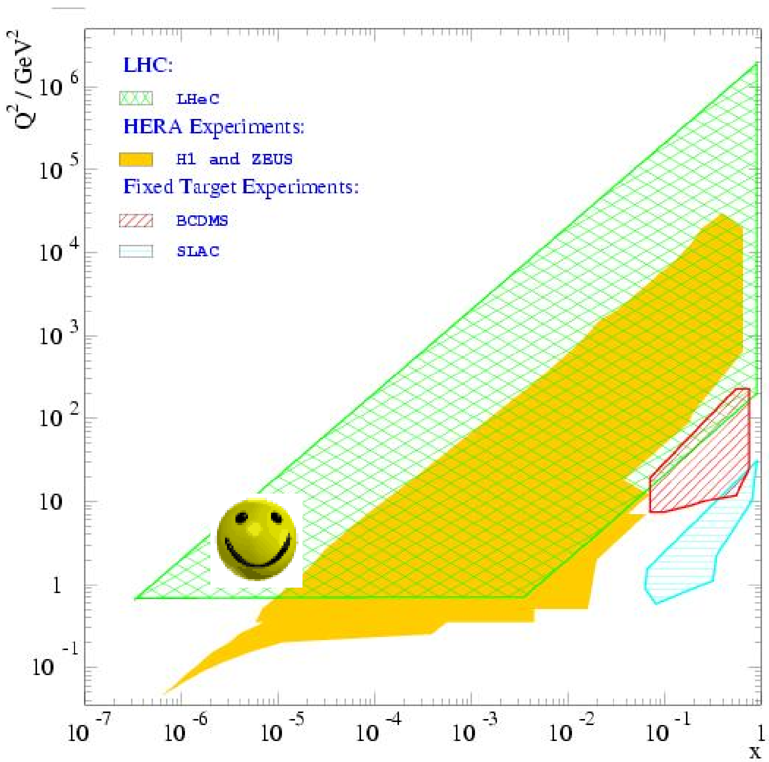
High Parton Densities Status and CDR Chapter Discussion

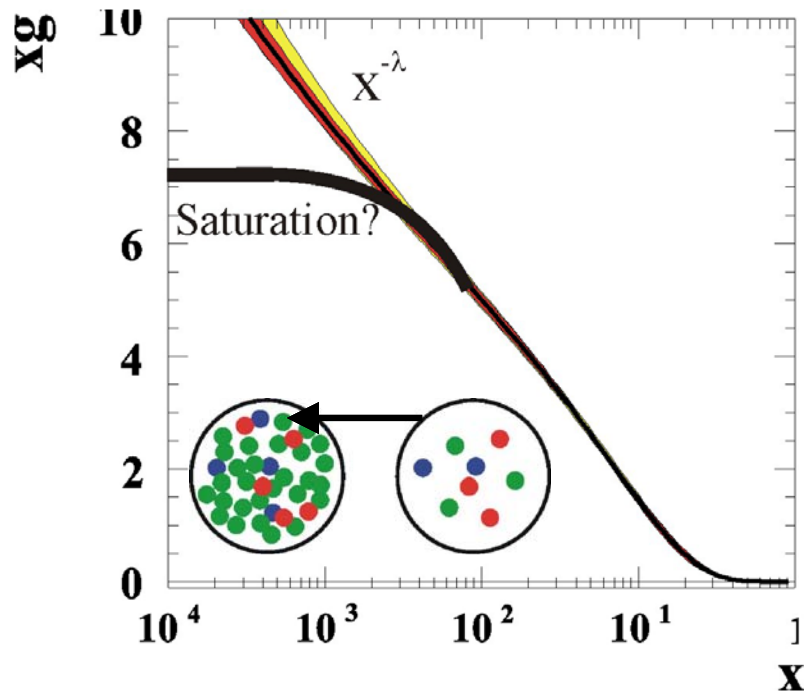
Nestor Armesto,
Brian Cole, Paul Newman,
Anna Stasto
and the working group
on High Parton Densities
in ep and eA

CERN LHeC Convenors' Meeting,
15 December 2009



Main Themes

The main theme of the HPD group's CDR contribution is the exploration of the non-linear dynamics (saturation effects) which come into play as the low x parton densities aprroach the unitarity limit in the perturbative regime.



- This most naturally follows on from the chapter on precision QCD and Electroweak Physics
- The physics to be explored is very similar in ep and eA, the case is strongest if they are explored together (and repetition is minimised)

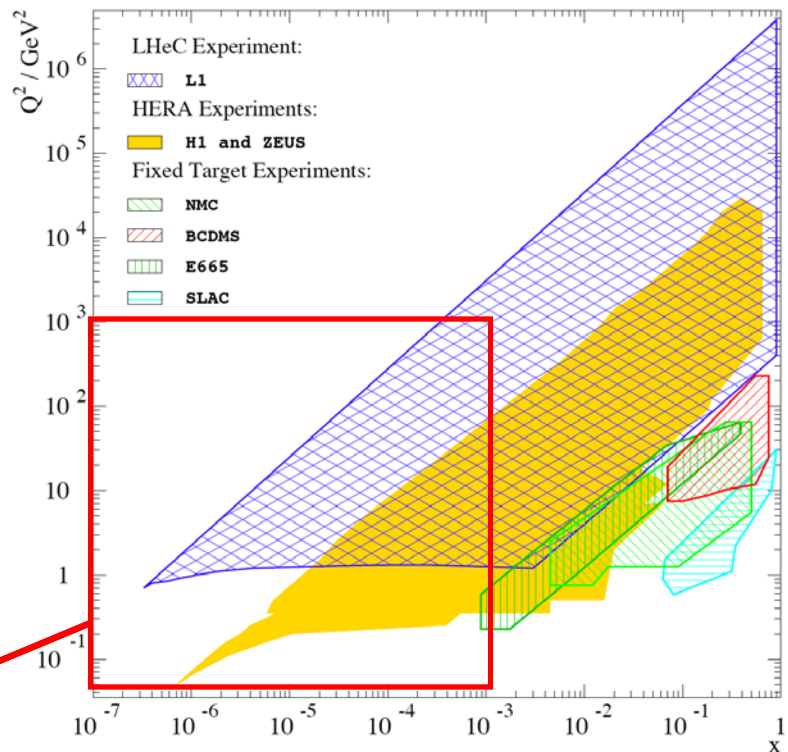
Other topics will of course be included (see later)

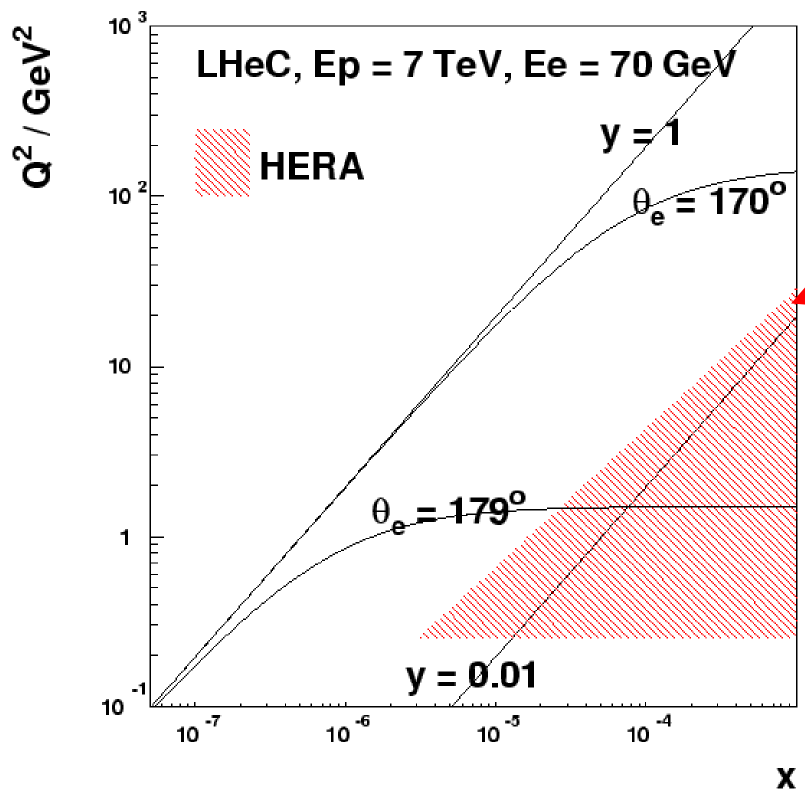
- More easily separated between ep and eA

Basic Inclusive Kinematics / Acceptance

Access to Q^2=1 GeV^2 in ep mode for all x > 5 x 10^{-7} IF we have acceptance to 179° (and @ low E_e')

Nothing fundamentally new in LHeC low x physics with θ<170°





Something of this type presumably appears under `design considerations'?

If so, we write the chapter assuming 1° acceptance and don't labour the point

CDR: 1) Introduction / Motivation

I. Introduction (Conveners) *[2]*

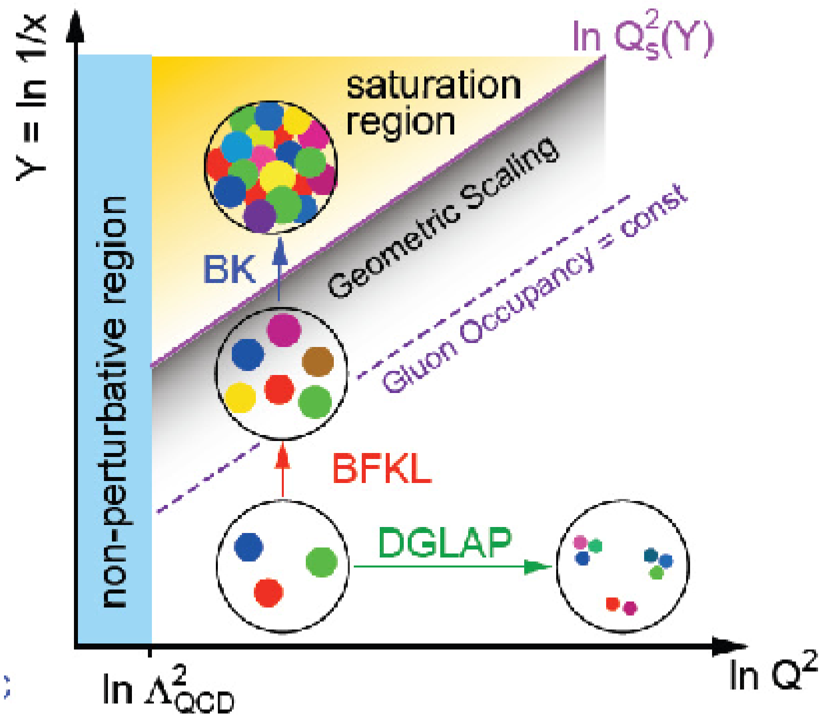
II. Physics at small x

1. Unitarity and QCD (A. Stasto, M. Strikman, J. Bartels) *[4]*

   a. From DGLAP to non-linear evolution equations in QCD: saturation *(plot of the $\ln 1/x - \ln Q^2$ plane with the name of evolution equations and the saturation line)*

   b. Saturation in pQCD: GLR-MQ, the CGC *(plot of the CGC evolution???)*

   c. The importance of diffraction.



