The LHeC Conceptual Design

Max Klein - University of Liverpool

A status report on behalf of the LHeC Study Group

2007 CERN SPC and [r]ECFA
2008 Divonne I, ICFA,ECFA
2009 Divonne II, NuPECC, ECFA

2010 Divonne III (28.-30.10.), ECFA
→ Conceptual Design Report

CERN Science Policy Committee 14.6.2010

http://cern.ch/lhec

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Accelerator Design [RR and LR]
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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
George Azuelos (Montreal)
Emmanuelle Perez (CERN),
Georg Weiglein (Durham)

Precision QCD and Electroweak
Olaf Behnke (DESY),
Paolo Gambino (Torino),
Thomas Gehrmann (Zuerich)
Claire Gwenlan (Oxford)

Physics at High Parton Densities
Nestor Armesto (Santiago),
Brian Cole (Columbia),
Paul Newman (Birmingham),
Anna Stasto (MSU)

“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

LEP*LHC (1984, 1990) - Lausanne, Aachen
E.Keil LHC project report 93 (1997)
Thera (2001),
QCD explorer (2003)
J.Dainton et al, 2006 JINST 1 10001

LHeC at DIS conferences since Madison 2005

Outline

Basic Project Considerations

Precision QCD and Electroweak Physics

New Physics with the LHeC and the LHC

High Density Matter (Low x and eA)

Detector Design

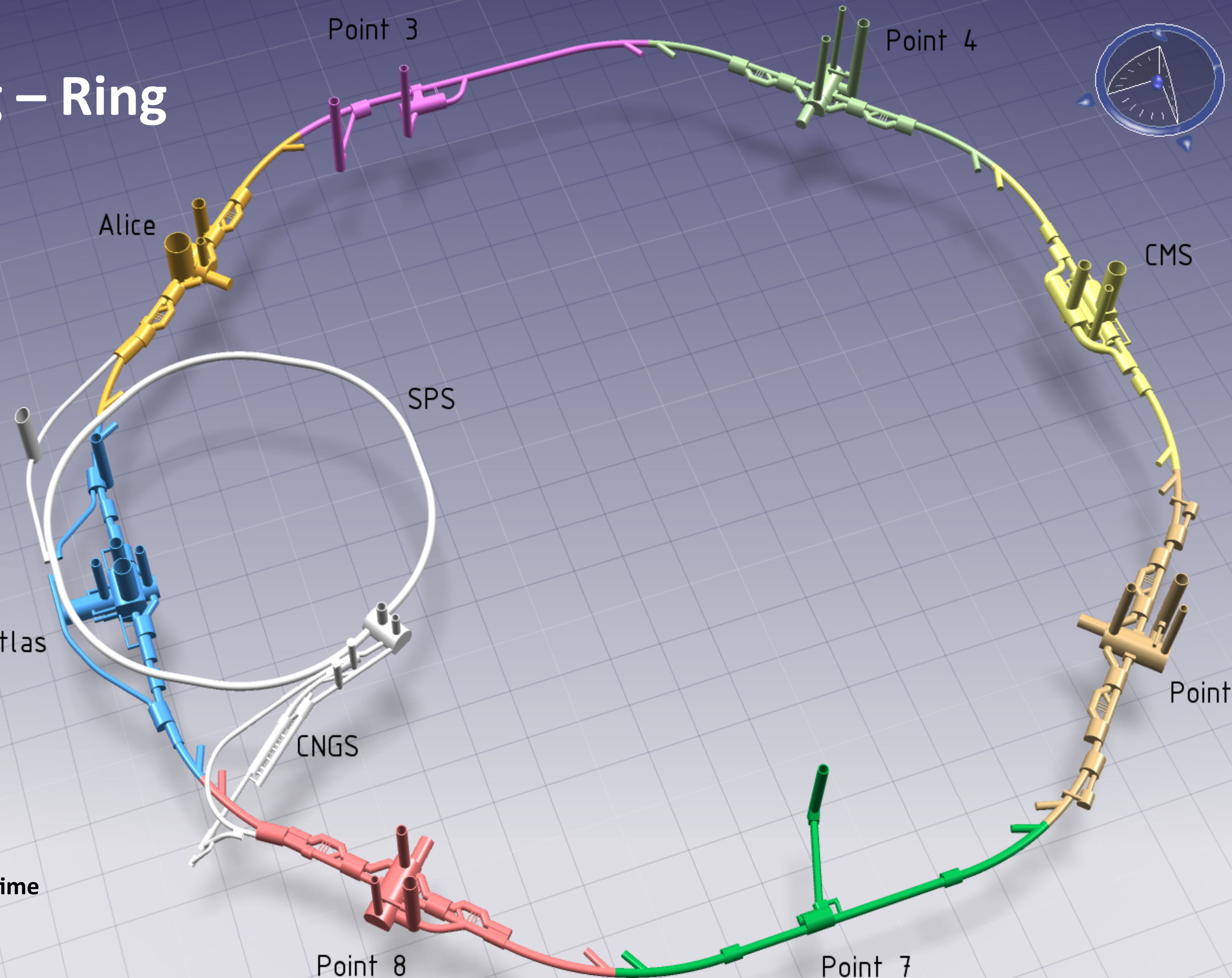
Accelerator: Ring-Ring

Accelerator: LINAC-Ring

Concluding Remarks

Please note: ALL plots and results are preliminary and being (re)done for the CDR

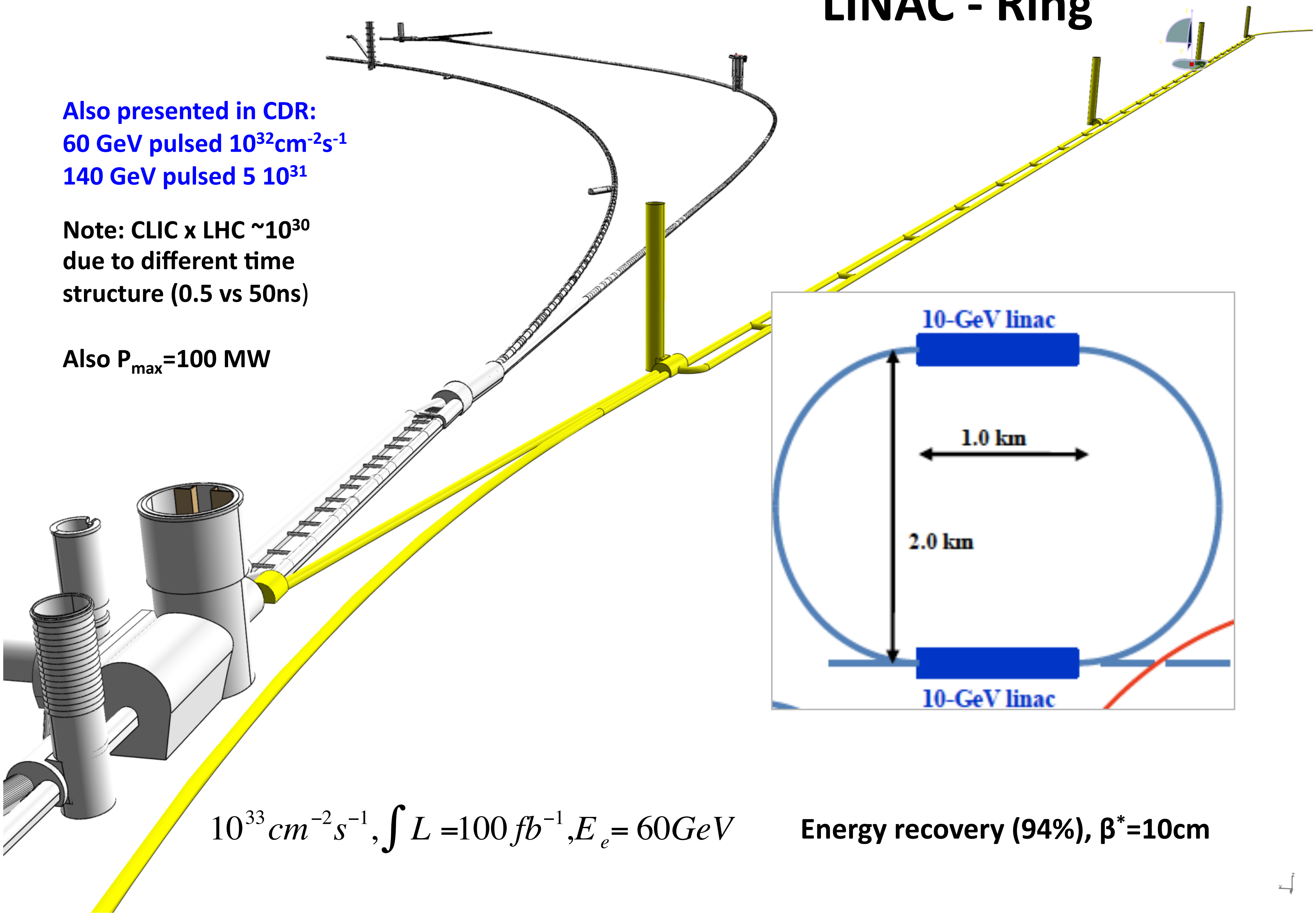
Ring – Ring



Dedicated injector
10 GeV
2 10^{10}e
(LEP: 4 10^{11})
~10 min filling time

$10^{33} cm^{-2} s^{-1}, \int L = 100 fb^{-1}, E_e = 60 GeV$ **100 times HERA luminosity, 50-100 times Q^2 and 1/x**

LINAC - Ring



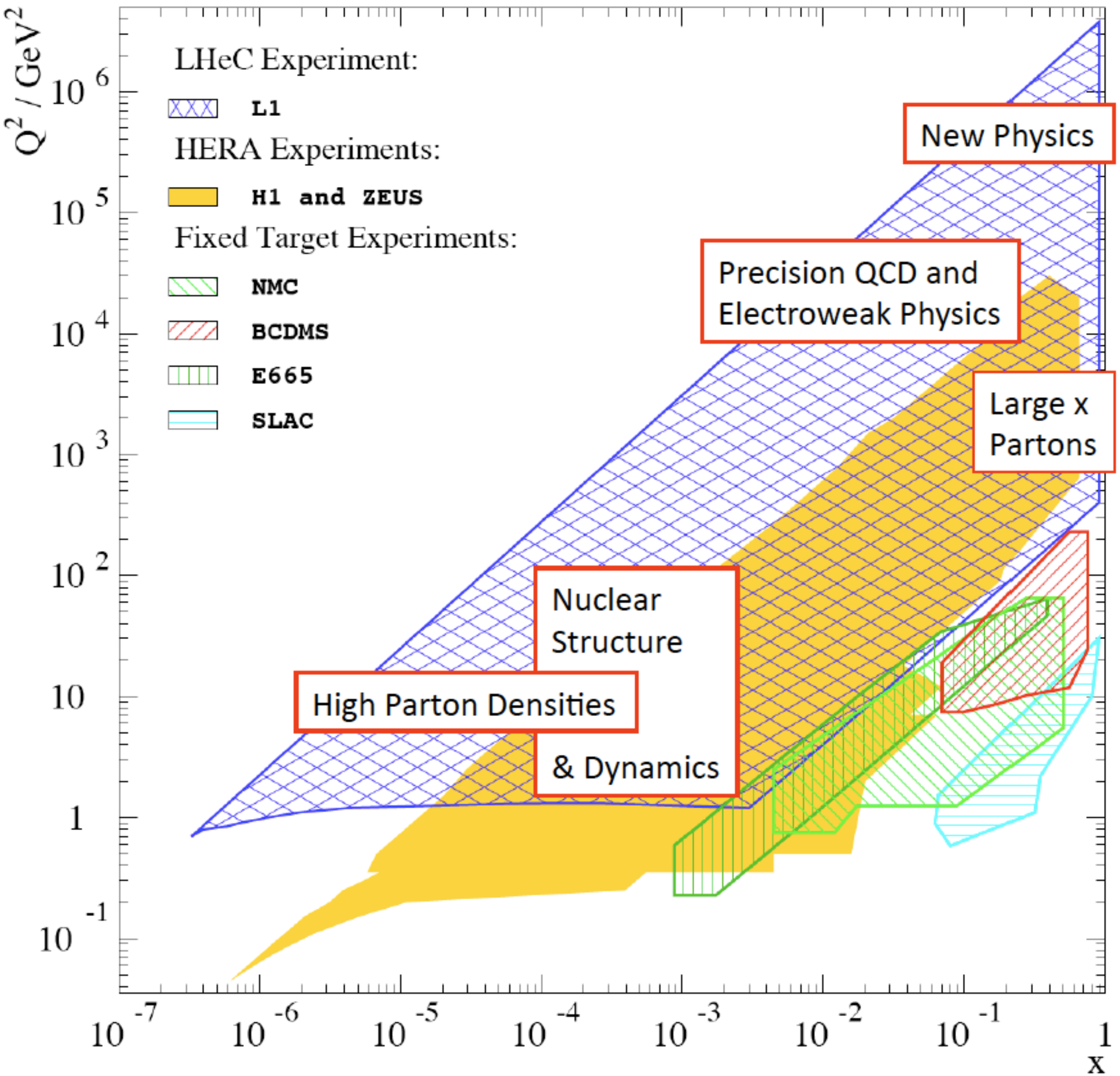
Also presented in CDR:
60 GeV pulsed $10^{32} cm^{-2} s^{-1}$
140 GeV pulsed $5\ 10^{31}$

Note: CLIC x LHC ~10^{30}
due to different time
structure (0.5 vs 50ns)

Also P_{max}=100 MW

$$10^{33} cm^{-2} s^{-1}, \int L = 100\, fb^{-1}, E_e = 60 GeV$$

Energy recovery (94%), β^*=10cm



LHeC Experiment:
L1
HERA Experiments:
H1 and ZEUS
Fixed Target Experiments:
NMC
BCDMS
E665
SLAC
New Physics
Precision QCD and Electroweak Physics
Large x Partons
Nuclear Structure
High Parton Densities
& Dynamics
Q^2 / GeV^2
x

HERA - an unfinished programme

Low x: DGLAP seems to hold though ln1/x is large
Gluon Saturation not proven

High x: would have required much higher luminosity
[u/d ?, xg ?]

Neutron structure not explored

Nuclear structure not explored

New concepts introduced, investigation just started:
-parton amplitudes (GPD's, proton hologram)
-diffractive partons
-unintegrated partons

Instantons not observed

Odderons not found
...

Fermions still pointlike
Lepton-quark states (as in RPV SUSY) not observed

*) For an experimental review see:
M.Klein, R.Yoshida, **"Collider Physics at HERA"**
arXiv 0805.3334, Prog.Part.Nucl.Phys.61,343(2008)
HERA II analysis still ongoing

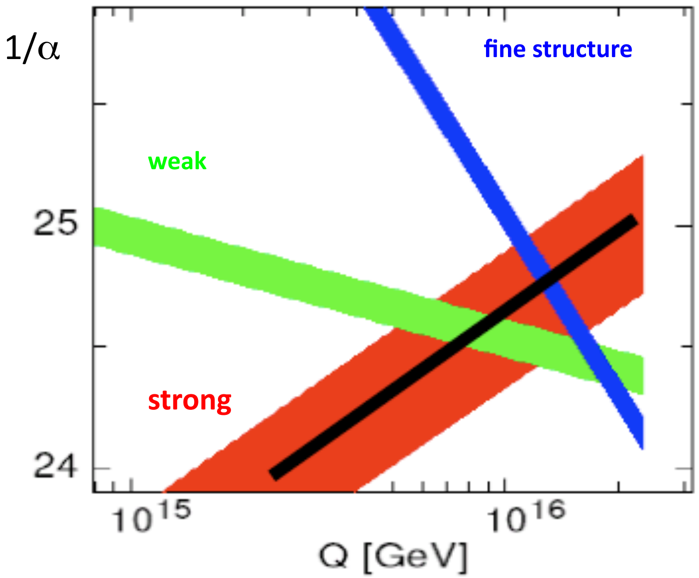
Precision QCD and Electroweak Physics

Based on weak = electromagnetic cross sections, p, d, $e^{\pm}$, P_e and high precision and full acceptance

Structure functions [F_2, F_L, xF_3^{gZ}, F_2^{gZ}; F_2^{cc}, F_2^{bb}, F_2^{ss}] in p/d and A
Quark distributions from direct measurements and QCD fits
Strong coupling constant α_s to per mille accuracy
Gluon distribution in full x range to unprecedented precision
Standard Model Higgs
Single top and anti-top quark production at high rate (5pb)
Electroweak couplings (light and heavy quarks and mixing angle)
Heavy quark fragmentation functions
Charm and beauty below and way beyond threshold at per cent accuracy
Heavy quarks in real photon-proton collisions [LR option]
Jets and QCD in photoproduction and DIS
Gluon structure of the photon
....

Strong Coupling Constant

Simulation of α_s measurement at LHeC



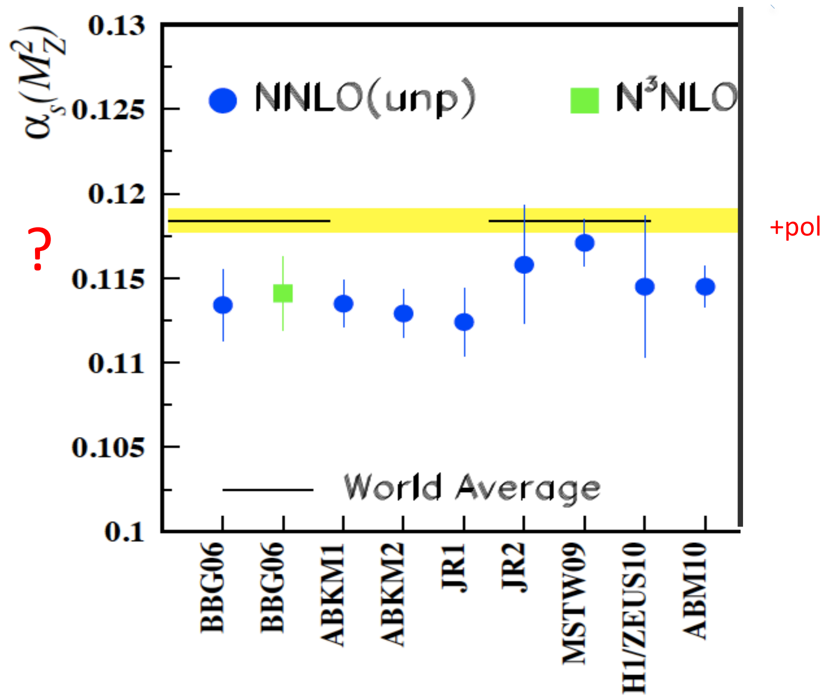
MSSM - B.Allnach et al, hep-ex/0403133

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%

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

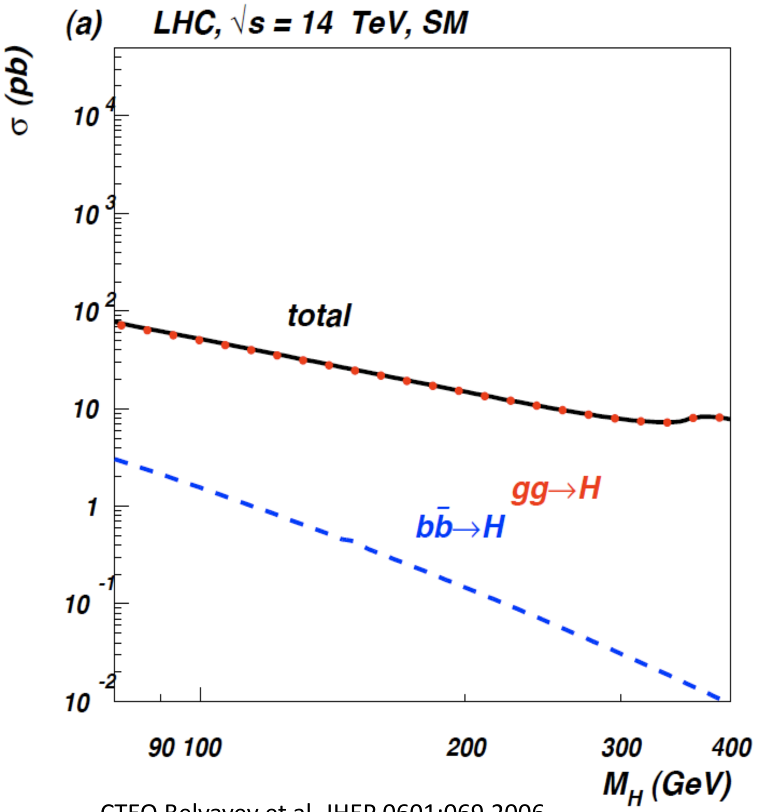
DIS tends to be lower than world average

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

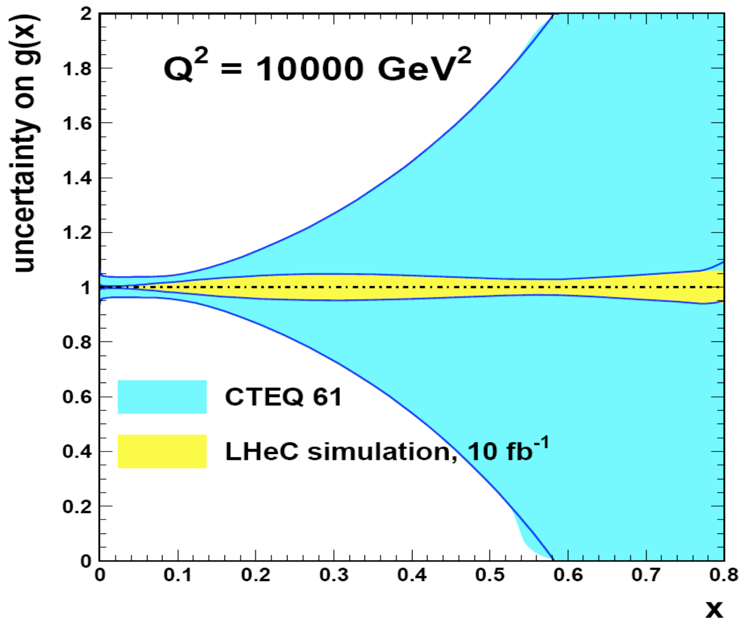


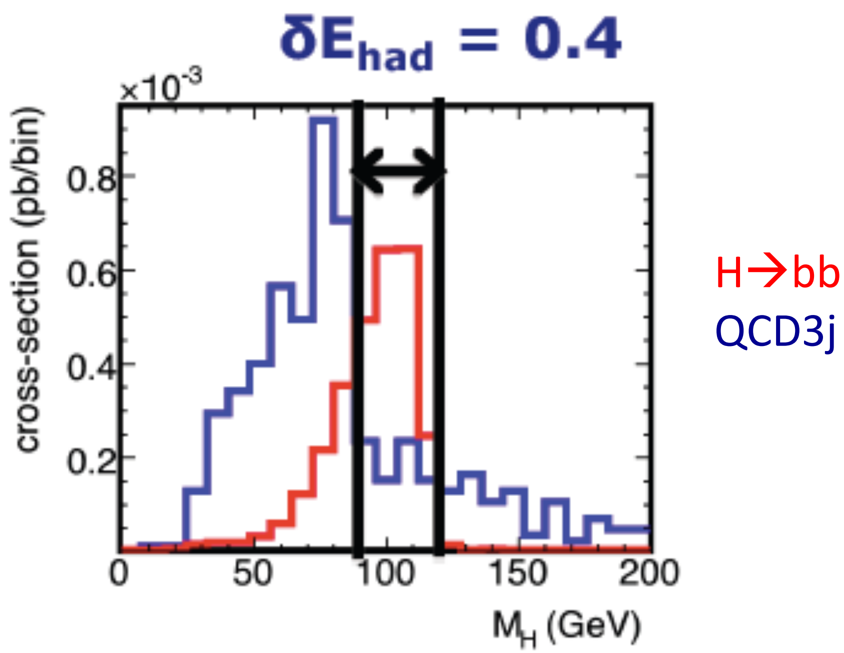
J.Bluemlein and H. Boettcher, arXiv 1005.3013 (2010)

