.3 for e^+)	
luminosity/ nucleon [10^{33} cm^{-2}s^{-1}]	**1 (10), 0.2**	

LHeC baseline (& pushed) parameters

LHeC ERL layout

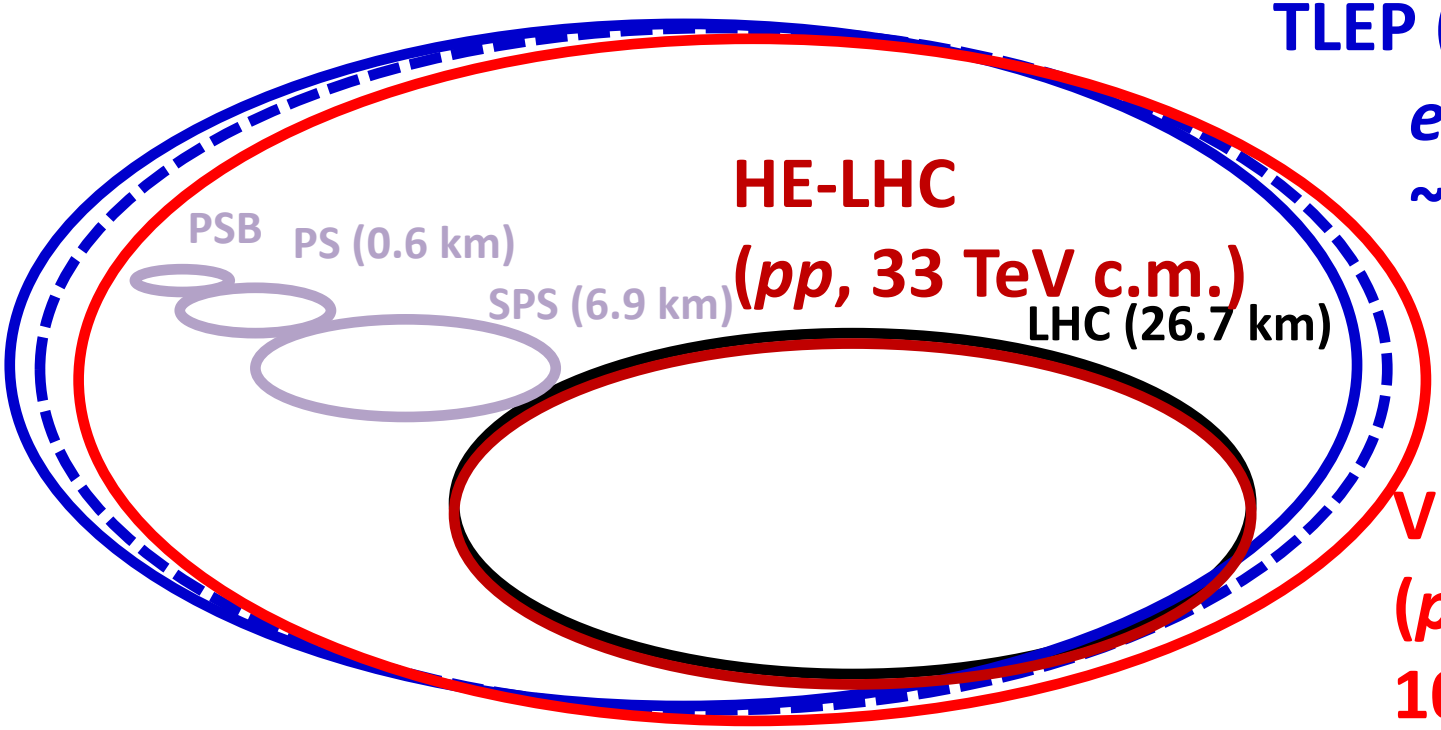
two 10-GeV SC linacs, 3-pass up, 3-pass down; 6.4 mA, 60 GeV e^-'s collide w. LHC protons/ions



(*C*=1/3 LHC allows for ion clearing gaps)

A. Bogacz, O. Brüning, M. Klein, D. Schulte, F. Zimmermann, et al

possible long-term strategy for HEP



TLEP (80 km, e^+e^-, up to ~350 GeV c.m.)

VHE-LHC (*pp*, up to 100 TeV c.m.) same detectors!

