Precision Measurements with the LHeC

Accelerator
Detector
Case Studies
Remarks

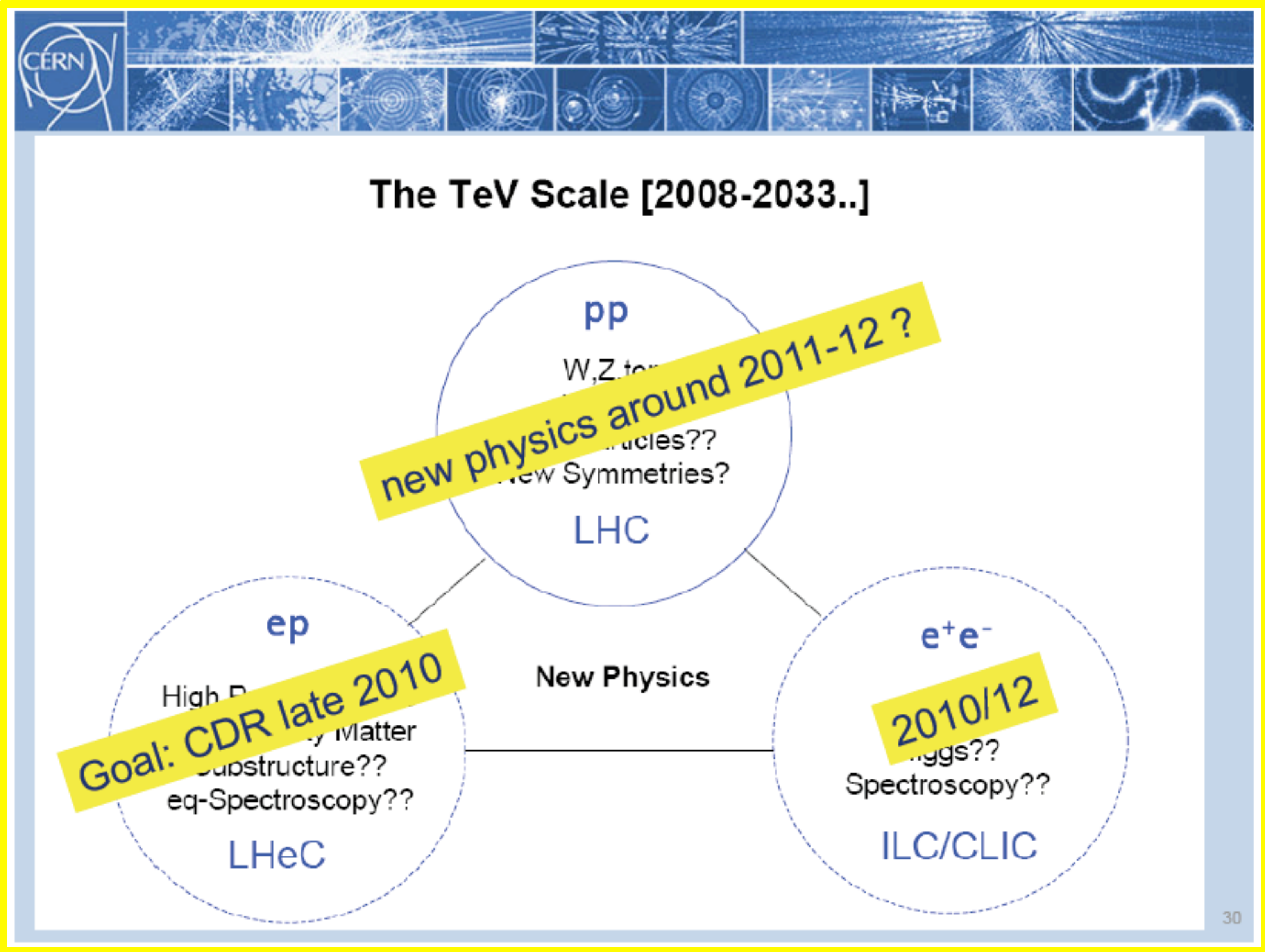
Max Klein
for the LHeC Study Group

UNIVERSITY OF LIVERPOOL

LHeC

Precision at the LHC, Workshop, Paris, 17.12.10

http://cern.ch/lhec



Rolf Heuer: 3/4. 12. 09 at CERN: From the Proton Synchroton to the Large Hadron Collider
50 Years of Nobel Memories in High-Energy Physics

LHeC Accelerator: Collaborating Institutes

CERN

SLAC
NATIONAL ACCELERATOR LABORATORY

NTNU
Norwegian University of Science and Technology

The Cockcroft Institute
of Accelerator Science and Technology

Jefferson Lab
Thomas Jefferson National Accelerator Facility

CLIC

ANKARA ÜNİVERSİTESİ
ANKARA ÜNİVERSİTESİ 1946

NİĞDE ÜNİVERSİTESİ 1992

ULUDAĞ ÜNİVERSİTESİ 1975

TOBB ETU

INFN
Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Legnaro

DESY

LAL Physique des accélérateurs

ECFA

EPFL
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

UNIVERSITY OF LIVERPOOL

BROOKHAVEN NATIONAL LABORATORY

СИБИРСКОЕ ОТДЕЛЕНИЕ РАН
ИНСТИТУТ ЯДЕРНОЙ ФИЗИКИ
им. Г.И.Будкера
630090 Новосибирск

KEK

Two Options

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

$$N_p = 1.7 \cdot 10^{11}, \varepsilon_p = 3.8\mu m, \beta_{px(y)} = 1.8(0.5)m, \gamma = \frac{E_p}{M_p}$$

$$L = 8.2 \cdot 10^{32} cm^{-2} s^{-1} \cdot \frac{N_p 10^{-11}}{1.7} \cdot \frac{m}{\sqrt{\beta_{px}\beta_{py}}} \cdot \frac{I_e}{50mA}$$

$$I_e = 0.35mA \cdot P[MW] \cdot (100/E_e[GeV])^4$$

Ring-Ring

Power Limit of 100 MW wall plug

“ultimate” LHC proton beam

60 GeV $e^{\pm}$ beam

→L = 2 10^{33} $cm^{-2}s^{-1}$ → O(100) fb^{-1}

LINAC Ring

Pulsed**, 60 GeV**: ~10^{32}

High luminosity:

Energy recovery: $P=P_0/(1-\eta)$

$\beta^*=0.1m$

[5 times smaller than LHC by reduced l*, only one p squeezed and IR quads as for HL-LHC]

L = 10^{33} $cm^{-2}s^{-1}$ → O(100) fb^{-1}

$$L = \frac{1}{4\pi} \cdot \frac{N_p}{\varepsilon_p} \cdot \frac{1}{\beta^*} \cdot \gamma \cdot \frac{I_e}{e}$$

$$N_p = 1.7 \cdot 10^{11}, \varepsilon_p = 3.8\mu m, \beta^* = 0.2m, \gamma = 7000/0.94$$

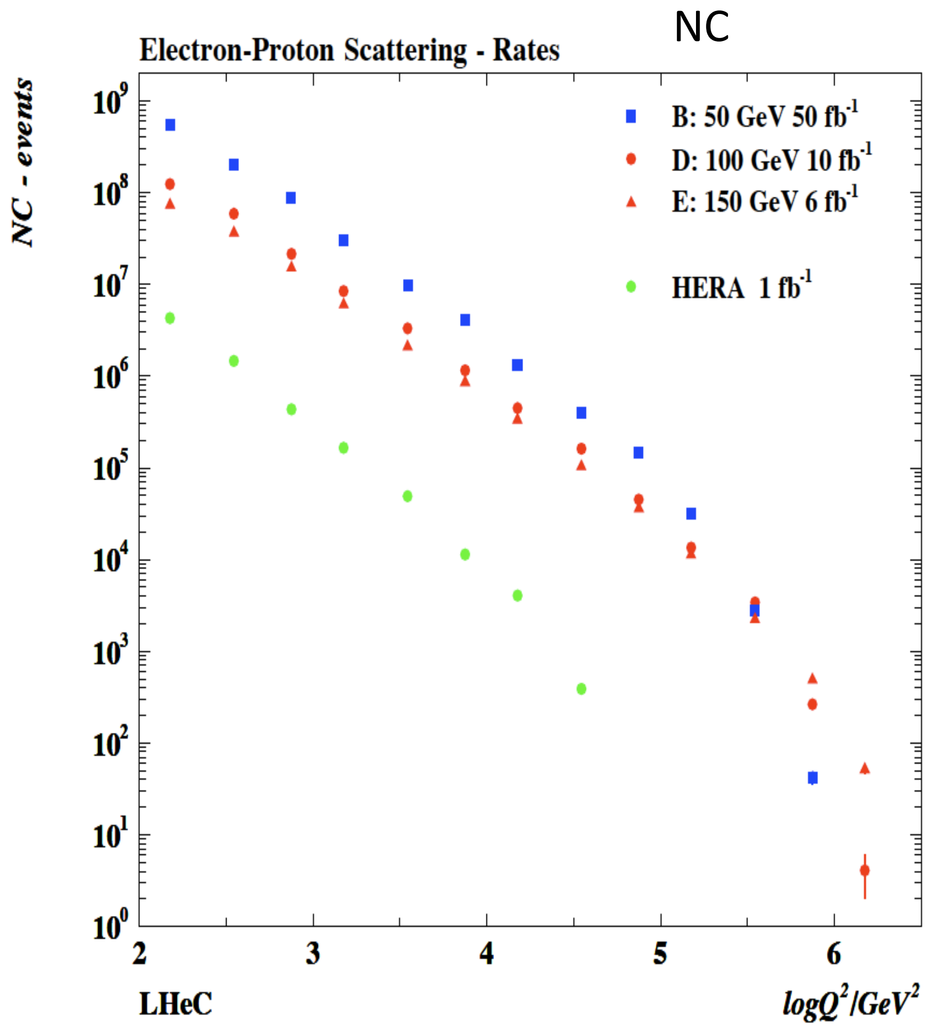
$$L = 8 \cdot 10^{31} cm^{-2} s^{-1} \cdot \frac{N_p 10^{-11}}{1.7} \cdot \frac{0.2}{\beta^*/m} \cdot \frac{I_e/mA}{1}$$

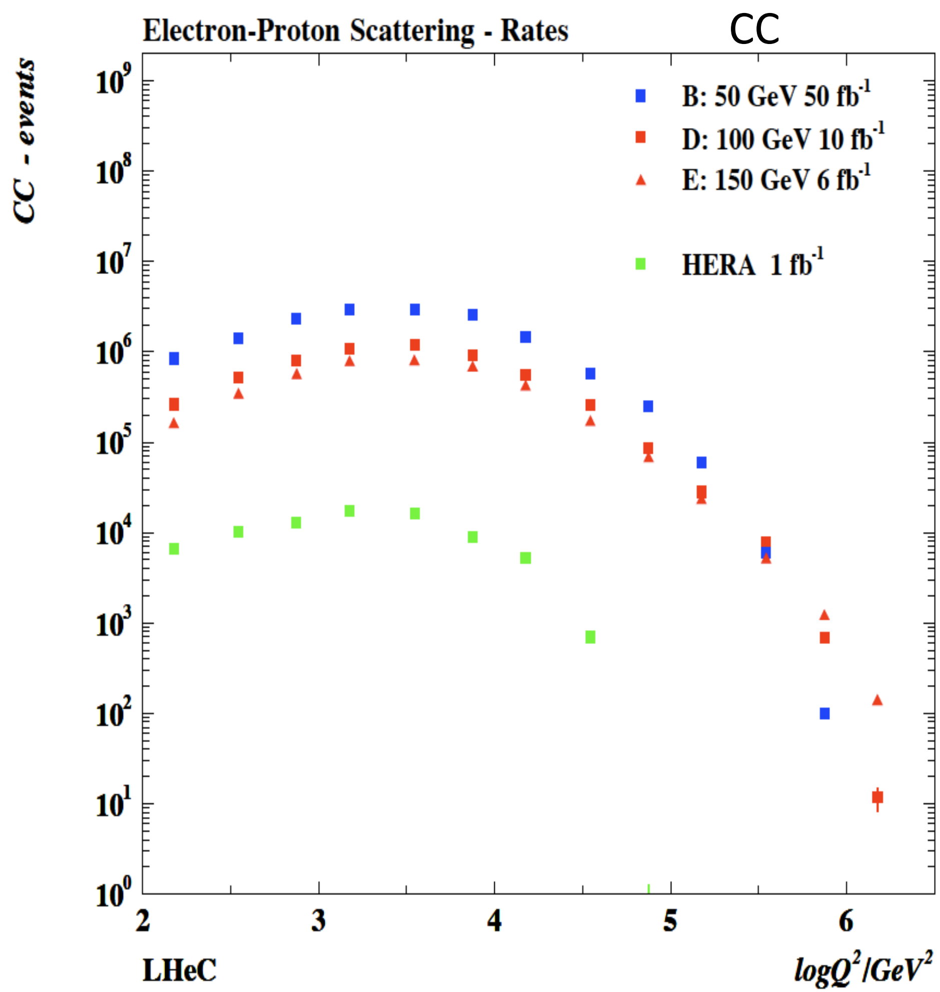
$$I_e = mA \frac{P/MW}{E_e/GeV}$$

Synchronous ep and pp operation (small ep tuneshifts)

The LHC p beams provide 100 times HERA’s luminosity

Statistics





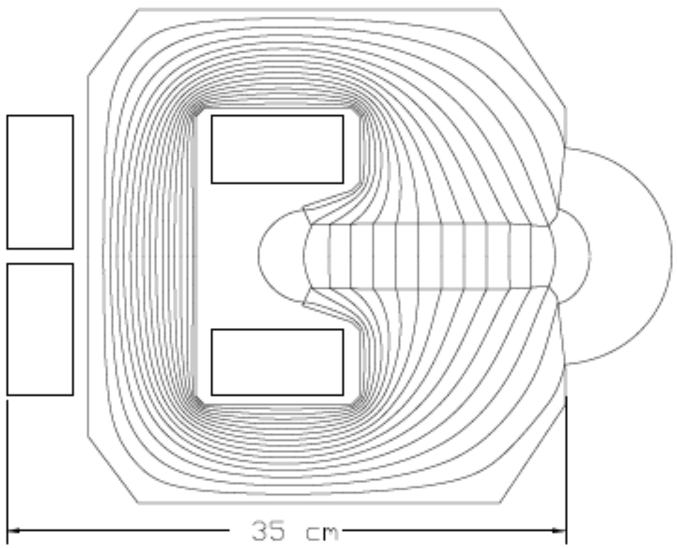
Need much higher luminosity than HERA to cover largest Q^2. Huge rates in electroweak region.

