# e+A(p) physics with an electron-ion collider at RHIC

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Brookhaven National Lab

on behalf of the BNL
EIC Science Task Force
and friends

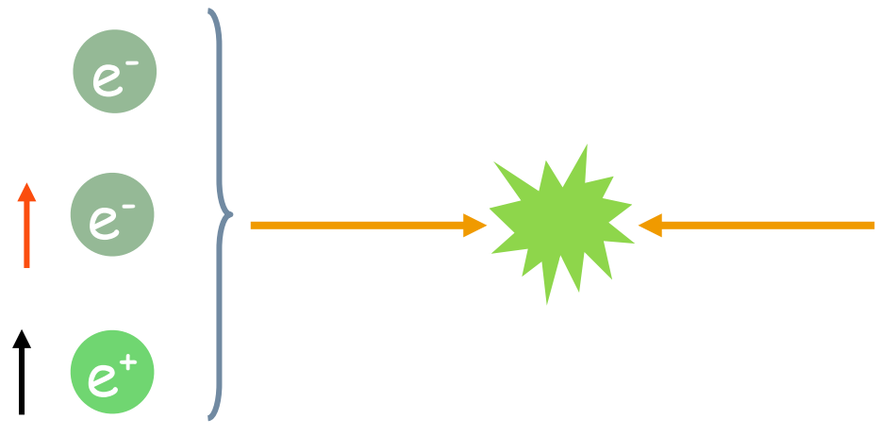
BROOKHAVEN
NATIONAL LABORATORY

# What is eRHIC?

## Electron accelerator

to be built

Unpolarized and
polarized leptons
5-20 (30) GeV

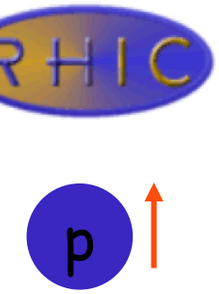



70% e- beam polarization goal

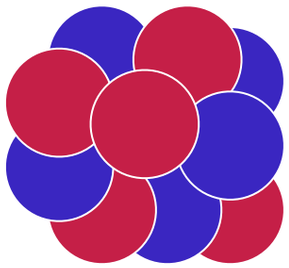
polarized positrons?

## RHIC

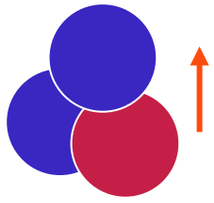
Existing = $2B




Polarized protons
50-250 GeV

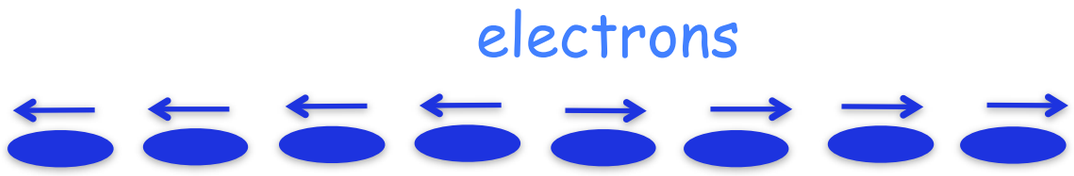


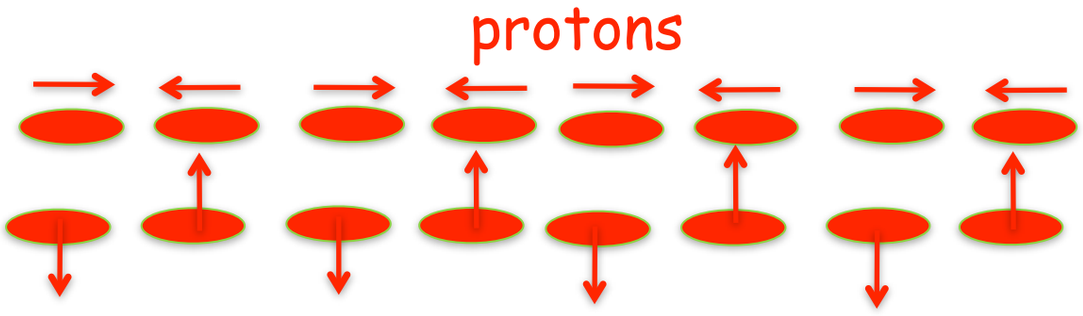
Light ions (d,Si,Cu)
Heavy ions (Au,U)
50-100 GeV/u



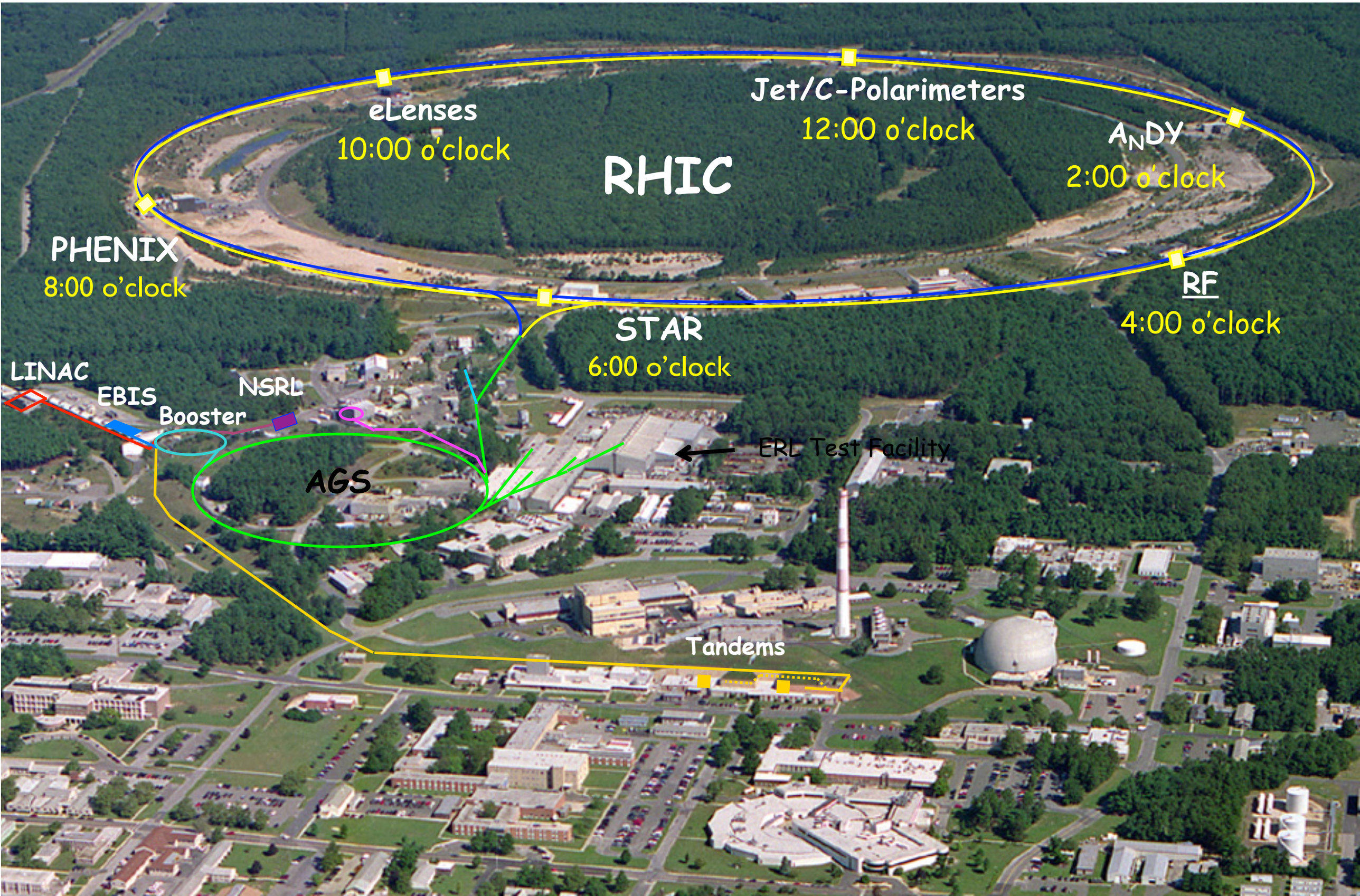
Polarized light ions $He^3$
166 GeV/u

Centre-of-mass energy range: $\sqrt{s}$=30-200 GeV; L~100-1000xHera
longitudinal and transverse polarization for p/$He^3$ possible



# From RHIC to eRHIC



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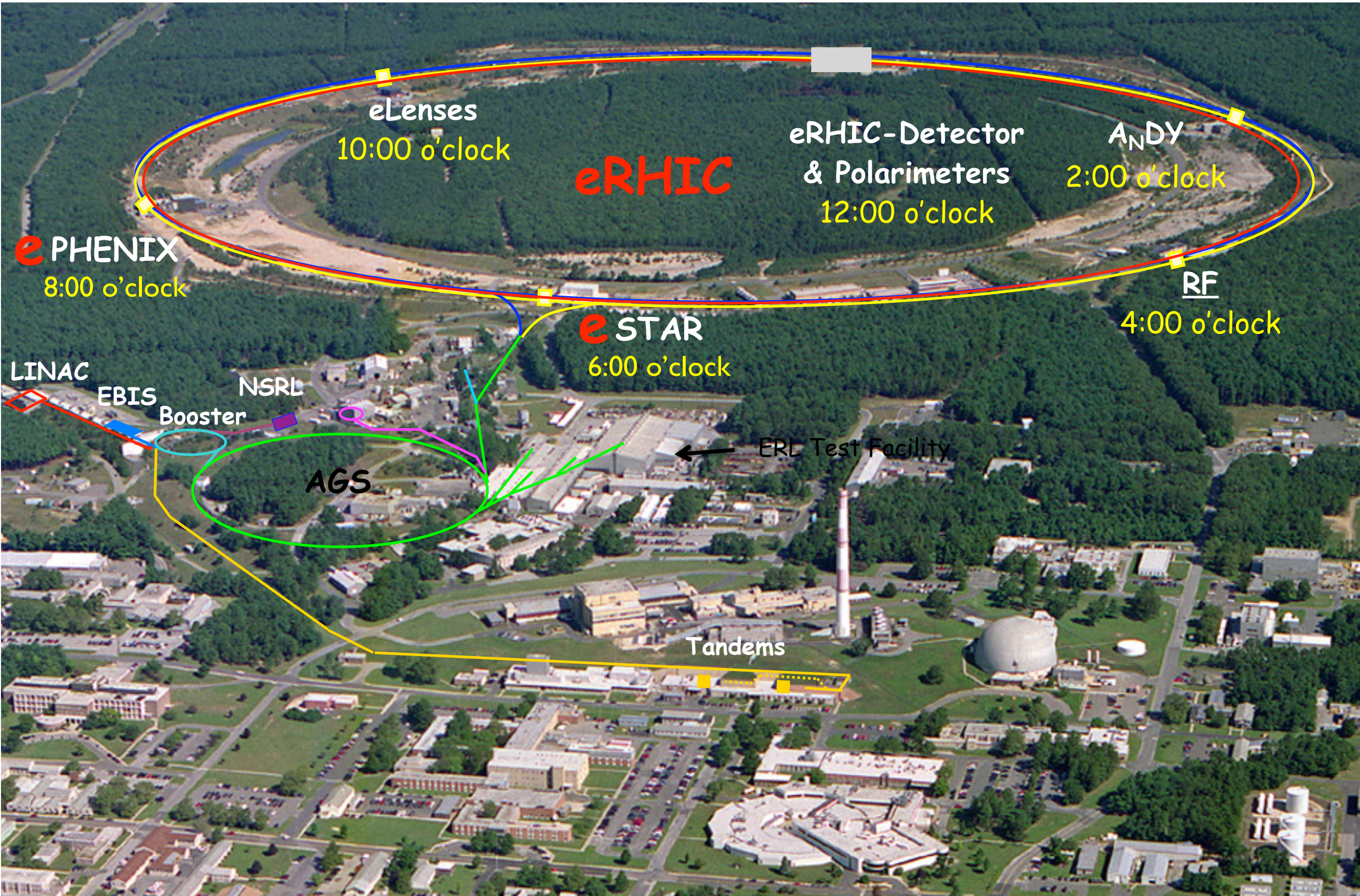
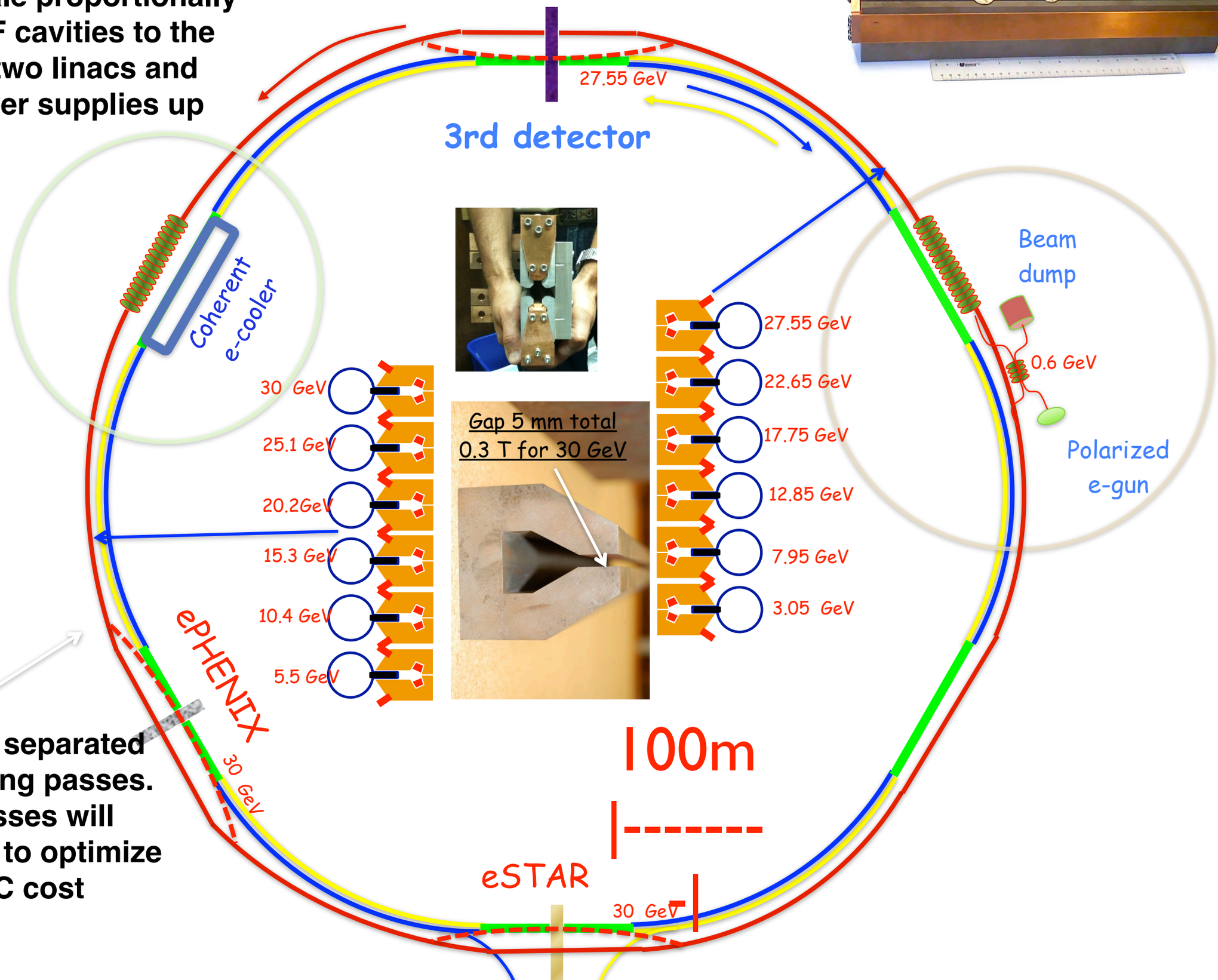


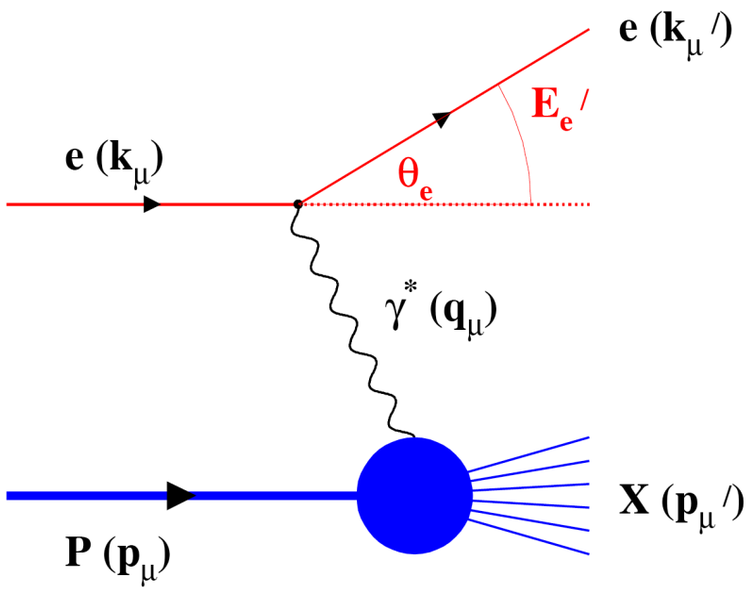
# From RHIC to eRHIC

**eRHIC staging:**
**All energies scale proportionally by adding SRF cavities to the injector and two linacs and cranking power supplies up**




**Vertically separated recirculating passes. # of passes will be chosen to optimize eRHIC cost**

# Detector requirements




## Inclusive Reactions:

- Momentum/energy and angular resolution of e' critical
- Very good electron pid
- Moderate luminosity $>10^{32}$ $cm^{-1}$ $s^{-1}$
- Need low x $\sim 10^{-4}$ → high $\sqrt{s}$ (Saturation and spin physics)

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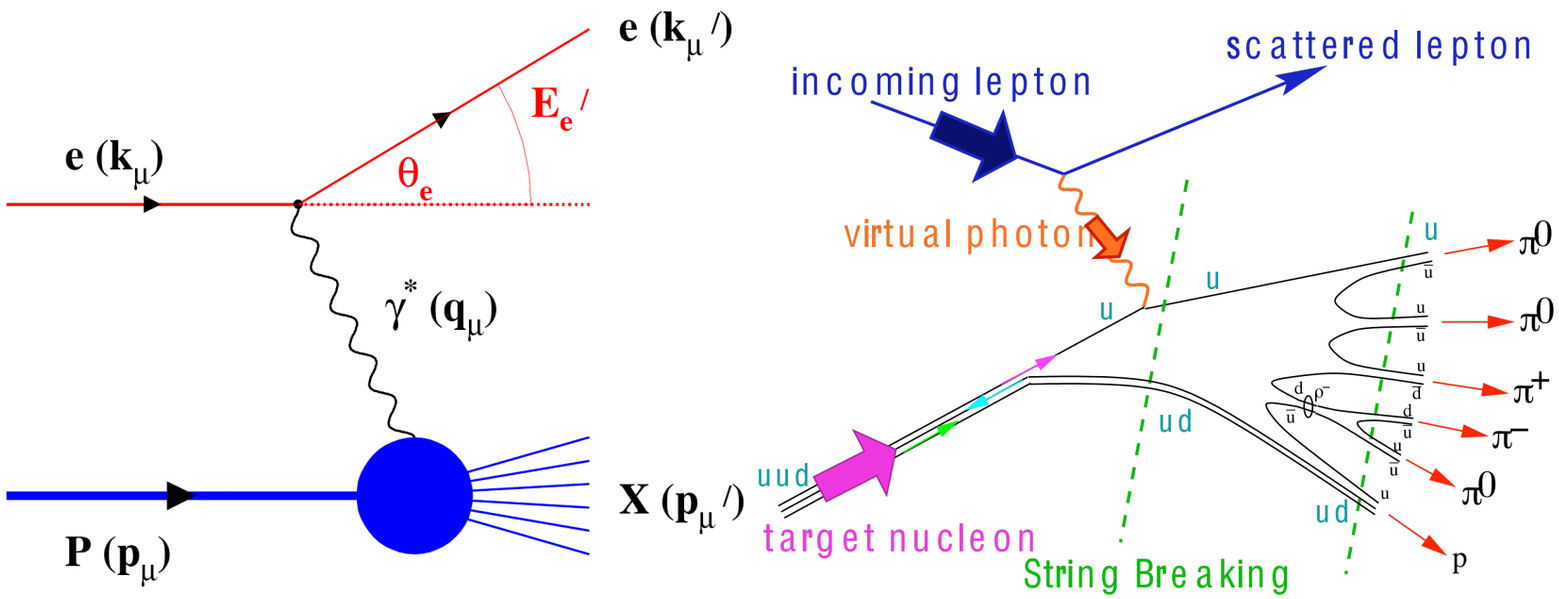


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## Semi-inclusive Reactions:

- Excellent particle ID: $\pi$,K,p separation over a wide range in $\eta$
- full $\Phi$-coverage around $\gamma^*$
- Excellent vertex resolution → Charm, bottom identification
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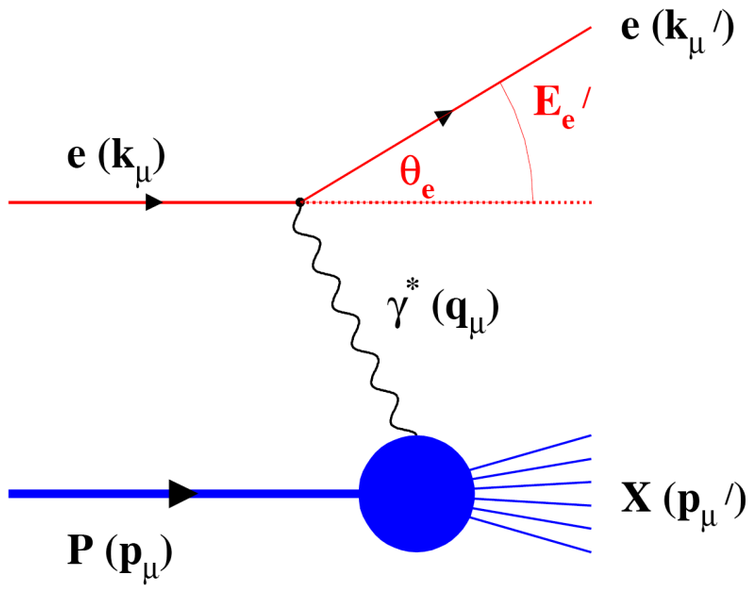
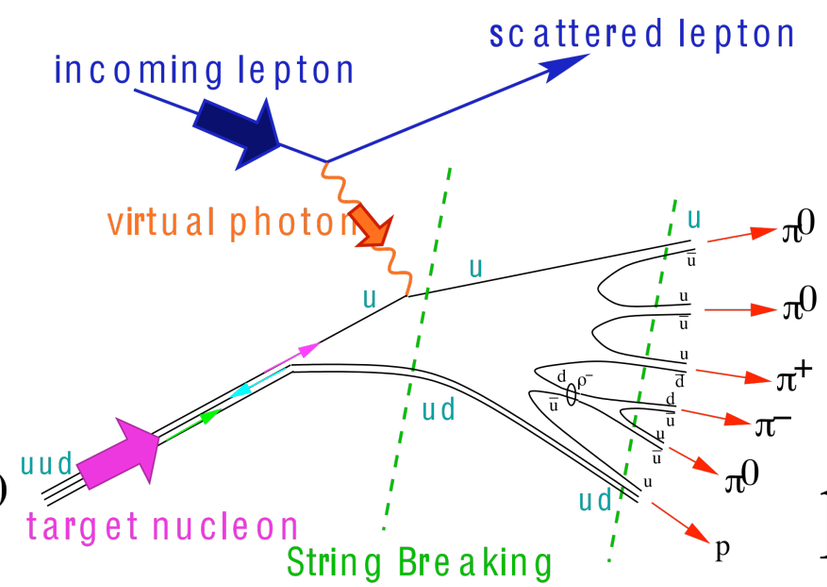
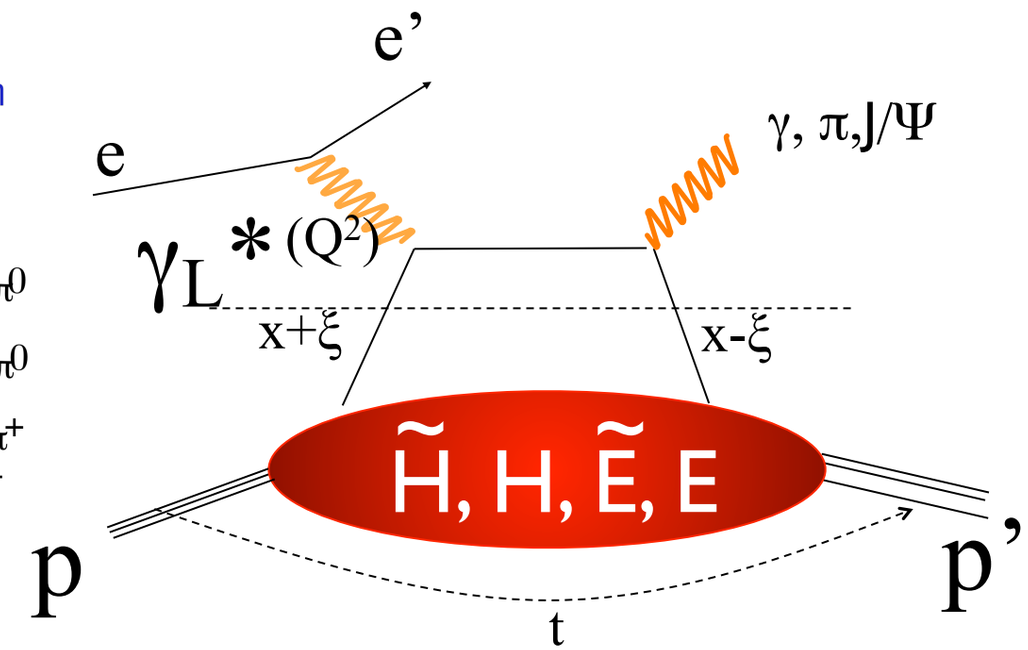
# Detector requirements

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## Exclusive Reactions:

- Exclusivity → high rapidity coverage → rapidity gap events
- high resolution in t → Roman pots
- high luminosity >$10^{33}$ $cm^{-1}$ $s^{-1}$ (4d binning (x,$Q^2$,t,Φ))

# The pillars of the eRHIC physics programme

- Wide physics programme with demanding requirements on detector and machine performance

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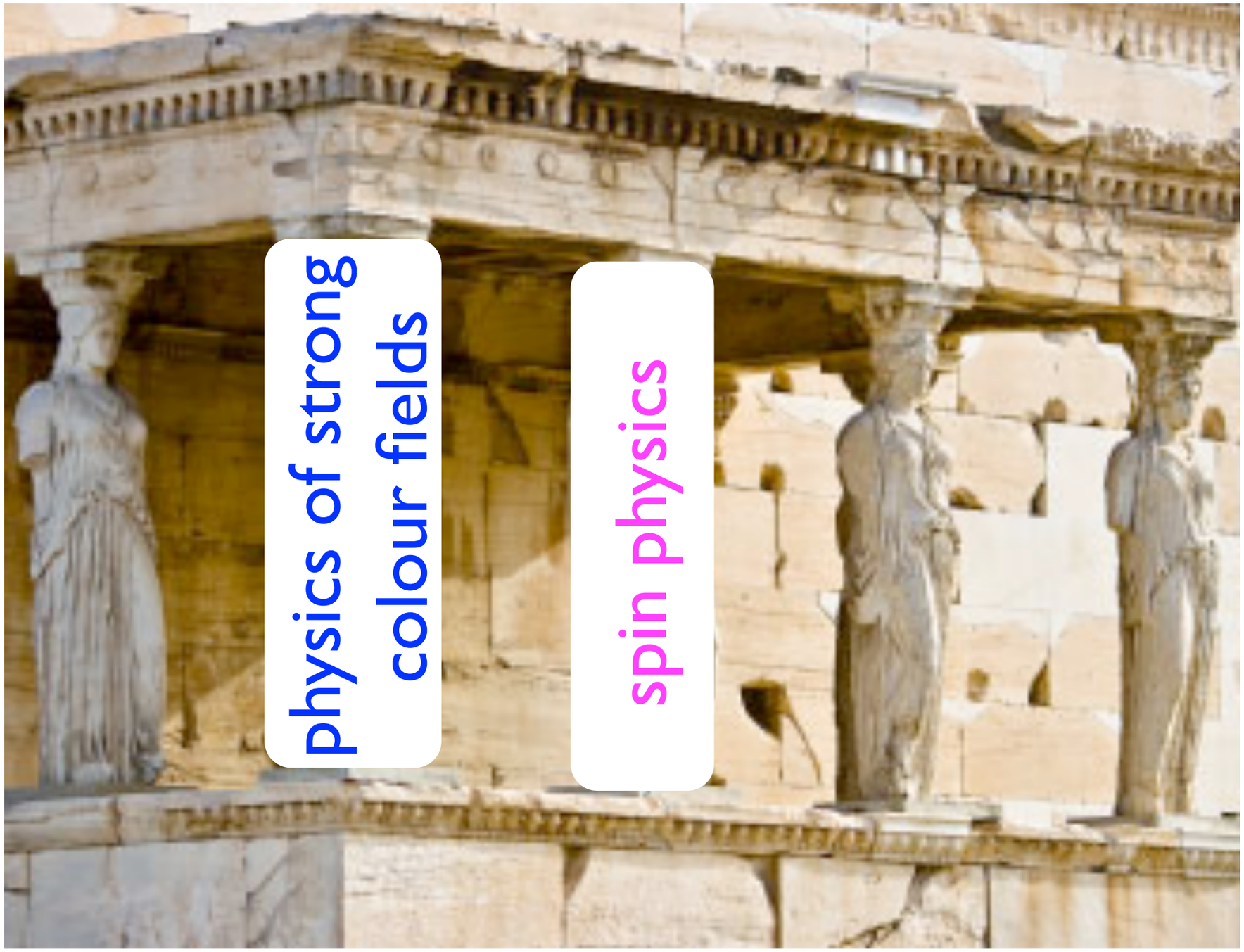


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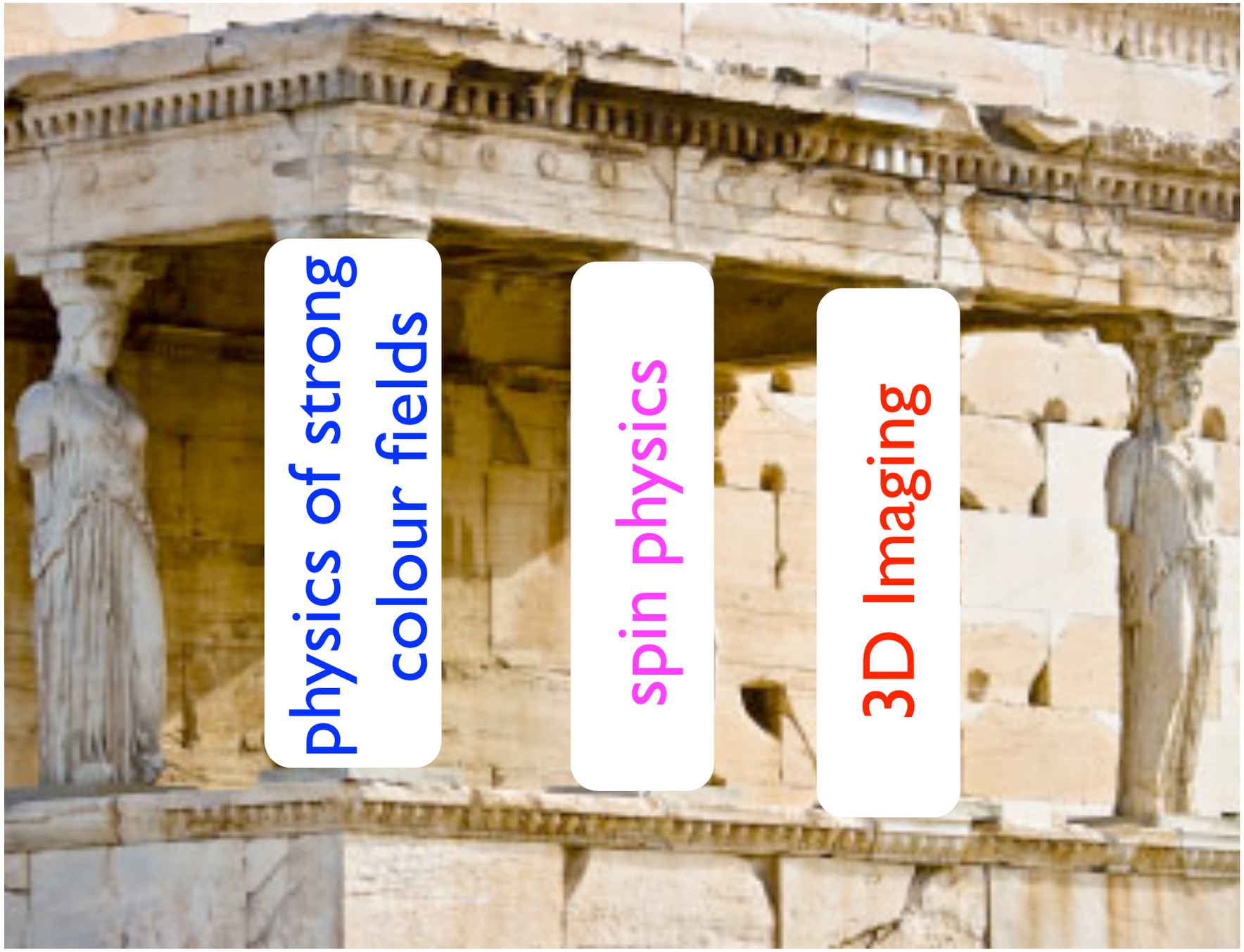


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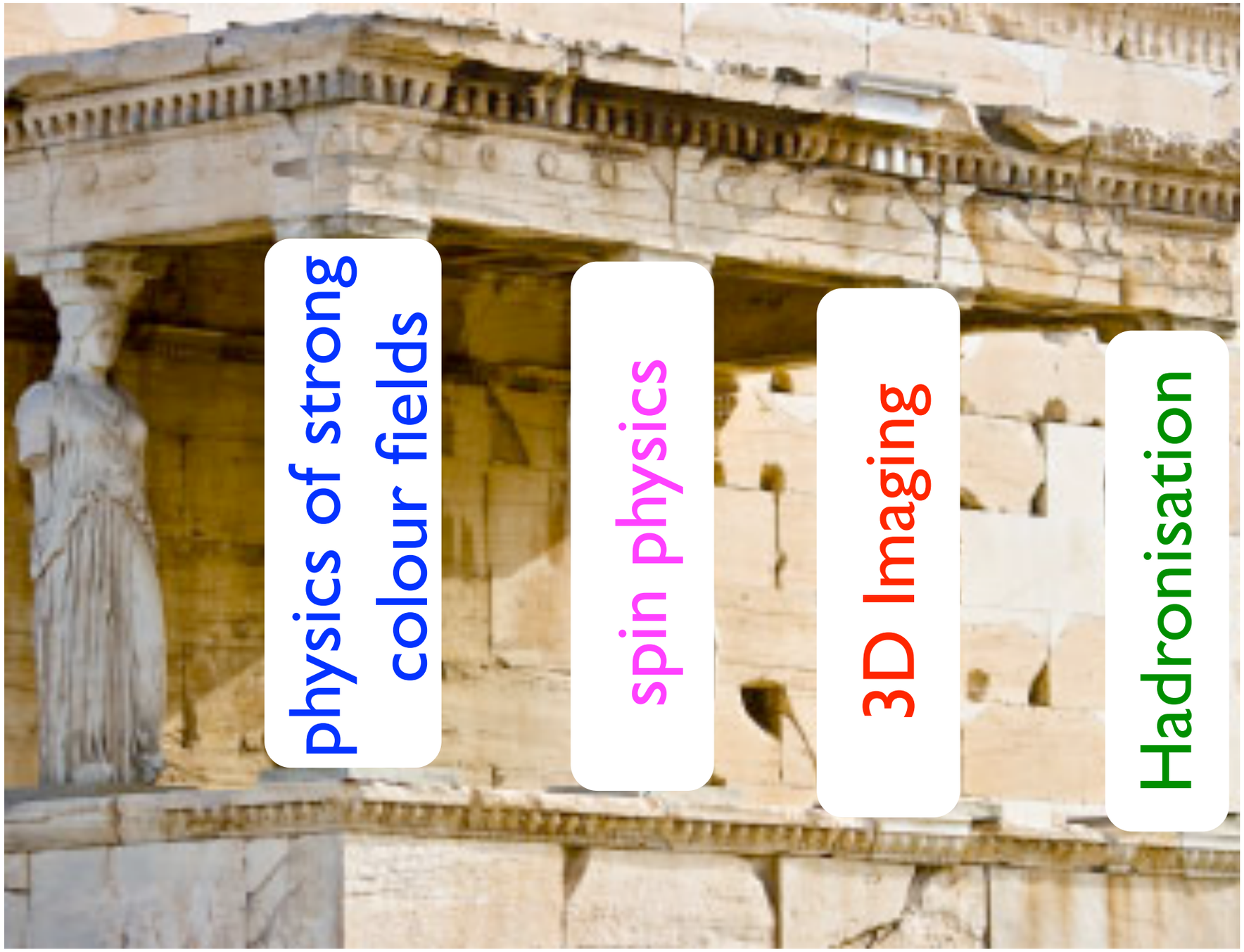


