

Future opportunities in DIS

DIS 07/ Plenary/ Joël Feltesse

Introduction

- The year 2007 is a turning point of high energy physics :
 - Data taking at HERA (H1, ZEUS, HERMES) comes to an end
 - Commissioning of the discovery facility, the LHC
- Are we close to the end of DIS physics ?

Outlook

- Open questions
- Proposed DIS projects
- Complementarity ep/pp, eA/pA/AA ...
- Comments (a personnal view)

Open or key Questions

- **Proton Structure** : spin, transverse momentum, spatial distribution of partons (GPD), u/d at large x.
- **Quarks and gluons in Nuclei.**
- **Understanding and exploring QCD.** Low x, high parton density, hard diffraction.
- **Precision of PDFs.** Is it important for the LHC ? How to improve it?
- Relation between **quark and lepton sectors** beyond the EW interaction?

Open question : proton structure

HERA has changed the image of the proton but :

Still do not know where the proton spin comes from ?

$$\frac{1}{2} = \frac{1}{2} \Delta \Sigma + \Delta G + L_q + L_g$$

Quark polarisation ? ~25 % only !!

Gluon polarisation ?

Orbital angular momentum ?

Very poor knowledge on transversity.

Open question : proton structure

GPDs describe correlations between the momentum and the spatial distributions of quarks.

Four new distributions = “GPDs”

helicity conserving $\rightarrow H(x, \xi, t), E(x, \xi, t)$
helicity flip $\rightarrow \tilde{H}(x, \xi, t), \tilde{E}(x, \xi, t)$

“Femto-photography” of the proton

Ji sum rule:

$$J^q = \frac{1}{2} \Delta \Sigma + L^q$$

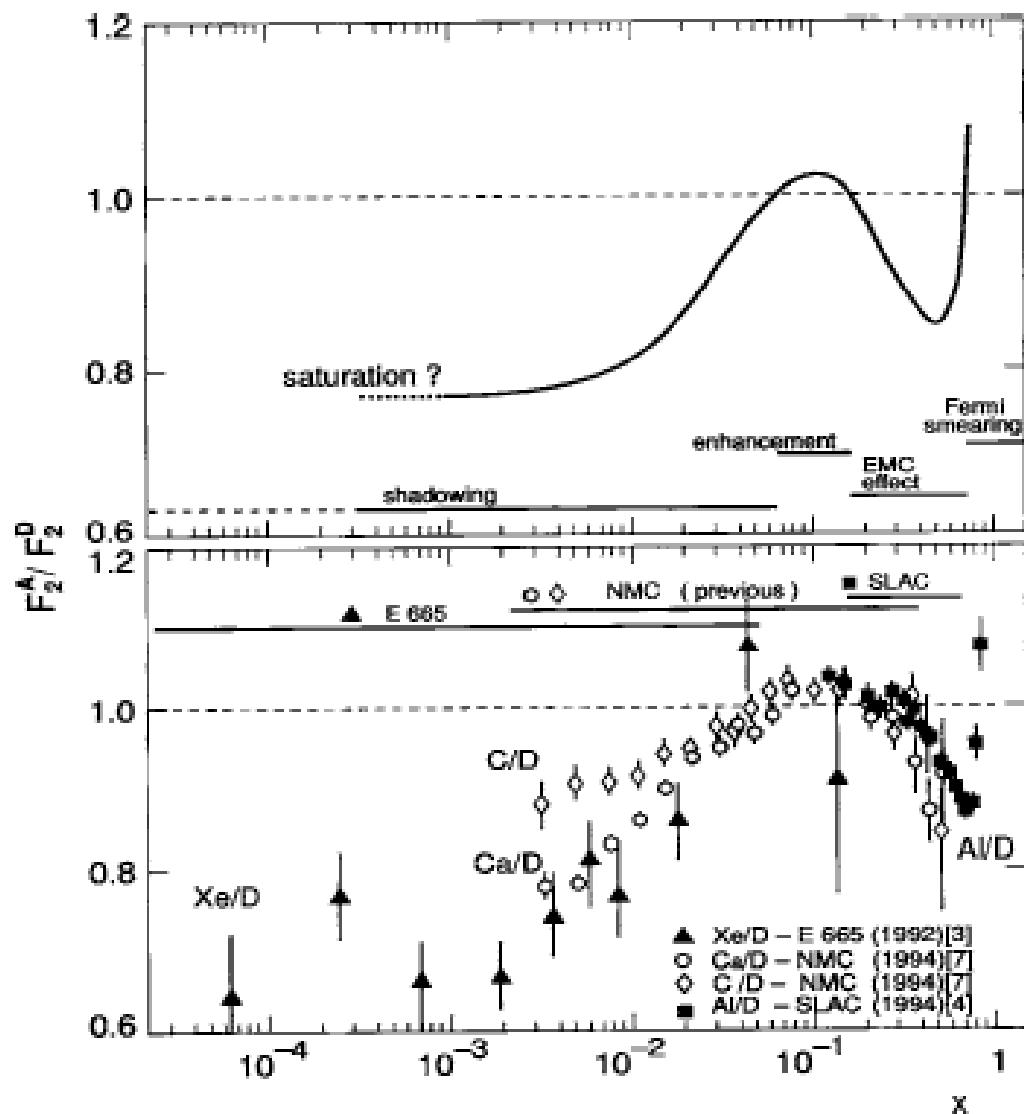
$$J^q = \frac{1}{2} \int_{-1}^1 x dx [H^q(x, \xi, t=0) + E^q(x, \xi, t=0)]$$

 **model-independent access to L !**

N.C.R. Makins, Workshop on QCD, Washington, DC, Dec 15-16, 2006

Can we get model independent GPDs from all exclusive measurements without extrapolation of the accessible kinematic range ?

Open question : quarks and gluons in nuclei



shadowing : $x g^A < x g^N$
and
saturation : $x g < x g^{\text{sat}}$

Can saturation explains
the shadowing ?

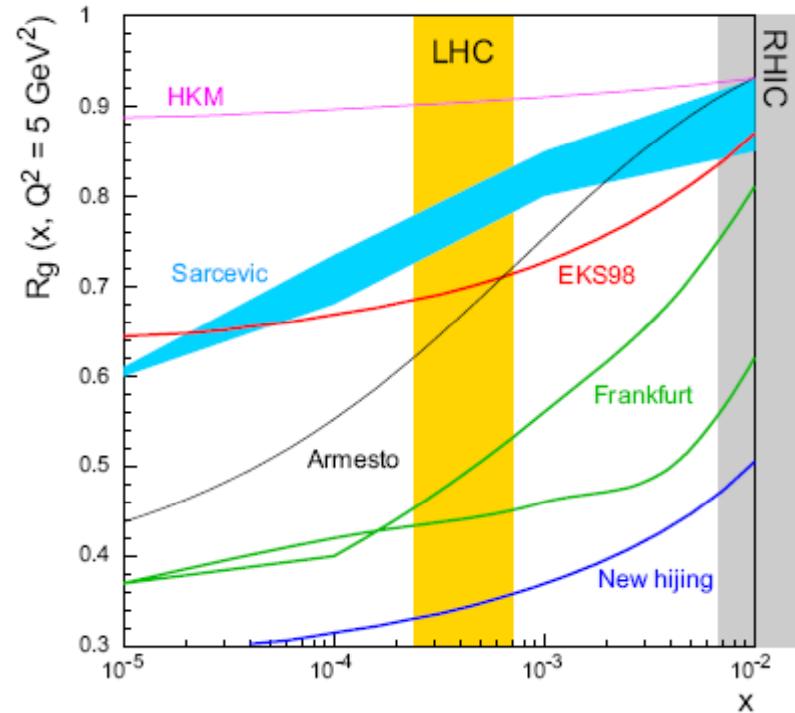
Open question : quarks and gluons in nuclei

Gluon in nuclei is terra incognita

Predicted ratio R_{pb} of
gluon distributions

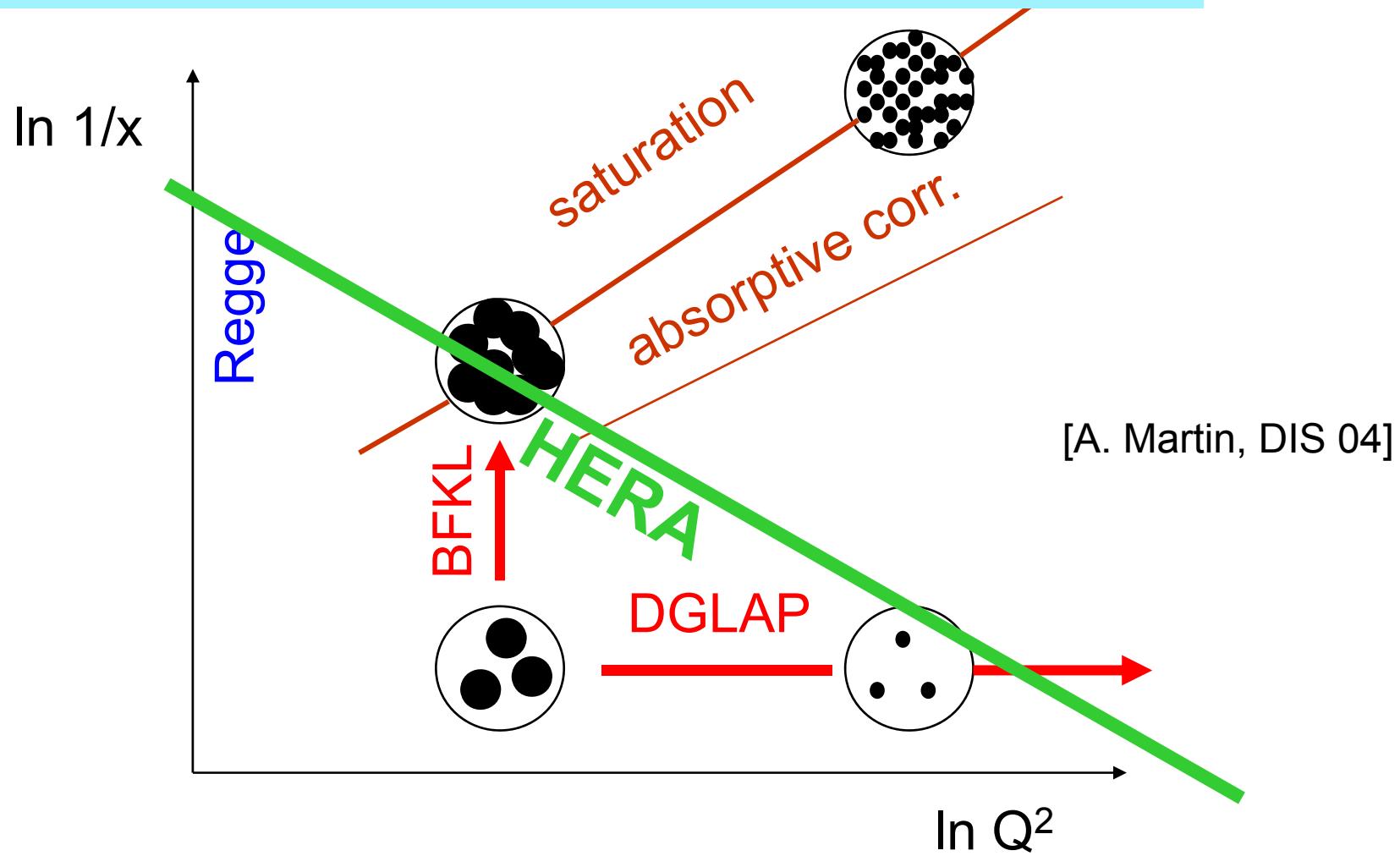
Lead / Deuterium.

For various models
of shadowing

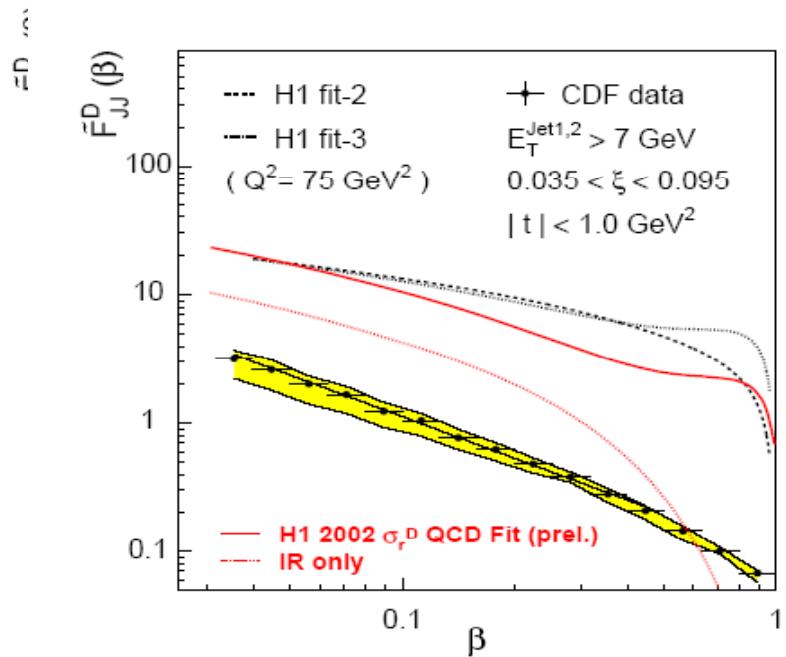


How important is it for understanding of hot and dense matter produced at RHIC and LHC ?

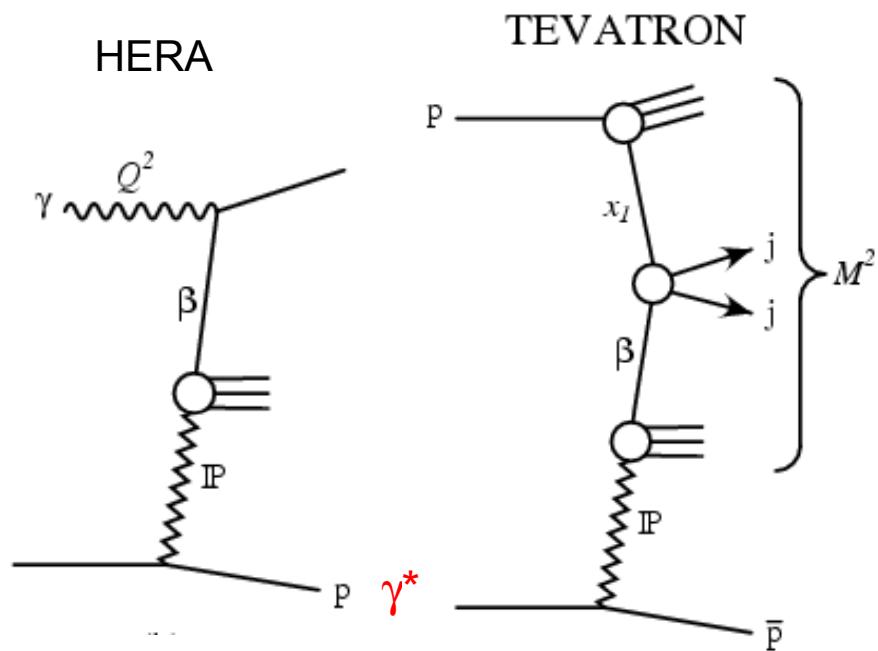
Open question : understanding QCD



Open question : understanding QCD



Factorization ?