(E. Meschi)

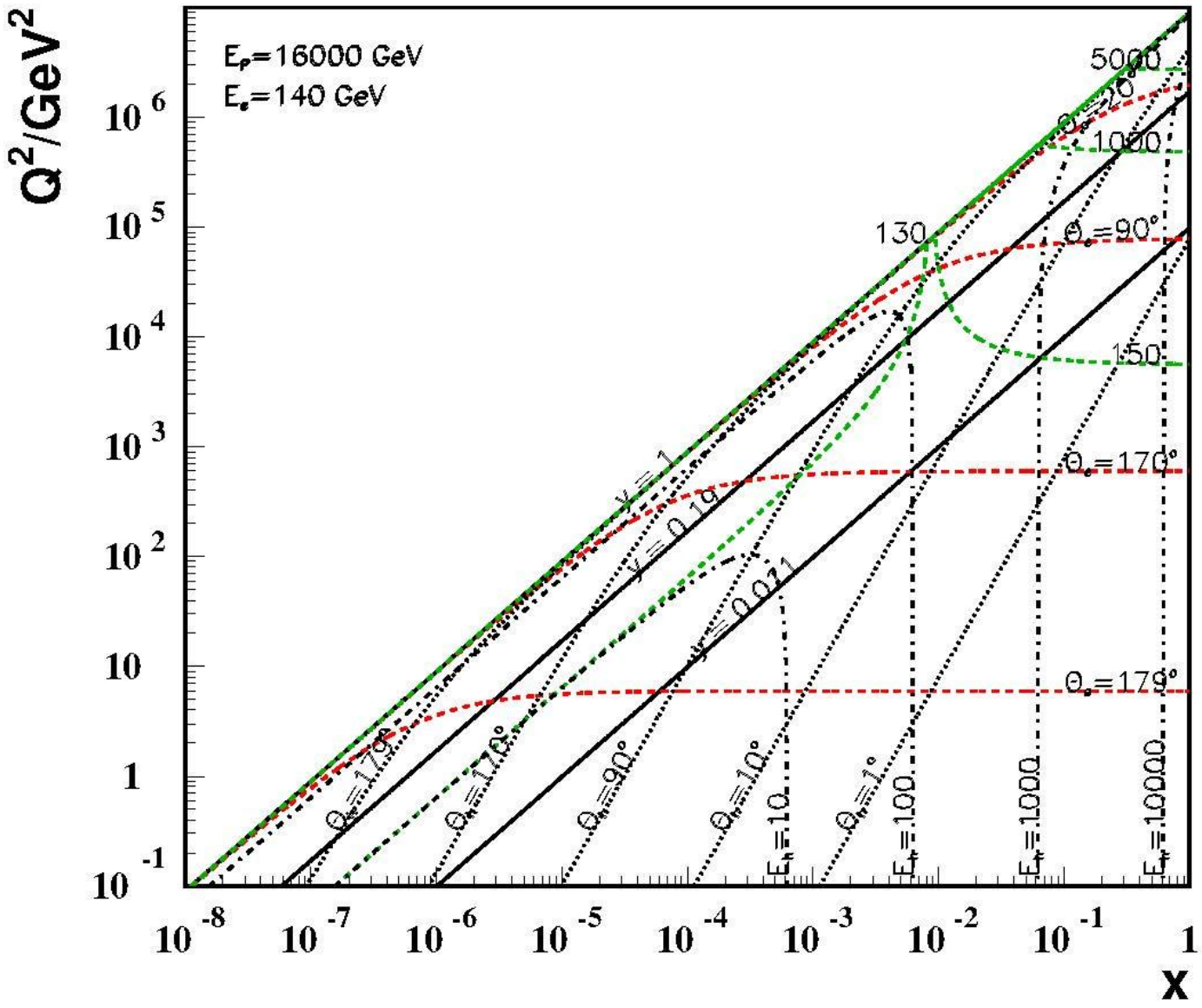
& $e^{\pm}$ (120 GeV) – *p* (7, 16 & 50 TeV) collisions ([(V)HE-]TLHeC)

≥50 years of e^+e^-, *pp*, *ep/A* physics at highest energies

parameters for *TLHeC* & *VHE-TLHeC* (e- at 120 GeV)

