Low x physics at LHeC from inclusive measurements

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on behalf of the working group on 'Physics at High Parton Densities'

Related talks on Low x exclusive and diffractive: Paul Newman, and Low x in eA (Brian Cole)

April 14, 2011, DIS 2011, Newport News, VA

Outline

- Structure functions at low x.
  - Exploring new dynamics.
- Dijets and forward jets.
- Photoproduction.
- Implications for the neutrino physics.

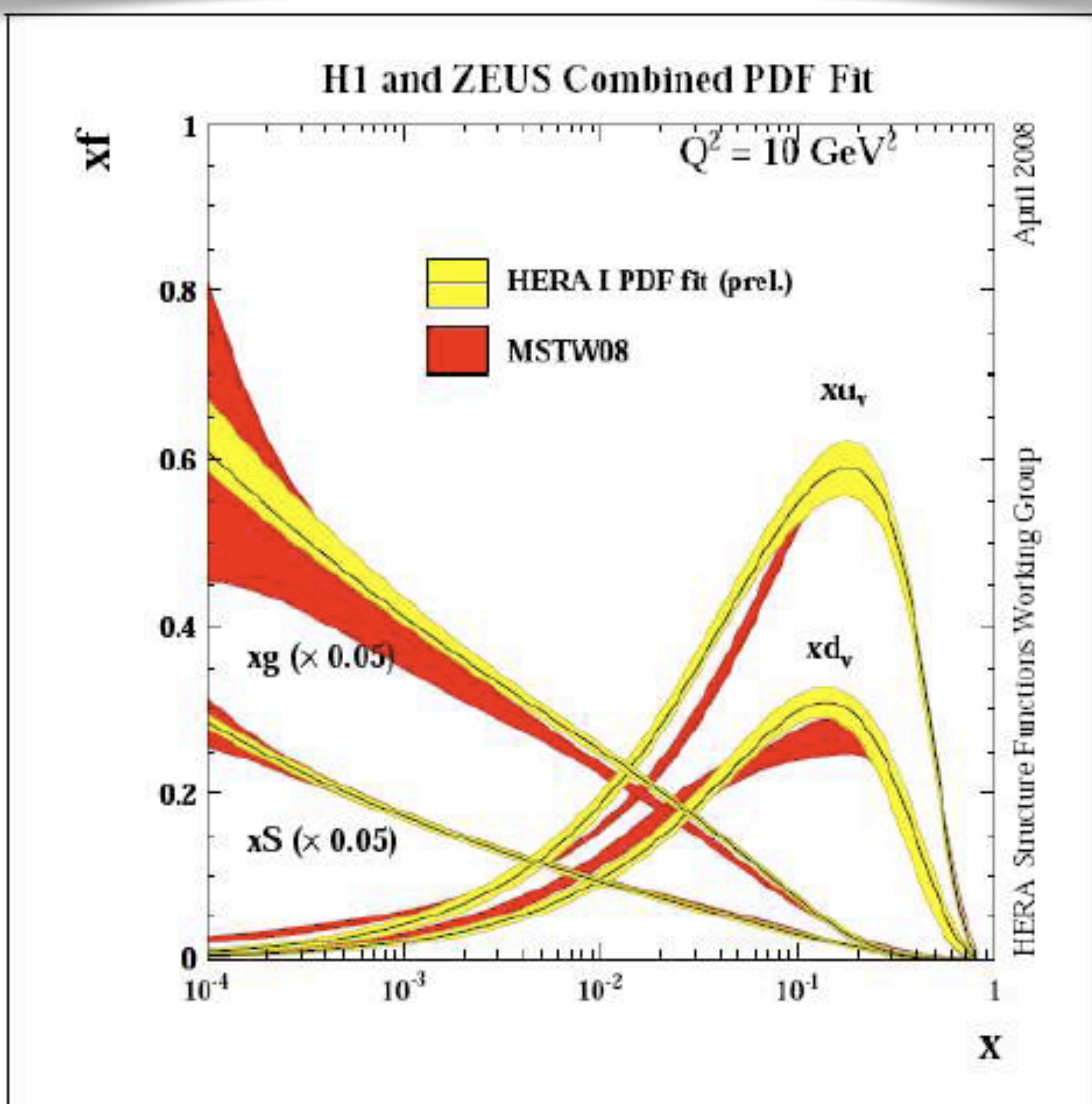
All the material presented in this talk is preliminary and will be published soon in LHeC Design Study Report, CERN 2011.

Why small x is so interesting?

Deep inelastic scattering is a classic scattering process in which one probes the structure of the hadron most precisely.

Important lesson from HERA : Observation of large scaling violations of the structure function F2.

Gluon density dominates at small x!



HERA established strong growth of the gluon density towards small x.

On the theoretical side: there is a divergence of the parton densities/cross sections at high energies/small x.

Increasing number of partonic fluctuations in the hadron wave function. Many body system.

New phenomena expected: dense parton regime, possibly new emergent phenomena, different effective degrees of freedom...

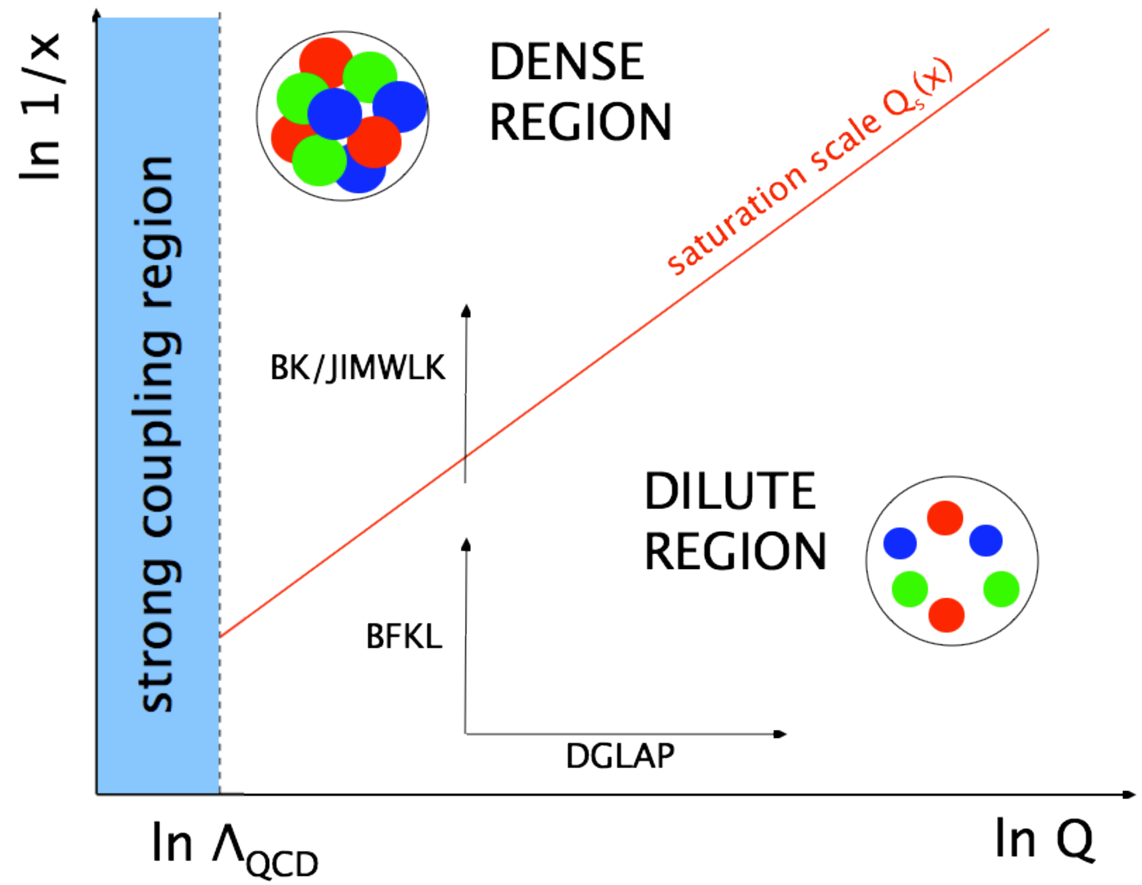
Unitarity must be preserved, how it is realized in microscopic terms?

New regime at small x: high parton density

- At small x the linear evolution gives strongly rising gluon density.
- Parton evolution needs to be modified to include the gluon recombination effects (in the dipole language it corresponds to multiple scatterings).
- Expect dynamically generated scale:

Saturation scale: $Q_s^2(x)$

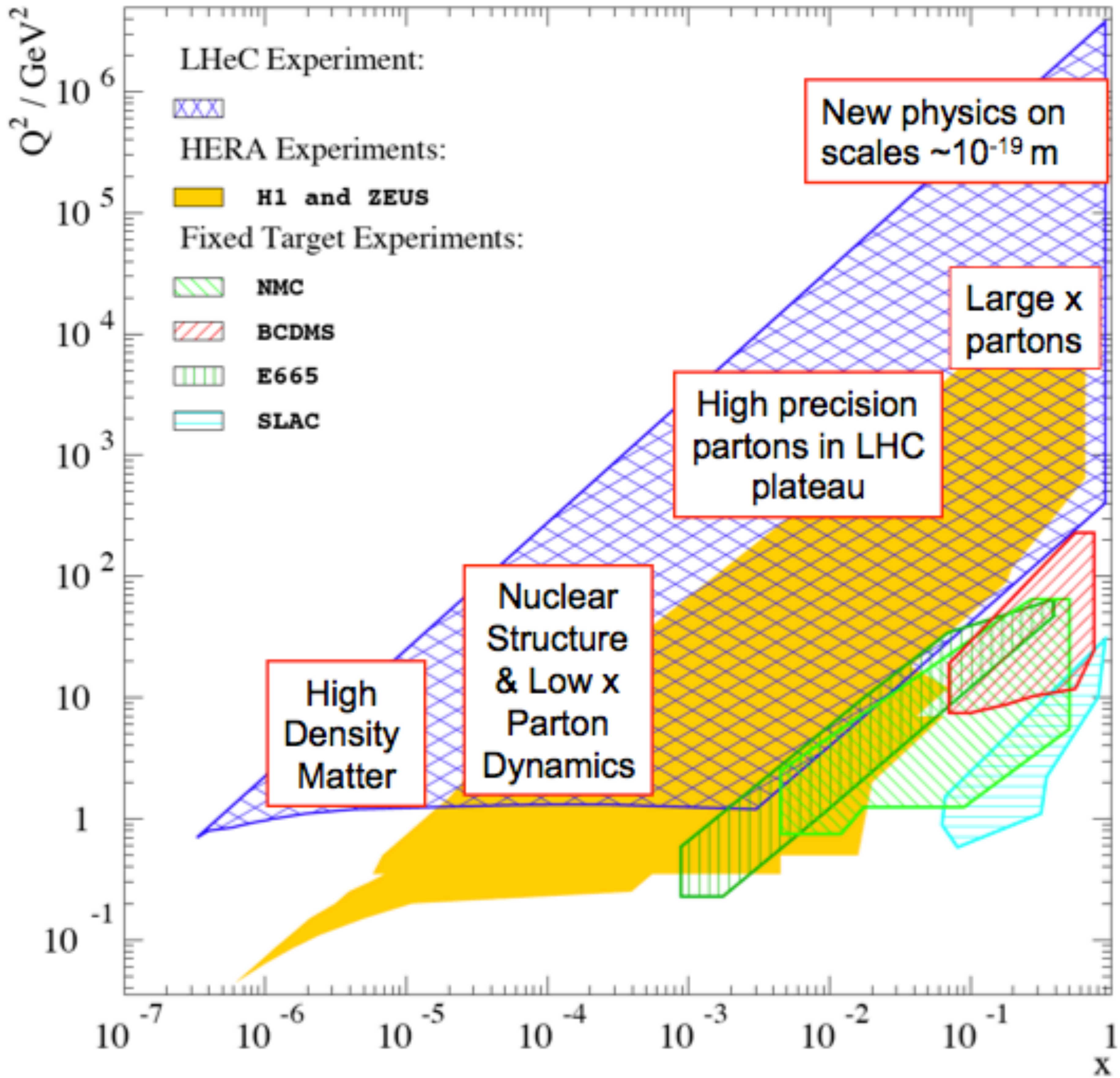
- Characterizes the boundary between the non-linear and linear regime.
- Increases with energy or with decreasing x.



