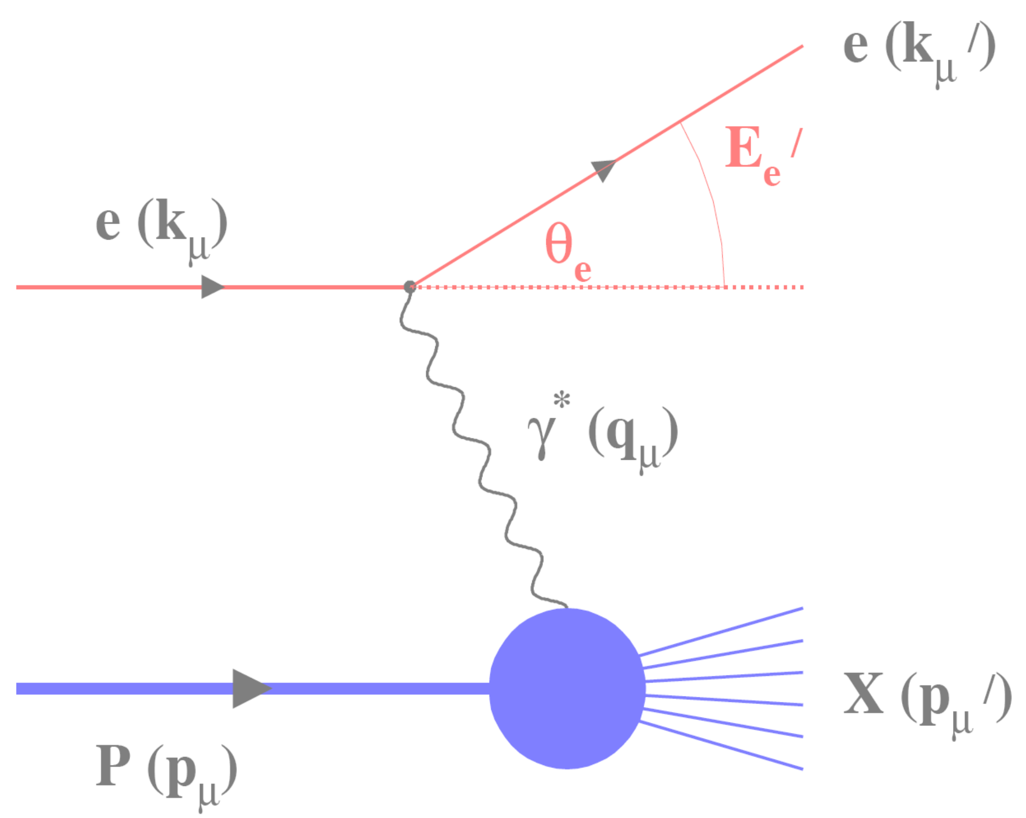
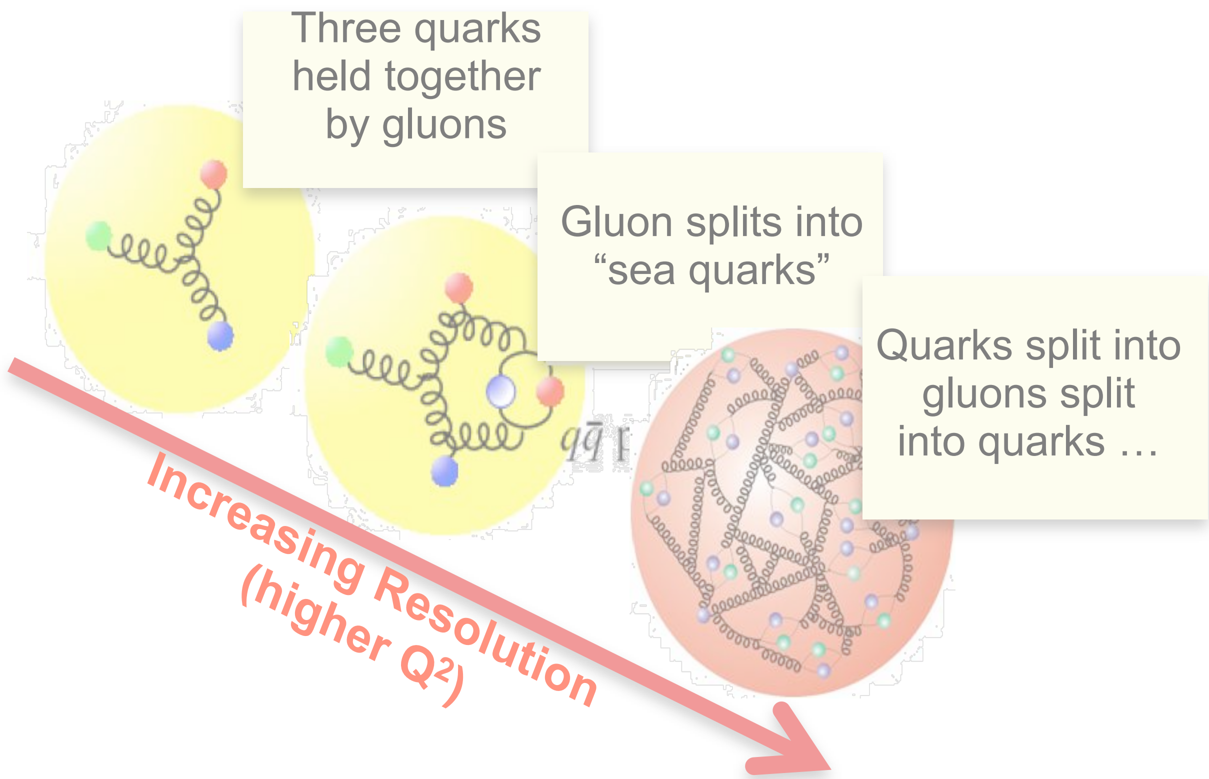
The importance of e+A collisions at an Electron-Ion Collider



Matthew A. C. Lamont
Brookhaven National Lab



BROOKHAVEN NATIONAL LABORATORY

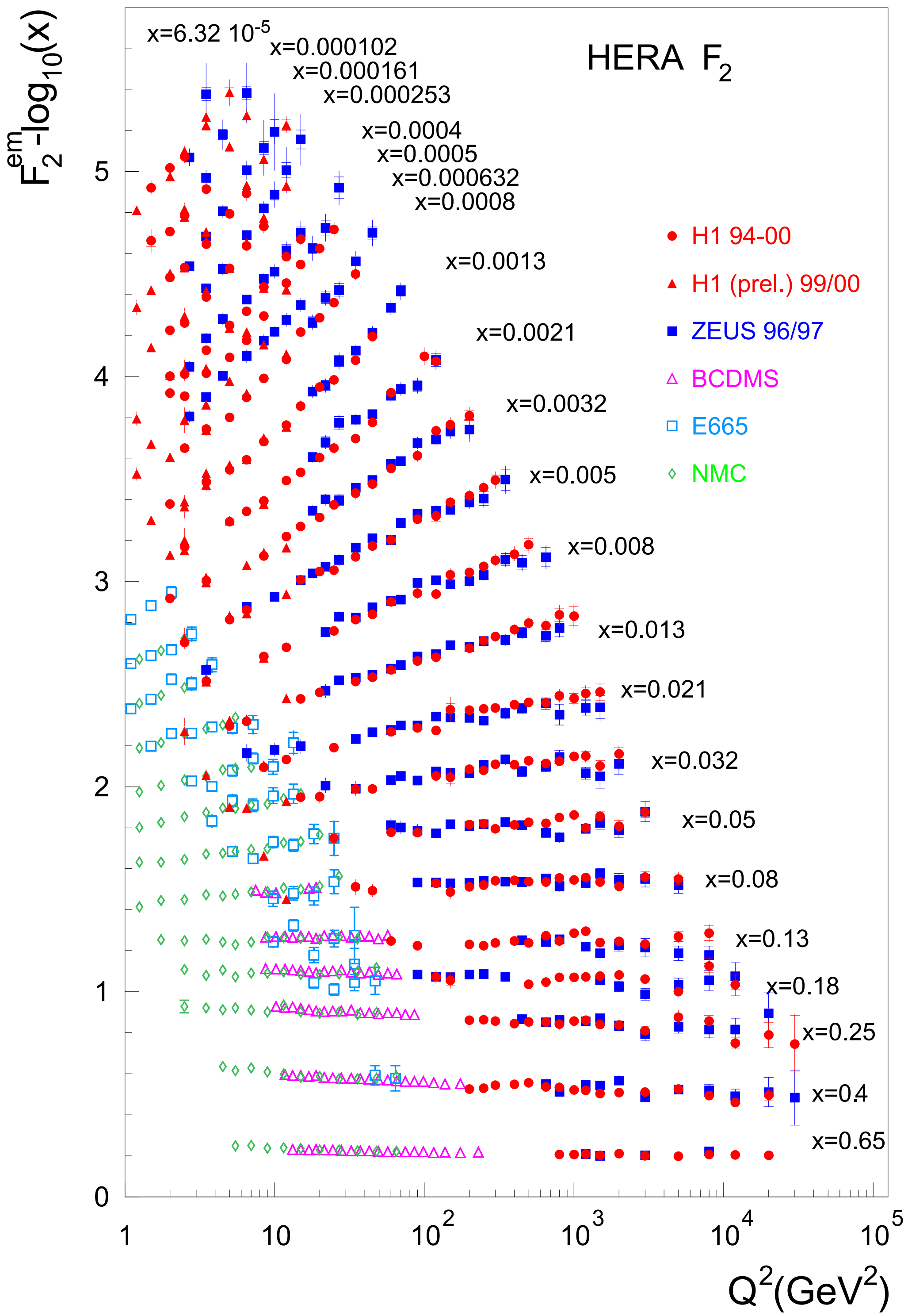
Office of Science
U.S. Department of Energy

What did we learn from e+p collisions at HERA?

$$\sigma_r(x, Q^2) = F_2^A(x, Q^2) - \frac{y^2}{Y+} F_L^A(x, Q^2)$$

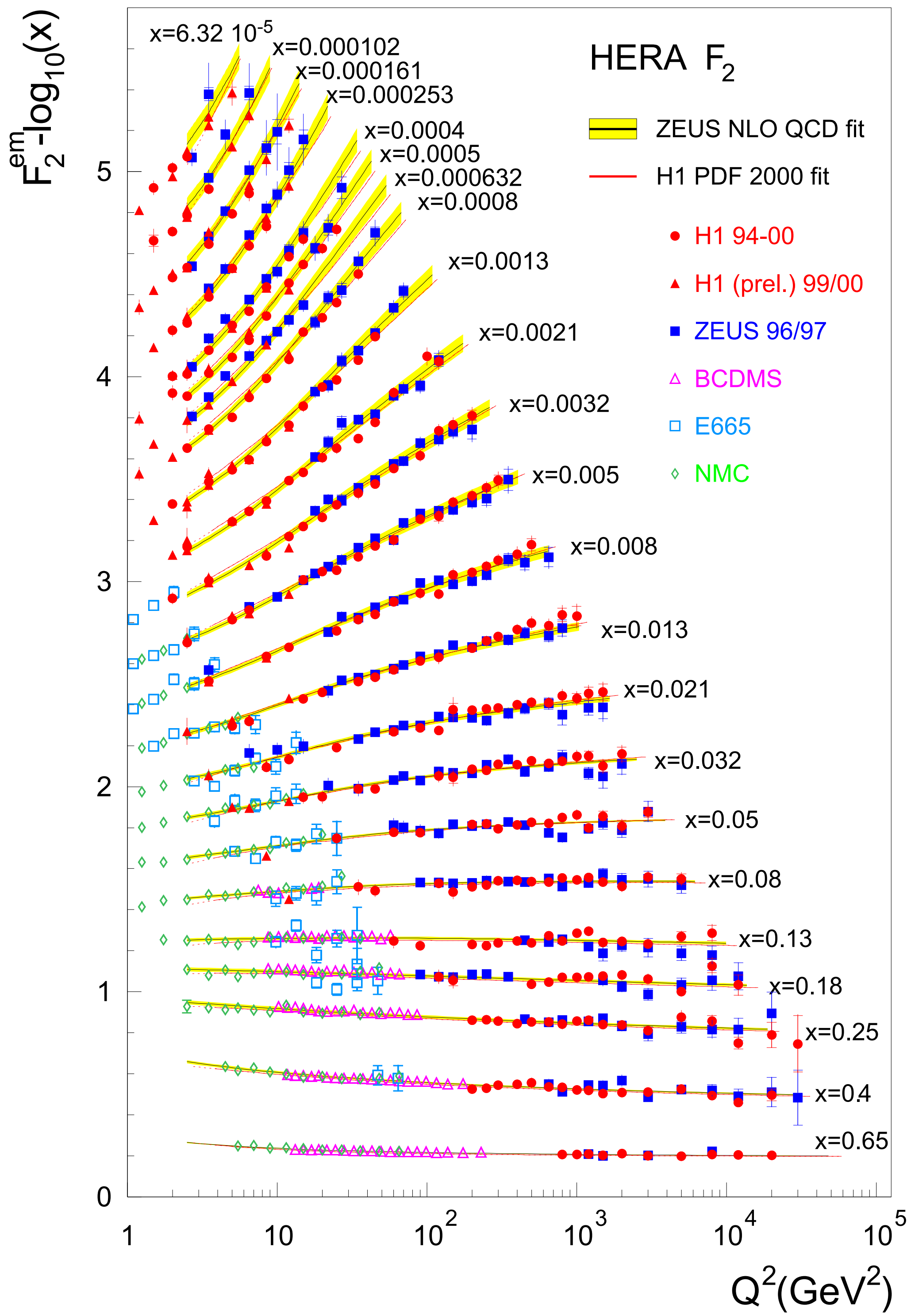
quark+anti-quark momentum distributions

gluon momentum distribution



What did we learn from e+p collisions at HERA?

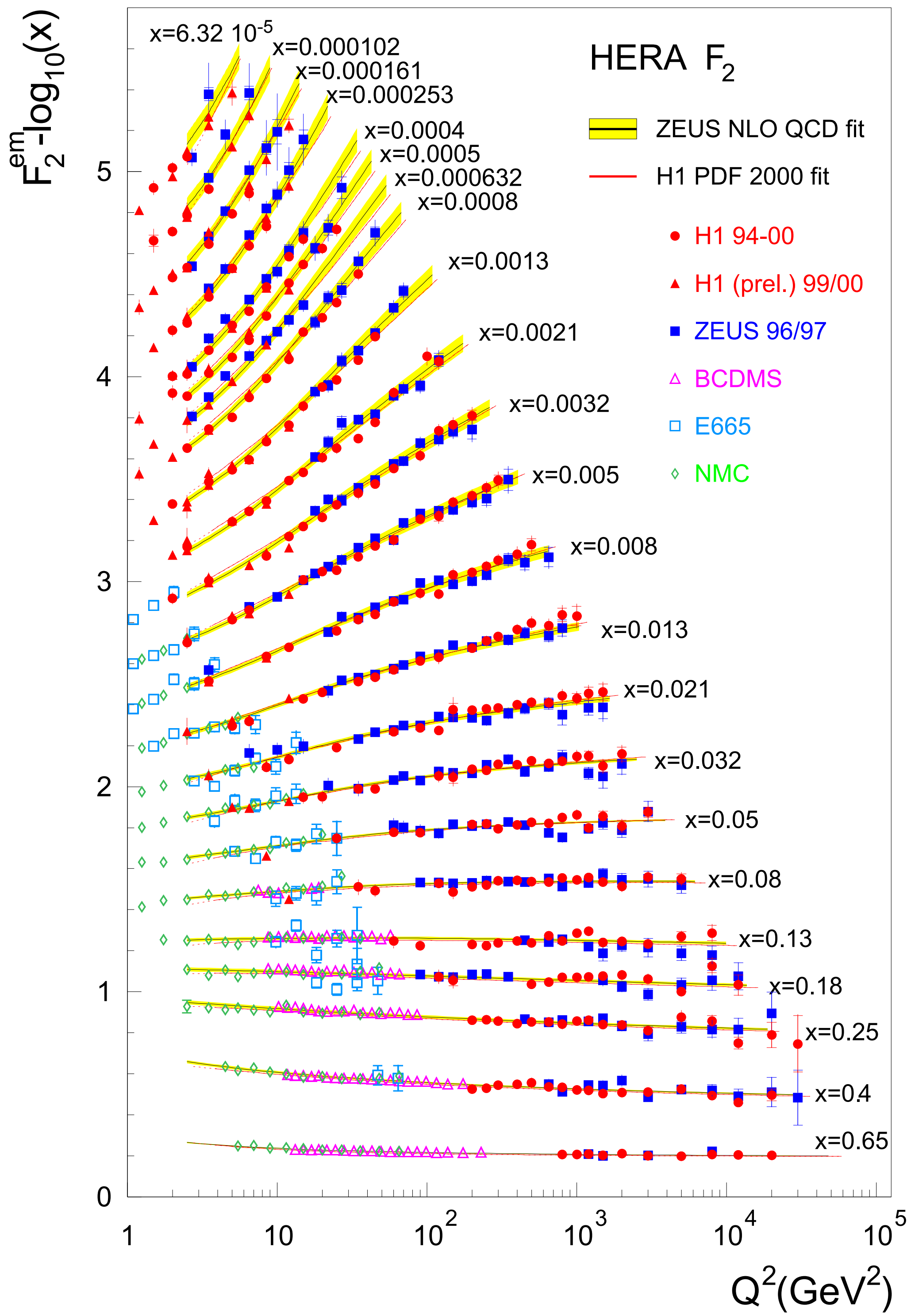
$$\sigma_r(x, Q^2) = F_2^A(x, Q^2) - \frac{y^2}{Y+} F_L^A(x, Q^2)$$



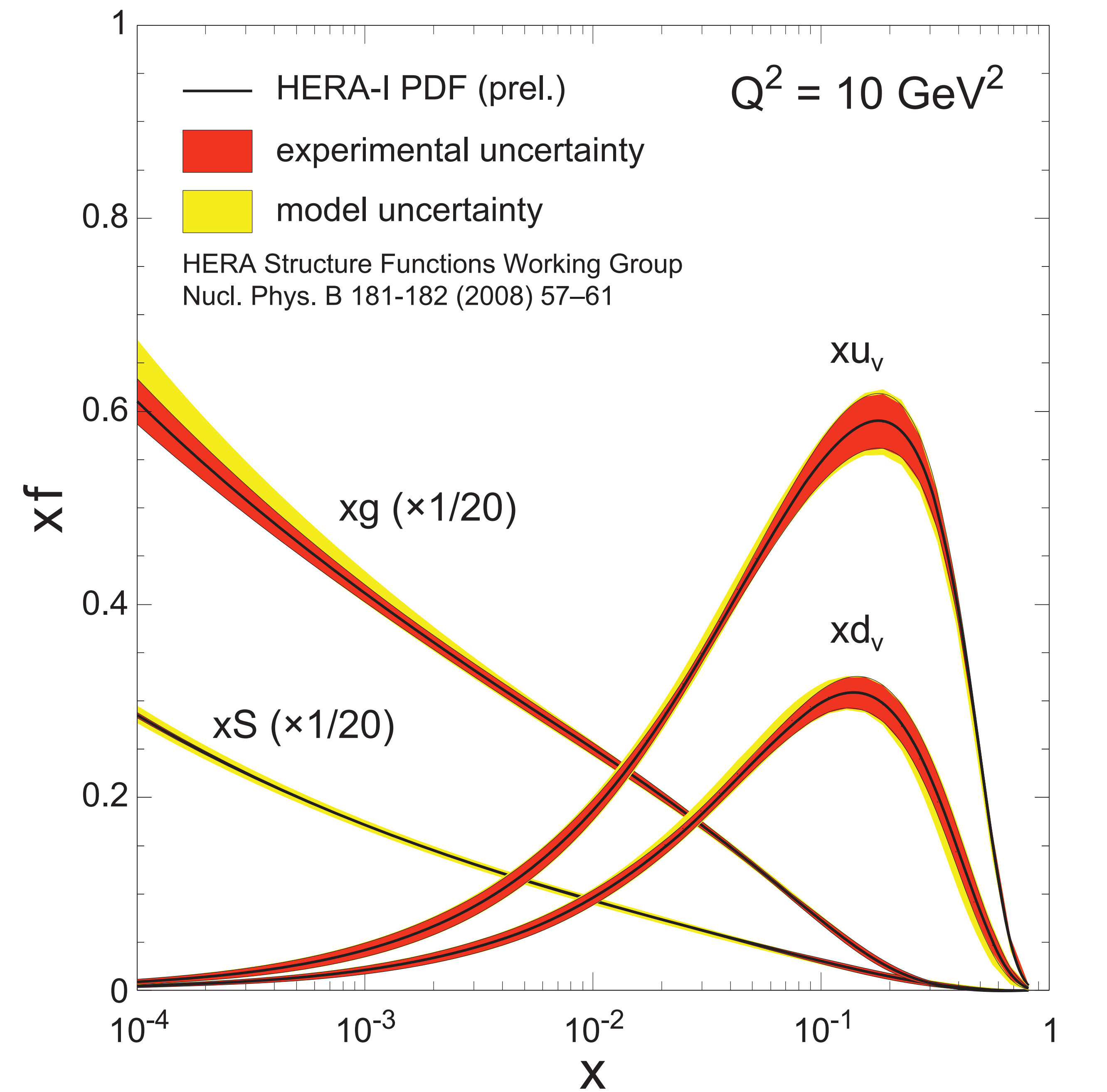
Scaling violation: $dF_2/dlnQ^2$ and linear DGLAP Evolution $\Rightarrow$ $G(x,Q^2)$

What did we learn from e+p collisions at HERA?

$$\sigma_r(x,Q^2) = F_2^A(x,Q^2) - \frac{y^2}{Y+} F_L^A(x,Q^2)$$

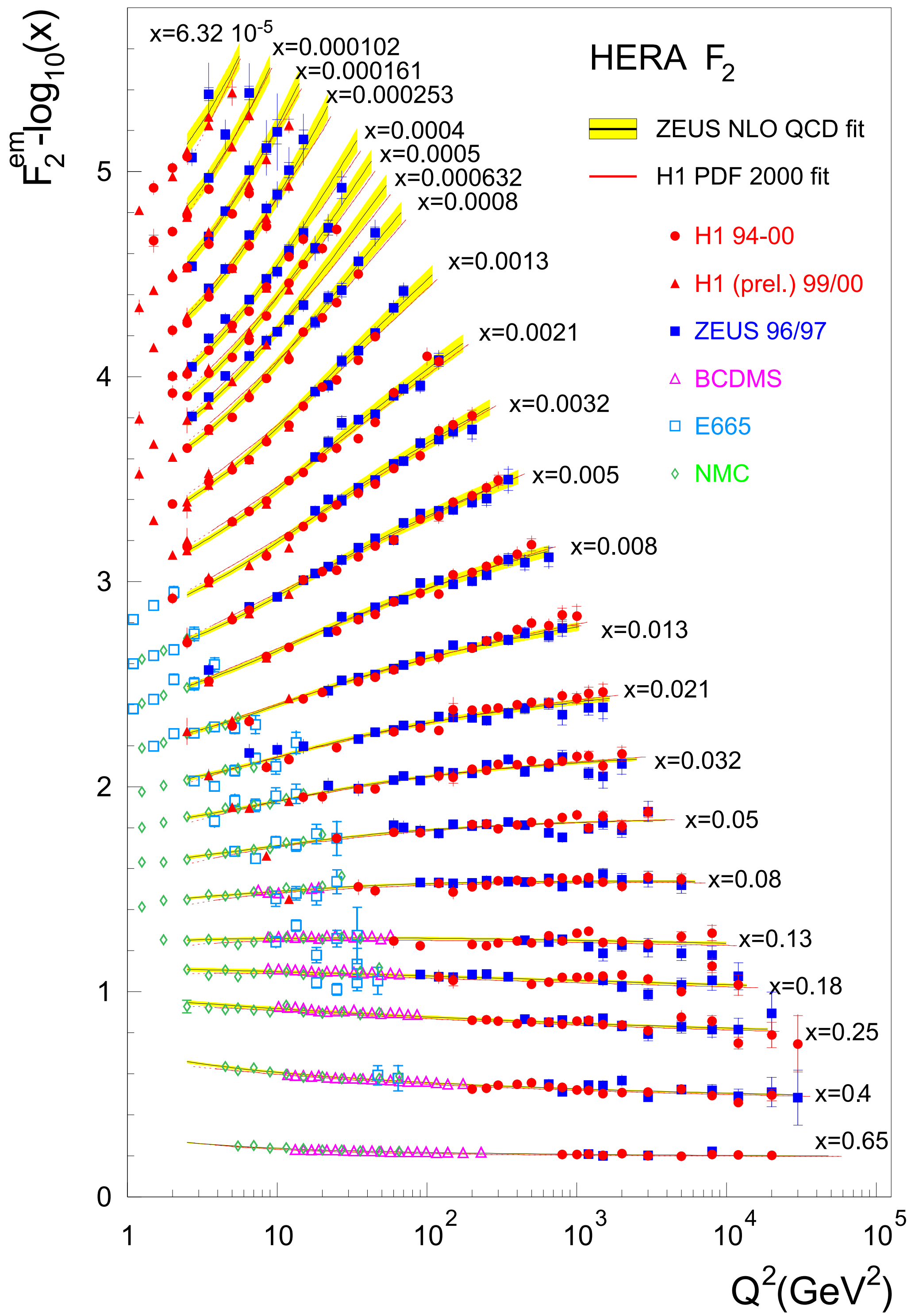


Scaling violation: $dF_2/dlnQ^2$ and linear DGLAP Evolution ⇒ $G(x,Q^2)$

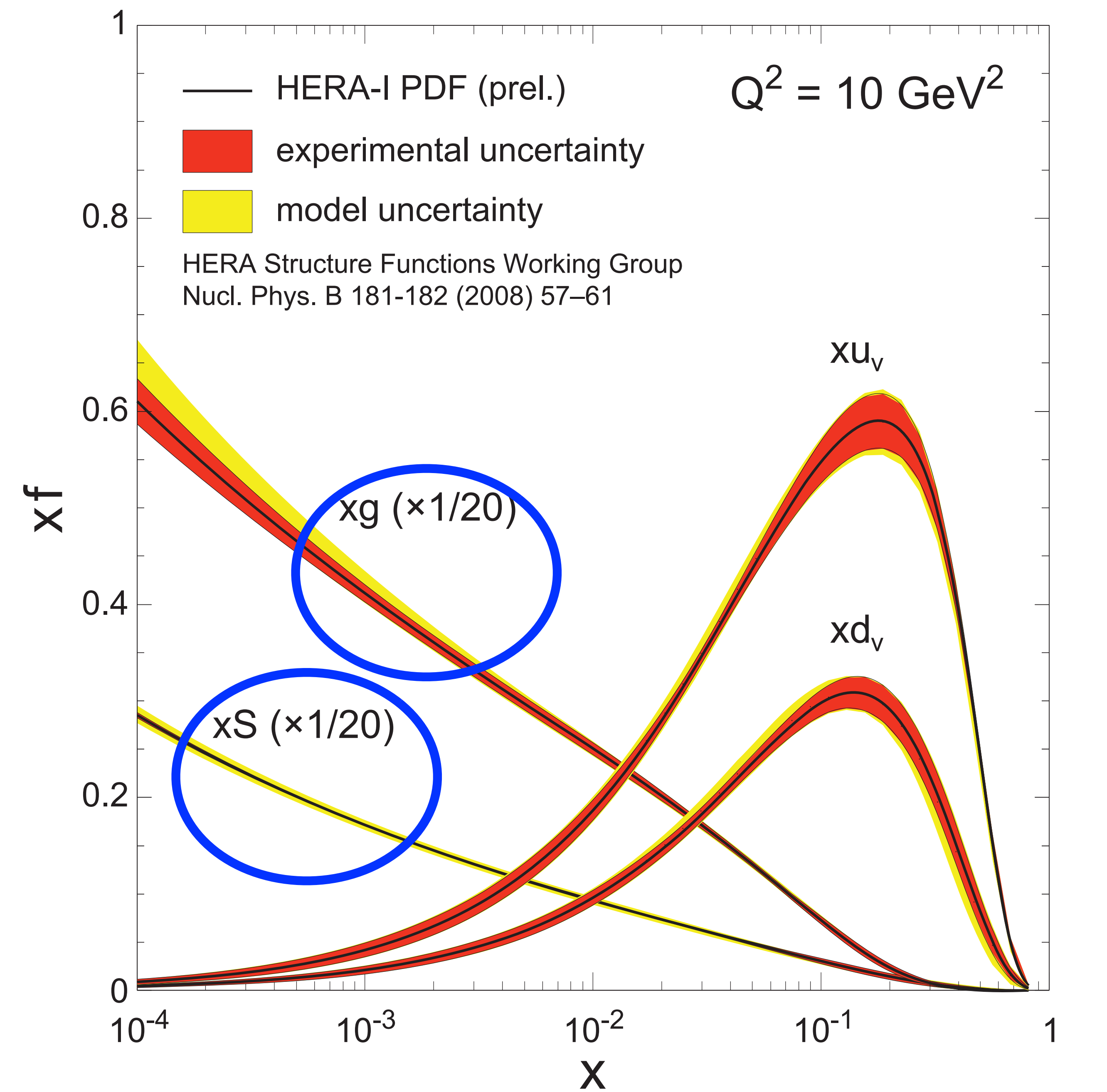


What did we learn from e+p collisions at HERA?

