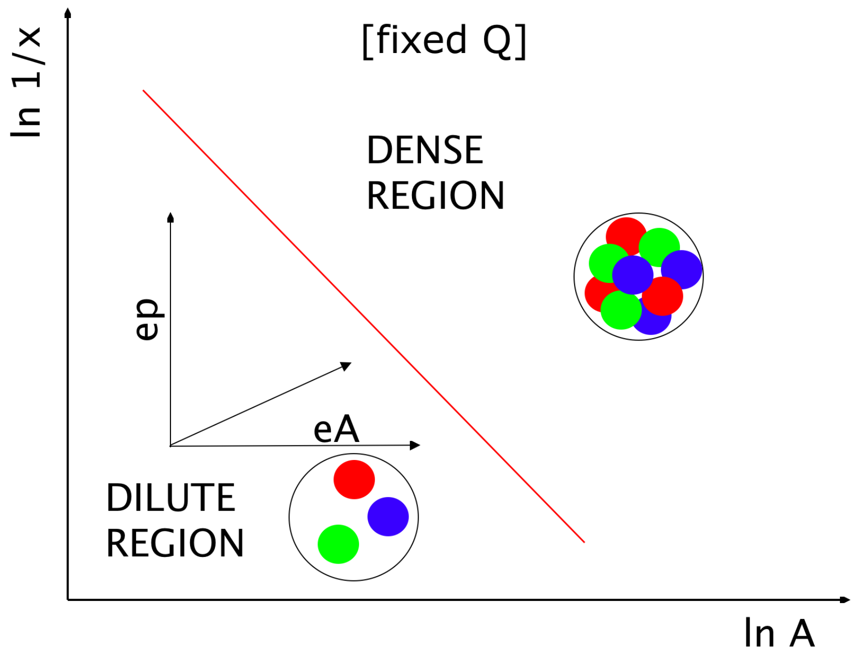
Electron-Ion Collisions at a Large Hadron electron Collider

Paul Newman
Birmingham University

… for the LHeC Study Group

Fri 6 July 2012



Can we add ep and eA collisions to the existing LHC pp, AA and pA programme?

… towards a full understanding of QCD at high temperatures, baryon and parton densities …

http://cern.ch/lhec

Material from recently released [Conceptual Design Report]

630 pages, summarising a 5 year workshop commissioned by CERN, ECFA and NuPECC

~200 participants from 69 institutes

CERN-OPEN-2012-015
LHeC-Note-2012-001 GEN
Geneva, June 13, 2012

LHeC

A Large Hadron Electron Collider at CERN

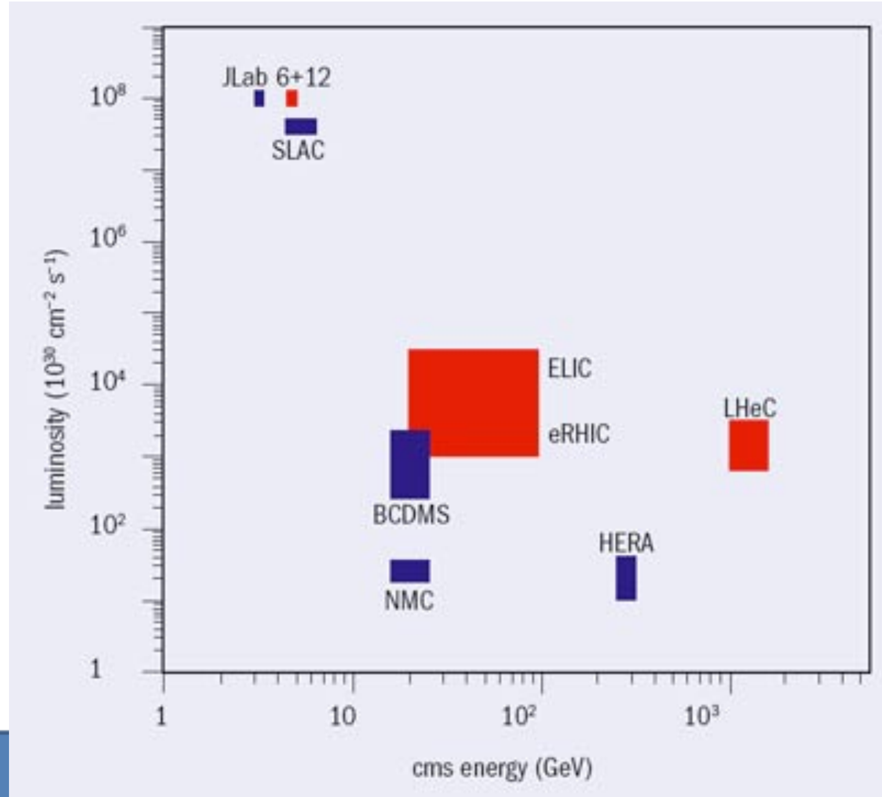
Report on the Physics and Design
Concepts for Machine and Detector

LHeC Study Group

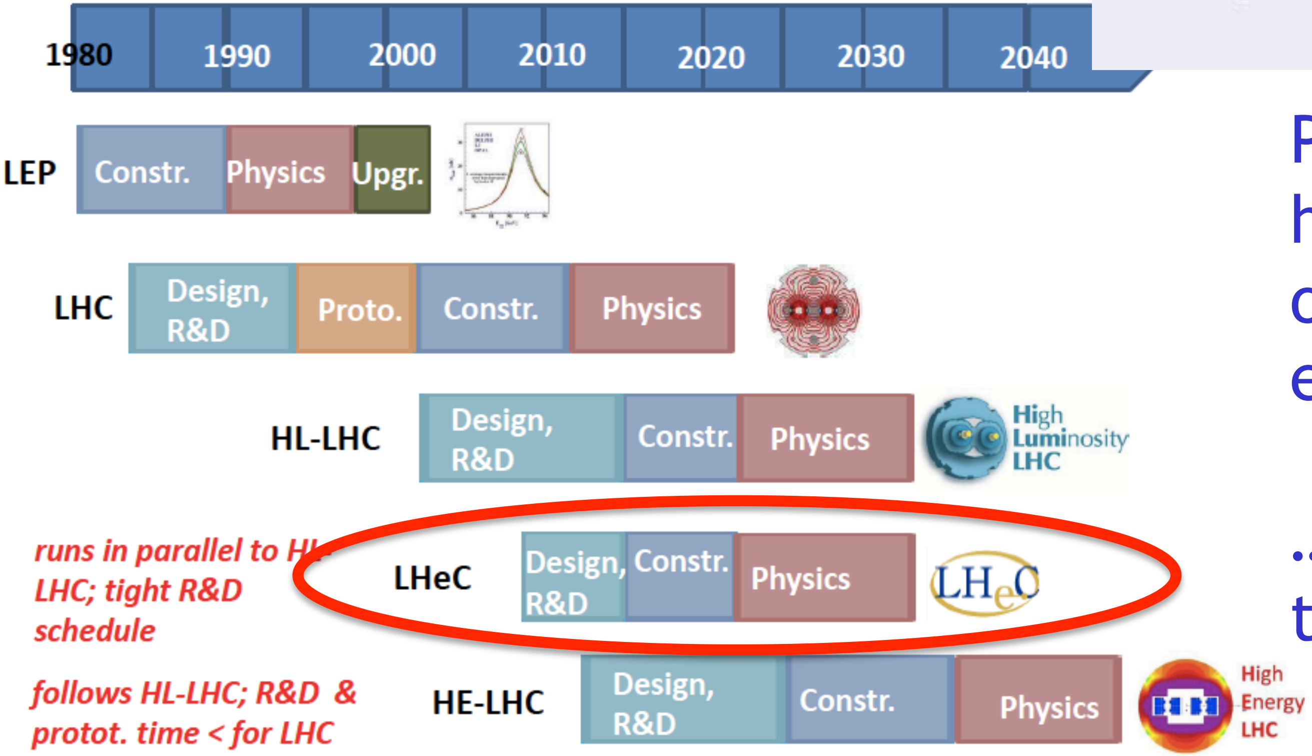
arXiv:1206.2913 [physics.acc-ph]

J. Phys. G39 (2012) 075001

Latest & most promising idea
to take lepton-hadron physics
to the TeV centre-of-mass scale
… at high luminosity



time line of CERN HEP projects



Potentially fits with
high luminosity phase
of LHC running from
early-mid 2020s

… moving forward
towards TDR ~ 2015

Other LHeC Talks at ICHEP'12

`Partons, QCD and Low x Physics at the LHeC'
Claudia Glasman, Thursday 10.15

`Design Concepts for a Large Hadron Electron Collider'
Max Klein, Saturday 11.30

`The LHeC Detector Design Concept'
Alessandro Polini, Saturday 15.15

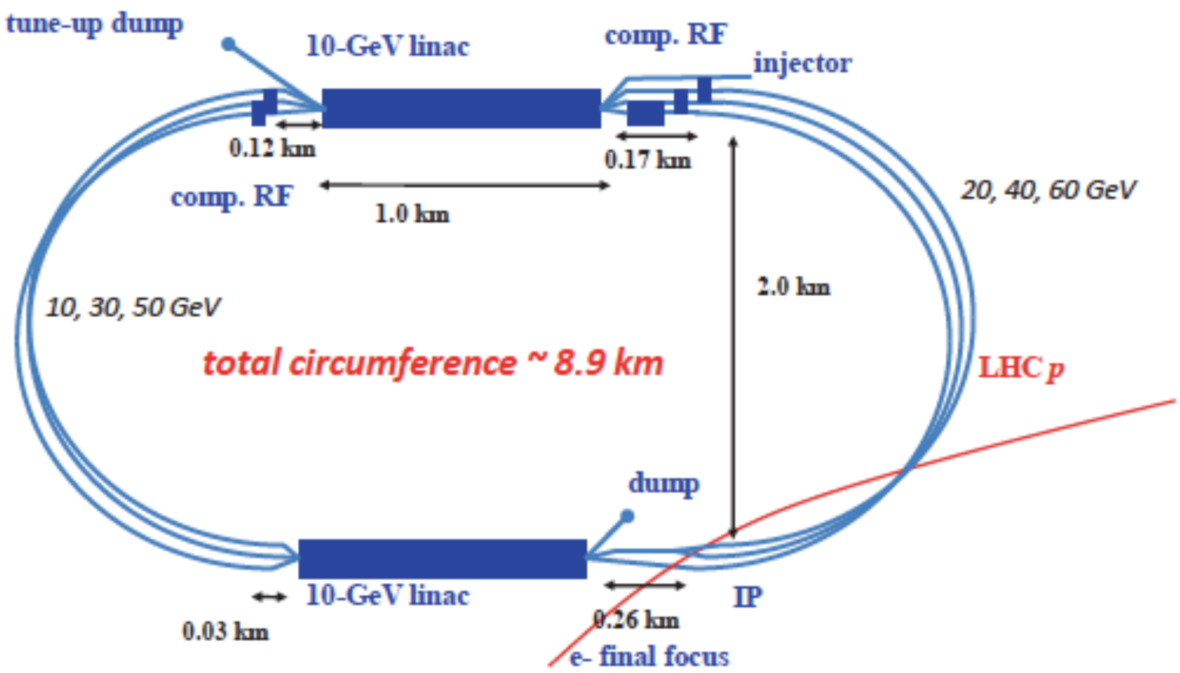
`Prospects for Higgs Physics at an LHeC'
Uta Klein, Saturday 17.00