The boundary between the two regimes needs to be determined experimentally.

Unique feature of the LHeC: can access the dense regime at fixed, semihard scales Q, while decreasing x.

Kinematics & Motivation (140 GeV x 7 TeV)



$\sqrt{s} = 2$ TeV

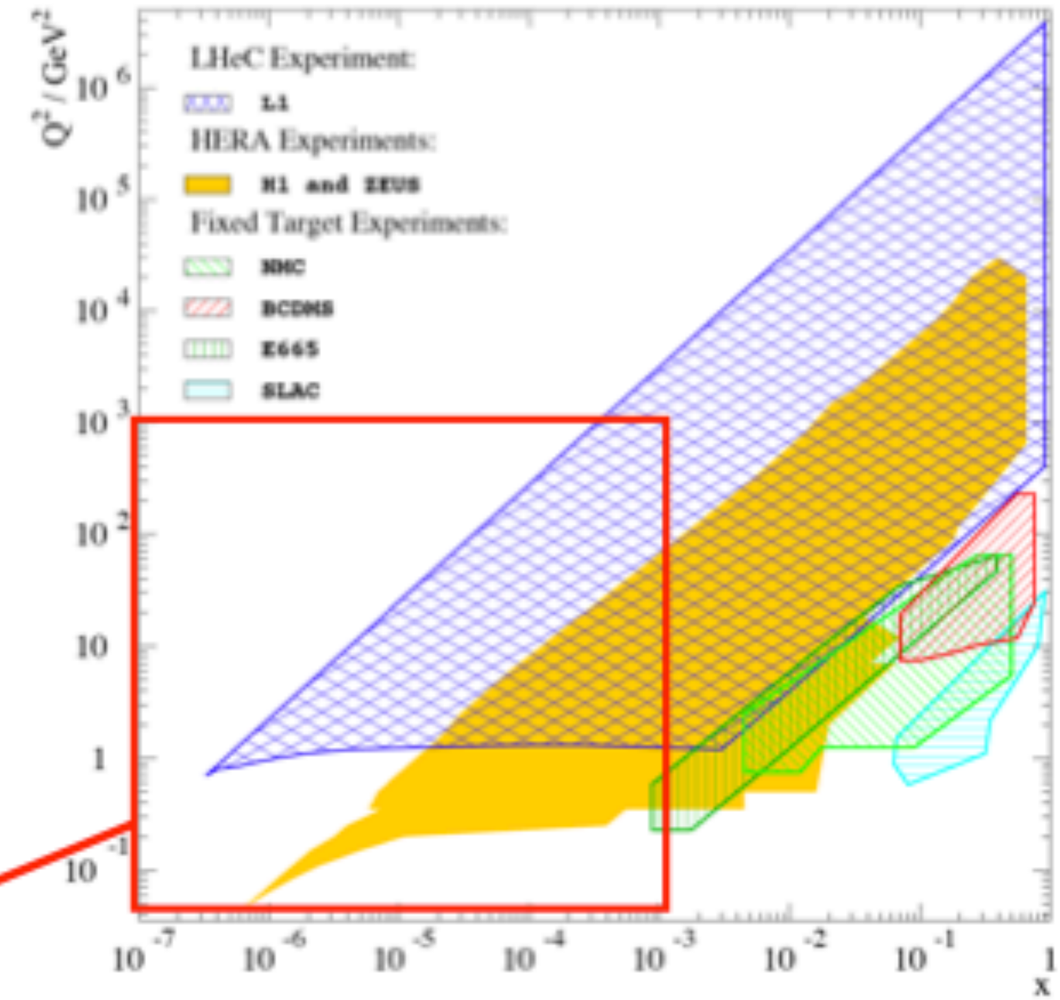
- High mass (M_{eq}, Q^2) frontier
- EW & Higgs
- Q^2 lever-arm at moderate & high x → PDFs
- Low x frontier → novel QCD ...

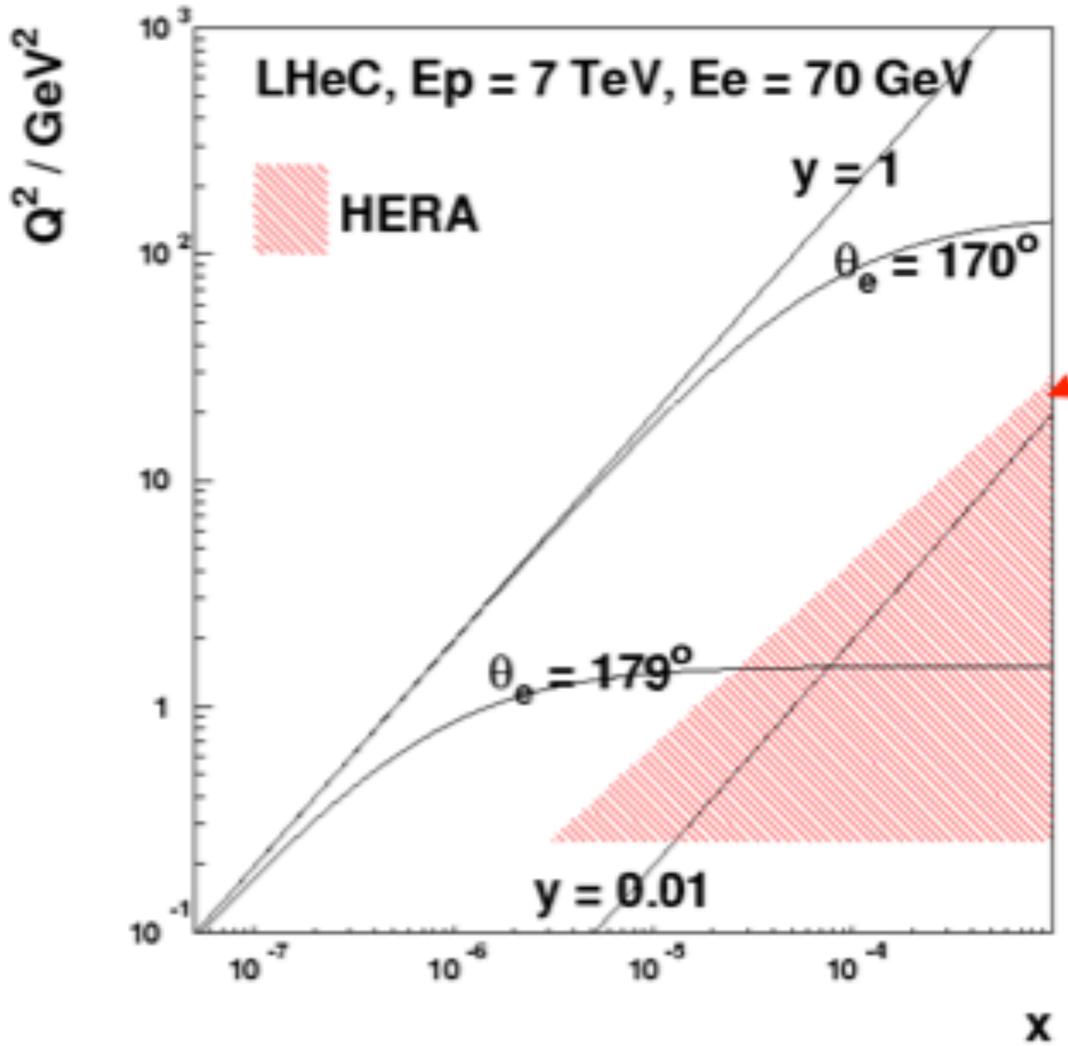
$x \geq 5.10^{-7}$ at $Q^2 \leq 1$ GeV^2

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°





... low x cross sections are large!

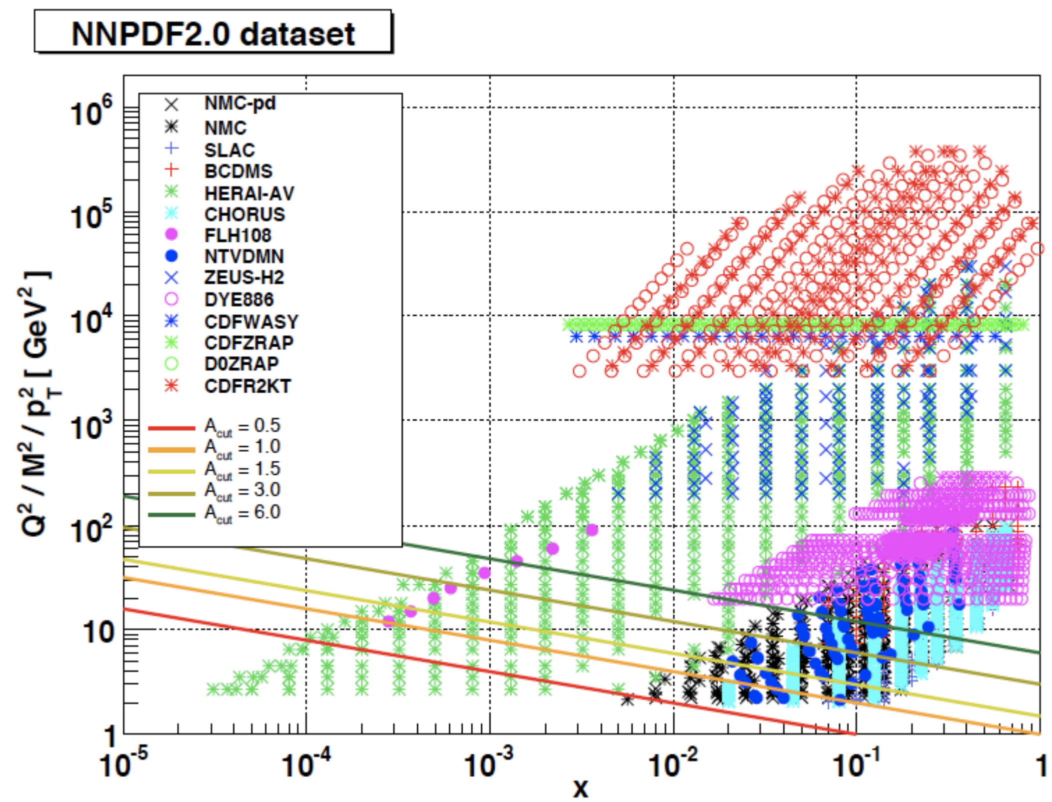
... luminosity in all realistic scenarios ample for most low x measurements