$$\sigma_r(x,Q^2) = F_2^A(x,Q^2) - \frac{y^2}{Y+} F_L^A(x,Q^2)$$

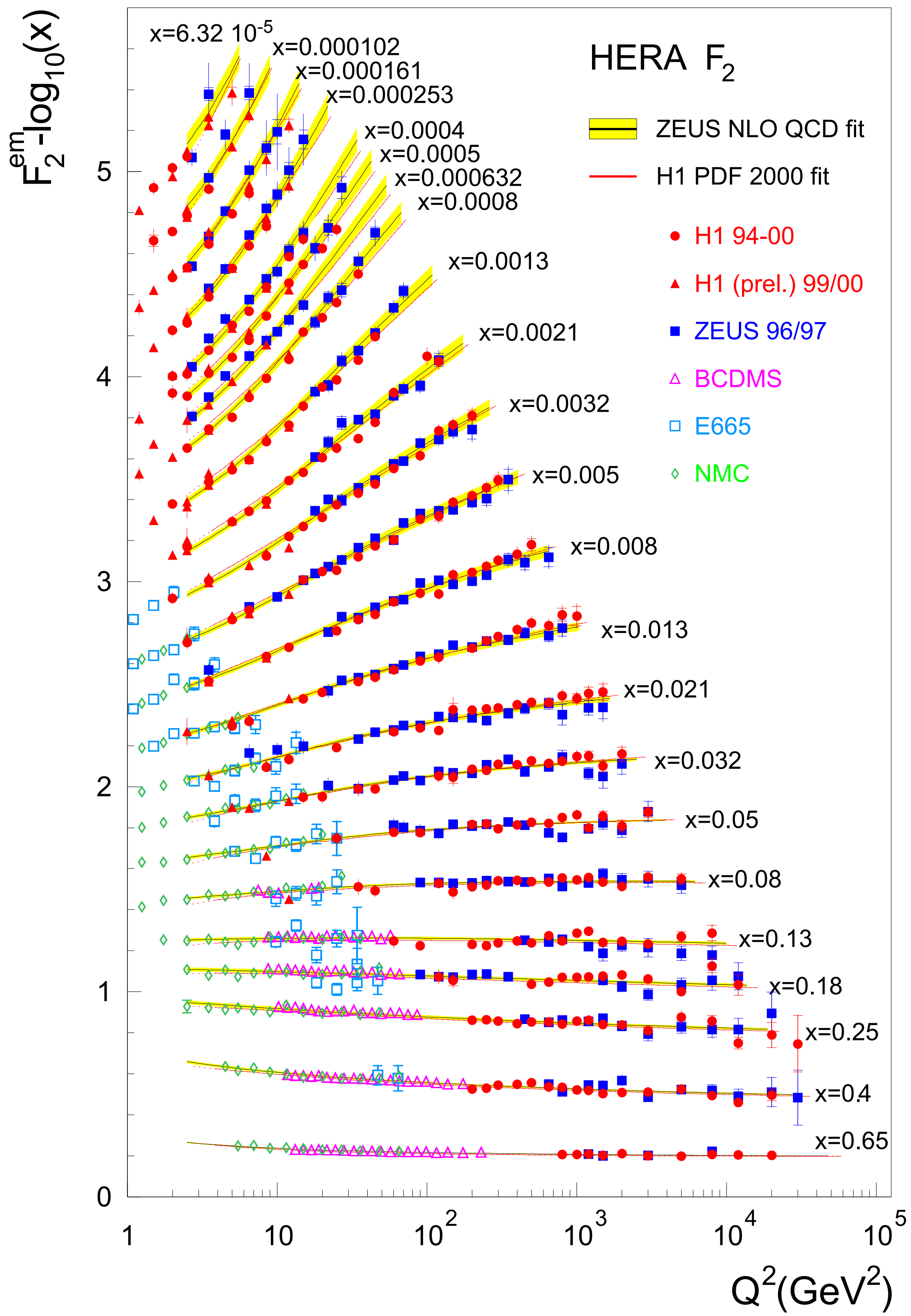


Scaling violation: $dF_2/dlnQ^2$ and linear DGLAP Evolution ⇒ $G(x,Q^2)$

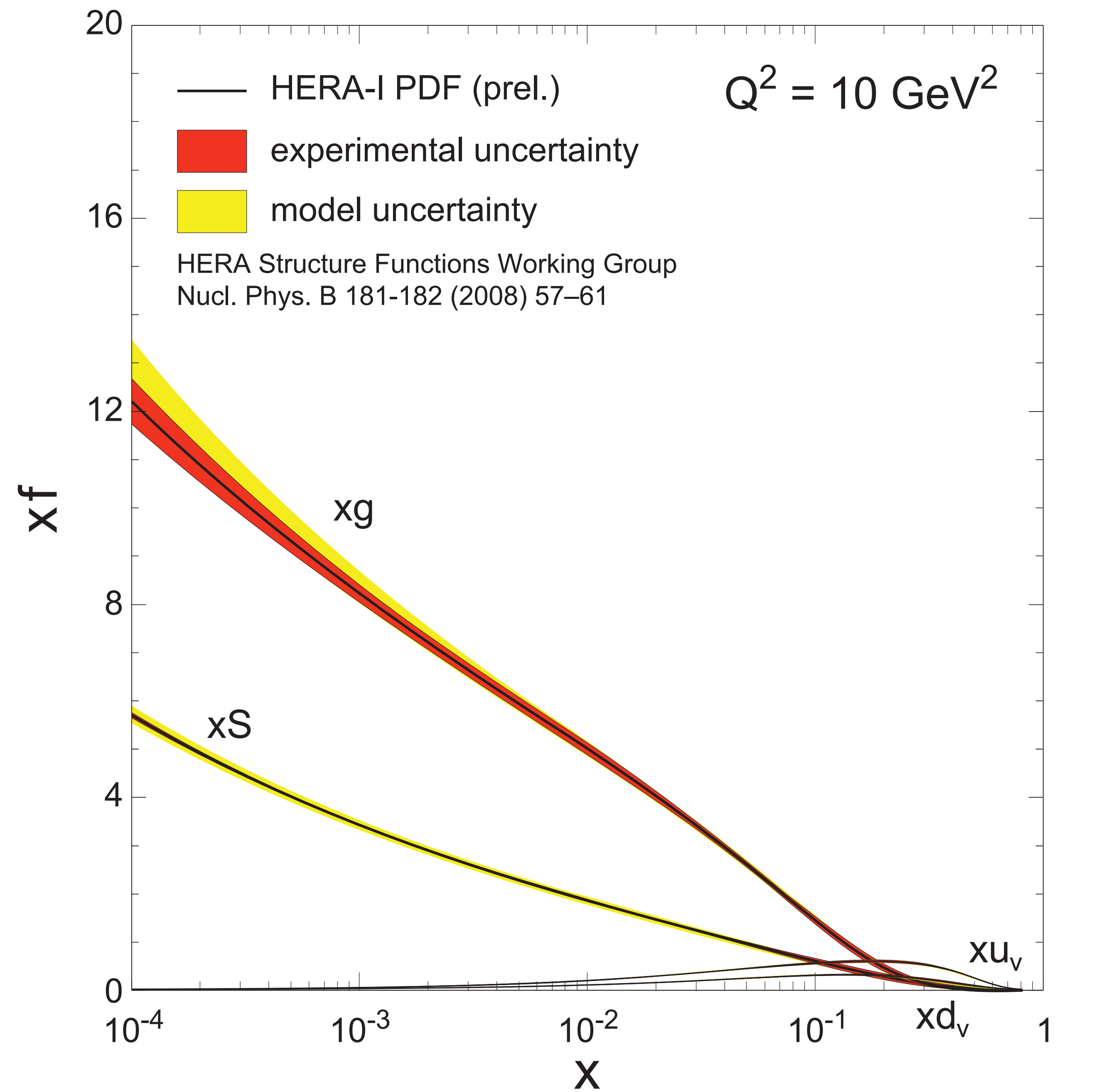


What did we learn from e+p collisions at HERA?

$$\sigma_r(x,Q^2) = F_2^A(x,Q^2) - \frac{y^2}{Y+} F_L^A(x,Q^2)$$

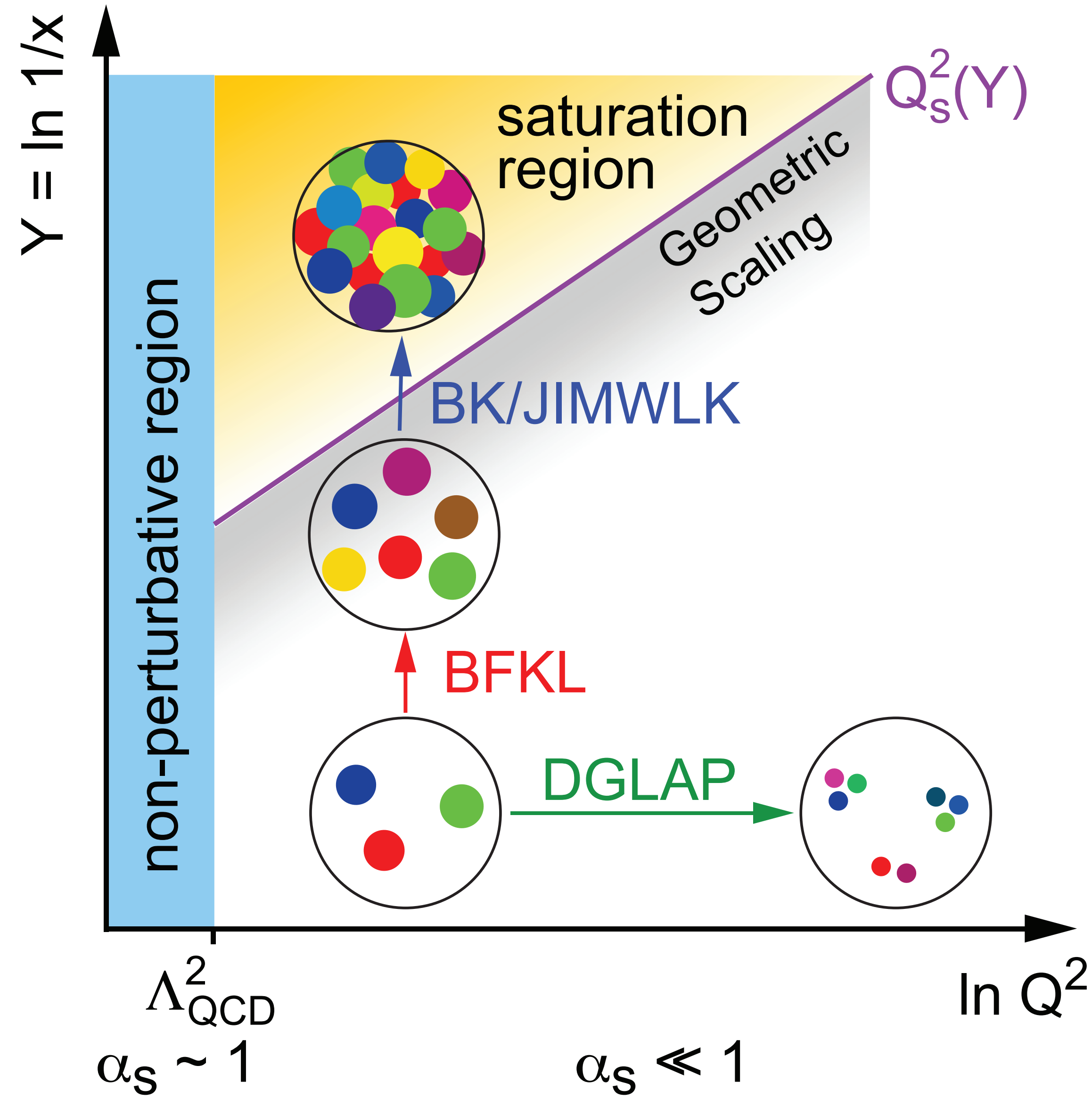


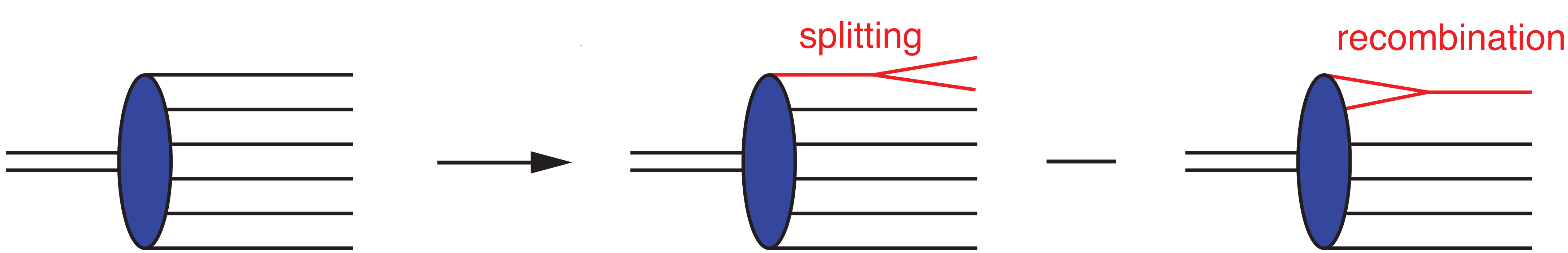
Scaling violation: $dF_2/dlnQ^2$ and linear DGLAP Evolution ⇒ $G(x,Q^2)$



Saturation Scale, Q_s

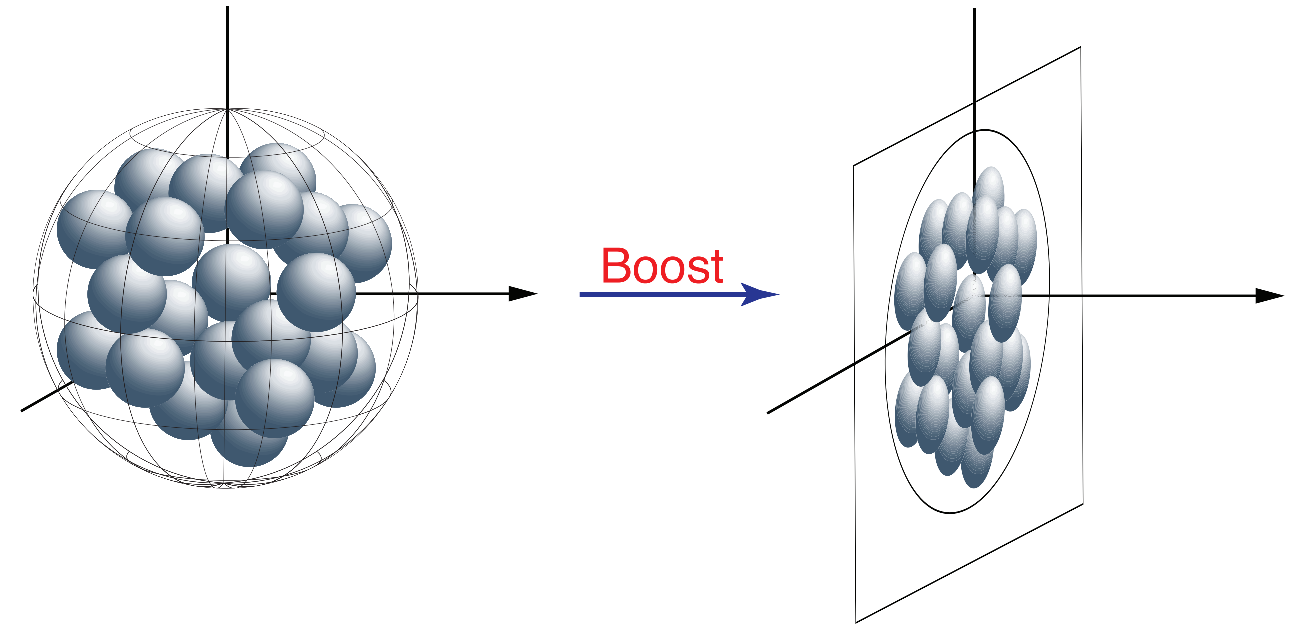
- As we go higher in energy (larger values of 1/x) we move away from the *linear BFKL* regime to the *non-linear BK/JIMWLK* realm
- Take advantage of the fact that gluons are self-interacting
  - ➡ Not only can we have gluon splitting, but also recombination
    - Tame the explosive growth of the gluon density in the nucleon observed from fitting HERA data





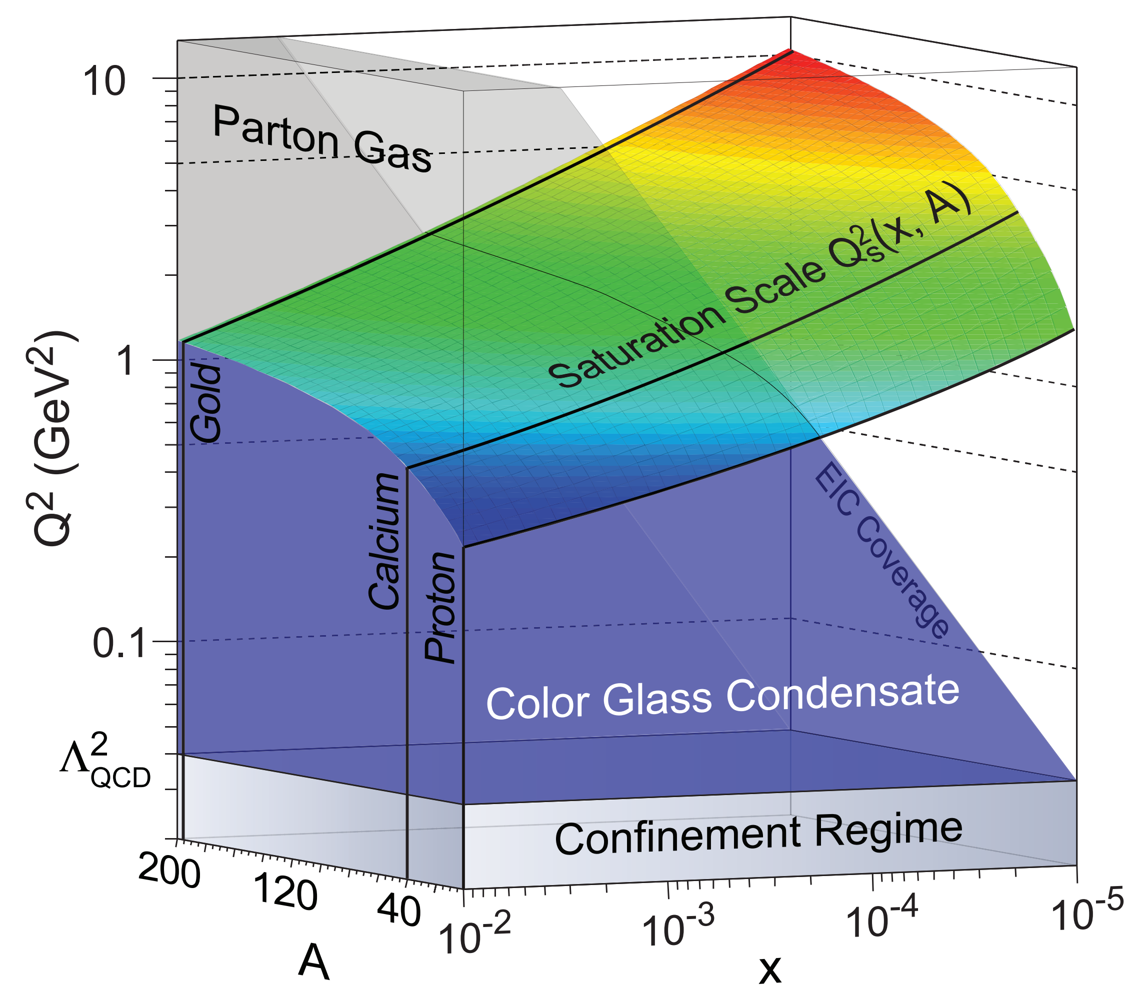
Nuclear “oomph” effect

- When we accelerate the nucleus to high energy, we give it a Lorentz boost



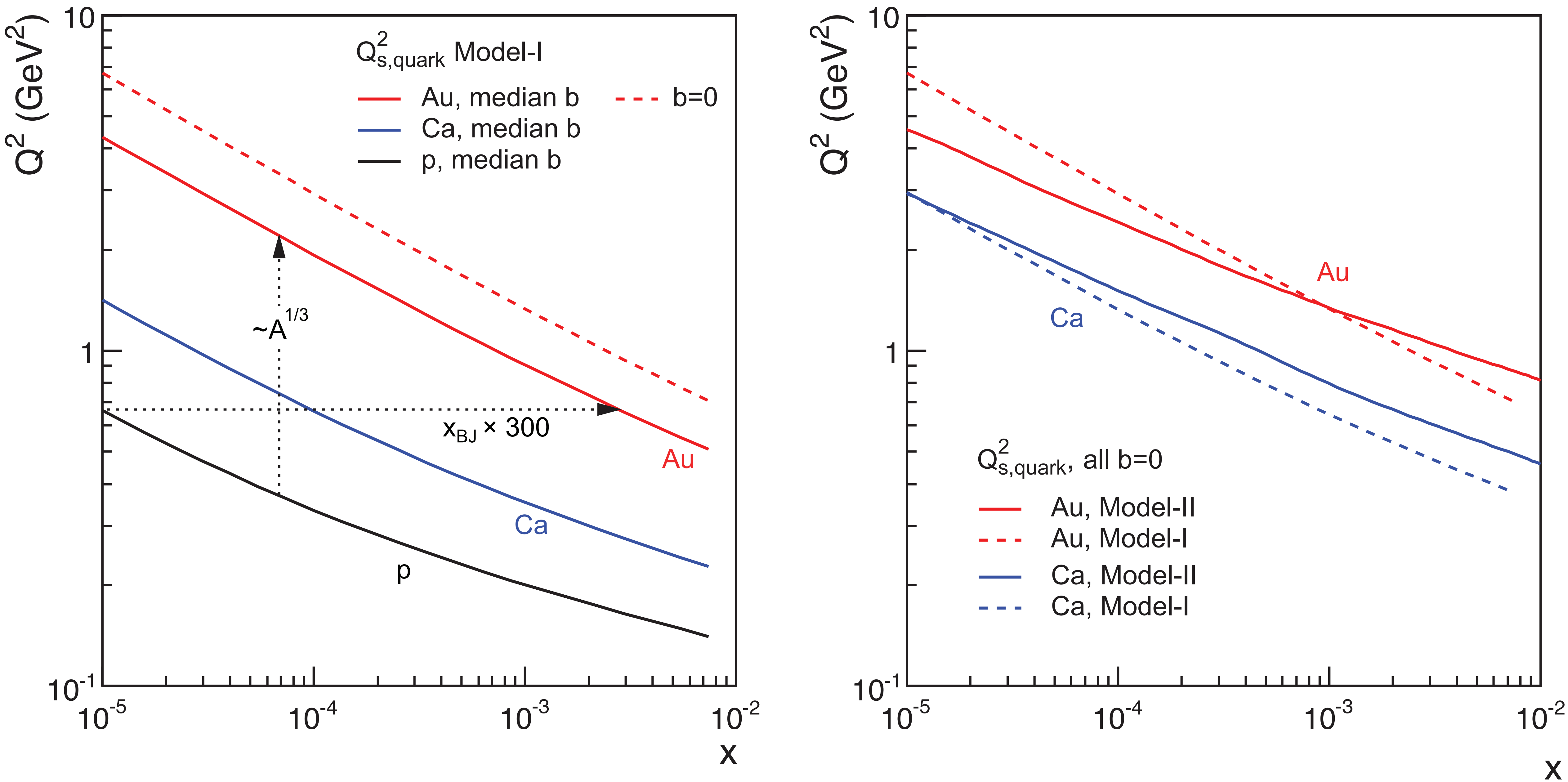
- Incoming probe interacts coherently with all of the nucleons in the nucleus
  - ➡ Q_s is given a boost simply by the geometry of the collision system

$$Q_s^2(x) \sim A^{1/3} \left(\frac{1}{x}\right)^{\lambda}$$

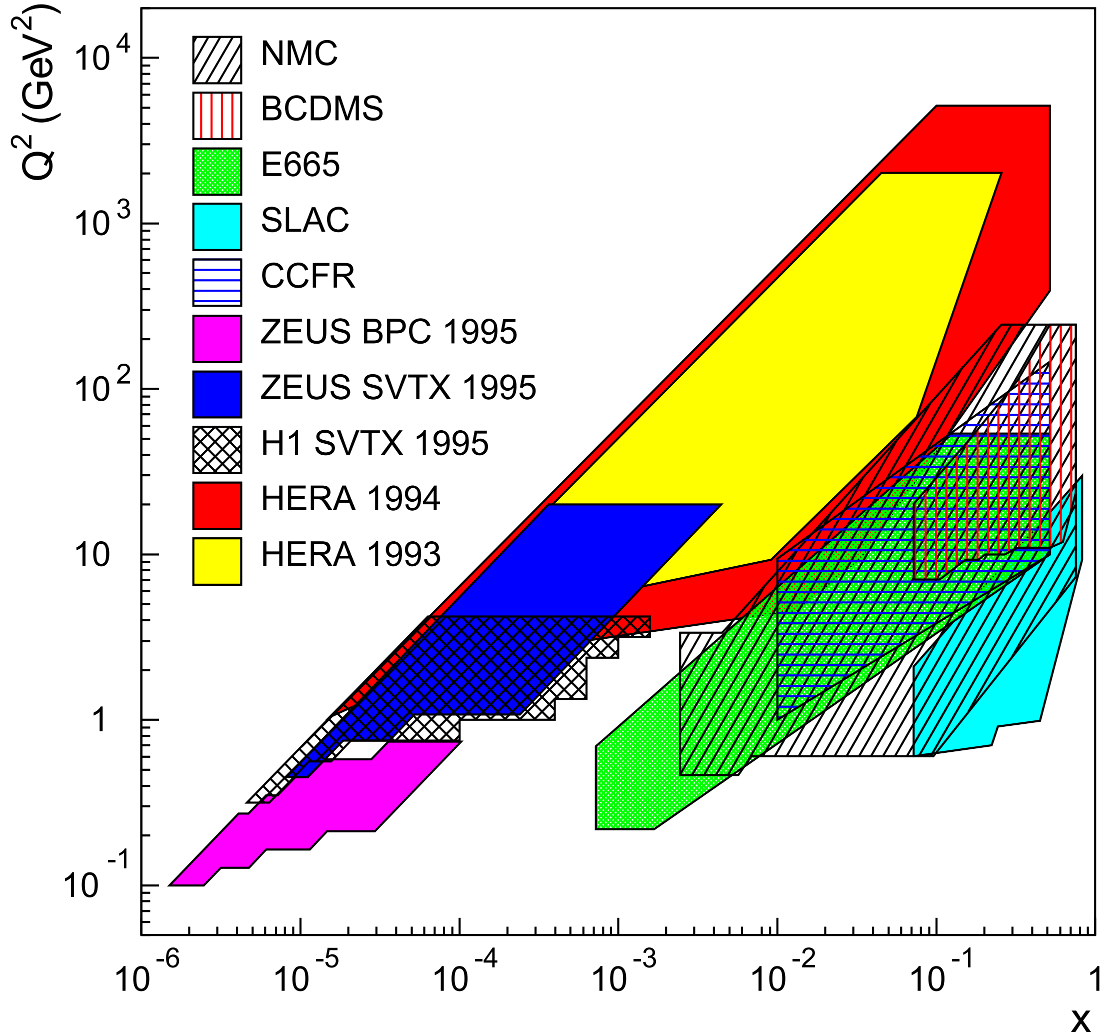


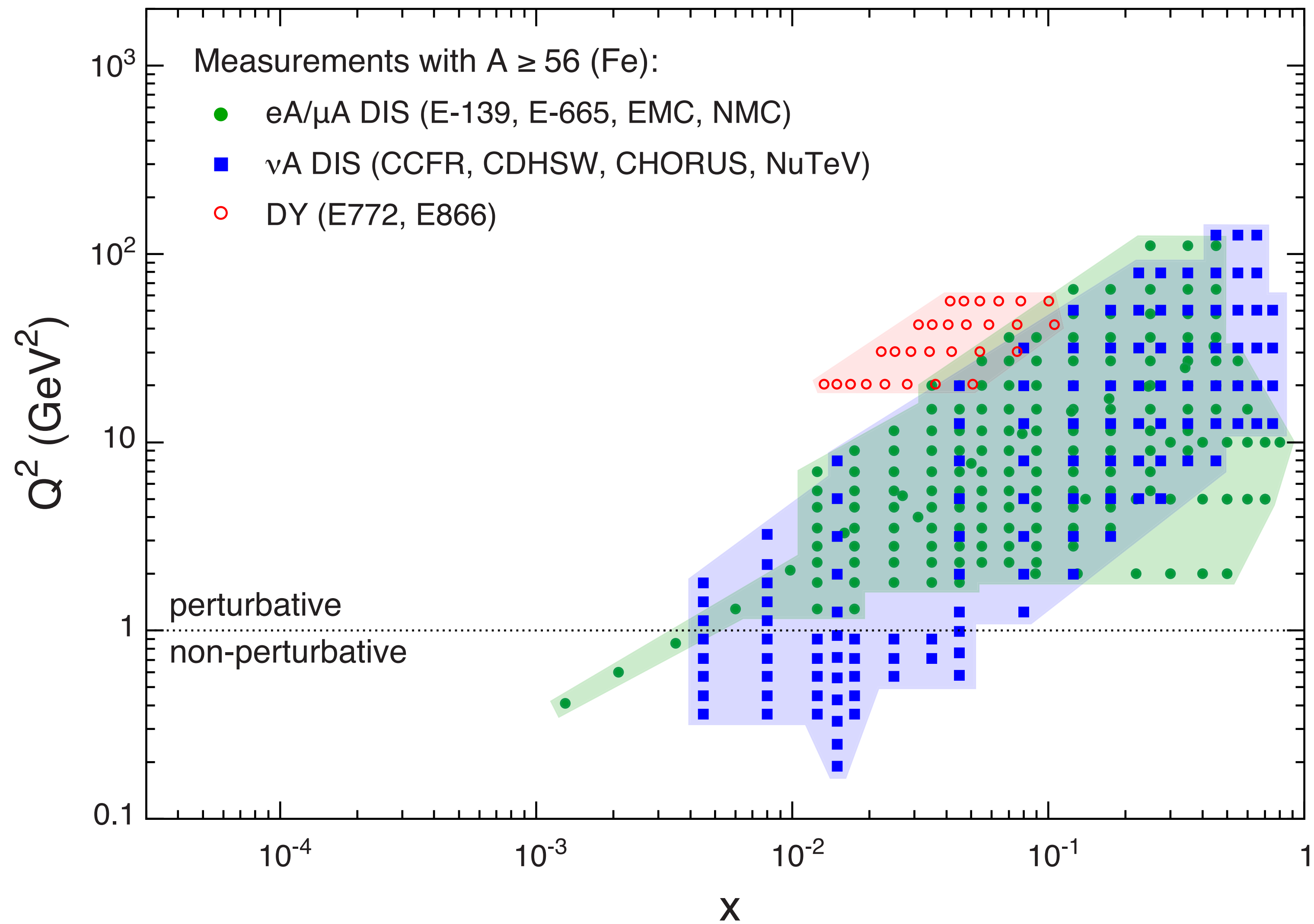
Nuclear "oomph" effect

Pocket formula: $Q_s^2(x) \sim A^{1/3}\left(\frac{1}{x}\right)^{\lambda} \sim \left(\frac{A}{x}\right)^{1/3}$



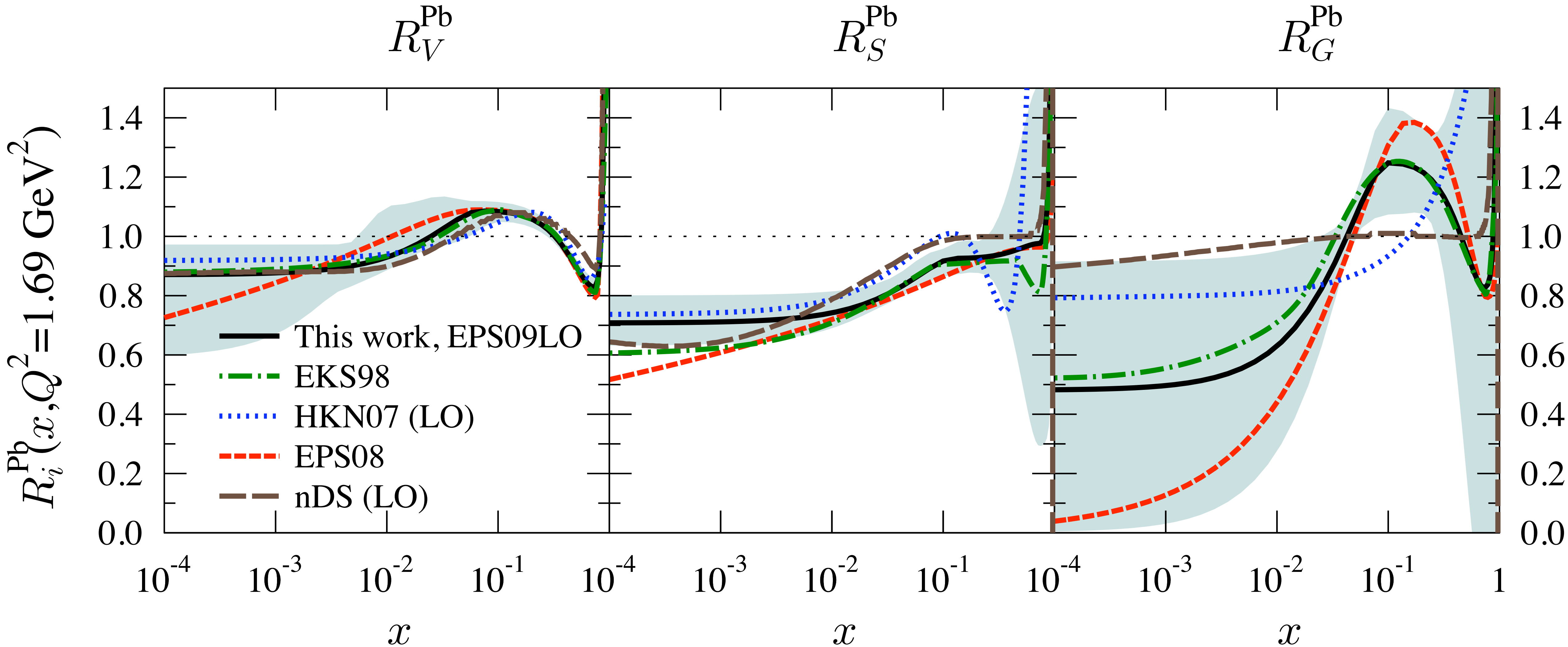
What do we know about the structure of nuclei?





