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)
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John Ellis (CERN)
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Steven Vigdor (BNL)
Frank Wilczek (MIT)
Ferdinand Willeke (BNL)

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

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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

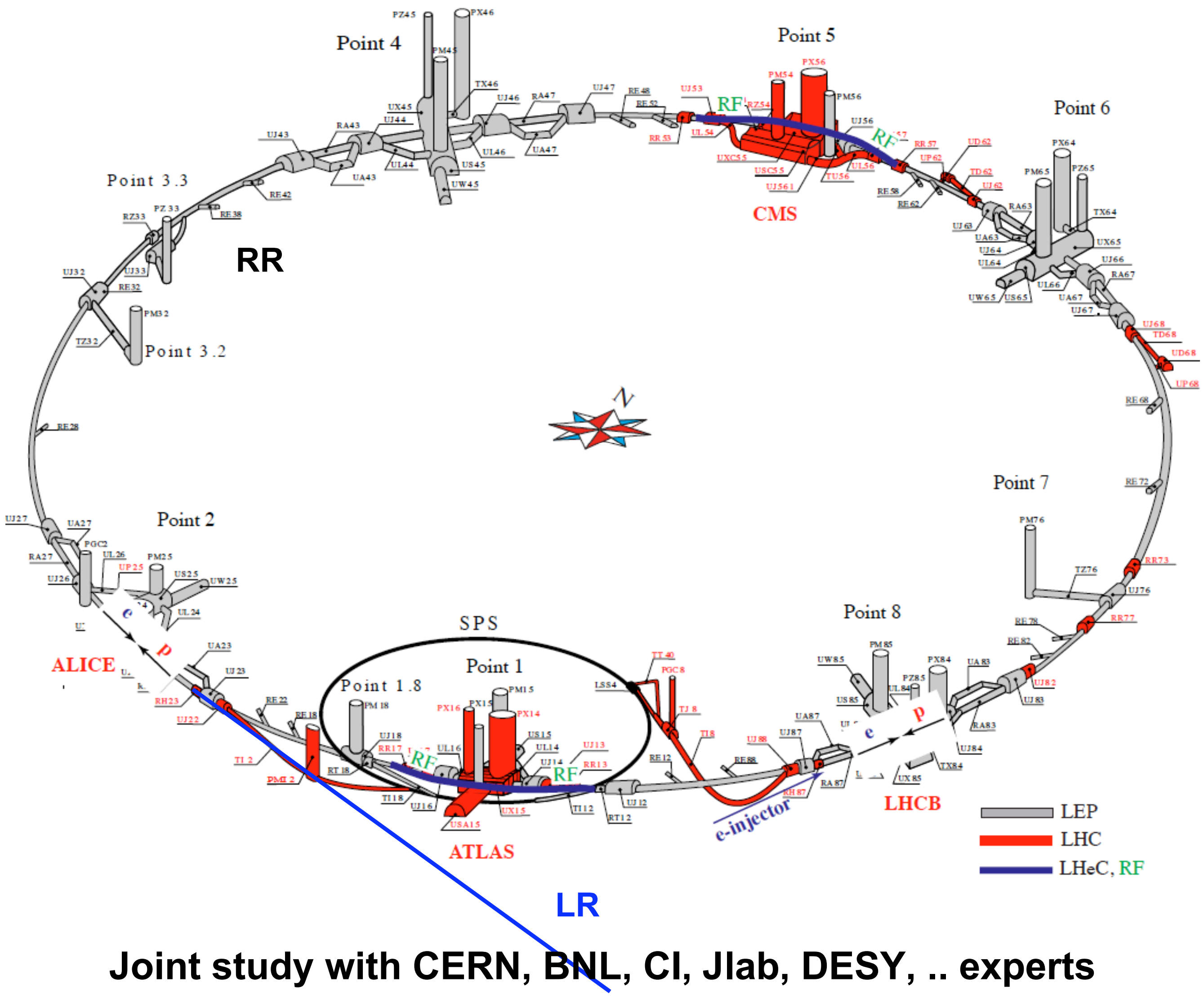
-Neutron structure terra incognita

Deuterons

-Partonic Structure of Nuclei

a series of nuclei, Ca, Pb

Machine Considerations



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

Max Klein LHeC ECFA 11/08

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

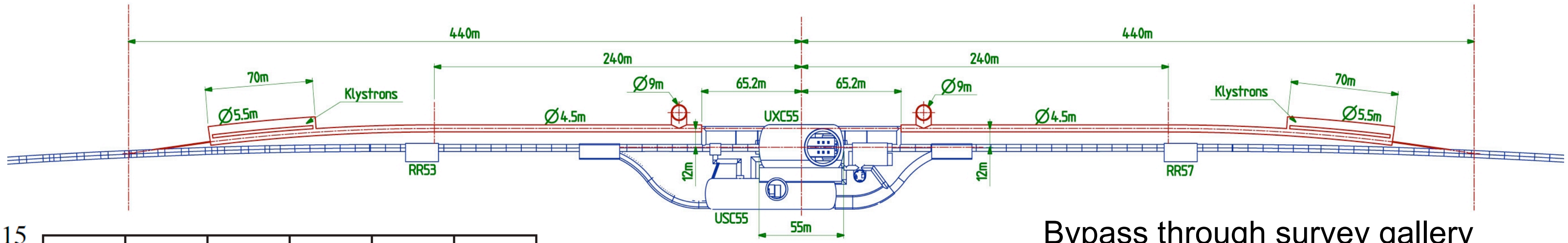
e Ring:

bypasses: 1 and 5
[use also for rf]

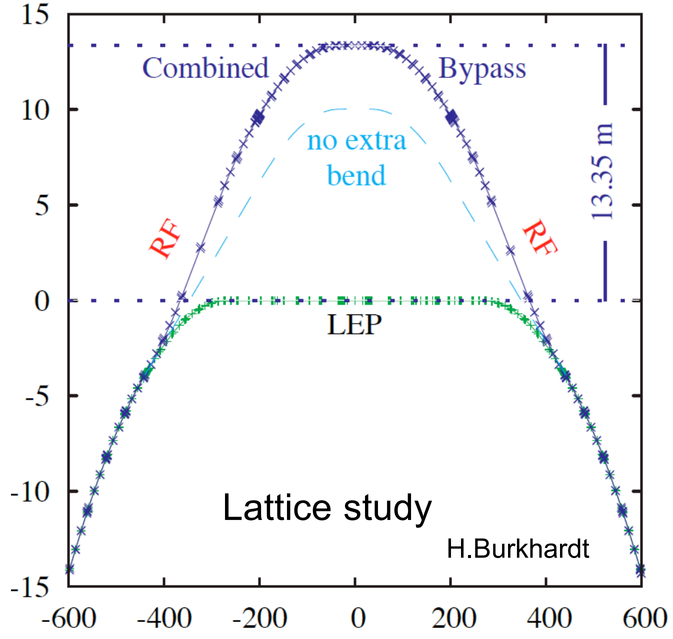
injector: SPL, or dedicated

e LINAC:

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

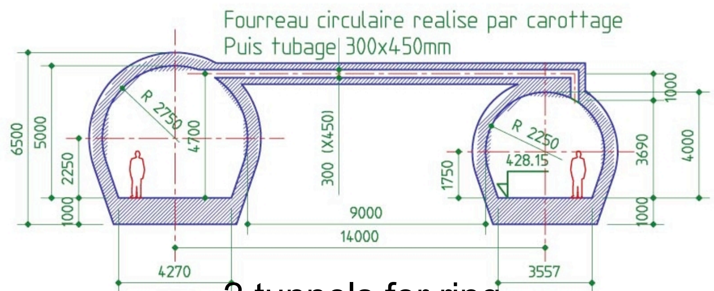


Bypass through survey gallery
13m distance, 2 shafts

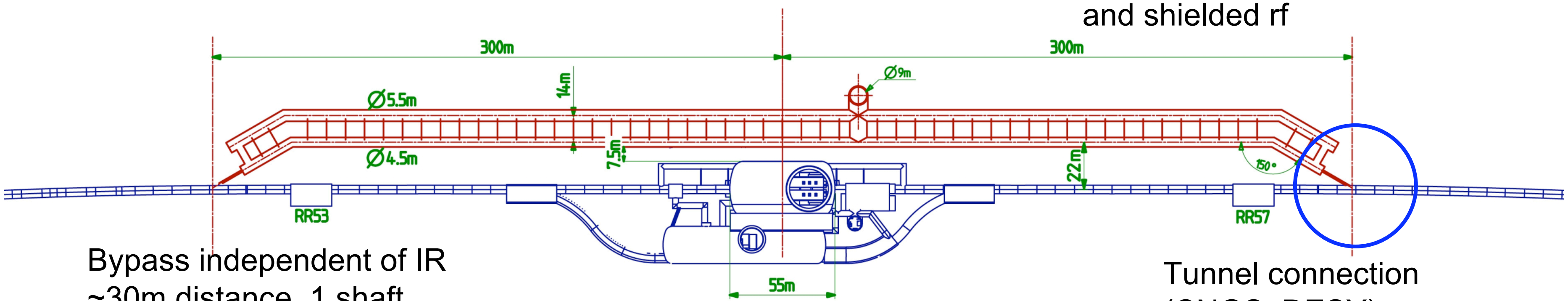


Bypass

point 5



2 tunnels for ring
and shielded rf

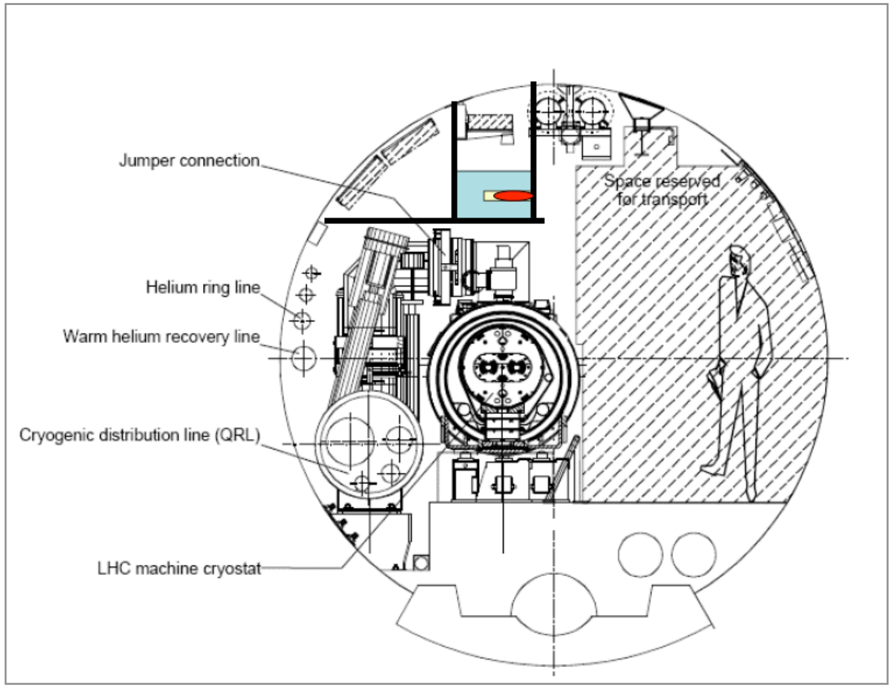


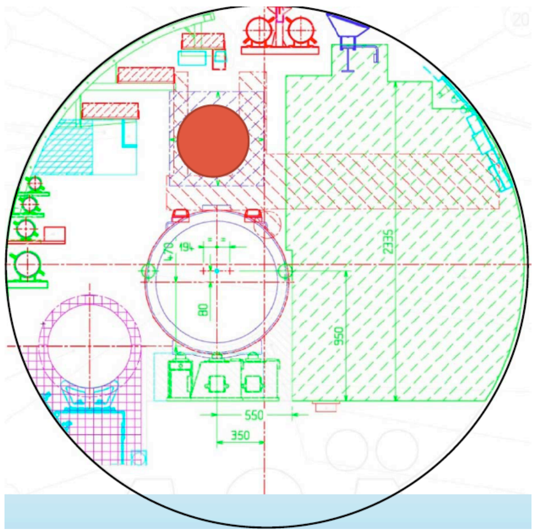
Bypass independent of IR
~30m distance, 1 shaft

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.

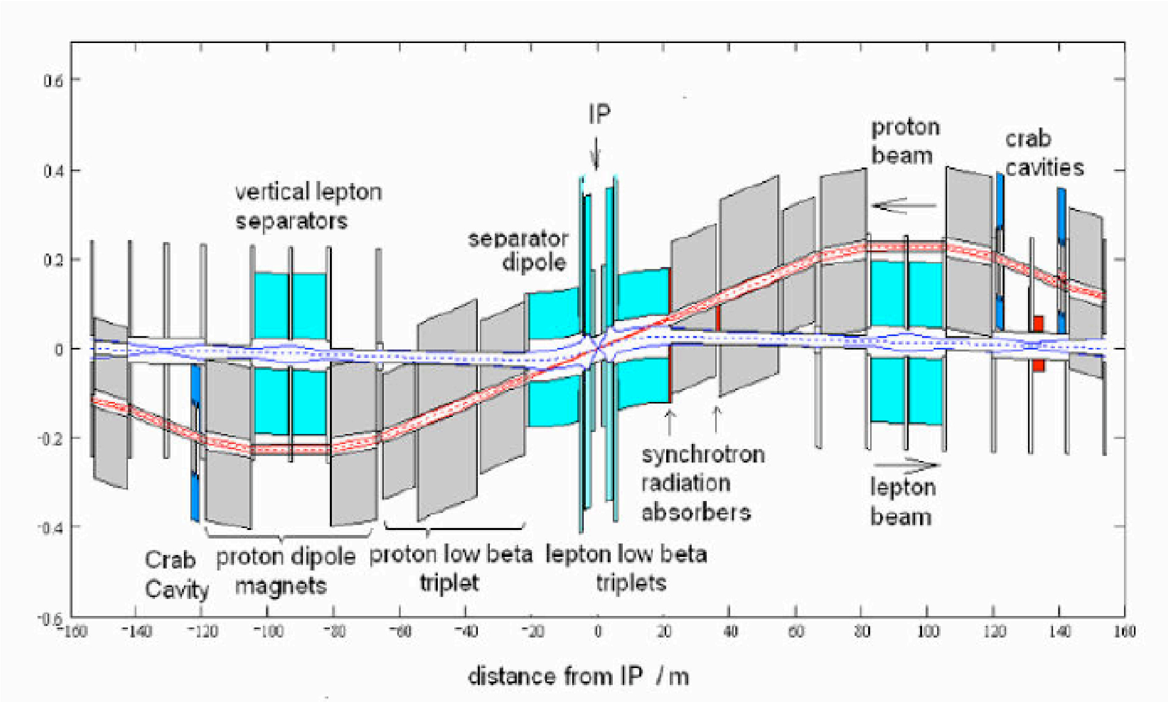
Injection:
LEP2 was 4 10^{11} e in 4 bunches
LHeC is 1.4 10^{10} in 2800 bunches
may inject at less than 20 GeV.

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

SC system at 1.9^o 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^o) and hi L (10^o ?)

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

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

$$L = 8.3 10^{32} \cdot \frac{I_e}{50mA} \frac{m}{\sqrt{\beta_{px}\beta_{pn}}} cm^{-2}s^{-1}$$

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.

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

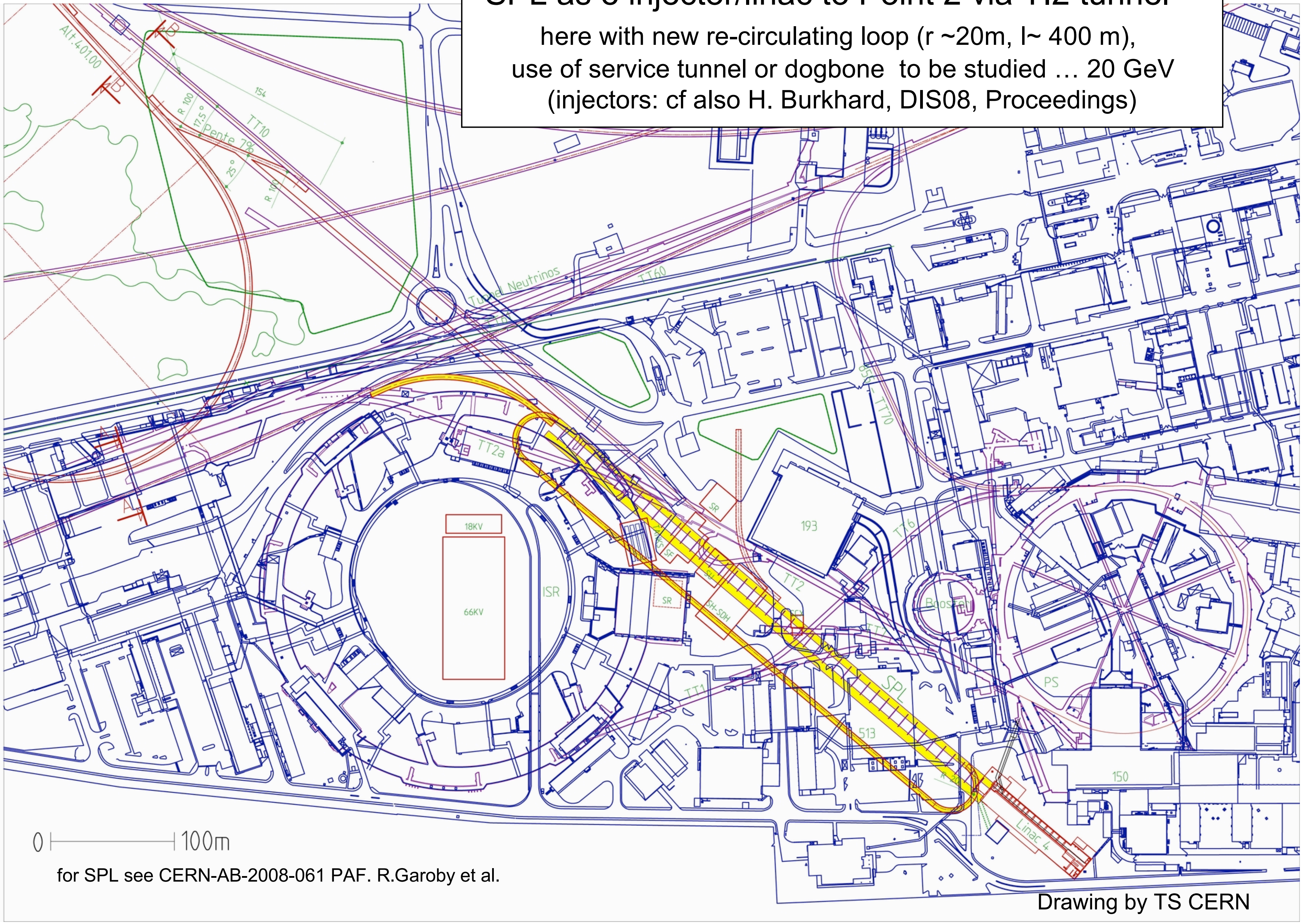
LHC upgrade: N_p increased.
Need to keep e tune shift low:
by increasing β_p, decreasing β_e
but enlarging e emittance,
to keep e and p matched.