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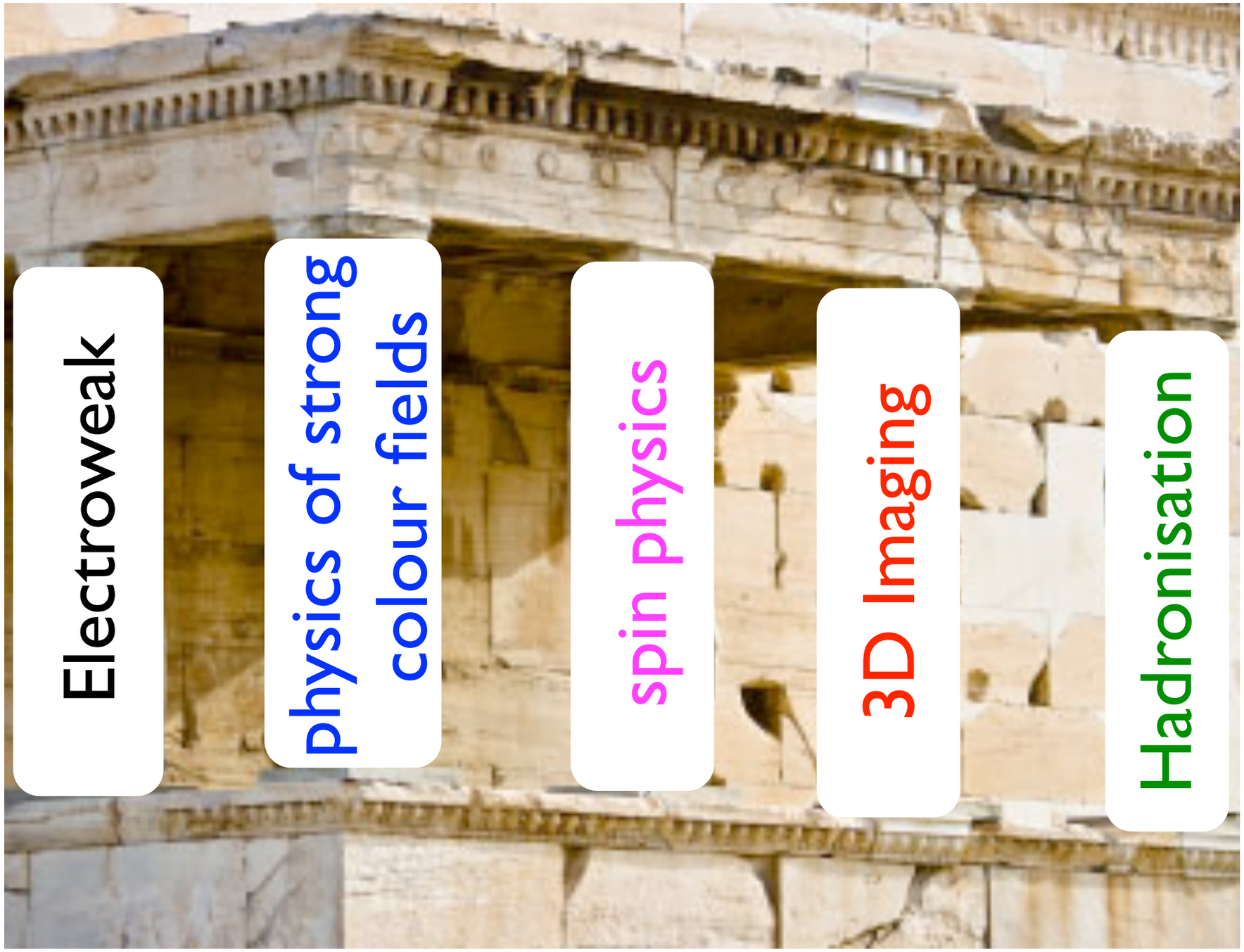


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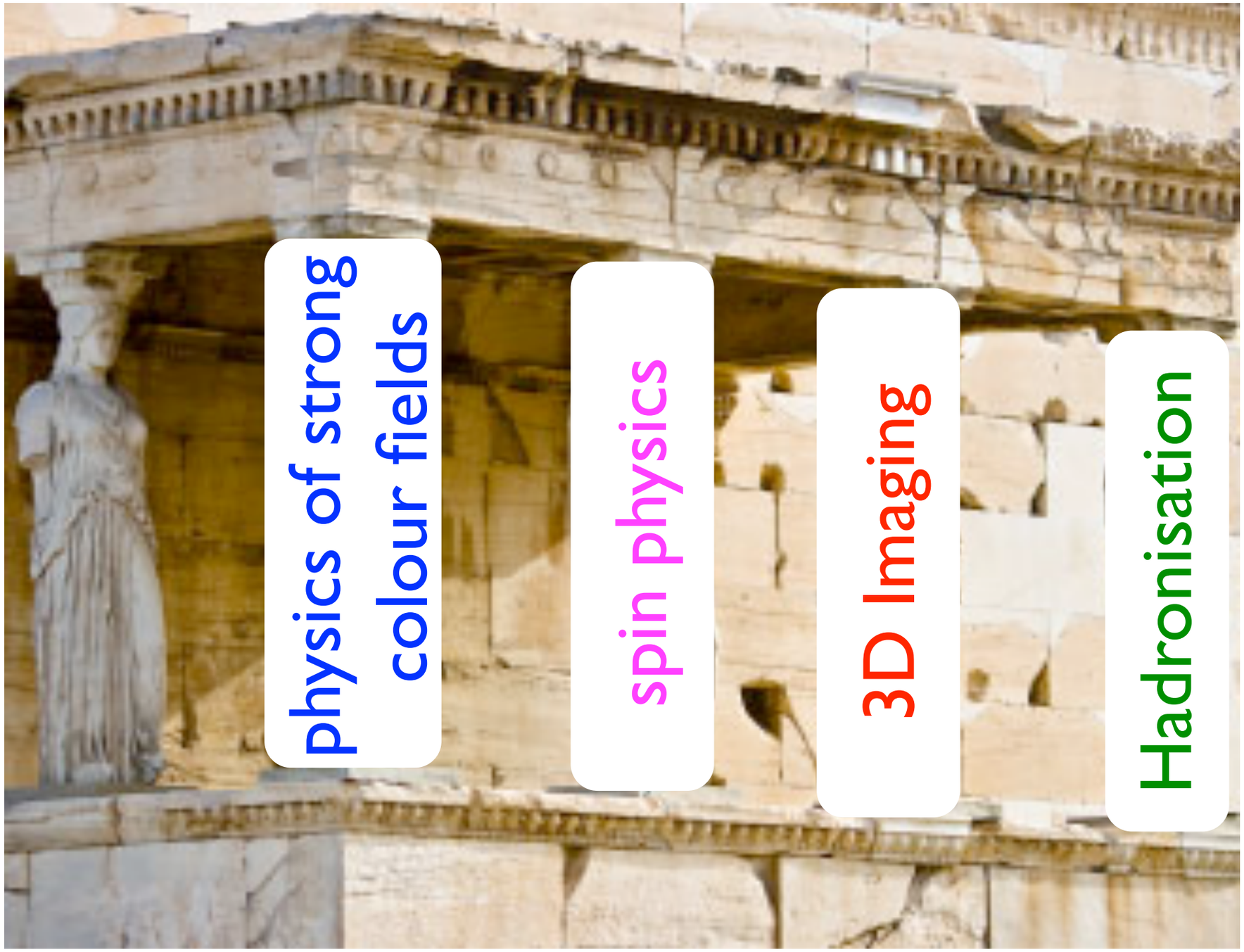


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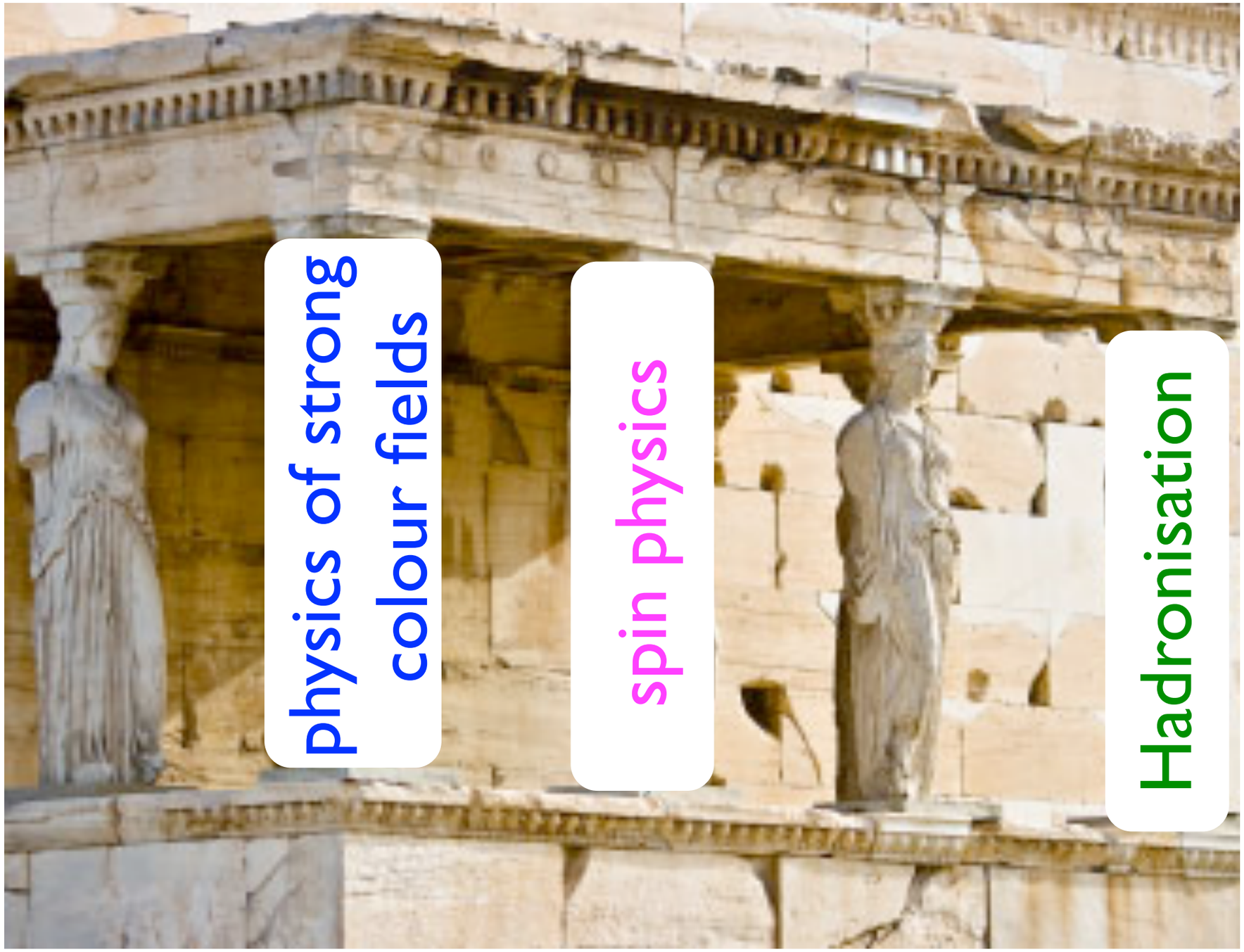
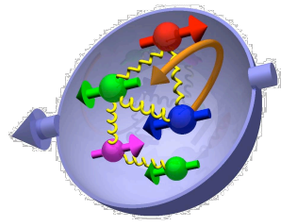



- Wide physics programme with demanding requirements on detector and machine performance

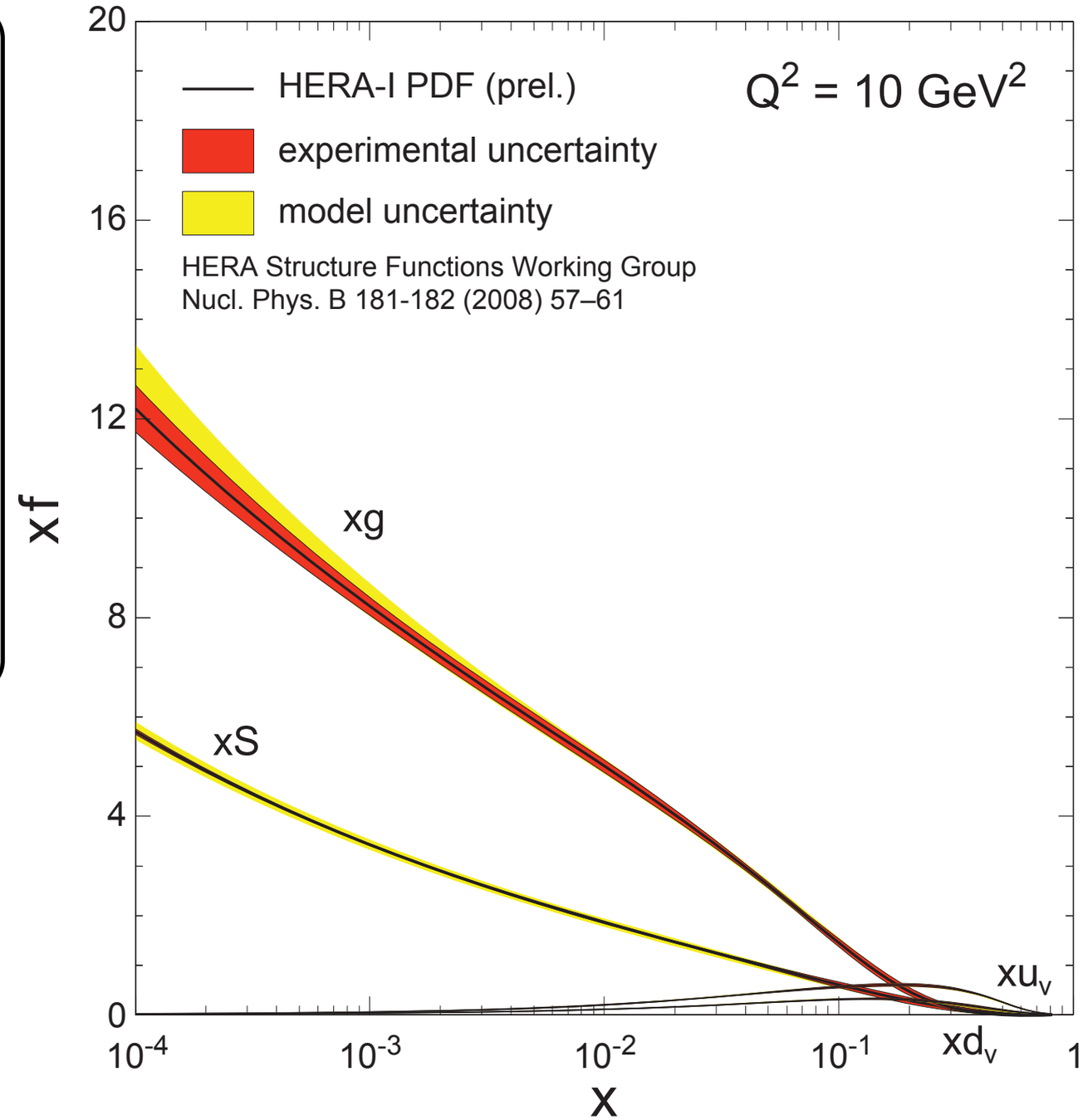
# Most compelling physics questions

Spin physics



- What is the polarisation of gluons at small x where they dominate?
- What is the x-dependence and flavour decomposition of the polarised sea?

Determine quark and gluon contributions to the proton spin at last!!



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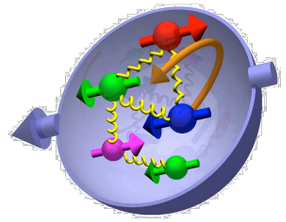

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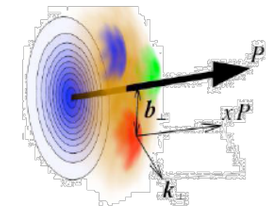
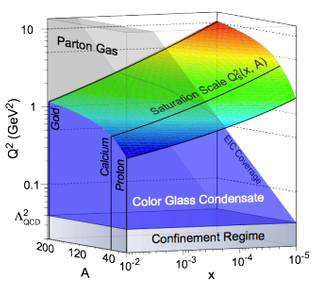
## Imaging

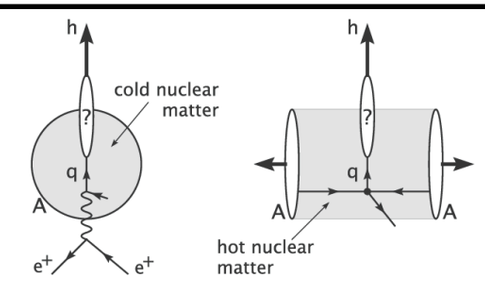



- What is the spatial distribution of quarks/ gluons in nucleons AND nuclei?
- Understand deep aspects of gauge theories revealed by $k_T$ dependent distributions

Possible window to orbital angular momentum

## Strong Colour Fields and Hadronisation




- Quantitatively probe the universality of strong colour fields in A+A, p+A and e+A
- Understand in detail the transition to the non-linear regime of strong gluon fields and the physics of saturation
- How do hard probes in e+A interact with the medium?

Currently have no experimental knowledge of gluons in nuclei at small x!!

# spin physics

# 10 week INT programme - Fall 2010

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Talks online

Application form

Exit report

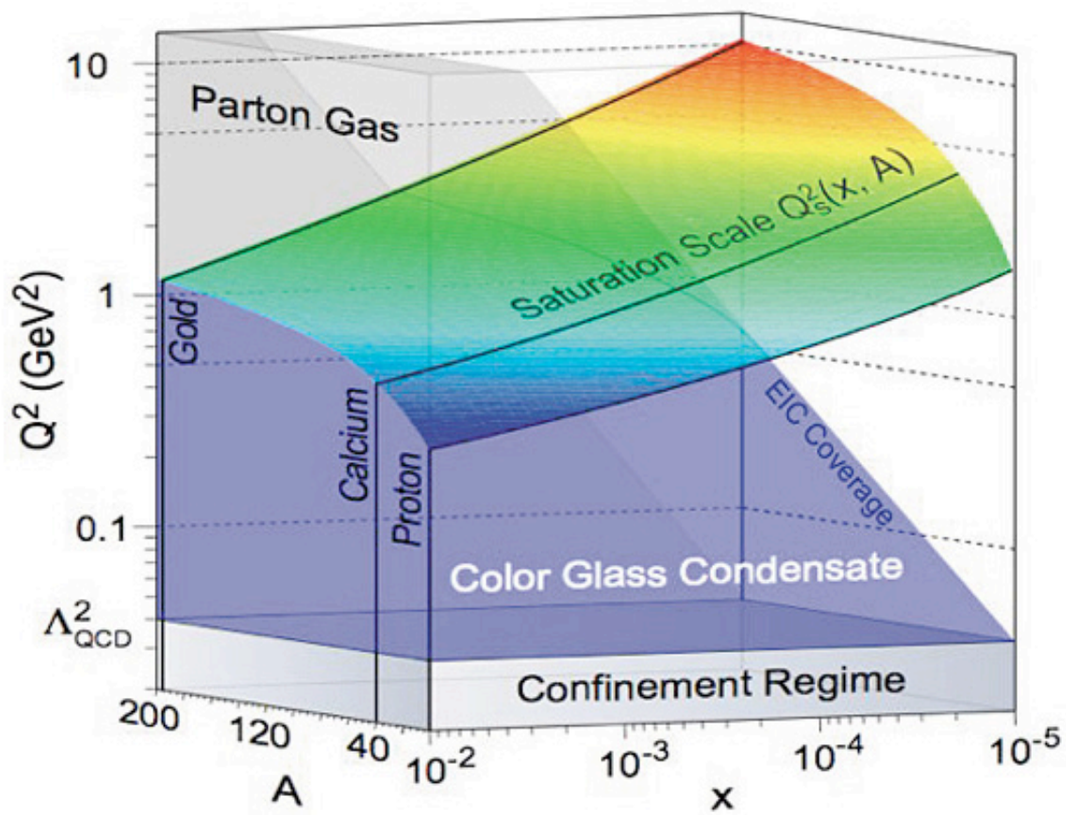
Friends of the INT

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 - Fall 2010

| week | dates | topics |
|---|---|---|
| 1 | 13–17 Sept | **Workshop** on "Perturbative and Non-Perturbative Aspects of QCD at Collider Energies"<br>Agenda |
| 2 | 20–24 Sept | open conceptual issues: factorization and universality, spin and flavor structure, distributions and correlations<br>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<br>Agenda for week 3<br>Agenda for week 4<br>Agenda for week 5 |
| 6–7 | 18–29 Oct | parton densities (unpolarized and polarized), fragmentation functions, electroweak physics<br>Agenda for week 6<br>Agenda for week 7 |
| 8–9 | 1–12 Nov | longitudinal and transverse nucleon structure; spin and orbital effects (GPDs, TMDs, and all that)<br>Agenda for week 8<br>Agenda for week 9 |
| 10 | 16–19 Nov | **Workshop** on "The Science Case for an EIC"<br>Agenda for week 10 |

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

# Golden measurements in spin

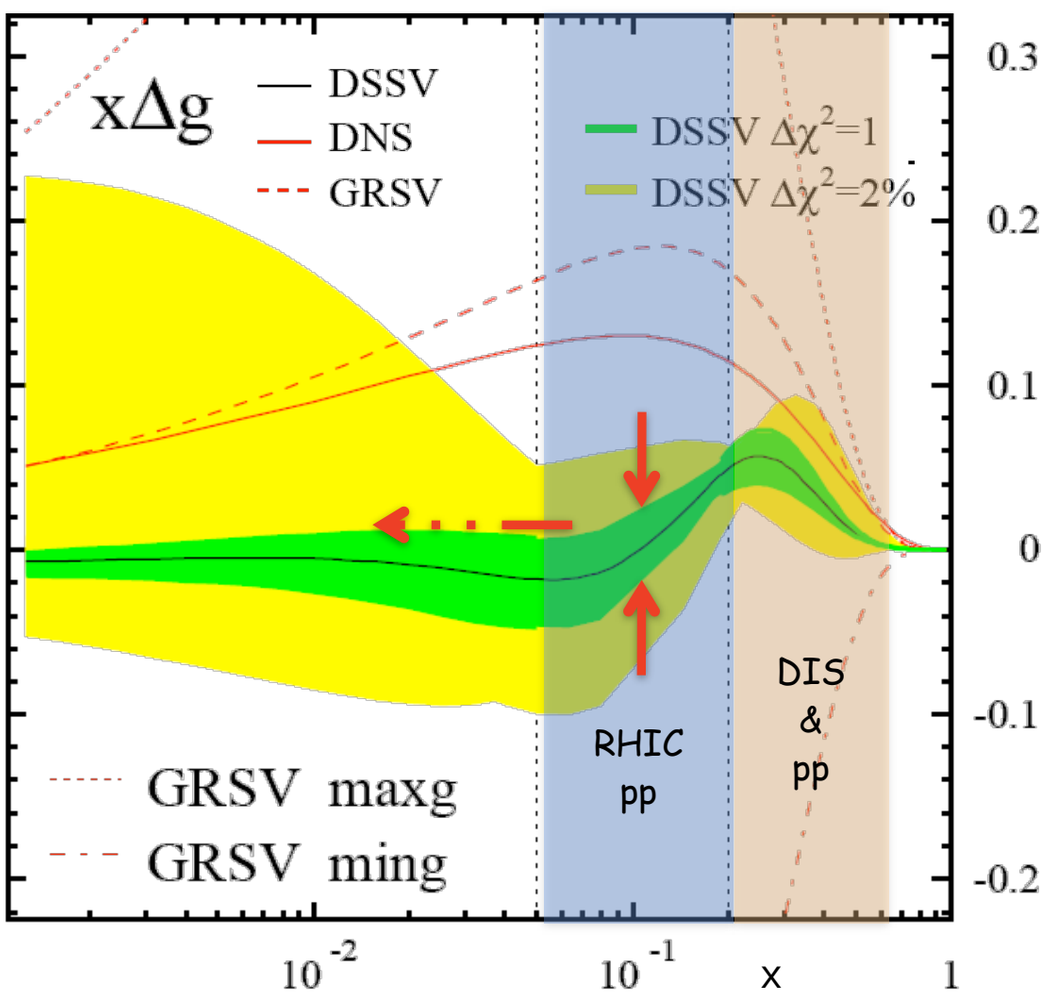
| Deliverables | Observables | What we learn | Requirements |
|---|---|---|---|
| polarised gluon distribution $\Delta g$ | scaling violations in inclusive DIS | gluon contribution to the proton spin | coverage down to x $\sim 10^{-4}$; $\mathcal{L}$ of about 10 $fb^{-1}$ |
| polarised quark and antiquark densities | semi-incl. DIS for pions and kaons | quark contr. to proton spin; asym. like $\Delta\bar{u}$-$\Delta\bar{d}$; $\Delta s$ | similar to DIS; good particle ID |
| novel electroweak spin structure functions | inclusive DIS at high $Q^2$ | flavour separation at medium-x and large $Q^2$ | $\sqrt{s} \geq 100$ GeV; $\mathcal{L} \geq 10$ $fb^{-1}$; positrons; polarised $^3$He beam |

# The quest for Δg - where do we stand?

- inclusive pions and jets remain the main probes
- jet/hadron correlations are essential to cover smaller x

**current status:**

DSSV global fit
de Florian, Sassot,
MS, Vogelsang

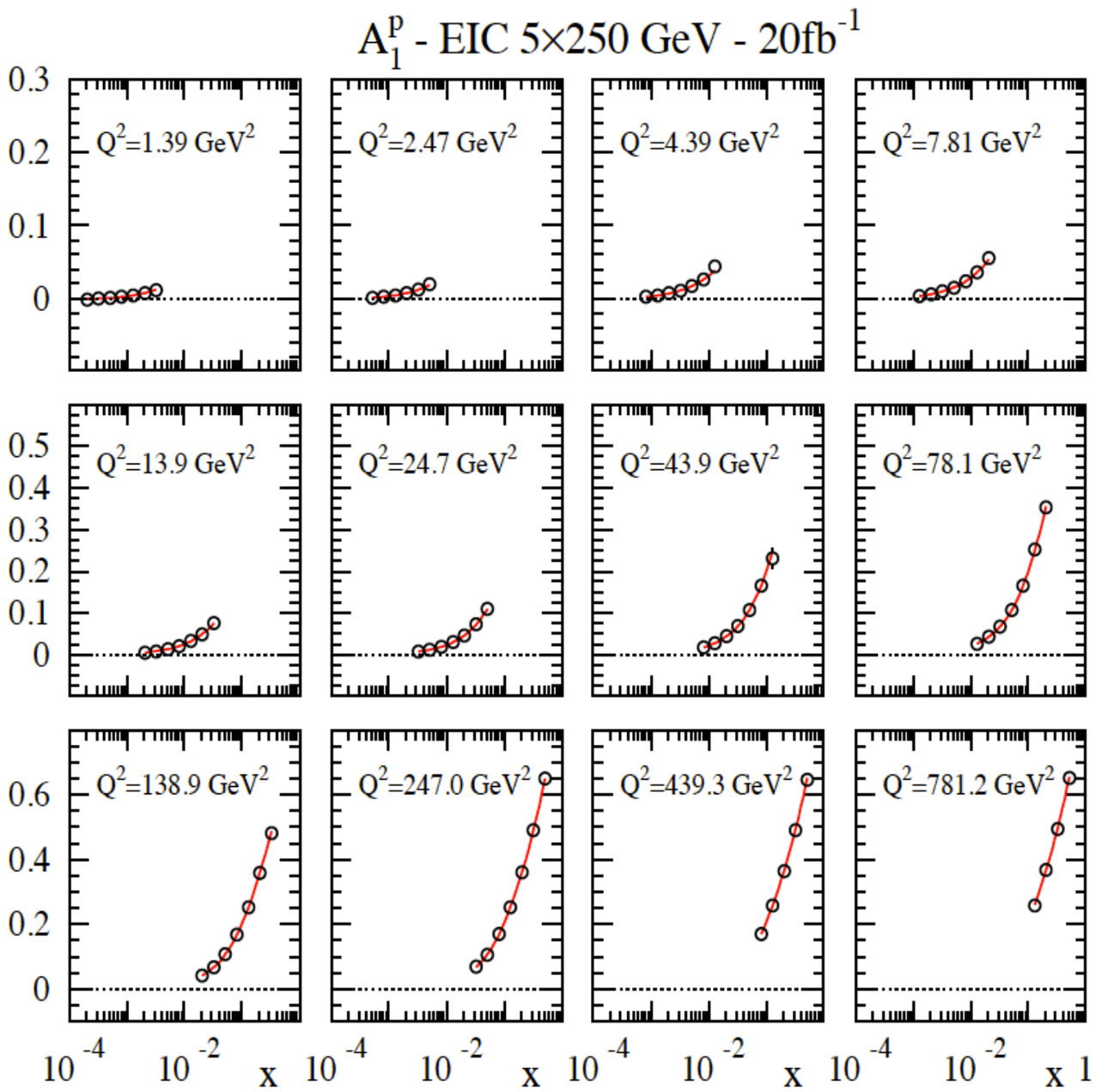


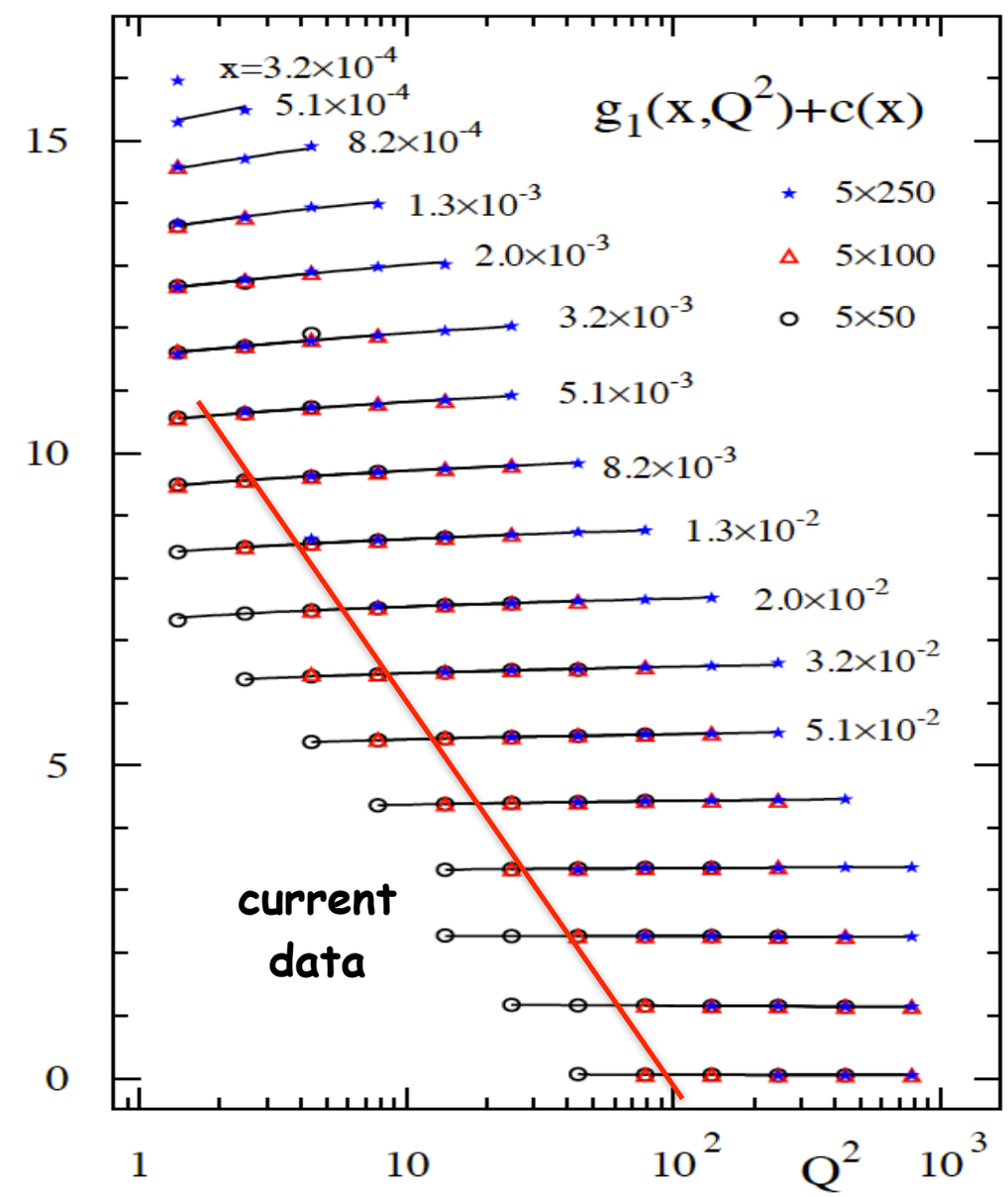

DSSV includes "only" RHIC run6 data

- low-x behaviour is unconstrained
  - ➡ significant polarisation still possible
  - ➡ no reliable error estimate for 1st moment
- By 2015 - expect to have:
  - ➡ DSSV 2.0 global analysis on new world data
  - ➡ reduced uncertainties in Δg in current x range
  - ➡ evidence of a node further scrutinised
  - ➡ extend x-range towards lower x
    - 500 GeV running and particle correlations