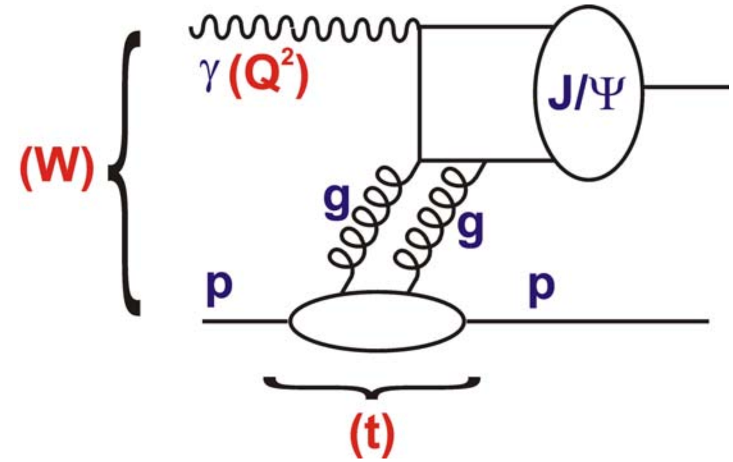
- Where saturation lives in the kinematic plane

- Theoretical descriptions:
  - Eikonalised DGLAP
  - BK equation / CGC

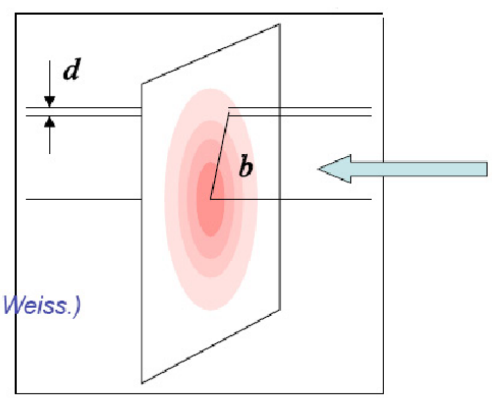
- Intro to observables … first mention of diffraction in CDR, so will need explanation

Diffractive Channels

Additional variable t gives access to impact parameter (b) dependent amplitudes

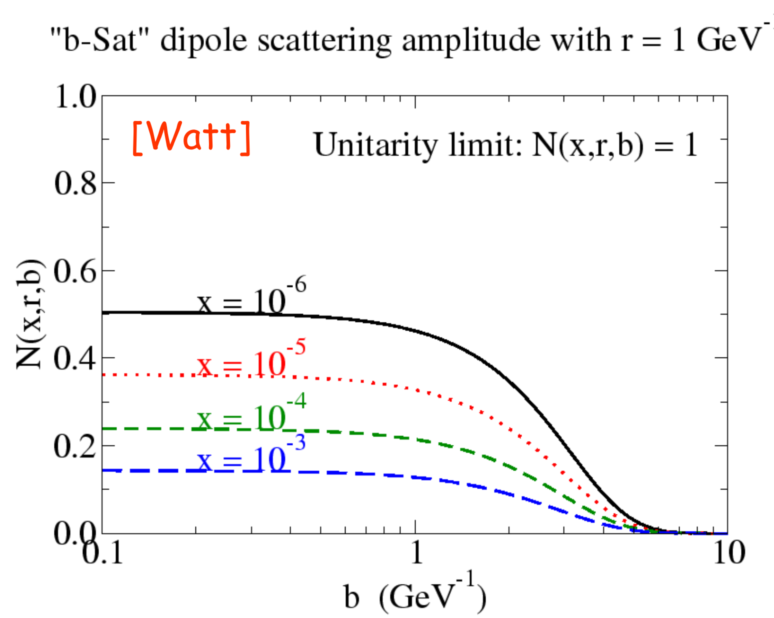


Large t (small b) probes densest packed bit of proton / nucleus … dipole scattering amplitude reaches large fraction of unitarity limit at low x values measurable at LHeC



(figure from C. Weiss.)

Central black region growing with decrease of x.



CDR: 1) Introduction / Motivation

2. Models motivated by HERA data *(would it be possible to gather all descriptions - one of each type - into three plots, one for F_2, one for F_L and one for inclusive diffraction???, one example from each type of models) [4]*

   a. DGLAP evolution (J. Rojo, S. Forte)

   b. Linear resummation schemes (S. Forte, A. Stasto)

   c. Dipole models (J. Albacete, A. Stasto, G. Watt)

Quick introduction to models of HERA data, probably with a couple of plots
Some of this is no doubt covered in the QCD / EW section

3. Low-x physics at the LHC: limitations in pp, pPb and PbPb (B. Cole, D. d'Enterria, C. Salgado) *(plot of the $\ln 1/x - \ln Q^2$ coverage, C. Salgado has it for pA) [2]*

After discussing HERA, important to assess where the field might be as the first phase of LHC unfolds
… why we need ep, eA for this and not only pp, pA, AA
… needs significant work
… `white paper' on pA @ LHC expected in Spring (Salgado)

CDR: 2) Some More Introduction to eA

4. Nuclear targets:
   a. Situation for nuclei (N Armesto, M. Strikman, K. Eskola) *(plot of the comparison of DGLAP approaches for nuclear ratios together with Mark's FGS) [1]*
   b. Significance for the heavy ion program (N. Armesto, B. Cole, U. Wiedemann) *[1]*
5. Implications for the ultrahigh energy neutrino interactions (A. Stasto, N. Armesto) *(plot of the relevant regions in x and Q^2 for tau eloss and neutrino cross section???) [1]*

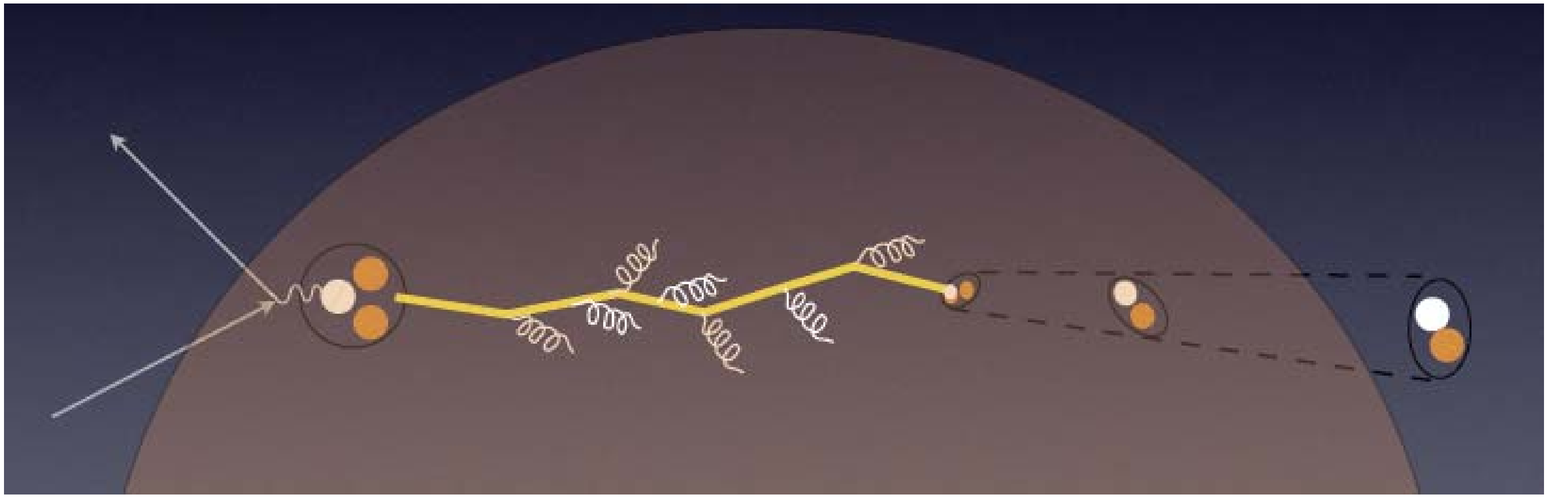
Introduction to how eA the physics impacts on the heavy ion programme:

- Explanation of how eA provides a clean way to determine the initial state of AA / pA & why that's important

- eA as a control experiment for AA (final state effects in an extended hadronic medium)

CDR: 2) Some More Introduction to eA

6. Perturbative and non-perturbative aspects of final state radiation and hadronization: jets and semi-inclusive observables in ep and eA (the ep part to be agreed with the QCD/EW group) (B. Cole, W. Brooks) *(this involves from the determination of α_s via jets and the input for fragmentation functions in the proton, to the corresponding nuclear cases) [1]*



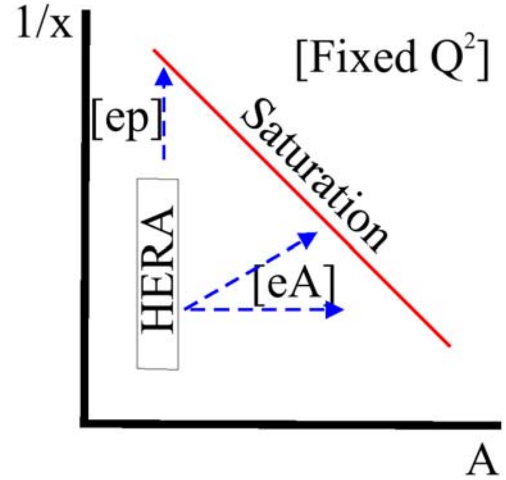
eA baseline to separate cold nuclear effects from QGP effects in AA

How particle production takes place: measurements of fragmentation / particle production and universality tests

HERA → LHeC

Enhance target `blackness' by:

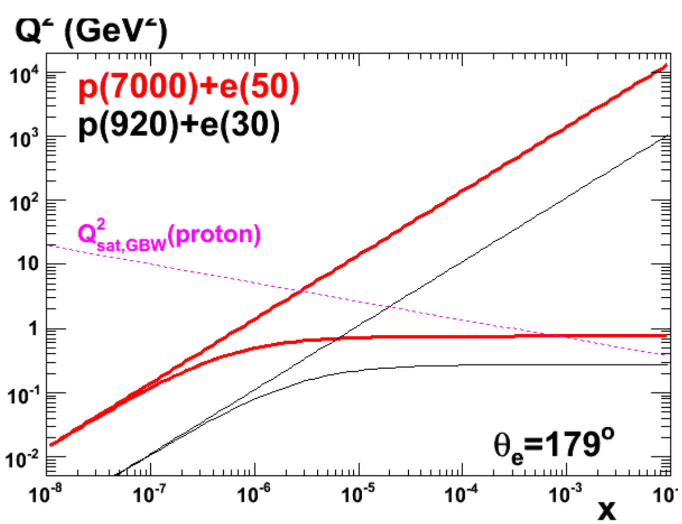
1) Probing lower x at fixed Q^2 in ep

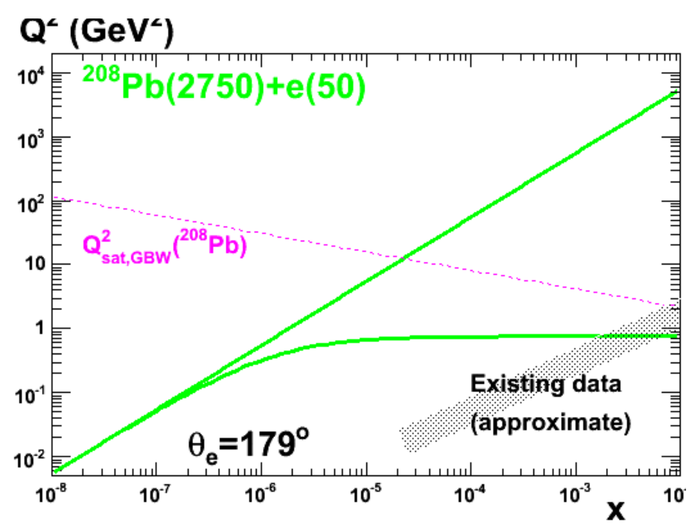


2) Increasing target matter in eA
… $A^{1/3}$ ~ 6 for Pb … worth 2 orders of magnitude in x

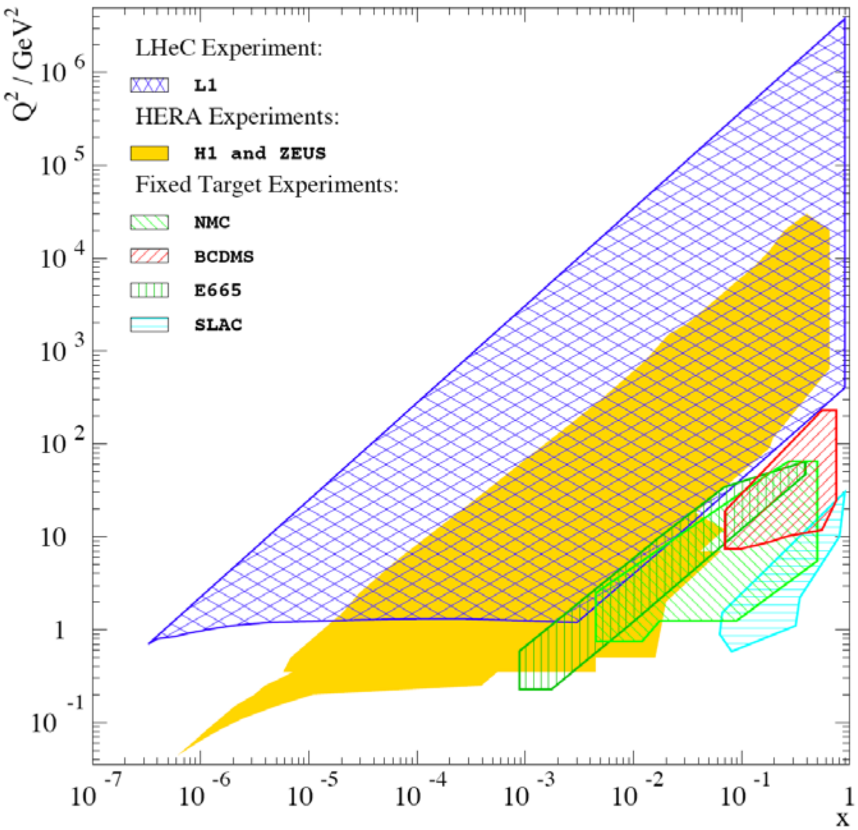
III. Prospects at the LHeC *(if not explicit, every numbered item should include a brief description of the present situation)*

1. Inclusive measurements, structure functions *(kinematics plot for ep, and by David d'Enterria for eA)*



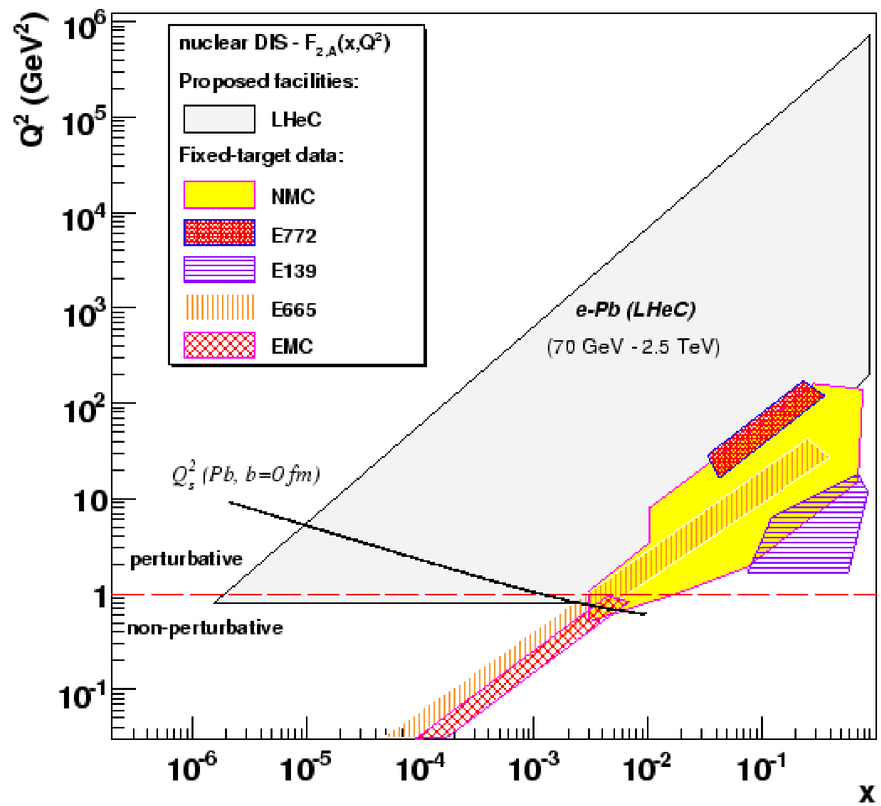


Current Version of ep, eA Kinematic Plane



… ep version certainly shown already by this Point in the CDR

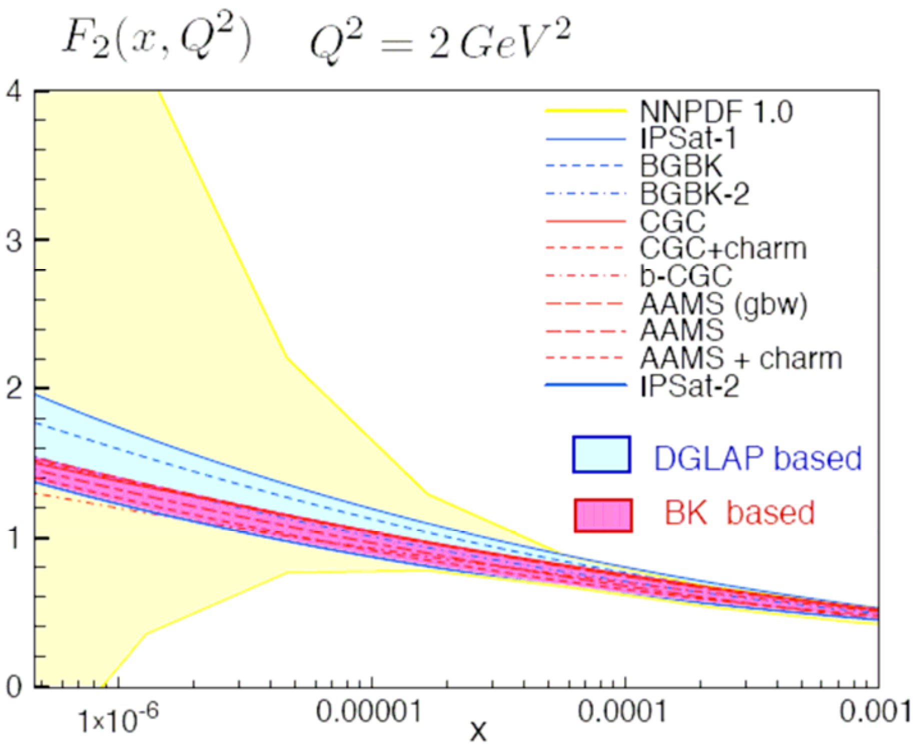
eA plot from David D'Enterria

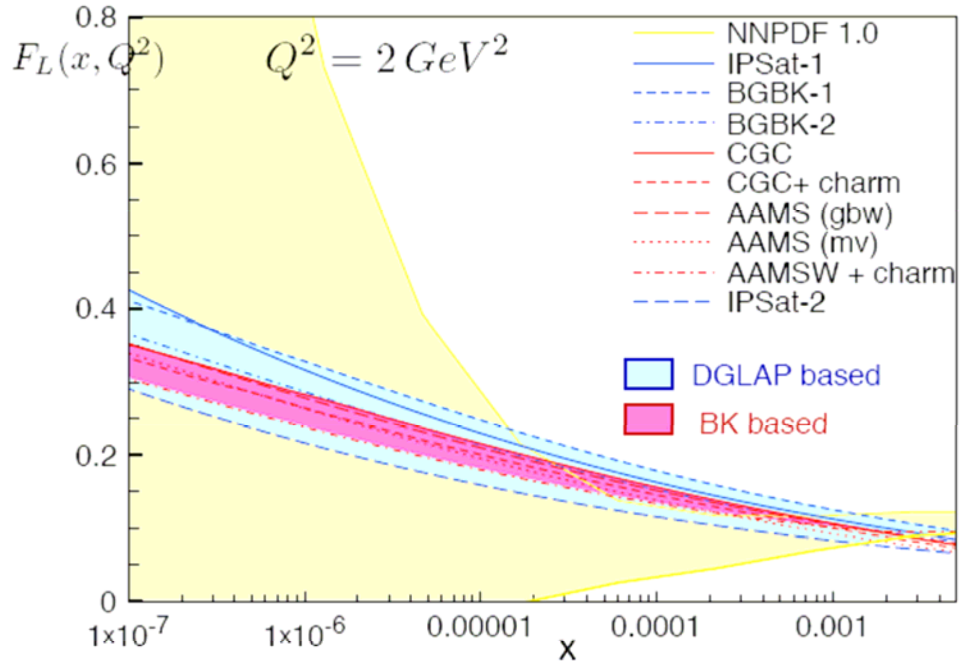


CDR: 3) LHeC Prospects

a. Predictions from different approaches for proton and nuclei (J. Albacete, A. Stasto, N. Armesto) *(plots of the comparison of different predictions and the pseudodata) [2]*

