High Parton Density Working Group

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on behalf of conveners:
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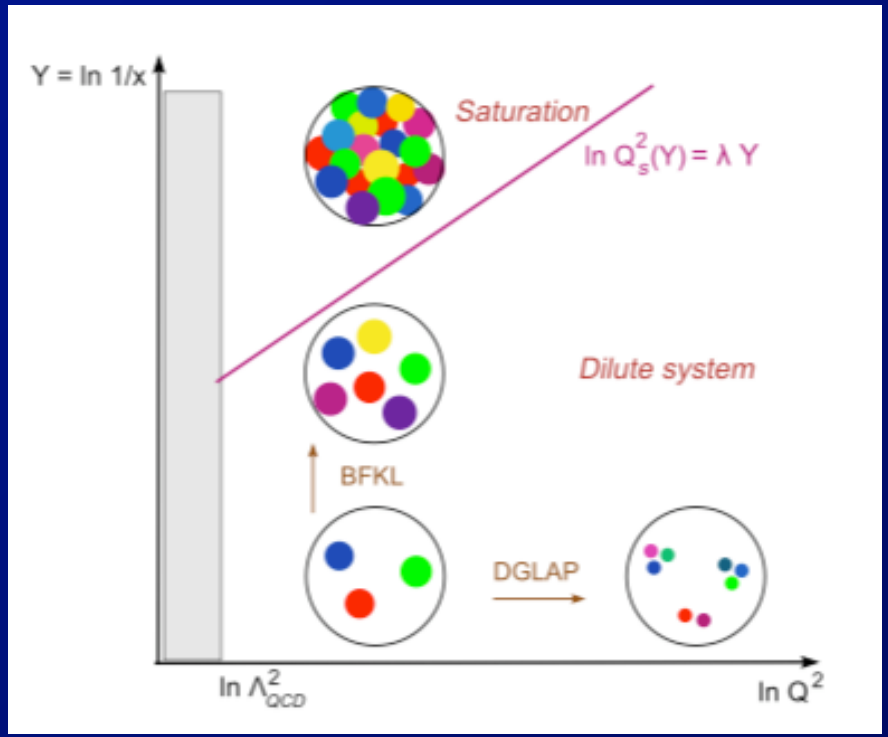


Many, many contributions to our work, workshops, impossible to cover everything in this talk. Apologies in advance for needing to be selective.

High Parton Density Working Group

- **Previous meetings:**
  - Divonne 2008
    - ⇒ First low-x pseudo-data available
  - Conveners meeting, February 2009
    - ⇒ Draft outline of HPD contribution to CDR
  - Madrid DIS 2008 pre-workshop, April 2008
  - HPD WG Pre-meeting @ CERN, June 2008
    - ⇒ Contributions covering all aspects of draft outline
    - ⇒ Extensive discussion re: strategy for pitching HPD part of LHeC physics program.

Draft CDR HPD Outline

I. Introduction

II. Unitarity/BBL

a. QCD and unitary/black-body limit: saturation
b. Recombination, saturation models, saturation scale (GLR, color glass condensate and JIMWLK, BK)
c. Dipole models
d. Nuclear targets
e. Significance for heavy ion program
f. Significance for the ultrahigh energy neutrino interactions

III. Lepton probes and main signatures

a. Low-x physics at LHC, limitations
b. Why electron probes
c. F_2: quark sensitive
d. Diffraction, why a good starting point, A and b sensitivity
e. Exclusive diffraction
f. other gluon sensitive measurements

IV. HERA data $\leftrightarrow$ saturation models

a. K-GB-W fits to HERA data
b. Updated dipole models and uncertainties
c. Regge models
d. Saturation in nuclei: A-dependence, LT shadowing, distinguishing saturation

V. Diffraction

1. Exclusive vector meson
   a. Forward tagging (neutron, proton, dissociating p/n)
   b. Plot of $\sigma(w)$ for different Q^2 proton and Pb, also for heavy flavor
   c. Plot of A(mplitude) vs b for different W, proton and Pb
2. Inclusive
   a. Deconstructing 50% diffractive/total
   b. Question: is diffractive/total more interesting (ideal) w/ nuclear targets
   c. Interesting question about DGLAP failure in evolution of F_2^d H1 data
   d. Semi-inclusive F_2^d/F_2 ratio (charm, jets)
   e. Unitarity limit on the dipole scattering amplitudes versus dipole size
   f. Leading twist versus multiple scattering contributions to nuclear shadowing and diffraction on nuclei
   g. Understanding the Gribov limit in dF_2^d/dM^2

VI. Inclusive measurements, structure functions

a. F_2, F_L statistical, systematic errors for proton, Pb vs (x, Q^2) for varying electron beam energies
b. Dipole model with saturation, fit with DGLAP (PDF flexibility, resummed approach)
c. Tests of violation of DGLAP evolution
d. Jets, heavy flavor as alternative measure of $G(x, Q^2)$

VII. Jet and multi-jet observables, parton dynamics

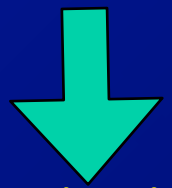
a. Forward di-jets, angular decorrelation
b. Unintegrated PDFs

VIII. Experimental issues

a. Nuclear radiative corrections, systematic errors
b. Forward acceptance
c. Forward electron, photon tagging
d. Forward neutron tagging
e. Forward proton tagging

Point of nomenclature:

~~**black body**~~



black disk

Feedback on Draft CDR Outline

- **My personal interpretation of feedback from Madrid and discussion at CERN workshop:**
  - Draft outline may suffer somewhat from the "can't see the forest for the trees problem"

    ⇒Compreshensive overview of the physics of saturation and the variety measurements that could help elucidate that phyiscs.
  - But, for LHeC CDR we (also) need to have concise physics message/goals.

    ⇒Extensive discussion @ CERN on this point
  - And we need to focus on measurements most important in exploring the physics at HPD.

    ⇒This particular point has been a key part of the discussion in all of our meetings so far.

HPD: Physics message/goals

- At CERN meeting it was argued (most explicitly by Albacete) that we should broaden the physics focus:
  - from "saturation" to "non-linear evolution"
    - ⇒ Avoid being tied to any specific model
  - general agreement from all participants
- An attempt to phrase physics goals in one sentence appropriate for (e.g.) summary of LHeC physics
  - "Search for and elucidate the role of non-linearities in QCD evolution at high parton densities indicating an approach to the unitarity limit"
    - ⇒Can we come out of this meeting with an improved/ refined version of this statement of phyiscs goals

HPD and e-A

- General view of participants in HPD discussions/meetings:
  - e-A is essential part of LHeC HPD physics program
- Also a consensus that e-A does not get enough emphasis in LHeC discussions.
  - Partly a sociological problem
    - ⇒Anything involving nuclei is viewed as "messy" by high-energy physicists
- Some questions we need to answer before proceeding with CDR
  - How to overcome this prejudice?
  - How to better state the case for e-A?
  - How to raise the importance of e-A in LHeC program?

HPD and e-A (2)

- **Possible extension of previous goals statement:**
  - "Search for and elucidate the role of non-linearities in QCD evolution at high parton densities indicating an approach to the unitarity limit"
    - ⇒Extend existing e-p measurements to lower x (at high enough Q^2 to be safely perturbative).
    - ⇒Using nuclei to increase parton density in controlled manner at fixed kinematics (at …)
- **Also important to LHeC motivation:**
  - Connections to other physics programs. For e-A:
    - ⇒Non-linearity/saturation crucial to understanding initial conditions of heavy ion collisions
    - ⇒Improved nuclear DIS measurements of broad importance to nuclear physics community
    - ⇒Space-time evolution of partons: nuclear SIDIS