Hints from HERA

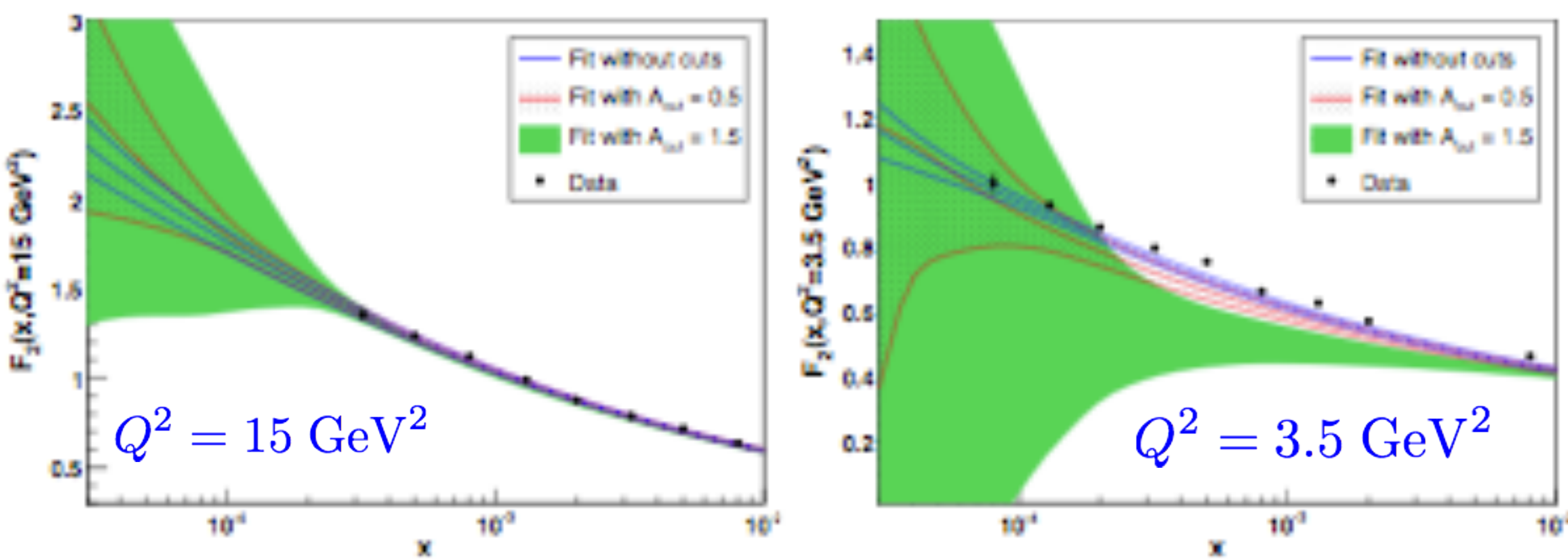
$$Q^2 \geq A_{\mathrm{cut}} \cdot x^{-\lambda}$$

- Tension in data at small x and Q^2 when introduced in a global fit (NNPDF2.0).

- Deviation incompatible with NNLO → need resummation at low x or non-linear effects.

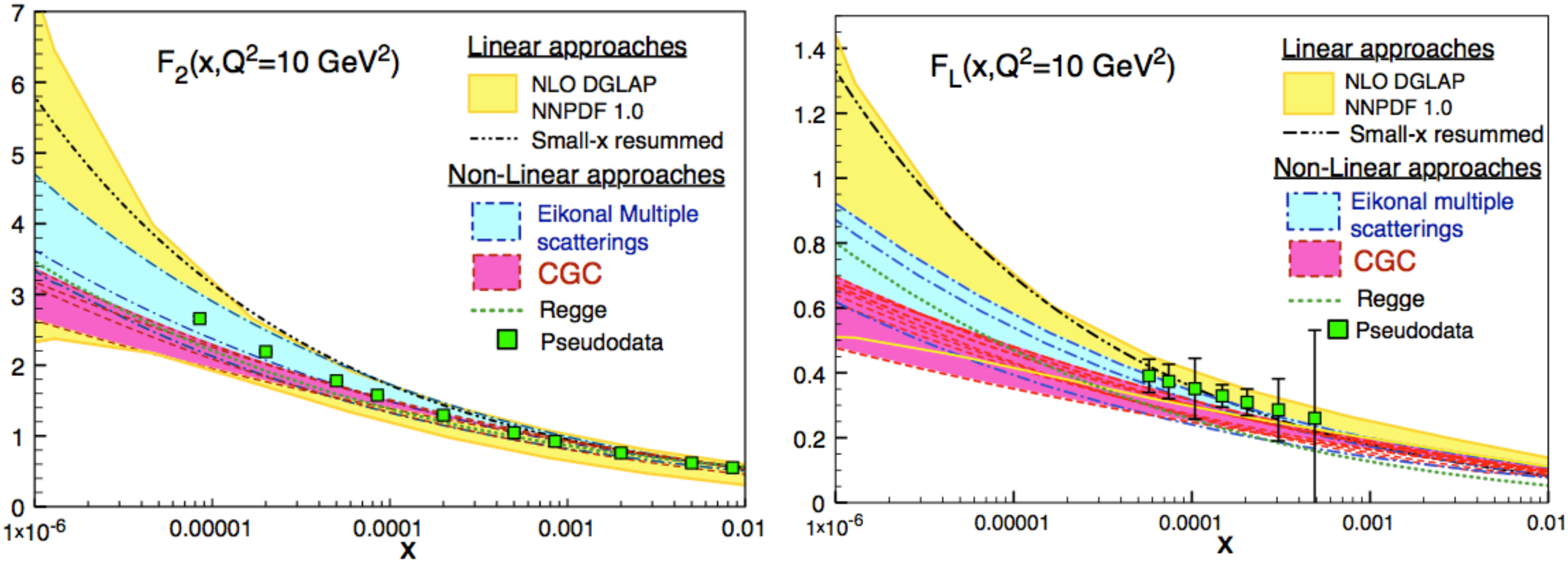


Caola,Forte,Rojo



Predictions for the proton

DGLAP approaches have large uncertainties at low x and even at moderate Q (larger uncertainties as Q is decreased)



Albacete

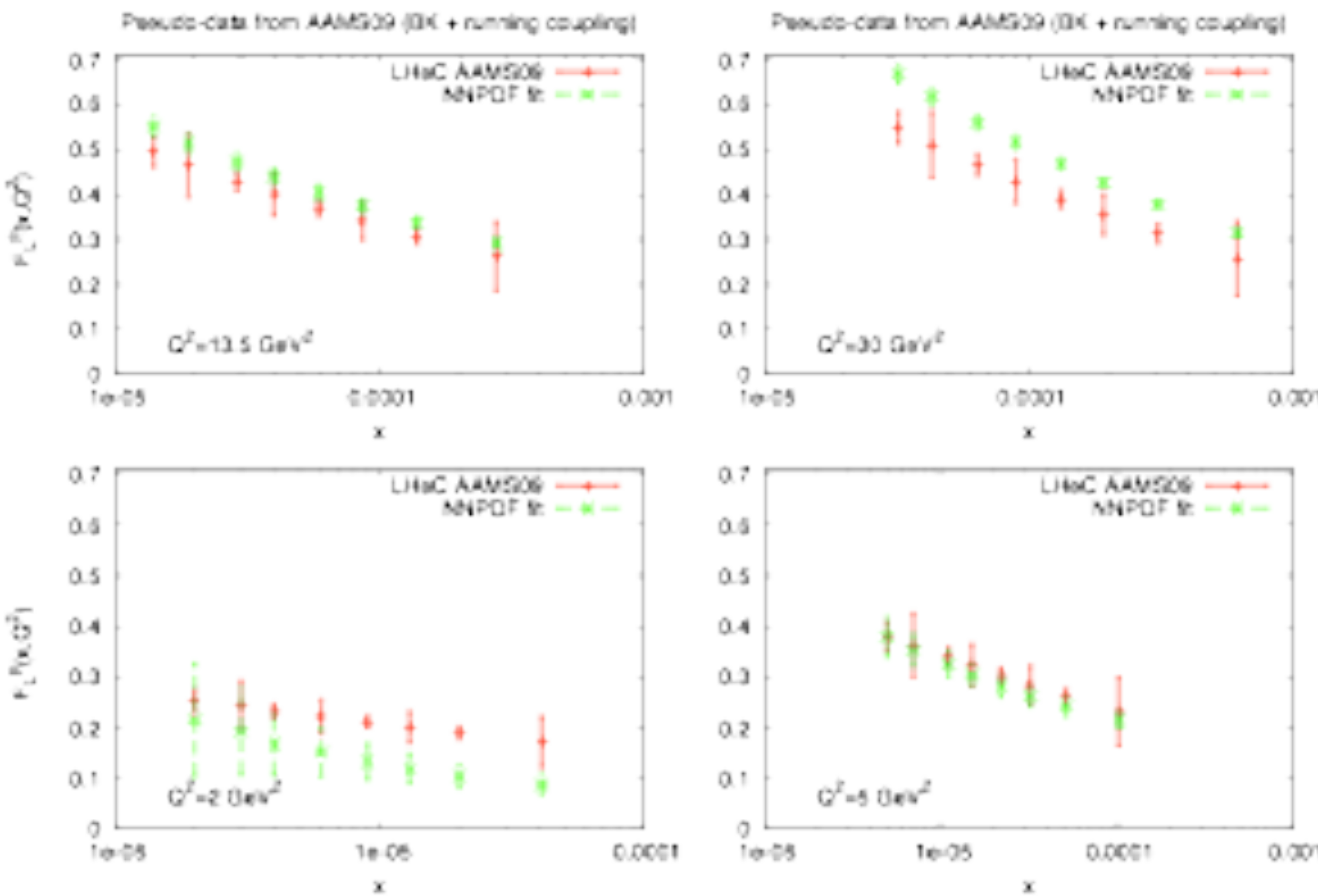
Interestingly, rather small band of uncertainties for models based on saturation as compared with the calculations based on the linear evolution. Possible cause: the nonlinear evolution washes out any uncertainties due to the initial conditions, or too constrained parametrization used within the similar framework.

approx. 2% error on the F2 pseudodata, and 8% on the FL pseudodata ,should be able to rule out many of the scenarios.

Testing nonlinear dynamics in ep

Simulated LHeC data using the nonlinear evolution which leads to the parton saturation at low x.

DGLAP fits (using the NNPDF) cannot accommodate the nonlinear effects if F2 and FL are simultaneously fitted.