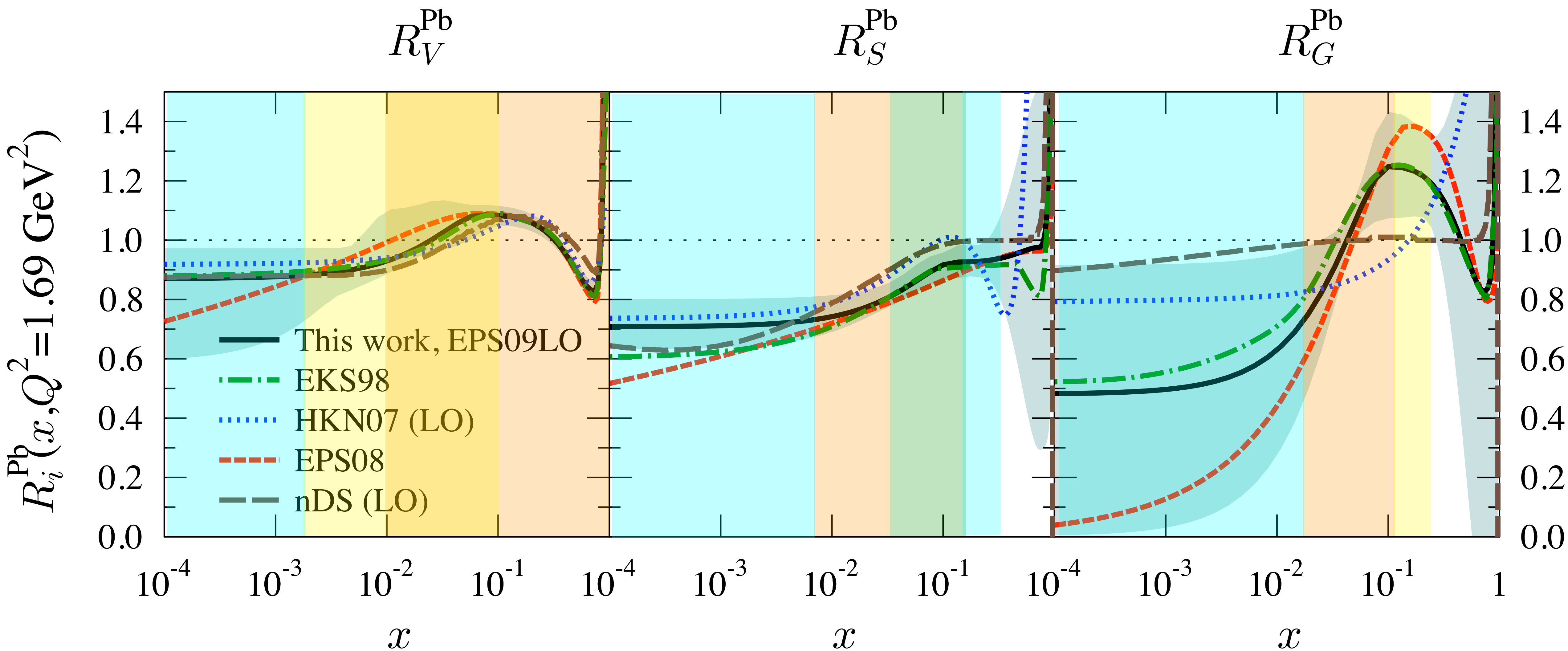
- e+p data covers large part of phase space
  - ➡ low x and large Q^2
- e+A data only a small fraction of this (e+A was a fixed target programme at HERA)
  - ➡ high-medium x and low Q^2

What do we know about the structure of nuclei?



The distribution of valence and sea quarks are relatively well known in nuclei - theories agree well

What do we know about the structure of nuclei?



Constrained by DIS

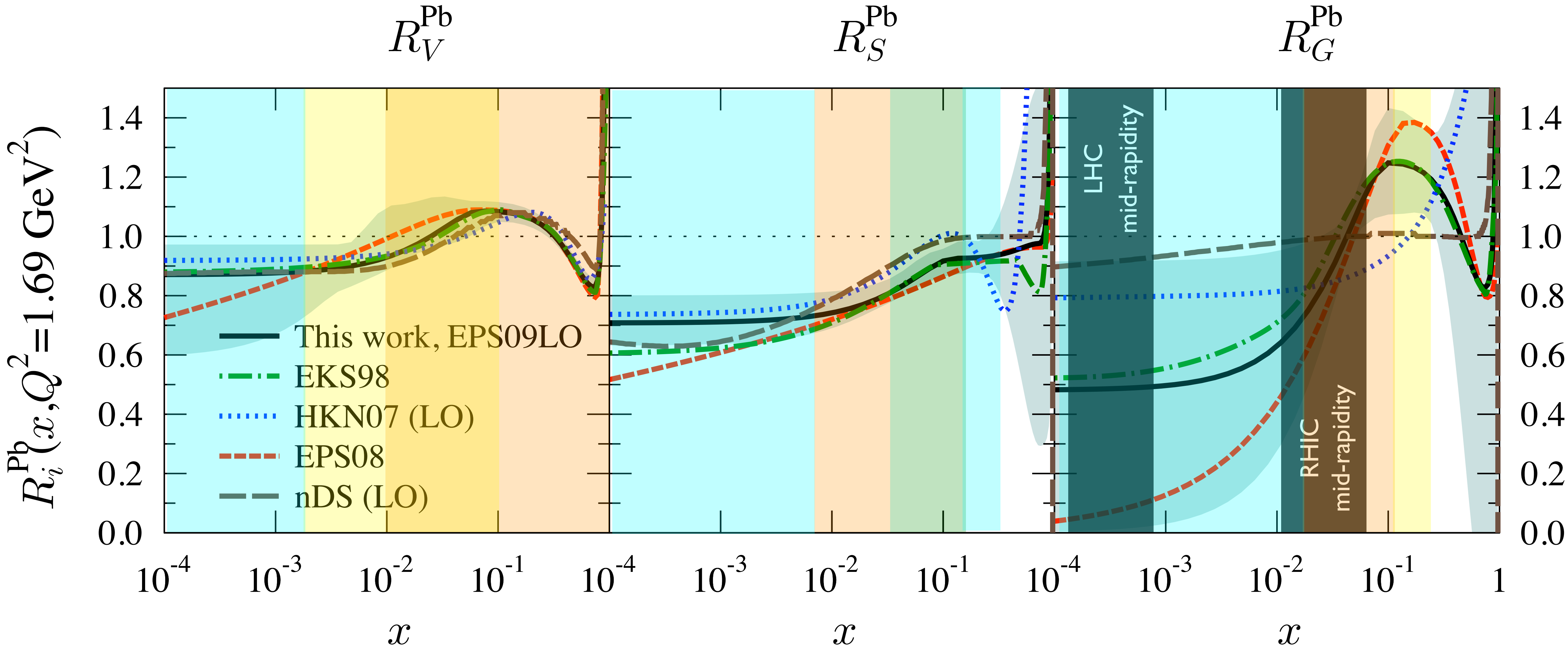
Constrained by DY

Constrained by sum rules

Assumptions

The distribution of valence and sea quarks are relatively well known in nuclei - theories agree well

What do we know about the structure of nuclei?



Constrained by DIS

Constrained by DY

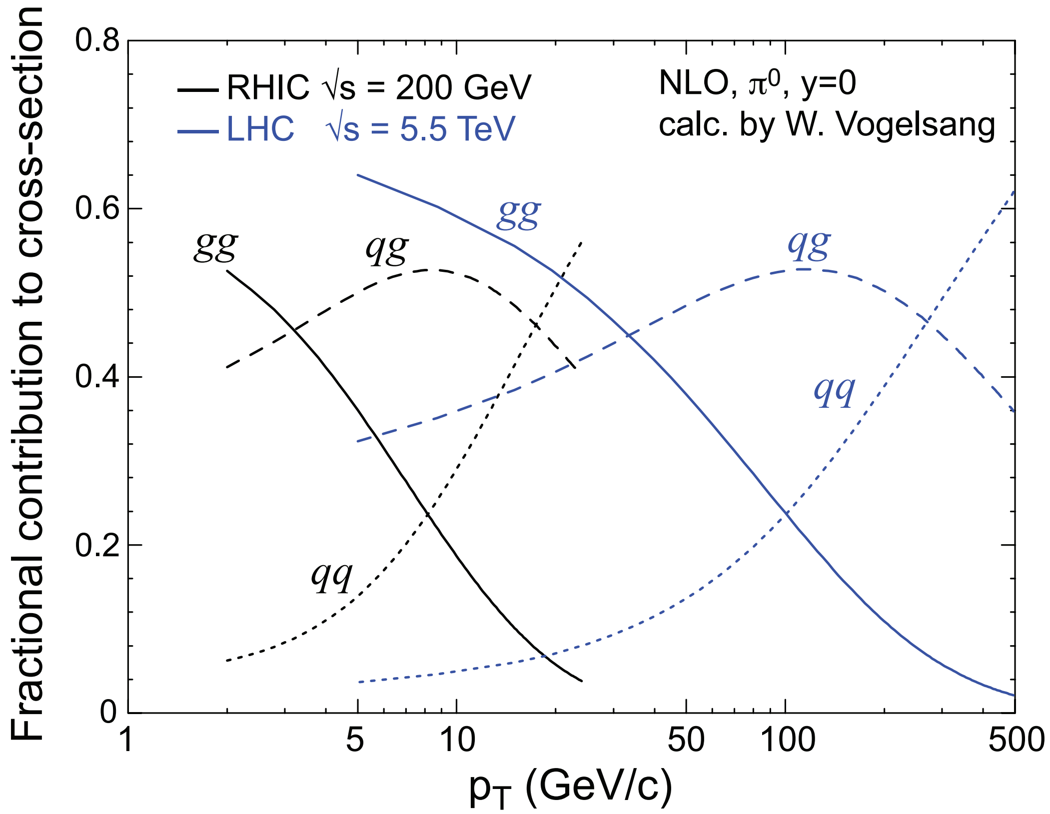
Constrained by sum rules

Assumptions

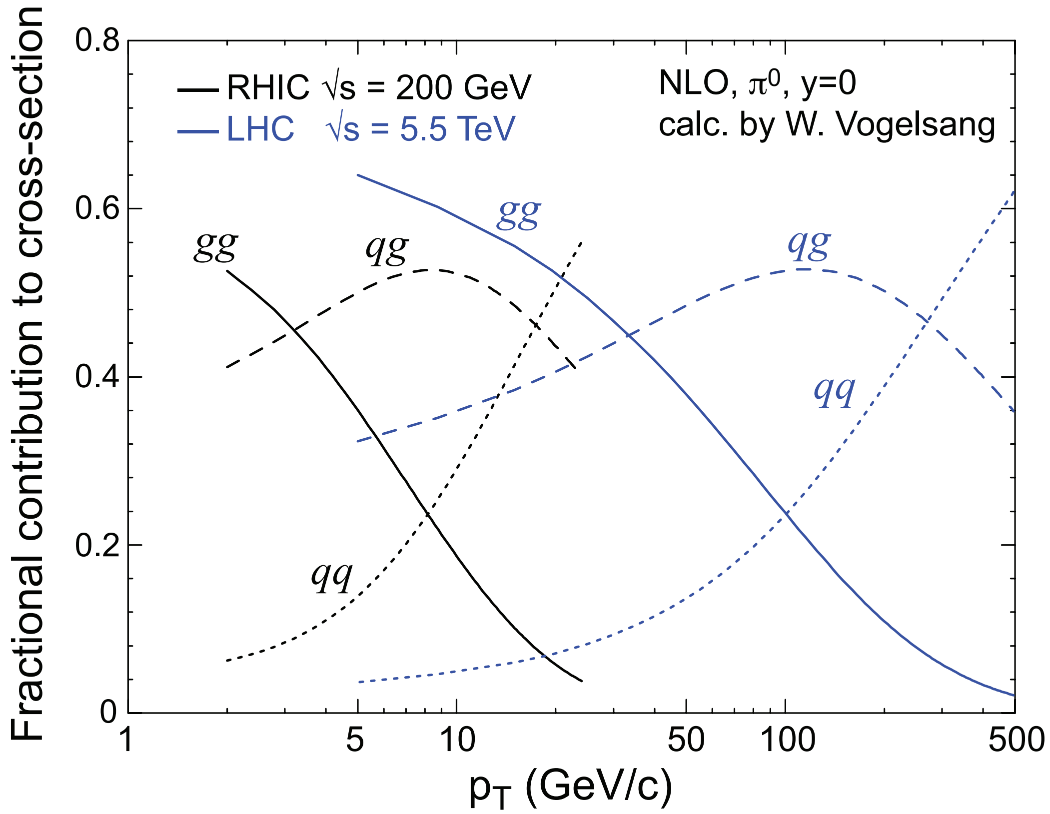
The distribution of valence and sea quarks are relatively well known in nuclei - theories agree well

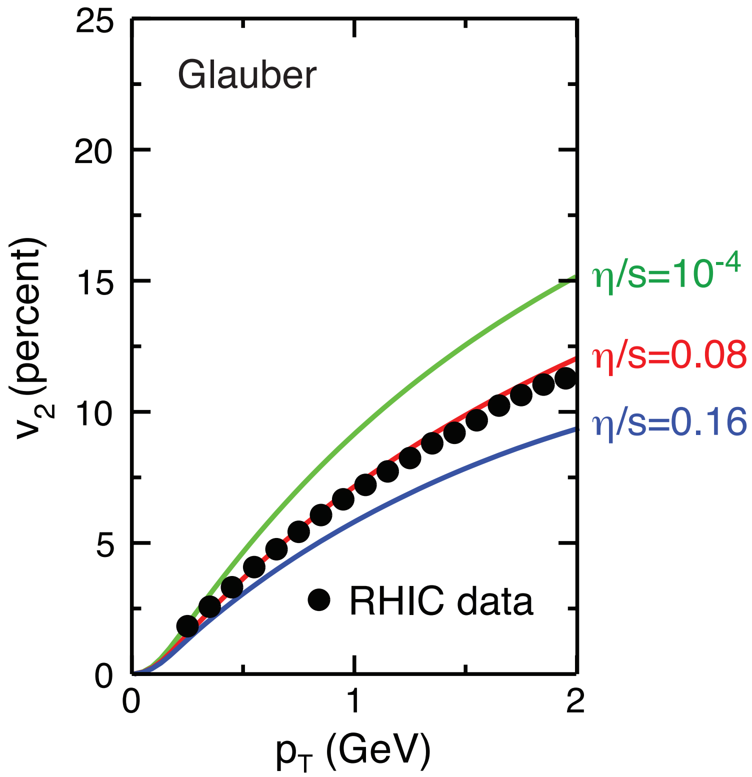
Large discrepancies exist in the gluon distributions from models for mid-rapidity LHC and forward RHIC rapidities !!

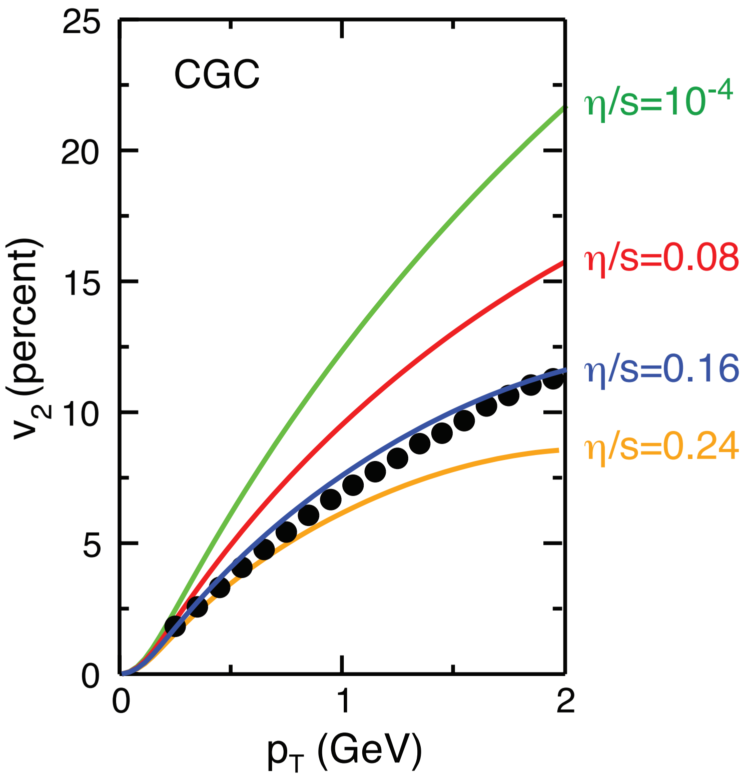
The need to know the gluons - initial conditions



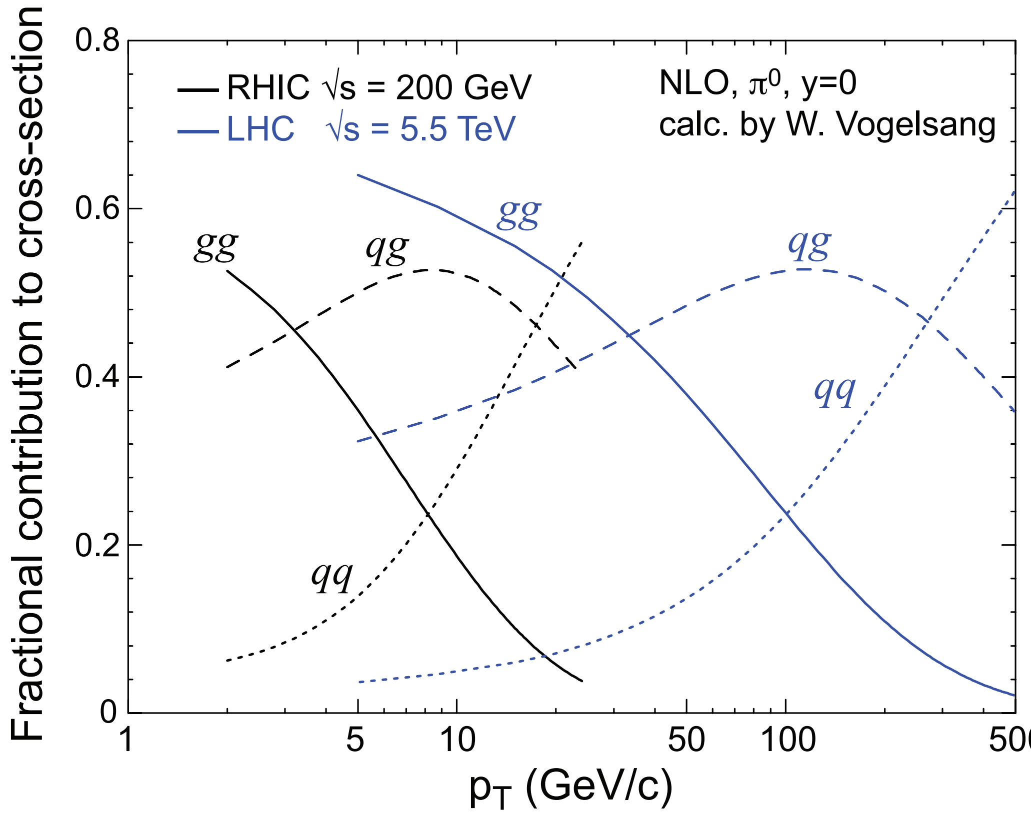
The need to know the gluons - initial conditions