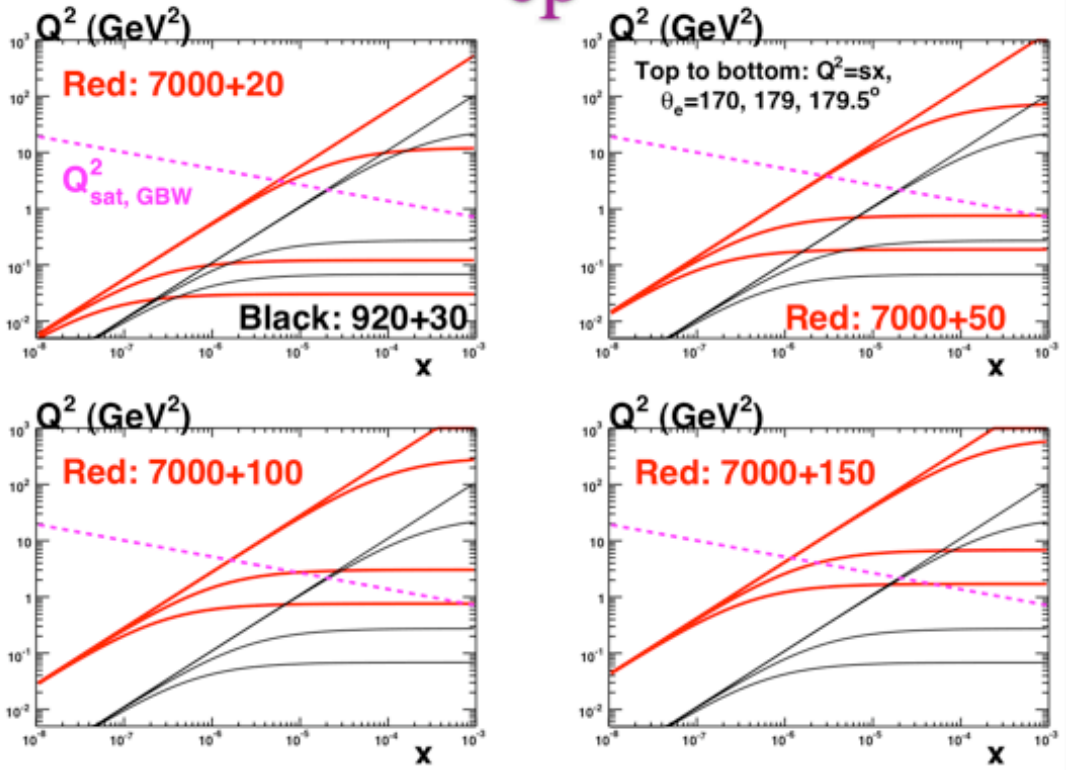
LHeC low-x kinematics (e-p)

LHeC kinematics

ep

Access to Q^2=1 GeV^2 for all $x > 5 \times 10^{-7}$ IF we have acceptance to 179°

→ Without low β magnets ~ 1 fb^{-1} / yr … definitive low x facility (parton saturation ?…)



LHeC extended kinematic range will allow to probe the nonlinear regime for fixed perturbative Q while decreasing x.

- From A. Stasto talk at CERN workshop
  - Acceptance down to ~1° essential to low-x program

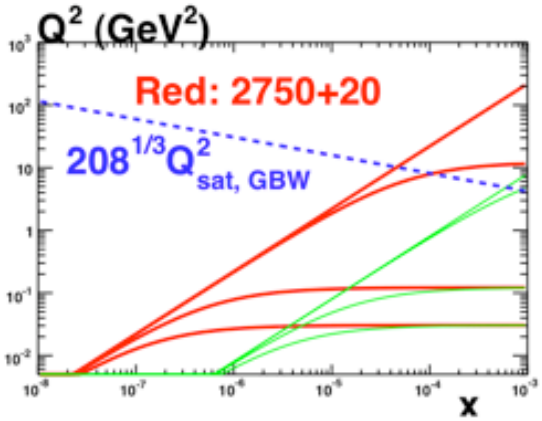
LHeC low-x kinematics (e-A)

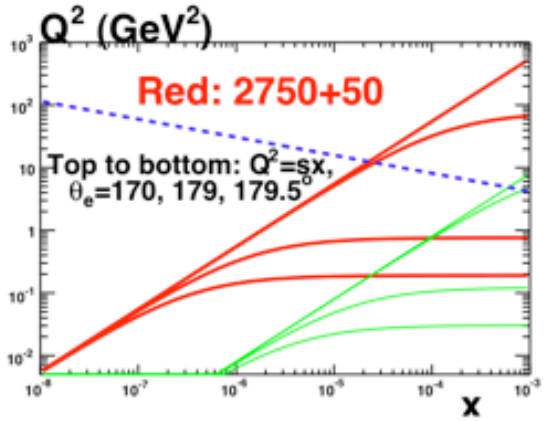
LHeC kinematics

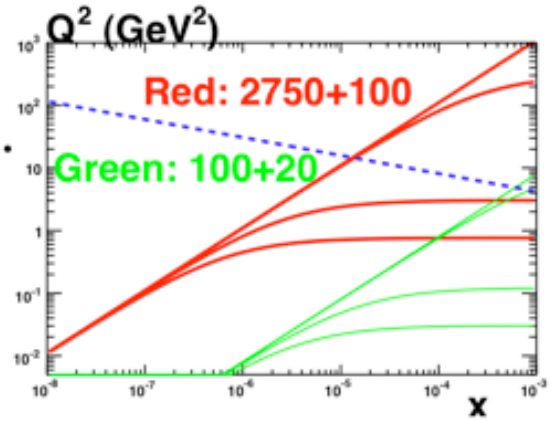
eA

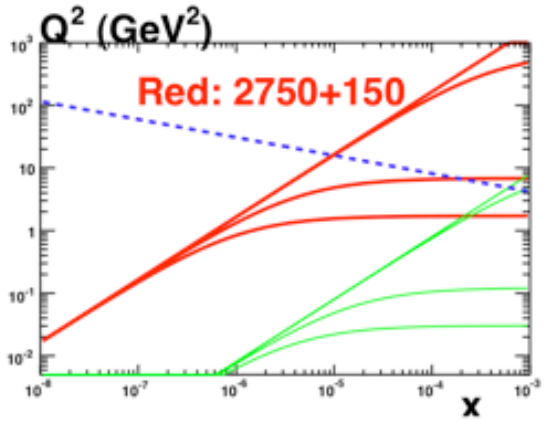
Kinematics in different scenarios.

Green: eRHIC range.









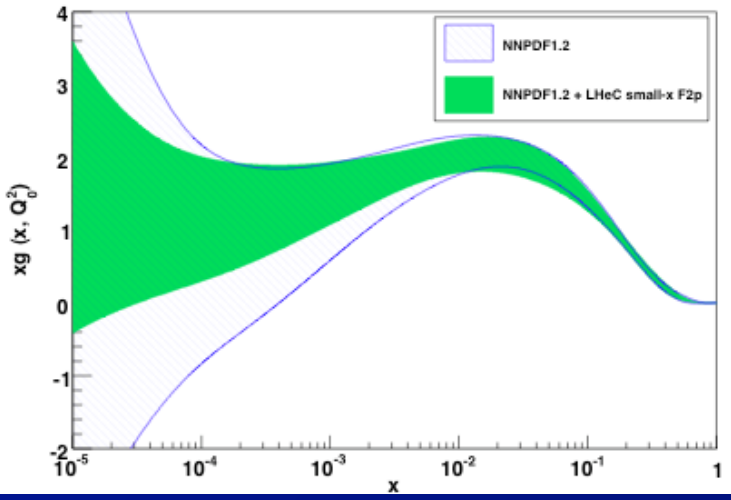
- From A. Stasto talk at CERN workshop

How to "see" non-linearities

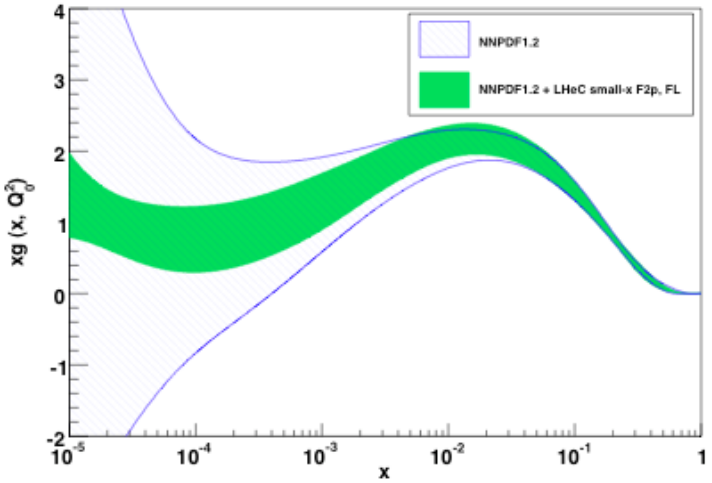
- **Each of HPD meetings has spent substantial time on crucial problem(s):**
  - How to convincingly demonstrate non-linear evolution in QCD?
  - Is there model-independent (model-insensitive) way to tell that we are seeing approach to unitarity limit?
- **General consensus:**
  - While inclusive F_2 measurements are easiest, have smallest systematic errors, they may not provide the most sensitive evidence for non-linear evolution
- **Alternatives (non-diffractive)**
  - F_L - more directly sensitive to $g(x, Q^2)$ but hard and will take time to run different energies
  - F_2^c - also sensitive to $g(x, Q^2)$
  - Forward di-jets

LHeC Data and PDFs

F_2^p and F_2^L NLO DGLAP in NNPDF analysis:
Gluon uncertainties with F_2^p LHeC data only



F_2^p and F_2^L NLO DGLAP in NNPDF analysis:
Gluon uncertainties with F_2^p and F_L^p LHeC data