Baseline# Design (Electron "Linac")

Design constraint: power consumption < 100 MW → E_e = 60 GeV

- Two 10 GeV linacs,
- 3 returns, 20 MV/m
- Energy recovery in same structures

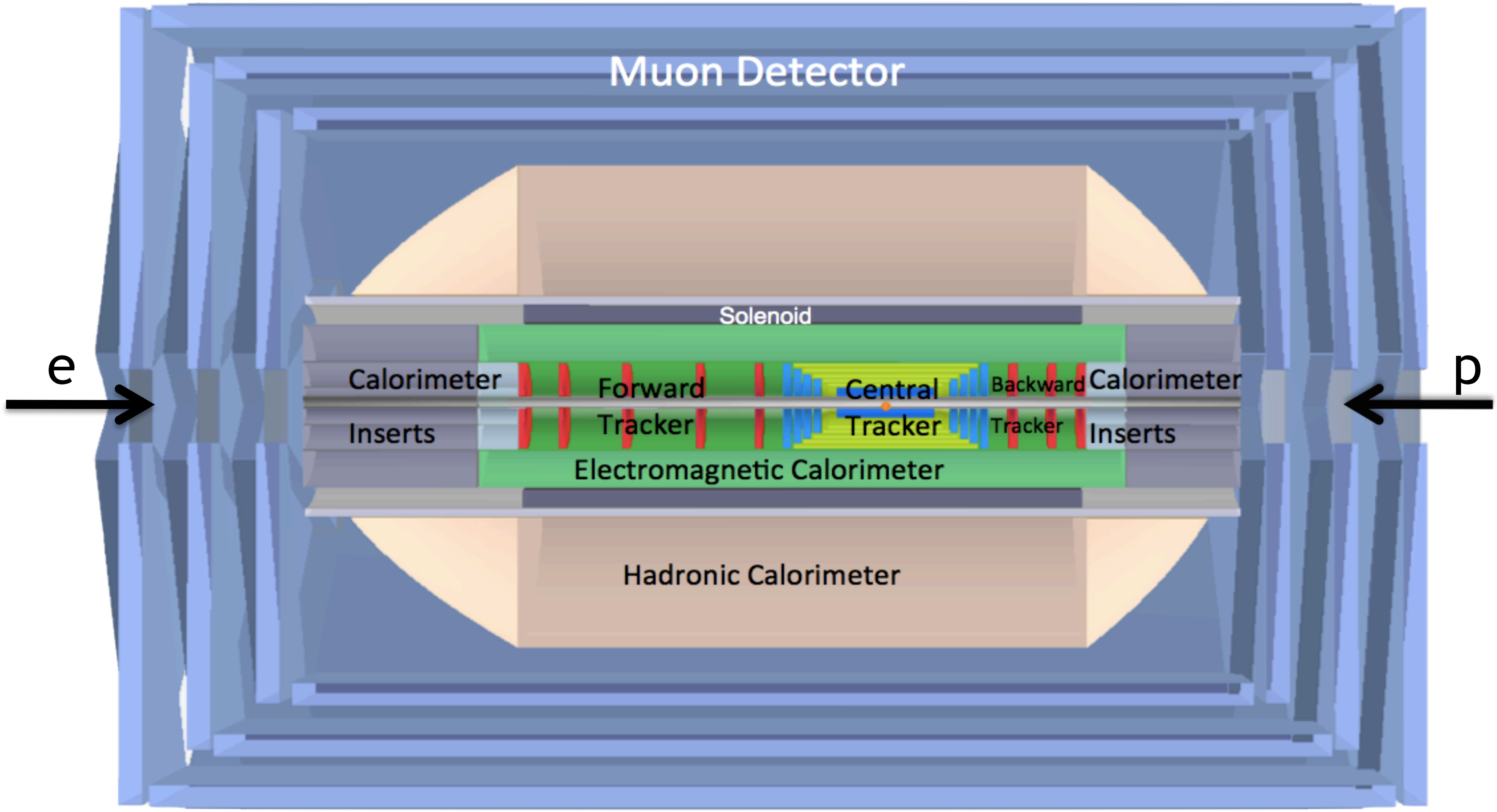
[CERN plans energy recovery prototype]



- ep Lumi ~ 10^{33} cm^{-2} s^{-1} corresponds to ~10 fb^{-1} per year (~ 100 fb^{-1} total)
- **eD and eA collisions have always been integral to programme**
- **e-nucleon Lumi estimates ~ 10^{31} (10^{32}) cm^{-2} s^{-1} for eD (ePb)**

Alternative designs based on electron ring and on higher energy, lower luminosity linac also exist

Detector Overview



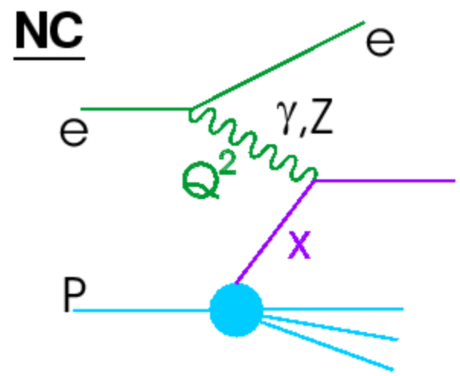
- Forward / backward asymmetry reflecting beam energies
- Present size 14m x 9m (c.f. CMS 21m x 15m, ATLAS 45m x 25m)
- **ZDC, proton spectrometer integral to design from outset**

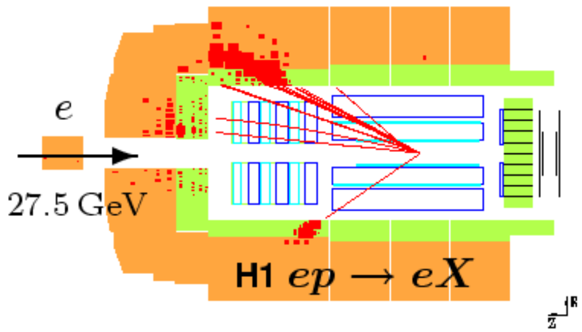
DIS: Parton Microscopy

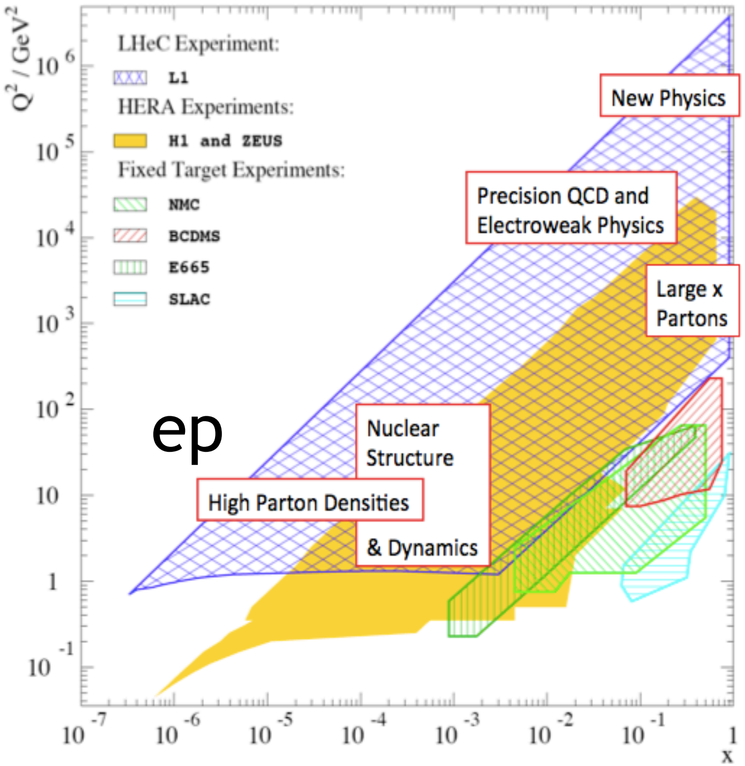
Q^2: exchanged boson resolving power

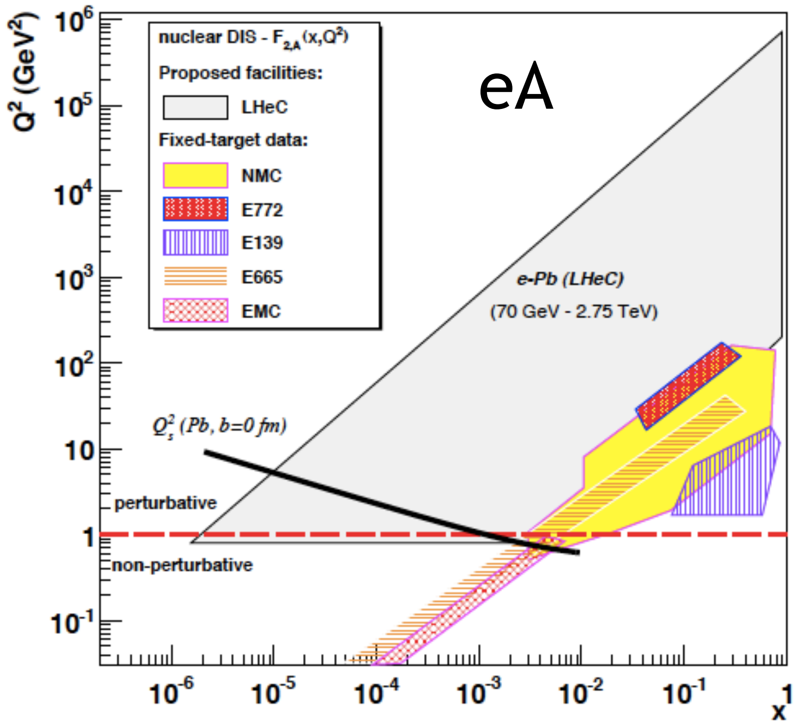
x: fractional momentum of struck quark

Only previously studied in collider mode at HERA (ep, 1992-2007)