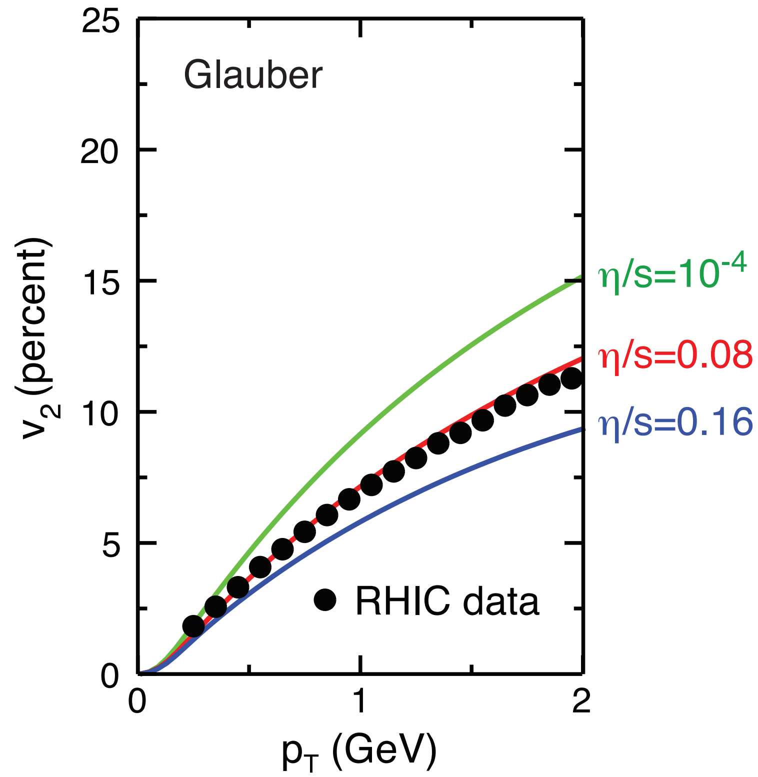


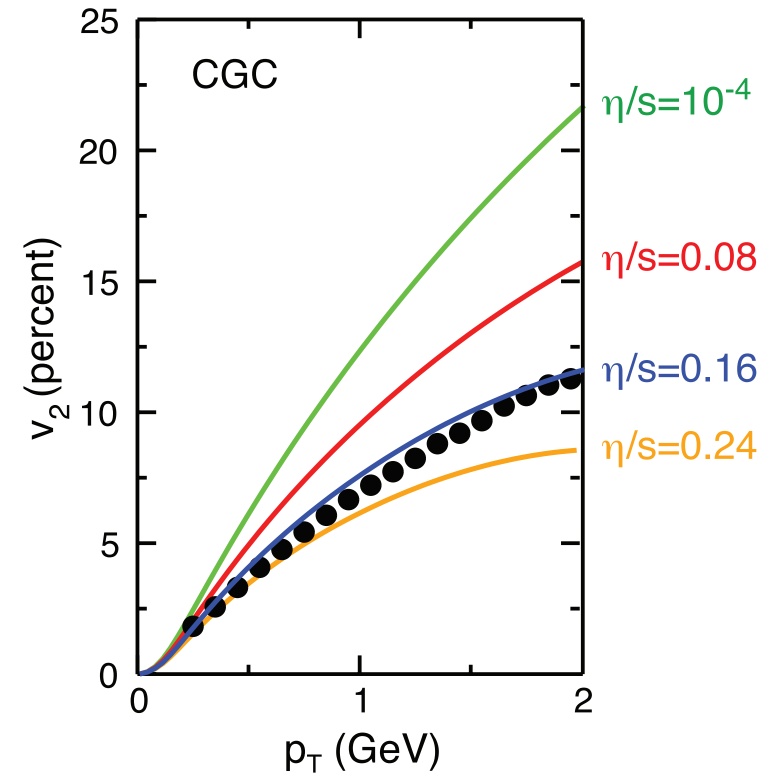


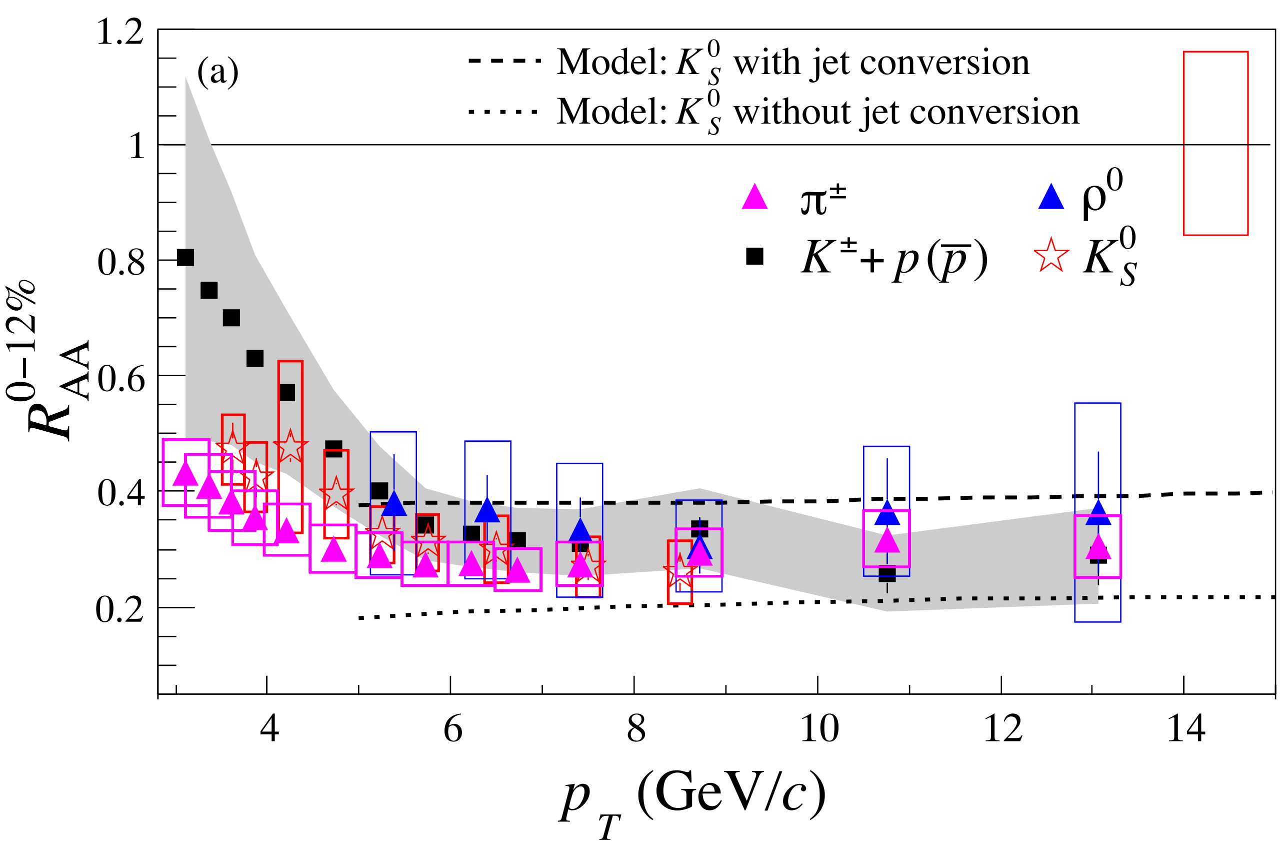


The need to know the gluons - initial conditions

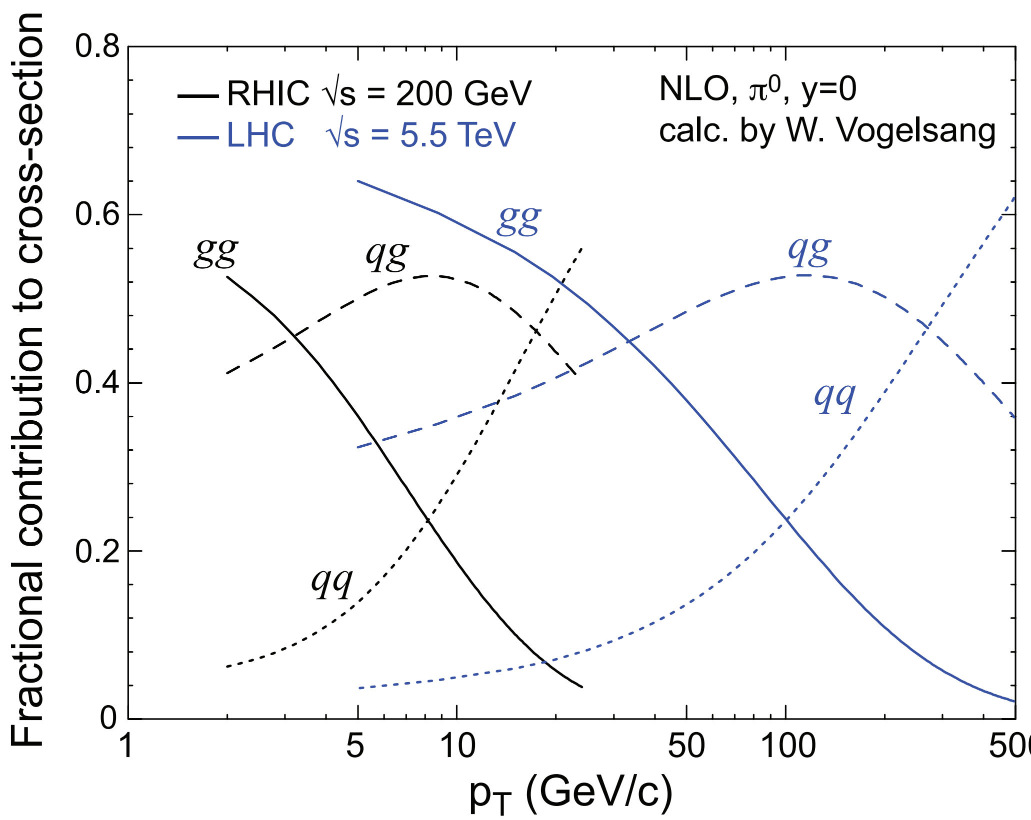


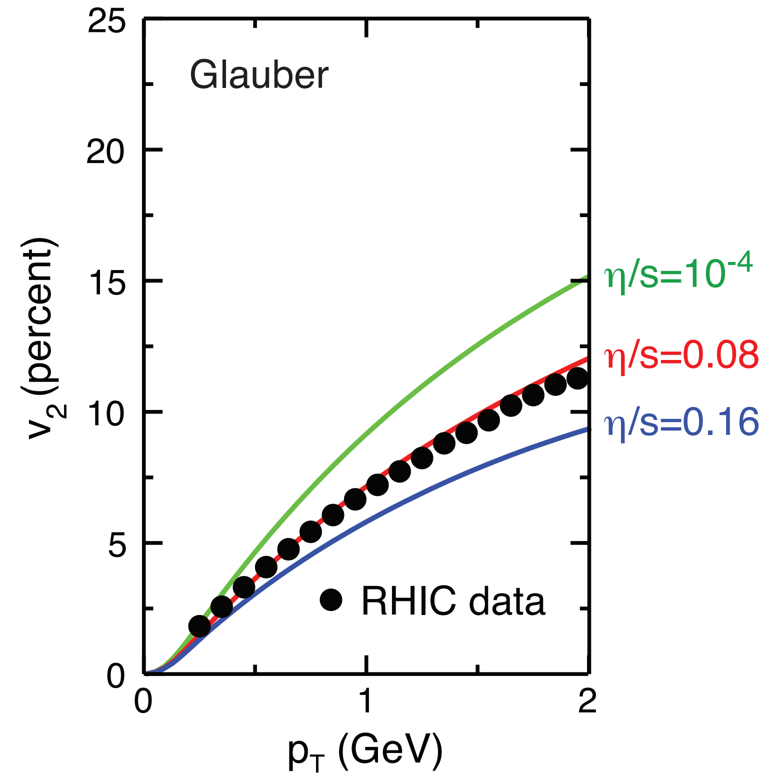


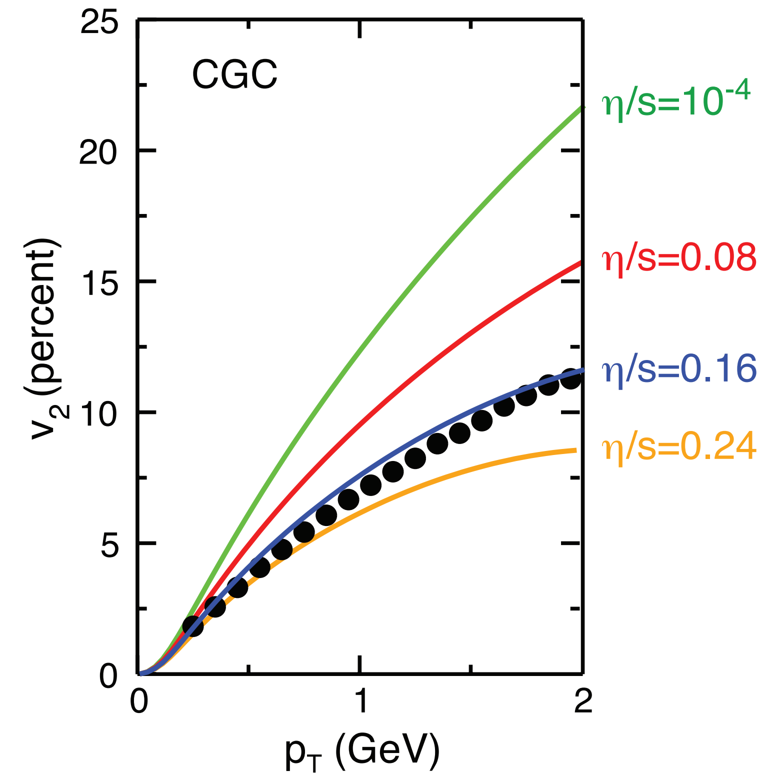


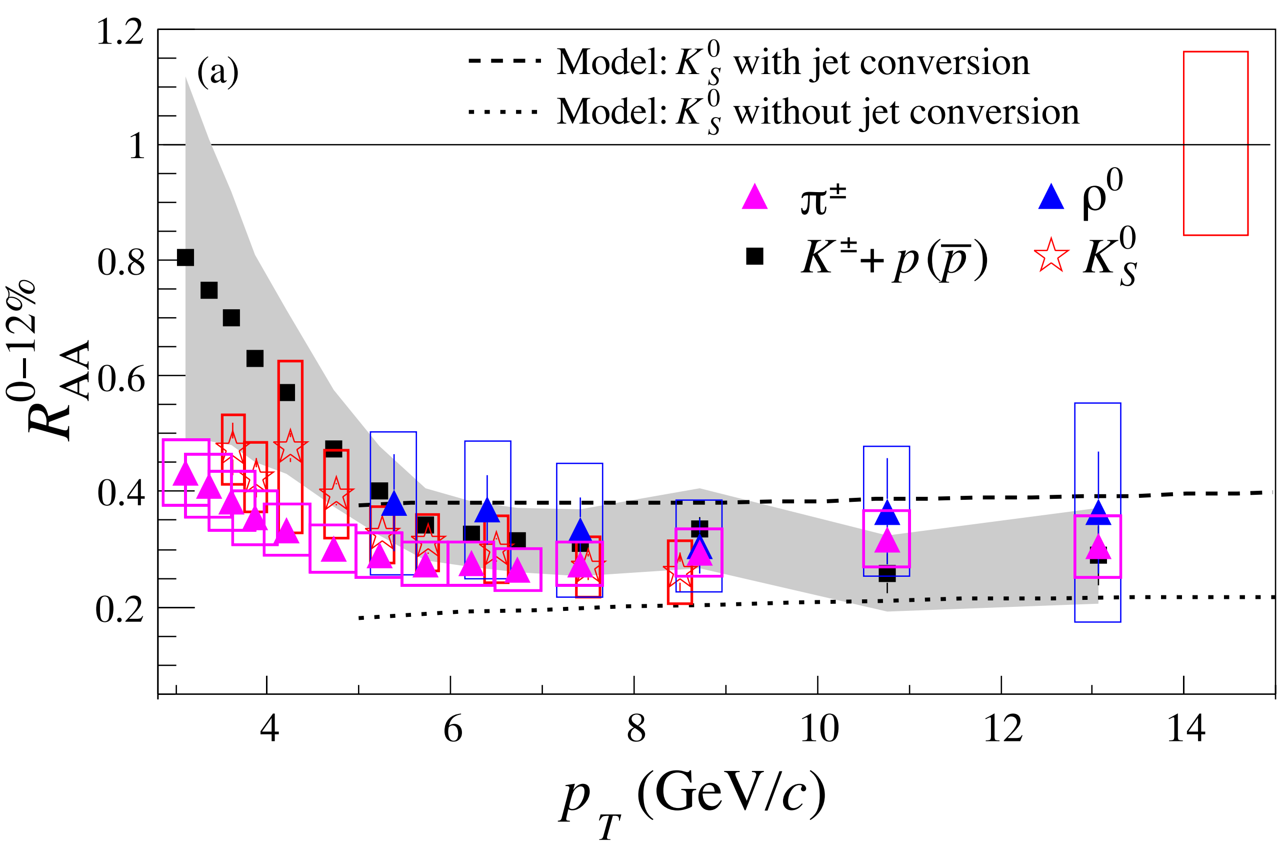


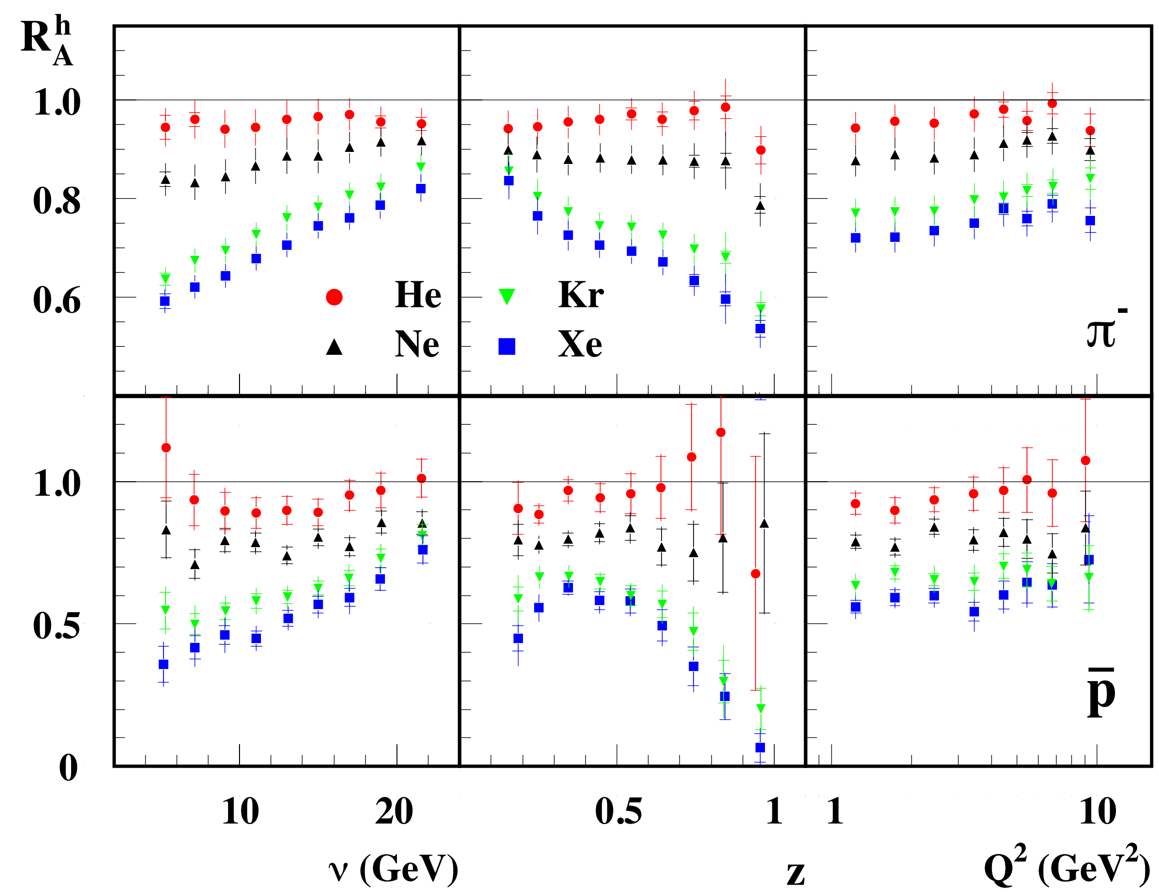
The need to know the gluons - initial conditions





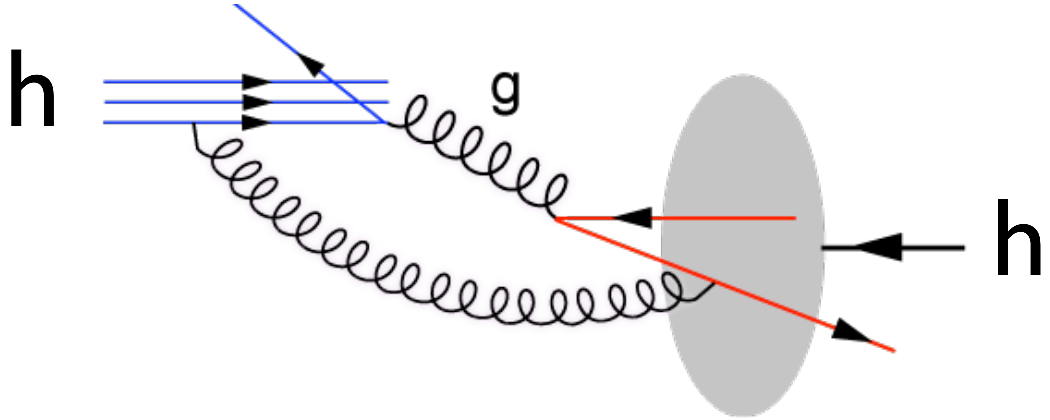






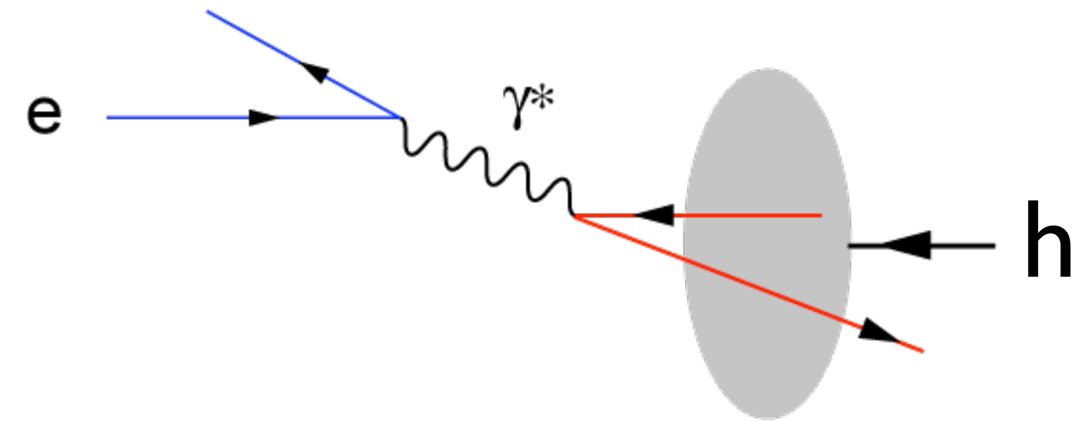
Why e+A and not p+A?

- Hadron-Hadron



  - ➡ Probe/Target interaction directly via gluons
  - ➡ Multiple colour interactions possible between probe and target
  - ➡ lacks the direct access to info of partons

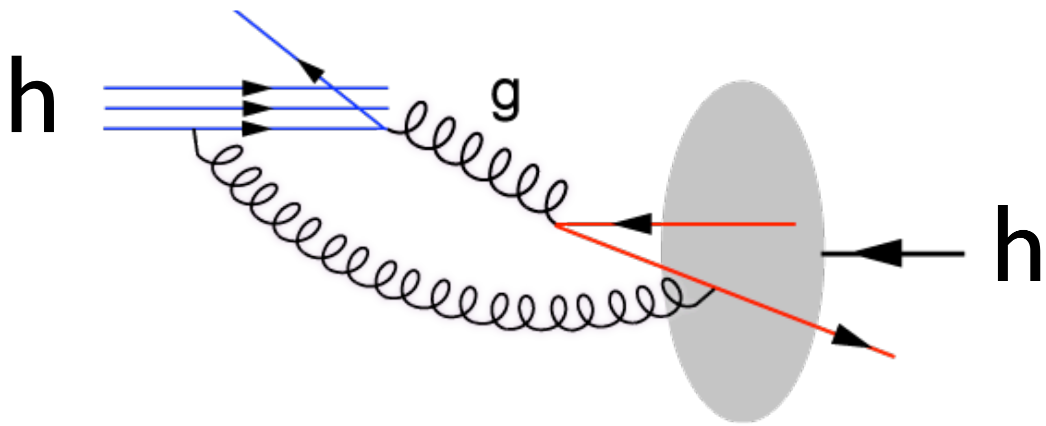
- Electron-Hadron (DIS)



  - ➡ Explore QCD and hadron structure via point-like probe
  - ➡ Indirect access to glue via modification of EM interaction
  - ➡ High precision and access to partonic kinematics

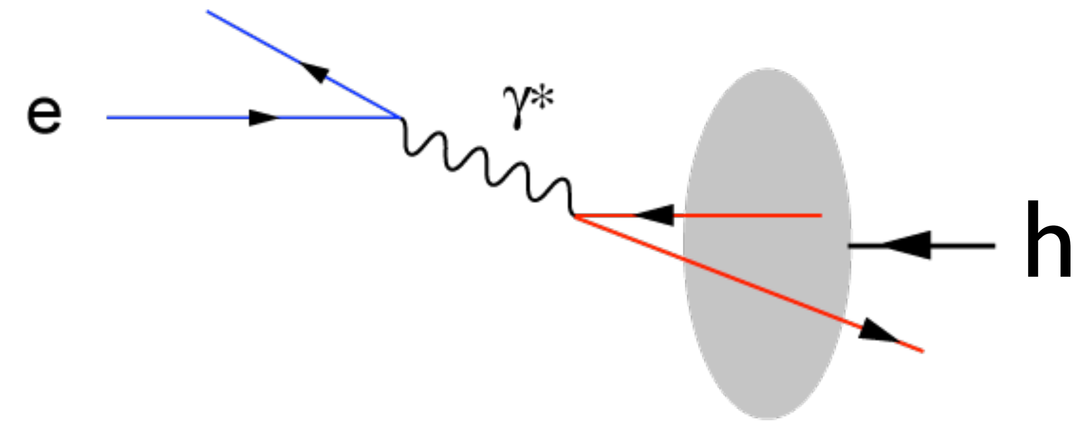
Why e+A and not p+A?

- Hadron-Hadron



  - ➡ Probe/Target interaction directly via gluons
  - ➡ Multiple colour interactions possible between probe and target
  - ➡ lacks the direct access to info of partons

- Electron-Hadron (DIS)



  - ➡ Explore QCD and hadron structure via point-like probe
  - ➡ Indirect access to glue via modification of EM interaction
  - ➡ High precision and access to partonic kinematics

Both are complementary and provide excellent information on properties of gluons in the nuclear wave functions

Precision measurements ⇒ ep, eA

Why e+A and not p+A?

- Hadron-Hadron
- Electron-Hadron (DIS)

h

h

➡ P
di

➡ M
p
ta

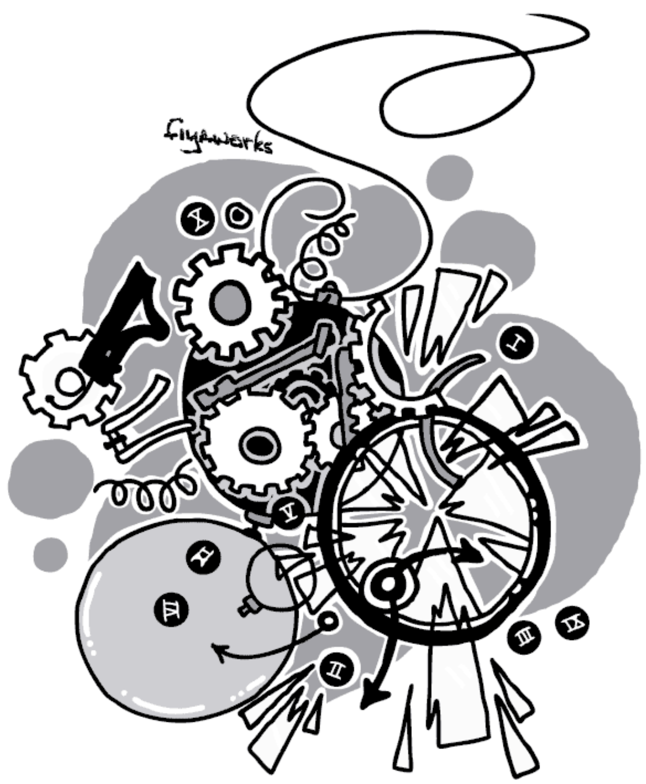
➡ la
o

n
robe

ia
action

ss to

Scattering of protons on protons
is like colliding Swiss watches to find out how they are built.



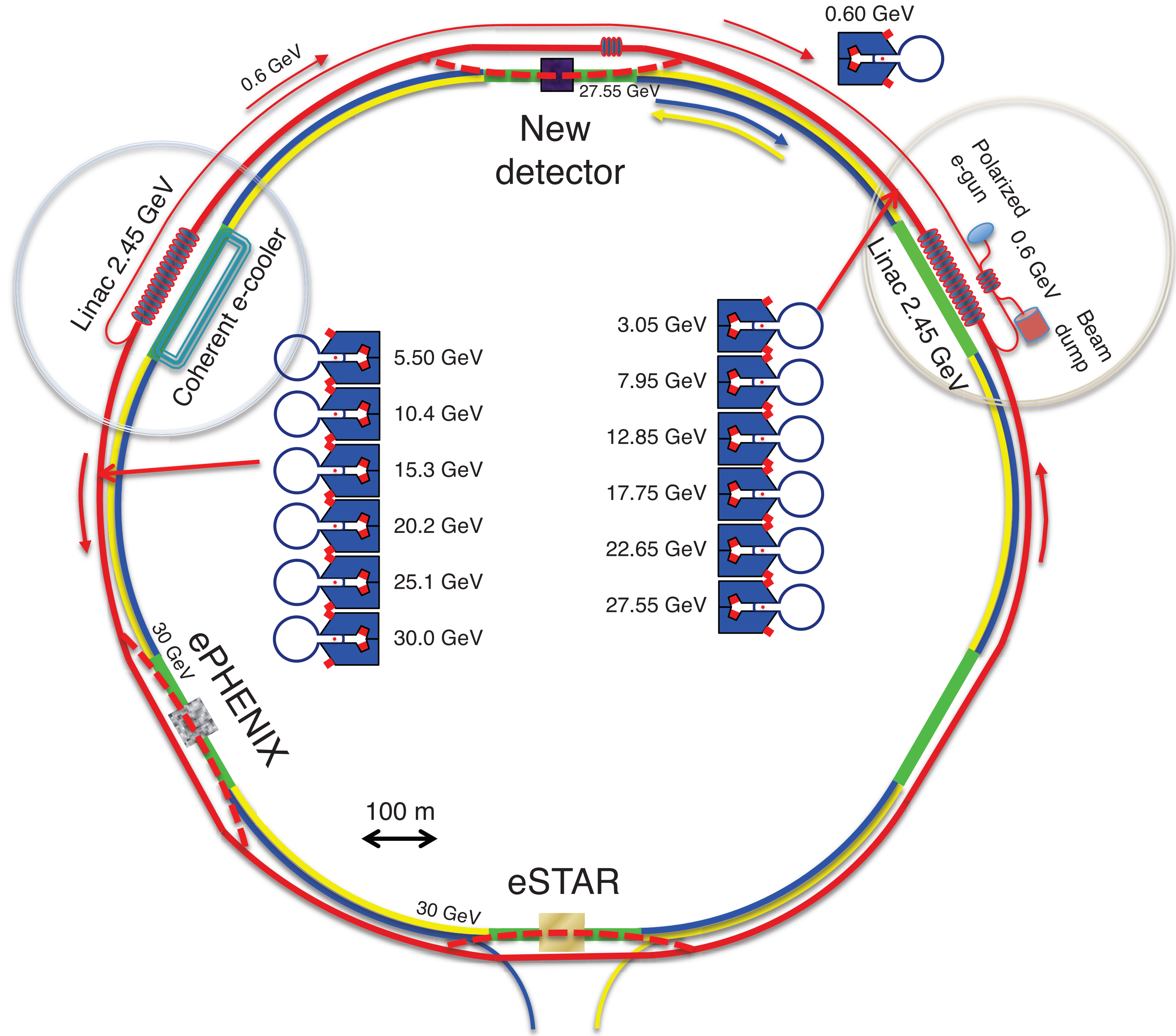
R. Feynman

Both ... on
properties of gluons in the nuclear wave functions

Precision measurements ⇒ ep, eA

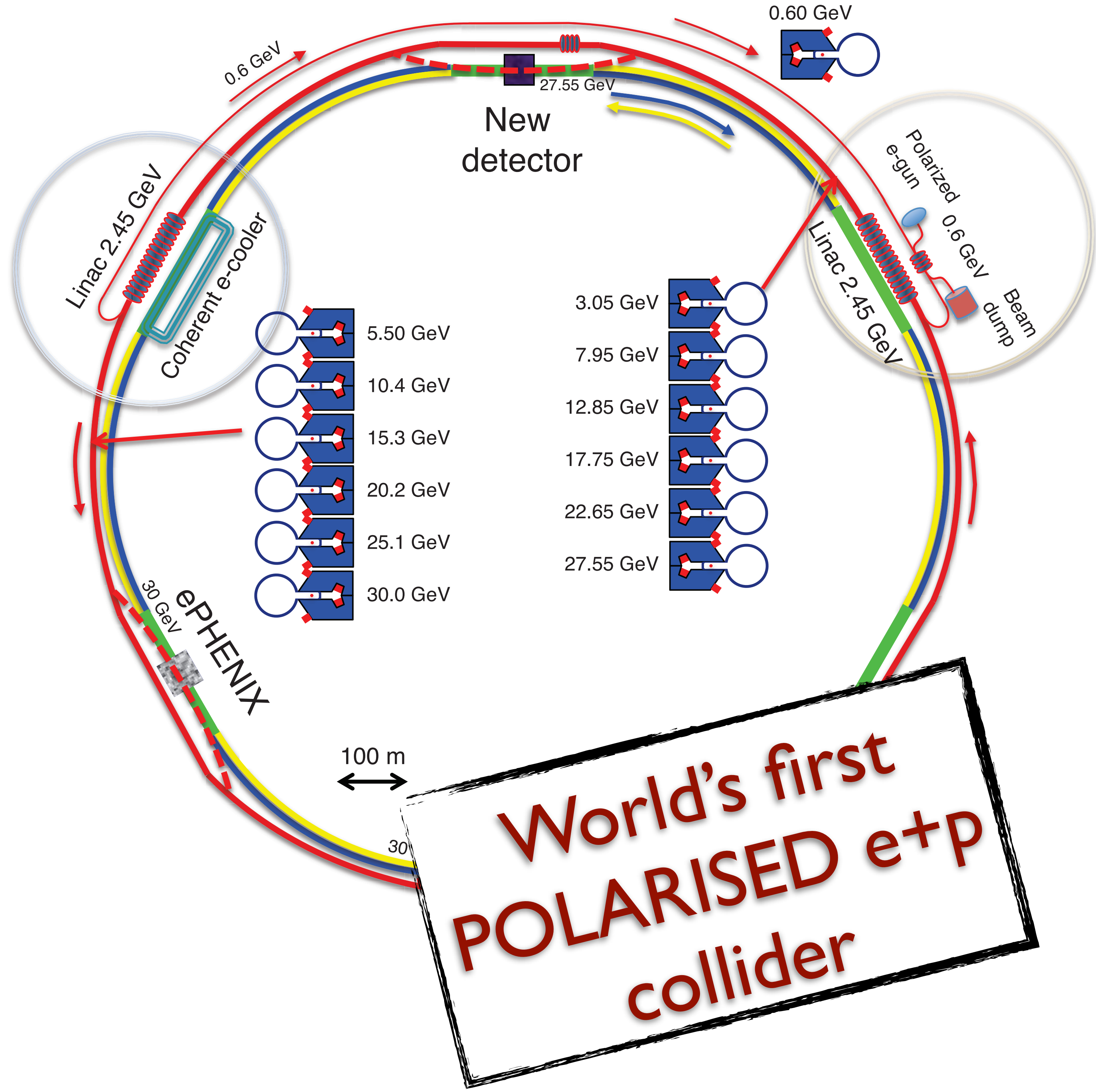
The eRHIC project

- eRHIC:
  - ➡ Utilises the RHIC ion beams
  - ➡ Two 2.45 GeV Energy Recovery Linacs (ERLs) accelerate the e^- beam
    - 6 separate rings accelerate the e^- up to a maximum energy of 30 GeV
  - ➡ 2-stage approach
    - Stage 1: e^- 5-10 GeV
    - Stage 2: e^- 20-30 GeV
  - ➡ Space for new detector at IP12
    - Possibilities for collisions in current STAR and PHENIX IPs



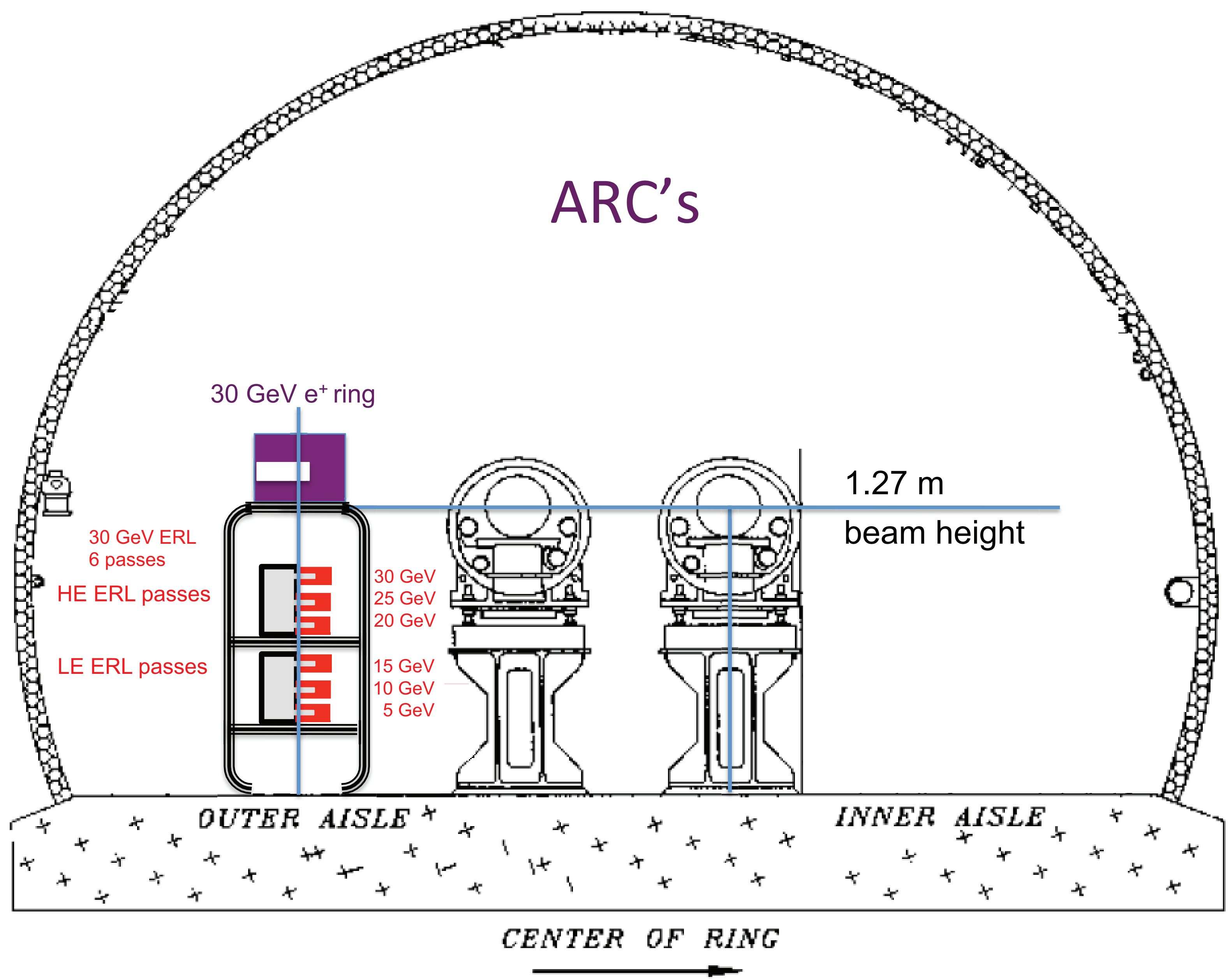
The eRHIC project

- eRHIC:
  - ➡ Utilises the RHIC ion beams
  - ➡ Two 2.45 GeV Energy Recovery Linacs (ERLs) accelerate the e⁻ beam
    - 6 separate rings accelerate the e⁻ up to a maximum energy of 30 GeV
  - ➡ 2-stage approach
    - Stage 1: e⁻ 5-10 GeV
    - Stage 2: e⁻ 20-30 GeV
  - ➡ Space for new detector at IP12
    - Possibilities for collisions in current STAR and PHENIX IPs



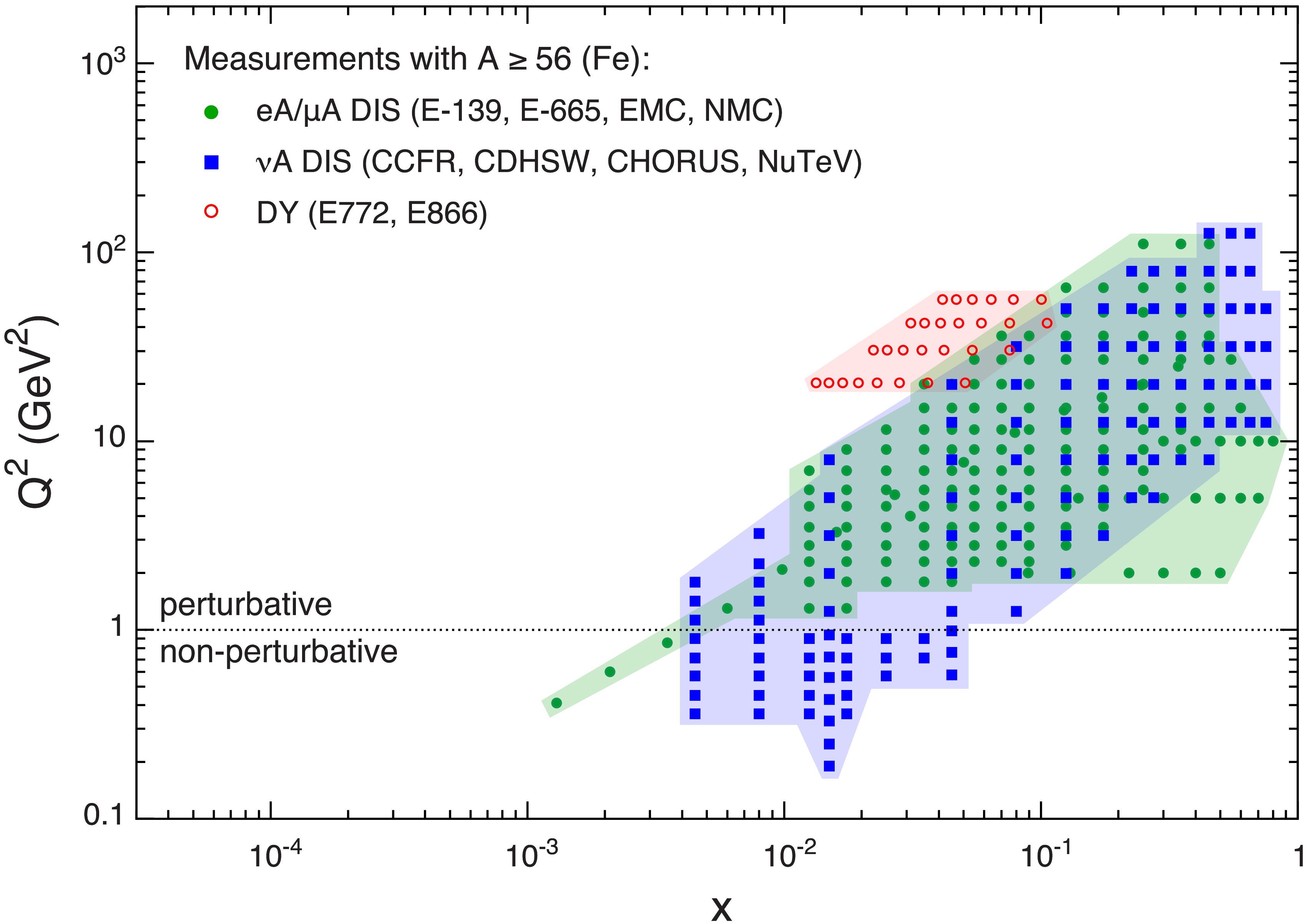
The eRHIC project

- eRHIC:
  - ➡ Utilises the RHIC ion beams
  - ➡ Two 2.45 GeV Energy Recovery Linacs (ERLs) accelerate the e^- beam
    - ‣ 6 separate rings accelerate the e^- up to a maximum energy of 30 GeV
  - ➡ 2-stage approach
    - ‣ Stage 1: e^- 5-10 GeV
    - ‣ Stage 2: e^- 20-30 GeV
  - ➡ Space for new detector at IP12
    - ‣ Possibilities for collisions in current STAR and PHENIX IPs