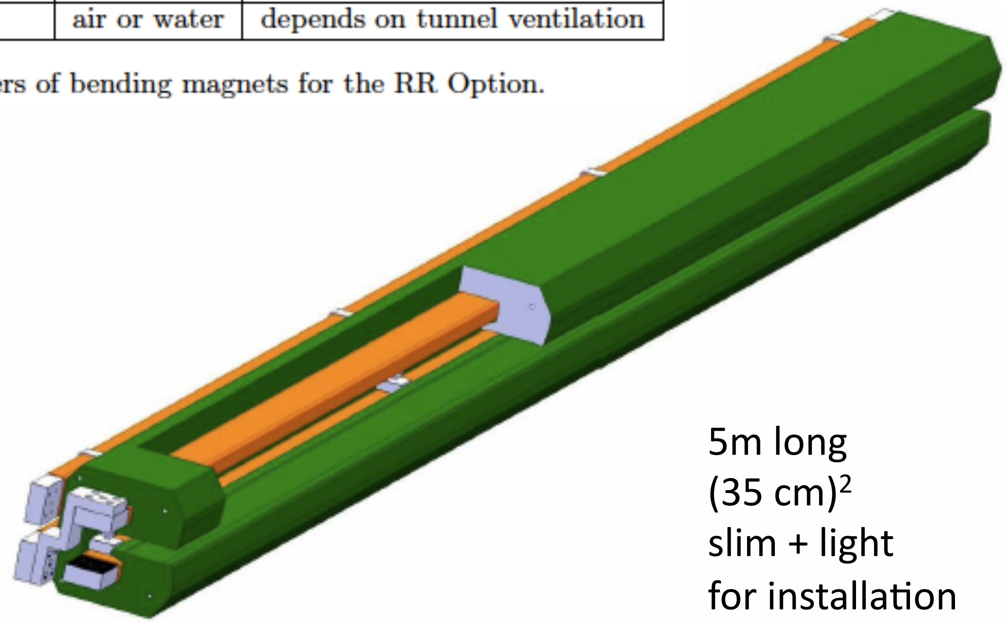
Ring Dipole Magnets

BINP &
CERN
prototypes

Parameter	Value	Units
Beam Energy	10-60	GeV
Magnetic Length	5.35	Meters
Magnetic Field	0.127-0.763	Tesla
Number of magnets	3080	
Vertical aperture	40	mm
Pole width	150	mm
Number of turns	2	
Current @ 0.763 T	1300	Ampere
Conductor material	copper	
Magnet inductance	0.15	milli-Henry
Magnet resistance	0.16	milli-Ohm
Power @ 60 GeV	270	Watt
Total power consumption @ 60 GeV	0.8	MW
Cooling	air or water	depends on tunnel ventilation

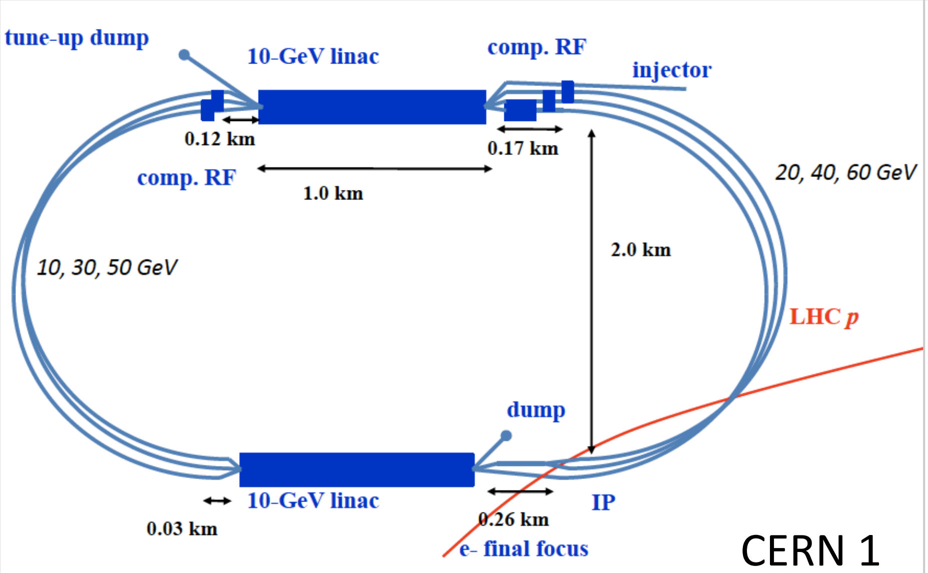
Table 3.2: Main parameters of bending magnets for the RR Option.

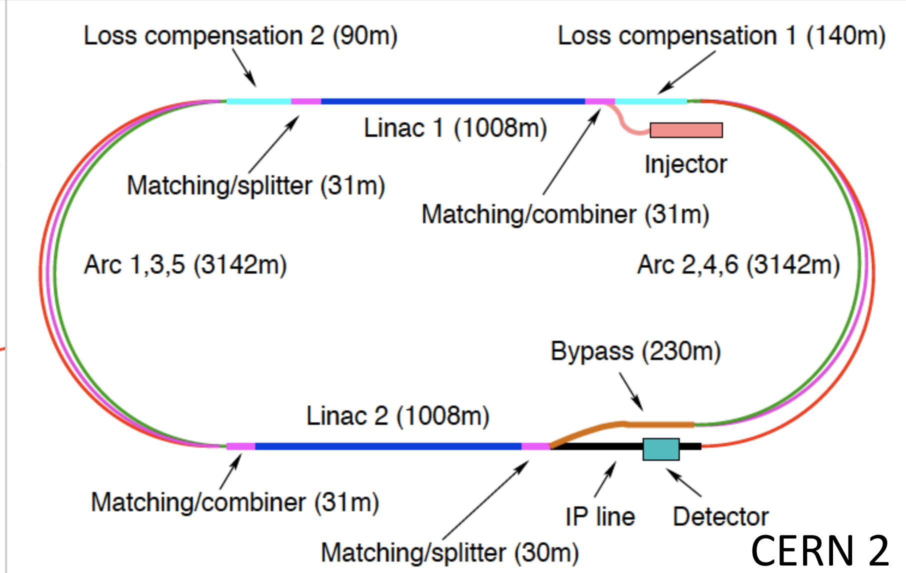


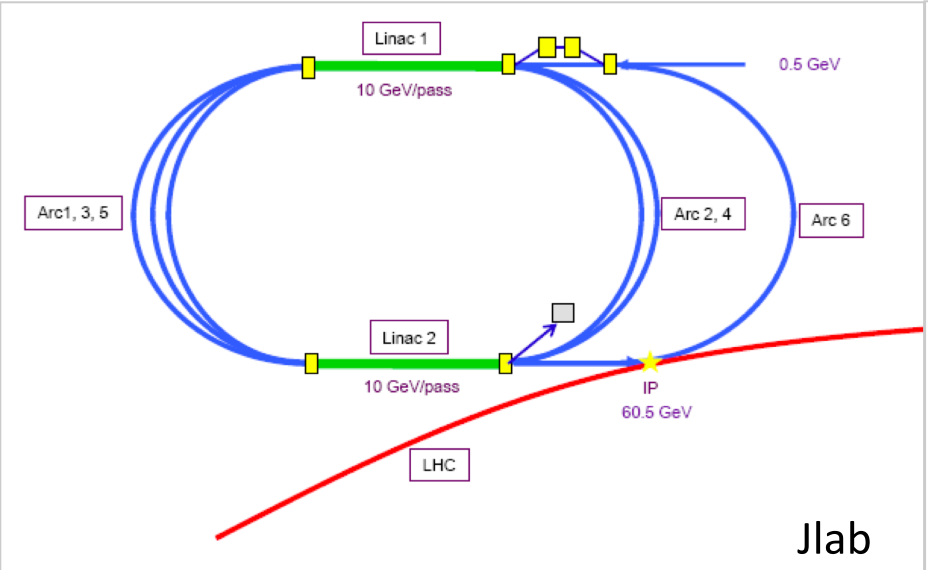


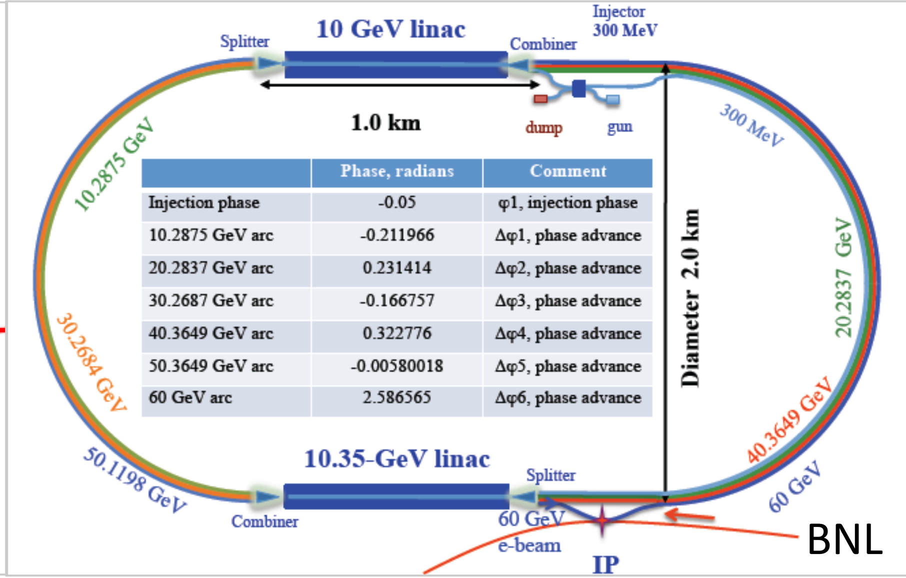
5m long
(35 cm)^2
slim + light
for installation

LINACs







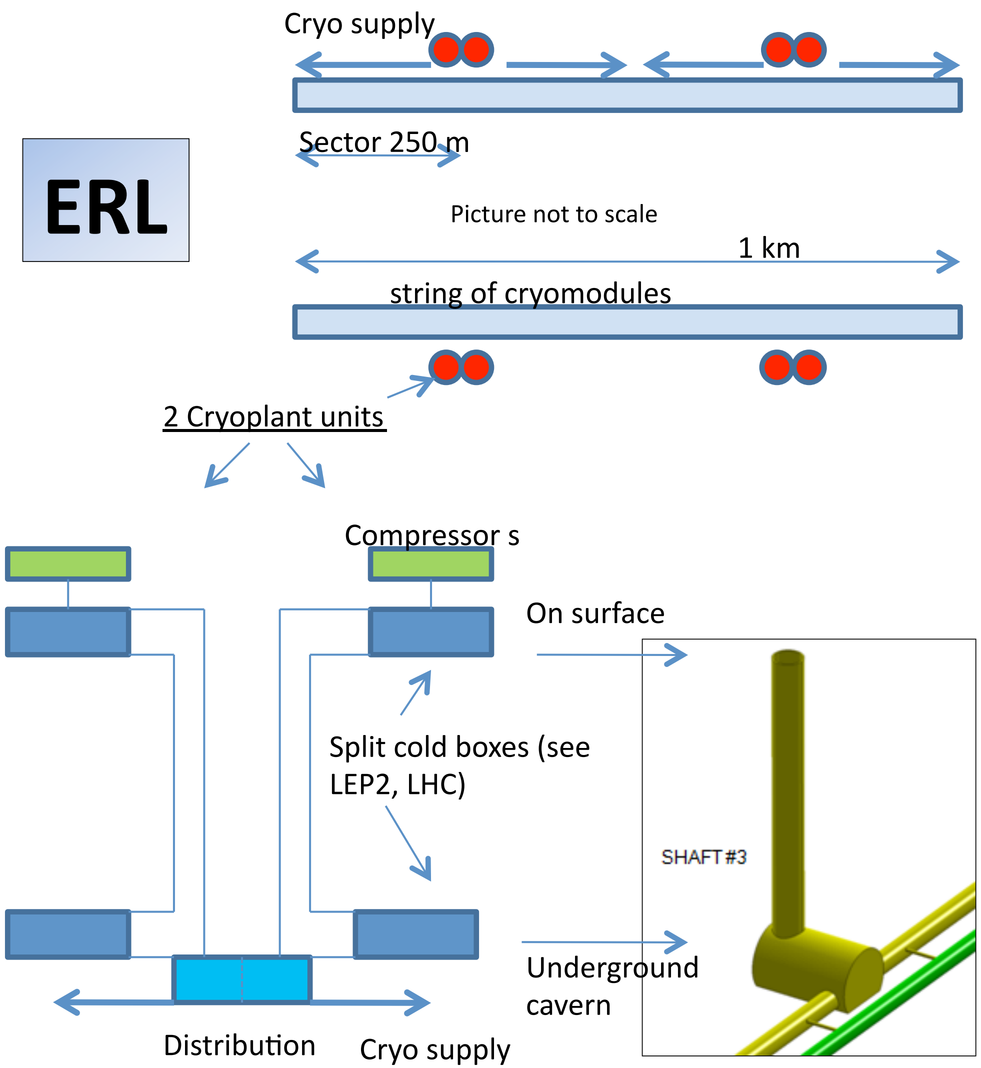


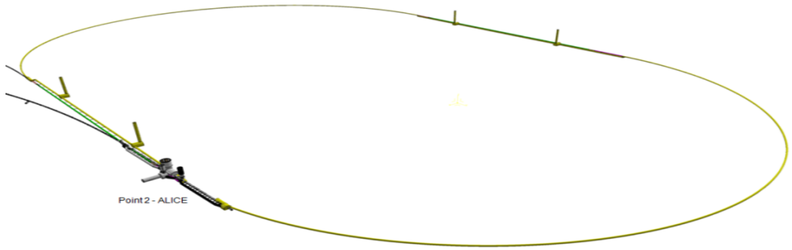
	Phase, radians	Comment
Injection phase	-0.05	φ1, injection phase
10.2875 GeV arc	-0.211966	Δφ1, phase advance
20.2837 GeV arc	0.231414	Δφ2, phase advance
30.2687 GeV arc	-0.166757	Δφ3, phase advance
40.3649 GeV arc	0.322776	Δφ4, phase advance
50.3649 GeV arc	-0.00580018	Δφ5, phase advance
60 GeV arc	2.586565	Δφ6, phase advance