# The quest for Δg - what can we do at eRHIC?

**strategy to quantify impact:** global QCD fits with realistic pseudo-data




measurements limited by systematics – need to control them very well

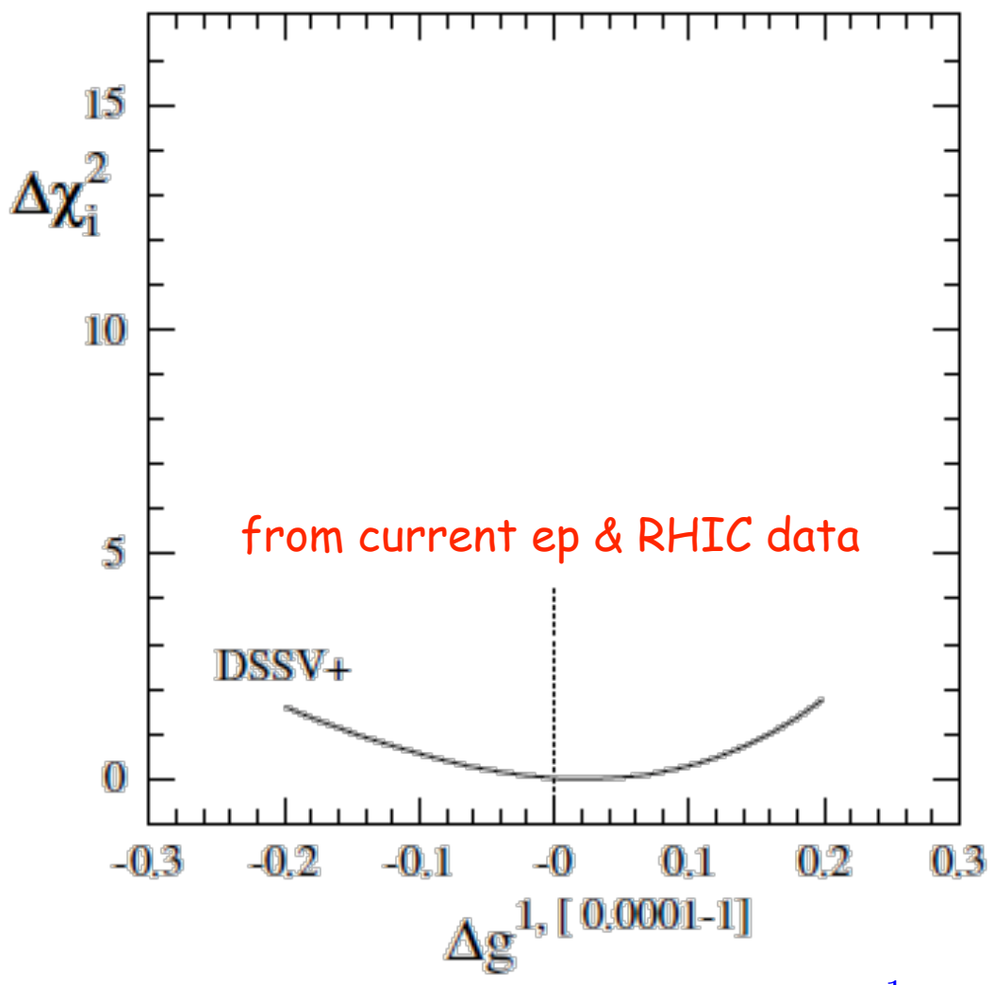
**issues:** bunch-by-bunch polarimetry, relative luminosity, detector performance, …

# The quest for Δg - what can we do at eRHIC?

how effective are scaling violations ?

quantitative studies based on simulated data for eRHIC stage-1: 5 x (50, 100, 250, 325) GeV

$\chi^2$ profile for $\int_{10^{-4}}^{1} \Delta g(x, Q^2)\, dx$




expect to determine $\int_0^1 dx\, \Delta g(x, Q^2)$ at about 10% level (more studies needed)

kinematic reach down to x = $10^{-4}$ essential to determine integral

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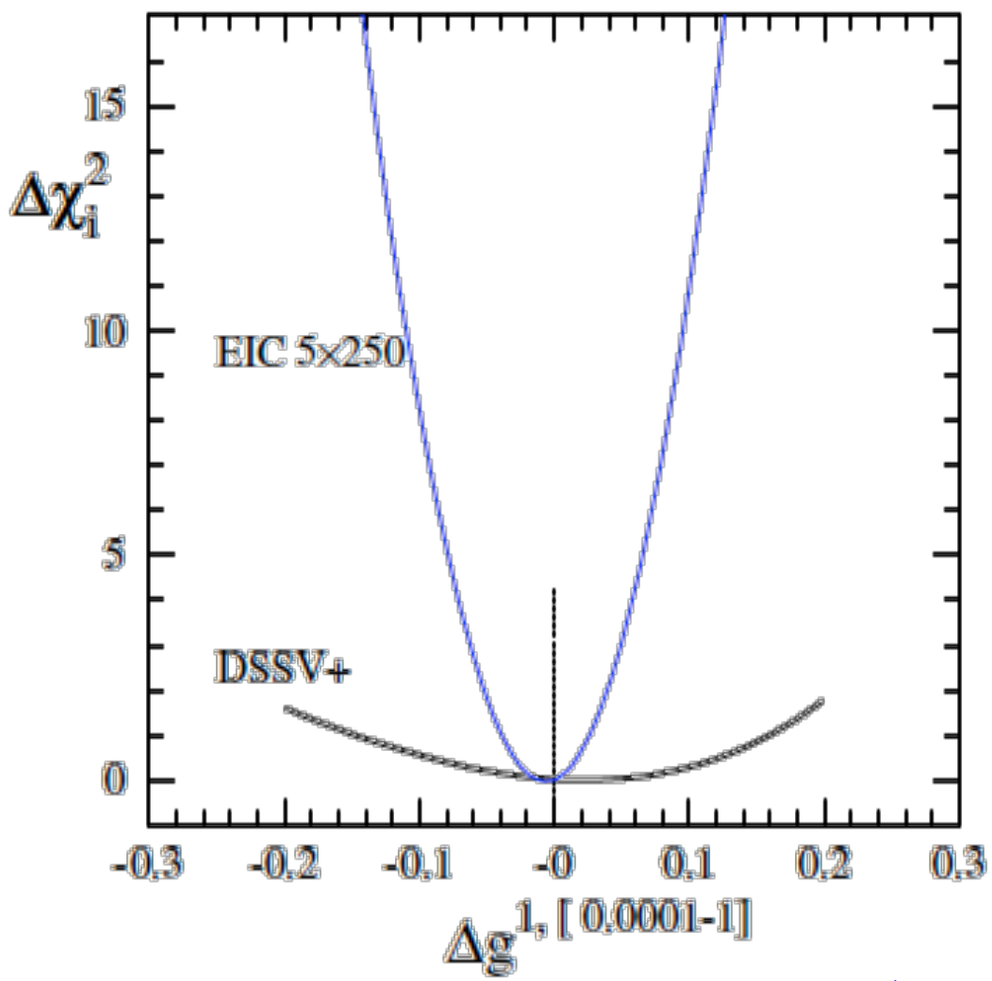


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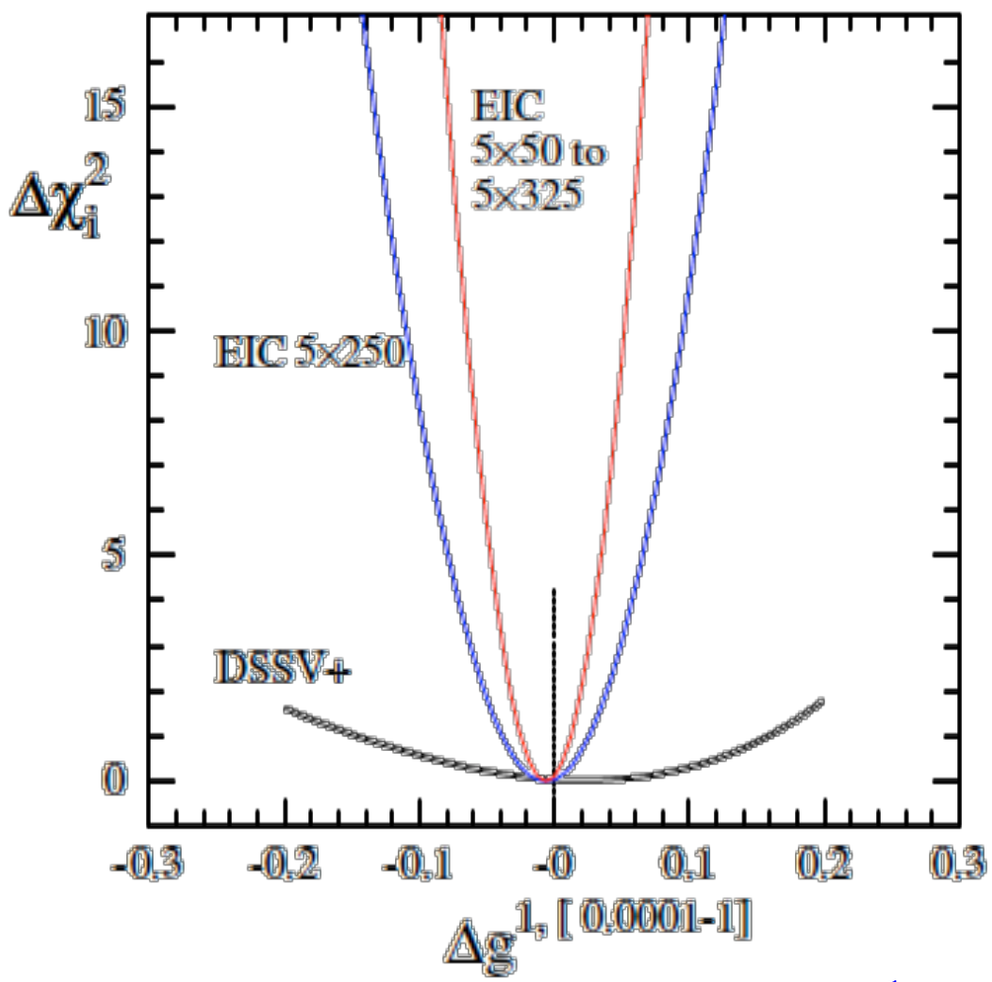


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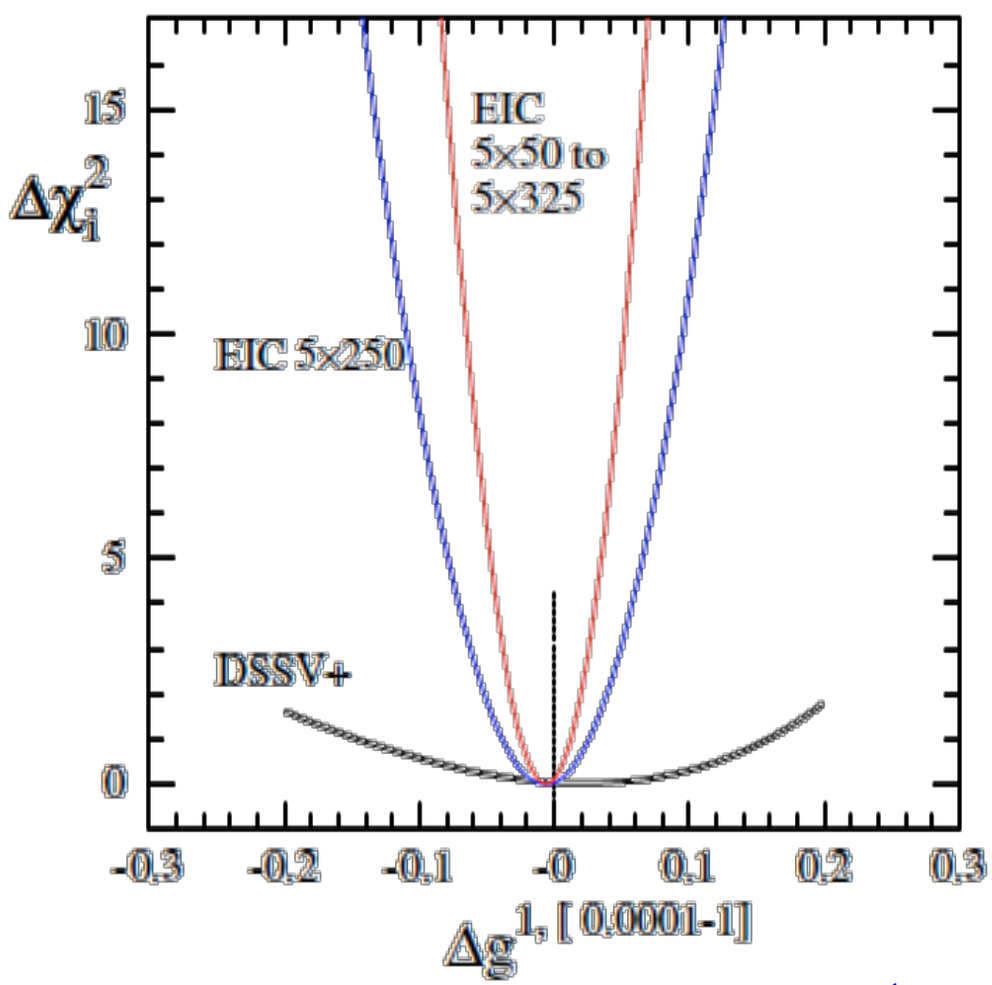
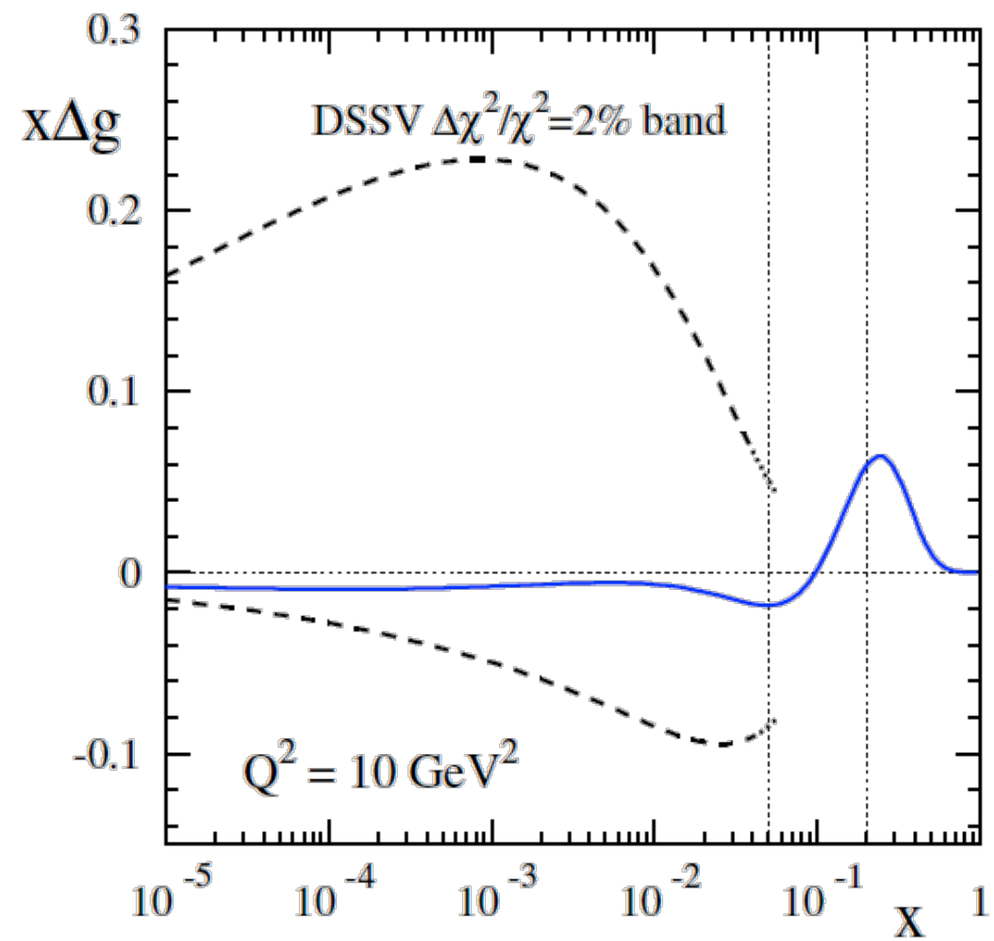



uncertainties on the x-shape of $\Delta g(x, Q^2)$

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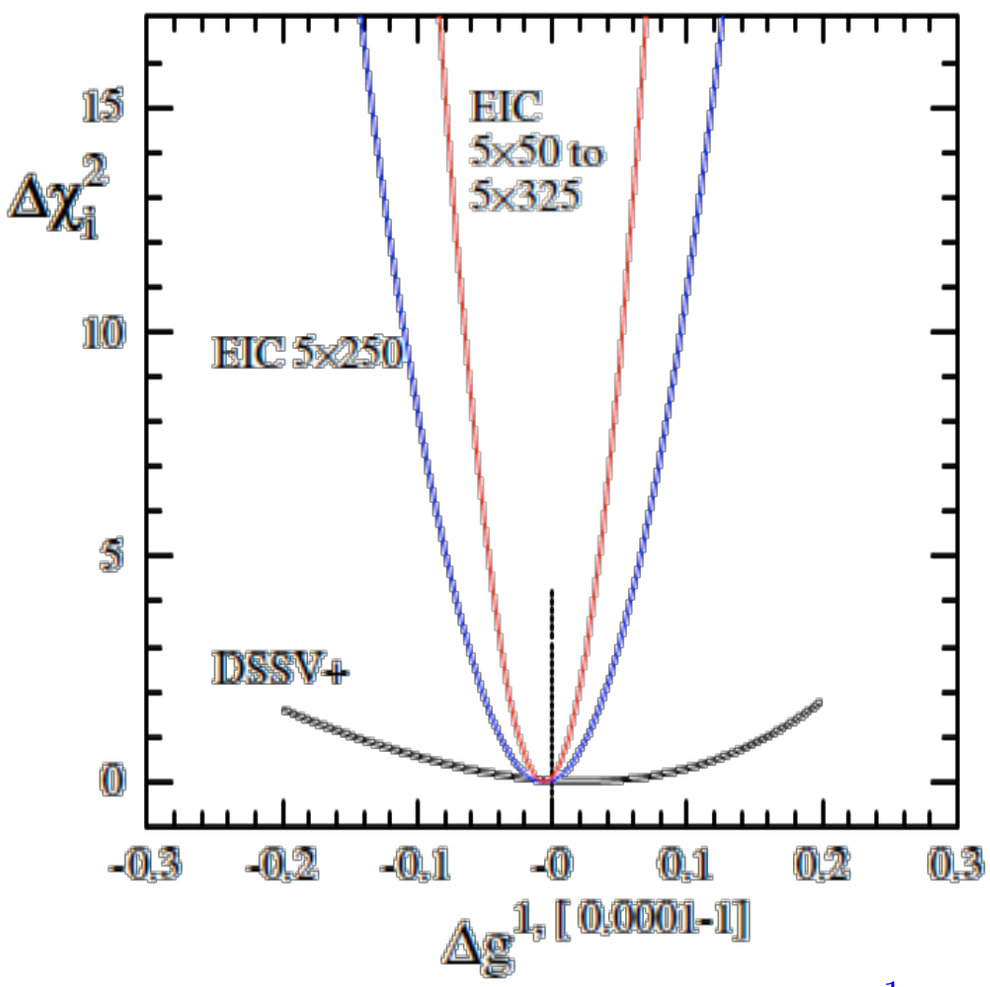


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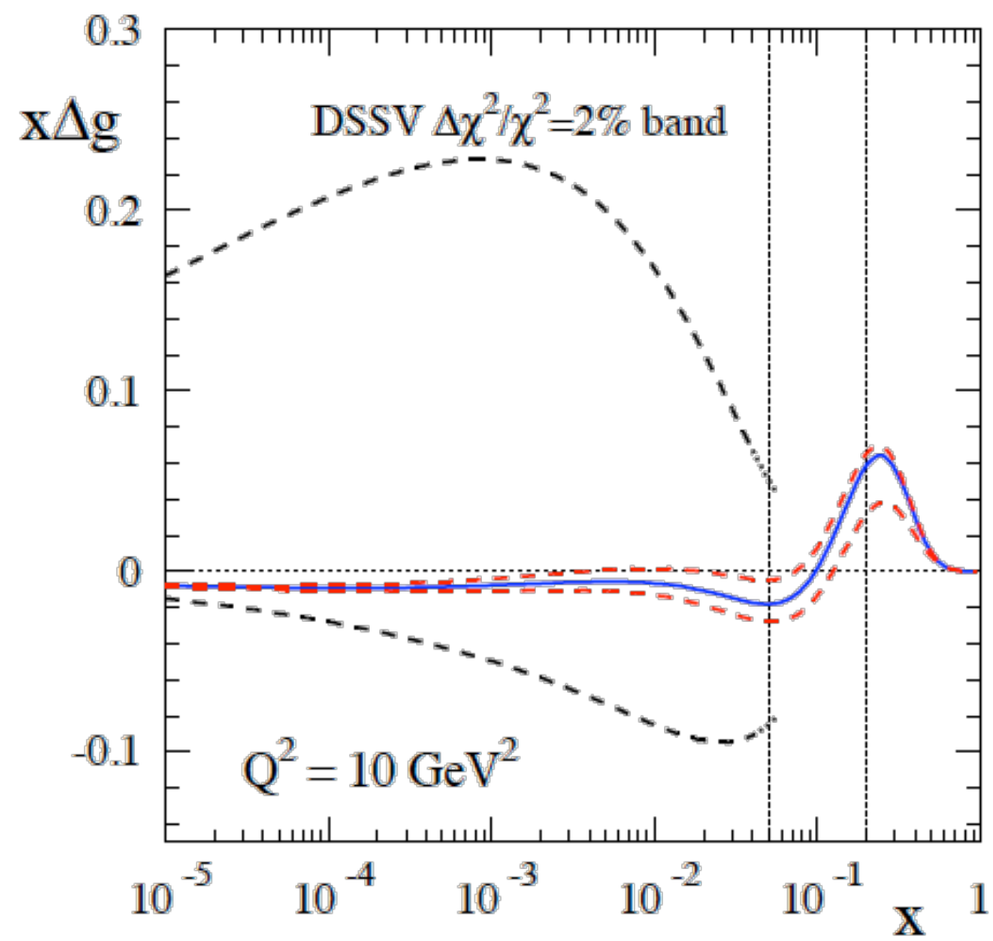


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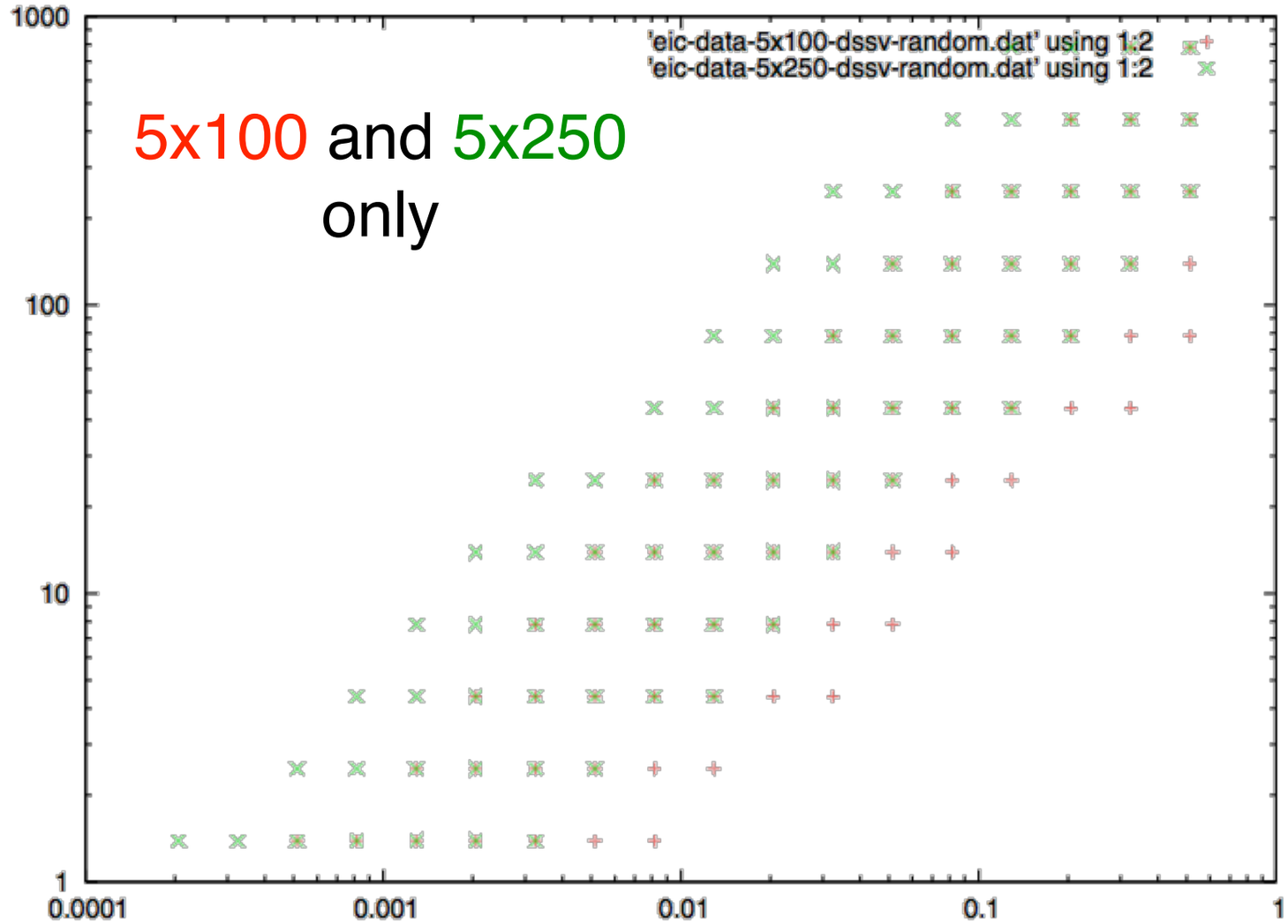
# New pseudo-data

data for DIS and SIDIS ($\pi^{\pm}$, $K^{\pm}$)

10 $fb^{-1}$ each, 70% beam pol.

Cuts:

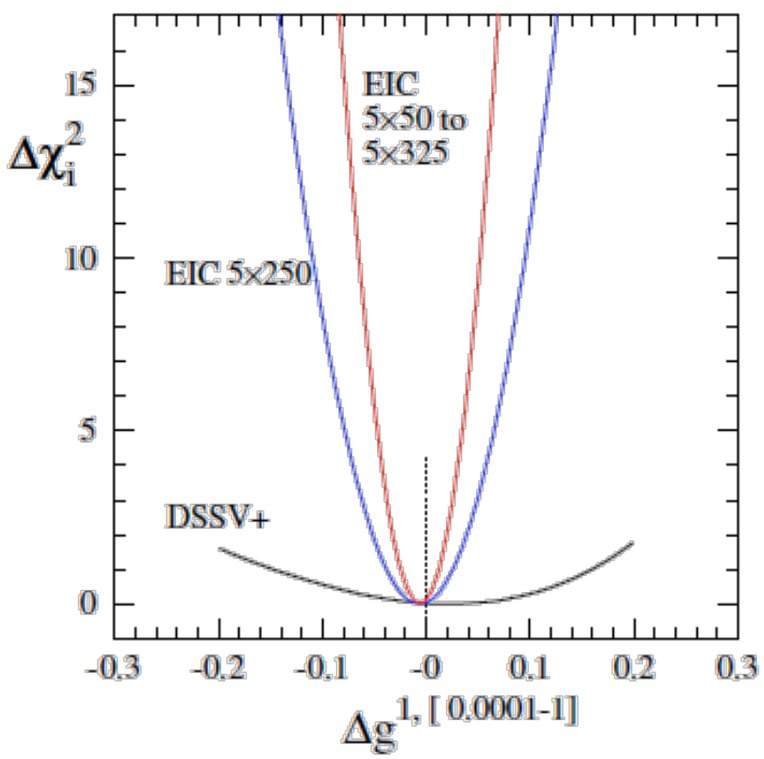
- $W^2 > 10$ $GeV^2$
- depol. factor > 0.1
- $0.001 < y < 0.95$
- $1^o < \theta < 179^o$
- $p_e > 0.5$ GeV
- $p_{hadr} > 1$ GeV

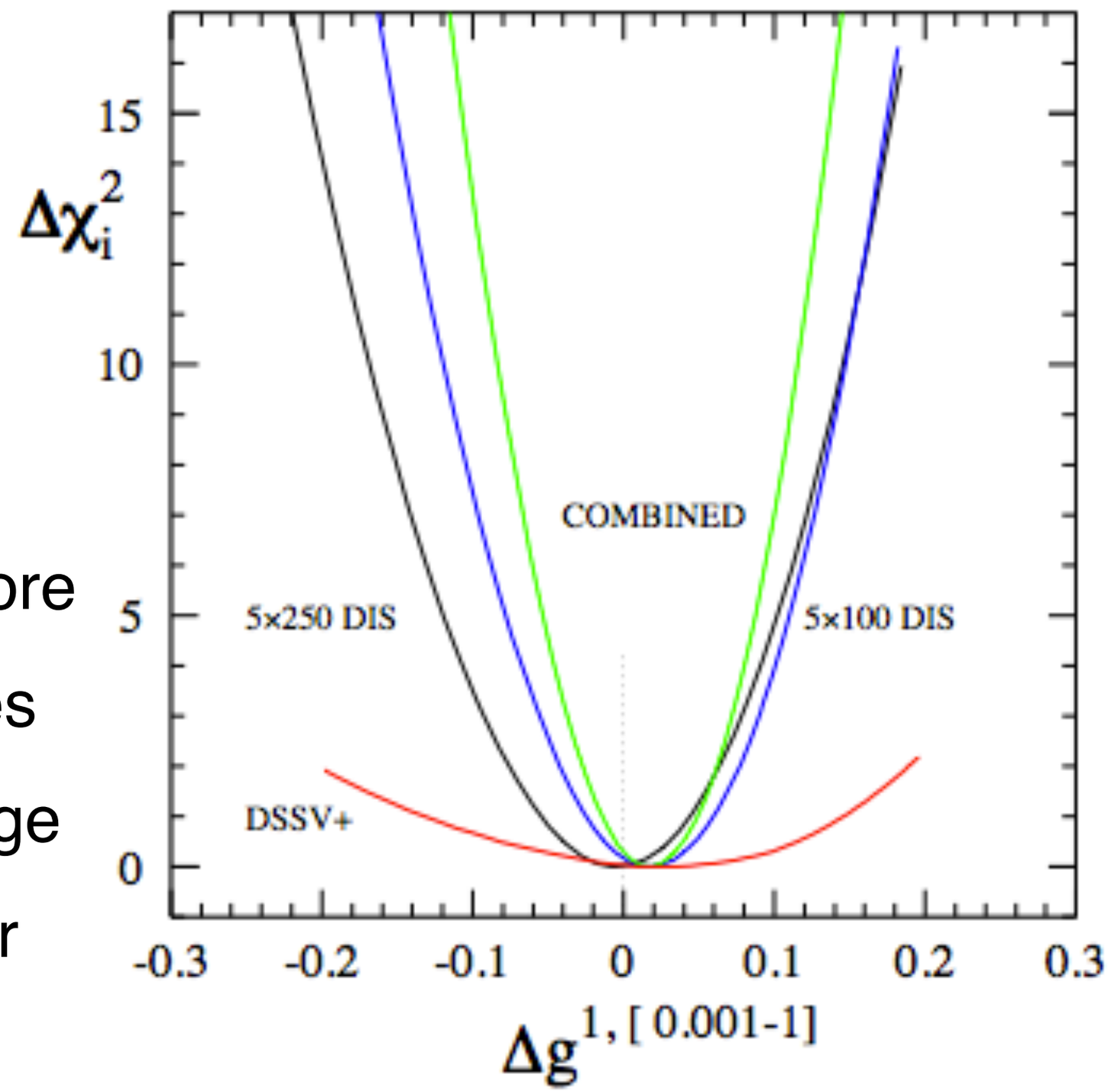



- Global analysis:
  - use relative uncertainty of each point to produce mock data (based on DSSV)
  - randomise data within 1σ
  - for SIDIS: incl. 5%(10%) uncertainty from pion (kaon) frag. functions
  - map out $\chi^2$ profiles with Lagrange multiplier method (Hessian is work in progress)

# Update on Δg

previous result

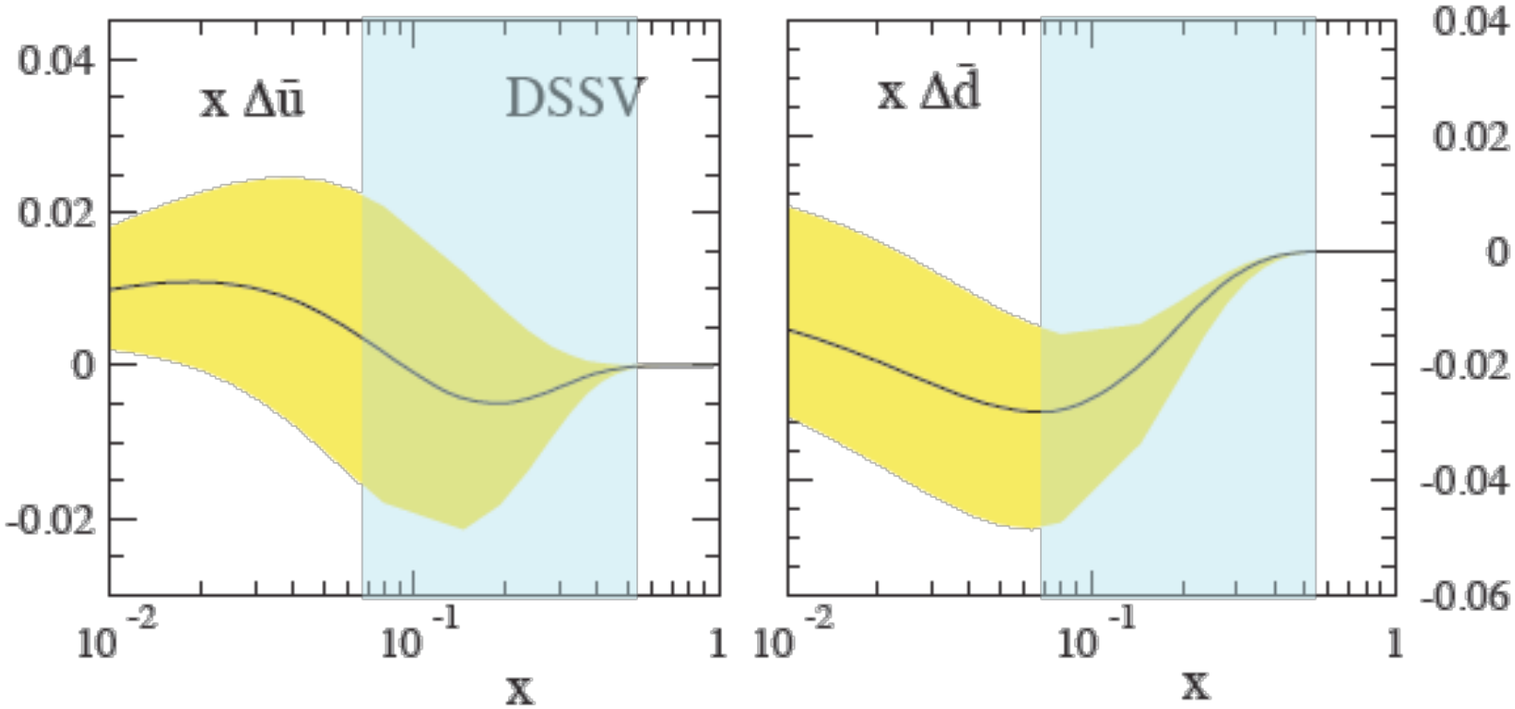


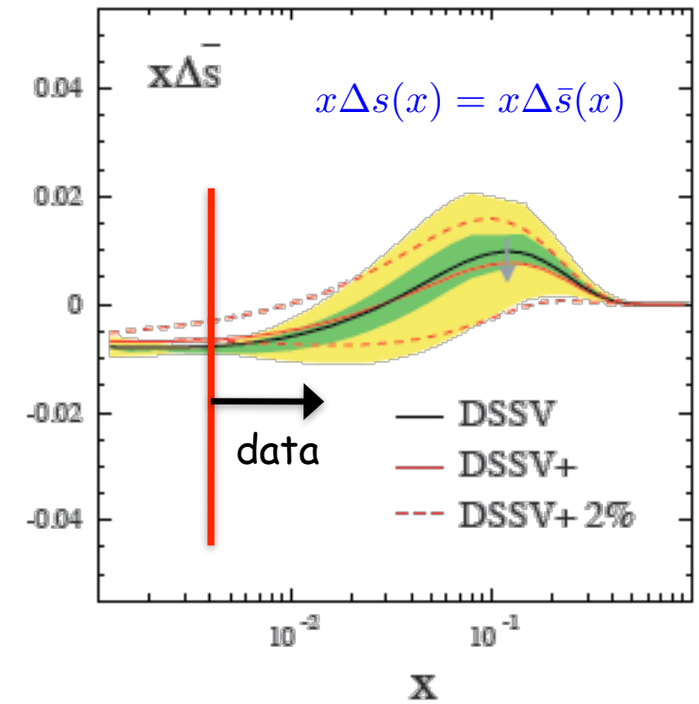

- Very similar results to before
- Slightly larger uncertainties
- need to study $10^{-4} \rightarrow 1$ range
- need to translate into error on x-shape of Δg