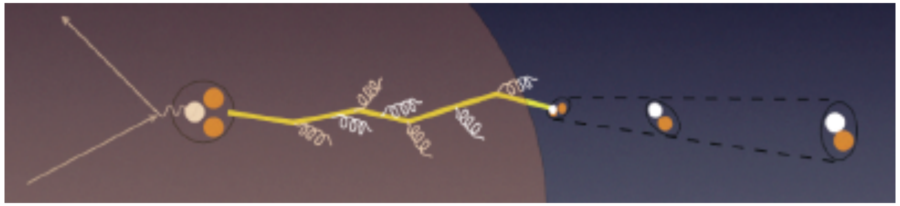




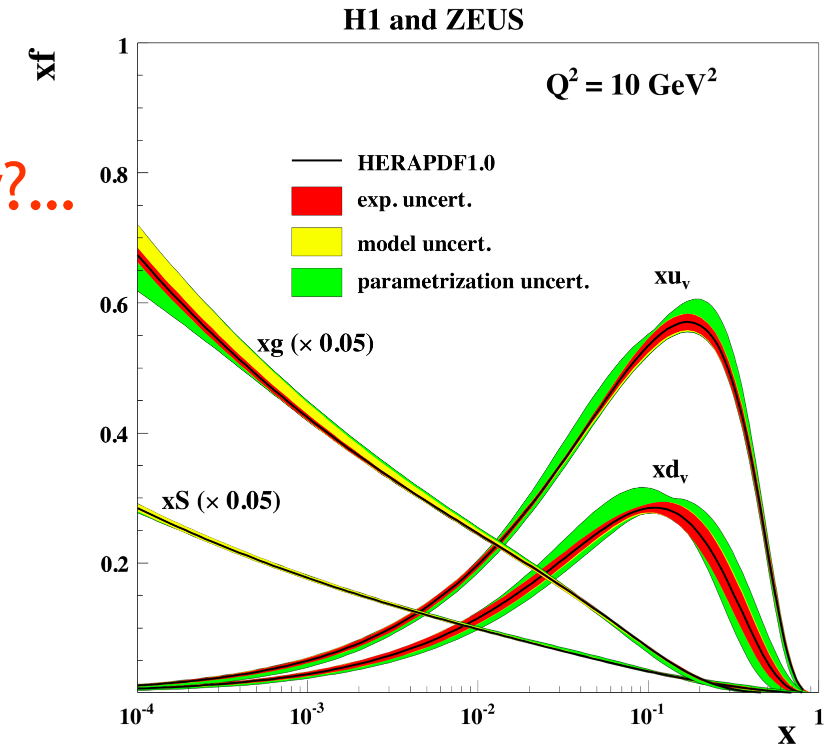
Some LHeC Heavy Ion Highlights

- Measurement of nuclear parton densities

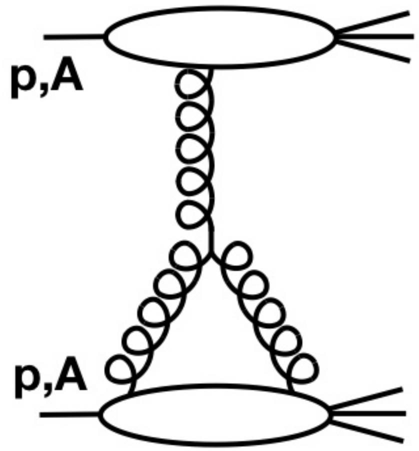
- Behaviour of struck quark passing through cold nuclear matter



- How is low x growth of parton densities tamed to satisfy unitarity?...



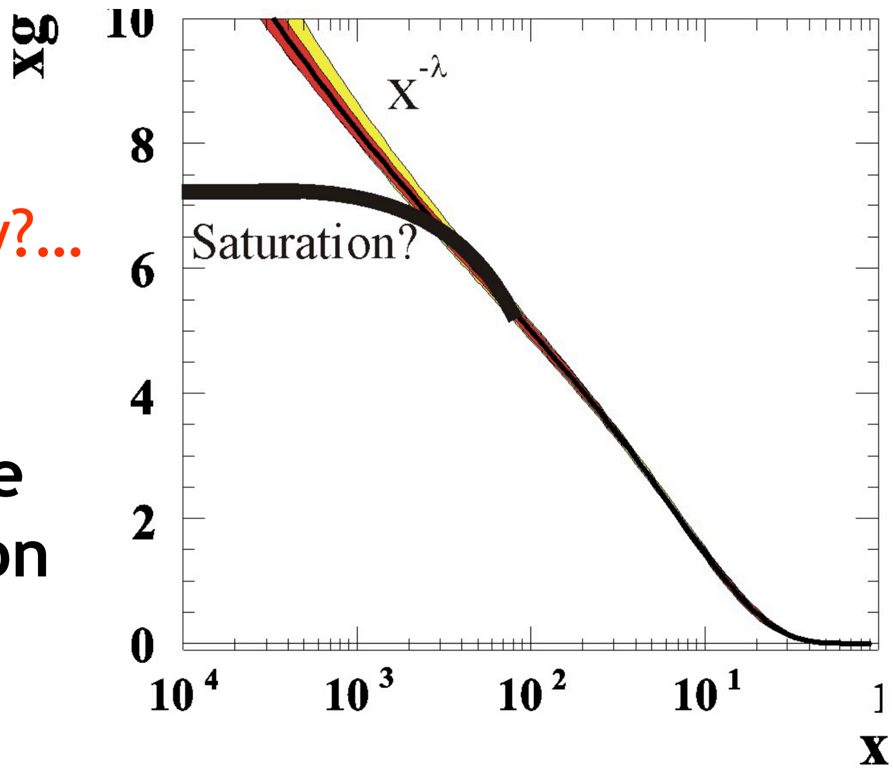
Some LHeC Heavy Ion Highlights



- Measurement of nuclear parton densities

- Behaviour of struck quark passing through cold nuclear matter

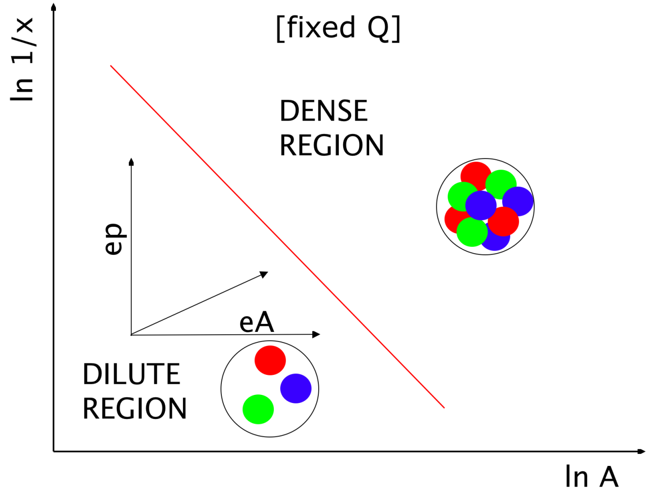
- How is low x growth of parton densities tamed to satisfy unitarity?… e.g recombination gg → g?



… new high density parton regime characterised by non-linear parton evolution dynamics (e.g. CGC) …

LHeC Strategy for making the target blacker

LHeC delivers a 2-pronged approach:



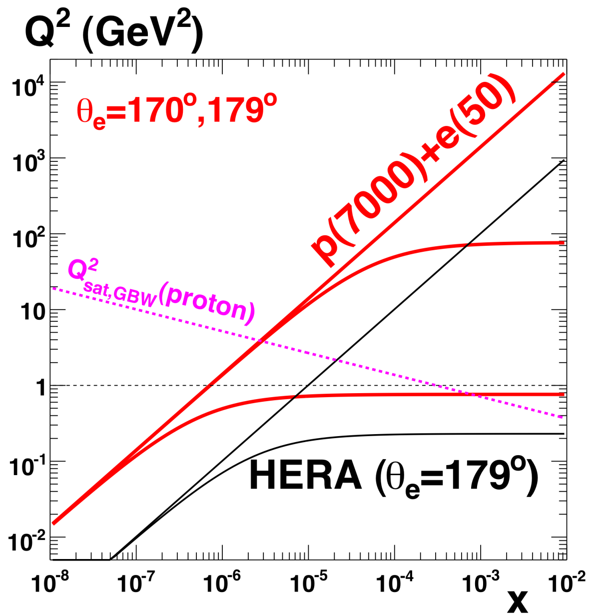
Enhance target `blackness' by:

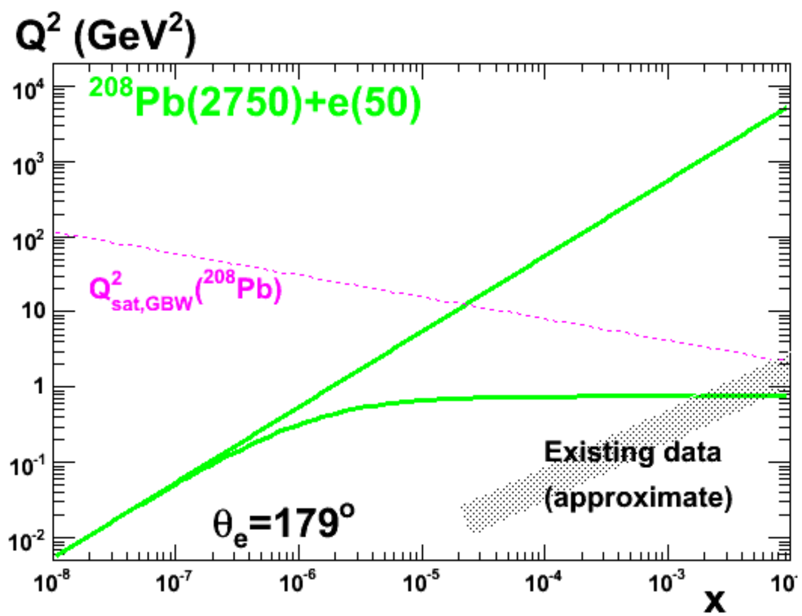
1) Probing lower x at fixed Q^2 in ep

[evolution of a single source]

2) Increasing target matter in eA

[overlapping many sources at fixed kinematics … density ~ $A^{1/3}$ ~ 6 for Pb … worth 2 orders of magnitude in x]





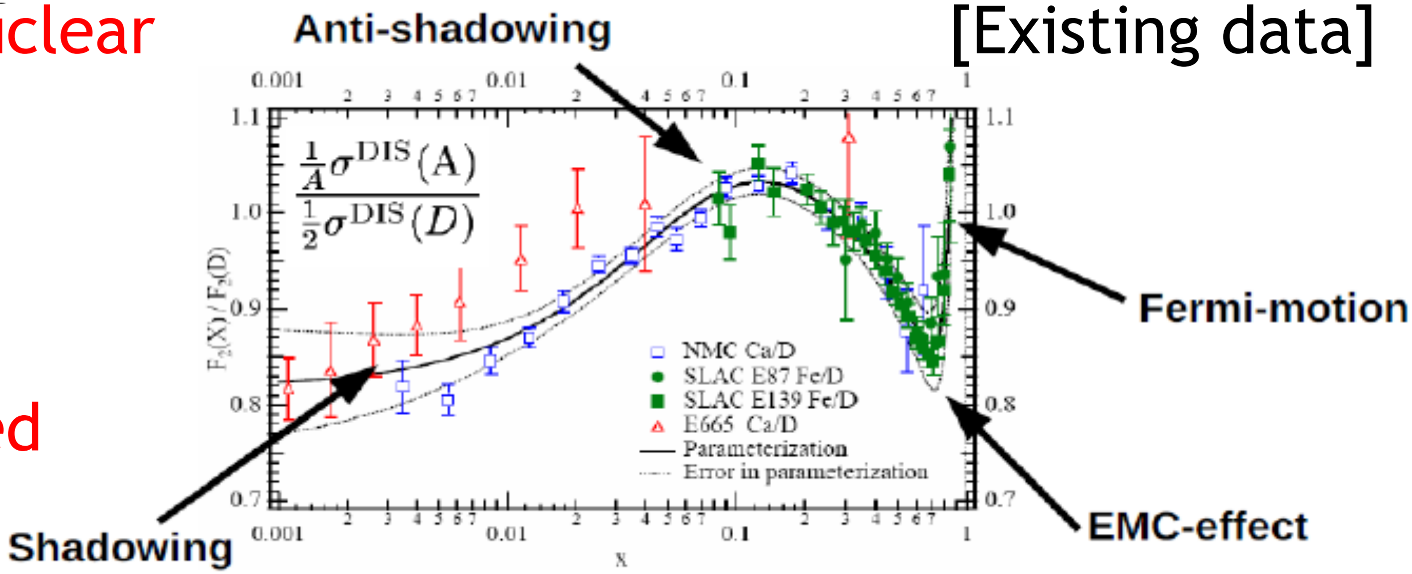
Current Status of Nuclear Parton Densities