Two 10 GeV Linacs, 3 returns, ERL, 720 MHz cavities, rf, cryo, magnets, injectors, sources, dumps…

Linac-Ring Cryogenics

ERL





CW operation, 18 MV/m
2 K thermal load: 37 W/m (for active length)
2 K total therma l load: 42 kW @ 2 K
Electric power: 30 MW
(with a COP of 700)

Cooling requirements dominated by dynamic losses at 2 K
(other loads neglected here for simplicity)

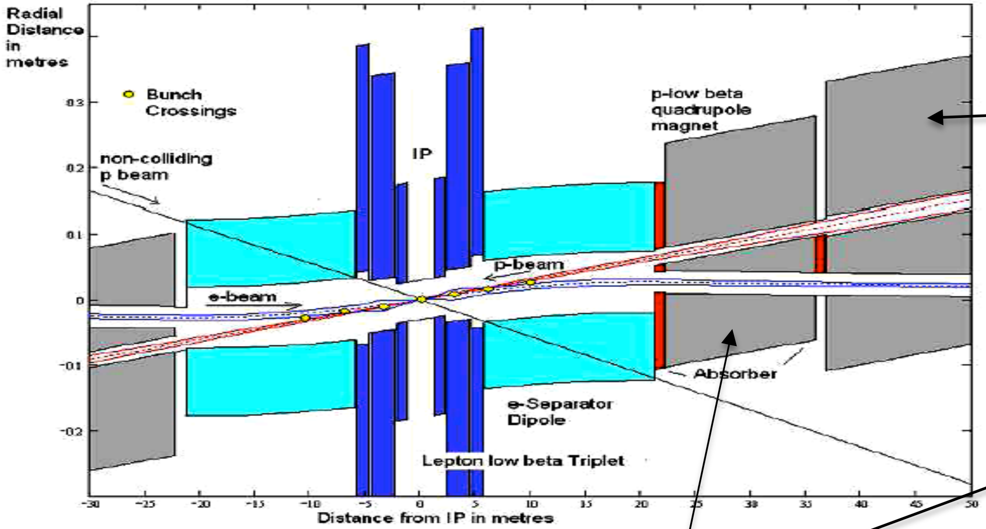
Lay-out is based on LHC cryogenic principles with split cold boxes (surface cold box and underground cold box with cold compressors).

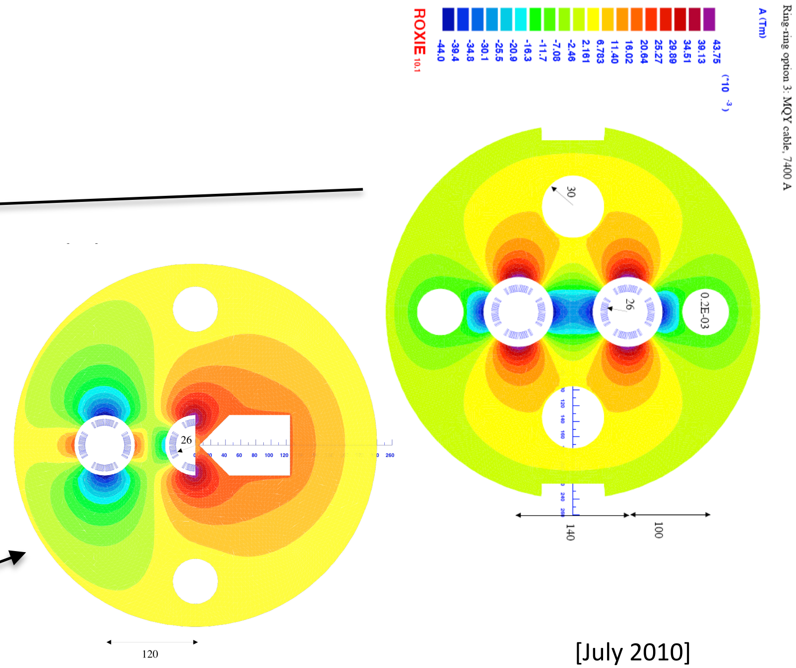
Refrigerator units of approx. 5 kW @ 2 K assumed. To be designed. Technology and experience: LHC, CEBAF (JLAB).

Interaction Region(s)

RR -Small crossing angle ~1mrad (25ns) to avoid first parasitic crossing (L x 0.77)
LR – Head on collisions, dipole in detector to separate beams
Synchrotron radiation –direct and back, absorption simulated (GEANT4) ..

Focus of current activity



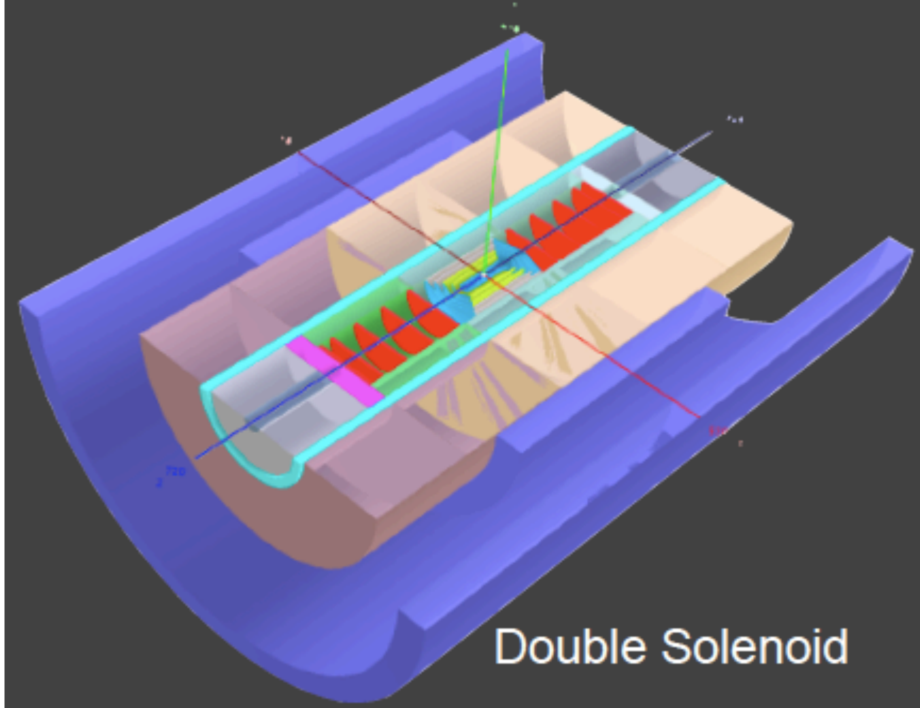


[July 2010]

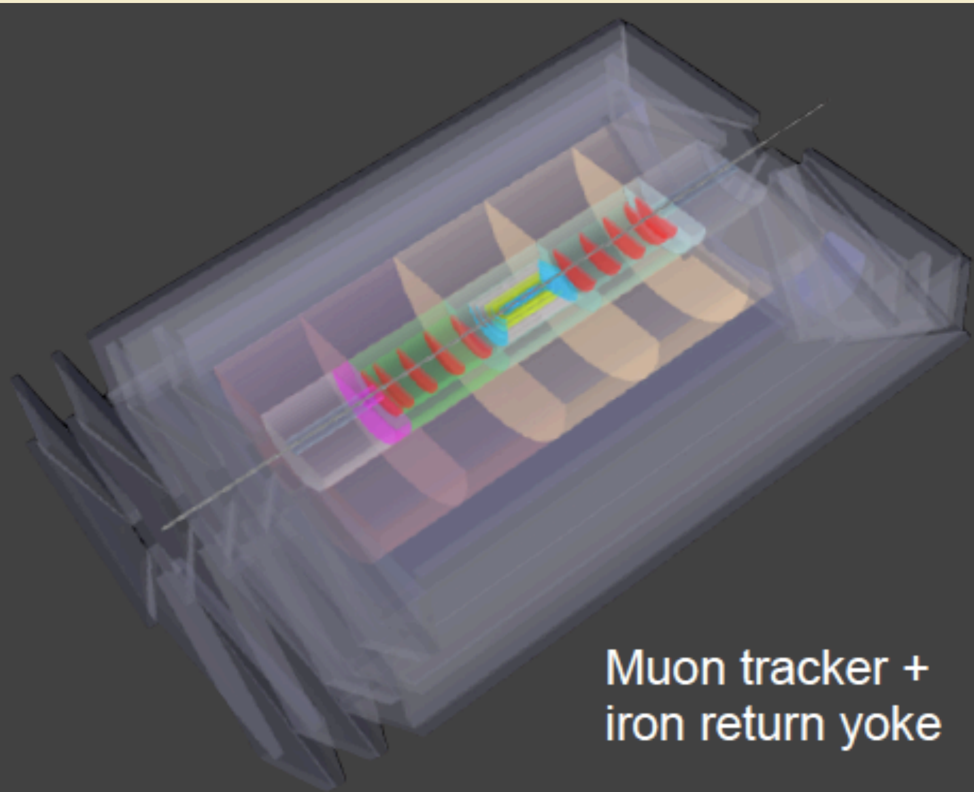
1st sc half quad (focus and deflect)
separation 5cm, g=127T/m, MQY cables, 4600 A

2nd quad: 3 beams in horizontal plane
separation 8.5cm, MQY cables, 7600 A

Double Solenoid Detector



Double Solenoid



Muon tracker +
iron return yoke

- 2 big Solenoids +5T/-1.5T outside HCAL (evaluated by H.Ten Kate) saving ~10kTons steel for return yoke (~10M$)
- superior muon track measurement in between the 2 magnets

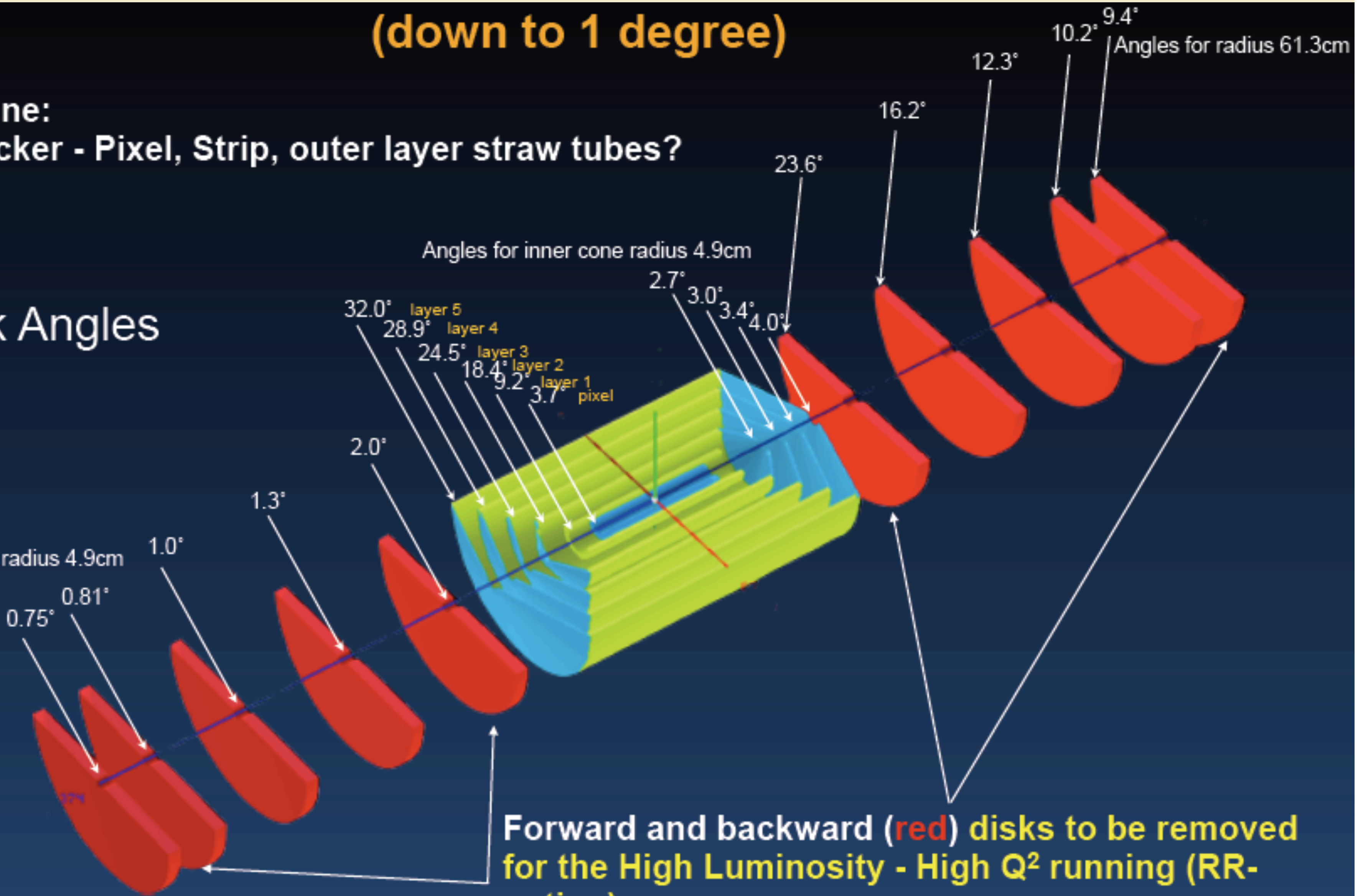
Fwd/Bwd asymmetry in energy deposited and thus in technology [W/Si vs Pb/Sc..]
Present dimensions: LxD =17x10m^2 [CMS 21 x 15m^2 , ATLAS 45 x 25 m^2]
Taggers at -62m (e),100m (γ,LR), -22.4m (γ,RR), +100m (n), +420m (p)

Track Detector Concept

(down to 1 degree)

Baseline:
Si Tracker - Pixel, Strip, outer layer straw tubes?

