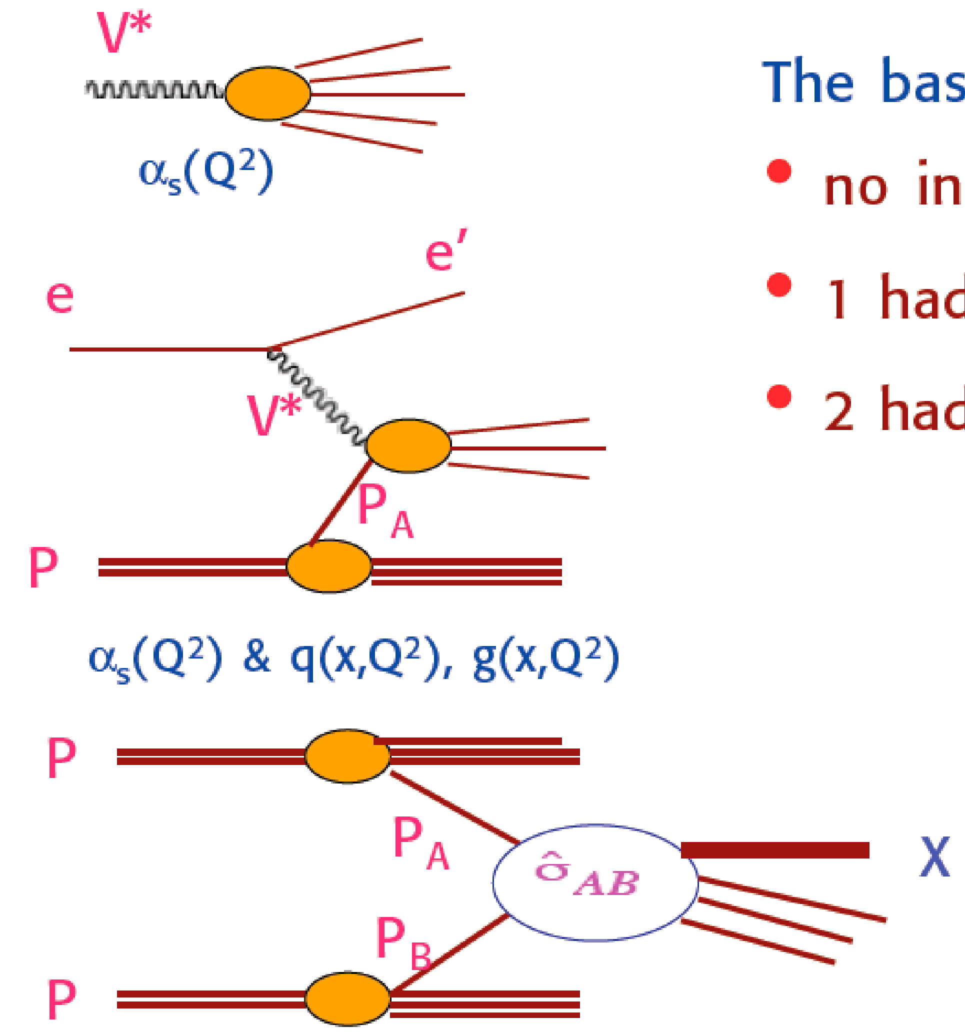
The LHeC Project

A. Caldwell on behalf of J. Dainton

All slides from M. Klein, ICFA08



The basic experimental set ups:

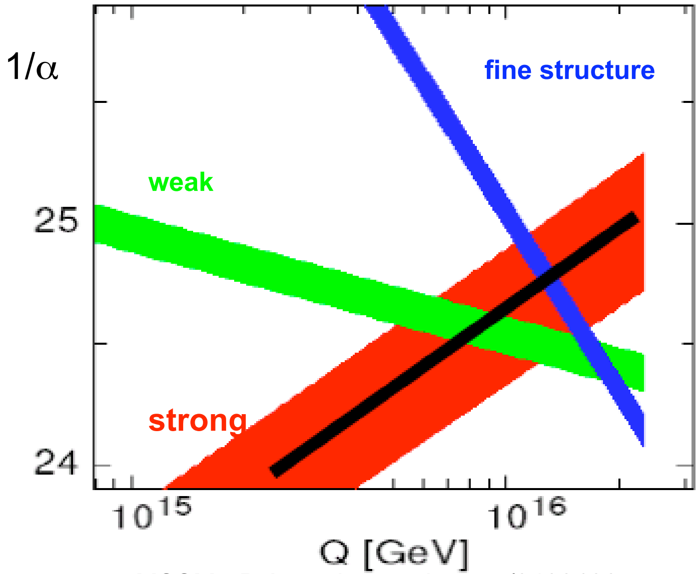
- no initial hadron (....LEP, ILC, CLIC)
- 1 hadron (....HERA, LHeC)
- 2 hadrons (....SppS, Tevatron, LHC)

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

G.Altarelli, LHeC Workshop Divonne 9/08

Strong Coupling Constant

Simulation of α_s measurement at LHeC



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

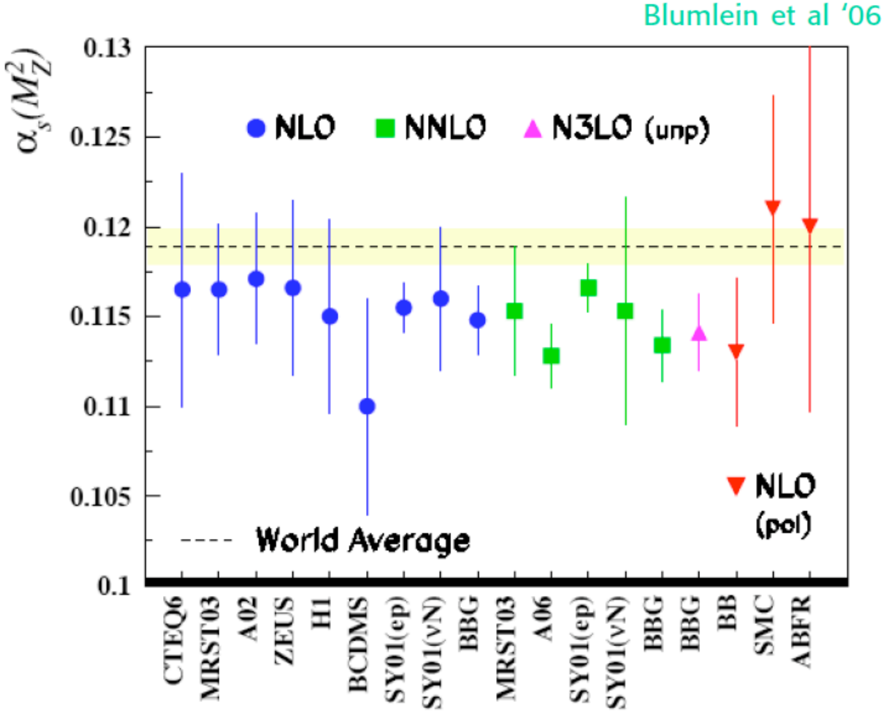
DATA	exp. error on α_s
NC e⁺ only	0.48%
NC	0.41%
NC & CC	**0.23% :=(1)**
(1) $\gamma_h > 5°$	0.36% :=(2)
(1) +BCDMS	0.22%
(2) +BCDMS	0.22%
(1) stat. *= 2	0.35%

DIS08, T.Kluge

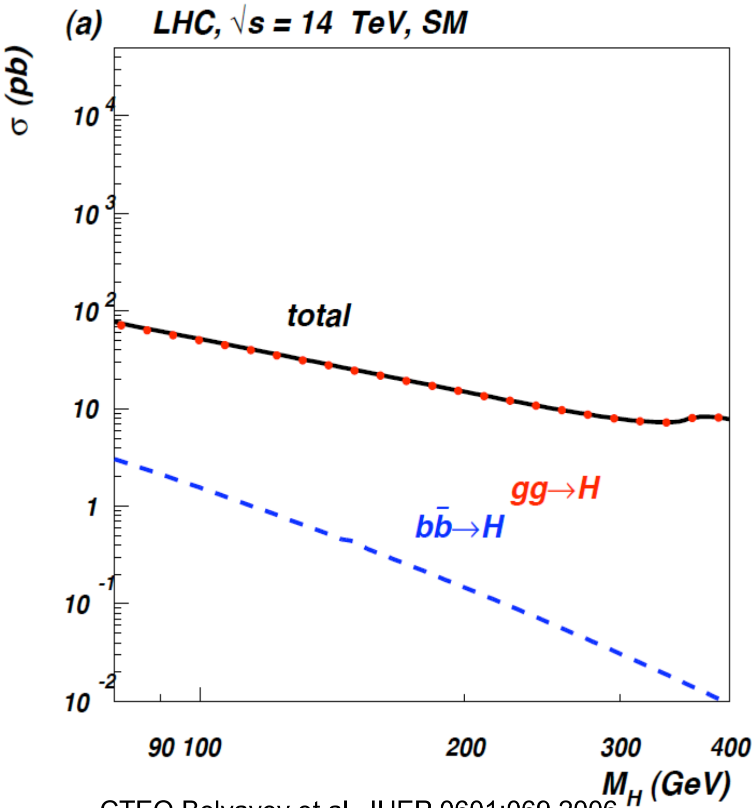
α_s least known of coupling constants
Grand Unification predictions suffer from $\delta\alpha_s$

DIS tends to be lower than world average

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



Gluon - SM Higgs

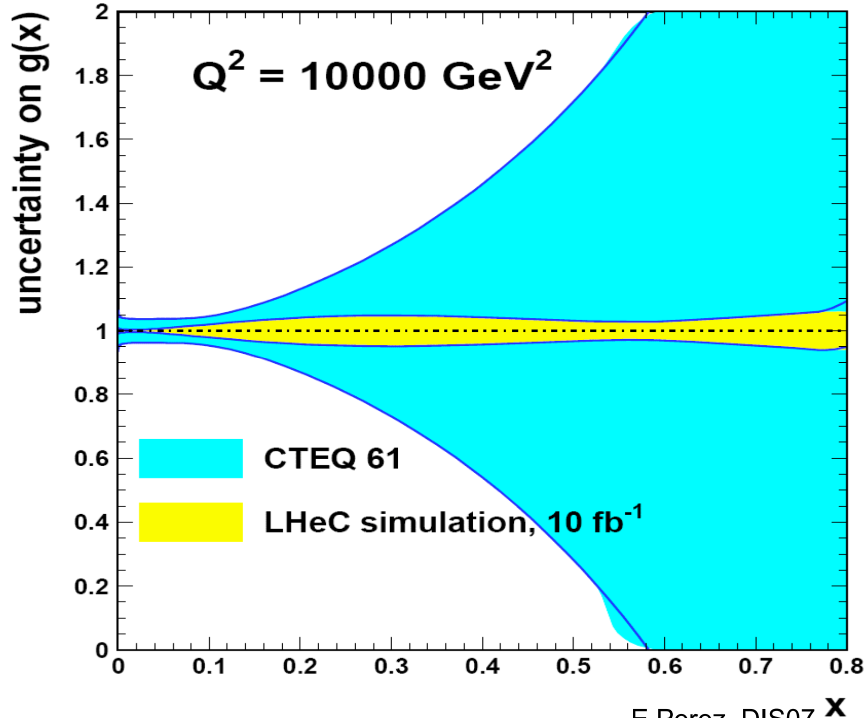


CTEQ Belyayev et al. JHEP 0601:069,2006

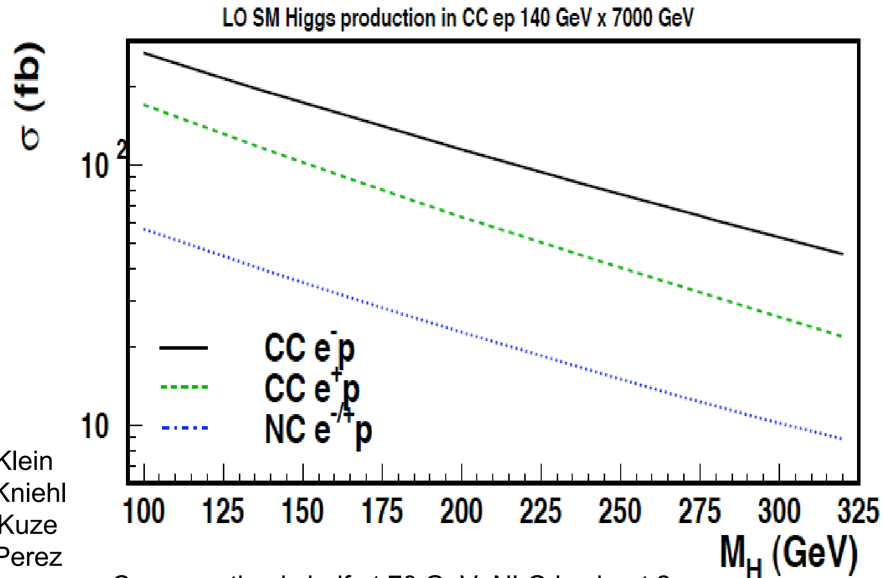
In SM Higgs production is gluon dominated