- Nice plots already for ep, comparing many QCD-motivated dipole models with full range allowed by NNPDF (Albacete)
- Still needed for eA (work ongoing)





CDR: 3) LHeC Prospects

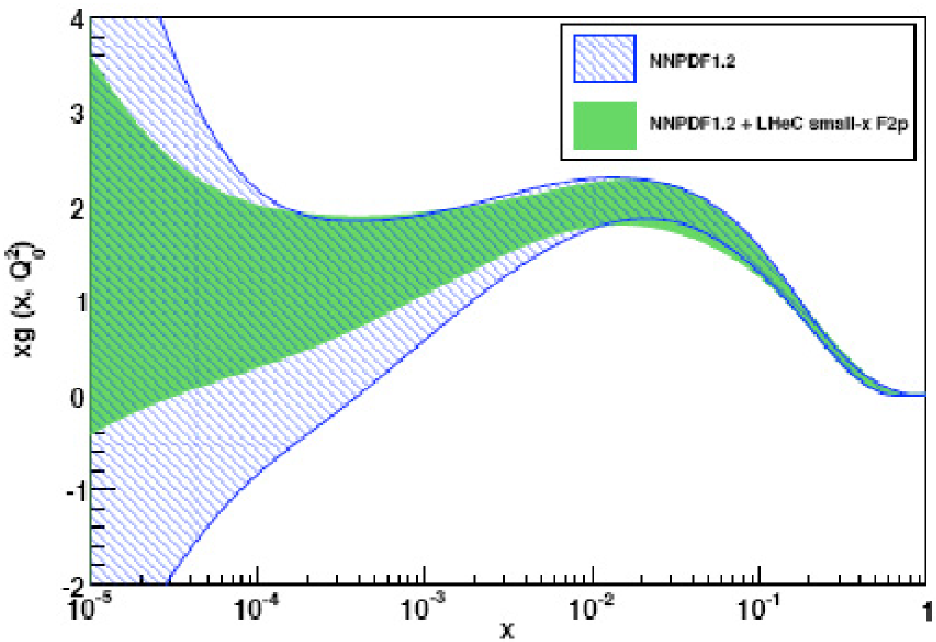
b. F_2, F_L pseudodata for proton and Pb vs. (x, Q^2) for varying electron beam energies (P. Newman, M. Klein, N. Armesto) *[2]*

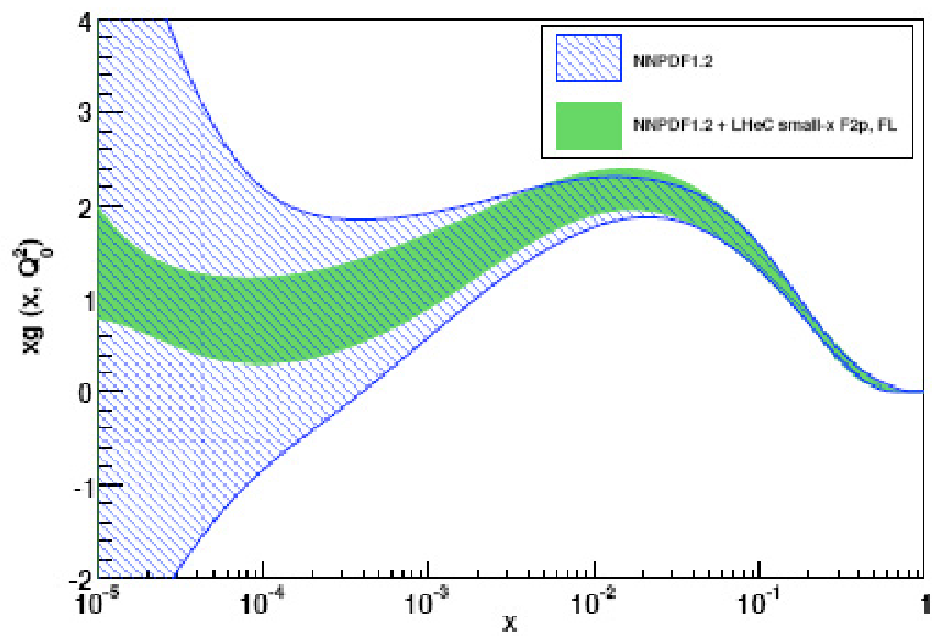
c. Impact of $F_2/F_L/F_2^c$ ep and eD pseudo-data on DGLAP fits to the low-x nucleon structure (to be agreed with the QCD/EW group) (J. Rojo, M.Klein) *[2]*

… Introduce the various pseudo-data sets and explain relation between E_e and low x reach

… Show impact on existing PDF fits, using NNPDF error bands

… Still plan to investigate other observables (F_2^c?)





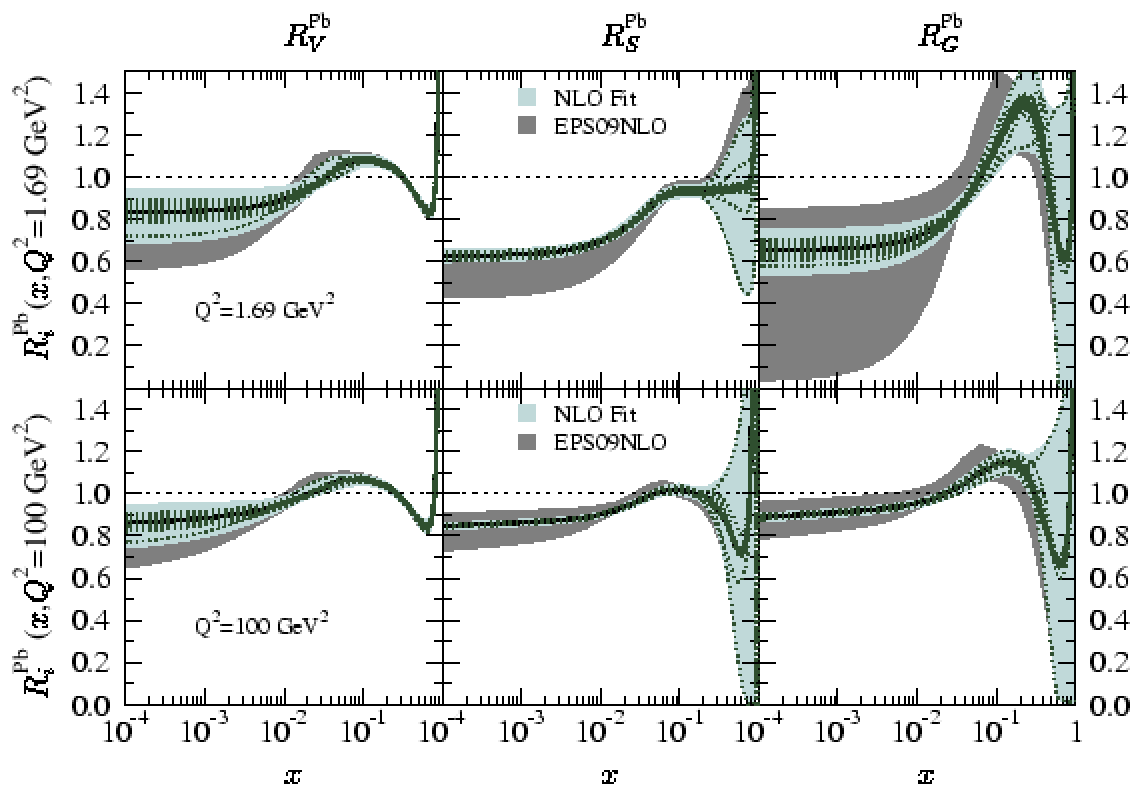
CDR: 3) LHeC Prospects

d. Impact of pseudo-data on DGLAP fits to nuclei (C. Salgado, K. Eskola, H.Paukkunen) [1]

Some nice work already done by Eskola / Paukkunen

… needs some refinement / clear statements on whether saturation can be unambiguously identified

… also compare what LHC pA will tell us (Wiedemann)



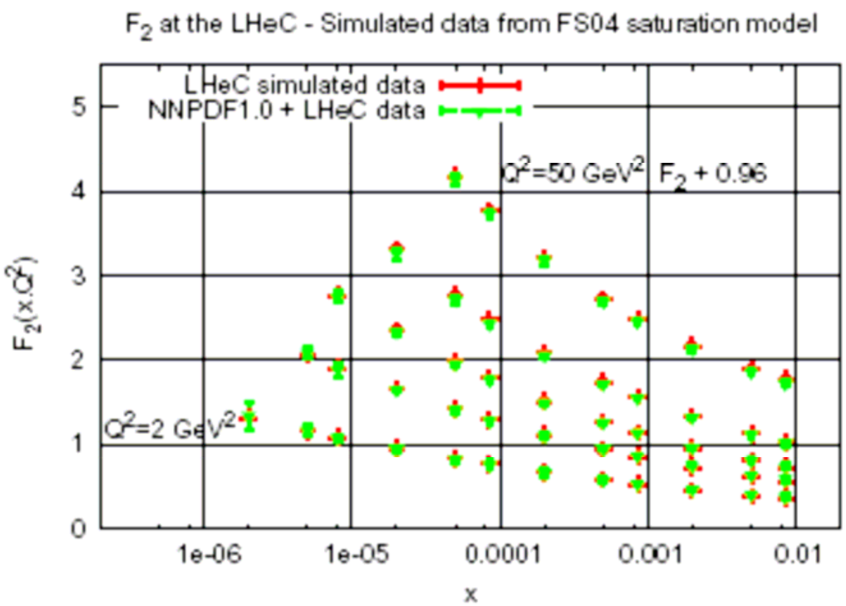
CDR: 3) LHeC Prospects

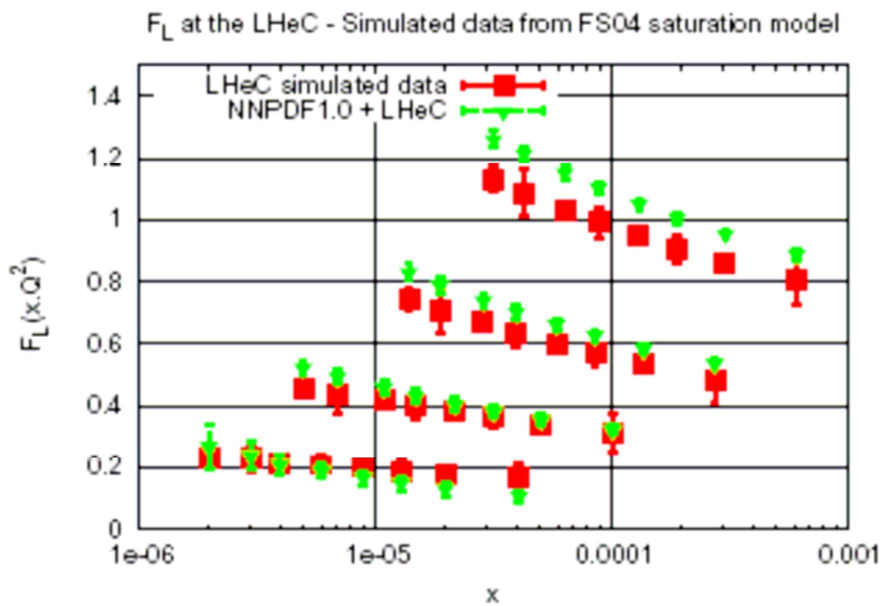
e. Testing the observability of non-linear dynamics from $F_2/F_L/F_2^c$ ep and eA data (J. Rojo, M. Klein, N. Armesto, P. Newman) *[1]*