Do we actually understand hard diffraction ?

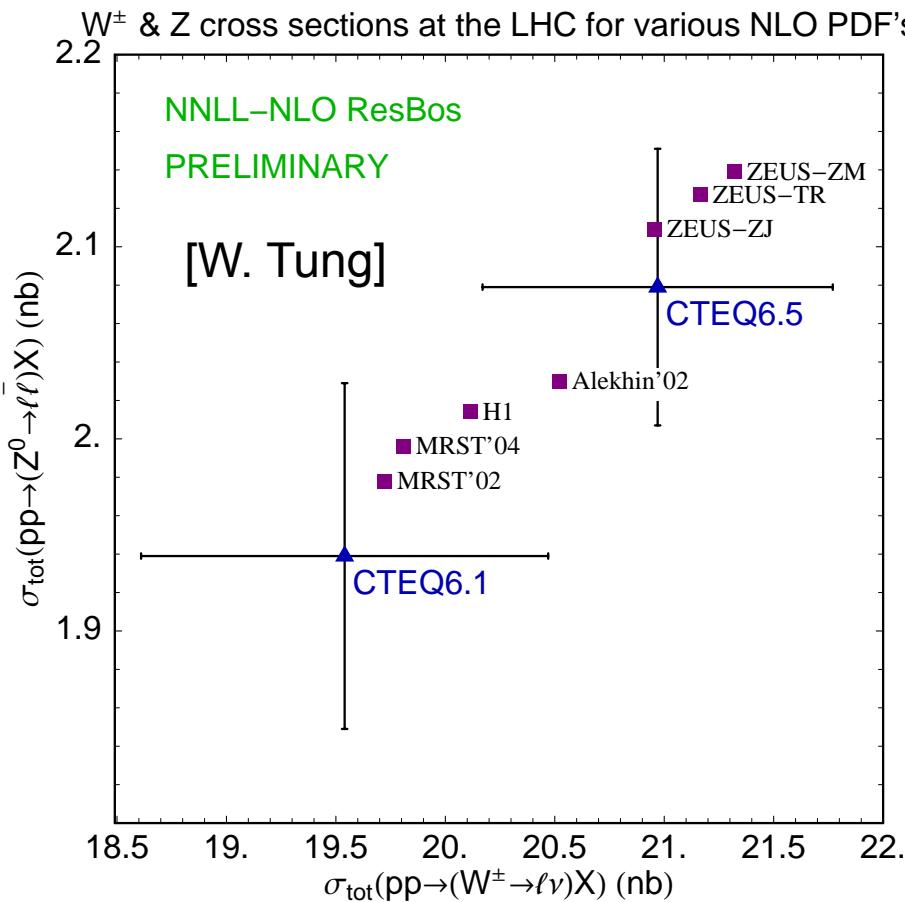
Open question : understanding and exploring QCD

HERA has opened up the small x and the hard diffraction domains.

Some theoretical developments are promising. Still far to be fully understood !

Need further experimental guidance
(ep,pp,eA,pA,AA)

Open question : precision for LHC

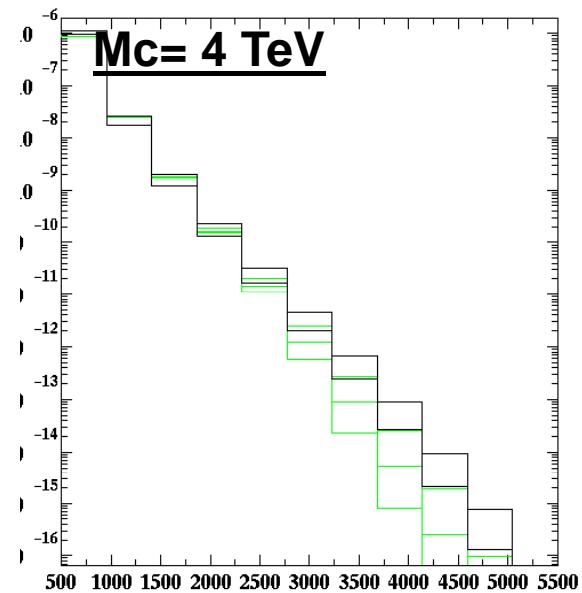
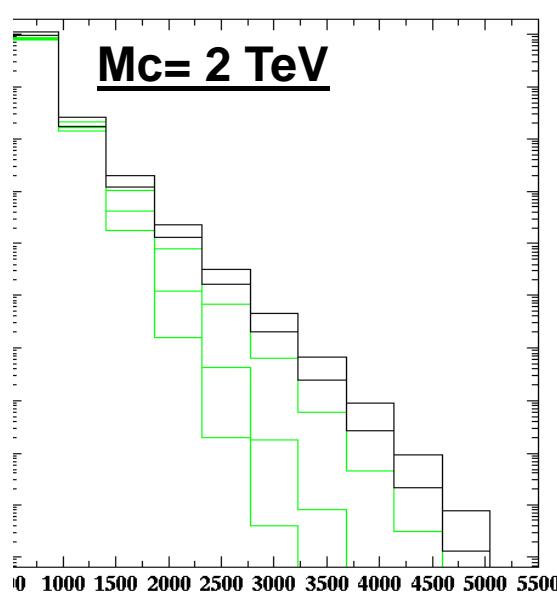
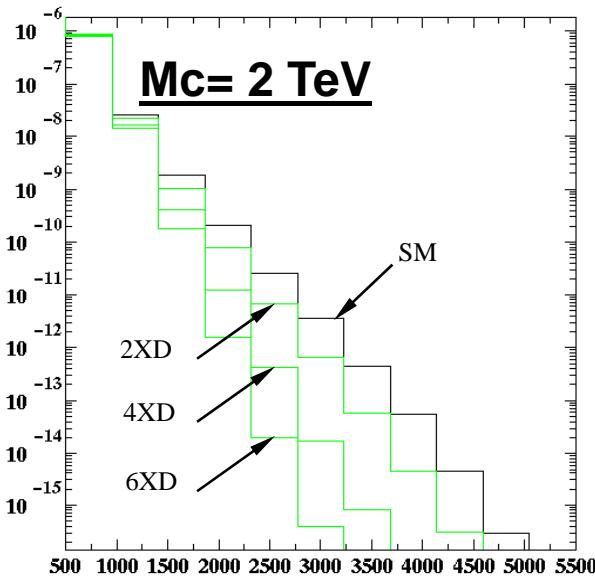


Still a large spread ~10 % on W and Z Cross section prediction.

More constraints on PDFs and α_s anticipated from analysis of HERA II.

Open question : precision for LHC

Example : Sensitivity of the di-jet cross section at large p_t to Xtra dimensions (D. Ferrag).



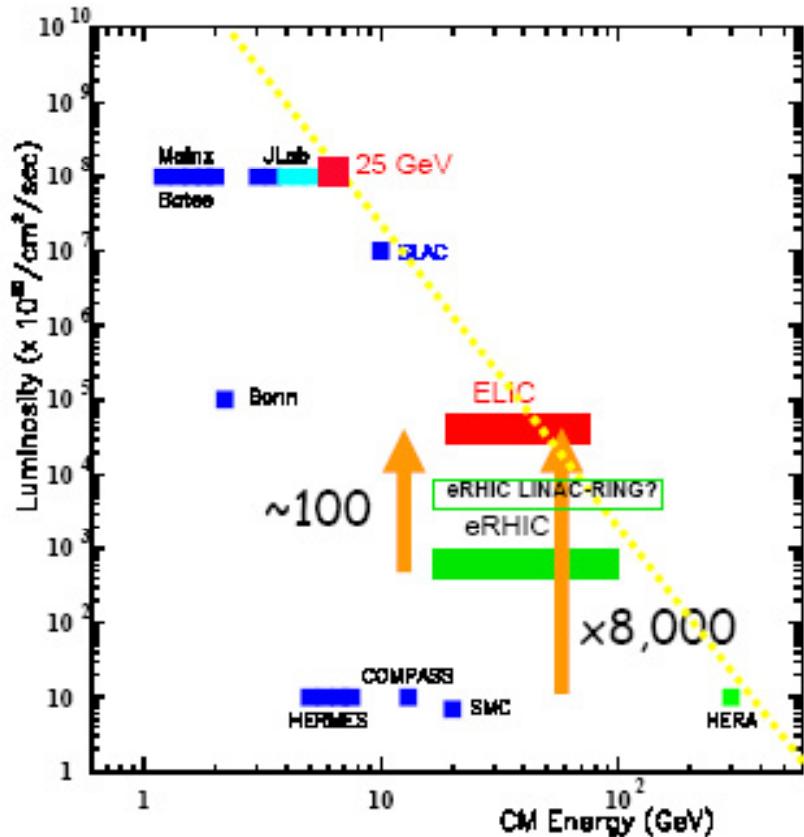
The main uncertainty comes from the gluon density at large x

Proposed projects

- CEBAF 12 GeV
- Electron Ion Collider (EIC)
 - eRHIC (Brookhaven)
 - Energy Recovery Linac (ERL)
 - Ring Ring
 - Electron Light Ion Collider (ELIC) at Jeff. Lab
- Large Hadron electron Collider (LHeC)

Jefferson Lab 12 GeV upgrade

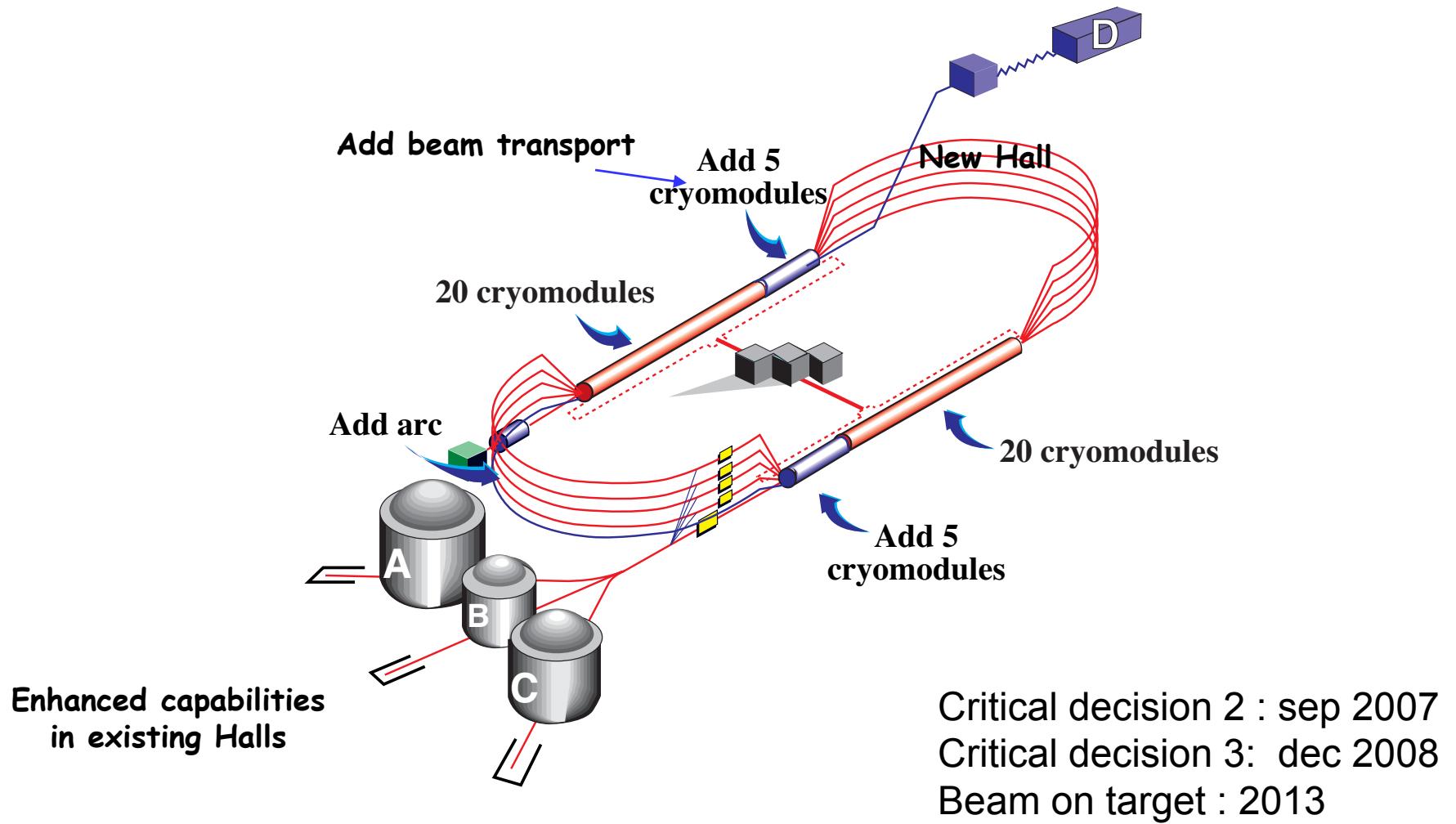
Luminosity plot from R. Ent



Luminosity : $10^{38} \text{ cm}^{-2}\text{s}^{-1}$

10^7 times HERMES Luminosity!