Gluon - SM Higgs



CTEQ Belyayev et al. JHEP 0601:069,2006



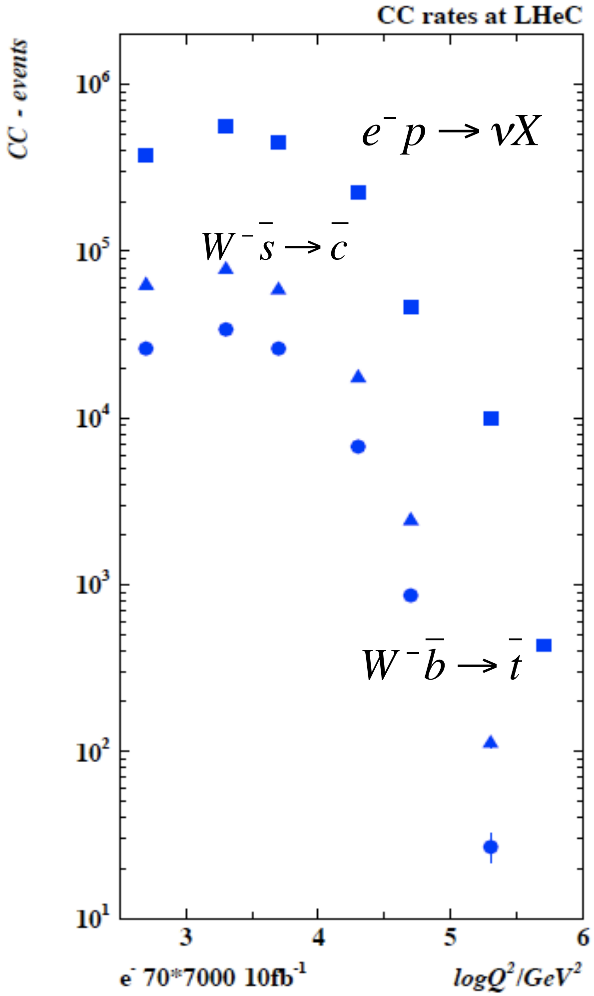


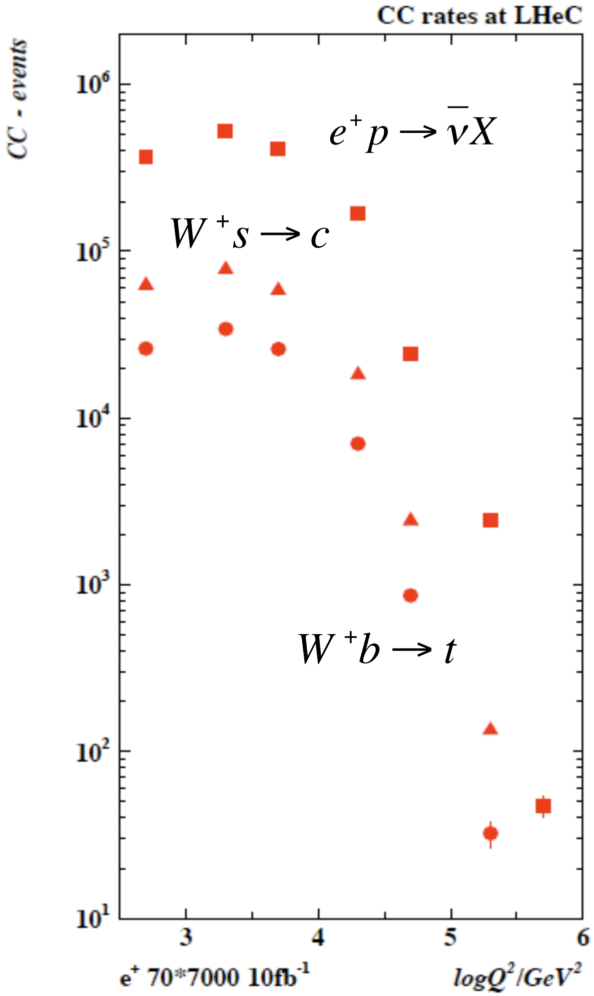
In SM Higgs production is gluon dominated

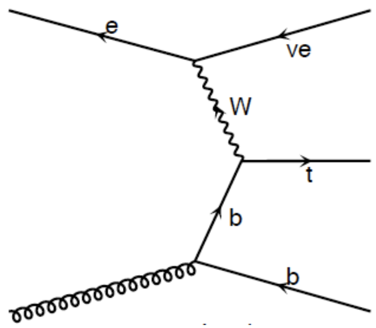
LHeC: huge x,Q^2 range for xg determination

WW to Higgs fusion has sizeable ep xsection

Single top and anti-top Production in charged currents





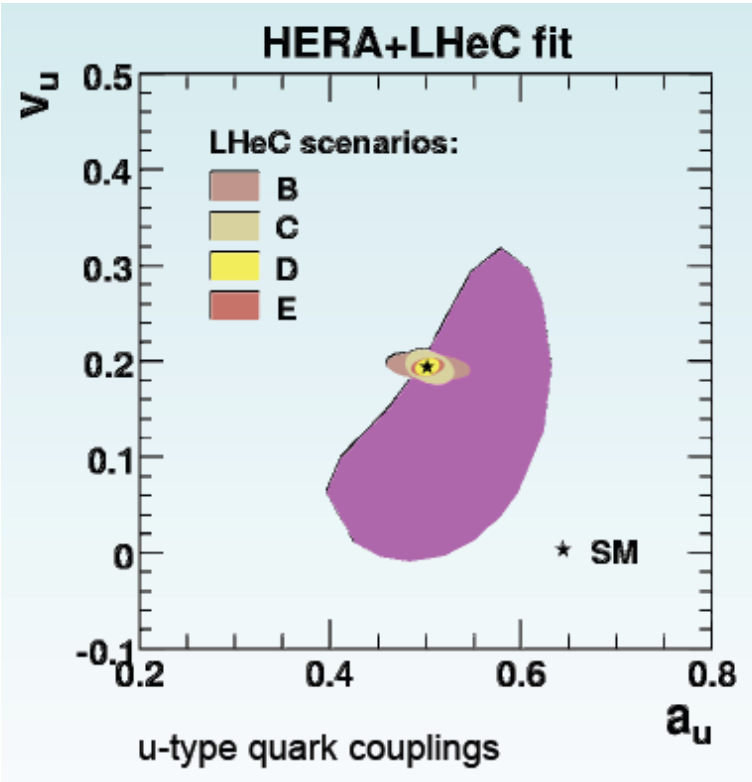


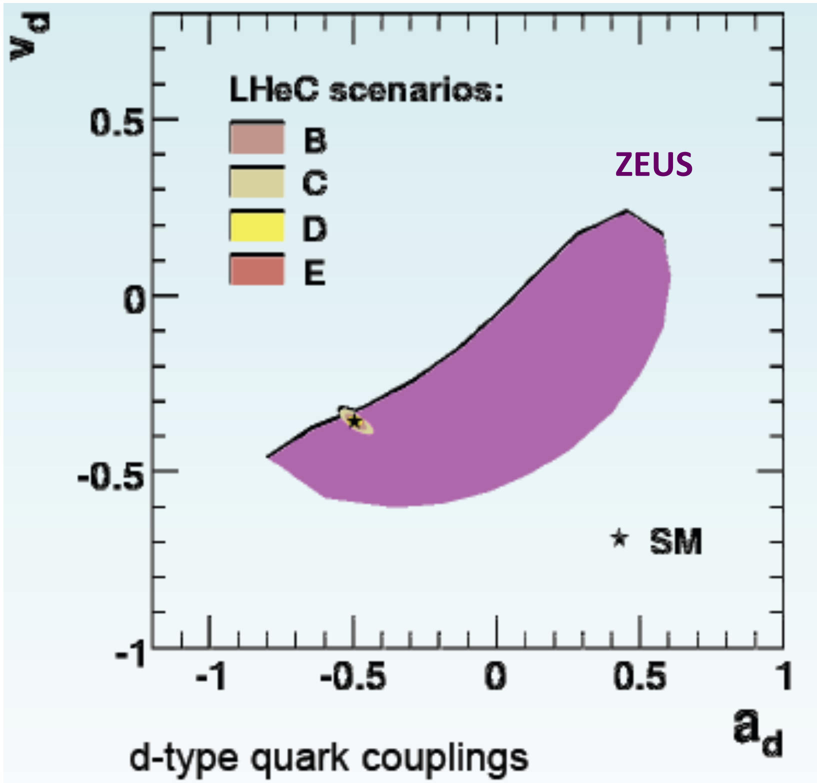
LHeC is a single top and single tbar quark `factory'

CC t cross section O(5)pb

CC events for 10 fb^{-1}

Electroweak Couplings





CDF: qq' → e+e- (Drell-Yan), A_{FB}

Phys.Rev. D71 (2005) 052002, hep-ex/0411059

LEP/SLC: ee→qq(γ), $a^2_q+v^2_q$

Phys.Rept.427:257,2006, hep-ex/0509008

For H1, CDF, LEP cf Z.Zhang DIS10

Physics Beyond the Standard Model

Based on high energy, luminosity, $e^{\pm}$,P_e and high precision and full acceptance

Lepto-Quarks [E6, bound states of technifermions, squarks decaying by RP violation..]
Contact Interactions [new physics at multiTev scale]
Excited Fermions
Higgs in SM and MSSM (in SM chapter)
Heavy Leptons
4th generation quarks
Z'
SUSY
…

New Physics at the LHeC

Divonne 08

- **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**

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

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

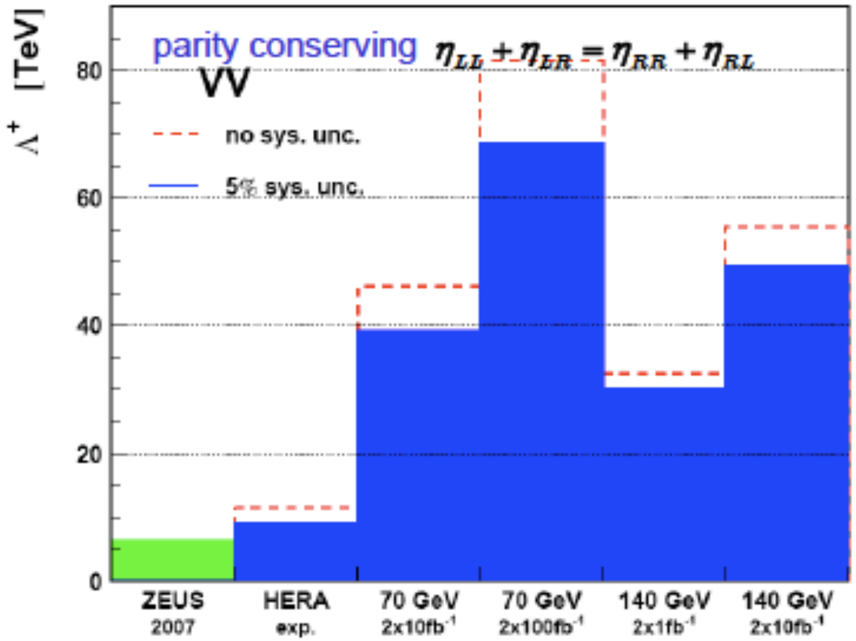
J.Bartels: Theory on low x

Contact Interactions

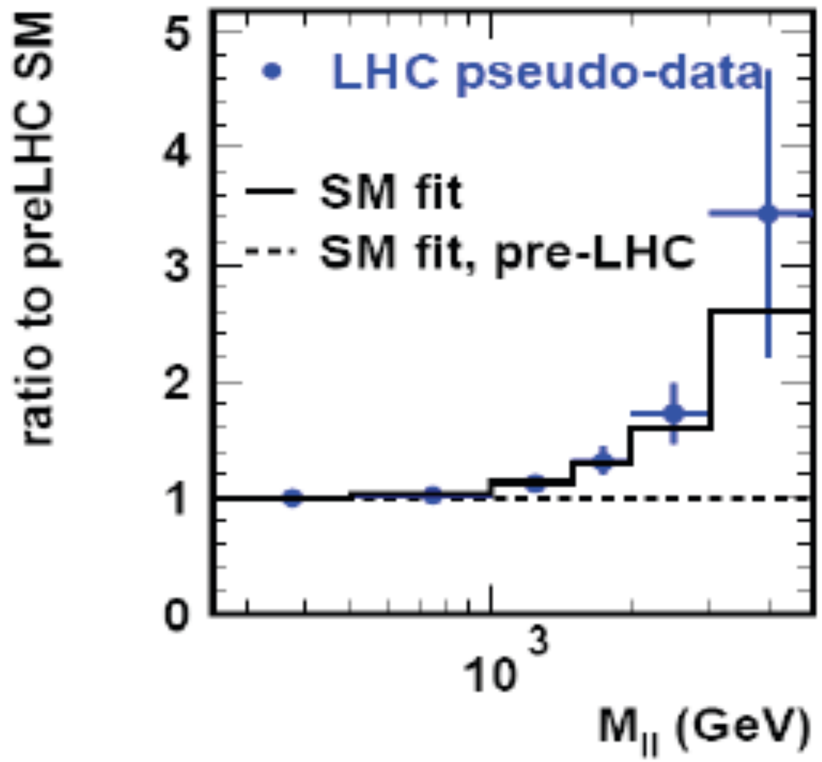
$$\mathcal{L} = \frac{4\pi}{2\Lambda^2} j_\mu^{(e)} j^{\mu(q)};$$

$$j_\mu^{(f=e,q)} = \eta_L \, \bar{f}_L \gamma_\mu f_L + \eta_R \, \bar{f}_R \gamma_\mu f_R + h.c.$$

$\Rightarrow$ all combinations of couplings $\eta_{ij} = \eta_i^{(e)} \eta_j^{(q)}$; $\quad q = u, d$

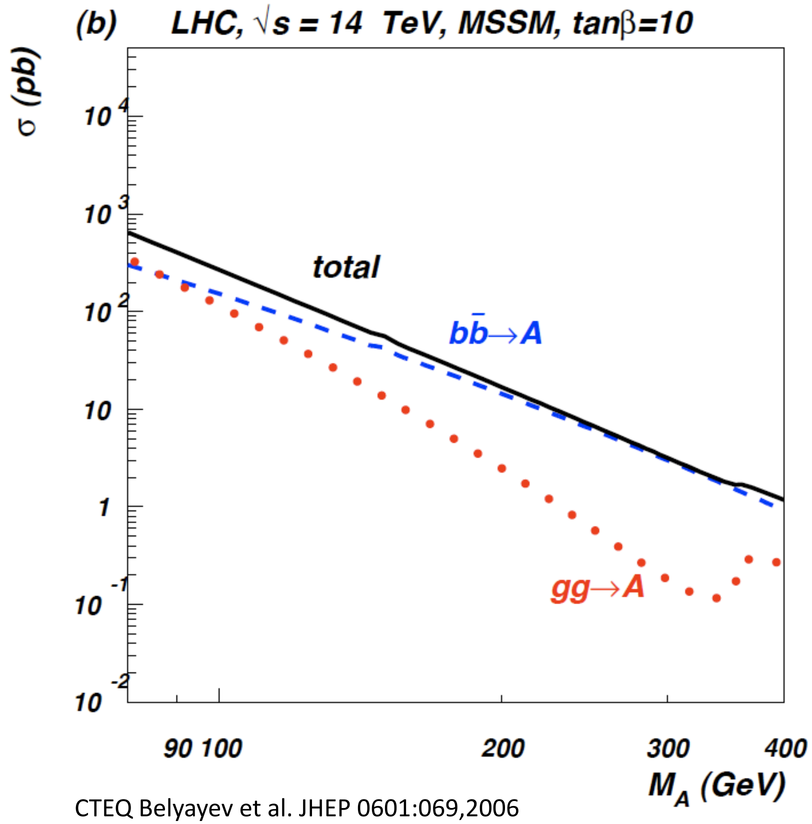


High luminosity vs high energy



CI study:
LHeC freezes the pdfs which allows new physics to be revealed.
HERA+BCDMS reshuffle the sea...

Beauty - MSSM Higgs

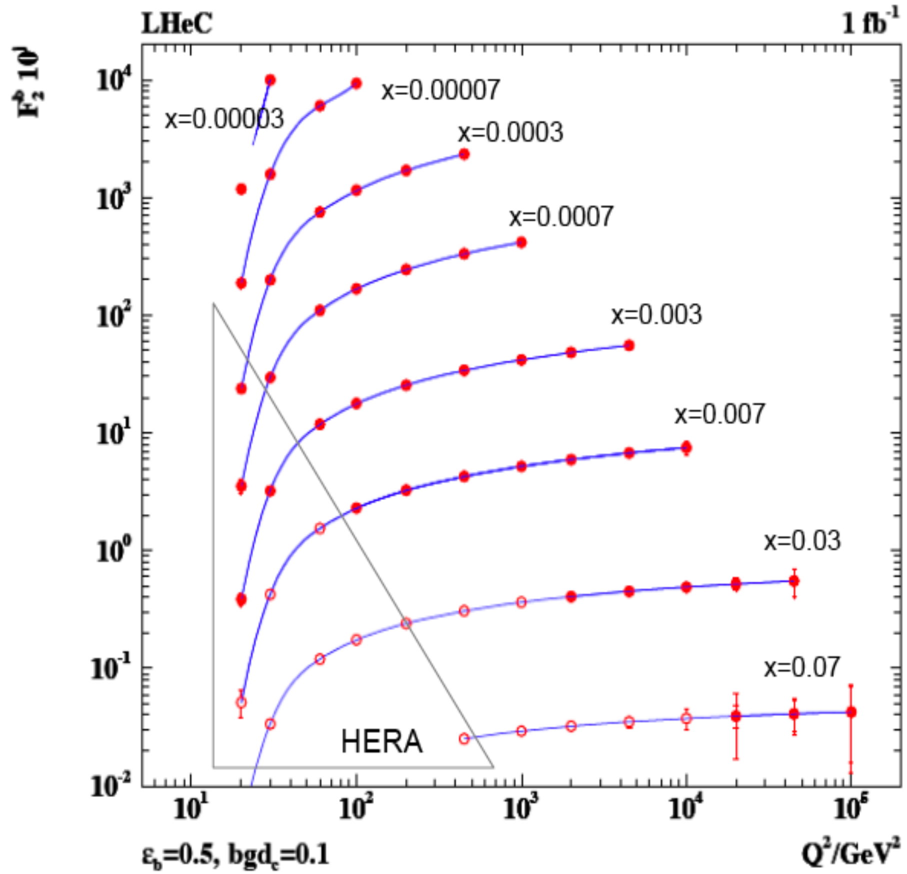


CTEQ Belyayev et al. JHEP 0601:069,2006

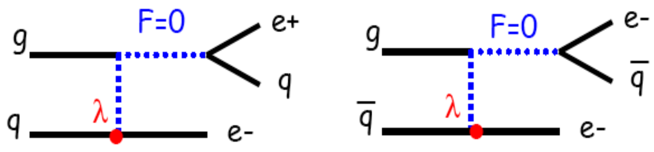
In MSSM Higgs production is b dominated

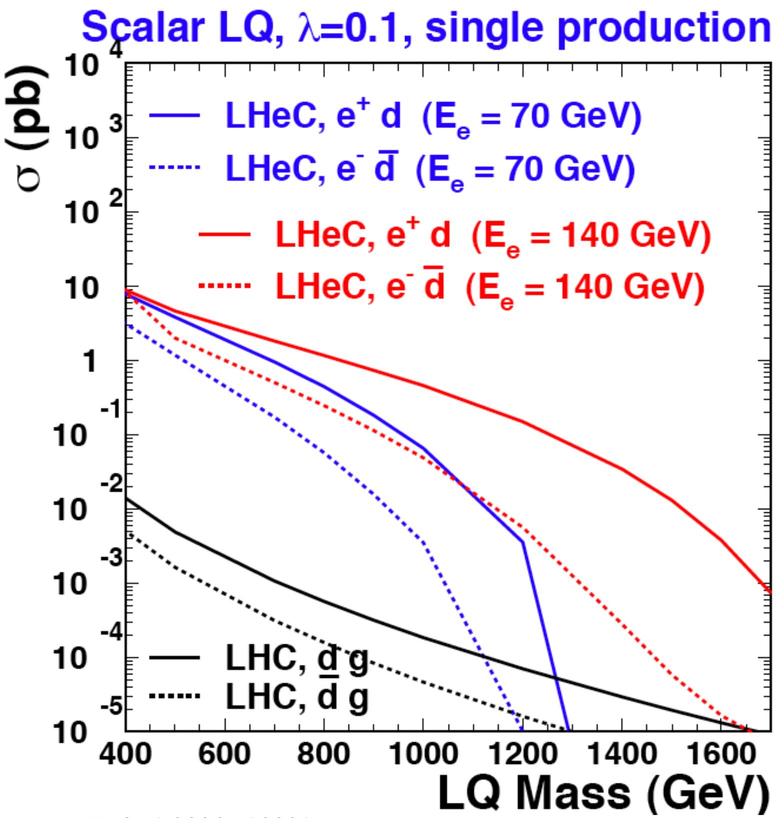
First measurements of b at HERA can be turned to precision measurement of b-df.