Work has been done in 2 frameworks

- NNPDF (Rojo-Chacon, Guffanti …)
- HERA code (Forshaw, Perez, PN, MK)

… motivates need for multiple observables





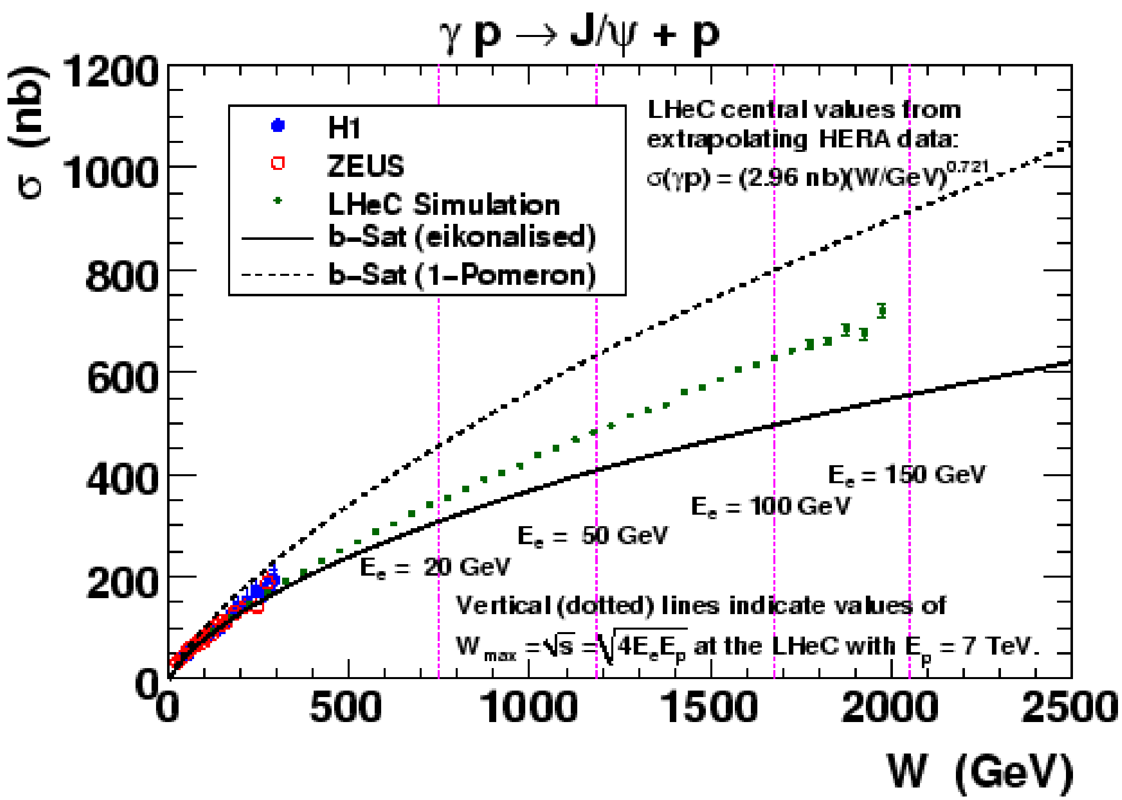
CDR: 3) LHeC Prospects

3. Exclusive vector meson production

   a. $\sigma(W)$ for proton and nuclei (P. Newman, H. Kowalski, T. Rogers, T. Teubner, G. Watt) *(plot of cross sections vs. W for J/ψ and Υ, SMOKING GUN?) [2]*

   b. Amplitude vs. impact parameter for proton and Pb (ibid.) *[1]*

Pseudo-data exist / can refine … instructive plots emerging



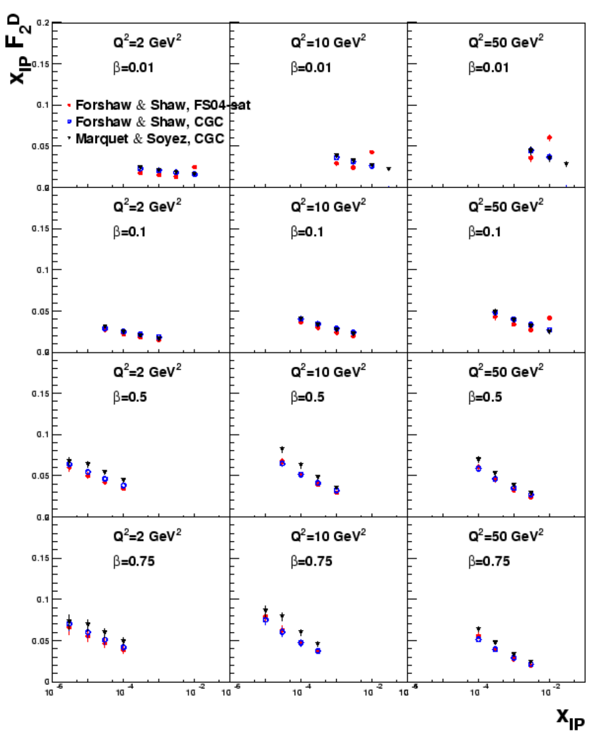
J/Ψ photoproduction identified as \`golden' diffractive channel

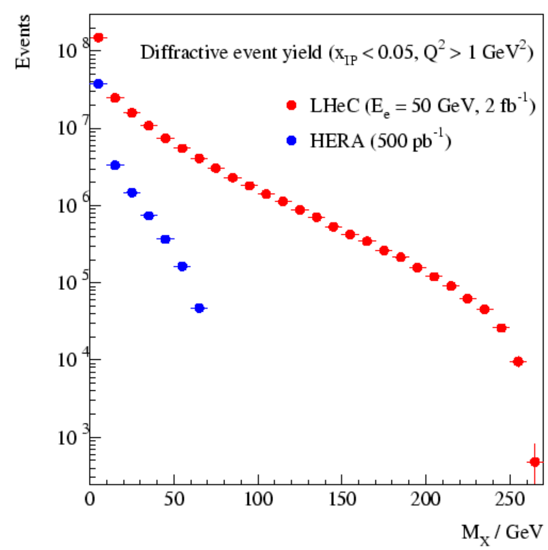
Final set of plots, also illustrating t dependence, still to be defined

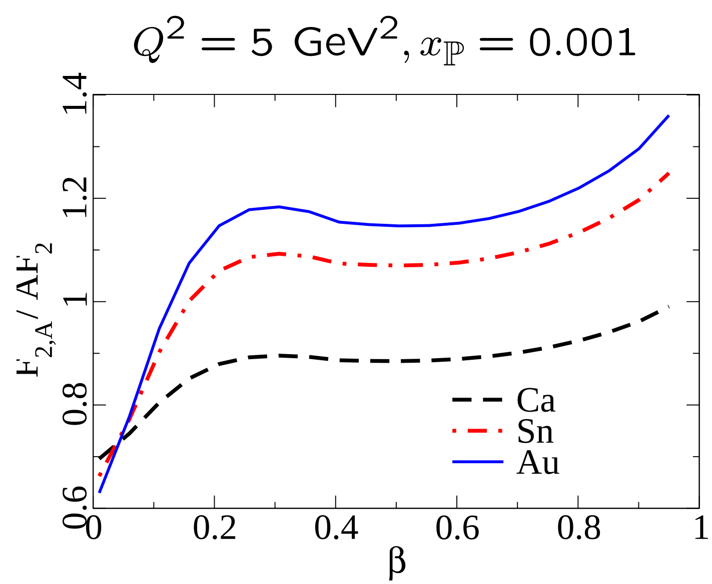
CDR: 3) LHeC Prospects

2. Inclusive diffraction *(plot of the ratio for p and Pb)*
   a. Inclusive diffraction pseudodata (P. Newman) *[1]*
   b. Ratio diffractive/total (A. Stasto, H. Kowalski) *[1]*
   c. Predictions for nuclear targets (M. Strikman, C. Marquet) *[1]*

- Pseudo-data exist, with some (not yet too convincing) plots
- First work on inclusive diffraction in eA done (Marquet)
- Quantitative relation to nuclear shadowing needs work
- Diffractive eA needs dedicated MC studies (DPMJET-II author