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	**$L=1.44*10^{33}$**	

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
(injectors: cf also H. Burkhard, DIS08, Proceedings)



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

Drawing by TS CERN

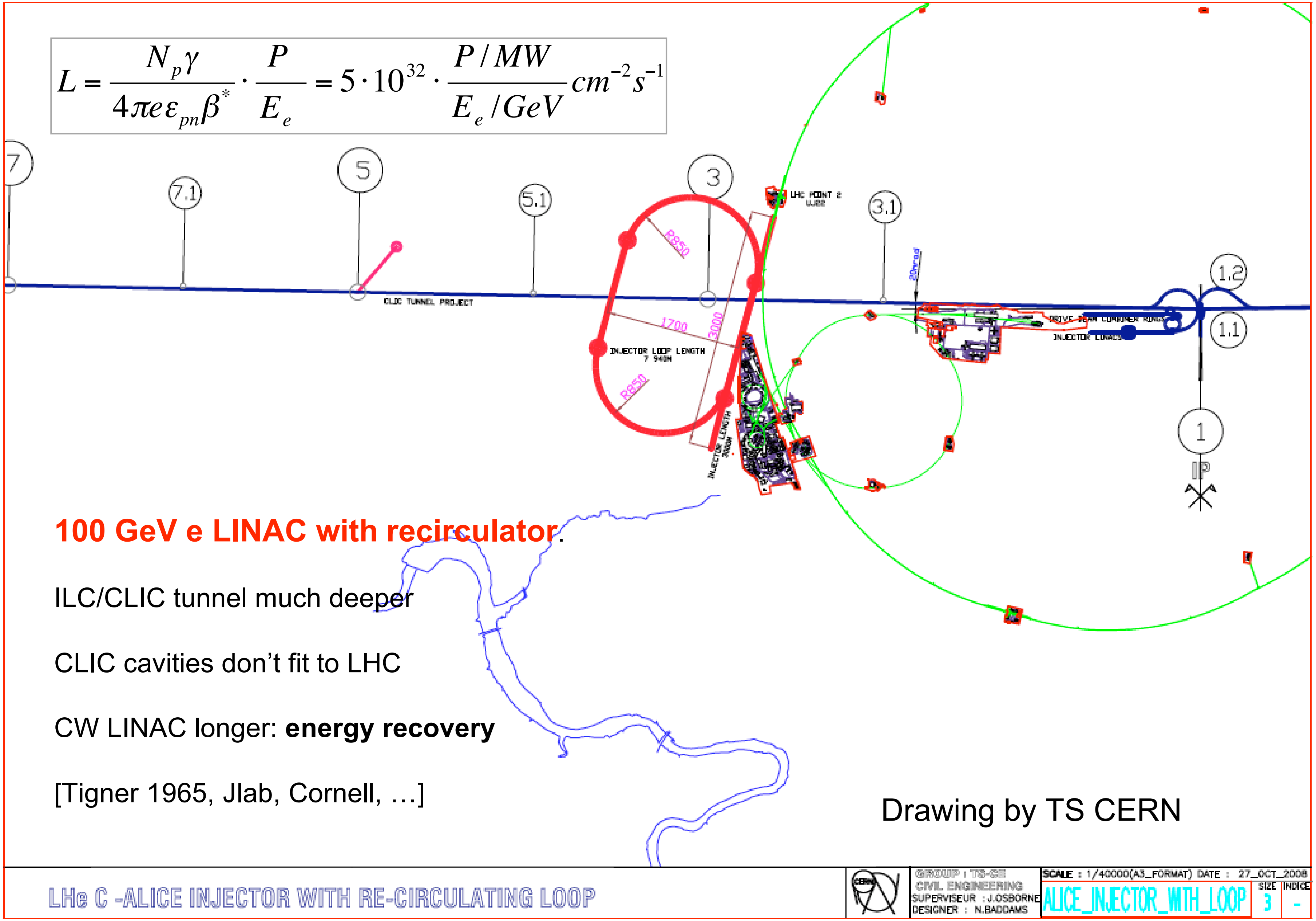
e- energy [GeV]	30	Pulsed 100	CW 100
comment	SPL* (20)+TI2	LINAC	LINAC
#passes	4+1	2	2
wall plug power RF+Cryo [MW]	100 (1 cr.)	100 (3 cr.)	100 (35 cr.)
bunch population [10^9]	10	3.0	0.1
duty factor [%]	5	5	100
average e- current [mA]	1.6	0.5	0.3
emittance $\gamma\varepsilon$ [μm]	50	50	50
RF gradient [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: $N_b=5\times10^{11}$, 50 ns spacing, $\gamma\varepsilon=3.75\ \mu$m, $\beta^*=0.1$ m, $\sigma_z=11.8$ 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.

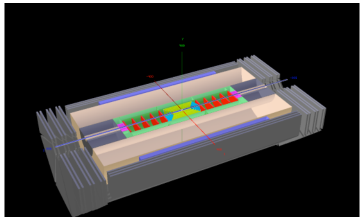
ILC/CLIC tunnel much deeper

CLIC cavities don't fit to LHC

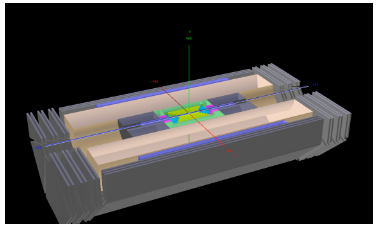
CW LINAC longer: **energy recovery**

[Tigner 1965, Jlab, Cornell, …]

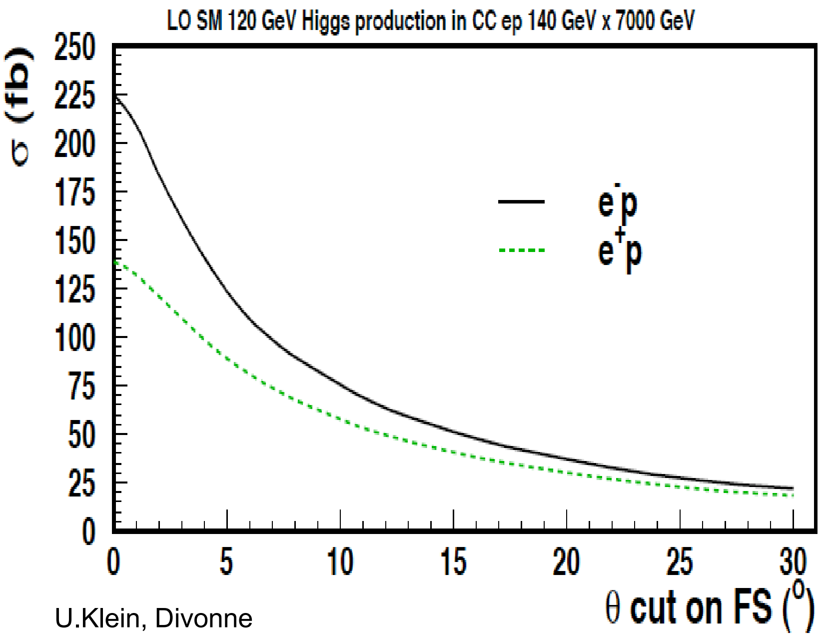
Drawing by TS CERN



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

	LHeC	HERA
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%

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

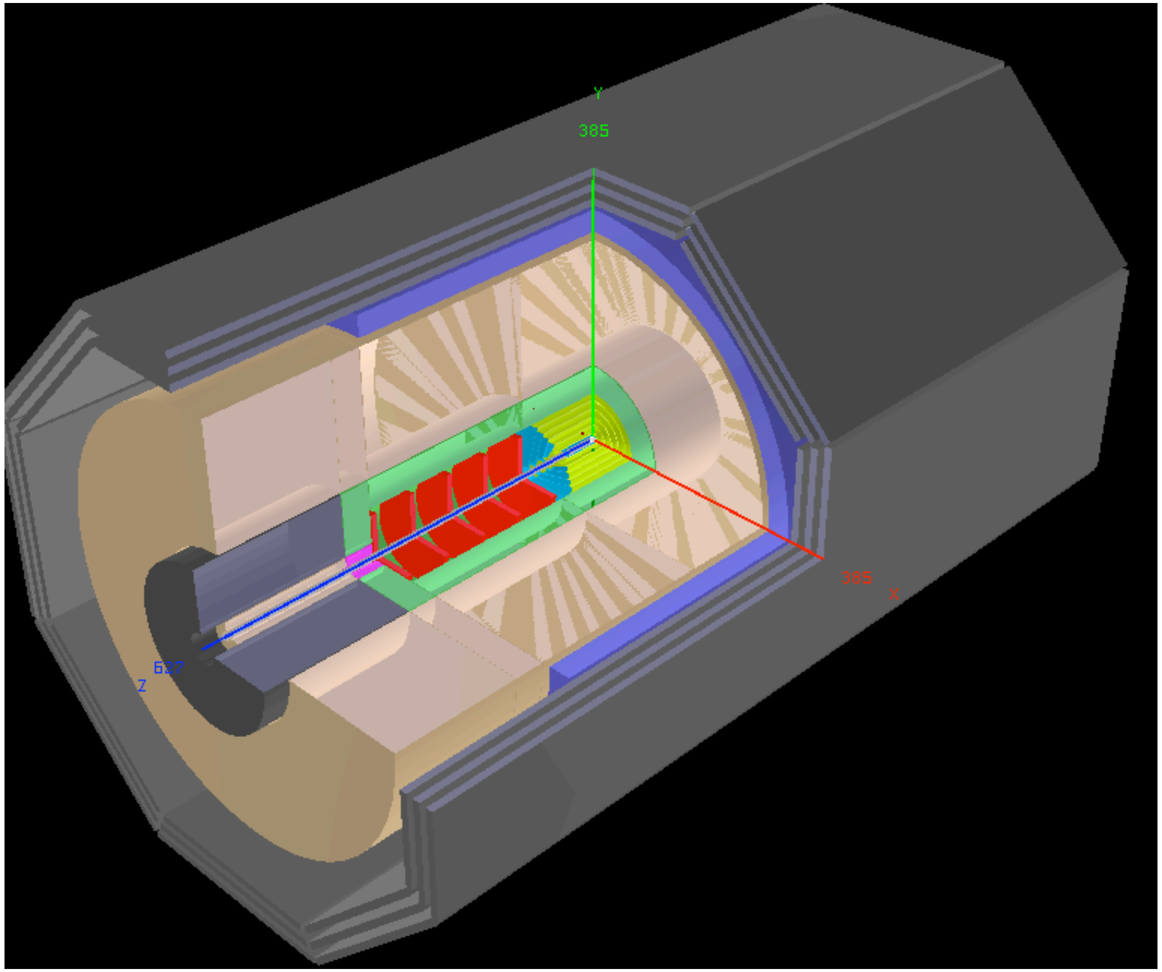
Hadronic Calo (Fe/LAr)
El.magn. Calo (Pb,Sc)
GOSSIP (fwd+central)
[Gas on Slimmed Si Pixels]
[0.6m radius for 0.05% * pt in 2T field]
Pixels
Elliptic beam pipe (~3cm)