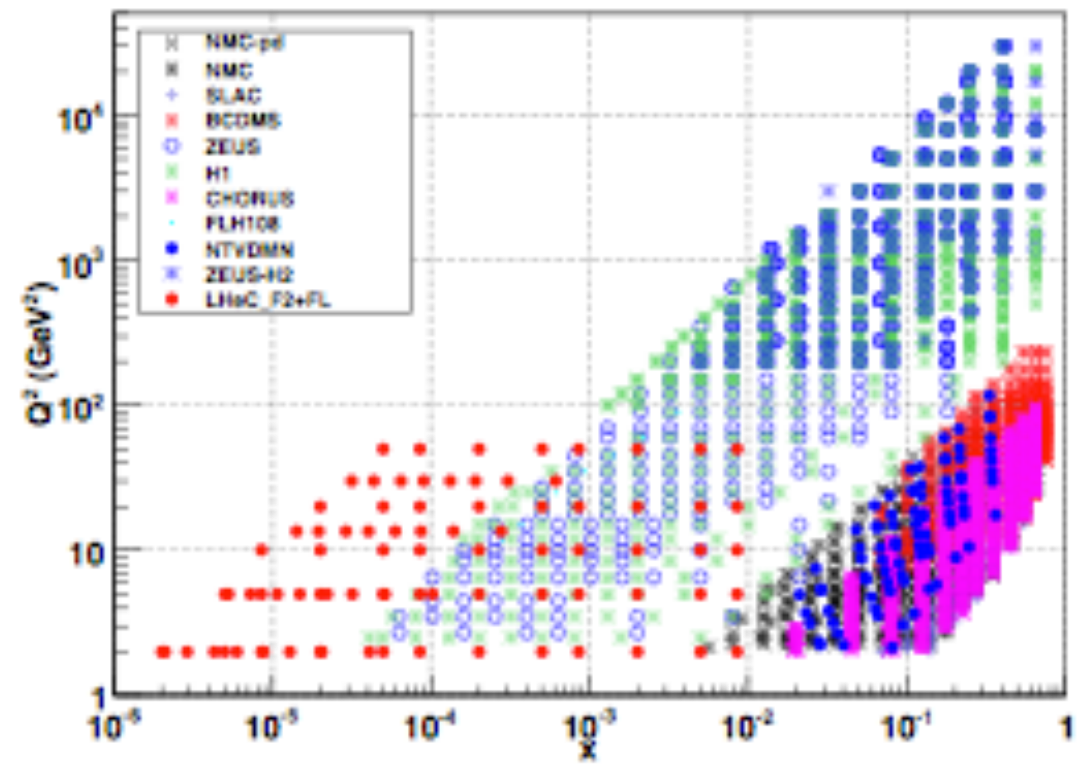


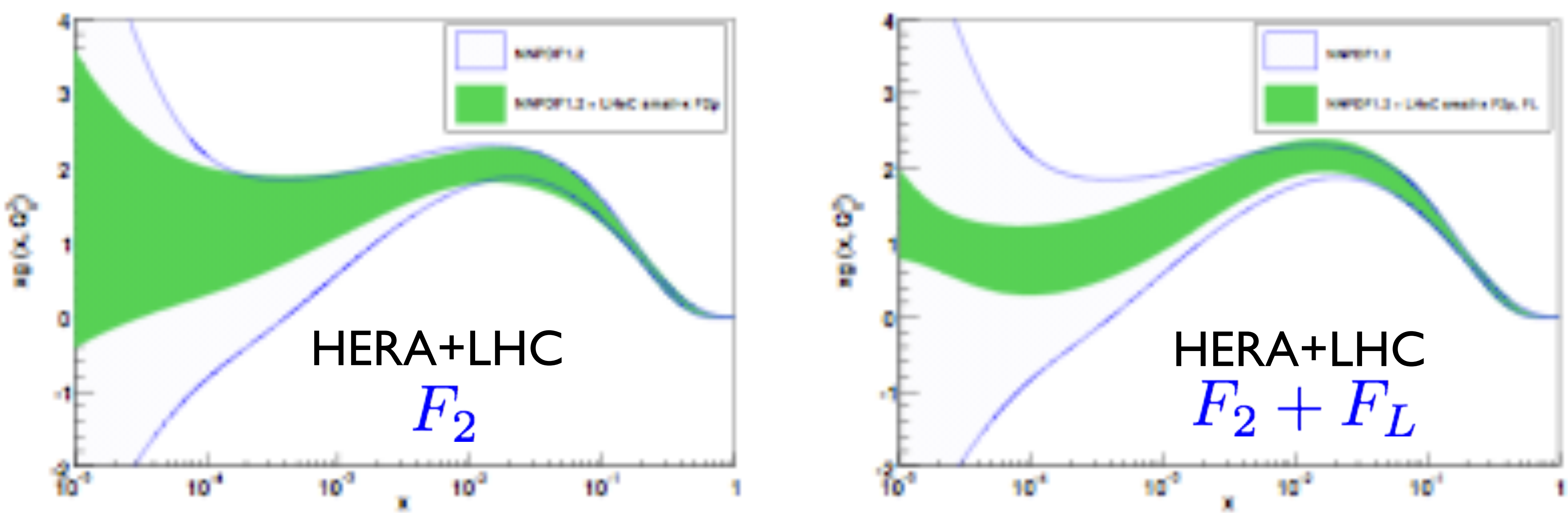
Albacete,Rojo

FL provides important constraint on the gluon density at low x.

Impact on DGLAP for p: F_2, F_L

- Inclusion of LHeC pseudodata for F_2, F_L in DGLAP fits improves the determination of the glue at small x.



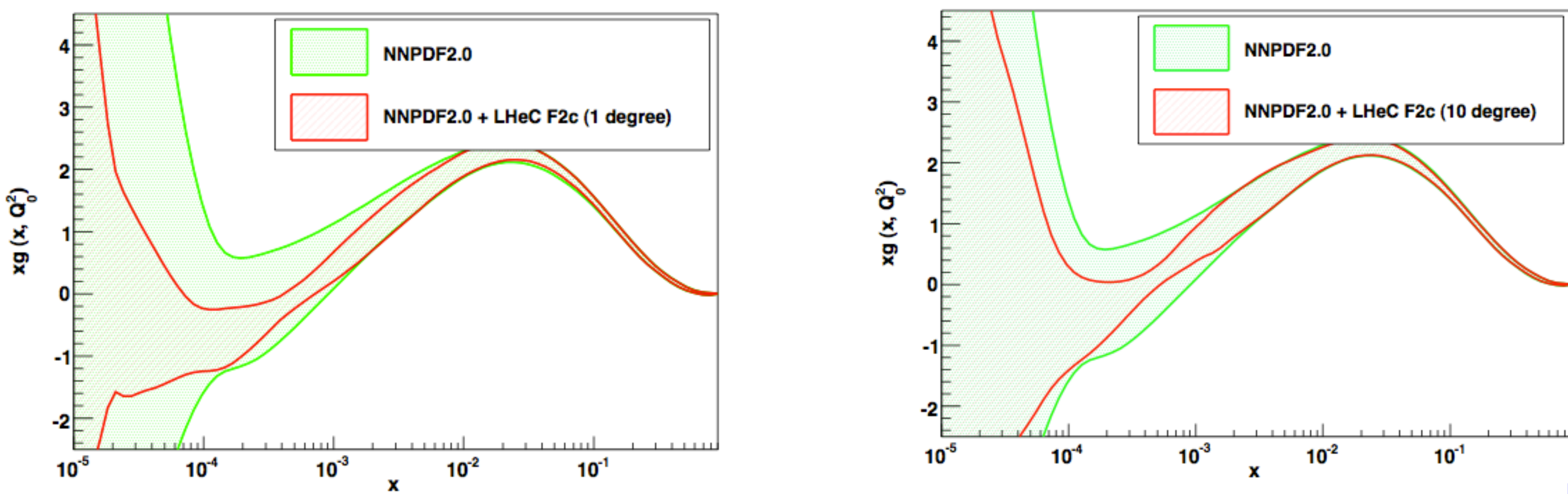


$$Q^2 = 2\ \mathrm{GeV}^2$$

Rojo

Impact of flavor decomposition

Longitudinal structure function difficult to measure. Possibility of using charm structure function to constrain the gluon distribution function.



Rojo

Charm structure function F2c can be used in addition to F2 to constrain the gluon density (red band corresponds to the analysis with the LHeC data on F2charm).

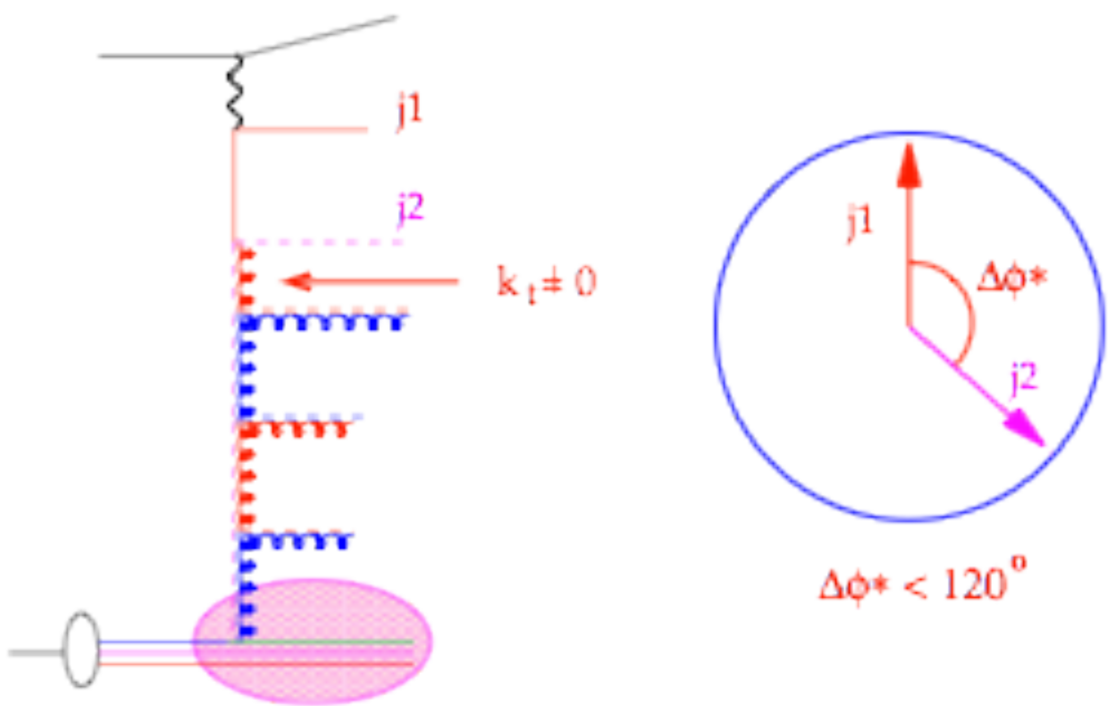
The advantage of 1 degree scenario is also illustrated.

<u>Conclusion:</u> for a better discrimination between models, especially involving nonlinear dynamics, two observables are necessary.

Parton dynamics

- Inclusive measurements provide constraints on the integrated parton distribution functions.
- Details of the dynamics need to be pinned down by more exclusive measurements.
- Unintegrated parton distribution functions needed, which have a better control of the kinematics of the process. LO with unintegrated pdfs descriptions are in general better than higher order terms in collinear approach.
- Angular decorrelation of dijets, forward jets, transverse energy flow, needed to constrain the parton dynamics.

Dijets in ep

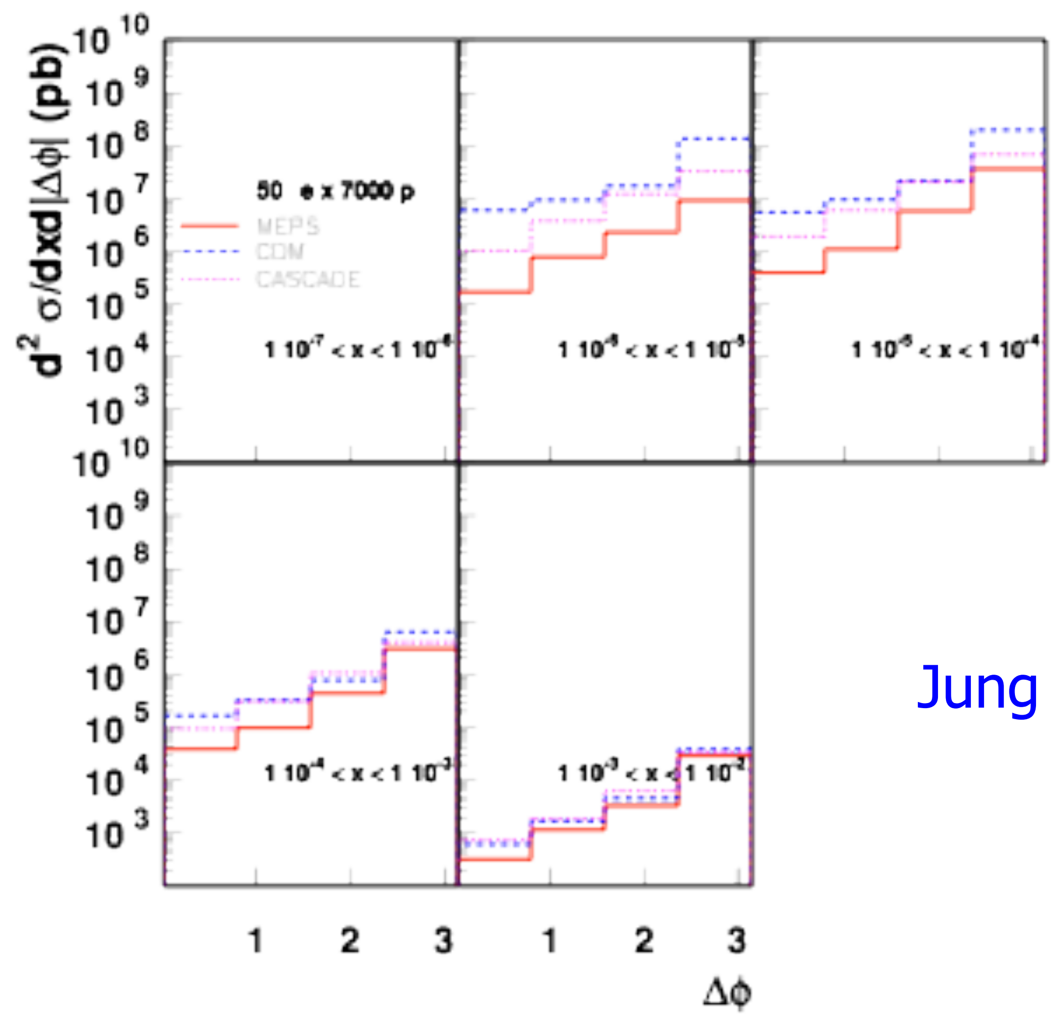


- Incoming gluon can have sizeable transverse momentum.
- Decorrelation of pairs of jets, which increases with decreasing value of x.
- Collinear approach typically produces narrow back-to-back configuration. Need to go to higher orders(NLO not sufficient).