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

WW to Higgs fusion has sizeable ep xsection



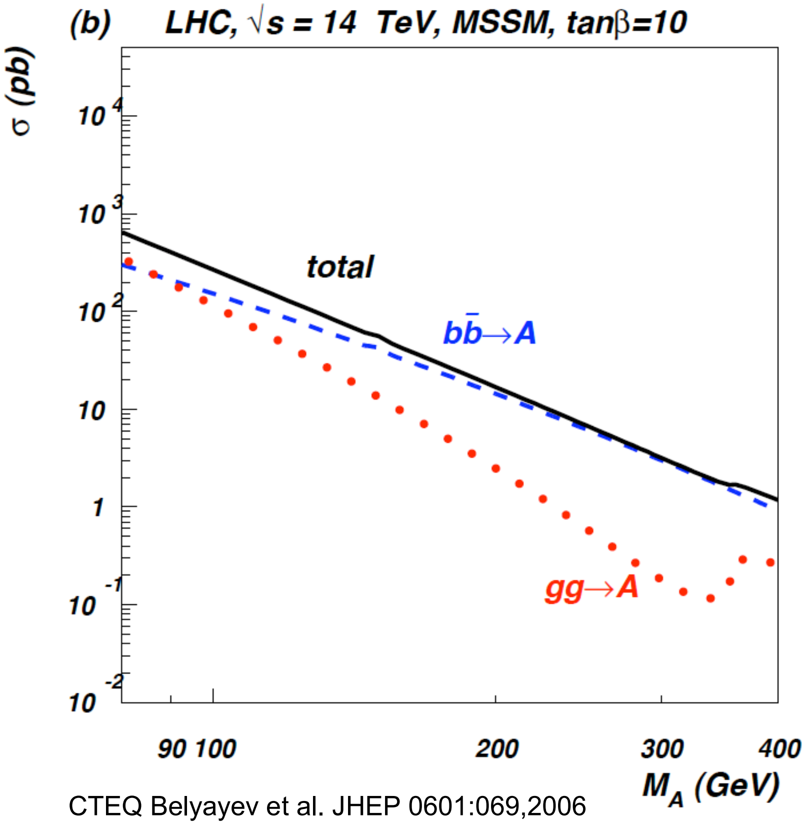
E.Perez, DIS07



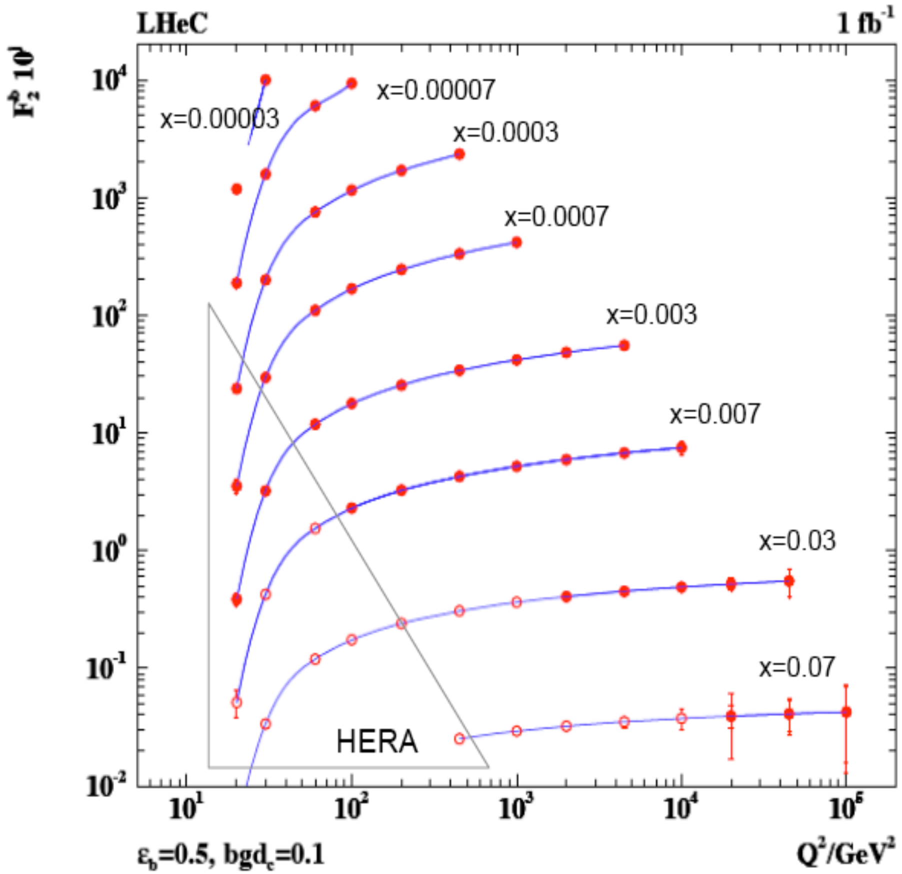
Cross section is half at 70 GeV. NLO is about 2

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

Beauty - MSSM Higgs



CTEQ Belyayev et al. JHEP 0601:069,2006



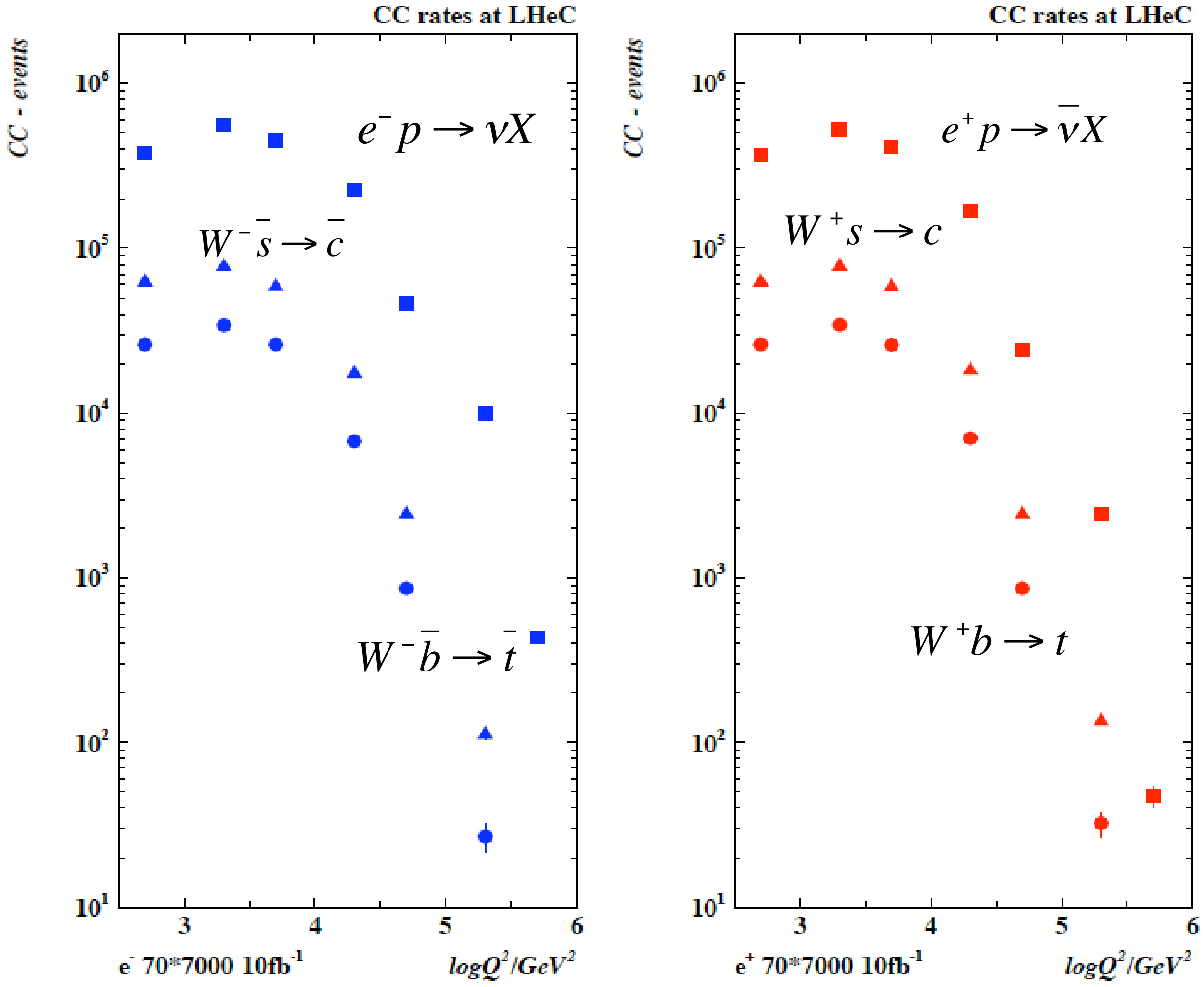
MK, A.Mehta (DIS07)

In MSSM Higgs production is b dominated

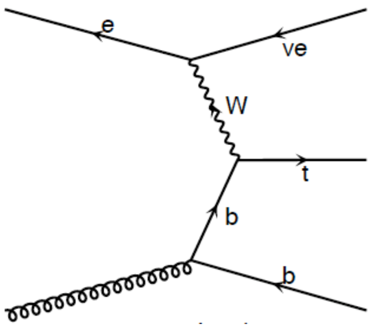
First measurements of b at HERA can be turned to precision measurement of b-df.

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

Single (anti) t and s Quark Production in CC



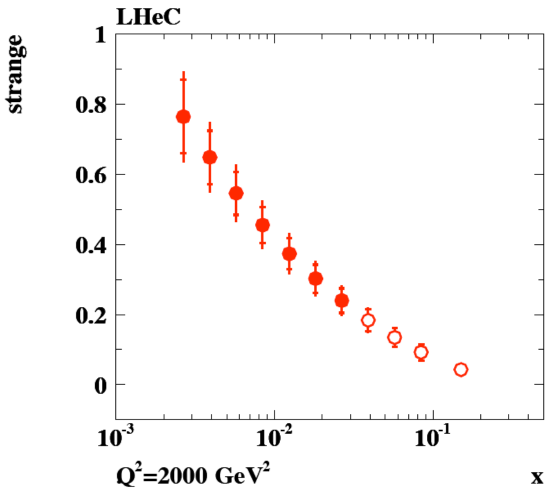
G.Brandt, MK



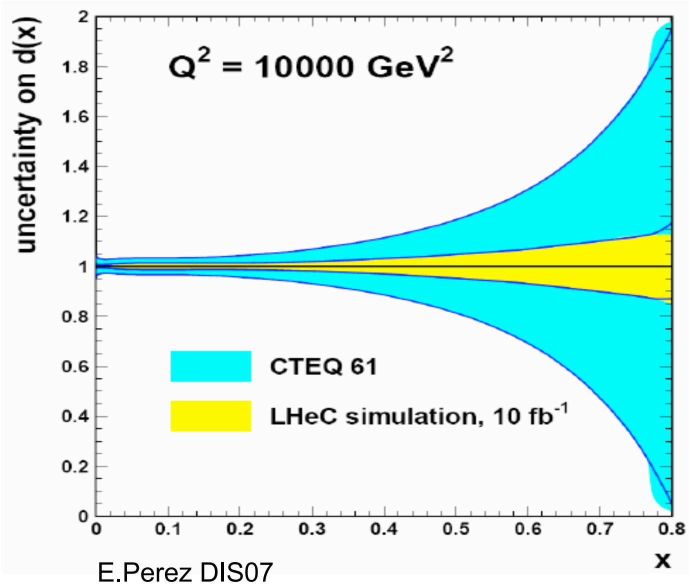
LHeC is a single top and single tbar quark `factory'

CC t cross section O(5)pb

s, sbar-df for the 1st time.



