Status Report on LHeC to ECFA
A Large Hadron electron Collider at the LHC
5-140 GeV $e^{\pm}$ on 1-7 TeV p,A

Max Klein
University of Liverpool and Cockcroft Institute
H1 and ATLAS

LHeC Scientific Advisory Committee

Guido Altarelli (Rome)
Stan Brodsky (SLAC)
Allen Caldwell -chair (MPI Munich)
Swapan Chattopadhyay (Cockcroft)
John Dainton (Liverpool)
John Ellis (CERN)
Jos Engelen (CERN)
Joel Feltesse (Saclay)
Lev Lipatov (St.Petersburg)
Roland Garoby (CERN)
Rolf Heuer (DESY)
Roland Horisberger (PSI)
Young-Kee Kim (Fermilab)
Aharon Levy (Tel Aviv)
Karlheinz Meier (Heidelberg, ECFA)
Richard Milner (Bates)
Steven Myers, (CERN)
Guenter Rosner (Glasgow, NuPECC)
Alexander Skrinsky (Novosibirsk)
Anthony Thomas (Jlab)
Steven Vigdor (BNL)
Frank Wilczek (MIT)
Ferdinand Willeke (BNL)

ECFA, CERN, 28.11.2008
http://www.lhec.org.uk

klein@ifh.de

Accelerator (Ring-Ring, Linac-Ring)
Interaction Region and Fwd/Bwd Detectors
Detector

Accelerator Design [RR and LR]

Oliver Bruening (CERN),

John Dainton (CI/Liverpool)

Interaction Region and Fwd/Bwd

Bernhard Holzer (DESY),

Uwe Schneeekloth (DESY),

Pierre van Mechelen (Antwerpen)

Detector Design

Peter Kostka (DESY),

Rainer Wallny (UCLA),

Alessandro Polini (Bologna)

Machine Requirements

-New physics expected at TeV scale. Low $x=Q^2/sy$, $s=4E_eE_p$

highest possible E_e and E_p **1 TeV with 50 GeV on 5000 GeV**

-New physics is rare [σ_{ep} (Higgs) = O(100)fb] , rate at high Q^2 , large x

L has to exceed 10^{32} and preferentially reaches 10^{33} and beyond

-New states, DVCS, electroweak physics

Need electrons and positrons and lepton beam polarisation

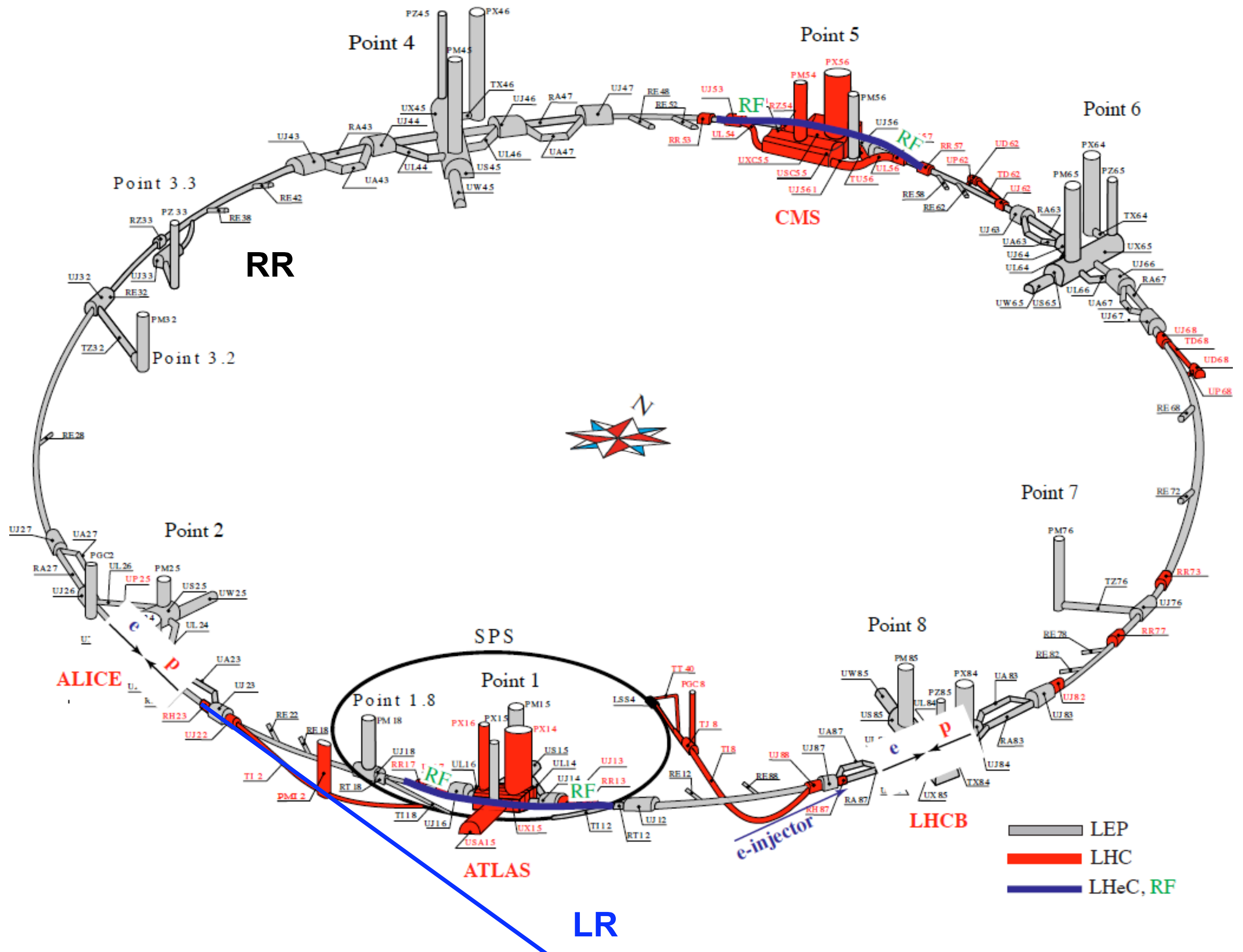
-Neutron structure terra incognita

Deuterons

-Partonic Structure of Nuclei

a series of nuclei, Ca, Pb

Machine Considerations



Joint study with CERN, BNL, CI, Jlab, DESY, .. experts

generalities

simultaneous ep and pp

power limit set to 100MW

IR at 2 or 8

p/A:

SLHC - high intensity p
(LPA/50ns or ESP/25ns)

Ions: via PS2
new source for deuterons

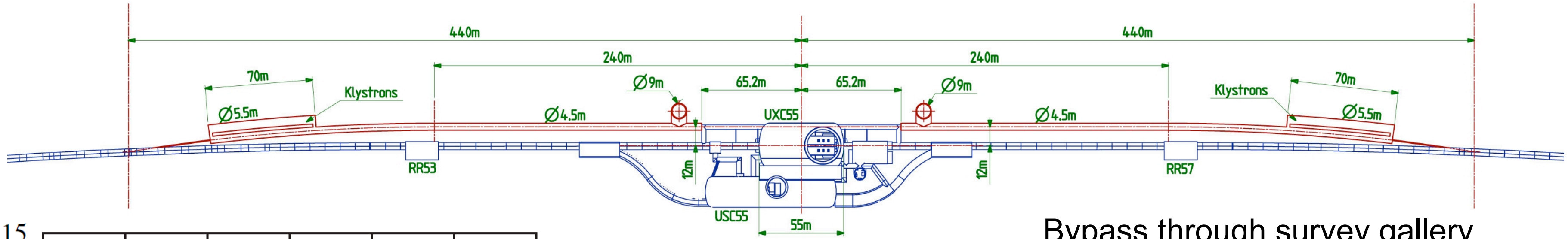
e Ring:

bypasses: 1 and 5
[use also for rf]

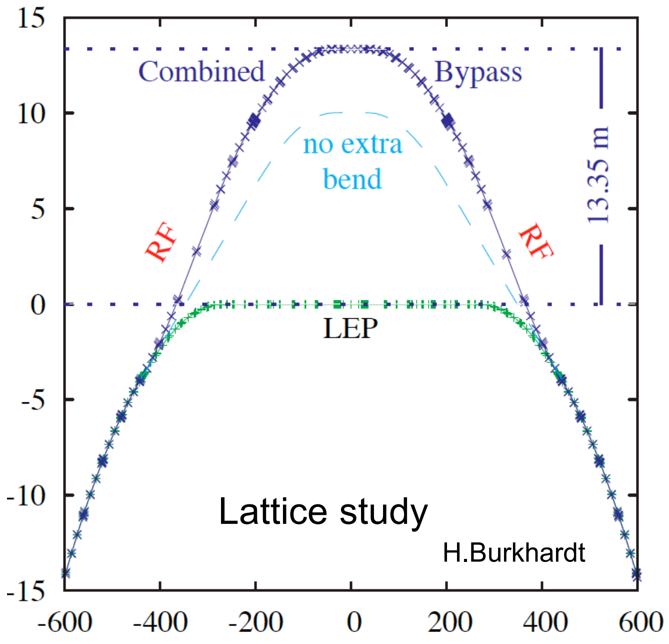
injector: SPL, or dedicated

e LINAC:

limited to ~6km (Rhone)
for IP2, longer for IP8
CLIC/ILC tunnel.?



Bypass through survey gallery
13m distance, 2 shafts

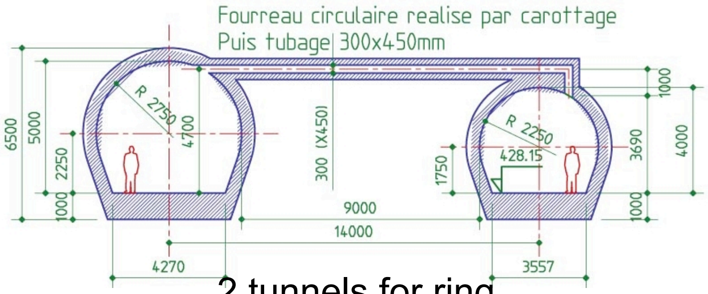


Lattice study

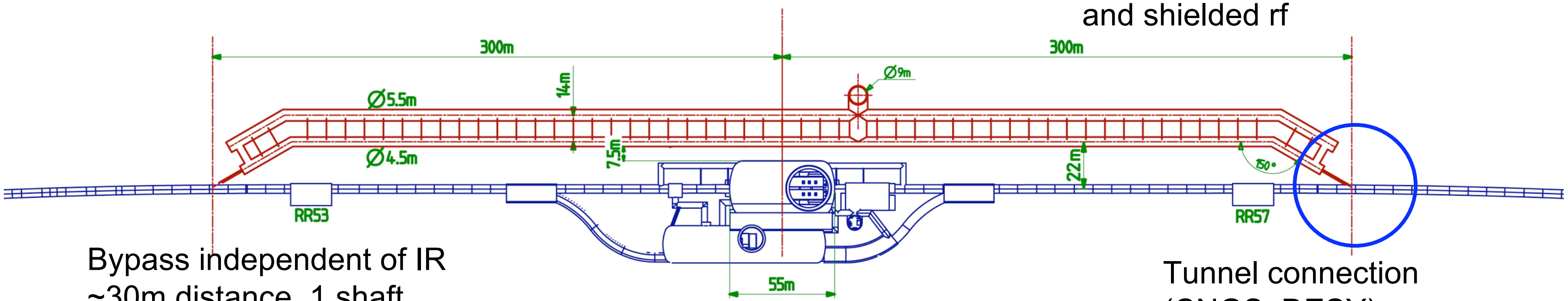
H.Burkhardt

Bypass

point 5



2 tunnels for ring
and shielded rf

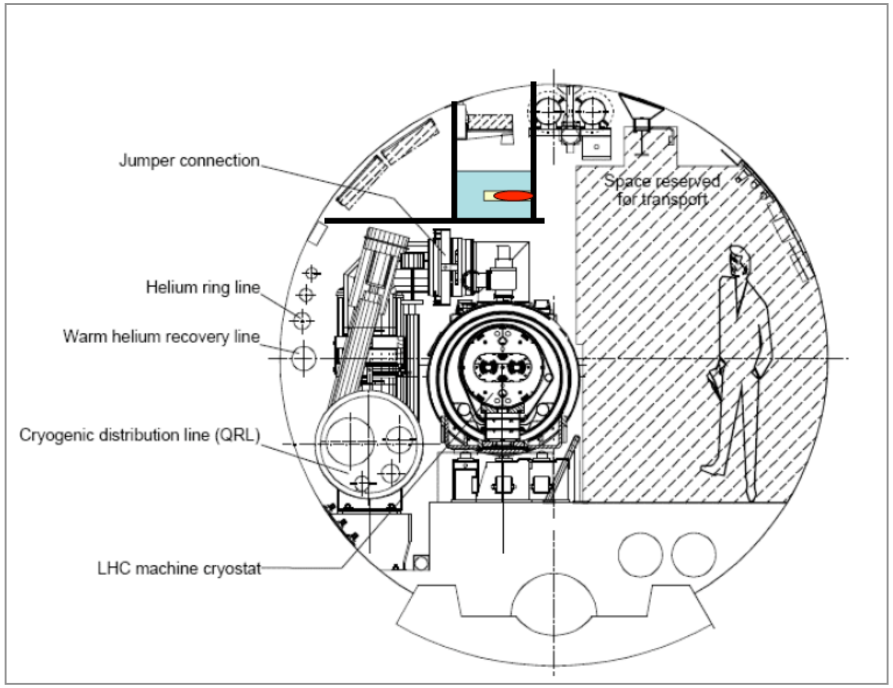


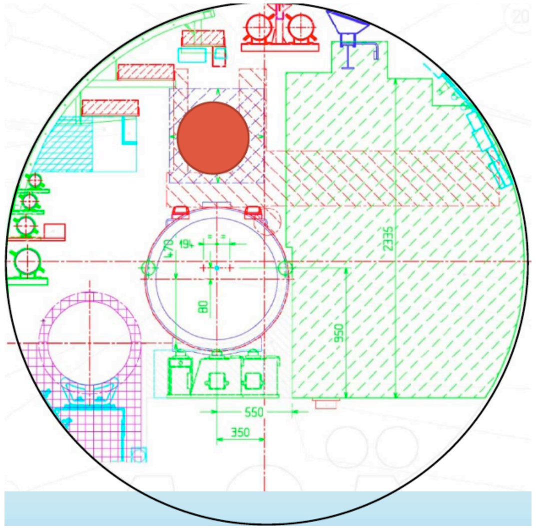
Bypass independent of IR
~30m distance, 1 shaft

Tunnel connection
(CNGS, DESY)

S.Myers, J.Osborne

e Ring Further Considerations





Mount e on top of p - feasible at first sight
needs further, detailed study of pathway

Installation: 1-2 years during LHC shutdowns.
LEP installation was ~1 year into empty tunnel.
Radiation load of LHC pp will be studied.

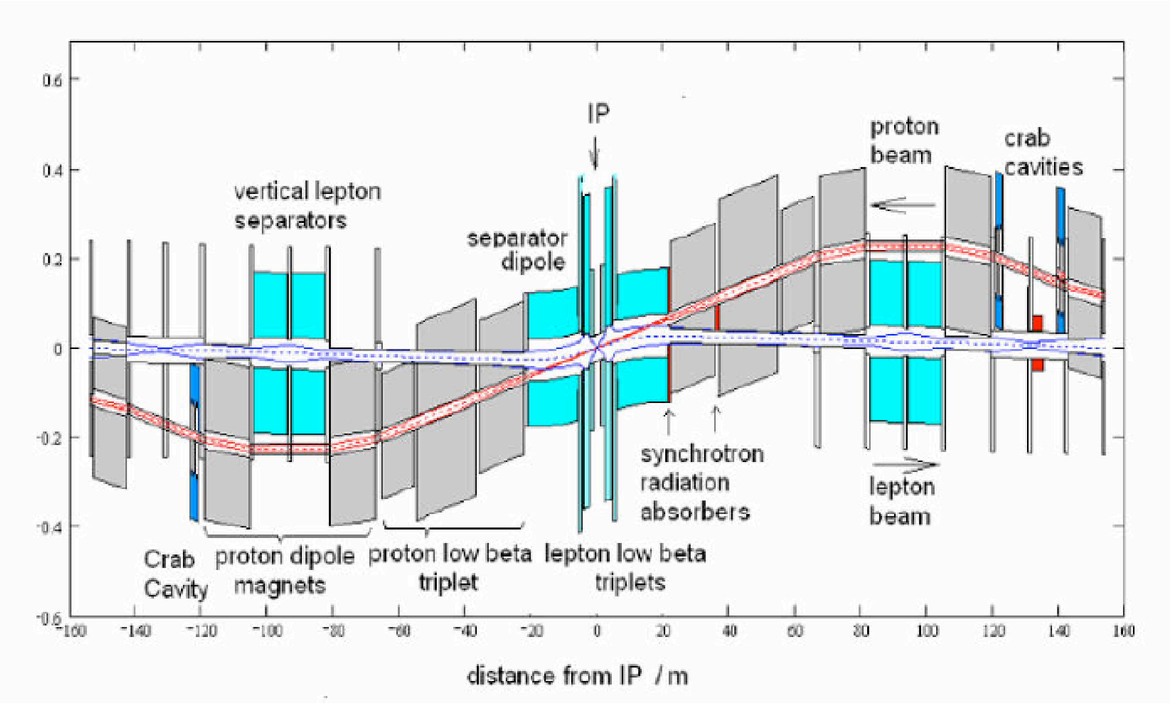
Injection:
LEP2 was 4 10^{11} e in 4 bunches
LHeC is 1.4 10^{10} in 2800 bunches
may inject at less than 20 GeV.

Power for 70 (50) GeV E_e fits into bypasses:

SC system at 1.9° K (1 GHz)
r.f. coupler to cavity: 500 kW CW - R+D
9 MV/cavity.
100(28) cavities for 900(250)MV
cavity: beam line of 150 (42) m
klystrons 100 (28) at 500kW
plus 90 m racks ..
gallery of 540 (150) m length required.

T.Linnecar

IR Design



builds on F.Willeke et al, 2006 JINST 1 P10001
design for 70 GeV on 7000 GeV, 10^{33}
and simultaneous ep and pp operation

Need low x (1°) and hi L (10° ?)

Separation (backscattering)

Synchrotron radiation (100 keV E_{crit})

Crab cavities
(profit from LHC developments)

e optics

p optics

Magnet designs for IR

S shaped IR for Linac-Ring option.

…

Input/experience from
HERA, LHC, ILC, eRHIC, SUPER-B

B.Holzer, A.Kling, et al

Ring-Ring Parameters

$$L = \frac{N_p \gamma}{4\pi e \varepsilon_{pn}} \cdot \frac{I_e}{\sqrt{\beta_{px}\beta_{py}}}$$

$$L = 8.310^{32} \cdot \frac{I_e}{50mA} \frac{m}{\sqrt{\beta_{px}\beta_{pn}}} cm^{-2}s^{-1}$$

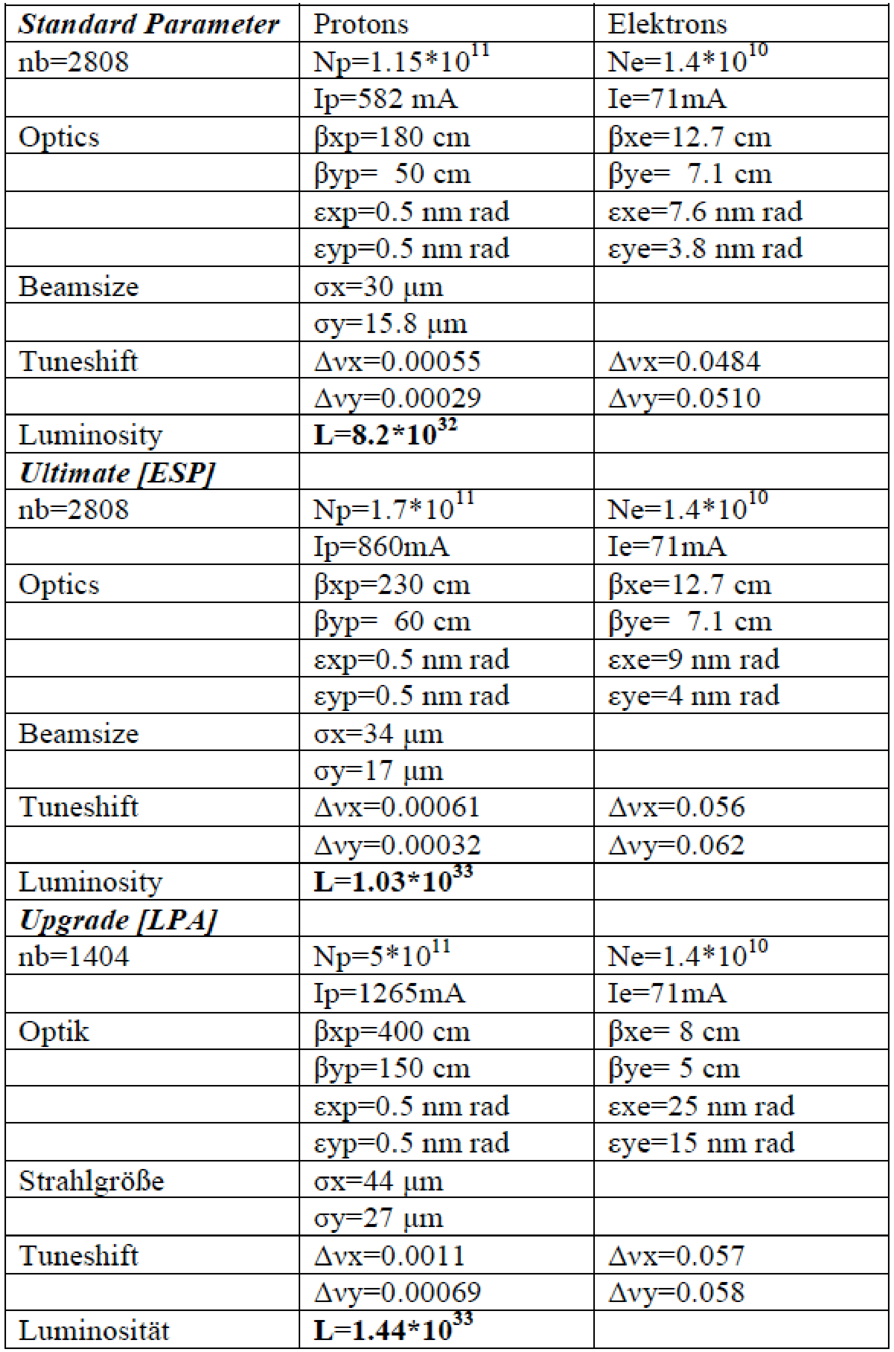
Luminosity safely 10^{33}cm^{-2}s^{-1}
HERA was 1-5 10^{31}

Table values are for 14 MW synrad loss (beam power) and 50 GeV on 7000 GeV. May have 50 MW and energies up to about 70 GeV.

$$I_e = 0.35mA \cdot \frac{P}{MW} \cdot \left(\frac{100GeV}{E_e}\right)^4$$

LHC upgrade: N_p increased.
Need to keep e tune shift low:
by increasing β_p, decreasing β_e
but enlarging e emittance,
to keep e and p matched.

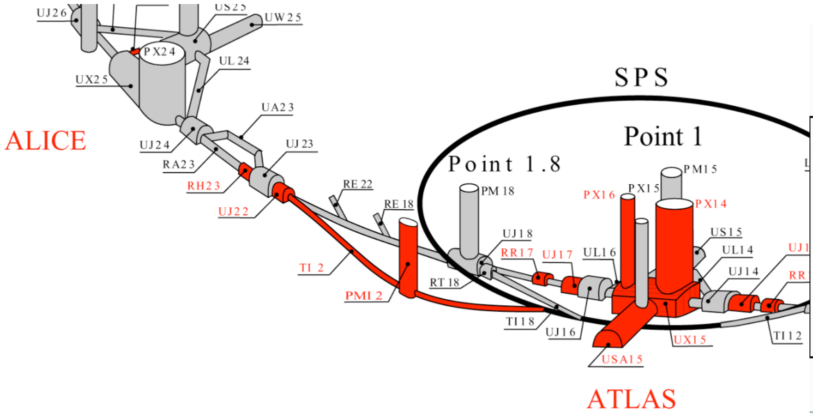
LHeC profits from LHC upgrade but not proportional to N_p

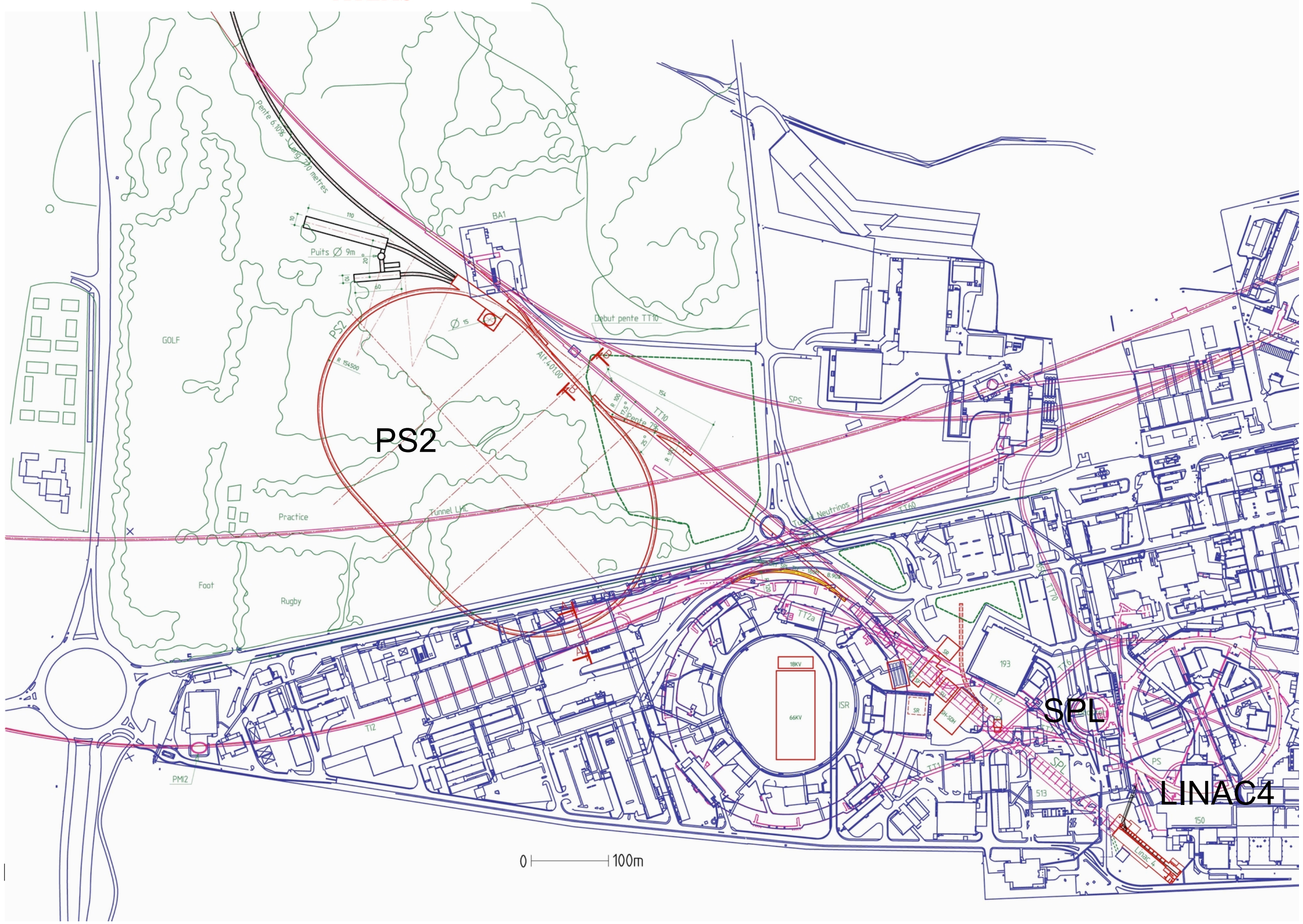


Standard Parameter	Protons	Elektrons
nb=2808	Np=1.15*10^{11}	Ne=1.4*10^{10}
	Ip=582 mA	Ie=71mA
Optics	βxp=180 cm	βxe=12.7 cm
	βyp= 50 cm	βye= 7.1 cm
	εxp=0.5 nm rad	εxe=7.6 nm rad
	εyp=0.5 nm rad	εye=3.8 nm rad
Beamsize	σx=30 μm	
	σy=15.8 μm	
Tuneshift	Δvx=0.00055	Δvx=0.0484
	Δvy=0.00029	Δvy=0.0510
Luminosity	**L=8.2*10^{32}**	
Ultimate [ESP]		
nb=2808	Np=1.7*10^{11}	Ne=1.4*10^{10}
	Ip=860mA	Ie=71mA
Optics	βxp=230 cm	βxe=12.7 cm
	βyp= 60 cm	βye= 7.1 cm
	εxp=0.5 nm rad	εxe=9 nm rad
	εyp=0.5 nm rad	εye=4 nm rad
Beamsize	σx=34 μm	
	σy=17 μm	
Tuneshift	Δvx=0.00061	Δvx=0.056
	Δvy=0.00032	Δvy=0.062
Luminosity	**L=1.03*10^{33}**	
Upgrade [LPA]		
nb=1404	Np=5*10^{11}	Ne=1.4*10^{10}
	Ip=1265mA	Ie=71mA
Optik	βxp=400 cm	βxe= 8 cm
	βyp=150 cm	βye= 5 cm
	εxp=0.5 nm rad	εxe=25 nm rad
	εyp=0.5 nm rad	εye=15 nm rad
Strahlgröße	σx=44 μm	
	σy=27 μm	
Tuneshift	Δvx=0.0011	Δvx=0.057
	Δvy=0.00069	Δvy=0.058
Luminosität	**L=1.44*10^{33}**	

e injector from SPL to Point 2 via TI2

Alternative injectors considered too
(cf H. Burkhard, DIS08, Proceedings)

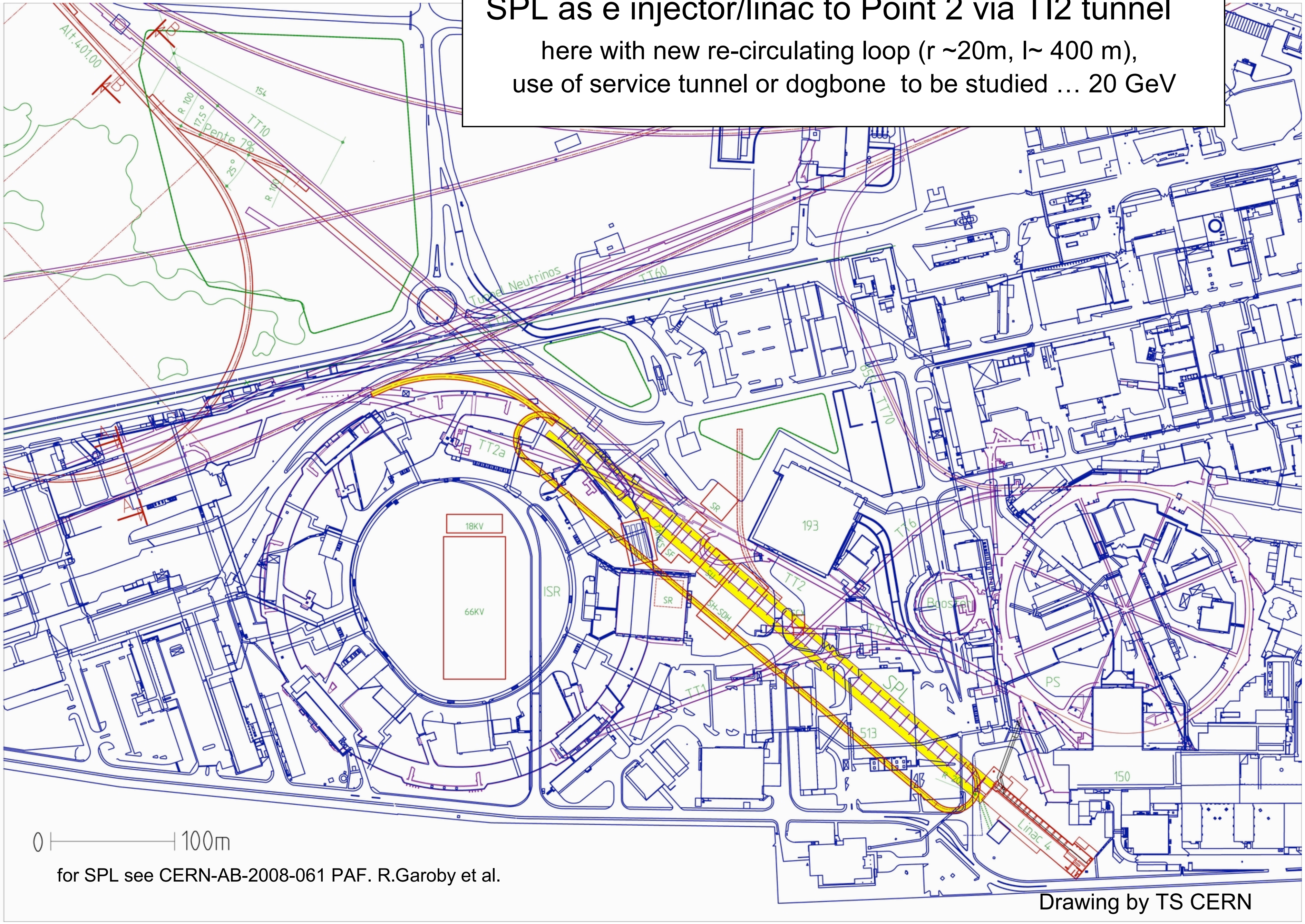




Max

SPL as e injector/linac to Point 2 via TI2 tunnel

here with new re-circulating loop (r ~20m, l~ 400 m),
use of service tunnel or dogbone to be studied … 20 GeV



for SPL see CERN-AB-2008-061 PAF. R.Garoby et al.