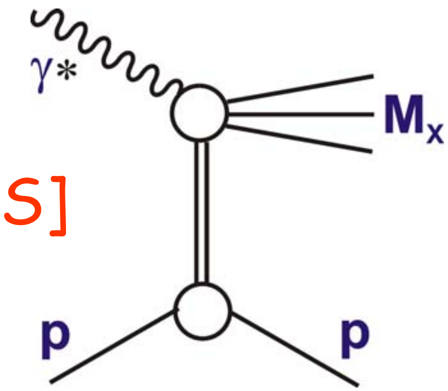




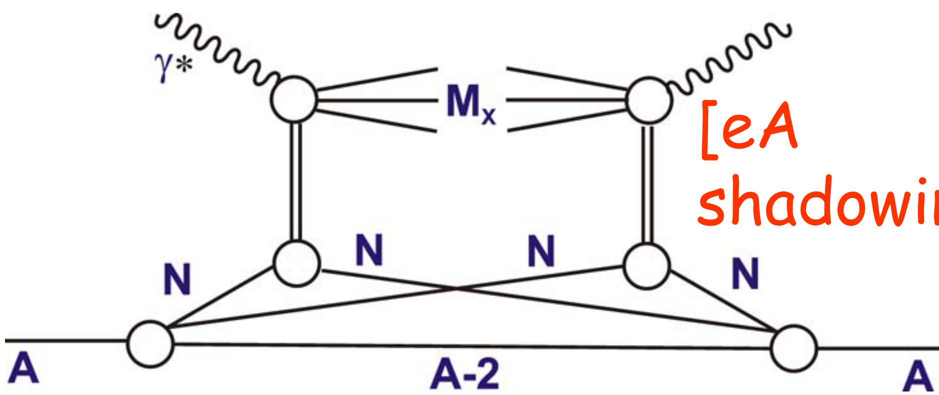


F_2^D and Nuclear Shadowing

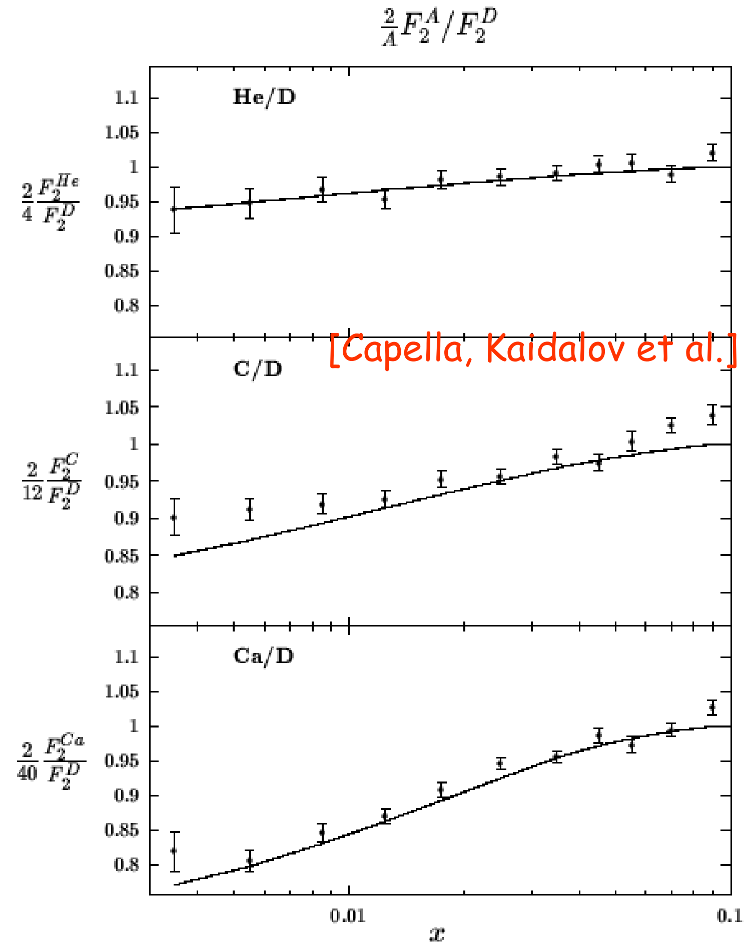
Nuclear shadowing can be described (Gribov-Glauber) as multiple interactions, starting from ep DPDFs



[Diff DIS]



[eA shadowing]



[Capella, Kaidalov et al.]

Would be good to put this on a quantitative basis in LHeC context

A couple of things not yet adequately covered

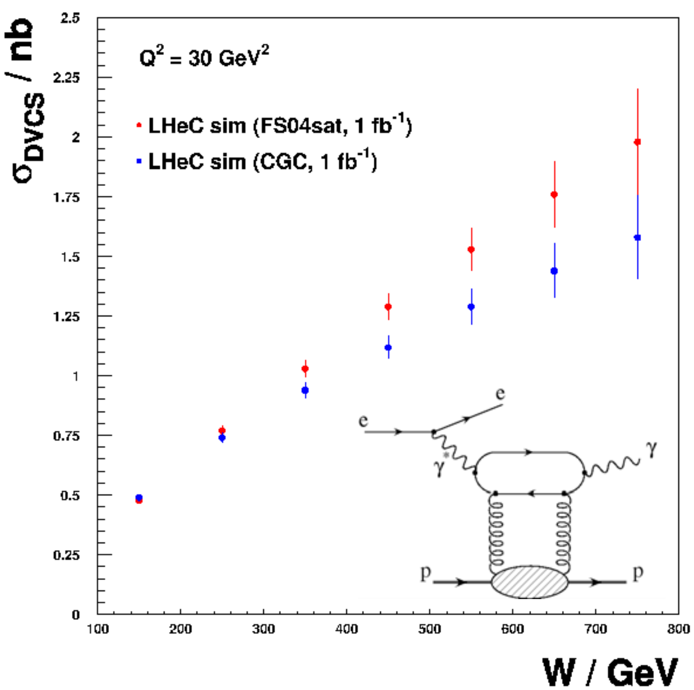
c. DVCS and GPDs (J. Collins, C. Weiss) [1]

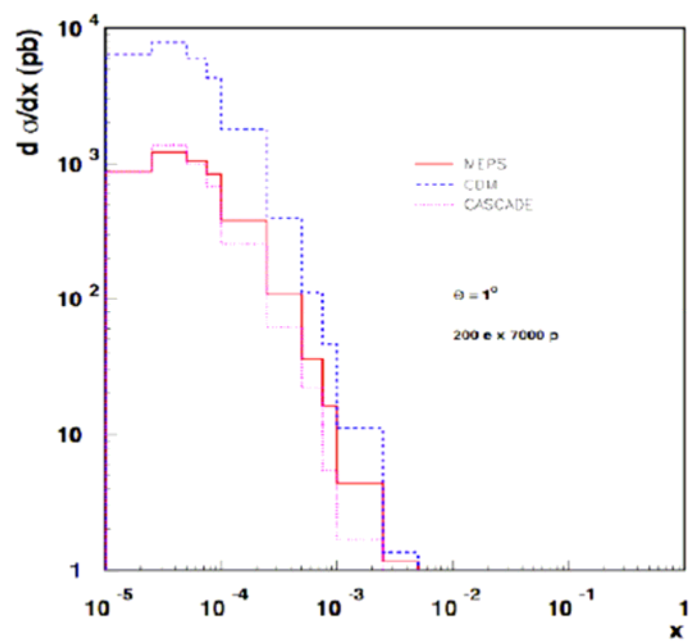
4. Jet and multi-jet observables, parton dynamics (J. Collins, H. Jung, E. Avsar, K. Kutak)

   a. Forward jets, dijets, angular decorrelation *(updated THERA plot) [1]*

   b. Unintegrated PDFs *[1]*

- DVCS / GPDs: First simulations + text from John Collins
- Parton Cascade Dynamics: Hope for Lonnblad / Jung study
- … not everything has to be covered in detail …





Proposed Chapter 11

11 Forward and Backward Detectors

11.1 Forward Detectors

11.1.1 Proton Tagger

11.1.2 Neutron Tagger

11.1.3 Deuteron Tagger

11.2 Backward Detectors

11.2.1 Electron Tagging

11.2.2 Photon Tagging

11.3 Measurement of the Luminosity

This makes a lot of sense as a stand-alone chapter

→ Happy to remove it from the HPD chapter

→ Happy to work on it with Detector / IR groups

Suggestion for Chapter 7 of Proposed CDR

7 DIS Scattering off Nuclei [IF eA SEPARATE]

7.1 Experimental Conditions

7.2 Neutron Measurements

7.2.1 Fermi Motion and Proton Tagging

7.2.2 Shadowing and Diffraction

7.2.3 Partons in the Neutron

7.3 Heavy Ions

7.3.1 Simulations

7.3.2 Parton Distributions in Nuclei

7.3.3 Saturation

7.3.4 Appearance of the Black Disk Limit

7.3.5 Relation to the Physics of the QGP

- 7.1, 7.2, 7.2.1 could be covered in chapter on forward / backward detectors (we are very willing to contribute)
- 7.2.3 probably belongs in the mainstream PDF discussion as part of the QCD / EW chapter
-7.2.3, 7.3 could be merged with the `High Parton Densities In ep section' → clear picture of what is gained in eA

Summary

Draft outline of ep and eA physics

- At least for main theme (exploring saturation) they naturally fit together

… for discussion

Some areas of analysis well advanced

- plots exist
- several highly enthusiastic and active people

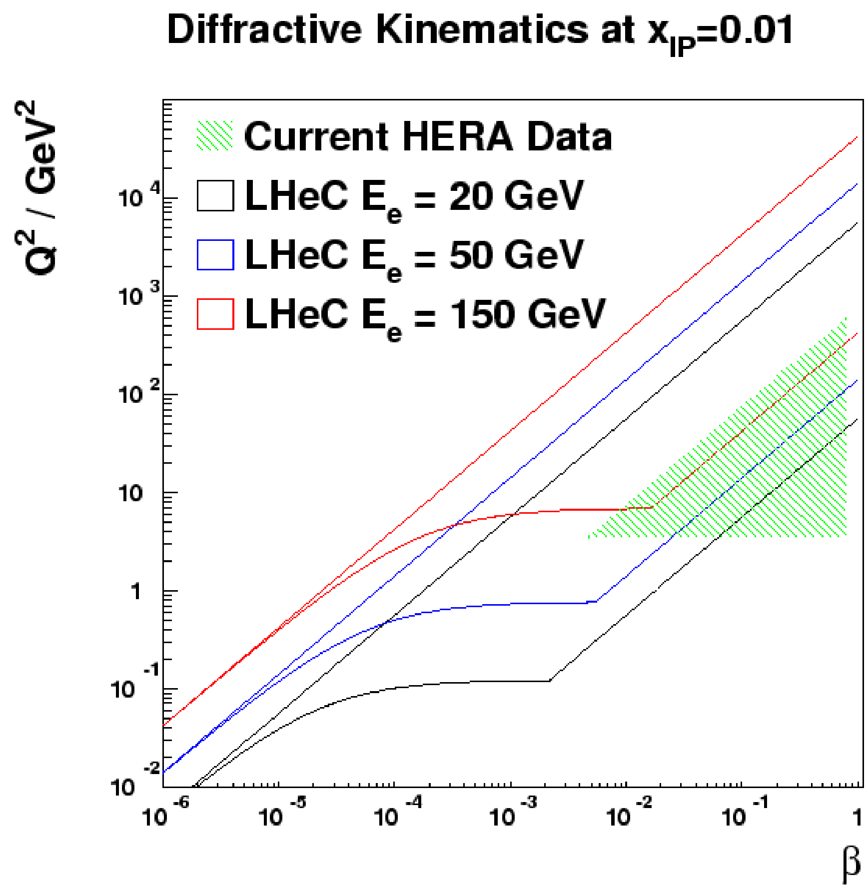
Most areas still need work, one or two uncovered