Light Quark Distributions

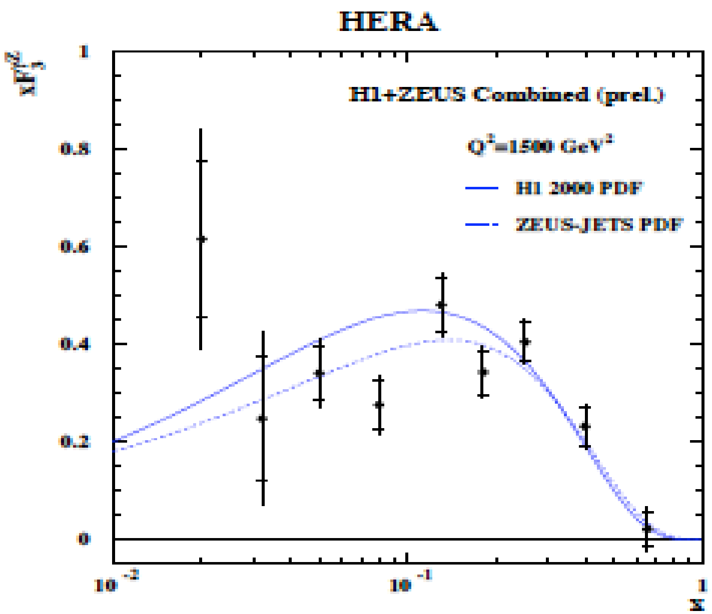


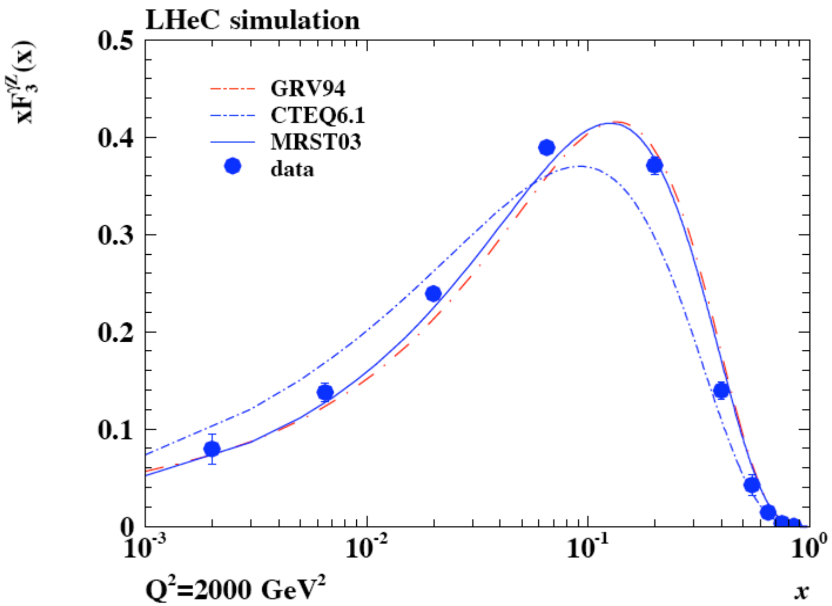
E.Perez DIS07

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

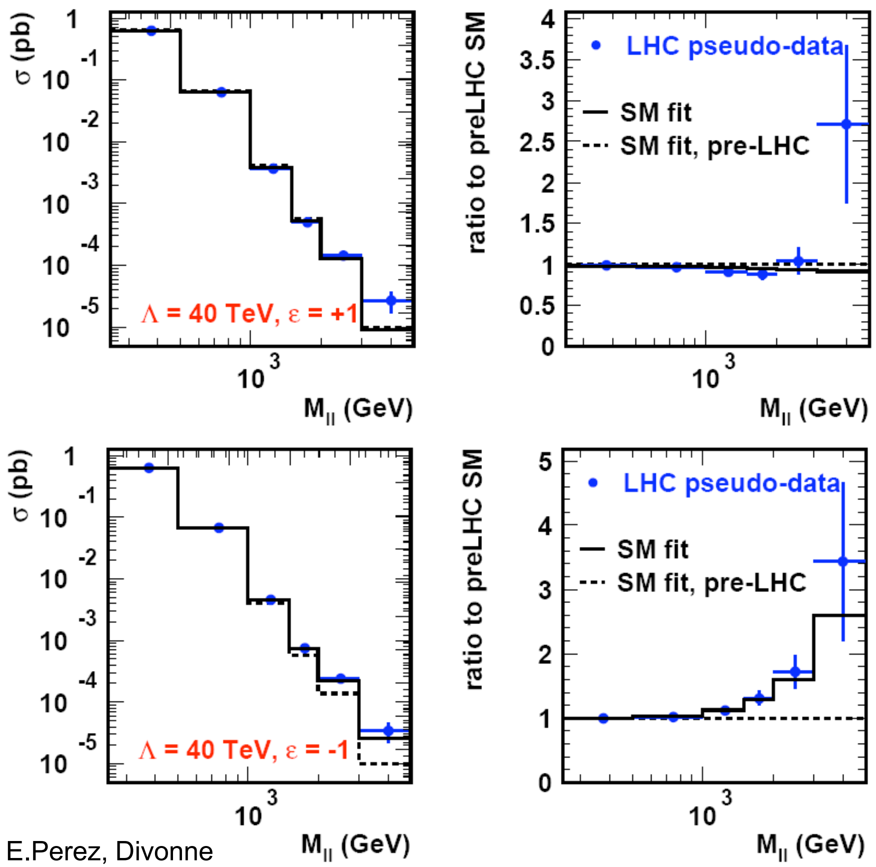
$$xF_3^{\gamma Z} = \frac{x}{3}(2u_v + d_v)$$



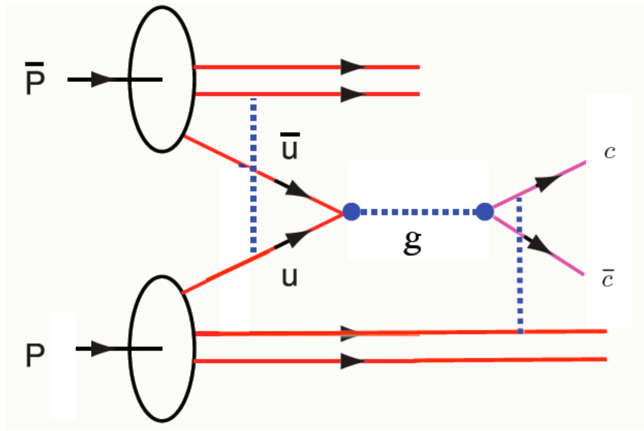


Max Klein LHeC ICFA08

pdf's and New Physics at the LHC



E.Perez, Divonne



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

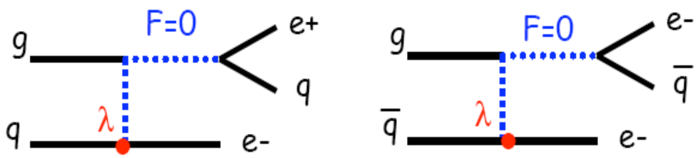
Important, perhaps crucial, to measure pdf's in the kinematic range of the LHC.
cf also ED limits vs pdf's.

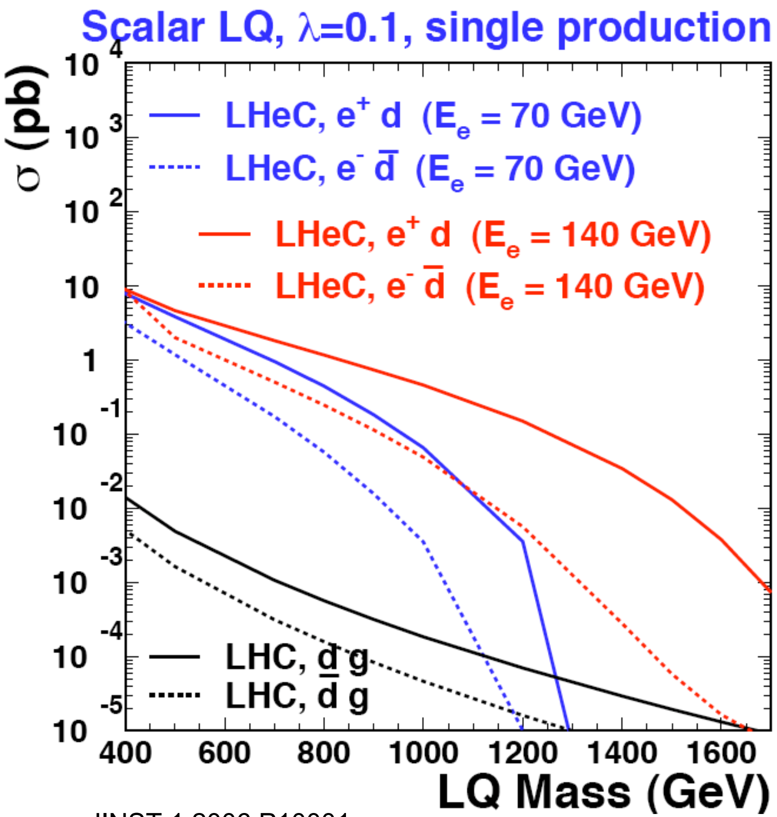
NP may be accommodated by HERA/BCDMS DGLAP fit. It can not by the fit to also LHeC.

(recall high Et excess at the Tevatron which disappeared when xg became modified)

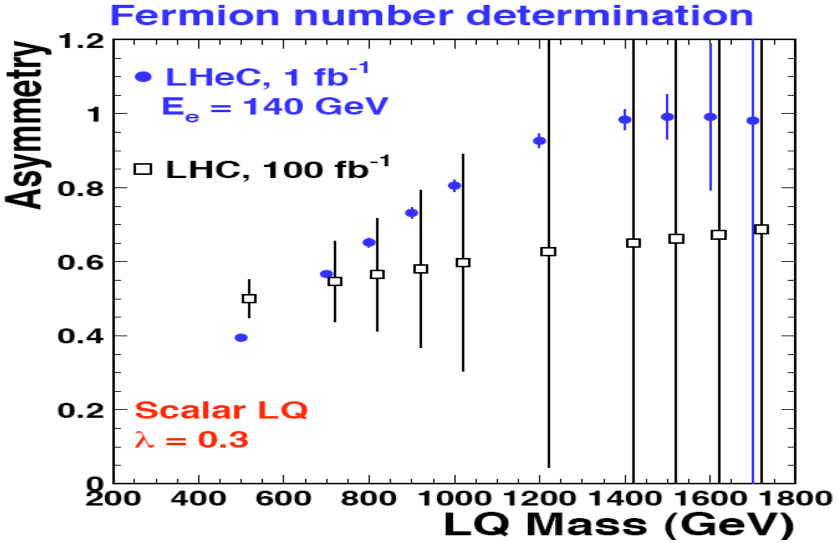
John Collins, Jian-Wei Qiu . ANL-HEP-PR-07-25, May 2007.
e-Print: **arXiv:0705.2141** [hep-ph]

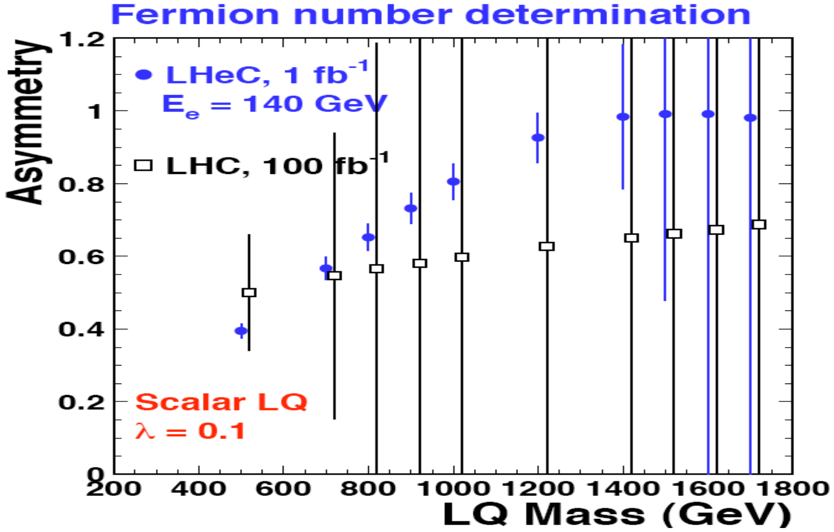
LQ Quantum Numbers





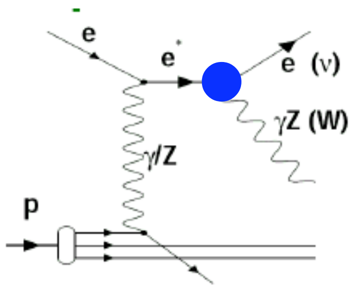
JINST 1 2006 P10001





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

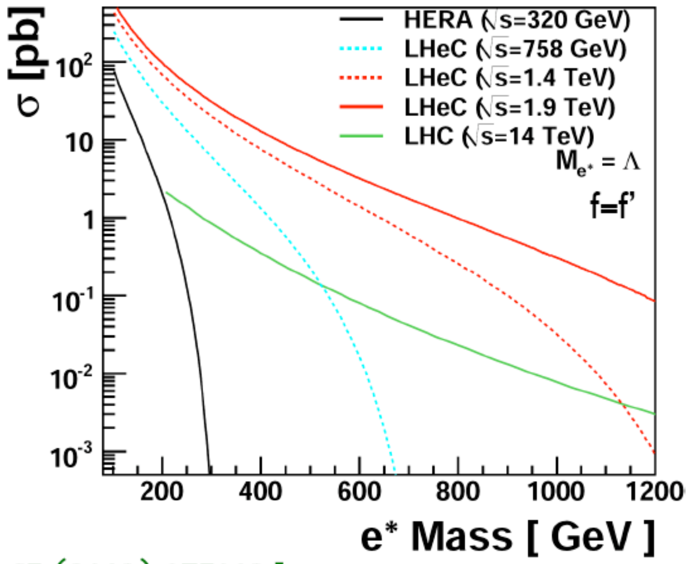
Electron-Boson Resonances : excited electrons