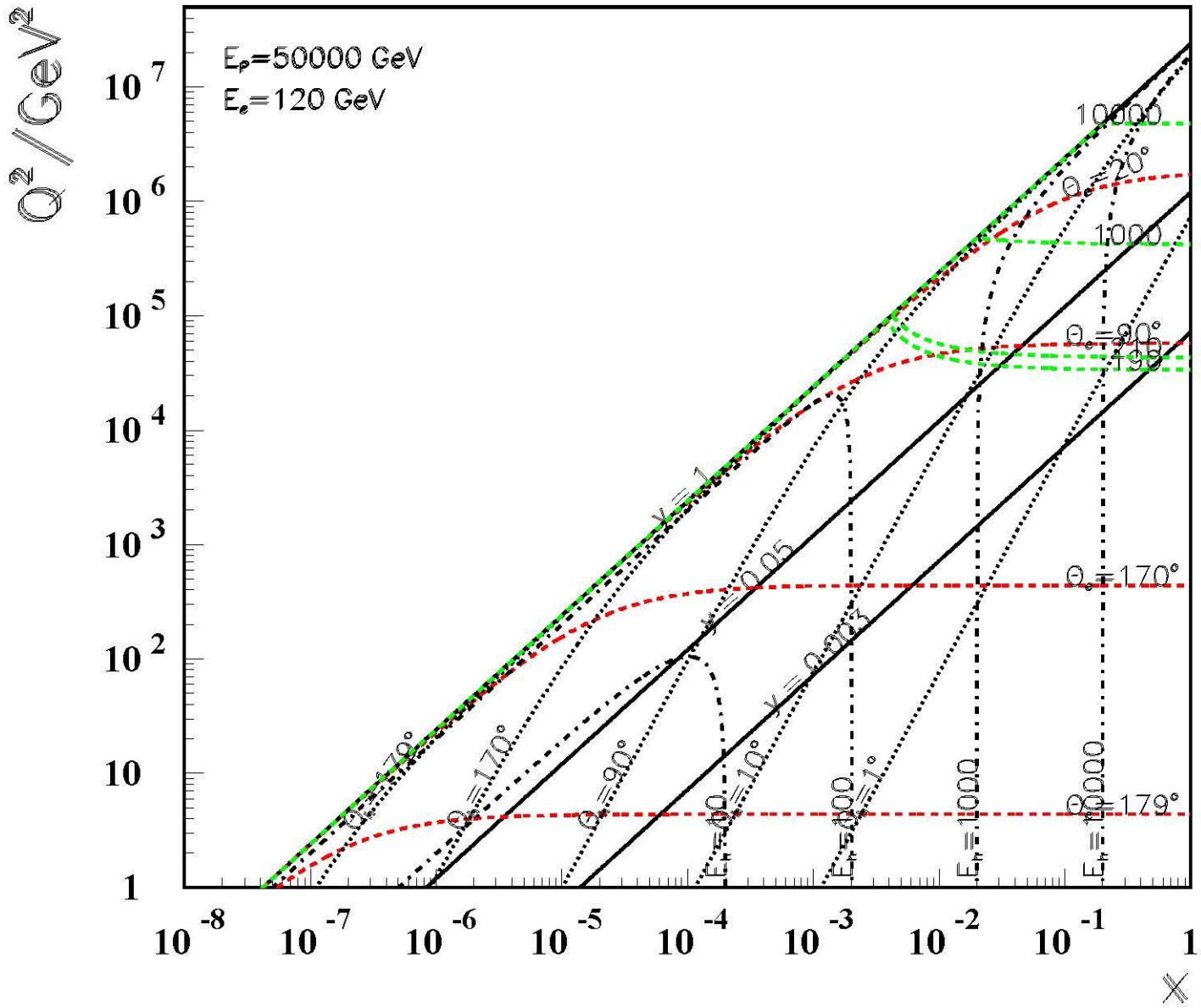
collider parameters	TLHeC		VHE-TLHeC	
species	$e^{\pm}$	p	$e^{\pm}$	p
beam energy [GeV]	**120**	**7000**	**120**	**50000**
bunch spacing [μs]	3	3	3	3
bunch intensity [10^{11}]	5	3.5	5	3.5
beam current [mA]	24.3	51.0	24.3	51.0
rms bunch length [cm]	0.17	4	0.17	2
rms emittance [nm]	10,2	0.40	10,2	0.06
$\beta_{x,y}$*[cm]	2,1	60,5	0.5,0.25	60,5
$\sigma_{x,y}$* [μm]	15, 4		6, 2	
beam-beam parameter ξ	0.05, 0.09	**0.03,0.01**	0.07,0.10	**0.03,0.007**
hourglass reduction	**0.63**		**0.42**	
CM energy [TeV]	1.8		4.9	
luminosity [10^{34}cm^{-2}s^{-1}]	**0.5**		**1.6**	