- Rich array of nuclear effects not fully understood

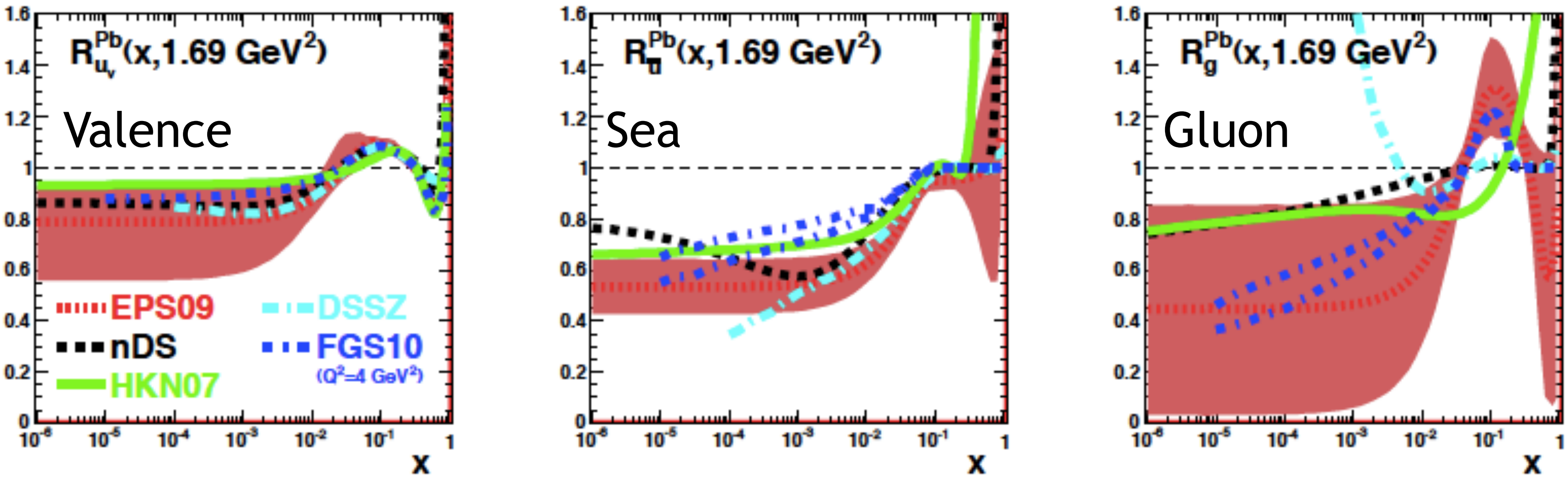
- All partons poorly constrained for $x < 10^{-2}$

- Gluon ~ unknown

[Existing data]

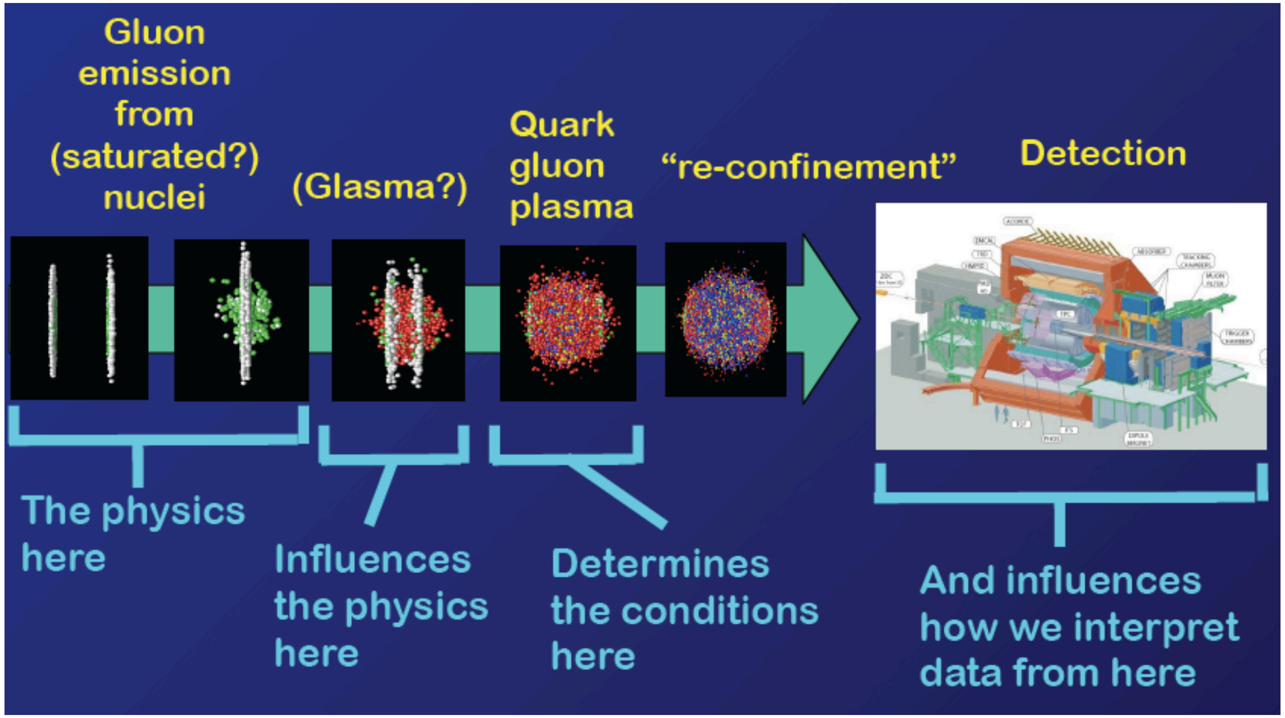


R_i = Nuclear PDF i / (A * proton PDF i)

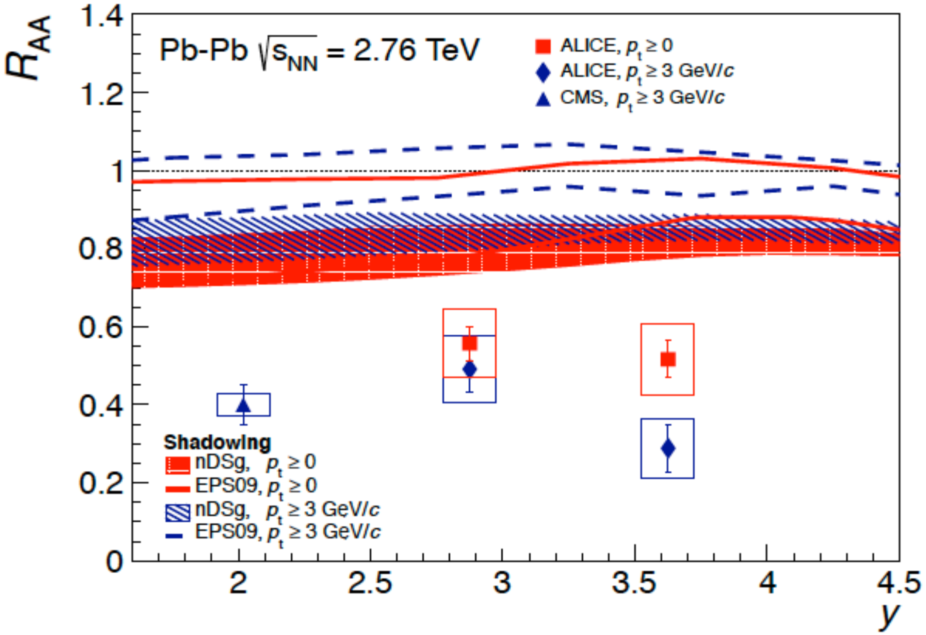


Complementarity of AA, pA and eA Physics

Need to constrain initial conditions to extract and quantify QGP properties from AA data