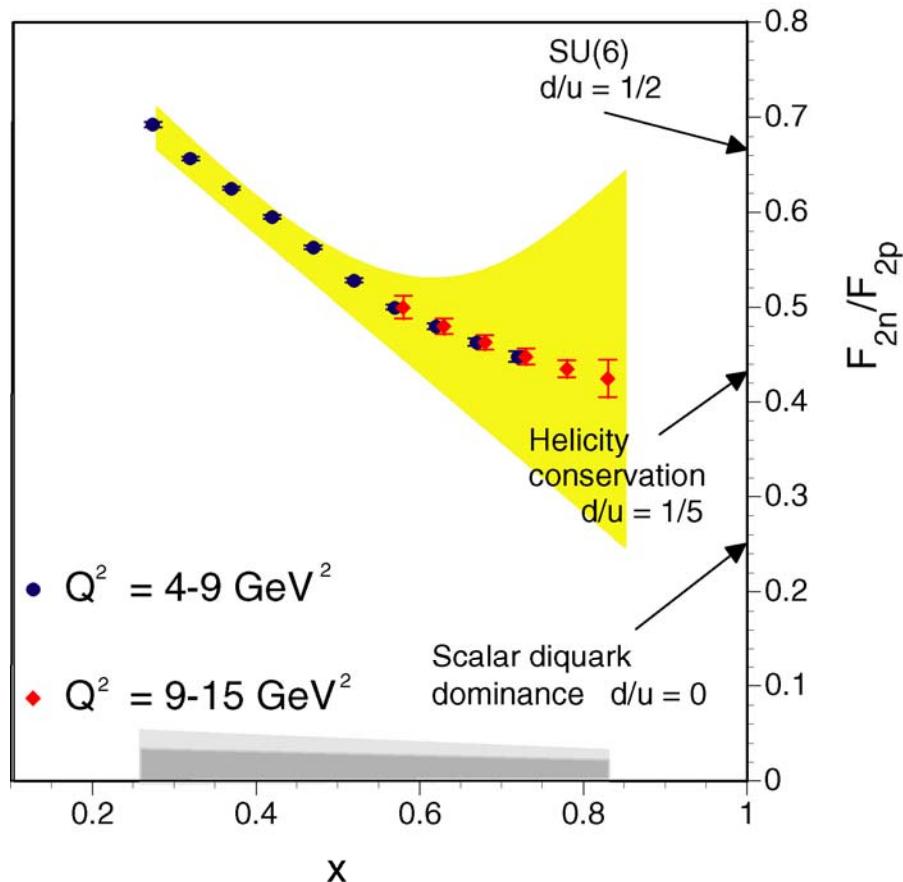
Jefferson Lab 12 GeV upgrade



Jefferson Lab 12 GeV upgrade

d/u as $x \rightarrow 1$. A long standing issue

F_2^n/F_2^p at 11 GeV



Extension of DIS measurements at **large x** :

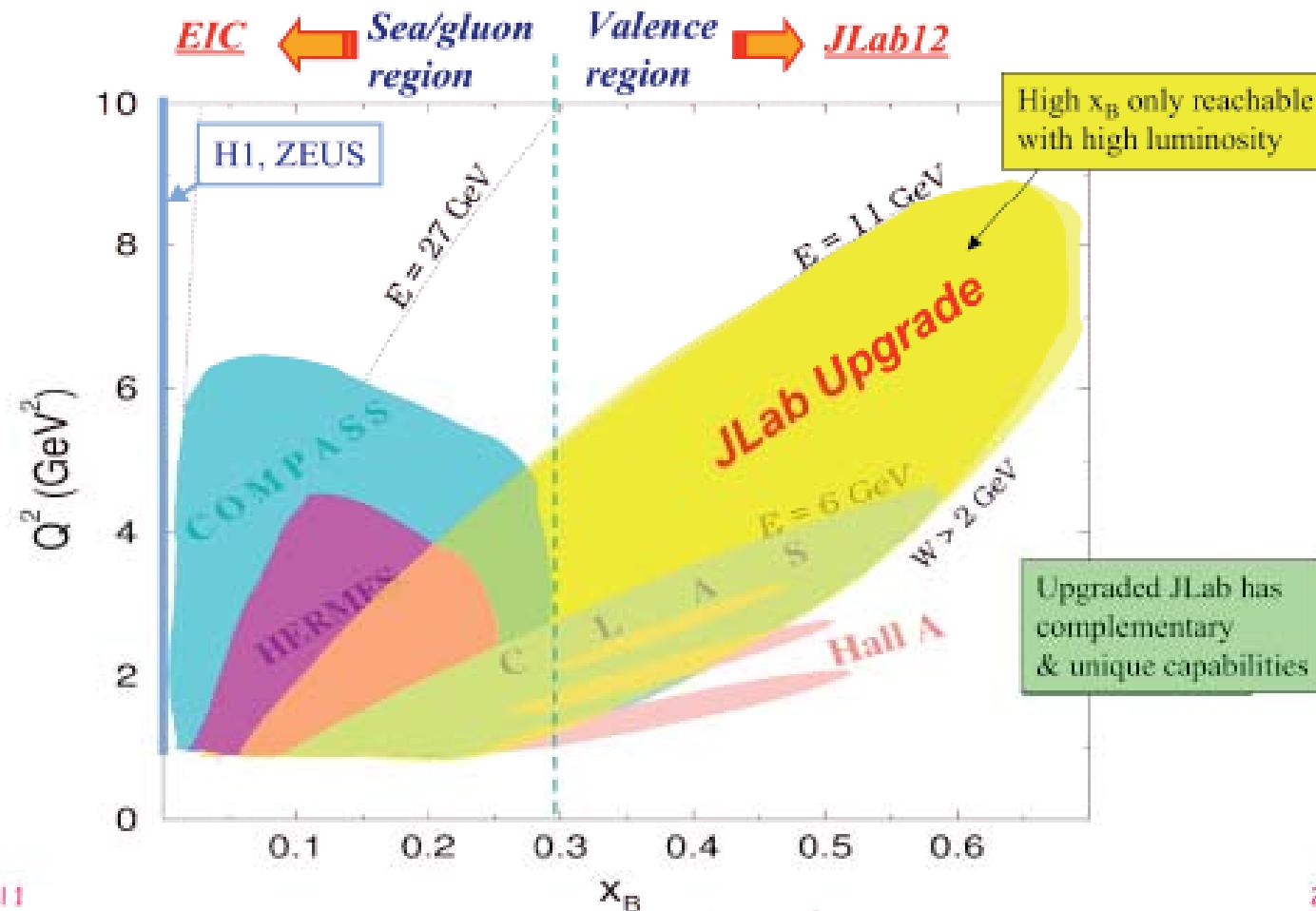
- Quark distributions in p,n,nuclei
- Spin distributions in p,n,nuclei
- Parity violation +exotic mesons

GPDs →

Jefferson Lab 12 GeV upgrade

(Z.E.Meziani)

Large phase space (ξ, t, Q^2) and High luminosity required



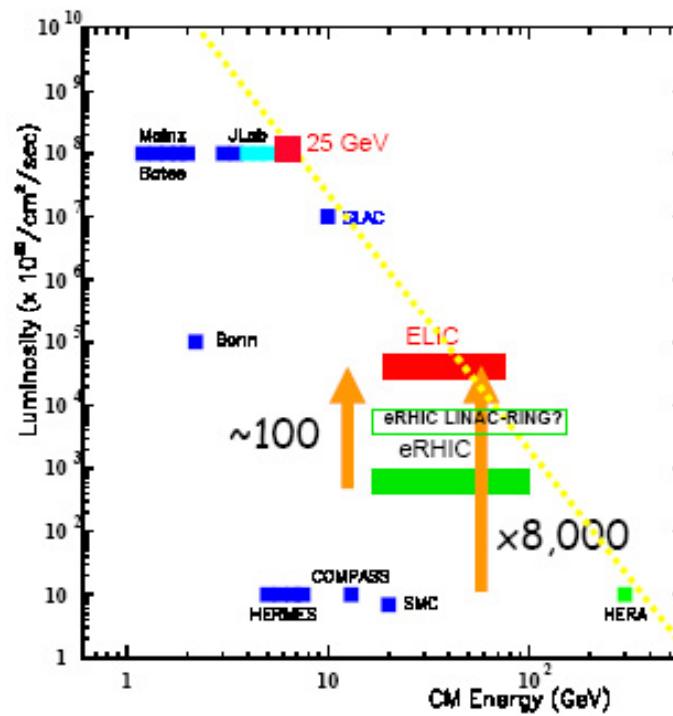
April 1

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18

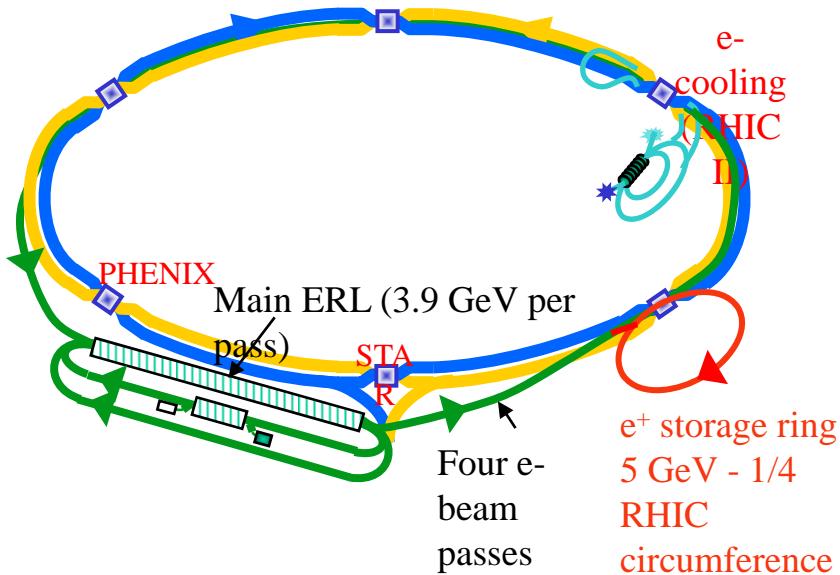
eRHIC (BNL)

Concept : Construct a polarized electron beam (**3-20 GeV**) to collide with the existent RHIC complex : polarized proton 30 to **250 GeV** and heavy ion up to Uranium at **100 GeV/c** per nucleon. Integrated Luminosity $\sim 50 \text{ fb}^{-1}$.

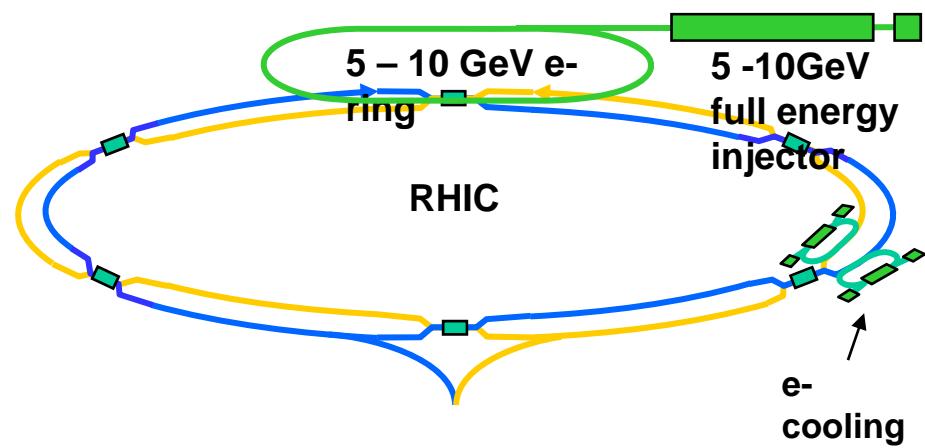


eRHIC : two designs under study

Energy Recovery Linac (ERL)



Ring-Ring

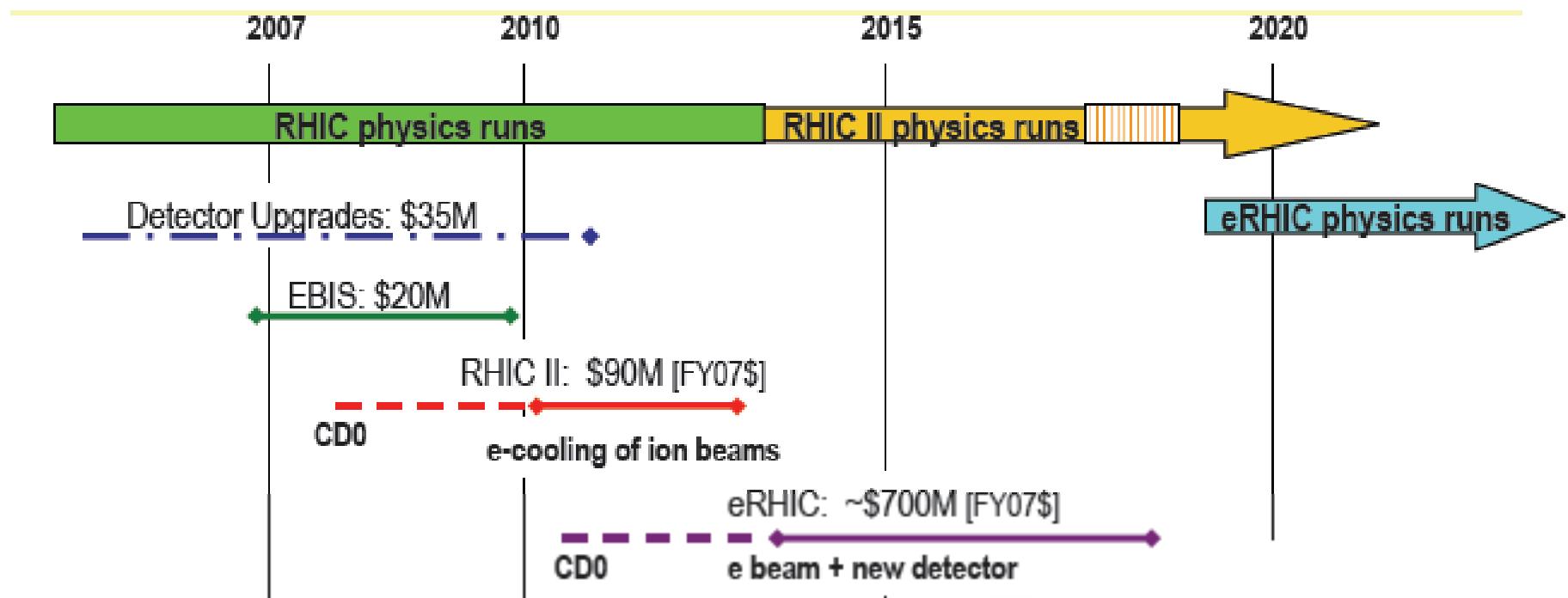


Electron from 3 to 20 GeV.
Luminosity up to few $10^{33} \text{ cm}^{-2} \text{ s}^{-1}$
+- 5m free at Interaction Point
Requires R&D for high current polarised source.