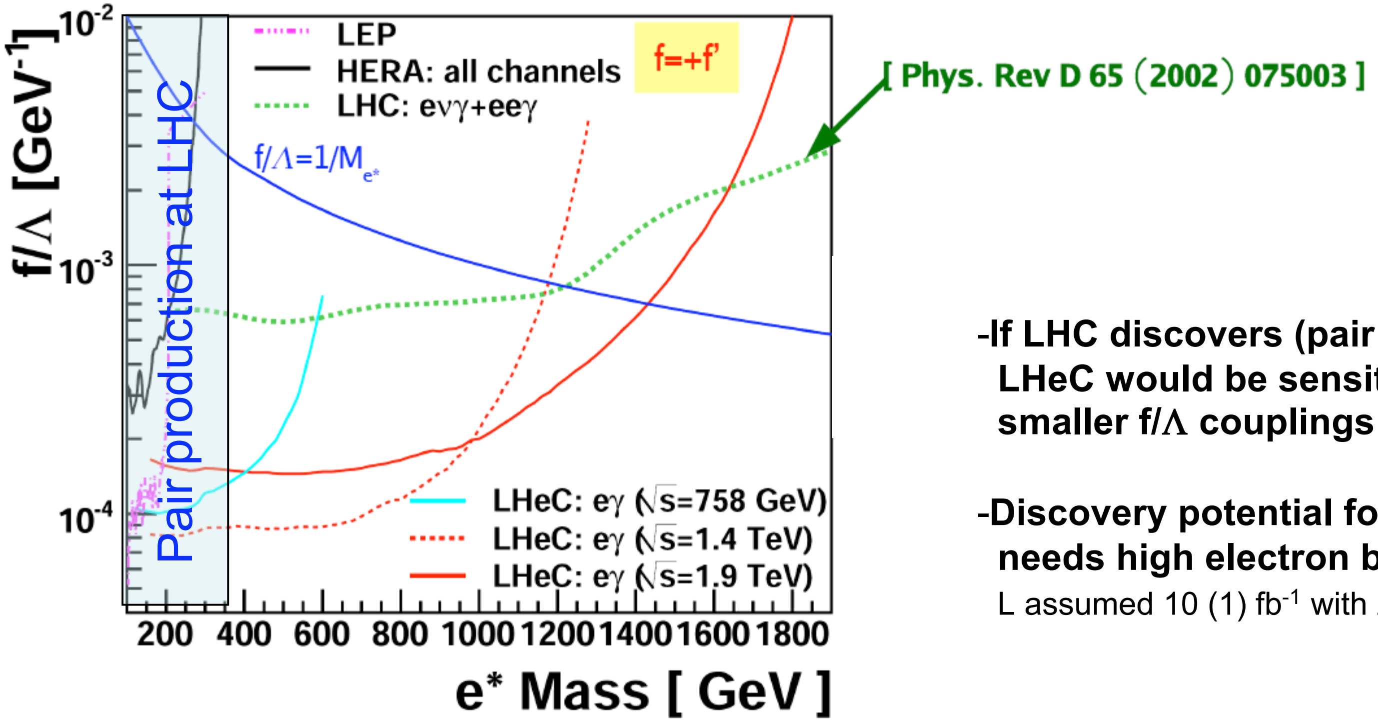
coupling
~ f / Λ

N. Trinh, E. Sauvan, Divonne

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



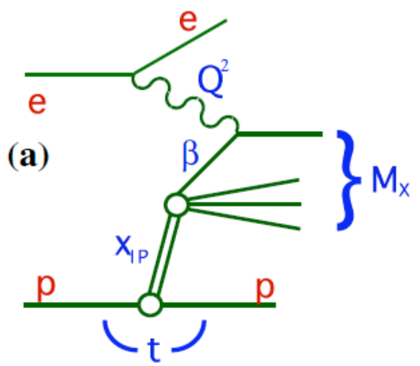
LHeC prelim. analysis, looking at e* → eγ

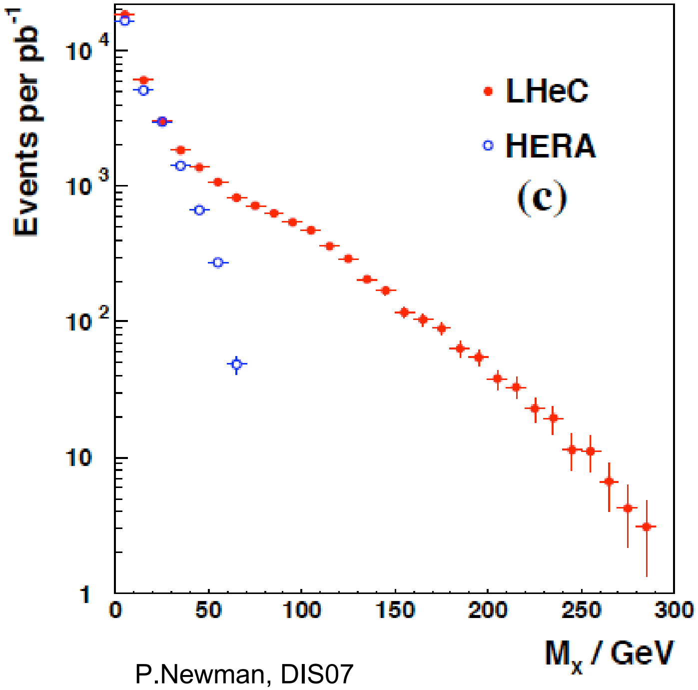


-If LHC discovers (pair prod) an e*:
LHeC would be sensitive to much smaller f/Λ couplings

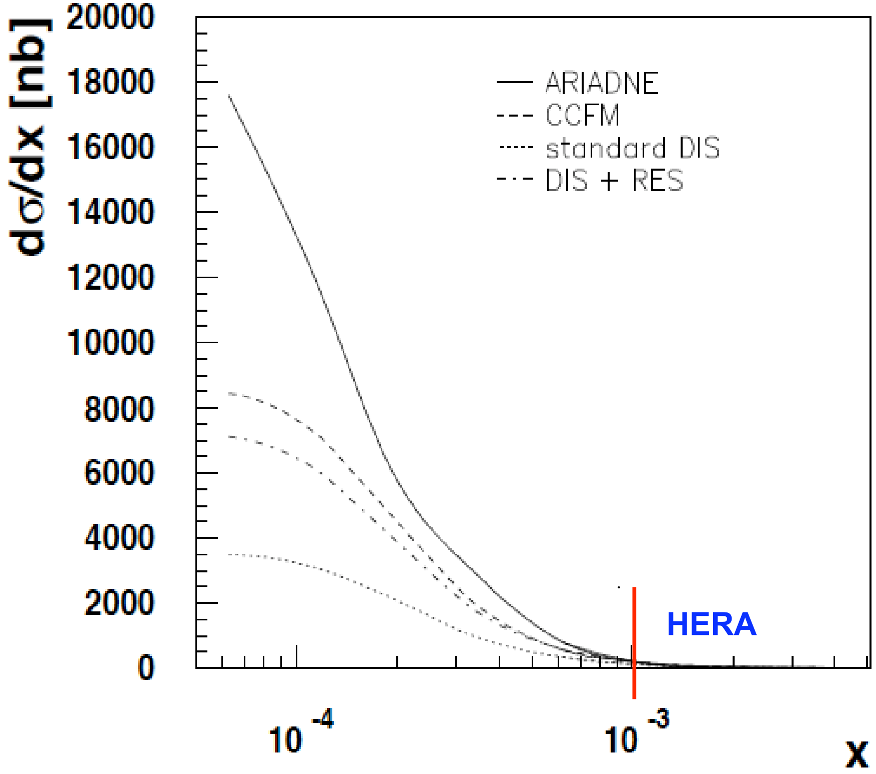
-Discovery potential for higher masses.
needs high electron beam energy
L assumed 10 (1) fb^{-1} with 20/70 (140) GeV

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





P.Newman, DIS07



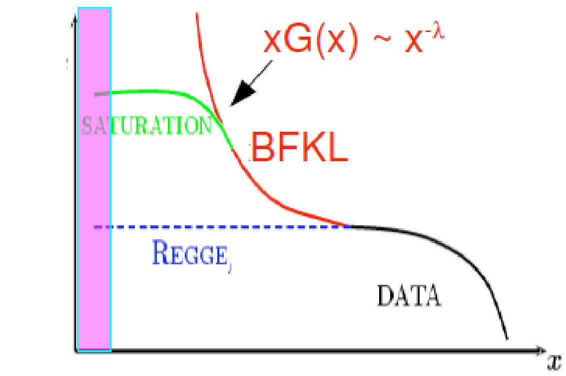
H.Jung, L.Loennblad, THERA study

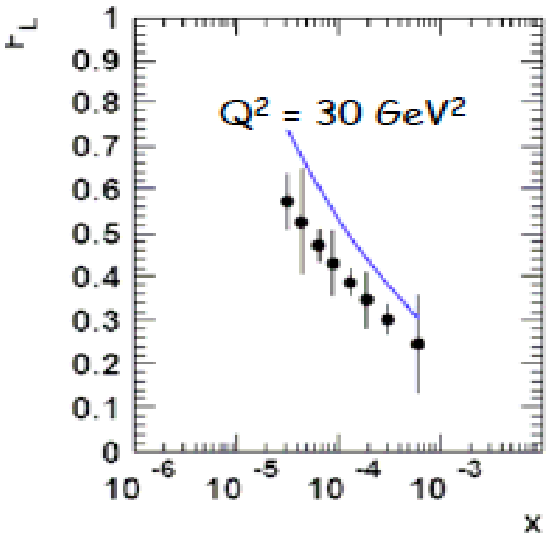
Diffraction to accompany (SUSY) Higgs fwd physics at LHC

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

Quark-Gluon Dynamics (saturation, GPDs)