Inclusive J/Ψ data

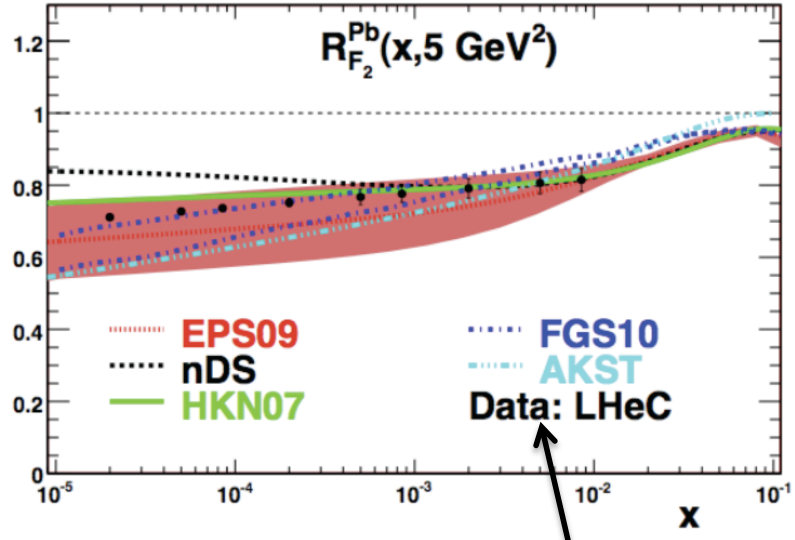


Low-x-sensitive AA data not described by existing nPDFs

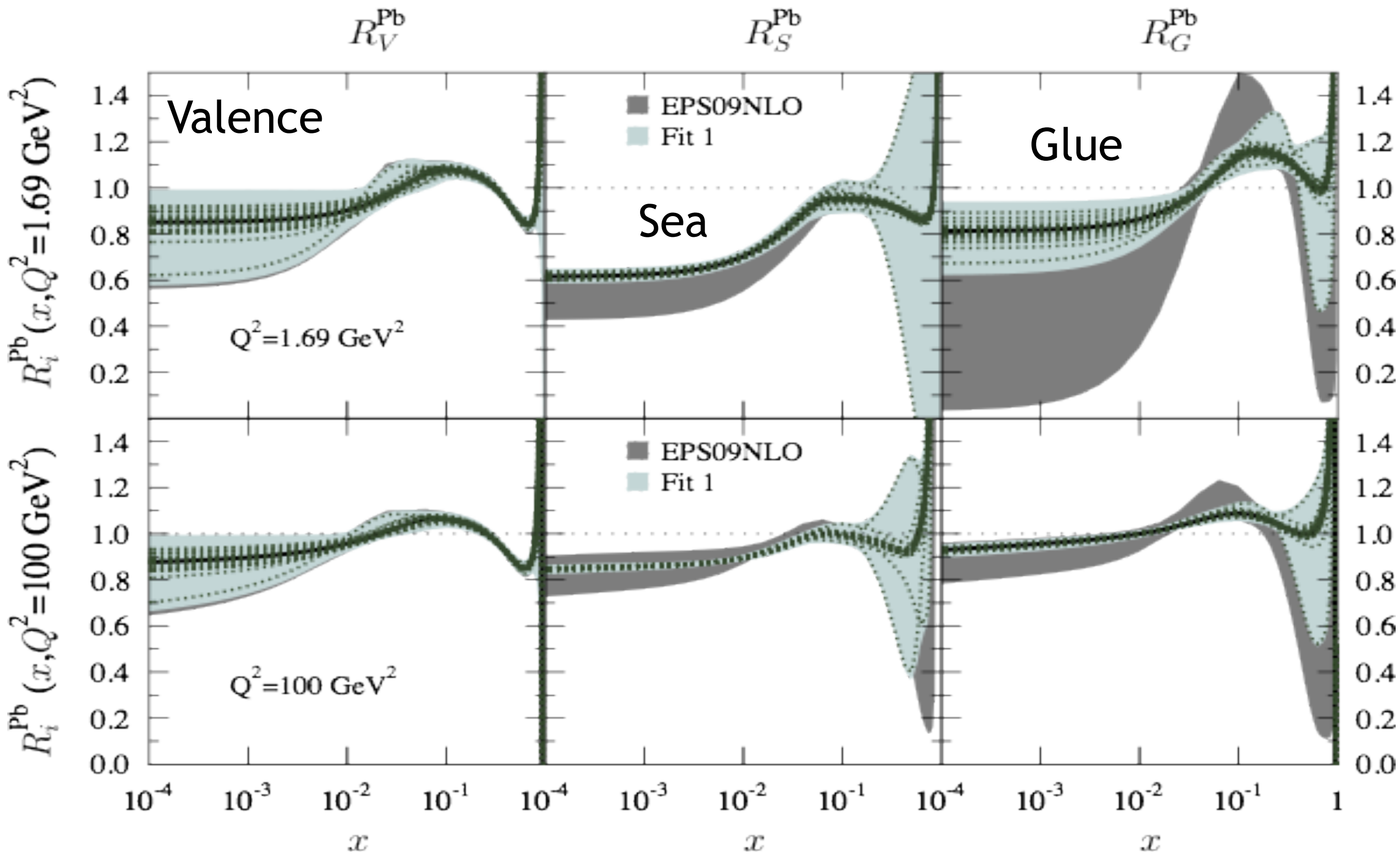
New effects likely to be revealed in tensions between eA and pA, AA (breakdown of factorisation)

Impact of eA F_2 LHeC data

- Simulated LHeC ePb F_2 measurement has huge impact on uncertainties
- Most striking effect for sea & gluons
- High x gluon uncertainty still large



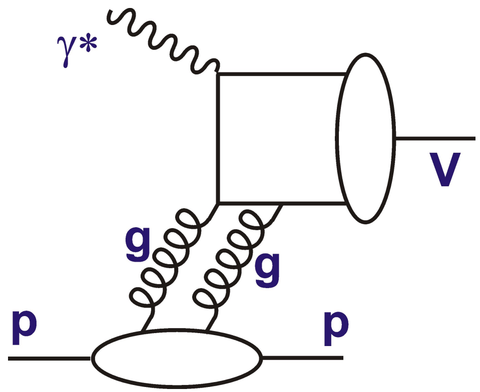
[Example pseudo-data from single Q^2 Value]



[Effects on EPS09 nPDF fit]

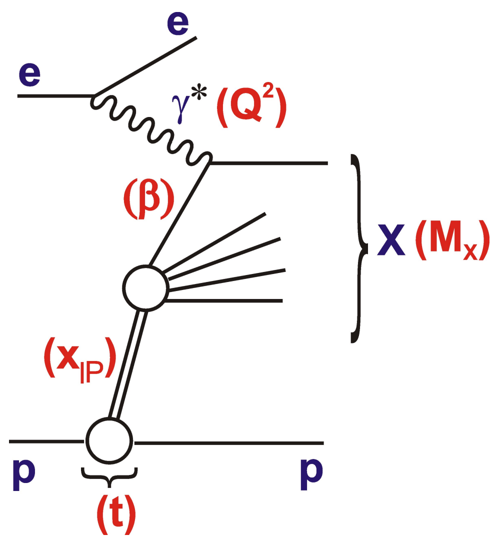
Exclusive / Diffractive Channels and Saturation

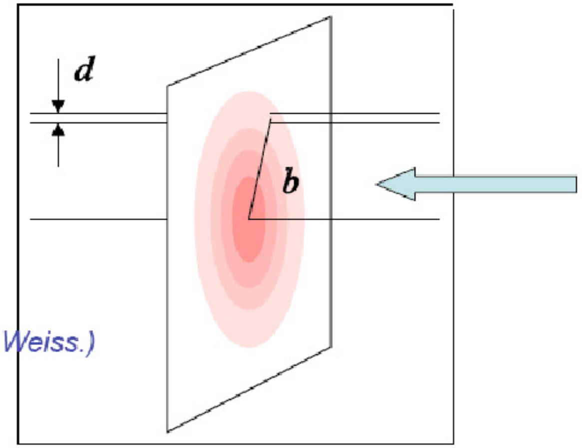
1) [Low-Nussinov] interpretation as 2 gluon exchange enhances sensitivity to low x gluon



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

→ Large t (small b) probes densest packed part of proton?



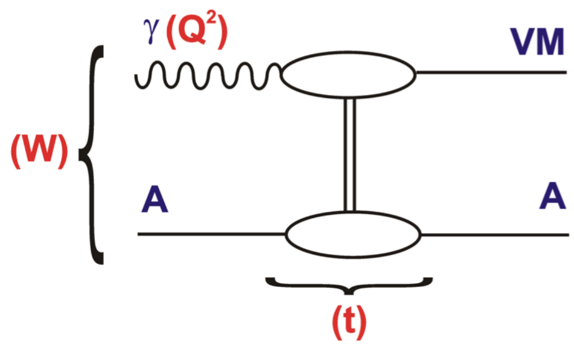


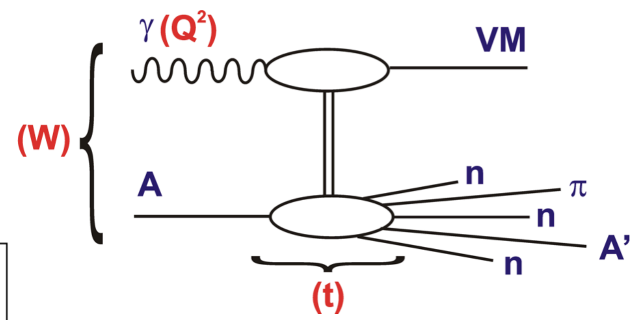
(figure from C. Weiss.)

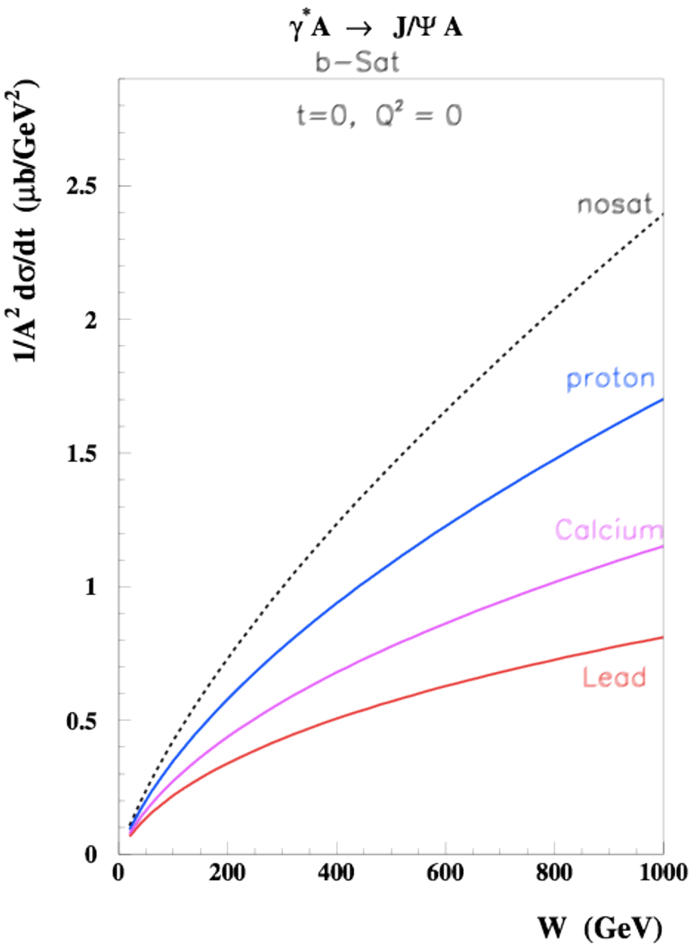
Central black region growing with decrease of x.

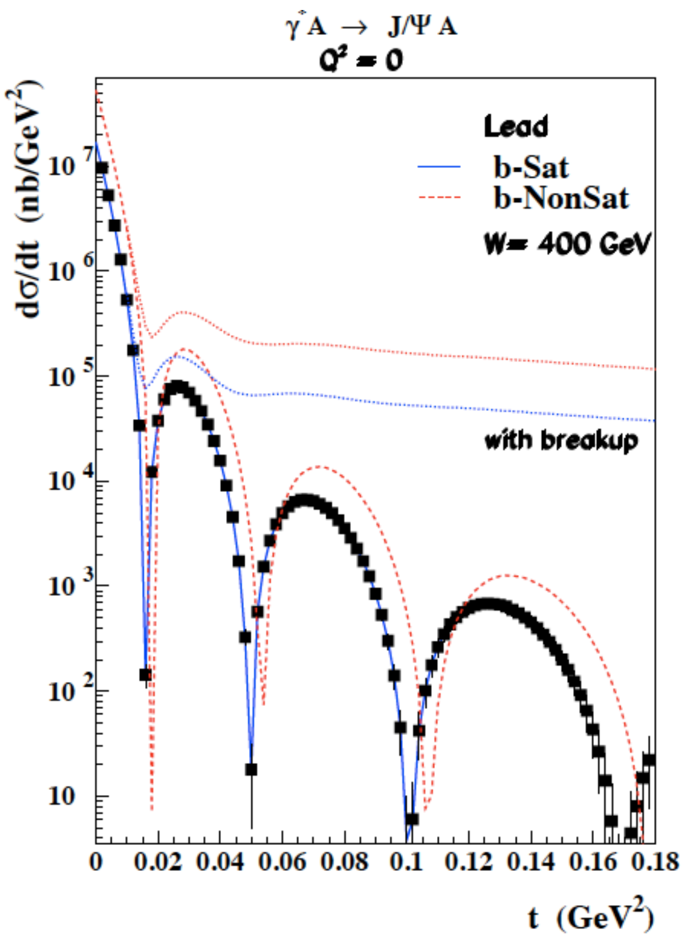
Exclusive Diffraction in eA

Experimentally clear signatures and theoretically cleanly calculable saturation effects in coherent diffraction case (eA → eVA)