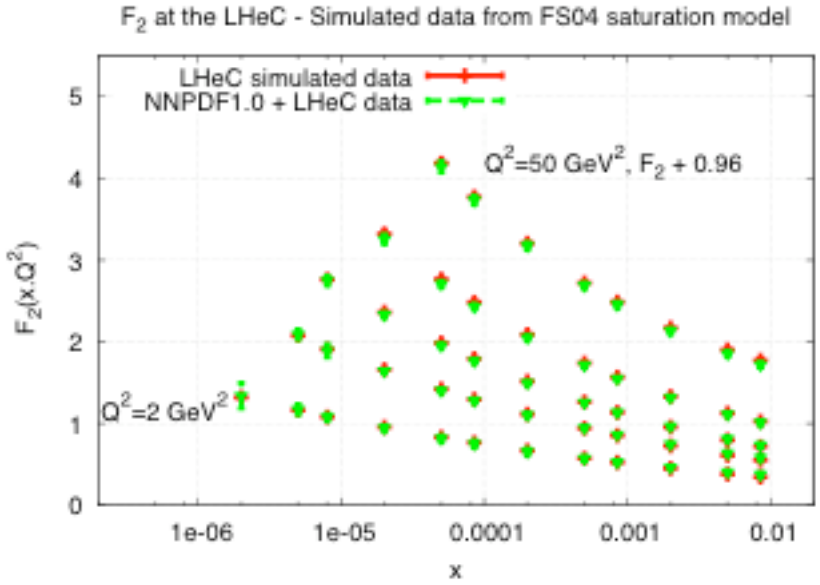


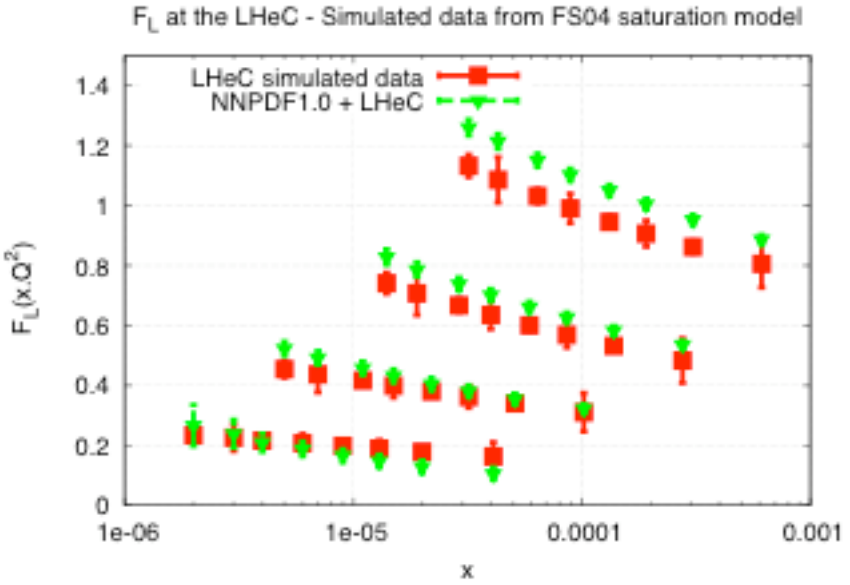
J. Rojo, from CERN HPD workshop, NNPDF analysis

extraction of xg from LHeC pseudo-data (no saturation)

LHeC Data and PDFs, non-linearities?

J. Rojo, from CERN HPD workshop



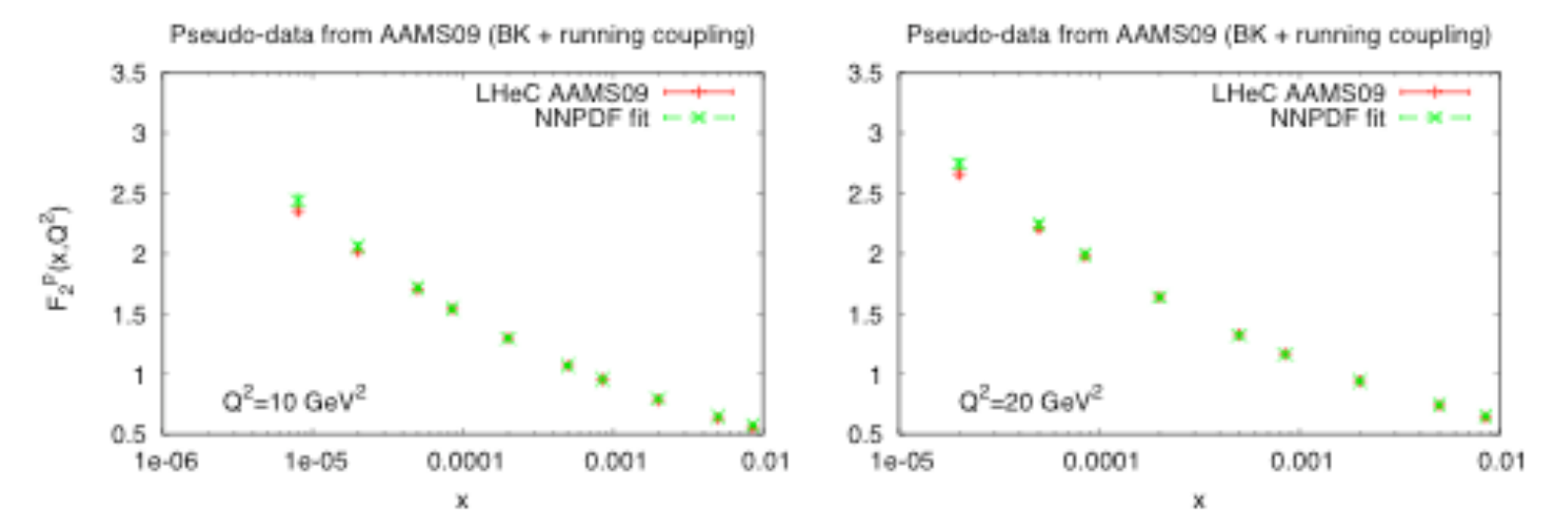


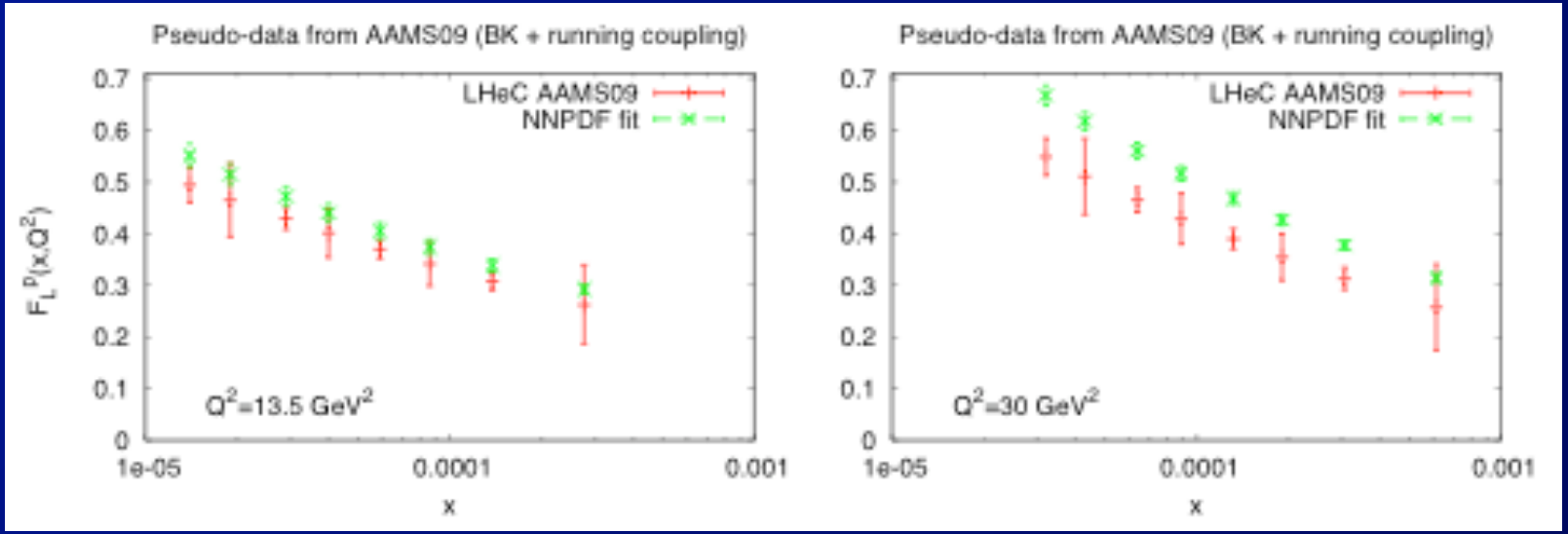
- **Can we see failure of linear evolution (including low-x resummation) with e-p data from LHeC?**
  - NNPDF fits to pseudo-data w/ saturation (here FS04)
  - Compare extracted PDFs, deviations indicate failure of linear evolution

    ⇒Need F_L to see significant

LHeC Data and PDFs, non-linearities?