$xG(x) = dN_g/dy$

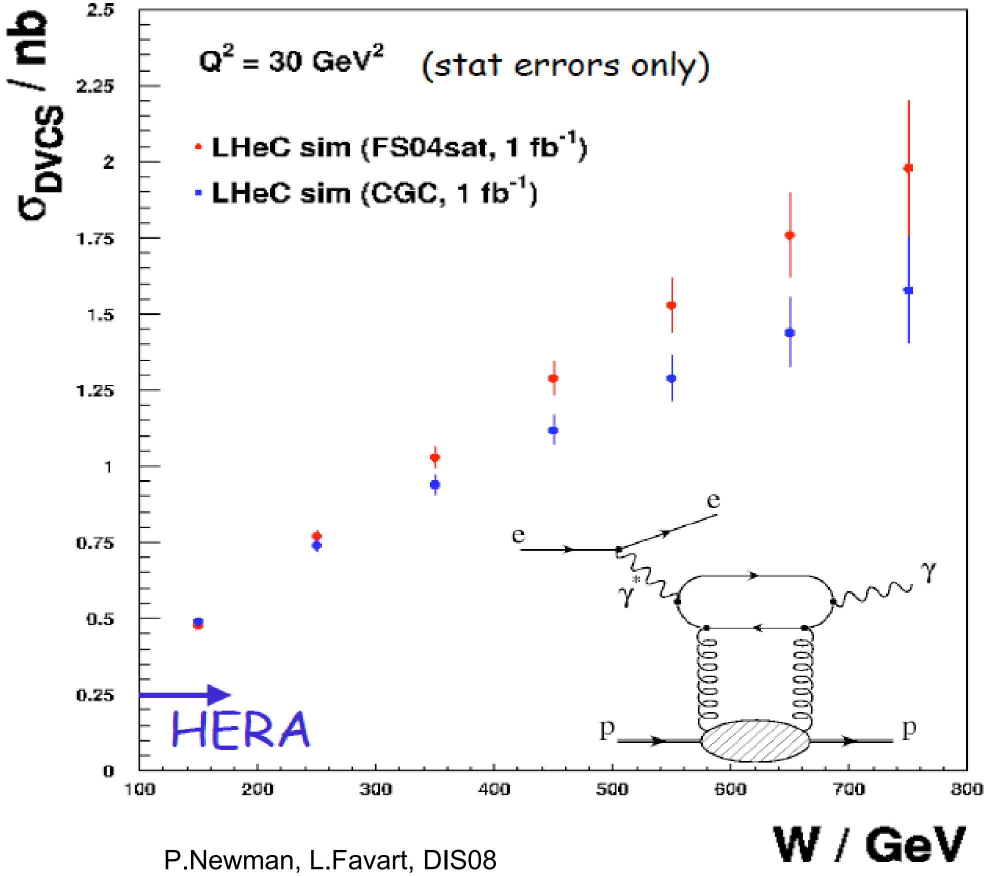




J.Forshaw et al, DIS08

LHeCsat data in NNPDF1.0

Divonne



P.Newman, L.Favart, DIS08

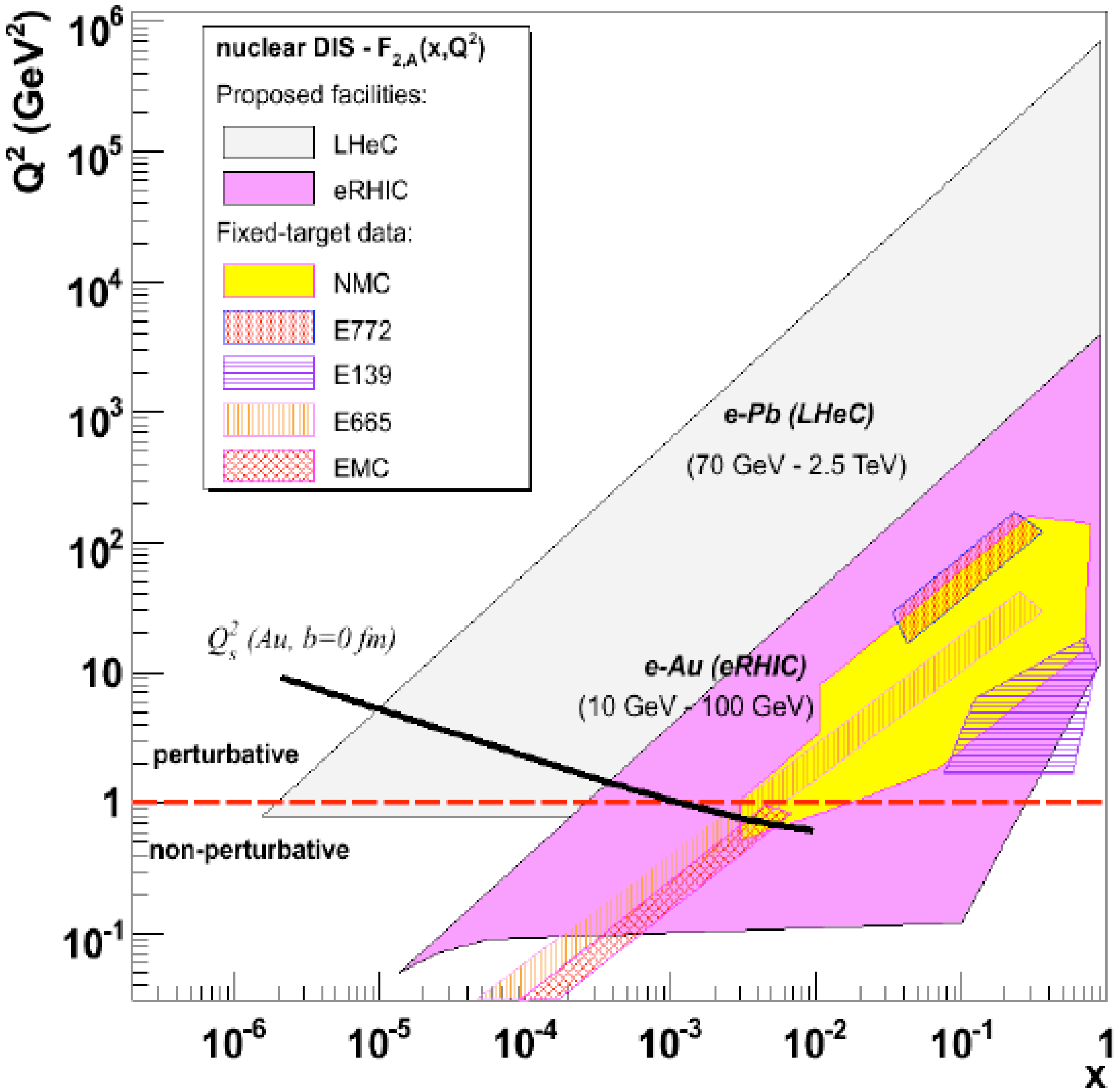
LHeC opens phase space to discover saturation in DIS

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.

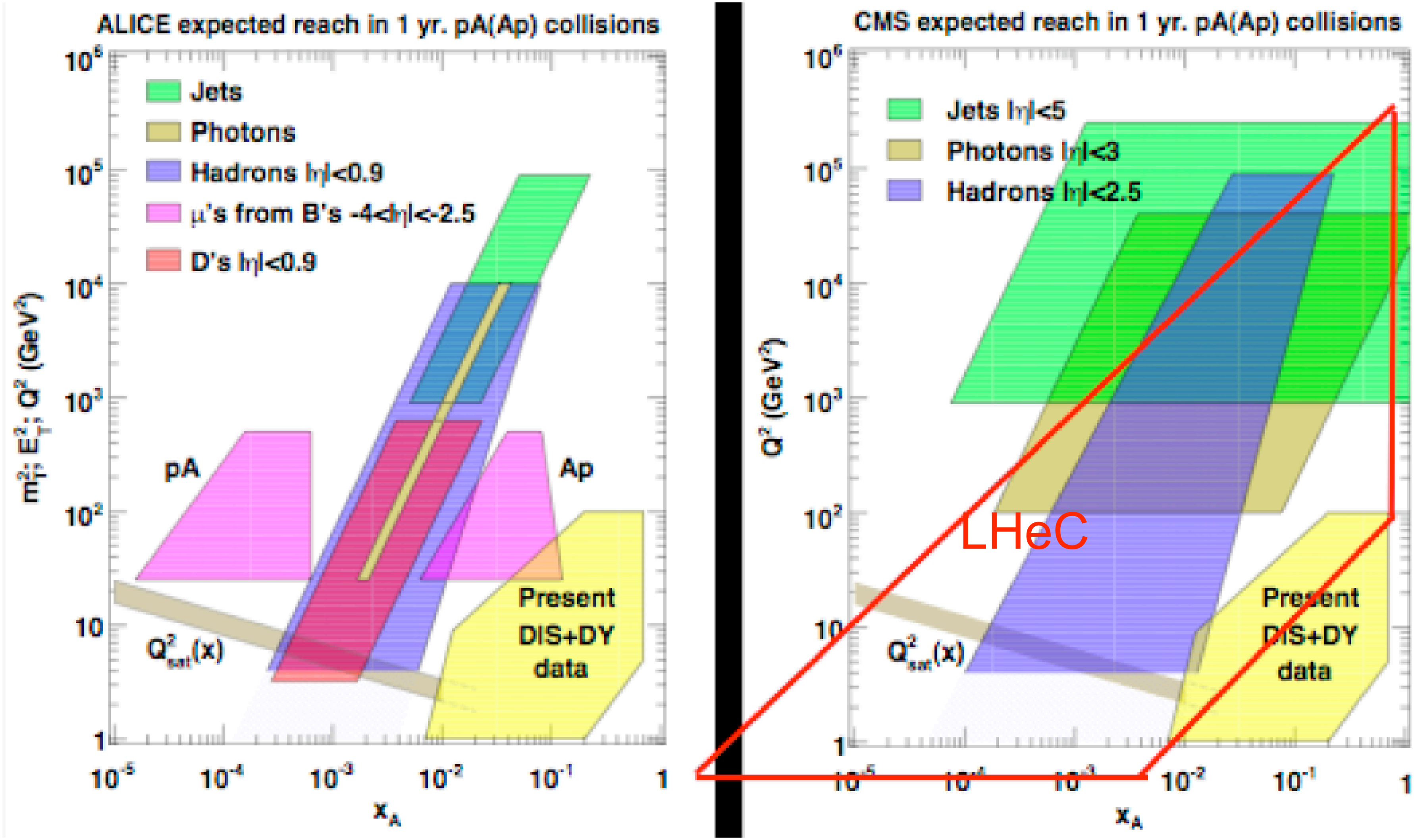
It accesses saturation effects at low x in DIS region ("beyond unitarity")

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

eRHIC with nuclei could be complementary.

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

Complementarity of Ap and ep



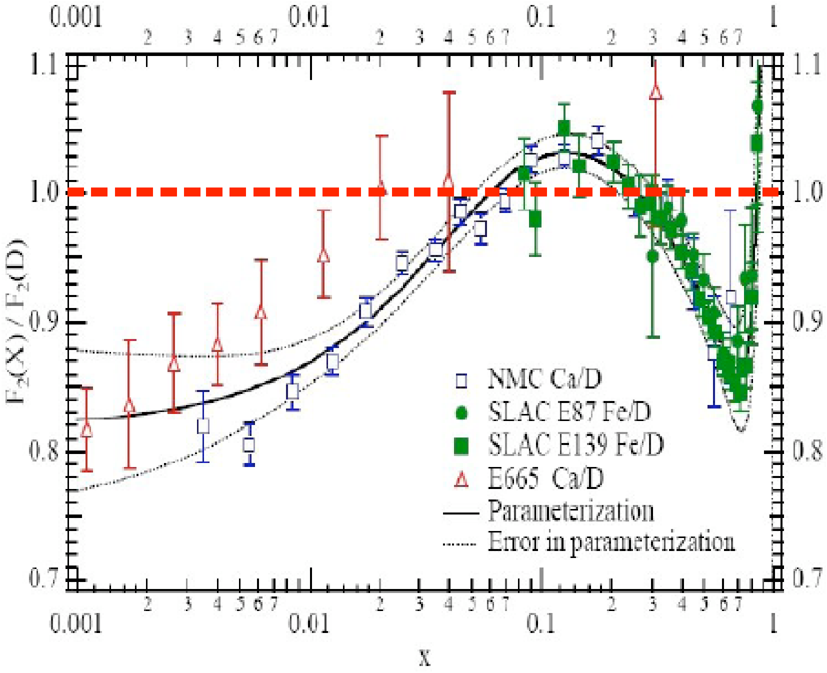
D'Enterria Divonne

Note that DY is not DIS

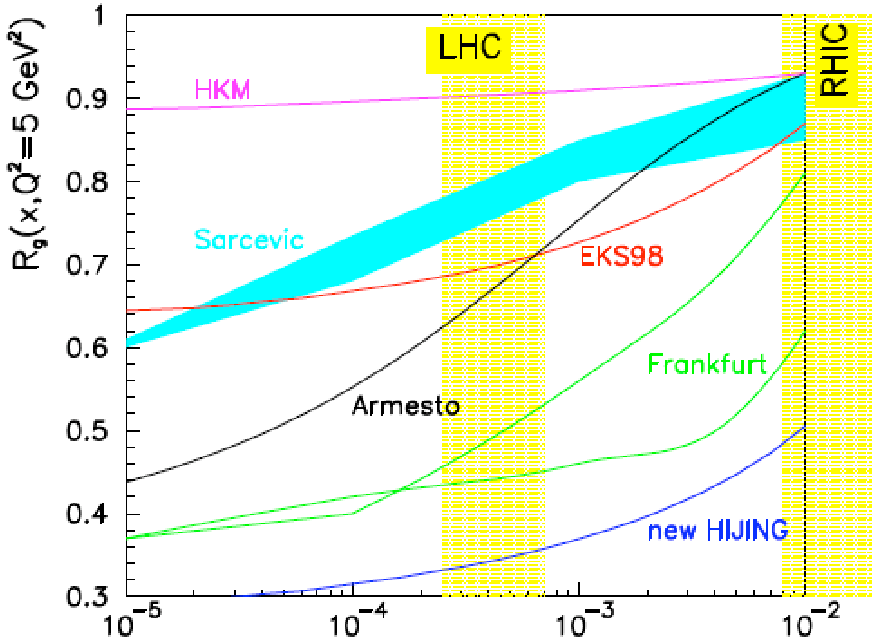
Need eA collider data to determine nuclear parton distributions in the kinematic range of pA/AA collisions at the LHC

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

Saturation - Black Hole Duality.?

4d Perturbative QCD

1. Dilute/dense transition
2. Geometric scaling
3. Critical exponent 2.44
4. IR/UV competition

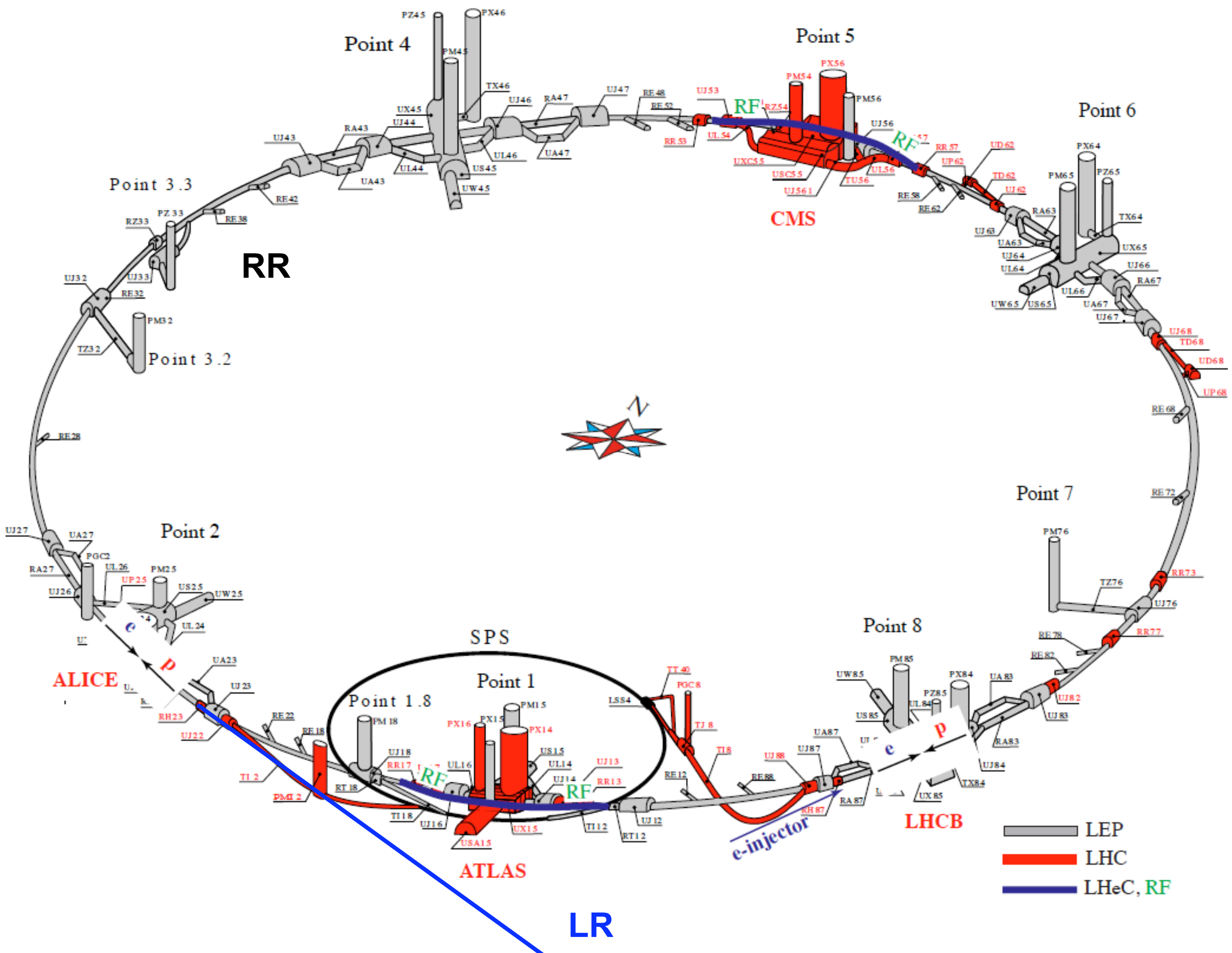
5d Tiny Black hole

1. Flat/black hole transition
2. CSS
3. Critical exponent 2.58
4. Gravity/kinetic competition

Agustin Sabio Vera (Divonne)