$$-1 < \eta_{\text{jet}} < 2.5 \qquad 0.1 < y < 0.6$$

$$E_{1T} > 7 \text{ GeV} \qquad Q^2 > 5 \text{ GeV}^2$$

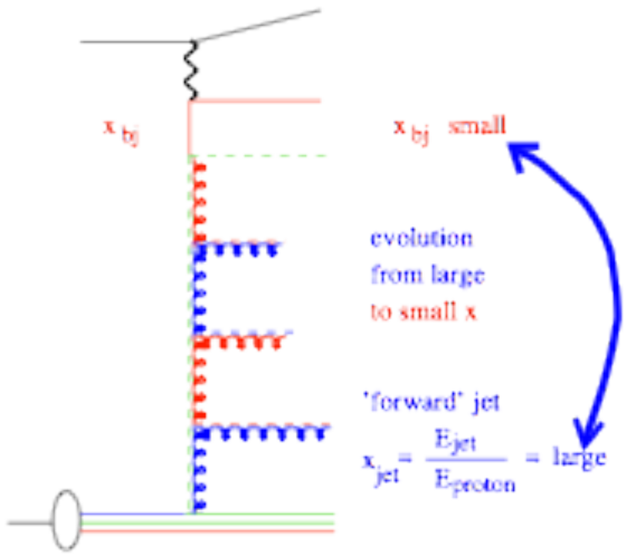
$$E_{2T} > 5 \text{ GeV}$$



Jung

- All simulations agree at large x.
- CDM, CASCADE give a flatter distribution at small x.

Forward jets



- Forward jet provides the second hard scale.
- By selecting it to be of the order of the photon virtuality, collinear configurations can be suppressed.
- Forward jet, large phase space for gluon emission.
- DGLAP typically underestimates the forward jet production.

Simulations for

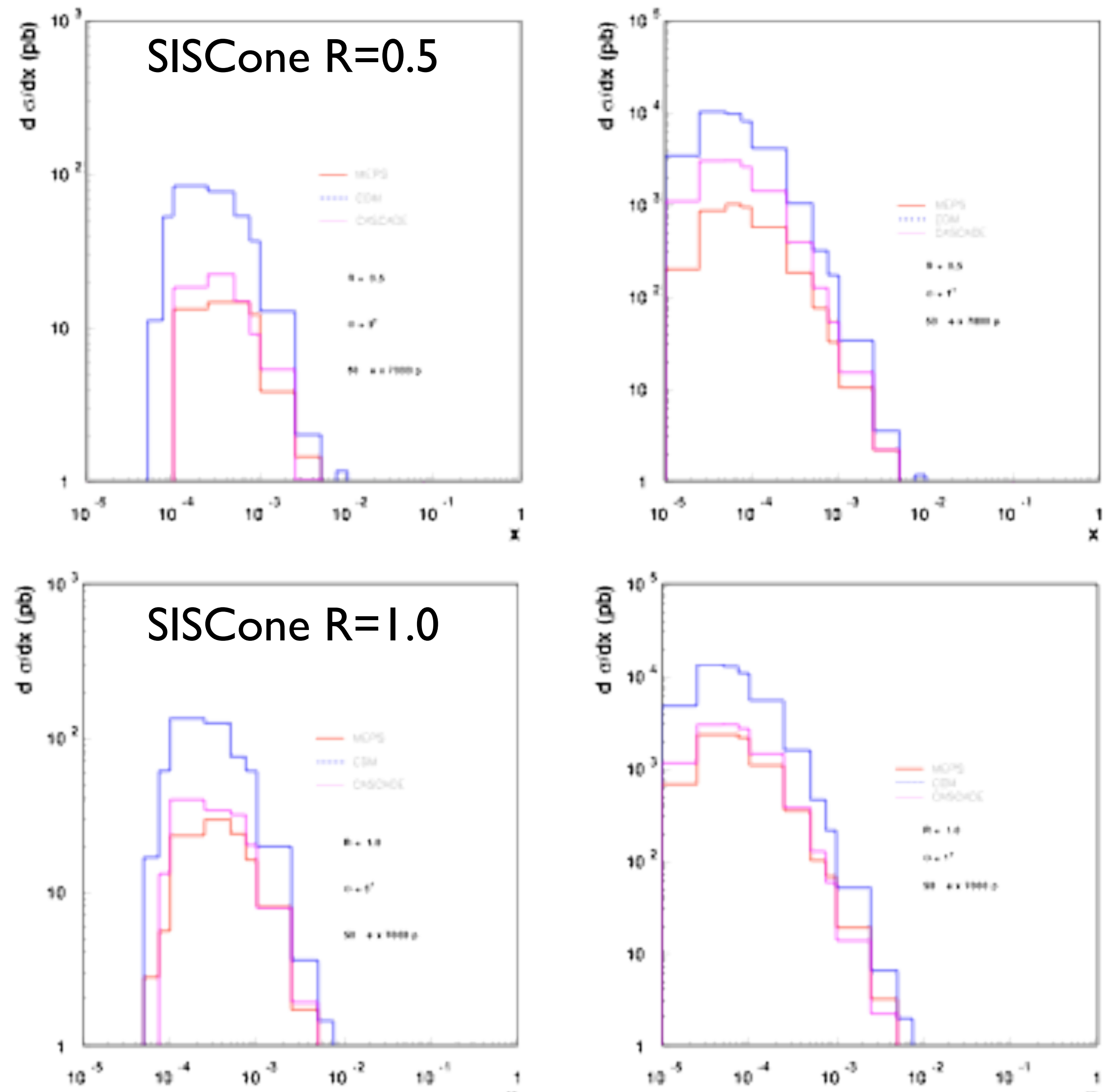
$\Theta > 3^o$ and $\Theta > 1^o$

Angular acceptance crucial for this measurement.

With $\Theta > 10^o$

all the signal for forward jets is lost.

Can explore also forward pions. Lower rates but no dependencies on the jet algorithms. Non-perturbative hadronisation effects included effectively in the fragmentation functions.



Jung

Photoproduction cross section

•Photoproduction cross section.

•Explore dual nature of the photon: pointlike interactions or hadronic behavior.

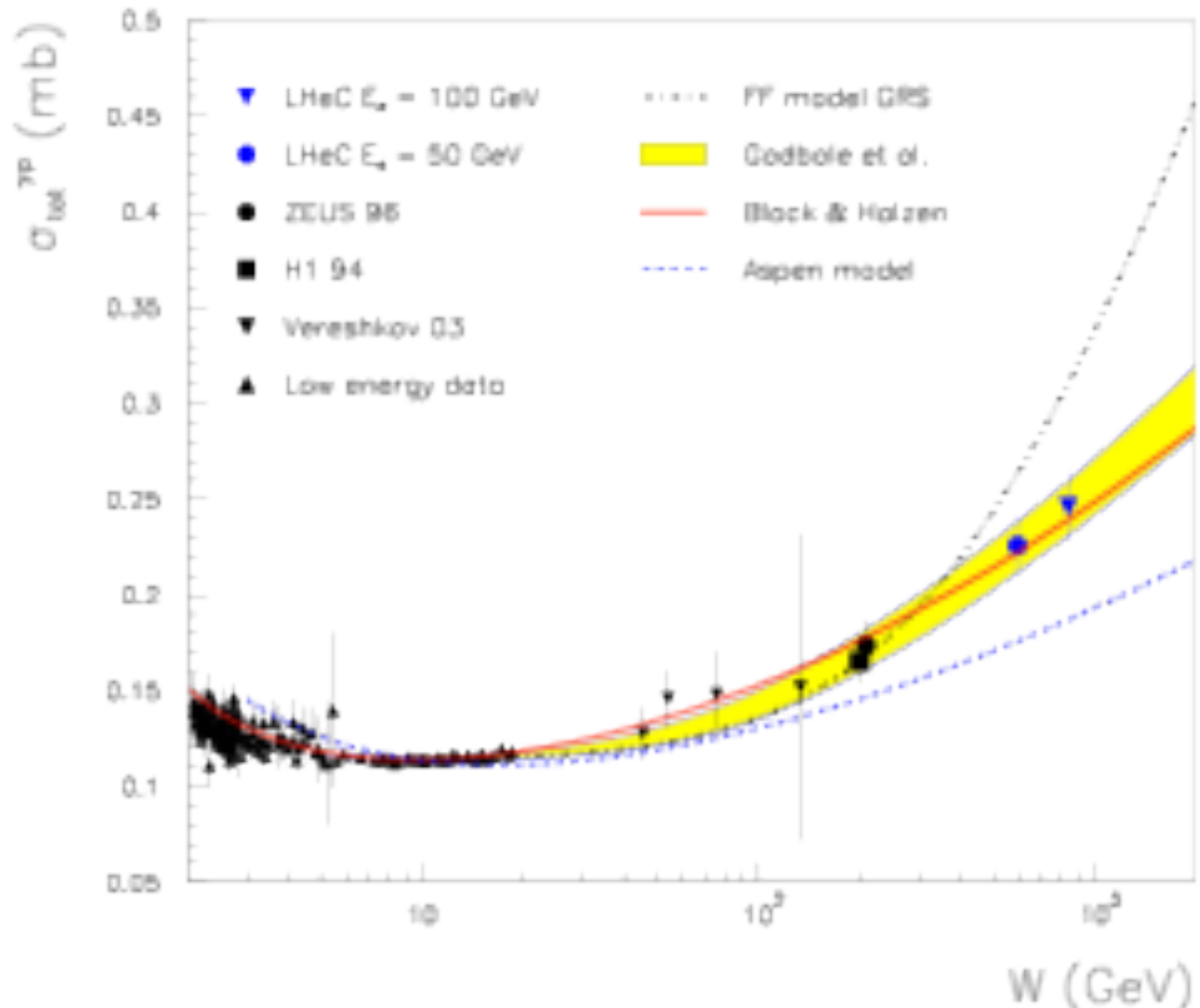
•Testing universality of hadronic cross sections, unitarity, transition between perturbative and nonperturbative regimes.

•Large divergence of the theoretical predictions beyond HERA measurements.

•Dedicated detectors for small angle scattered electrons at 62m from the interaction point.

•Events with $y \sim 0.3$ $Q^2 \sim 0.01$ could be detected

Pancheri



Systematics is the limiting factor here. Assumed 7% for the simulated data as in H1 and ZEUS.