Drawing by TS CERN

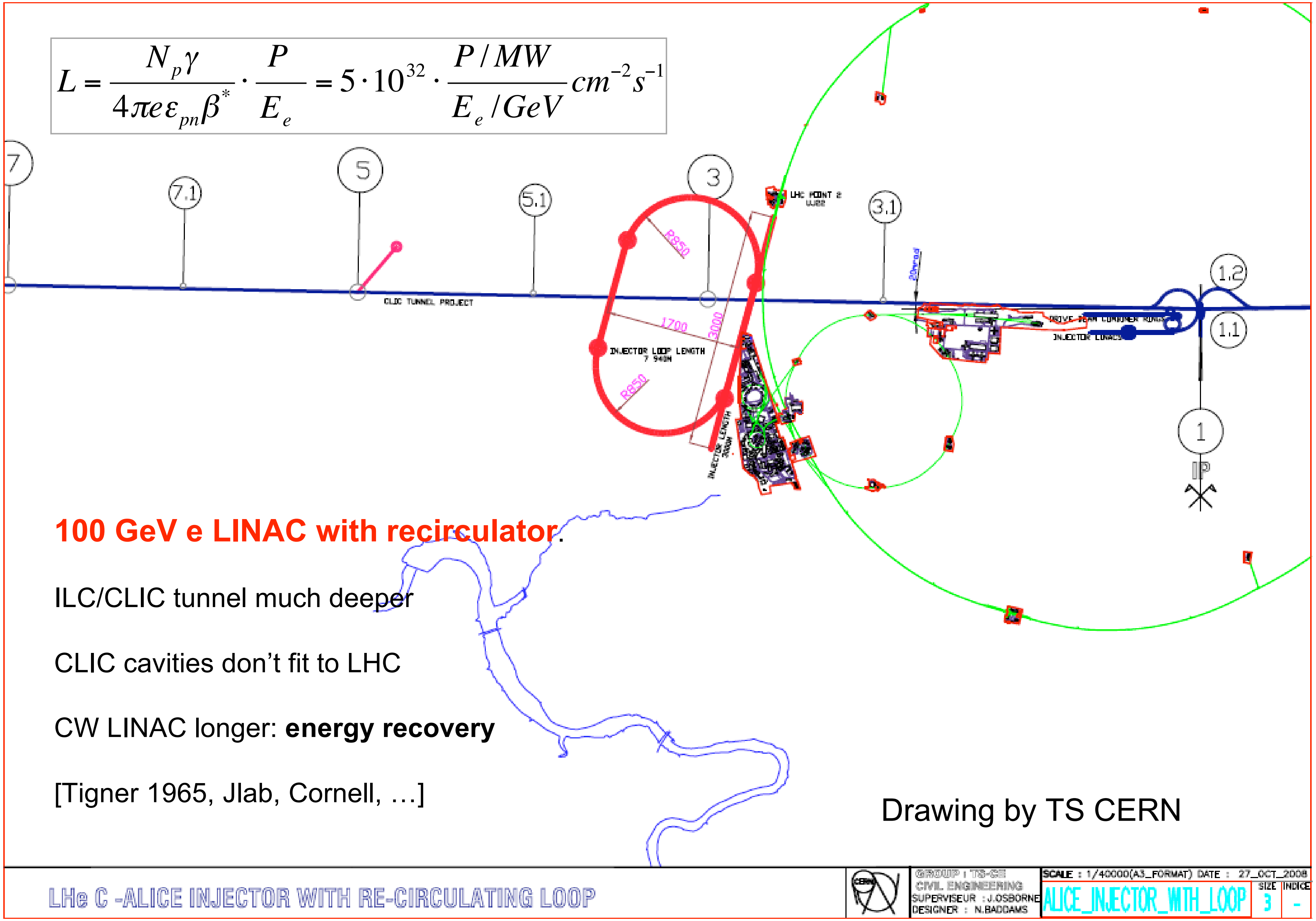
		Pulsed	CW
e- energy [GeV]	**30**	**100** ●	**100**
comment	SPL* (20)+TI2	LINAC	LINAC
#passes	4+1	2	2
wall plug power RF+Cryo [MW]	100 (1 cr.)	100 (3 cr.)	100 (35 cr.)
bunch population [10^9]	10	3.0	0.1
duty factor [%]	5	5	100
average e- current [mA]	1.6	0.5	0.3
emittance $\gamma\varepsilon$ [μm]	50	50	50
RF gradient [MV/m]	25	25	13.9
total linac length β=1 [m]	350+333	3300	6000
minimum return arc radius [m]	240 (final bends)	1100	1100
beam power at IP [MW]	24	48	30
e- IP beta function [m]	0.06	0.2	0.2
ep hourglass reduction factor	0.62	0.86	0.86
disruption parameter D	56	17	17
luminosity [10^{32} cm^{-2} s^{-1}]	**2.5**	**2.2**	**1.3**

proton parameters: LPA upgrade SLHC: N_b=5x10^{11}, 50 ns spacing, $\gamma\varepsilon$=3.75 μm, β^*=0.1 m, σ_z=11.8 cm

cf also H.Braun DIS08

F.Zimmermann, S. Chattopadhyay

$$L = \frac{N_p \gamma}{4\pi e \varepsilon_{pn} \beta^*} \cdot \frac{P}{E_e} = 5 \cdot 10^{32} \cdot \frac{P/MW}{E_e/GeV} cm^{-2} s^{-1}$$



100 GeV e LINAC with recirculator.

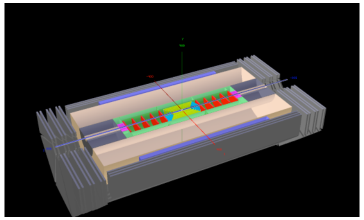
ILC/CLIC tunnel much deeper

CLIC cavities don’t fit to LHC

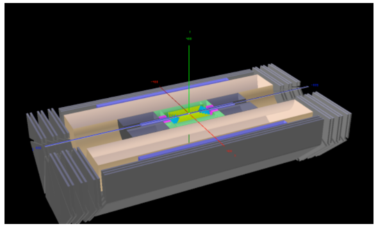
CW LINAC longer: **energy recovery**

[Tigner 1965, Jlab, Cornell, …]

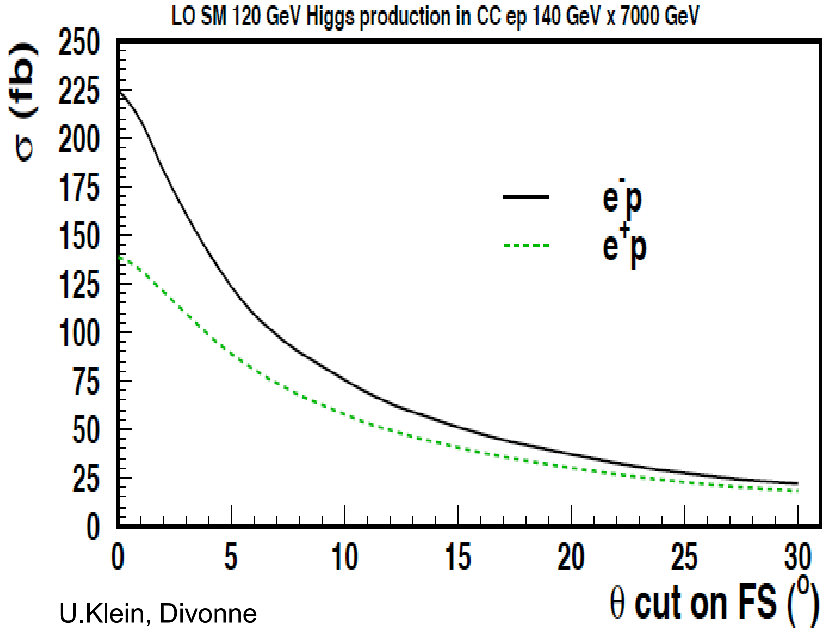
Drawing by TS CERN



Detector Design Considerations



Large fwd acceptance and high luminosity



U.Klein, Divonne

Forward tagging of p,n,d
Backward tagging of e,γ
Tagging of c and b in max. angular range
High resolution final state (Higgs to bbar)

High precision tracking and calorimetry

Largest possible acceptance	1-179°	7-177°
High resolution tracking	0.1 mrad	0.2-1 mrad
Precision electromagnetic calorimetry	0.1%	0.2-0.5%
Precision hadronic calorimetry	0.5%	1%
High precision luminosity measurement	0.5%	1%
	LHeC	HERA

L1 Detector: version for low x Physics

Muon chambers
(fwd,bwd,central)

Coil (r=3m l=8.5m, 2T)
[Return Fe not drawn]

Central Detector

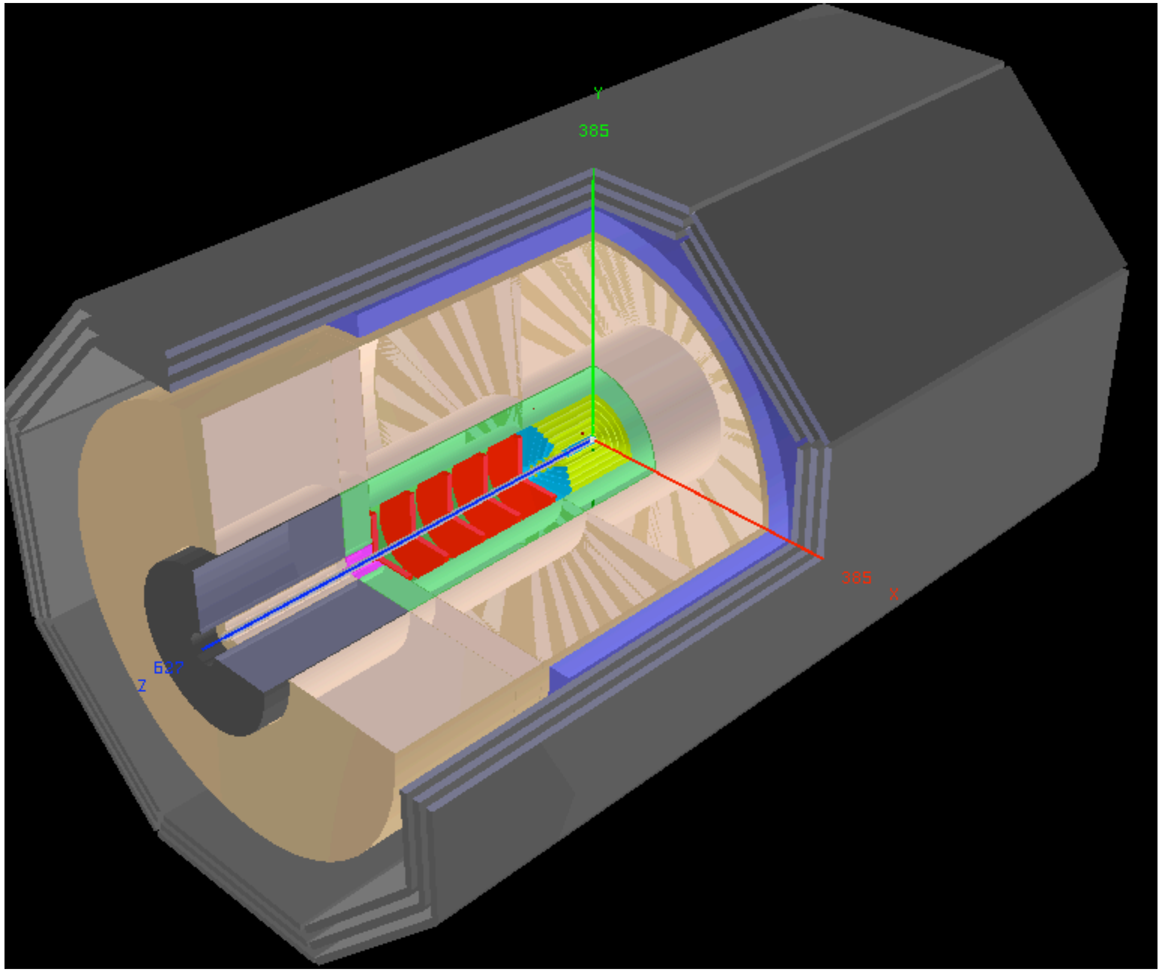
Hadronic Calo (Fe/LAr)
El.magn. Calo (Pb,Sc)
GOSSIP (fwd+central)
[Gas on Slimmed Si Pixels]
[0.6m radius for 0.05% * pt in 2T field]
Pixels
Elliptic beam pipe (~3cm)

Fwd Spectrometer
(down to 1^o)

Tracker
Calice (W/Si)
FwdHadrCalo

Bwd Spectrometer
(down to 179^o)

Tracker
Spacal (elm, hadr)



P.Kostka, A.Pollini, R.Wallny et al

To be extended further in fwd direction. Tag p,n,d. Also e,γ (bwd)

L1 Detector: version for hiQ^2 Physics

Muon chambers
(fwd,bwd,central)

Coil (r=3m l=8.5m, 2T)

Central Detector

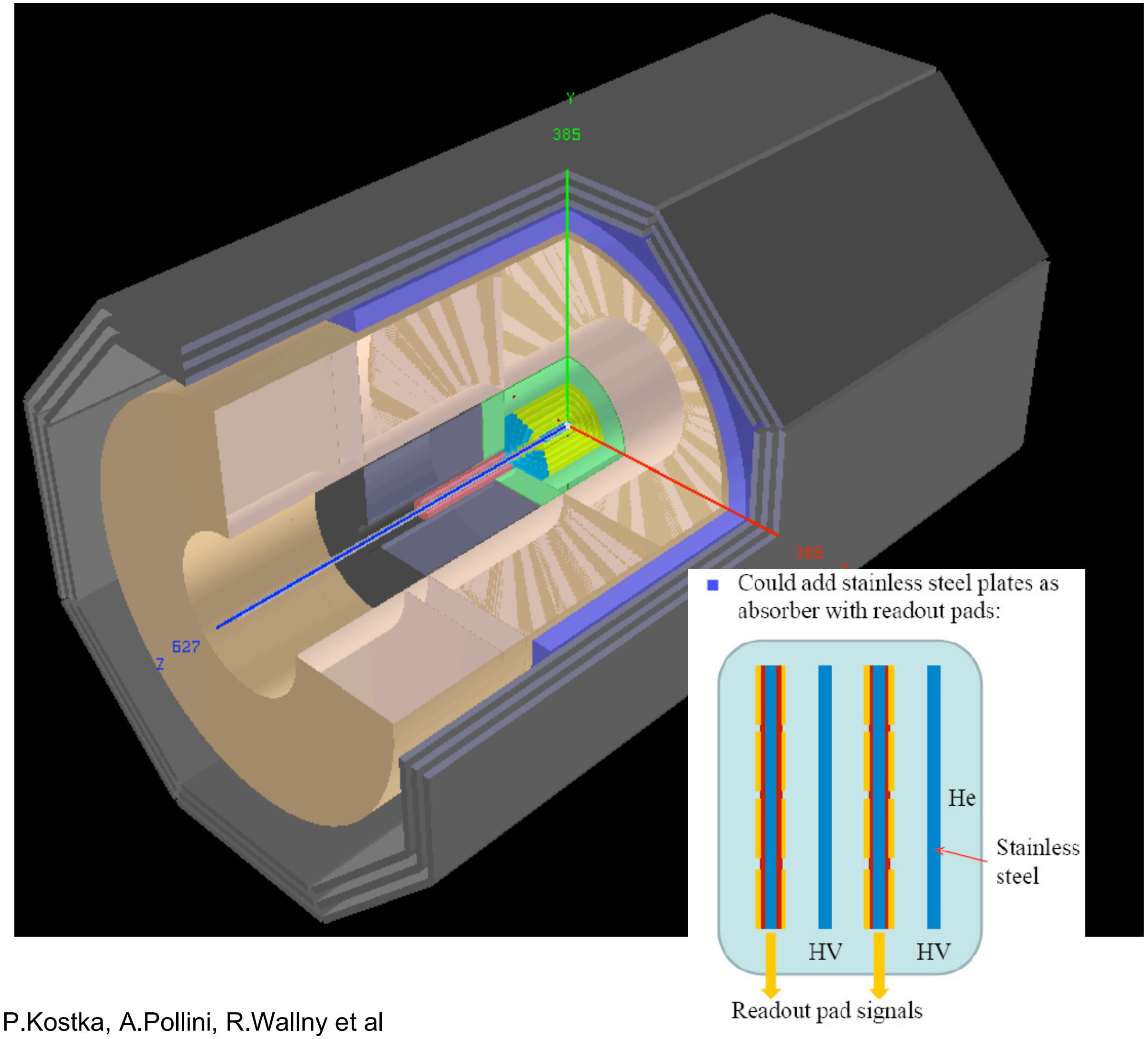
Hadronic Calo (Fe/LAr)
El.magn. Calo (Pb,Sc)
GOSSIP (fwd+central)
Pixels
Elliptic pipe (~3cm)

Fwd Calorimeter
(down to 10^o)

Lepton low β magnets
FwdHadrCalo

Bwd Spectrometer
(down to 170^o)

Lepton low β magnets
Spacal (elm, hadr)



- Could add stainless steel plates as absorber with readout pads:

P.Kostka, A.Pollini, R.Wallny et al

Active magnets? T.Greenshaw

Max Klein LHeC ECFA 11/08

New Physics at High Scales
Precision QCD and Electroweak Physics
High Parton Densities

New Physics at Large Scales

Emmanuelle Perez (CERN),

Georg Weiglein (Durham)

Precision QCD and Electroweak

Olaf Behnke (DESY),

Paolo Gambino (Torino),

Thomas Gehrmann (Zuerich)

Physics at High Parton Densities

Nestor Armesto (CERN),

Brian Cole (Columbia),

Paul Newman (Birmingham),

Anna Stasto (MSU)

New Physics at the LHeC

Wide range of basic physics

Maximum $W < 1.4$ TeV
for $E_e = 140$ GeV, $E_p = 7$ TeV

- **Lepto-Quark Production and Decay (s and t-channel effects)**
- **Squarks and Gluinos**
- **ZZ, WZ, WW elastic and inelastic collisions**
- **Technicolor**
- **Novel Higgs Production Mechanisms**
- **Composite electrons**
- **Lepton-Flavor Violation**
- **QCD at High Density in ep and eA collisions**
- **Odderon**

Broad physics goals (to be discussed at the Workshop)

- Proton structure and QCD physics in the domain of x and Q^2 of LHC experiments
- Small-x physics in eP and eA collisions
- Probing the $e^{\pm}$-quark system at ~TeV energy

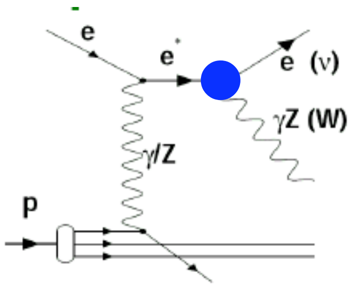
  eg leptoquarks, excited e*'s, mirror e, SUSY with no R-parity......
- Searching for new EW currents

  eg RH W's, effective eeqq contact interactions...

G. Altarelli

J.Bartels: Theory on low x

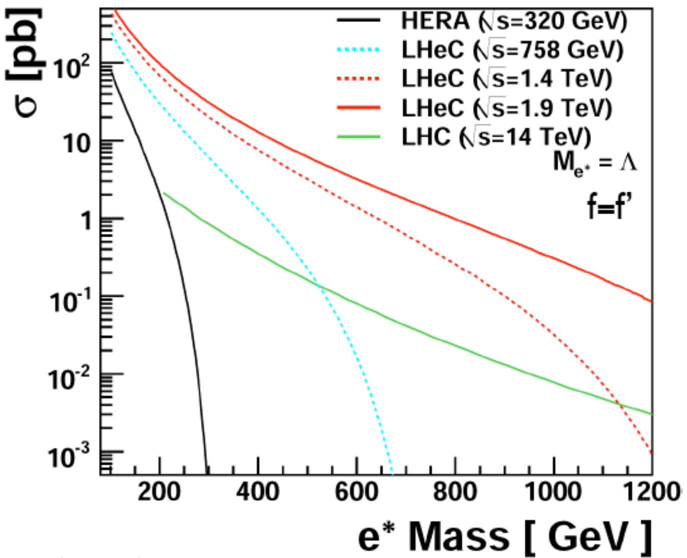
Electron-Boson Resonances : excited electrons



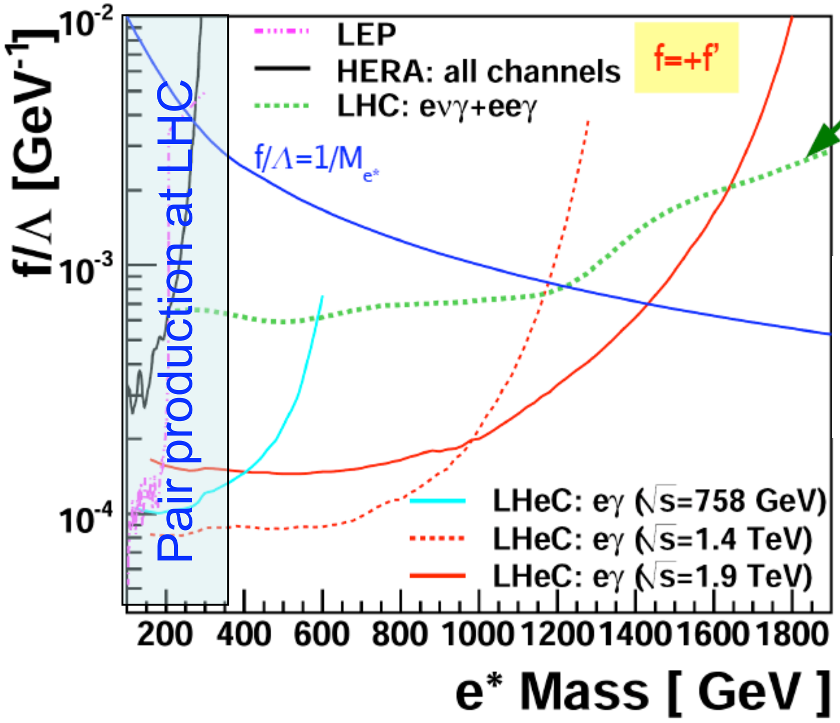
coupling
~ f / Λ

N. Trinh, E. Sauvan, Divonne

Single e* production x-section in ep is high.



LHeC prelim. analysis, looking at e* → eγ



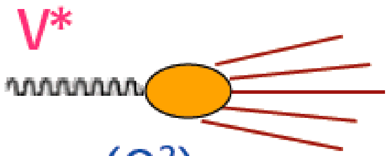
[Phys. Rev D 65 (2002) 075003]

**-If LHC discovers (pair prod) an e*:
LHeC would be sensitive to much smaller f/Λ couplings**

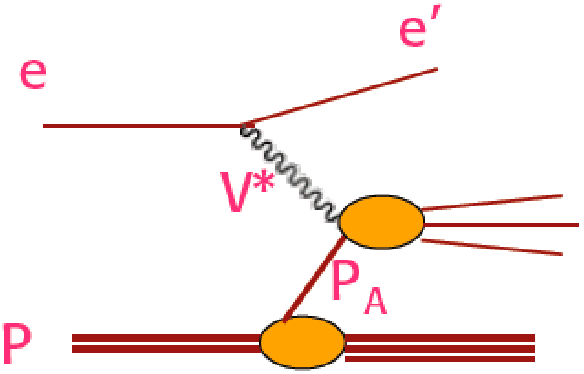
-Discovery potential for higher masses.

- needs high electron beam energy

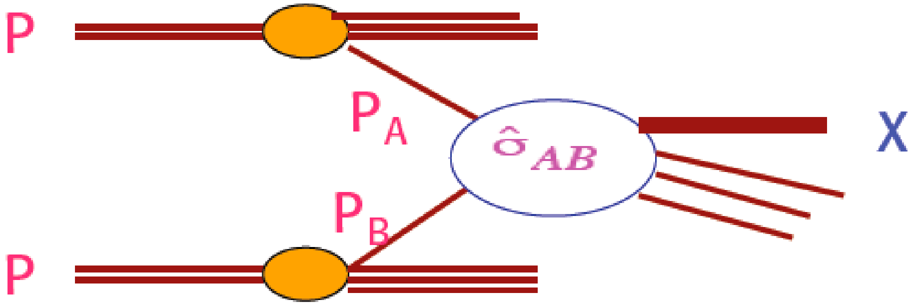
L assumed 10 (1) fb^{-1} with 20/70 (140) GeV



$\alpha_s(Q^2)$



$\alpha_s(Q^2)$ & $q(x,Q^2)$, $g(x,Q^2)$



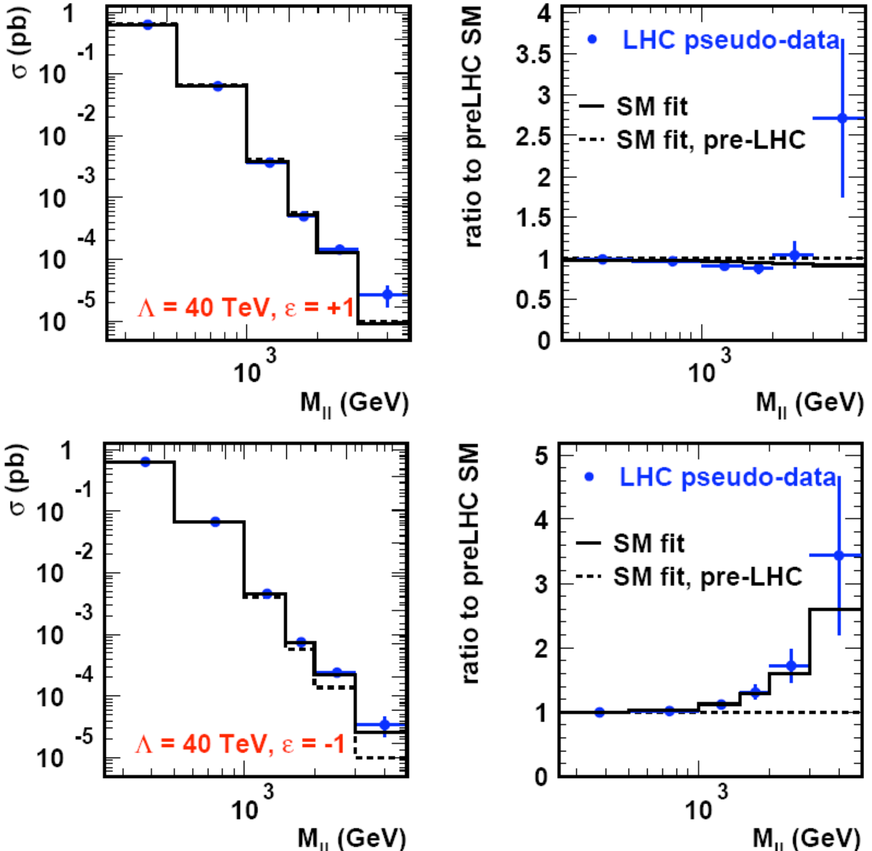
The basic experimental set ups:

- no initial hadron (....LEP, ILC, CLIC)
- 1 hadron (....HERA, LHeC)
- 2 hadrons (....SppS, Tevatron, LHC)

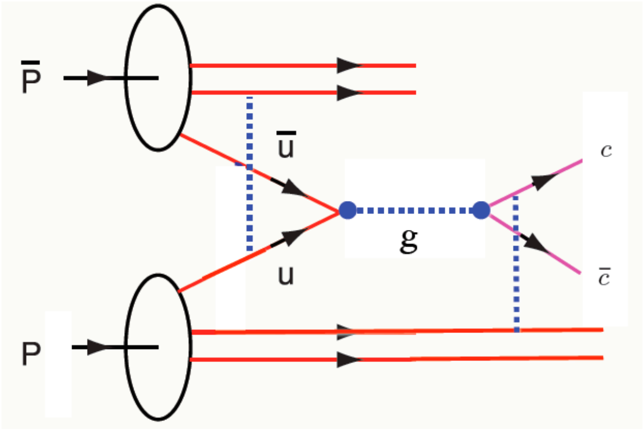
Progress in particle physics needs their continuous interplay to take full advantage of their complementarity

G.Altarelli, LHeC Workshop Divonne 9/08

New Physics and the LHC-LHeC Interplay



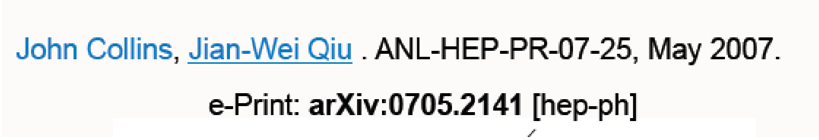
E.Perez, Divonne



Factorisation is violated in production of high p_T particles (IS and FS i.a.s).