Fwd Spectrometer
(down to 1°)

Tracker
Calice (W/Si)
FwdHadrCalo

Bwd Spectrometer
(down to 179°)

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

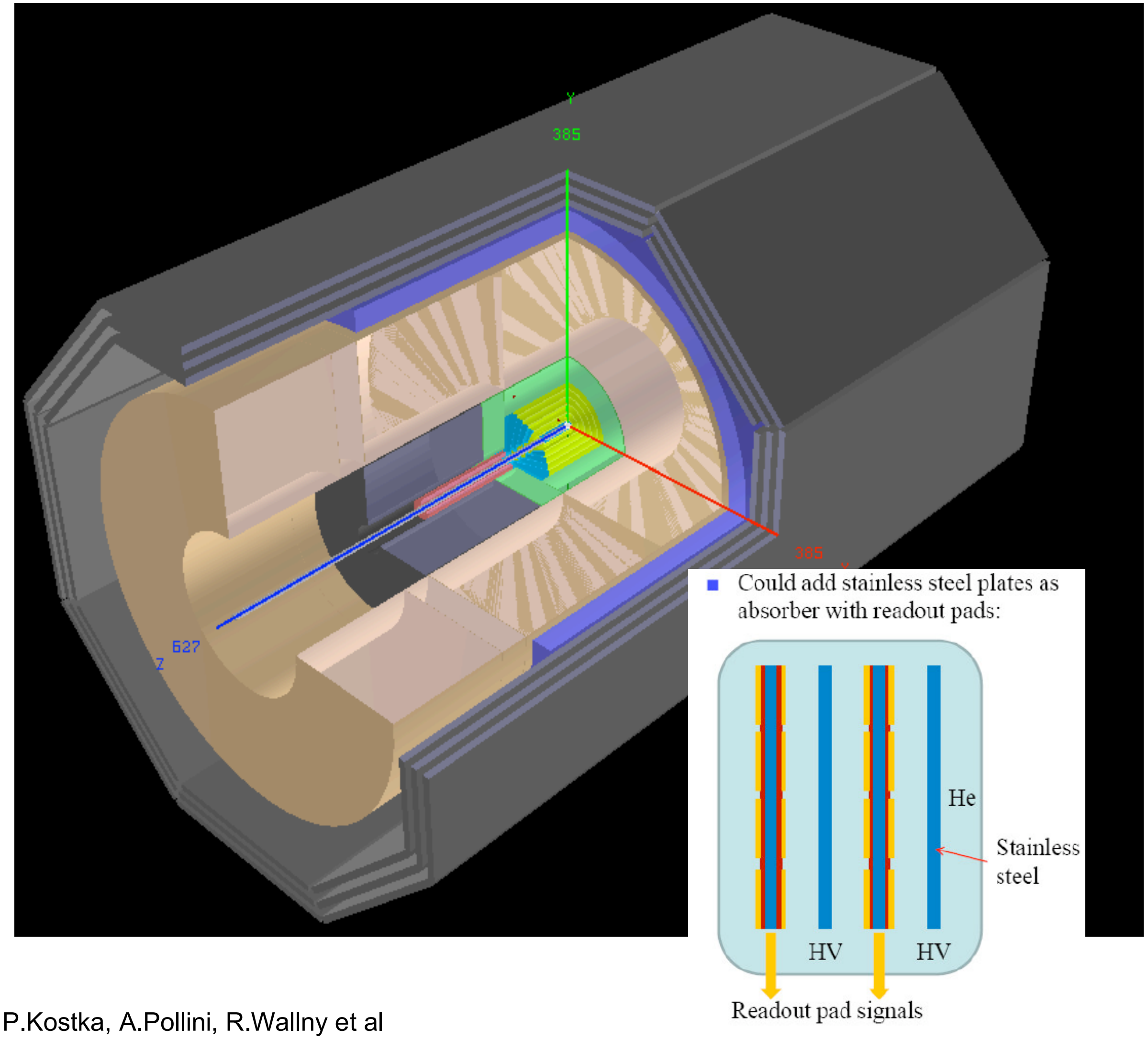
Hadronic Calo (Fe/LAr)
El.magn. Calo (Pb,Sc)
GOSSIP (fwd+central)
Pixels
Elliptic pipe (~3cm)

Fwd Calorimeter
(down to 10°)

Lepton low β magnets
FwdHadrCalo

Bwd Spectrometer
(down to 170°)

Lepton low β magnets
Spacal (elm, hadr)



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

Active magnets? T.Greenshaw

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

- **Lepto-Quark Production and Decay (s and t-channel effects)**

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

- **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**

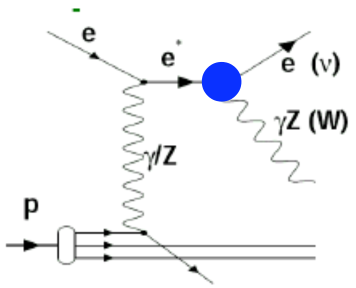
Broad physics goals (to be discussed at the Workshop)

- 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

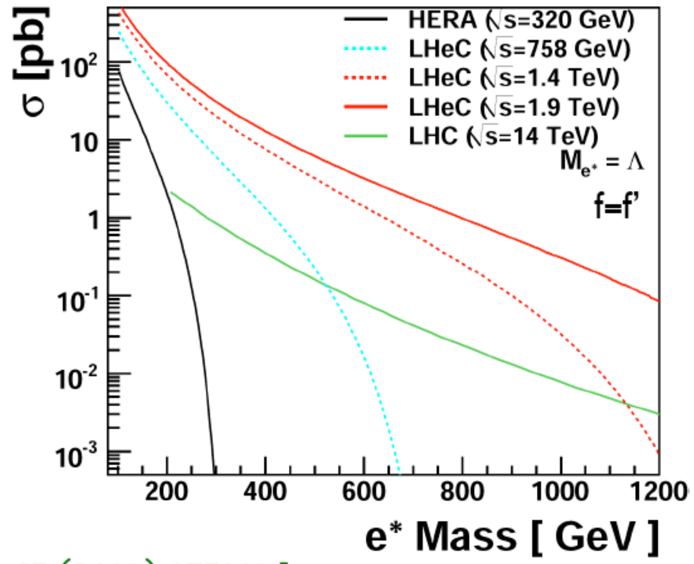
Electron-Boson Resonances : excited electrons