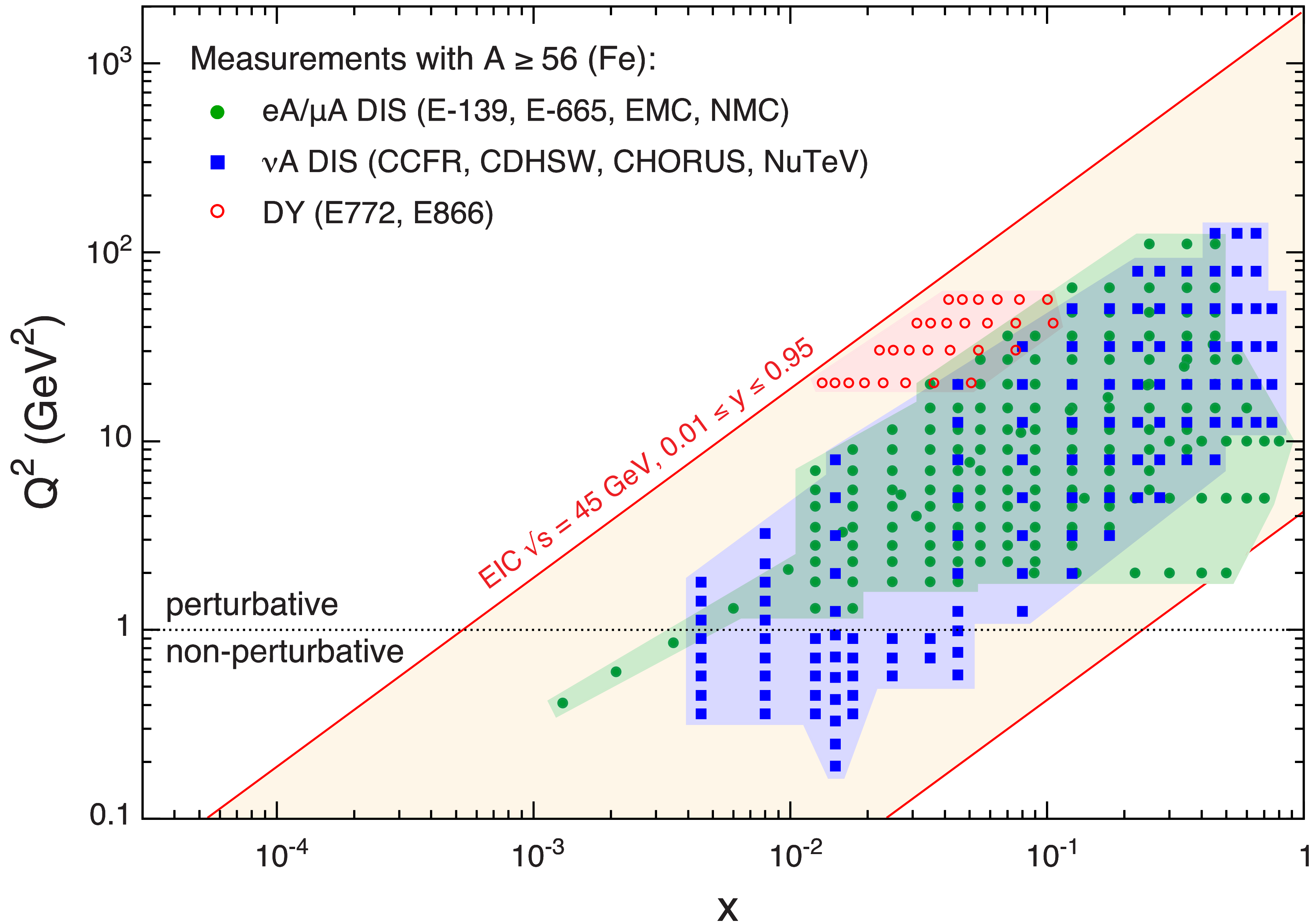
The eRHIC project

- eRHIC:
  - ➡ Utilises the RHIC ion beams
  - ➡ Two 2.45 GeV Energy Recovery Linacs (ERLs) accelerate the e^- beam
    - ‣ 6 separate rings accelerate the e^- up to a maximum energy of 30 GeV
  - ➡ Space for new detector at IP12
    - ‣ Possibilities for collisions in current STAR and PHENIX IPs



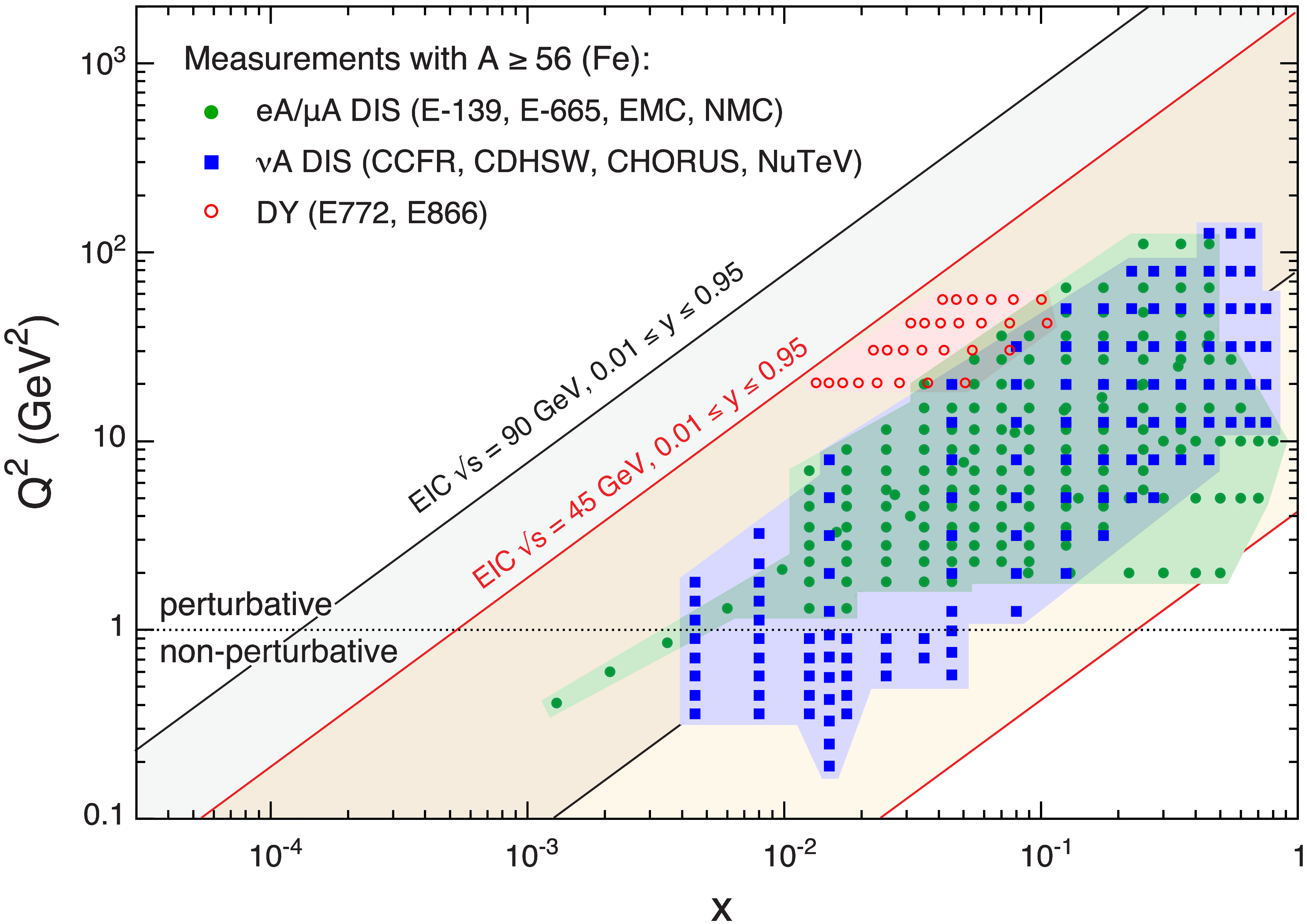
The eRHIC project

- eRHIC:
  - ➡ Utilises the RHIC ion beams
  - ➡ Two 2.45 GeV Energy Recovery Linacs (ERLs) accelerate the e^- beam
    - 6 separate rings accelerate the e^- up to a maximum energy of 30 GeV
  - ➡ Space for new detector at IP12
    - Possibilities for collisions in current STAR and PHENIX IPs



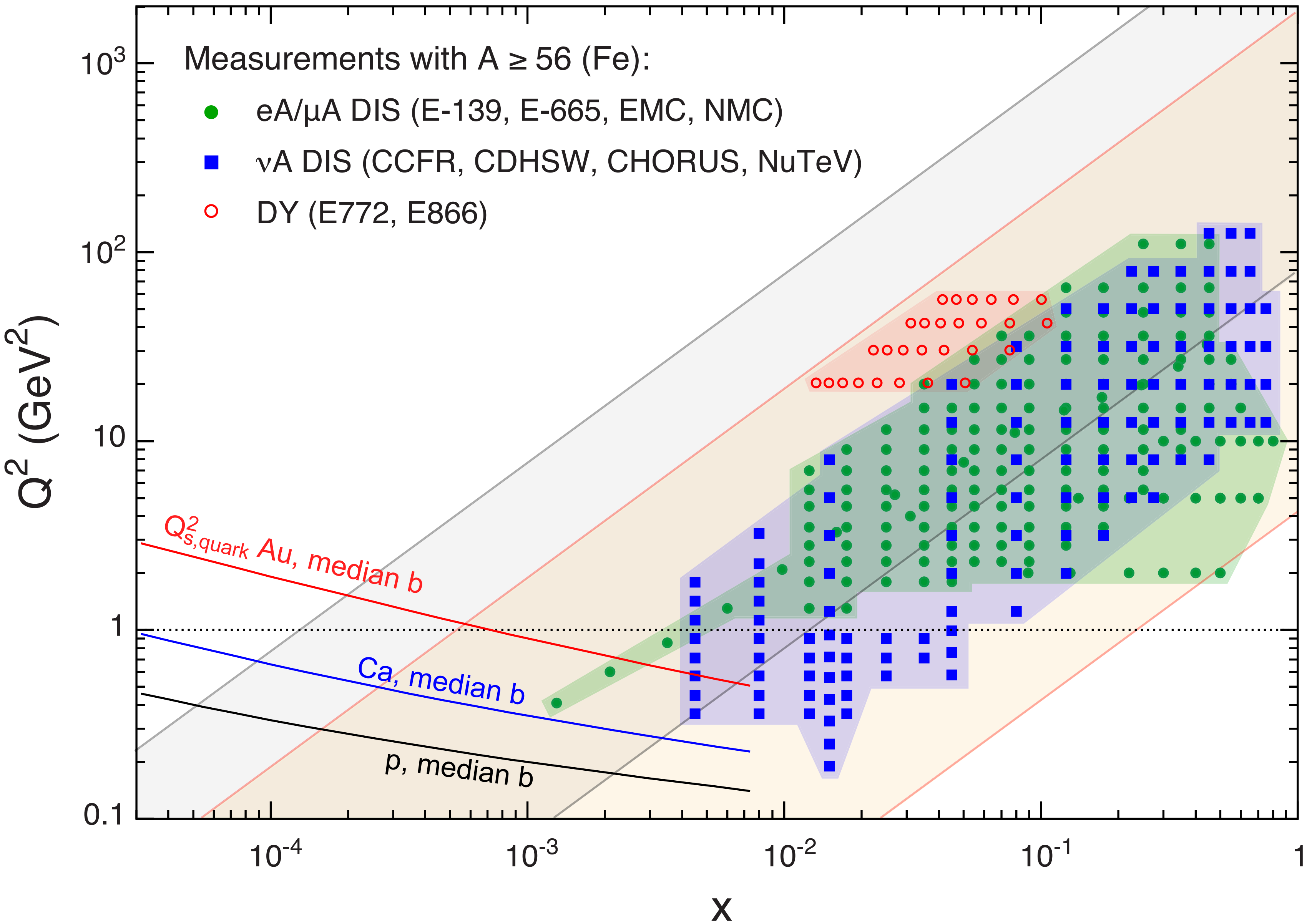
The eRHIC project

- eRHIC:
  - ➡ Utilises the RHIC ion beams
  - ➡ Two 2.45 GeV Energy Recovery Linacs (ERLs) accelerate the e⁻ beam
    - 6 separate rings accelerate the e⁻ up to a maximum energy of 30 GeV
  - ➡ Space for new detector at IP12
    - Possibilities for collisions in current STAR and PHENIX IPs



The eRHIC project

- eRHIC:
  - ➡ Utilises the RHIC ion beams
  - ➡ Two 2.45 GeV Energy Recovery Linacs (ERLs) accelerate the e⁻ beam
    - 6 separate rings accelerate the e⁻ up to a maximum energy of 30 GeV
  - ➡ Space for new detector at IP12
    - Possibilities for collisions in current STAR and PHENIX IPs



10 week INT programme - Autumn 2010

Organizers:
Daniel Boer
KVI, University of Groningen
D.Boer@rug.nl

Markus Diehl
DESY
markus.diehl@desy.de

Richard Milner
MIT
milner@mit.edu

Raju Venugopalan
Brookhaven National Laboratory
raju@quark.phy.bnl.gov

Werner Vogelsang
University of Tübingen
werner.vogelsang@uni-tuebingen.de

Program Coordinator:
Inge Dolan
inge@phys.washington.edu
(206) 685-4286

Talks online

Application form

Exit report

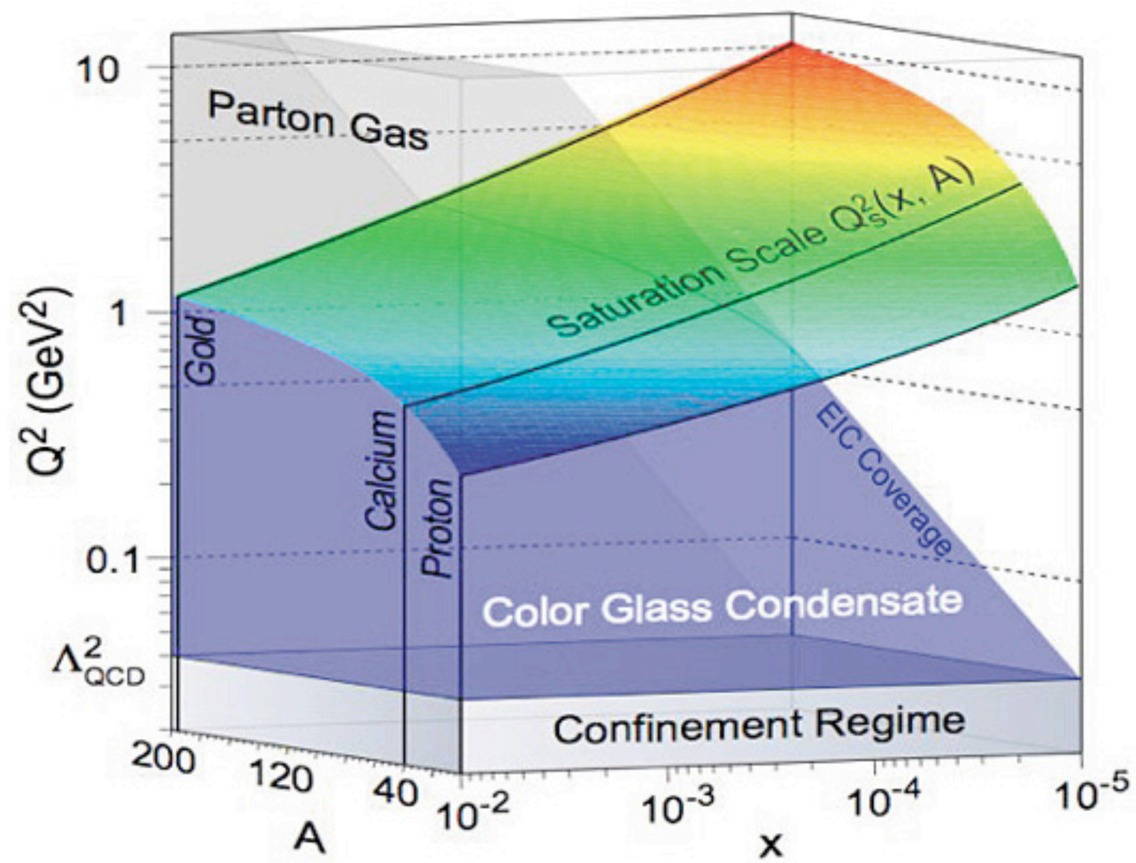
Friends of the INT

Obtain an INT preprint number

INT homepage

Gluons and the quark sea at high energies: distributions, polarization, tomography

September 13 to November 19, 2010



This INT program will address open questions about the dynamics of gluons and sea quarks in the nucleon and in nuclei. Answers to these questions are crucial for a deeper understanding of hadron and nuclear structure in QCD at high energies. Many of them are relevant for understanding QCD final states at the LHC, which often provide a background for physics beyond the standard model. The topics addressed in this program have important ramifications for understanding the matter produced in heavy-ion collisions at RHIC and the LHC.

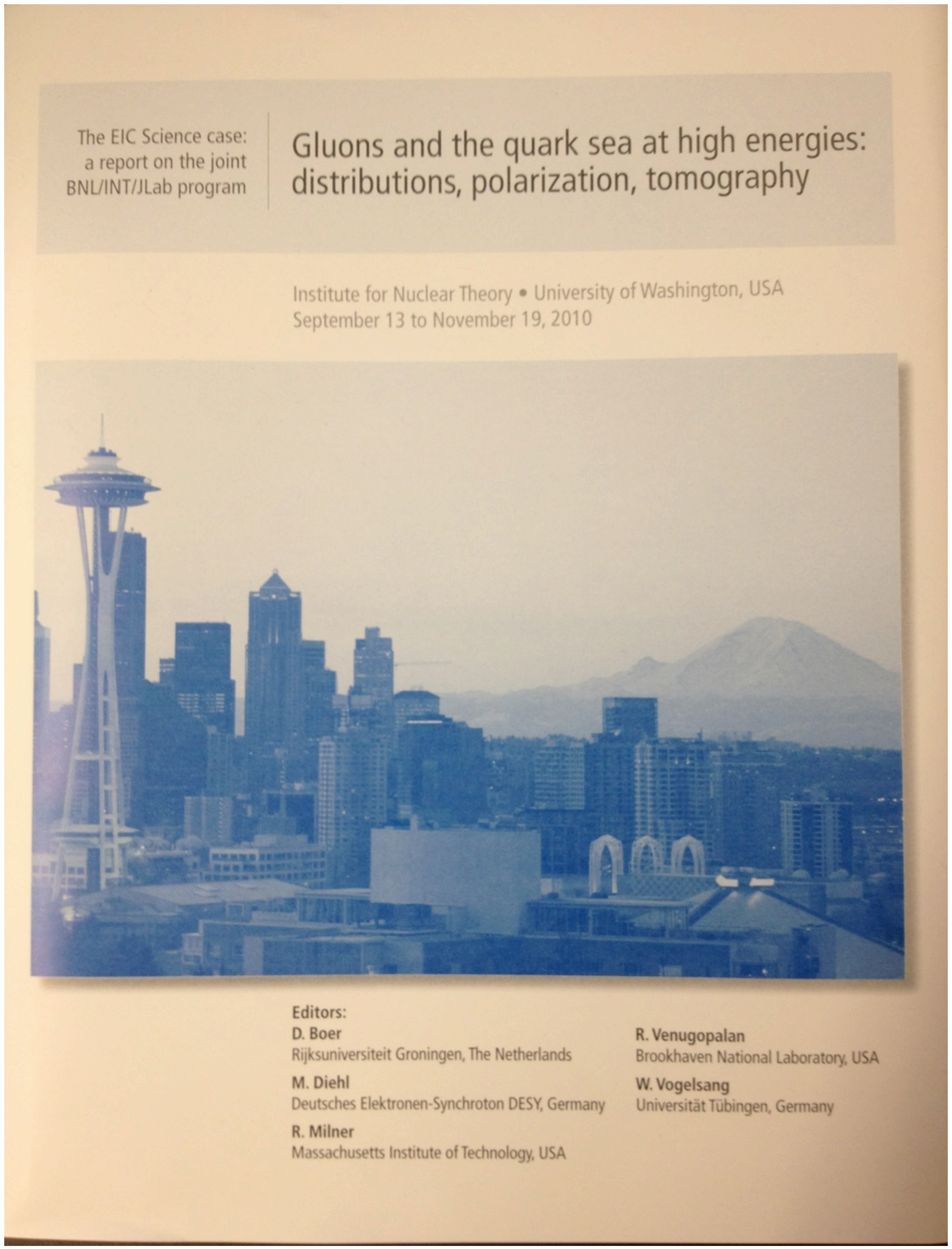
http://www.int.washington.edu/PROGRAMS/10-3/

10 week INT programme - Autumn 2010

week	dates	topics
1	13–17 Sept	**Workshop** on "Perturbative and Non-Perturbative Aspects of QCD at Collider Energies" Agenda
2	20–24 Sept	open conceptual issues: factorization and universality, spin and flavor structure, distributions and correlations Agenda
3–5	27 Sept – 15 Oct	small x, saturation, diffraction, nuclear effects; connections to p+A and A+A physics; fragmentation/hadronization in vacuum and in medium Agenda for week 3 Agenda for week 4 Agenda for week 5
6–7	18–29 Oct	parton densities (unpolarized and polarized), fragmentation functions, electroweak physics Agenda for week 6 Agenda for week 7
8–9	1–12 Nov	longitudinal and transverse nucleon structure; spin and orbital effects (GPDs, TMDs, and all that) Agenda for week 8 Agenda for week 9
10	16–19 Nov	**Workshop** on "The Science Case for an EIC" Agenda for week 10

http://www.int.washington.edu/PROGRAMS/10-3/

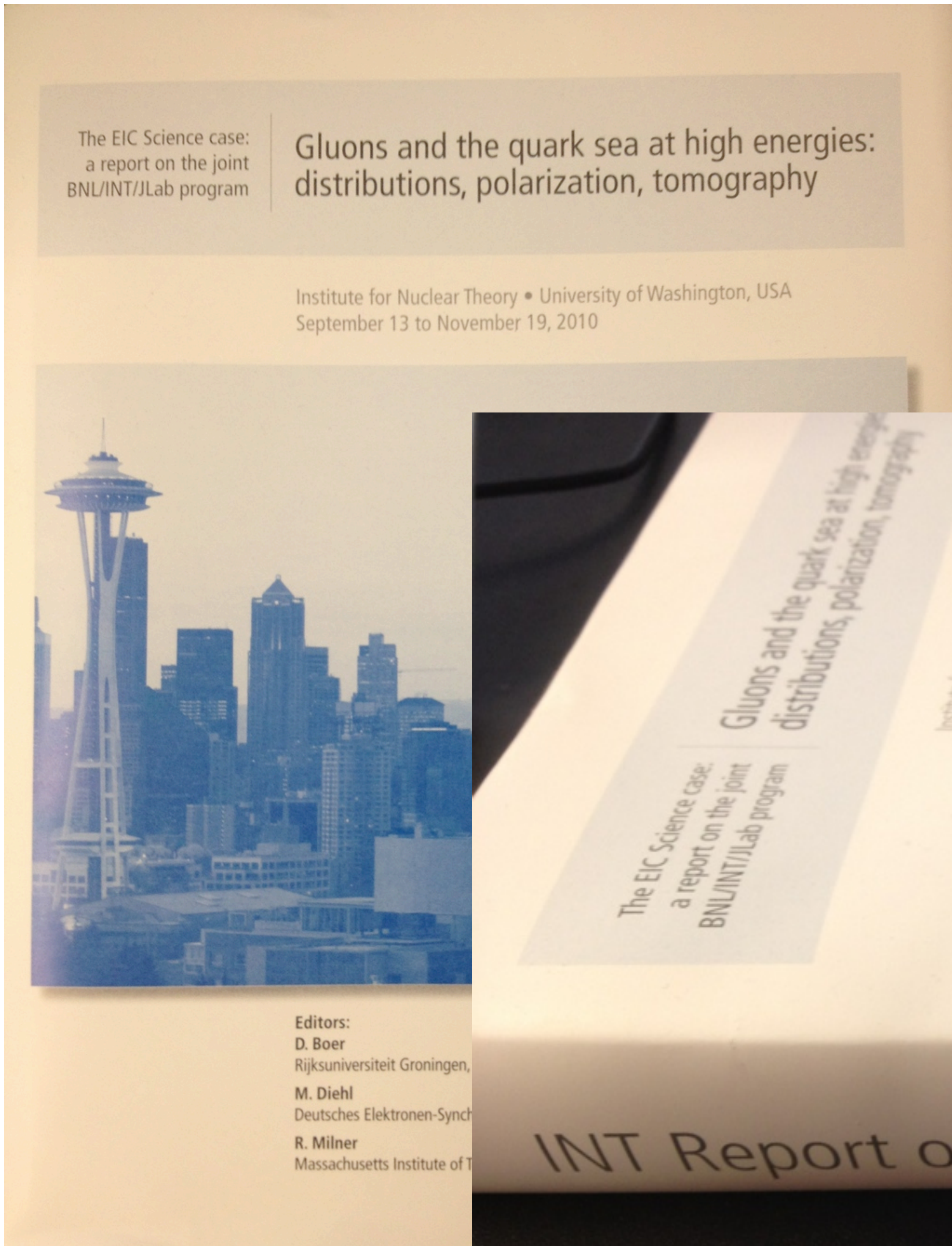
INT Writeup….

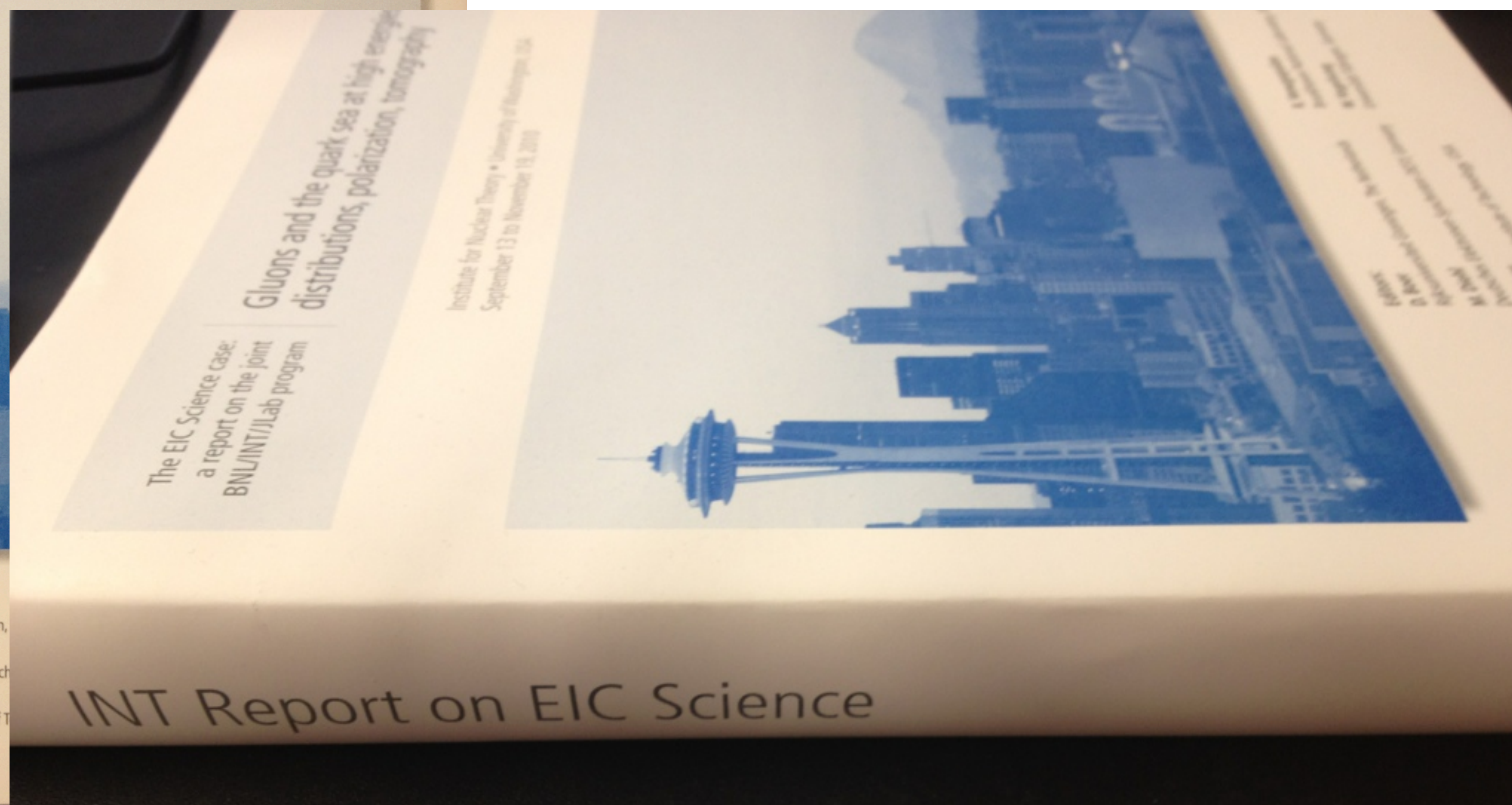


- ~ 6 months to write
  - ➡ 189 authors
  - ➡ 7 chapters, 550 pages
- arXiv:1108.1713

INT Writeup….

- ~ 6 months to write
  - ➡ 189 authors
  - ➡ 7 chapters, 550 pages
- arXiv:1108.1713





Followup EIC White Paper

Electron Ion Collider:

The Next QCD Frontier

Understanding the glue that binds us all

Chapter 3

The Nucleus: A Laboratory for QCD

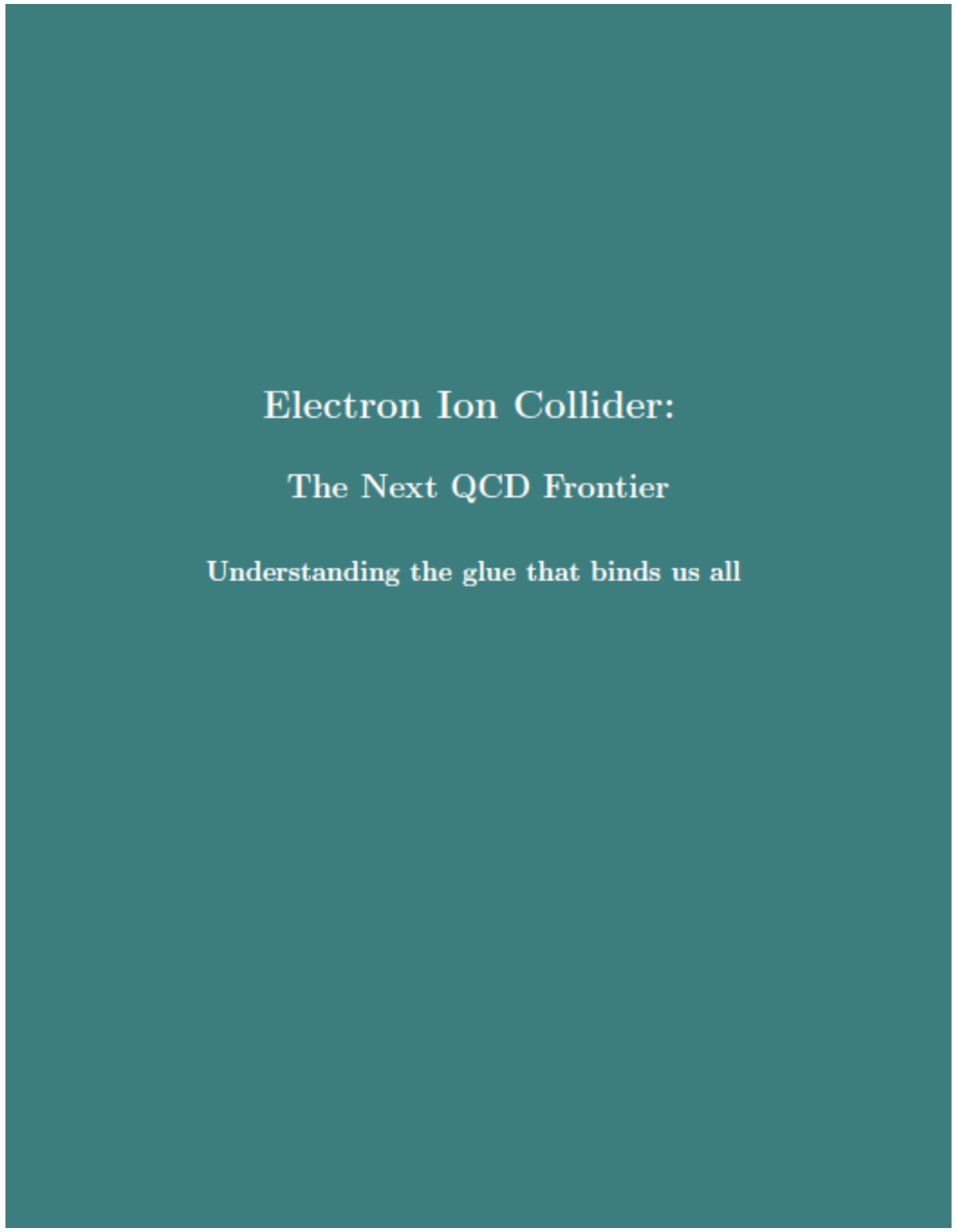
QCD, the accepted theory of strong interactions, is in general very successful in describing a broad range of hadronic and nuclear phenomena. One of the main achievements in our understanding of QCD is the running of the strong coupling constant and related to it asymptotic freedom, which is a name for the theoretically predicted and experimentally established fact that quarks and gluons are almost free at very short (asymptotic) distances inside the hadrons [113, 114]. QCD is often studied in the deep inelastic scattering (DIS) experiments, in which one probes the inner structure of the proton or nucleus by scattering a small probe (a lepton) on it. The lepton probes the quark distribution in the proton or nucleus by exchanging a photon with it. The past DIS experiments were very successful in determining the quark structure of the proton and of some light nuclei.