Important, perhaps crucial, to measure pdf's in the kinematic range of the LHC. cf also ED limits vs pdf's.

NP may be accommodated by HERA/BCDMS DGLAP fit. It can not by the fit to also LHeC.



John Collins, Jian-Wei Qiu . ANL-HEP-PR-07-25, May 2007.

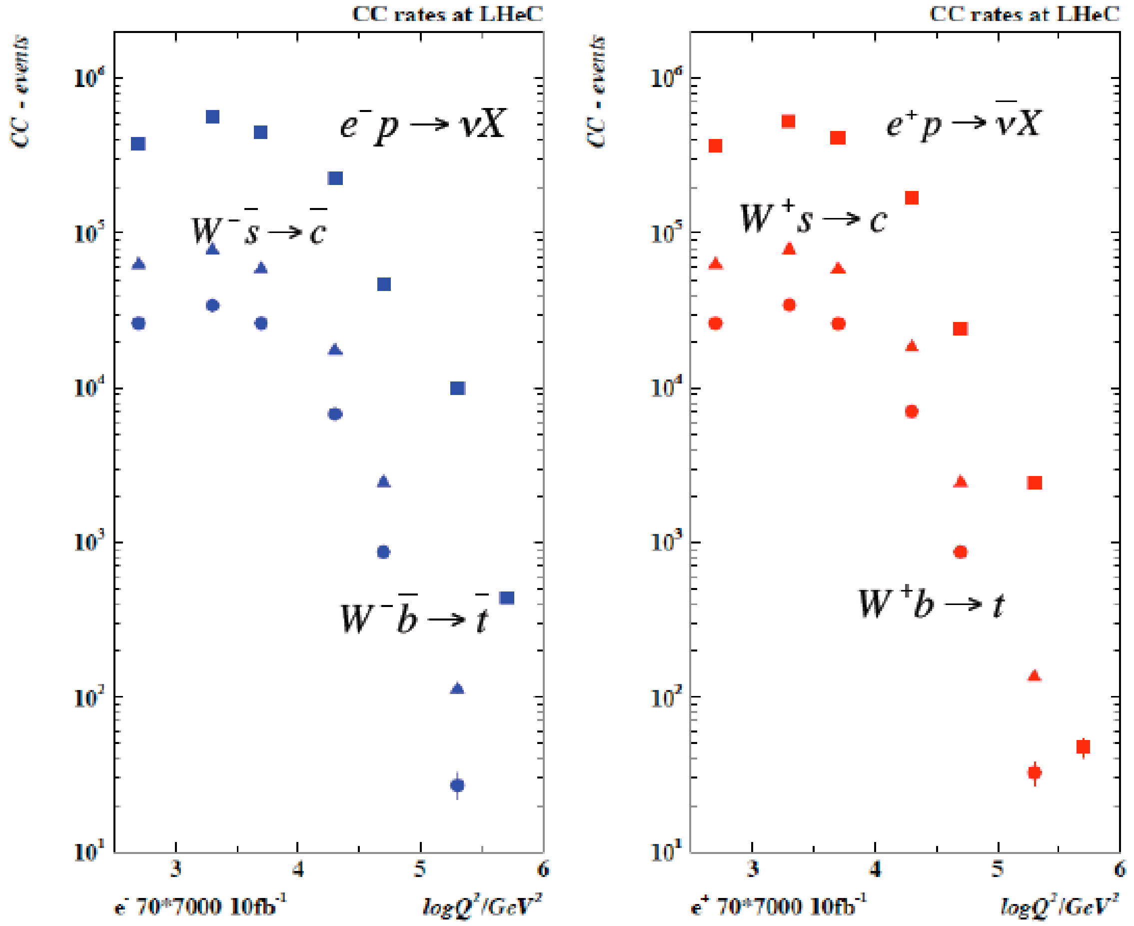
e-Print: **arXiv:0705.2141** [hep-ph]

Complete Unfolding of Partons

u
d
u_v
d_v
ubar
dbar
s
sbar
c/cbar
b/bbar
t
tbar
xg

with
NC,CC
$e^{\pm}p,e^{\pm}D$

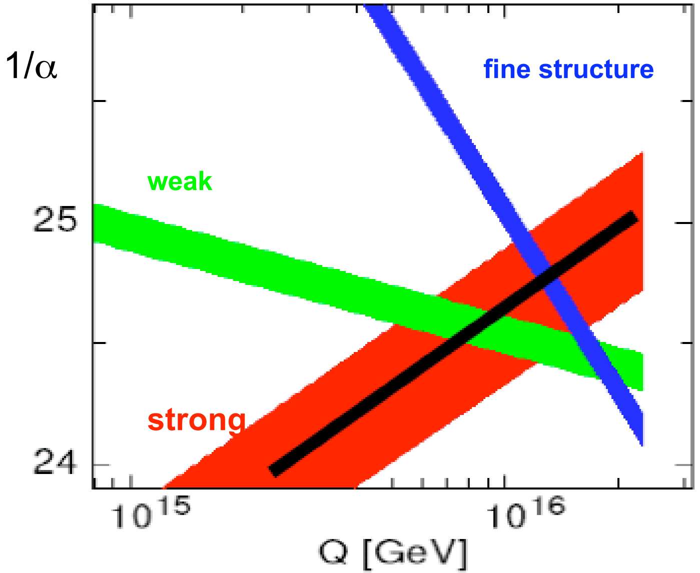
Single anti-top and top physics at the LHeC



G.Brandt, MK

High Precision - Strong Coupling Constant

Simulation of α_s measurement at LHeC



MSSM - B.Allnach et al, hep-ex/0403133

DATA	exp. error on α_s
NC e⁺ only	0.48%
NC	0.41%
NC & CC	**0.23% :=(1)**
(1) γ_h>5°	0.36% :=(2)
(1) +BCDMS	0.22%
(2) +BCDMS	0.22%
(1) stat. *= 2	0.35%

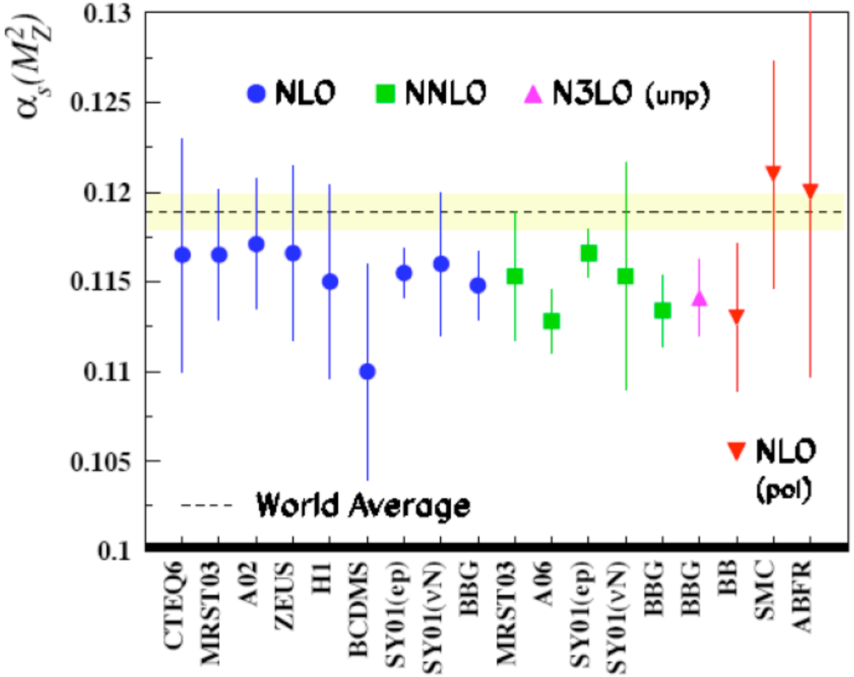
DIS08, T.Kluge

α_s least known of coupling constants
Grand Unification predictions suffer from $\delta\alpha_s$

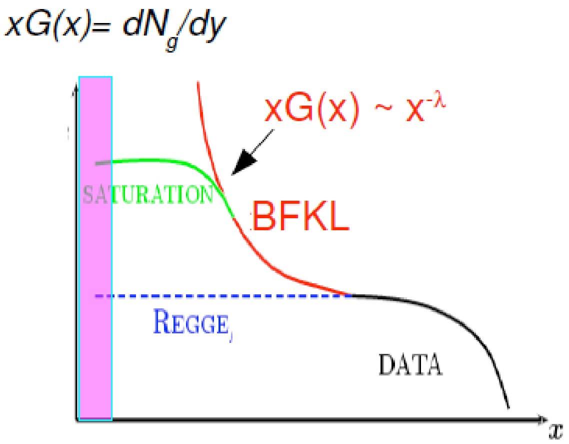
DIS tends to be lower than world average

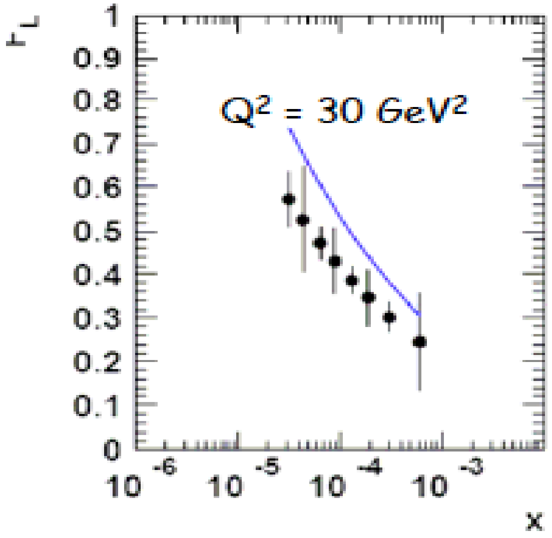
LHeC: per mille accuracy indep. of BCDMS.
Challenge to experiment and to h.o. QCD

Blumlein et al '06



Quark-Gluon Dynamics (saturation, GPDs)

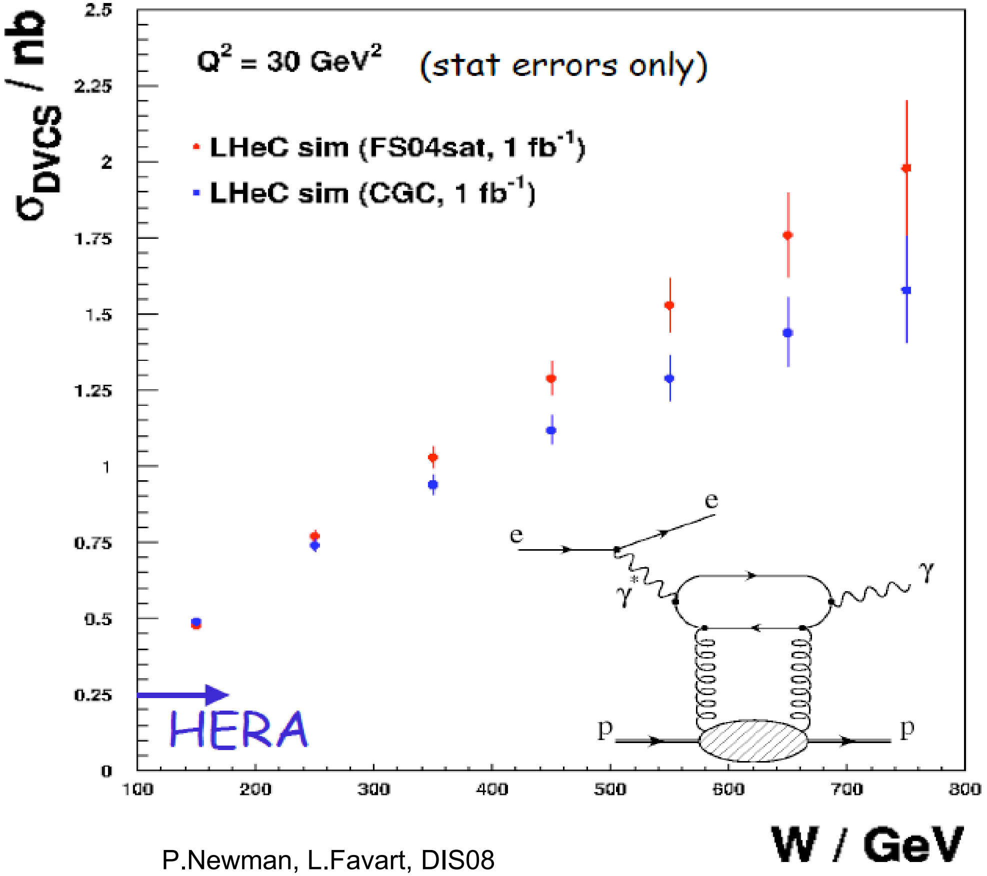




J.Forshaw et al, DIS08

LHeCsat data in NNPDF1.0

Divonne



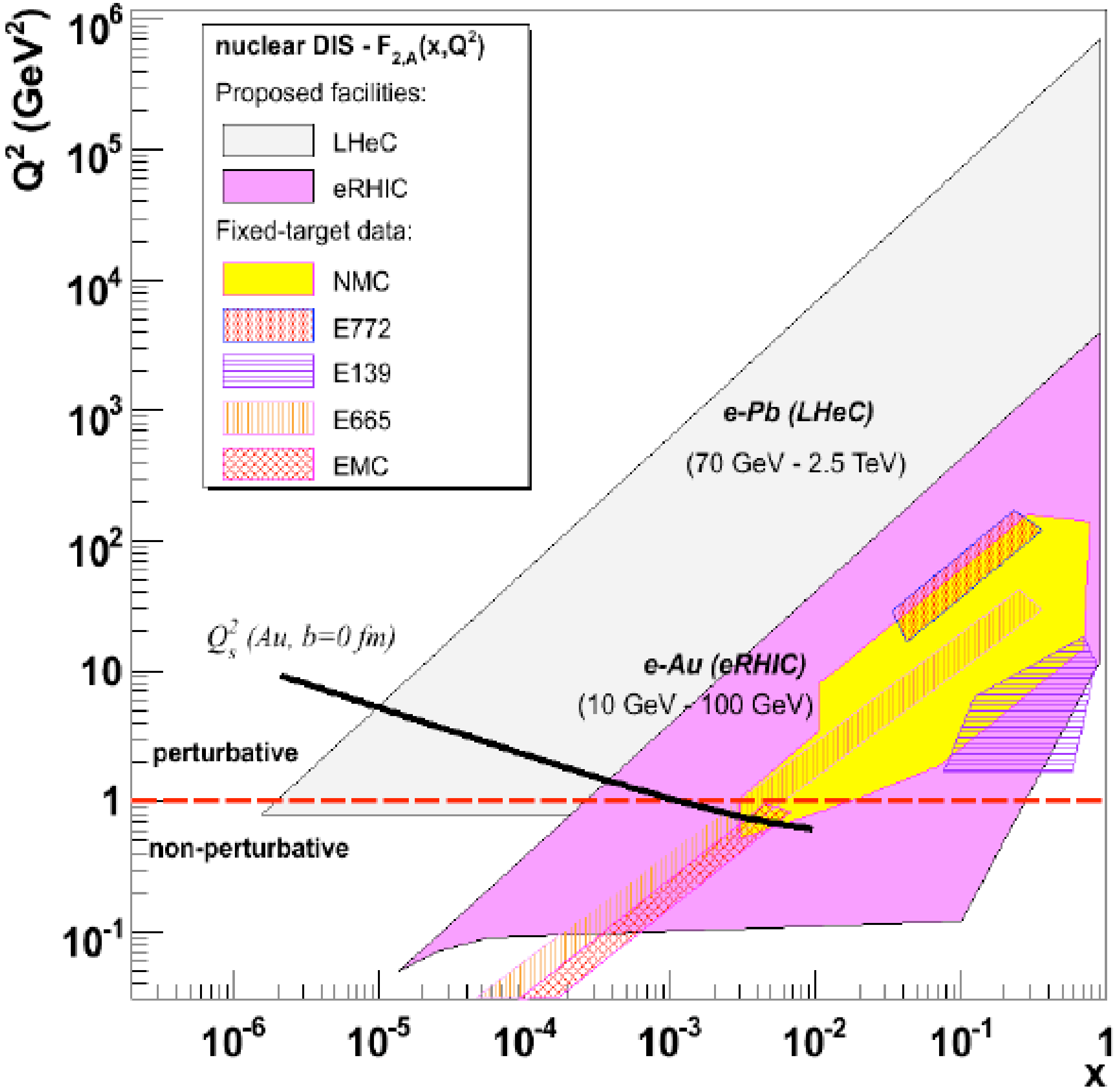
P.Newman, L.Favart, DIS08

LHeC opens phase space to discover saturation in DIS

J.Bartels at Divonne on low x theory

High luminosity, polarisation, accuracy for GPD's (DVCS)

Deep Inelastic Scattering off Nuclei (D,A)



DdE, arXiv:0706.4182

LHeC extends kinematic range of partonic structure of nuclei by 3-4 orders of magnitude.

It accesses saturation effects at low x in DIS region (“beyond unitarity”)

$$\frac{g_A/\pi r_A^2}{g_p/\pi r_p^2} = A^{1/3}\frac{g_A}{Ag_p}$$

eRHIC with nuclei could be complementary.

Deuterons: n structure!

LHeC-A appears as natural complement and possible extension of ALICE physics programme.

Steps towards CDR

ECFA (11/07)

1st ECFA CERN Workshop 9/08

NuPECC (9/08), ICFA (10/08)

ECFA (11/08)

Joint workshop of convenors and steering group (12/08)

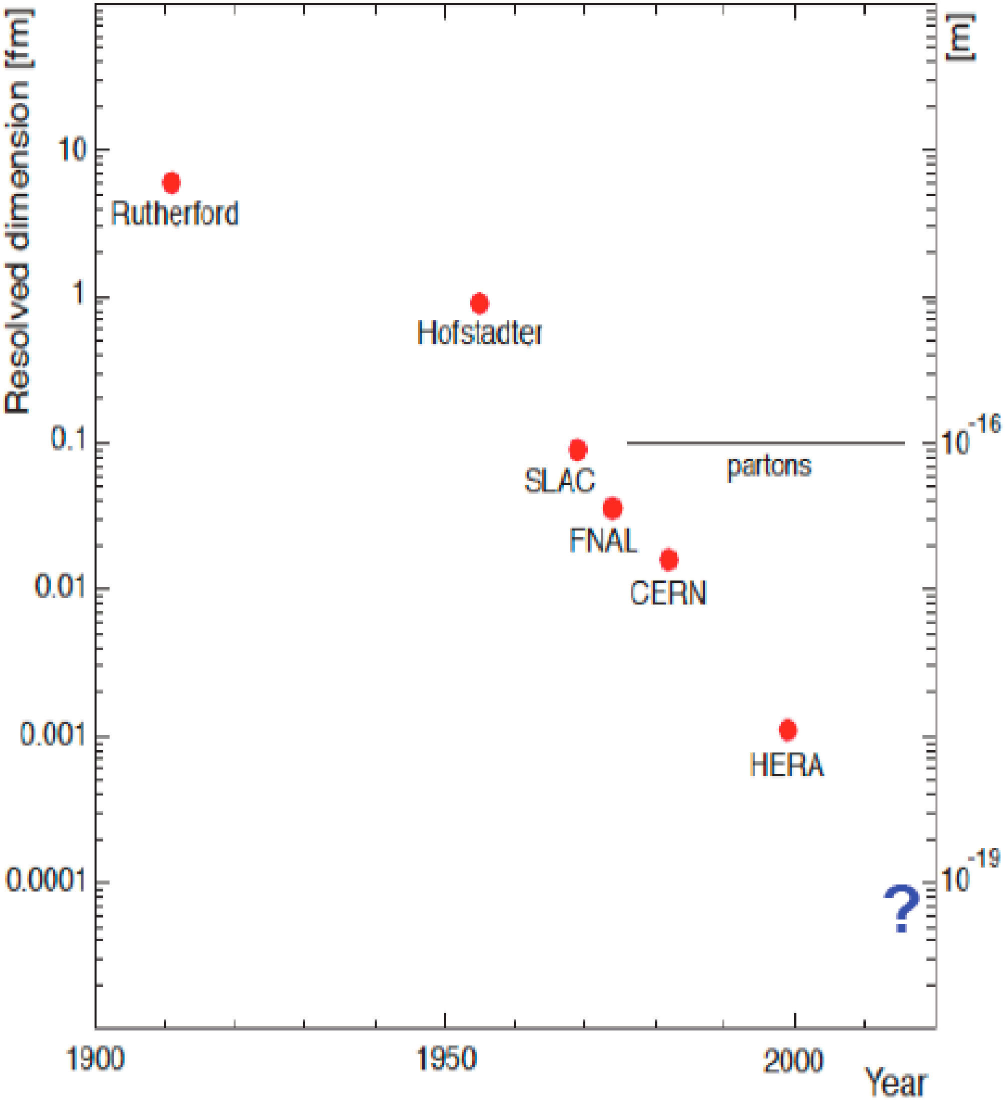
Technical Workshop (~3/09)

Physics Workshop (4/09)

2nd ECFA CERN Workshop 9/09

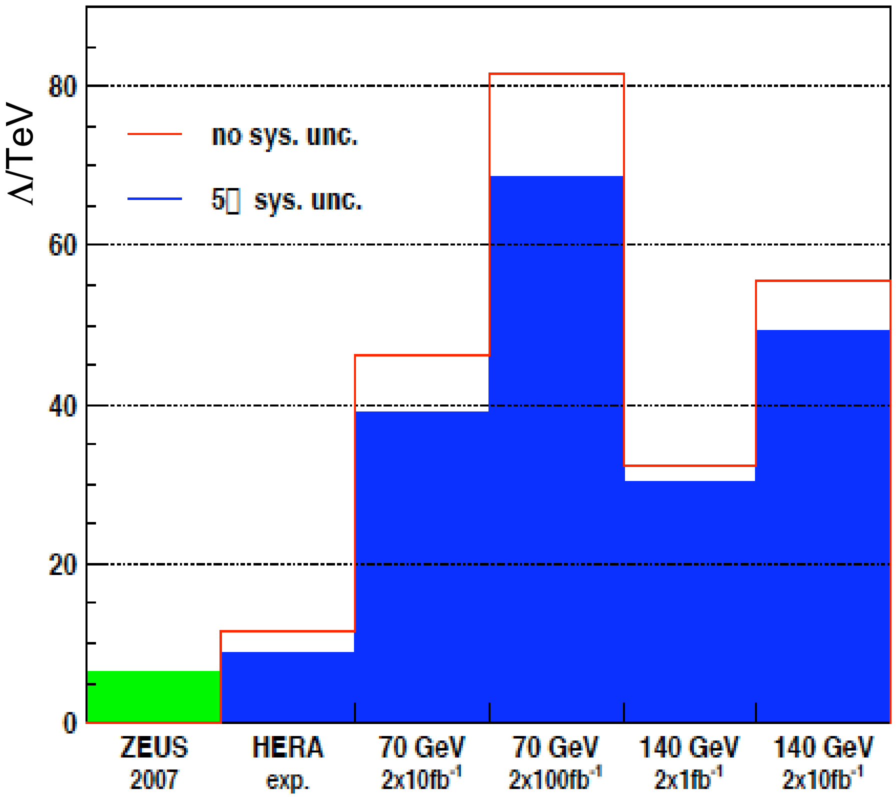
Final Report to ECFA 11/09

Written CDR (5/10)



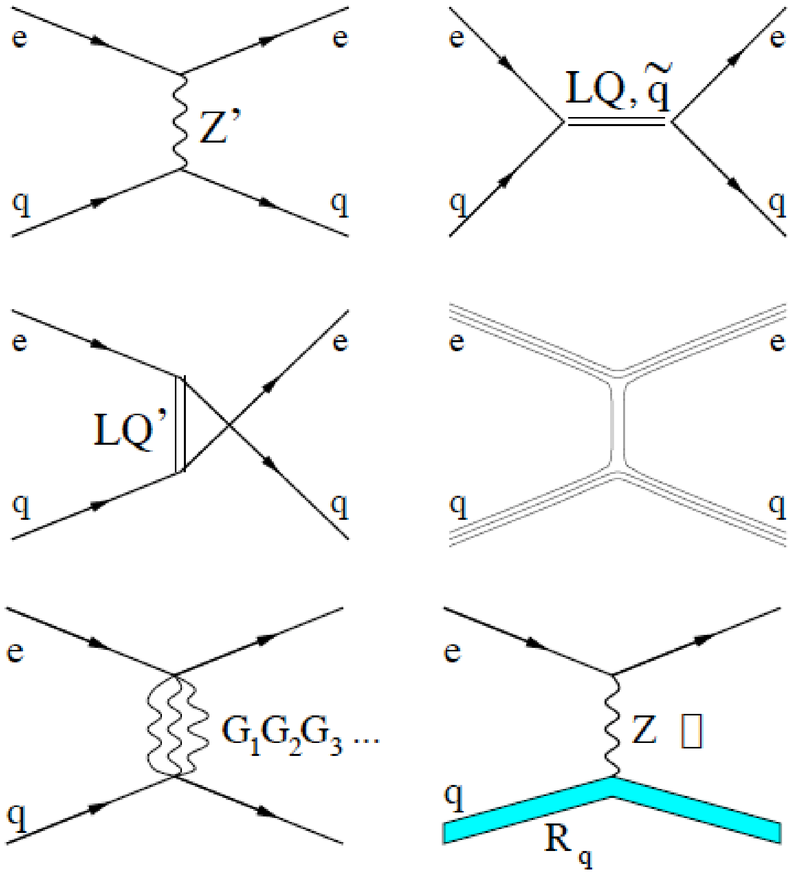
Contact Interactions [generic, ED, quark form factor]

Limits for PC (VV) model A.Zarnecki DIS08



Luminosity vs Energy

Possible “new physics” processes:



Max Klein LHeC ECFA 11/08

The LHeC project has gained momentum, its CDR will be written, and can be based on more than one option, a rich physics programme. It deserves more work yet to be done, for which your continued support and encouragement will be crucial.

DIS08 (Brodsky, Kluge, Foreshaw, Zarnecki, Burkhard, Braun)
EPAC08
(Zimmermann, Jowett, Dainton)
Divonne 9/11 (~70 talks)

http://www.lhec.org.uk

Many thanks to

Accelerator experts of CERN, DESY + elsewhere
Experimentalists and theorists
Steering group and WG convenors
Scientific Advisory Committee
CERN, ECFA, NuPECC, ICFA,

Jill Karlson Forestier and Patricia Mage-Granados,
…

Steering Group

Oliver Bruening	(CERN)
John Dainton	(Cockcroft)
Albert DeRoeck	(CERN)
Stefano Forte	(Milano)
Max Klein - chair	(Liverpool)
Paul Newman	(Birmingham)
Emmanuelle Perez	(CERN)
Wesley Smith	(Wisconsin)
Bernd Surrow	(MIT)
Katsuo Tokushuku	(KEK)
Urs Wiedemann	(CERN)

backup

Further Tasks on Machine and Detector

for the CDR - incomplete

-Ring: installation: pathway and radiation
    injector (SPL and its possible use for an initial eA phase)

-LINAC: energy recovery for ~100 GeV beam? what is the luminosity in e^+ ?