# What about Δq?

current uncertainties DSSV



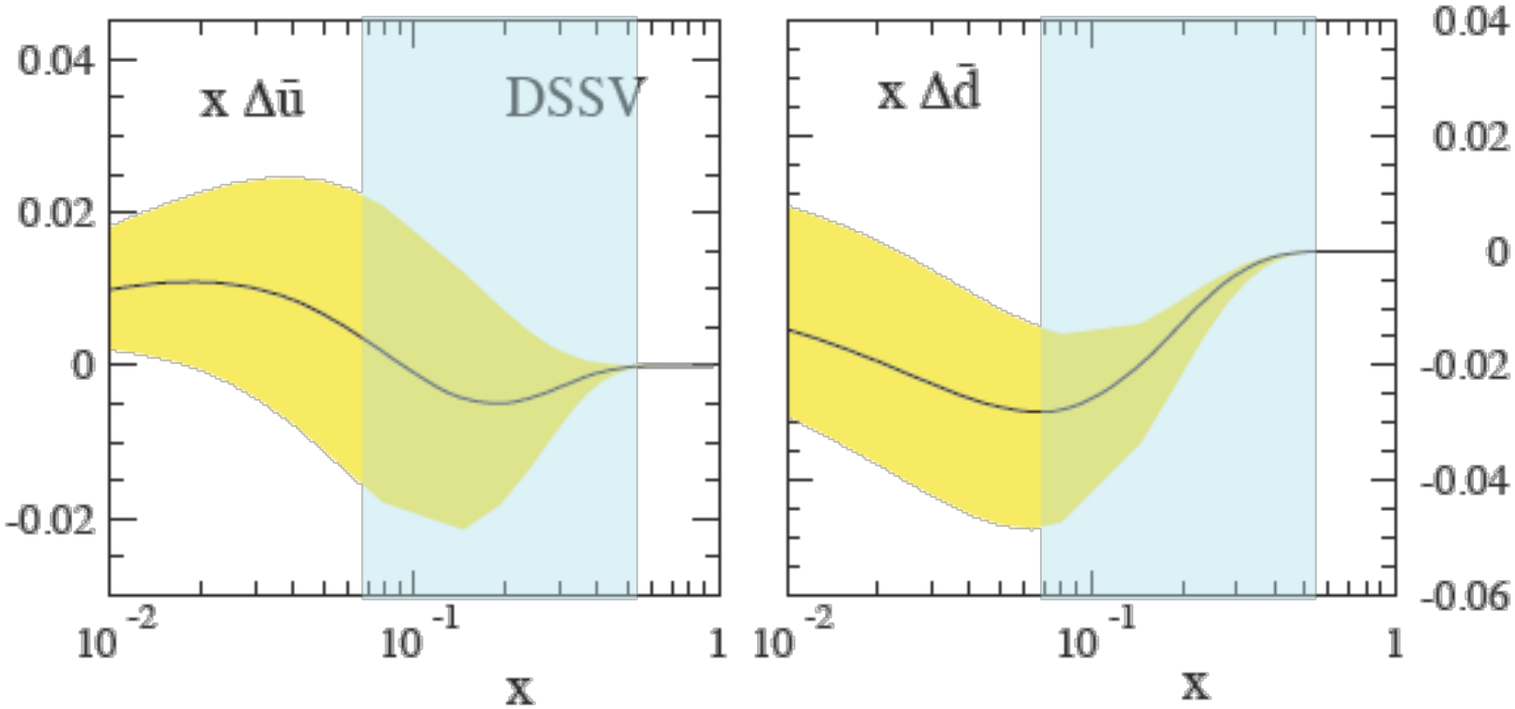

DSSV (incl. latest COMPASS data)

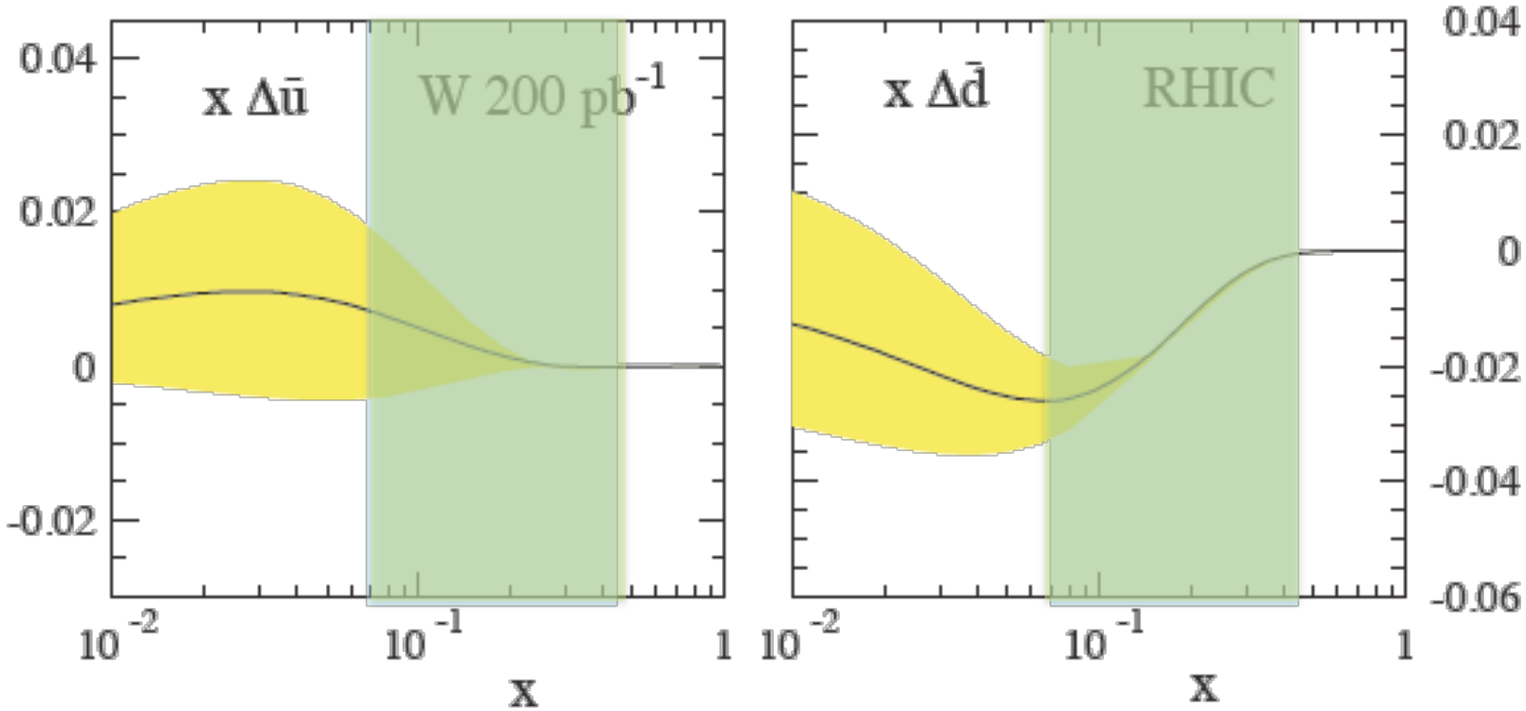



- **surprise:** Δs small & positive from SIDIS data
- but 1st moment is negative and sizable due to “constraint” from hyperon decays (F,D) (assumed SU(3) symmetry - debatable M. Savage)
- drives uncertainties on ΔΣ (spin sum)

# What about Δq?

current uncertainties DSSV

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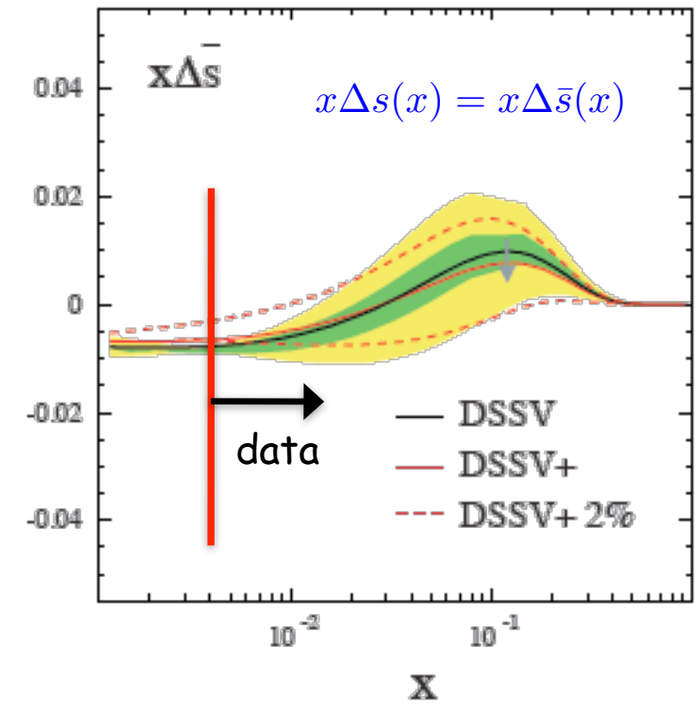
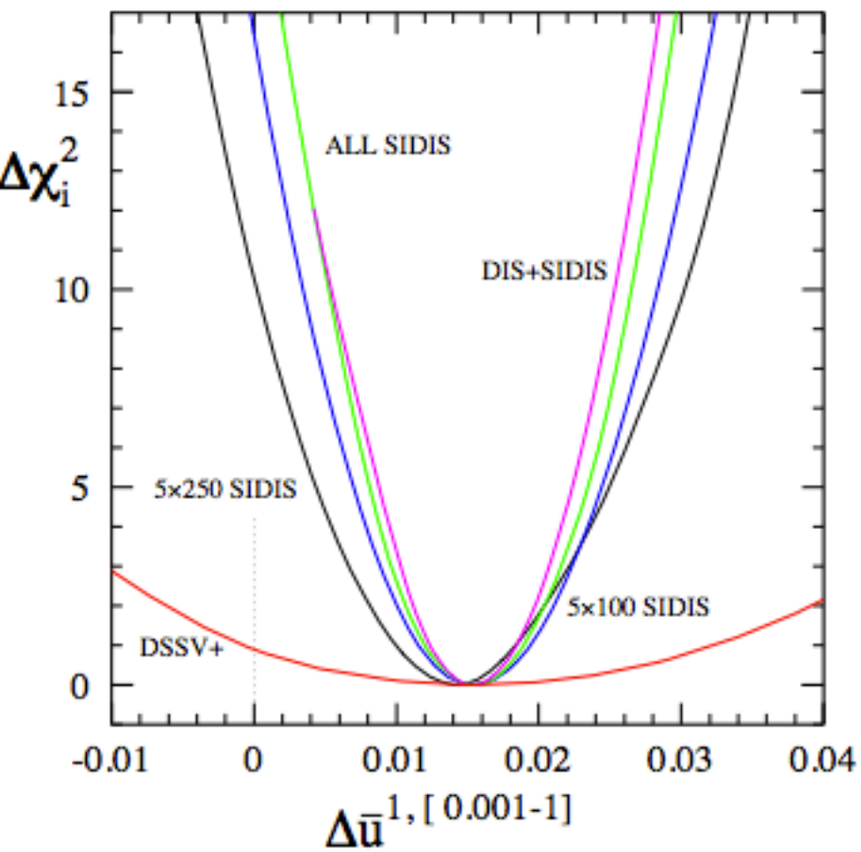



simulated impact of RHIC

- W boson data on global fit
- reduction of uncertainties for 0.07 < x < 0.4 can test consistency of low $Q^2$ SIDIS data in that x regime

# First results on the quark sea




- very encouraging results
- as expected, DIS has no impact
- need to study 0.0001-1 range
- need to translate into error on x-shape

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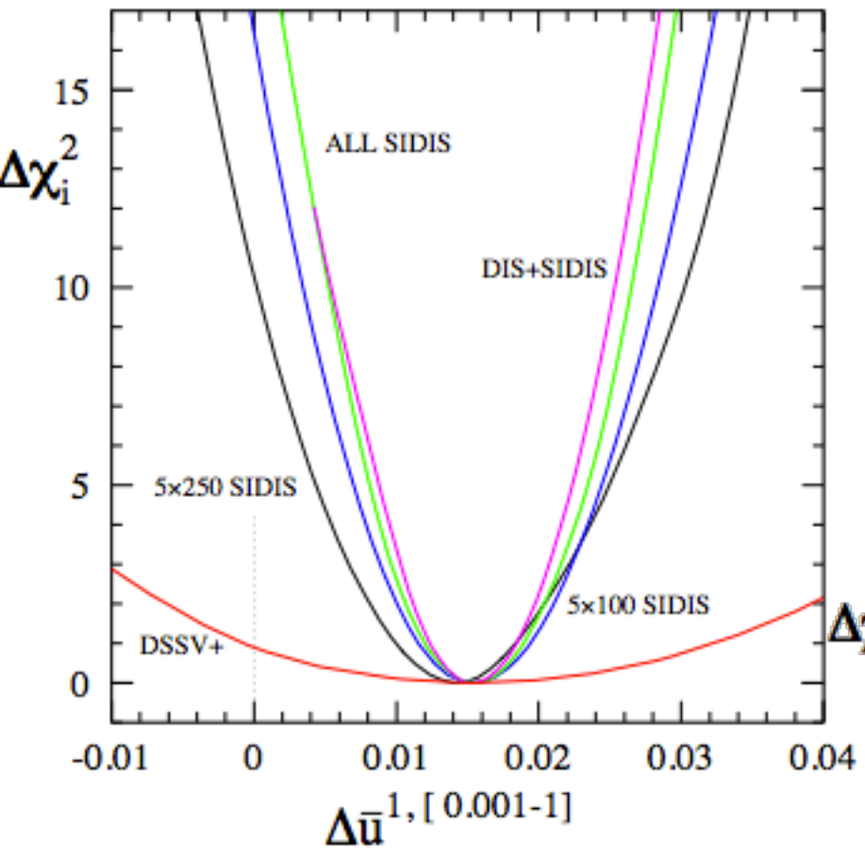


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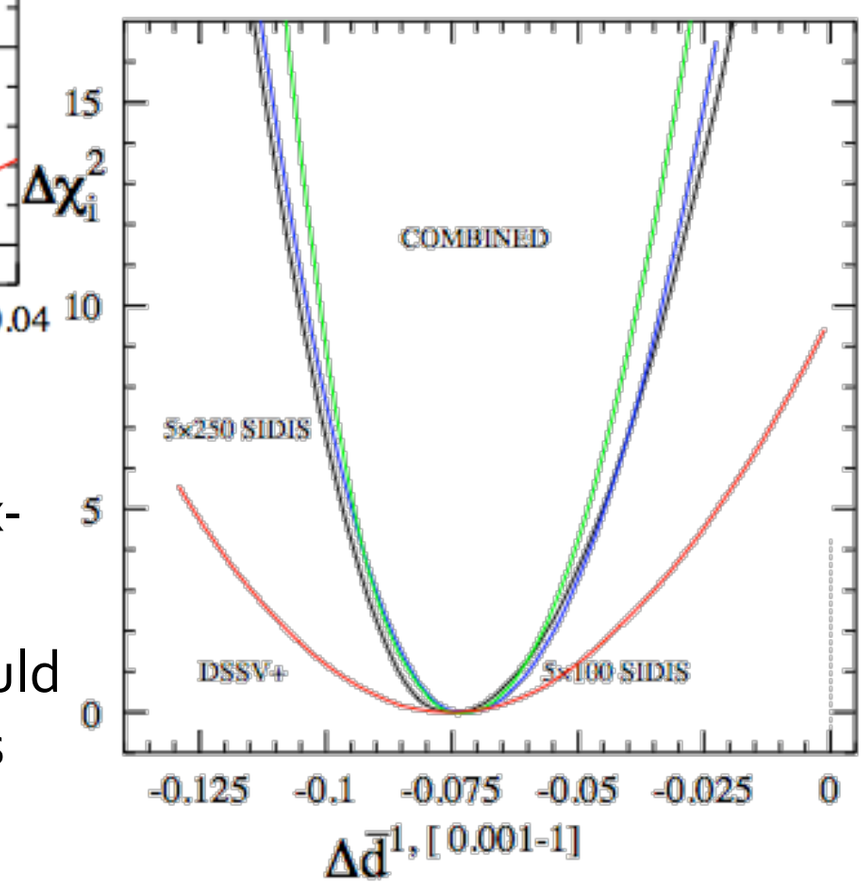
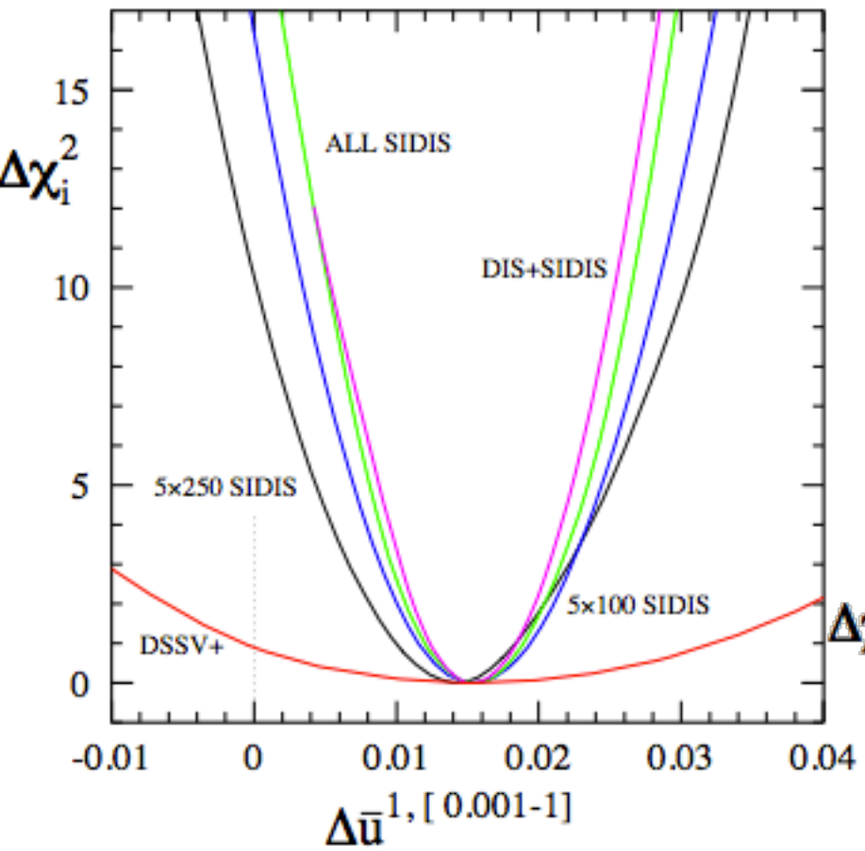



- note the change of scale on x-axis
- perhaps "neutron beam" would lead to further improvements

# First results on the quark sea

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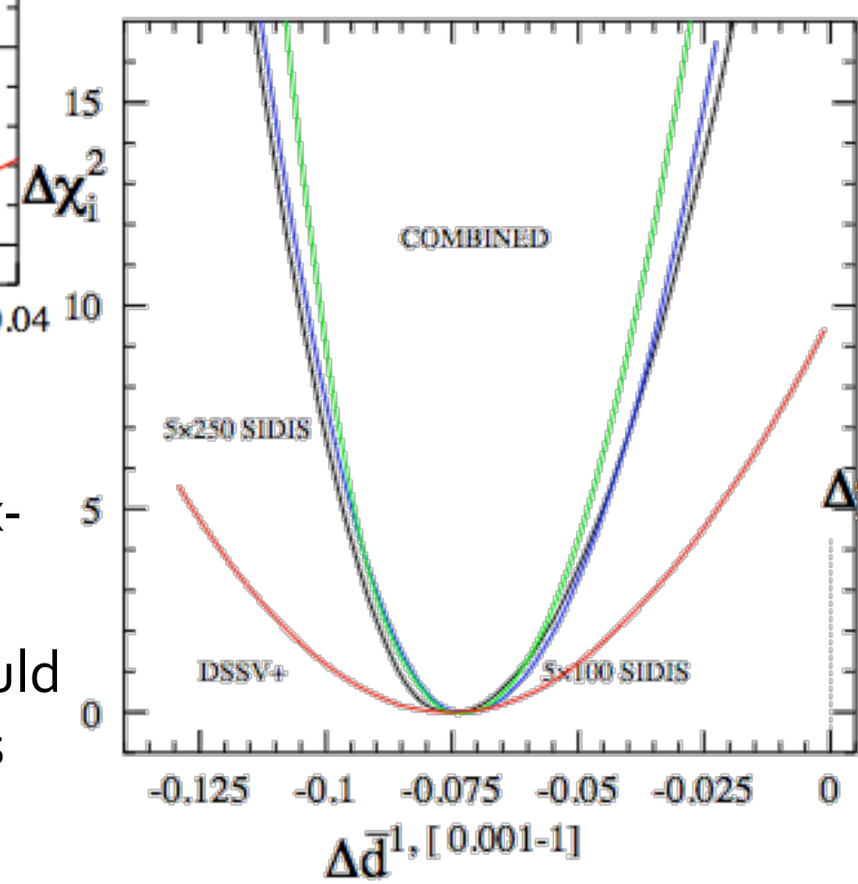


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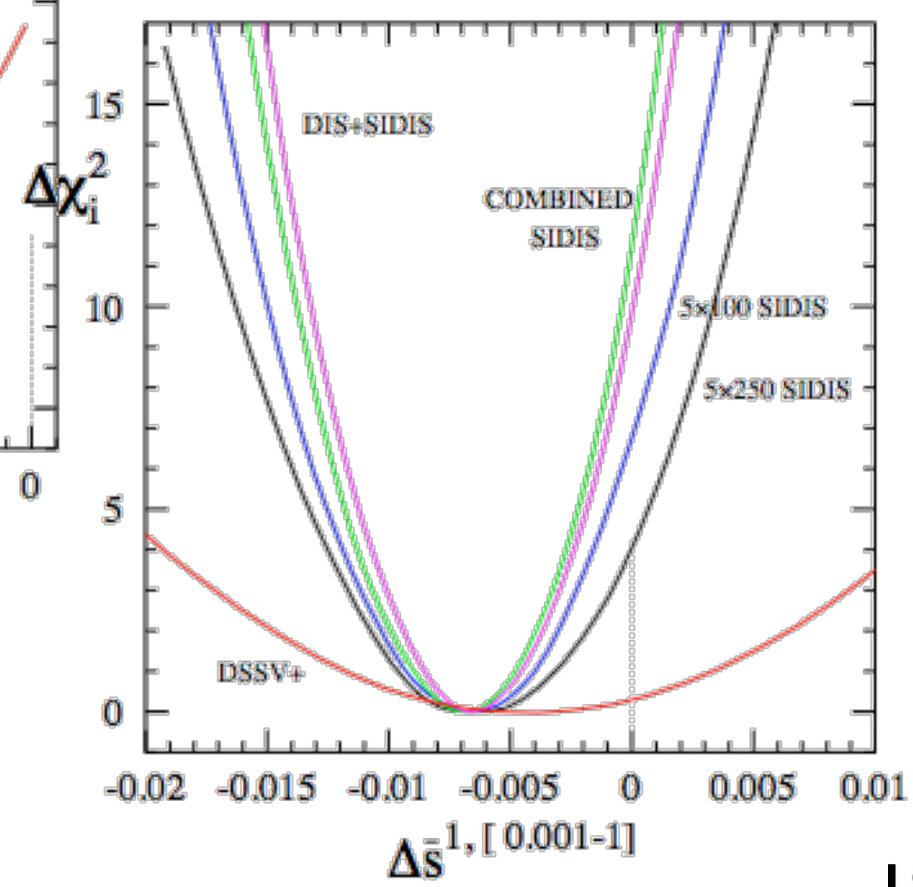


- should be able to test "constraint" from SU(3) symmetry (F,D values from hyperon decays)

# e+A physics

# 10 week INT programme - Fall 2010

| week | dates | topics |
|---|---|---|
| 1 | 13–17 Sept | **Workshop** on "Perturbative and Non-Perturbative Aspects of QCD at Collider Energies"<br>Agenda |
| 2 | 20–24 Sept | open conceptual issues: factorization and universality, spin and flavor structure, distributions and correlations<br>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<br>Agenda for week 3<br>Agenda for week 4<br>Agenda for week 5 |
| 6–7 | 18–29 Oct | parton densities (unpolarized and polarized), fragmentation functions, electroweak physics<br>Agenda for week 6<br>Agenda for week 7 |
| 8–9 | 1–12 Nov | longitudinal and transverse nucleon structure; spin and orbital effects (GPDs, TMDs, and all that)<br>Agenda for week 8<br>Agenda for week 9 |
| 10 | 16–19 Nov | **Workshop** on "The Science Case for an EIC"<br>Agenda for week 10 |

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

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# Golden 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 $Q_s$ |
| 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 |

# Silver Measurements

| Deliverables | Observables | What we learn | Stage-I | Stage-II |
|---|---|---|---|---|
| integrated gluon distributions | $F^c_{2,L}$, $F^D_{2,L}$ | nuclear wave function; saturation, $Q_s$ | difficult measurement / interpretation | saturation regime |
| flavour separated nuclear PDFs | charged current and γZ structure functions | EMC effect origin | full flavour separation for $10^{-2} < x < 1$ | measure $Q_s$ |
| $k_T$ dependent gluons | SIDIS at small x | non-linear QCD evolution / universality | onset of saturation | rare probes and bottom; large-x gluons |
| 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

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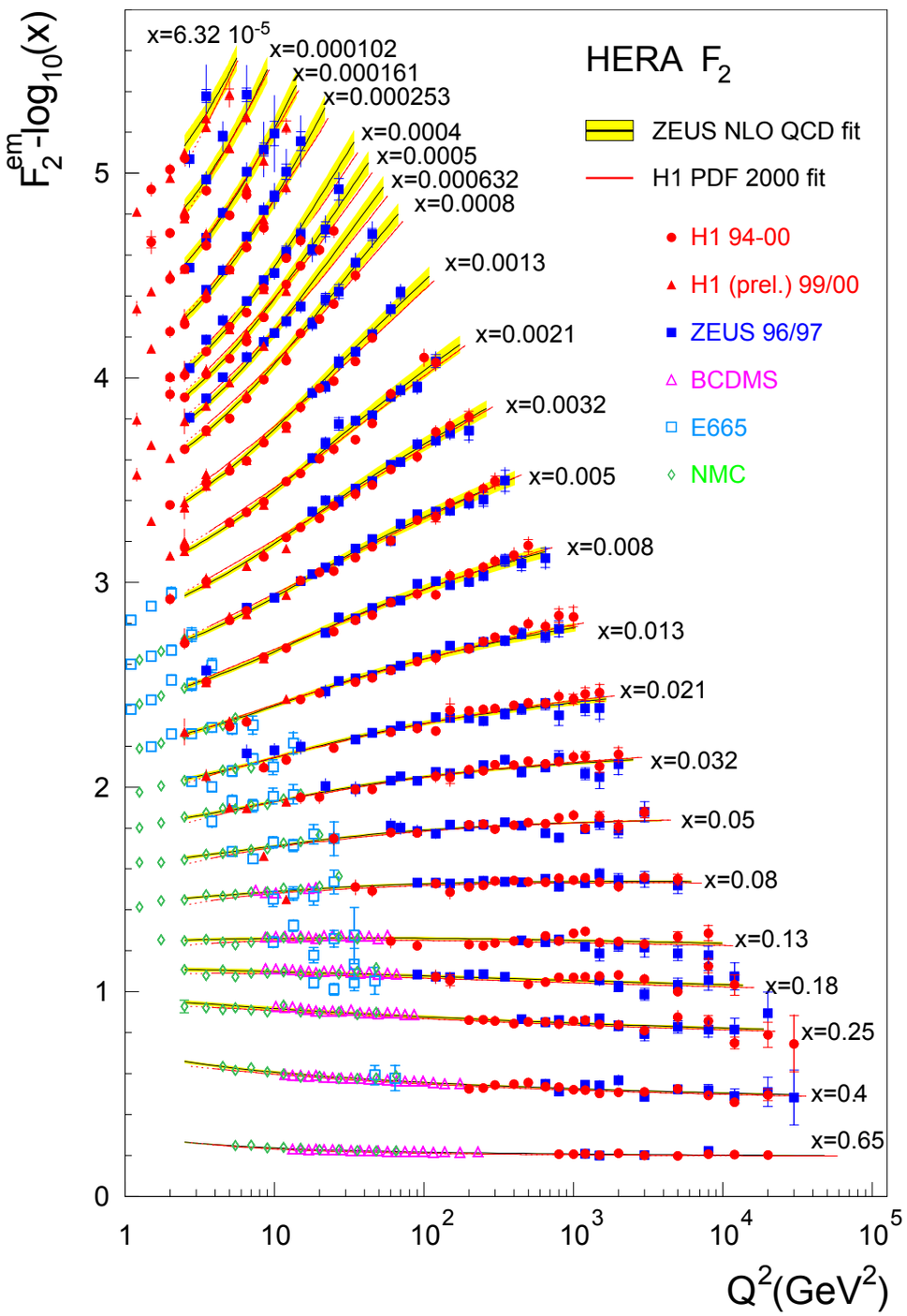
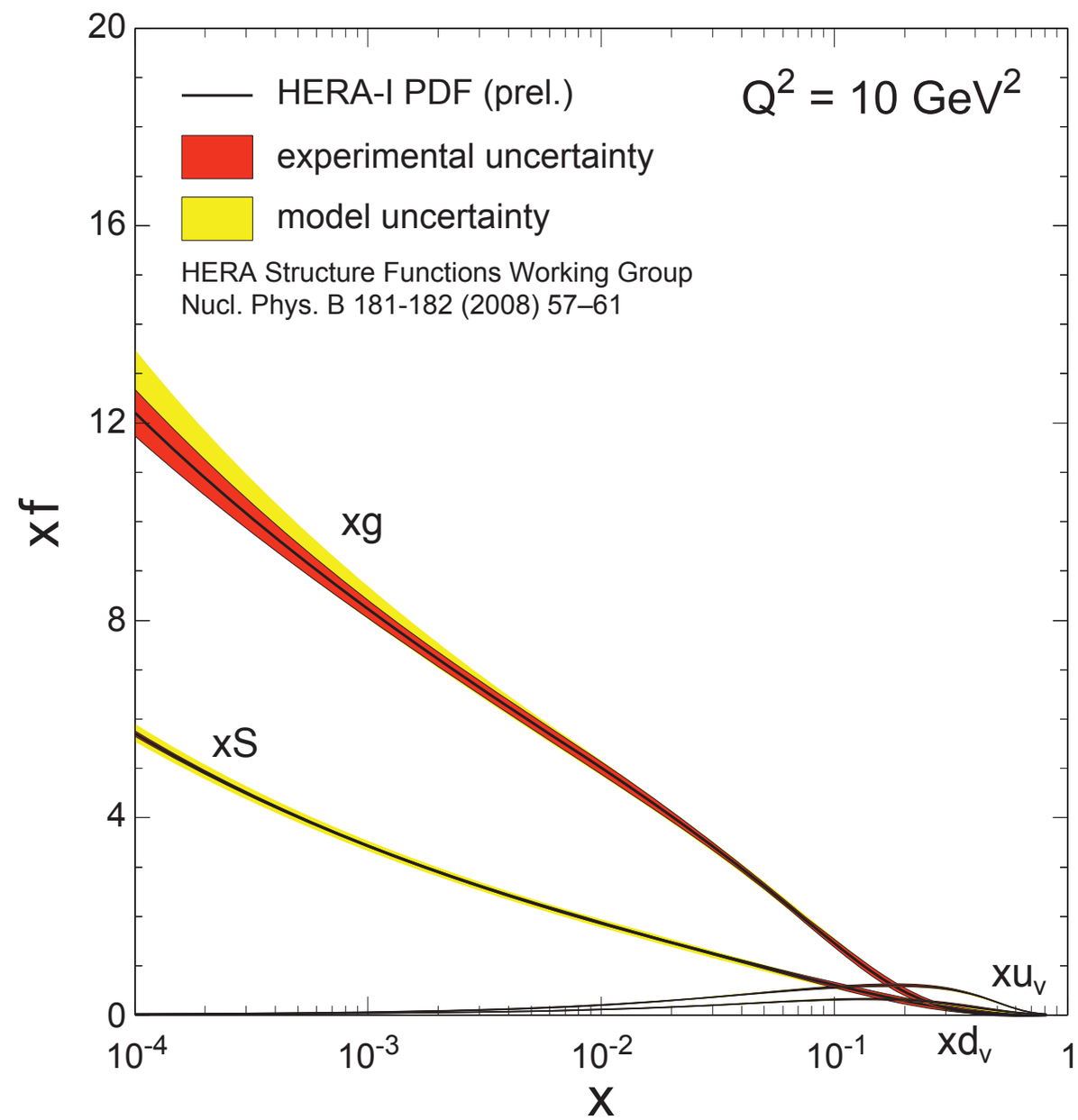
charm diffractive