Despite the many successes in our understanding of QCD, some profound mysteries remain. One of them is quark confinement: quarks can not be free (for a long time) in nature and are always confined inside bound states – the hadrons. Another one is the mass of the proton (and other hadrons), which, at 938 MeV is much larger than the sum of the valence quark masses (about 10 MeV). Both of these problems at the moment can only be tackled by numerical QCD simulations on the lattice. The current consensus is that the gluons are responsible for both the quark confinement and much of the hadronic mass. The gluons, which bind quarks together into mesons (bound states of a quark and an anti-quark) and baryons (bound states of three quarks), significantly contribute to the masses of hadrons. At the same time gluons are significantly less well-understood than quarks. Unlike photons, the carriers of the electromagnetic force, gluons interact with each other. The underlying non-linear dynamics of this self-interaction is hard to put under theoretical control. Gluons are quite little-studied for particles providing over 98% of the proton and neutron masses, generating much of the visible matter mass in the Universe.[1] In addition, it is known that gluons play a dominant role in high energy DIS, hadronic and nuclear collisions, being responsible for much of the particle production and total cross sections in these processes. In high-energy heavy-ion collisions it is the gluons which are likely to be responsible for production and thermalization of the medium made out of deconfined

[1] One may compare the gluons to the Higgs boson, the search for which received a lot of attention in recent decades: while the Standard Model Higgs, if found, would account for the masses of all the known quarks along with the $W^{\pm}$ and Z bosons, this would still add up to only about 5% of the mass in the visible Universe.

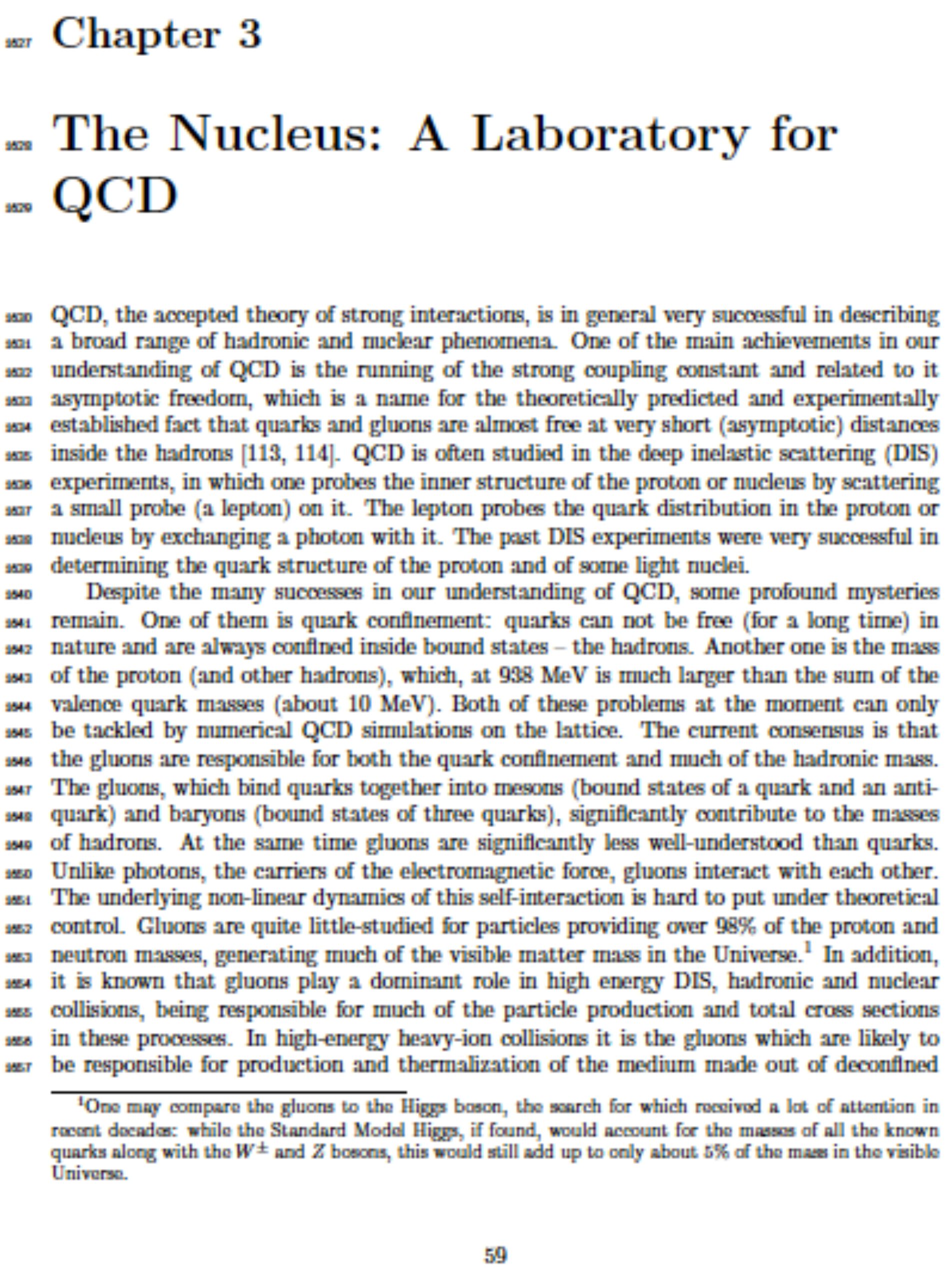
59

Followup EIC White Paper


Electron Ion Collider:

The Next QCD Frontier

Understanding the glue that binds us all


Chapter 3

The Nucleus: A Laboratory for QCD

QCD, the accepted theory of strong interactions, is in general very successful in describing a broad range of hadronic and nuclear phenomena. One of the main achievements in our understanding of QCD is the running of the strong coupling constant and related to it asymptotic freedom, which is a name for the theoretically predicted and experimentally established fact that quarks and gluons are almost free at very short (asymptotic) distances inside the hadrons [113, 114]. QCD is often studied in the deep inelastic scattering (DIS) experiments, in which one probes the inner structure of the proton or nucleus by scattering a small probe (a lepton) on it. The lepton probes the quark distribution in the proton or nucleus by exchanging a photon with it. The past DIS experiments were very successful in determining the quark structure of the proton and of some light nuclei.

Despite the many successes in our understanding of QCD, some profound mysteries remain. One of them is quark confinement: quarks can not be free (for a long time) in nature and are always confined inside bound states – the hadrons. Another one is the mass of the proton (and other hadrons), which, at 938 MeV is much larger than the sum of the valence quark masses (about 10 MeV). Both of these problems at the moment can only be tackled by numerical QCD simulations on the lattice. The current consensus is that the gluons are responsible for both the quark confinement and much of the hadronic mass. The gluons, which bind quarks together into mesons (bound states of a quark and an anti-quark) and baryons (bound states of three quarks), significantly contribute to the masses of hadrons. At the same time gluons are significantly less well-understood than quarks. Unlike photons, the carriers of the electromagnetic force, gluons interact with each other. The underlying non-linear dynamics of this self-interaction is hard to put under theoretical control. Gluons are quite little-studied for particles providing over 98% of the proton and neutron masses, generating much of the visible matter mass in the Universe.[1] In addition, it is known that gluons play a dominant role in high energy DIS, hadronic and nuclear collisions, being responsible for much of the particle production and total cross sections in these processes. In high-energy heavy-ion collisions it is the gluons which are likely to be responsible for production and thermalization of the medium made out of deconfined

[1]One may compare the gluons to the Higgs boson, the search for which received a lot of attention in recent decades: while the Standard Model Higgs, if found, would account for the masses of all the known quarks along with the $W^\pm$ and Z bosons, this would still add up to only about 5% of the mass in the visible Universe.

59

- Final draft has just been released to the community for consideration
- 148 pages in total
  - ➡ 50 pages of which dedicated to discussing e+A part of the project

Fundamental questions which arise:

- What is the role of strong gluon fields, parton saturation effects and collective gluon excitations in scattering off nuclei?

  ➡ tantalising hints of a saturated/CGC regime have been observed at HERA/RHIC/LHC

Fundamental questions which arise:

- What is the role of strong gluon fields, parton saturation effects and collective gluon excitations in scattering off nuclei?
  - ➡ tantalising hints of a saturated/CGC regime have been observed at HERA/RHIC/LHC
- Can we experimentally find the evidence of non-linear QCD evolution in high-energy scattering off nuclei?
  - ➡ x-dependence of DIS cross-sections and structure functions
  - ➡ The discovery of the saturation regime would not be complete without unambiguous evidence in favour of these non-linear equations

Fundamental questions which arise:

- What is the momentum and spatial distribution of gluons and sea quarks in nuclei?
  - ➡ Large-x: the physics of multiple scatterings at allows us to reconstruct the momentum and impact parameter distributions of gluons and sea quarks in nuclei
  - ➡ Small-x: momentum distribution may allow us to identify the saturation scale, Q_s

Fundamental questions which arise:

- What is the momentum and spatial distribution of gluons and sea quarks in nuclei?
  - ➡ Large-x: the physics of multiple scatterings at allows us to reconstruct the momentum and impact parameter distributions of gluons and sea quarks in nuclei
  - ➡ Small-x: momentum distribution may allow us to identify the saturation scale, Q_s
- Are there strong colour (quark and gluon density) fluctuations inside of a large nucleus? How does the nucleus respond to the propagation of a colour charge through it?
  - ➡ Need to understand fluctuations in order to fully understand the spatial and momentum distributions of sea quarks and gluons

Important Measurements

Deliverables	Observables	What we learn	Stage-1	Stage-II
integrated gluon distributions	$F_{2,L}$	nuclear wave function; saturation, Q_s	gluons at $10^{-3} < x < 1$	saturation regime
k_T dependent gluons; gluon correlations	di-hadron correlations	non-linear QCD evolution / universality	onset of saturation	measure Q_s
b-dependent gluons; gluon correlations	DVCS; diffractive vector mesons	interplay between small-x evolution and confinement	moderate x with light, heavy nuclei	smaller x, saturation
transport coefficients in cold matter	large-x SIDIS; jets	parton energy loss, shower evolution; energy loss mechanisms	light flavours and charm; jets	rare probes and bottom; large-x gluons

Important Measurements

See talk later today by Tobias Toll

b-dependent gluons; gluon correlations	DVCS; diffractive vector mesons	interplay between small-x evolution and confinement	moderate x with light, heavy nuclei	smaller x, saturation

Integrated gluon distributions from inclusive structure functions

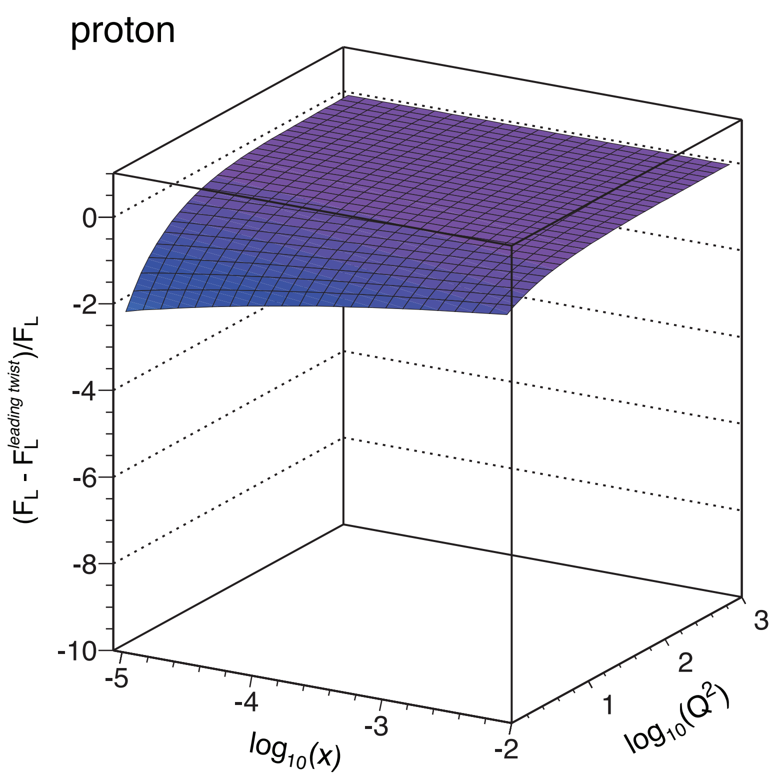
Deliverables	Observables	What we learn	Stage-I	Stage-II
integrated gluon distributions	$F_{2,L}$	nuclear wave function; saturation, Q_s	gluons at $10^{-3} < x < 1$	saturation regime

integrated gluon distributions	$F^{c}_{2,L}$, $F^{D}_{2,L}$	nuclear wave function; saturation, Q_s	difficult measurement / interpretation	saturation regime

charm diffractive

The effects of higher-twist corrections on F_L

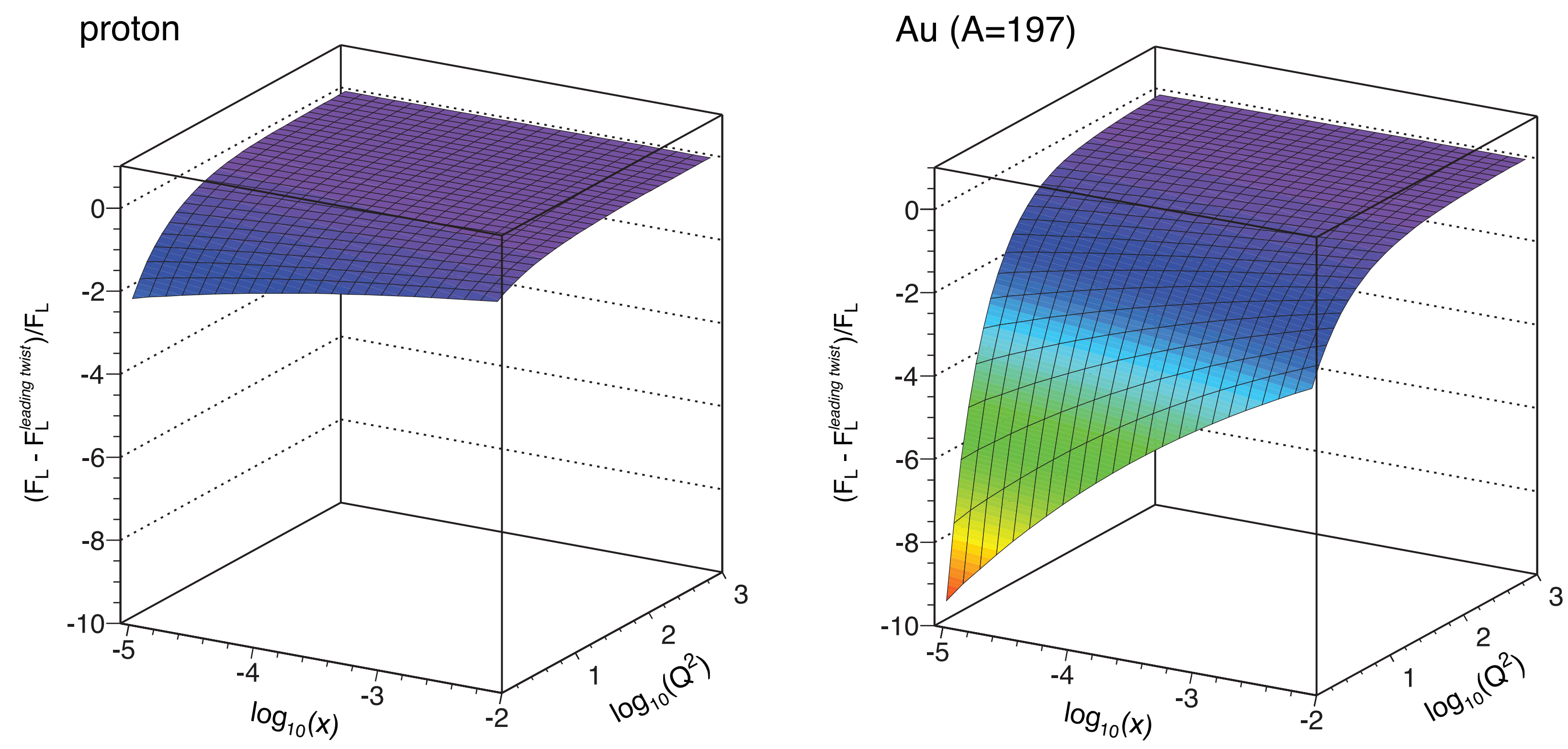
$$\frac{F_L - F_L^{leading\ twist}}{F_L}$$



- Plotting F_L-$F_L^{leading\ twist}/F_L$ coming out of saturation inspired GBW model
    - ➡ protons: little effect of leading twist corrections, only starting to come in at small-x and small Q2

The effects of higher-twist corrections on F_L

$$\frac{F_L - F_L^{leading\ twist}}{F_L}$$



- Plotting F_L-$F_L^{leading\ twist}/F_L$ coming out of saturation inspired GBW model
  - ➡ protons: little effect of leading twist corrections, only starting to come in at small-x and small Q2
  - ➡ Au: much larger corrections coming from leading twist contributions
    - ‣ nuclear "oomph" effects well manifested in the F_L structure function

Measuring the gluons: extracting F_L

$$\sigma_r(x, Q^2) = F_2^A(x, Q^2) - \frac{y^2}{Y^+} F_L^A(x, Q^2)$$

Measuring the gluons: extracting F_L

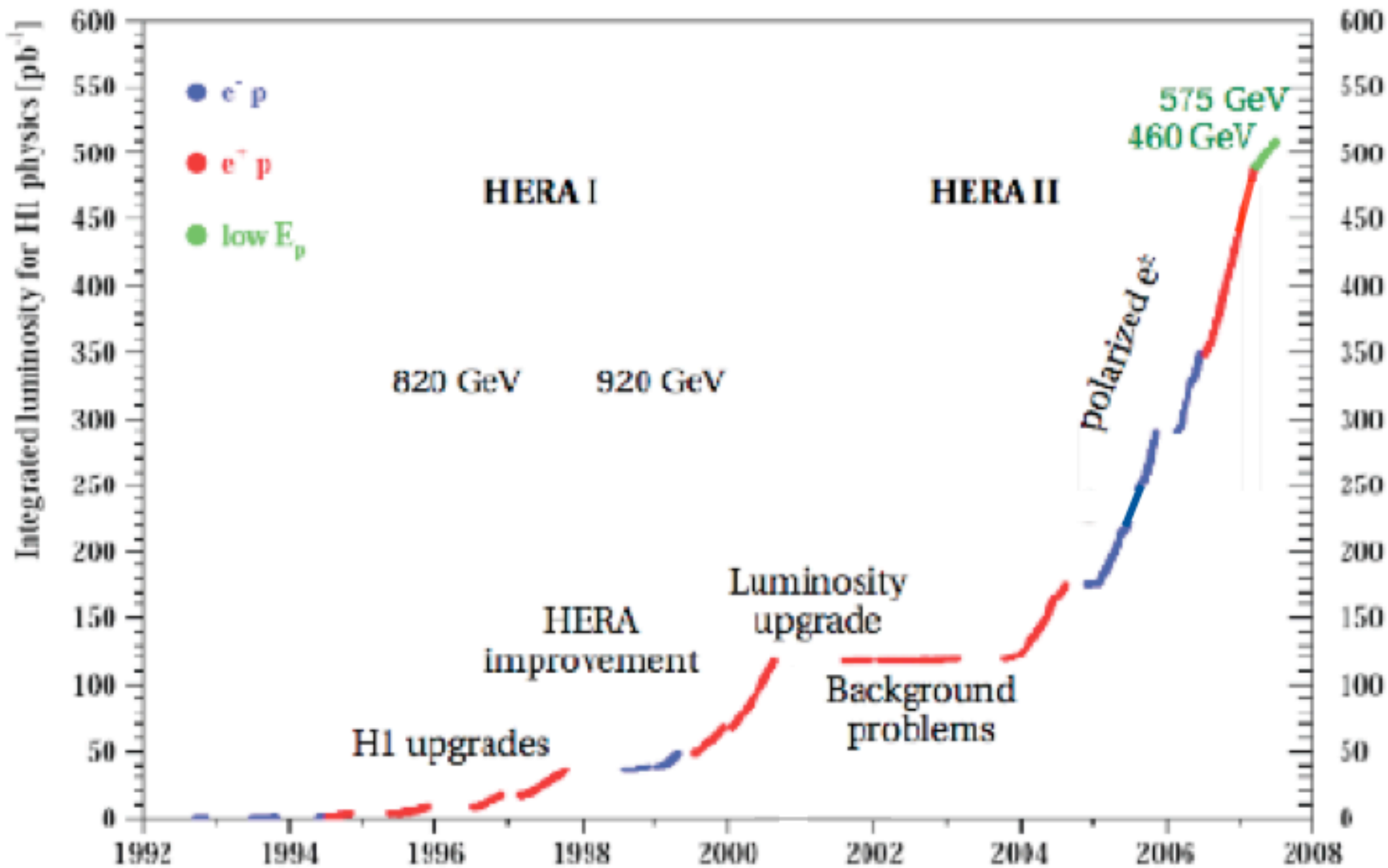
$$\sigma_r(x,Q^2) = F_2^A(x,Q^2) - \frac{y^2}{Y^+} F_L^A(x,Q^2)$$

- $F_L \sim \alpha_s \, xG(x,Q^2)$
  - ➡ $y = Q^2/xs$
  - ➡ require an energy scan to extract F_L

Measuring the gluons: extracting F_L

$$\sigma_r(x,Q^2) = F_2^A(x,Q^2) - \frac{y^2}{Y+} F_L^A(x,Q^2)$$

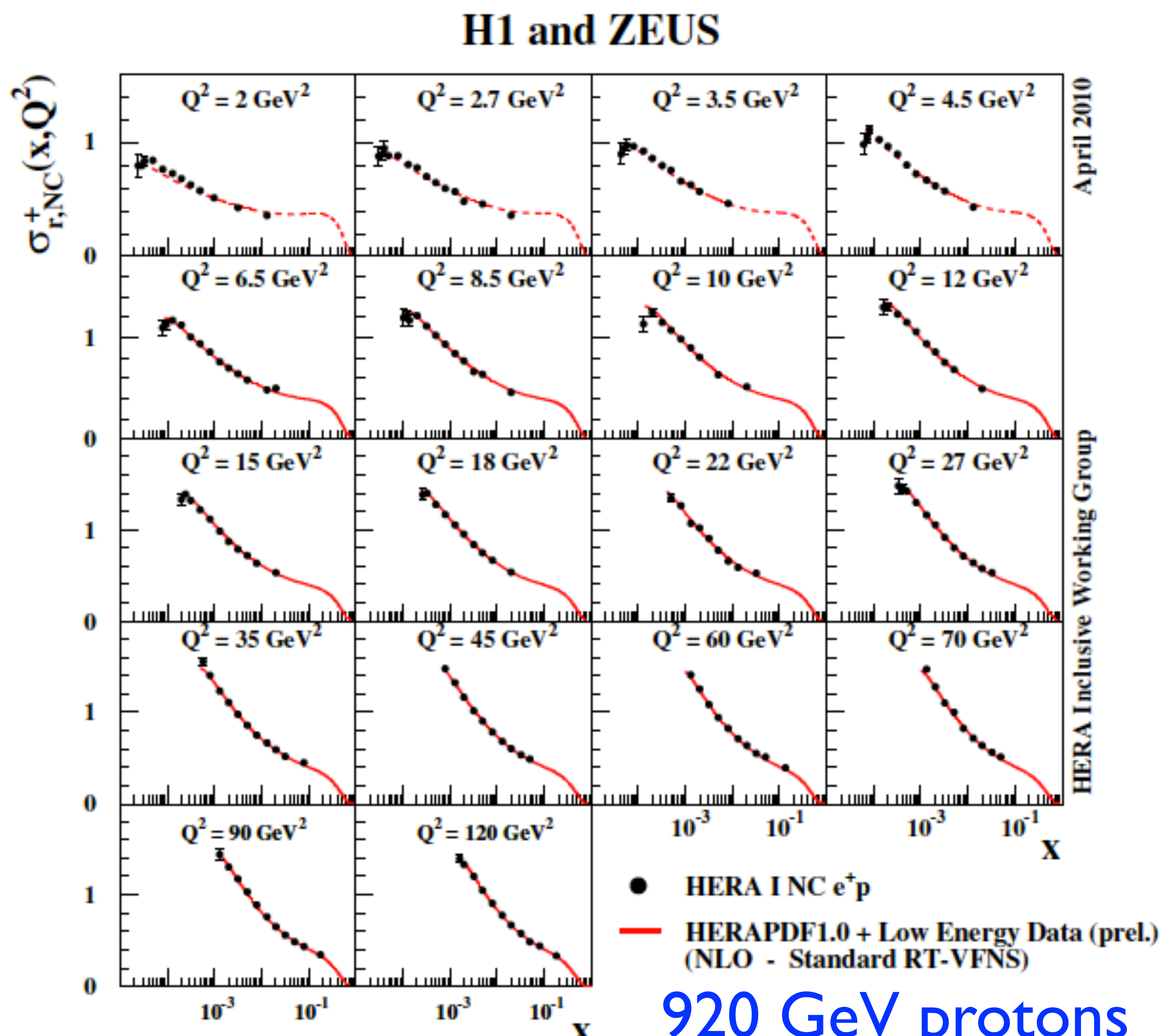
- $F_L \sim \alpha_s \, xG(x,Q^2)$
  - ➡ $y = Q^2/xs$
  - ➡ require an energy scan to extract F_L
- 3 different proton energies run at HERA
  - ➡ 2 low-statistics runs
  - ➡ bad for F_L extraction



Measuring the gluons: extracting F_L

$$\sigma_r(x,Q^2) = F_2^A(x,Q^2) - \frac{y^2}{Y+} F_L^A(x,Q^2)$$

- $F_L \sim \alpha_s\, xG(x,Q^2)$
    - ➡ $y = Q^2/xs$
    - ➡ require an energy scan to extract F_L
- 3 different proton energies run at HERA
    - ➡ 2 low-statistics runs
    - ➡ bad for F_L extraction

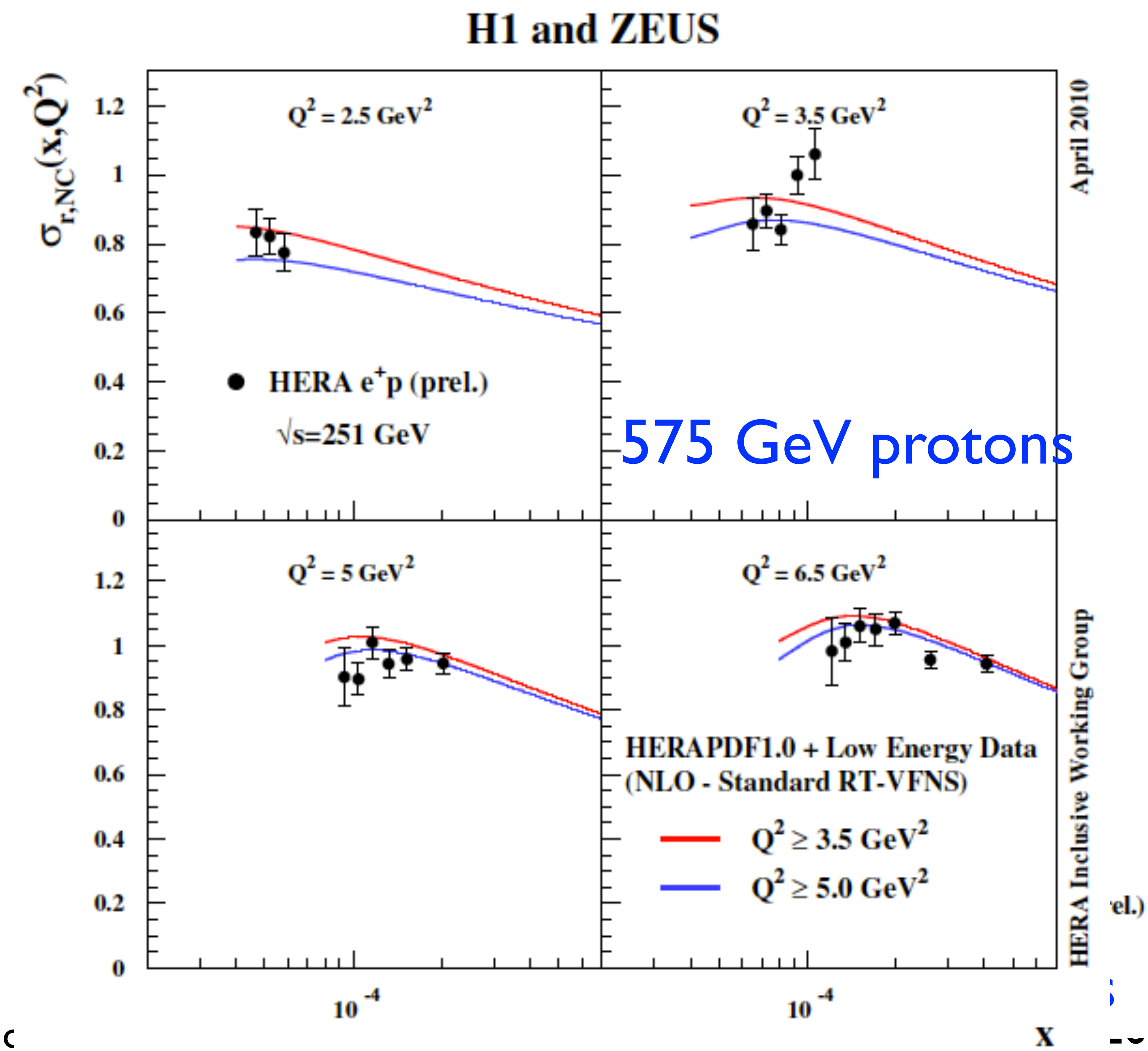


920 GeV protons

Measuring the gluons: extracting F_L

$$\sigma_r(x,Q^2) = F_2^A(x,Q^2) - \frac{y^2}{Y+} F_L^A(x,Q^2)$$

- $F_L \sim \alpha_s\, xG(x,Q^2)$
  - ➡ $y = Q^2/xs$
  - ➡ require an energy scan to extract F_L
- 3 different proton energies run at HERA
  - ➡ 2 low-statistics runs
  - ➡ bad for F_L extraction