J. Rojo, from CERN HPD workshop

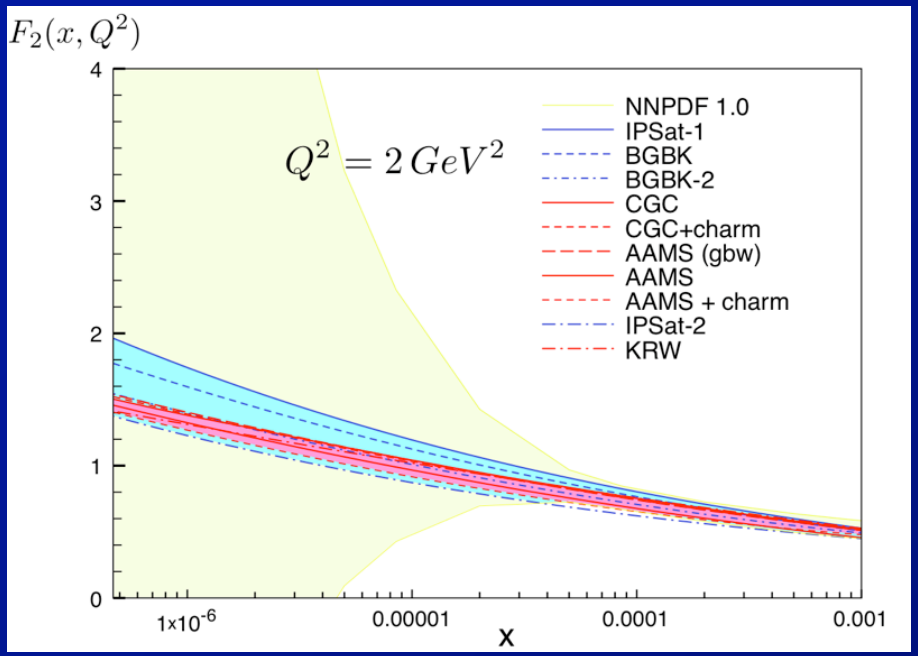


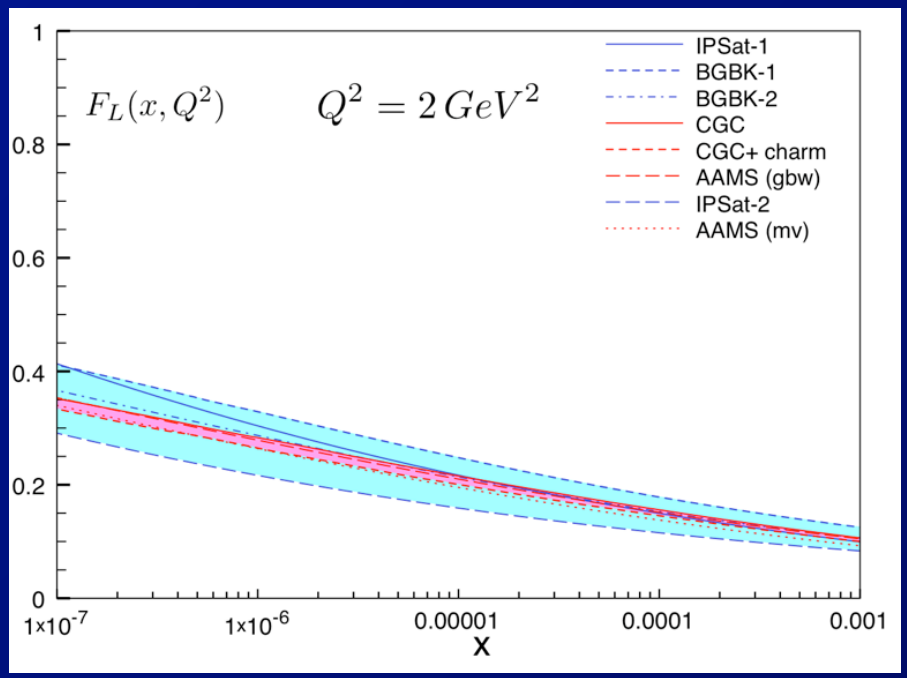


- **Similar conclusions w/ more modern saturation**

F_2, F_L in saturation (dipole) models

From J. Albacete, CERN HPD workshop





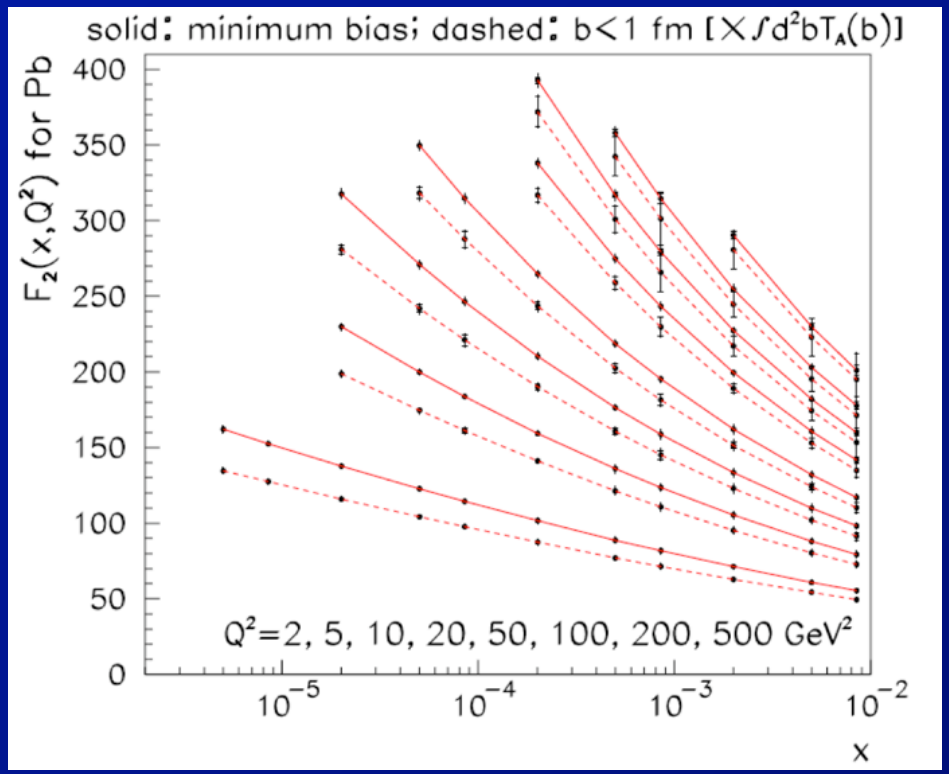
- **Saturation naturally implemented in dipole picture, but how robust are the dipole calculations (model sensitivity)**
  - Compare a wide selection of dipole calculations that provide good fits to HERA data

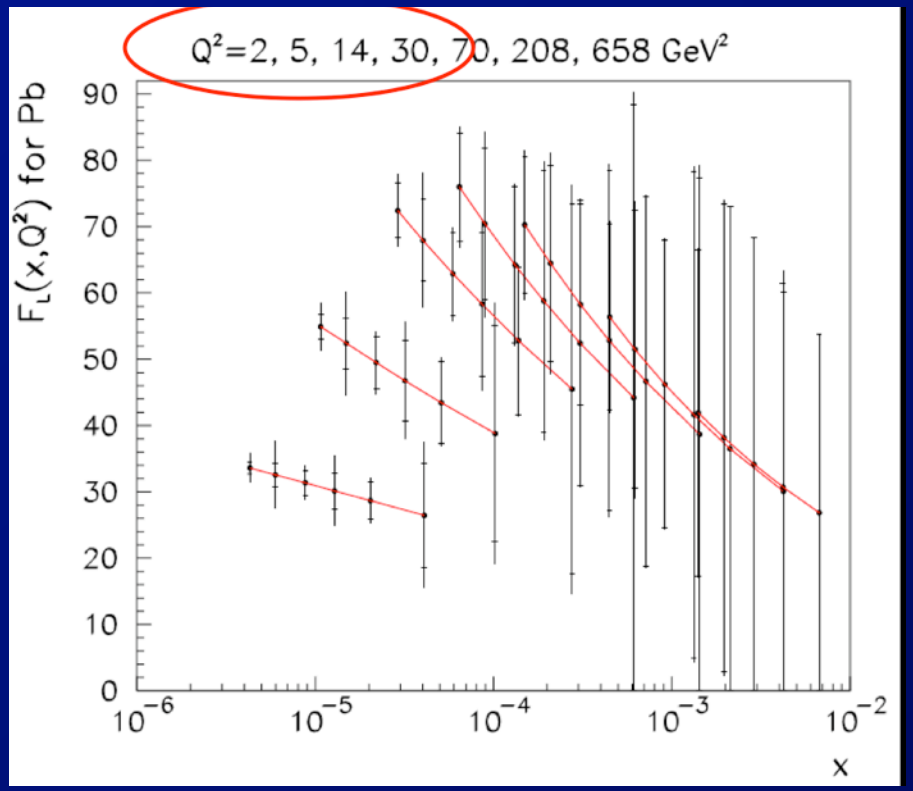
    ⇒Generally good agreement

    ⇒Can define theoretical error (within assumptions)