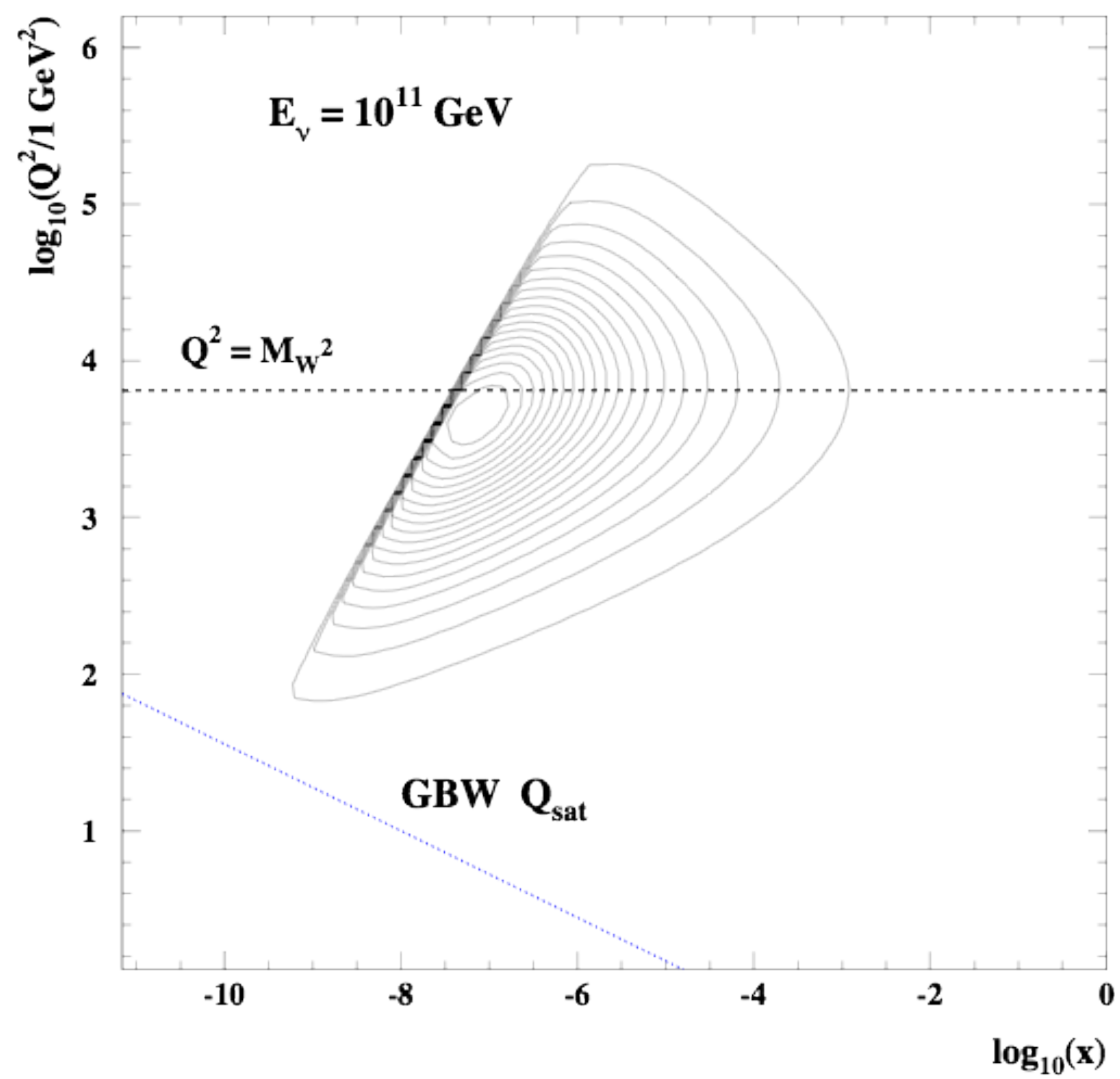
Relevance of LHeC for neutrino interactions

High energy neutrino interactions probe extremely small values of x

$$x \sim 10^{-8}$$

Smaller than constraints on pdfs from colliders

Contours enclose $5\%, 10\%, 15\%, \ldots$ contribution to the differential cross section $\frac{d^2\sigma^{\nu N}}{dxdQ^2}$



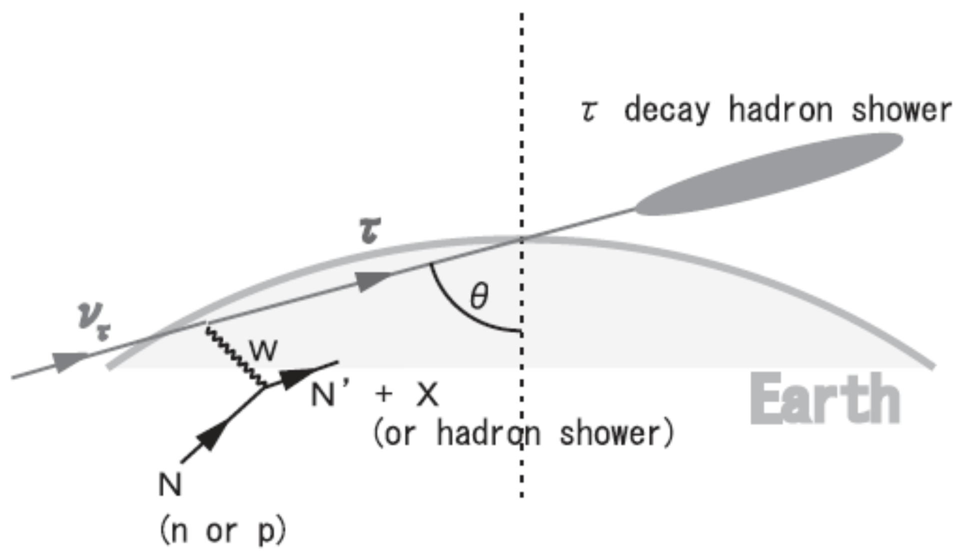
Cross section dominated by large Q

$$Q^2 \sim M_W^2$$

Relevant for UHE neutrino observatories ICECUBE

Relevance of LHeC for neutrino interactions

Oscillation enhance the possibility of direct observation of tau neutrinos at Earth. Short lifetime of tau, causes it to quickly decay in flight and produce a shower. Search for Earth skimming tau neutrinos



Energy loss of tau:

$$-\left\langle \frac{dE}{dX} \right\rangle = a(E) + b(E)E$$

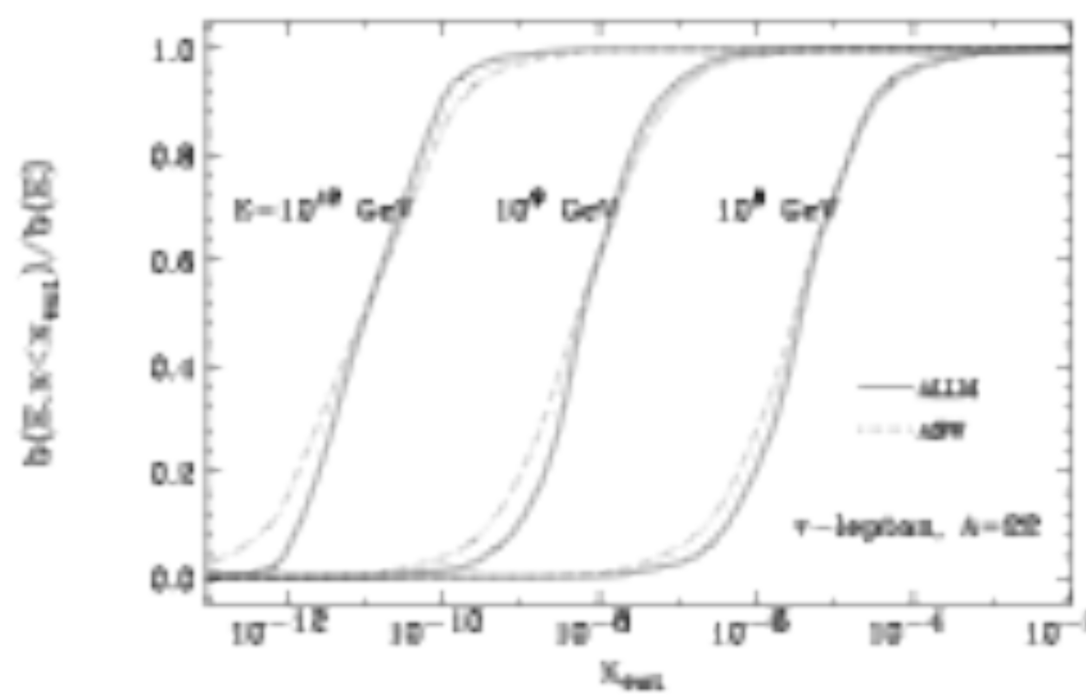
ionization

dominated by pair production, bremsstrahlung and photonuclear interactions

photonuclear contributions:

$$b(E) = \frac{N_A}{A} \int dy \, y \int dQ^2 \frac{d\sigma^{\gamma A}}{dQ^2 dy}$$

dominant at high energies



Armesto

Energy loss of tau again dominated by small x region.

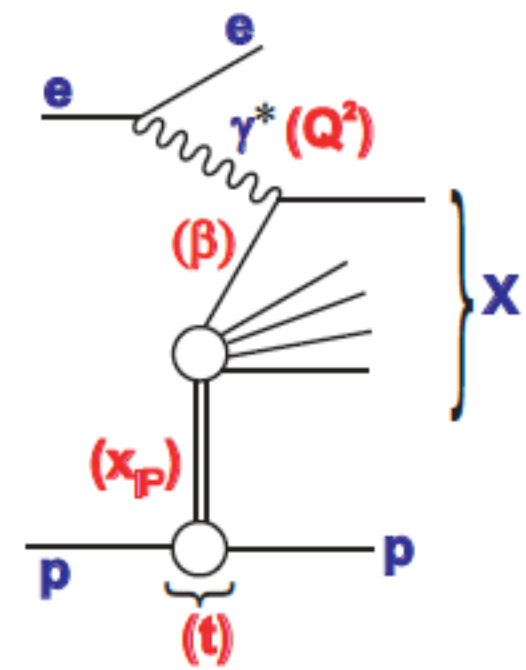
Conclusions

- LHeC can better explore semihard regime, and search for new phenomena at low x.
- Excellent constraint of the gluon density at low x.
- For a better discrimination need additional observable. Longitudinal structure function provides with more direct constraint, also charm structure function works well.
- New regime for dijet and forward jet production. Sensitivity to constrain unintegrated parton distributions.
- Forward jet analysis requires good angular acceptance. Forward pions also possible, transverse energy flow measurements.
- Possibility of the measurement of the photoproduction cross section. Need dedicated electron detectors 62m away from the interaction point. Accuracy limited by systematics, but still very good resolution to discriminate between various models.
- Relevance for the neutrino interactions, constraints on cross sections and energy losses.

Backup

The importance of diffraction

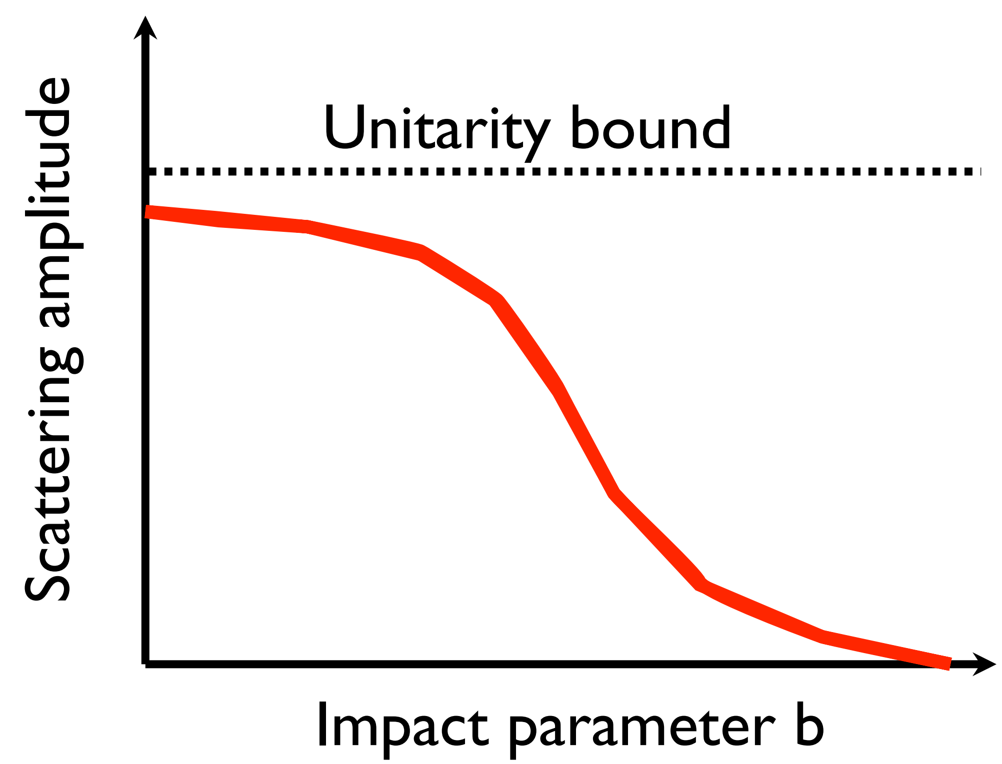
• Diffraction i.e. events with a rapidity gap due to the exchange of a color neutral object, are ~10 % of the total cross section at HERA.