-Infrastructure (Interaction Region, SPL/TI2, LINAC site)

-IR for ring and for LINAC and its interface with LHC, e beam and the detector

-Optics and lattice designs (high luminosity and small angle acceptance)

-Identification of R+D projects for LHeC (active magnets?, rf Coupler, …)

-Complete Detector Design

-Design Taggers (fwd and bwd)

Further Tasks on Physics

for the CDR - incomplete

-Complete studies on Physics Beyond the Standard Model

-Simulations on top and Higgs Physics

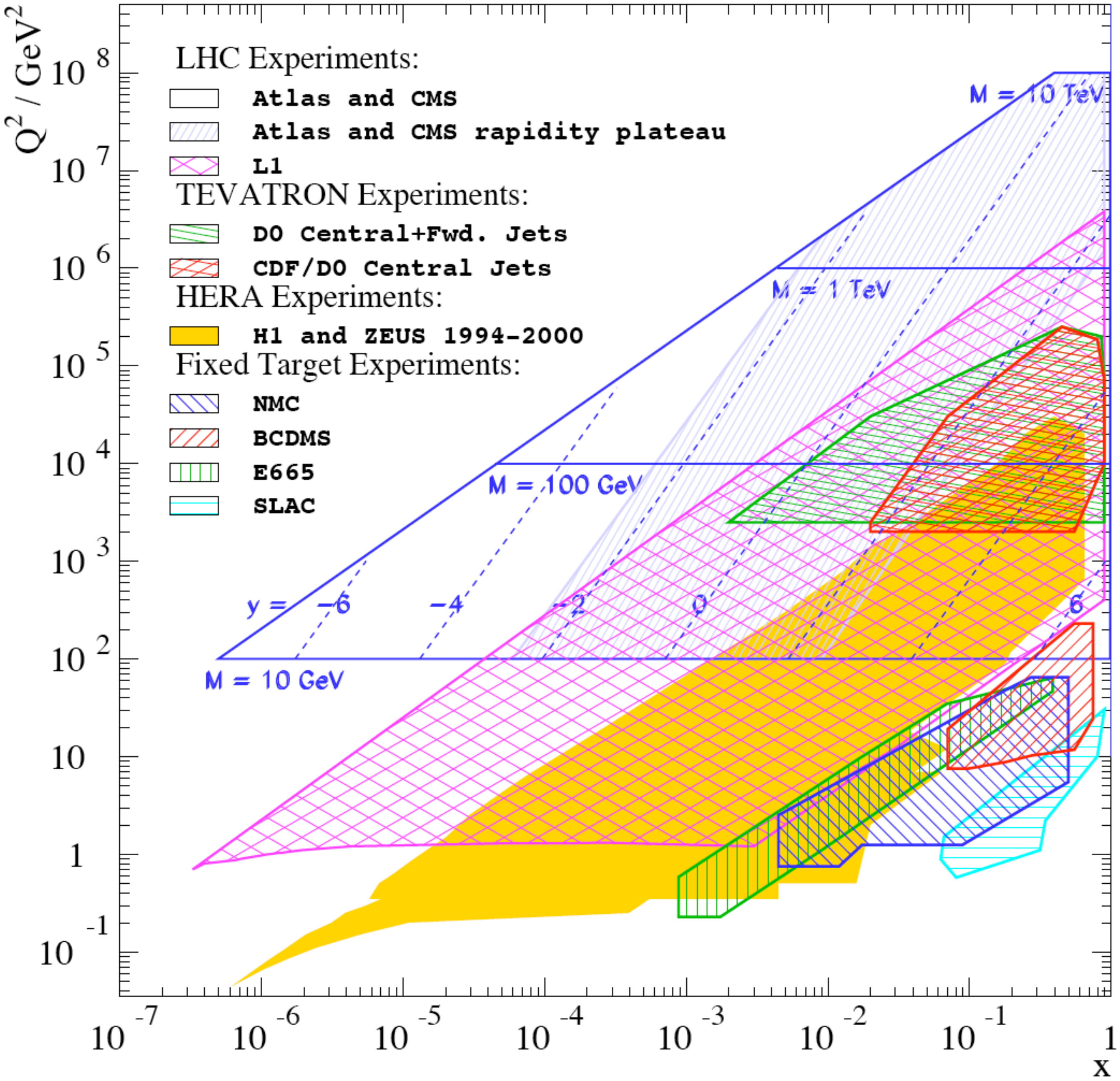
-Potential on electroweak measurements

-DVCS and final state physics

-Nuclear Parton Distributions

-Luminosity measurement

-LHC/LC and LHeC complementarity



Q^2 / GeV^2
10^8
10^7
10^6
10^5
10^4
10^3
10^2
10
1
10^{-1}
10^{-7}
10^{-6}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1
x
LHC Experiments:
Atlas and CMS
Atlas and CMS rapidity plateau
L1
TEVATRON Experiments:
D0 Central+Fwd. Jets
CDF/D0 Central Jets
HERA Experiments:
H1 and ZEUS 1994-2000
Fixed Target Experiments:
NMC
BCDMS
E665
SLAC
M = 10 TeV
M = 1 TeV
M = 100 GeV
M = 10 GeV
y = −6
−4
−2
0
6

ep with the LHC

three ECFA CERN Studies

If a hadron collider will be built in the LEP tunnel then ep collisions are really a must

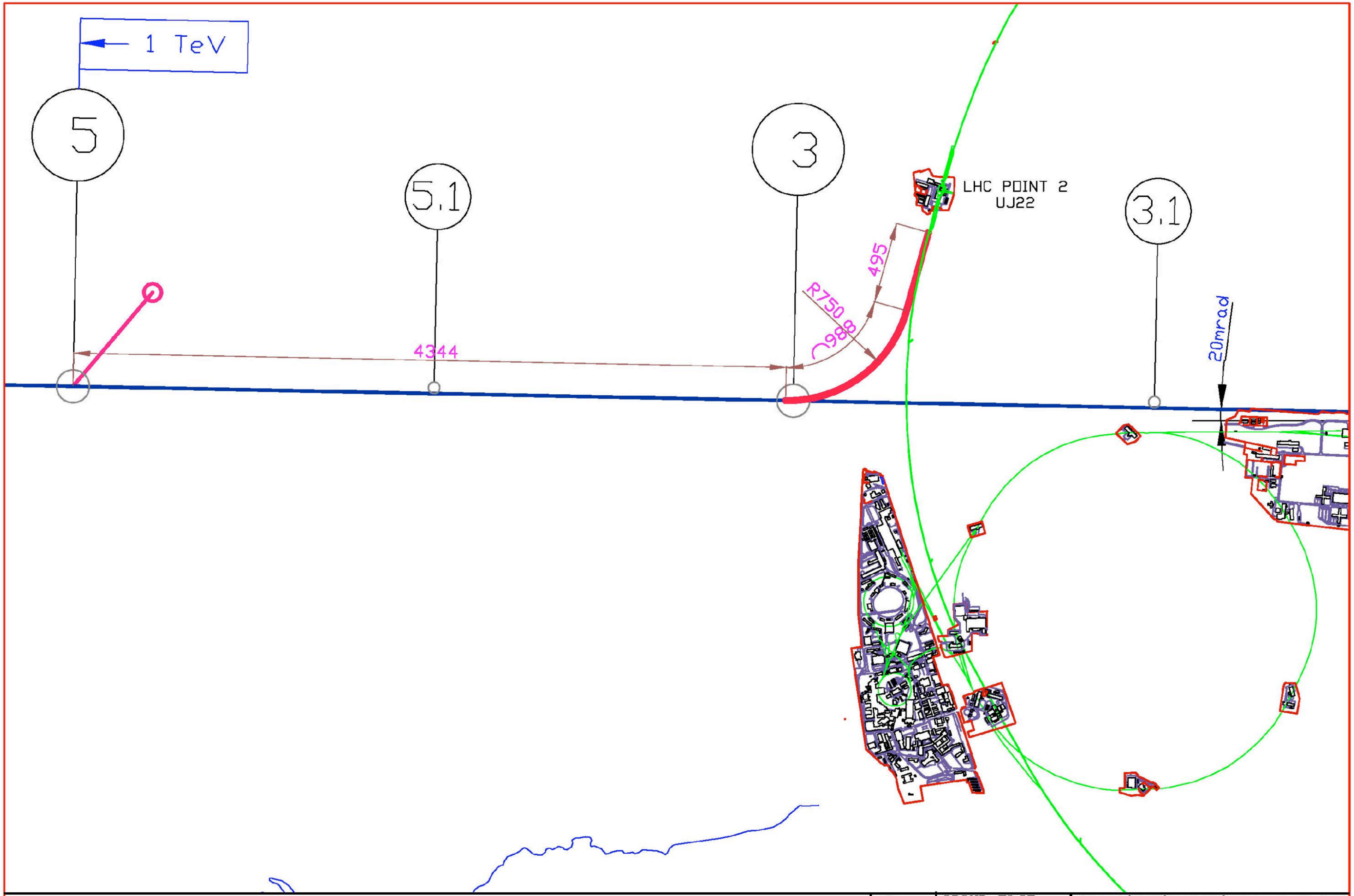
G.Altarelli et al, **Lausanne LHC Workshop 1984**, Proc. p549

"Now we are entering the post-TeV era, jumping not one but two
orders of magnitude to a lab equivalent of order 50 TeV at HERA.
If the LHC is successfully commissioned in the LEP tunnel in 1997,
then we may hope to see collisions between electrons from LEP
and protons from the LHC in the next millenium giving a lab equivalent
around 10 TeV (1 PeV). " F.Close Singapor 1990

Aachen Workshop 1990

It would be a waste not to exploit the 7 TeV beams for
eP and eA physics at some stage during the LHC time

G.Altarelli et al, **Divonne LHeC Workshop 2008**



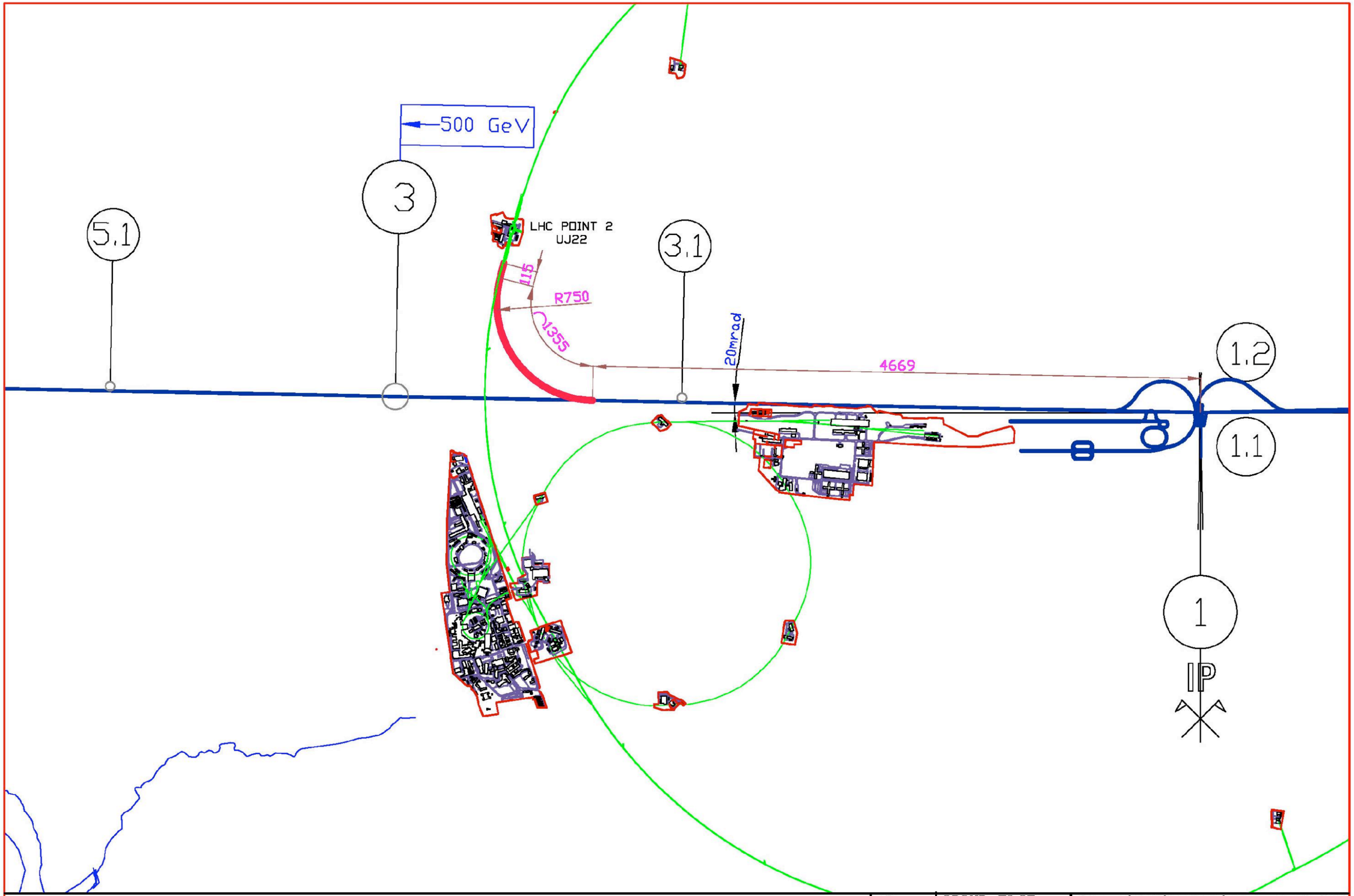
LHe C -ALICE INJECTOR FROM CLIC 1 TeV PHASE

GROUP : TS-CE
CIVIL ENGINEERING
SUPERVISEUR : J.OSBORNE
DESIGNER : N.BADDAMS

SCALE : 1/20000(A3_FORMAT) DATE : 14_OCT_2008

ALICE_INJECTOR_FROM_CLIC_1_TEV

SIZE 3
INDICE -



LHe C -ALICE INJECTOR FROM CLIC 500 GeV PHASE

GROUP : TS-CE
CIVIL ENGINEERING
SUPERVISEUR : J.OSBORNE
DESIGNER : N.BADDAMS

SCALE : 1/20000(A3_FORMAT) DATE : 14_OCT_2008

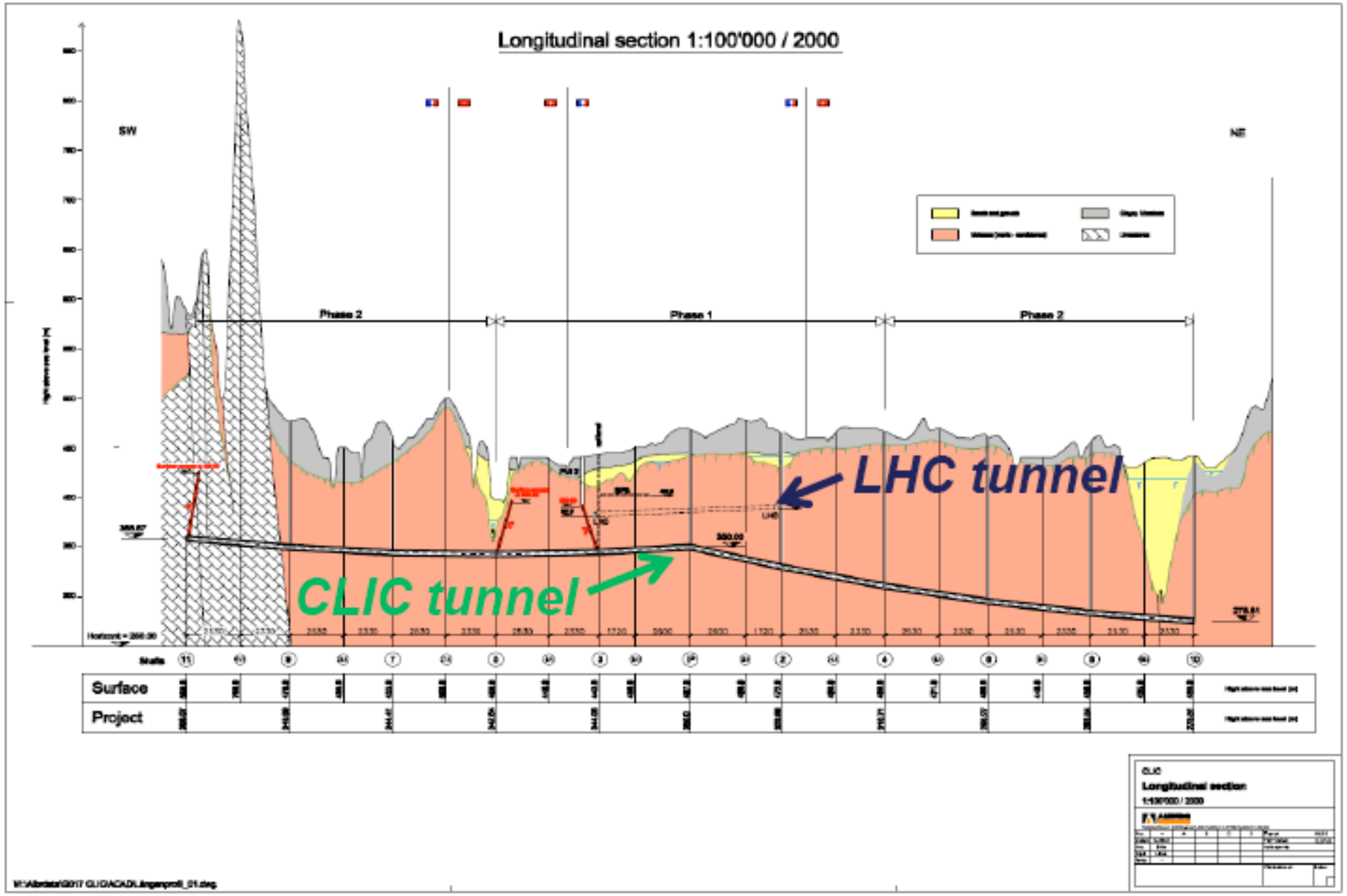
ALICE_INJECTOR_FROM_CLIC_500_GEV

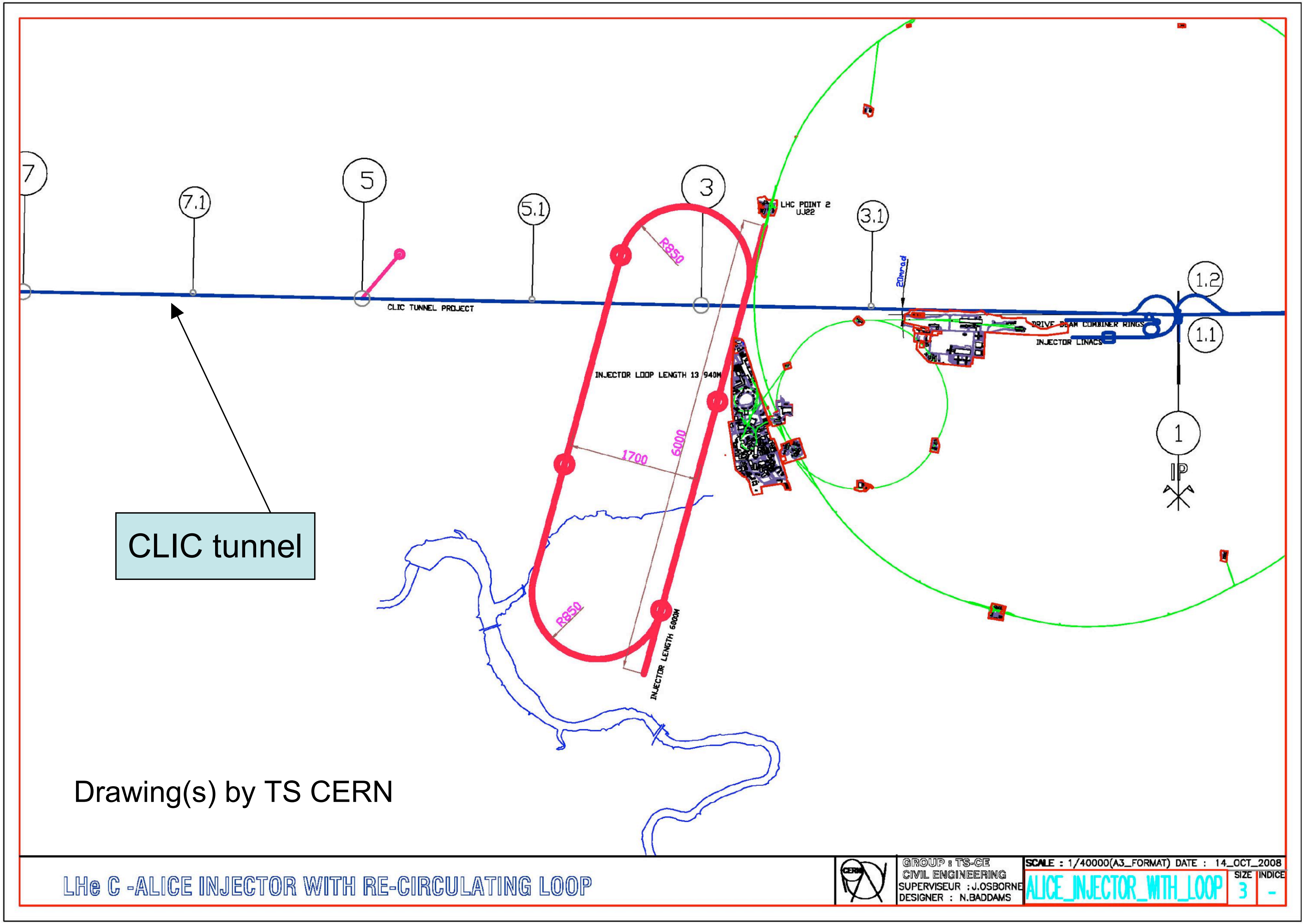
SIZE 3

INDICE -

Can tunnel for LHeC Linac be build as first part of a LC tunnel at CERN ?

Tunnel studies for CLIC and ILC at CERN both have tunnels which are deeper underground than LHC and seen from top they both pass close to LHC ring center. Therefore they are not suited to send e$^-$ beam tangential to LHC ring.





CLIC tunnel

Drawing(s) by TS CERN

Luminosity: Linac-Ring

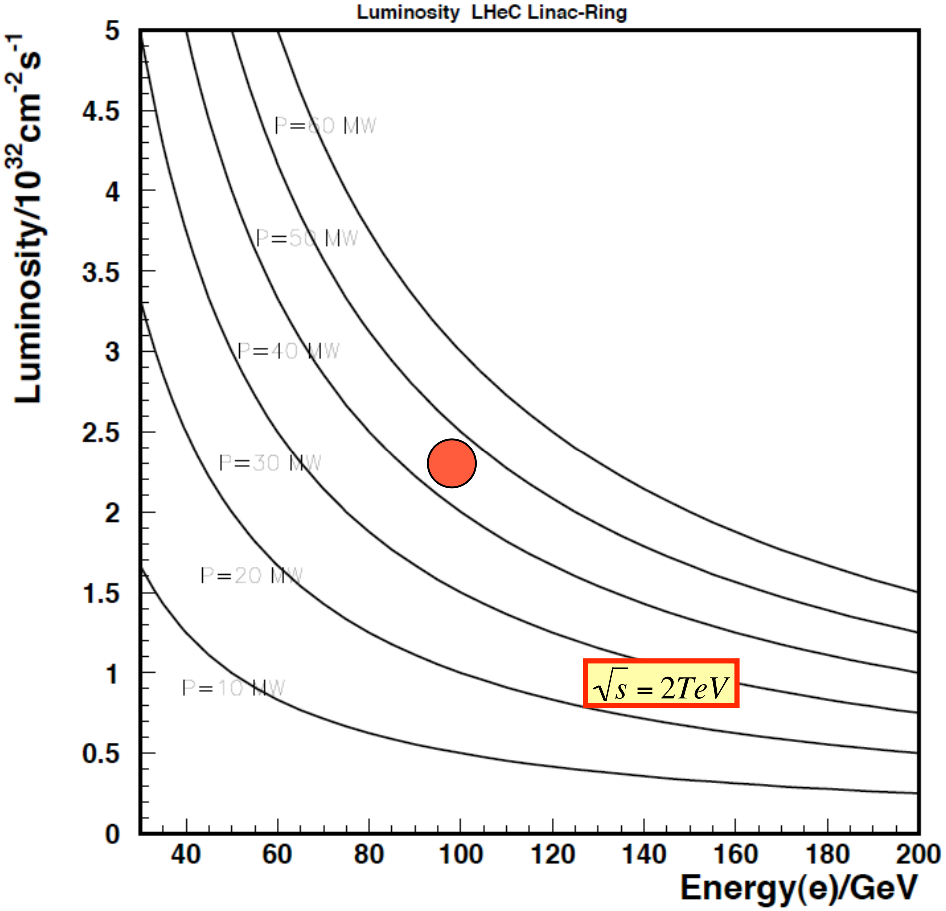
$$L = \frac{N_p \gamma}{4\pi e \varepsilon_{pn} \beta^*} \cdot \frac{P}{E_e} = 5 \cdot 10^{32} \cdot \frac{P/MW}{E_e/GeV} cm^{-2} s^{-1}$$

M.Tigner, B.Wiik, F.Willeke, Acc.Conf, SanFr.(1991) 2910

SLHC - LPA

cf. R.Garoby EPS07,
J.Koutchouk et al PAC07

$$\varepsilon_{pn} = 3.8\mu m$$
$$N_p = 5 \cdot 10^{11}$$
$$\beta^* = 0.10m$$



LINAC is not physics limited in energy, but with its cost/length + power

- **10^{32} are in reach at large E_e.**

LINAC - no periodic loss+refill,
~twice as efficient as ring…
8,4,3fb^{-1} /year at (50)100[150] GeV

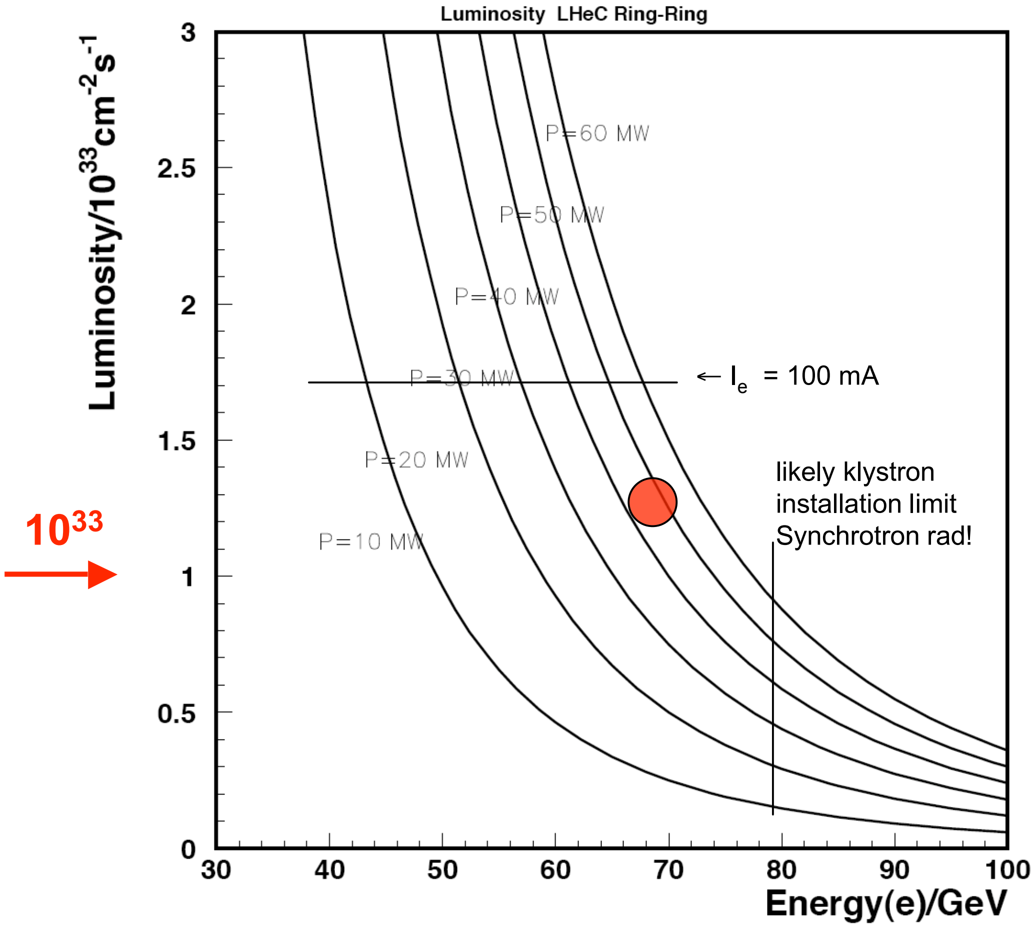
Note: positron source challenge:

LHeC 10^{32} needs few times 10^{14} /sec

Luminosity: Ring-Ring

$$L = \frac{N_p \gamma}{4\pi e \varepsilon_{pn}} \cdot \frac{I_e}{\sqrt{\beta_{px}\beta_{py}}} = 8.310^{32} \cdot \frac{I_e}{50mA} \frac{m}{\sqrt{\beta_{px}\beta_{pn}}} cm^{-2} s^{-1}$$

$$\varepsilon_{pn} = 3.8\mu m$$
$$N_p = 1.1 \cdot 10^{11}$$
$$\sigma_{p(x,y)} = \sigma_{e(x,y)}$$
$$\beta_{px} = 1.8m$$
$$\beta_{py} = 0.5m$$



$$I_e = 0.35mA \cdot \frac{P}{MW} \cdot \left(\frac{100GeV}{E_e}\right)^4$$

Power to beam ~ 50 MW:
50 (70) GeV: 4 (1) 10^{33}cm^{-2} s^{-1}
2x larger for ESP ('ultimate') beam

HERA was 1-5 10^{31} cm^{-2} s^{-1}

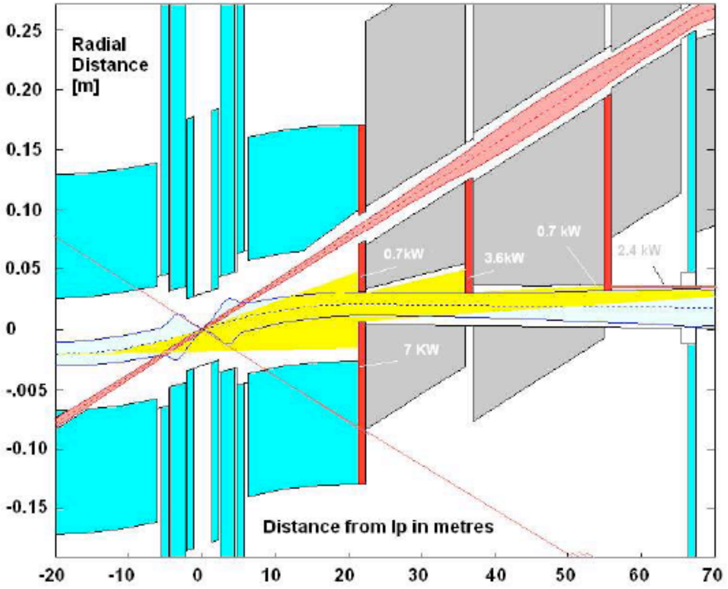
At E_e=50 GeV: ∫ L~100 fb^{-1} /a
with SLHC: L near to 10^{34}cm^{-2} s^{-1}

Ten times lower than SLHC, but
300 times higher than HERA II
and no pile up ….