Electron storage ring (5-10 GeV)
Existing technology.
Luminosity 5-10 smaller than ERL

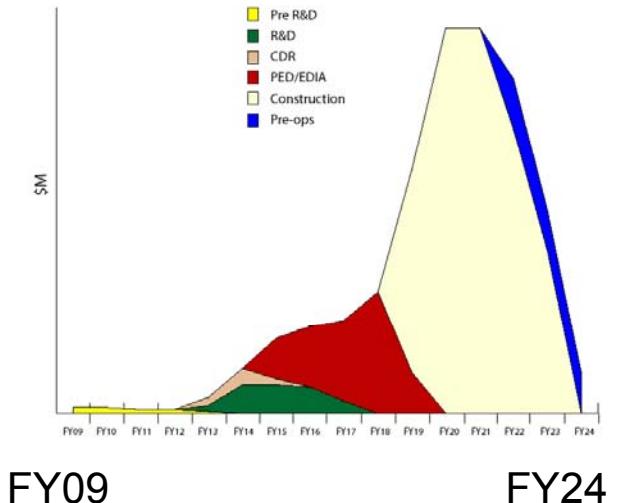
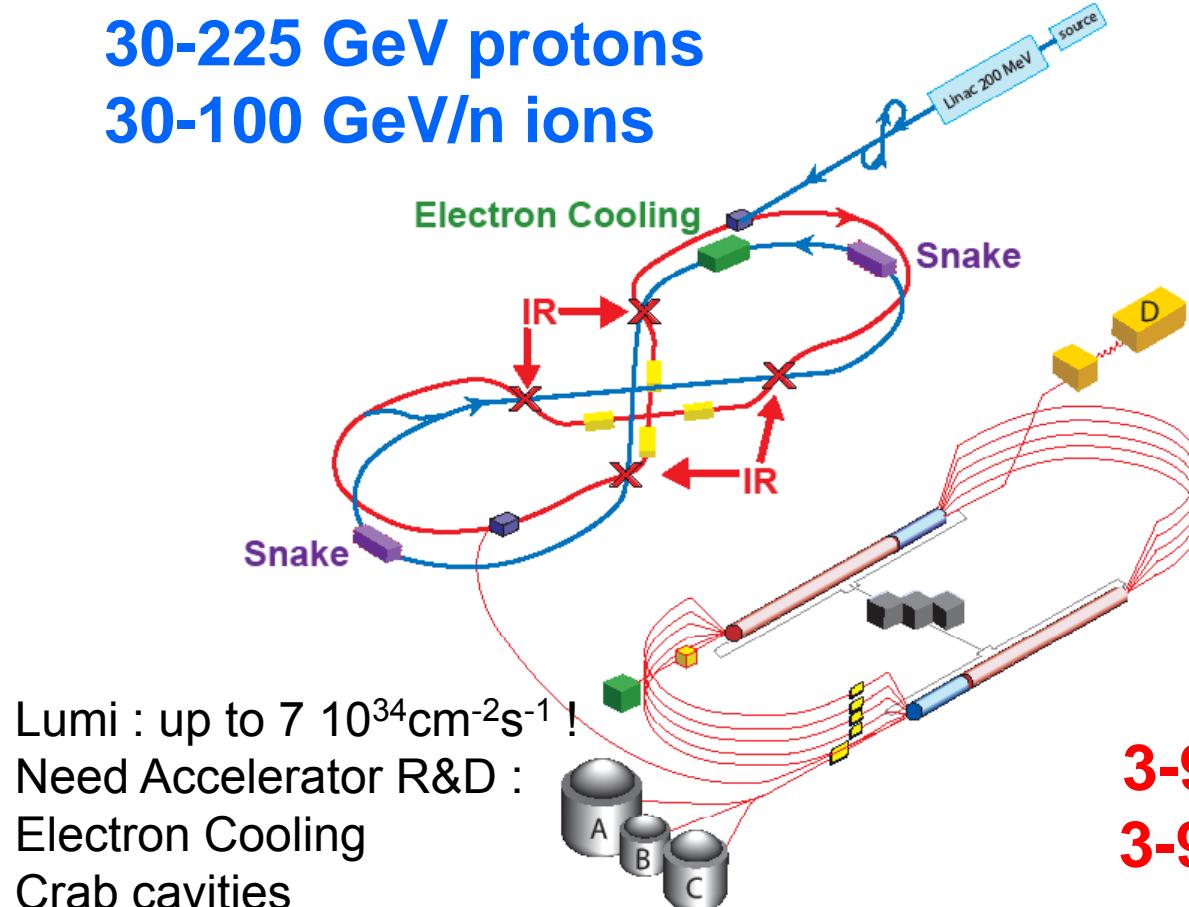
eRHIC (BNL)

(Aronson)



ELIC at Jefferson National Laboratory

**30-225 GeV protons
30-100 GeV/n ions**

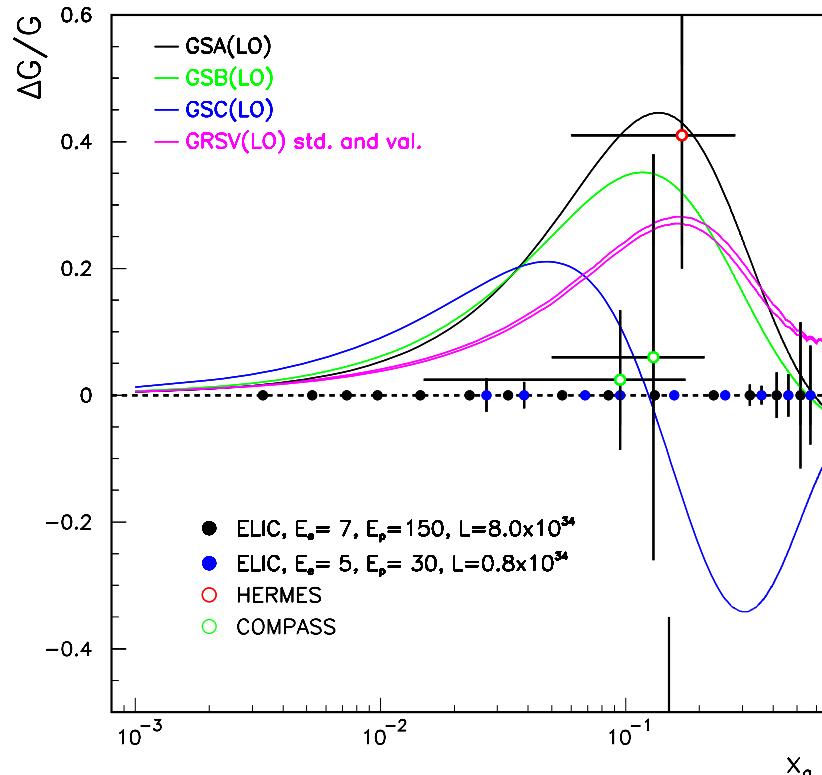


**3-9 GeV electrons
3-9 GeV positrons**

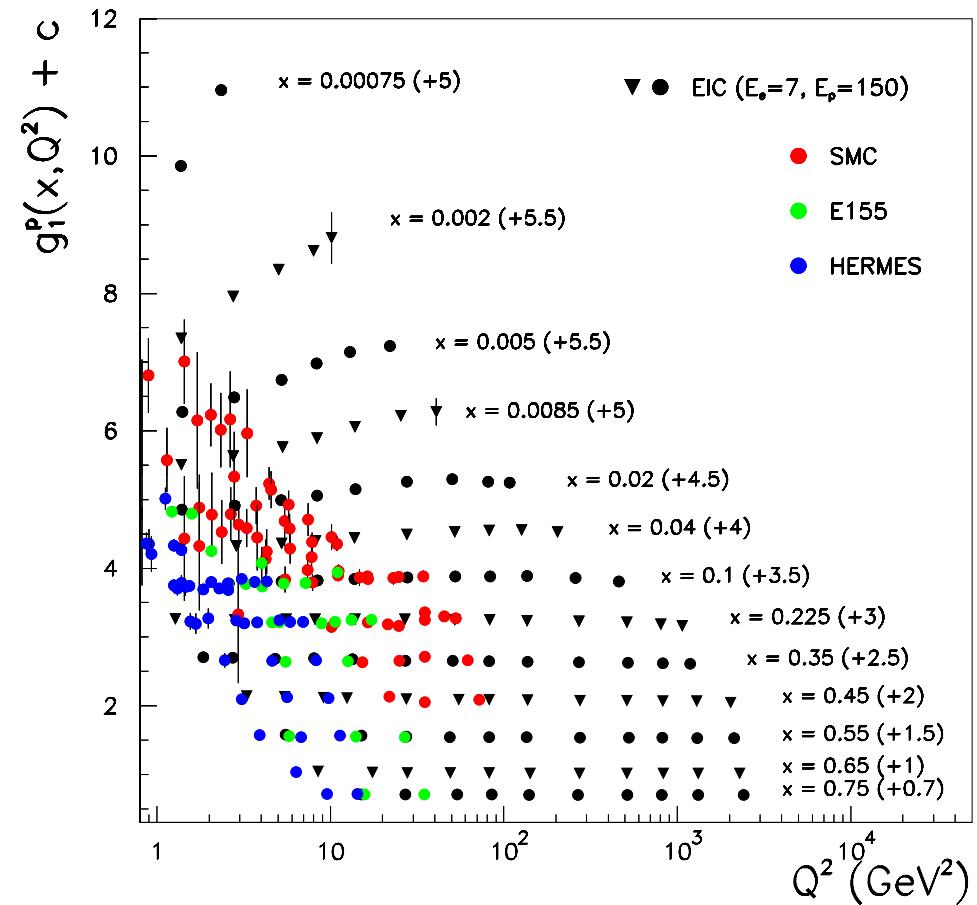
Highlights of the EIC (eRHIC/ELIC) programme

- Proton Structure : spin, transverse momentum, spatial distribution (GPD).
- Nuclear matter : Quarks and gluons in Nuclei at very low x .
- Understanding QCD. Low x , high parton density, hard diffraction.

Highlights of the EIC : spin distribution



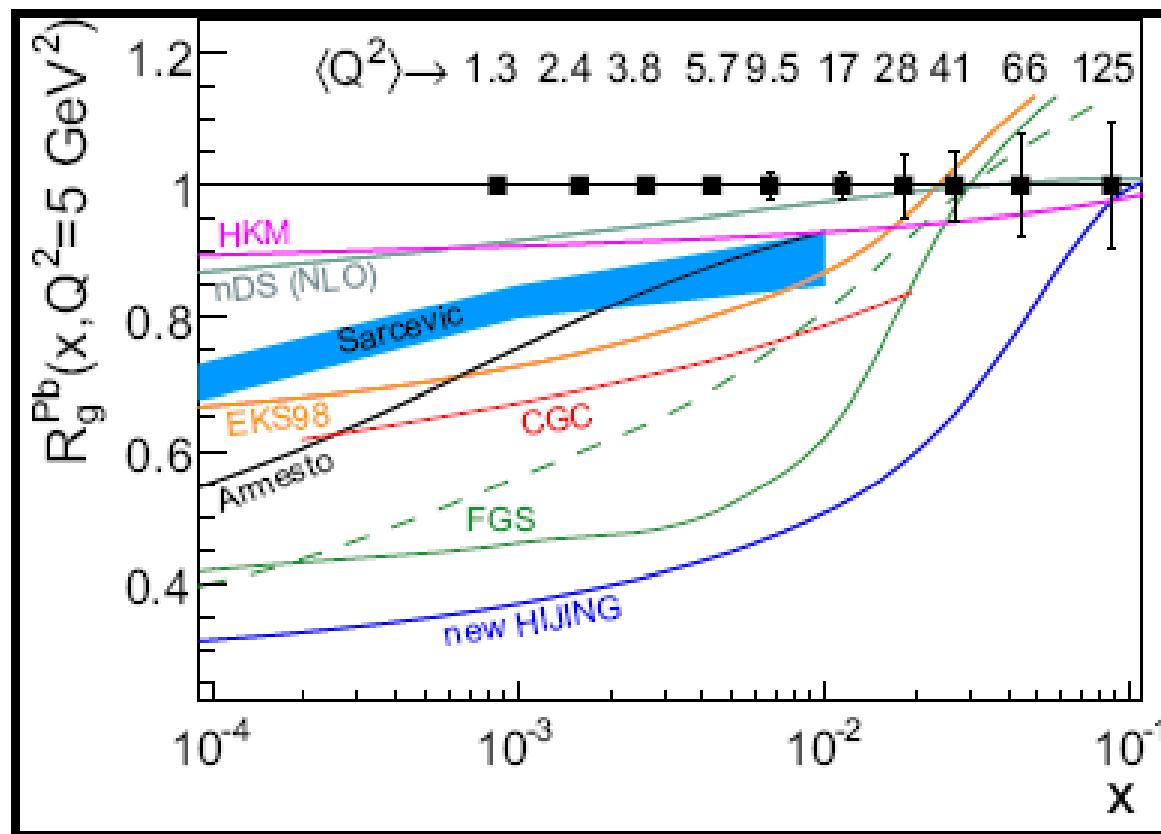
ΔG from charm production



(Antje Bruell)

Highlights of the EIC : gluons in nuclei

Ratio of gluon distribution. Lead/Deuterium



Statistical errors for gluon distribution extracted from F_L and scaling violations measurements.

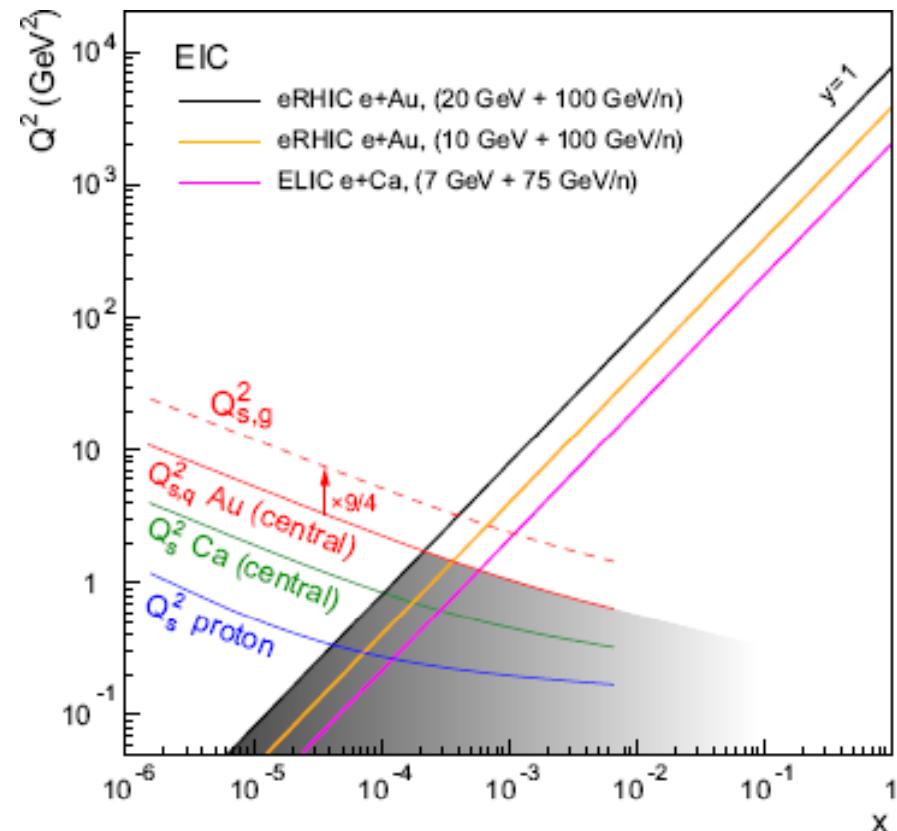
Statistics is not an issue!