Track Angles

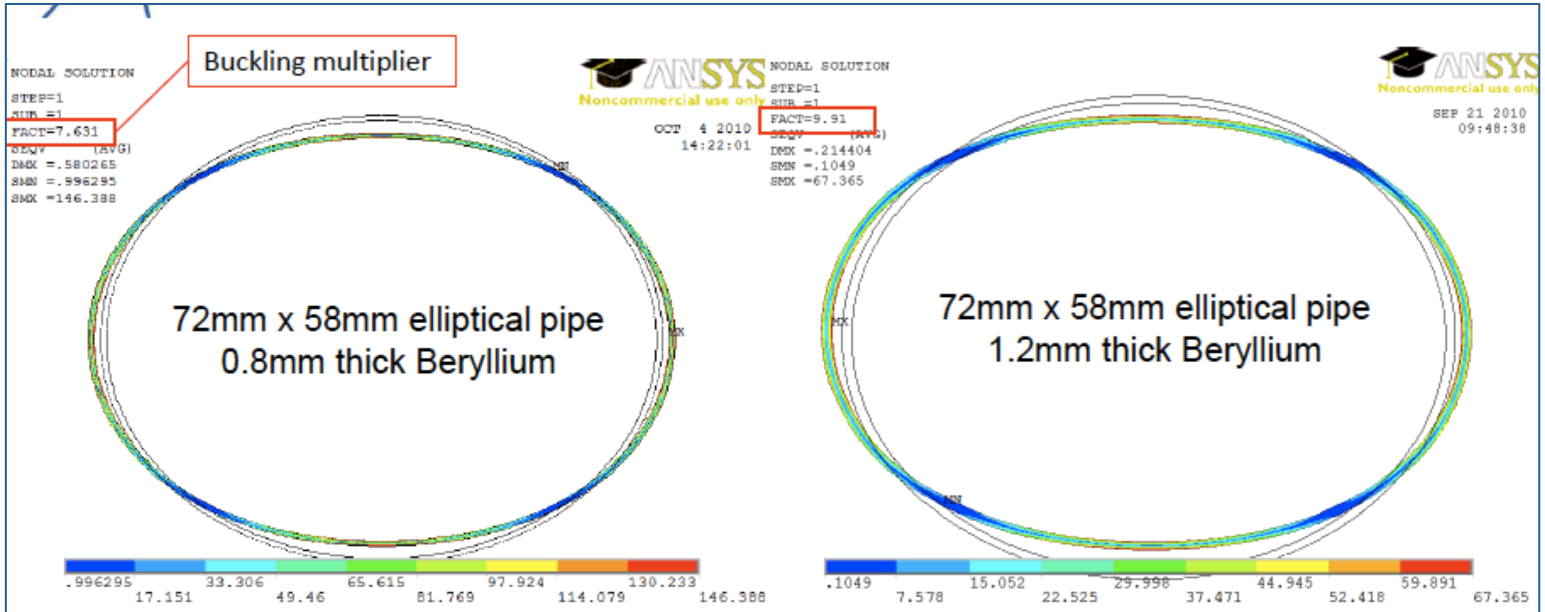


Forward and backward (red) disks to be removed for the High Luminosity - High Q² running (RR-option)

Alternative technologies: MAPS, DEPFET, GOSSIP* (talk of H.van de Graf)

*Gas On Slimmed Silicon Pixels (or Strixels/Pads) - *NIKHEF*

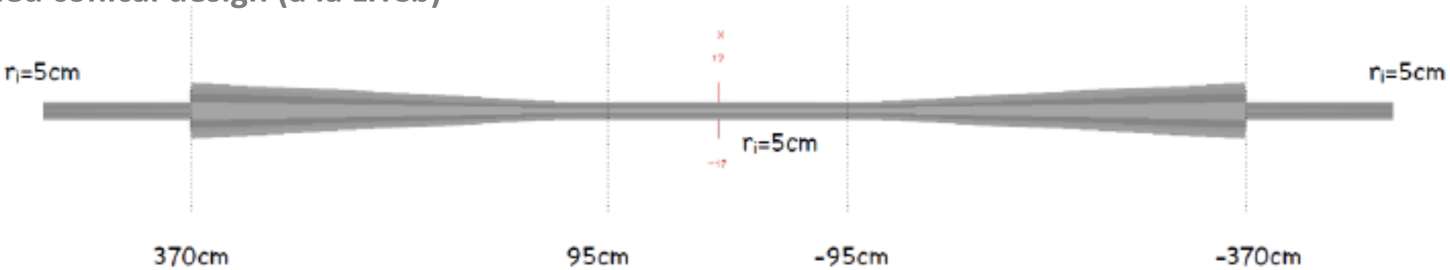
Beam Pipe Design



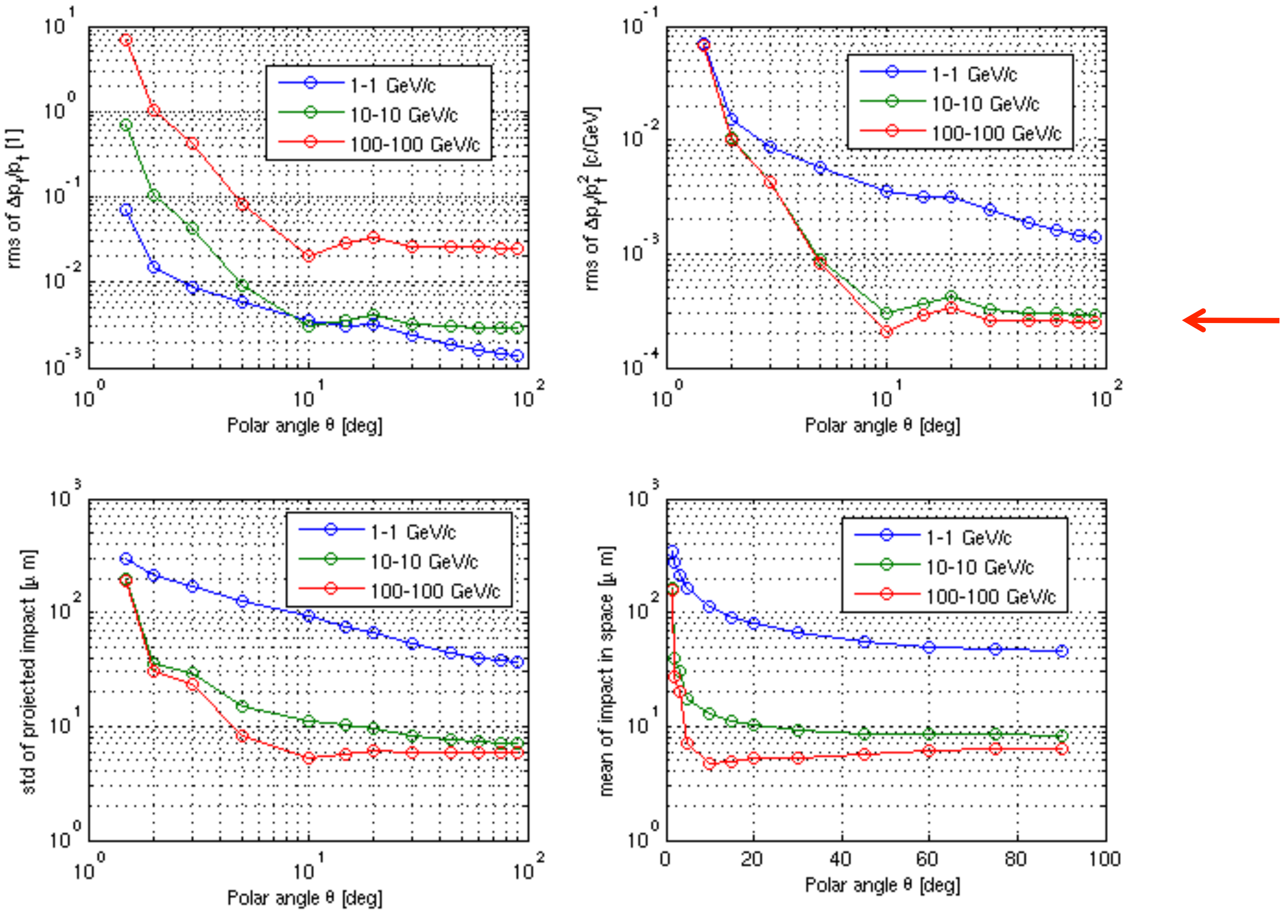
Equivalent Stress Contours
+
Deformed/Undeformed Shapes

Minimum thickness for Be, elliptical (constant geometry) pipe in order of 1mm

Also studied conical design (a la LHCb)



Momentum Resolution



$$H1:CJC:\frac{\delta p_T}{p_T^2} := 3\cdot 10^{-3}\,GeV^{-1}$$
$$B = 1.2T, \Delta \approx 200\mu m, N \approx 20 : L = 1m$$

$$\frac{\delta p_T}{p_T^2} = \frac{\Delta}{0.3BL^2}\cdot\sqrt{\frac{720}{N+4}} = 1.7\cdot 10^{-4}\,GeV^{-1}$$
$$B = 3.5T, \Delta \approx 10\mu m, N \approx 2*5+3 : L = 0.6m$$

Calorimeter - Resolutions and Scales

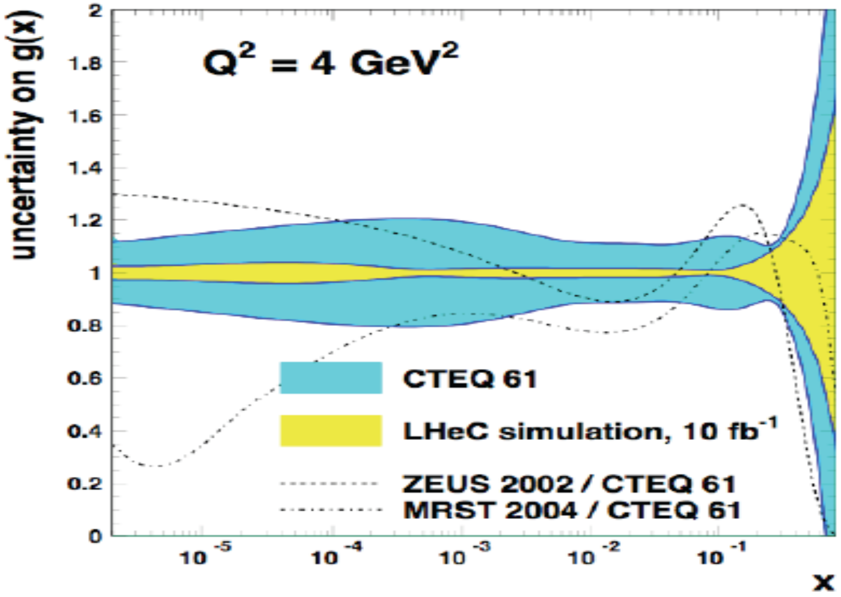
approximate angular range / degrees	backward 179 - 135	barrel 135 -45	forward 45-1
electron energy/GeV	3-100	10-400	50-5000
x_e	$10^{-7}-1$	$10^{-4}-1$	$10^{-2}-1$
elm scale calibration in %	0.1	0.2	0.5
elm energy resolution $\delta E/E$ in $\% \cdot \sqrt{E/GeV}$	10	15	15
hadronic final state energy/GeV	3-100	3-200	3-5000
x_h	$10^{-7}-10^{-3}$	$10^{-5}-10^{-2}$	$10^{-4}-1$
hadronic scale calibration in %	2	1	1
hadronic energy resolution in $\% \cdot \sqrt{E/GeV}$	60	50	40

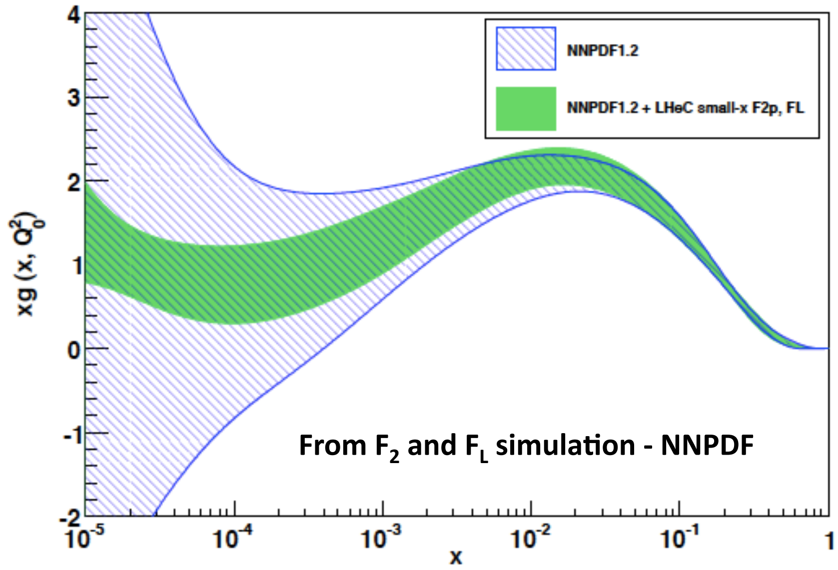
Table 6.1: Summary of calorimeter kinematics and requirements for the default design energies of $60 \times 7000\,\mathrm{GeV}^2$, see text. The forward (backward) calorimetry has to extend to $1^\circ(179^\circ)$.