Machine Considerations and Studies

high $E_{e,p,A}$, $e^{\pm}$ polarised, high Luminosity



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

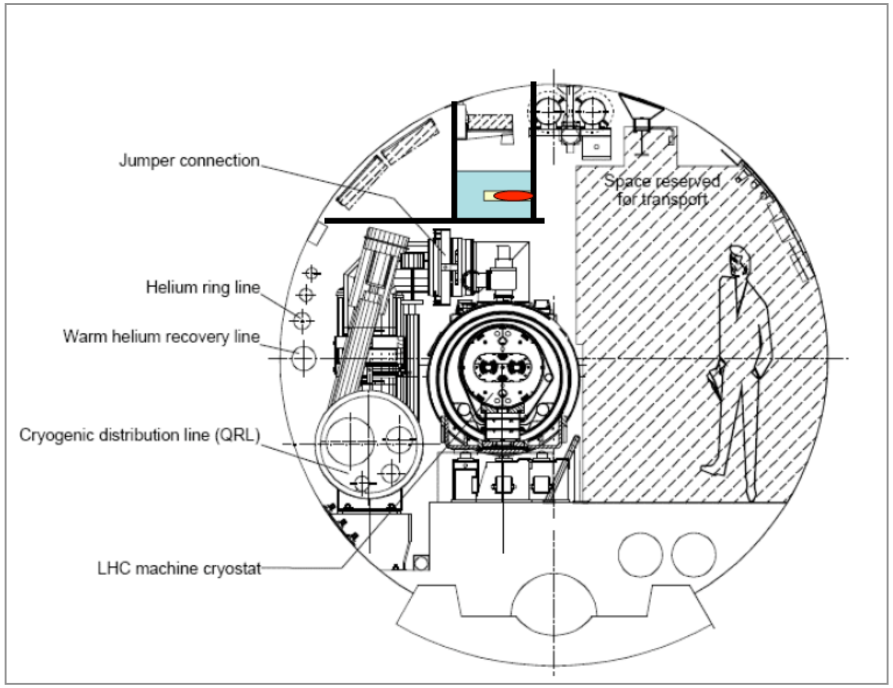
e Ring:

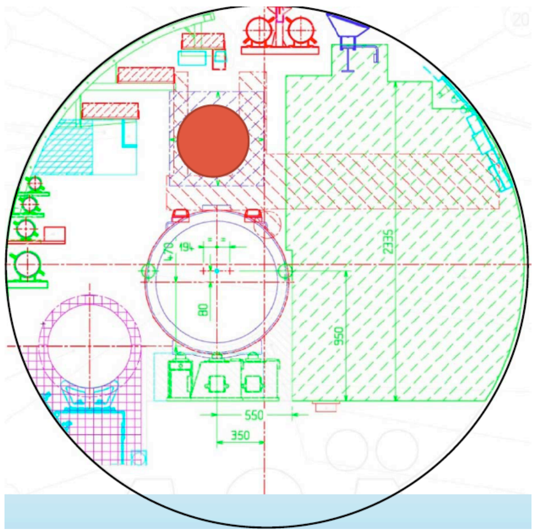
bypasses: 1 and 5
[use also for rf]

injector: SPL, or dedicated

e LINAC:

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





e Ring Further Considerations

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

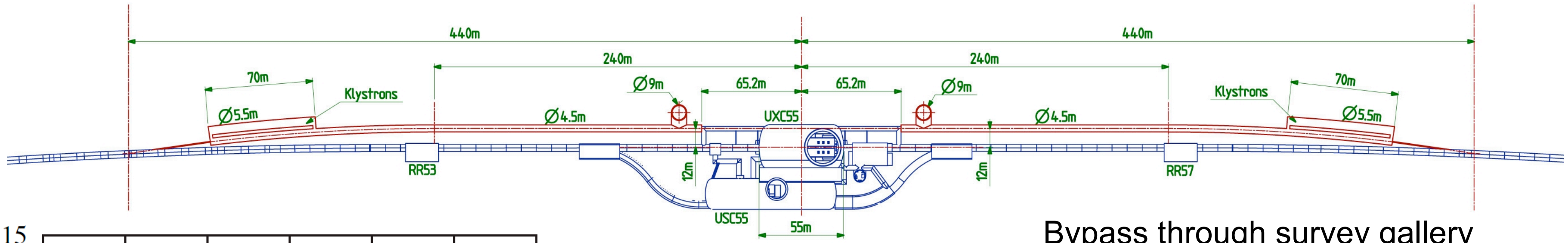
Installation: 1-2 years during LHC shutdowns.
LEP installation was ~1 year into empty tunnel.
Radiation load of LHC pp will be studied.

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.

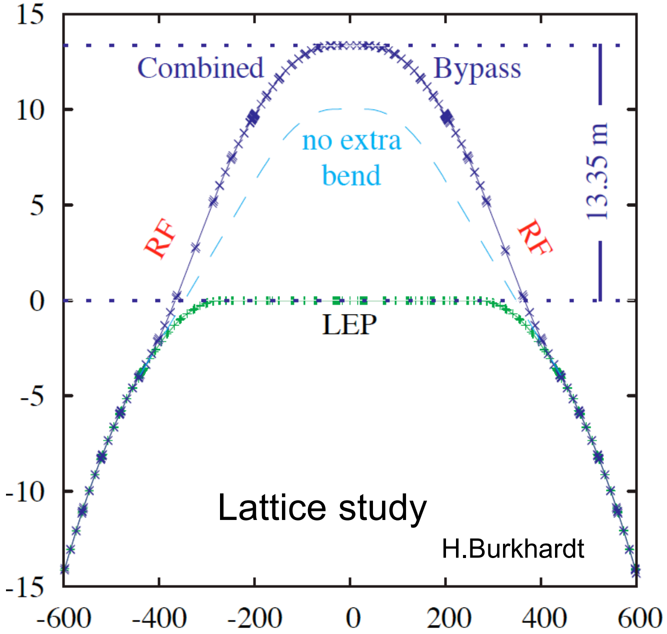
Power for 70 (50) GeV E_e fits into bypasses:

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

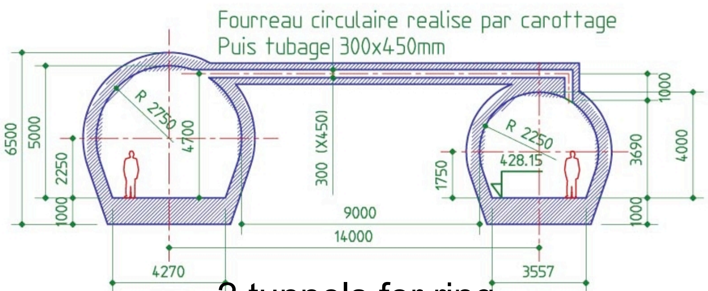


Bypass through survey gallery
13m distance, 2 shafts

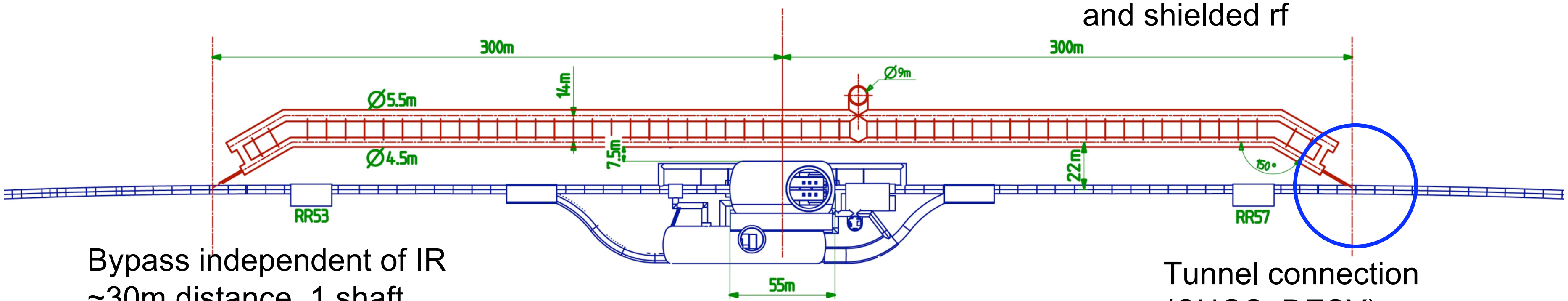


Bypass

point 5



2 tunnels for ring
and shielded rf

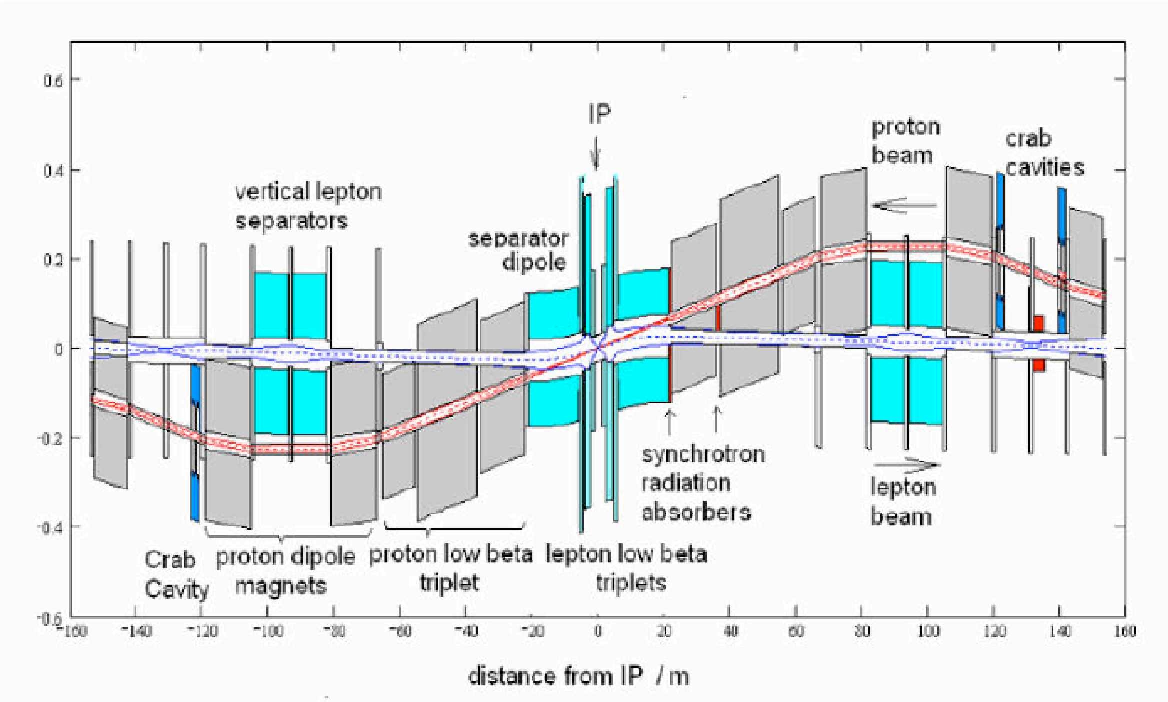


Bypass independent of IR
~30m distance, 1 shaft

Tunnel connection
(CNGS, DESY)