# Measuring the glue via Structure Functions

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



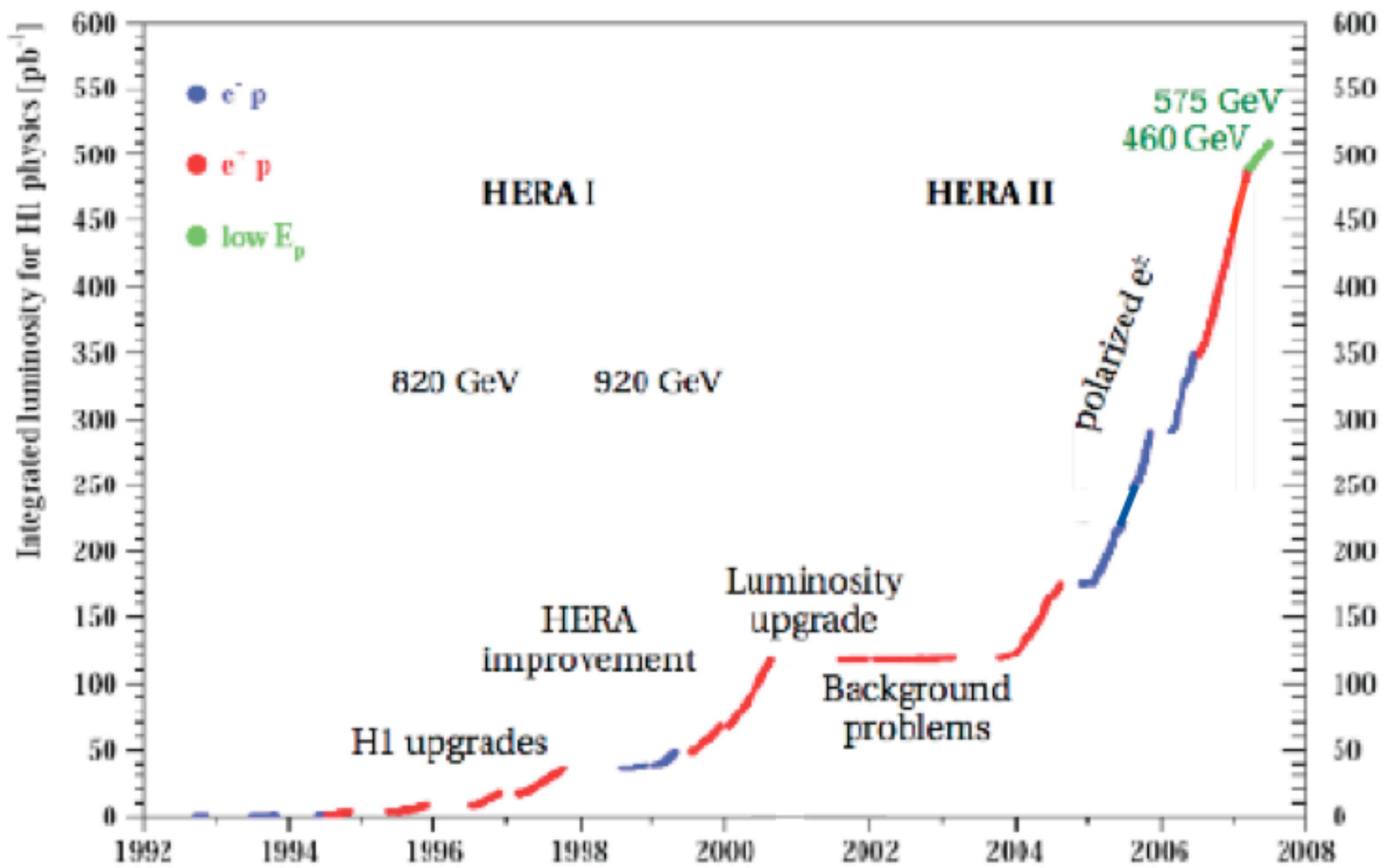

Scaling violation: $dF_2/d\ln Q^2$ and linear DGLAP Evolution $\Rightarrow G(x,Q^2)$



# 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 $F_L$
- 3 different proton energies run at HERA
  - 2 low-statistics runs
  - bad for $F_L$ extraction



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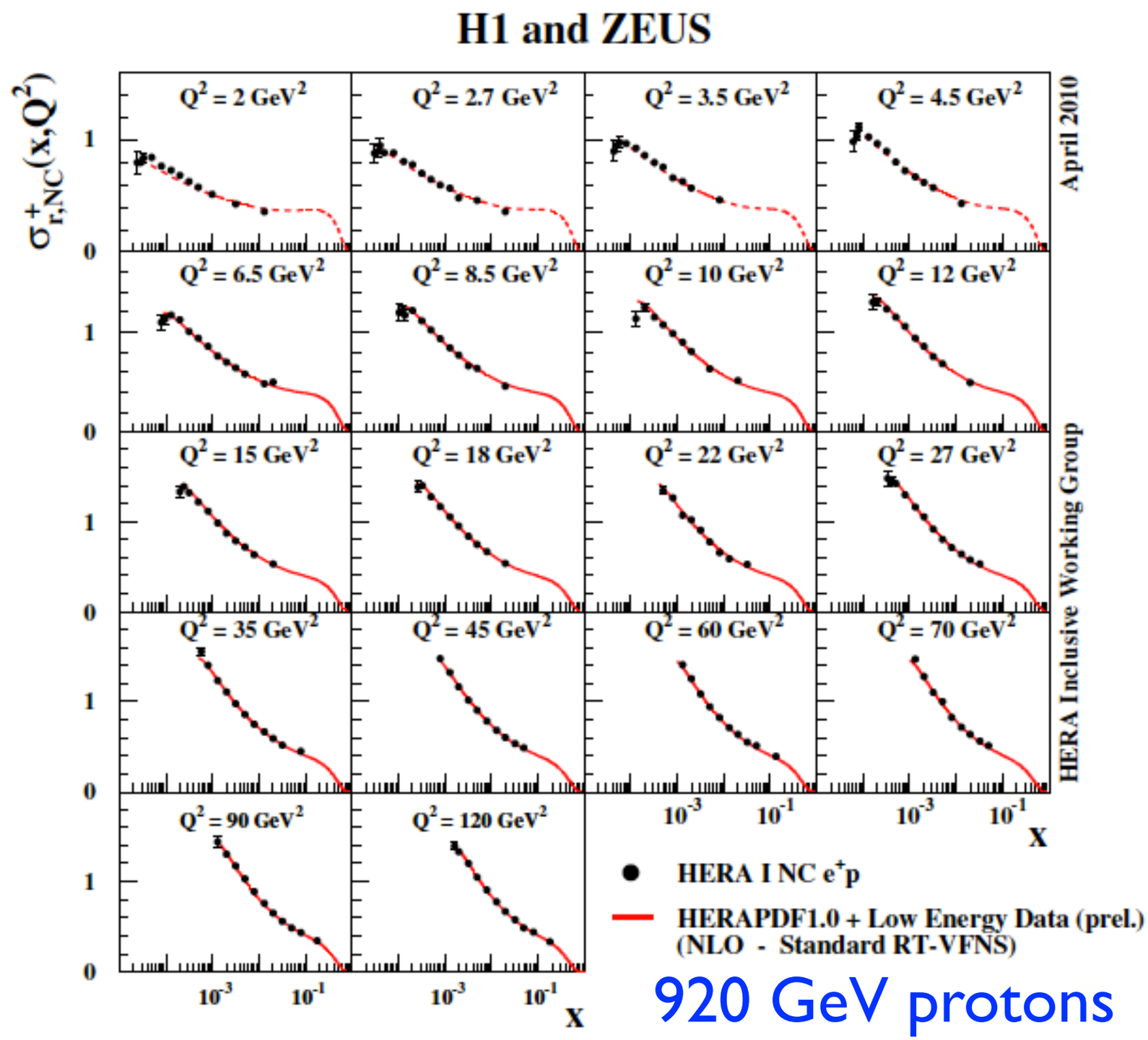


920 GeV protons

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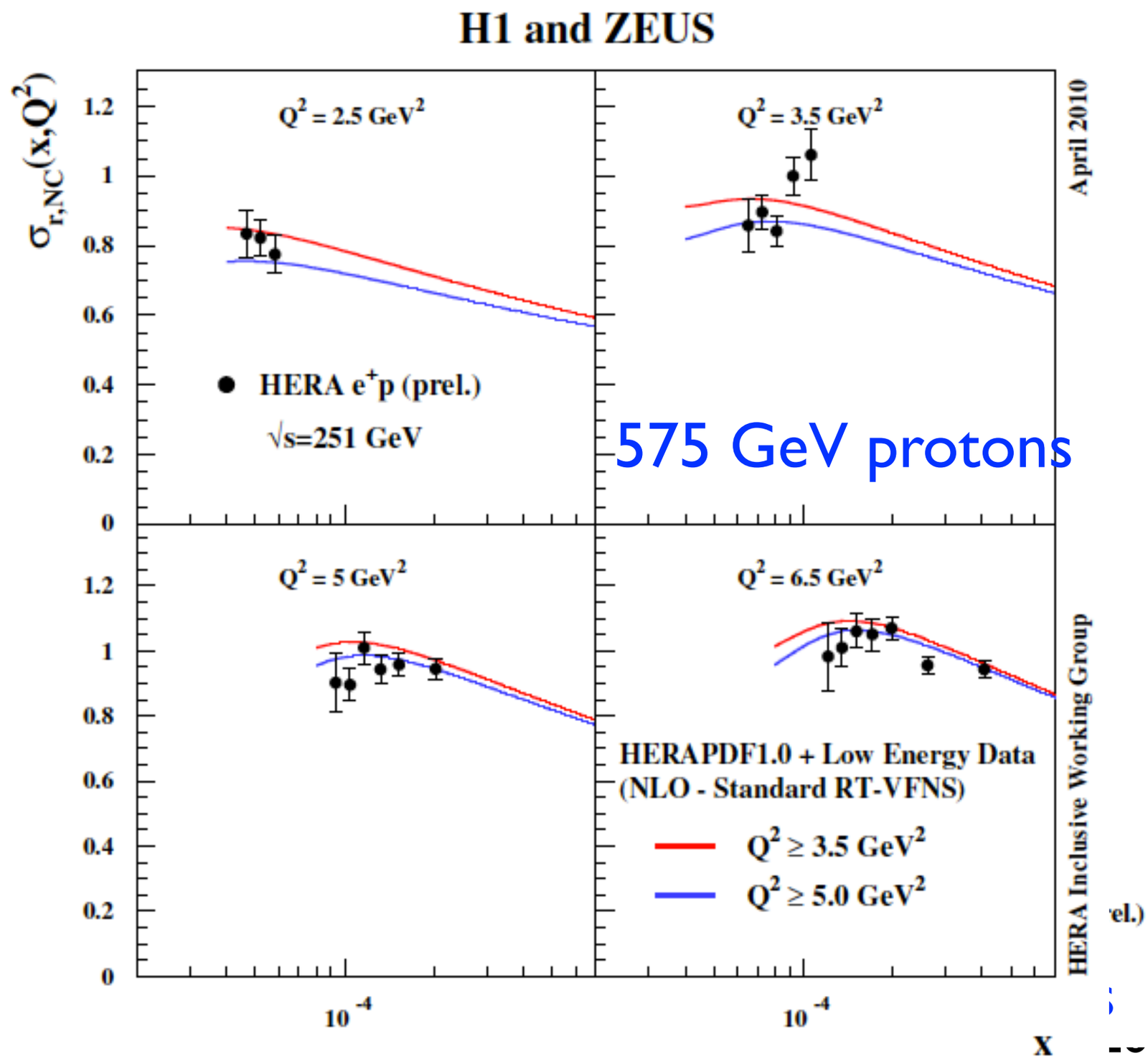

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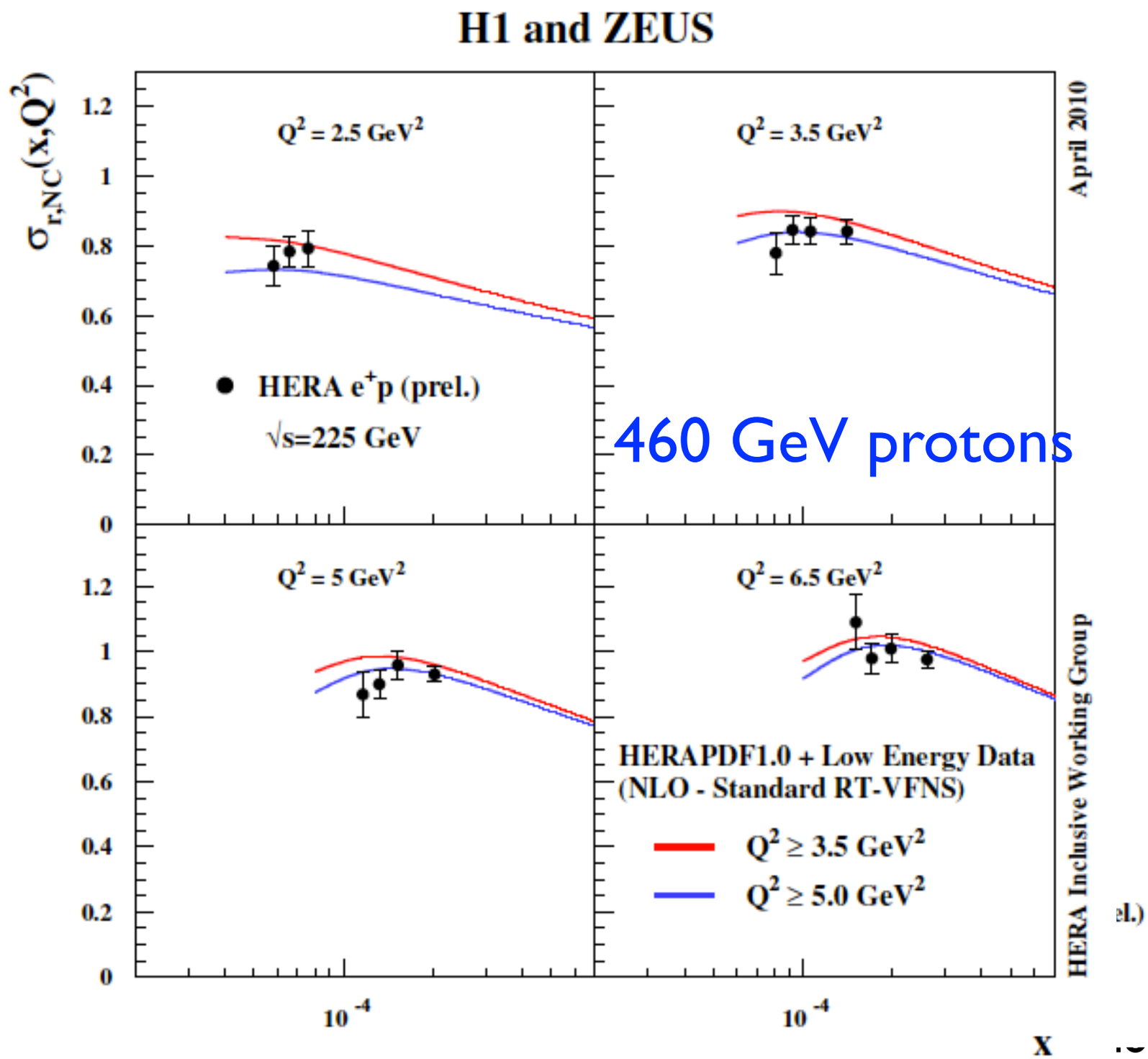

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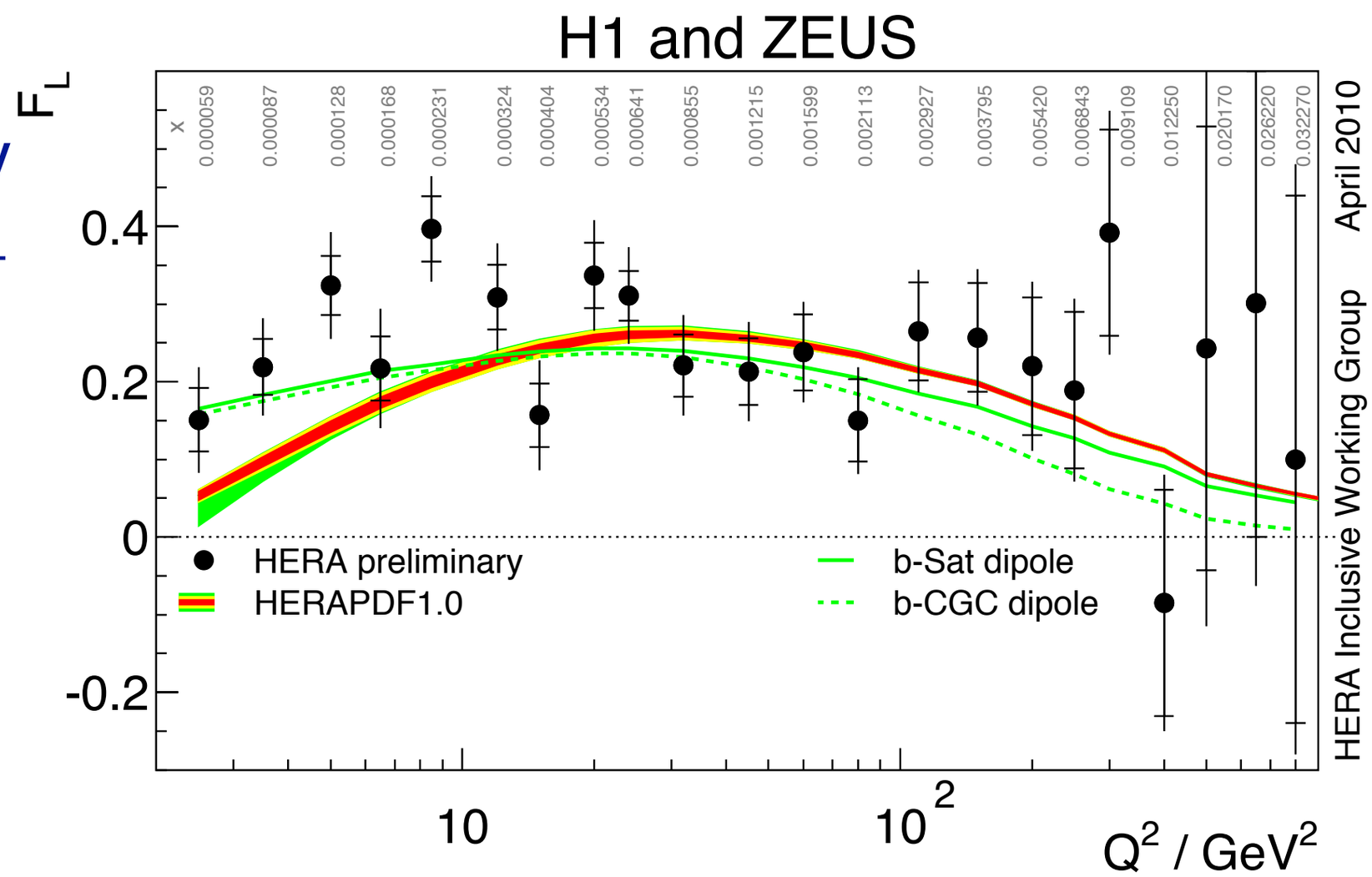
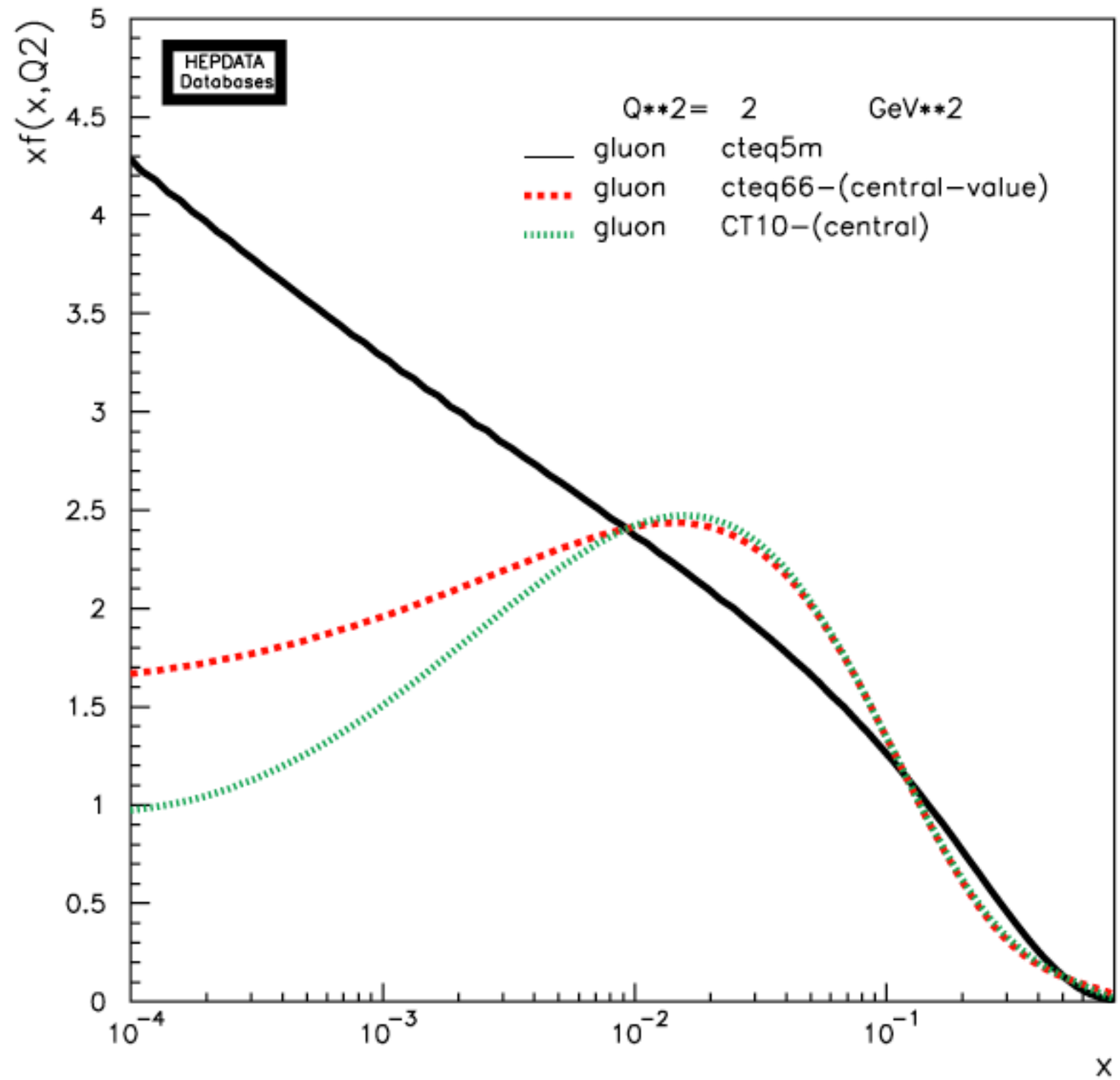


# Are $F_2/F_L$ good differentiators of models?

- In order to see if measuring $F_2/F_L$ at an EIC is "worthwhile", we need to see if a measurement could differentiate between models
- Models:
  - MSTW08: code downloadable from HEPFORGE. Code to extract $F_2/F_L$ obtained privately from Graeme Watt
    - Global fit, using total cross-section from HERA
    - DGLAP evolution
  - IPSat: data kindly provided by T. Lappi
    - Fit to ZEUS'96 data - $\chi^2$/d.o.f. ~ 1.2
  - bCGC: data kindly provided by T. Lappi
    - Fit to Zeus'96 data - $\chi^2$/d.o.f. ~ 1.62
  - rcBK: AAQMS data kindly provided by J. Albacete
    - Evolution along x with BK equation
    - Fit to H1+ZEUS combined 2006 data
  - Leading-Twist Shadowing: FGS10 data kindly provided by V. Guzey
    - Evolved with DGLAP
- Data:
  - $F_2$: H1&Zeus combined data from: http://www-h1.desy.de/psfiles/papers/desy09-158.pdf
  - $F_L$: H1 data from: http://www-h1.desy.de/psfiles/papers/desy10-228.pdf

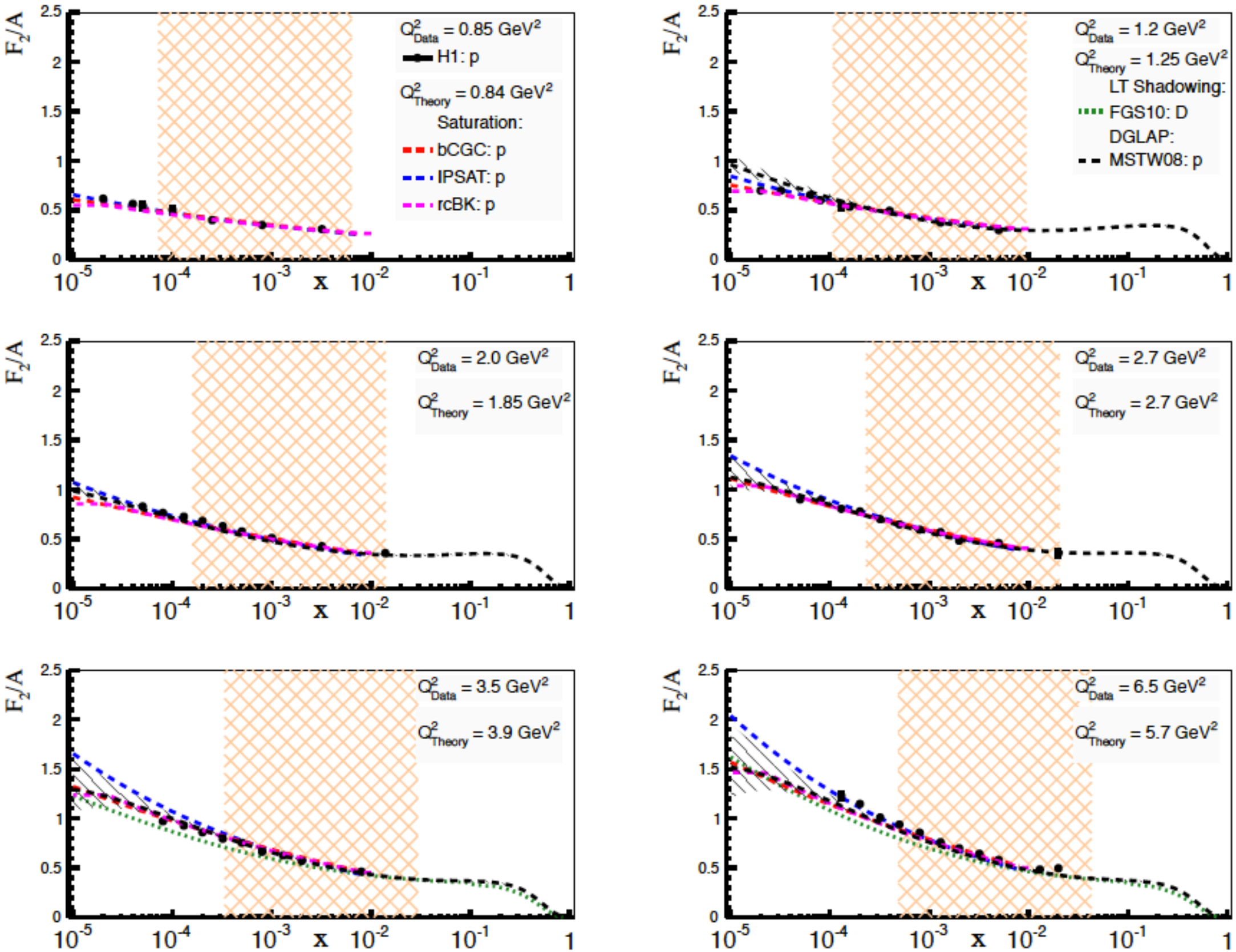
# Using the correct PDF

- The current implementation of FGS10 uses CTEQ5m as its PDF
- This overestimates the gluon contribution quite drastically compared to more modern calculations

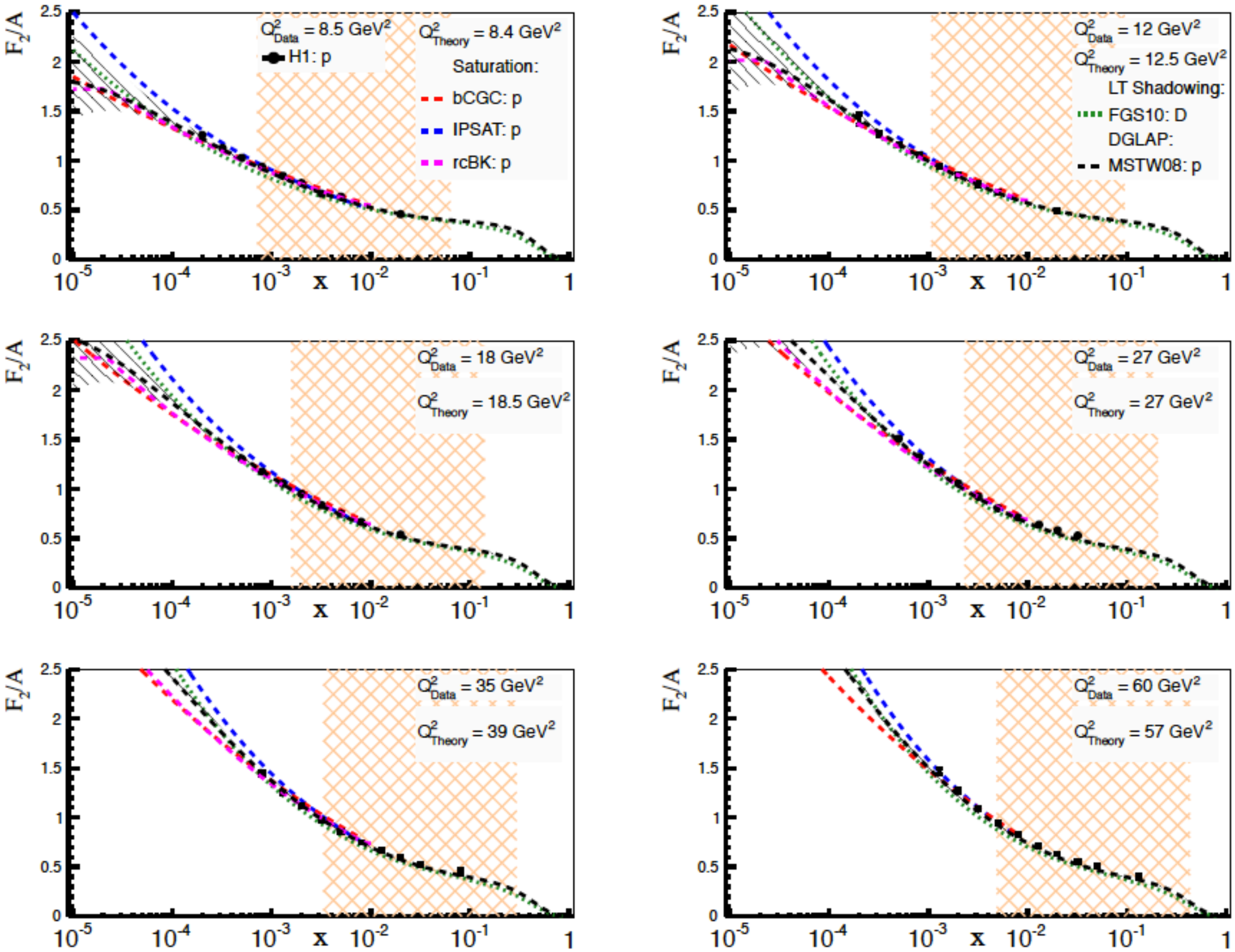



- ➡ New curves are on their way from FGS10 with CTEQ6
- ➡ Not ready for this meeting
- ➡ Following $F_L$ data therefore still uses CTEQ5m for FGS10

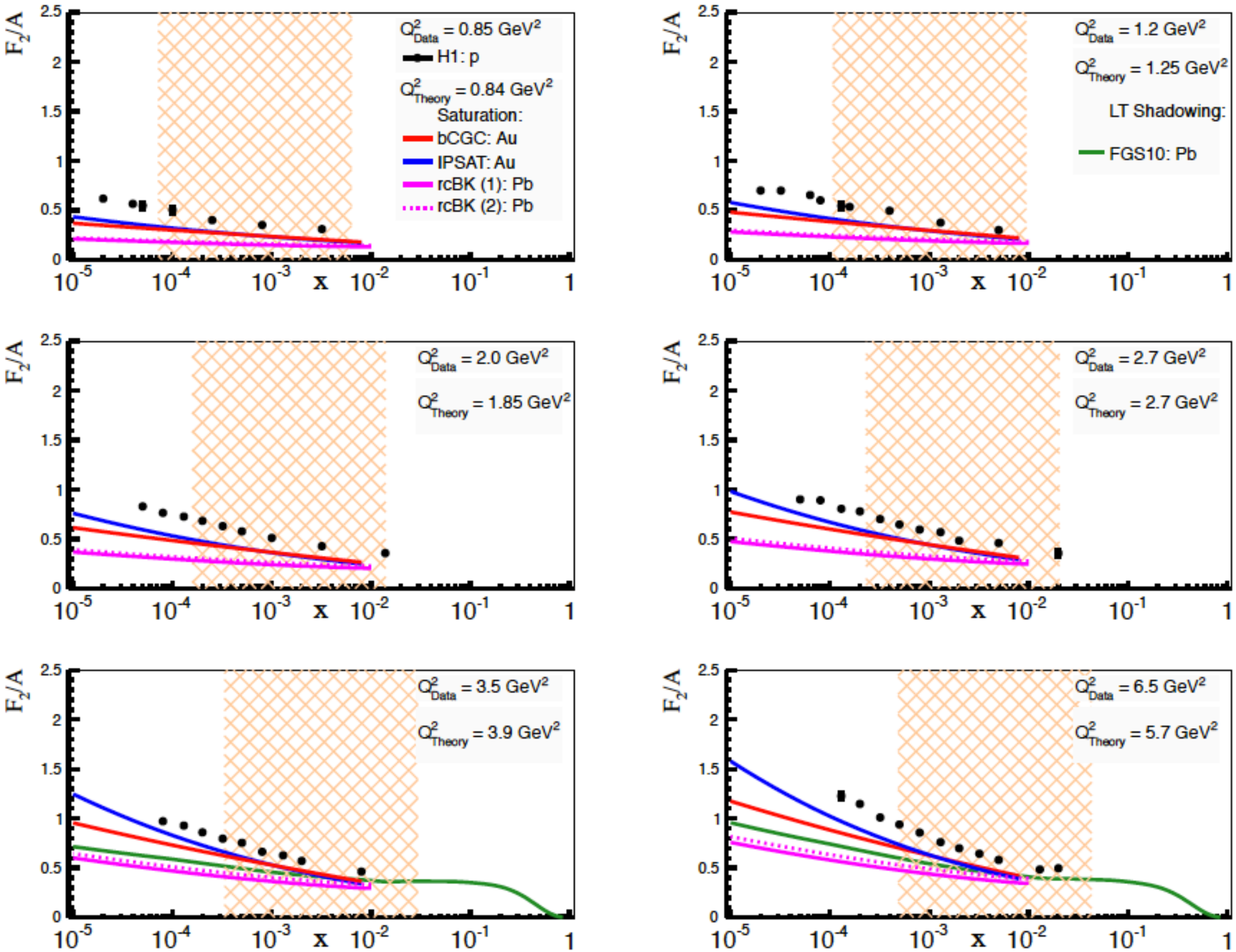
# $F_2(p)$ - low $Q^2$


$F_2/A$
$Q^2_{Data}$ = 0.85 GeV$^2$
H1: p
$Q^2_{Theory}$ = 0.84 GeV$^2$
Saturation:
bCGC: p
IPSAT: p
rcBK: p
$Q^2_{Data}$ = 1.2 GeV$^2$
$Q^2_{Theory}$ = 1.25 GeV$^2$
LT Shadowing:
FGS10: D
DGLAP:
MSTW08: p
$Q^2_{Data}$ = 2.0 GeV$^2$
$Q^2_{Theory}$ = 1.85 GeV$^2$
$Q^2_{Data}$ = 2.7 GeV$^2$
$Q^2_{Theory}$ = 2.7 GeV$^2$
$Q^2_{Data}$ = 3.5 GeV$^2$
$Q^2_{Theory}$ = 3.9 GeV$^2$
$Q^2_{Data}$ = 6.5 GeV$^2$
$Q^2_{Theory}$ = 5.7 GeV$^2$
x