Highlights of the EIC : saturation at low x

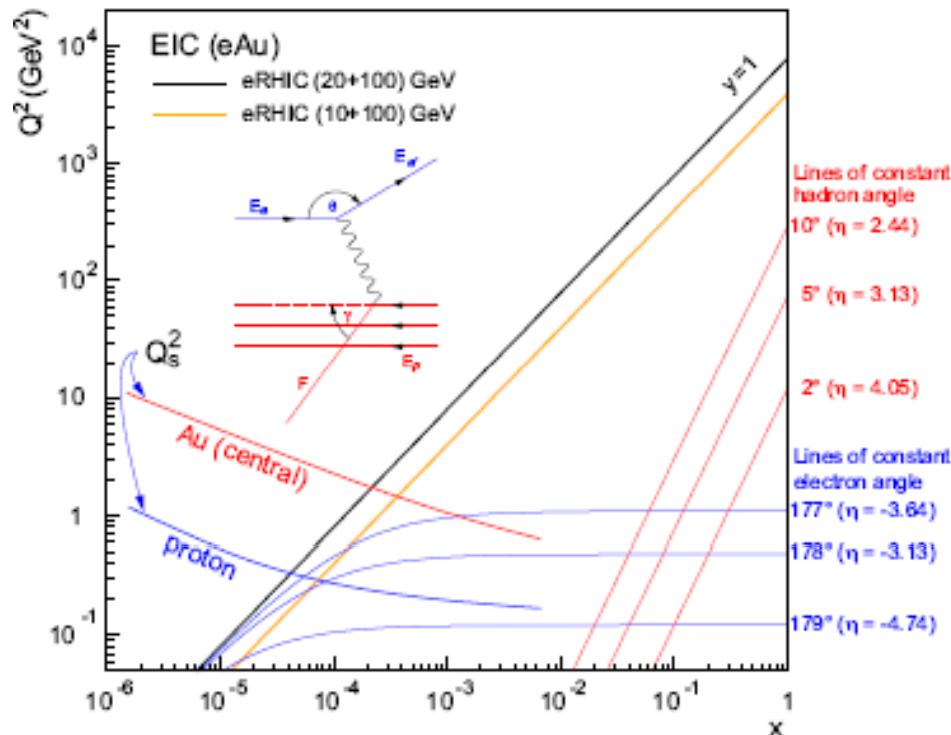
[Raju Venugopalan]

$$Q_S^2 \propto \left(\frac{A}{x}\right)^{1/3}$$

DIS on Nuclei :
a ‘cheap’ way to reach
saturation at $Q^2 \sim \text{few GeV}^2$?



Detector(s) for EIC

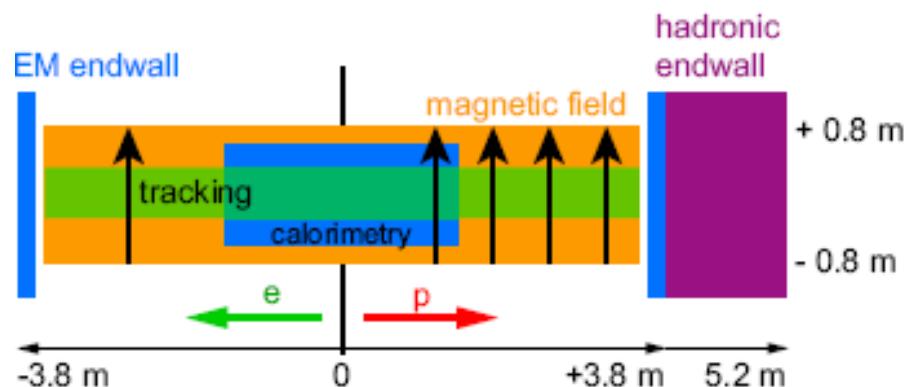


Challenging requirements :

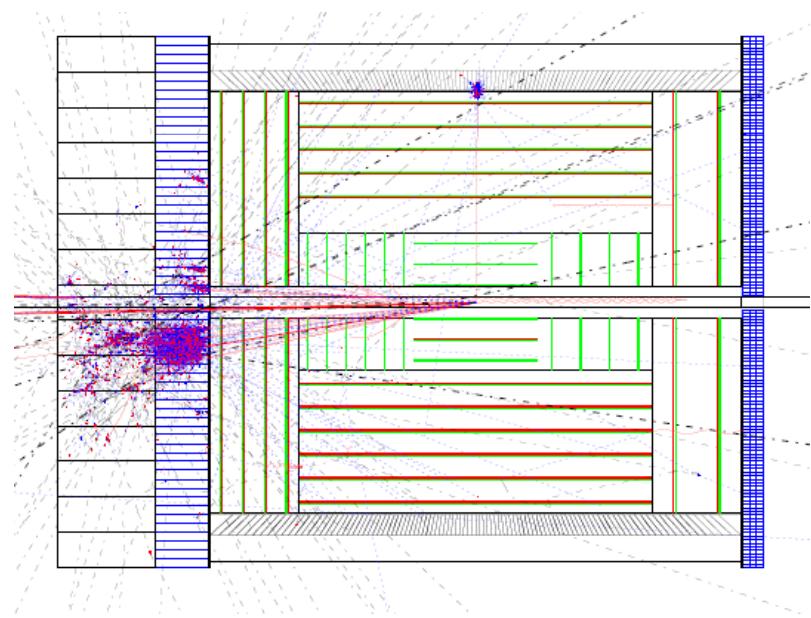
- 1) Excellent electron and hadron measurement close to beam axes
 - 2) High luminosity with focusing magnets close to the IP
- Two detector concepts are being considered

Detector(s) for EIC

A detector focused on
rear/forward acceptance

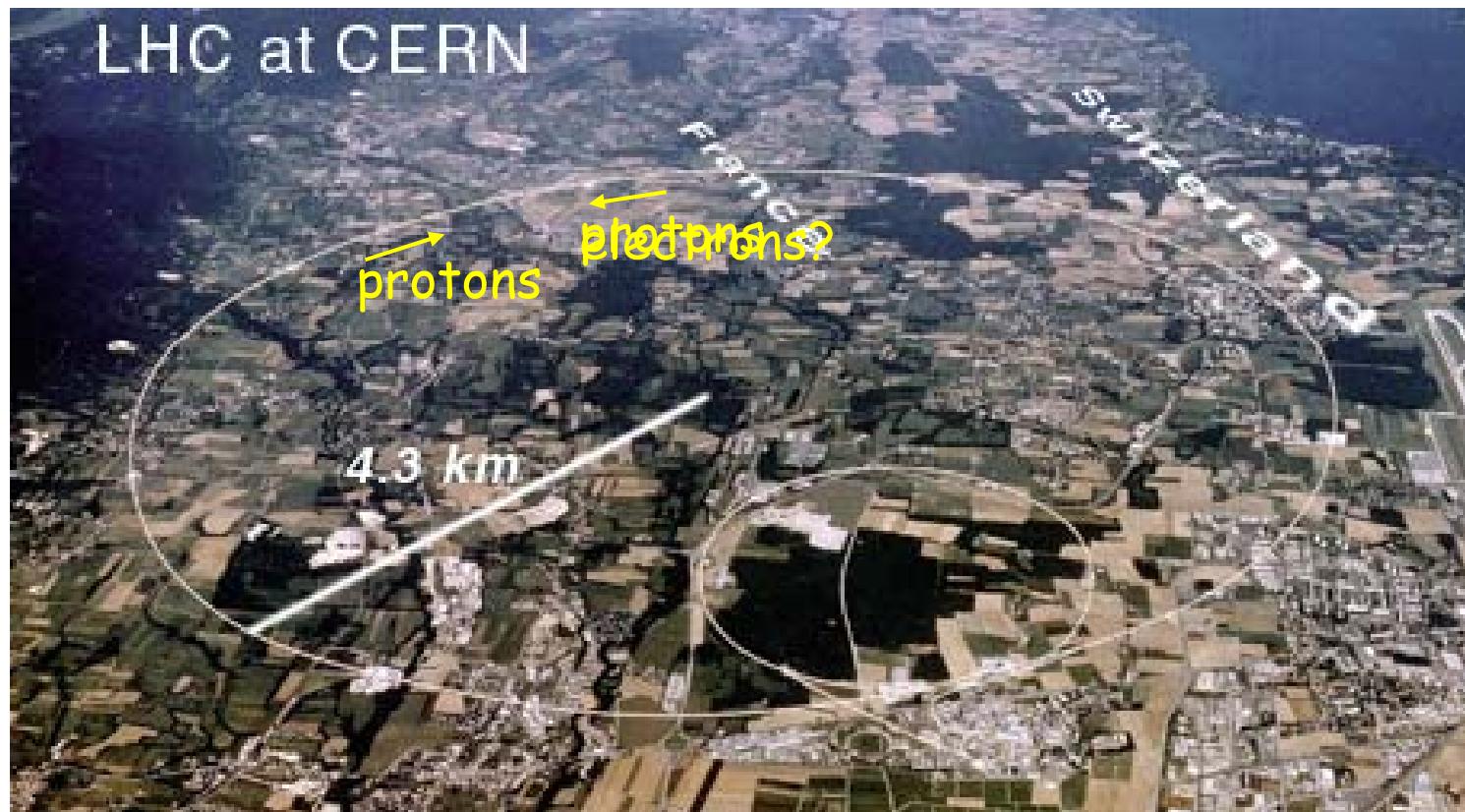


A wide acceptance detector
similar to H1 and ZEUS



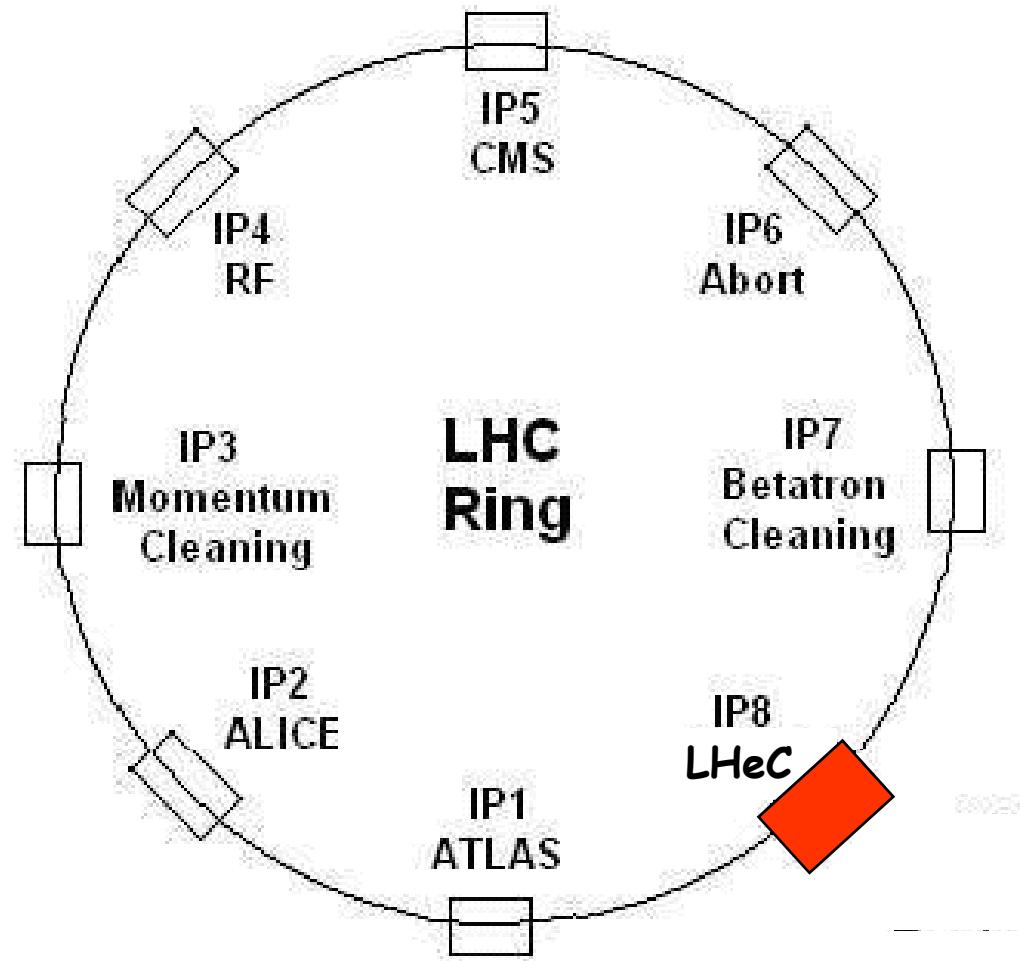
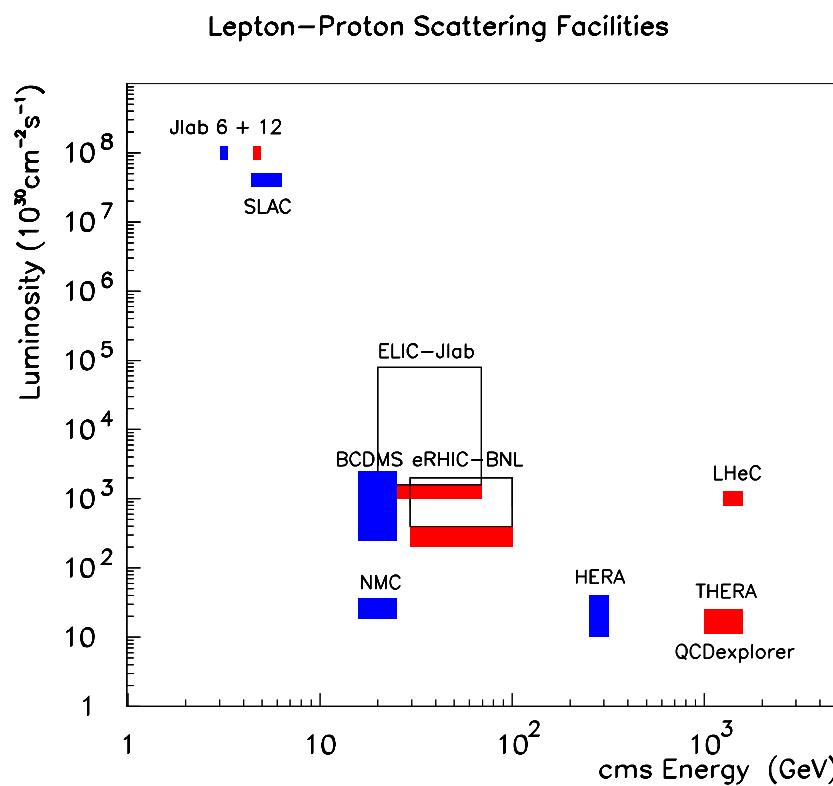
Large electron Hadron Collider

"standard" LHC protons ... with electrons



Large electron Hadron Collider

70 e \times 7000 p GeV
Luminosity $10^{33} \text{cm}^{-1}\text{s}^{-1}$



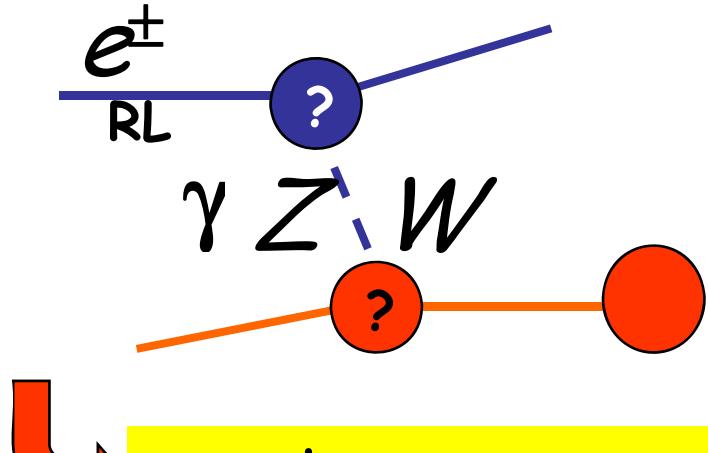
Highlight of the LHeC : kinematic reach

(J. Dainton)