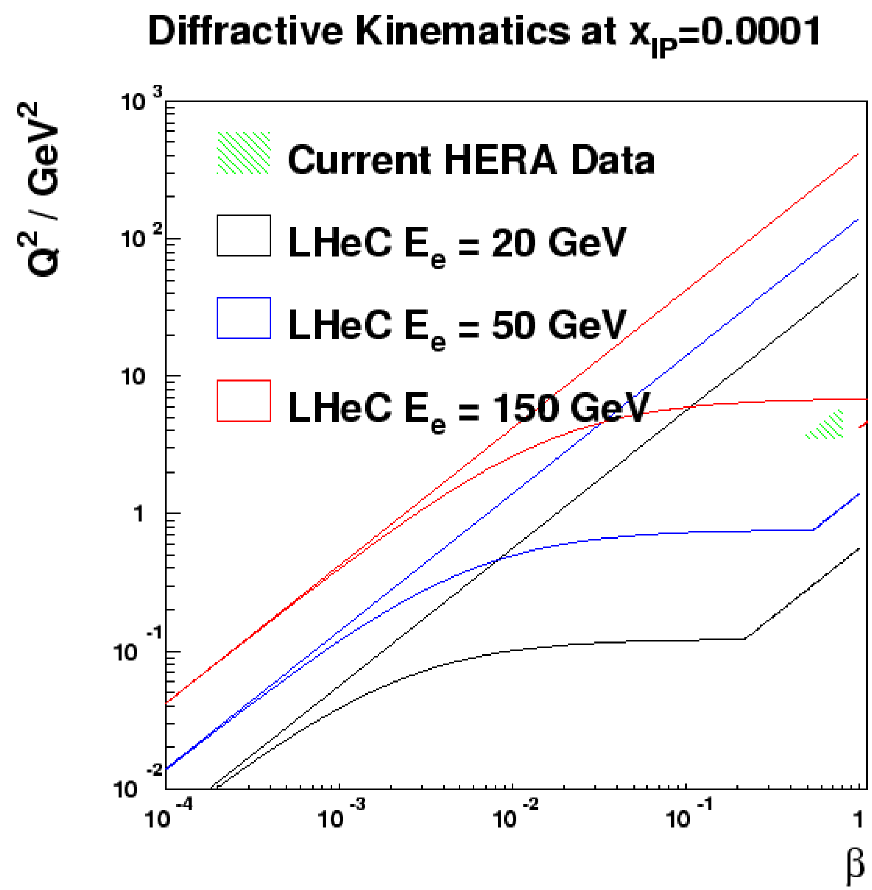
- we should anyway avoid getting too long!

How to make best progress?

- Organise joint discussions with detector / IR / QCD&EW groups
- Another working group meeting (cf June 2009)

Diffractive Kinematic Plane at LHeC



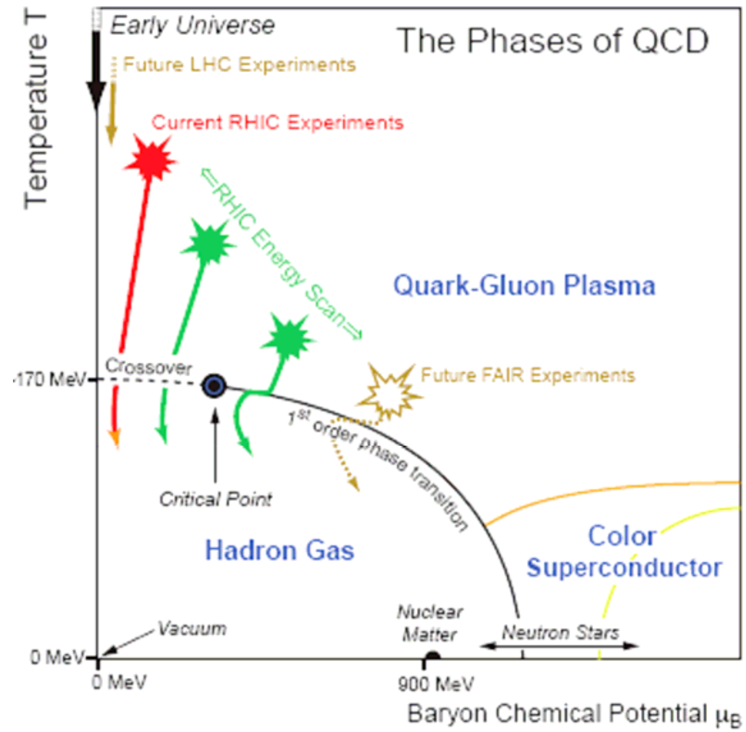


- Higher E_e yields acceptance at higher Q^2 (pQCD), lower x_{IP} (clean diffraction) and β (low x effects)
- Similar to inclusive case, 170° acceptance kills most of plane

Back-Ups Follow

Many other reasons for eA (Ullrich)

As well as identifying non-linear dynamics, measuring nuclear effects in DIS will tell us lots about heavy ions / q-g plamsa:…
"Symbiotic Relationship between eA and AA" …



- Initial Conditions (saturation/CGC?)
  - impact on understanding of QGP properties (e.g. η/s)
- Thermalization (Glasma)
- Energy Loss (baseline/control) & Fragmentation
- Saturation & Multiplicity
- Understanding nuclear effects ((anti)-shadowing, EMC)

What about eA?

Common misconception: Final states in DIS from nuclei are not significantly more complicated than in DIS from protons

→ scattered electron, current jet essentially identical

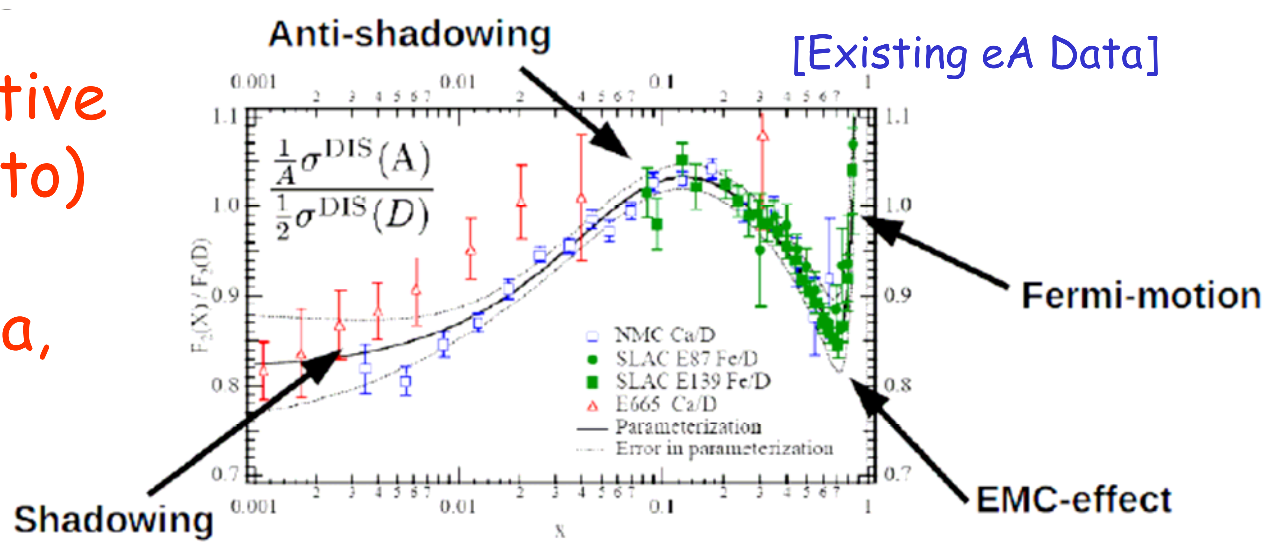
→ target remnant more complicated, but very forward

A highlight of this meeting: quantified impact of LHeC data on nuclear parton densities:

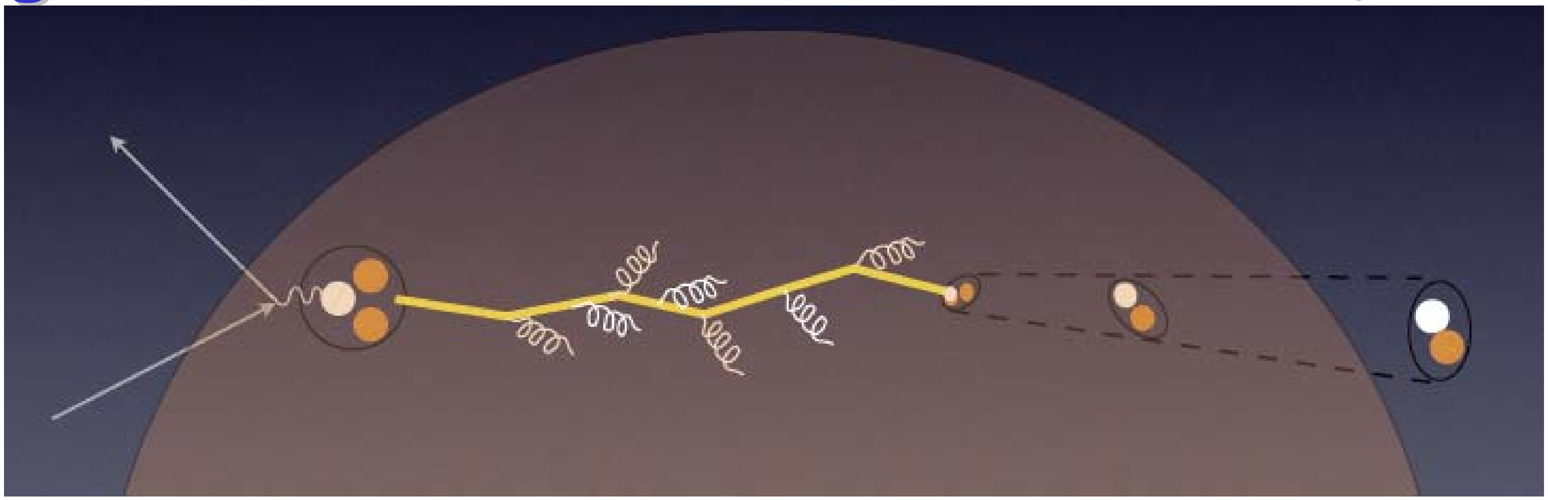
→ pseudo-data → precision and kinematic range (Klein)

→ dipole based model, including shadowing derived from diffractive ep scattering (Armesto)

→ fits for nuclear PDFs in EPS09 (Eskola, Paukkunen)



e.g. Final State Interactions in eA (Brooks)



Parton multiple scattering in medium
Hadron formation inside medium … can also interact …
Hadronis'n amplitudes inside & outside medium can interfere
Model of low energy data … several observable effects @ LHeC