Kinematics at HE-TLHeC



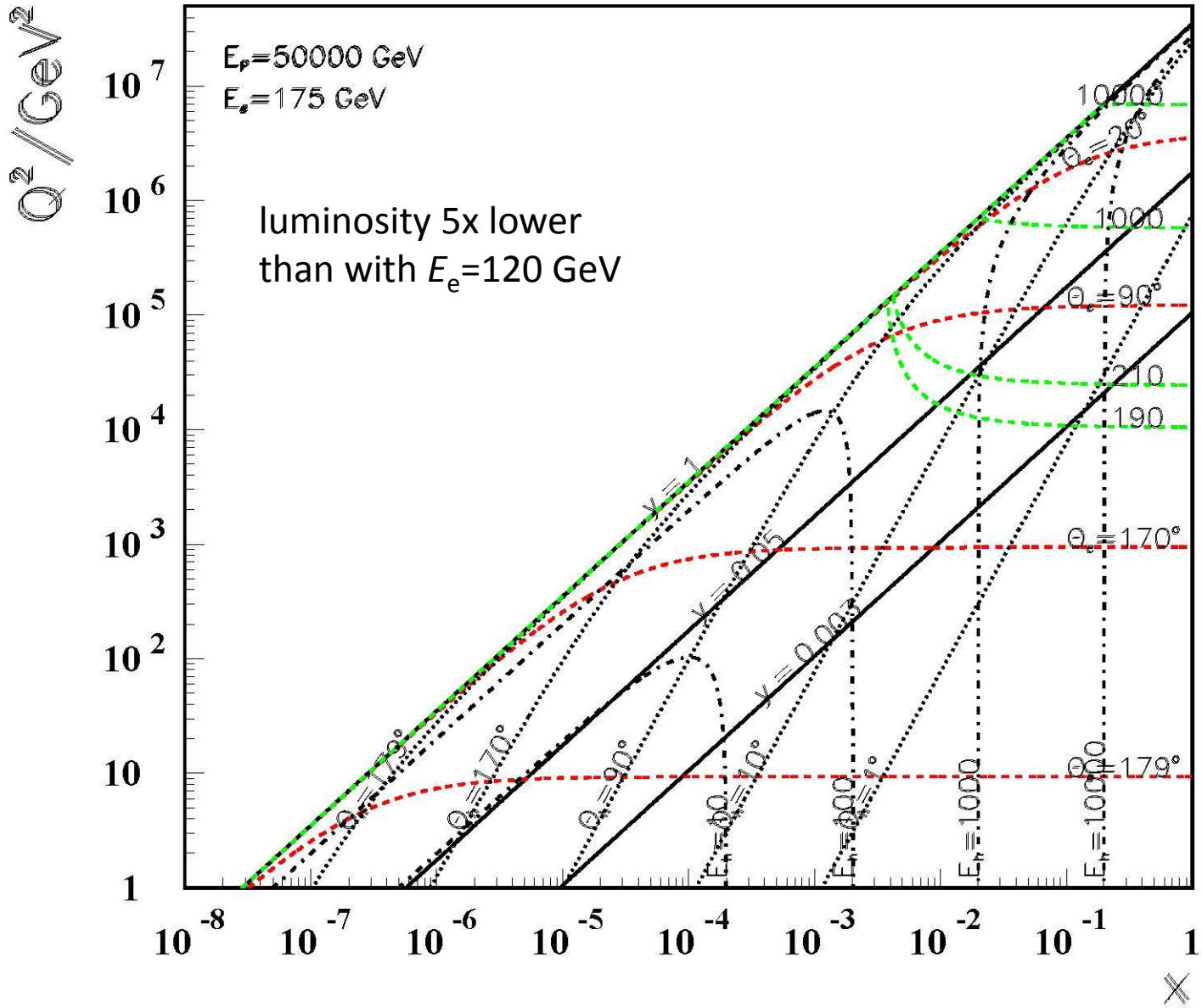
M. Klein

Kinematics at VHE-TLHeC



M. Klein

Kinematics at VHE-TLHeC



M. Klein

scaling is

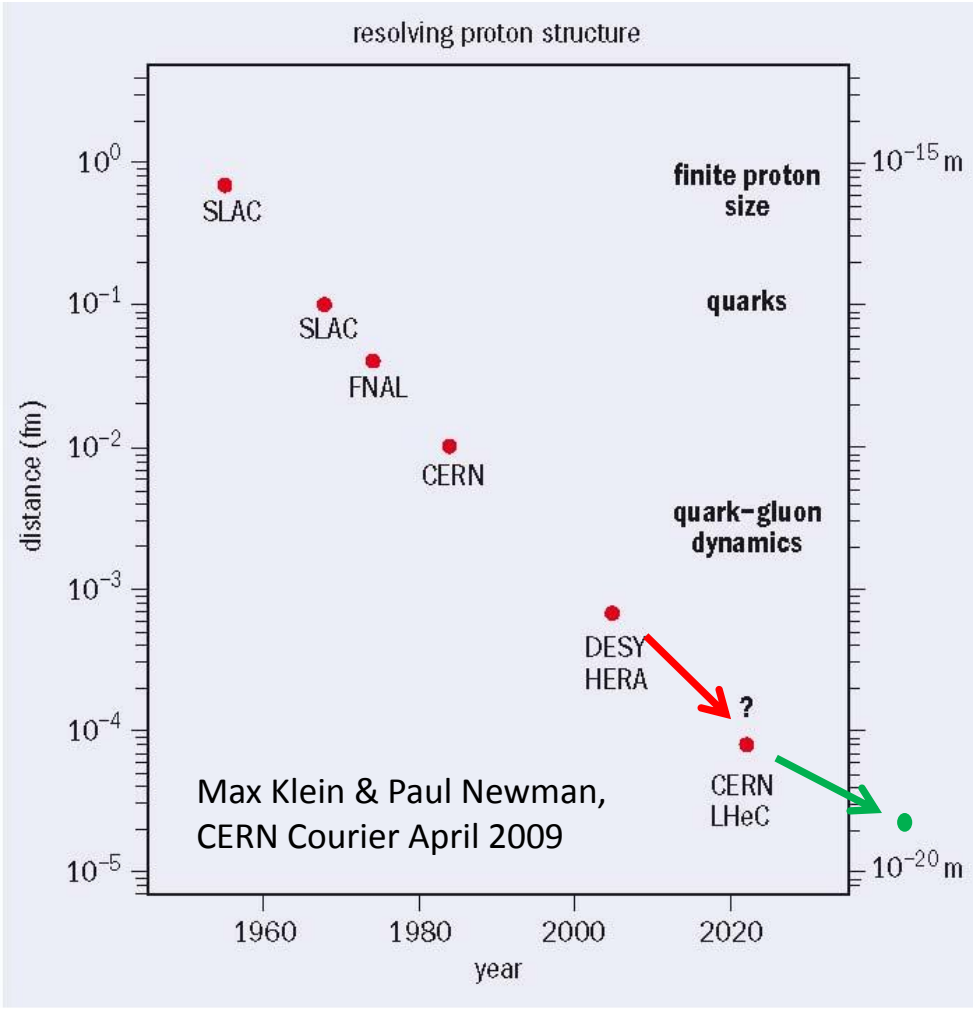
$$L \propto \frac{1}{E_e^4} \propto \frac{1}{E_{CM}^8}$$