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

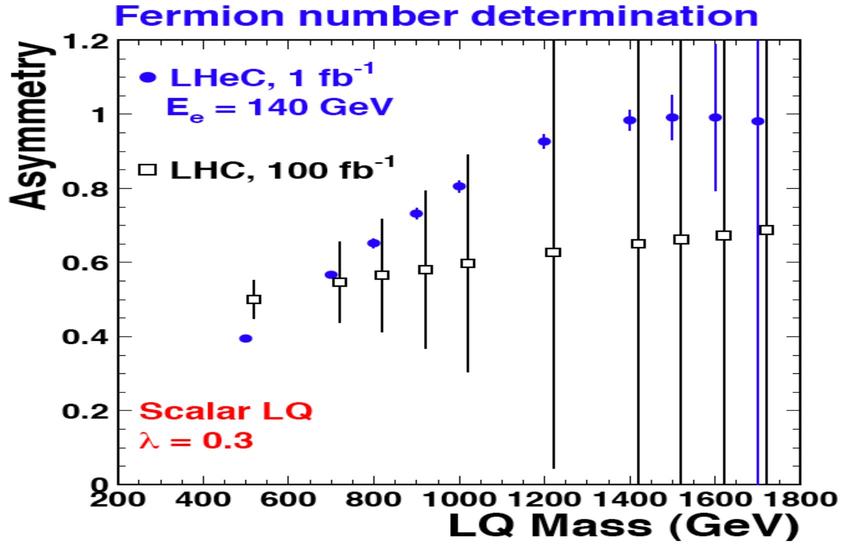


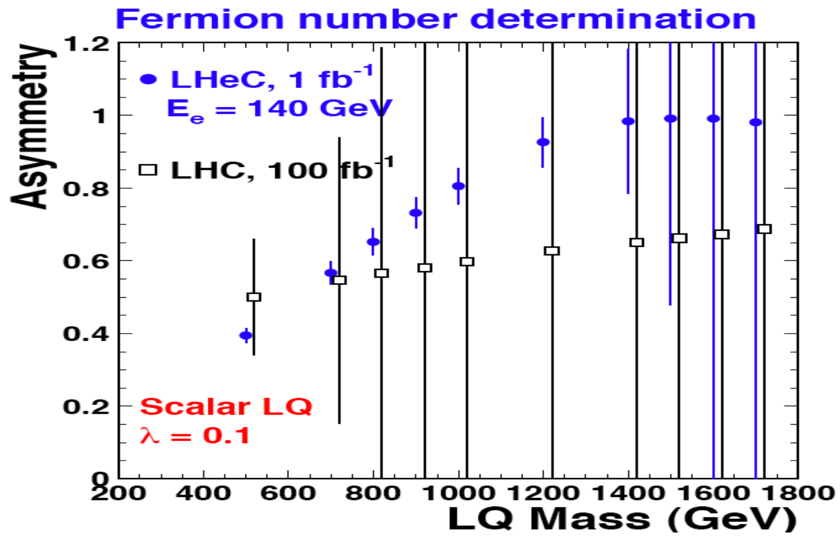
LQ Quantum Numbers





JINST 1 2006 P10001





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

Surprises and Theory

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?

Tbilissi 76

Things may evolve differently than we think, but we may rely on the ingenuity of our theory colleagues to deal with the unexpected.

Design a maximum energy, high luminosity, affordable **collider**

$E^+ \rightarrow e^+ g$

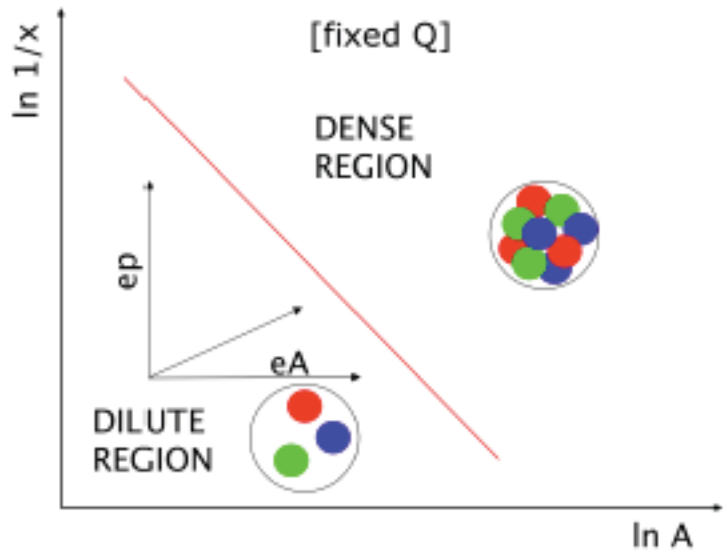
S.Adler, arXiv:hep-th/9610104

In summary, we suggest that the production and decay of the excess HERA events, interpreted as leptogluons, could be accounted for in our model when augmented by either the assumption that the Z_6 condensate that breaks $SU(4)$ to color $SU(3)$ contains a small component that further breaks color $SU(3)$ to glow $SO(3)$, or by the assumption that color symmetry remains exact but that color neutralization is incomplete in hard processes.

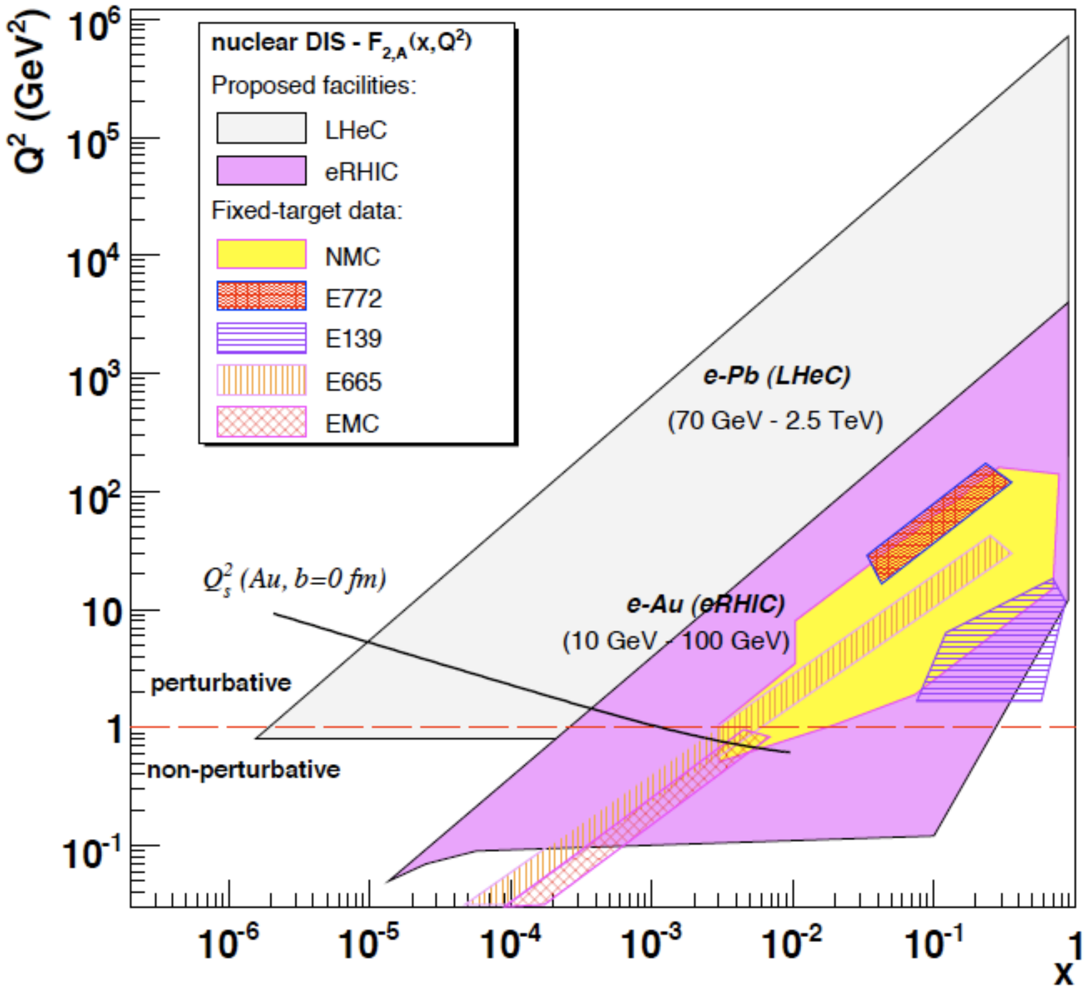
Low x Physics: non-linear parton evolution (ep/eA)

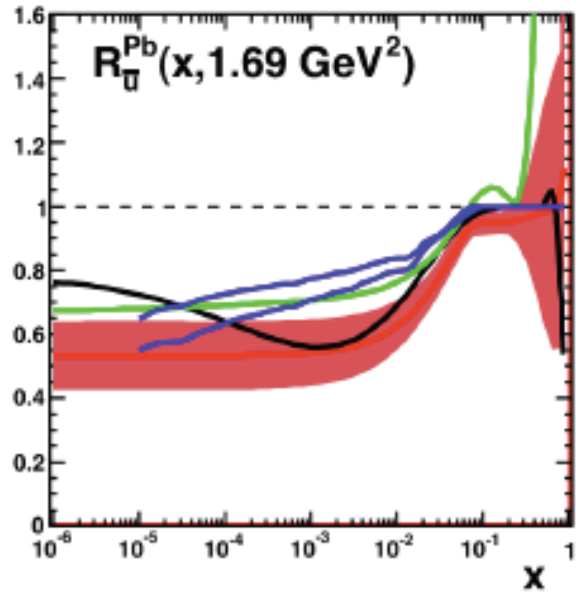
Based on p/A [$e^{\pm}$,P_e] and high precision and full acceptance in forward and backward region

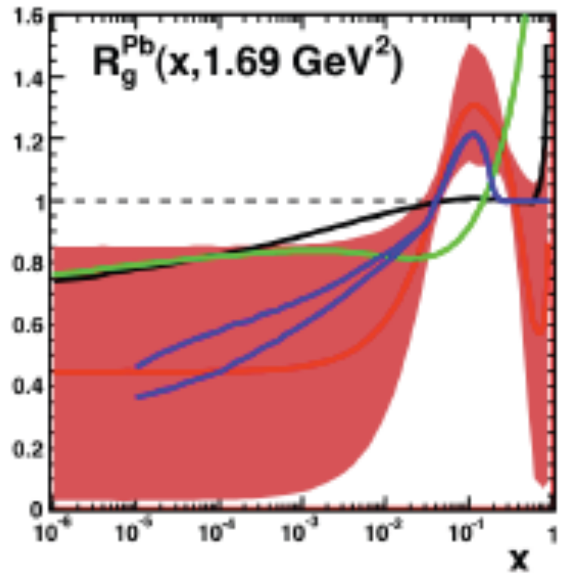
Unitarity and QCD
Expectations from LHC
DIS on nuclei
New physics at low x
Diffraction
Vector Mesons
Deeply Virtual Compton Scattering
Jets and Parton Dynamics
Forward jets and parton emission
Initial QGP [AA-eA]
UHE Neutrino Scattering and LHeC



eA → eX



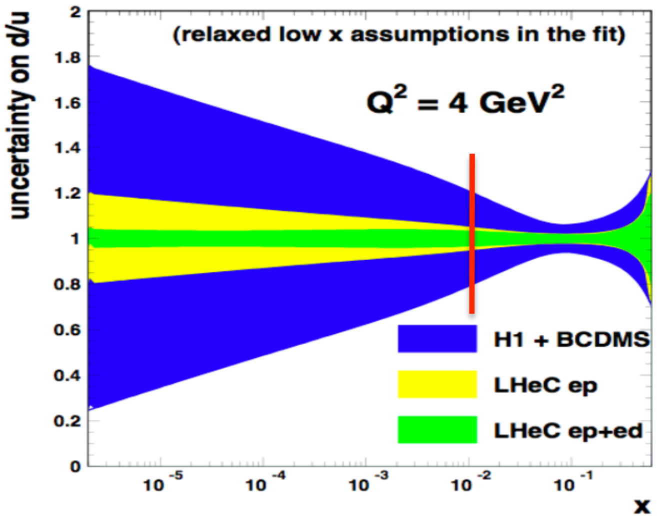




Extension of kinematic range by 3-4 orders of magnitude into saturation region (with p and A)
Like LHeC ep without HERA.. (e.g. heavy quarks in A)

Rich Neutron Physics from eD

d/u at low x from deuterons

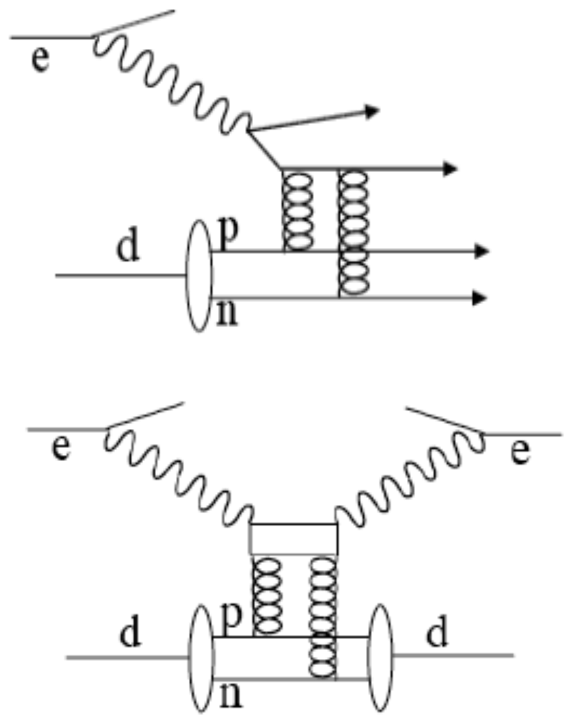


Neutron structure unknown in HERA range and below, yet crucial to resolve its partonic structure and to predict scattering on nucleons. Stabilizes QCD evolution (singlet – non singlet parts!)

Collider eD: low x: diffraction-shadowing,
high : tag p spectator to en interaction

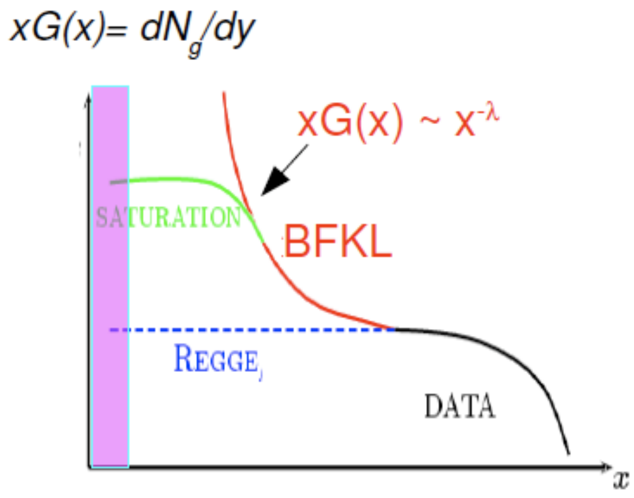
(13) There are five color-singlet combinations of the deuteron wavefunction in QCD, only one of which is the standard proton-neutron state. The "hidden color" [13] components will lead to high multiplicity final states in deep inelastic electron-deuteron scattering.

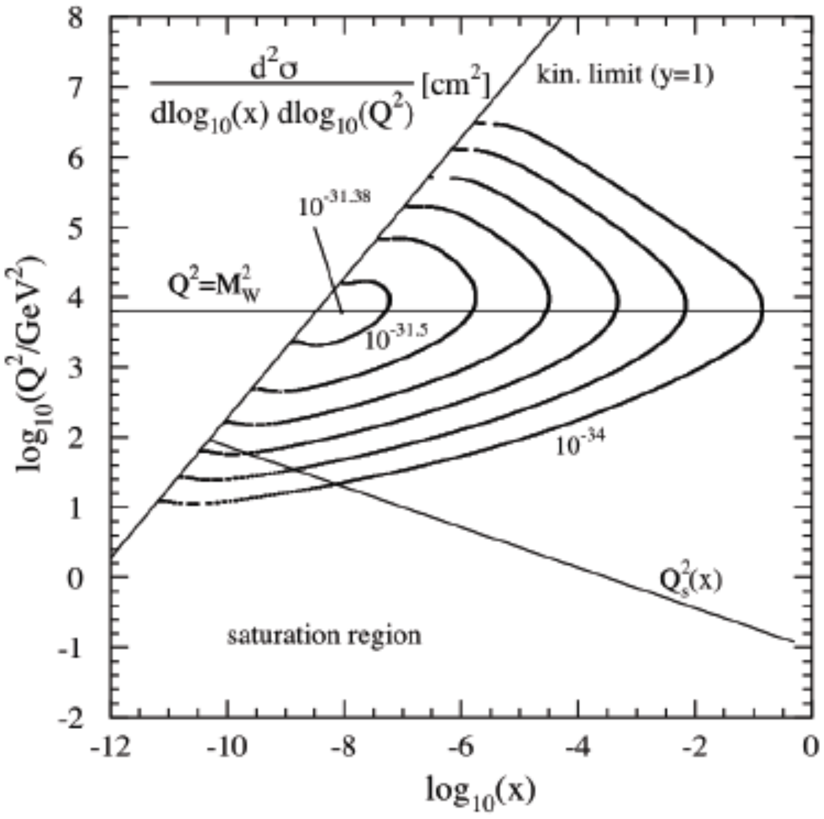
Brodsky

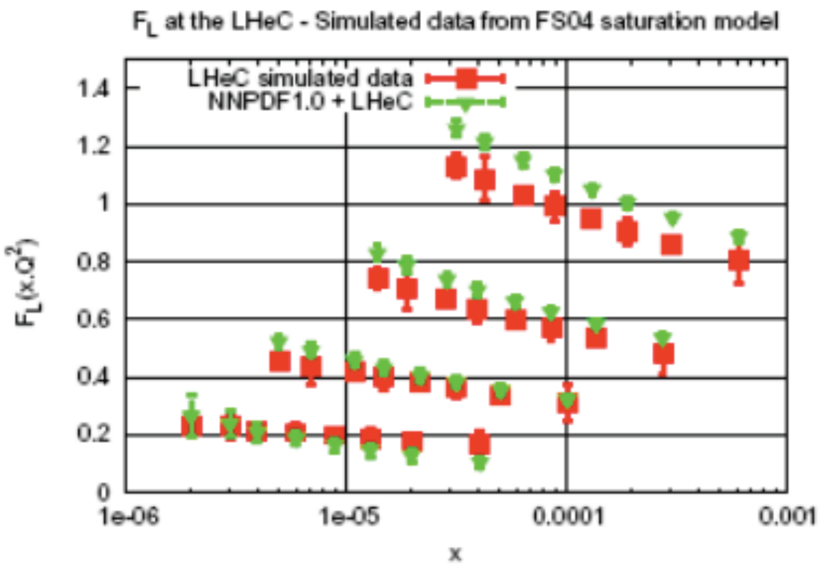


In eA at the collider, test Gribovs relation between shadowing and diffraction, control nuclear effects at low Bjorken x to high accuracy

Saturation of Gluon Density



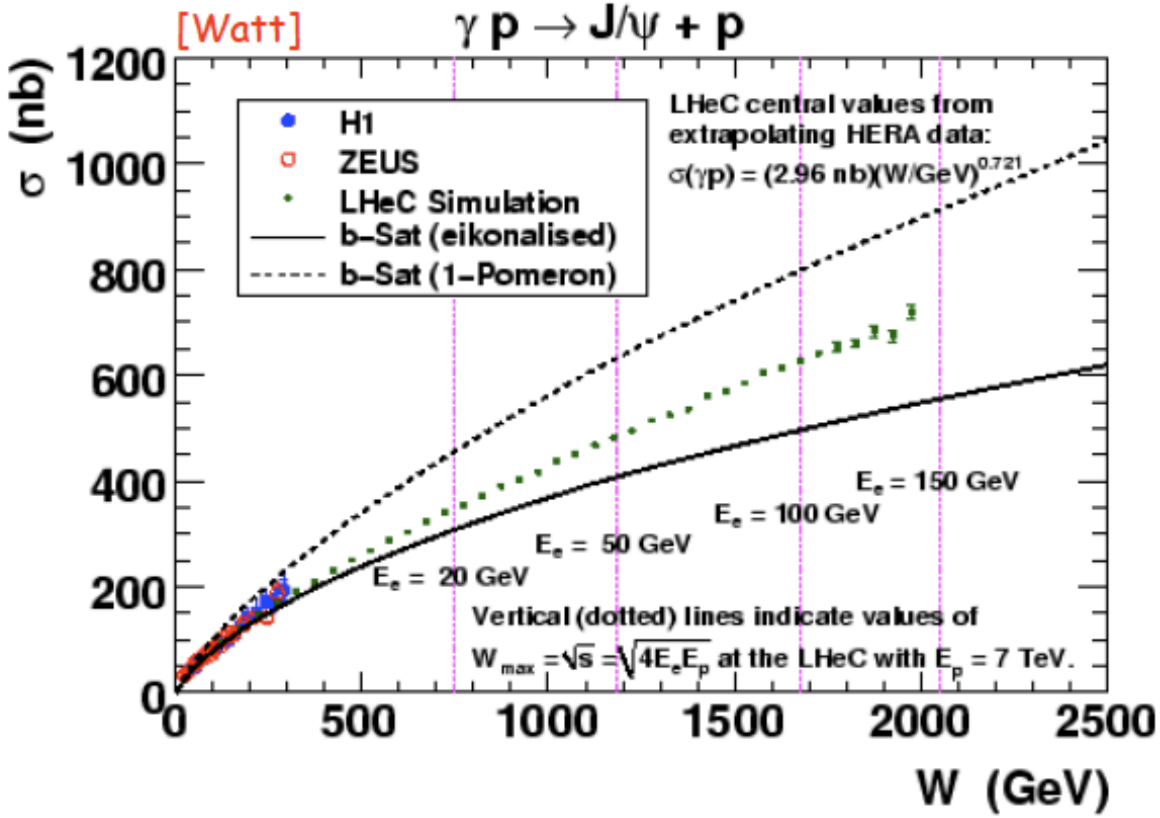


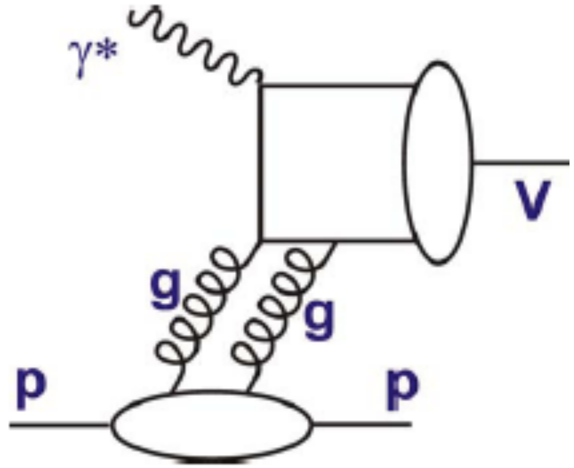


MUST show up as LHeC measures in unitarity limited region. Can be uniquely identified (inclusive F_2/F_L, diffraction, J/ψ).