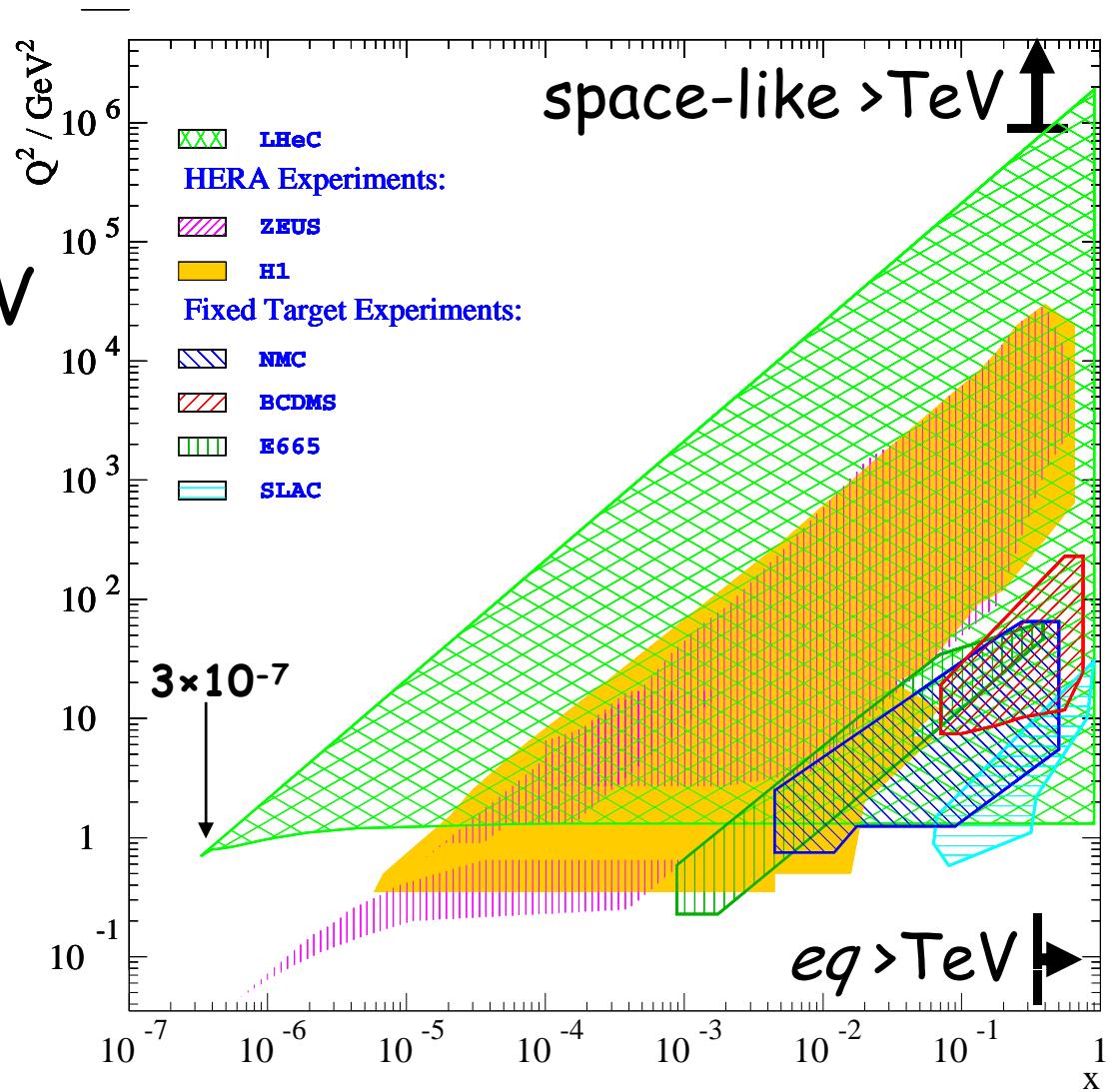
- $70 \otimes 7000 \text{ GeV}$

e^\pm p

cm energy 1400 GeV



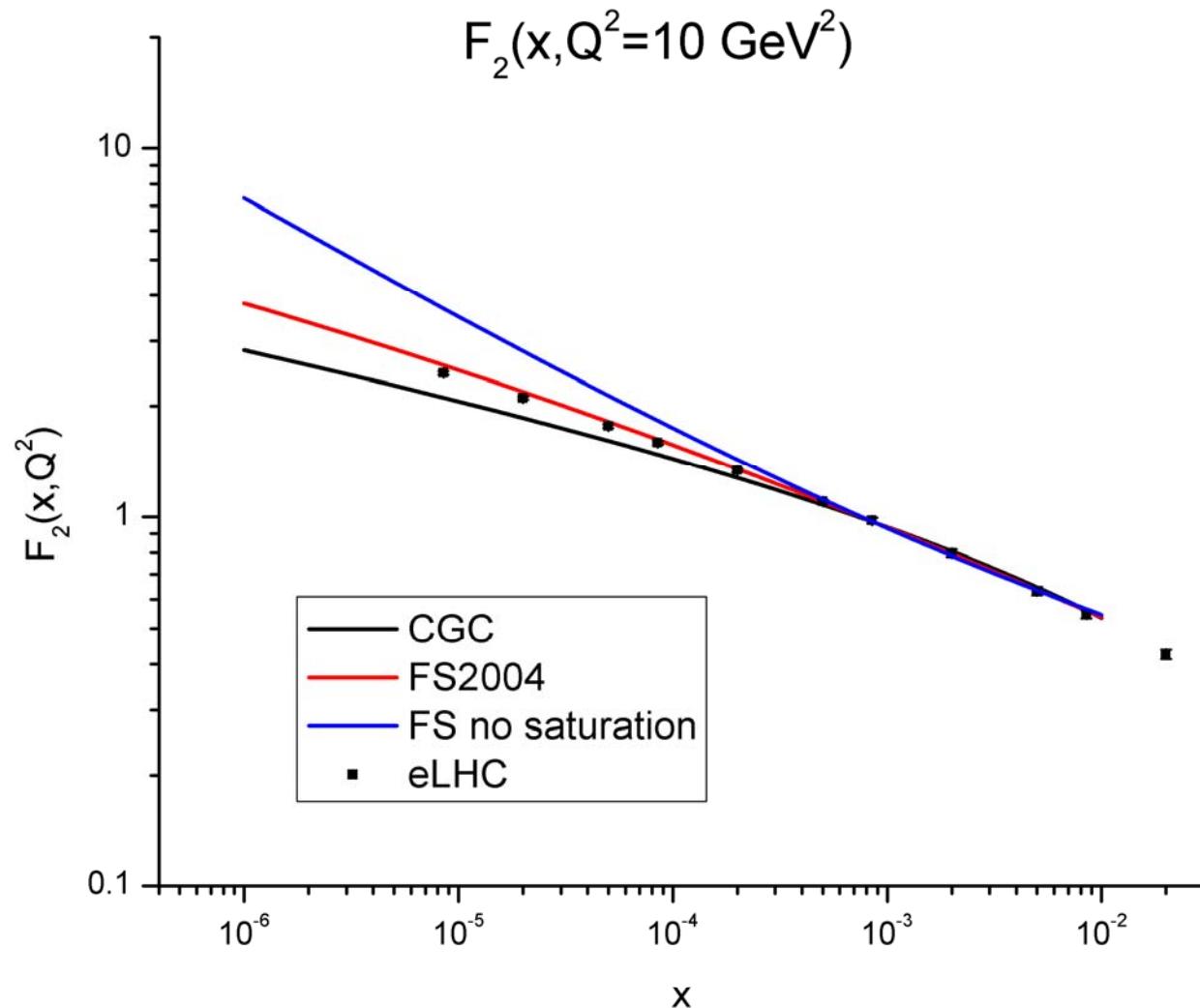
quark structure
@ $\geq 0.0001 \text{ fm}$



Highlights of the LHeC programme

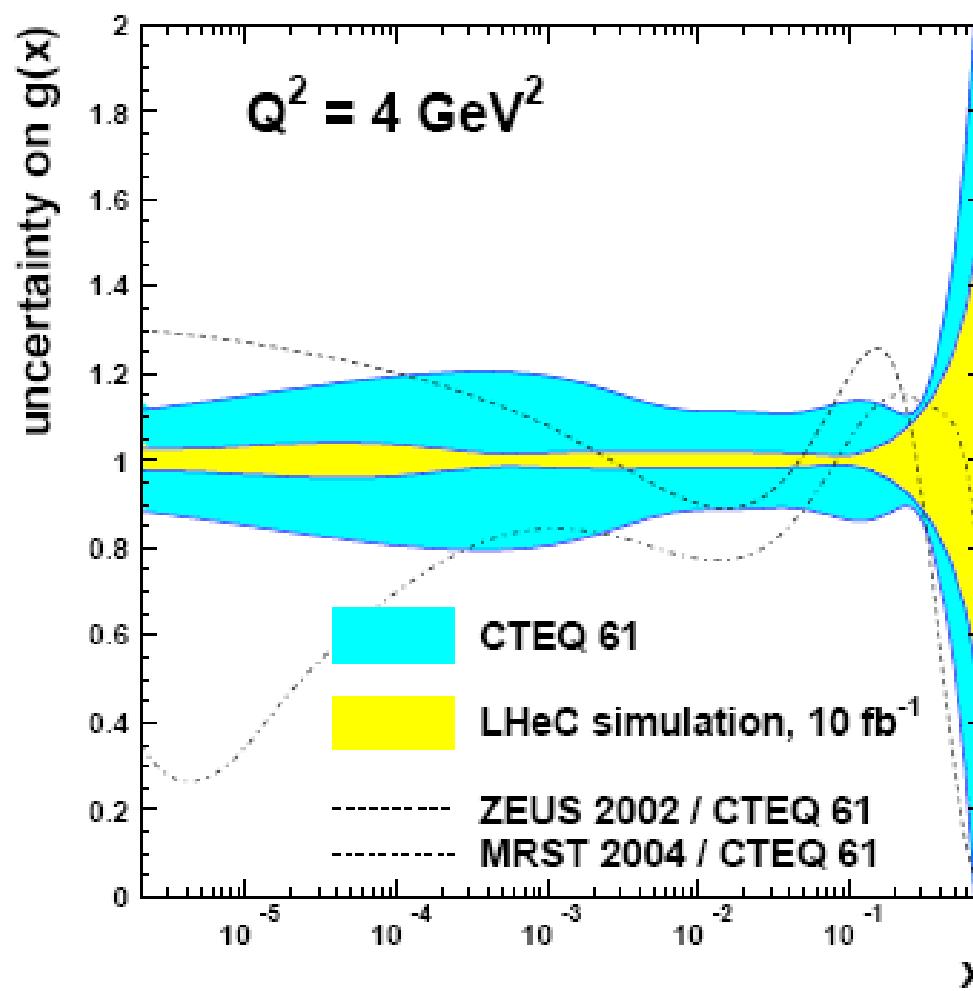
- Understanding QCD. Low x , high parton density, hard diffraction.
- PDFs at very very low x and at large x .
- Nuclear matter : Quarks and gluons in Nuclei at very low x .
- Lepton-quark interactions

Highlight of the LHeC : very very low x



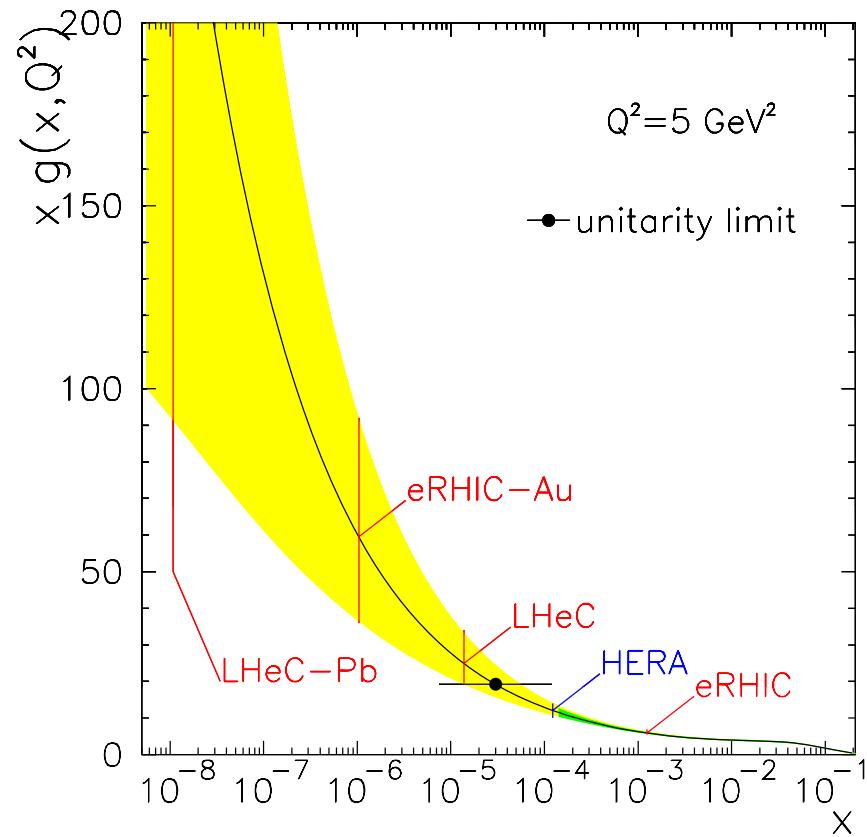
(P.Newman)

Highlight of the LHeC

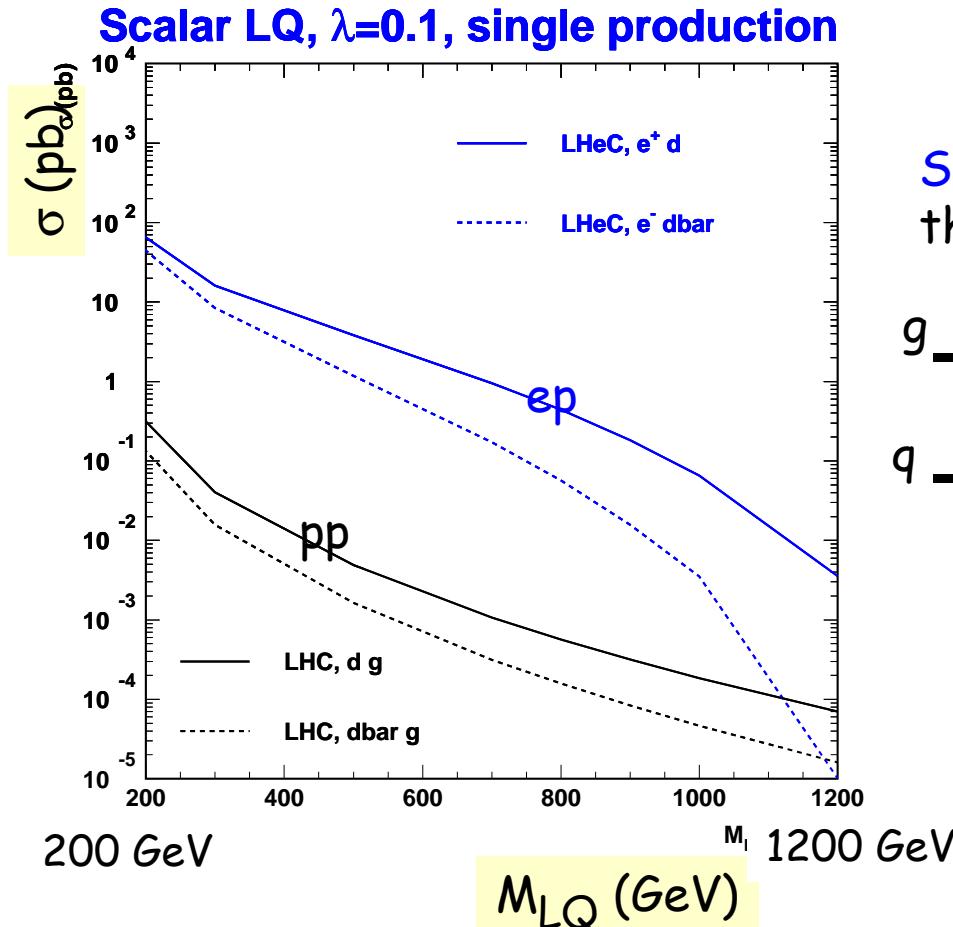


(Max Klein)