● F.Willeke et al (JINST 2006)

cf also A.Verdier 1990, E.Keil 1986

Design Details

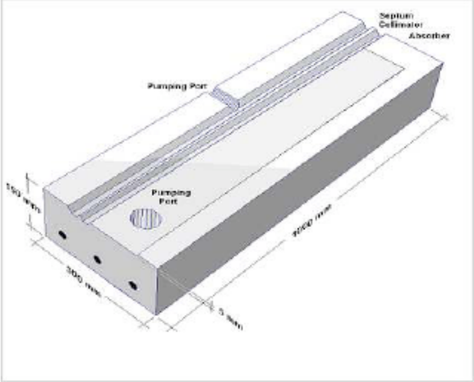


Synchrotron radiation fan

and HERA type absorber

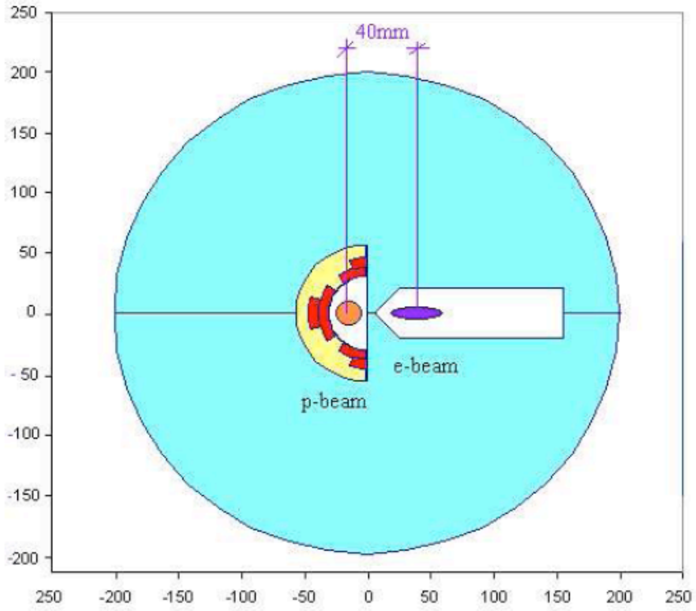
$9.1kW$

$E_{crit} = 76keV$

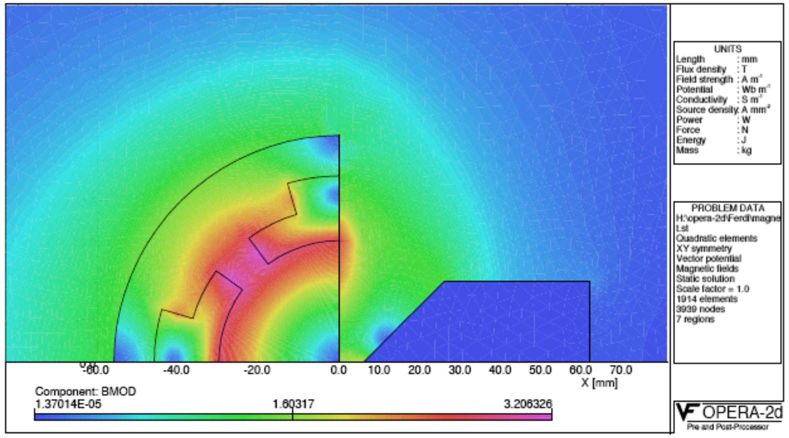


100W/mm^2

cf also W.Bartel Aachen 1990



First p beam lens: septum quadrupole.
Cross section and Field calculation



A first ‘complete’ design for 10^{33}

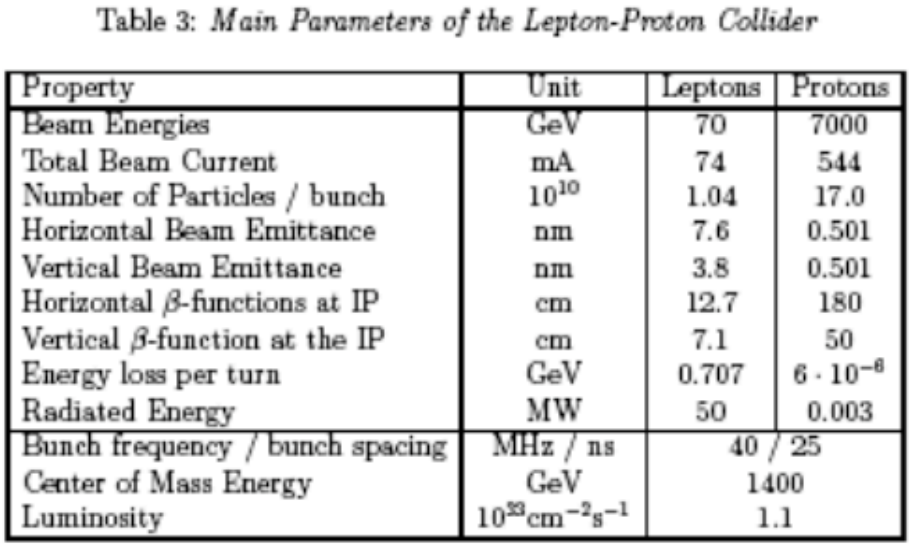
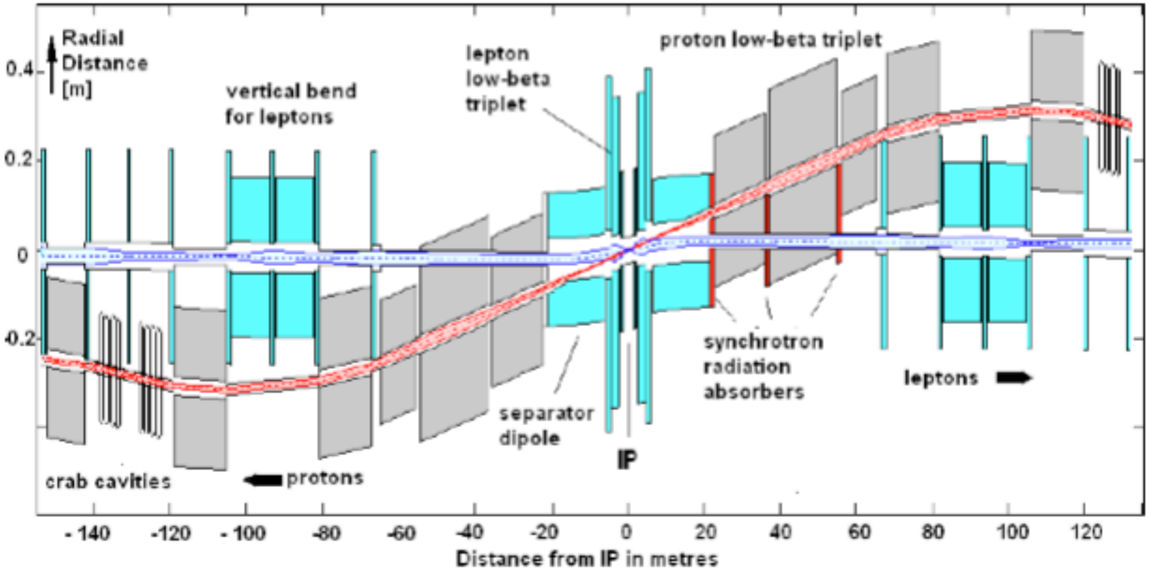
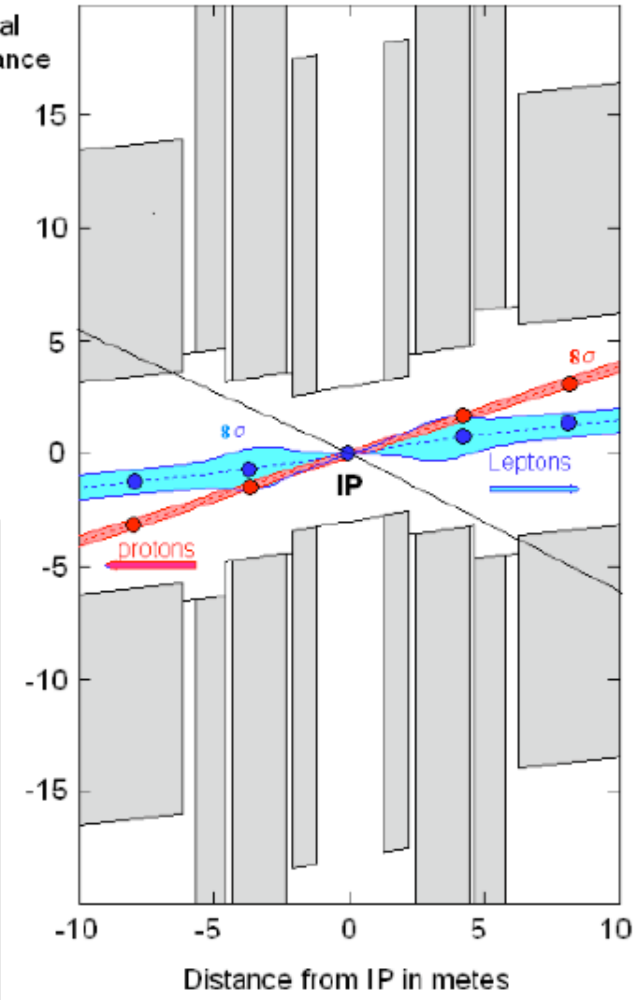


Table 3: *Main Parameters of the Lepton-Proton Collider*

Property	Unit	Leptons	Protons
Beam Energies	GeV	70	7000
Total Beam Current	mA	74	544
Number of Particles / bunch	10^{10}	1.04	17.0
Horizontal Beam Emittance	nm	7.6	0.501
Vertical Beam Emittance	nm	3.8	0.501
Horizontal β-functions at IP	cm	12.7	180
Vertical β-function at the IP	cm	7.1	50
Energy loss per turn	GeV	0.707	$6 \cdot 10^{-6}$
Radiated Energy	MW	50	0.003
Bunch frequency / bunch spacing	MHz / ns	40 / 25	
Center of Mass Energy	GeV	1400	
Luminosity	$10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$	1.1	





Parameters for pulsed Linacs for 140 GeV, $10^{32}\mathrm{cm}^{-2}\mathrm{s}^{-1}$

SC technology

NC technology

	X FEL 20 GeV	LHeC 140 GeV, $10^{32}\mathrm{cm}^{-2}\mathrm{s}^{-1}$	LHeC 140 GeV, $10^{32}\mathrm{cm}^{-2}\mathrm{s}^{-1}$
I_{Beam} during pulse	5 mA	11.4 mA	0.4 A
N_E	$0.624 \cdot 10^{10}$	$5.79 \cdot 10^{10}$	$6.2 \cdot 10^{10}$
Bunch spacing	0.2 μs	0.8 μs	25 ns
Pulse duration	0.65 ms	1.0 ms	4.2 μs
Repetition rate	10 Hz	10 Hz	100 Hz
G	23.6MV/m	23.6MV/m	20.0 MV/m
Total Length	1.27 km	8.72 km	8.76 km
P_{Beam}	0.65 MW	16.8 MW	16.8 MW
Grid power for RF plant	4 MW	59 MW	96 MW
Grid power for Cryoplant	3 MW	20 MW	-
P_{Beam}/P_{AC}	10%	21%	18%

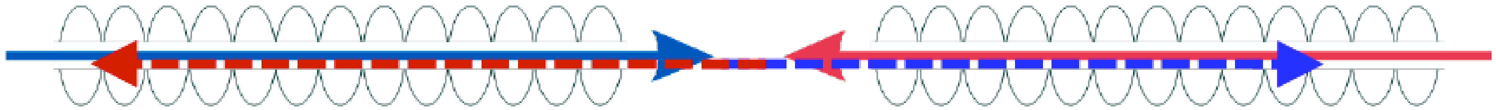
H.Braun, DIS08 workshop, cf also EPAC paper and F.Zimmermann here.

Energy Recovery

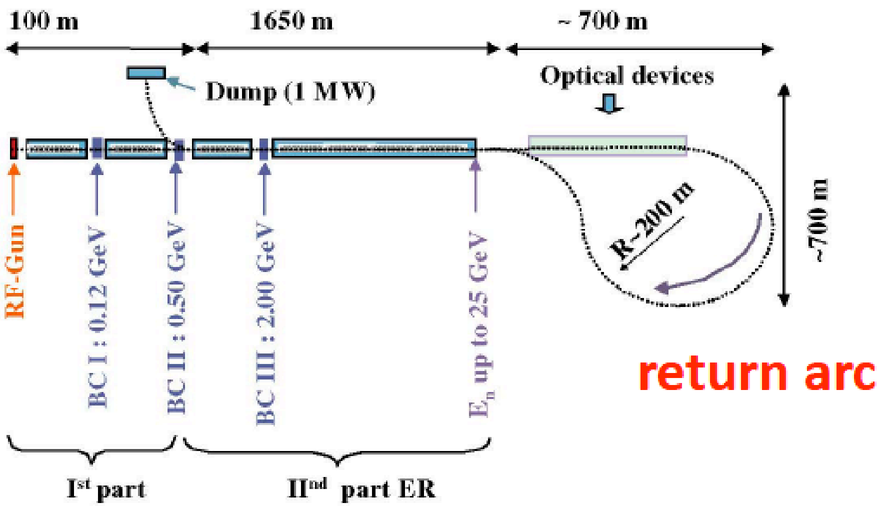
Jlab: recirculating linac, 99.5% of energy recovered at 150 MeV and 10 mA, ~98% recovery at 1 GeV and 100 µA with beam swung between 20 MeV to 1 GeV, plans for multi-GeV linacs withcurrents of ~100 mA

S. Chattopadhyay

M. Tigner, "A possible apparatus for electron clashing-beam experiments," Nuovo Cim.37:1228-1231 (1965).

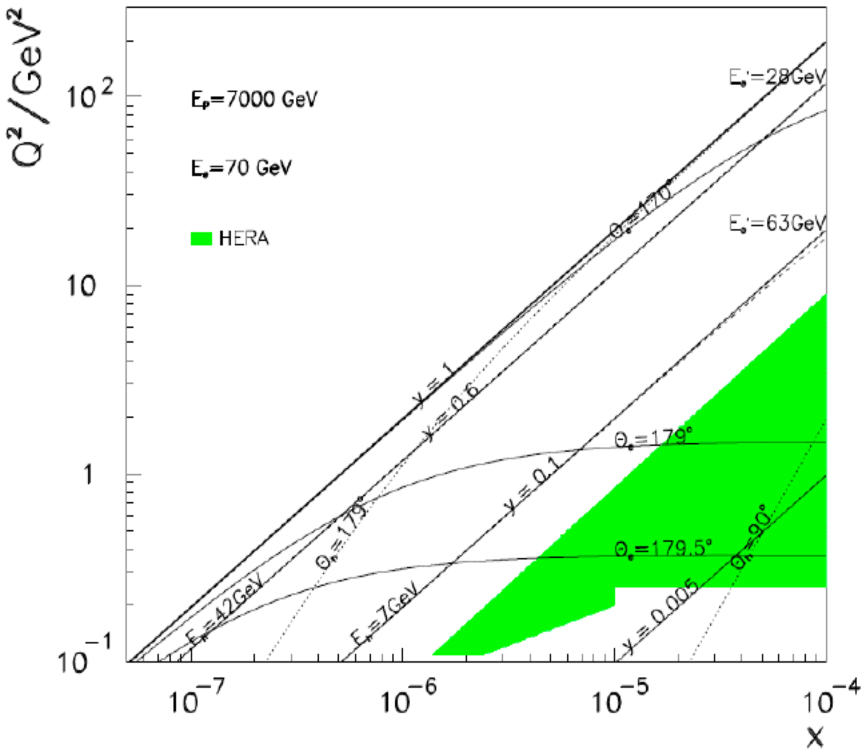


J. Sekutowicz et al, "Proposed continuous wave energy recovery operation of an XFEL," Phys.Rev.ST Accel.Beams 8:010701,2005, up to 98% efficient

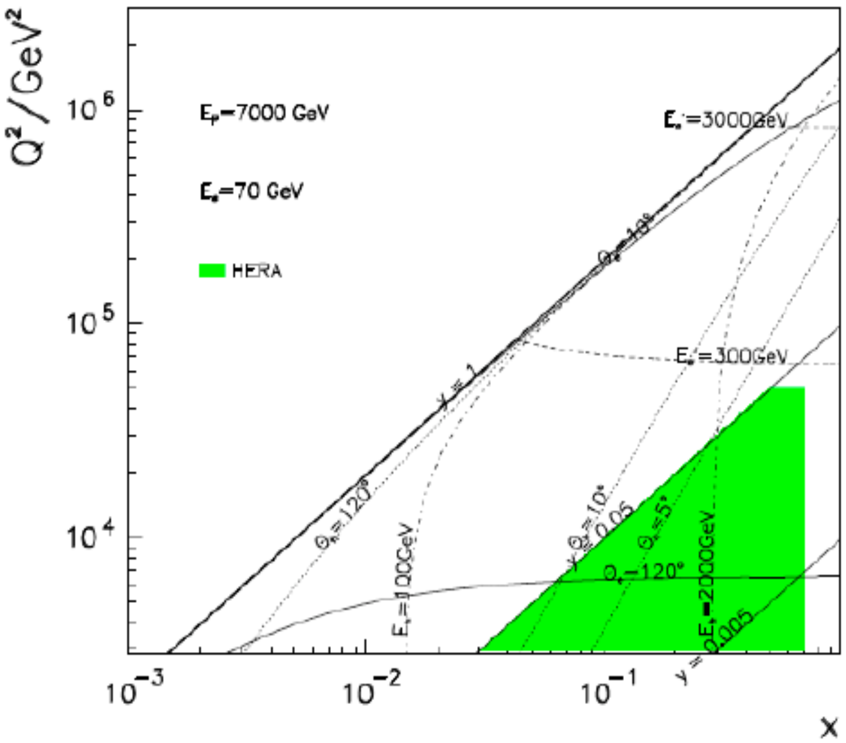


Interaction Region - Kinematics

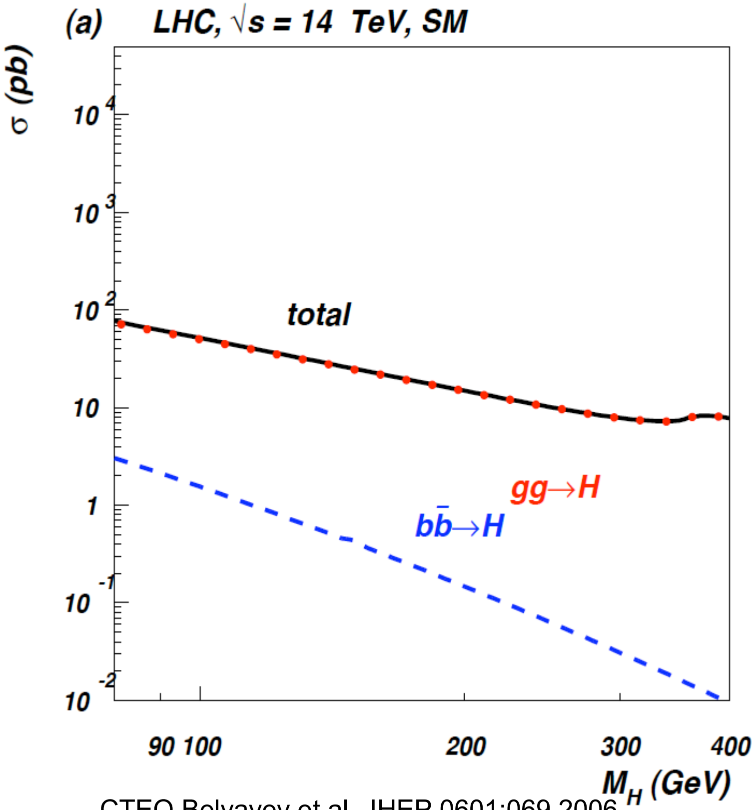
LHeC – Low x Kinematics



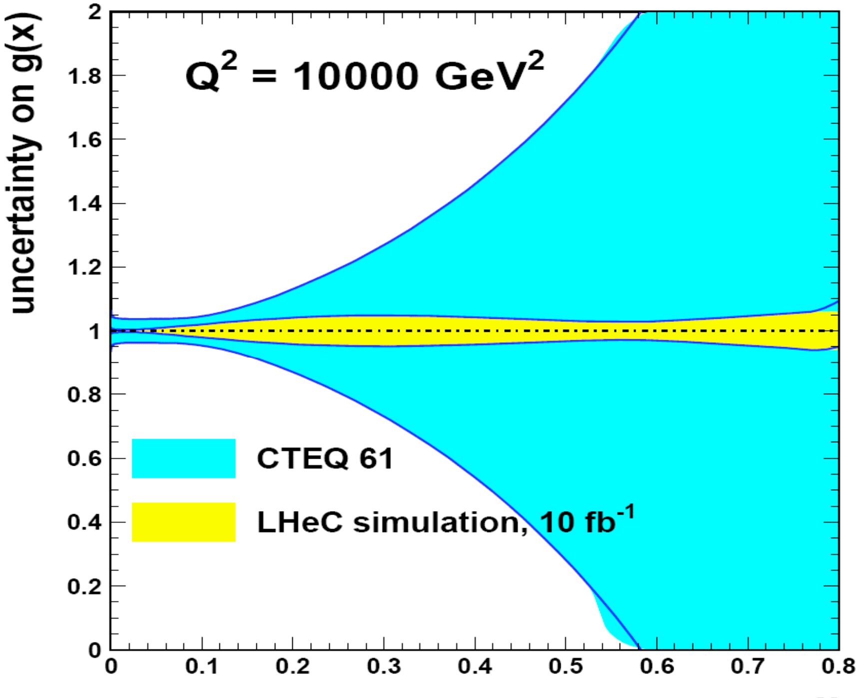
LHeC – High Q² Kinematics



Gluon - SM Higgs



CTEQ Belyayev et al. JHEP 0601:069,2006

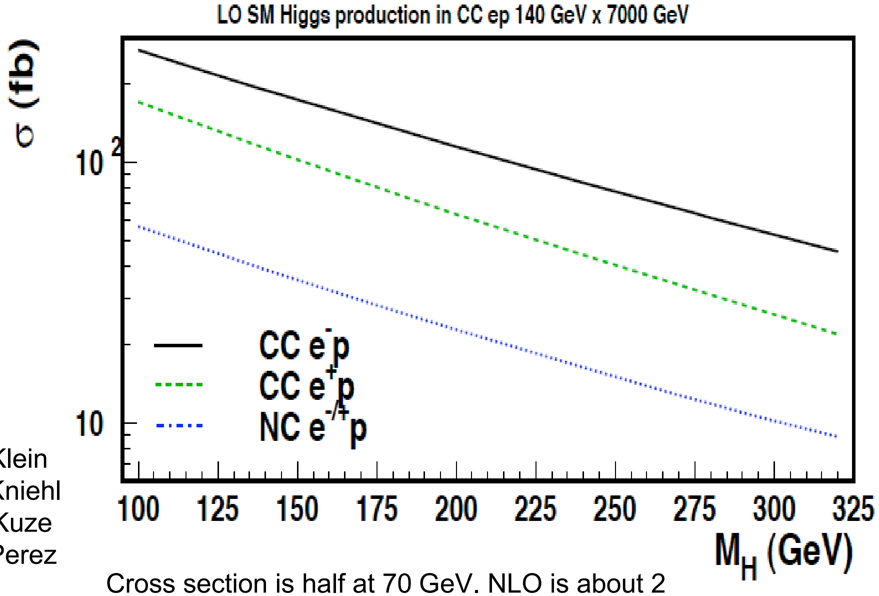


E.Perez, DIS07

In SM Higgs production is gluon dominated

LHeC: huge x,Q^2 range for xg determination

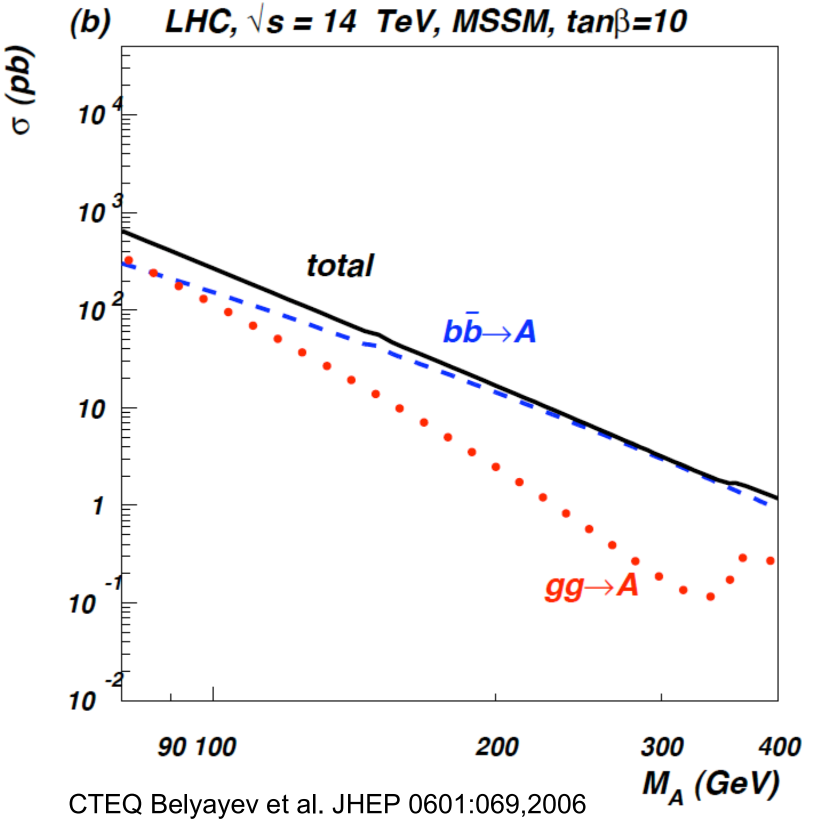
WW to Higgs fusion has sizeable ep xsection



U.Klein
B.Kniehl
M.Kuze
E.Perez

Cross section is half at 70 GeV. NLO is about 2

Beauty - MSSM Higgs

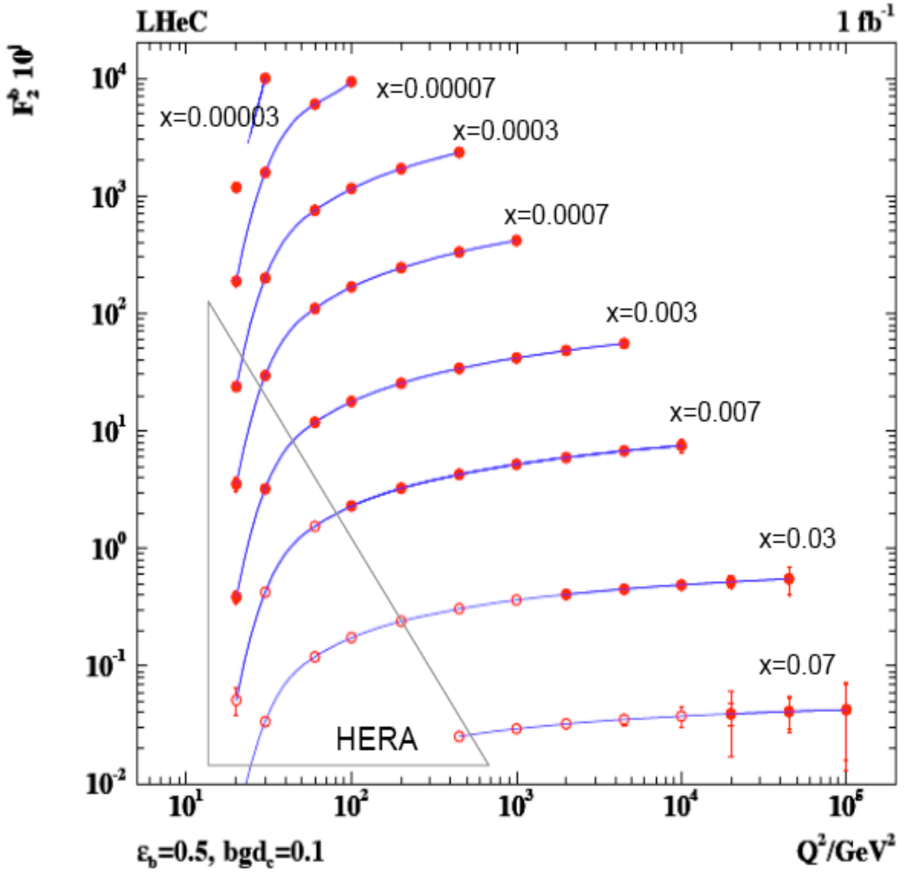


CTEQ Belyayev et al. JHEP 0601:069,2006

In MSSM Higgs production is b dominated

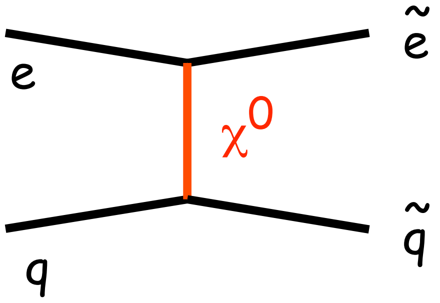
First measurements of b at HERA can be turned to precision measurement of b-df.

LHeC: higher fraction of b, larger range, smaller beam spot, better Si detectors



O.Behnke, MK, A.Mehta

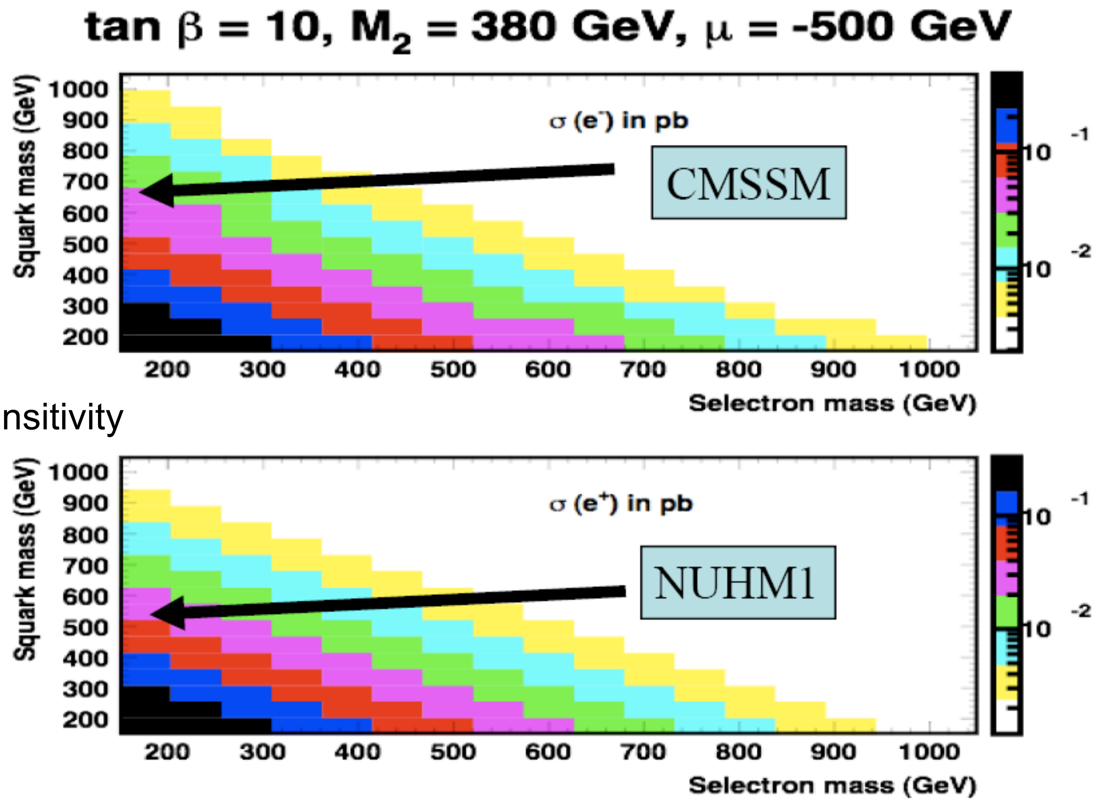
Supersymmetry (R-parity conserved)



Pair production via t-channel exchange of a neutralino.
Cross-section sizeable when ΣM below ~ 1 TeV.
Such scenarios are “reasonable”.