S.Myers, J.Osborne

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 and beam line

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

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

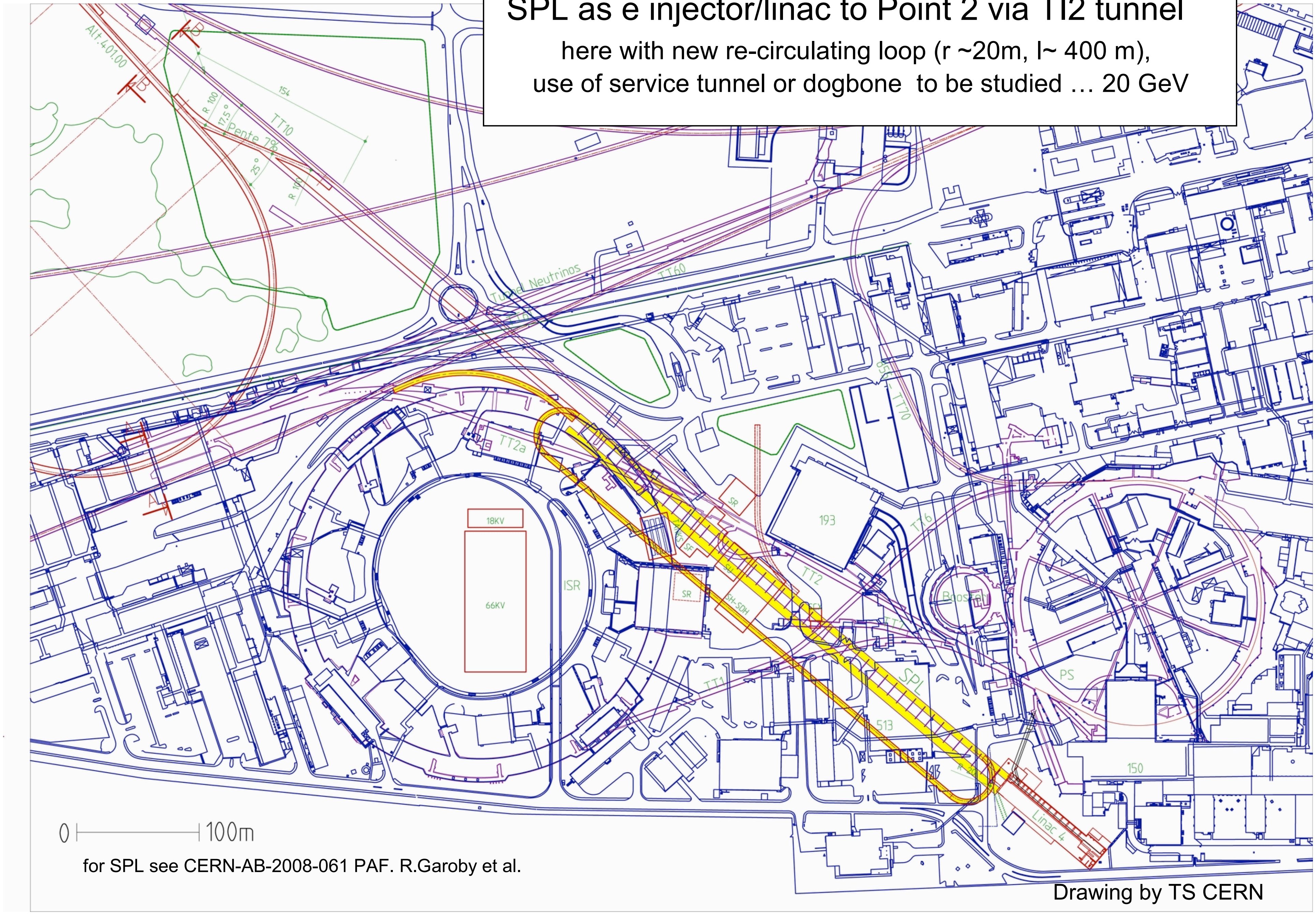
LHC upgrade: N_p increased.
Need to keep e tune shift low:
by increasing β_p, decreasing β_e
but enlarging e emittance,
to keep e and p matched.

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	Δνx=0.00055	Δνx=0.0484
	Δνy=0.00029	Δνy=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	Δνx=0.00061	Δνx=0.056
	Δνy=0.00032	Δνy=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	Δνx=0.0011	Δνx=0.057
	Δνy=0.00069	Δνy=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



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

Drawing 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

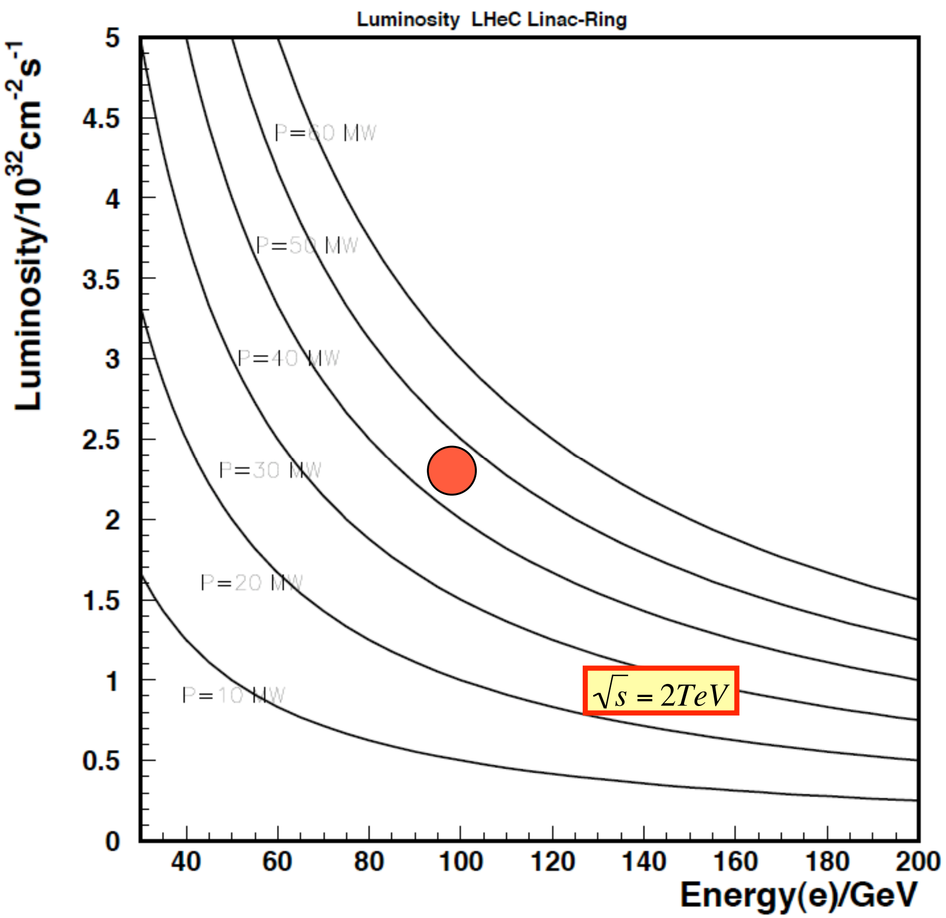
SLHC - LPA

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

$\varepsilon_{pn} = 3.8 \mu m$

$N_p = 5 \cdot 10^{11}$

$\beta^* = 0.10 m$



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

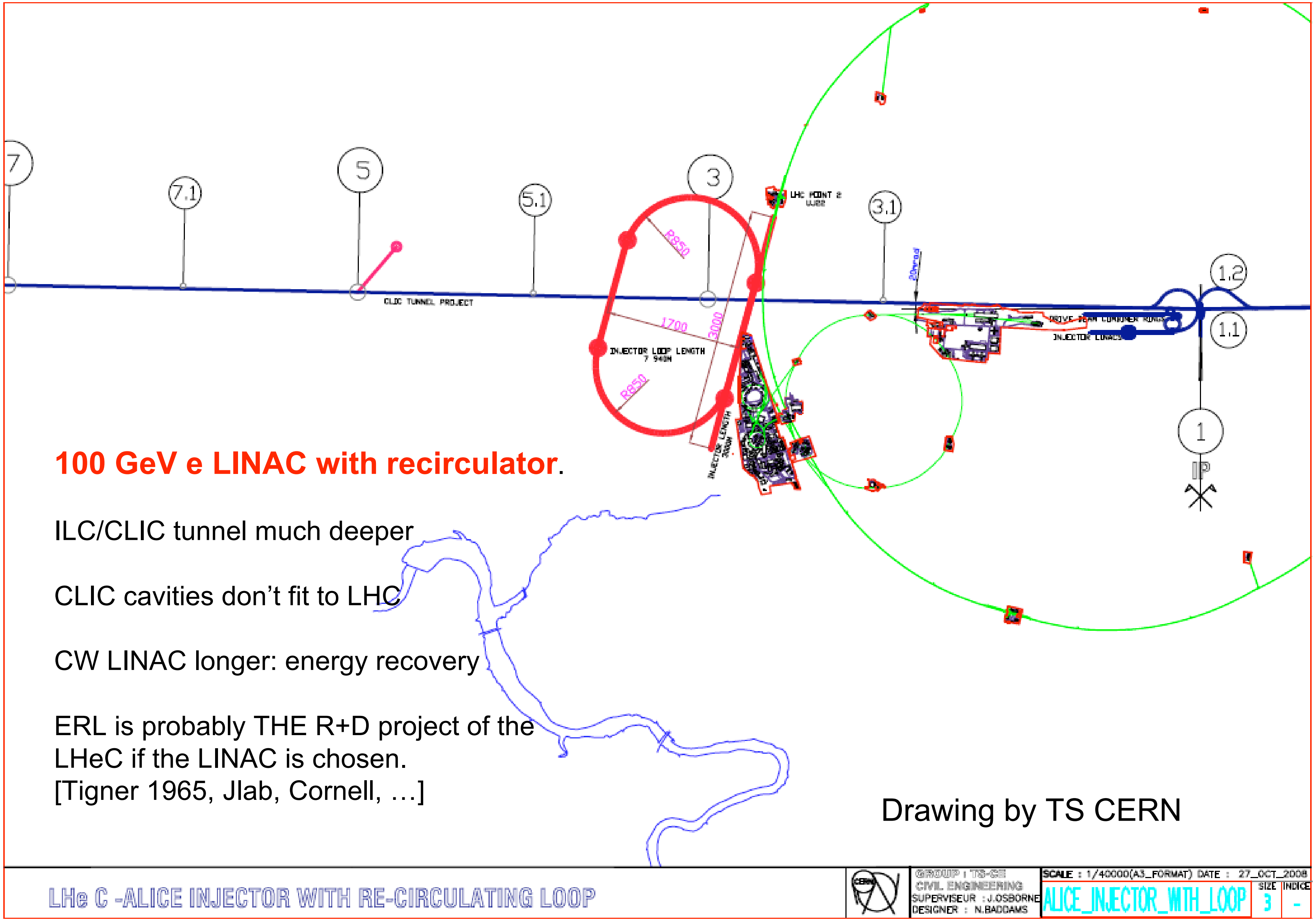
Note: positron source challenge:

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

		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

F.Zimmermann, S. Chattopadhyay



100 GeV e LINAC with recirculator.

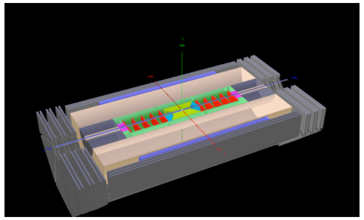
ILC/CLIC tunnel much deeper

CLIC cavities don't fit to LHC

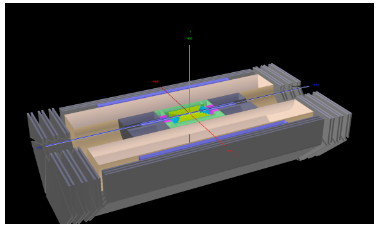
CW LINAC longer: energy recovery

ERL is probably THE R+D project of the LHeC if the LINAC is chosen.
[Tigner 1965, Jlab, Cornell, …]

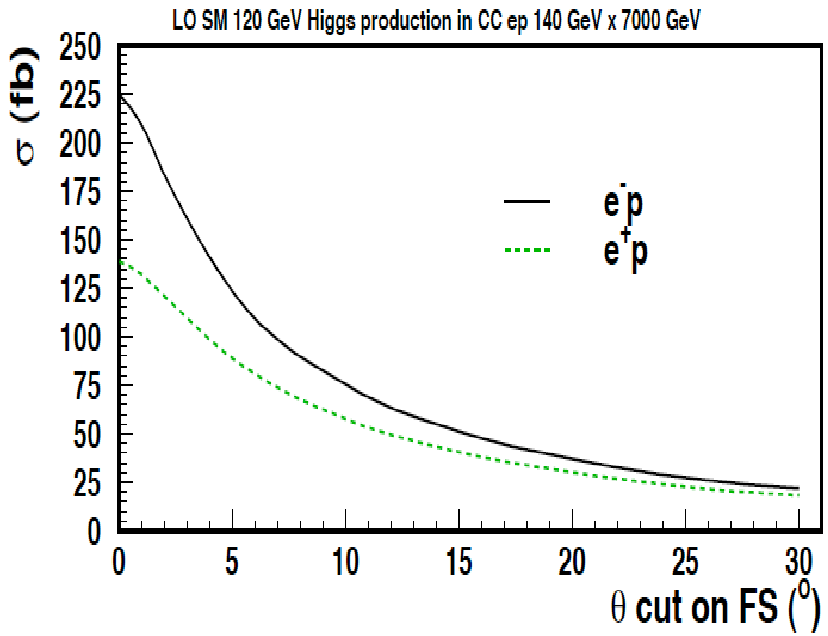
Drawing by TS CERN



Detector Design Considerations



Large fwd acceptance and high luminosity



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%

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)