assuming that we adjust emittance optics (or wigglers) to keep emittance constant

maybe it is better to run at E_e=60 GeV like LHeC?

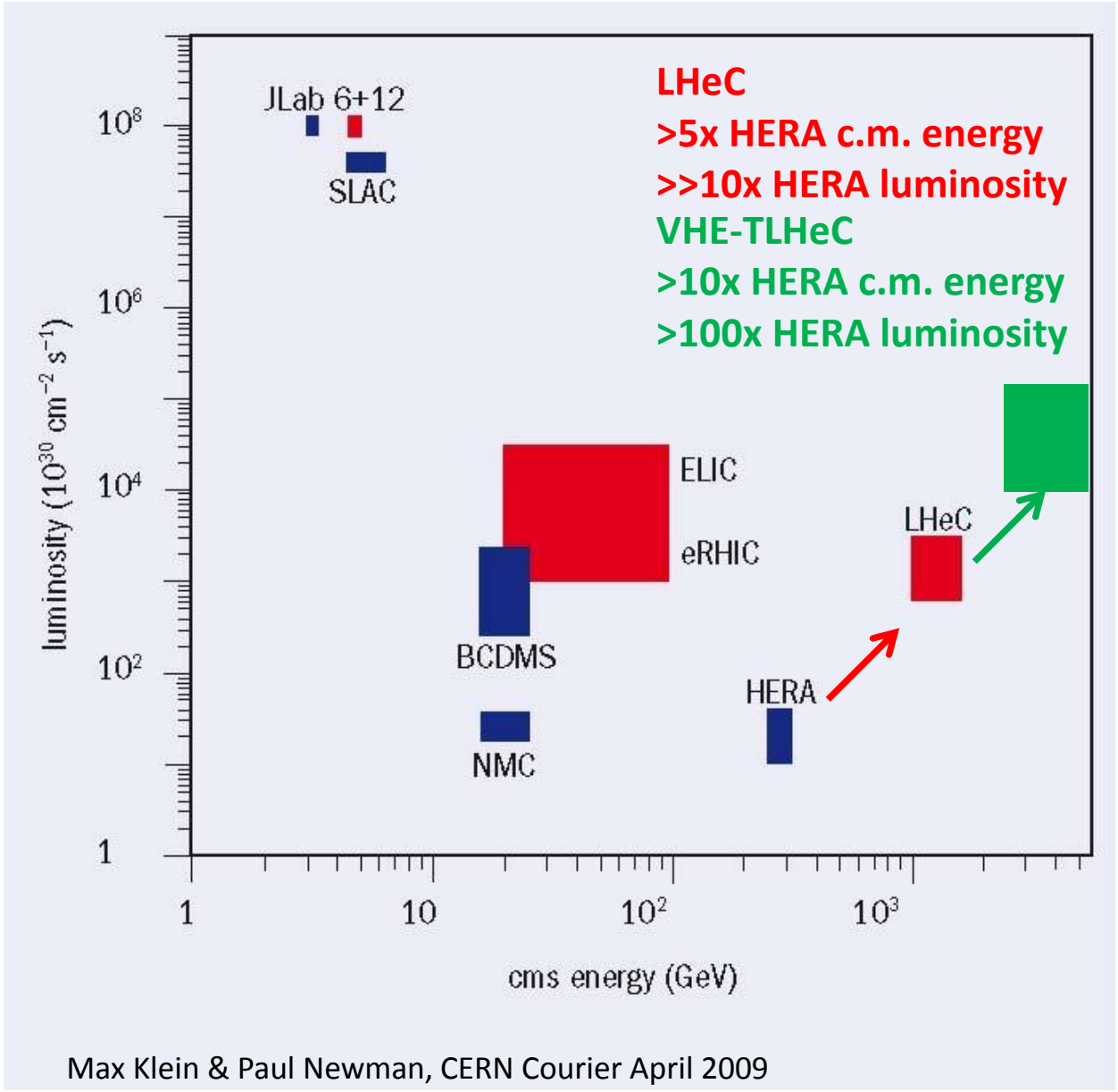
parameters for *TLHeC* & *VHE-TLHeC* (e^- at 60 GeV)