E.g. global SUSY fit to EW & B-physics observables plus cosmological constraints (O. Buchmueller et al, 2008), within two SUSY models (CMSSM & NUHM) leads to masses of ~ (700, 150) GeV.

SUSY cross-section at LHeC:
about 15 fb for these scenarios.


tan β = 10, M_2 = 380 GeV, μ = -500 GeV

Added value w.r.t. LHC to be studied :

- could extend a bit over the LHC slepton sensitivity
- precise mass measurements
- relevant information on χ^0 sector

The Complementarity of e^+e^-,pp,ep

PETRA: 3 jets and DIS@CERN/FNAL: logarithmic scaling violations: QCD, gluons

HERA: Leptoquark Signals and Tevatron: Not seen

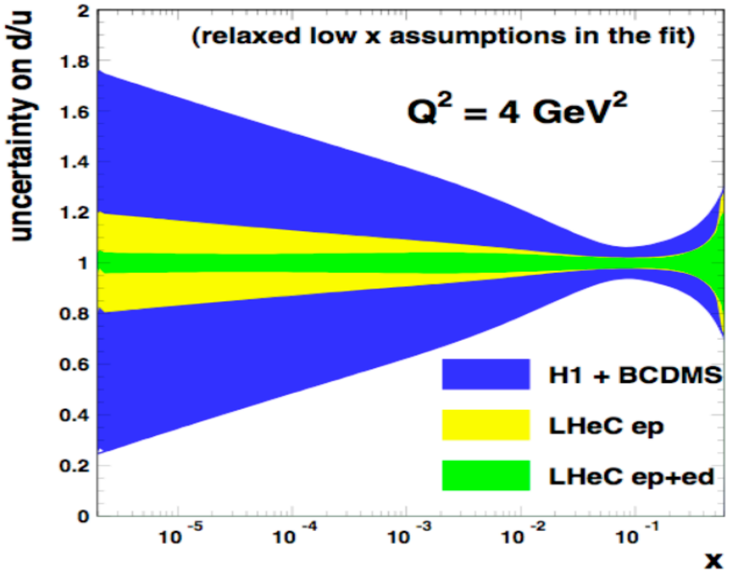
LEP/SLC: electroweak theory to high orders and Tevatron: top quark

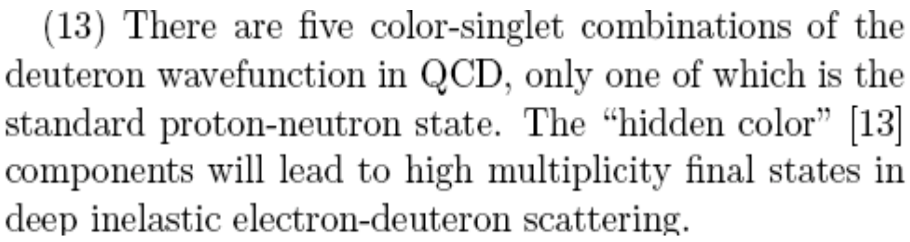
Tevatron: high Et jet access and HERA: gluon distribution

has been crucial for establishing new physics, now called standard, and for understanding exotics.

Neutron Structure (ed → eX)

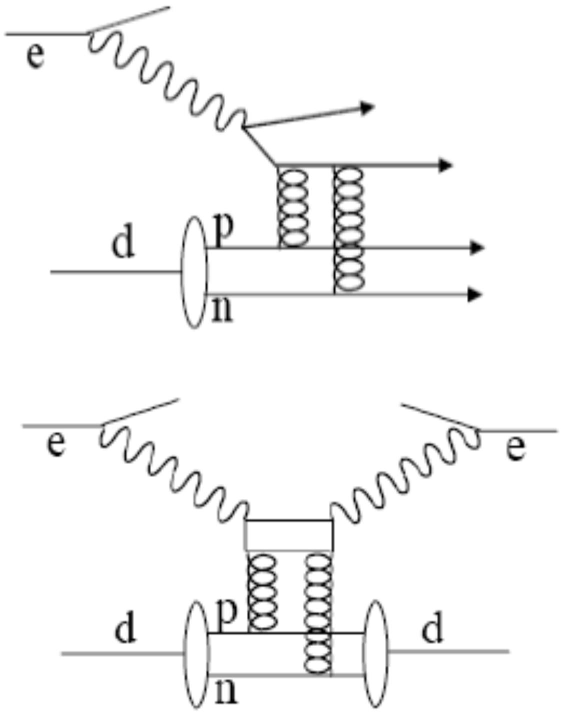
d/u at low x from deuterons





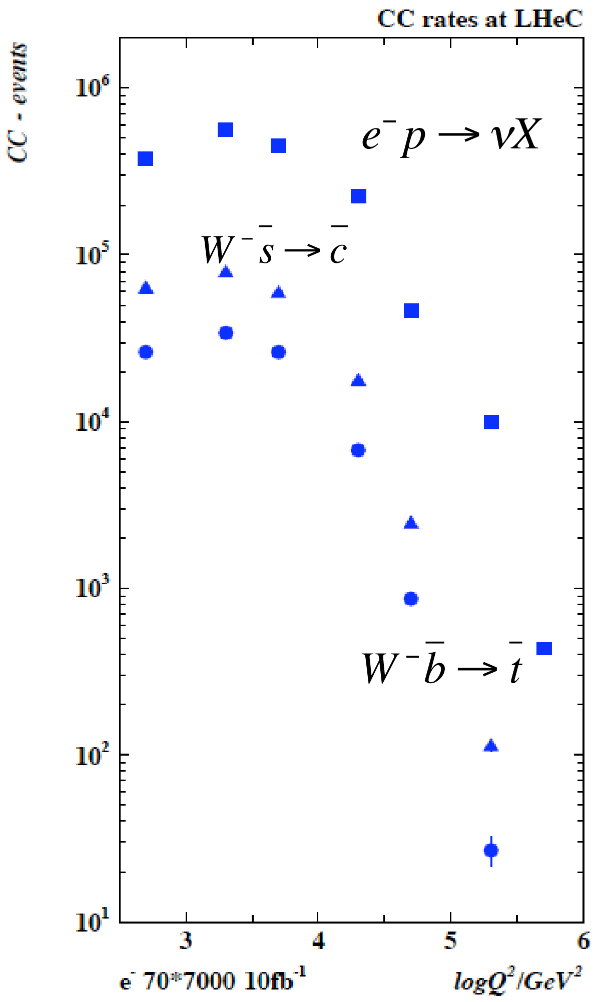
(13) There are five color-singlet combinations of the deuteron wavefunction in QCD, only one of which is the standard proton-neutron state. The "hidden color" [13] components will lead to high multiplicity final states in deep inelastic electron-deuteron scattering.

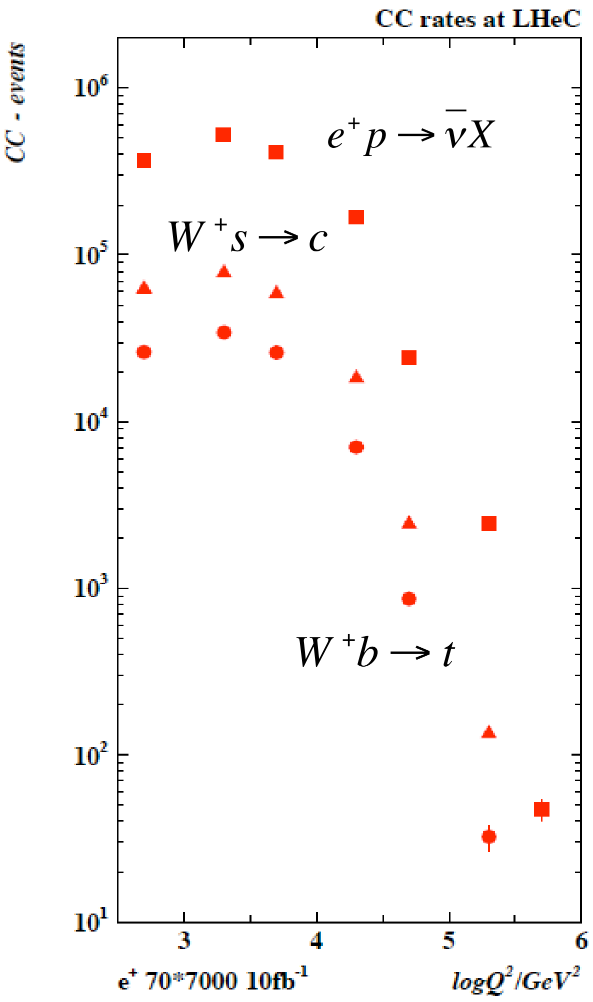
crucial constraint on evolution (S-NS), improved α_s



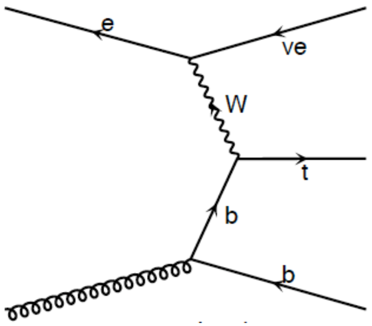
In eA at the collider, test Gribovs relation between shadowing and diffraction, control nuclear effects at low Bjorken x to high accuracy

Single (anti) t and s Quark Production in CC





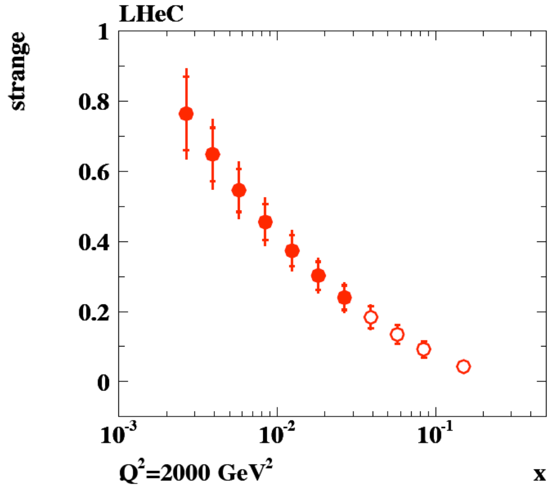
G.Brandt, MK



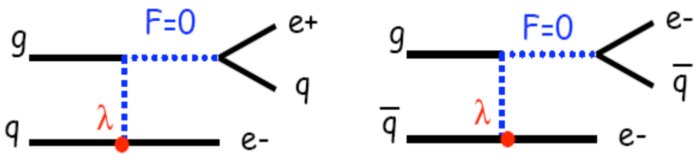
LHeC is a single top and single tbar quark `factory'

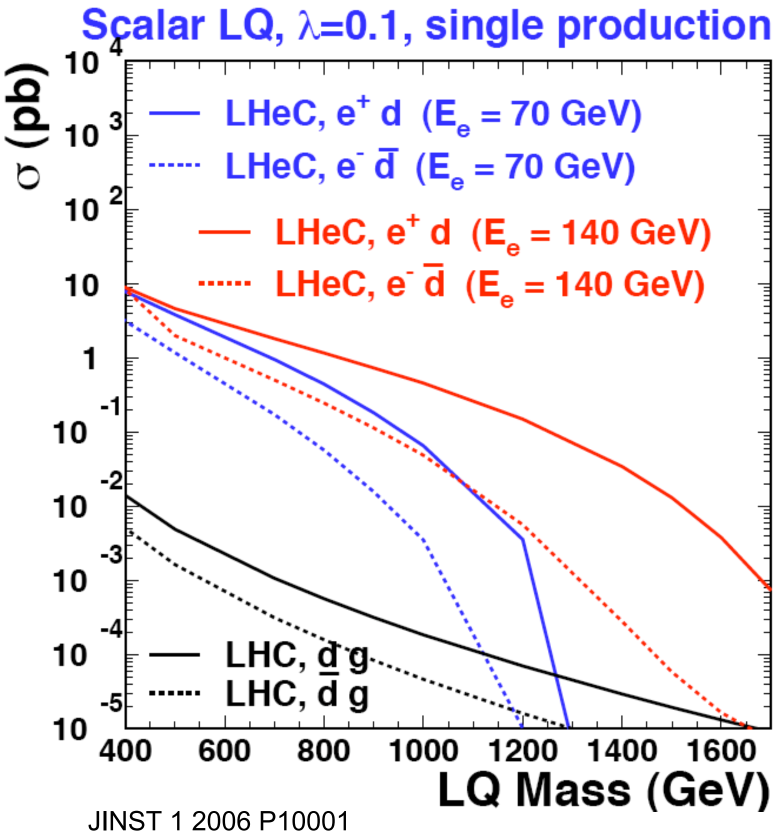
CC t cross section O(5)pb

s, sbar-df for the 1st time.

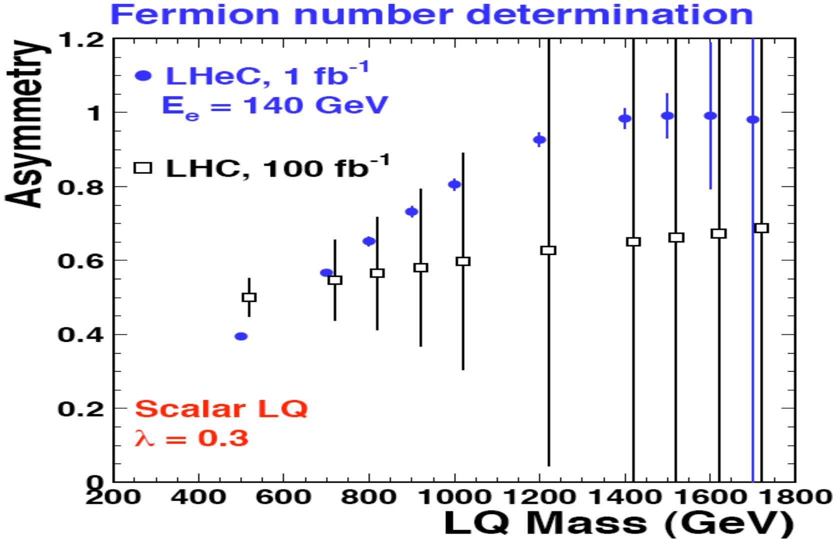


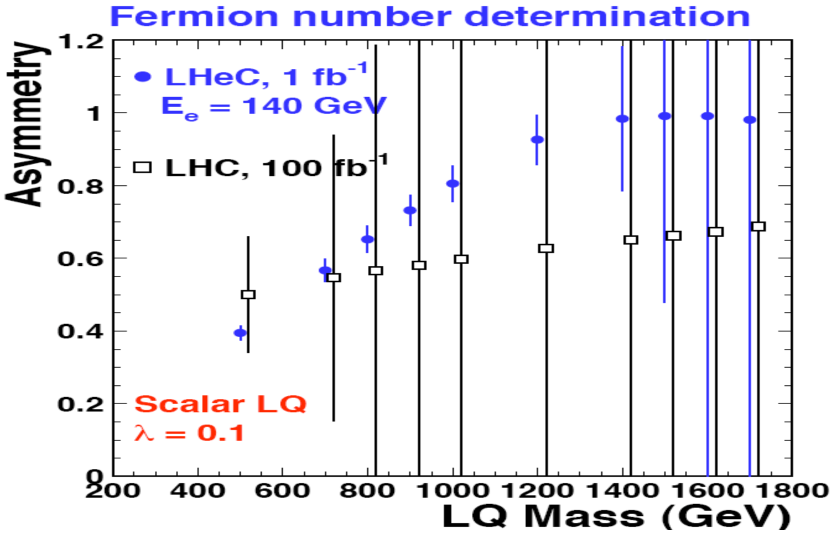
LQ Quantum Numbers





JINST 1 2006 P10001



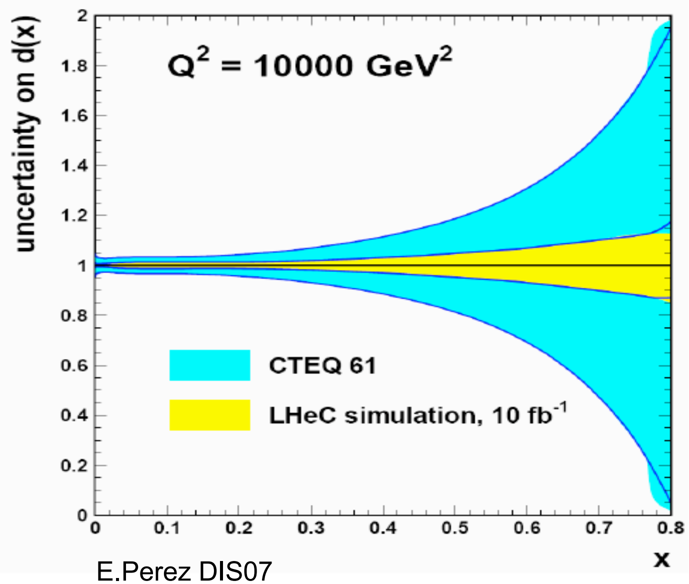


Charge asymmetry much cleaner in ep than in pp. Similar for simultaneous determination of coupling and quark flavour. Polarisation for spectroscopy

Light Quark Distributions

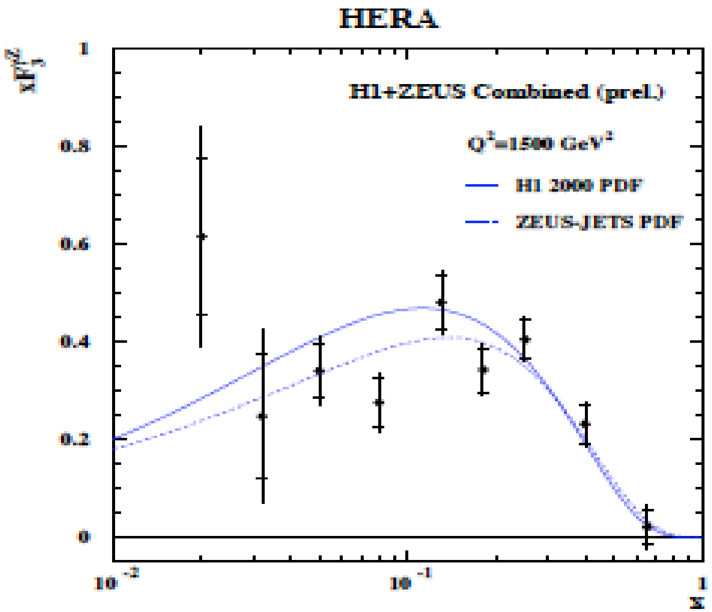
d and u at high x: a longstanding puzzle
NC/CC: free of HT, nuclear corrections.
Essential for predictions at high x

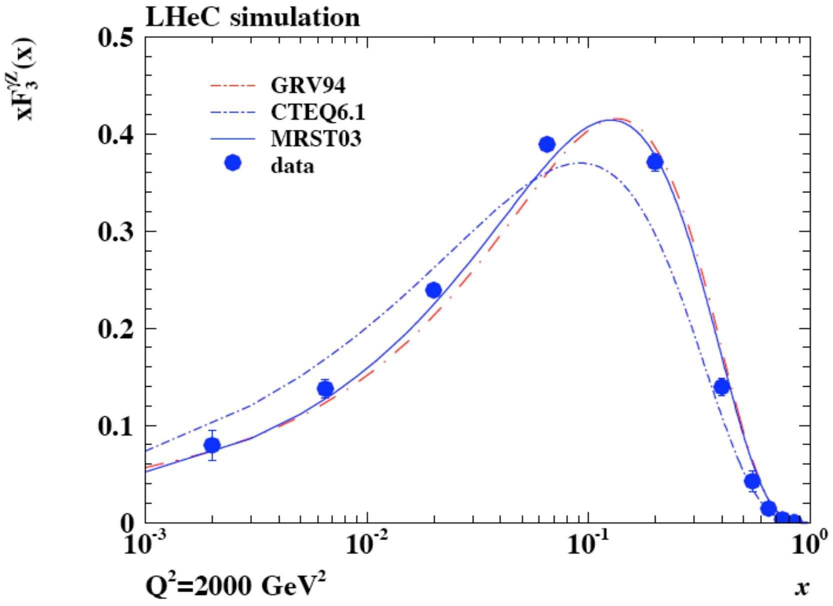
LHeC is an electroweak machine.
e.g.: Charge asymmetry in NC measures
valence quarks down to x ~10^{-3} at high Q^2



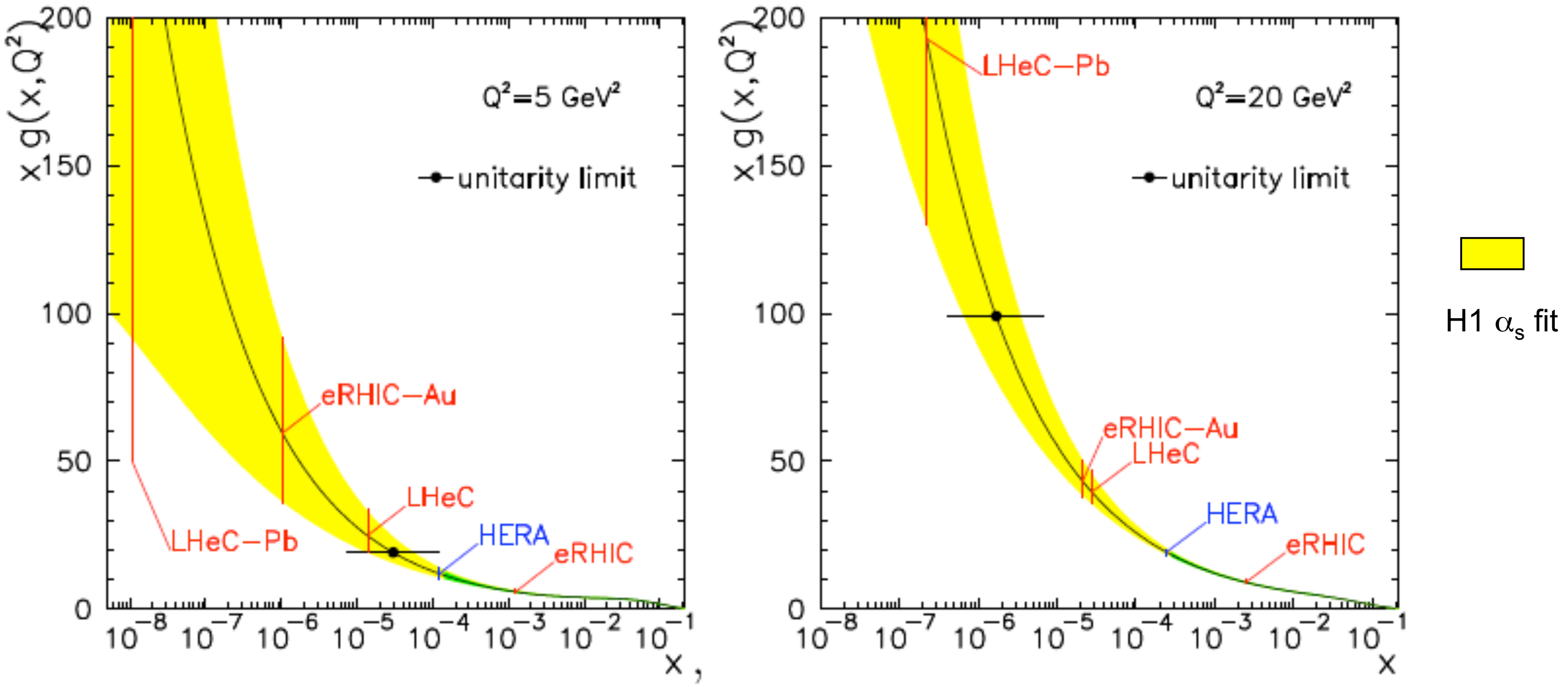
E.Perez DIS07

$$\boxed{xF_3^{\gamma Z} = \frac{x}{3}(2u_v + d_v)}$$





Density Amplification and Unitarity Limit



High density $$\frac{g_A/\pi r_A^2}{g_p/\pi r_p^2} = A^{1/3}\frac{g_A}{Ag_p}$$

Unitarity $$\boxed{xg(x,Q^2) \leq \frac{1}{\pi N_c \alpha_s(Q^2)} Q^2 R^2 \simeq \frac{Q^2}{\alpha_s}}$$

Striking effects predicted:

Bj → black disc limit $F_2 \sim Q^2 \ln(1/x)$
~50% diffraction
colour opacity, change of J/Ψ(A) …

Saturation - Black Hole Duality.?

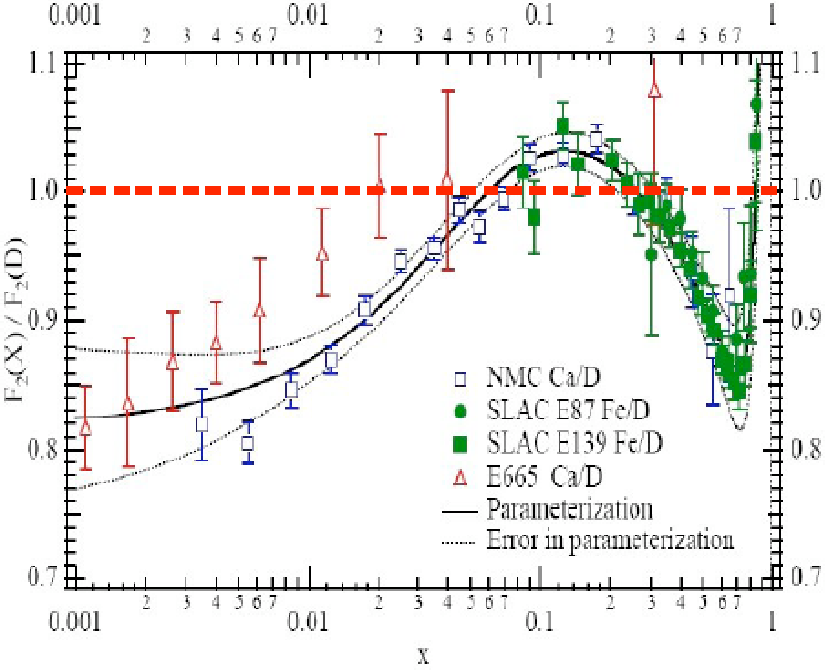
4d Perturbative QCD	5d Tiny Black hole
1. Dilute/dense transition	1. Flat/black hole transition
2. Geometric scaling	2. CSS
3. Critical exponent 2.44	3. Critical exponent 2.58
4. IR/UV competition	4. Gravity/kinetic competition

Agustin Sabio Vera (Divonne)

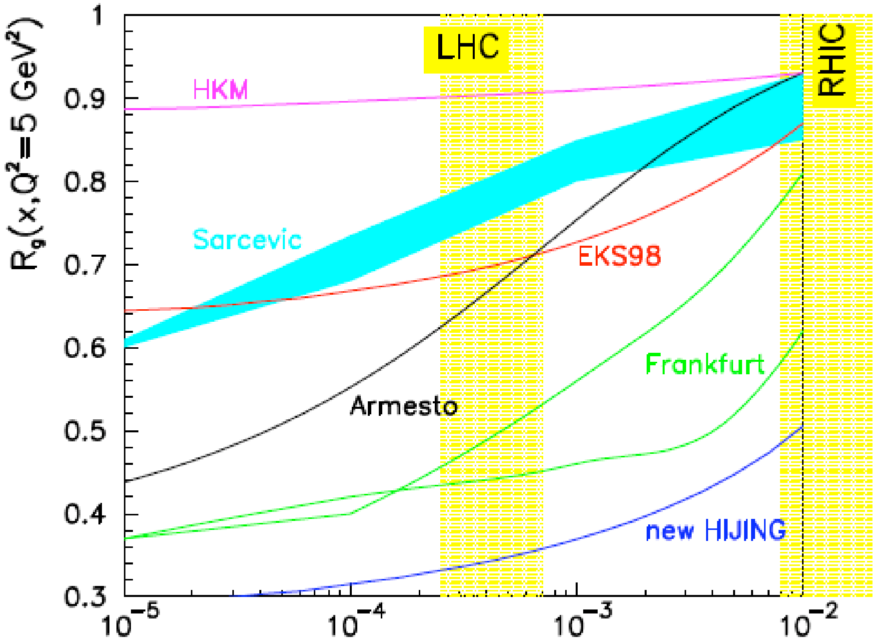
Need eA collider data to determine nuclear parton distributions in the kinematic range of pA/AA collisions at the LHC

NuPECC EIC-LHeC Study group

Tullio Bressani, INFN, Torino Univ.
Jens Jørgen Gaardhøje, Niels Bohr Inst.
Günther Rosner, Glasgow Univ.
Hans Ströher, FZ Juelich



See e.g. M.Arneodo
Phys. Rept. 240 (94) 301



K.Eskola et al. JHEP 0807 (08)102

A Final Remark

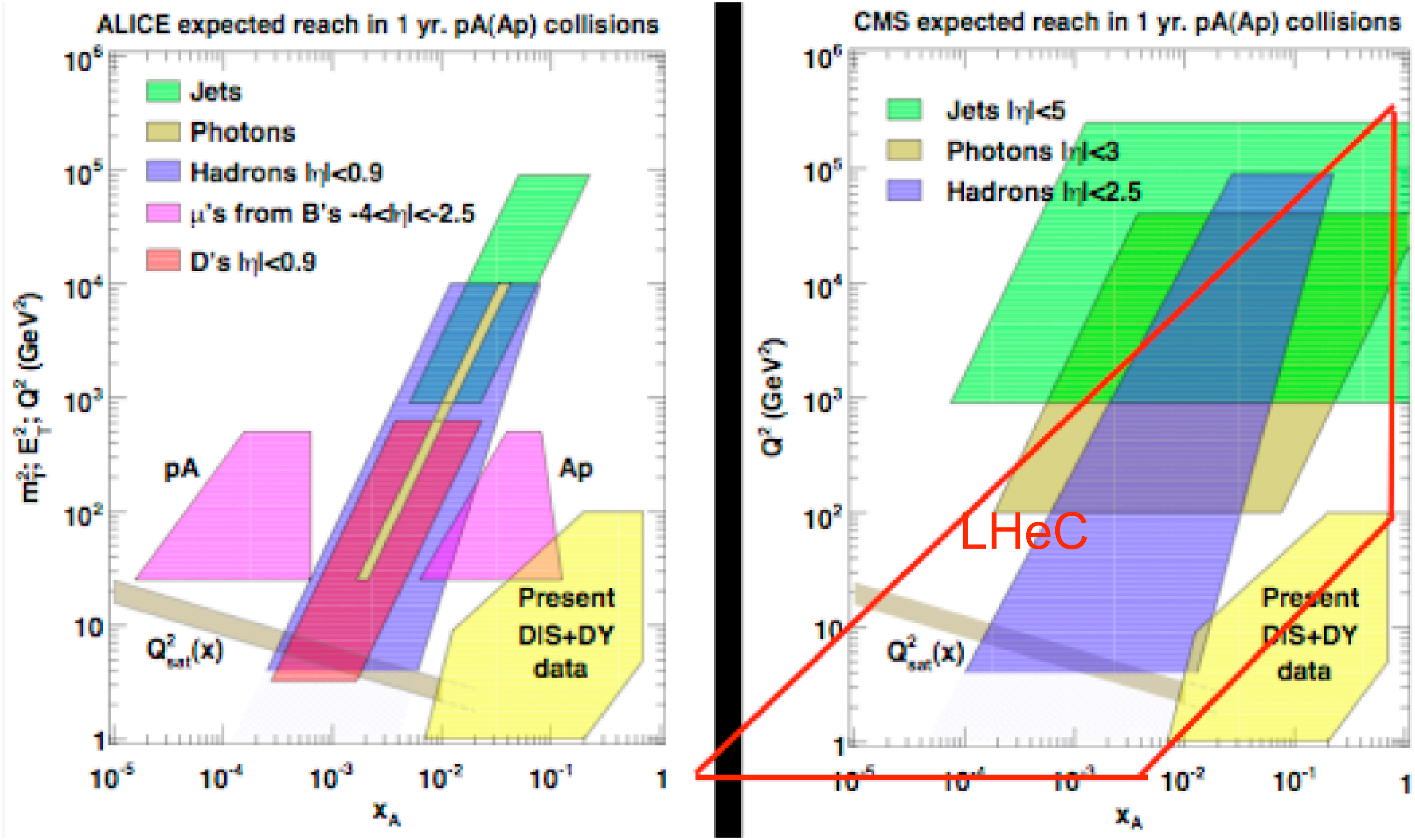
“Now we are entering the post-TeV era, jumping not one but two orders of magnitude to a lab equivalent of order 50 TeV at HERA. If the LHC is successfully commissioned in the LEP tunnel in 1997, then we may hope to see collisions between electrons from LEP and protons from the LHC in the next millenium giving a lab equivalent around 10^3 TeV (1 PeV). “ F.Close Singapor 1990

A new eN machine operating at TeV energies so far appears doable, luminous and interesting. It is a complement to the LHC.