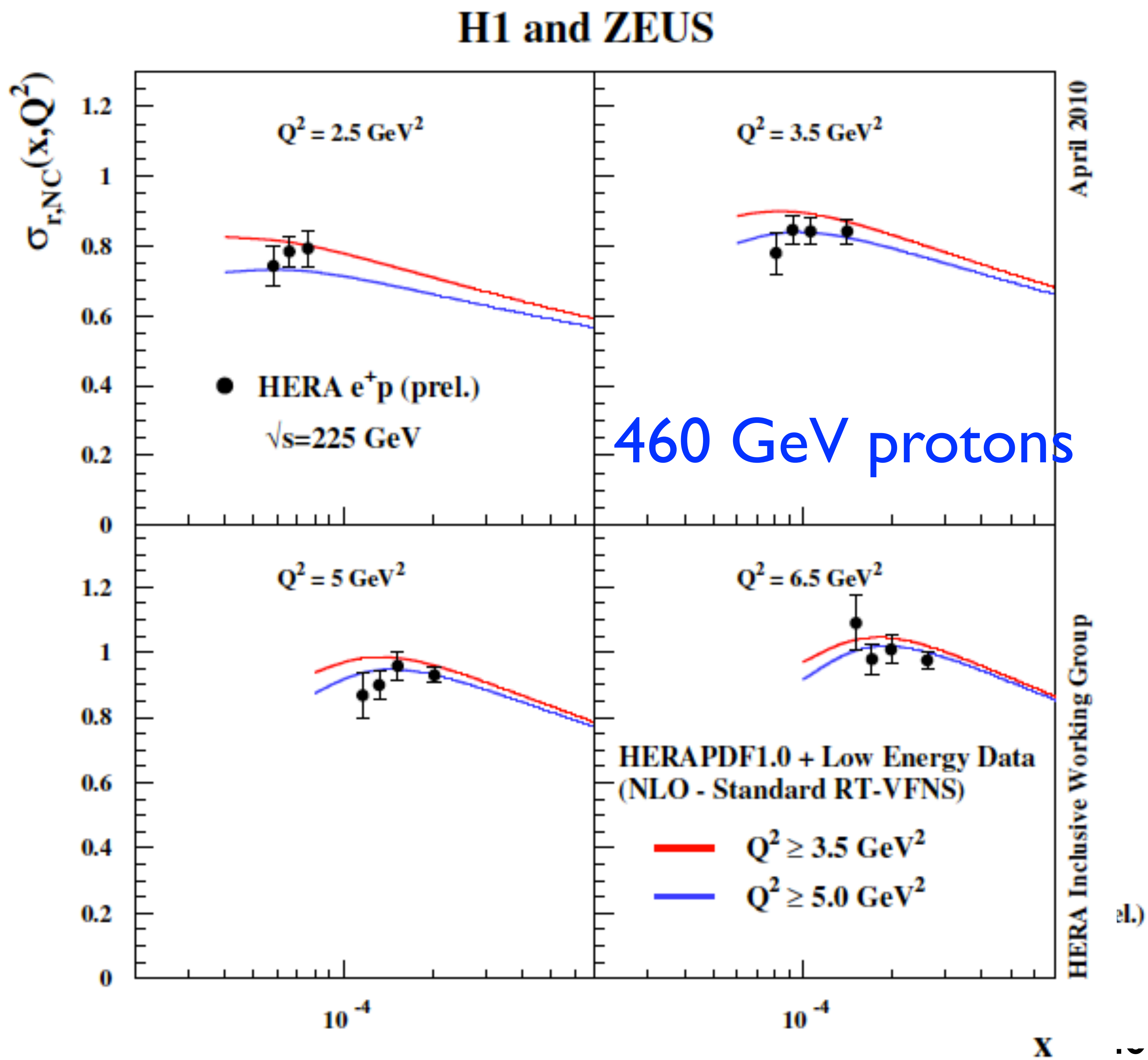


Ho

Measuring the gluons: extracting F_L

$$\sigma_r(x,Q^2) = F_2^A(x,Q^2) - \frac{y^2}{Y+} F_L^A(x,Q^2)$$

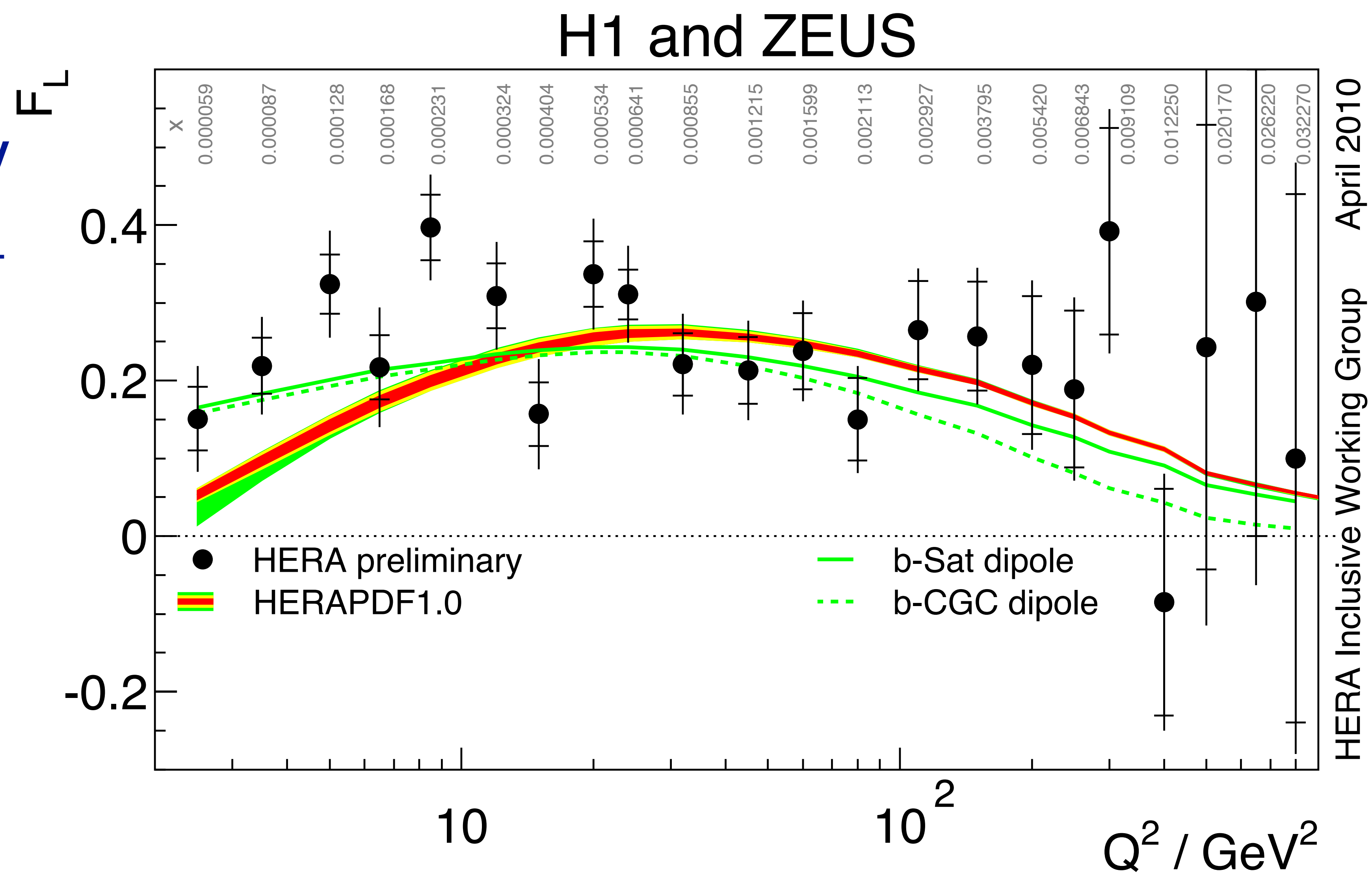
- $F_L \sim \alpha_s \, xG(x,Q^2)$
  - ➡ $y = Q^2/xs$
  - ➡ require an energy scan to extract F_L
- 3 different proton energies run at HERA
  - ➡ 2 low-statistics runs
  - ➡ bad for F_L extraction



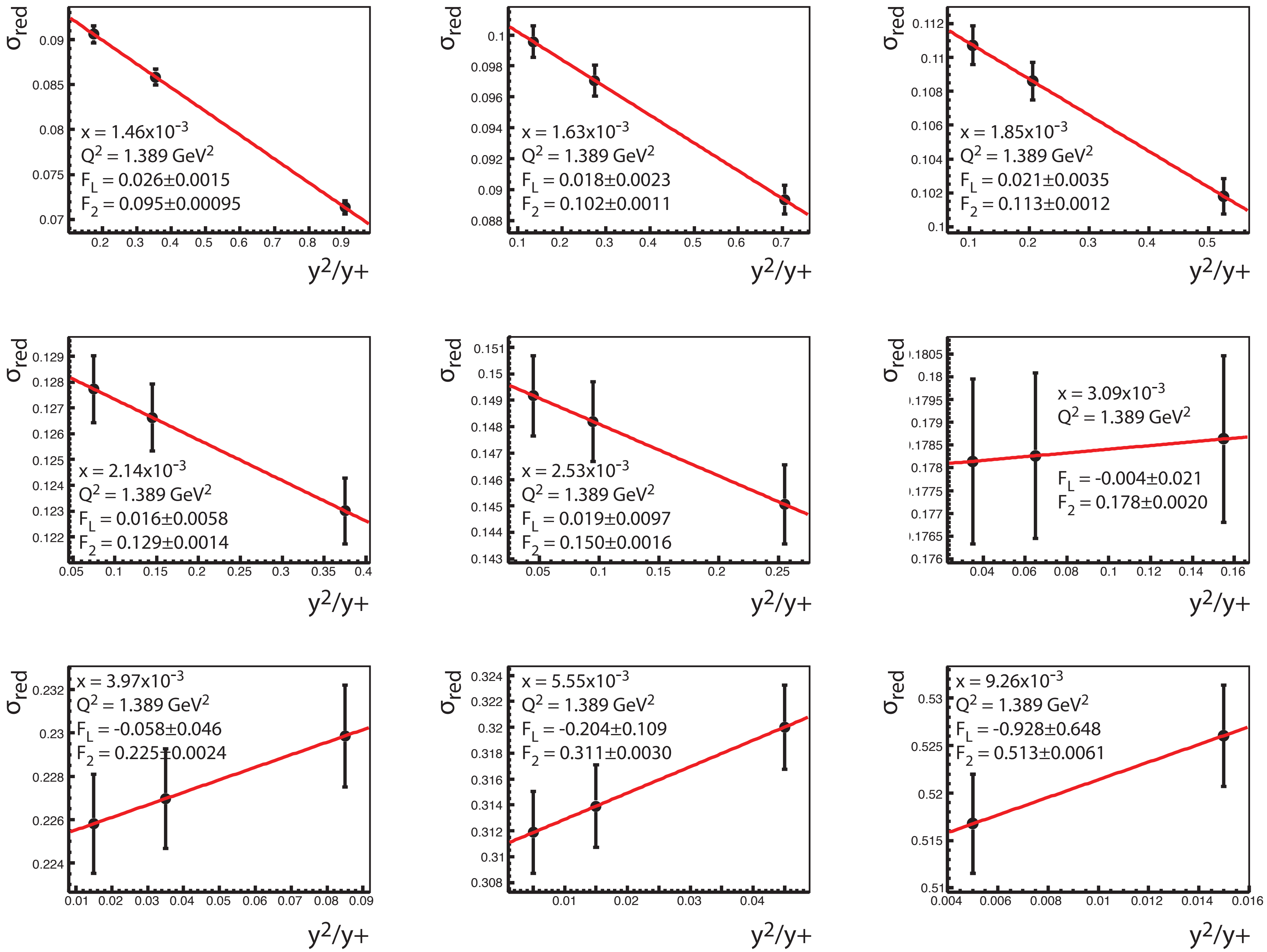
Measuring the gluons: extracting F_L

$$\sigma_r(x,Q^2) = F_2^A(x,Q^2) - \frac{y^2}{Y+} F_L^A(x,Q^2)$$

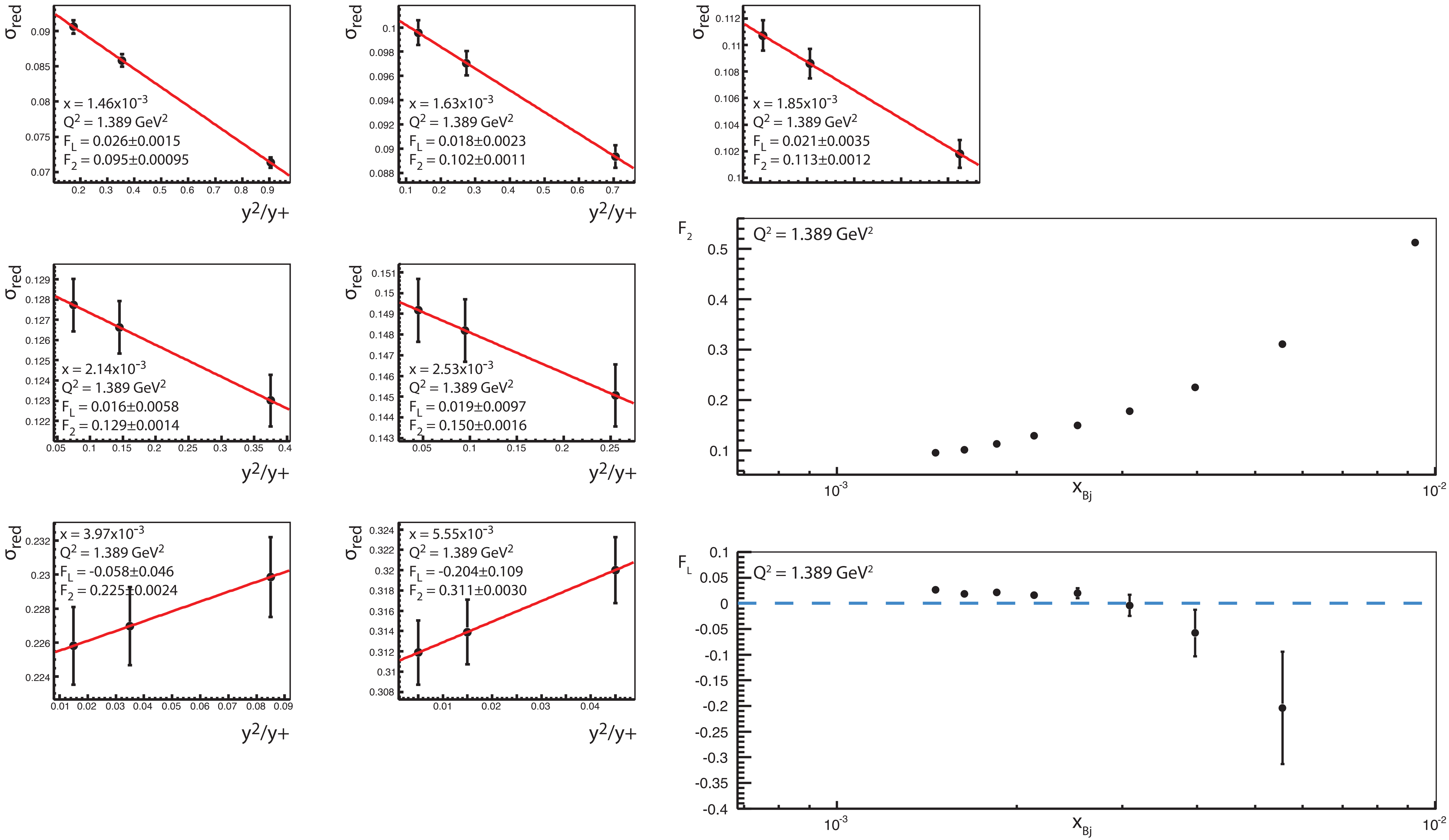
- $F_L \sim \alpha_s\, xG(x,Q^2)$
  - ➡ $y = Q^2/xs$
  - ➡ require an energy scan to extract F_L
- 3 different proton energies run at HERA
  - ➡ 2 low-statistics runs
  - ➡ bad for F_L extraction



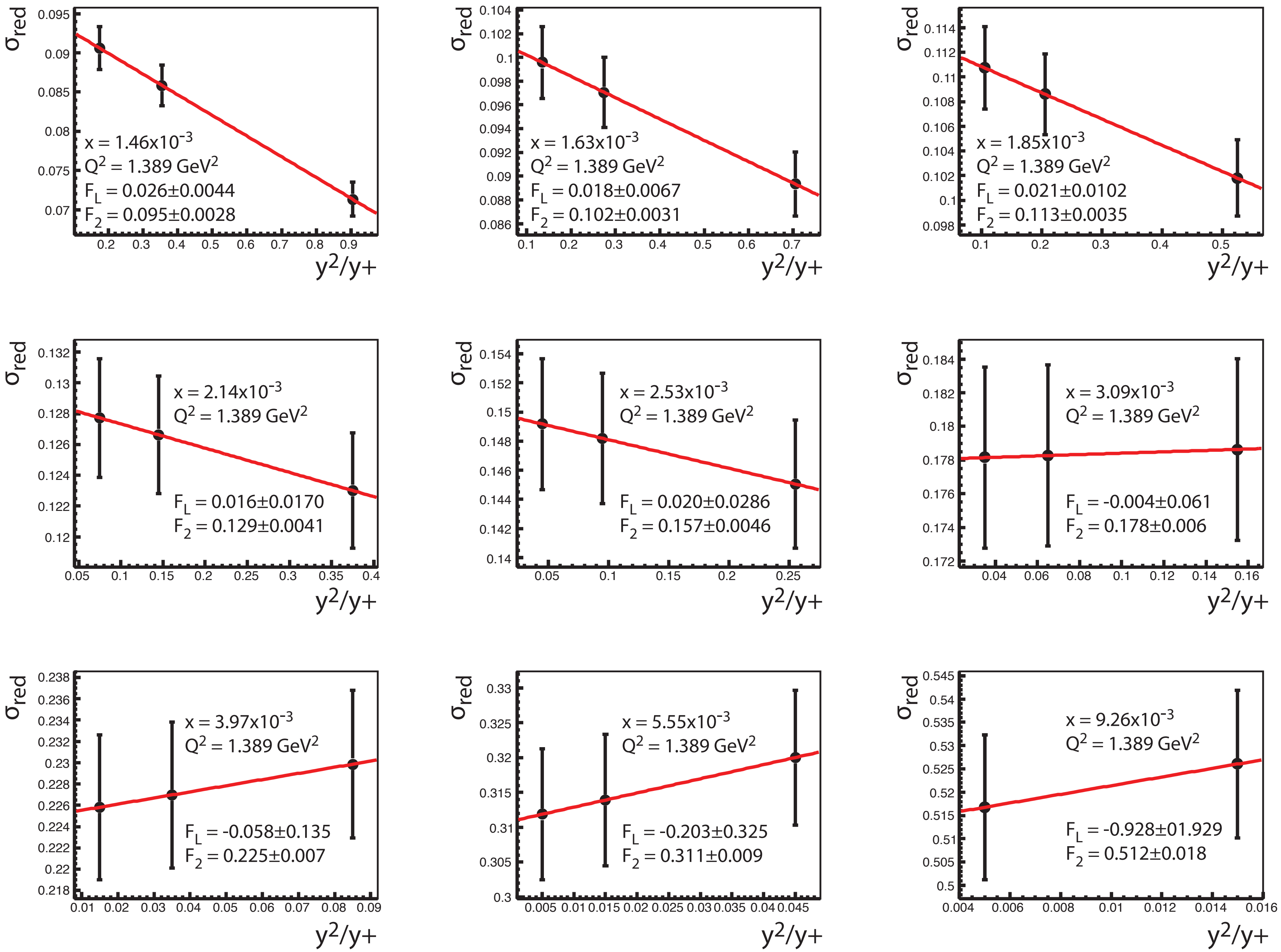
Feasibility study: $\sigma_r(x, Q^2) = F_2^A(x, Q^2) - \frac{y^2}{Y^+} F_L^A(x, Q^2)$



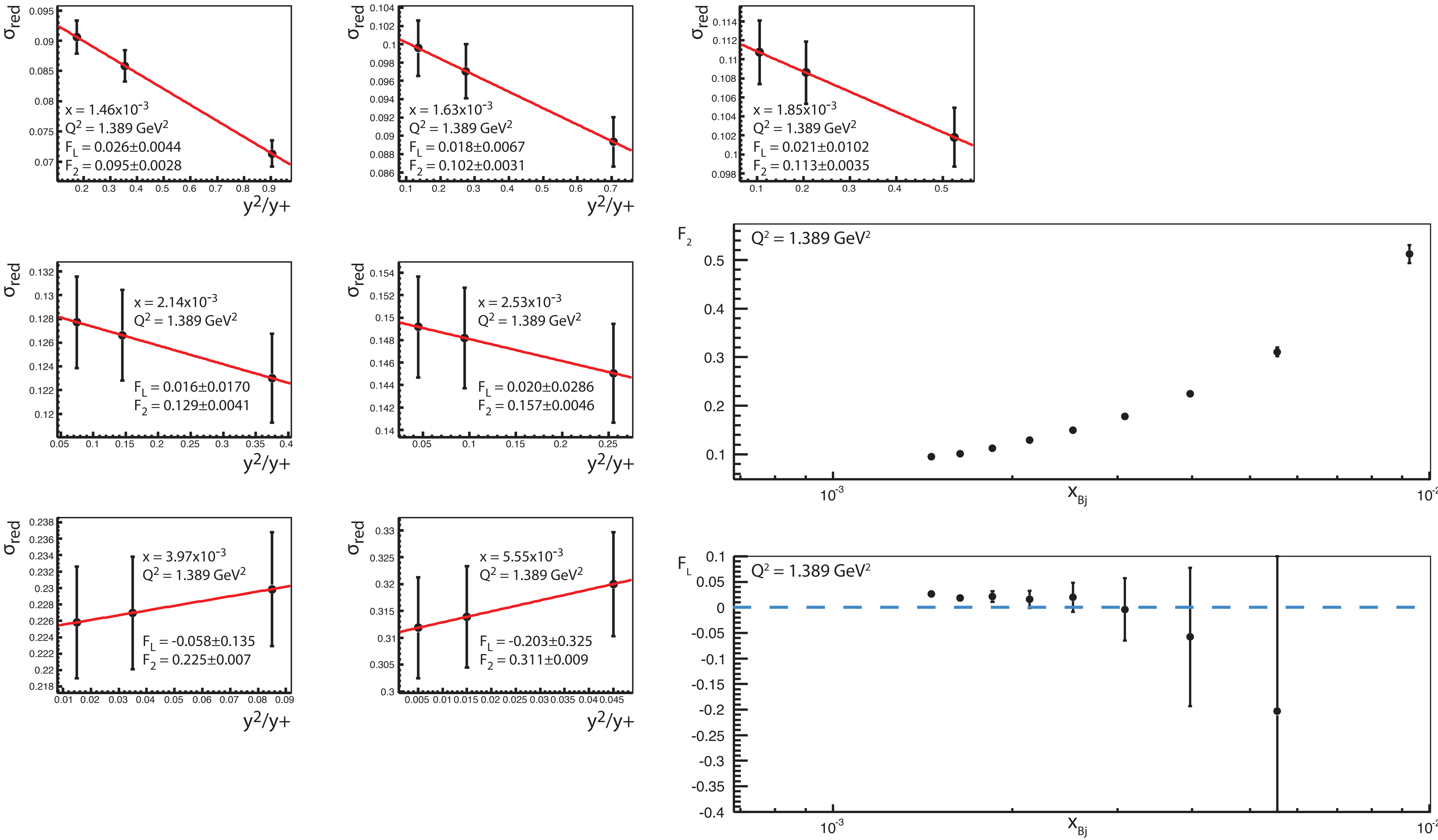
Feasibility study: $\sigma_r(x,Q^2) = F_2^A(x,Q^2) - \frac{y^2}{Y+}F_L^A(x,Q^2)$



Feasibility study: $\sigma_r(x,Q^2) = F_2^A(x,Q^2) - \frac{y^2}{Y^+}F_L^A(x,Q^2)$



Feasibility study: $\sigma_r(x,Q^2) = F_2^A(x,Q^2) - \frac{y^2}{Y^+} F_L^A(x,Q^2)$



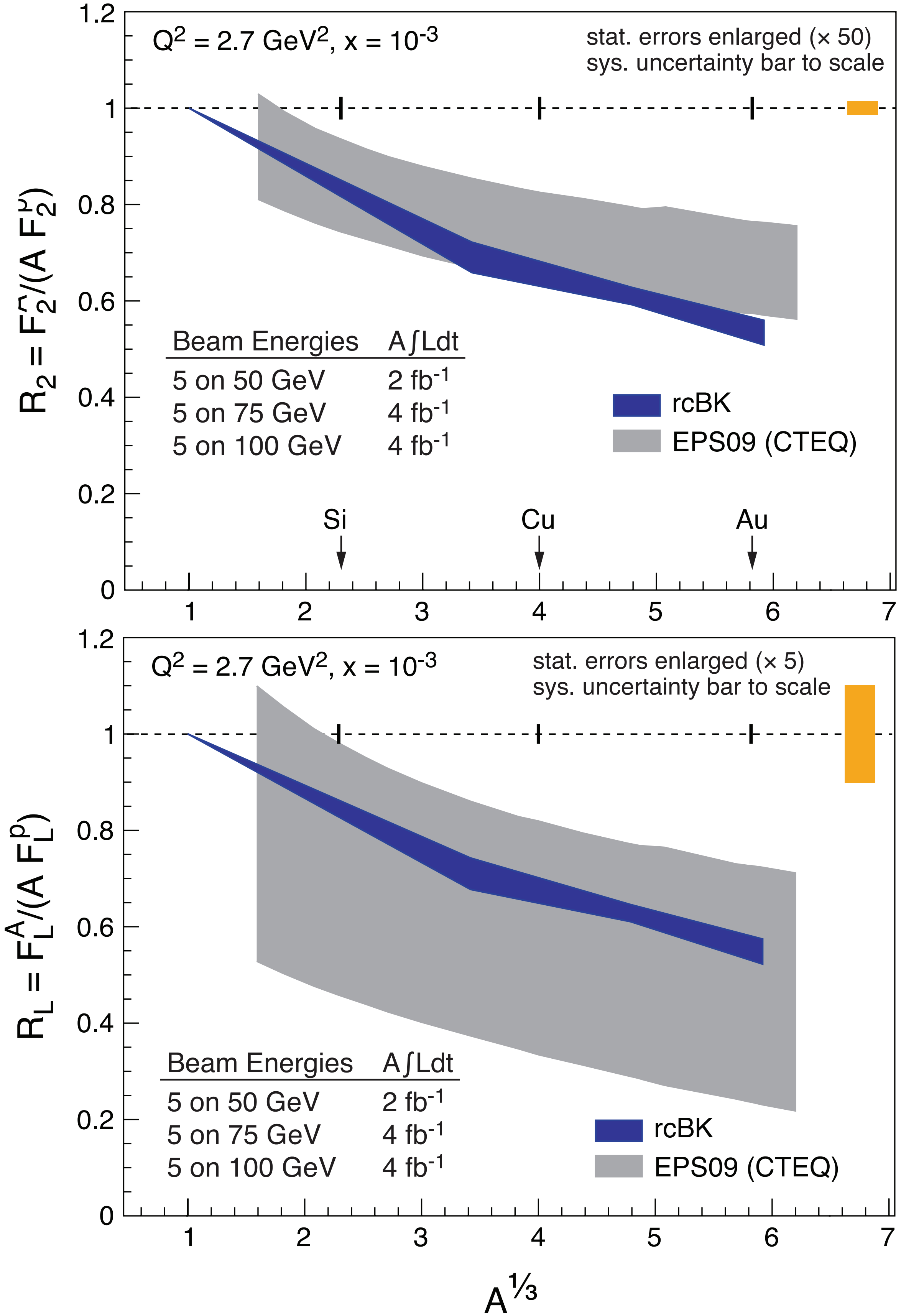
Feasibility study: $\sigma_r(x,Q^2) = F_2^A(x,Q^2) - \frac{y^2}{Y^+} F_L^A(x,Q^2)$

Strategies:
slope of y^2/Y_+ for different s at fixed x & Q^2

e+Au: 1st stage
5x50 - $A\int Ldt = 2\ fb^{-1}$
5x75 - $A\int Ldt = 4\ fb^{-1}$
5x100 - $A\int Ldt = 4\ fb^{-1}$
running combined
~6 months total running
(50% eff)

statistical errors are swamped by the 1% systematic errors

Will be dominated by systematics, but would need a full detector simulation in order to estimate them



k_T dependent gluons, gluon correlations from di-hadron correlations, SIDIS (semi-inclusive DIS)

Deliverables	Observables	What we learn	Stage-I	Stage-II
k_T dependent gluons	SIDIS at small x	non-linear QCD evolution / universality	onset of saturation	rare probes and bottom; large-x gluons

Direct link between p_T of produced hadron and that of the small-x gluon

$$e+A \rightarrow e + h + X$$

k_T dependent gluons, gluon correlations from di-hadron correlations, SIDIS (semi-inclusive DIS)

$$e + A \rightarrow e + h_1 + h_2 + X$$

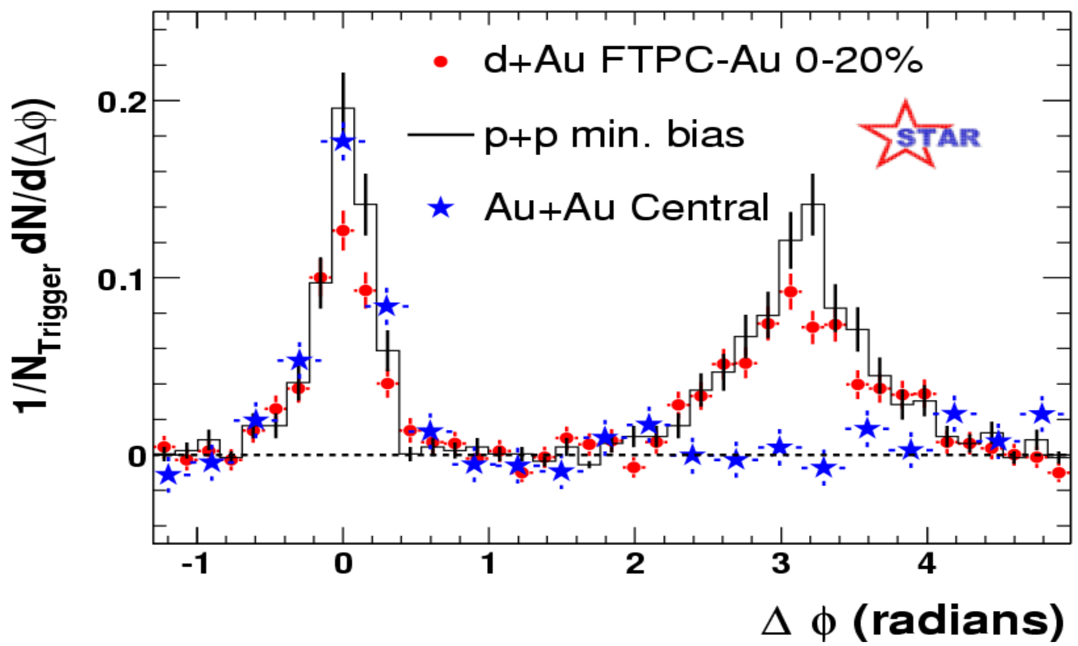
Deliverables	Observables	What we learn	Stage-I	Stage-II
k_T dependent gluons; gluon correlations	di-hadron correlations	non-linear QCD evolution / universality	onset of saturation	measure Q_s