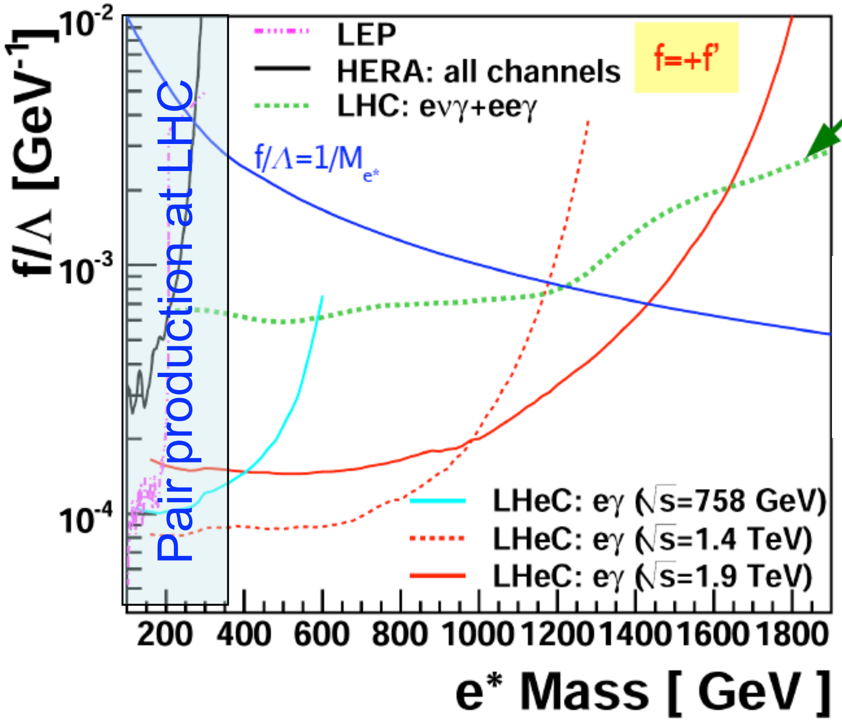
coupling
~ f / Λ

N. Trinh, E. Sauvan, Divonne

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



LHeC prelim. analysis, looking at e* → eγ

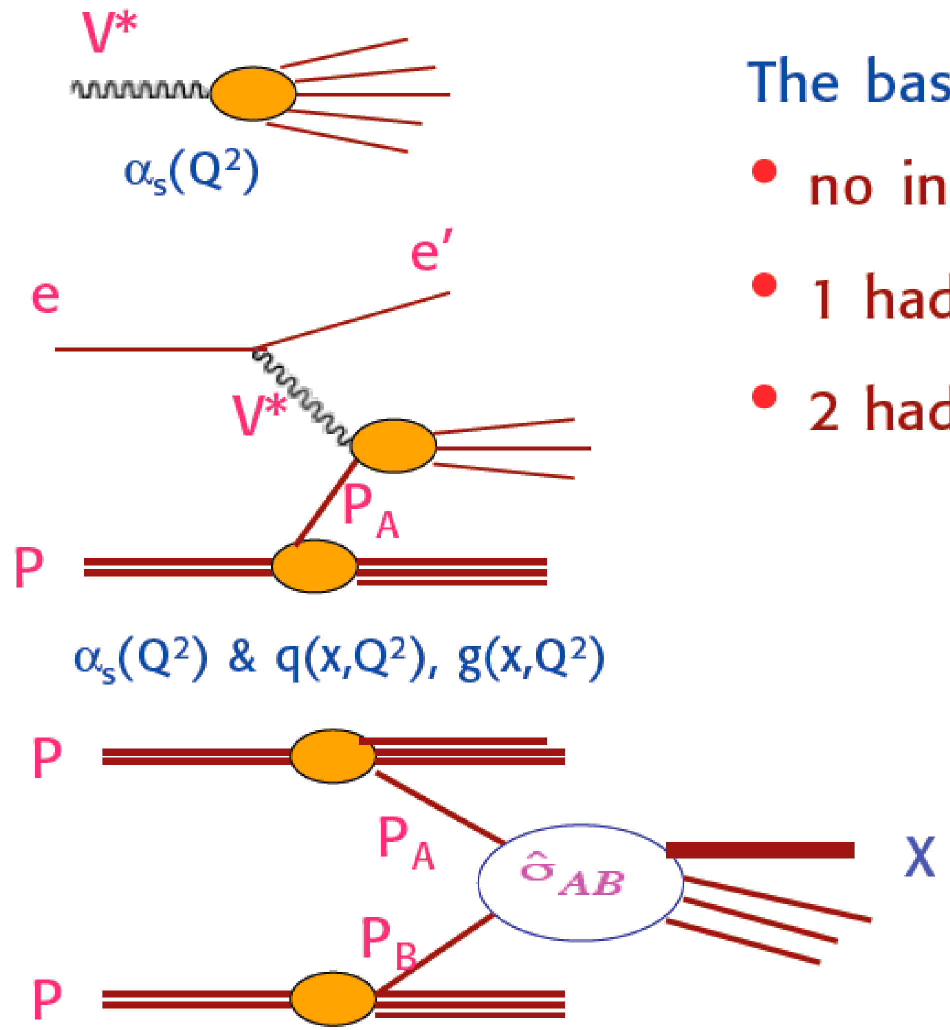


[Phys. Rev D 65 (2002) 075003]

-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



The basic experimental set ups:

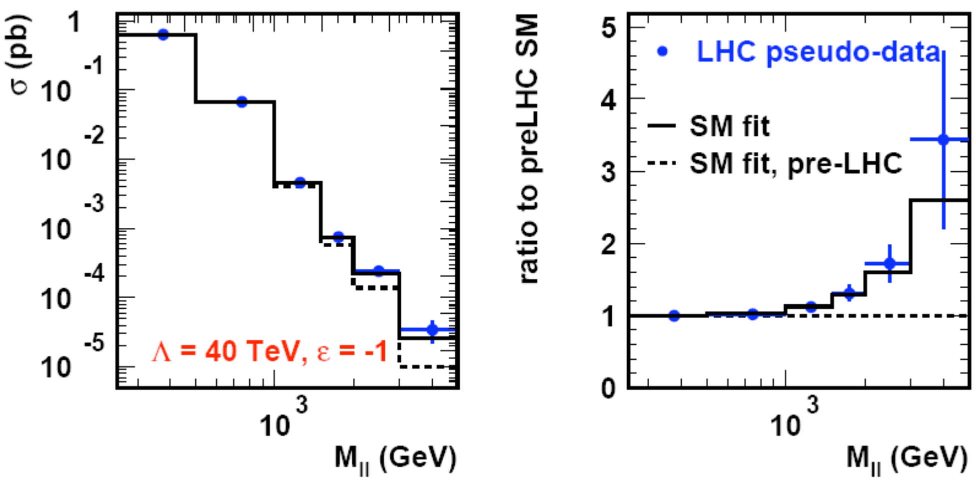
- no initial hadron (....LEP, ILC, CLIC)
- 1 hadron (....HERA, LHeC)
- 2 hadrons (....SppS, Tevatron, LHC)

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

G.Altarelli, LHeC Workshop Divonne 9/08

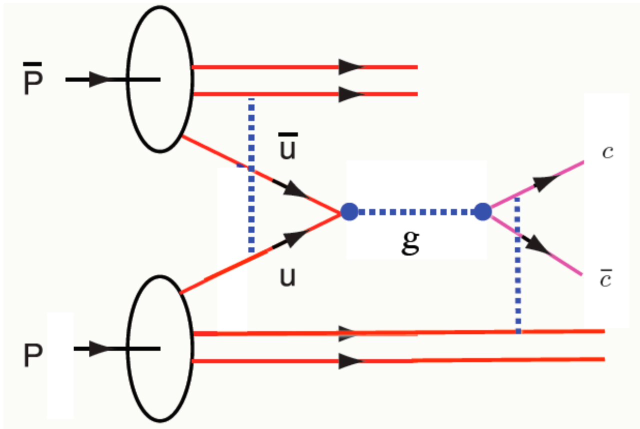
New Physics and the LHC-LHeC Interplay

Drell Yan at LHC



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

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.

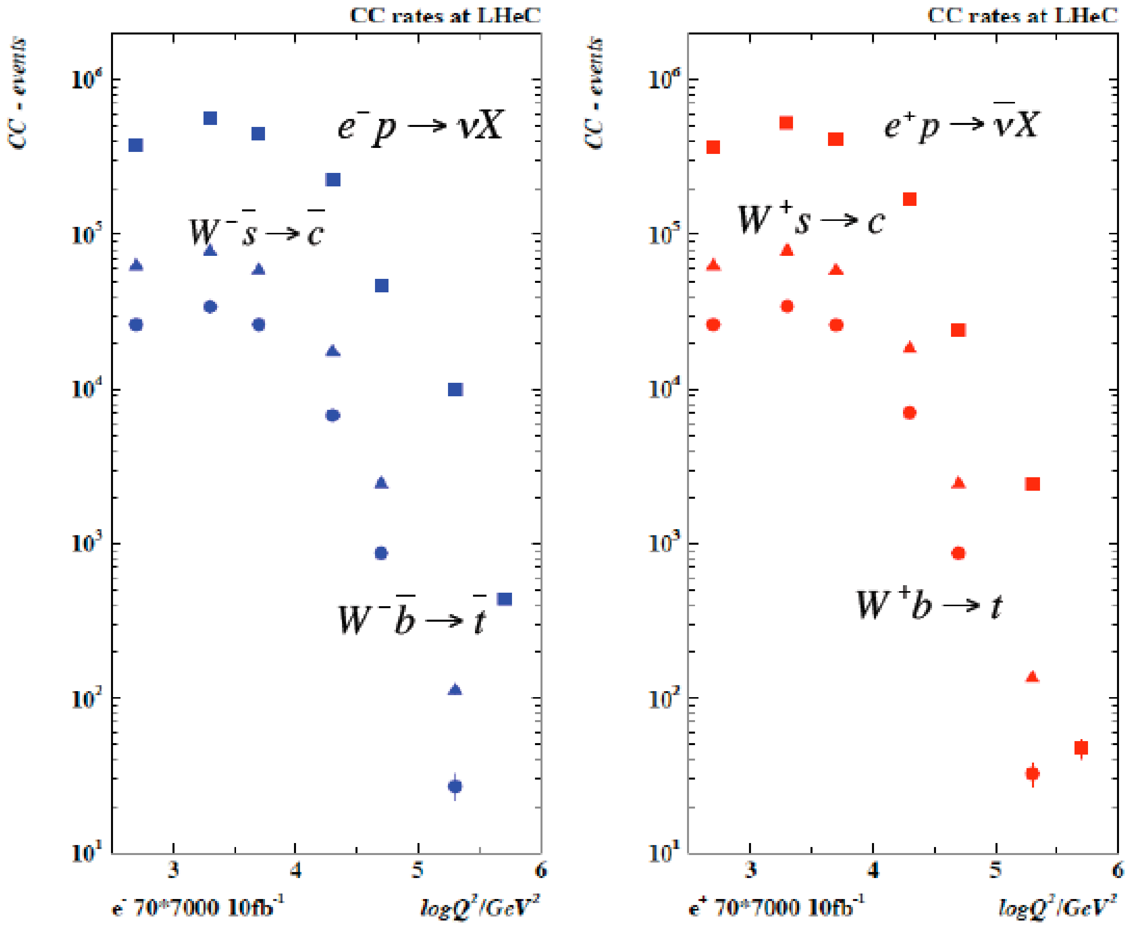
John Collins, Jian-Wei Qiu . ANL-HEP-PR-07-25, May 2007.
e-Print: **arXiv:0705.2141** [hep-ph]