The CDR on the LHeC aims at contributing to an informed decision on the development of high energy accelerator physics. You are very welcome to join.

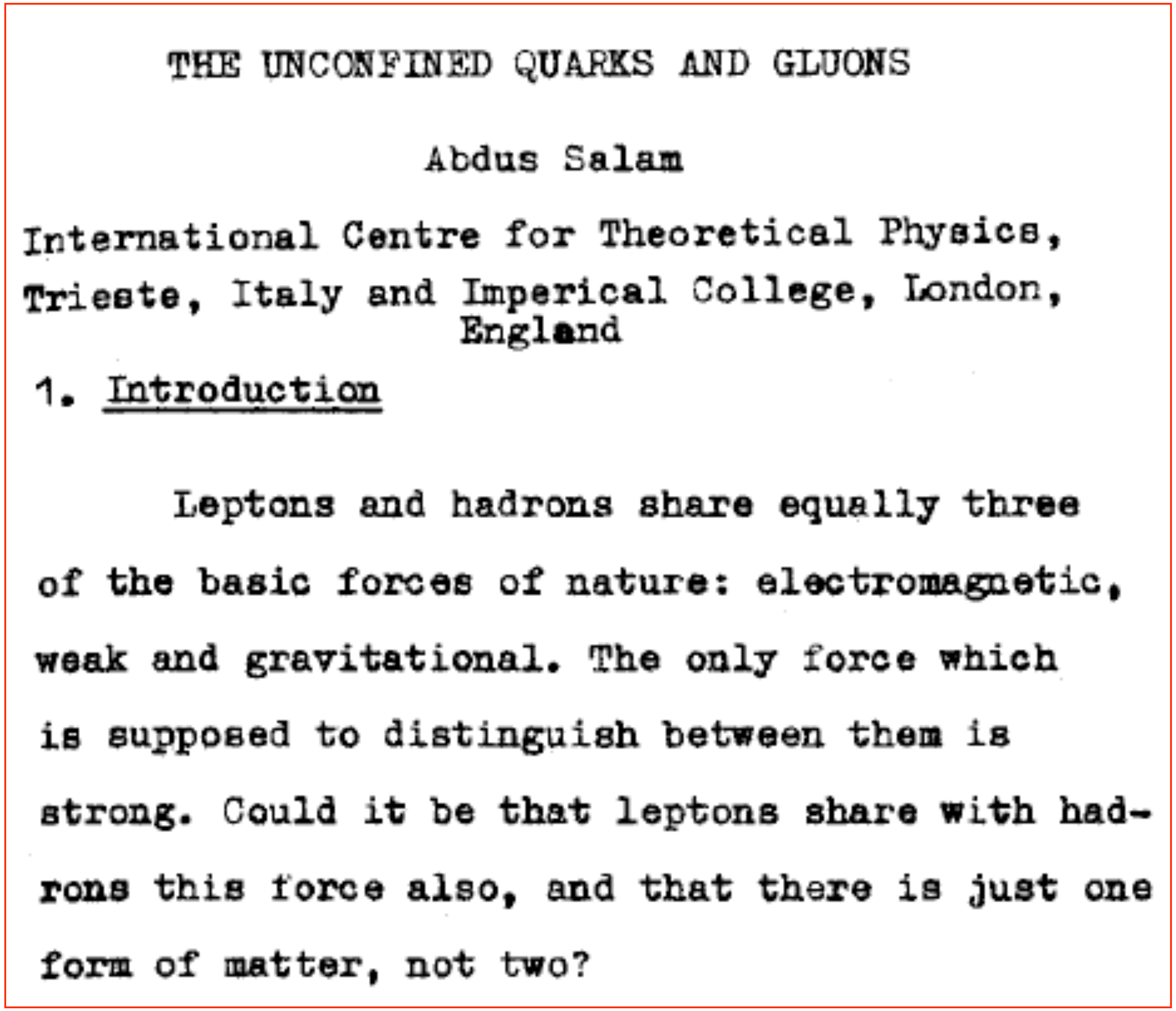
http://www.lhec.org.uk

Complementarity of Ap and ep



D'Enterria Divonne

Note that DY is not DIS



THE UNCONFINED QUARKS AND GLUONS

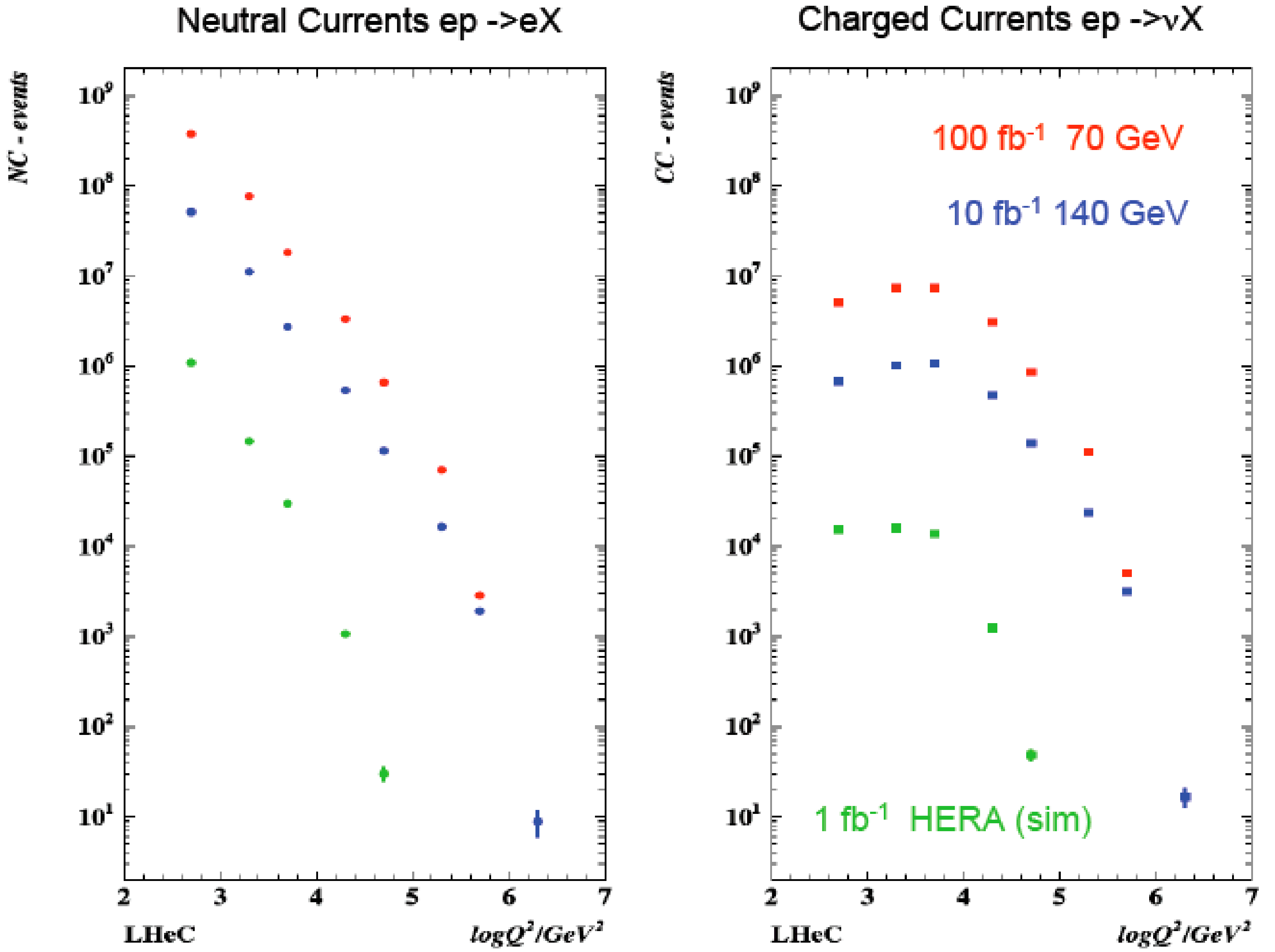
Abdus Salam

International Centre for Theoretical Physics,
Trieste, Italy and Imperical College, London,
England

1. Introduction

Leptons and hadrons share equally three of the basic forces of nature: electromagnetic, weak and gravitational. The only force which is supposed to distinguish between them is strong. Could it be that leptons share with hadrons this force also, and that there is just one form of matter, not two?

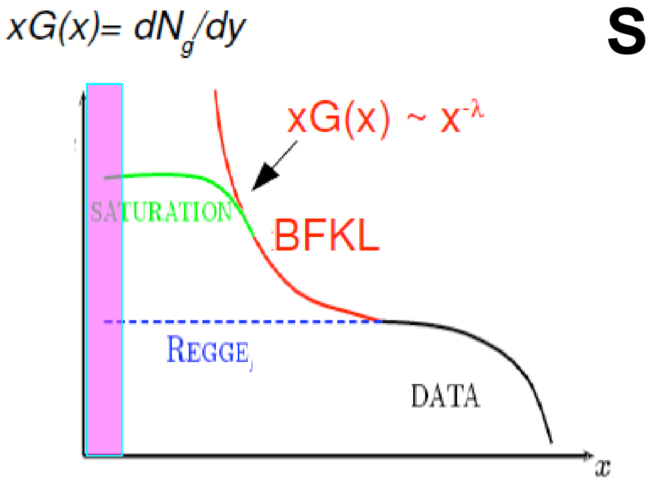
ICHEP1976 Tbilissi



Neutral Currents ep ->eX

Charged Currents ep ->νX

Saturation?

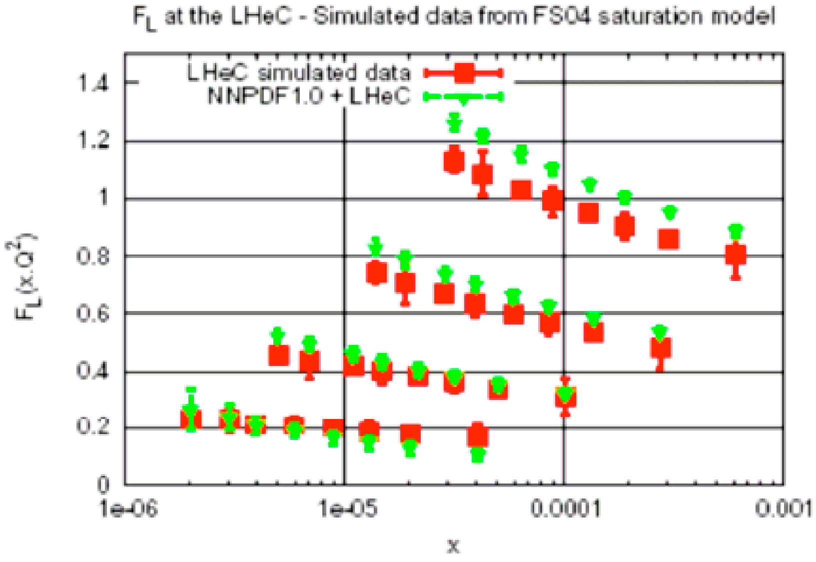


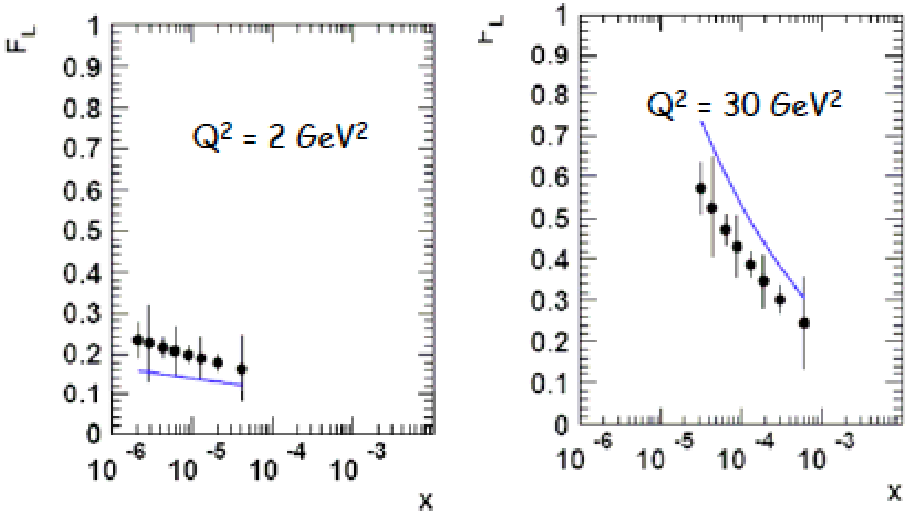
Cross sections shall saturate because of unitarity.
(notice link to superhigh energy neutrino physics)

A new phase of matter:
density high but coupling is small (CGC).

HFS, fwd jets, unintegrated pdf's, diffraction, F_L
The dynamics at low x is not settled with HERA
(energy too small, no nuclei)

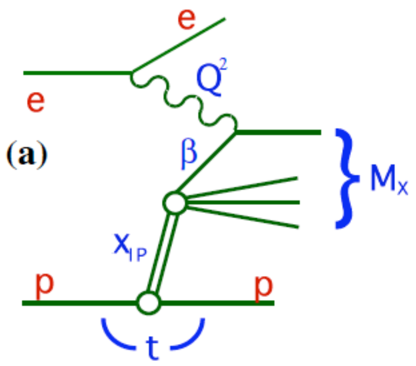
LHeCsat data in NNPDF1.0

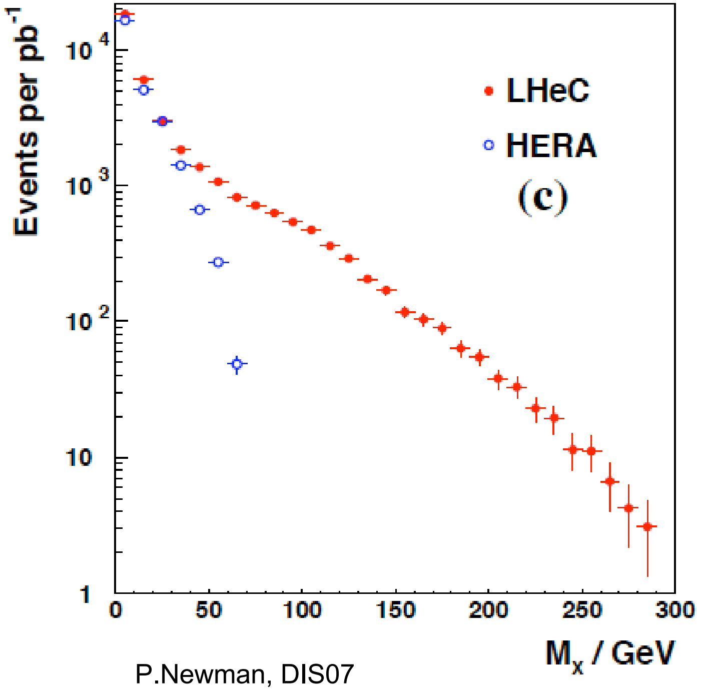




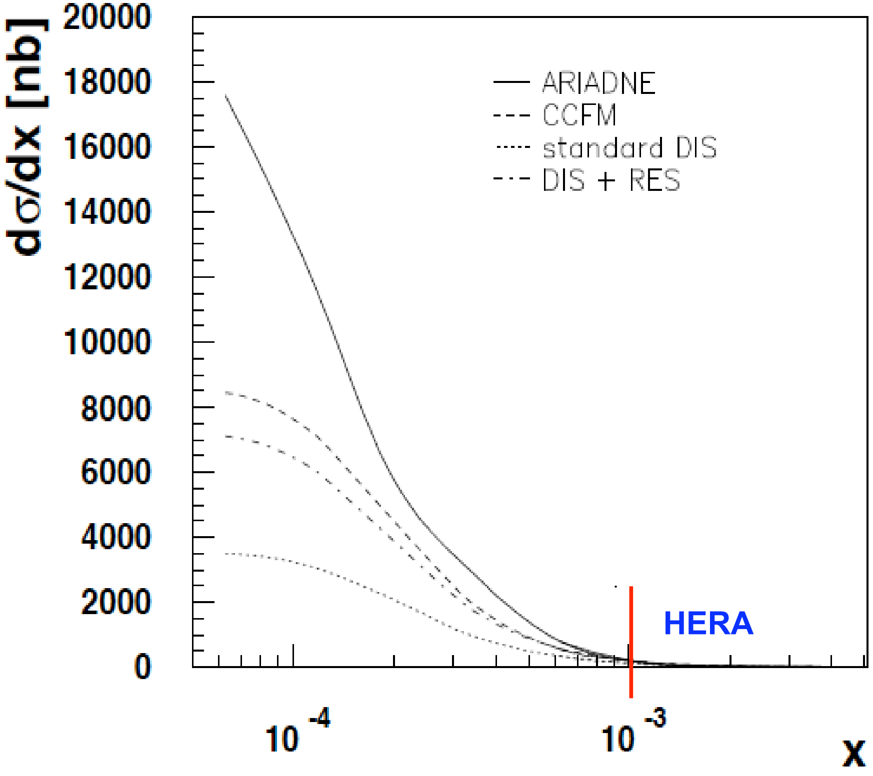
Measurements of F_2 and F_L at LHeC should allow to establish saturation in DIS range

Quark-Gluon Dynamics - Diffraction and HFS (fwd jets)





P.Newman, DIS07

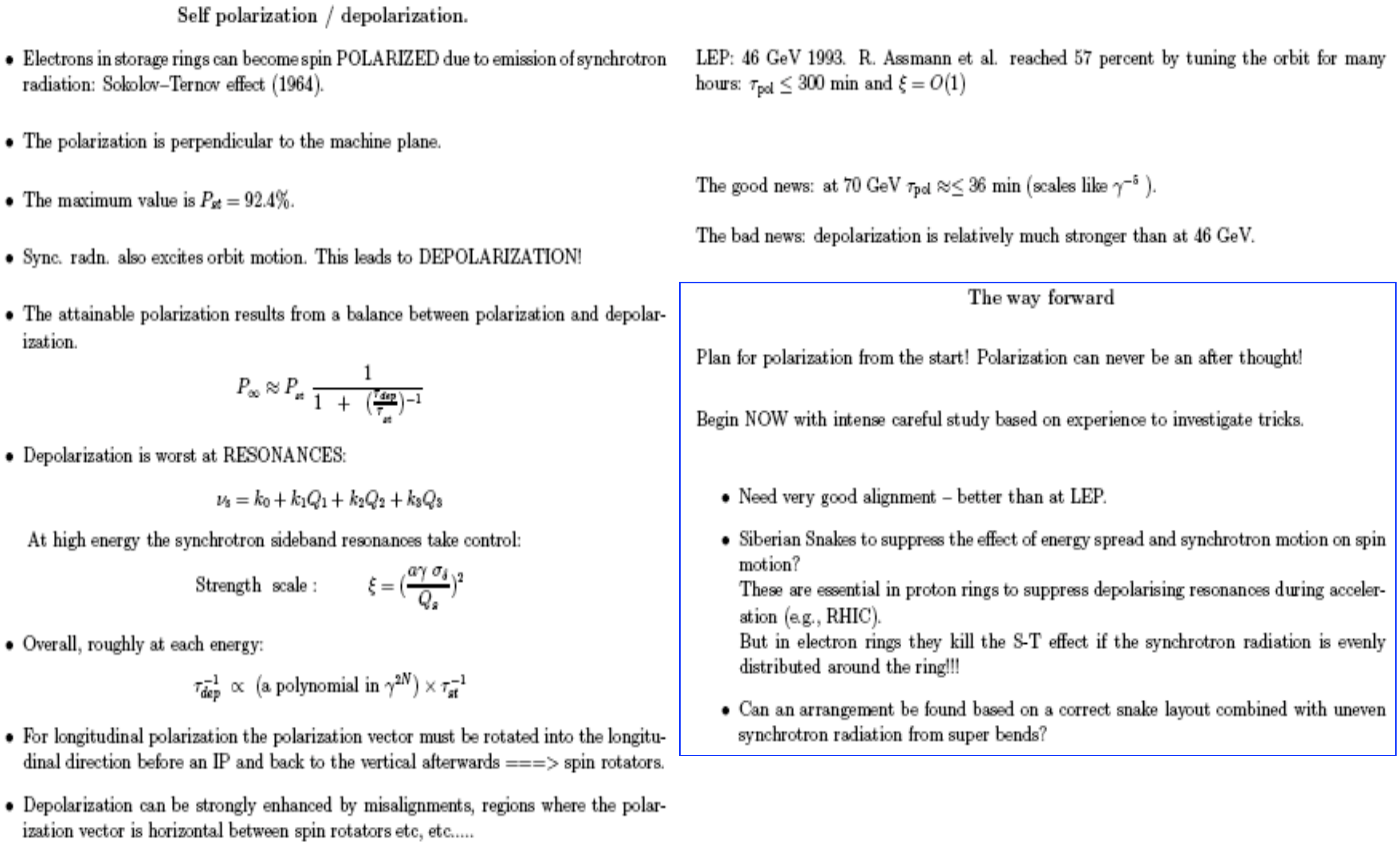


H.Jung, L.Loennblad, THERA study

Diffraction to accompany (SUSY) Higgs fwd physics at LHC

Understand multi-jet emission (unintegr. pdf's), tune MC's
At HERA resolved γ effects mimic non-kt ordered emission
Crucial measurements for QCD, and for QCD at the LHC

Lepton Polarisation



Self polarization / depolarization.

- Electrons in storage rings can become spin POLARIZED due to emission of synchrotron radiation: Sokolov–Ternov effect (1964).
- The polarization is perpendicular to the machine plane.
- The maximum value is $P_{st} = 92.4\%$.
- Sync. radn. also excites orbit motion. This leads to DEPOLARIZATION!
- The attainable polarization results from a balance between polarization and depolarization.

$$P_{\infty} \approx P_{st} \frac{1}{1 \; + \; (\frac{\tau_{dep}}{\tau_{st}})^{-1}}$$

- Depolarization is worst at RESONANCES:

$$\nu_s = k_0 + k_1 Q_1 + k_2 Q_2 + k_3 Q_3$$

At high energy the synchrotron sideband resonances take control:

$$\text{Strength scale :} \qquad \xi = (\frac{a\gamma \; \sigma_\delta}{Q_s})^2$$

- Overall, roughly at each energy:

$$\tau_{dep}^{-1} \; \propto \; (\text{a polynomial in } \gamma^{2N}) \times \tau_{st}^{-1}$$

- For longitudinal polarization the polarization vector must be rotated into the longitudinal direction before an IP and back to the vertical afterwards ===> spin rotators.
- Depolarization can be strongly enhanced by misalignments, regions where the polarization vector is horizontal between spin rotators etc, etc.....

LEP: 46 GeV 1993. R. Assmann et al. reached 57 percent by tuning the orbit for many hours: $\tau_{pol} \leq 300$ min and $\xi = O(1)$

The good news: at 70 GeV $\tau_{pol} \approx\leq 36$ min (scales like γ^{-5}).

The bad news: depolarization is relatively much stronger than at 46 GeV.

The way forward

Plan for polarization from the start! Polarization can never be an after thought!

Begin NOW with intense careful study based on experience to investigate tricks.

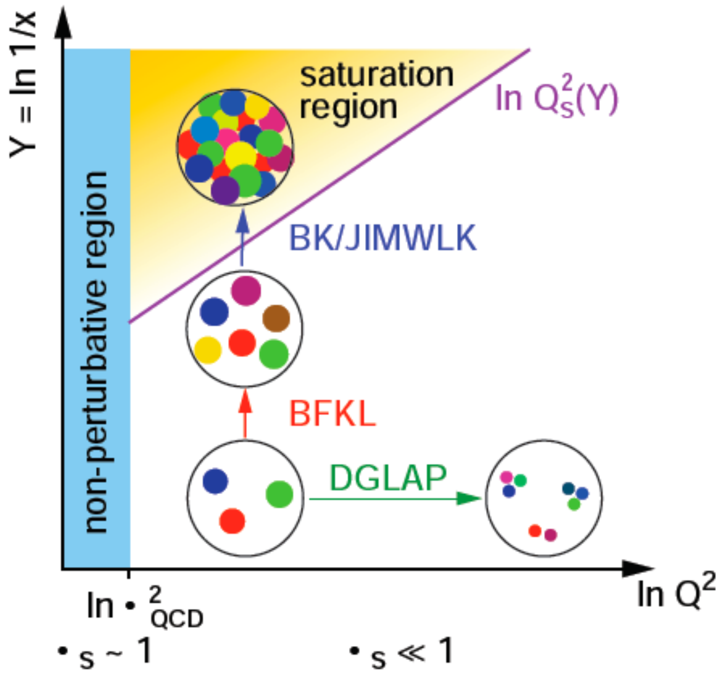
- Need very good alignment – better than at LEP.
- Siberian Snakes to suppress the effect of energy spread and synchrotron motion on spin motion?
  These are essential in proton rings to suppress depolarising resonances during acceleration (e.g., RHIC).
  But in electron rings they kill the S-T effect if the synchrotron radiation is evenly distributed around the ring!!!
- Can an arrangement be found based on a correct snake layout combined with uneven synchrotron radiation from super bends?