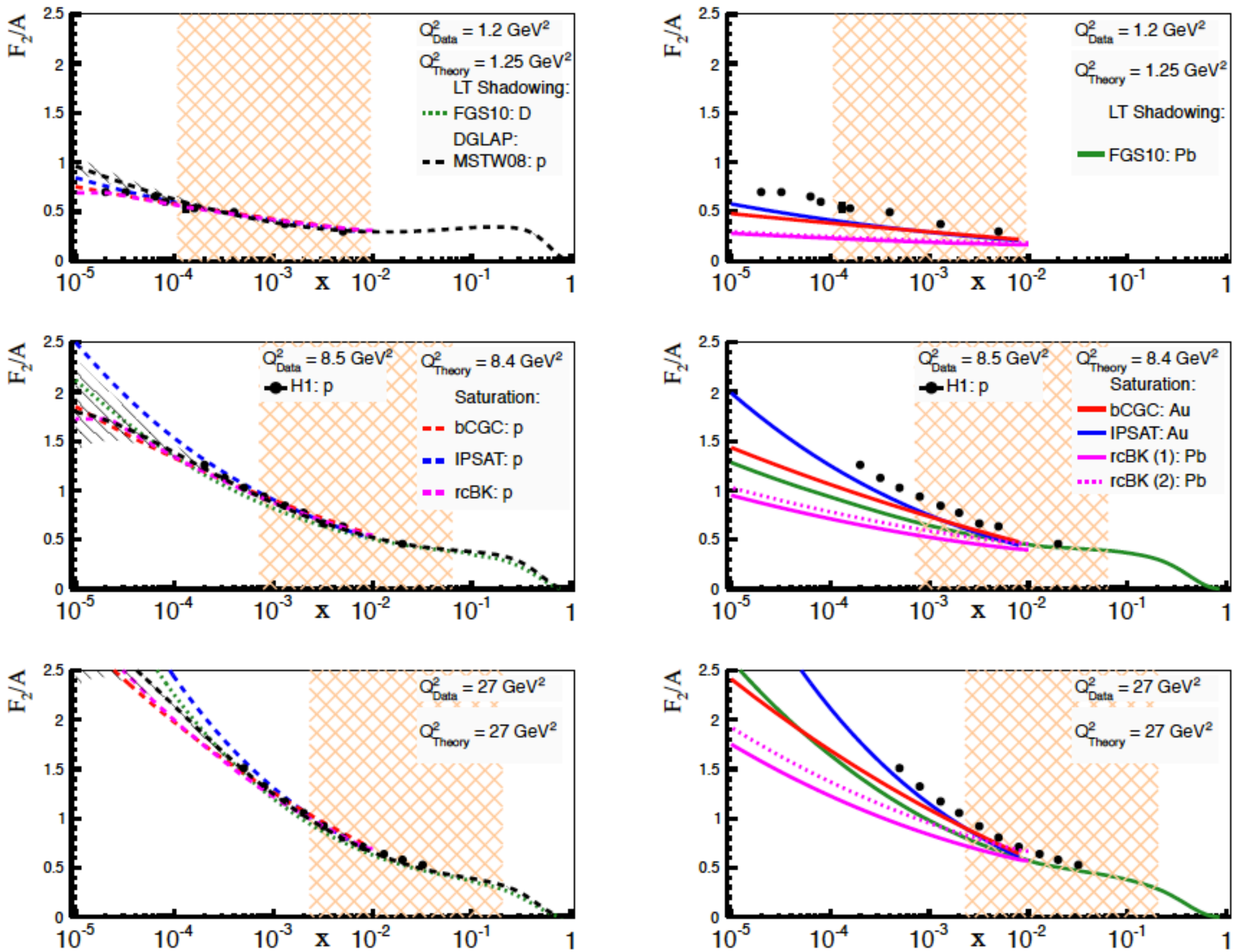
# $F_2(p)$ - higher $Q^2$



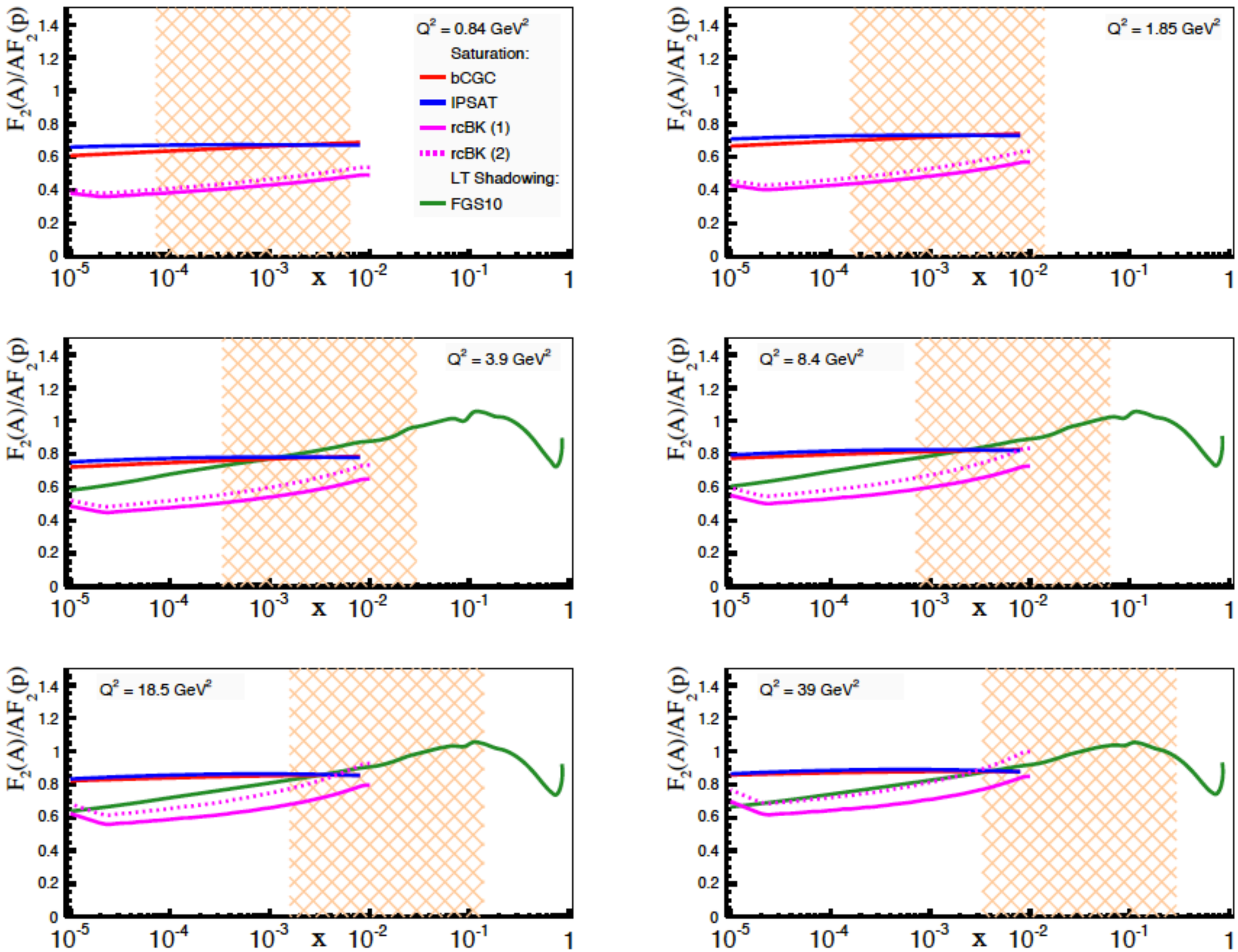
# $F_2(A)/A$ - low $Q^2$


F2/A
x
Q2Data = 0.85 GeV2
H1: p
Q2Theory = 0.84 GeV2
Saturation:
bCGC: Au
IPSAT: Au
rcBK (1): Pb
rcBK (2): Pb
Q2Data = 1.2 GeV2
Q2Theory = 1.25 GeV2
LT Shadowing:
FGS10: Pb
Q2Data = 2.0 GeV2
Q2Theory = 1.85 GeV2
Q2Data = 2.7 GeV2
Q2Theory = 2.7 GeV2
Q2Data = 3.5 GeV2
Q2Theory = 3.9 GeV2
Q2Data = 6.5 GeV2
Q2Theory = 5.7 GeV2

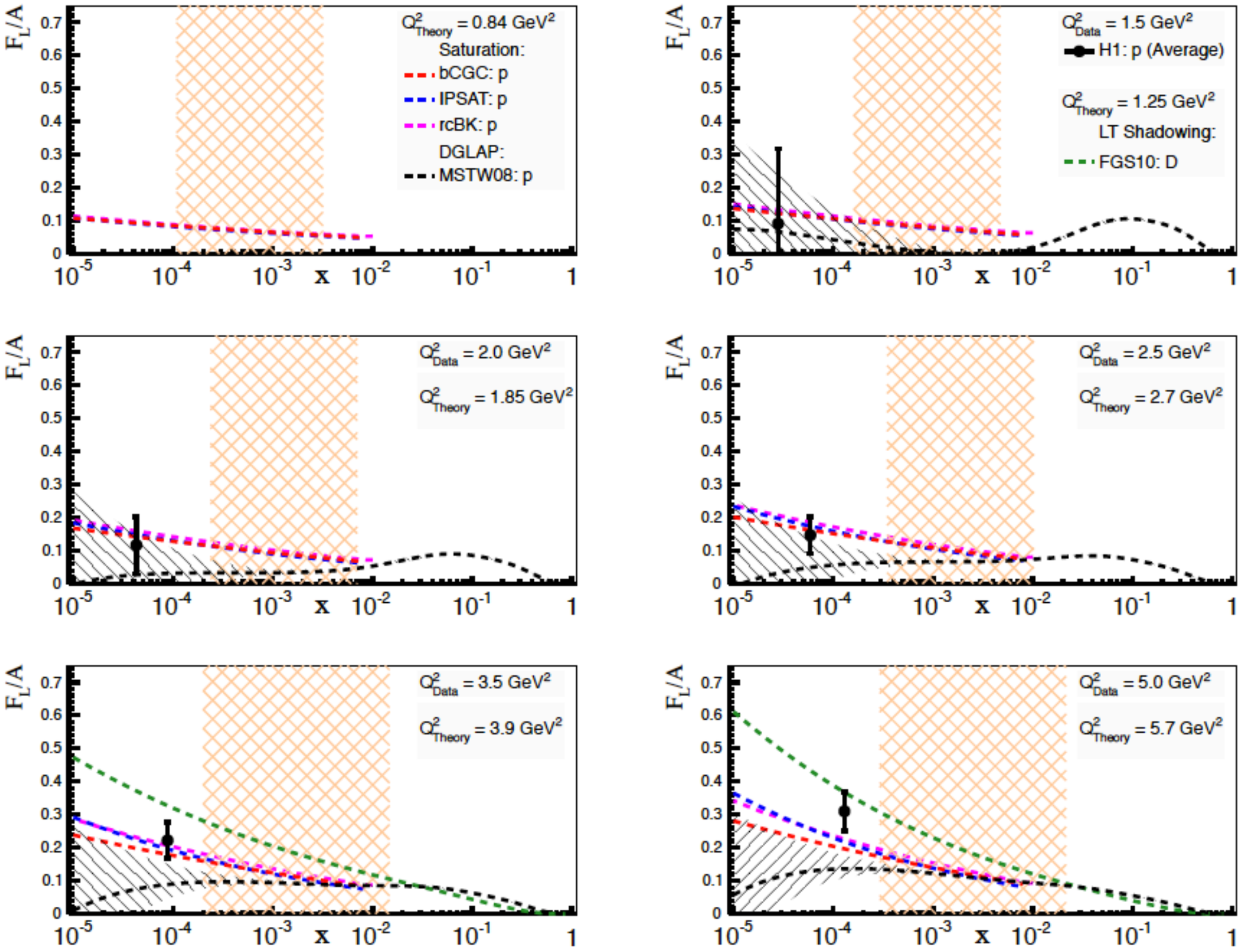
# $F_2(A)/A$ - p vs A


$F_2/A$
$Q^2_{Data}$ = 1.2 GeV$^2$
$Q^2_{Theory}$ = 1.25 GeV$^2$
LT Shadowing:
FGS10: D
DGLAP:
MSTW08: p
FGS10: Pb
$Q^2_{Data}$ = 8.5 GeV$^2$
$Q^2_{Theory}$ = 8.4 GeV$^2$
H1: p
Saturation:
bCGC: p
IPSAT: p
rcBK: p
bCGC: Au
IPSAT: Au
rcBK (1): Pb
rcBK (2): Pb
$Q^2_{Data}$ = 27 GeV$^2$
$Q^2_{Theory}$ = 27 GeV$^2$
x

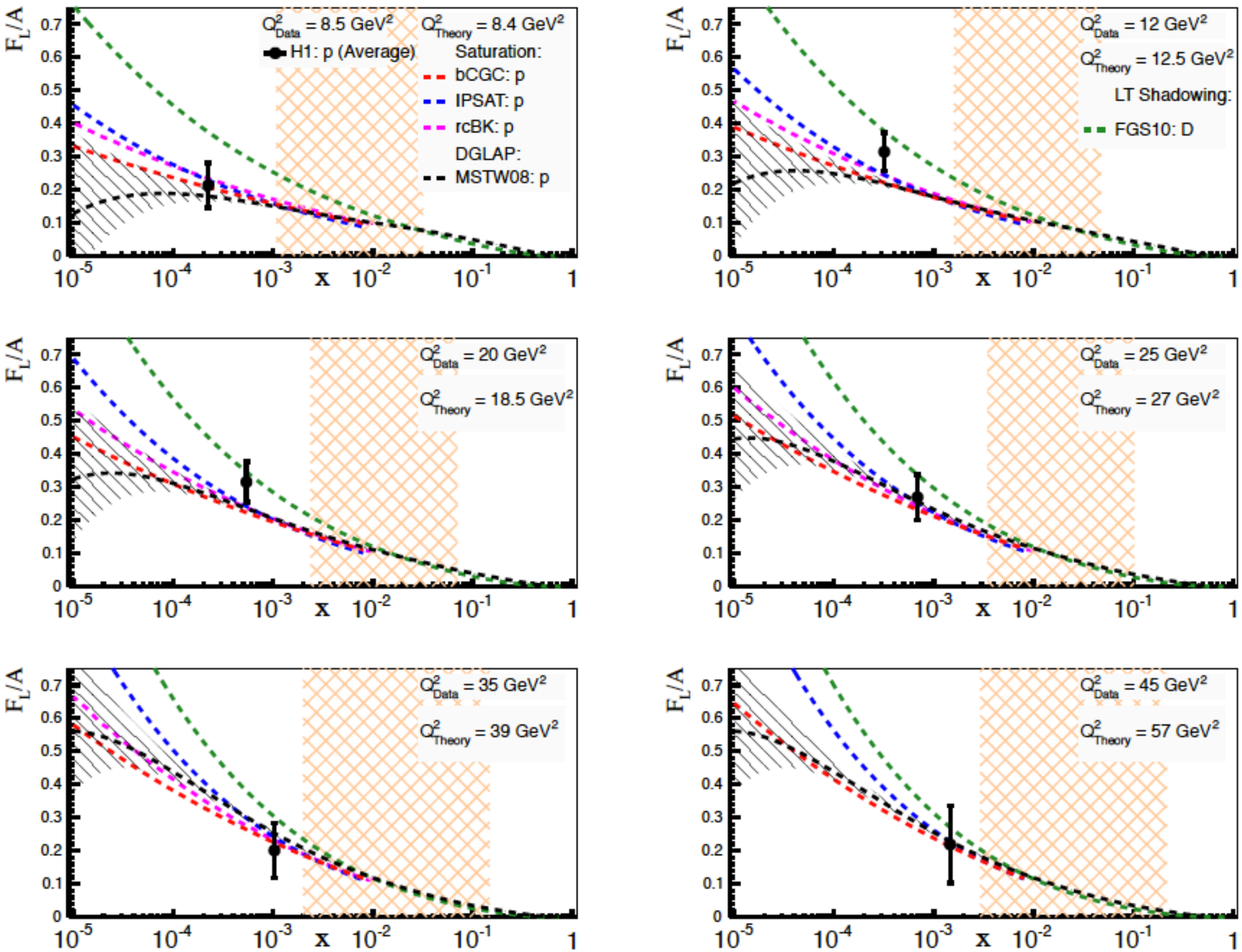
# $F_2$ ratios: $F_2(A)/AF_2(p)$



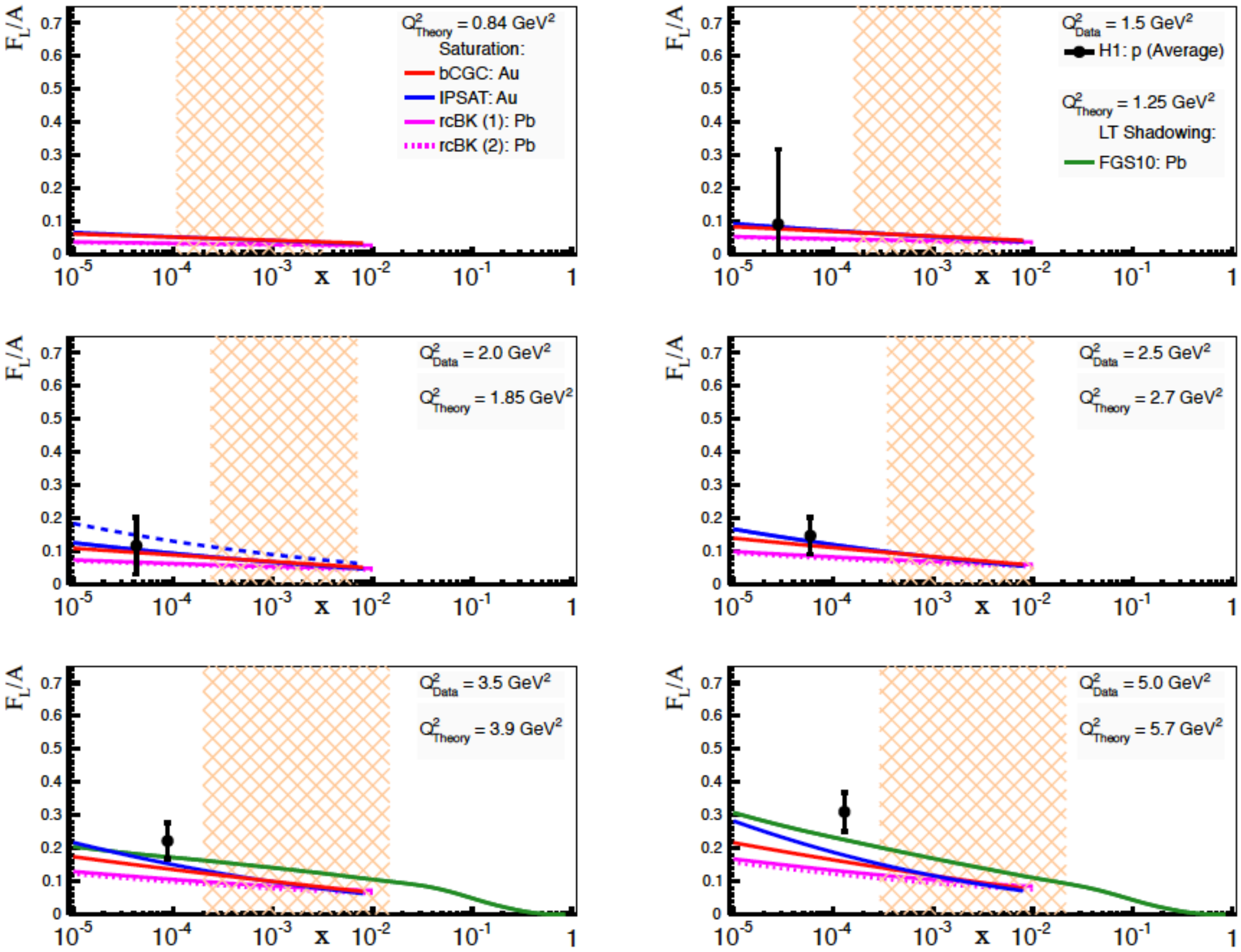
# $F_L(p)$ - low $Q^2$


$F_L/A$
$Q^2_{Theory}$ = 0.84 GeV$^2$
Saturation:
bCGC: p
IPSAT: p
rcBK: p
DGLAP:
MSTW08: p
$Q^2_{Data}$ = 1.5 GeV$^2$
H1: p (Average)
$Q^2_{Theory}$ = 1.25 GeV$^2$
LT Shadowing:
FGS10: D
$Q^2_{Data}$ = 2.0 GeV$^2$
$Q^2_{Theory}$ = 1.85 GeV$^2$
$Q^2_{Data}$ = 2.5 GeV$^2$
$Q^2_{Theory}$ = 2.7 GeV$^2$
$Q^2_{Data}$ = 3.5 GeV$^2$
$Q^2_{Theory}$ = 3.9 GeV$^2$
$Q^2_{Data}$ = 5.0 GeV$^2$
$Q^2_{Theory}$ = 5.7 GeV$^2$
x

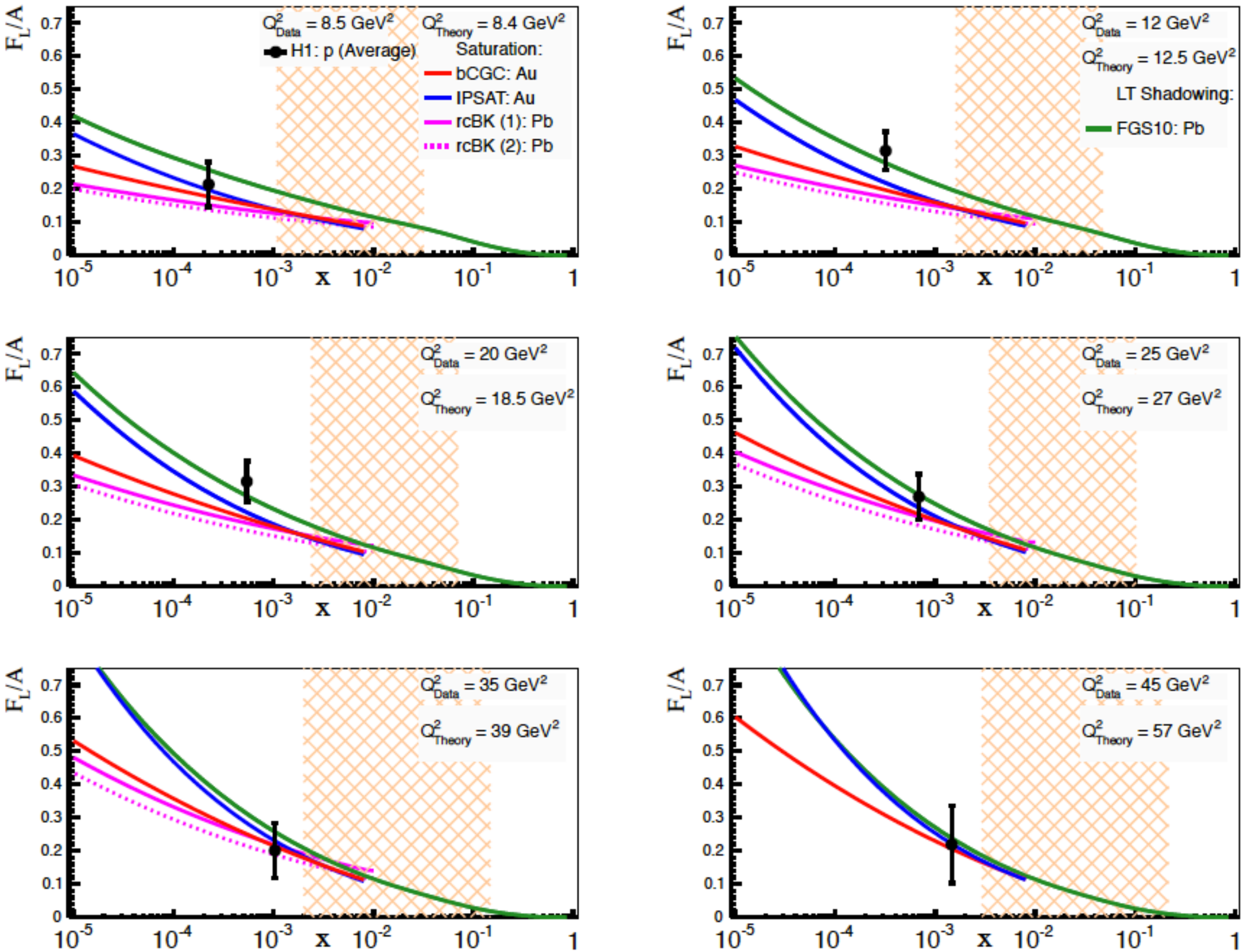
# $F_L(p)$ - higher $Q^2$



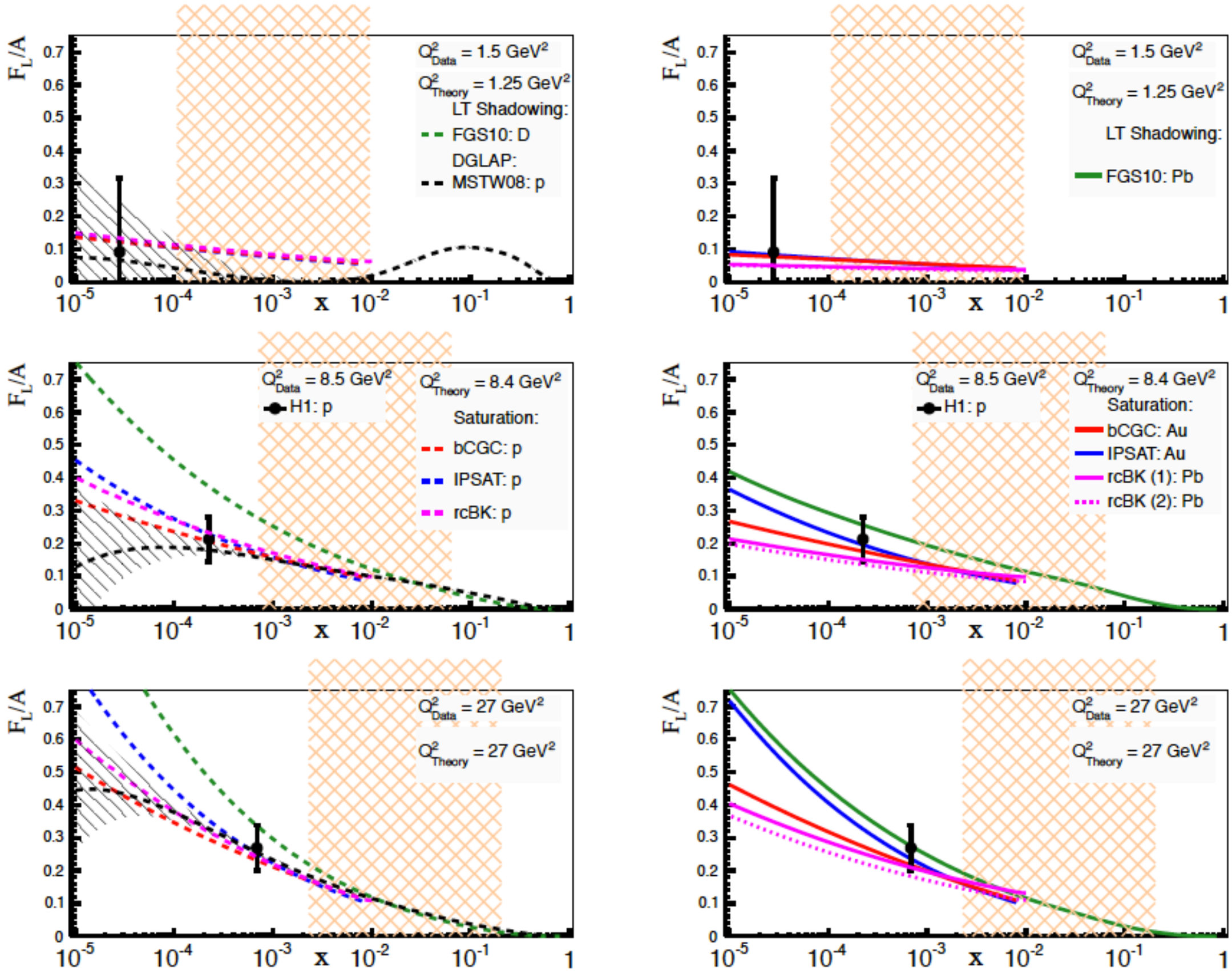
# $F_L(A)/A$ - low $Q^2$


$F_L/A$
$Q^2_{Theory}$ = 0.84 GeV$^2$
Saturation:
bCGC: Au
IPSAT: Au
rcBK (1): Pb
rcBK (2): Pb
$Q^2_{Data}$ = 1.5 GeV$^2$
H1: p (Average)
$Q^2_{Theory}$ = 1.25 GeV$^2$
LT Shadowing:
FGS10: Pb
$Q^2_{Data}$ = 2.0 GeV$^2$
$Q^2_{Theory}$ = 1.85 GeV$^2$
$Q^2_{Data}$ = 2.5 GeV$^2$
$Q^2_{Theory}$ = 2.7 GeV$^2$
$Q^2_{Data}$ = 3.5 GeV$^2$
$Q^2_{Theory}$ = 3.9 GeV$^2$
$Q^2_{Data}$ = 5.0 GeV$^2$
$Q^2_{Theory}$ = 5.7 GeV$^2$
x

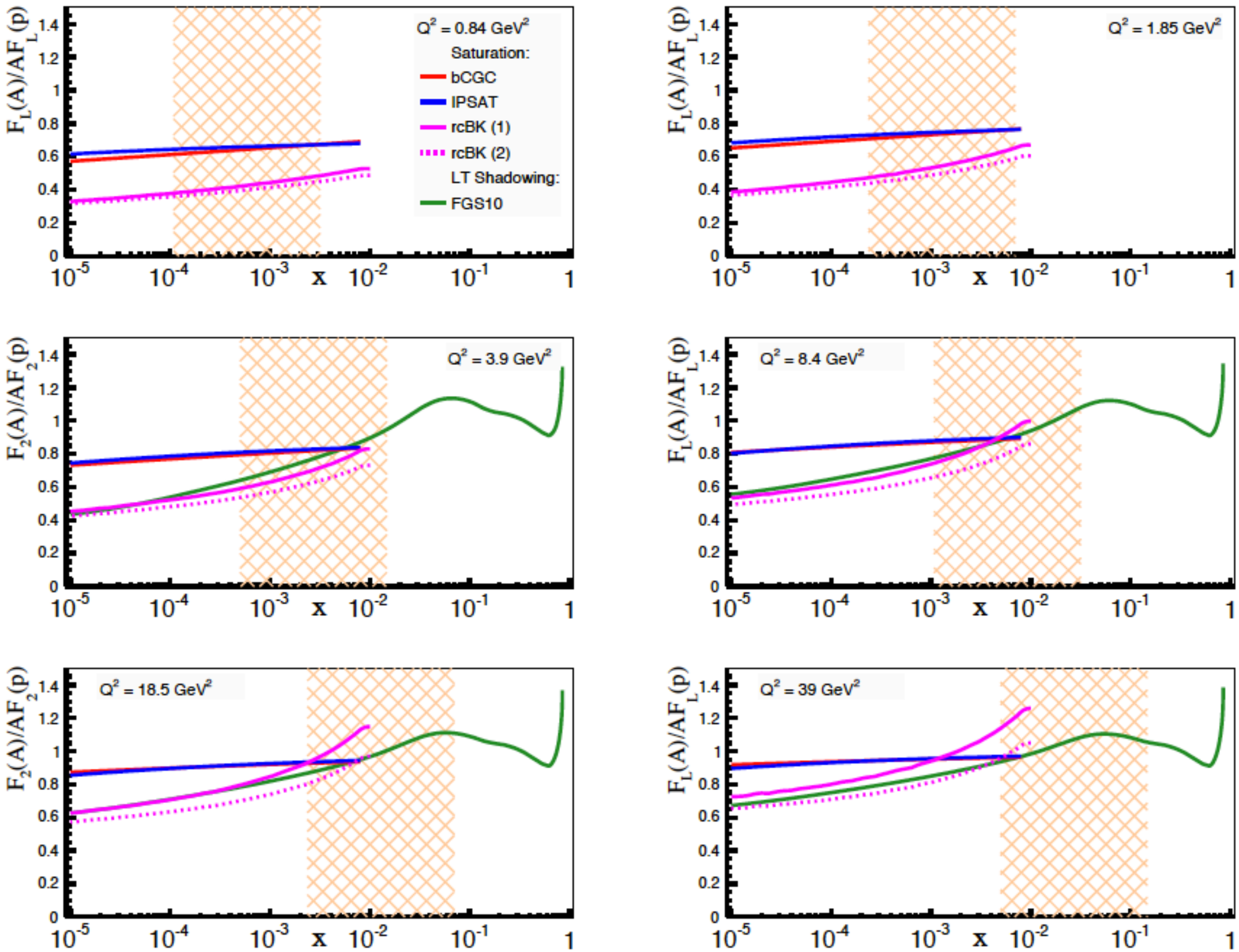
# $F_L(A)/A$ - higher $Q^2$



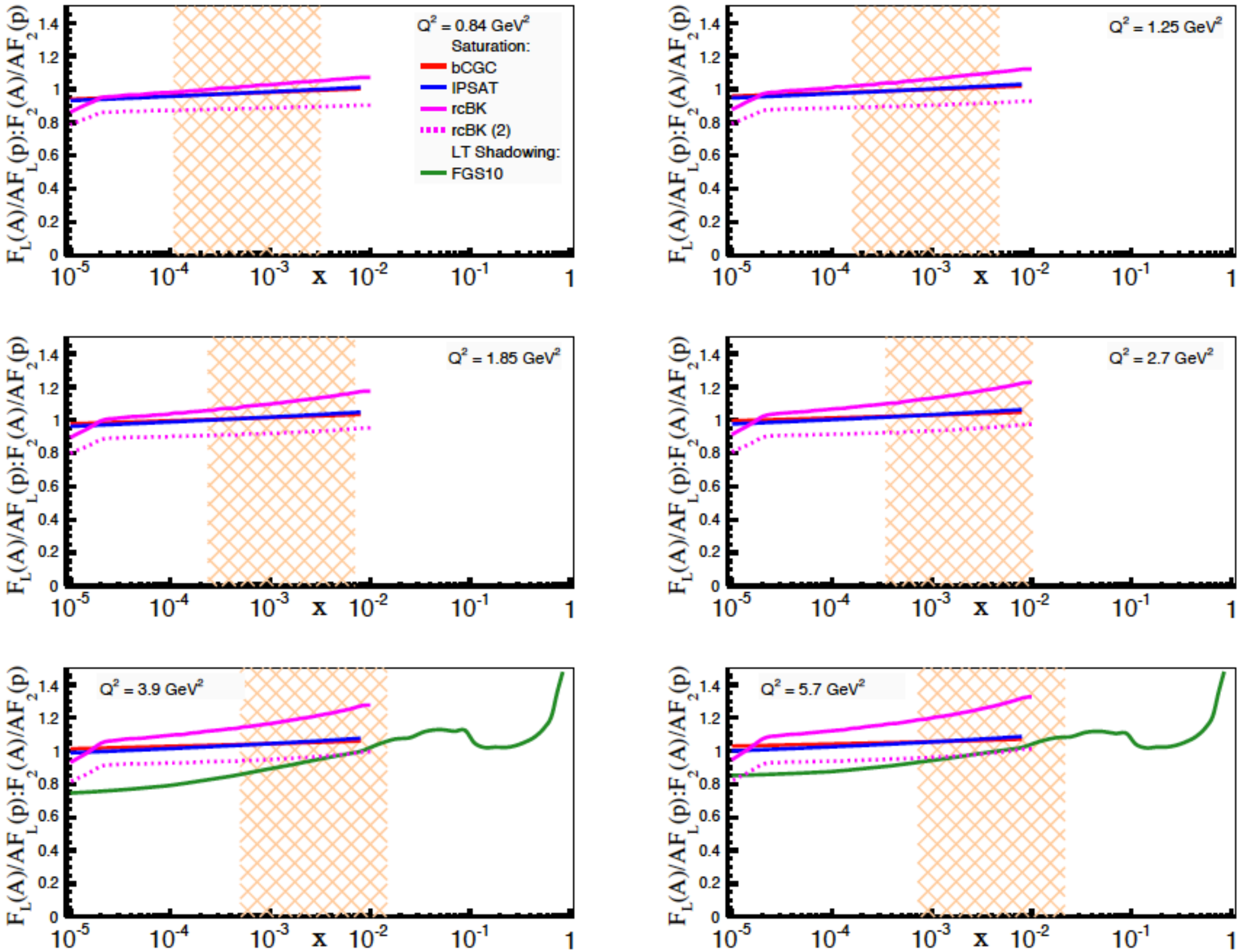
# $F_L(A)/A$ - p vs A


$F_L/A$
$Q^2_{Data}$ = 1.5 GeV²
$Q^2_{Theory}$ = 1.25 GeV²
LT Shadowing:
FGS10: D
DGLAP:
MSTW08: p
FGS10: Pb
$Q^2_{Data}$ = 8.5 GeV²
$Q^2_{Theory}$ = 8.4 GeV²
H1: p
Saturation:
bCGC: p
IPSAT: p
rcBK: p
bCGC: Au
IPSAT: Au
rcBK (1): Pb
rcBK (2): Pb
$Q^2_{Data}$ = 27 GeV²
$Q^2_{Theory}$ = 27 GeV²
x