collider parameters	TLHeC		VHE-TLHeC	
species	$e^{\pm}$	p	$e^{\pm}$	p
beam energy [GeV]	**60**	**7000**	**60**	**50000**
bunch spacing [μs]	0.2	0.2	0.2	0.2
bunch intensity [10^{11}]	5	3.5	5	3.5
beam current [mA]	390	51.0	390	51.0
rms bunch length [cm]	0.18	4	0.18	2
rms emittance [nm]	10, 2	0.40	10, 2	0.06
$\beta_{x,y}$*[cm]	2, 1	60, 5	0.5, 0.25	60,5
$\sigma_{x,y}$* [μm]	15, 4		6, 2	
beam-beam parameter ξ	**0.10, 0.18**	**0.03,0.01**	**0.14, 0.20**	**0.03,0.007**
hourglass reduction	**0.63**		**0.42**	
CM energy [TeV]	1.3		3.5	
luminosity [10^{34}cm^{-2}s^{-1}]	**8.0**		**25.6**	



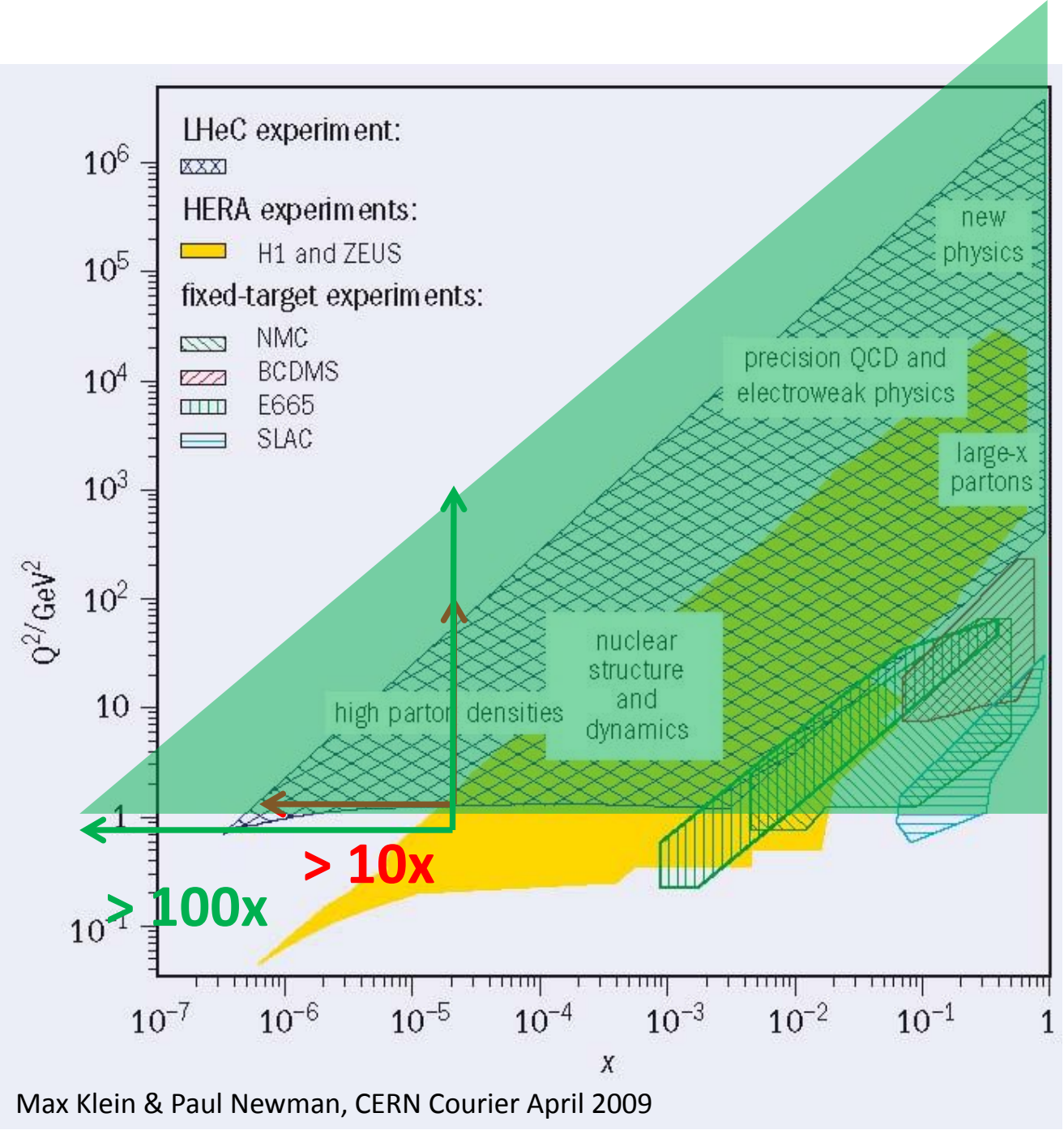
VHE-TLHeC

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