Acceptance and Calibration

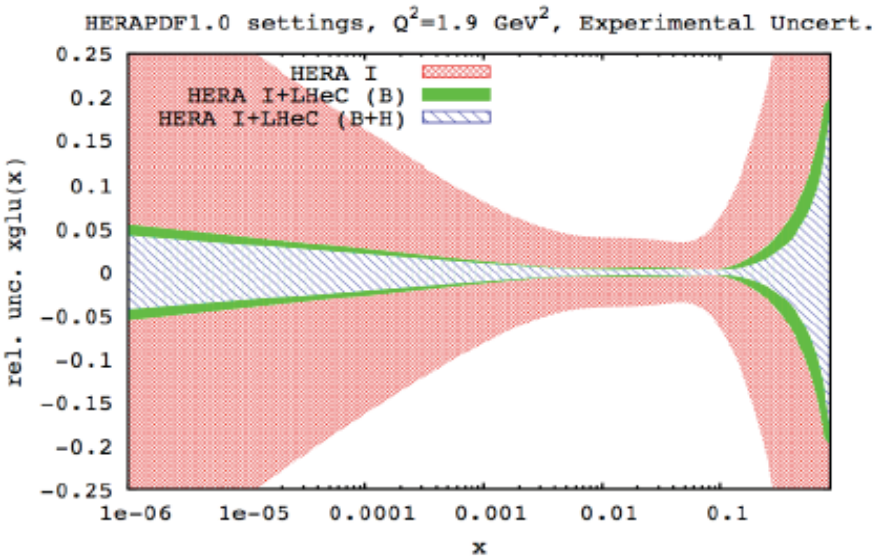
High luminosity to reach high Q^2 and large x		
10^{33}	1-5 10^{31}	
Largest possible acceptance		Acceptance
1-179°	7-177°	
High resolution tracking		Modern Si
0.1 mrad	0.2-1 mrad	
Precision electromagnetic calorimetry		DA, kin peak, High statistics
0.1%	0.2-0.5%	
Precision hadronic calorimetry		may be possible track+calo, e/h
0.5%	1%	
High precision luminosity measurement		Lumi will be hard
0.5%	1%	
LHeC	H1	

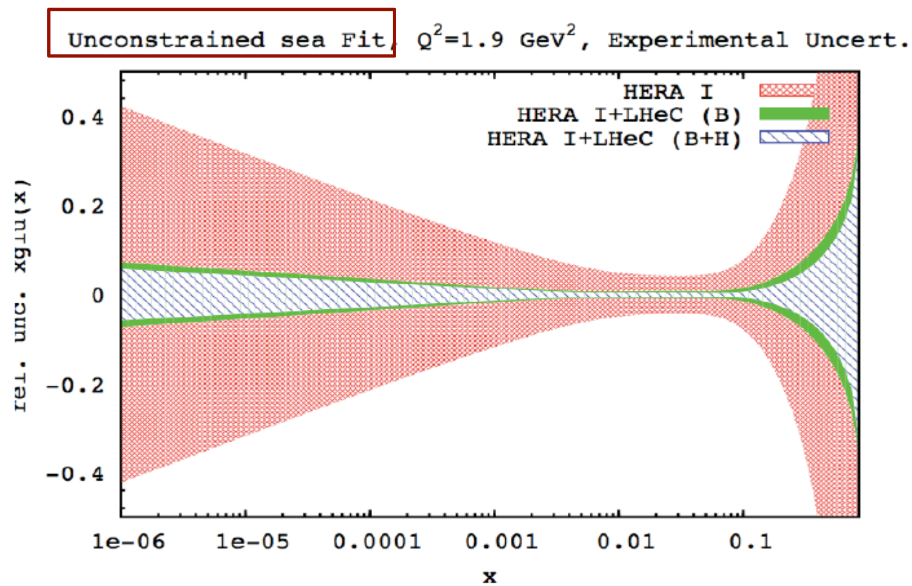
Gluon Distribution





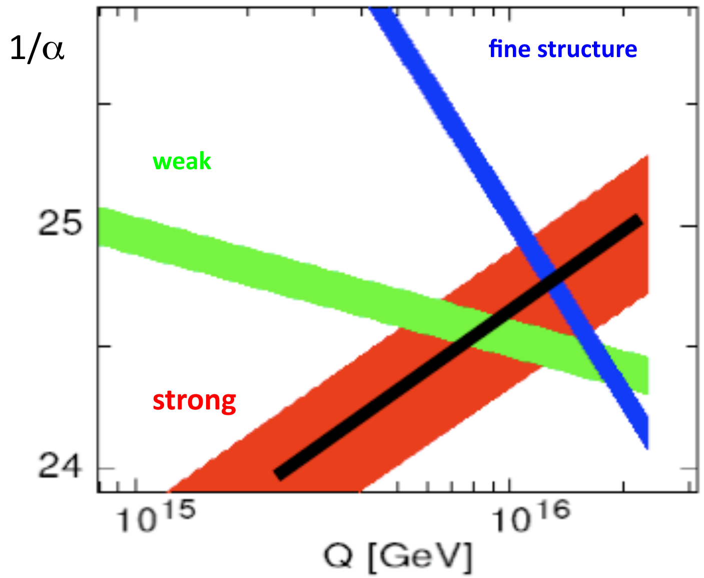
NLO QCD “Fits” of LHeC simulated data





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%

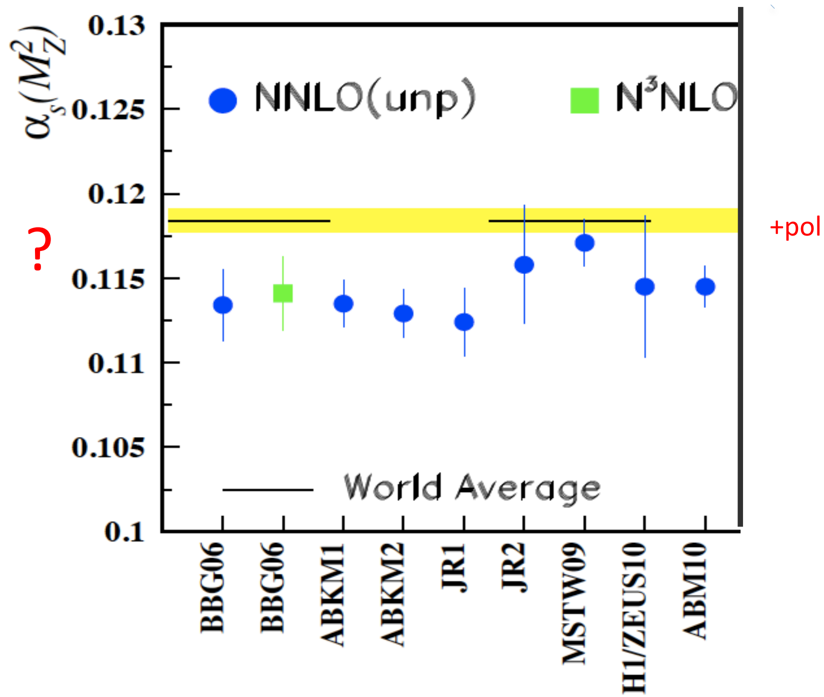
α_s least known of coupling constants

Grand Unification predictions suffer from $\delta\alpha_s$

DIS tends to be lower than world average

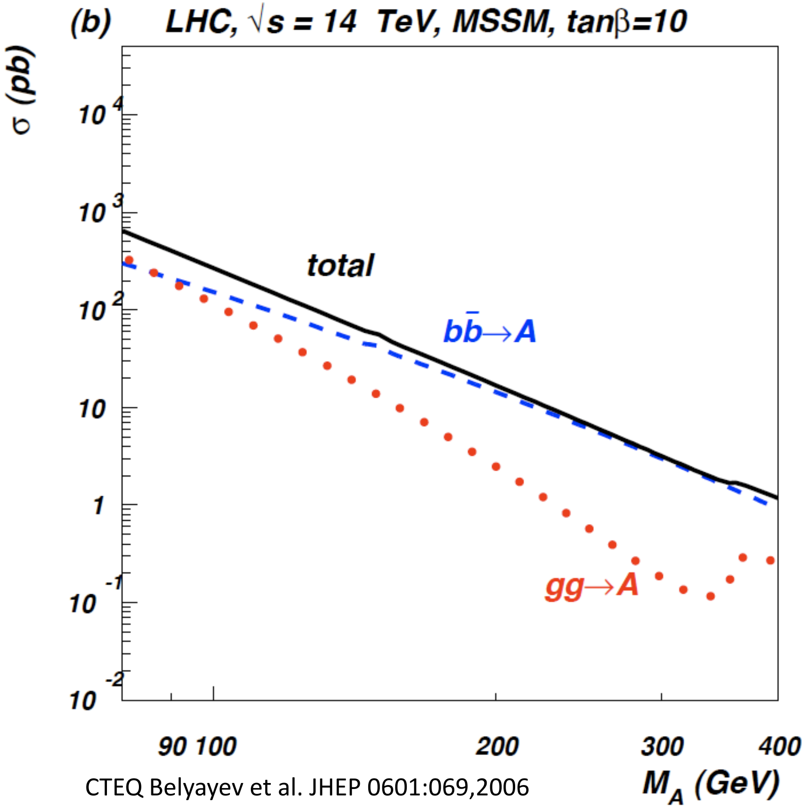
LHeC: per mille accuracy indep. of BCDMS.

Challenge to experiment and to h.o. QCD

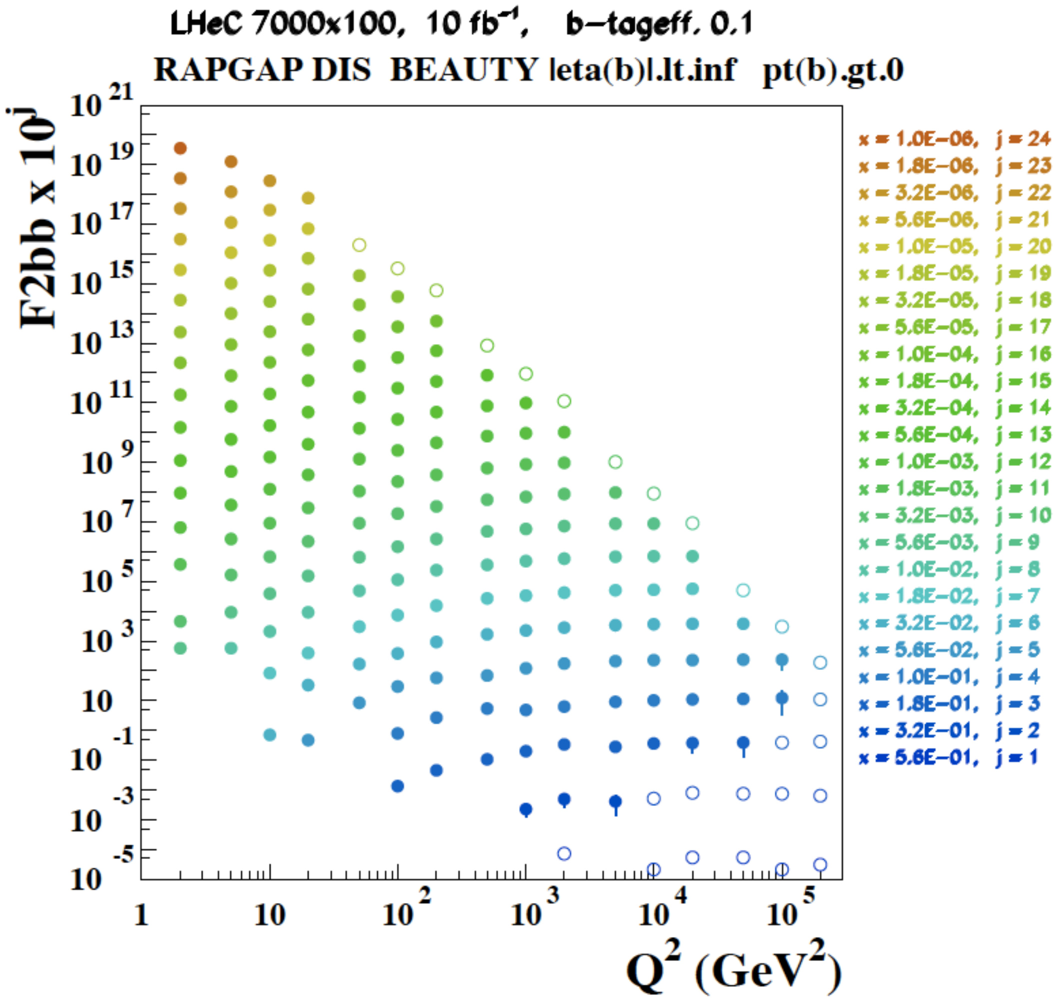


J.Bluemlein and H. Boettcher, arXiv 1005.3013 (2010)