# $F_L$ ratios: $F_L(A)/AF_L(p)$



# Double ratios - $F_L(A)/AF_L(p)$: $F_2(A)/AF_2(p)$



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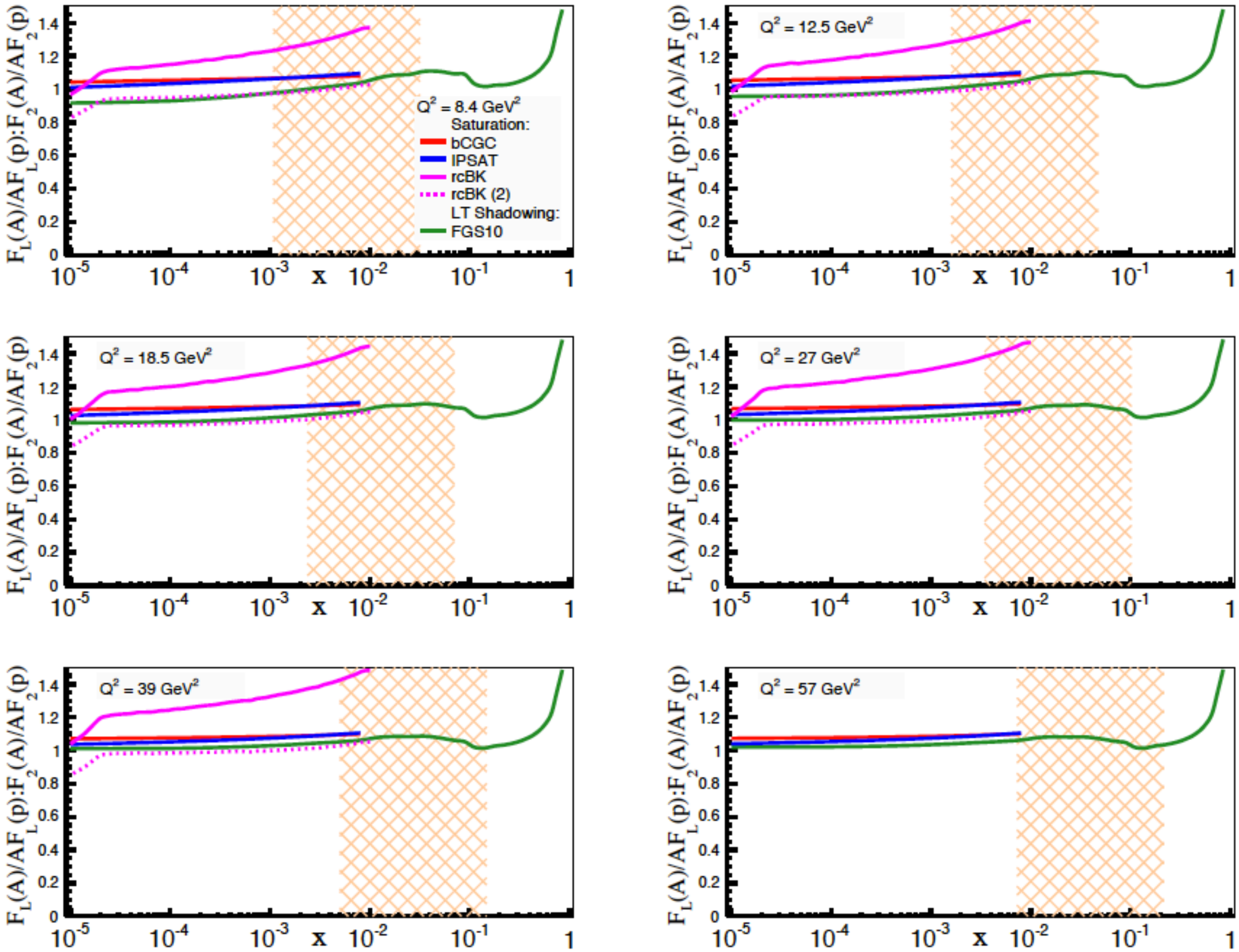

# Feasibility study: $\sigma_r(x,Q^2) = F_2^A(x,Q^2) - \frac{y^2}{Y^+} F_L^A(x,Q^2)$

- Simulated data for e+A coverage in x-$Q^2$ space
  - ➡ 3 energies is the minimum requirement in the $F_L$ capability study
  - ➡ 1st stage only gets to medium x
  - ➡ Need high electron energy to get to “small” x

x

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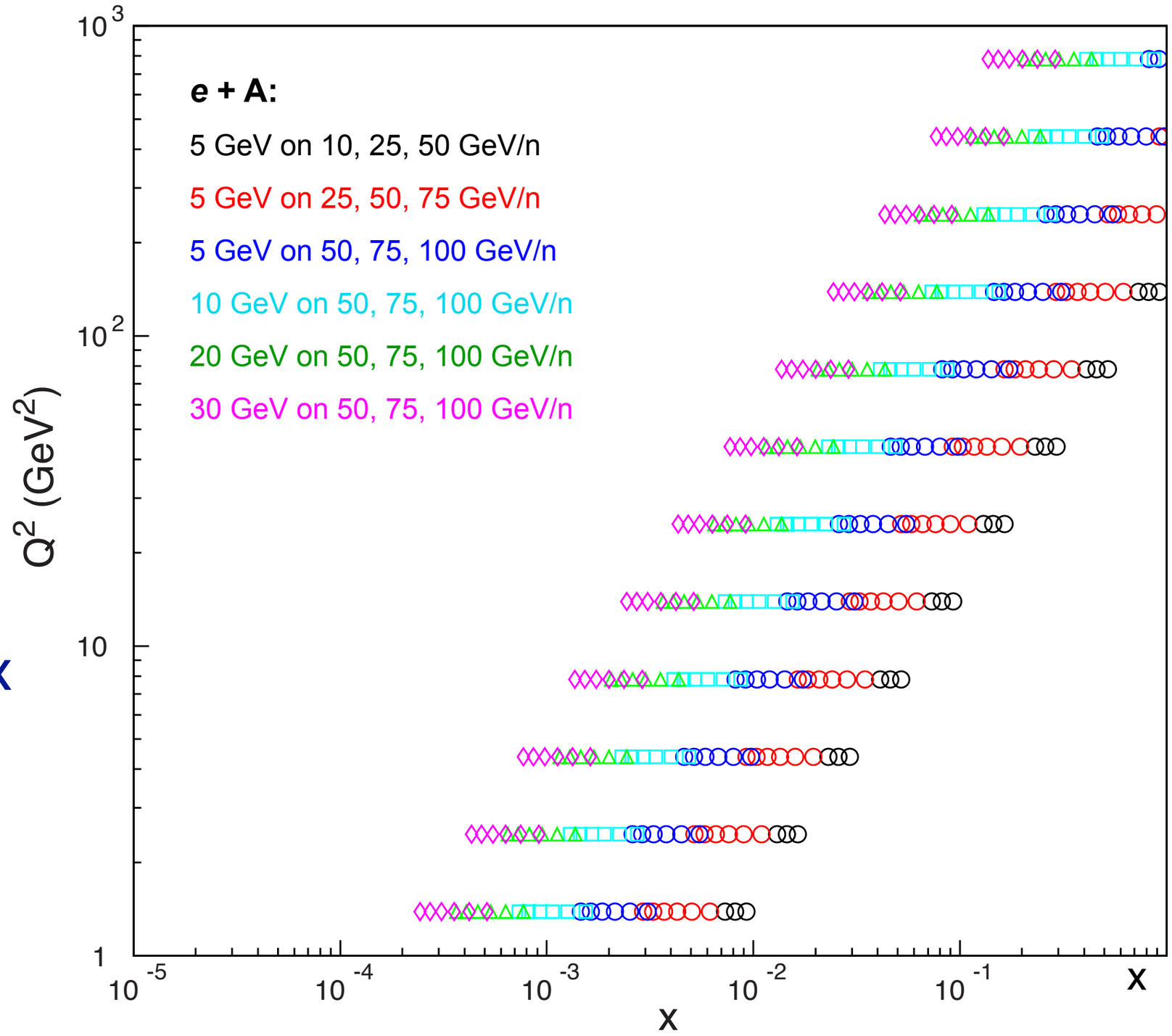


# Feasibility study: $\sigma_r(x,Q^2) = F_2^A(x,Q^2) - \frac{y^2}{Y^+} F_L^A(x,Q^2)$

Strategies:

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

e+p: 1st stage

5x50 - 5x325

running combined

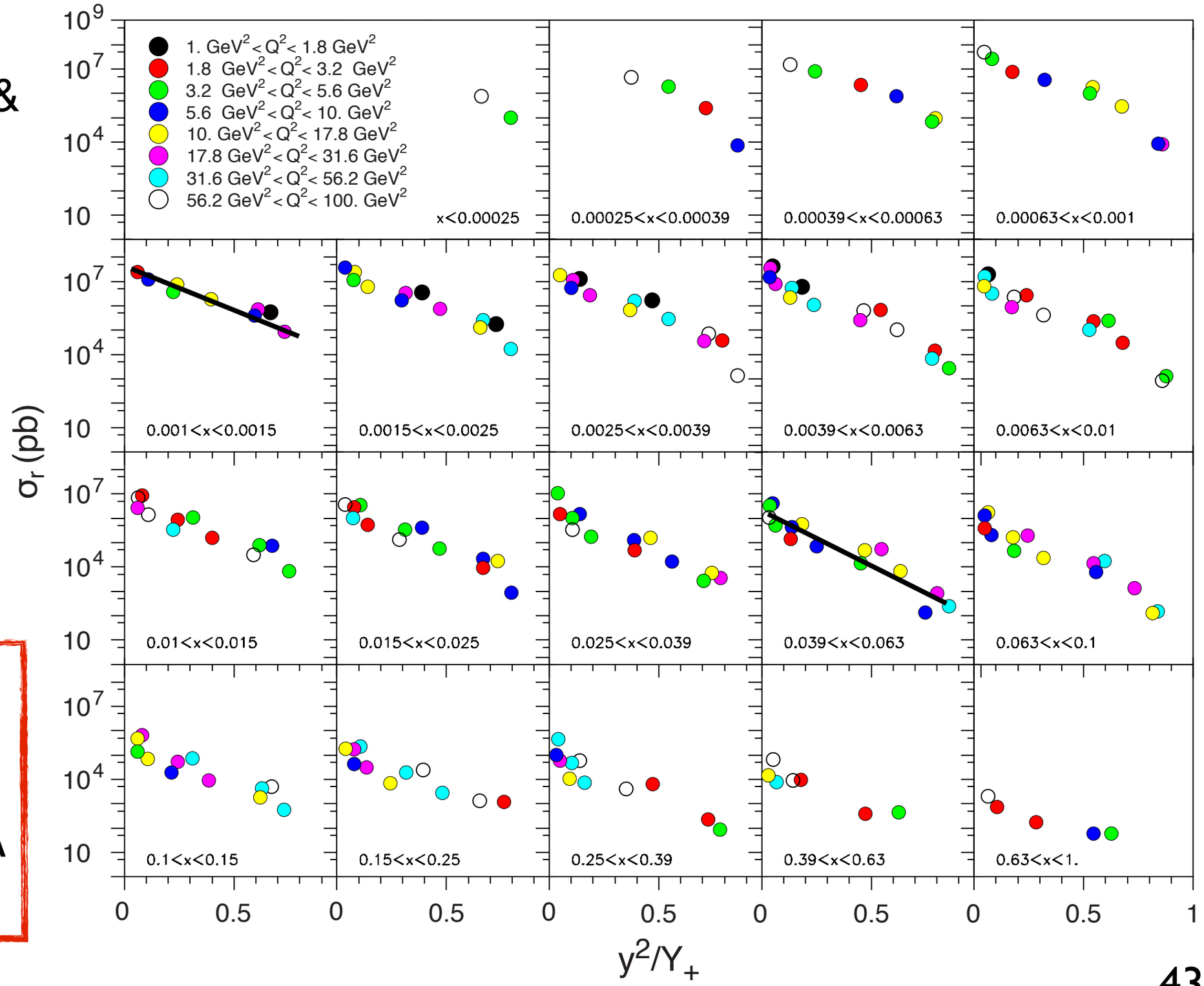
4 weeks/each

(50% eff)

stat. error shown and negligible

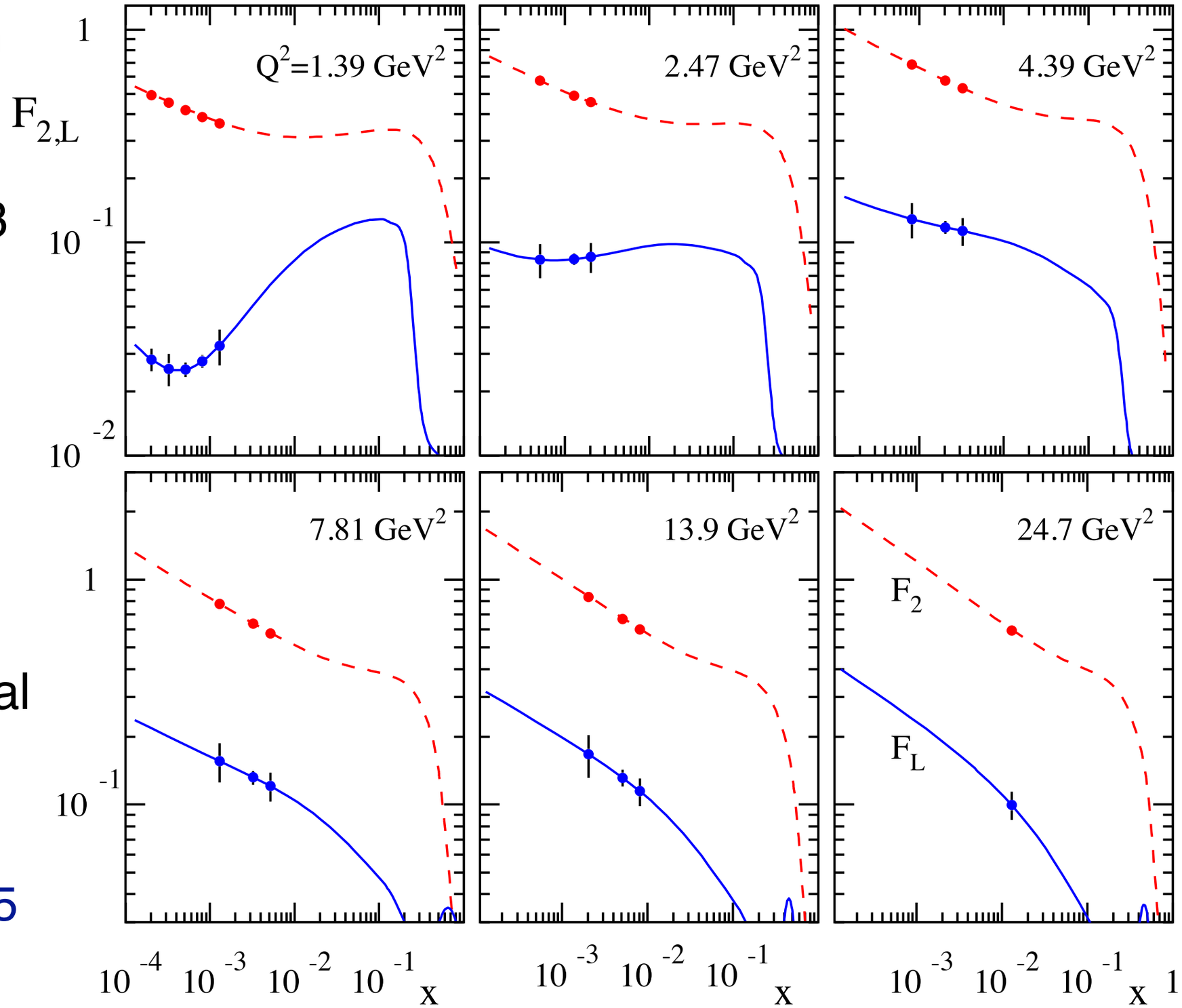
To Do:

refine method & test how well we can extract $F_L$ in e+A collisions

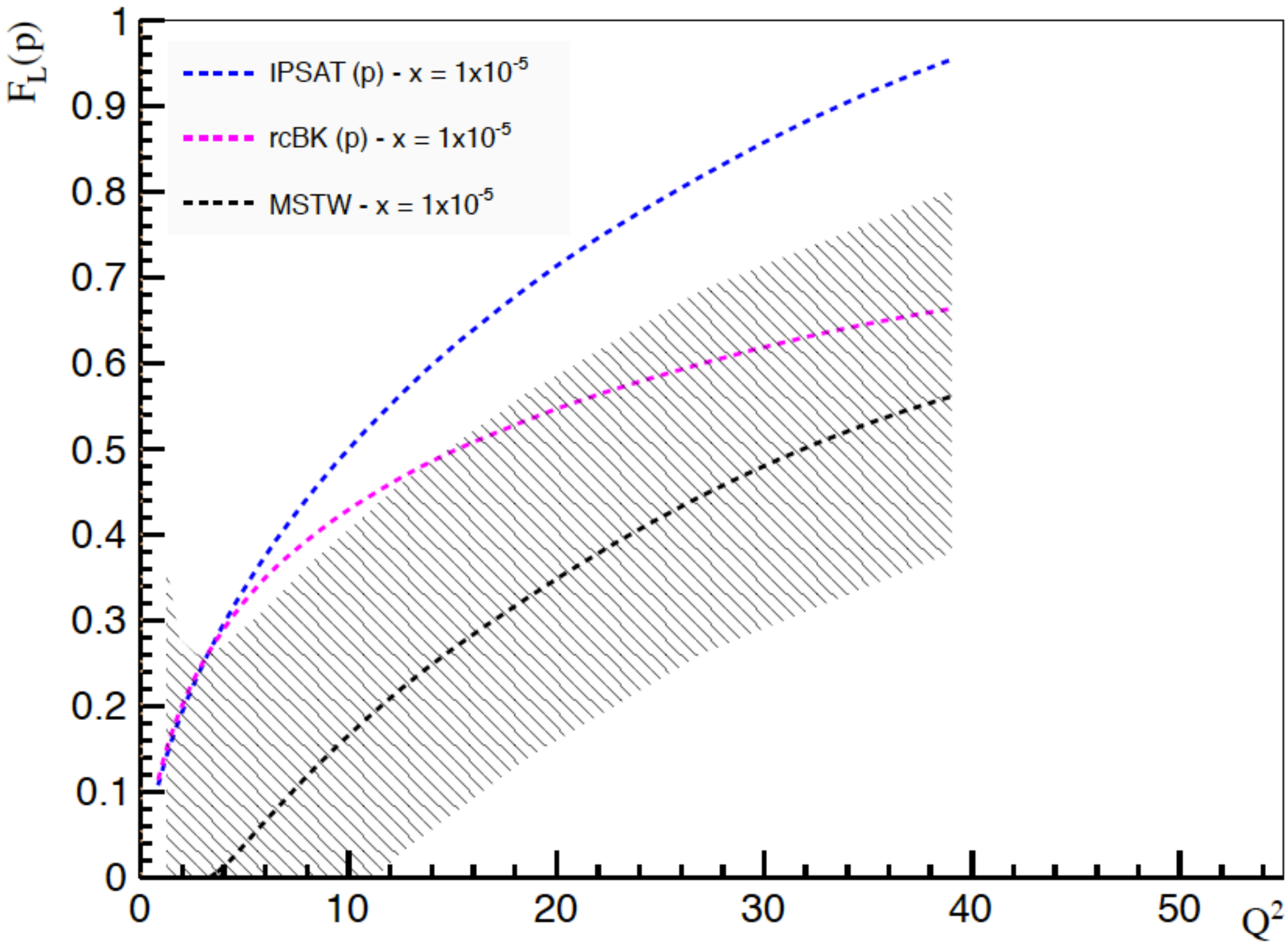


# Extracting $F_2$ and $F_L$ at the EIC

- $F_{2,L}$ extracted from pseudo-data generated for 1 month running at 3 eRHIC energies
  - 5+100 GeV
  - 5+250 GeV
  - 5+325 GeV
- Data, with errors, added to theoretical expectations from ABKM09 PDF set
  - valid for $Q^2 > 2.5$ GeV$^2$



# Evolution of $F_L(p)$ with $Q^2$ - fixed x



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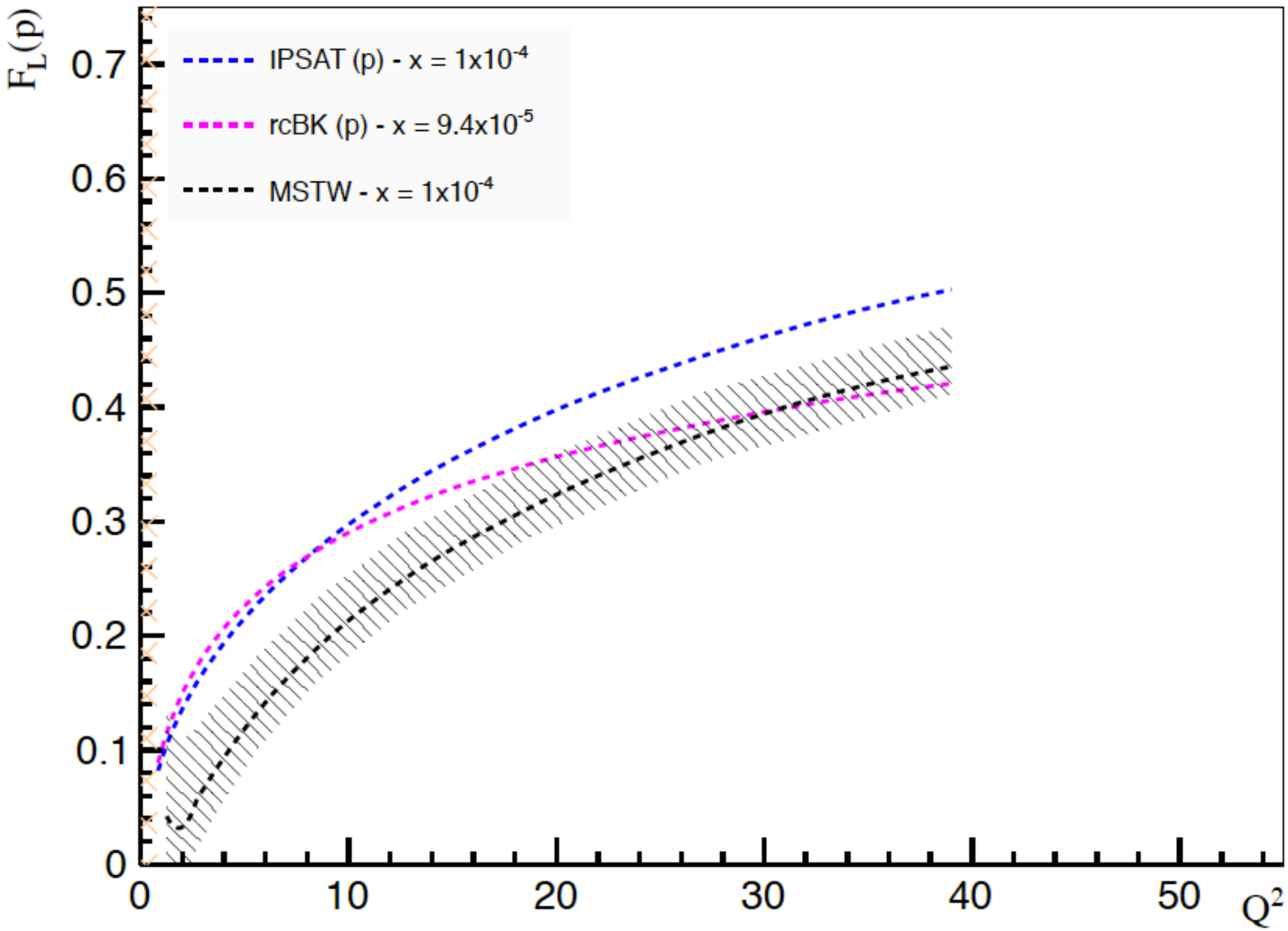

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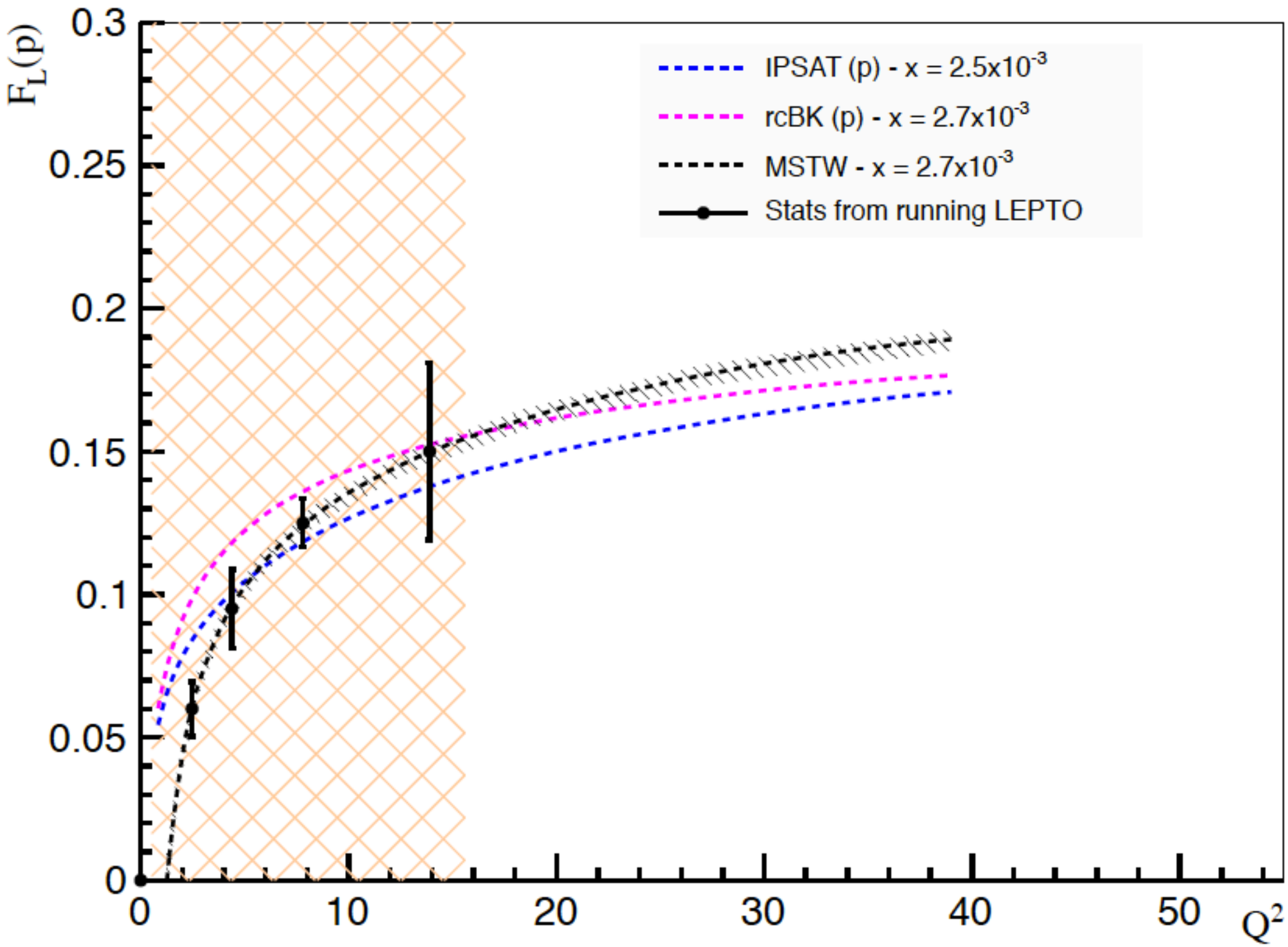
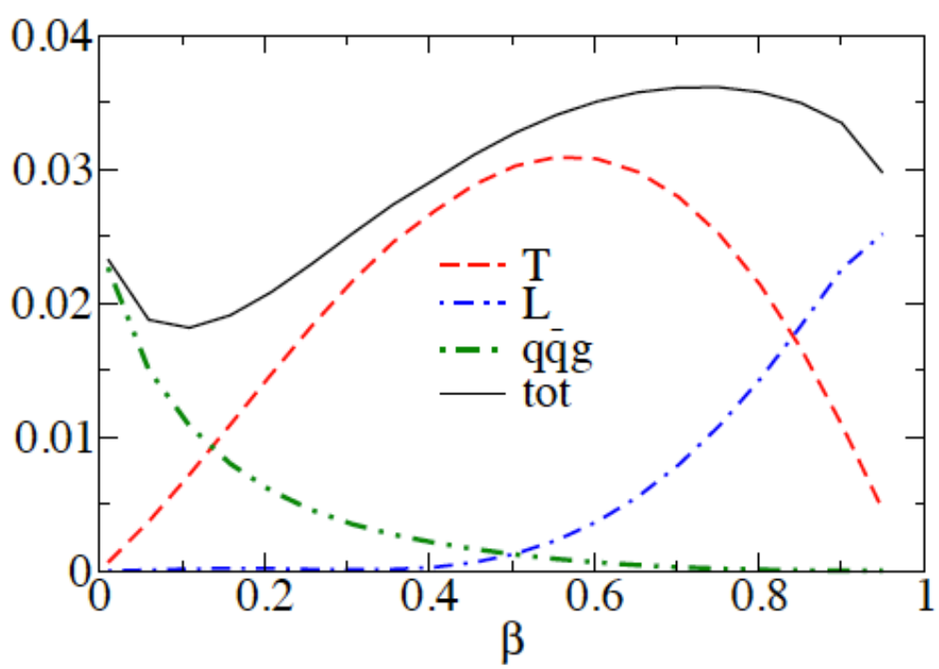


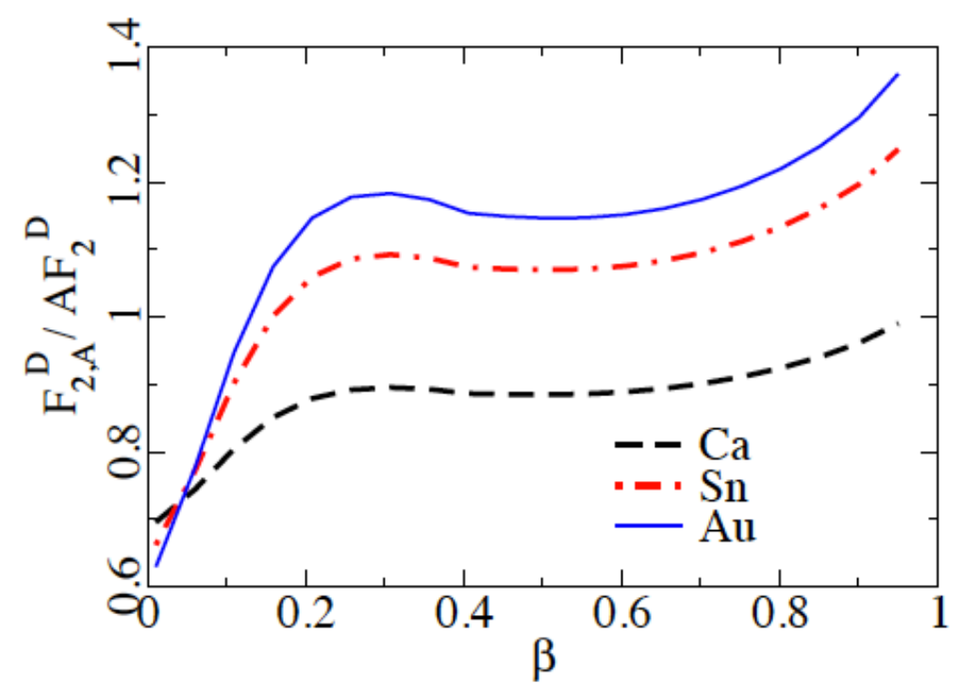
# Charm and diffractive structure functions, $F^D_{2,L}$, $F^c_{2,L}$

- $F^c_{2,L}$ give more direct access to the gluon distribution than the inclusive $F_2$ structure function
  - ➡ QCD calculations with non-zero $m_c$ are scheme dependent and can absorb saturation signals if not handled correctly
- $F^D_{2,L}$ is also sensitive to the gluon distribution
  - ➡ Differences between linear and non-linear models appear at higher $Q^2$ than for $F_2$ (8 $GeV^2$ vs 2 $GeV^2$)
    - More experimentally challenging measurement than $F_2$

$$x_{\mathbb{P}} = 10^{-3}$$

$$Q^2 = 5GeV^2$$



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

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

| Deliverables | Observables | What we learn | Stage-I | Stage-II |
|---|---|---|---|---|

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

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

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

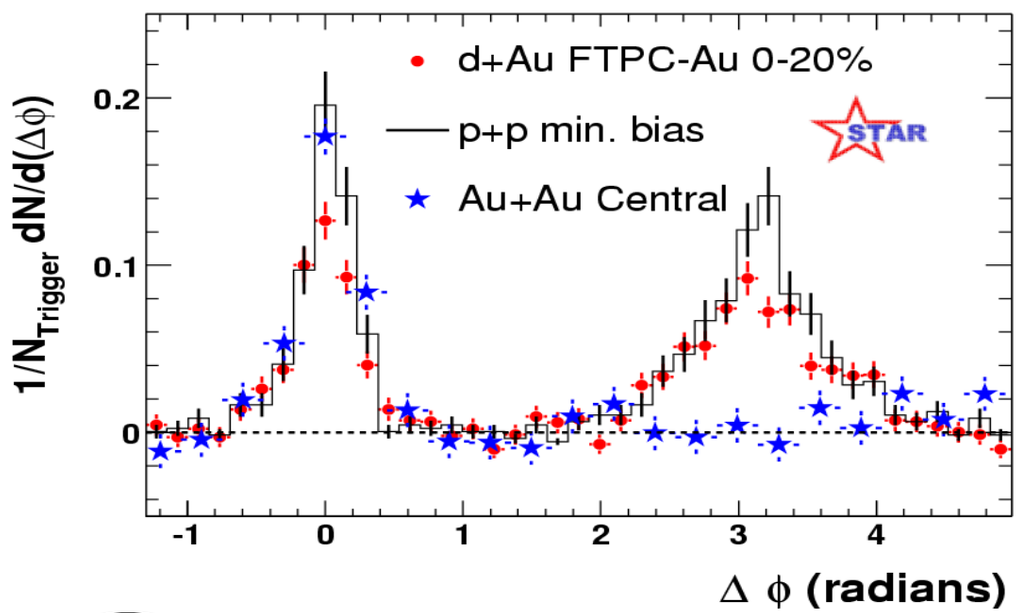
| Deliverables | Observables | What we learn | Stage-I | Stage-II |
|---|---|---|---|---|
| $k_T$ dependent gluons; gluon correlations | di-hadron correlations | non-linear QCD evolution / universality | onset of saturation | measure $Q_s$ |