Nuclear PDF, LHeC

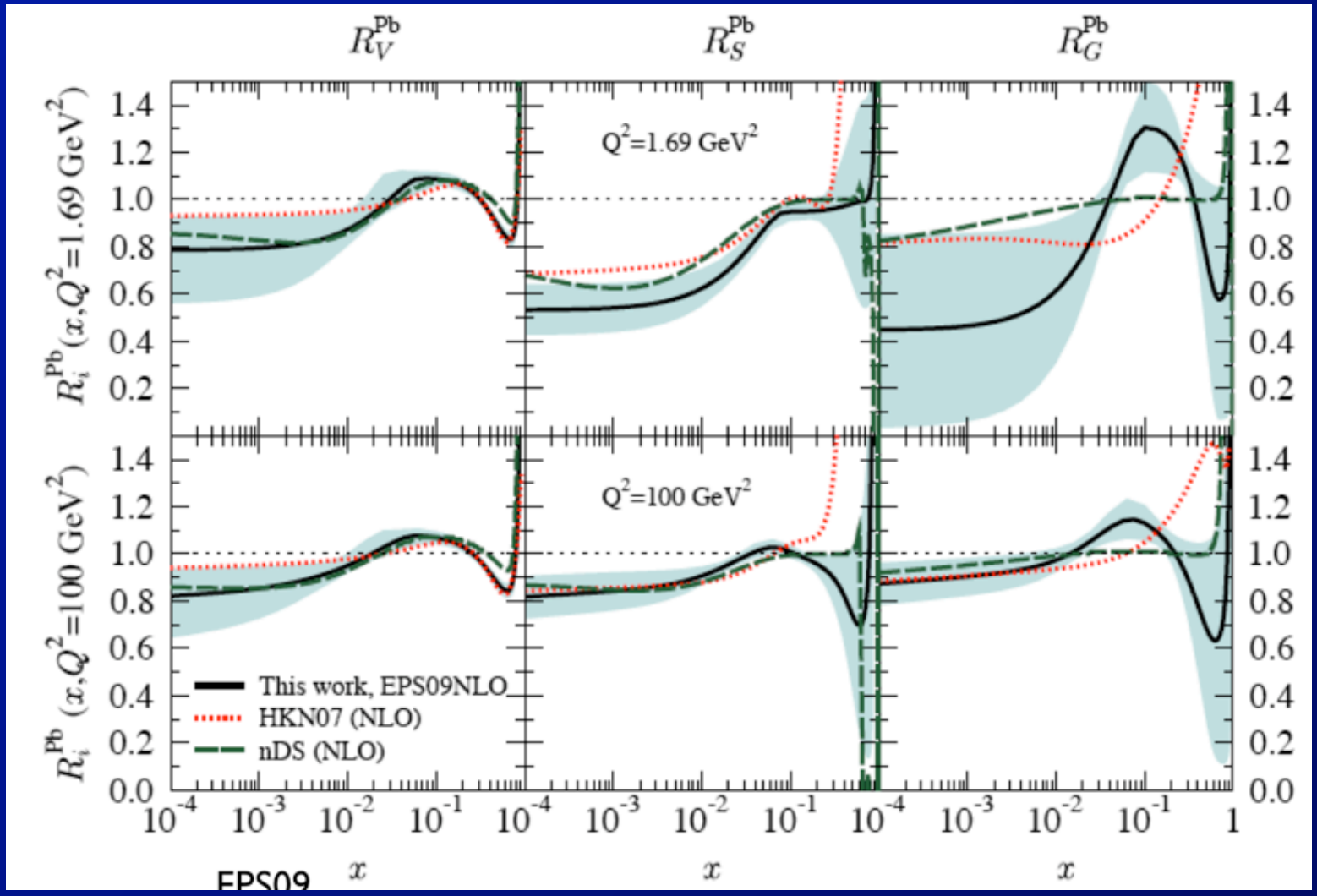
N. Armesto, CERN HPD workshop





- **Nuclear pseudo-data for a given set of assumptions re: nuclear running**
  - Excellent statistics for F_2, not so good for F_L
    - ⇒But, sensitive to assumptions re: nuclear operation
  - F_L still as necessary with nuclei?

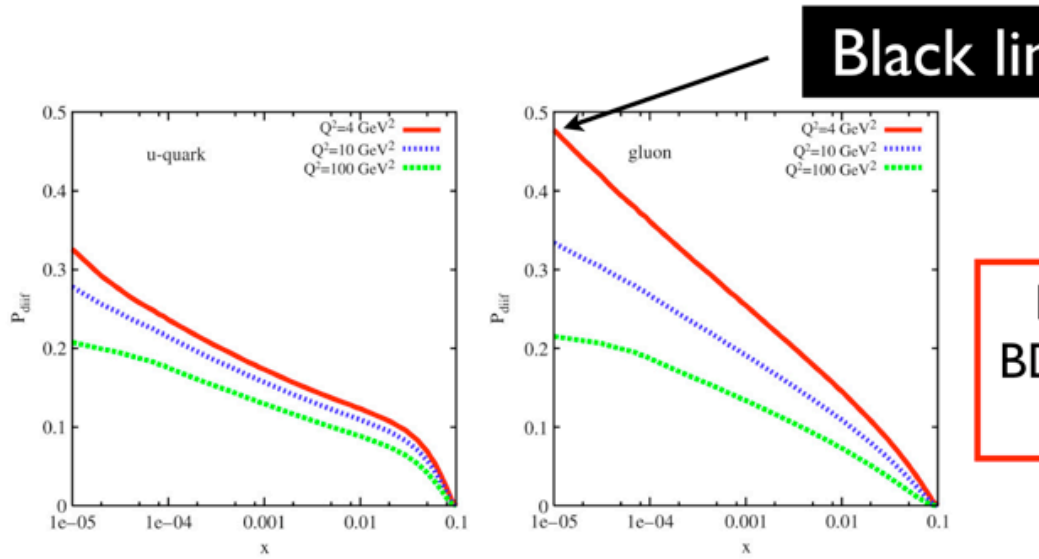
Nuclear PDFs, LHeC Improvement



- **Have almost no knowledge of shadowing, anti-shadowing of gluons in nuclei, serious problem**
  - **LHeC huge improvement (Eskola)**

Diffraction, unitarity

- **Diffraction: probing approach to unitarity limit?**



Black limit

Evidence for onset of BDR at HERA for gluons at Q=2 GeV

The probability of hard diffraction on the nucleon, $P_{j\ diff}$ as a function of x and Q^2 for u quarks (left) and gluons (right) based on the current HERA data. Guzey et al

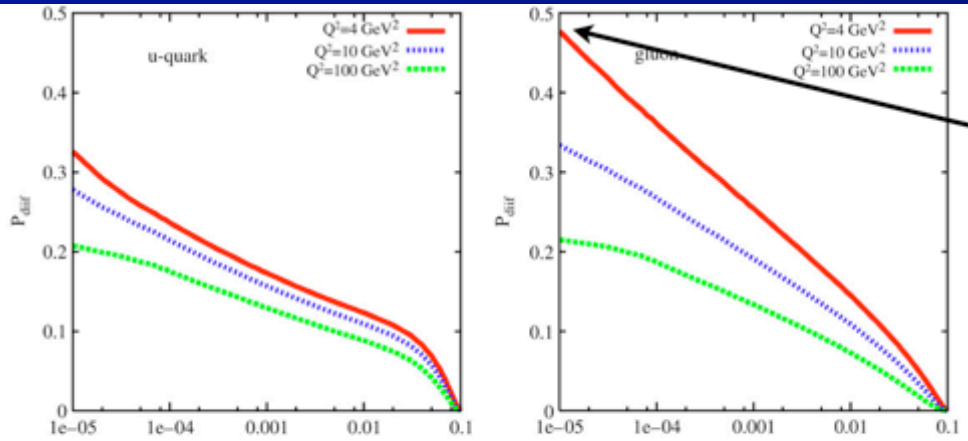
Warning - curves for $x <$ few $\cdot 10^{-4}$ is extrapolation of the fits.