Beauty - MSSM Higgs



CTEQ Belyayev et al. JHEP 0601:069,2006

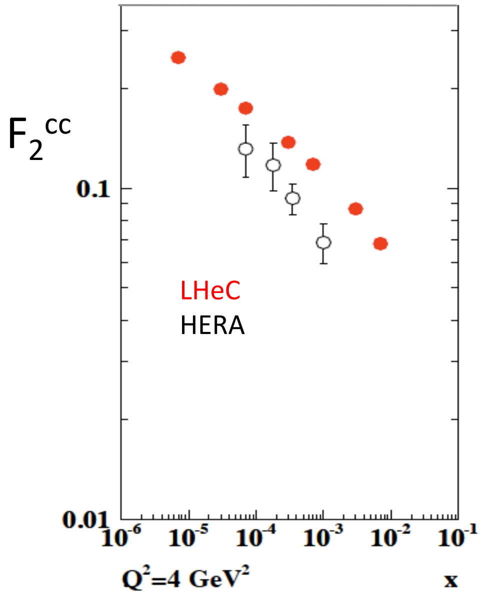


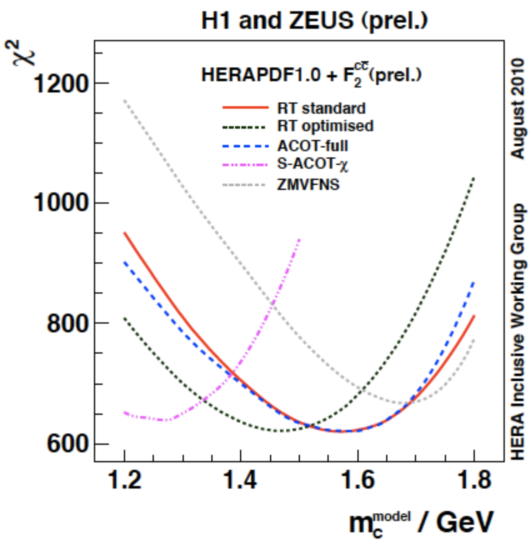
In MSSM Higgs production is b dominated

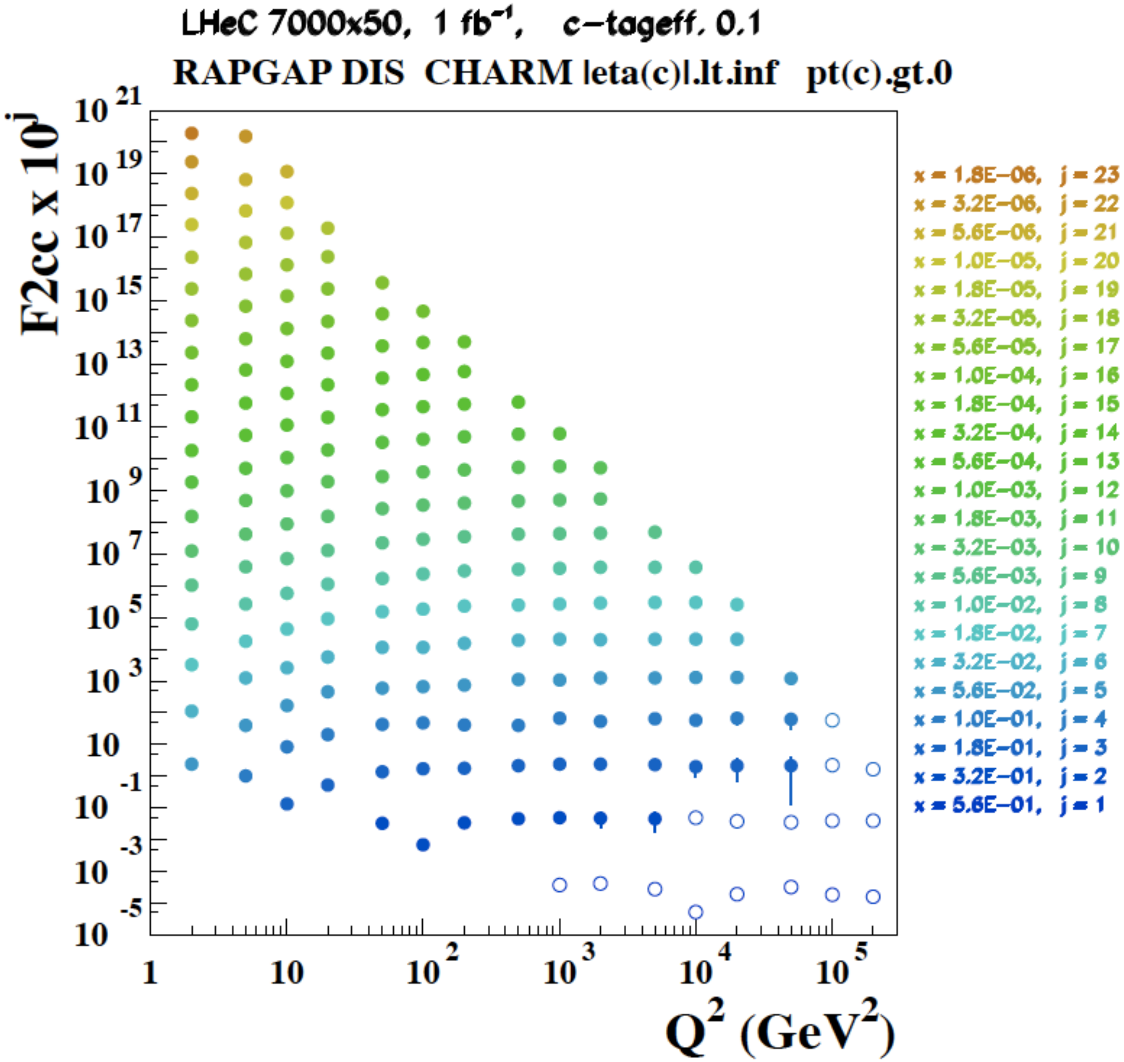
HERA: First measurements of b to ~20%
LHeC: precision measurement of b-df

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

Charm – α_s

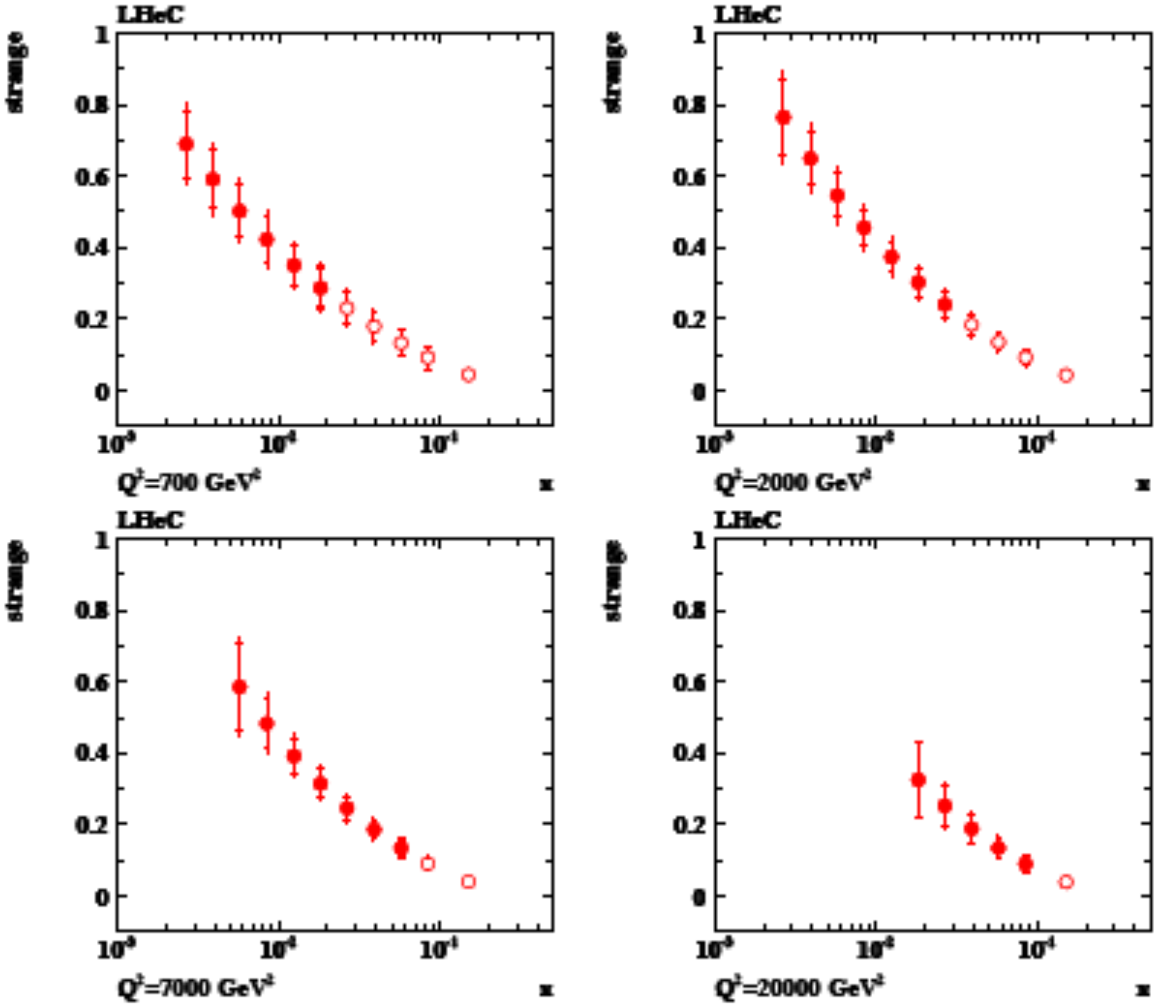






LHeC: higher fraction of c, larger range, smaller beam spot, better Si detectors

Strange (=? anti-strange) Quark



$W^{+}s \rightarrow c$

$1\,fb^{-1}$

$\varepsilon_{c} = 0.1$

$\varepsilon_{q} = 0.01$

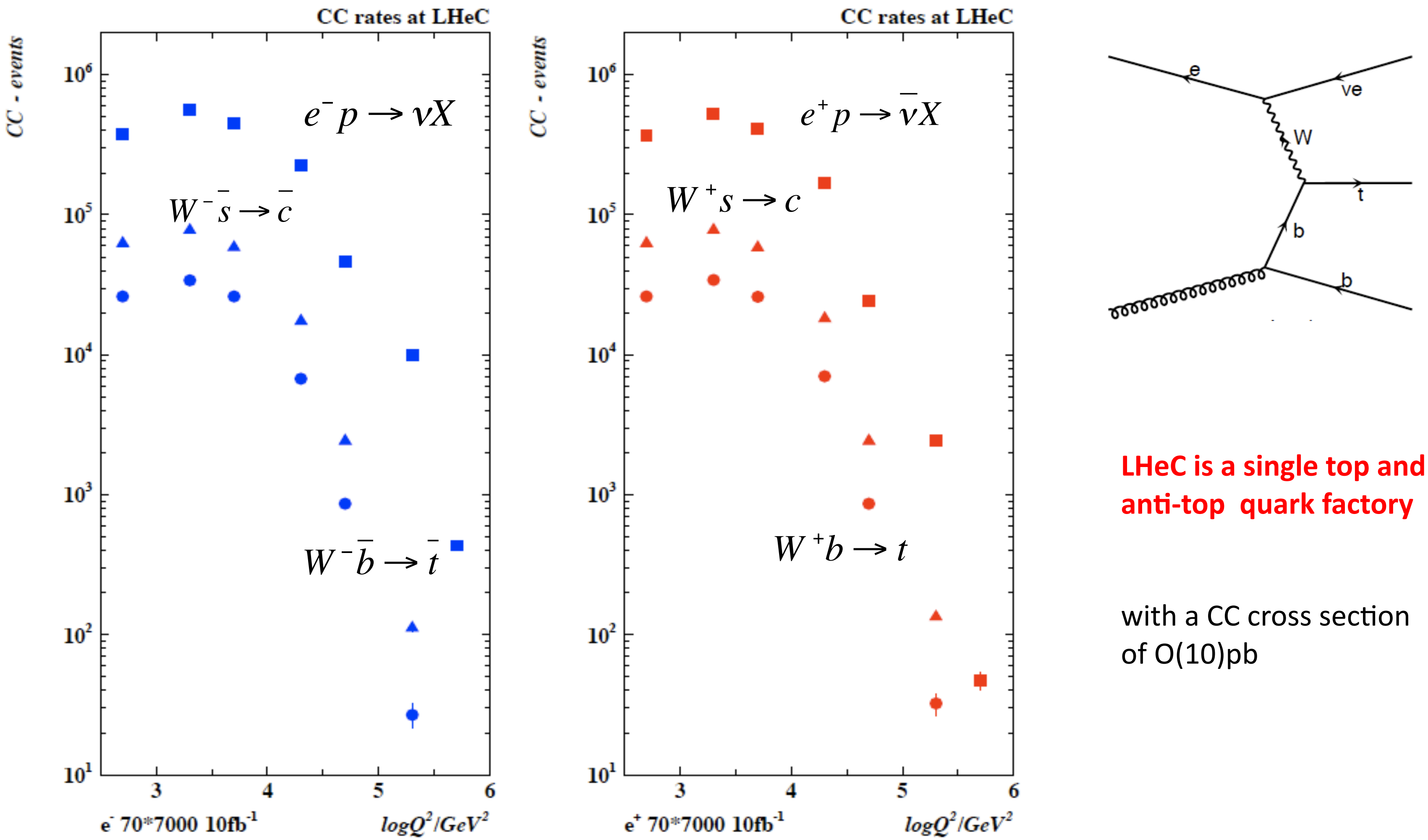
$\delta_{syst} = 0.1$

$\circ - \vartheta_{h} \geq 1^{o}$

$\bullet - \vartheta_{h} \geq 10^{o}$

Some dimuon and K data
never properly measured

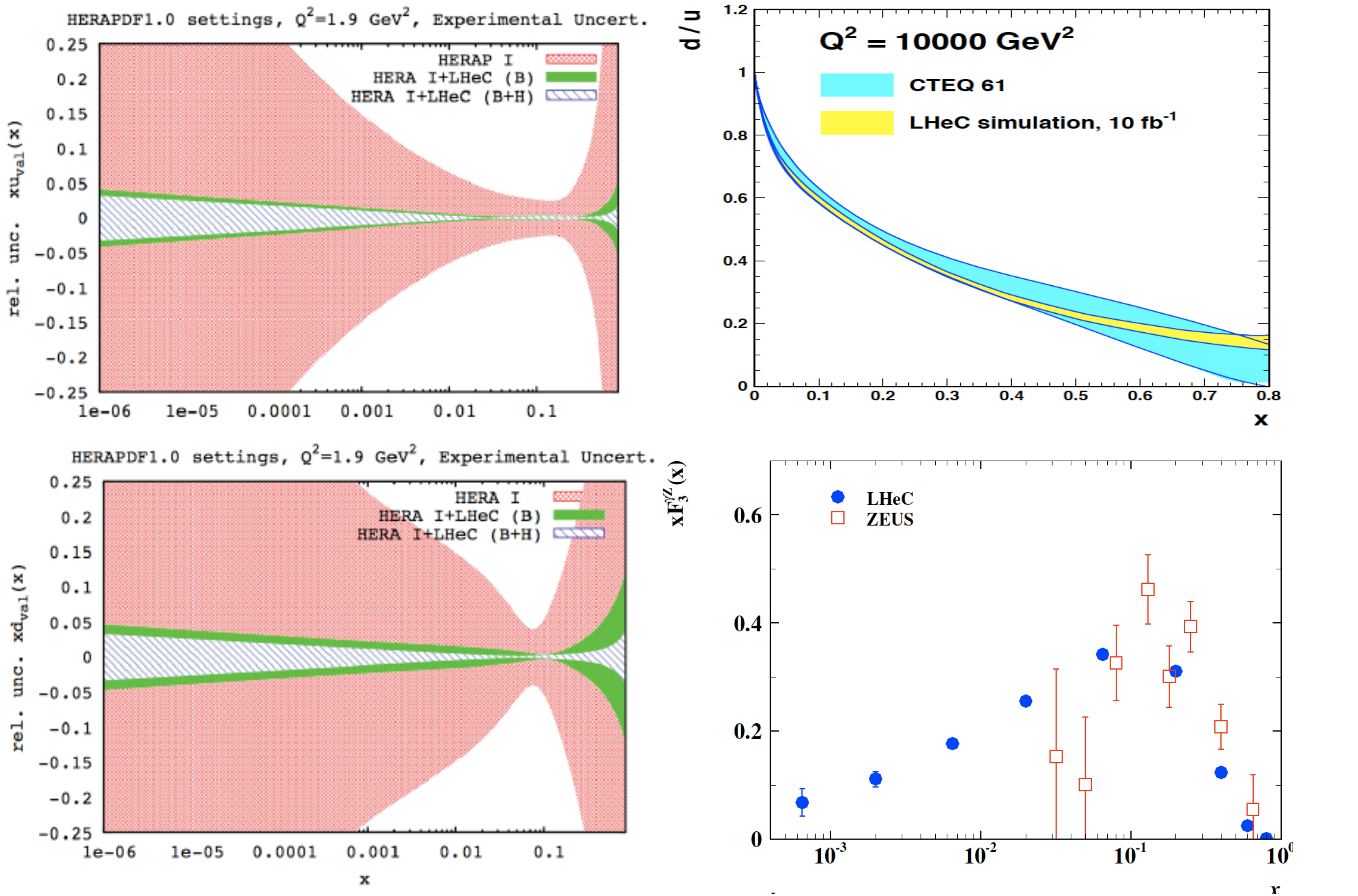
$\overline{\text{Top}}$ and Top Production at the LHeC (CC)