Complete Unfolding of Partons

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

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

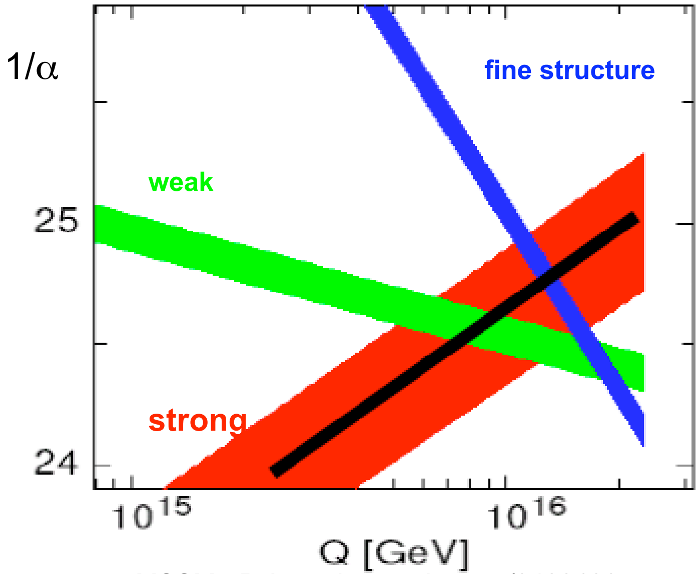
Single anti-top and top physics at the LHeC



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%

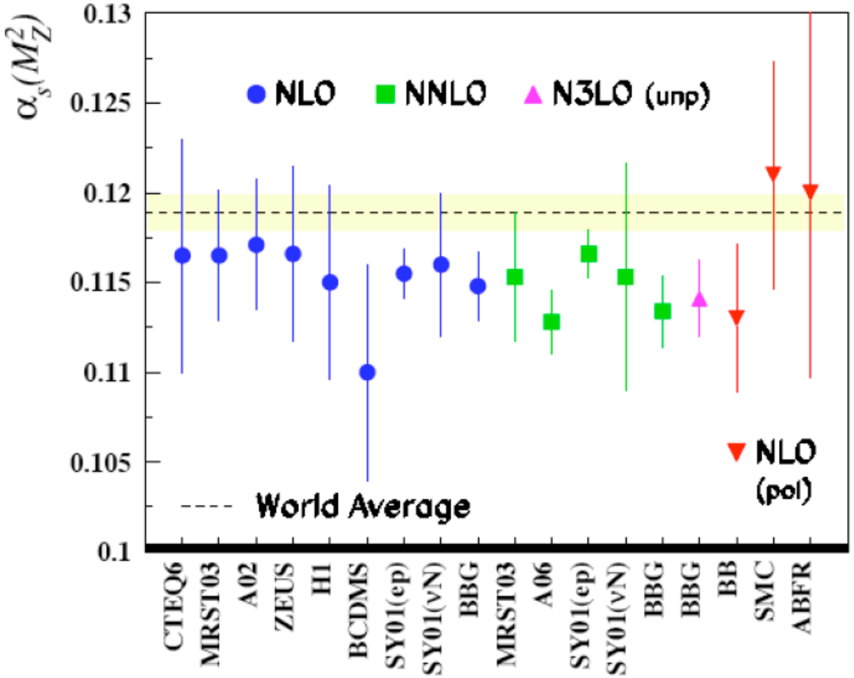
DIS08, T.Kluge

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

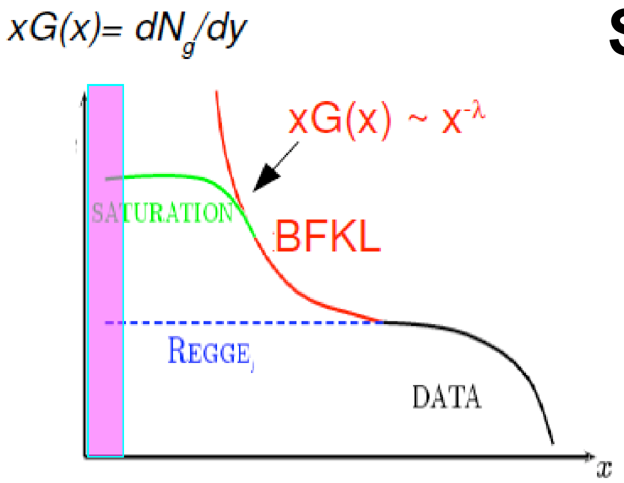
DIS tends to be lower than world average

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

Blumlein et al '06



Saturation?

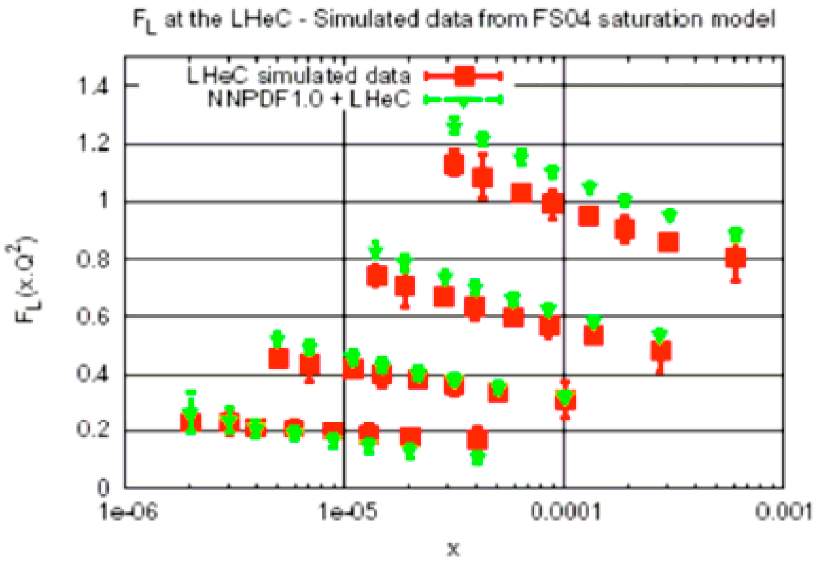


Cross sections shall saturate because of unitarity.
(notice link to superhigh energy neutrino physics)

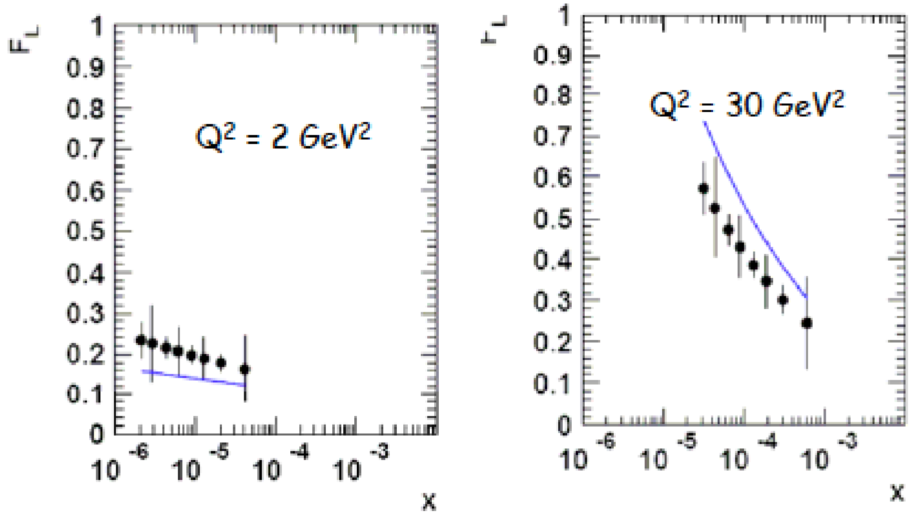
A new phase of matter:
density high but coupling is small (CGC).