For gluon channel $B=7\ GeV^{-2}$ leads to impact factor $\Gamma_{gg}(b=0, Q^2=4\ GeV^2) \sim 1$ for $x \sim 10^{-3}$ $\Rightarrow$ new regime? increase of B?

From M. Strikman, CERN HPD workshop

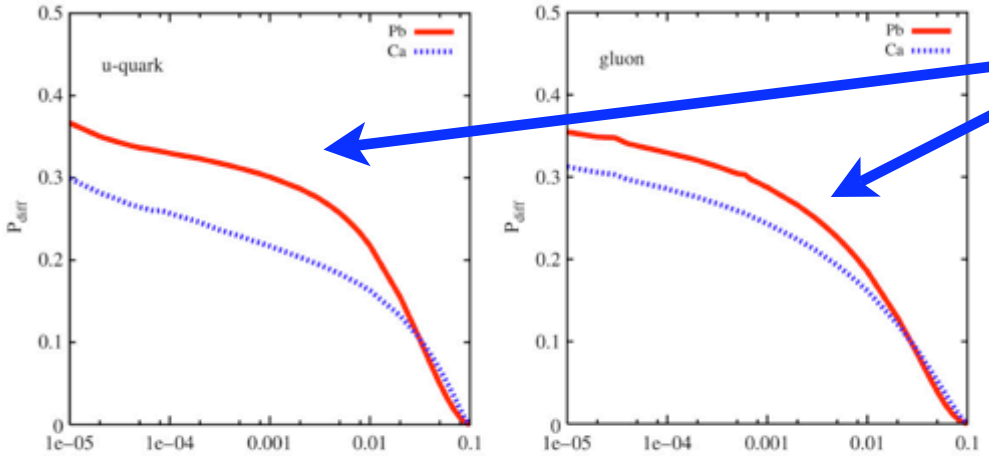
Diffraction, unitarity in nuclei

- **Diffraction: probing approach to unitarity limit?**



Black limit

The probability of hard diffraction on the nucleon, $P_{j\ diff}$ as a function of x and Q^2 for u quarks (left) and gluons (right).



Nominally at unitary limit but < 0.5 due to nuclear profile (edge)

The probability of hard diffraction, $P_{j\ diff}$ as a function of x and Q^2 for u quarks (left) and gluons (right) for Q^2=4 GeV^2

From M. Strikman, CERN HPD workshop

Diffraction via dipole picture

From C. Marquardt, CERN HPD workshop

Hard diffraction and saturation

- the total cross sections

in DIS

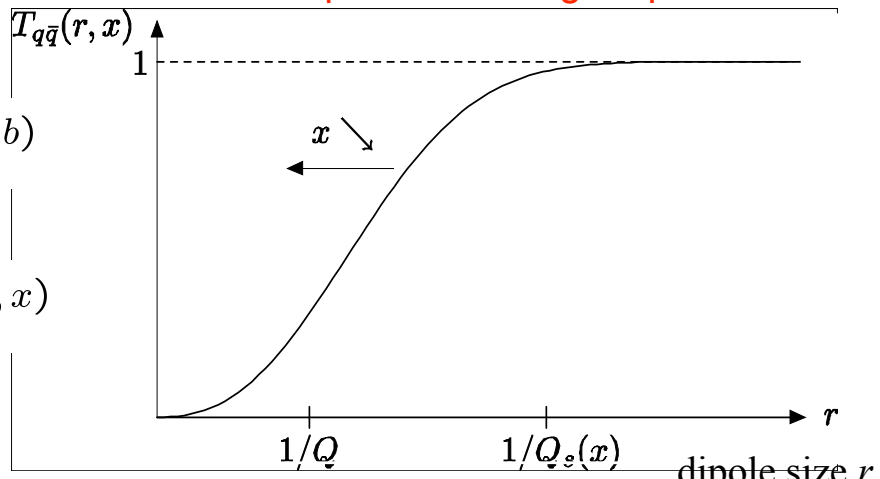
$$\int d^2r\ dz\ \sum_\lambda |\psi_\lambda(r,z,Q^2)|^2 \int d^2b\ T_{q\bar{q}}(r,x,b)$$

in DDIS

$$\int d^2r\ dz\ \sum_\lambda |\psi_\lambda(r,z,Q^2)|^2 \int d^2b\ T^2_{q\bar{q}}(r,b,x)$$

- diffraction directly sensitive to saturation

the dipole scattering amplitude



contribution of the different r regions in the hard regime

$$Q^2 > Q_S^2$$

$$\int r dr |\psi|^2 T_{q\bar{q}} \to\ Q^2\sigma_{DIS} \approx\ 1\ +\ \ln(Q^2/Q_S^2)\ +\ 1$$

$$\int r dr |\psi|^2 T^2_{q\bar{q}} \to\ Q^2\sigma_{DDIS} \approx\ \frac{1}{Q^2}\ +\ 1\ +\ 1$$

σ_{DIS} dominated by relatively hard sizes $1/Q < r < 1/Q_S$

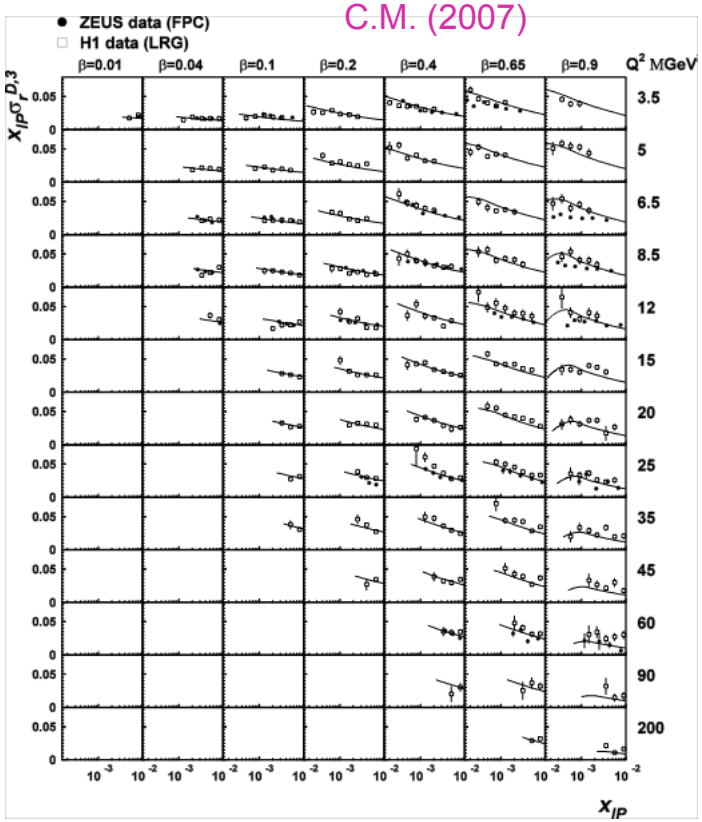
σ_{DDIS} dominated by semi-hard sizes $r \sim 1/Q_S$

Diffraction, saturation, Hera

From C. Marquardt, CERN HPD workshop

Comparison with HERA data

C.M. (2007)

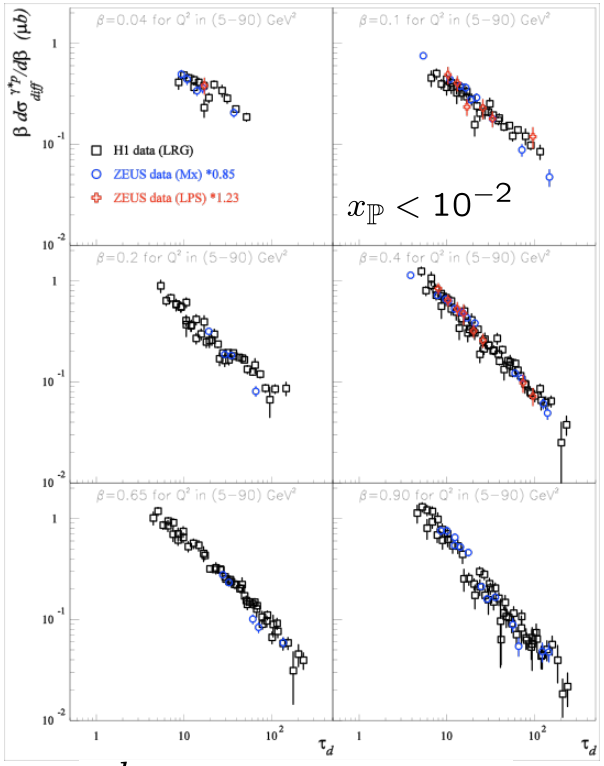


parameter-free predictions
with IIM model

(~450 points) $\chi^2/\text{points} = 1.2$

geometric scaling C.M. and Schoeffel (2006)