D.Barber

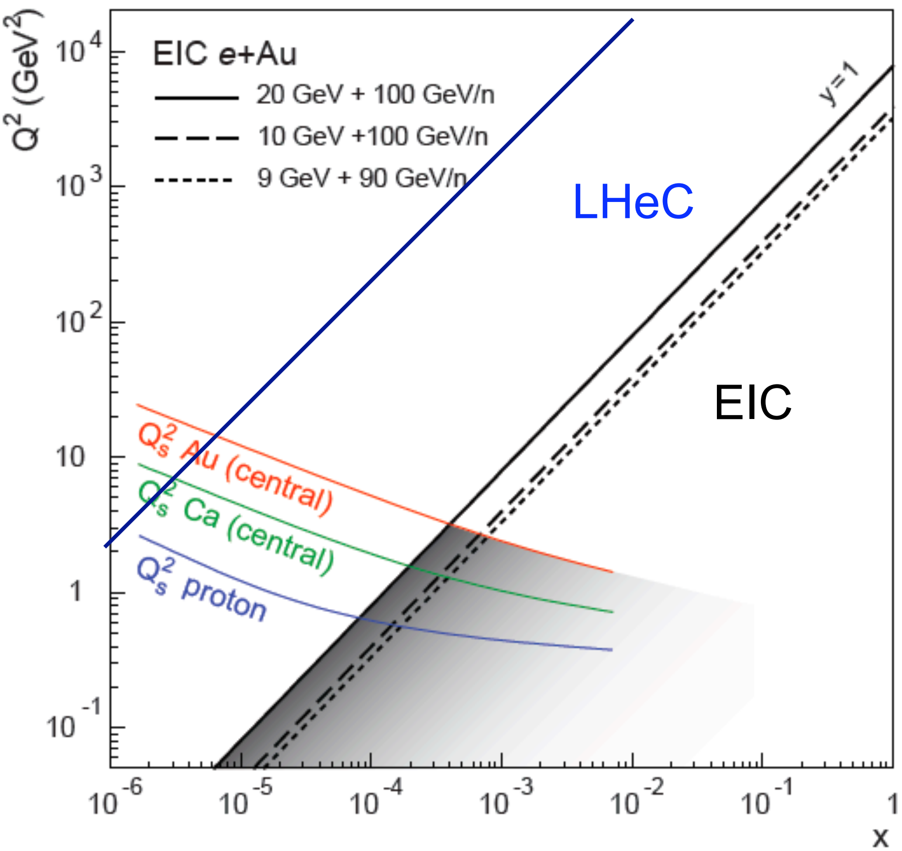
eA@LHeC

Welcome to the NuPECC study group

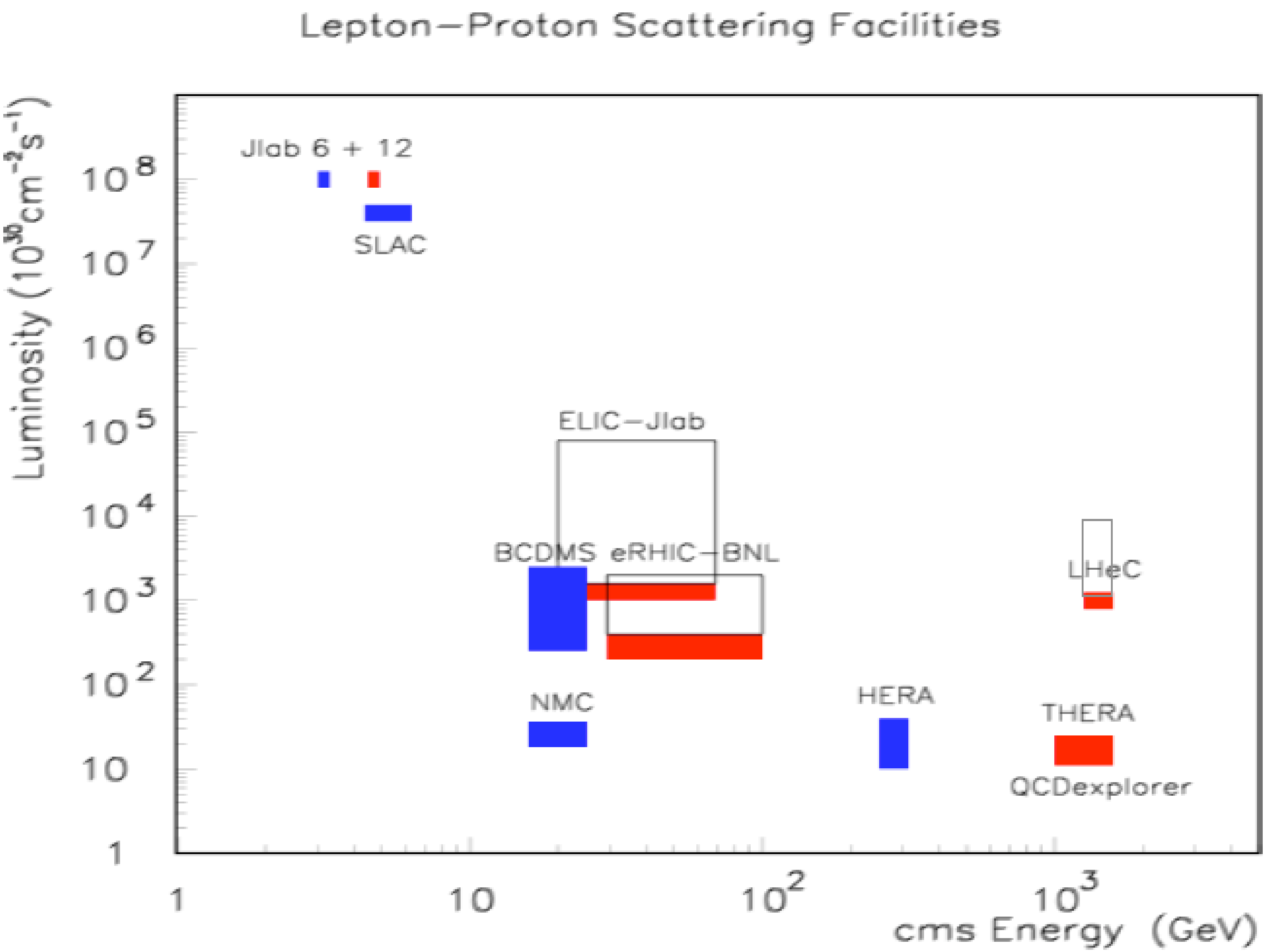
Tullio Bressani, INFN, Torino Univ.
Jens Jørgen Gaardhøje, Niels Bohr Inst.
Günther Rosner, Glasgow Univ. (chair)
Hans Ströher, FZ Juelich



Measurement of nuclear parton distributions
Non-linear effects (xg ‘beyond’ unitarity)
50% diffraction ..



The LHeC extends the measurement of nuclear structure in lA by four orders of magnitude as HERA did skip the eA phase. eA in relation to ALICE programme and the EIC


Lepton–Proton Scattering Facilities
Luminosity ($10^{30}cm^{-2}s^{-1}$)
10^8
10^7
10^6
10^5
10^4
10^3
10^2
10
1
Jlab 6 + 12
SLAC
ELIC–Jlab
BCDMS
eRHIC–BNL
LHeC
NMC
HERA
THERA
QCDexplorer
1
10
10^2
10^3
cms Energy (GeV)

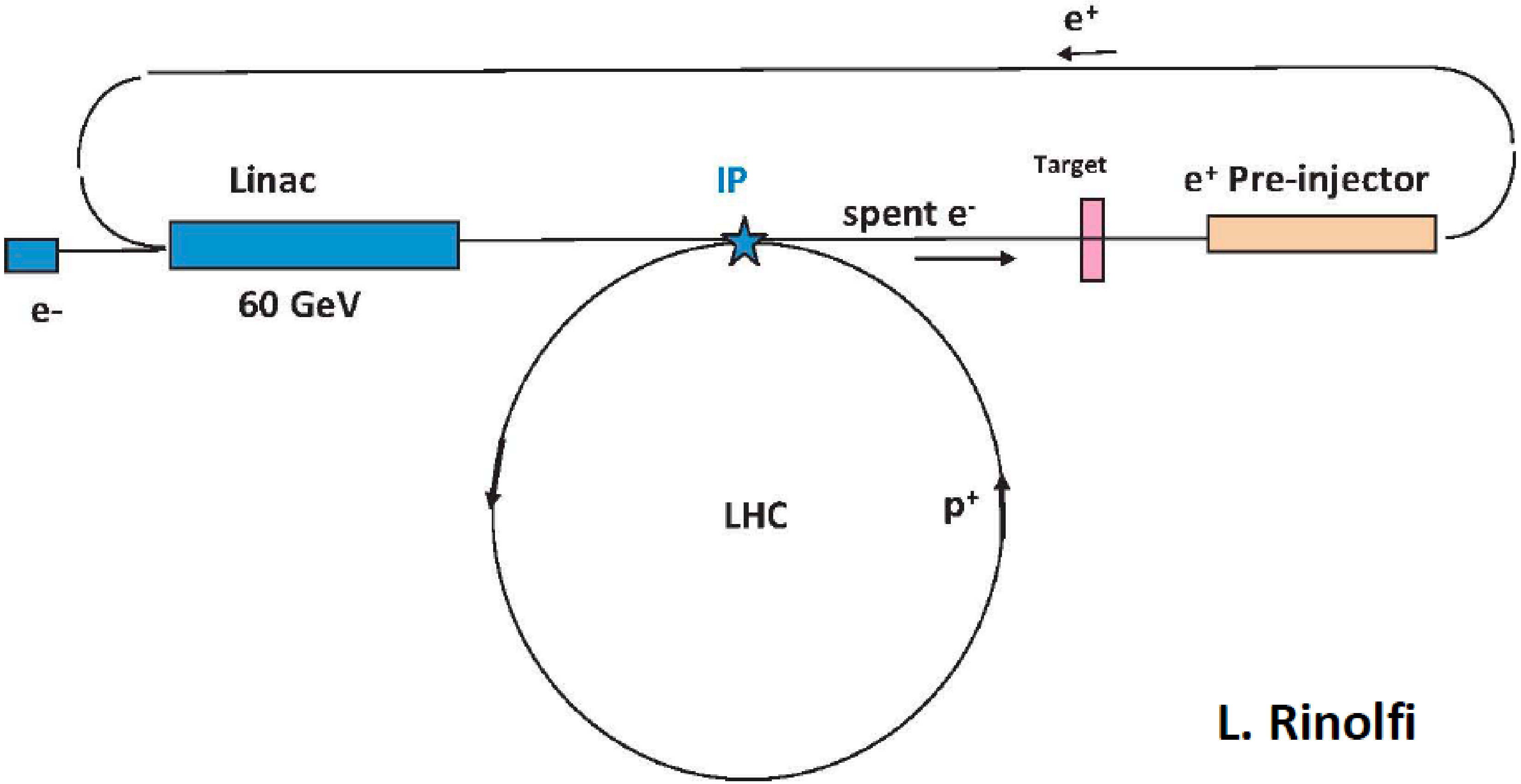
e- source

the e- beam can be produced from a polarized dc gun (e.g. SLC, E-158, or NLC type), with 90% polarization

depending on the bunch charge a normalized emittance between 10 and 100 μm is expected after bunching and acceleration

this is much (~3 orders of magnitude) smaller than might be hoped for in a ring at 70 GeV beam energy

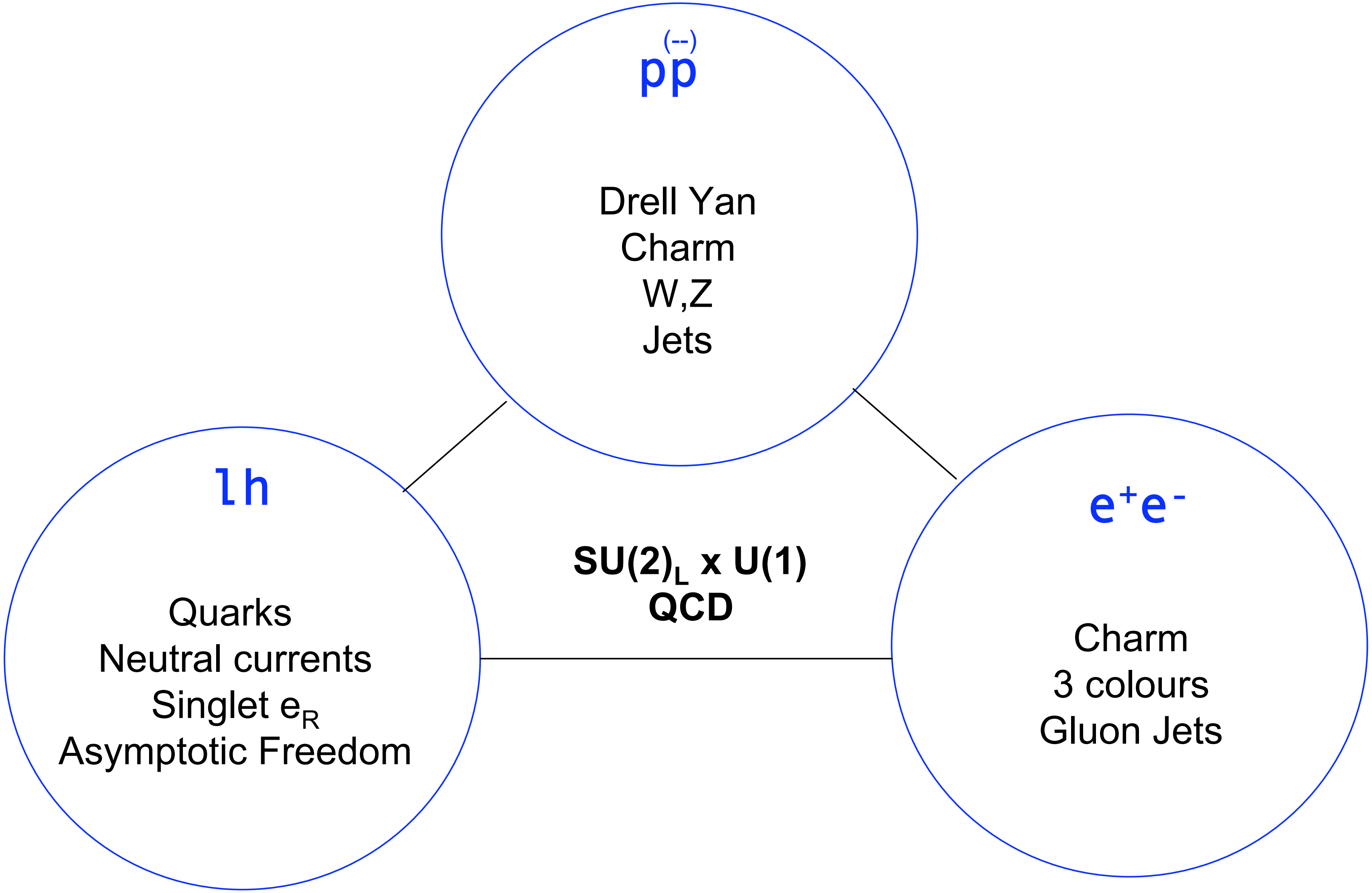
e+ production



L. Rinolfi

schematic linac-ring collider with integrated e+ production

The 10-100 GeV Energy Scale [1968-1986]



$p\overset{(--)}{p}$

Drell Yan
Charm
W,Z
Jets

lh

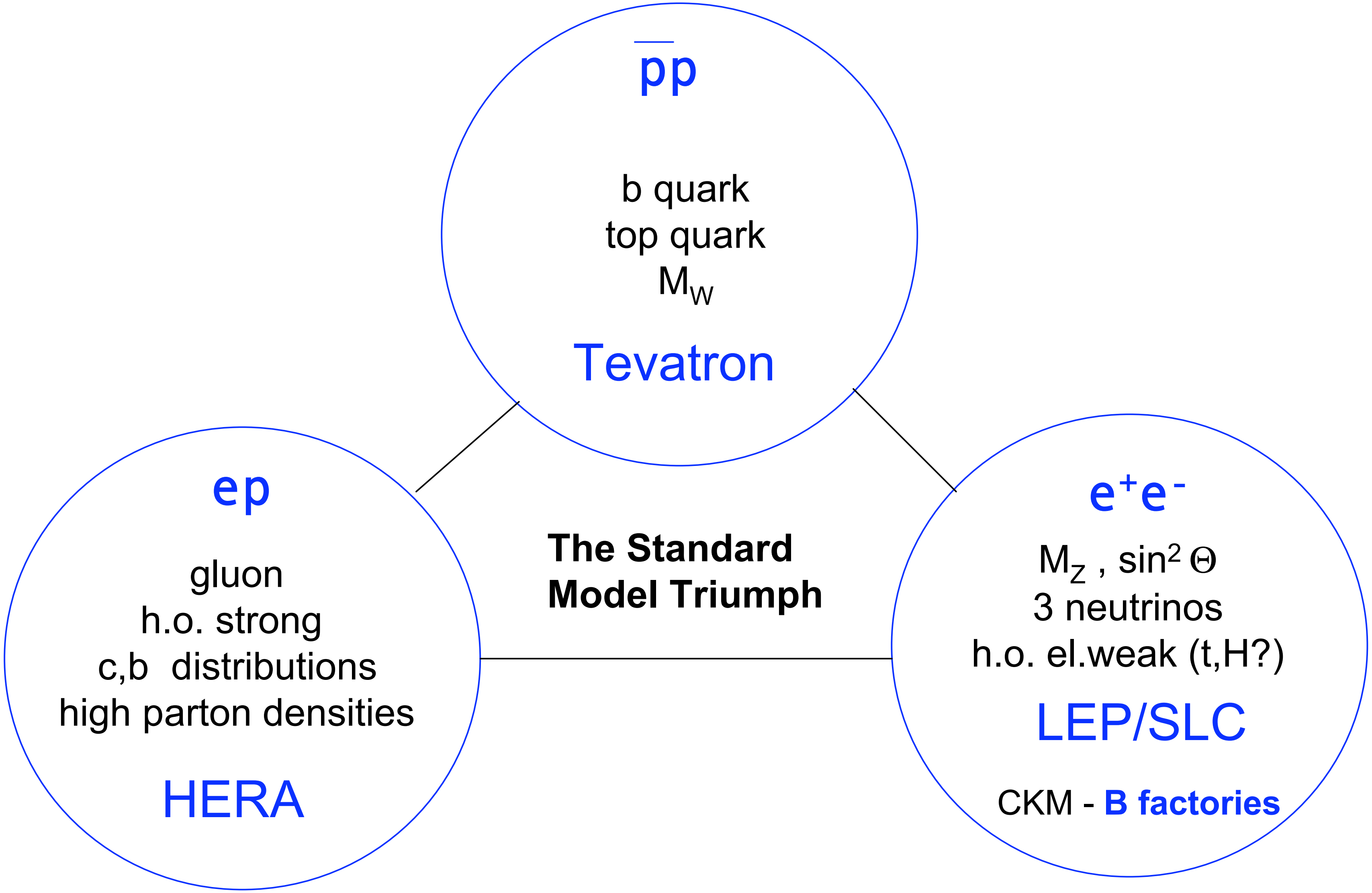
Quarks
Neutral currents
Singlet e_R
Asymptotic Freedom

$SU(2)_L \times U(1)$
QCD

e^+e^-

Charm
3 colours
Gluon Jets

The Fermi Scale [1985-2010]



$\bar{p}p$

b quark
top quark
M_W

Tevatron

ep

gluon
h.o. strong
c,b distributions
high parton densities

HERA

The Standard Model Triumph

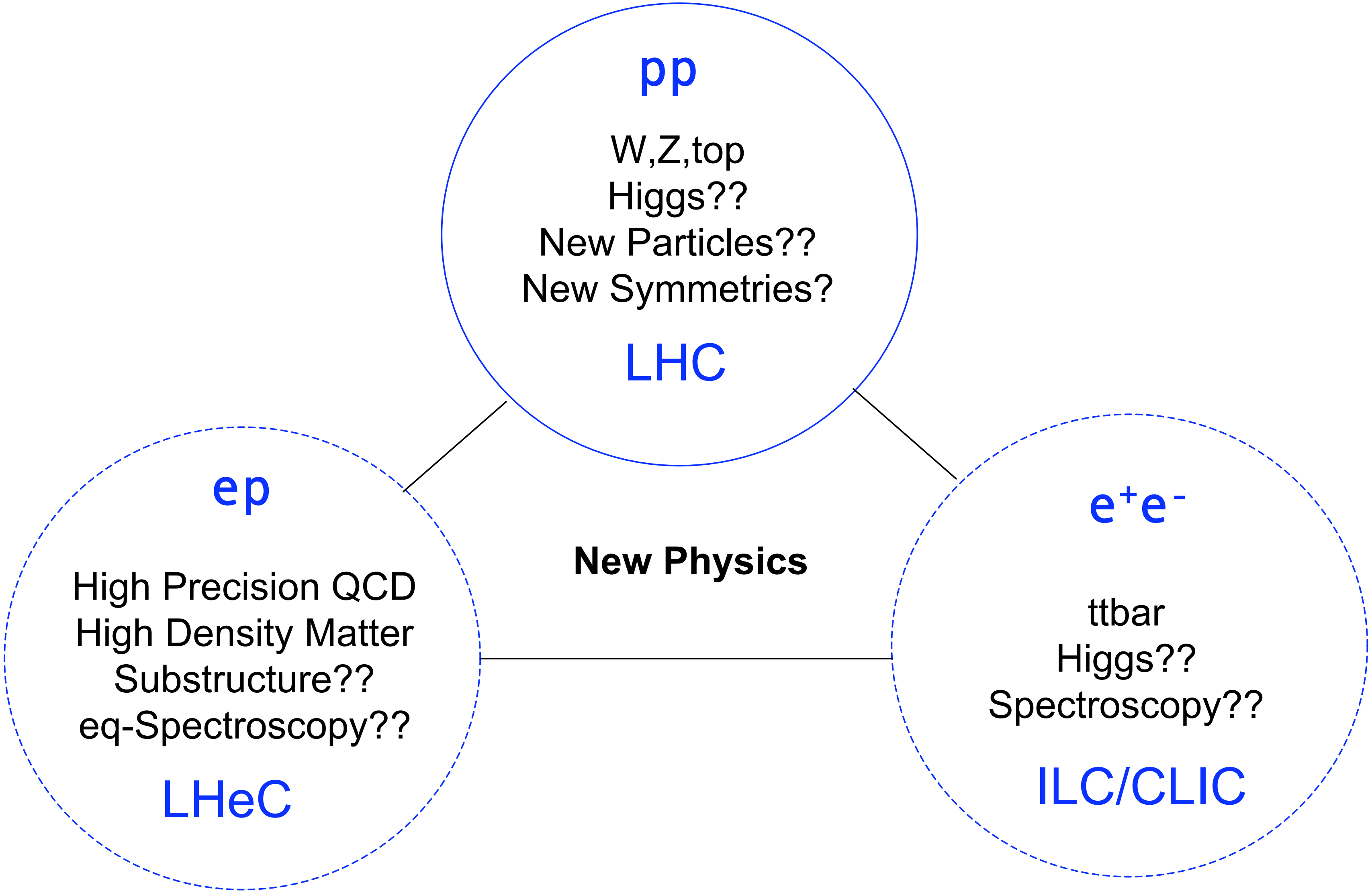
e^+e^-

M_Z , $\sin^2 \Theta$
3 neutrinos
h.o. el.weak (t,H?)

LEP/SLC

CKM - **B factories**

The TeV Scale [2008-2033..]



pp

W,Z,top
Higgs??
New Particles??
New Symmetries?

LHC

ep

High Precision QCD
High Density Matter
Substructure??
eq-Spectroscopy??

LHeC

New Physics

e^+e^-

ttbar
Higgs??
Spectroscopy??

ILC/CLIC

Predicting is difficult, in particular if it concerns the future

First ECFA-CERN Workshop on the LHeC Divonne 1.-3.9.08

Opening: J.Ellis, Kh.Meier, G.Rosner, J.Engelen, G.Altarelli

Accelerator Design [RR and LR]

Oliver Bruening (CERN),

John Dainton (CI/Liverpool)

Interaction Region and Fwd/Bwd

Bernhard Holzer (DESY),

Uwe Schneeekloth (DESY),

Pierre van Mechelen (Antwerpen)

Detector Design

Peter Kostka (DESY),

Rainer Wallny (UCLA),

Alessandro Polini (Bologna)

New Physics at Large Scales

Emmanuelle Perez (CERN),

Georg Weiglein (Durham)

Precision QCD and Electroweak

Olaf Behnke (DESY),

Paolo Gambino (Torino),

Thomas Gehrmann (Zuerich)

Physics at High Parton Densities

Nestor Armesto (CERN),

Brian Cole (Columbia),

Paul Newman (B’ham),

Anna Stasto (MSU)

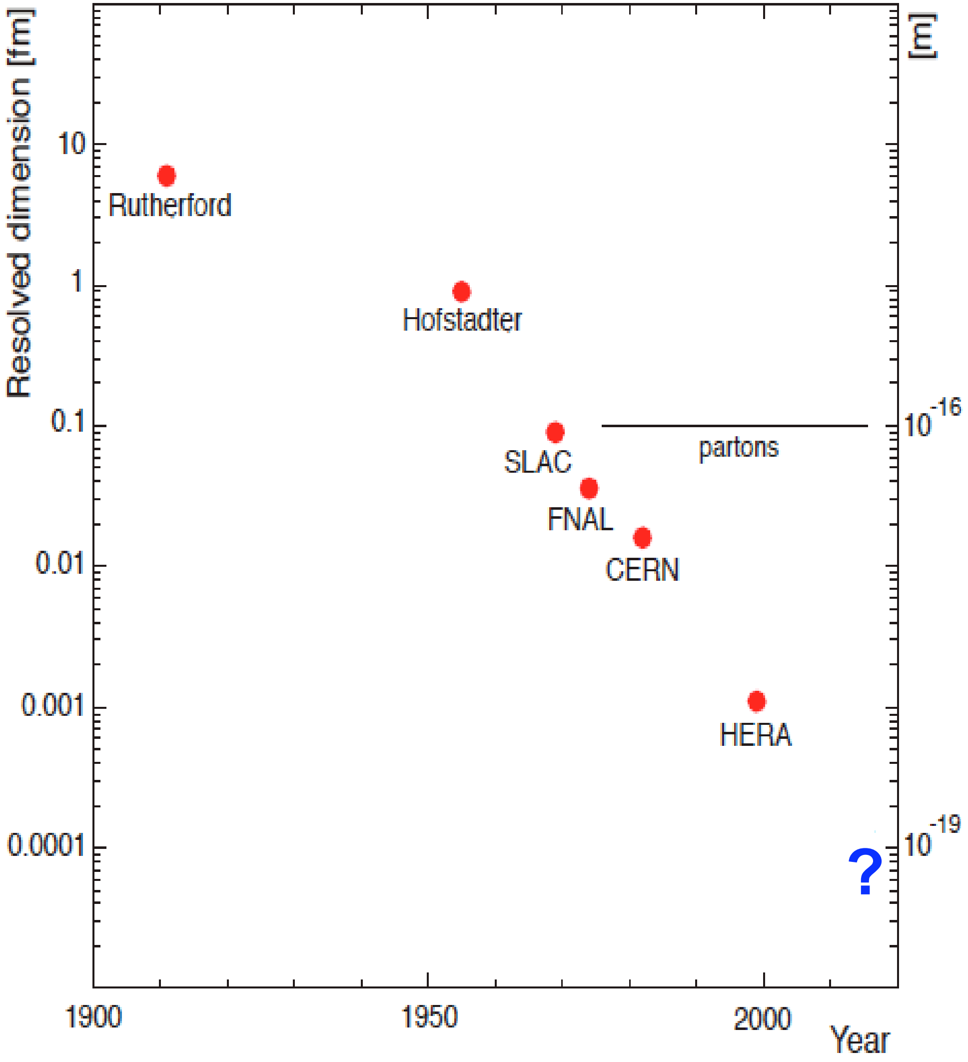
The LHeC is a PeV equivalent fixed target ep scattering experiment.

At ~50 000 times higher Q^2 than the SLAC MIT experiment it needs an only few times longer LINAC (or a ring).

Its physics potential is extremely rich.

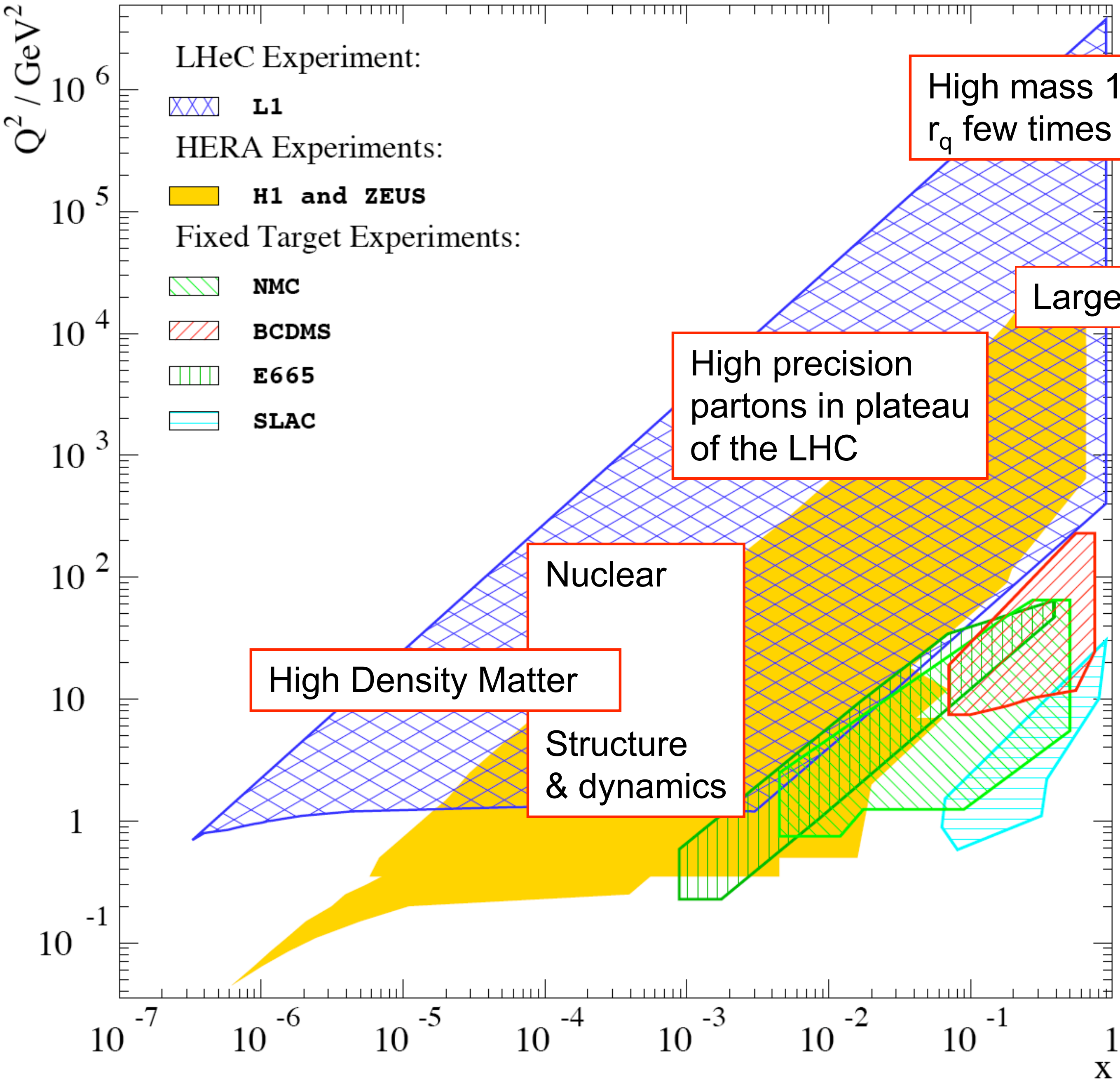
Its technology is at hand, but it poses R&D challenges too.

“It would be a vaste not to exploit the LHC for ep / A at some stage” (G.Altarelli)



The LHeC would be a tribute to Wolfgang P. and Bjoern W. and the continuation of an historic path

http://www.lhec.org.uk



High mass 1-2 TeV
r_q few times 10^{-20} m

Large x

High precision
partons in plateau
of the LHC

Nuclear

High Density Matter

Structure
& dynamics

Former considerations:

ECFA Study 84-10
G.Altarelli et al.

J.Feltesse, R.Rueckl et al.
Aachen Workshop (1990)

The THERA Book (2001)&
Part IV of TESLA TDR

Max Klein LHeC ECFA 11/08