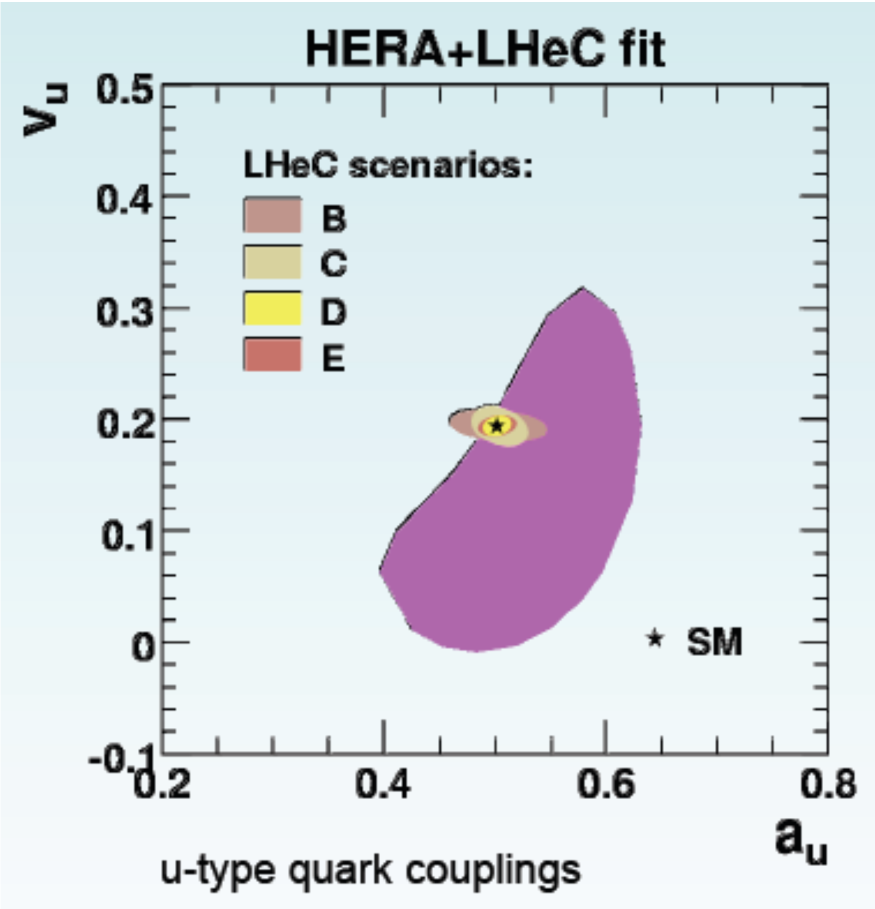
LHeC is a single top and anti-top quark factory

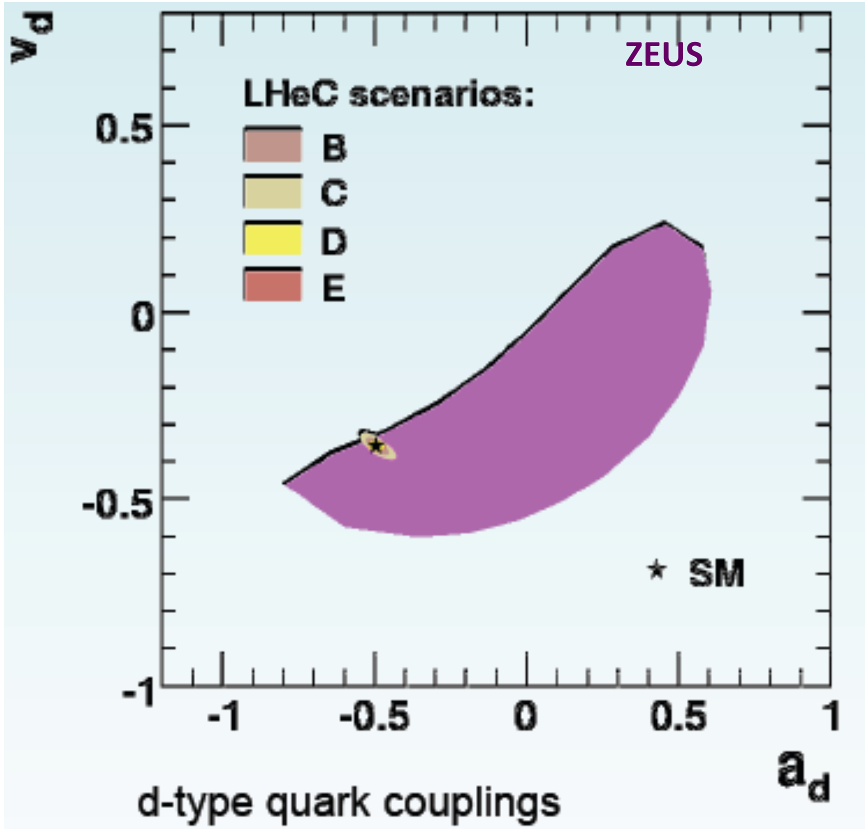
with a CC cross section of O(10)pb

Valence Quarks



Weak NC Couplings of Light Quarks



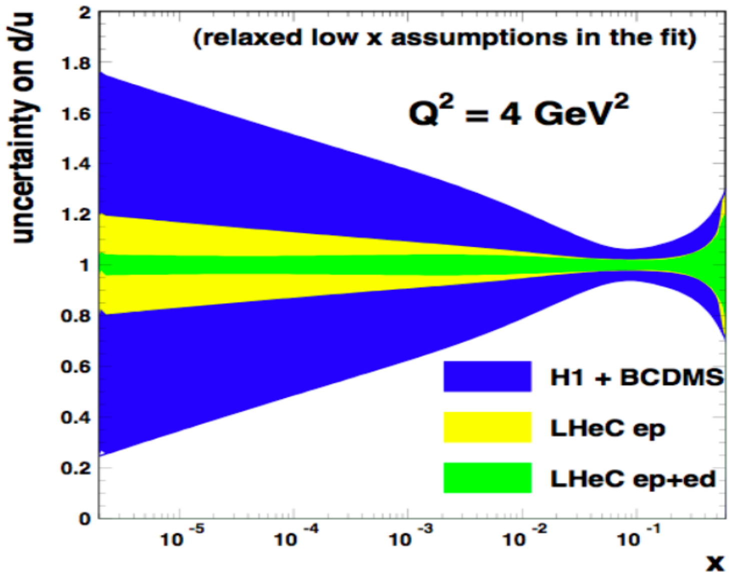


For H1, CDF, LEP cf Z.Zhang DIS10

Per cent accuracy of NC couplings

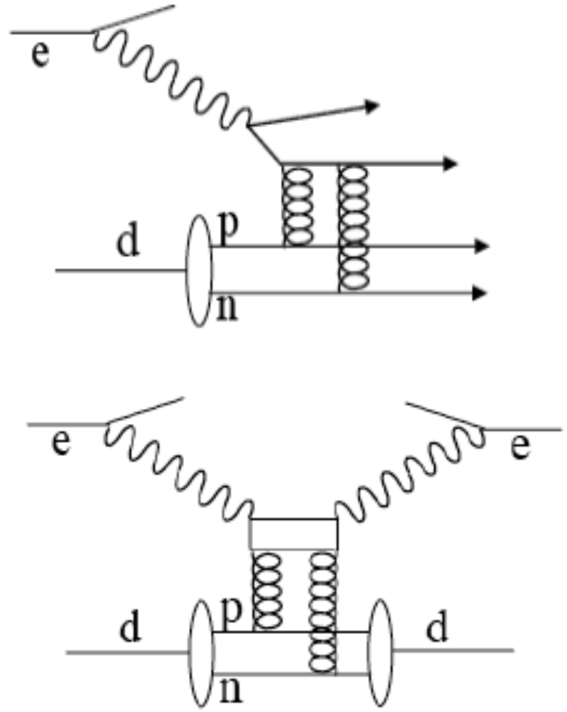
Neutron Structure (ed → eX)

d/u at low x from deuterons



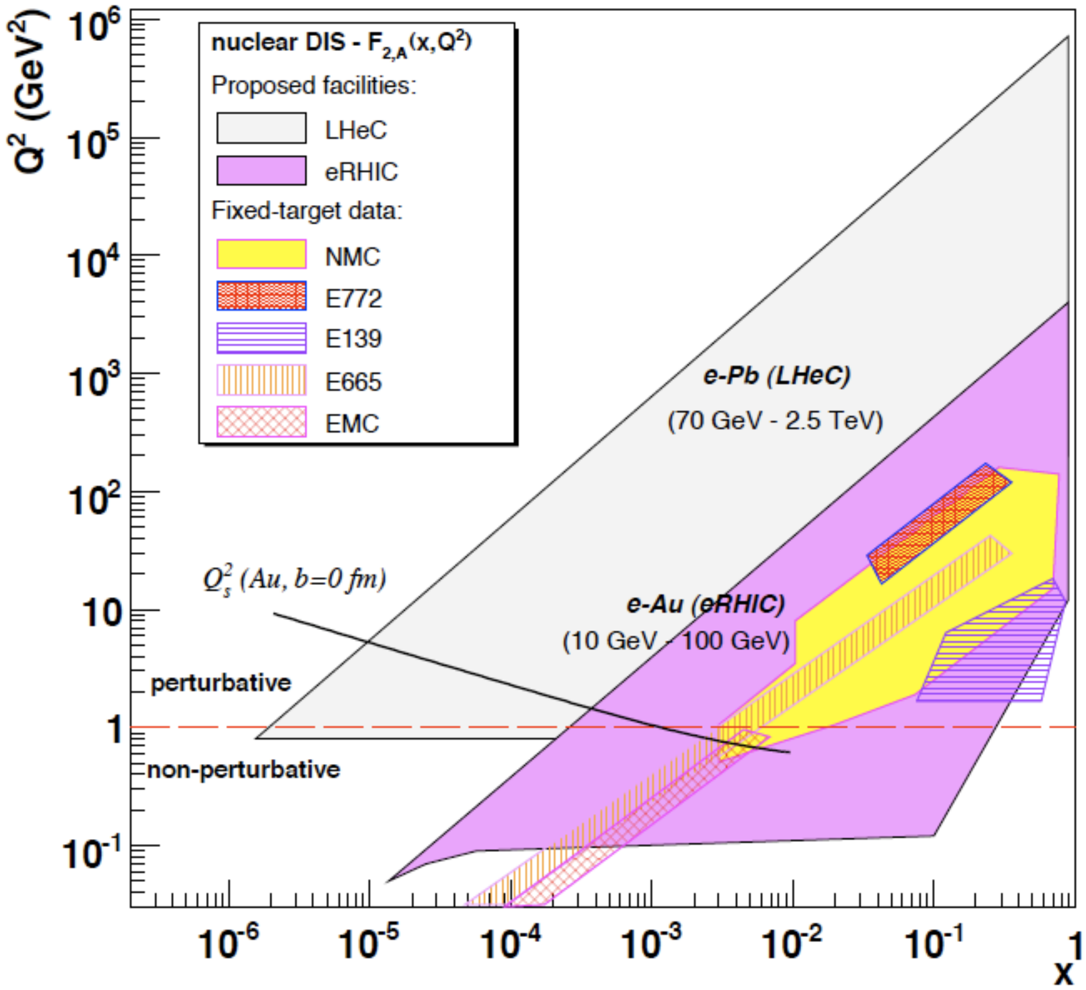
(13) There are five color-singlet combinations of the deuteron wavefunction in QCD, only one of which is the standard proton-neutron state. The "hidden color" [13] components will lead to high multiplicity final states in deep inelastic electron-deuteron scattering.