With eA reach effectively x of 10^{-8} (UHEν)

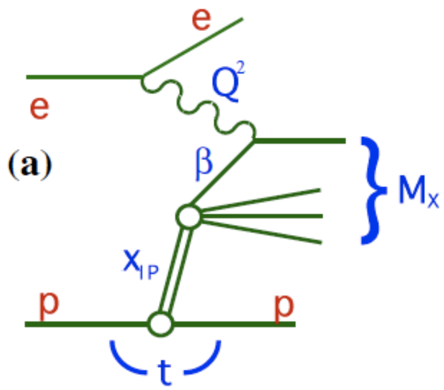
J/ψ – golden channel



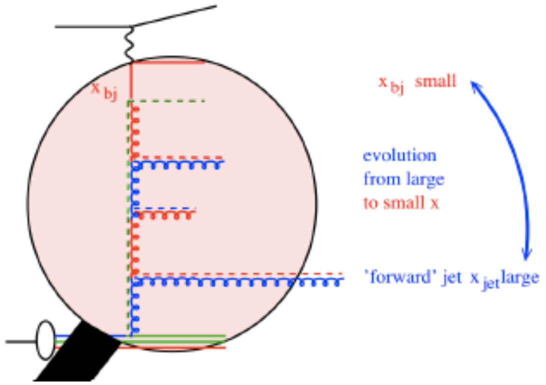


cf also:
A.Caldwell, H.Kowalski
PR C81:025203,2010
Investigation of nuclear
matter with J/Psi

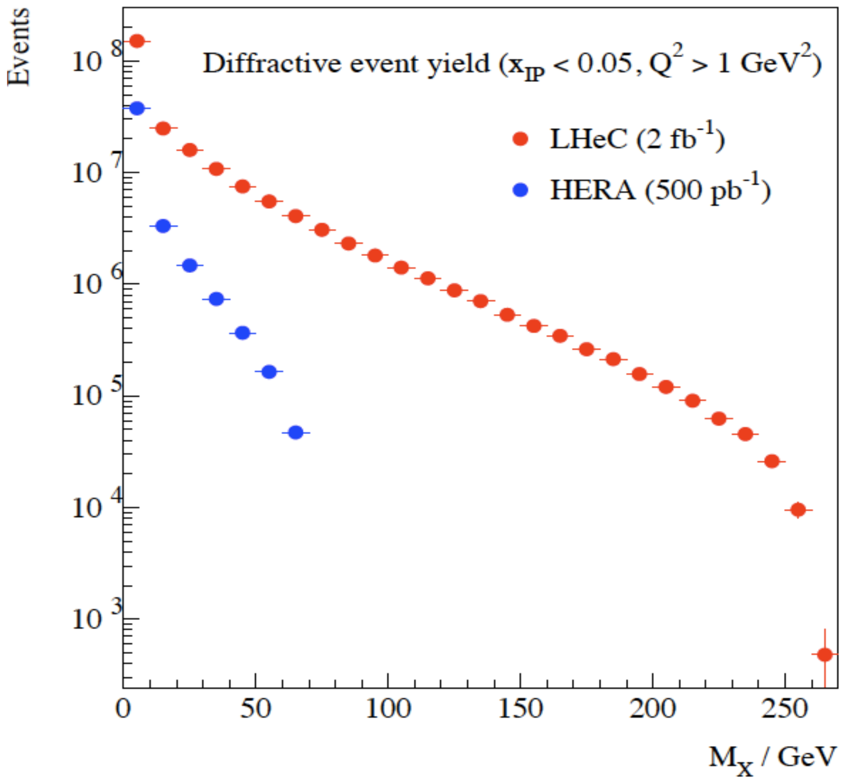
Quark-Gluon Dynamics - Diffraction and HFS (fwd jets)

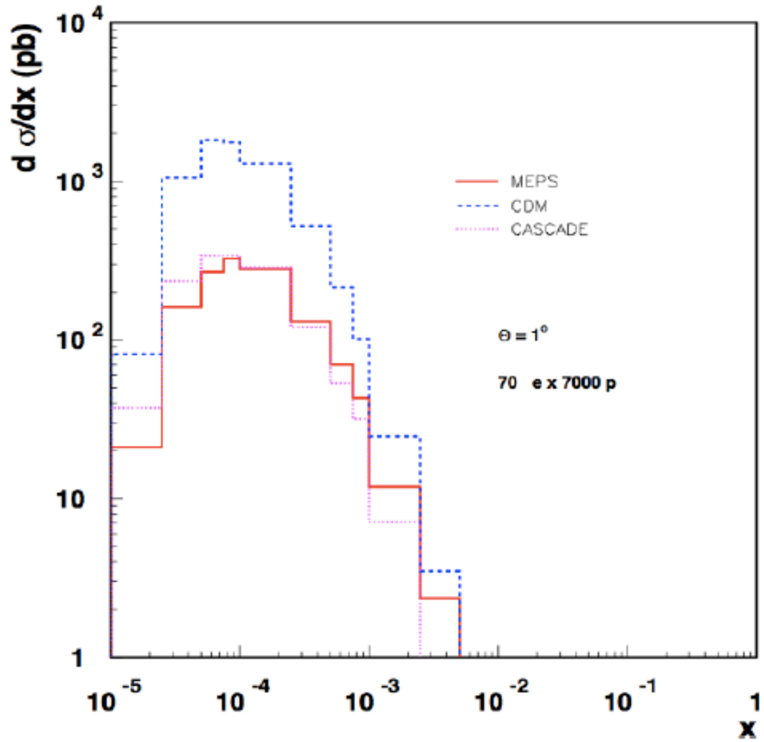


Production of high mass 1⁻ states

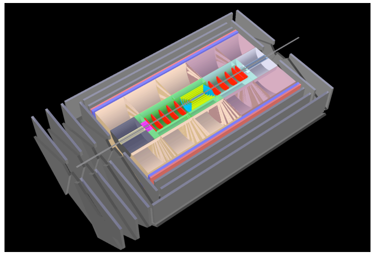


Understand multi-jet emission (unintegr. pdf's), tune MC's



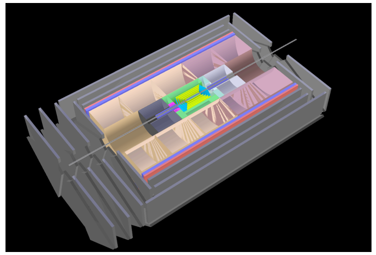


At HERA resolved γ effects mimic non-kt ordered emission



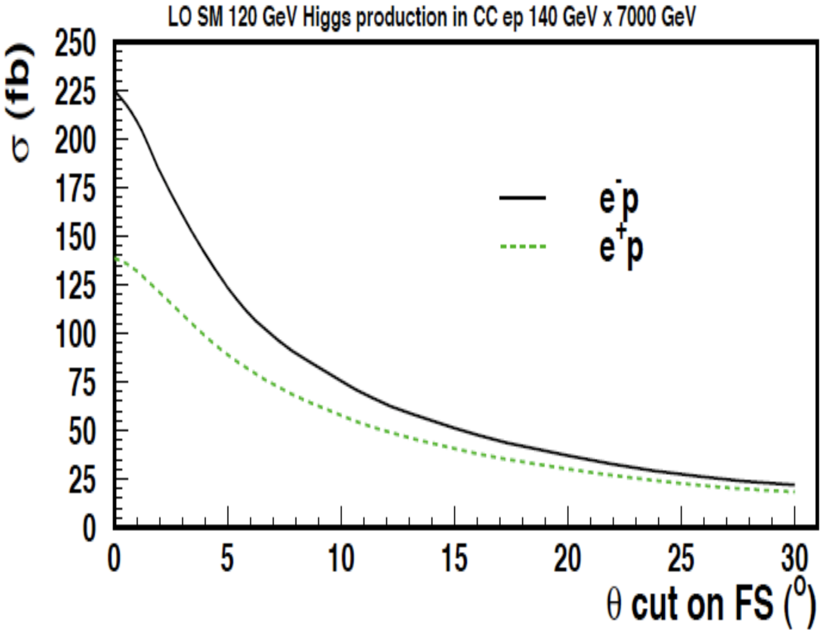
Detector Design

Based on HERA, LHC, ILC R&D



Large fwd acceptance and high luminosity

High precision tracking and calorimetry



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)

	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%

LHeC Detector: version for low x

Muon chambers
(fwd,bwd,central)

Coil (r=3m l=11.8m, 3.5T)
[Return Fe not drawn]

Central Detector

Pixels
Elliptic beam pipe

Silicon (fwd/bwd+central)
[Strip or/and Gas on Slimmed Si Pixels]
[0.6m radius for 0.03% * p_t in 3.5T field]

El.magn. Calo (Pb,Scint. $30X_0$)
Hadronic Calo (Fe/LAr; Cu/Brass-Scint. 9-12λ)

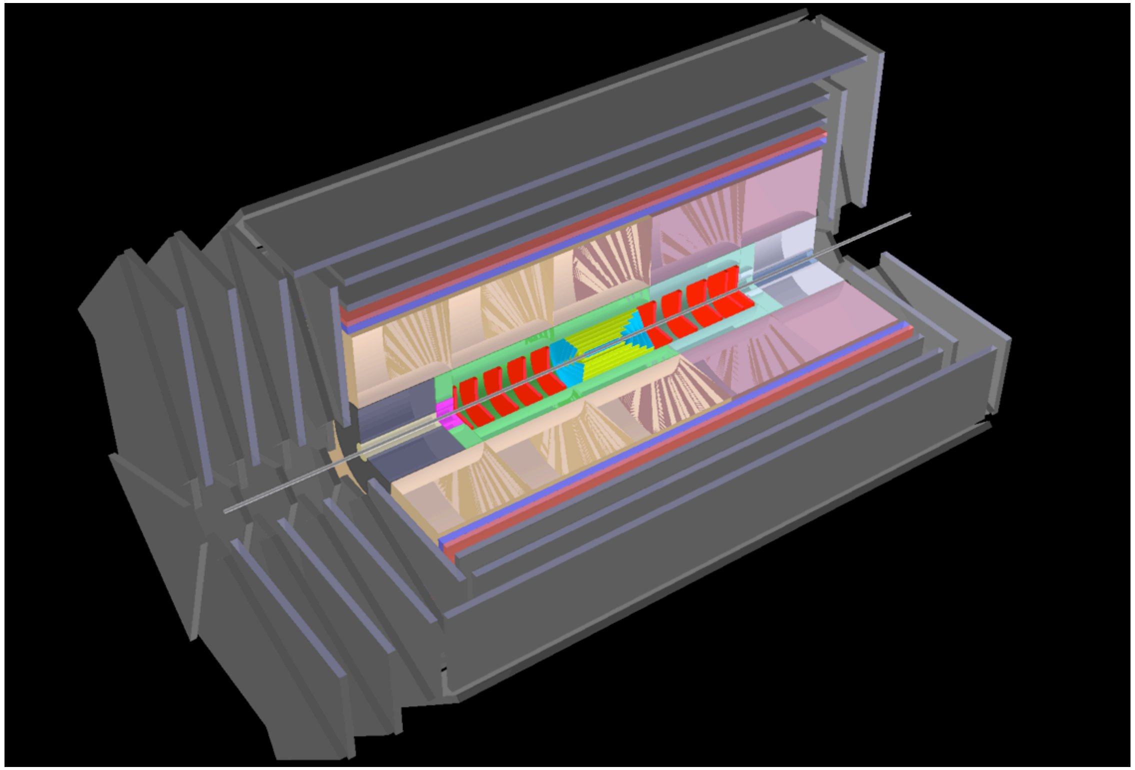
Fwd Detectors

(down to 1^o)
Silicon Tracker
[Pix/Strip/Strixel/Pad Silicon or/and Gas on Slimmed Si Pixels]

Calice (W/Si); dual ReadOut - Elm Calo
FwdHadrCalo:
Cu/Brass-Scintillator

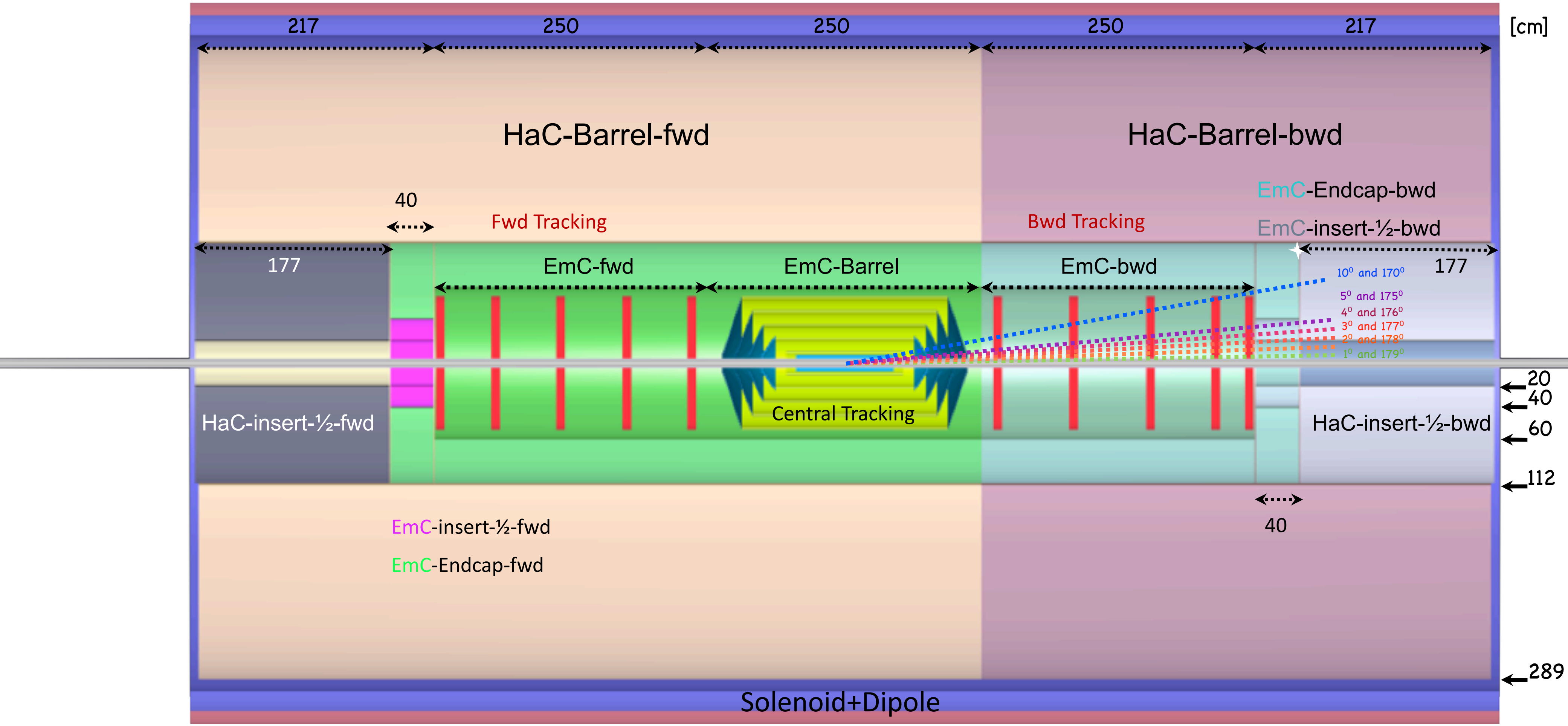
Bwd Detectors

(down to 179^o)
Silicon Tracker
[Pix/Strip/Strixel/Pad Silicon or/and Gas on Slimmed Si Pixels]
Cu/Brass-Scintillator,
Pb-Scintillator (SpaCal - hadr, elm)



Dimensions defined by beam pipe (Nomex/Be sandwich?) – work in progress.

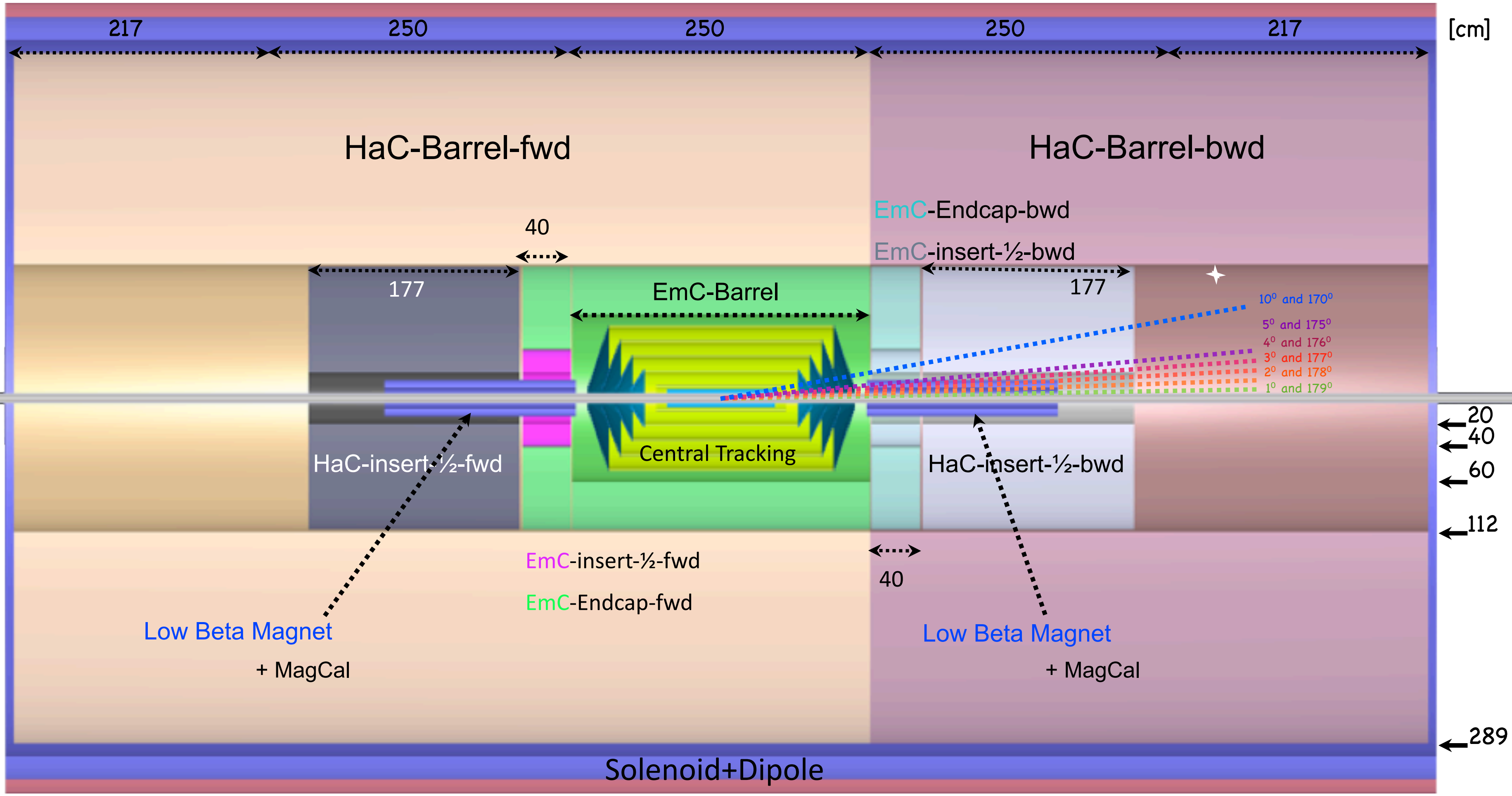
The Detector - Low Q^2 Setup



Fwd/Bwd asymmetry in energy deposited and thus in technology [W/Si vs Pb/Sc..]

Present dimensions: LxD =17x10m^2 [CMS 21 x 15m^2 , ATLAS 25 x 45 m^2]

The Detector - High Q² Setup



Aim of current evaluations: avoid detector split in two phases: time and effort

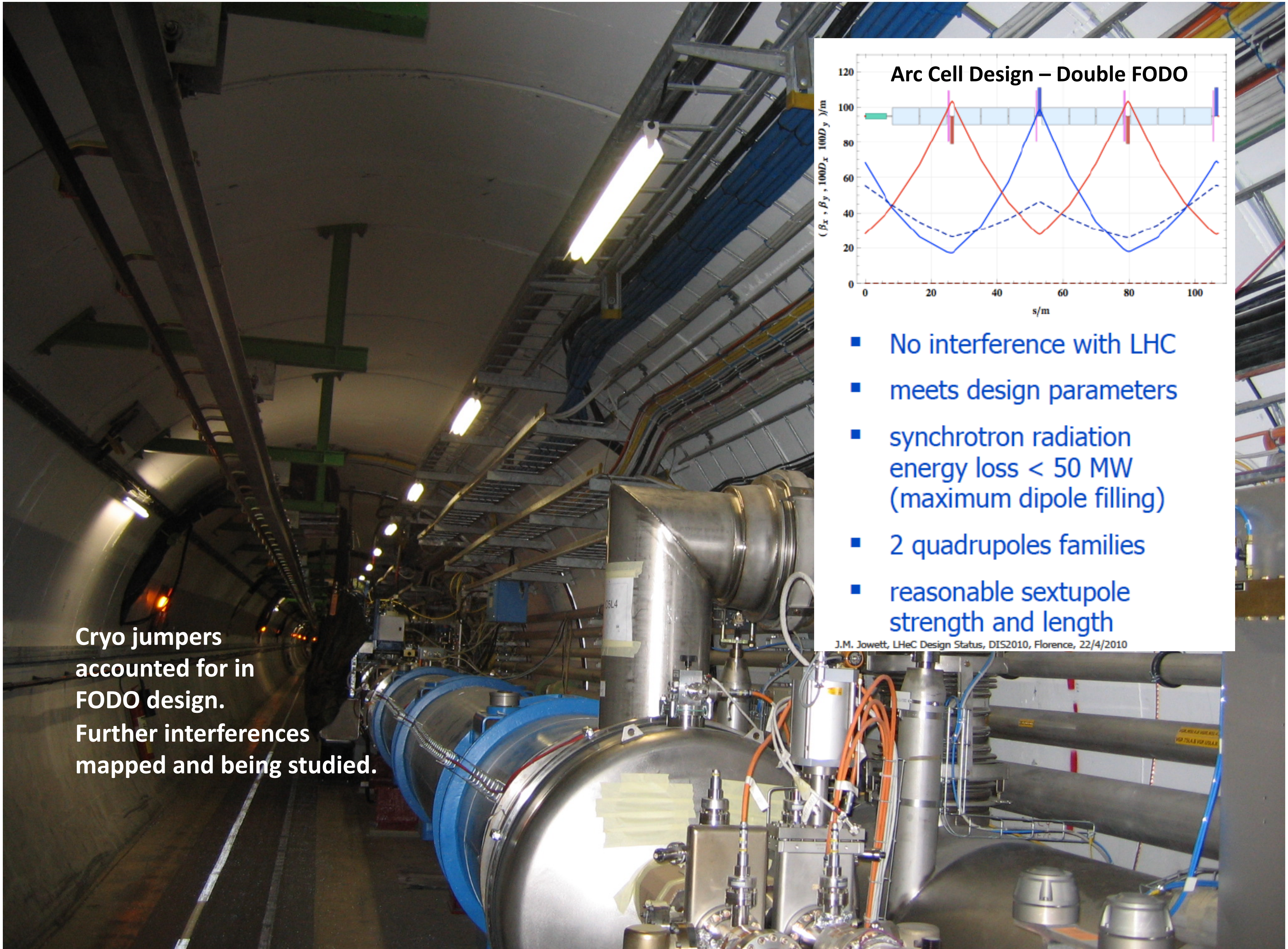
Accelerator: Ring - Ring

Based on HERA, LEP and LHC Experience

Workpackages for CDR

- Baseline Parameters and Installation Scenarios
- Lattice Design [Optics, Magnets, Bypasses, IR for high L and 1°]
- Rf Design [Installation in bypasses, Crabs]
- Injector Complex [Sources, Injector]
- Injection and Dump
- Beam-beam effects
- Impedance and Collective Effects
- Vacuum and Beam Pipe
- Integration and Machine Protection
- Powering Issues
- e Beam Polarization
- Deuteron and Ion Beams

BINP Novosibirsk
BNL
CERN
Cockcroft
Cornell
DESY
EPFL Lausanne
KEK
Liverpool U
SLAC
TAC Turkey

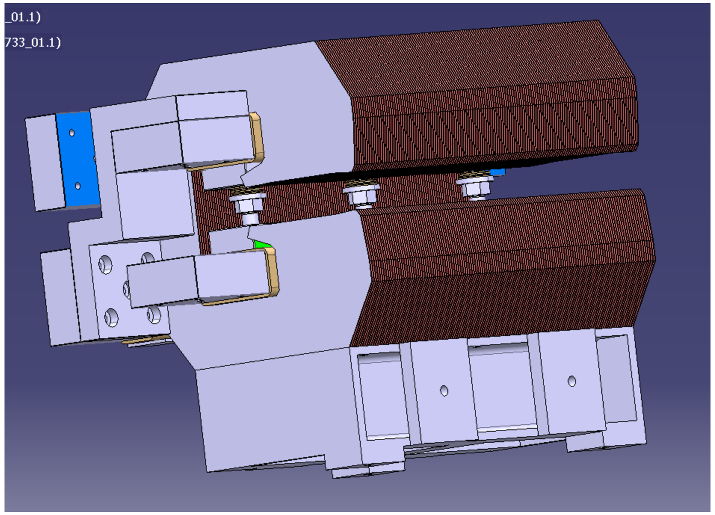


- No interference with LHC
- meets design parameters
- synchrotron radiation energy loss < 50 MW (maximum dipole filling)
- 2 quadrupoles families
- reasonable sextupole strength and length

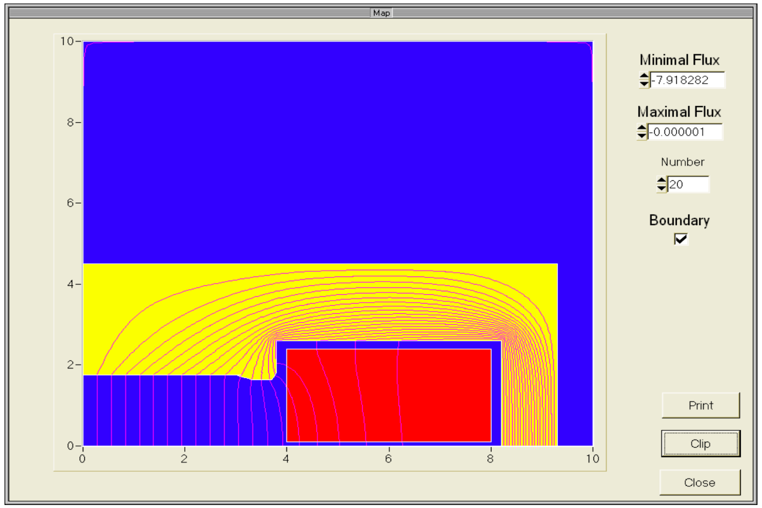
J.M. Jowett, LHeC Design Status, DIS2010, Florence, 22/4/2010

Cryo jumpers accounted for in FODO design. Further interferences mapped and being studied.