Max Klein & Paul Newman, CERN Courier April 2009

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



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***, ***LHeC*** and ***VHE-TLHeC***

another advantage of
TLHeC and VHE-TLHeC:

e^+p collisions at the same luminosity as e^-p!

this is very challenging for LHeC

conclusions

TLEP & VHE-LHC or (HE-)LHC
bring **VHE-TLHeC or TLHeC $e^{\pm}p$ collisions "for free"**

2-3 orders of magnitude in Q^2 and x beyond HERA and 1-2 orders of magnitude beyond LHeC

running at different e^- energies together with TLEP operation modes

glorious history of deep inelastic scattering

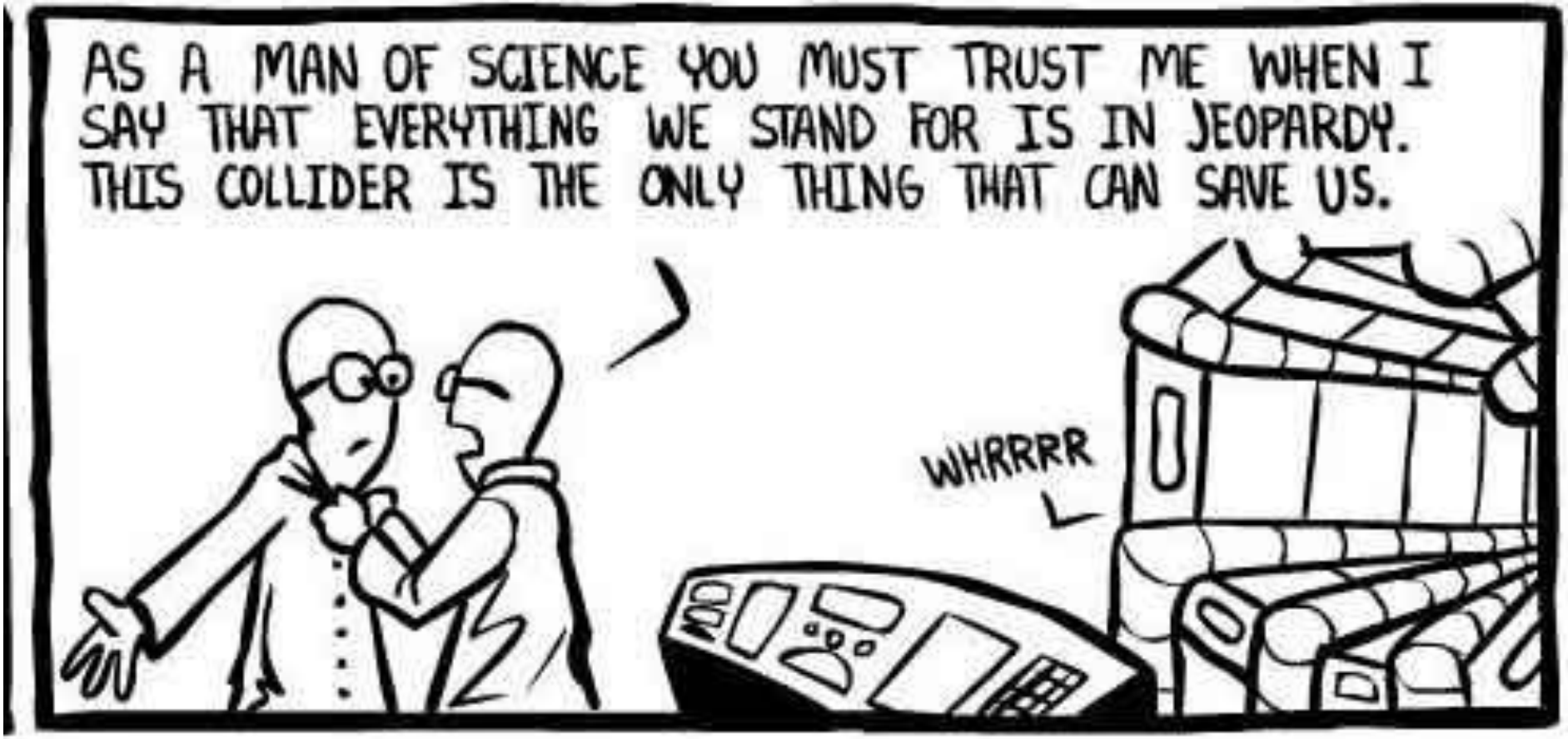
1911 discovery of atomic nucleus, by Ernest Rutherford