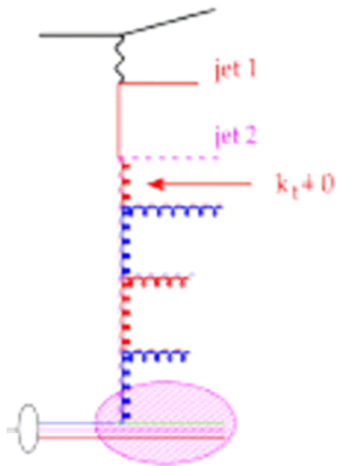
At ***HIGH ENERGIES***:

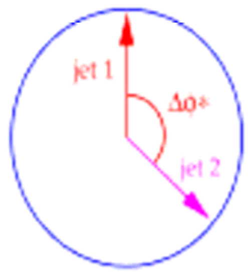
- Test the predicted universal breakdown of QCD factorization at large Feynman *x*
- Expect perturbative energy loss to be purely proportional to path length squared
- Expect increase in jet broadening and quark energy loss

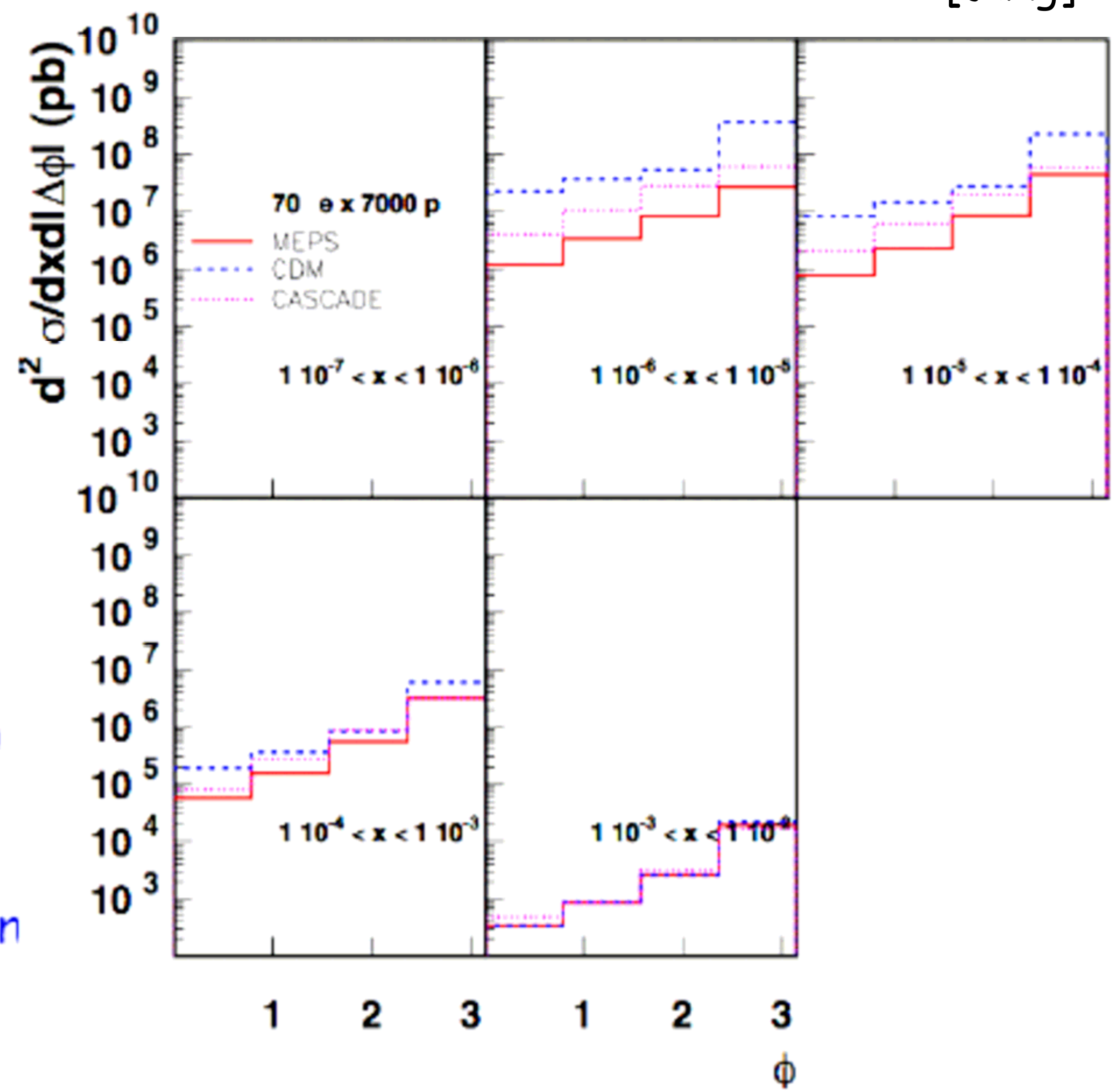
[Relation to jet quenching as a QGP signature?]

Azimuthal (de)correlations between Jets

[Jung]





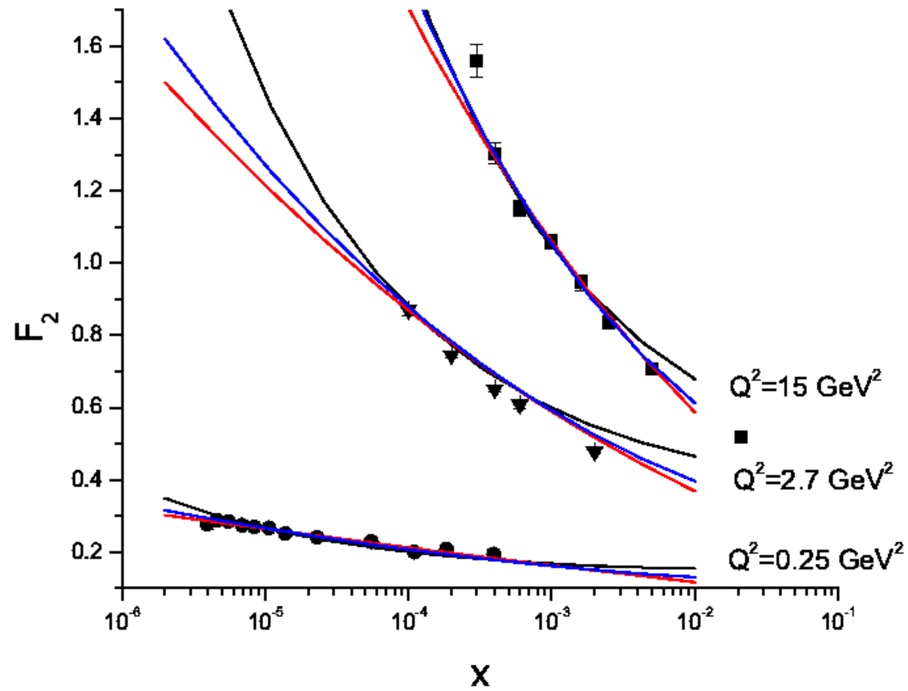


- $5 < Q^2 < 100 \text{ GeV}^2$
  $-1 < \eta < 2.5$
  $E_T > 5 \text{ GeV}$
- small $k_t \rightarrow \Delta\phi \sim 180$
- large k_t from evolution

Parton Saturation after HERA?

e.g. Forshaw, Sandapen, Shaw
hep-ph/0411337,0608161
… used for illustrations here

Fit inclusive HERA data
using dipole models
with and without parton
saturation effects



FS04 Regge (~FKS): 2 pomeron model, <u>no saturation</u>
FS04 Satn: <u>Simple implementation of saturation</u>
CGC: <u>Colour Glass Condensate version of saturation</u>

- *All three models can describe data with $Q^2 > 1 GeV^2$, $x < 0.01$*
- *Only versions with saturation work for $0.045 < Q^2 < 1$ GeV^2*

<u>… any saturation at HERA not easily interpreted partonically</u>

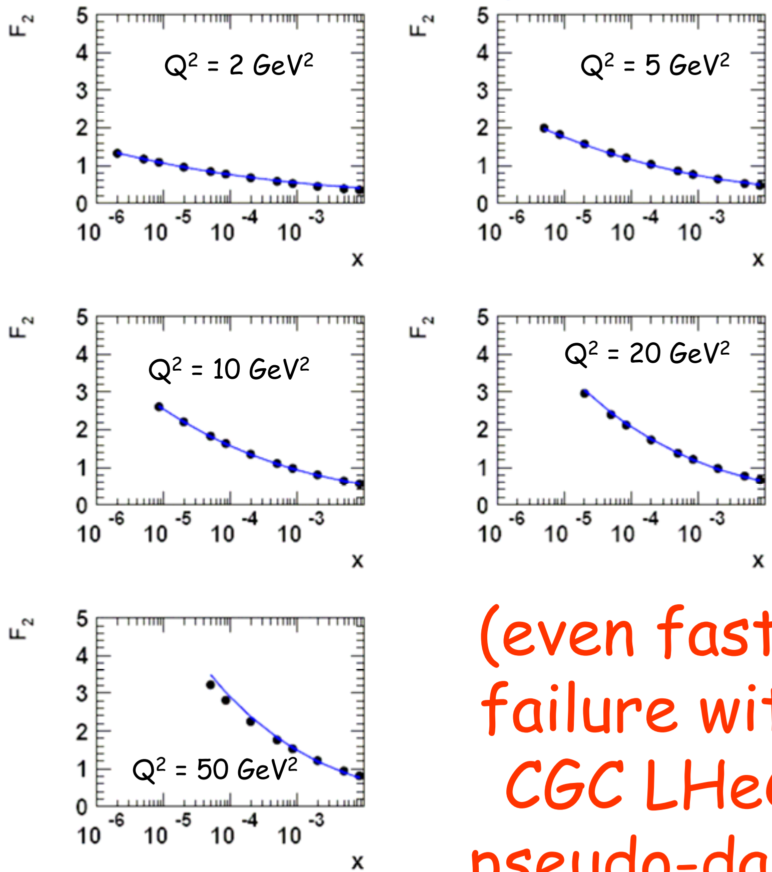
Can DGLAP adjust to fit LHeC sat models?

[Forshaw, Klein, PN, Perez]

- Attempt to fit ZEUS and LHeC saturated pseudo-data in increasingly narrow (low) Q^2 region until good fit obtained
- Use dipole-like (GBW) gluon parameterisation at Q_0^2

$$xg(x, Q_0^2) = A_g \left(1 - \exp\left[-B_g \log^2 \left(\frac{x}{x_0} \right)^{\lambda} \right] \right) (1-x)^{C_g}$$

FS04 dataset, F2



- Fitting F_2 only, a good fit cannot be obtained beyond the range $2 < Q^2 < 20$ GeV^2
- This fit fails to describe F_L

(even faster failure with CGC LHeC pseudo-data)

FS04 dataset, FL