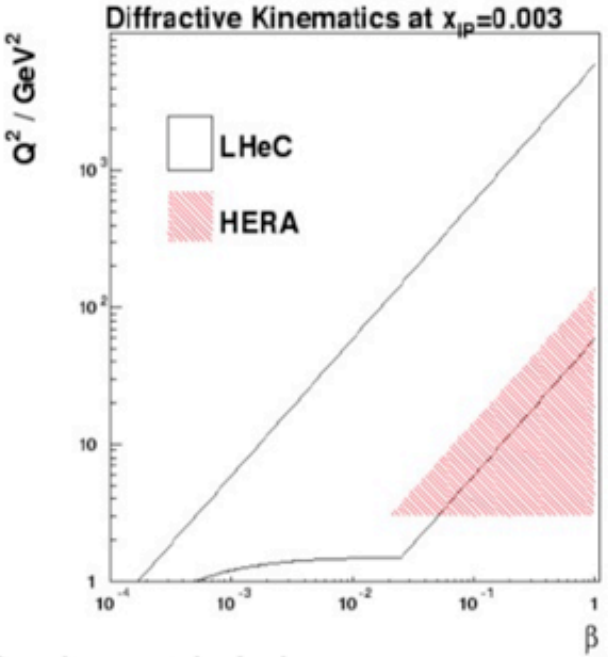
at fixed β , the scaling variable is $Q^2/Q_s^2(x_{\mathbb{P}})$



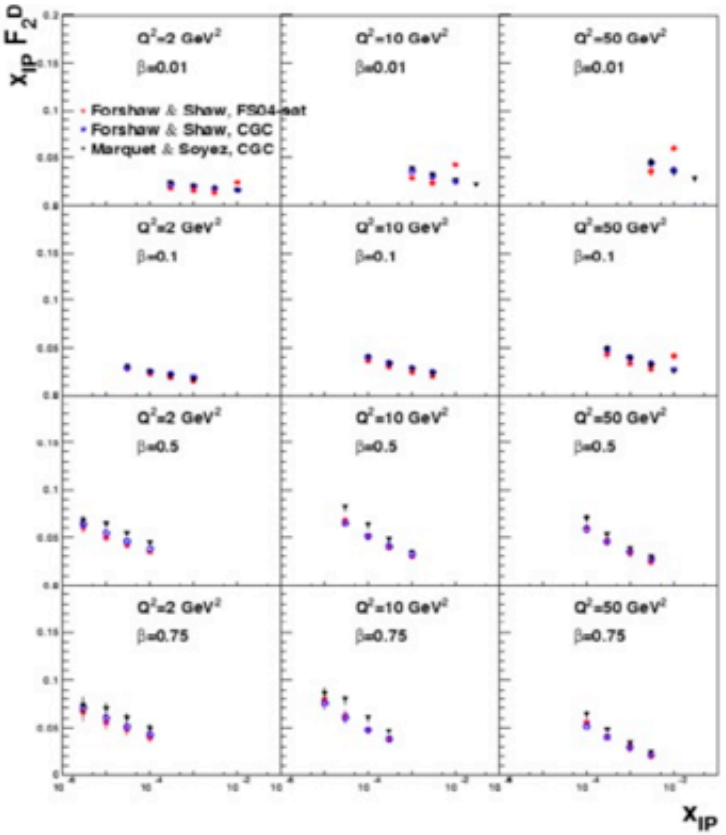
$$\beta\frac{d\sigma}{d\beta}(\beta, \tau_d \equiv Q^2/Q_s^2(x_{\mathbb{P}}))$$

Inclusive Diffraction @ LHeC

Diffraction at LHeC: new possibilities



- Studies with 1 degree acceptance,
- Diffractive-PDFs
- Factorization in much bigger range
- Diffractive masses $M_X \sim 100\text{GeV}$ with $x_{I\!P} = 0.01$
- X can include W,Z,b



Forshaw, Marquet, Newman

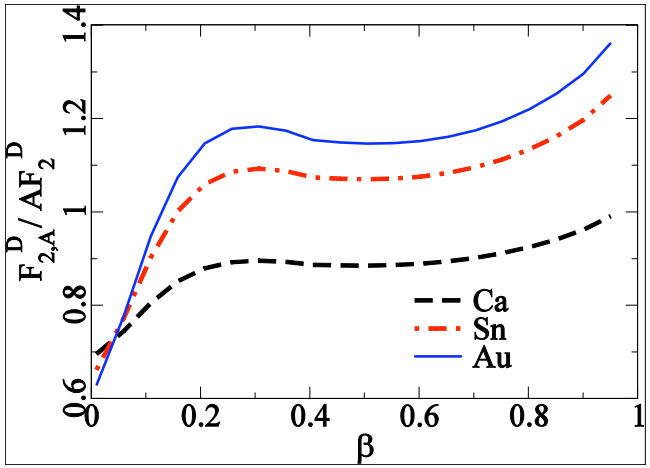
Simulated diffractive data available

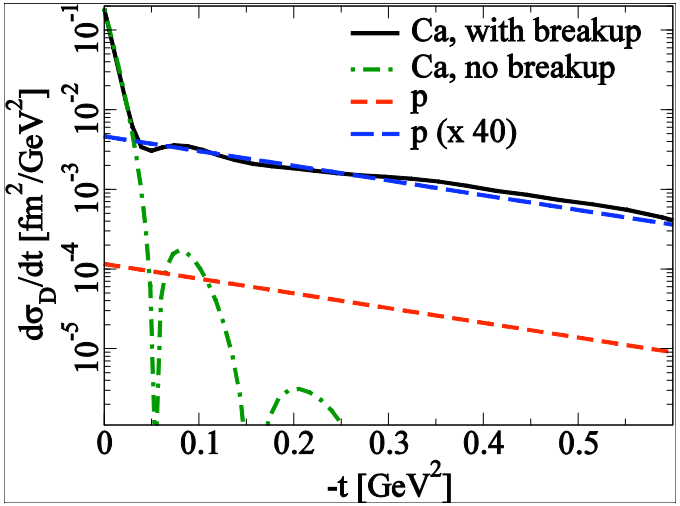
- **From talk by P. Newman Divonne 2008**

Nuclear Inclusive Diffraction

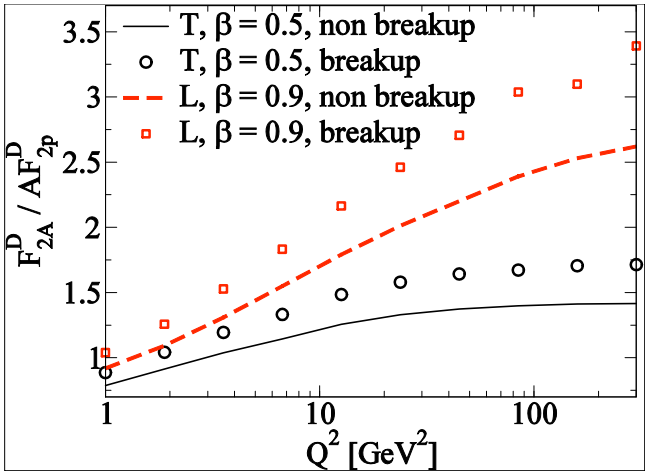
Kowalski, Lappi, C.M. and Venugopalan (2008)

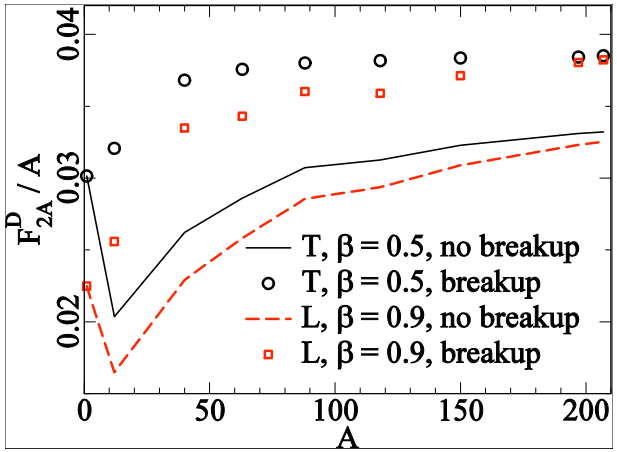
$$\frac{F_2^{D,A}}{AF_2^{D,p}}(\beta, Q^2 = 5\ \text{GeV}^2, x_{\mathbb{P}} = 0.001)$$