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



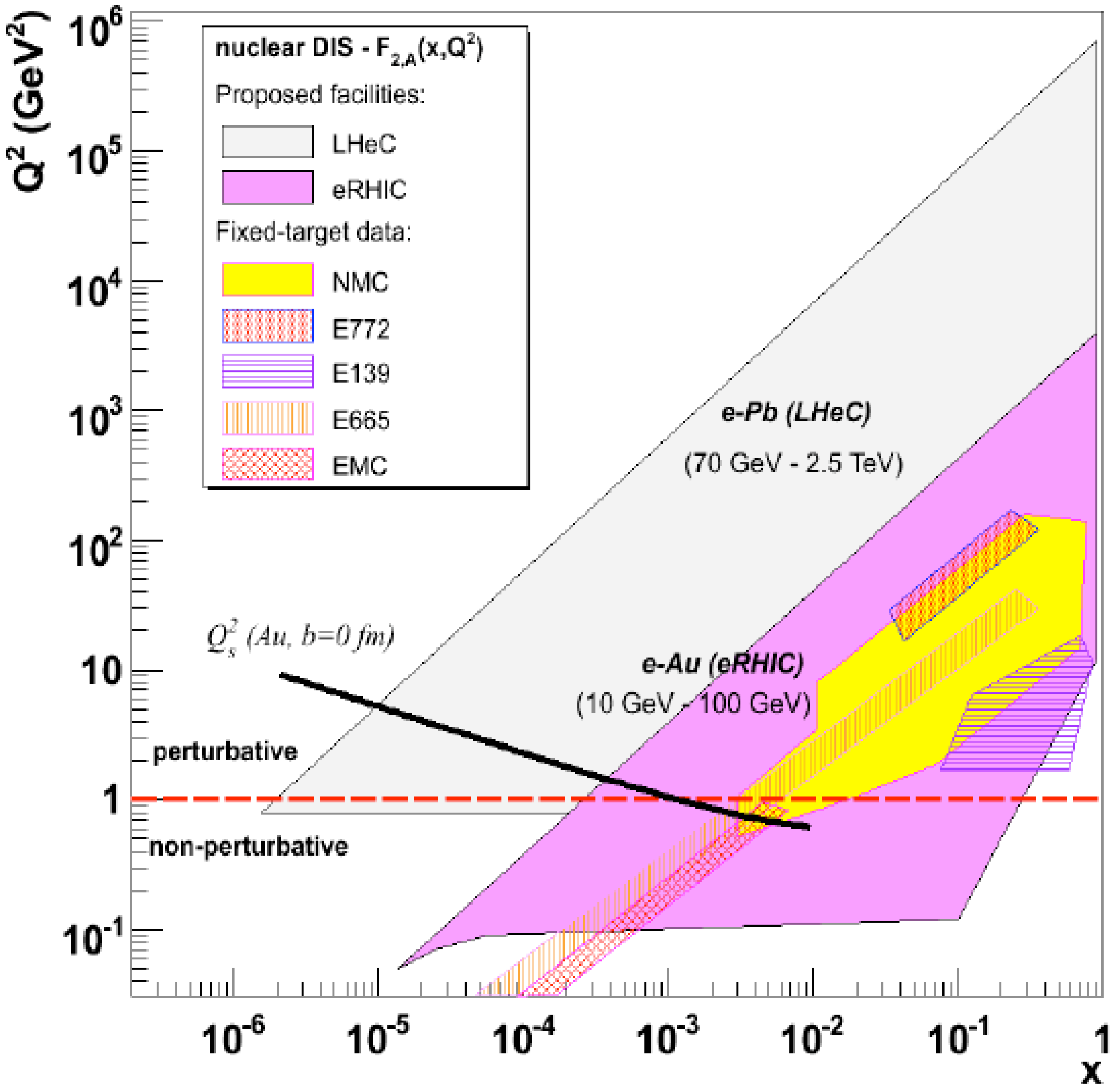
J.Forshaw et al.



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

DIS off Nuclei (D,A)

DdE, arXiv:0706.4182



NuPECC study group

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

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")

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

eRHIC with nuclei could be complementary.

LHeC-A appears as natural complement 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)

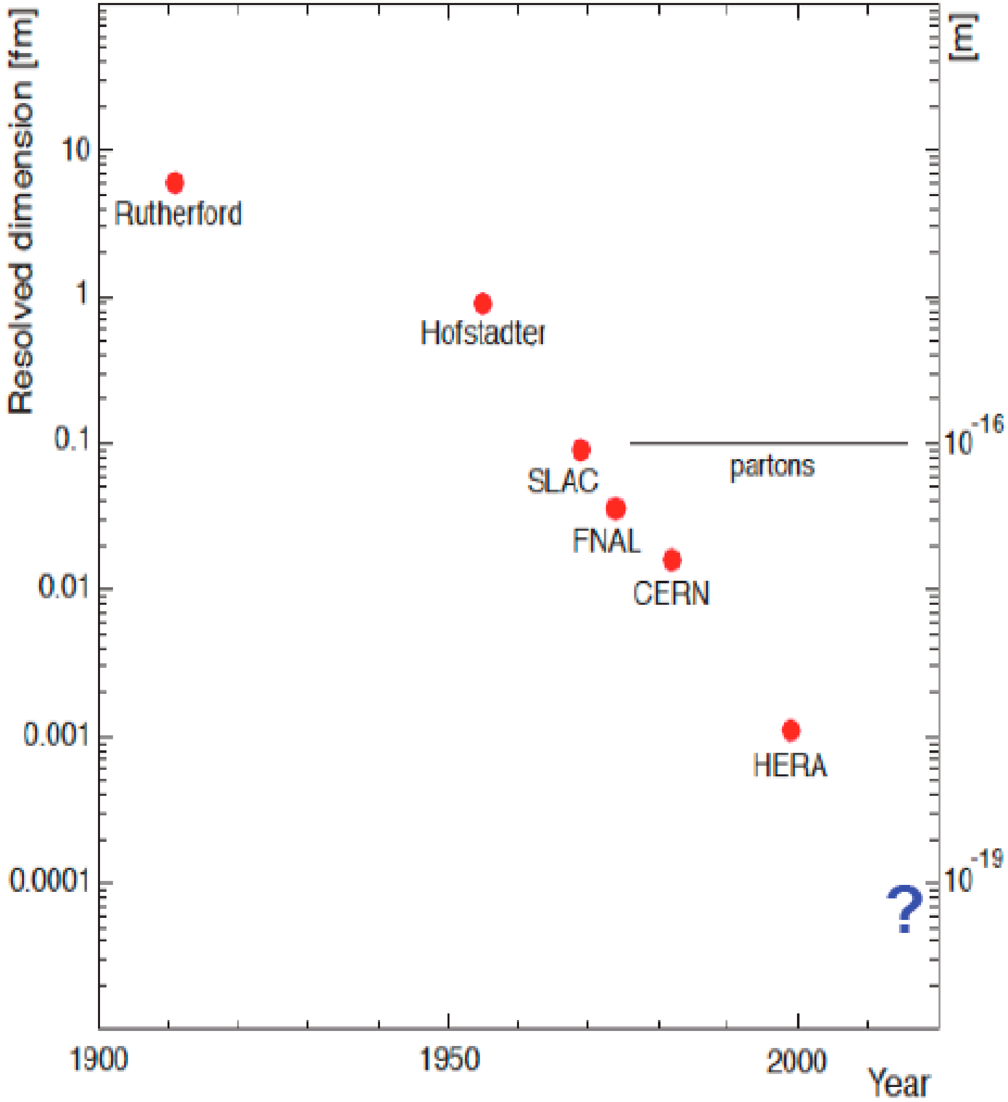
Technical Workshop (~3/09)

Physics Workshop (4/09)

2nd ECFA CERN Workshop 9/09

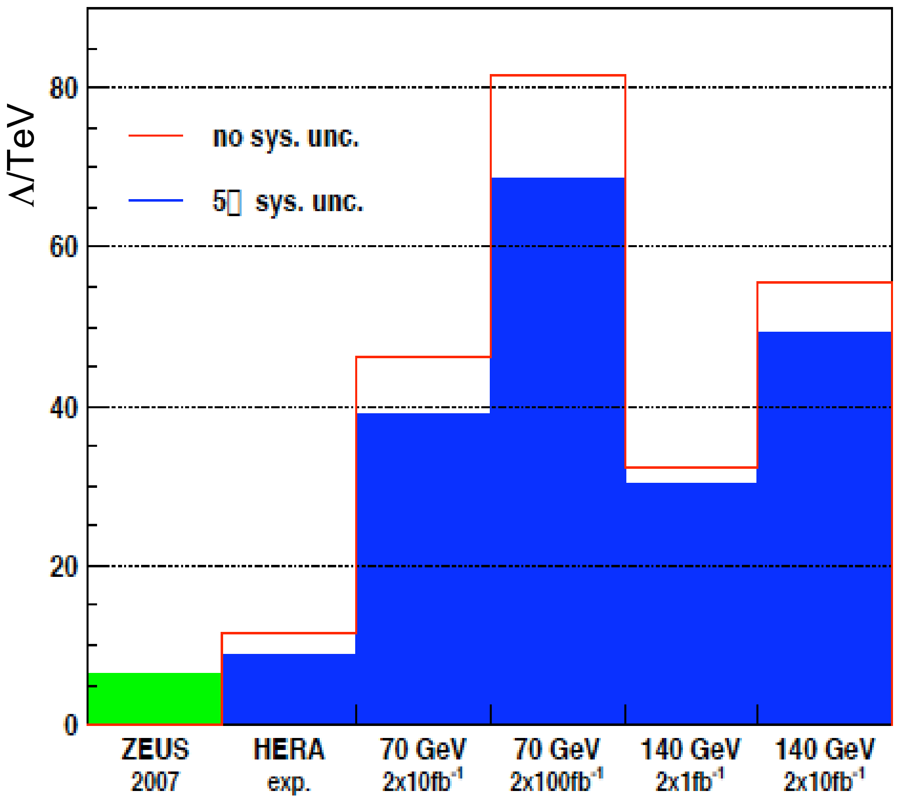
Final Report to ECFA 11/09

Written CDR (5/10)



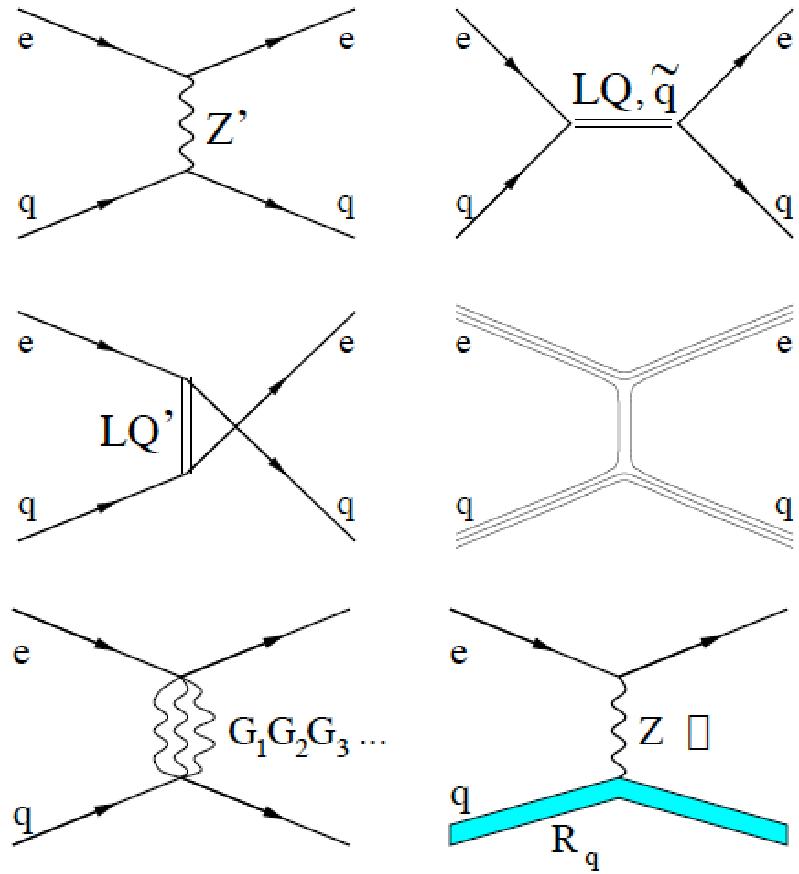
Contact Interactions [generic, ED, quark form factor]