CERN: 40cm model design



Novosibirsk: Hysteresis loop measurements



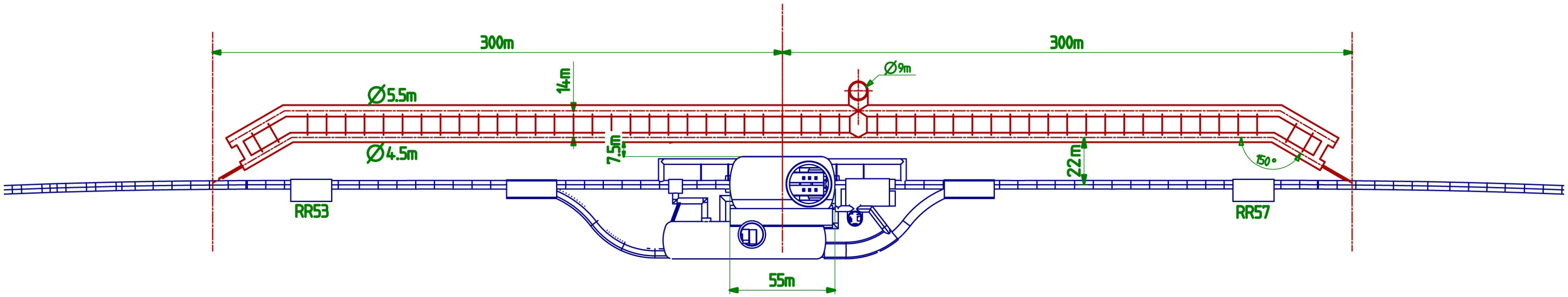
Dipole Magnets

Accelerator	LEP	LHeC
Cross Section/ cm^2	50 x 50	20 x 10
Magnetic field/ T	0.02-0.11	0.01-0.10
Energy Range/GeV	20-100	10-80
Good Field Area/cm^2	5.9 x 5.9	6 x 3.8
FODO length/m	76	107 [double]
Magnet length/m	11.5	5.5
segmentation	8x31x6	8x23x15
Number of magnets	1488+192 [DS]	3080+320
Weight / kg/m	800	200

Fe based magnet prototypes [BINP-CERN] → CDR

challenges:
compact design for installation
good reproducibility at injection: 0.01T to $10^{-3..-4}$

Bypasses



Away from galeries

Double tunnel: use to install rf [typically 0.5-1km]

Aim to keep $U_e=U_p$

Tunnel connection (CGNS, DESY)

Possibly in line with P1,5 redesigns

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 sync.rad loss (beam power) and 70 GeV on 7000 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.

Ring LHeC profits from LHC upgrade
but not proportional to N_p
Crucial for LINAC

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}**	

Accelerator: LINAC - Ring

Based on ILC, SLC and LHC Experience

Workpackages for CDR

Baseline Parameters [Designs, Real photon option, ERL]
Sources [Positrons, Polarisation]
Rf Design
Injection and Dump
Beam-beam effects
Lattice/Optics and Impedance
Vacuum and Beam Pipe
Integration and Layout
Interaction Region
Powering Issues
Magnets
Cryogenics

BINP Novosibirsk
BNL
CERN
Cockcroft
Cornell
DESY
EPFL Lausanne
KEK
Liverpool U
SLAC
TAC Turkey

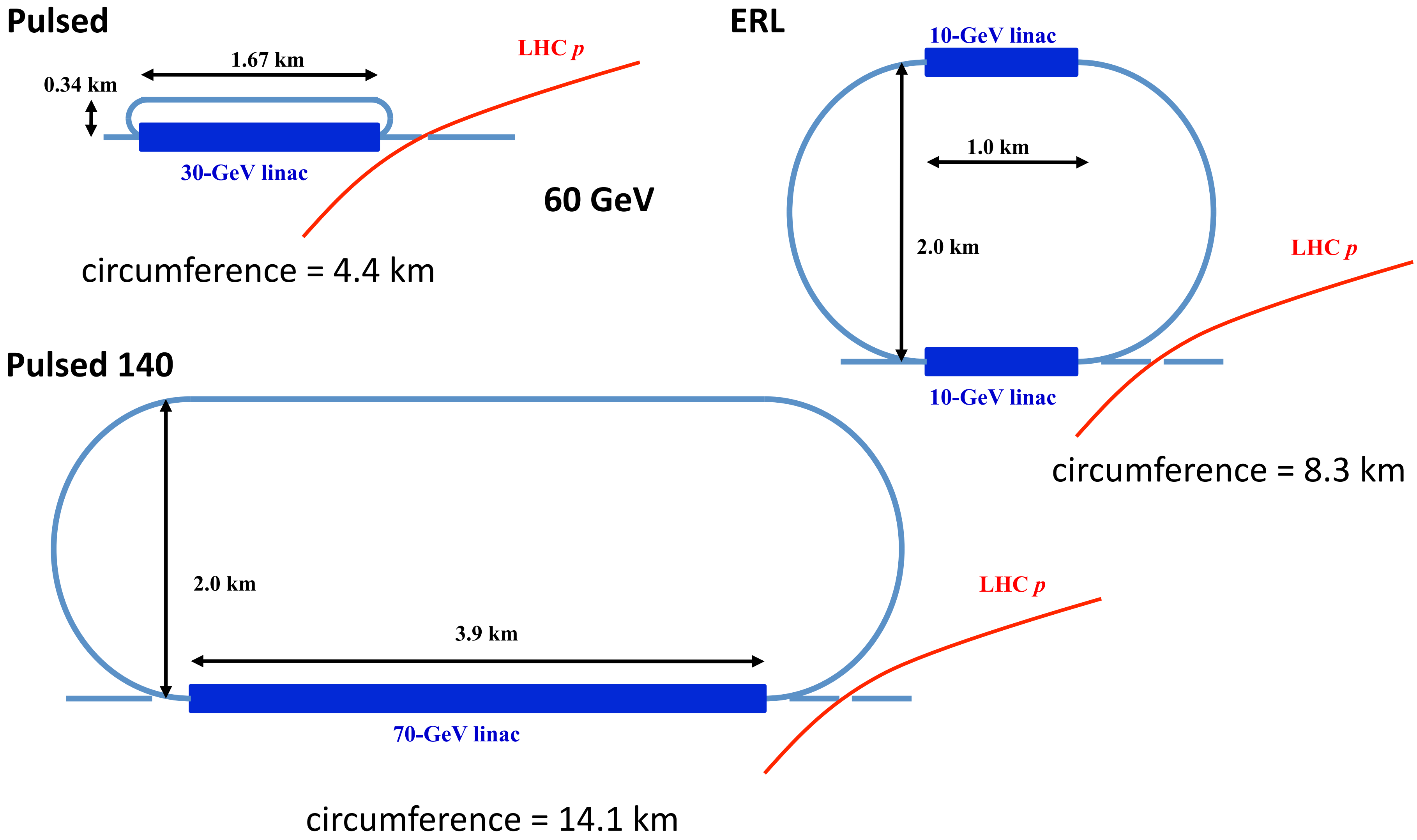
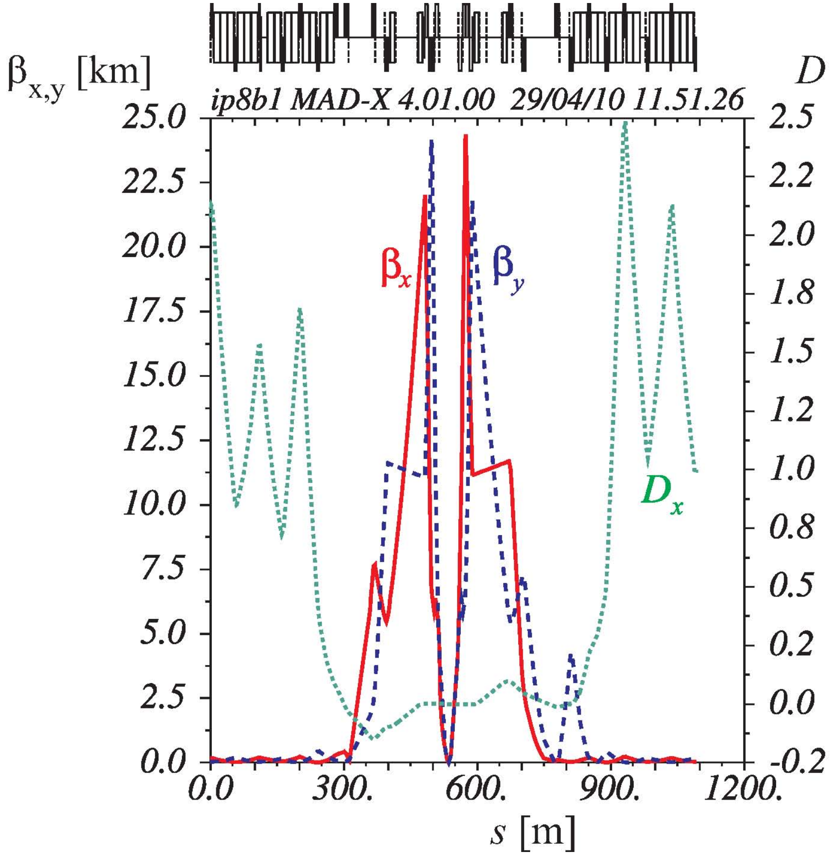
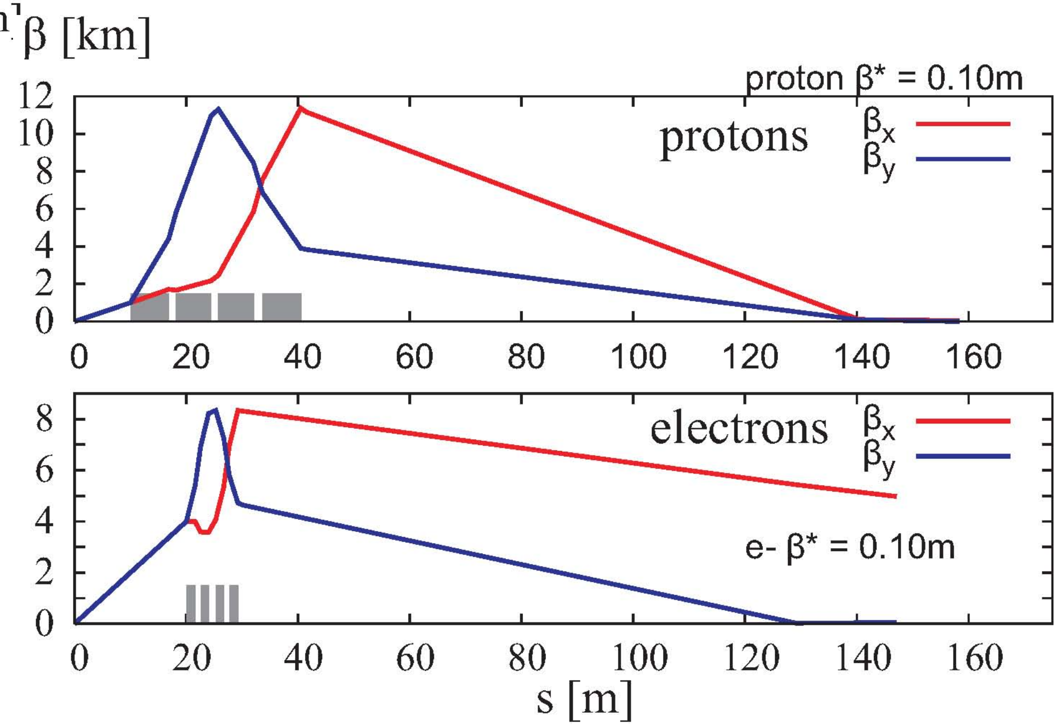

Pulsed
1.67 km
0.34 km
30-GeV linac
LHC p
60 GeV
circumference = 4.4 km
ERL
10-GeV linac
1.0 km
2.0 km
10-GeV linac
LHC p
circumference = 8.3 km
Pulsed 140
2.0 km
3.9 km
70-GeV linac
LHC p
circumference = 14.1 km

Table 2: Parameters of the first two proton quadrupoles [4].

magnet	pipe radius	gradient	field at pipe
Q1	26 mm	318.6 T/m	8.4 T
Q2	36 mm	250.0 T/m	9.1 T





LHC proton interaction-region optics for $\beta^*_{x,y}$=0.1 m, scaled from the nominal IR optics (left) [5],
and a new IR optics with $\beta^*_{x,y}$=0.1 m for protons [l^*=10 m] (top right) and electrons [l^*=20 m] (bottom right) [4]

LINAC-Ring Parameters

Table 4: Lepton beam parameters and luminosity.

	p-60	erl	p-140
e^- energy at IP [GeV]	60	60	140
luminosity [10^{32} cm^{-2}s^{-1}]	1.1	10.1	0.4
polarization [%]	90	90	90
bunch population [10^9]	4.5	2.0	1.6
e^- bunch length [μm]	300	300	300
bunch interval [ns]	50	50	50
transv. emit. $\gamma\epsilon_{x,y}$ [μm]	50	50	100
rms IP beam size [μm]	7	7	7
hourglass reduction H_{hg}	0.91	0.91	0.94
crossing angle θ_c	0	0	0
repetition rate [Hz]	10	CW	10
bunches/pulse [10^5]	1	N/A	1
pulse current [mA]	16	10	6.6
beam pulse length [ms]	5	N/A	5
ER efficiency η	0	94%	0
total wall plug power [MW]	100	100	100

Table 2: SC linac parameters. *RT: room temperature.

	p-60	erl	p-140
RF frequency [MHz]	700	700	700
cavity length [m]	1	1	1
energy gain / cavity	31.5	18	31.5
R/Q [Ω]	403	403	403
Q_0 [10^{10}]	1	2.5	1
power loss, stat [W/cav.]	5	5	5
power loss, RF [W/cav]	12.3	32	12.3
power loss, total [W/cav]	17.3	37.2	17.3
real-est. gradient [MeV/m]	17.8	10.26	17.8
length/GeV [m]	55.7	97.5	55.7
#cavities/(1 GeV)	31.8	55.6	31.8
power loss/GeV (2 K) [kW]	0.55	2.06	0.55
"W per W" (1.8 K to RT*)	600	600	600
power loss/GeV (RT*) [MW]	0.33	1.24	0.3
final energy [GeV]	60	60	140
# passes for acceleration	2	3	2
# passes for deceleration	0	3	0
total linac length [km]	1.67	1.95	3.90
tot. cryo power (RT) [MW]	9.9	24.75	23.1
av. beam current [mA]	0.74	6.6	0.27
beam power at IP [MW]	45	396	39
RF power [MW]	89	(22)	75.6
cryo + RF power [MW]	99	(47)	98.4

For ERL version:
2 x 560, 1m long cavities
25 MW cryo power

Cf recent papers to IPAC10 at Kyoto (from LHeC web page)

Project + Concluding Remarks

Proposal as endorsed by ECFA (30.11.2007)

As an add-on to the LHC, the LHeC delivers in excess of 1 TeV to the electron-quark cms system. It accesses high parton densities 'beyond' what is expected to be the unitarity limit. Its physics is thus fundamental and deserves to be further worked out, also with respect to the findings at the LHC and the final results of the Tevatron and of HERA.

First considerations of a ring-ring and a linac-ring accelerator layout lead to an unprecedented combination of energy and luminosity in lepton-hadron physics, exploiting the latest developments in accelerator and detector technology.

It is thus proposed to hold two workshops (2008 and 2009), under the auspices of ECFA and CERN, with the goal of having a Conceptual Design Report on the accelerator, the experiment and the physics. A Technical Design report will then follow if appropriate.

Unanimously supported by rECFA and ECFA plenary in November 2007
NuPECC: Long Range Plan being finalised: LHeC listed there (Madrid 5/10)

Schedule+Remarks

If the LHeC is to be realised it has to start operation by 2020/22 [programme, effort]

this is possible:
HERA: Proposal 1984 – Operation 1992. LEP: Proposal 1983 – Operation 1989
The major technologies for the accelerator and the detector exist. **It can be built.**

Steps: CDR 2010/11 [15.9. – Divonne III 28.10.-30.10. – ECFA – Referees/SAC - Printed Spring 2011]
Evaluation. When positive: set up professional project structure for
TDR by end of 2013 for either Ring or LINAC [charge, pol, L, cost, IR, Det, LHC interference ..]

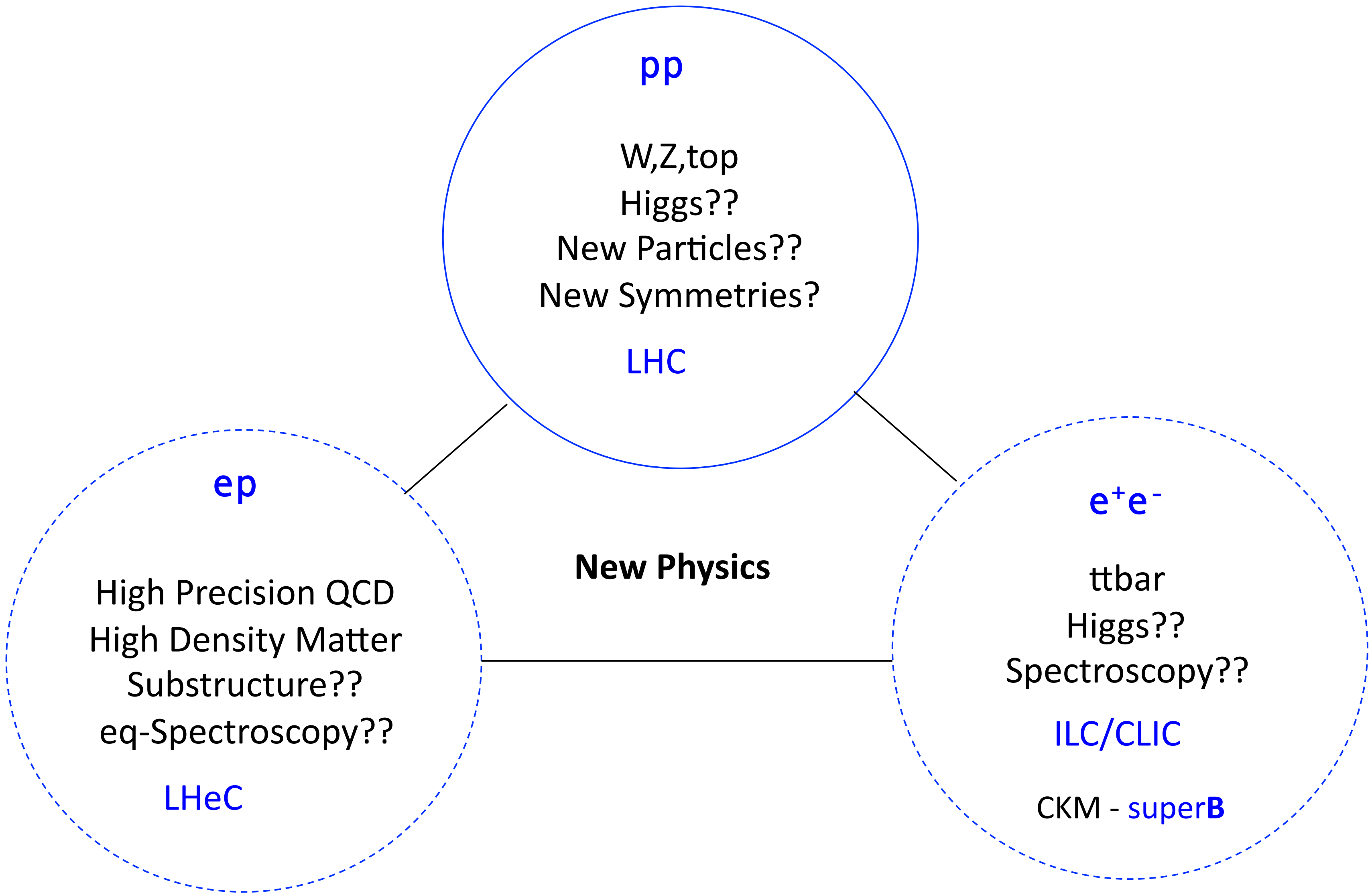
Crucial for CDR: Concluding the work (IR→ Detector, writing the chapters -70 authors)

A detailed installation plan is being worked out for the Accelerator and the Detector in order to understand the interference with the LHC developments.

The high luminosity ingredients for the LINAC would require to strongly couple R&D with ongoing developments (Nb_3 Sn, positron sources, ERL, crab cavities).

In the long term perspective a 140 GeV electron beam coupled with a 16 TeV LHC' beam would mean that this field can be brought to 3 TeV cms and x ~10^{-7}

The TeV Scale [2010-2035..]