With nuclear break-up



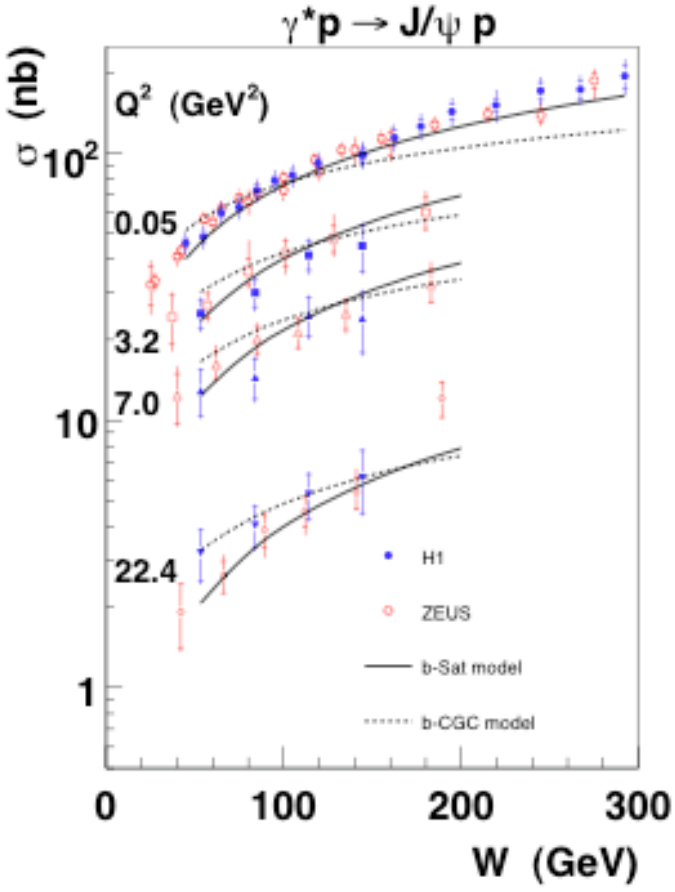


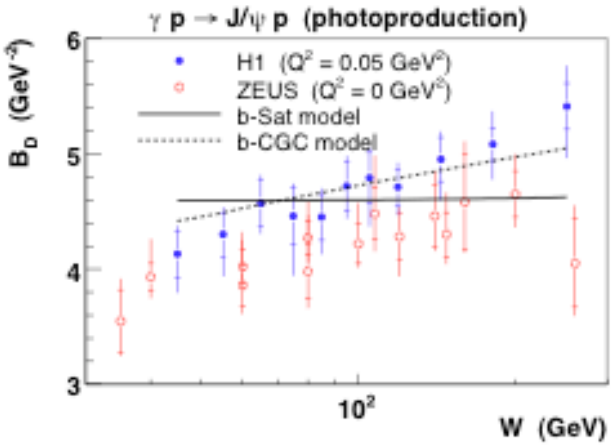
- Detection of nuclear break-up crucial.

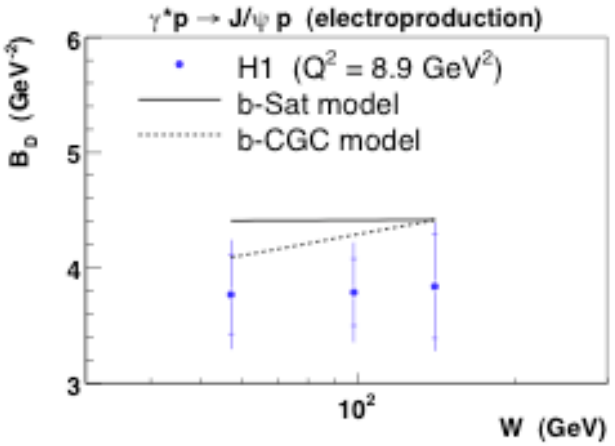
Exclusive Diffraction

- **From G. Watt, CERN HPD workshop**

Exclusive J/ψ photoproduction at HERA



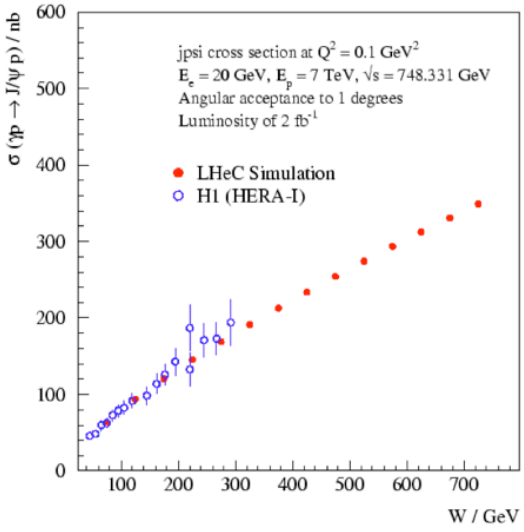


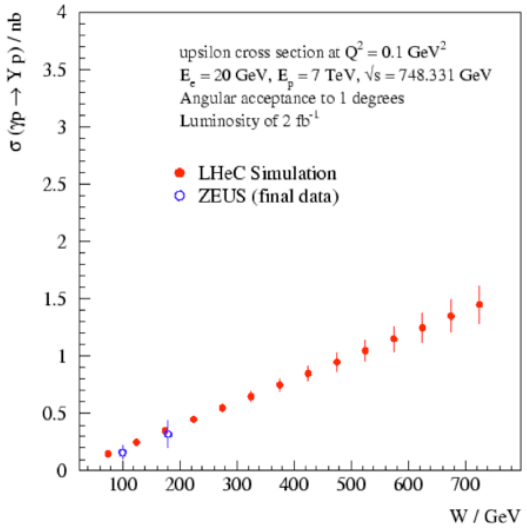


- W dependence of J/ψ photoproduction favours b-Sat model.
- Slope of B_D (t-slope) vs. W, i.e. $\alpha'_{\mathbb{P}}$, favours b-CGC model.

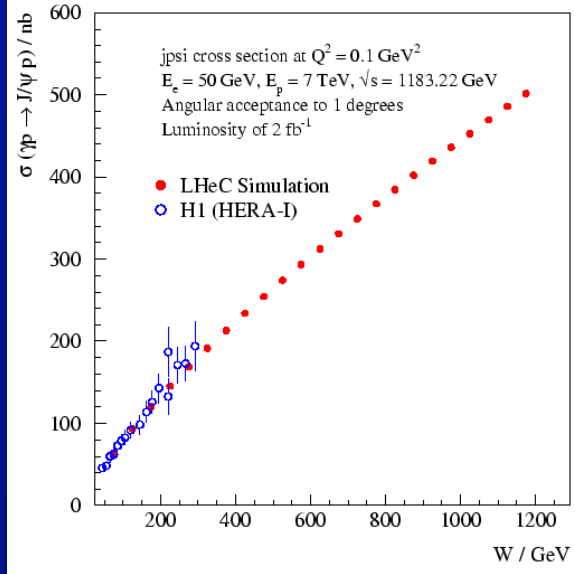
Exclusive Diffraction at LHeC

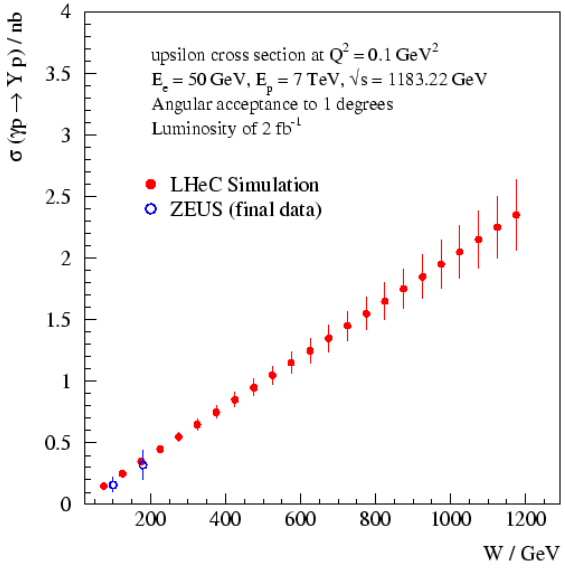
SPL Scenario – photoproduction cross secs





Dedicated Low x Ring-Ring Scenario





From P. Newman, CERN HPD workshop

e-p only

pseudo-data for two different LHeC scenarios

Current Status

- **Have calculations and/or pseudo-data for most channels of interest**
  - Missing pseudo-data for nuclear diffraction
  - Not much for F_2^c -- especially test of sensitivity to non-linear effects as alternative to F_L.
  - Jets are also behind other channels
- **Lacking Monte Carlo/event generator studies**
  - Especially for e-A (generator?)

    ⇒Synergy with EIC effort
- **Have started looking into nuclear radiative corrections**
  - Needs serious effort
- **How some questions raised above re: HPD physics in larger LHeC program.**

Next Steps

Timeline

- This meeting: collect contributions. Specify the most interesting/sensitive observables.
- July-August 2009: upgrade the CDR section outline with more details/predictions/ calculations.
- Beginning of September 2009: Divonne workshop.
- September 2009: start detailed write-up of the CDR section.

From CERN HPD workshop

- **Next steps:**
  - Start writing based on results of this meeting
  - Fill in the essential missing pieces
  - How many measurements should appear in CDR?