Highlight of the LHeC : access to very low x in protons and nuclei

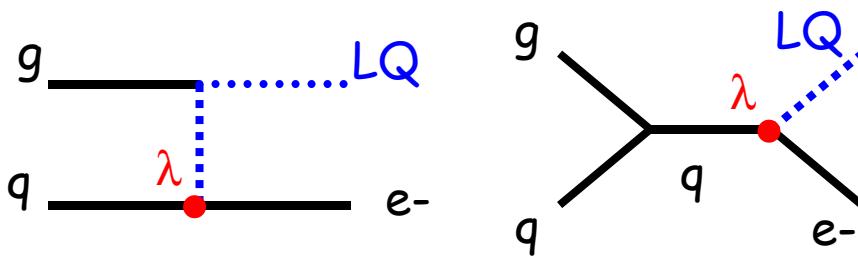


Highlight of the LHeC : Lepto-quark production



(E. Perez)

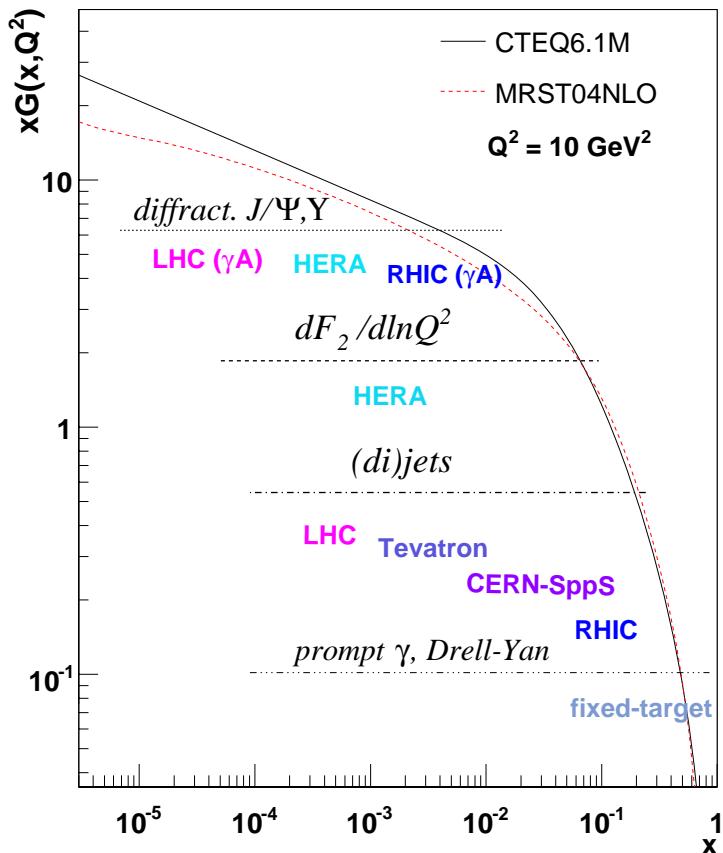
Single LQ production also possible at the LHC.



Smaller x-section than at LHeC.
And large background from $Z + 1$ jet.

If LHC observes a LQ-like resonance, $M < 1 \text{ TeV}$, with indications (single prod) that λ not too small, LHeC would determine the Fermion number.

Complementarity of pp and ep on PDFs



(D.D'Enterria (HERA-LHC WS))

Measurements from LHC itself may improve knowledge of
Gluon PDF at low- x (W prodn) and high- x (high ET jets)
Low- x valence PDFs (and maybe higher- x) W asymmetry

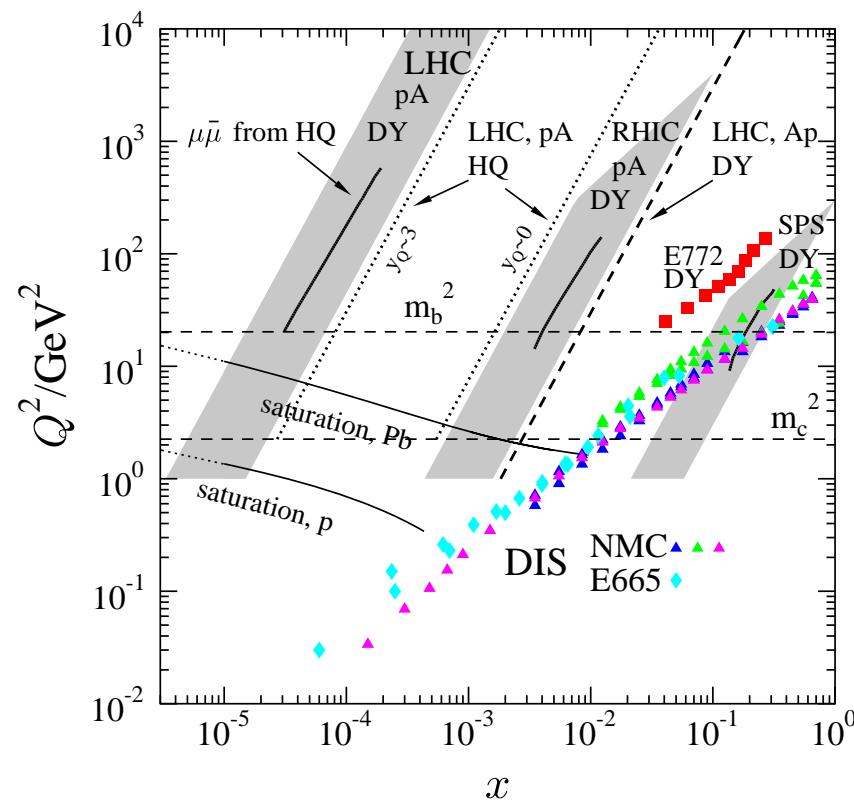
(A M Cooper-Sarkar)

Don't expect miracles. It is not a substitute to
DIS measurements.

Complementarity of pA and eA nuclear distributions

RHIC and LHC in p-A collisions would have access to the mid- Q^2 saturation domain.

However factorization is uncertain in the strong gluon field regime. eA data may turn out to be vital to understand hot dense gluonic matter.



Complementarity of RHIC and EIC spin measurements

- At large x : Δu , $\Delta \bar{u}$, Δd , $\Delta \bar{d}$ measurements should come from Jlab-12 GeV and from RHIC (W physics).
- Hermes, Compass and RHIC give some to constrain ΔG down to $x=0.01$
- EIC gives access to very low x ,
Crucial for the integral of spin distributions :

$$\int_0^1 dx \Delta g(x, Q^2)$$

Crucial for the Bjorken Sum Rule.

$$\int_0^1 dx [g_p^1(x, Q^2) - g_n^1(x, Q^2)] = \frac{1}{6} g^A [1 + O(\alpha_s) + \dots]$$

Tentative conclusion (a personnal view)

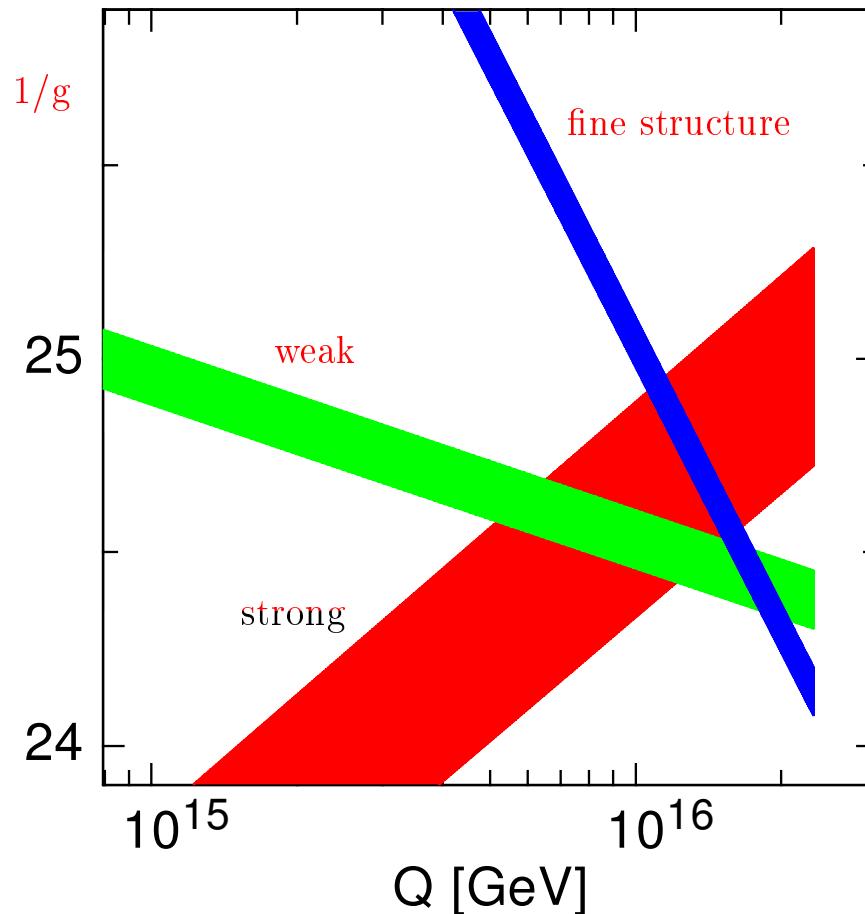
- **Physics adressed by DIS physics will not stop** with the end of data taking at HERA.
- **Legacy of HERA** : The final data should be an important asset to high energy physics. Many results are dominated by experimental and theoretical systematic errors. All efforts should be made to achieve the **highest possible precision**. It would be a safe investment in the future.
- **Jefferson Lab 12 GeV** (on track for CD2). On track to get new and precise insights into the valence quark region at Q^2 of a few GeV^2
- **Electron Ion Collider** at BNL or Jefferson Lab. A real break through in spin and nuclear matter physics. Urgent to establish a process to **make a choice** : trade between luminosity, energy, time schedule and cost.
- **LHeC at CERN**. A very attractive physics programme. BUT. It would be in competition in Europe with the upgrade of LHC or(and) with a Linear Collider. Uncertain to be supported by the high energy physics community and our funding agencies, **unless**
new developments at LHC indicate that the physics case « becomes even more desirable ».

EXTRAS

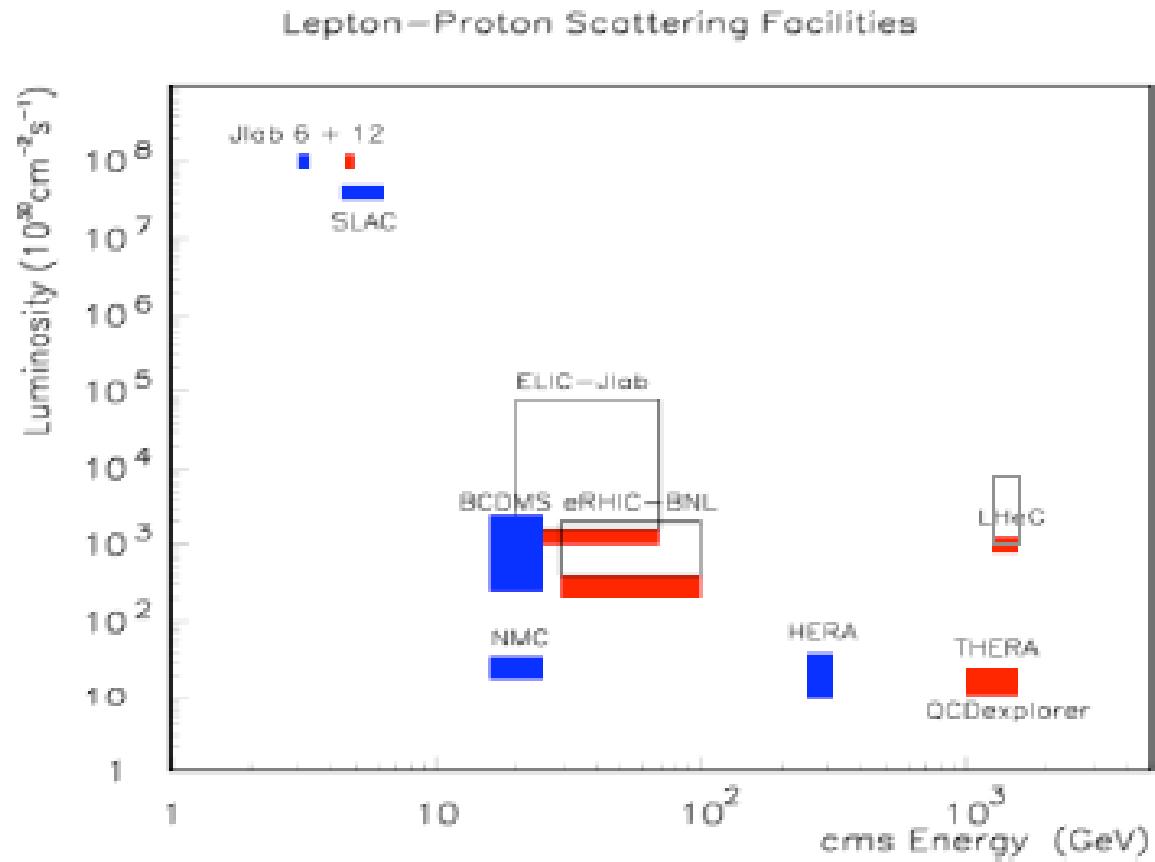
Open question : precision on α_s

$\Delta\alpha_s(M_Z) \sim 0.002$ is
a clear limitation !

Can DIS experiments
do better ?
Can Lattice Calculations
take over from exp. data?