Limits for PC (VV) model A.Zarnecki DIS08



Luminosity vs Energy

Possible "new physics" processes:



The LHeC project has gained momentum, its CDR will be written, and can be based on more than one option and 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, SUSY and Higgs Physics

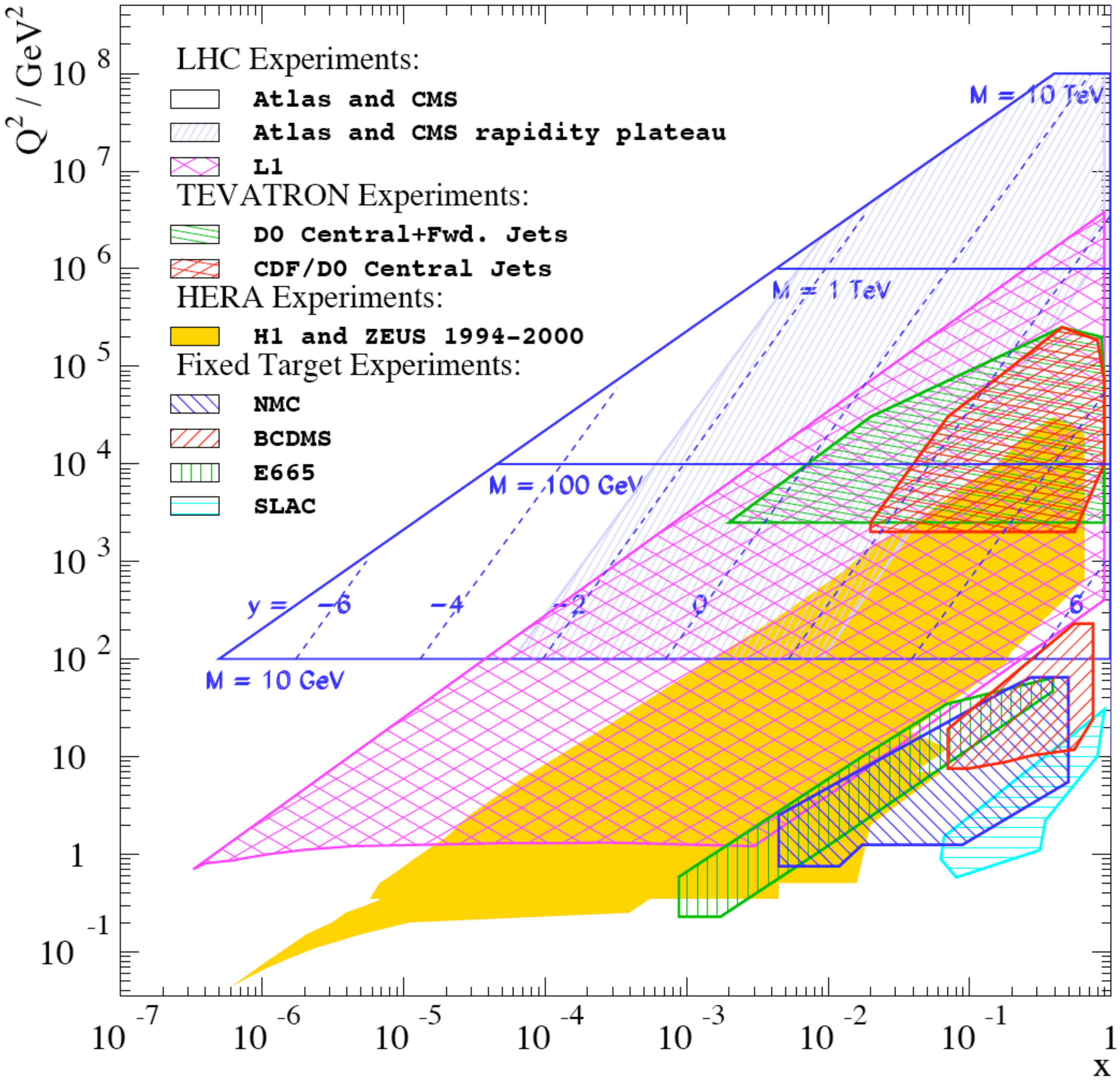
-Potential on electroweak measurements

-DVCS and final state physics

-Nuclear Parton Distributions

-Luminosity measurement

-LHC/LC and LHeC complementarity



Q^2 / GeV^2
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 2 4 6
x

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**

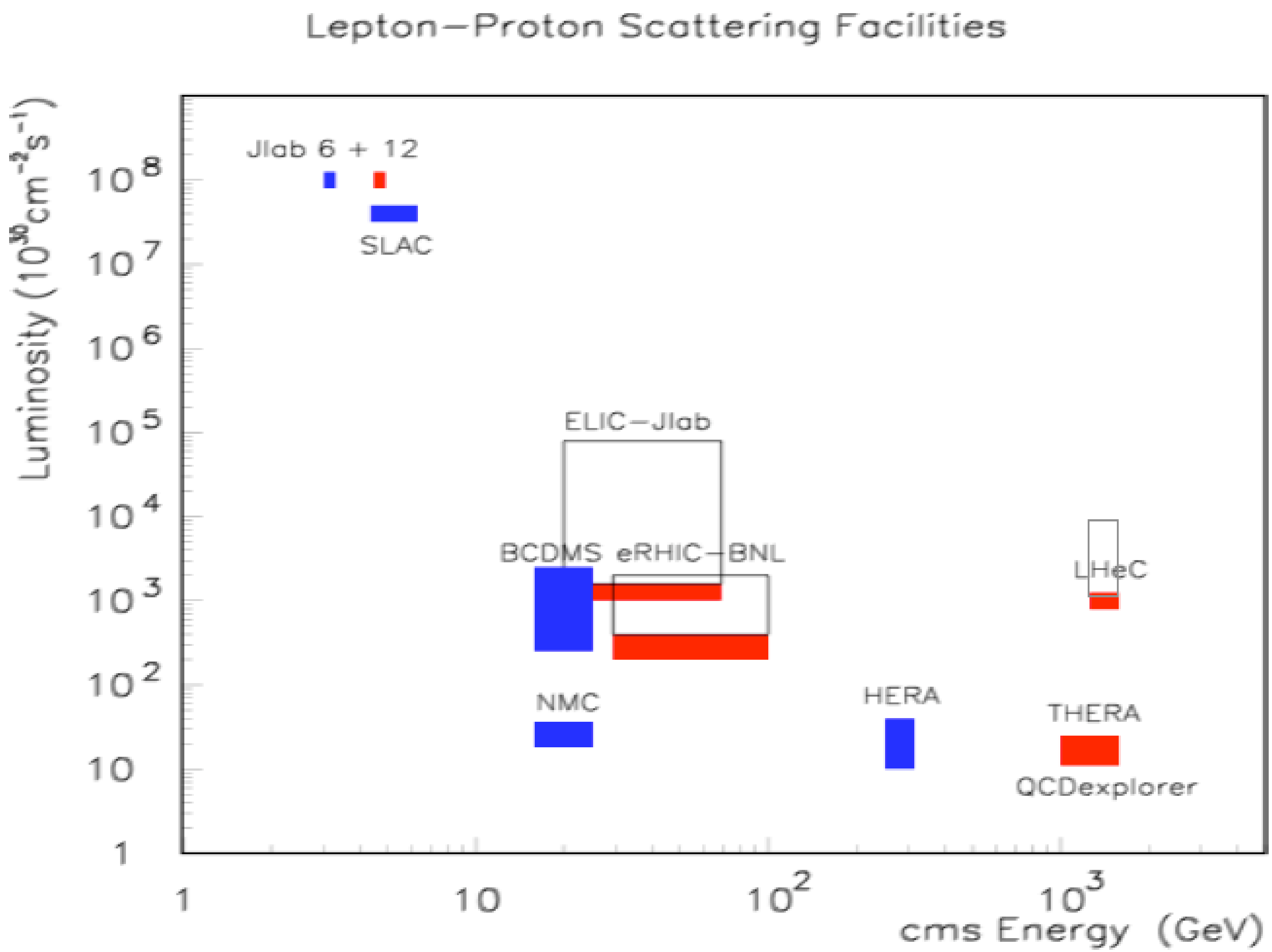
Parameters for pulsed Linacs for 140 GeV, $10^{32} cm^{-2} s^{-1}$

SC technology → LHeC (SC)

NC technology → LHeC (NC)

	X FEL 20 GeV	LHeC 140 GeV, $10^{32} cm^{-2} s^{-1}$	LHeC 140 GeV, $10^{32} cm^{-2} s^{-1}$
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.


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