Deep Inelastic Scattering

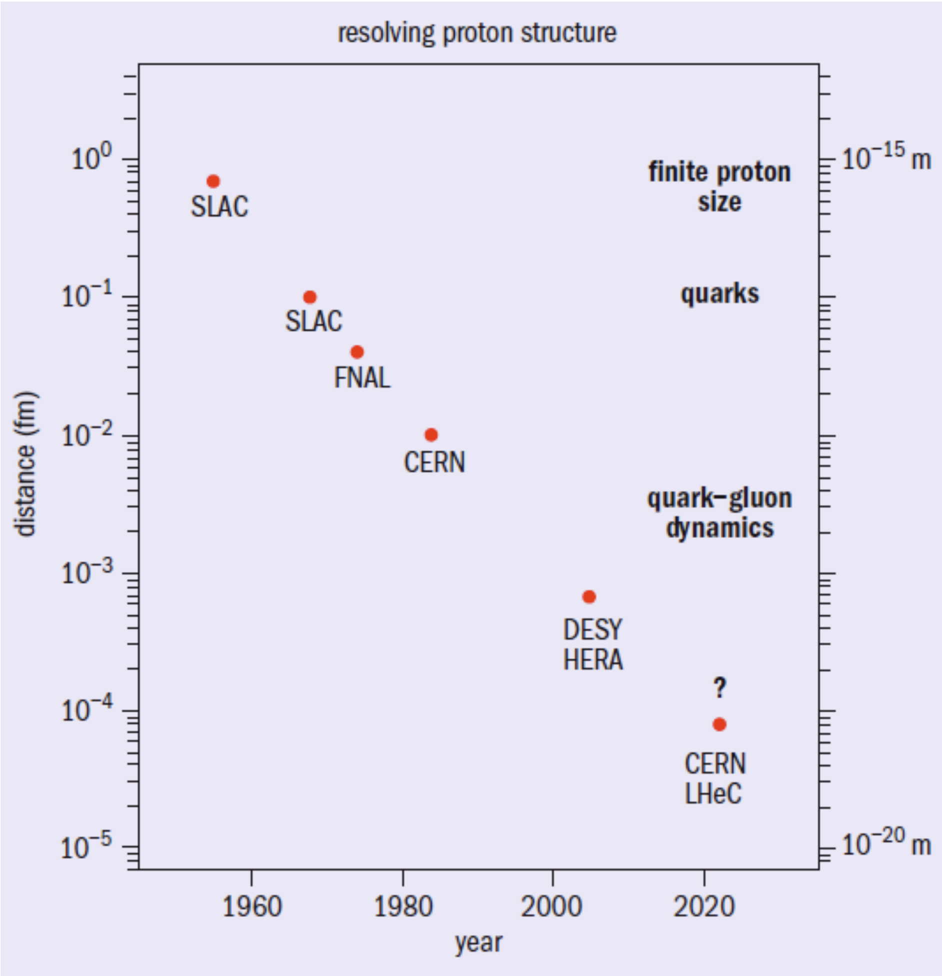


Fig. 1. Distance scales resolved in successive lepton–hadron scattering experiments since the 1950s, and some of the new physics revealed.

http://cern.ch/lhec

SLAC 69: 2m LINAC: a "bold extrapolation of existing technology" to "collect data which may be of future use…"

CERN – Mecca of pp [SppS] and DIS [μ,ν]

50 000 times Q^2 possibly with 10 times the accelerator length when comparing with SLAC69!

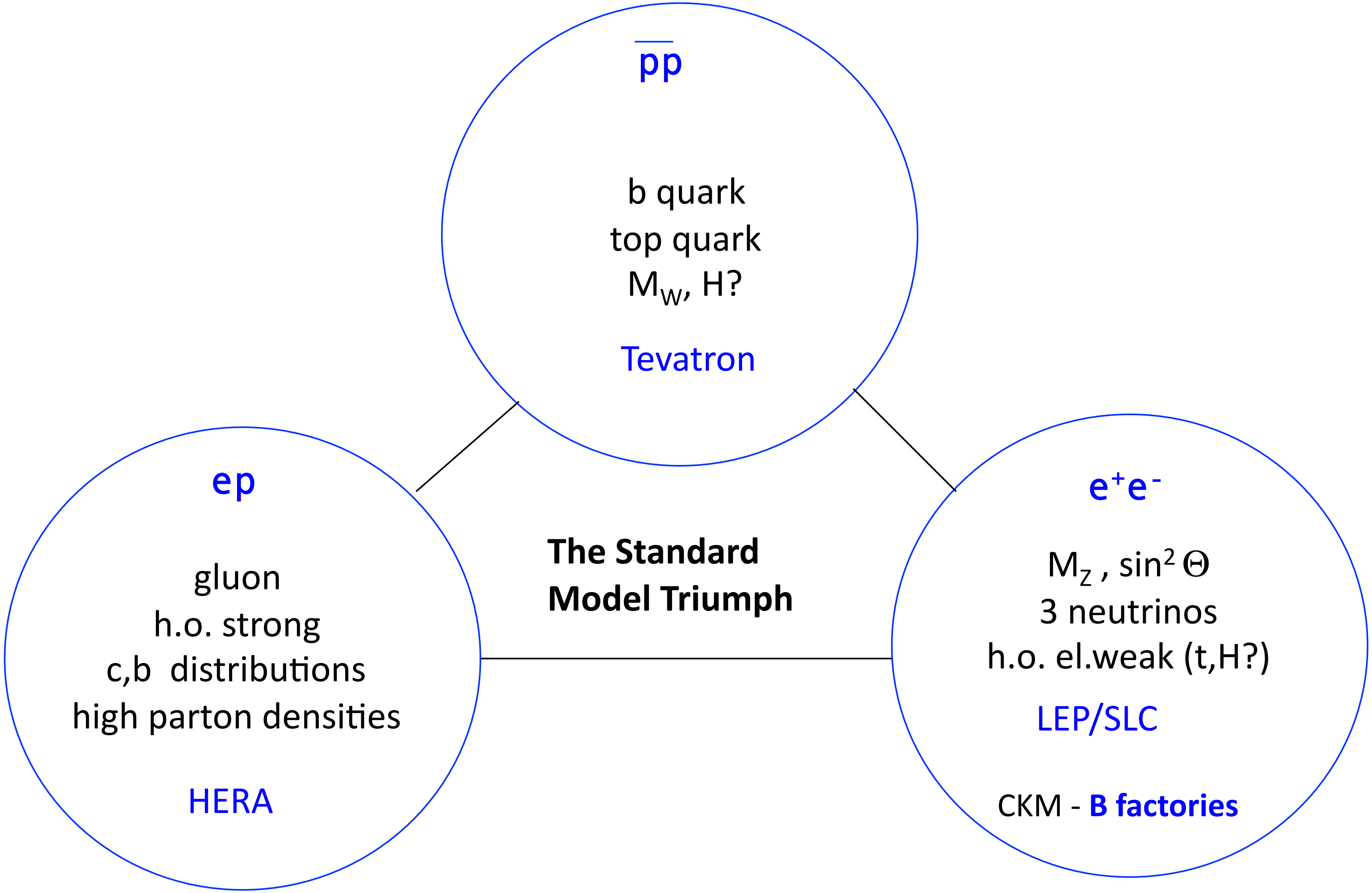
It would be a waste not to exploit the 7 TeV beams for eP and eA physics at some stage during the LHC time

G. Altarelli
Divonne 08

Many thanks to too many people to be named here..

backup

The Fermi Scale [1985-2010]



Physics Programme of the LHeC

+ Unfolding completely the parton structure of the proton (neutron and photon) and search for sub-substructure down to ten times below HERA's limit

+ Sensitive exploration of new symmetries and the grand unification of particle interactions with electroweak and strong interaction measurements of unprecedented precision.

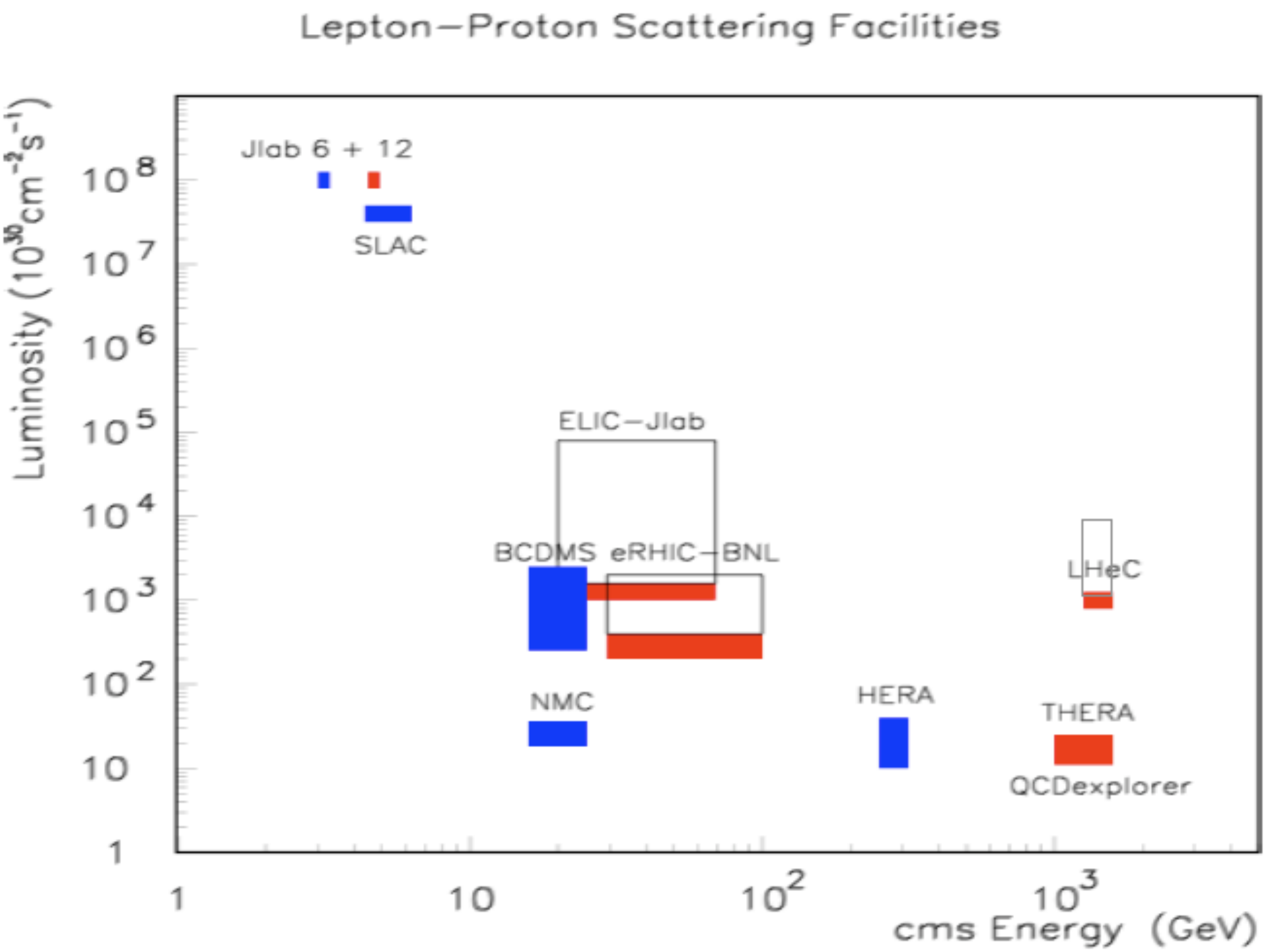
+ Search for and exploration of new, Terascale physics, in particular for singly produced new states (RPV SUSY, LQ, excited fermions) complementary to the LHC

+ Exploration of high density matter [low x physics beyond the expected unitarity limit for the growth of the gluon density]

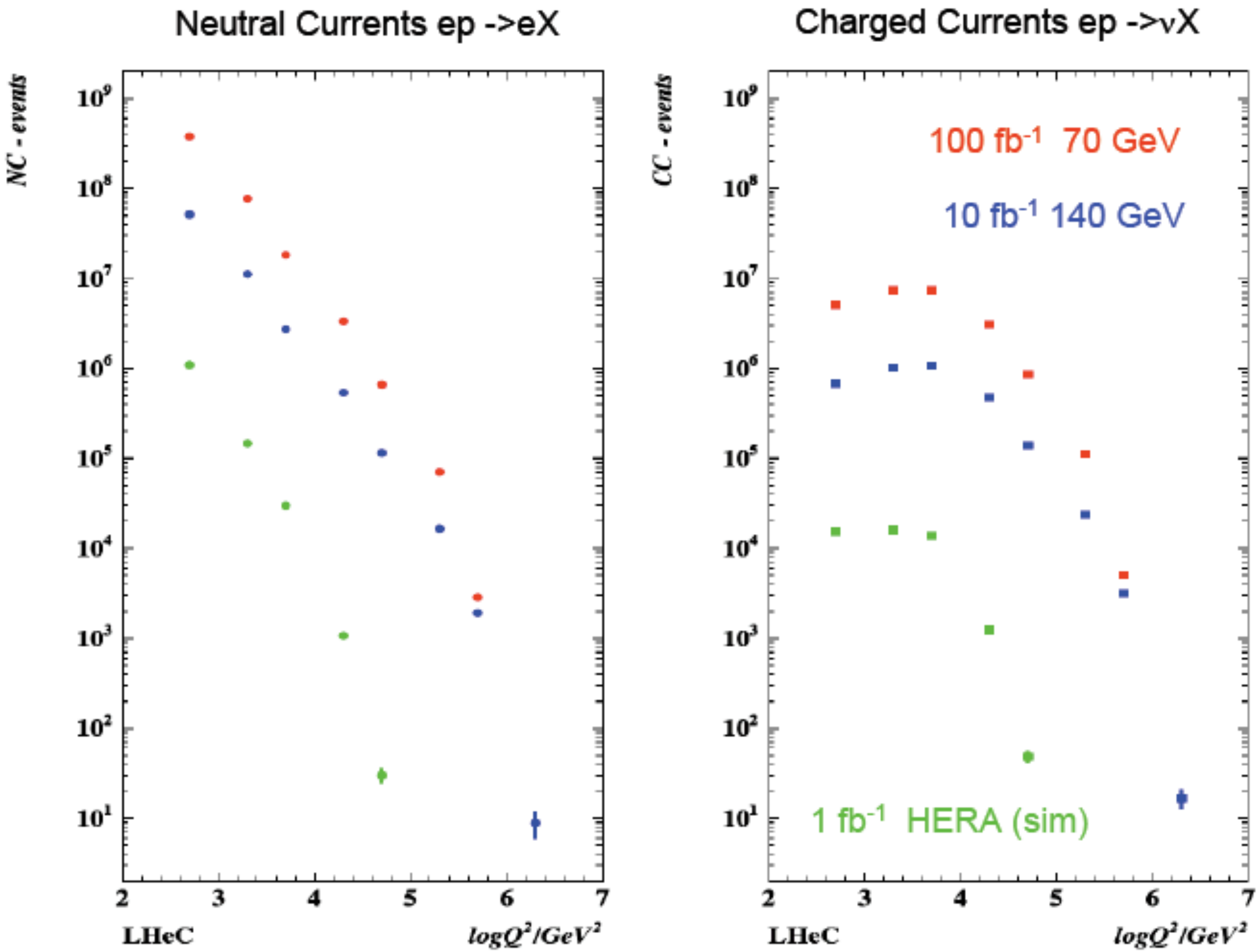
+ Unfolding the substructure and parton dynamics inside nuclei and the study of quark-gluon plasma matter by an extension of the kinematic range by four orders of magnitude.

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
Divonne 08



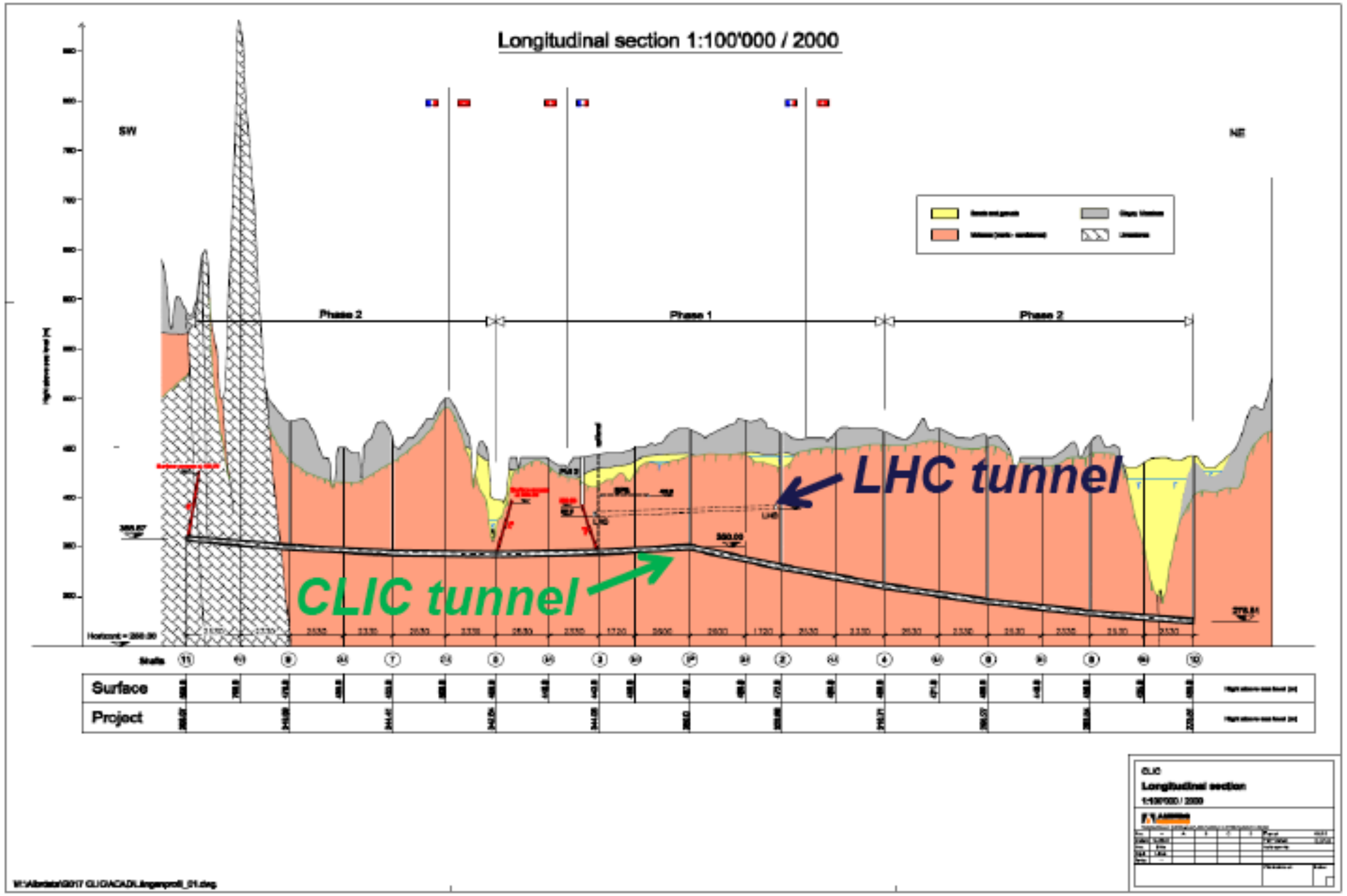
Lepton−Proton Scattering Facilities
Luminosity ($10^{30}cm^{-2}s^{-1}$)
cms Energy (GeV)
Jlab 6 + 12
SLAC
ELIC−Jlab
BCDMS
eRHIC−BNL
LHeC
NMC
HERA
THERA
QCDexplorer
10^8
10^7
10^6
10^5
10^4
10^3
10^2
10
1
1
10
10^2
10^3



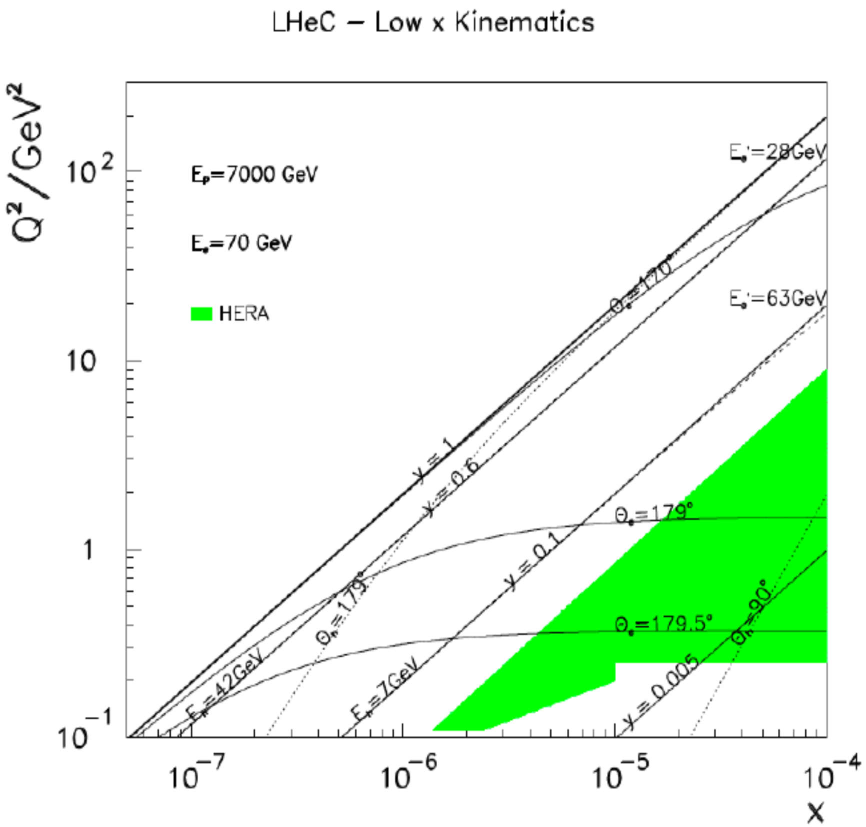
Neutral Currents ep ->eX
Charged Currents ep ->νX
NC - events
CC - events
100 fb-1 70 GeV
10 fb-1 140 GeV
1 fb-1 HERA (sim)
LHeC
logQ2/GeV2

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

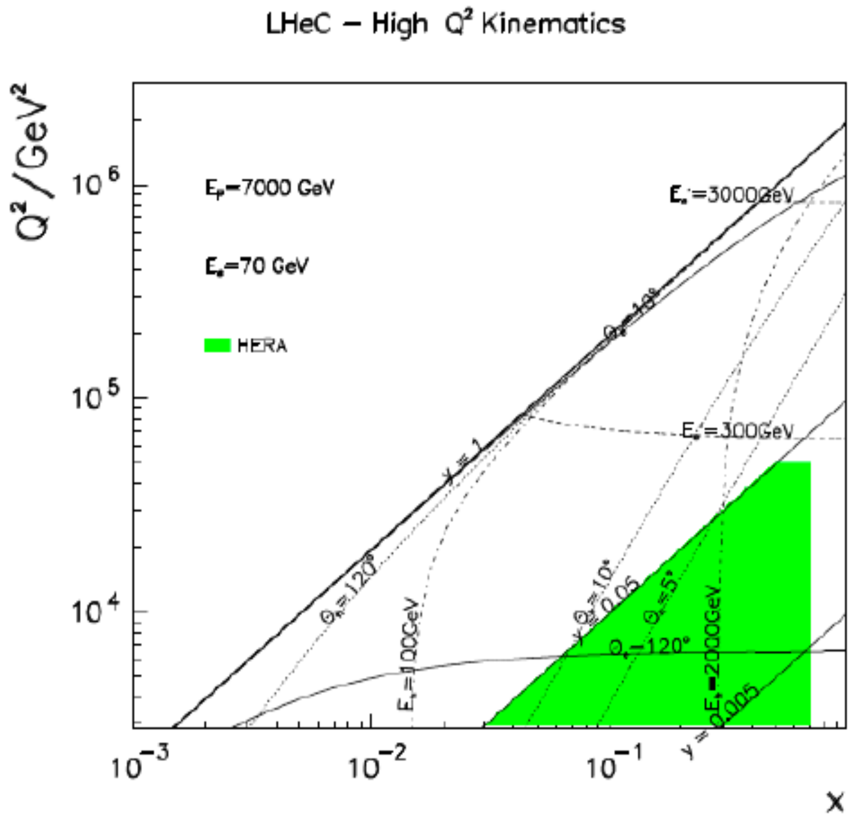
Tunnel studies for CLIC and ILC at CERN both have tunnels which are deeper underground than LHC and seen from top they both pass close to LHC ring center. Therefore they are not suited to send e^- beam tangential to LHC ring.