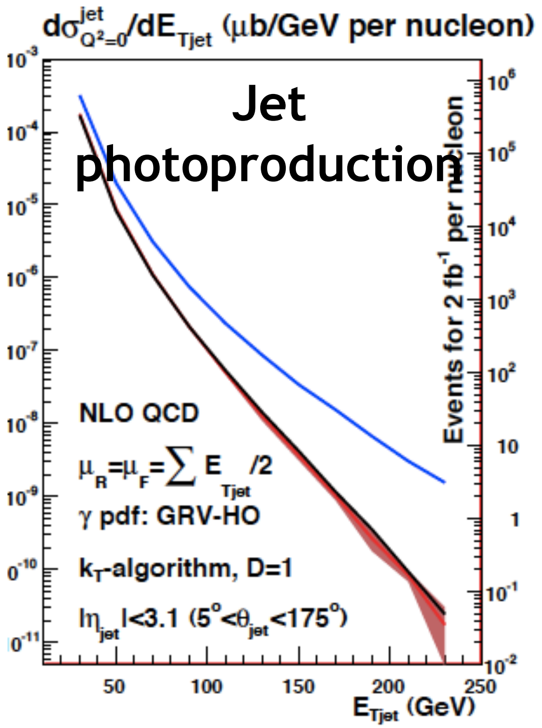


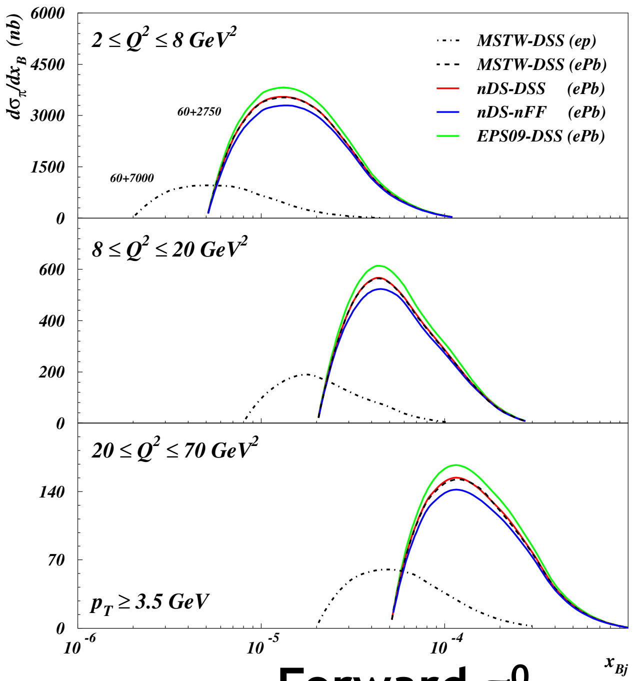


Experimental separation of incoherent diffraction based mainly on ZDC

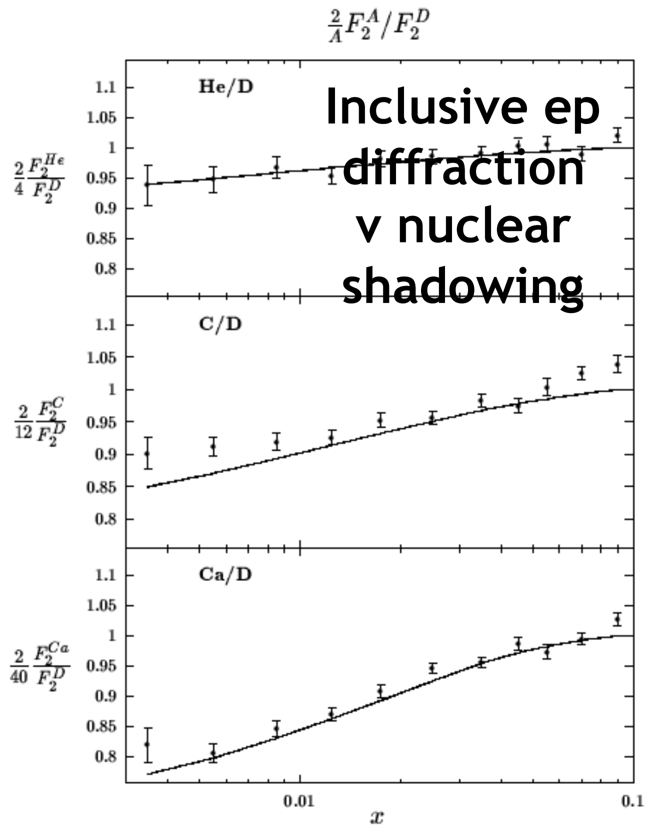
… saturation smoking gun?

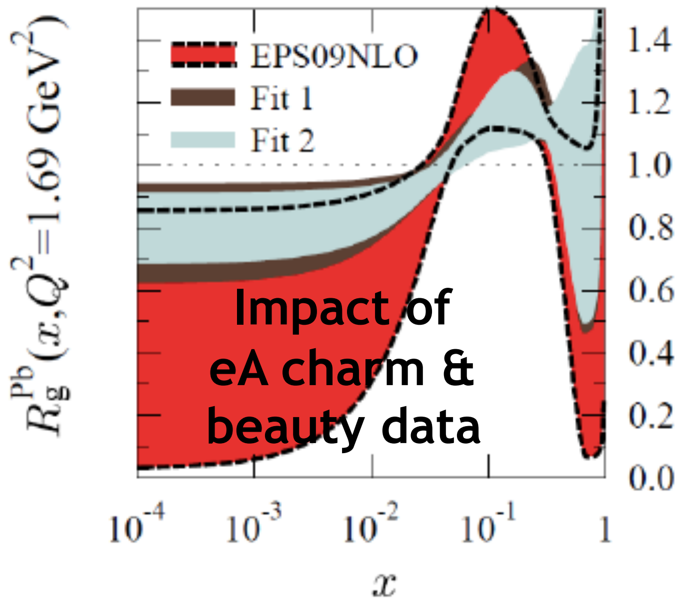
Some other LHeC eA Studies …





Forward π^0 production & fragmentation





Mainly zeroth order feasibility studies

Many more processes and observables still to be investigated

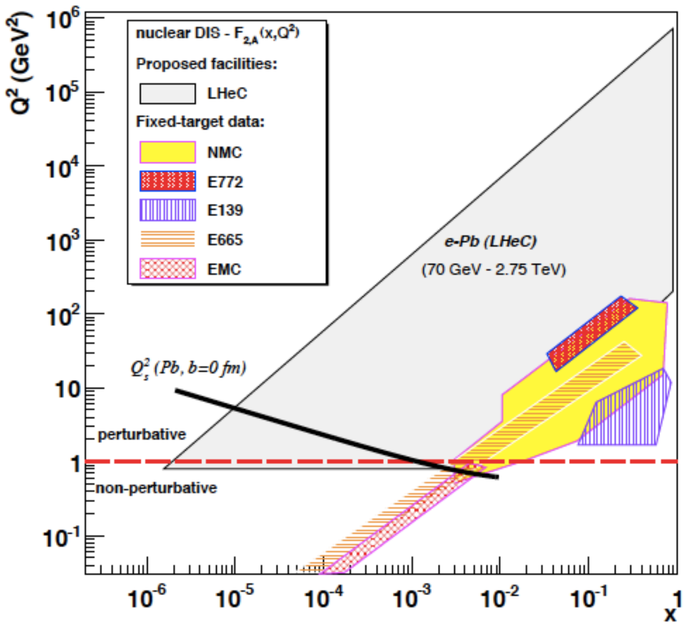
Summary

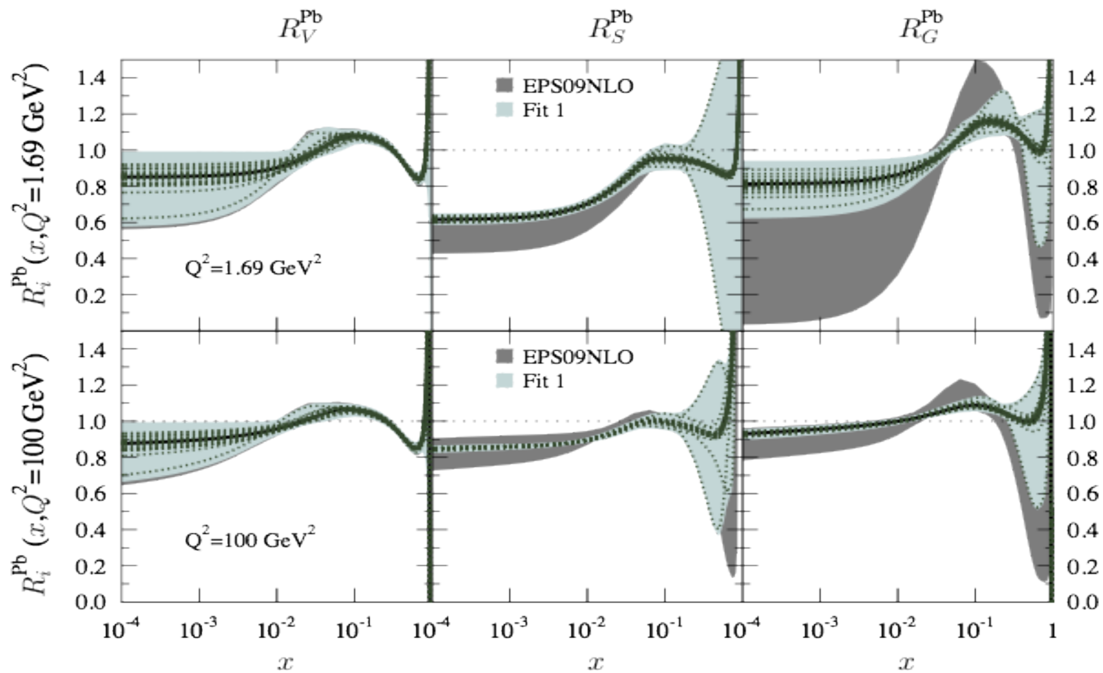
[More at http://cern.ch/lhec]

- LHC is a new world for heavy ions even more than for protons

- LHeC adds ep and eA to existing pp, pA and AA programme
  - 3-4 orders of magnitude in nPDF kinematic range
  - New non-linear QCD dynamics of parton saturation
  - Baseline for establishing QGP effects
  - ...