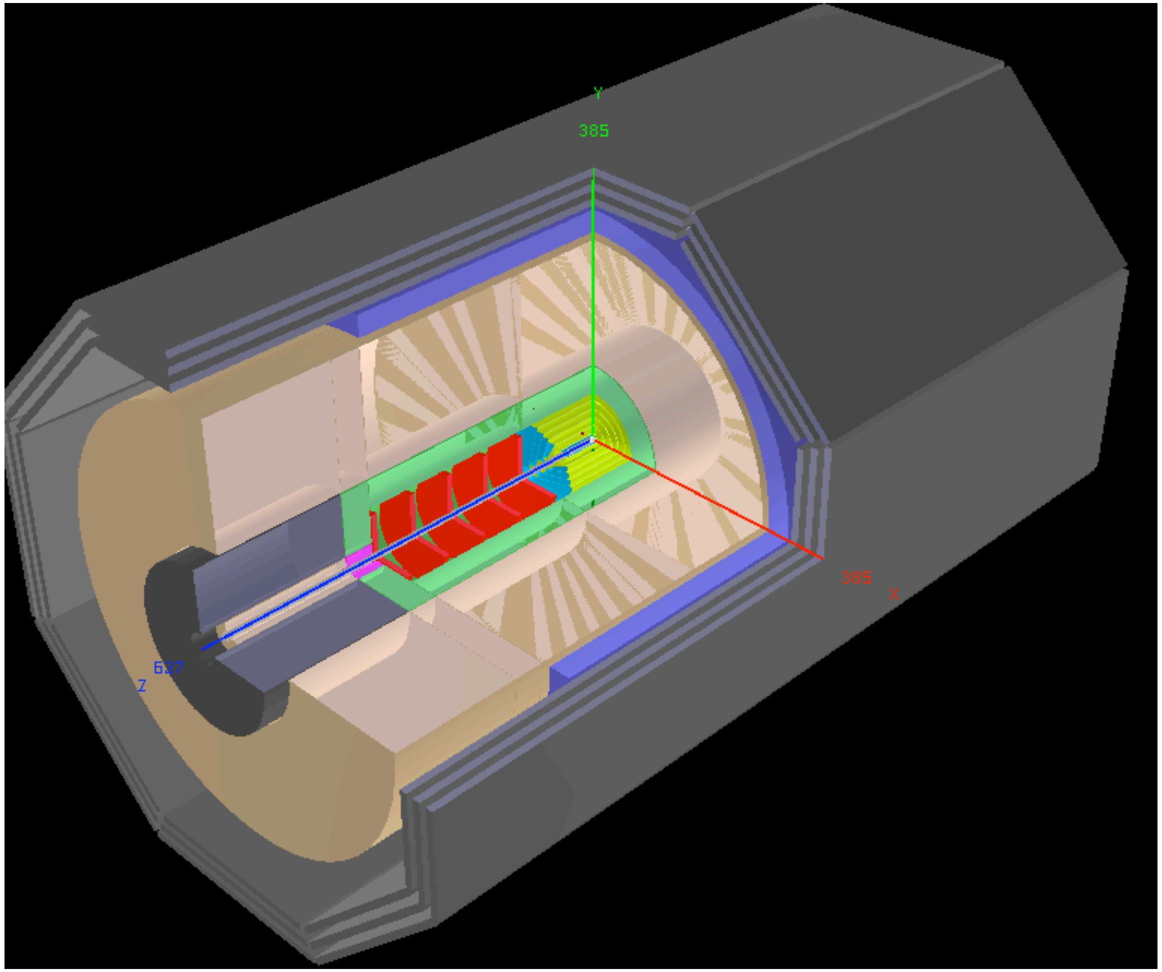
Fwd Spectrometer
(down to 1°)

Tracker
Calice (W/Si)
FwdHadrCalo

Bwd Spectrometer
(down to 179°)

Tracker
Spacal (elm, hadr)

L1 Detector: version for low x Physics



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

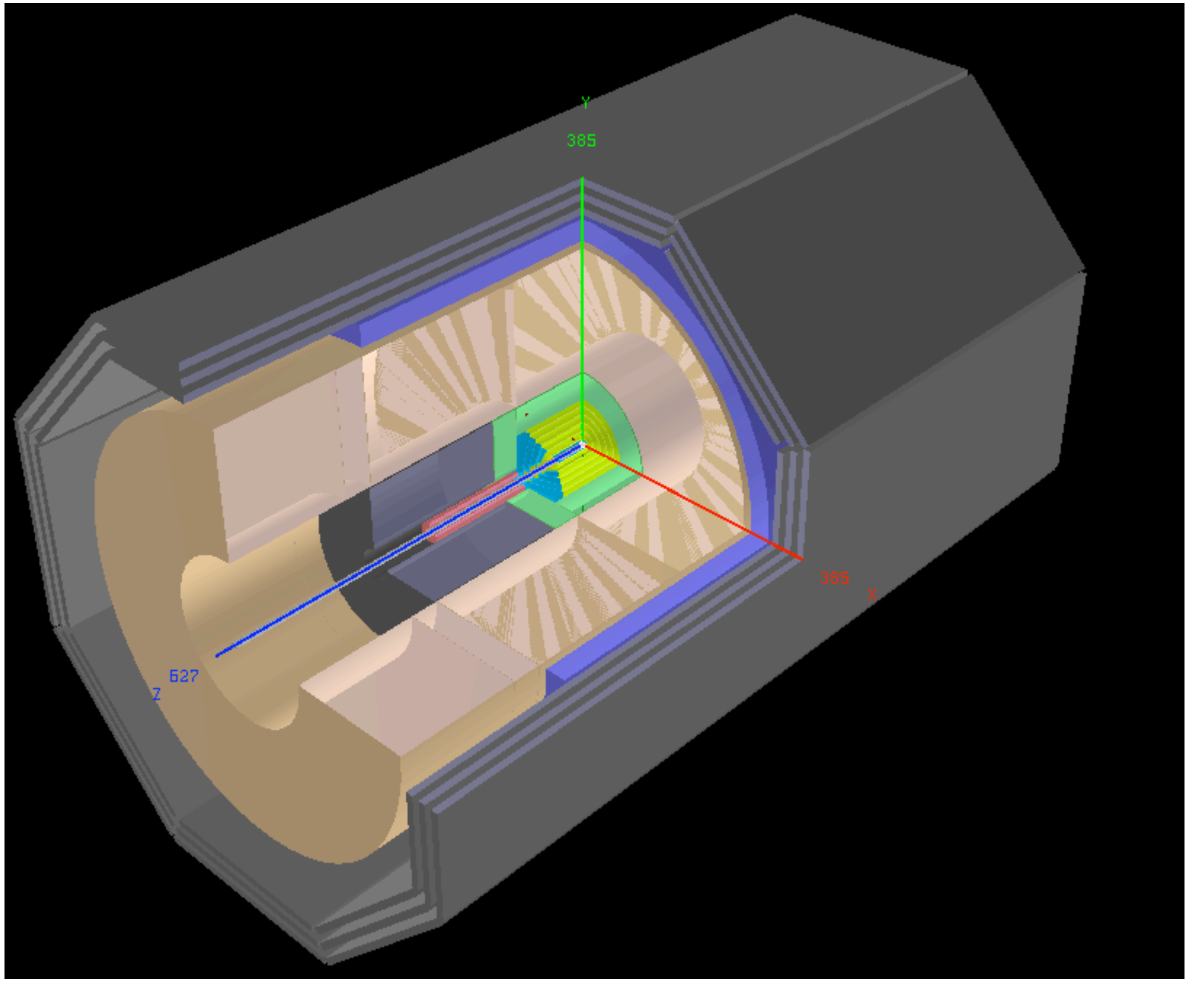
Hadronic Calo (Fe/LAr)
El.magn. Calo (Pb,Sc)
GOSSIP (fwd+central)
Pixels
Elliptic pipe (~3cm)

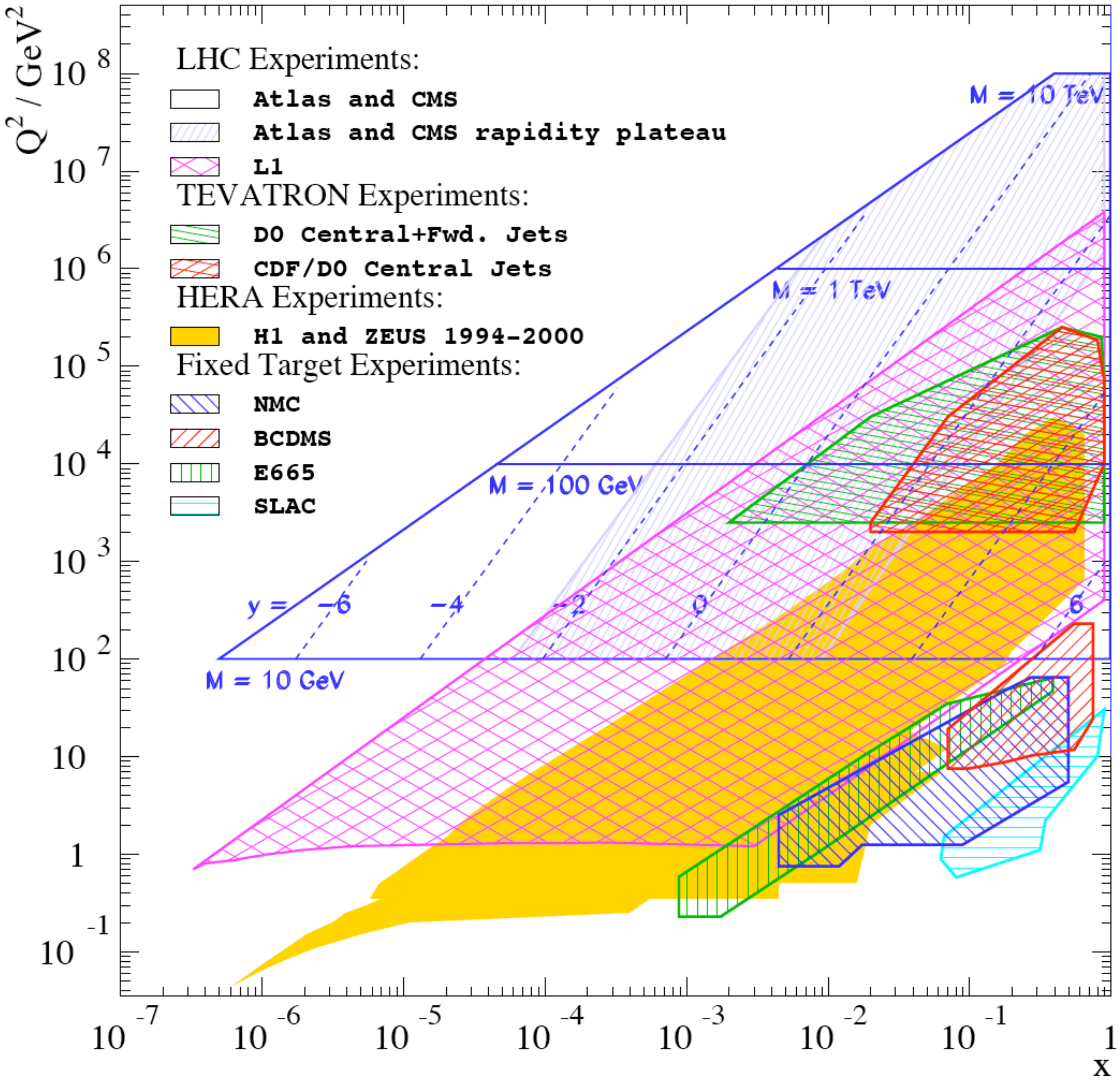
Fwd Calorimeter
(down to 10°)

Lepton low β magnets
FwdHadrCalo

Bwd Spectrometer
(down to 170°)

Lepton low β magnets
Spacal (elm, hadr)





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
Q^2 / GeV^2
x

Towards the CDR by 2009

ECFA + CERN in 11/07 set the task to work out a CDR within 2 years on the physics, machine and detector for a TeV energy ep collider based on the LHC

DIS workshops since 05,
EPAC08.
ECFA-CERN: Divonne - 9/08.

Scientific Advisory Committee

Guido Altarelli (Rome)
Stan Brodsky (SLAC)
Allen Caldwell -chair (MPI Munich)
Swapan Chattopadhyay (Cockcroft)
John Dainton (Liverpool)
John Ellis (CERN)
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Bernd Surrow	(MIT)
Katsuo Tokushuku	(KEK)
Urs Wiedemann	(CERN)

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)