LHeC – HERA - Kinematics

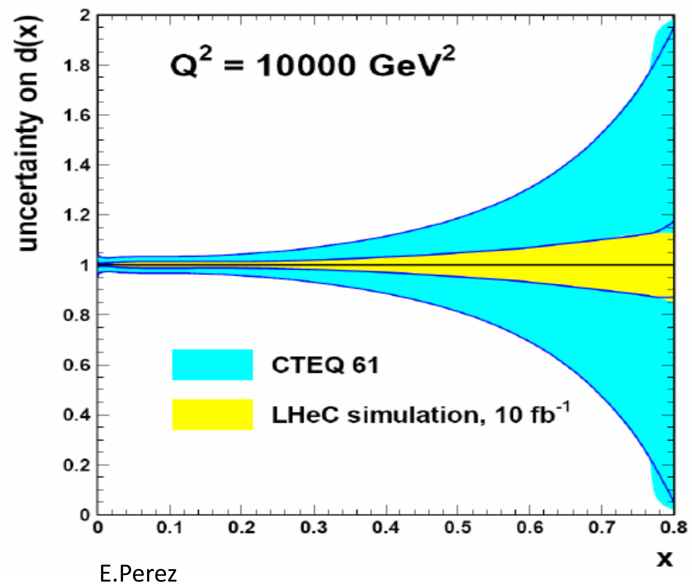


Low x,Q^2 requires small angle acceptance for both e and hadronic final state.



Large x requires small angle acceptance for hadronic final state. TeV energies in forward p direction

Light Quark Distributions

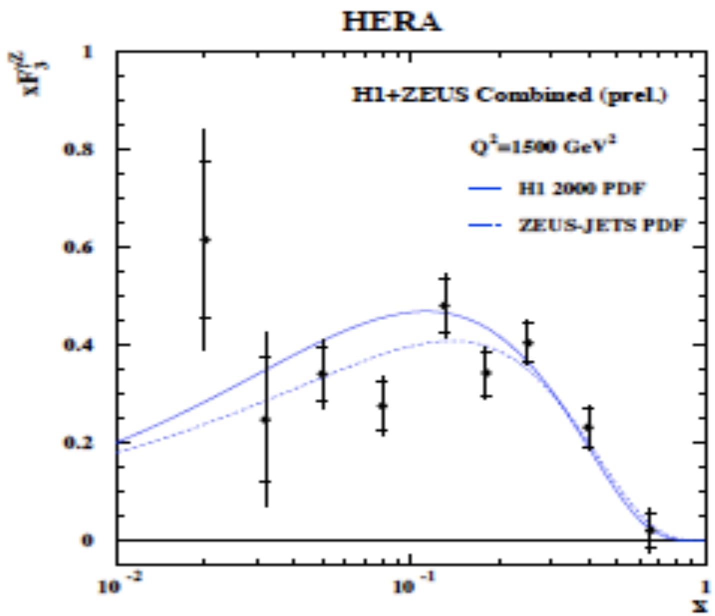


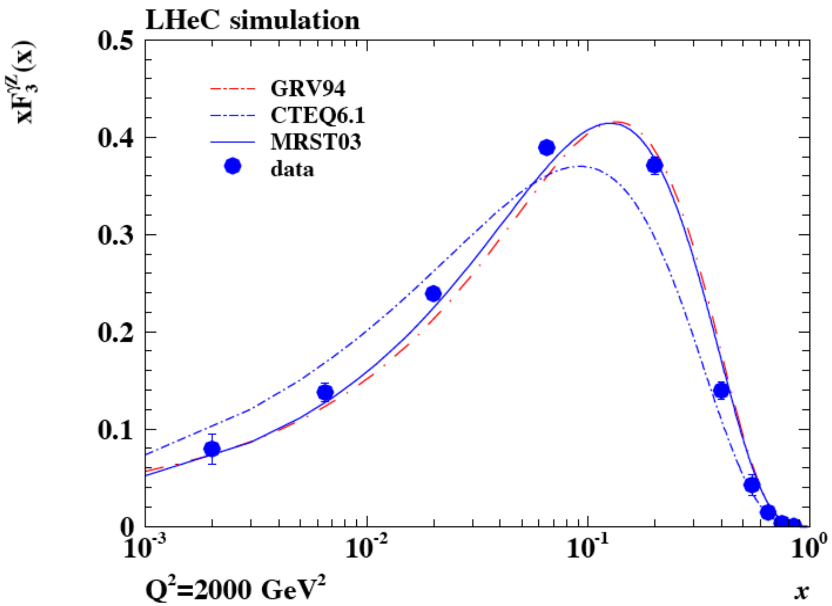
E.Perez

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

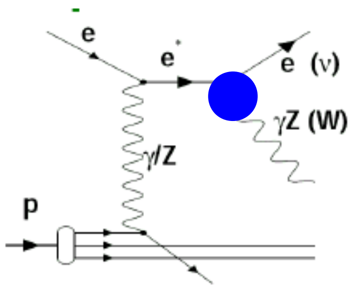
LHeC is an electroweak machine.
e.g.: Charge asymmetry in NC measures
valence quarks down to x ~10^{-3} at high Q^2

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



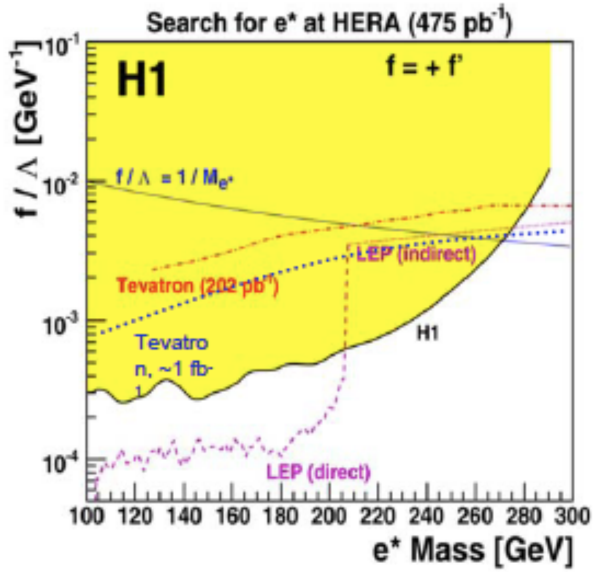


Electron-Boson Resonances : excited electrons



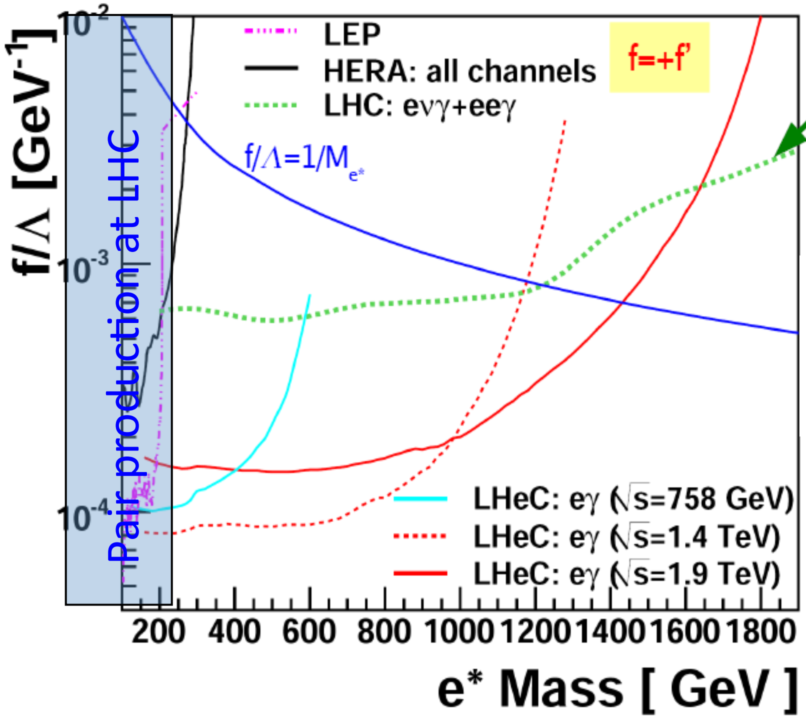
coupling
~ f / Λ

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



PL B666 (2008)131

LHeC prelim. analysis, looking at e* → eγ



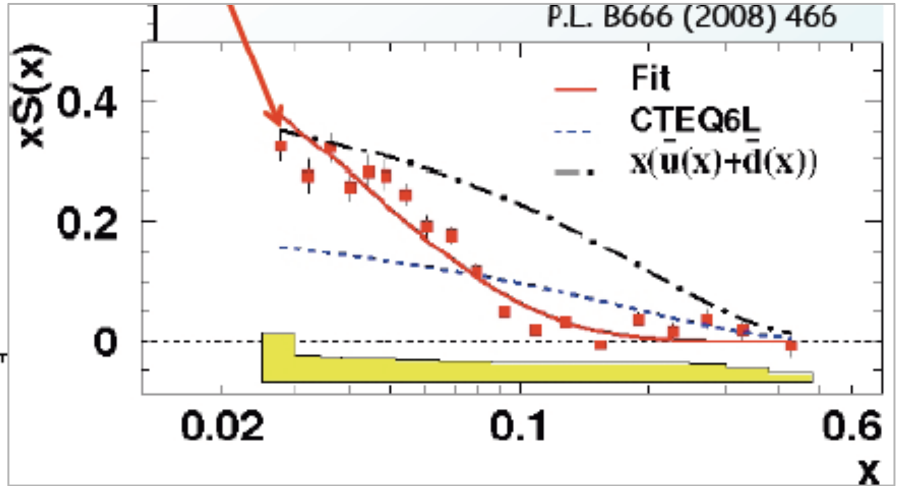
[Phys. Rev D 65 (2002) 075003]

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

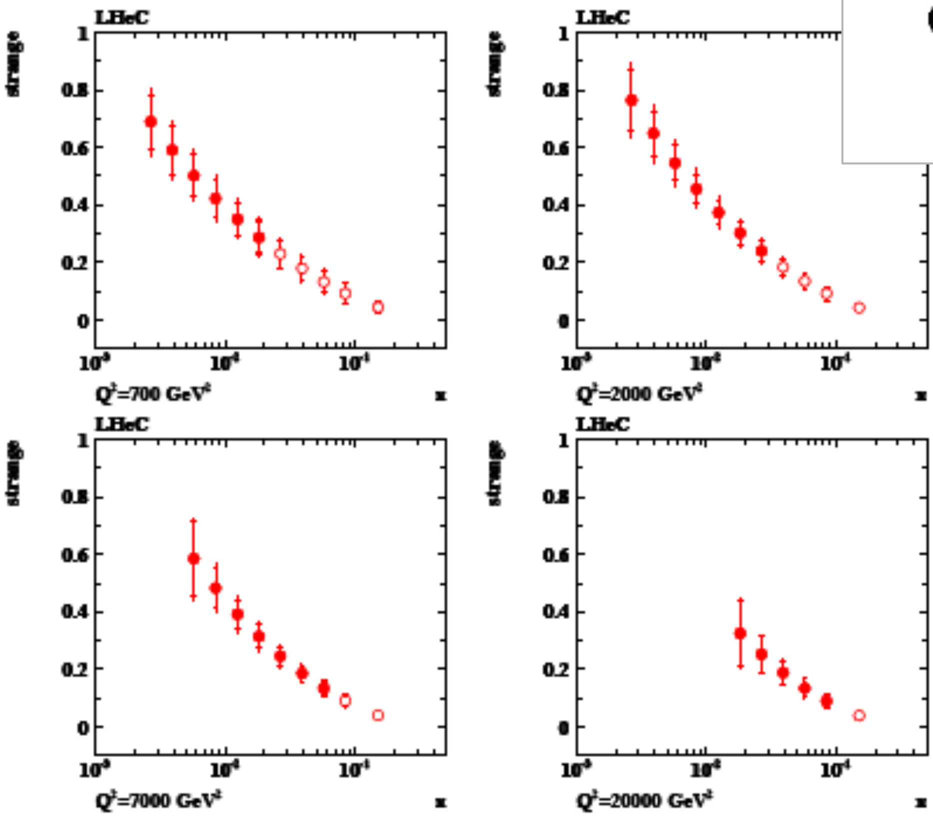
- L assumed 10 (1) fb^{-1} with 20/70 (140) GeV

Anti-Strange Quark Distribution

s not measured with H1,ZEUS
HERMES (N_K); much larger
dimuon data: s.ne.sbar?

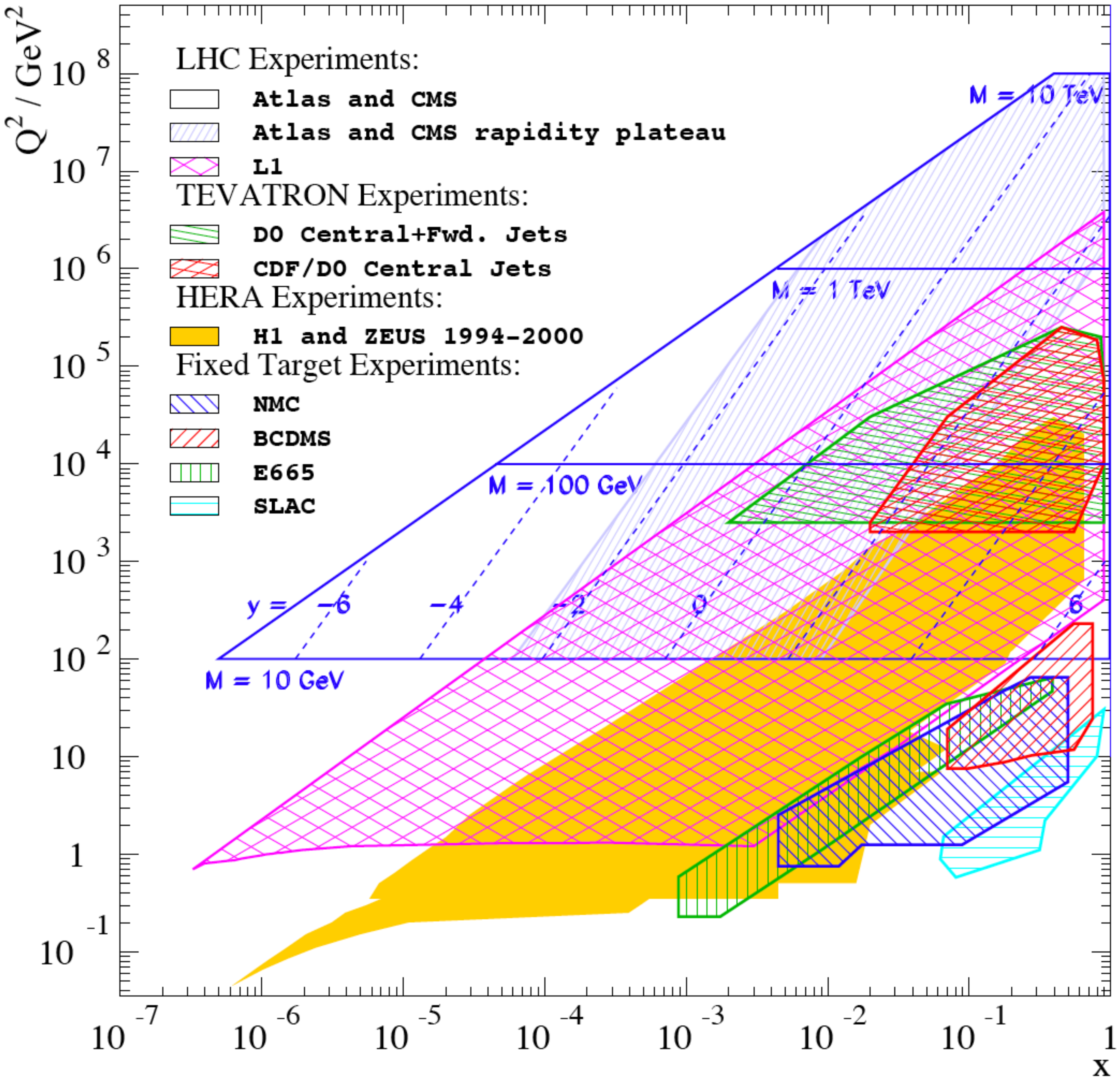


HERMES, K.Rith EPS09



$W^- sbar \rightarrow cbar$
$1 fb^{-1}$
$\varepsilon_c = 0.1$
$\varepsilon_q = 0.01$
$\delta_{syst} = 0.1$
$\circ - \vartheta_h \geq 1^o$
$\bullet - \vartheta_h \geq 10^o$

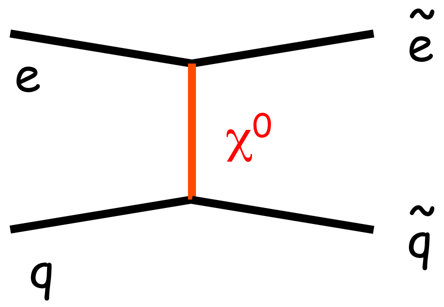
LHeC: measure both strange and anti-s with high precision for the first time



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

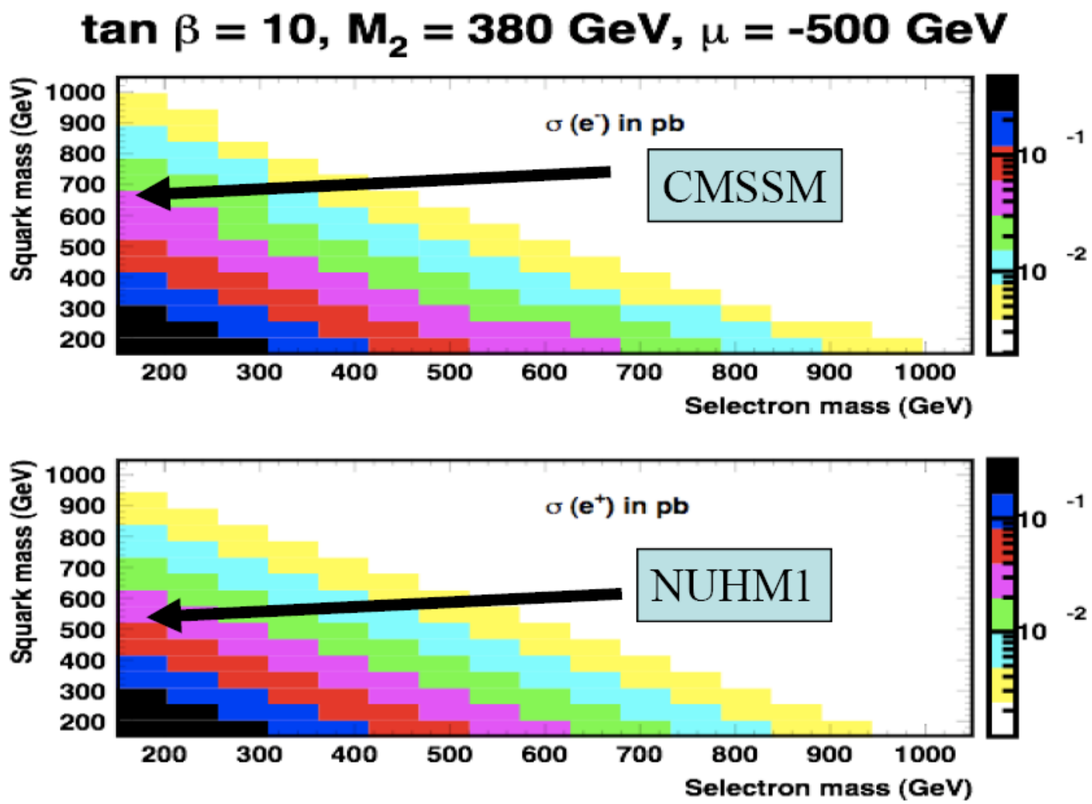
Supersymmetry (R-parity conserved)

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.



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

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

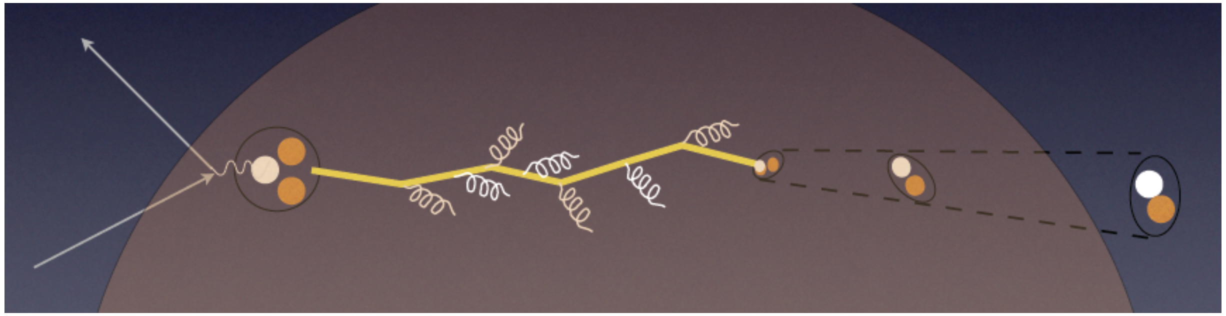
In-medium Hadronisation

The study of particle production in eA (fragmentation functions and hadrochemistry) allows the study of the space-time picture of hadronisation (the final phase of QGP).

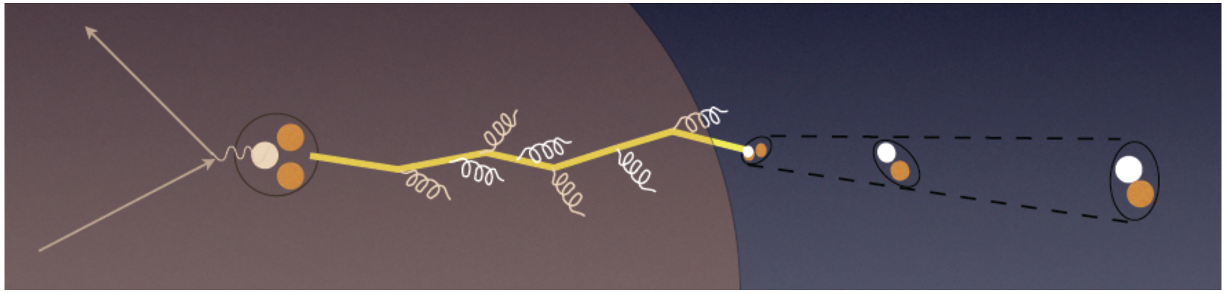
Low energy (ν): need of hadronization inside.