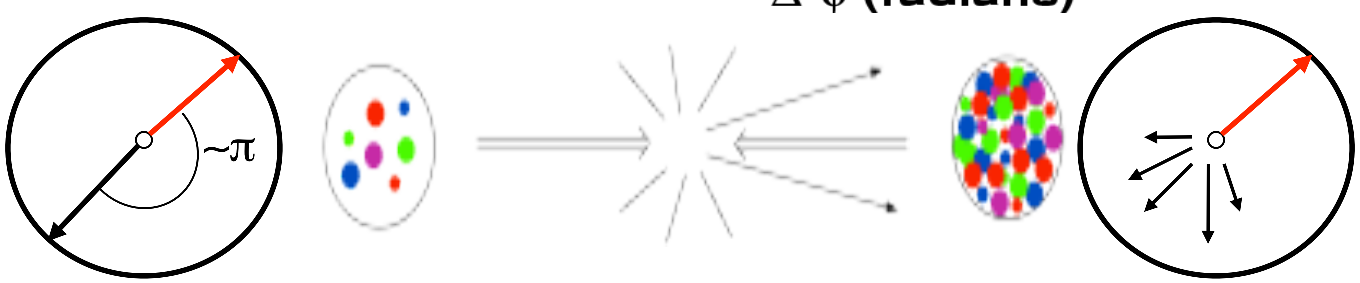
$$e + A \rightarrow e + h + X$$

k_T dependent gluons	SIDIS at small x	non-linear QCD evolution / universality	onset of saturation	rare probes and bottom; large-x gluons

di-hadron Correlations in d+A

comparisons between d+Au → h_1 h_2 X (or p +Au → h_1 h_2 X) and p+p → h_1 h_2 X





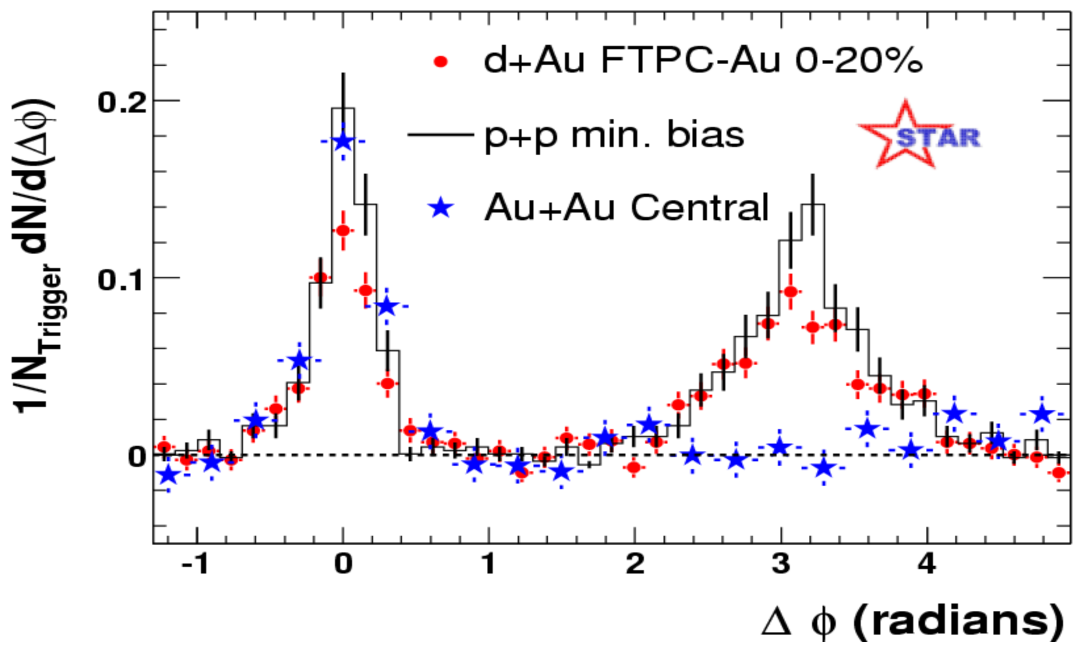
- At y=0, suppression of away-side jet is observed in A+A collisions
- No suppression in p+p or d+A

➡ x ~ 10^{-2}

$$x_A = \frac{k_1 e^{-y_1} + k_2 e^{-y_2}}{\sqrt{s}} << 1$$

di-hadron Correlations in d+A

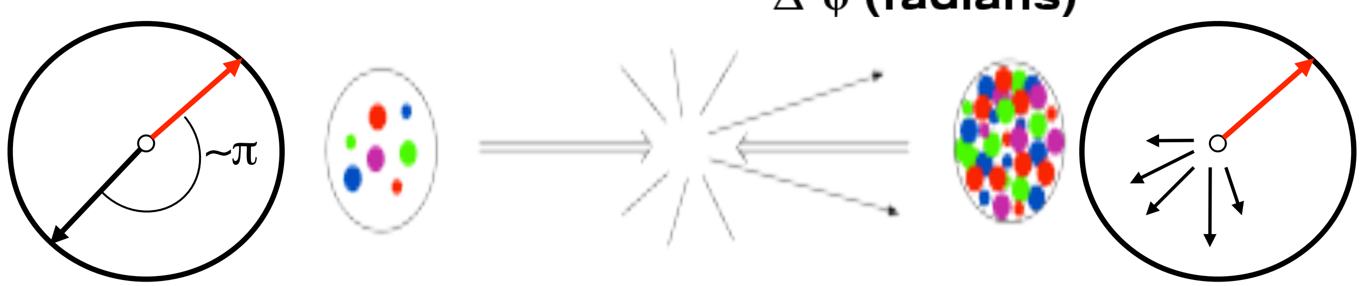
comparisons between d+Au → h_1 h_2 X (or p +Au → h_1 h_2 X) and p+p → h_1 h_2 X



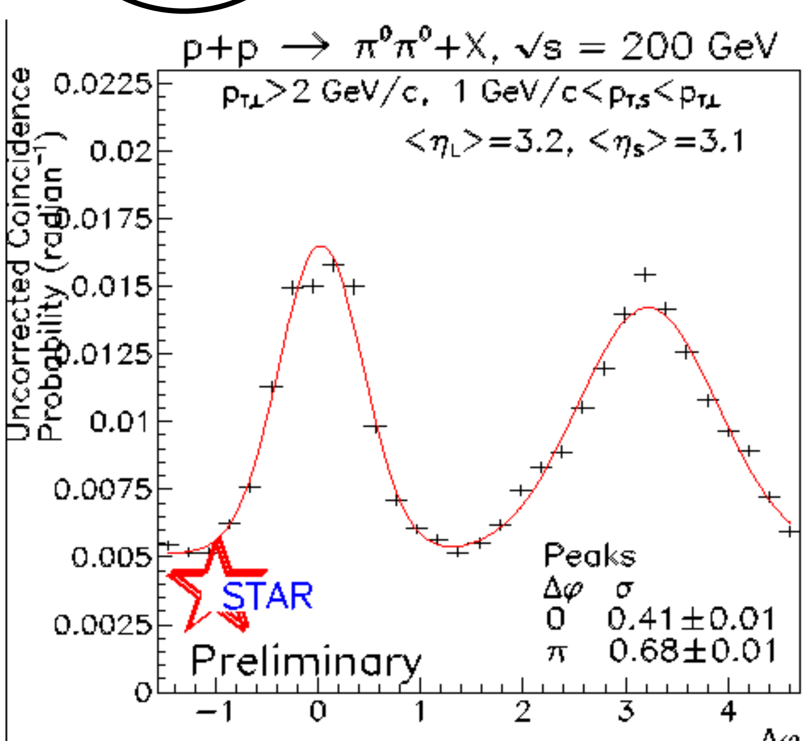
- At y=0, suppression of away-side jet is observed in A+A collisions
- No suppression in p+p or d+A

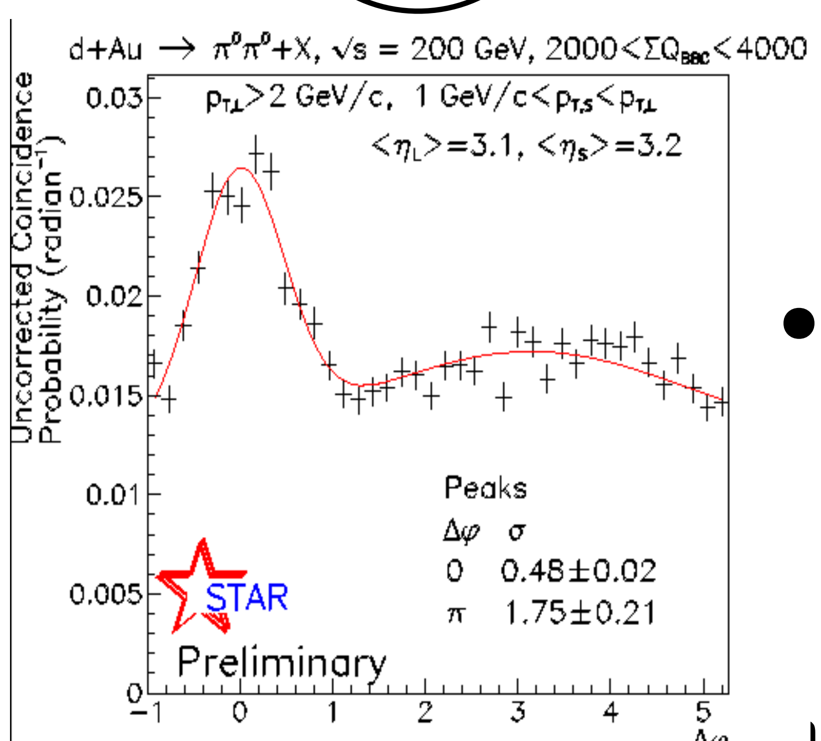
➡ x ~ 10^{-2}

$$x_A = \frac{k_1 e^{-y_1} + k_2 e^{-y_2}}{\sqrt{s}} << 1$$



- However, at forward rapidities (y ~ 3.1), an away-side suppression is observed in d+Au
- Away-side peak also much wider in d+Au compared to p+p



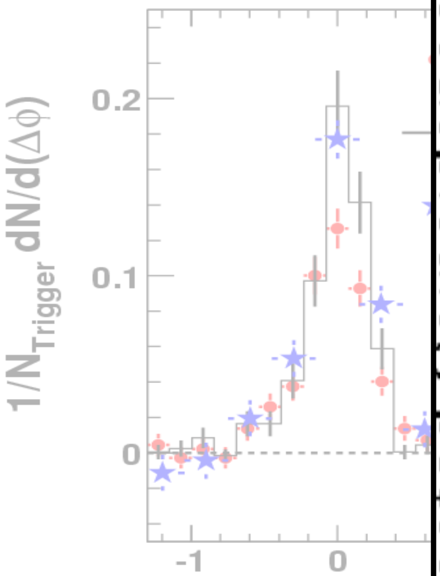


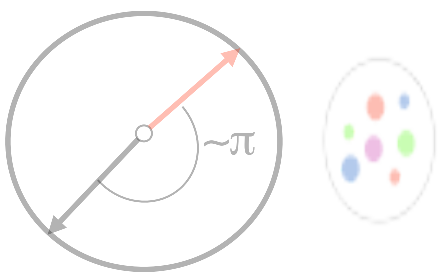
➡ x ~ 10^{-3}

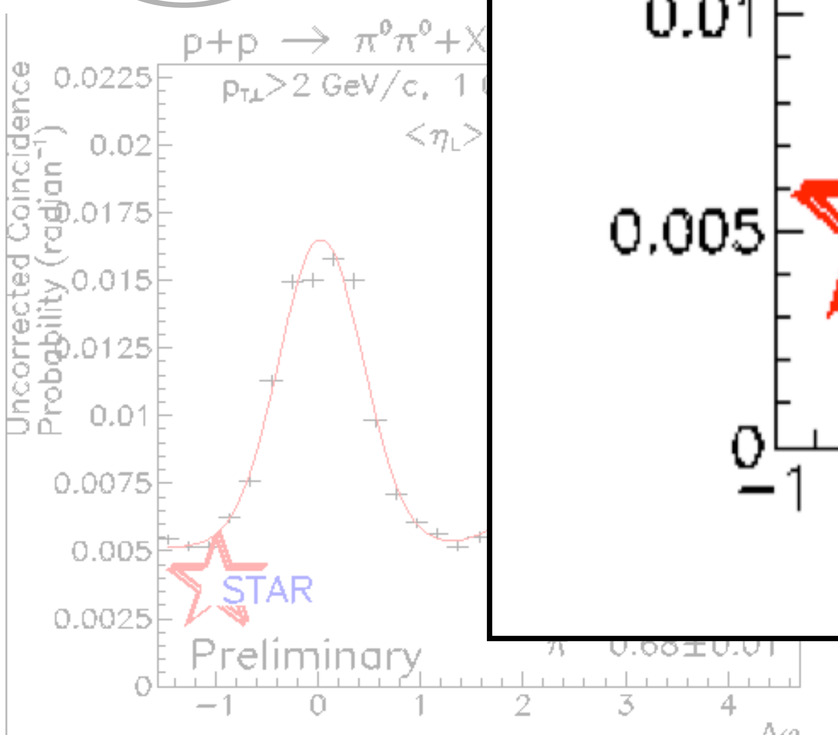
il.gov

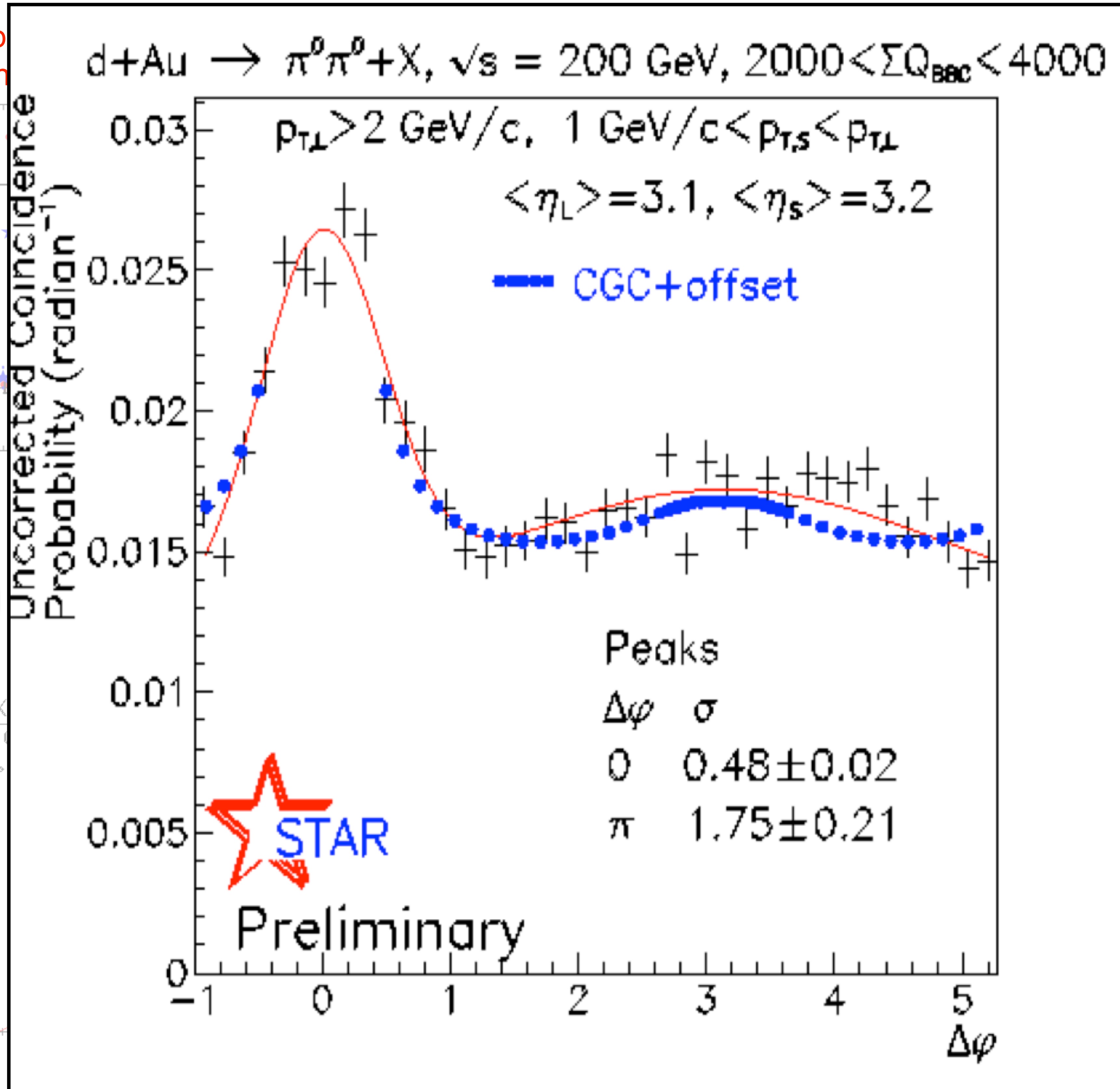
di-hadron Correlations in d+A

comparisons b
+Au → h_1 h









of away-
in A+A

+p or d+A

$+ k_2 e^{-y_2}$
$\sqrt{s}$ <<1

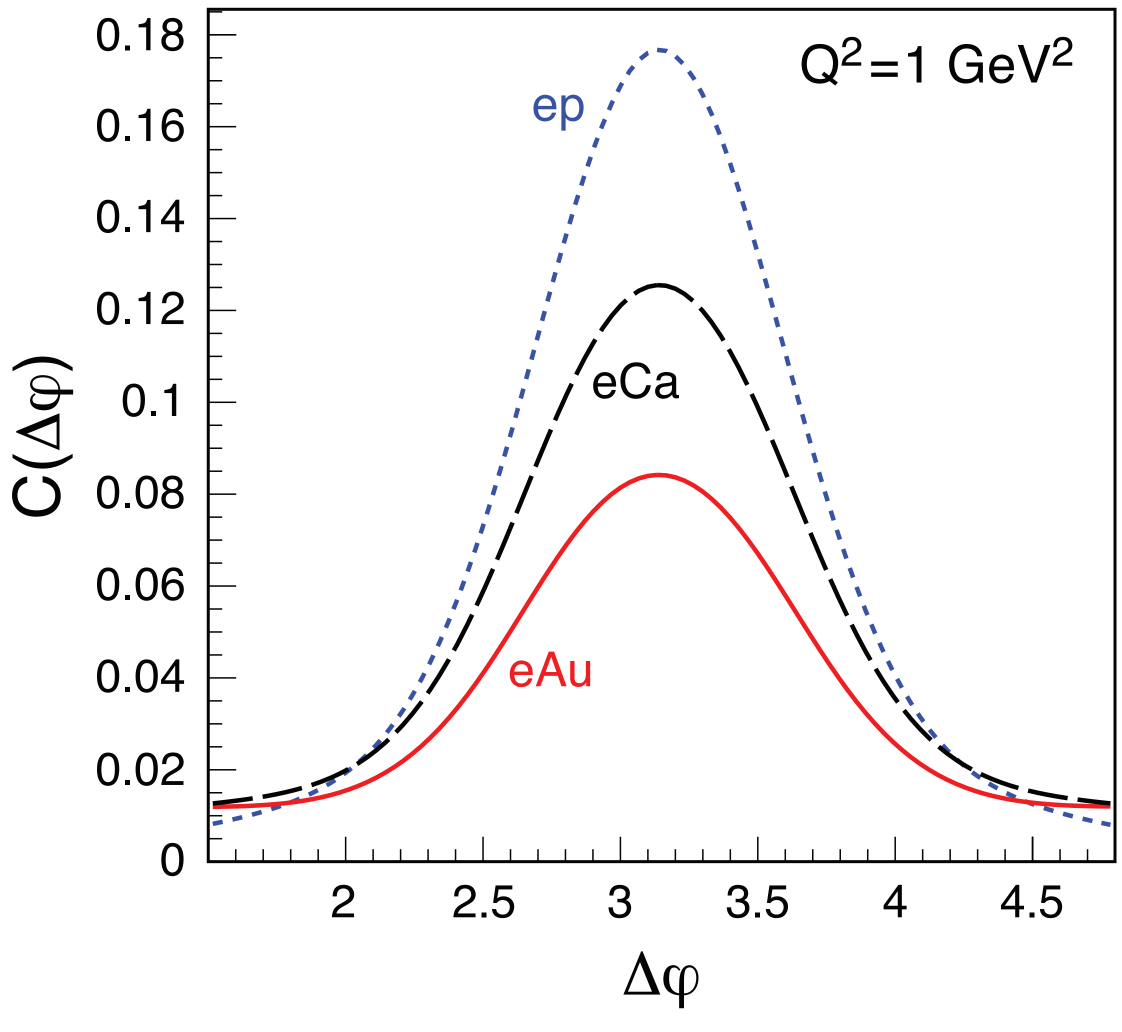
orward
3.1), an
ppression is
+Au

ak also
d+Au
p+p

➡ $x \sim 10^{-3}$

di-hadron correlations in e+A

Never been measured - we expect to see the same effect in e+A as in d+A

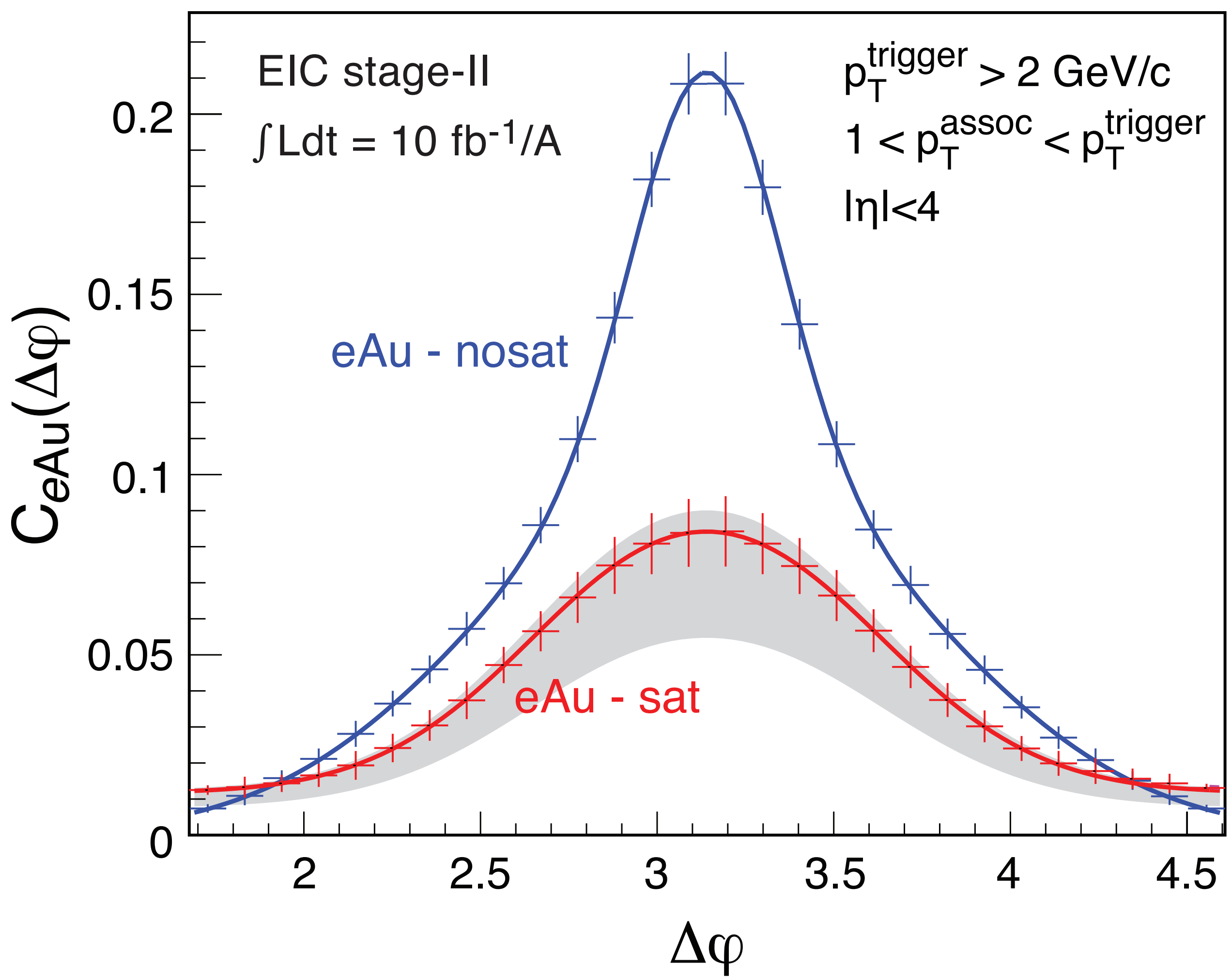


Dominguez, Xiao and Yuan (2012)

- At small-x, multi-gluon distributions are as important as single-gluon distributions and they contribute to di-hadron correlations
  - ➡ The non-linear evolution of multi-gluon distributions is different from that of single-gluon distributions and it is equally important that we understand it
- The d+Au RHIC data is therefore subject to many uncertainties
  - ➡ these correlations in e+A can help to constrain them better

di-hadron correlations in e+A

Never been measured - we expect to see the same effect in e+A as in d+A

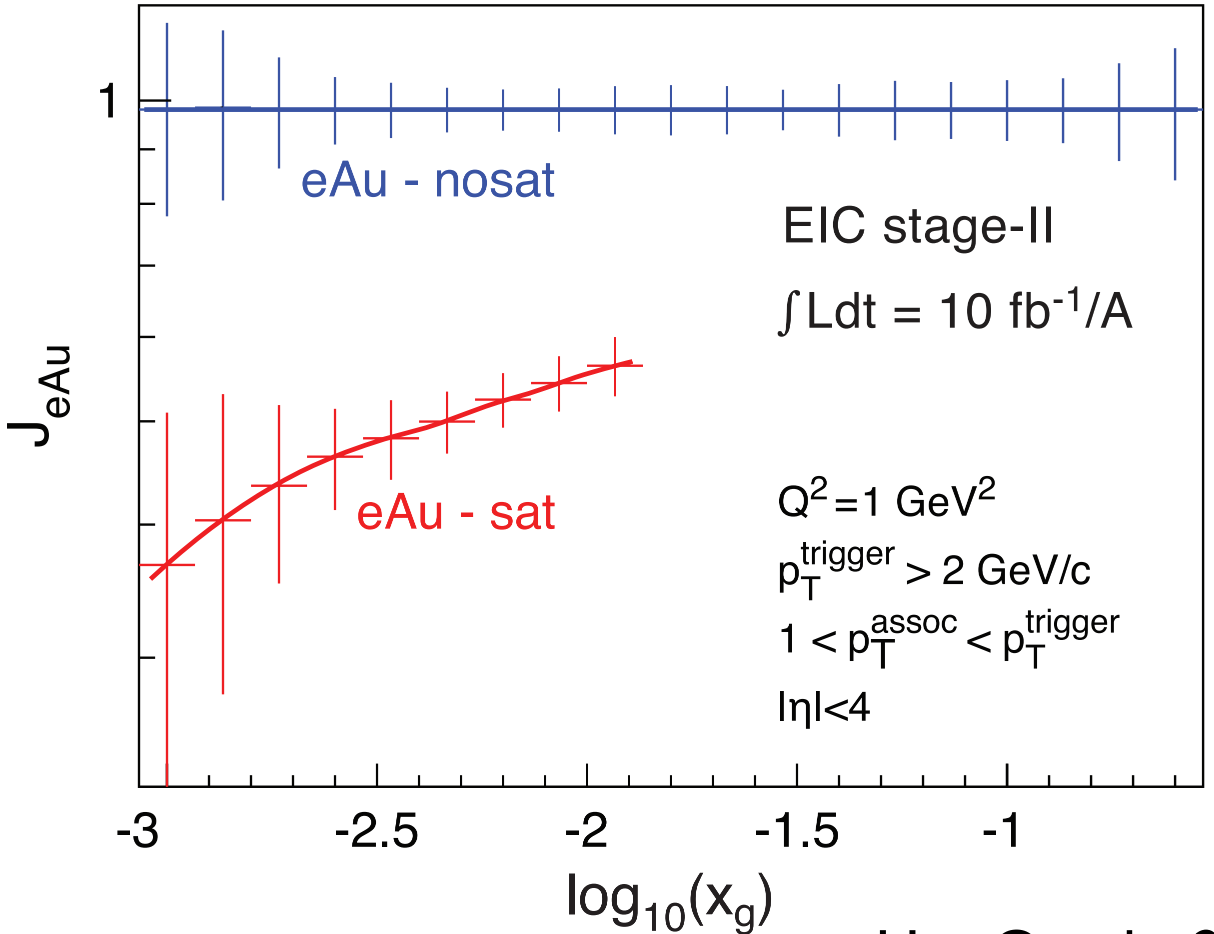


Dominguez, Xiao and Yuan (2012)

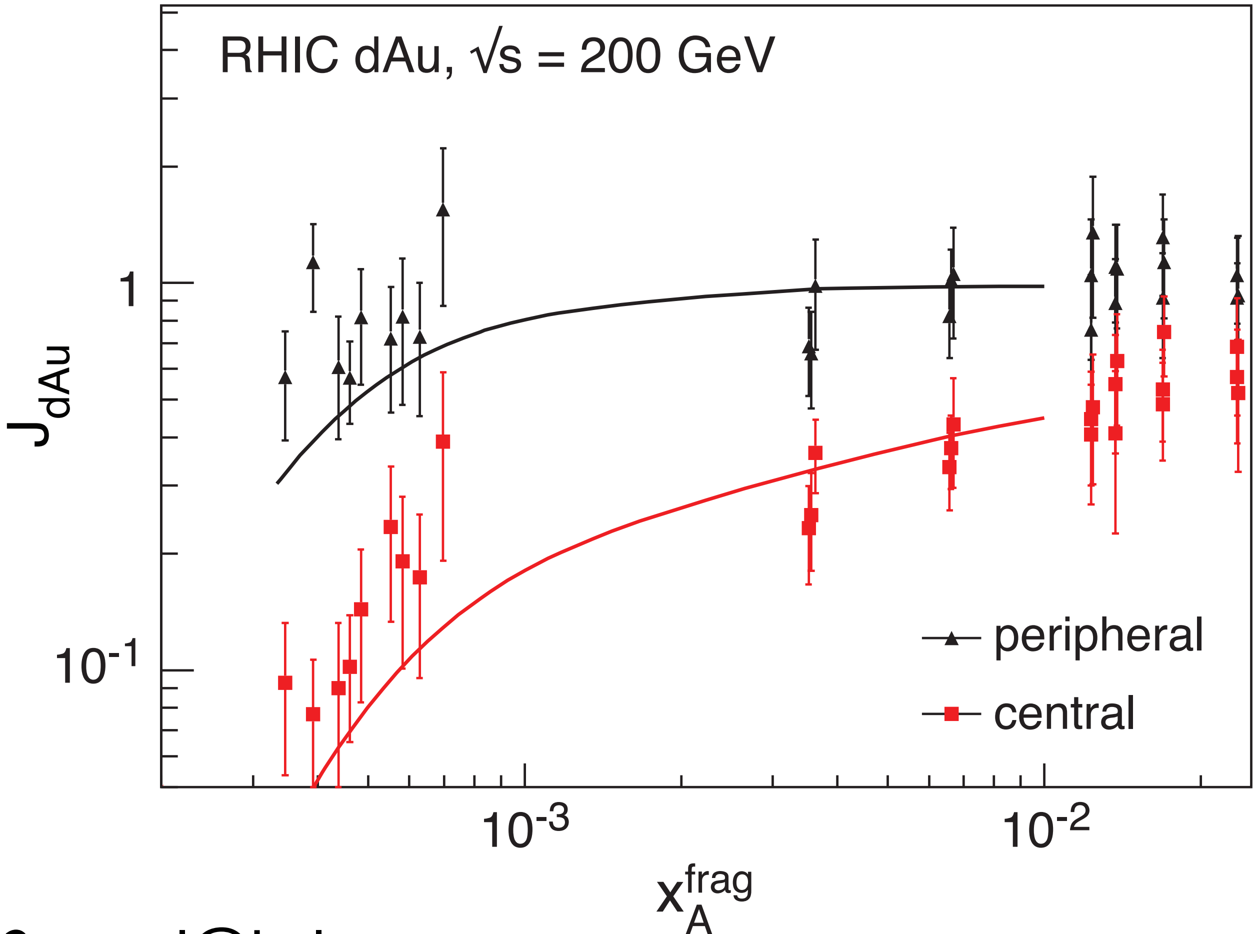
- At small-x, multi-gluon distributions are as important as single-gluon distributions and they contribute to di-hadron correlations
  - ➡ The non-linear evolution of multi-gluon distributions is different from that of single-gluon distributions and it is equally important that we understand it
- The d+Au RHIC data is therefore subject to many uncertainties
  - ➡ these correlations in e+A can help to constrain them better

di-hadron Correlations - relative yields

- PHENIX measured J_{dAu} - relative yield of di-hadrons produced in d+Au compared to p+p collisions
  - ➡ Suppression in central events compared to peripheral as a function of x_A^{frag}
    - Curves come from saturation model
- Can perform the same measurement in e+A collisions



forward-forward mid-forward



Summary and Conclusions

- The e+A physics programme at an EIC will give us an unprecedented opportunity to study gluons in nuclei
- Low-x: Measure the properties of gluons where saturation is the dominant governing phenomena
- Higher-x: Understand how fast partons interact as they traverse nuclear matter and provide new insight into hadronization
- Understanding the role of gluons in nuclei is crucial to understanding RHIC (and LHC) heavy-ion results

Good headway can be made on these measurements already with a stage-I eRHIC (E_e = 5 GeV)

- The INT programme in the Fall of 2010 allowed us to formulate the observables in terms of golden and silver measurements
    - ➡ A detailed write-up of the whole programme is on the ArXiv: 1108.1713
    - ➡ An EIC White Paper (not just e+A) has just been released to the community

BACKUP