1950's discovery of structure of nuclei and nucleons, by
Robert Hoffstadter

1966-1978: discovery of the quark, by
Richard Taylor, Henry Kendall, and Jerome Friedman

next Nobel Prize at LHeC or VHE-TLHeC!?

… and a last argument for the VHE-TLHeC



appendix:

LEP2, LHEC, LEP3 & TLEP parameters

LEP3/TLEP parameters -1

soon at SuperKEKB:
β_x*=0.03 m, β_Y*=0.03 cm

	LEP2	LHeC	LEP3	TLEP-Z	TLEP-H	TLEP-t
beam energy E_b [GeV]	104.5	60	120	45.5	120	175
circumference [km]	26.7	26.7	26.7	80	80	80
beam current [mA]	4	100	7.2	1180	24.3	5.4
#bunches/beam	4	2808	4	2625	80	12
#e-/beam [10^{12}]	2.3	56	4.0	2000	40.5	9.0
horizontal emittance [nm]	48	5	25	30.8	9.4	20
vertical emittance [nm]	0.25	2.5	0.10	0.15	0.05	0.1
bending radius [km]	3.1	2.6	2.6	9.0	9.0	9.0
partition number J_ε	1.1	1.5	1.5	1.0	1.0	1.0
momentum comp. α_c [10^{-5}]	18.5	8.1	8.1	9.0	1.0	1.0
SR power/beam [MW]	11	44	50	50	50	50
β^*_x [m]	1.5	0.18	0.2	0.2	0.2	0.2
β^*_y [cm]	5	10	0.1	0.1	0.1	0.1
σ^*_x [μm]	270	30	71	78	43	63
σ^*_y [μm]	3.5	16	0.32	0.39	0.22	0.32
hourglass F_{hg}	0.98	0.99	0.59	0.71	0.75	0.65
ΔE^{SR}_{loss}/turn [GeV]	3.41	0.44	6.99	0.04	2.1	9.3

SuperKEKB:$\varepsilon_y/\varepsilon_x$=0.25%

LEP3/TLEP parameters -2

LEP2 was not beam-beam limited

	LEP2	LHeC	LEP3	TLEP-Z	TLEP-H	TLEP-t
$V_{RF,tot}$ [GV]	3.64	0.5	12.0	2.0	6.0	12.0
$\delta_{max,RF}$ [%]	0.77	0.66	5.7	4.0	9.4	4.9
ξ_x/IP	0.025	N/A	0.09	0.12	0.10	0.05
ξ_y/IP	0.065	N/A	0.08	0.12	0.10	0.05
f_s [kHz]	1.6	0.65	2.19	1.29	0.44	0.43
E_{acc} [MV/m]	7.5	11.9	20	20	20	20
eff. RF length [m]	485	42	600	100	300	600
f_{RF} [MHz]	352	721	700	700	700	700
δ^{SR}_{rms} [%]	0.22	0.12	0.23	0.06	0.15	0.22
$\sigma^{SR}_{z,rms}$ [cm]	1.61	0.69	0.31	0.19	0.17	0.25
L/IP[10^{32}cm^{-2}s^{-1}]	1.25	N/A	94	10335	490	65
number of IPs	4	1	2	2	2	2
Rad.Bhabha b.lifetime [min]	360	N/A	18	74	32	54
Υ_{BS} [10^{-4}]	0.2	0.05	9	4	15	15
n_γ/collision	0.08	0.16	0.60	0.41	0.50	0.51
ΔE^{BS}/collision [MeV]	0.1	0.02	31	3.6	42	61
ΔE^{BS}_{rms}/collision [MeV]	0.3	0.07	44	6.2	65	95
critical SR energy [MeV]	0.81	0.18	1.47	0.02	0.43	1.32

LEP data for 94.5 - 101 GeV consistently suggest a beam-beam limit of ~0.115 (R.Assmann, K. C.)