Parton propagation: pt broadening

Hadron formation: attenuation



High energy (ν): partonic evolution altered in the nuclear medium.



W.Brooks, Divonne09

LHeC :

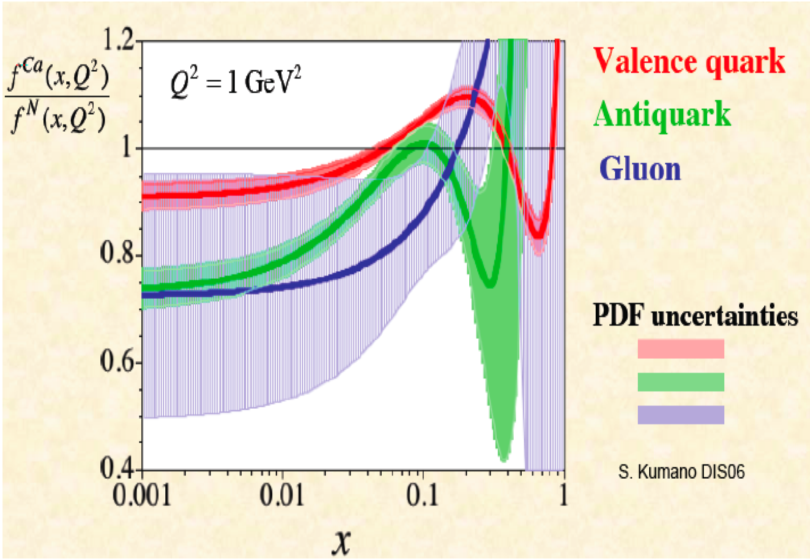
+ study the transition from small to high energies in much extended range wrt. HERMES, Jlab

+ testing the energy loss mechanism crucial for understanding of the medium produced in HIC

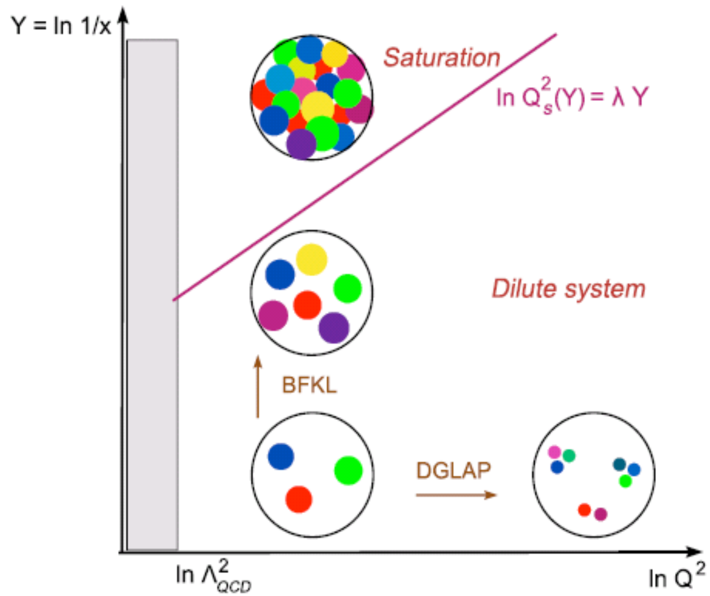
+ detailed study of heavy quark hadronisation ...

Nuclear Physics with the LHeC

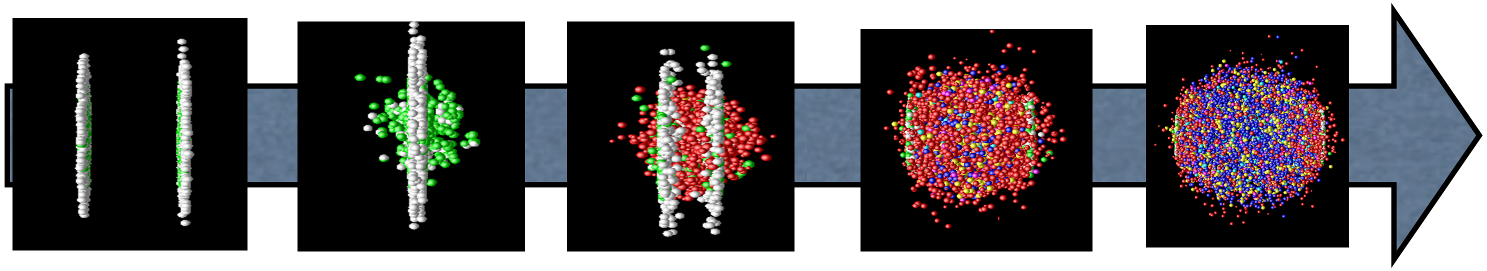
Nuclear Parton Distribution Functions



Saturation (low x, nonlinear QCD)



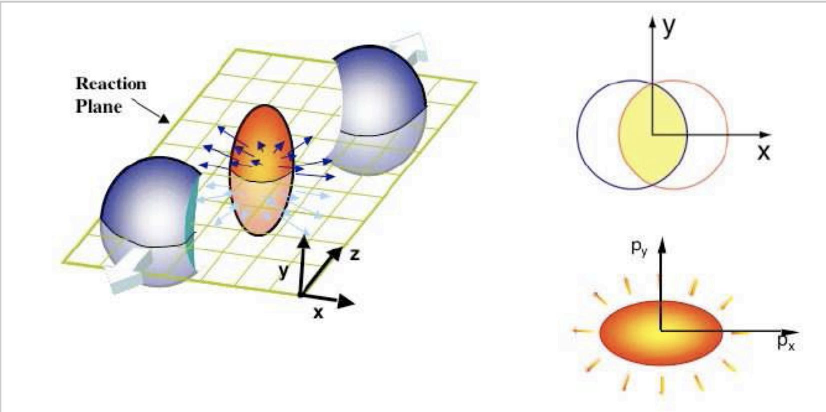
Quark Gluon Plasma, its initial and final states



Gluon emission from saturated nuclei Glasma? QGP Reconfinement

Quark Gluon Plasma

Landau 1953. **RHIC**: QGP strongly coupled plasma with liquid behaviour
instead of weakly interacting gas of partons



M.Tannenbaum, Rept.Prog.Phys 65 (2006) 2005

Related to cold atoms and to superstring theory [AdS/CFT]

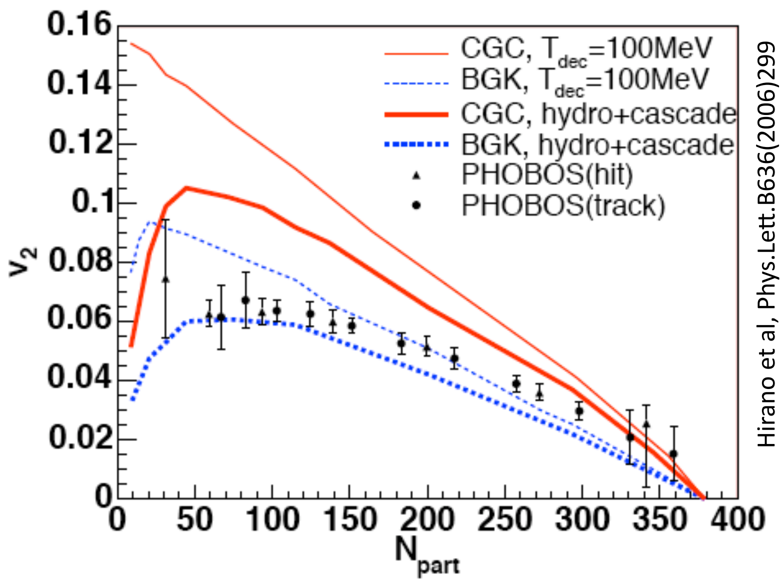
Collective flow in non-central collisions anisotropic

Anisotropy proportional to 1/viscosity of fireball,
dominantly elliptic (“v_2” coefficient)

QGP most perfect liquid – smallest shear viscosity/entropy

Conclusions depend on initial fireball eccentricity

eA to measure the initial conditions of QGP.



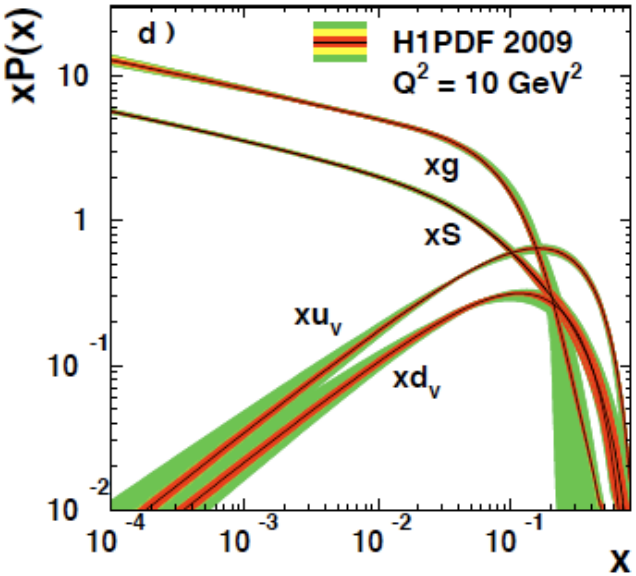
Hirano et al, Phys.Lett.B636(2006)299

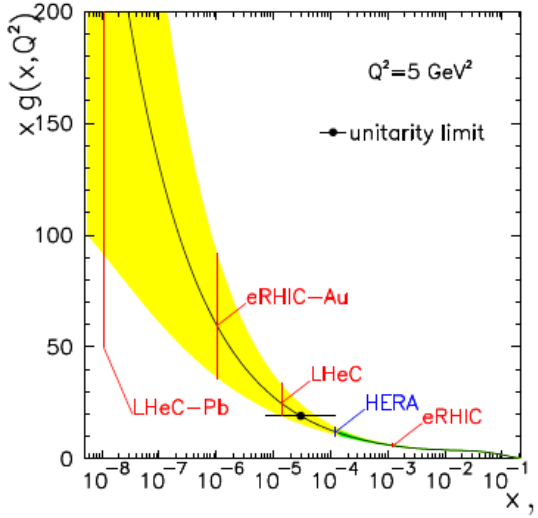
U.Heinz arXiv:0907.4256 (nucl.th)

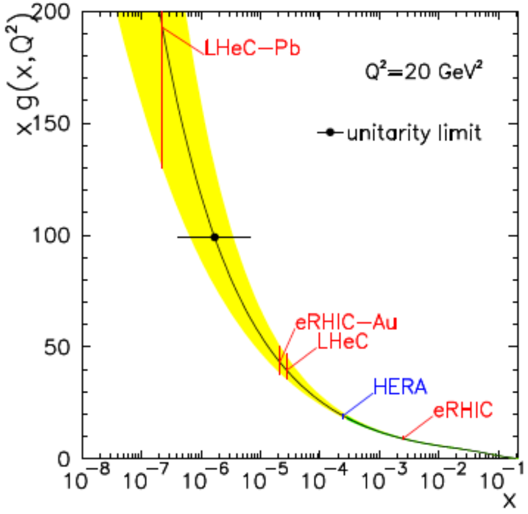
Colour Glass Condensate - Saturation

Perturbatively calculable via non-linear evolution equations

HERA: Quark and gluon densities in p rise towards low Bjorken x. Gluon dominant but no clear proof of nonlinear effects.







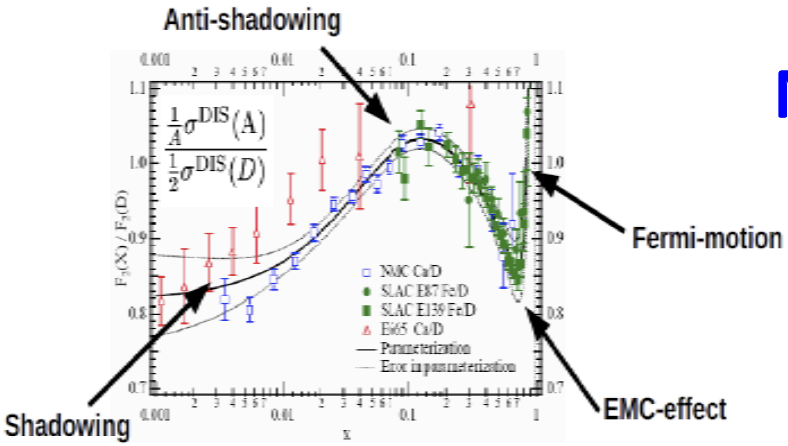
Expect saturation of rise at **$Q^2_s \approx xg\,\alpha_s \approx c\, x^{-\lambda} A^{1/3}$**

Qualitative change of scattering behaviour:

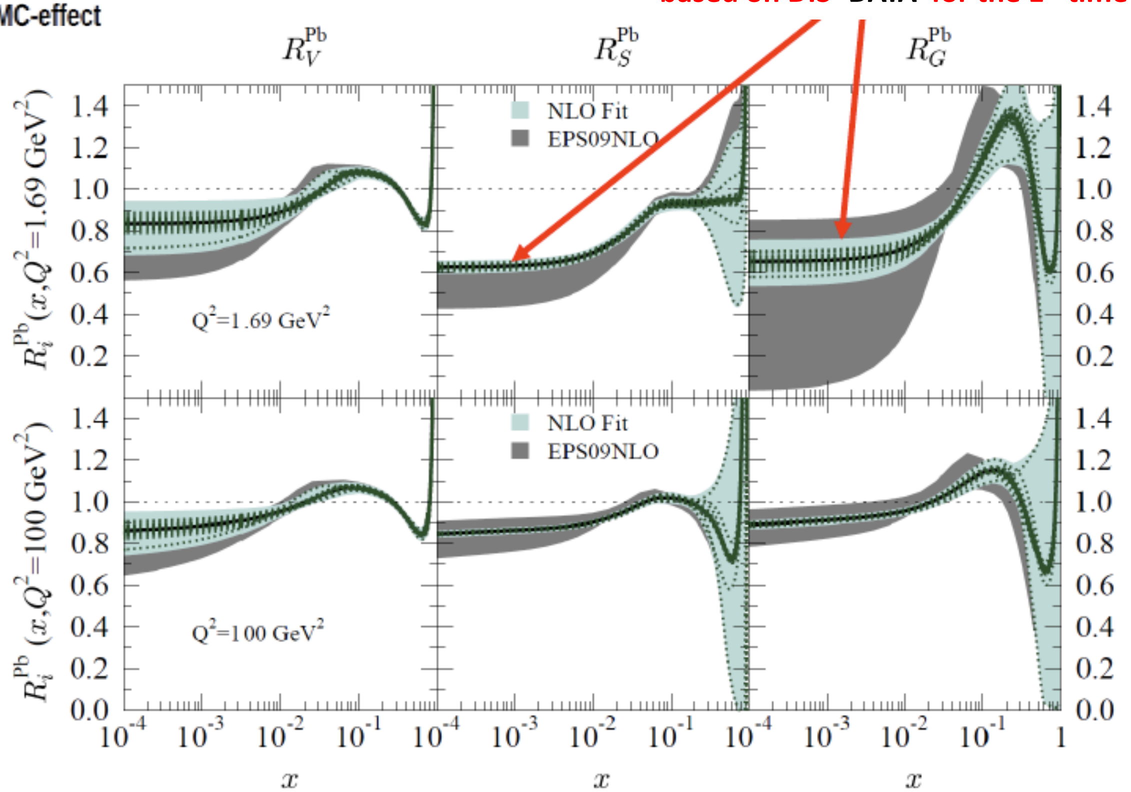
- Saturation of cross sections amplified with $A^{1/3}$ (A wider than p)
- Rise of diffraction to 50% of cross section
- hot spots of gluons or BDL?

The LHeC is bound to discover saturation in DIS both in ep and in eA in a region where α_s is small

Nuclear Parton Distributions



Study using eA LHeC pseudodata
Quantitative improvement, but
based on DIS `DATA' for the 1st time



K.Eskola, H.Paukkunen, C.Salgado, Divonne09

Fermi motion ← p tagging

p, D, Ca, Pb

LHeC will have immense impact on the partonic structure of nuclei

→ A complete determination of nPDFs in grossly extended range, into nonlinear regime

Table 2: SC linac parameters. *RT: room temperature.

	p-60	erl	p-140
RF frequency [MHz]	700	700	700
cavity length [m]	1	1	1
energy gain / cavity	31.5	18	31.5
R/Q [Ω]	403	403	403
Q_0 [10^{10}]	1	2.5	1
power loss, stat [W/cav.]	5	5	5
power loss, RF [W/cav]	12.3	32	12.3
power loss, total [W/cav]	17.3	37.2	17.3
real-est. gradient [MeV/m]	17.8	10.26	17.8
length/GeV [m]	55.7	97.5	55.7
#cavities/(1 GeV)	31.8	55.6	31.8
power loss/GeV (2 K) [kW]	0.55	2.06	0.55
"W per W" (1.8 K to RT*)	600	600	600
power loss/GeV (RT*) [MW]	0.33	1.24	0.3
final energy [GeV]	60	60	140
# passes for acceleration	2	3	2
# passes for deceleration	0	3	0
total linac length [km]	1.67	1.95	3.90
tot. cryo power (RT) [MW]	9.9	24.75	23.1
av. beam current [mA]	0.74	6.6	0.27
beam power at IP [MW]	45	396	39
RF power [MW]	89	(22)	75.6
cryo + RF power [MW]	99	(47)	98.4

Optics: β^*~ 0.1 m by combination of 3 ingredients:

(1)A **shorter free length to the interaction point, *l** of 10 m**, instead of 23 m for the LHC pp collisions, eases the requirements on the magnet aperture (~*l**) and reduces the chromaticity (~l^*/β^*).
(2)The triplet aperture must accommodate only one squeezed proton beam, instead of two for pp collisions, which **increases the aperture available for the single main beam by some 50%.** By itself this would allow decreasing β^* by more than a factor of 2 aperture-wise.
(3) Changing the superconductor material **from Nb-Ti to Nb_3Sn** may increase the maximum field and/or aperture by up to a factor of 2 [11]. Since (1) and (2) together can already achieve β^*~ 0.1 m,the new superconductor is not strictly necessary for reaching β^*=0.1 m, but it provides additional safety margin, e.g. for a thicker beam screen and cold bore or for spurious dispersion.

Conceptual Design Report
Large Hadron Electron Collider (LHeC) at CERN

DRAFT - February 2009

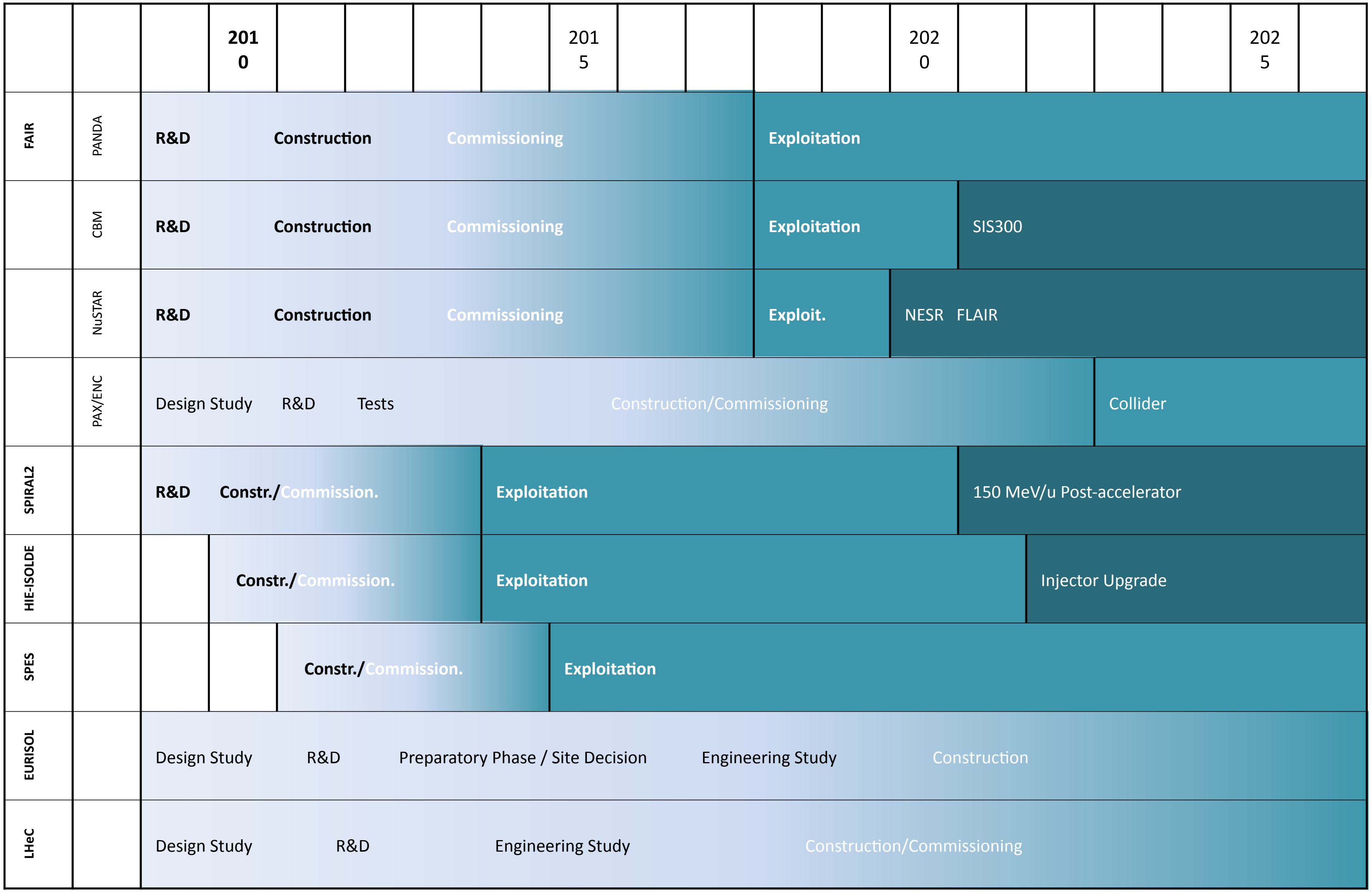
Table 1: IP beam parameters of protons and electrons.

	protons	electrons
energy [GeV]	7000	60
Lorentz factor γ	7460	117400
tr. norm. emittance $\gamma\epsilon_{x,y}$ [μm]	3.75	50
tr. geom. emittance $\epsilon_{x,y}$ [nm]	0.50	0.43
IP beta function $\beta^*_{x,y}$ [m]	0.10	0.12
rms IP beam size $\sigma^*_{x,y}$ [μm]	7	7
rms IP divergence $\sigma'^*_{x,y}$ [μrad]	70	58
disruption parameter D	2×10^{-6}	6.0
disruption angle θ_0 [μrad]	0.06	572
beam current [mA]	430–580	6.6

assumptions: $\sigma^*_p = \sigma^*_e$
LHC design emittance and bunch length.
proton IP beta function β^*=0.1 m

disruption angle θ_0 : conservative upper bound for largest deflection angle in collision [6]. Its numerical value for electrons ~ times the rms divergence of a non-colliding beam. → 10 σ beam minimum stay clear to extract e- beam from IP

NuPECC – Roadmap 5/2010: New Large-Scale Facilities



G. Rosner, NuPECC Chair, Madrid 5/10 - DRAFT