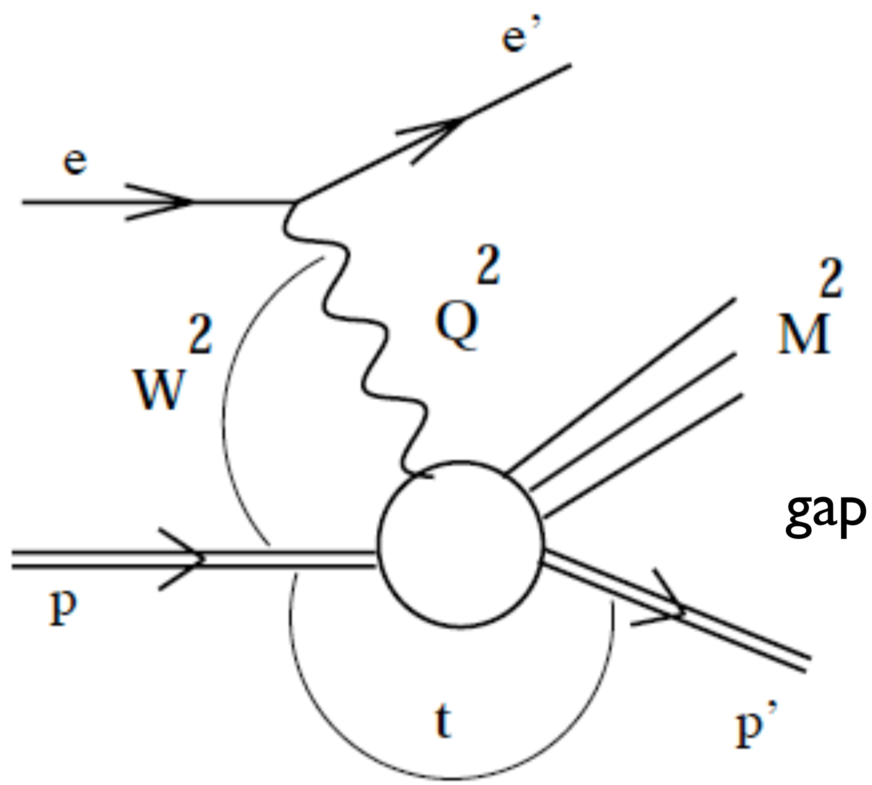
● Diffraction is characterized by softer scales than inclusive measurements: additional possibility to check saturation ideas at same Q.

•Diffraction is a collective phenomenon; explore relation with saturation.

● A scanning in momentum transfer t provides an impact parameter ($t \propto 1/b$) scan of the hadron: unitarity and saturation effects expected to be larger in the center of the hadron (density effect).



Inclusive diffraction



$$e + p \to e' + p' + X$$

Proton stays intact and separated by a rapidity gap

$$x_{I\!P} = \frac{Q^2 + M^2 - t}{Q^2 + W^2}$$

momentum fraction of the Pomeron with respect to the hadron

$$\beta = \frac{Q^2}{Q^2 + M^2 \quad t}$$

momentum fraction of the struck parton with respect to the Pomeron

$\Delta\eta = \ln 1/x_{I\!P}$ Rapidity gap

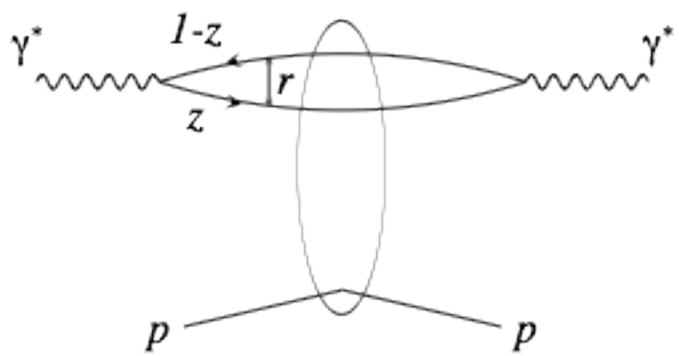
LHeC :

- Enhanced sensitivity to semi-hard regime
- Explore relation with saturation at unprecedented low x
- Test factorization (or lack of it)
- Gap survival issues
- Additional momentum transfer dependence allows access to measure the impact parameter profile of the interaction region

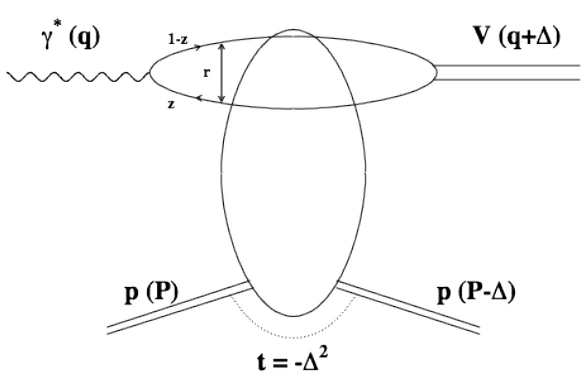
Diffraction and saturation

Dipole model at high energy: photon fluctuates into qqbar pair and undergoes an interaction with the target

$$\sigma_{T,L}(x,Q^2) = \int d^2\mathbf{r} \int_0^1 dz \sum_f |\Psi^f_{T,L}(\mathbf{r},z,Q^2)|^2 \, \hat{\sigma}(x,\mathbf{r}) \, .$$

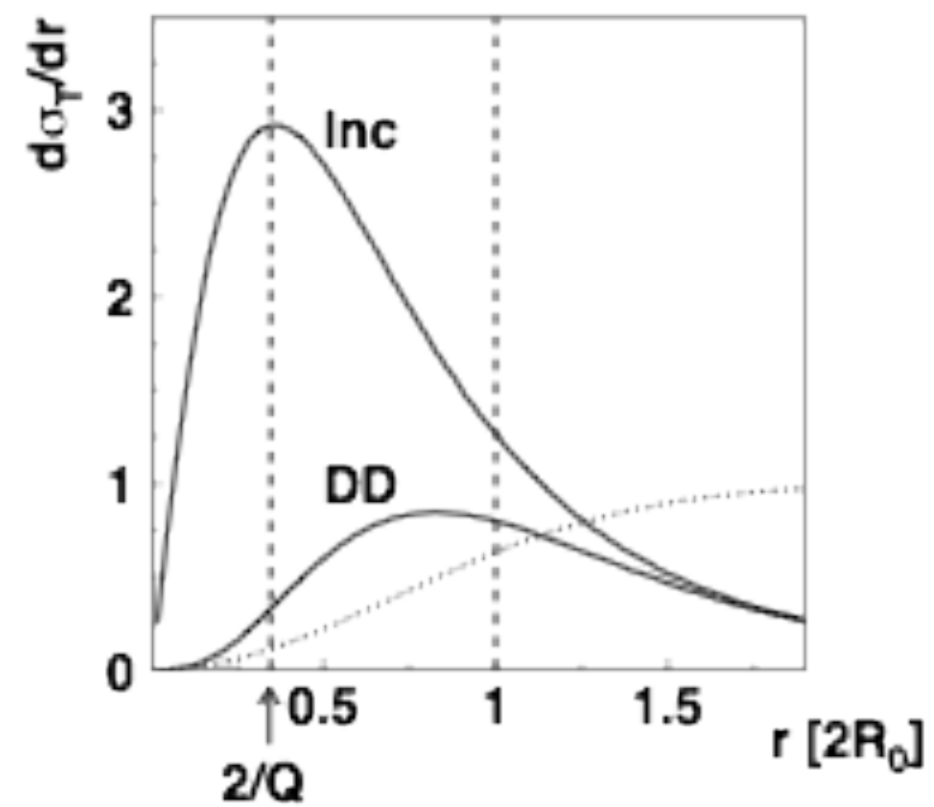


Inclusive: dominated by relatively hard component



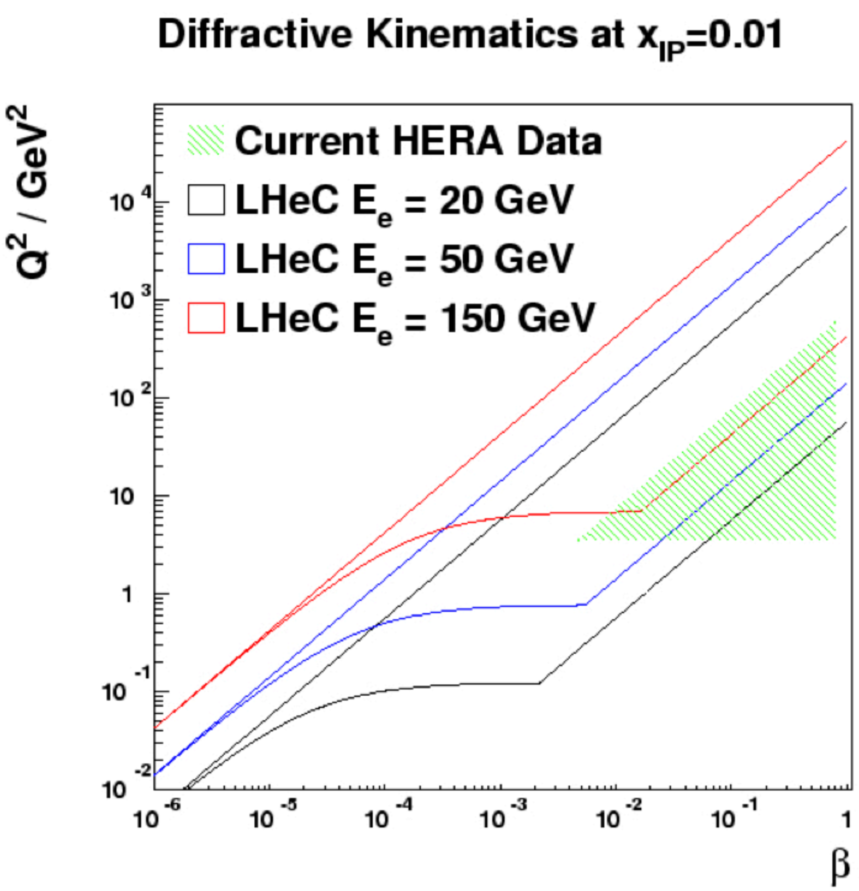
Diffractive: dominated by the semi-hard momenta