- Conceptual Design Report available. Moving towards TDR





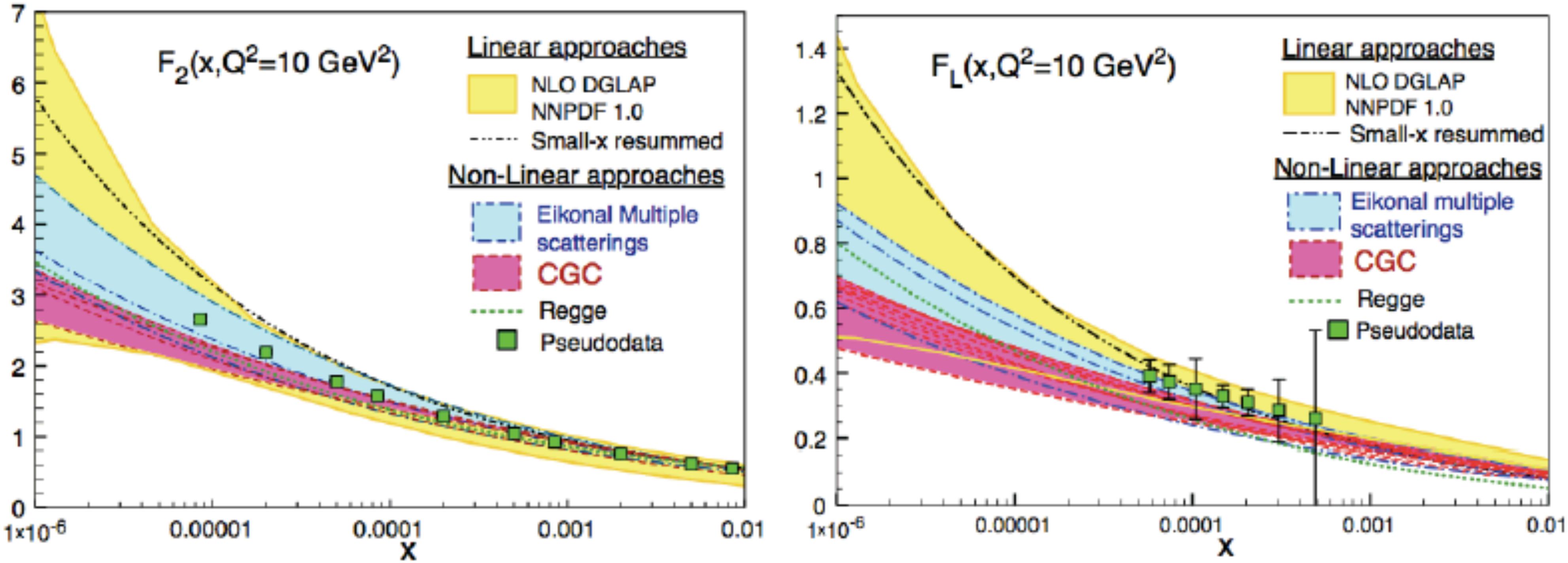
… with thanks to Nestor Armesto, Brian Cole, Max Klein, Anna Stasto and many experimentalist, theorist & accelerator scientist colleagues …

LHeC Study Group

J.L.Abelleira Fernandez[16,23], C.Adolphsen[57], A.N.Akay[03], H.Aksakal[39], J.L.Albacete[52], S.Alekhin[17,54], P.Allport[24], V.Andreev[34], R.B.Appleby[14,30], E.Arikan[39], N.Armesto[53,a], G.Azuelos[33,64], M.Bai[37], D.Barber[14,17,24], J.Bartels[18], O.Behnke[17], J.Behr[17], A.S.Belyaev[15,56], I.Ben-Zvi[37], N.Bernard[25], S.Bertolucci[16], S.Bettoni[16], S.Biswal[41], J.Blümlein[17], H.Böttcher[17], A.Bogacz[36], C.Bracco[16], G.Brandt[44], H.Braun[65], S.Brodsky[57,b], O.Brüning[16], E.Bulyak[12], A.Buniatyan[17], H.Burkhardt[16], I.T.Cakir[02], O.Cakir[01], R.Calaga[16], V.Cetinkaya[01], E.Ciapala[16], R.Ciftci[01], A.K.Ciftci[01], B.A.Cole[38], J.C.Collins[48], O.Dadoun[42], J.Dainton[24], A.De.Roeck[16], D.d'Enterria[16], A.Dudarev[16], A.Eide[60], R.Enberg[63], E.Eroglu[62], K.J.Eskola[21], L.Favart[08], M.Fitterer[16], S.Forte[32], A.Gaddi[16], P.Gambino[59], H.García Morales[16], T.Gehrmann[69], P.Gladkikh[12], C.Glasman[28], R.Godbole[35], B.Goddard[16], T.Greenshaw[24], A.Guffanti[13], V.Guzey[19,36], C.Gwenlan[44], T.Han[50], Y.Hao[37], F.Haug[16], W.Herr[16], A.Hervé[27], B.J.Holzer[16], M.Ishitsuka[58], M.Jacquet[42], B.Jeanneret[16], J.M.Jimenez[16], J.M.Jowett[16], H.Jung[17], H.Karadeniz[02], D.Kayran[37], A.Kilic[62], K.Kimura[58], M.Klein[24], U.Klein[24], T.Kluge[24], F.Kocak[62], M.Korostelev[24], A.Kosmicki[16], P.Kostka[17], H.Kowalski[17], G.Kramer[18], D.Kuchler[16], M.Kuze[58], T.Lappi[21,c], P.Laycock[24], E.Levichev[40], S.Levonian[17], V.N.Litvinenko[37], A.Lombardi[16], J.Maeda[58], C.Marquet[16], B.Mellado[27], K.H.Mess[16], A.Milanese[16], S.Moch[17], I.I.Morozov[40], Y.Muttoni[16], S.Myers[16], S.Nandi[55], Z.Nergiz[39], P.R.Newman[06], T.Omori[61], J.Osborne[16], E.Paoloni[49], Y.Papaphilippou[16], C.Pascaud[42], H.Paukkunen[53], E.Perez[16], T.Pieloni[23], E.Pilicer[62], B.Pire[45], R.Placakyte[17], A.Polini[07], V.Ptitsyn[37], Y.Pupkov[40], V.Radescu[17], S.Raychaudhuri[35], L.Rinolfi[16], R.Rohini[35], J.Rojo[16,31], S.Russenschuck[16], M.Sahin[03], C.A.Salgado[53,a], K.Sampei[58], R.Sassot[09], E.Sauvan[04], U.Schneekloth[17], T.Schörner-Sadenius[17], D.Schulte[16], A.Senol[22], A.Seryi[44], P.Sievers[16], A.N.Skrinsky[40], W.Smith[27], H.Spiesberger[29], A.M.Stasto[48,d], M.Strikman[48], M.Sullivan[57], S.Sultansoy[03,e], Y.P.Sun[57], B.Surrow[11], L.Szymanowski[66,f], P.Taels[05], I.Tapan[62], T.Tasci[22], E.Tassi[10], H.Ten.Kate[16], J.Terron[28], H.Thiesen[16], L.Thompson[14,30], K.Tokushuku[61], R.Tomás García[16], D.Tommasini[16], D.Trbojevic[37], N.Tsoupas[37], J.Tuckmantel[16], S.Turkoz[01], T.N.Trinh[47], K.Tywoniuk[26], G.Unel[20], J.Urakawa[61], P.VanMechelen[05], A.Variola[52], R.Veness[16], A.Vivoli[16], P.Vobly[40], J.Wagner[66], R.Wallny[68], S.Wallon[43,46,f], G.Watt[16], C.Weiss[36], U.A.Wiedemann[16], U.Wienands[57], F.Willeke[37], B.-W.Xiao[48], V.Yakimenko[37], A.F.Zarnecki[67], Z.Zhang[42], F.Zimmermann[16], R.Zlebcik[51], F.Zomer[42]

Back-ups

Example Low x Study in ep



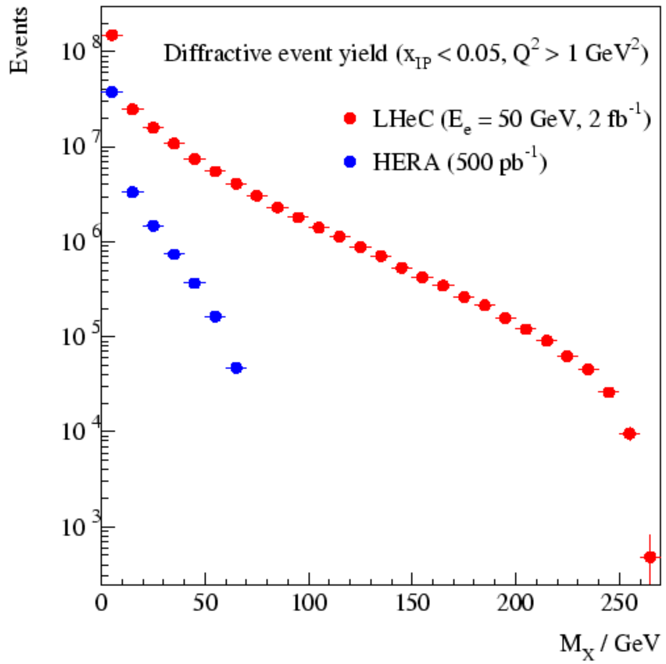
• We should be able to distinguish between different QCD-based models for the onset of non-linear dynamics

• Unambiguous observation of saturation will be based on tension between different observables

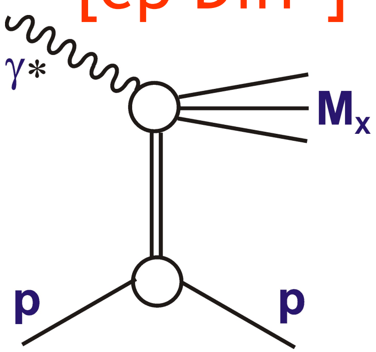
e.g. F_2 v F_L in ep and / **or F_2 in ep v eA**

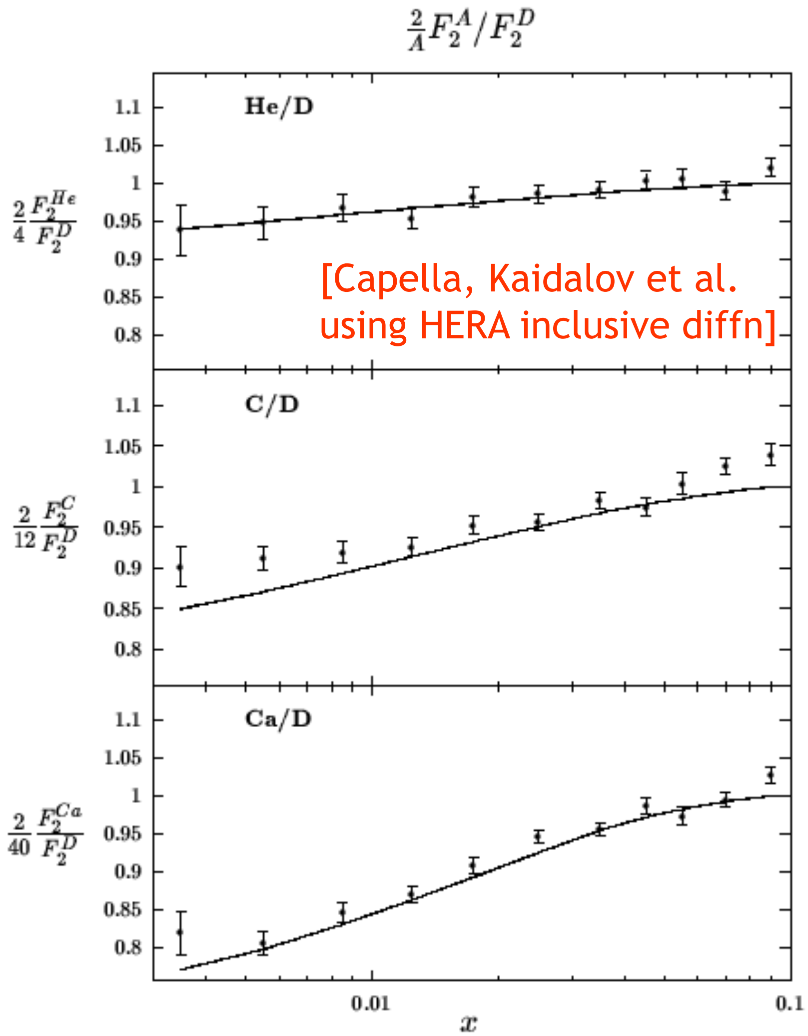
Inclusive ep Diffraction and Nuclear Shadowing