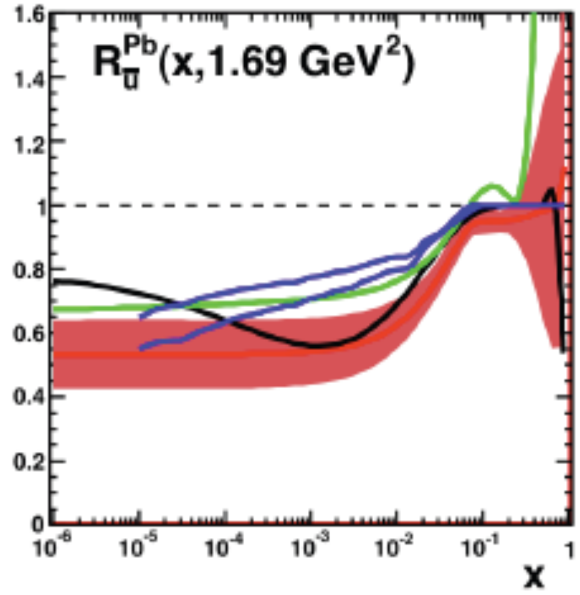
crucial constraint on evolution (S-NS), improved α_s

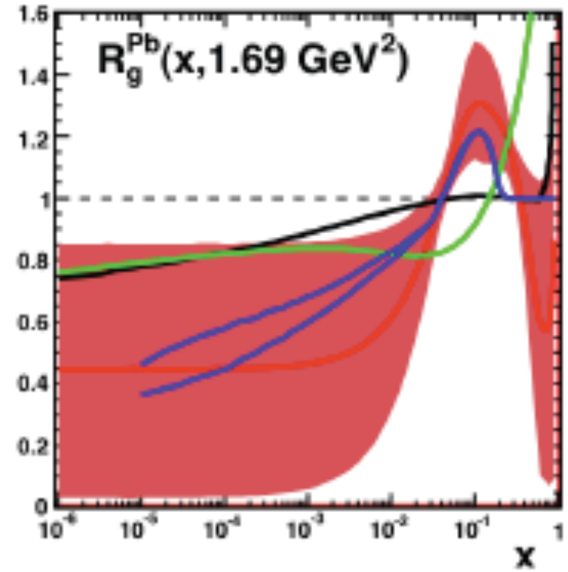


In eA at the collider, test Gribovs relation between shadowing and diffraction, control nuclear effects at low Bjorken x to high accuracy

Electron-Ion Scattering: 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)

paris

Organisation + Status for the CDR

Scientific Advisory Committee

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Sergio Bertolucci (CERN)
Stan Brodsky (SLAC)
Allen Caldwell -chair (MPI Munich)
Swapan Chattopadhyay (Cockcroft)
John Dainton (Liverpool)
John Ellis (CERN)
Jos Engelen (CERN)
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Lev Lipatov (St.Petersburg)
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Wesley Smith (Wisconsin)
Bernd Surrow (MIT)
Katsuo Tokushuku (KEK)
Urs Wiedemann (CERN)
Frank Zimmermann (CERN)

Working Group Convenors

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 (U Zurich),
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)

Today: writing … for the

Referees of CERN

QCD/electroweak:
Guido Altarelli, Alan Martin, Vladimir Chekelyan

BSM:
Michelangelo Mangano, Gian Giudice, Cristinel Diaconu

eA/low x
Al Mueller, Raju Venugopalan, Michele Arneodo

Detector
Philipp Bloch, Roland Horisberger

Interaction Region Design
Daniel Pitzl, Mike Sullivan

Ring-Ring Design
Kurt Huebner, Sasha Skrinsky, Ferdinand Willeke

Linac-Ring Design
Reinhard Brinkmann, Andy Wolski, Kaoru Yokoya

Energy Recovery
Georg Hoffstatter, Ilan Ben Zvi

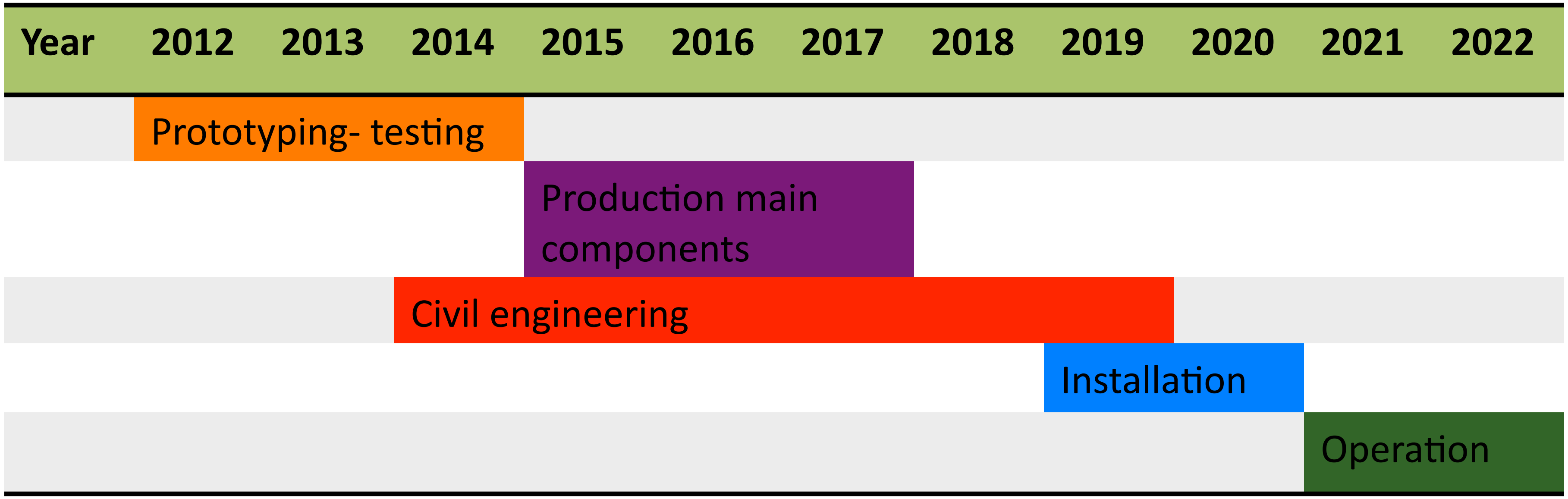
Magnets
Neil Marx, Martin Wilson

Installation and Infrastructure
Sylvain Weisz

Expect CDR in spring 2011

LHeC_DRAFT_Timeline

Based on LHC constraints, ep/A programme, series production, civil engineering etc



Variations on timeline:

➔ production of main components can overlap with civil engineering

➔ Installation can overlap with civil engineering

➔ Additional constraints from LHC operation not considered here

➔ in any variation, a start by 2020 requires launch of prototyping of key components by 2012

[shown to ECFA 11/2010: mandate to 2012]

Summary

The LHeC has the potential to become an exciting 5th big experiment at the LHC

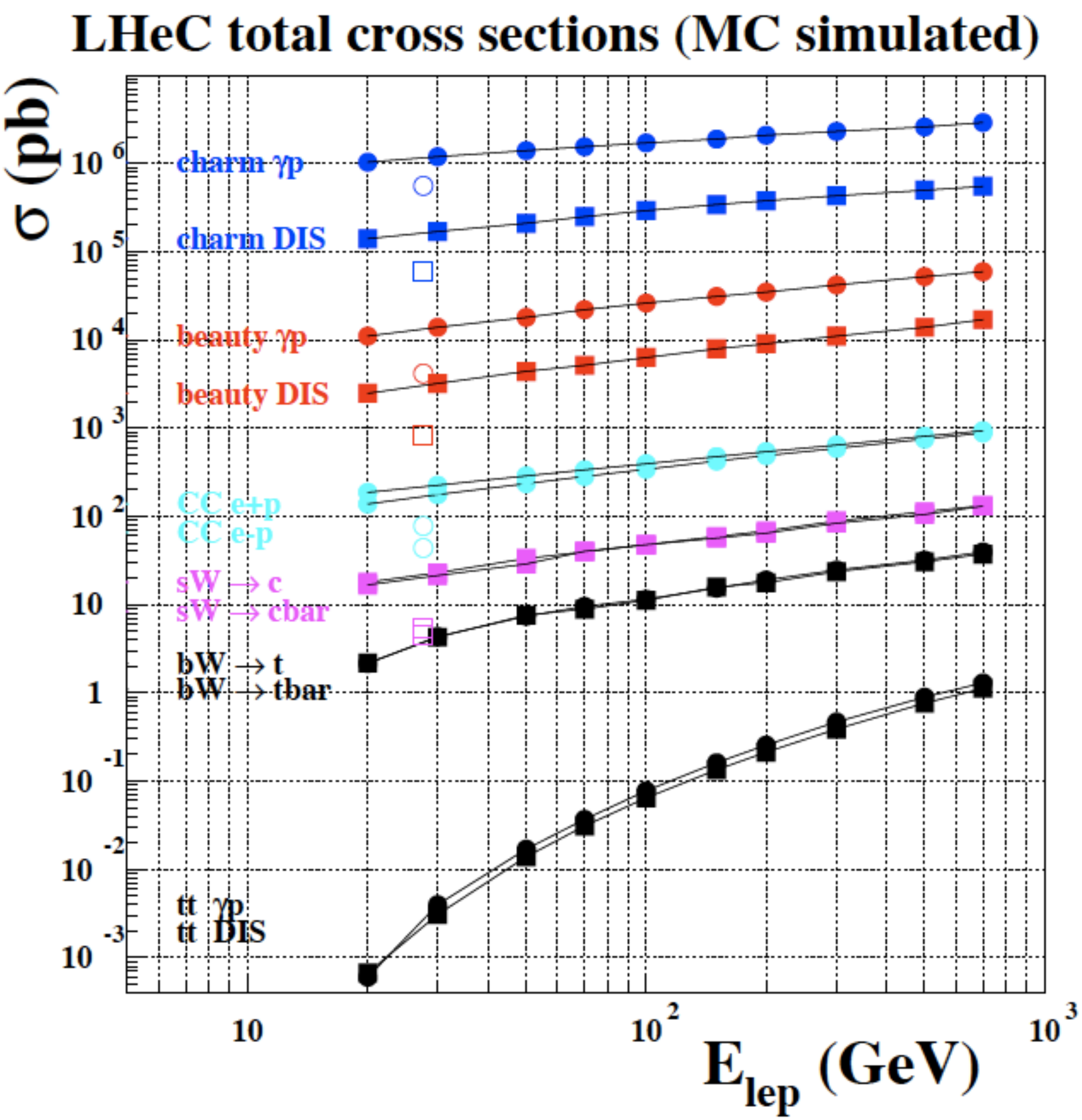
It needs a new polarised electron/positron beam, and two options are under consideration, a 'Linac' and a ring, with a 'linear' injector.., both promising to deliver O(50) fb^{-1} thus reaching Q^2 = 1 TeV^2, high x and $x=10^{-6}$ in DIS..

The .. MORE/BETTER needed..

THANKS to ..

backup

Heavy Flavours at the LHeC



HERA - 'an unfinished business'

Low x: DGLAP holds though ln1/x is large
Saturation not proven

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

Neutron structure not explored

Nuclear structure not explored

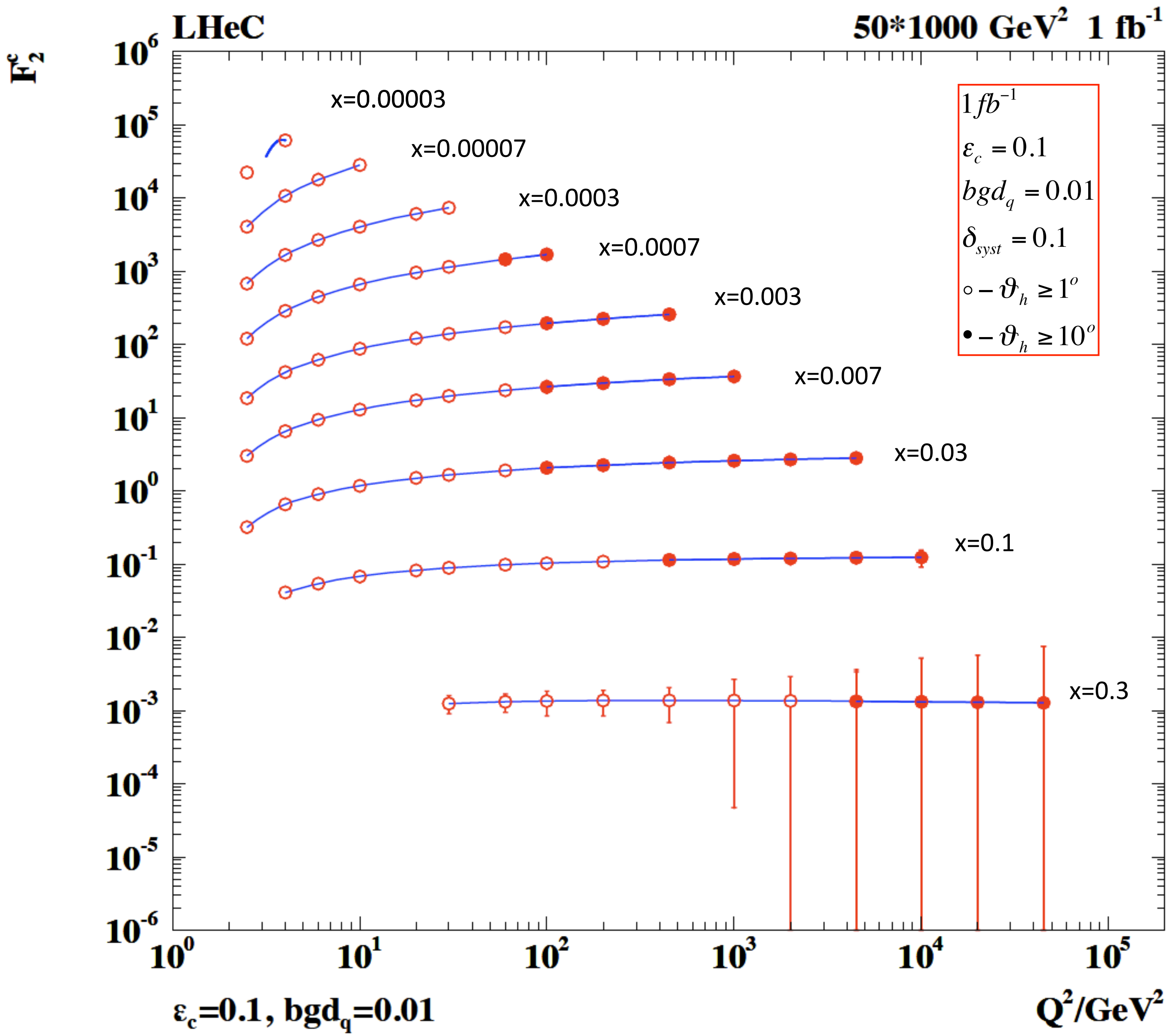
New concepts introduced, investigation just started:
-parton amplitudes (GPD's, proton hologram)
-diffractive partons
-unintegrated partons

Instantons not observed

Odderons not found
…

Lepton-quark states not observed

Try to see charm at large x



Even in the most favourable beam energy setting, a search for intrinsic charm at x >=0.1 would require charm tagging down to few degrees…