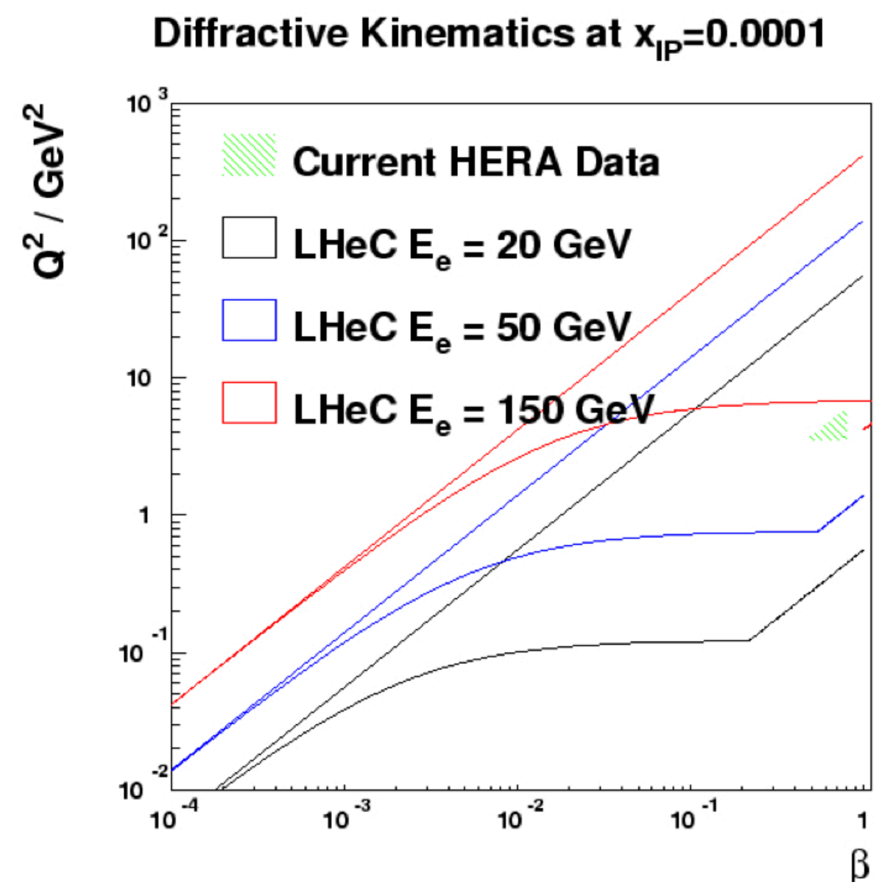
overlap function in the dipole model
typical dipole sizes involved in the process

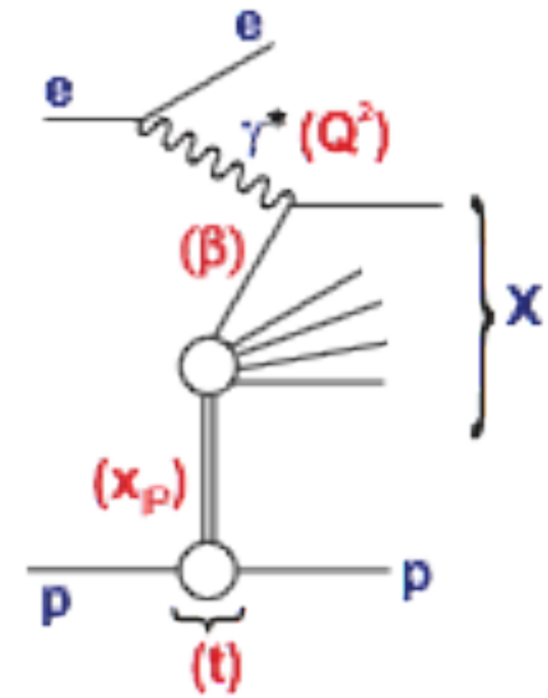


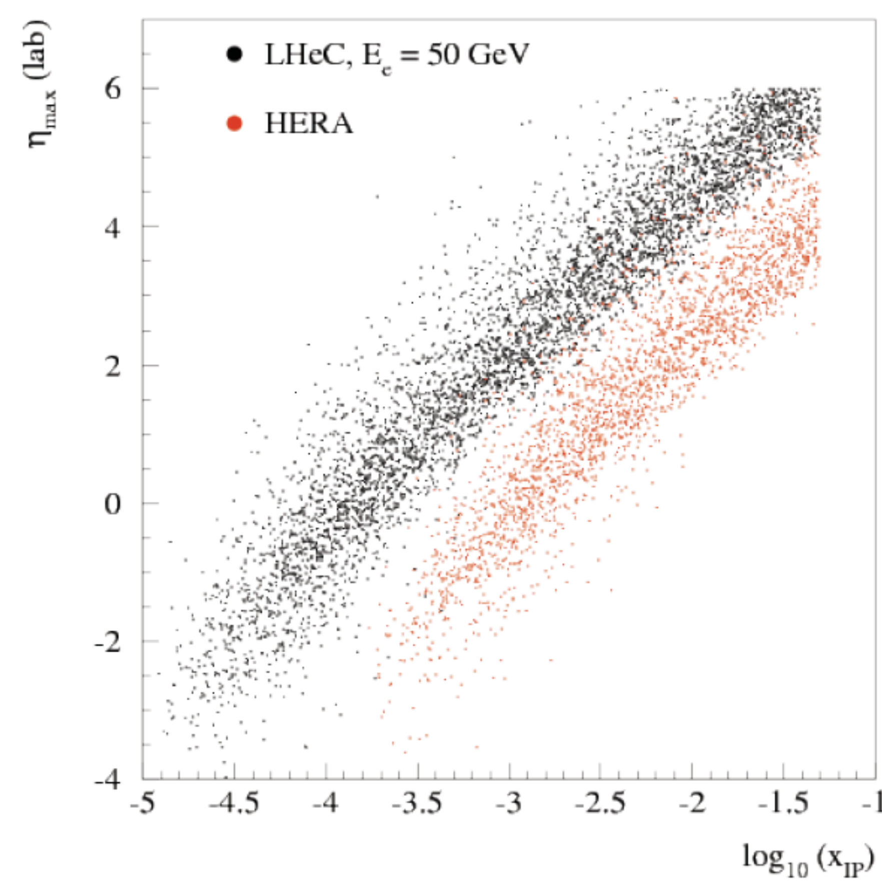
Diffraction is a collective phenomenon.
Explore relation with saturation.

Inclusive diffraction: new possibilities







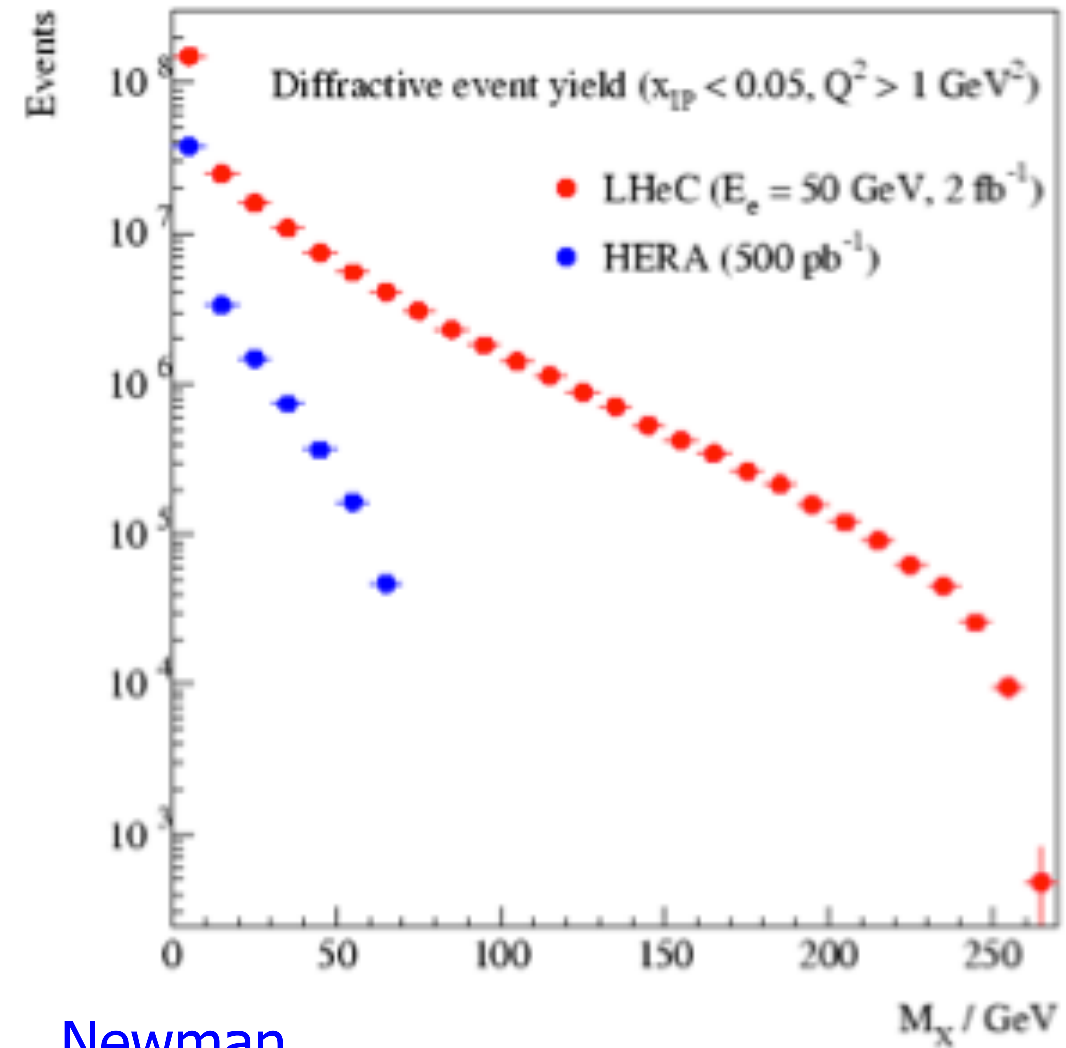


- Studies with 1 degree acceptance,
- Constraints on diffractive-PDFs
- Factorization (tests) in much bigger kinematics range.
- Diffraction is much more sensitive to the semi-hard regime.
- Enhanced sensitivity to nonlinear/saturation effects.

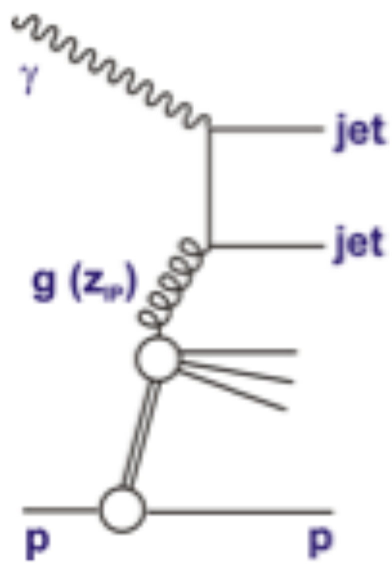
Inclusive diffraction: final states

Diffractive masses up to hundreds of GeV can be produced with low x_{IP}

Precise tests of the diffractive PDFs and factorization possible. Final states (jets) with high p_T

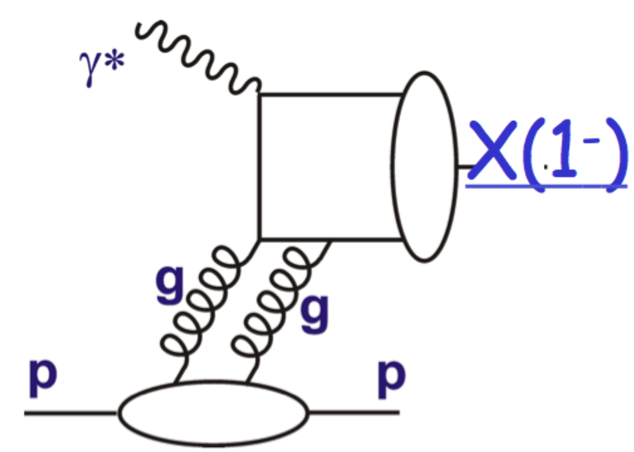


Newman



New diffractive channels (W/Z/beauty/Higgs?...)

Unfold quantum numbers precisely, measure new 1^- exclusive final states



Inclusive diffraction

Newman

- The diffractive structure function can be described in theory using factorization framework and parton distribution functions.

•LHeC: precise characterization of dpdf's, much wider range than HERA.

- Benchmark for factorization breaking in hard diffraction in hadron colliders (gap survival).