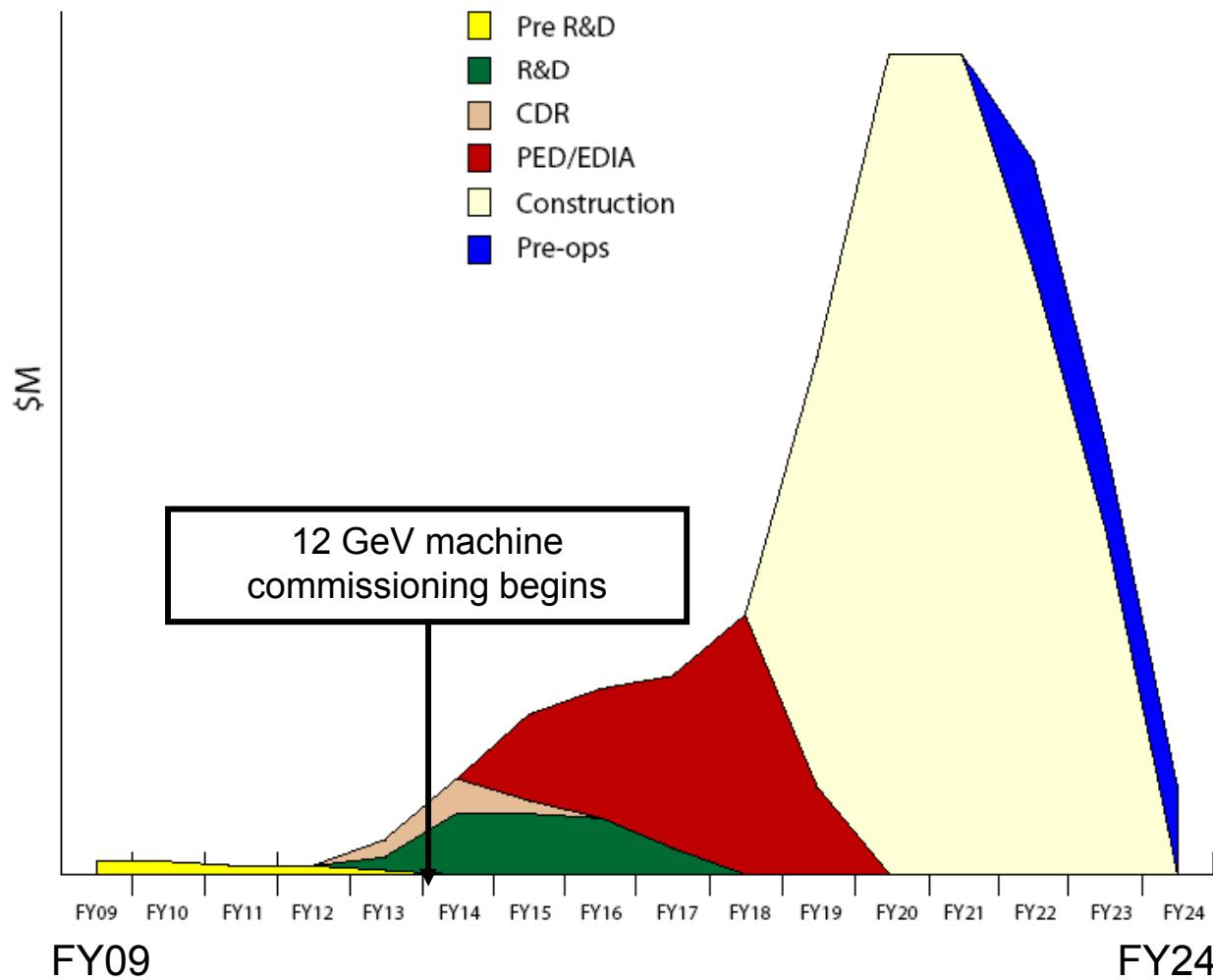


Jefferson Lab 12 GeV upgrade

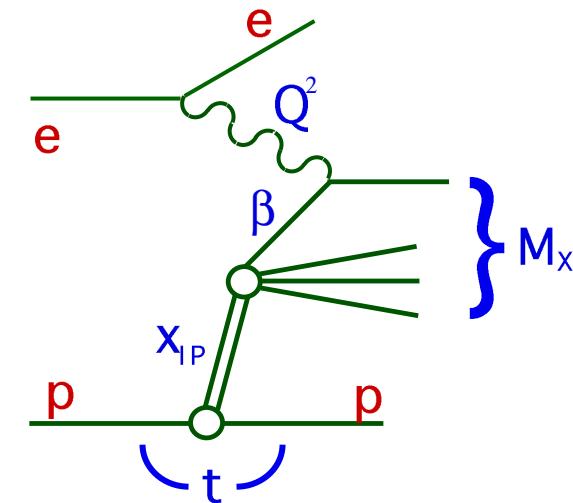


ELIC at Jefferson National Laboratory

L. Mermanga
EIC Coll. Meet
6/7 April 2007

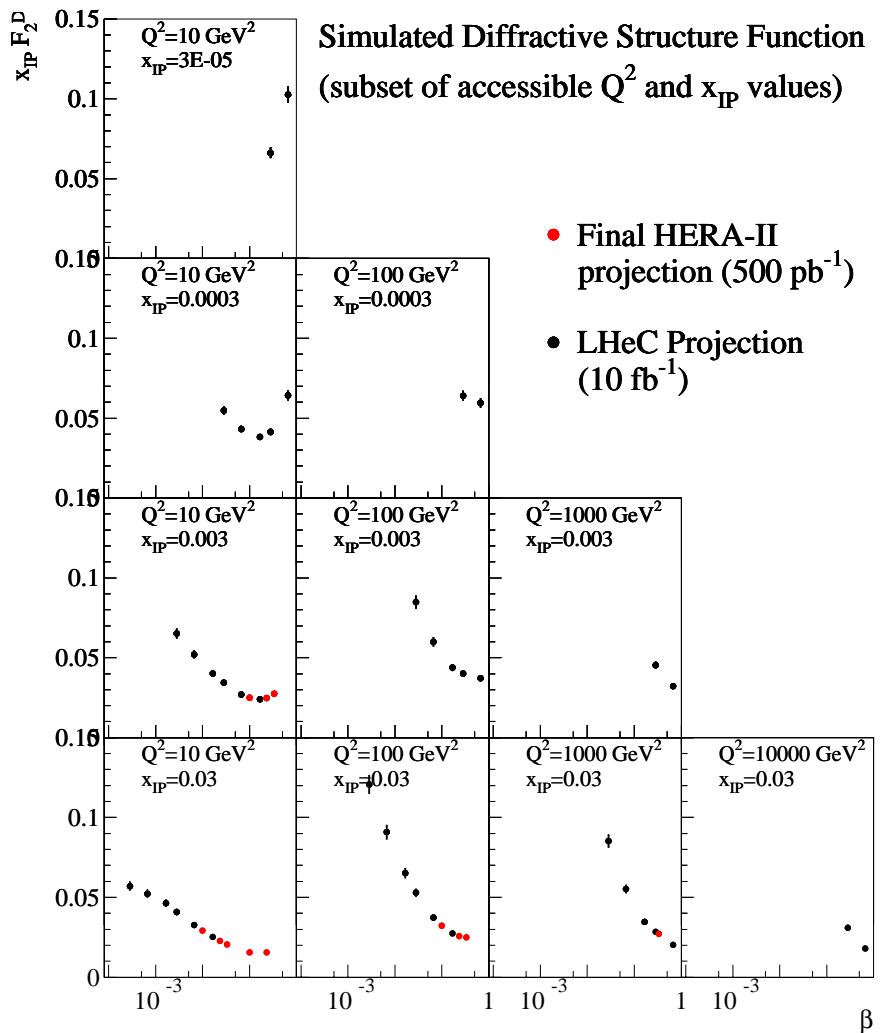


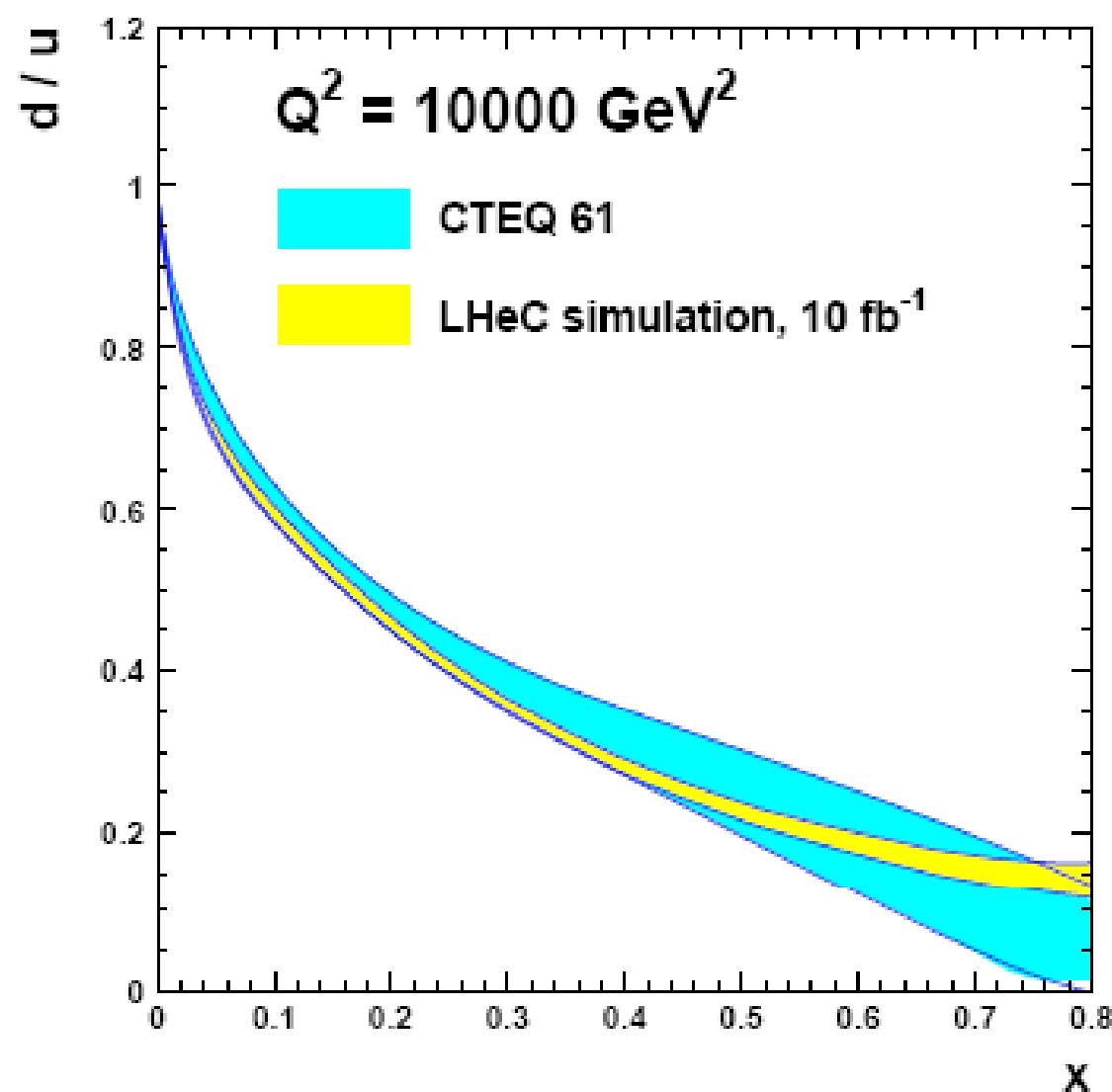
Highlight of the LHeC : kinematic coverage in diffractive processes



Extension by a factor 50

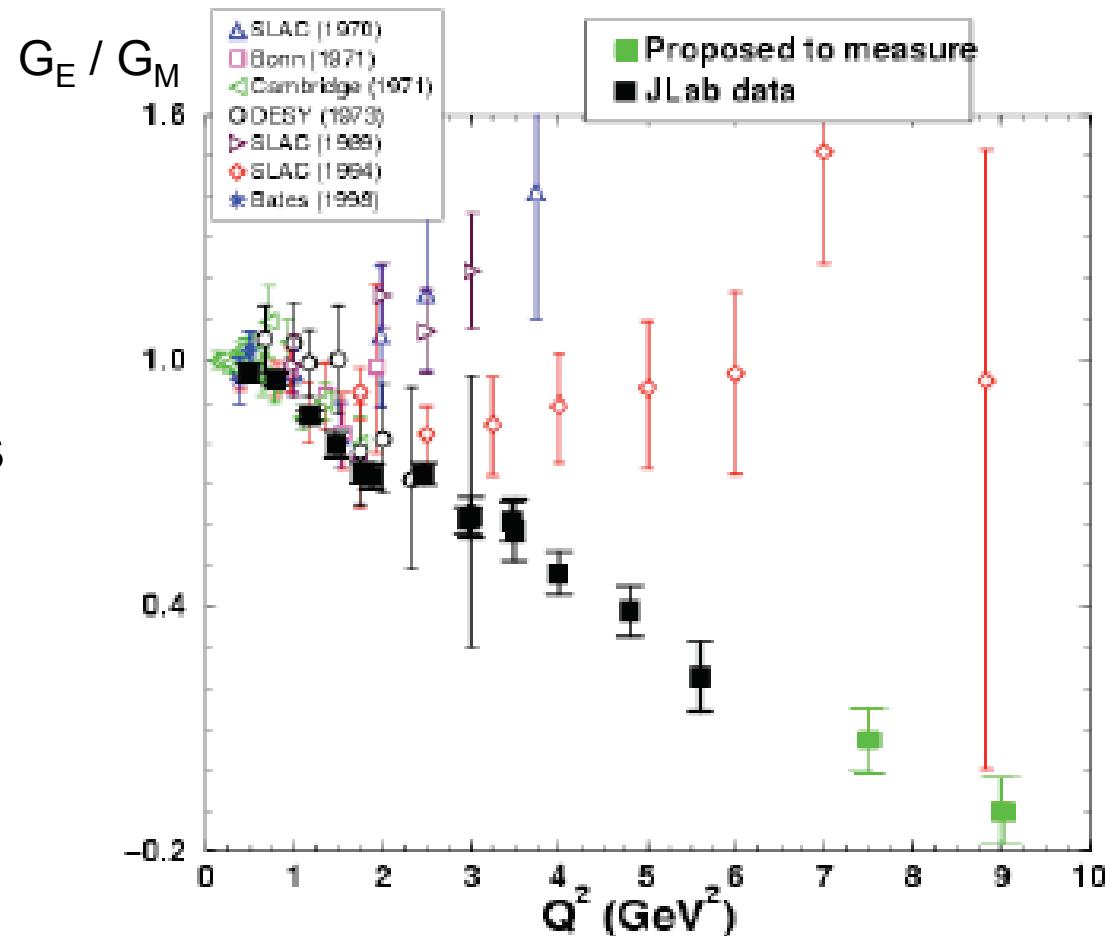
to lower X_{Pom}
to lower β
to higher Q^2





Complementarity of measurement at JLab (e-N) and GSI (pbar at 15 GeV)

- Non-kt integrated quark distributions
- GPD's
- G_E and G_M



Complementarity of measurements at J-Parc (50 GeV) and Fermilab (800 GeV)