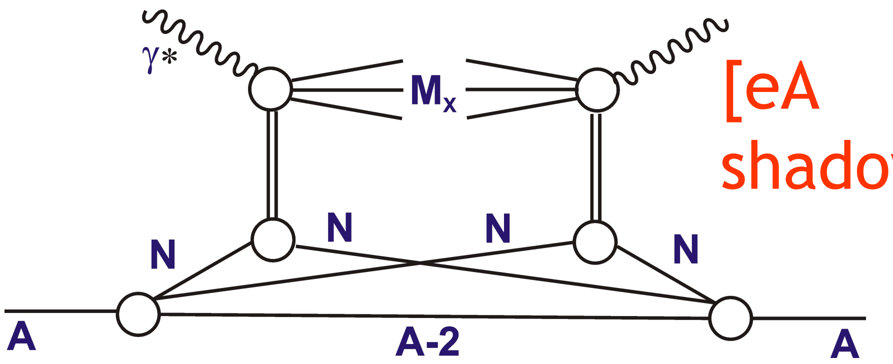
(Gribov-Glauber) nuclear shadowing as multiple interactions, starting from ep DPDFs



[ep Diff^n]



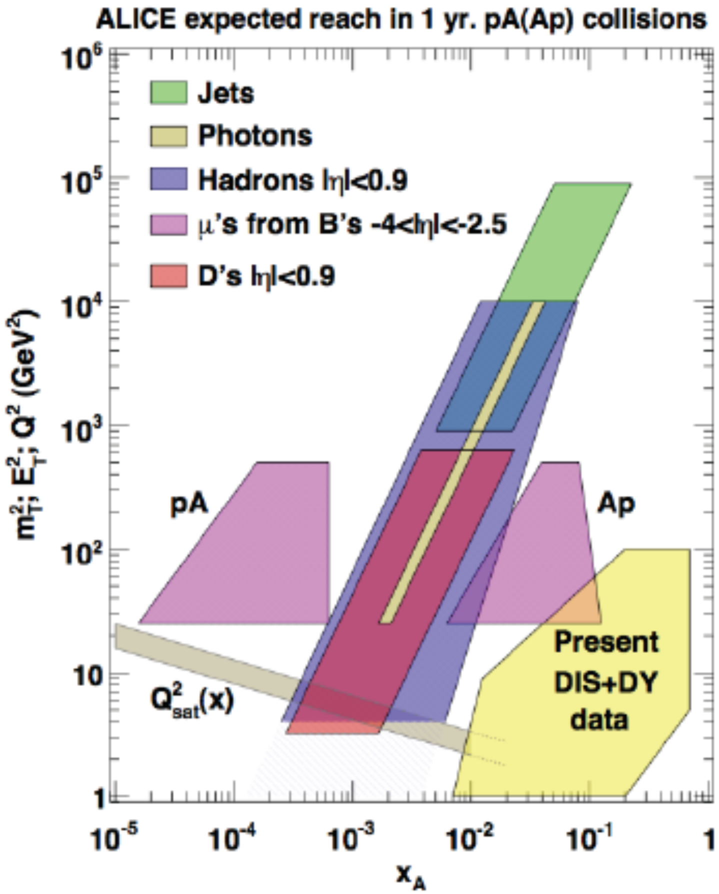


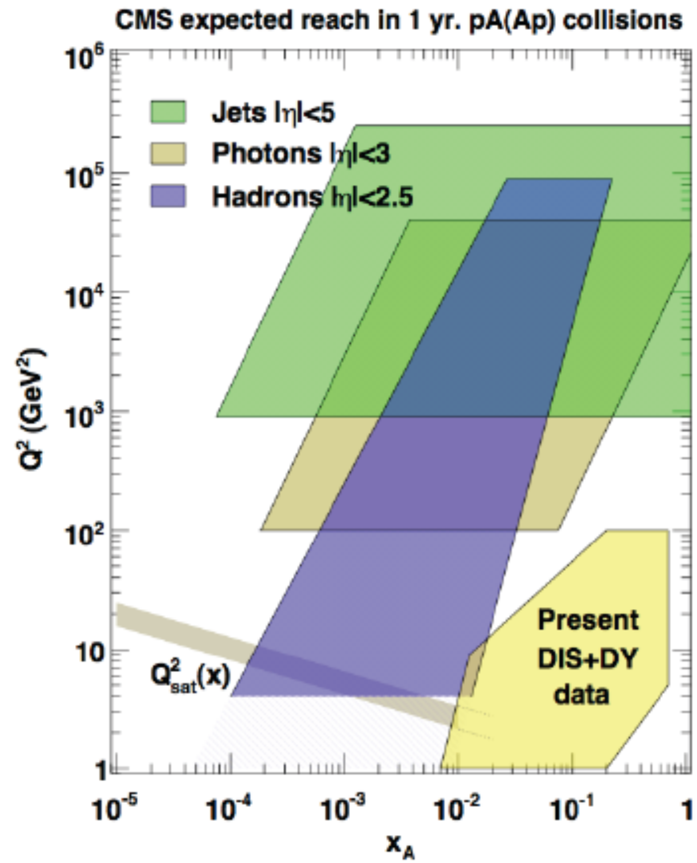


[eA shadowing]

LHeC delivers precise inclusive diffraction data in unprecedented ep and eA kinematic range.

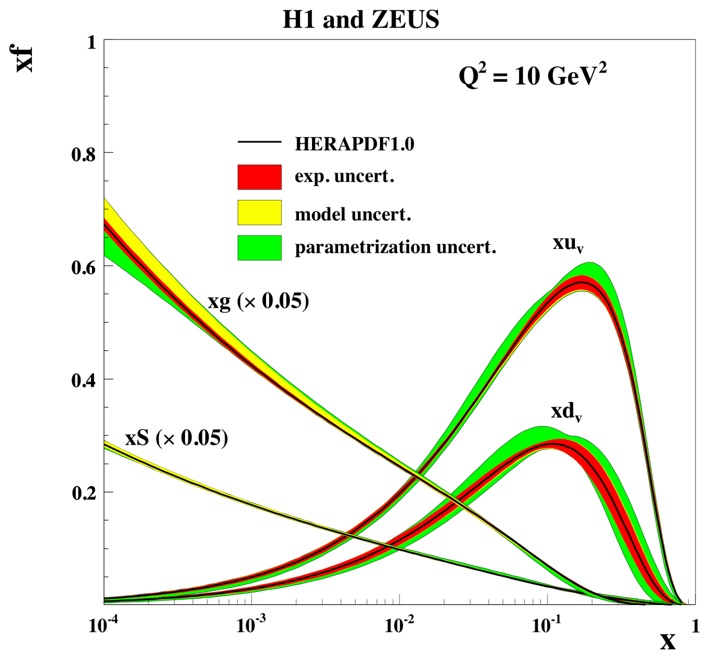
Complementarity of pA and eA Physics





- LHeC offers access to lower x than is realistically achievable in pA at the LHC
- Clean final states / theoretical control - to (N)NLO in pQCD
- New effects anyway likely to be revealed in tensions between eA and pA, AA (breakdown of factorisation)

HERA's achievements … and limitations

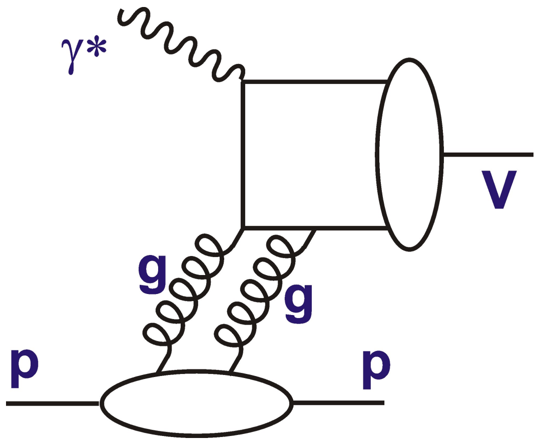


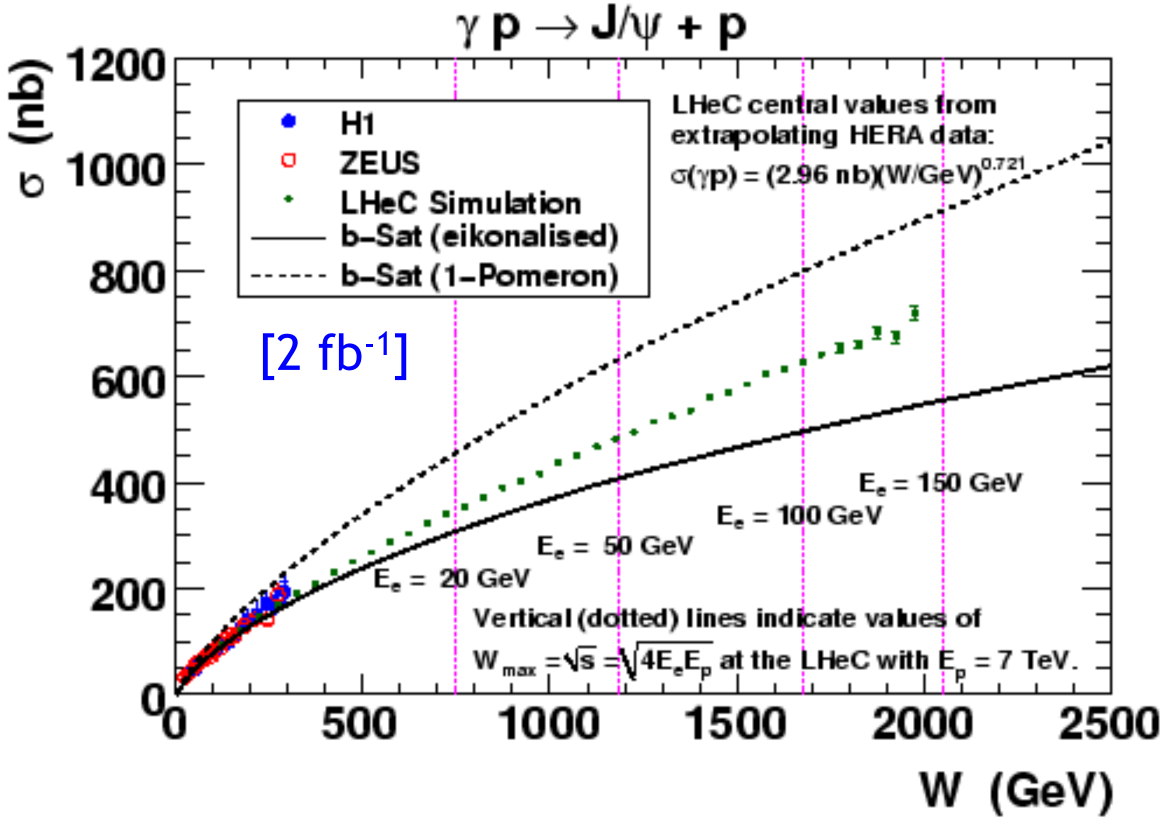
☺ Proton parton densities in unprecedented kinematic range with high precision in most of LHC region

☹ Insufficient lumi for high x precision
☹ Assumptions on flavour decomposition
☹ No deuterons … u and d not separated, no isoscalar target
☹No heavy ions (wasted opportunity!)

Simulation of J/ψ Photoproduction in ep

e.g. "b-Sat" Dipole model
- "eikonalised": with impact-parameter dependent saturation
- "1 Pomeron": non-saturating





- Simulated data shown are extrapolations of HERA power law fit

- Significant non-linear effects expected in LHeC kinematic range, even for ep.

→ Sat^n smoking gun?