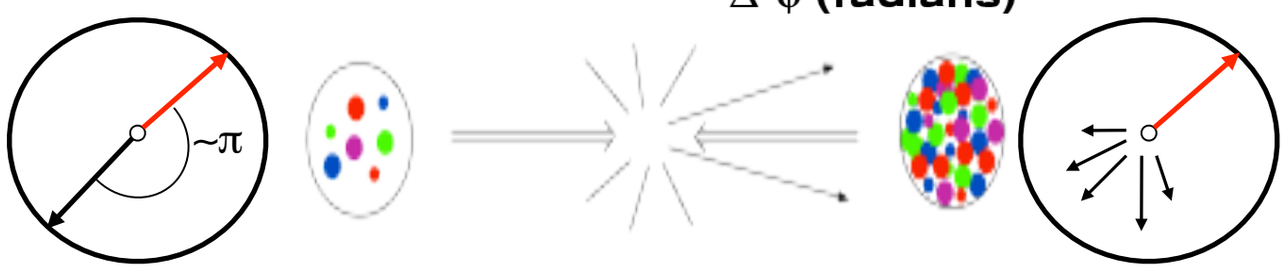
$$e+A \rightarrow e + h + X$$

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

# di-hadron angular 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 ~ $10^{-2}$

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

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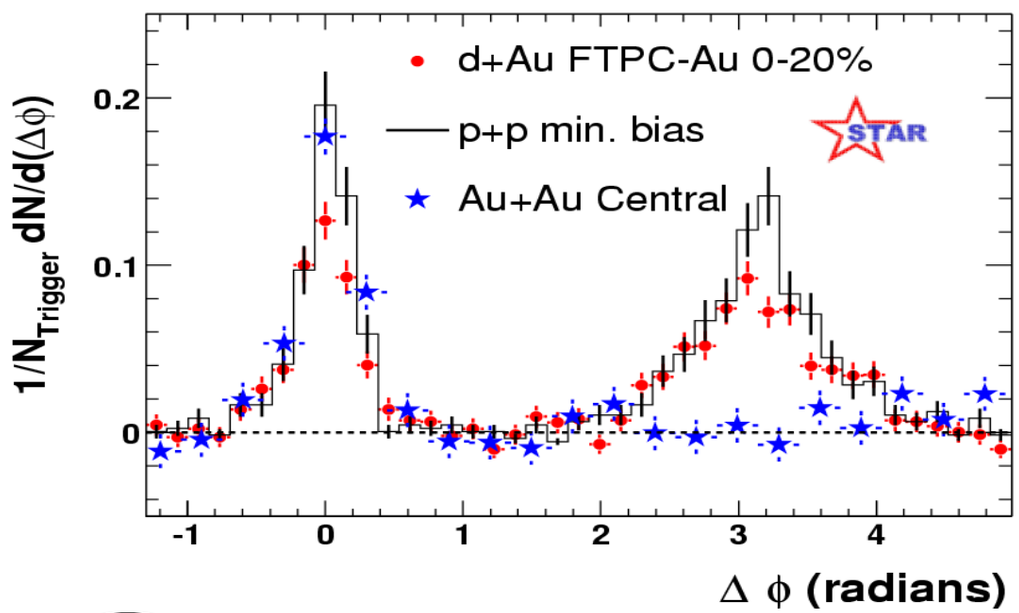


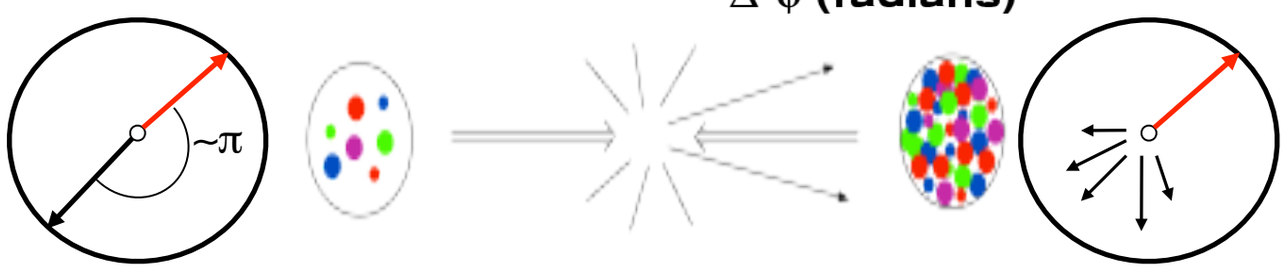


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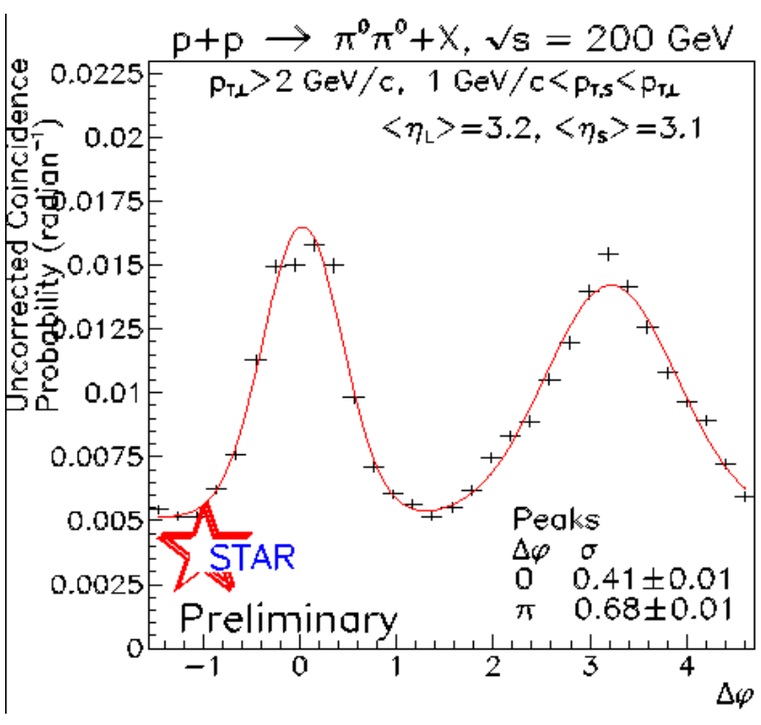
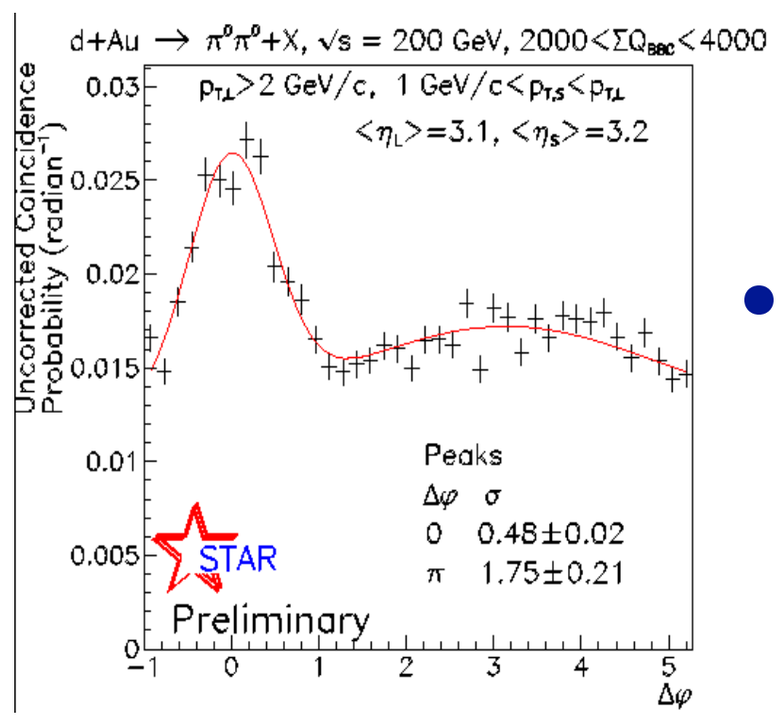
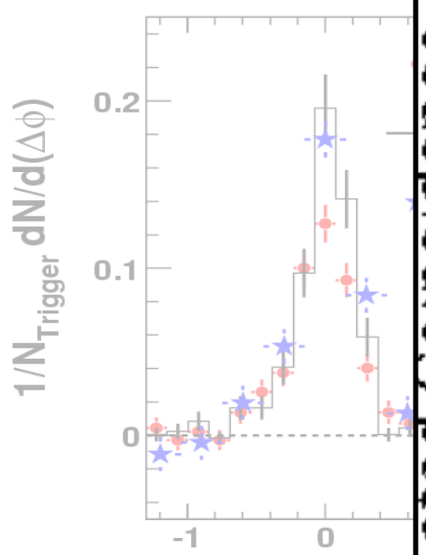


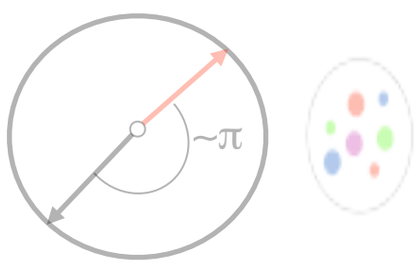



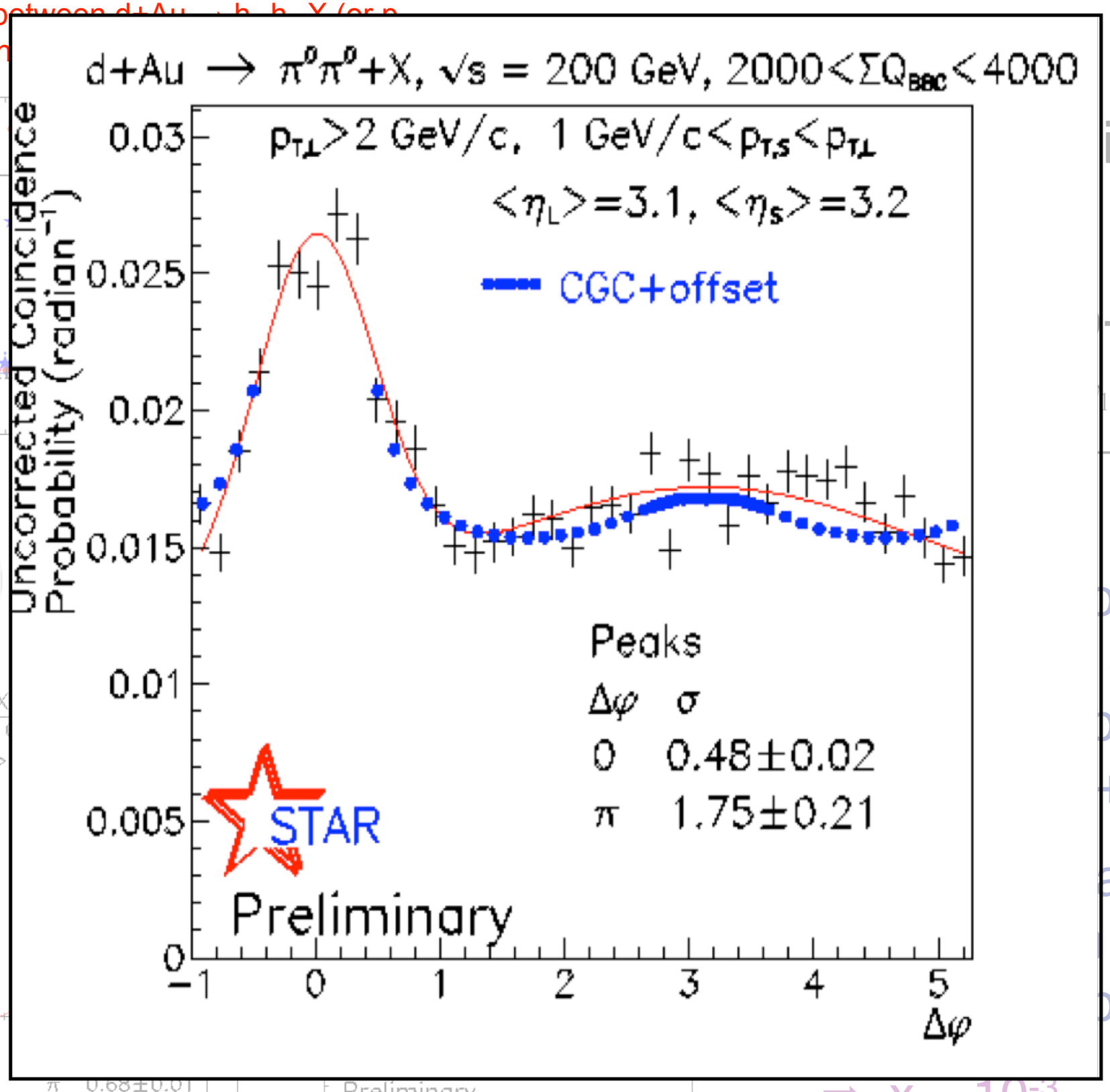

- However, at forward rapidities (y ~ 3.1), an away-side suppression is observed in d+Au
- Away-side peak also much wider in d+Au compared to p+p
  - ➡ x ~ $10^{-3}$

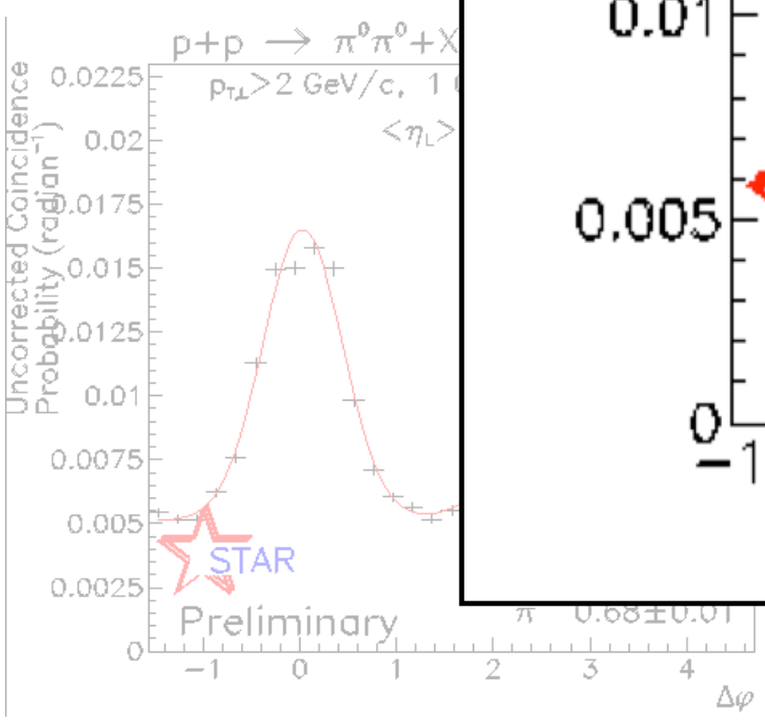
# di-hadron angular correlations in d+A

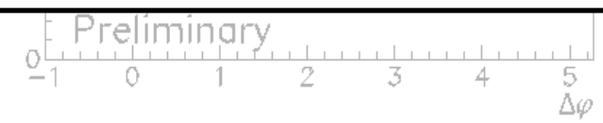
comparisons between d+Au → h, h, X (or p
+Au → $h_1$ h

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in A+A

+p or d+A

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$\sqrt{s}$ <<1

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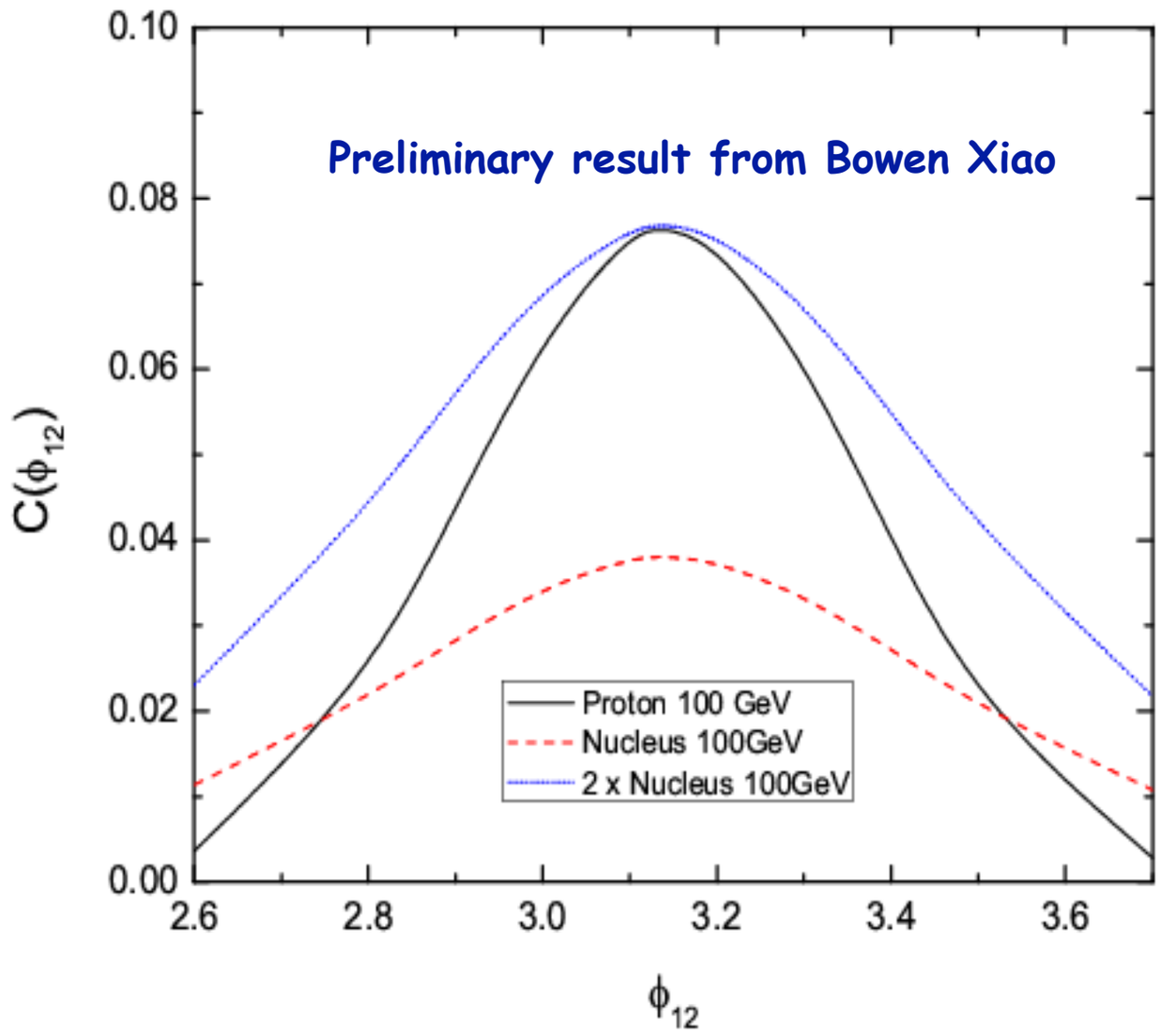
# di-hadron correlations in e+A

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




$Q^2 = 4\text{GeV}^2$; $z_{h1} = z_{h2} = 0.3$

$2\ \text{GeV} < p_T^T < 3\text{GeV}$

$1\text{GeV} < p_T^A < 2\text{GeV}$

- 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

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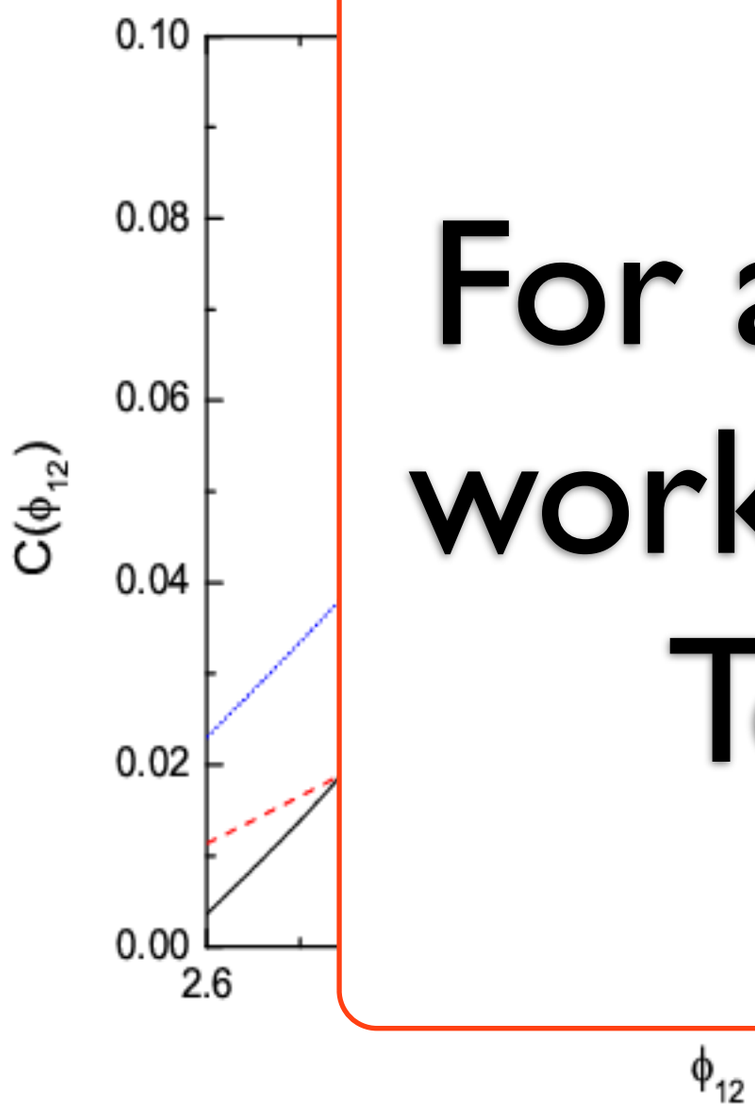


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**For a discussion of this work, see talk by Tobias Toll on Thursday**

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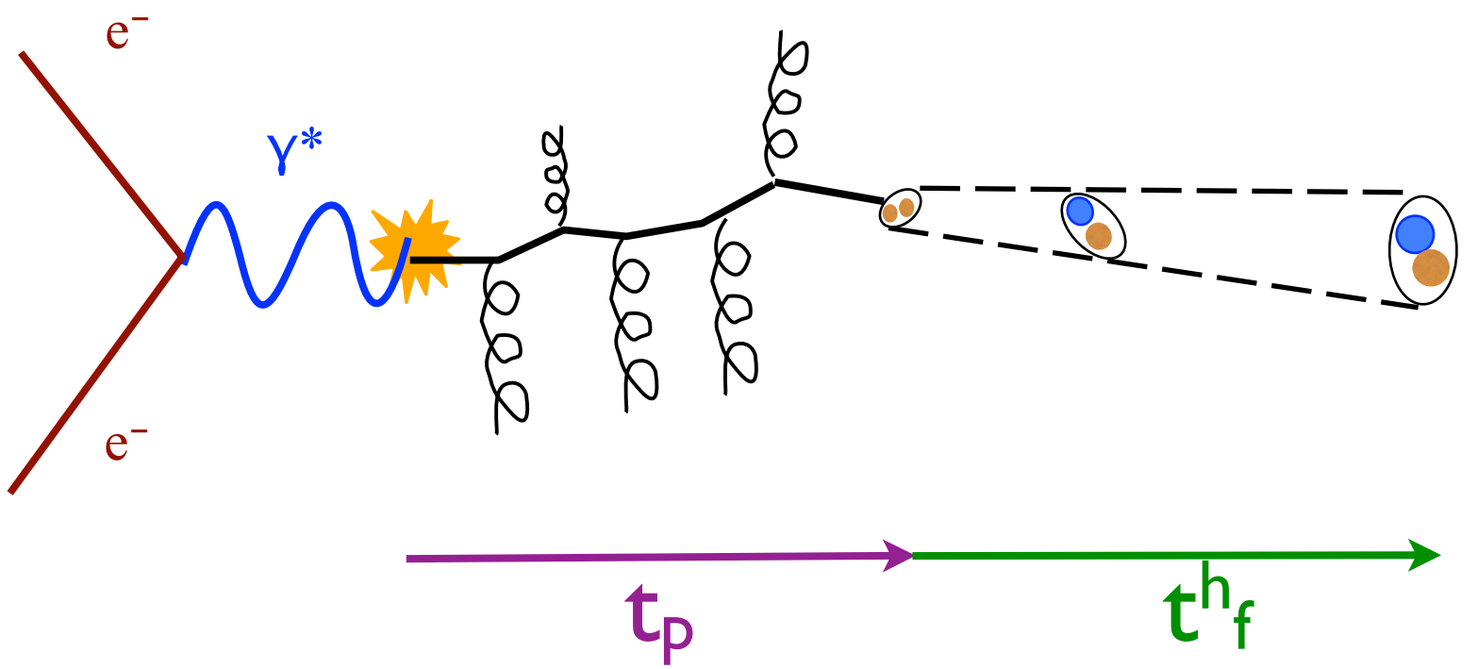
# transport coefficients in cold nuclear matter from large-x semi-inclusive DIS and jets

# Transport coefficients in cold nuclear matter

| Deliverables | Observables | What we learn | Stage-I | Stage-II |
|---|---|---|---|---|
| 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 |

# Jets and hadronization

A. Accardi
R. Dupre

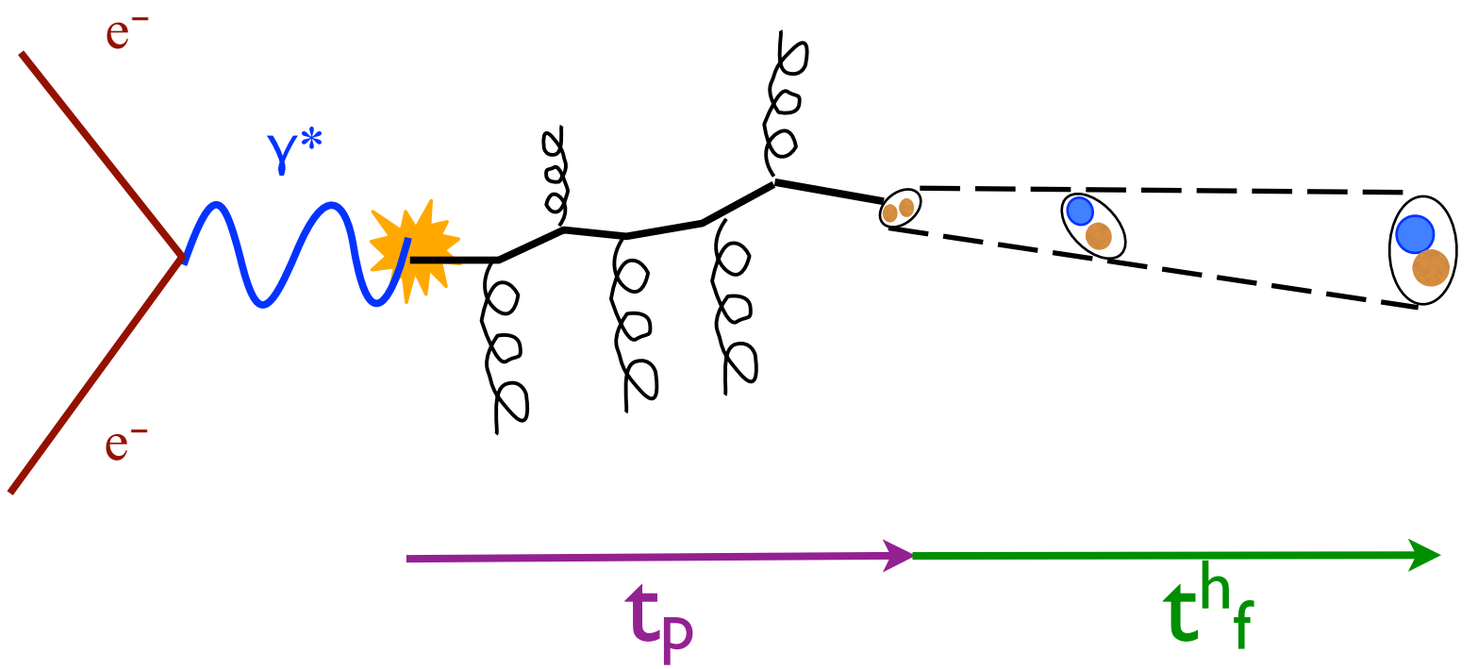



- $t_p$ - production time of propagating quark
- $t^h_f$ - hadron formation time

# Jets and hadronization

A. Accardi
R. Dupre

What happens if we add a nuclear medium?

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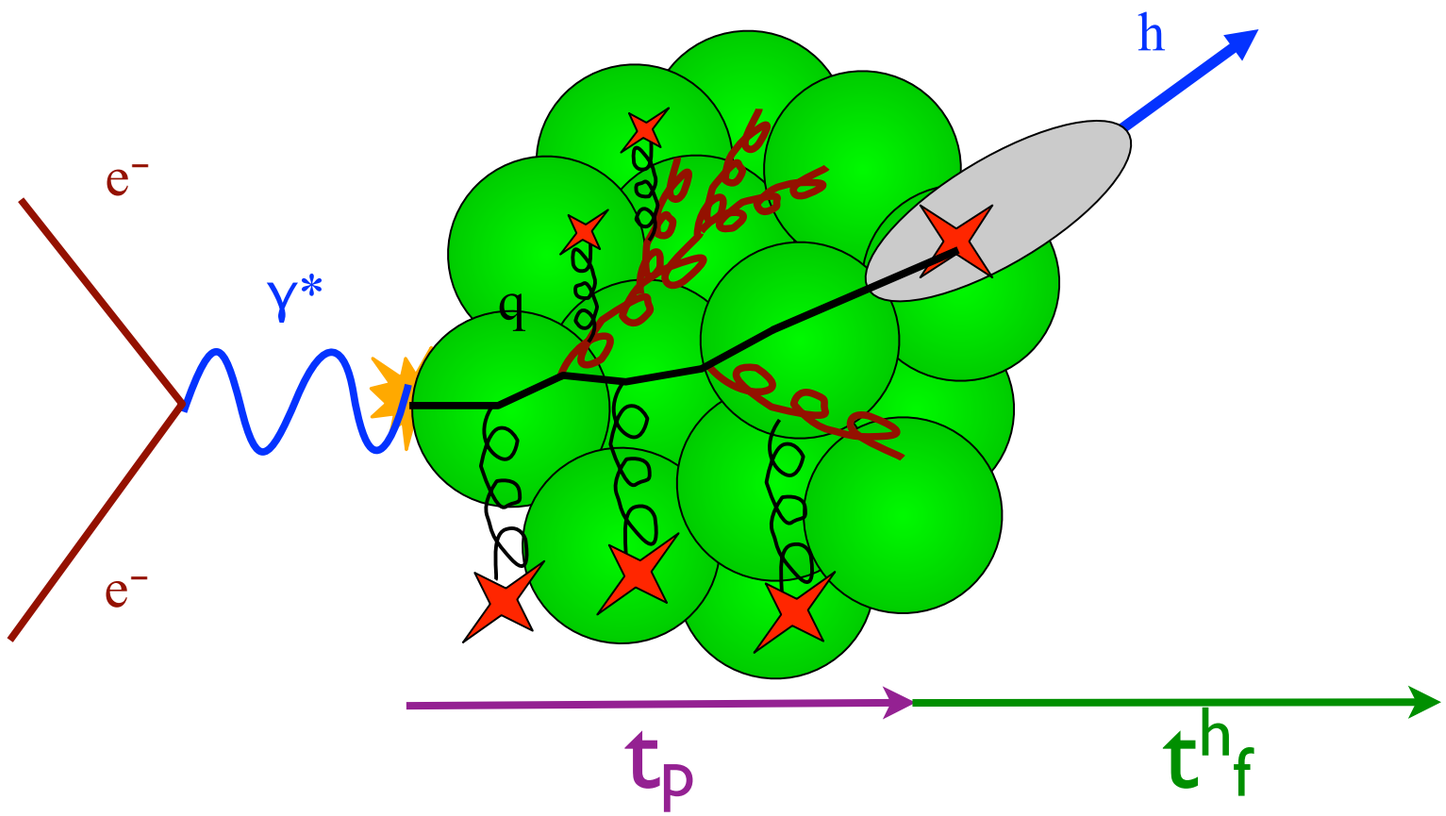


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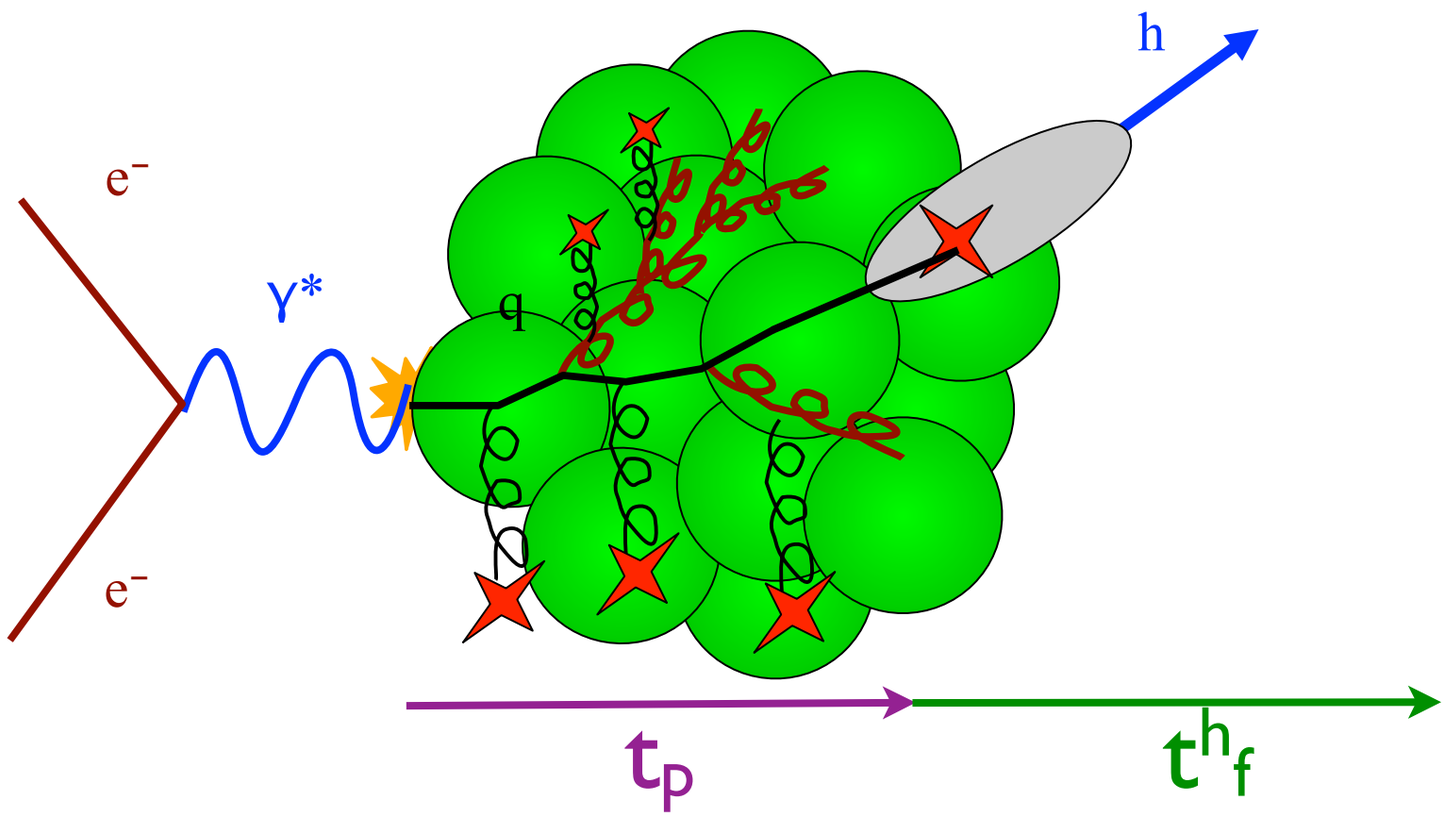


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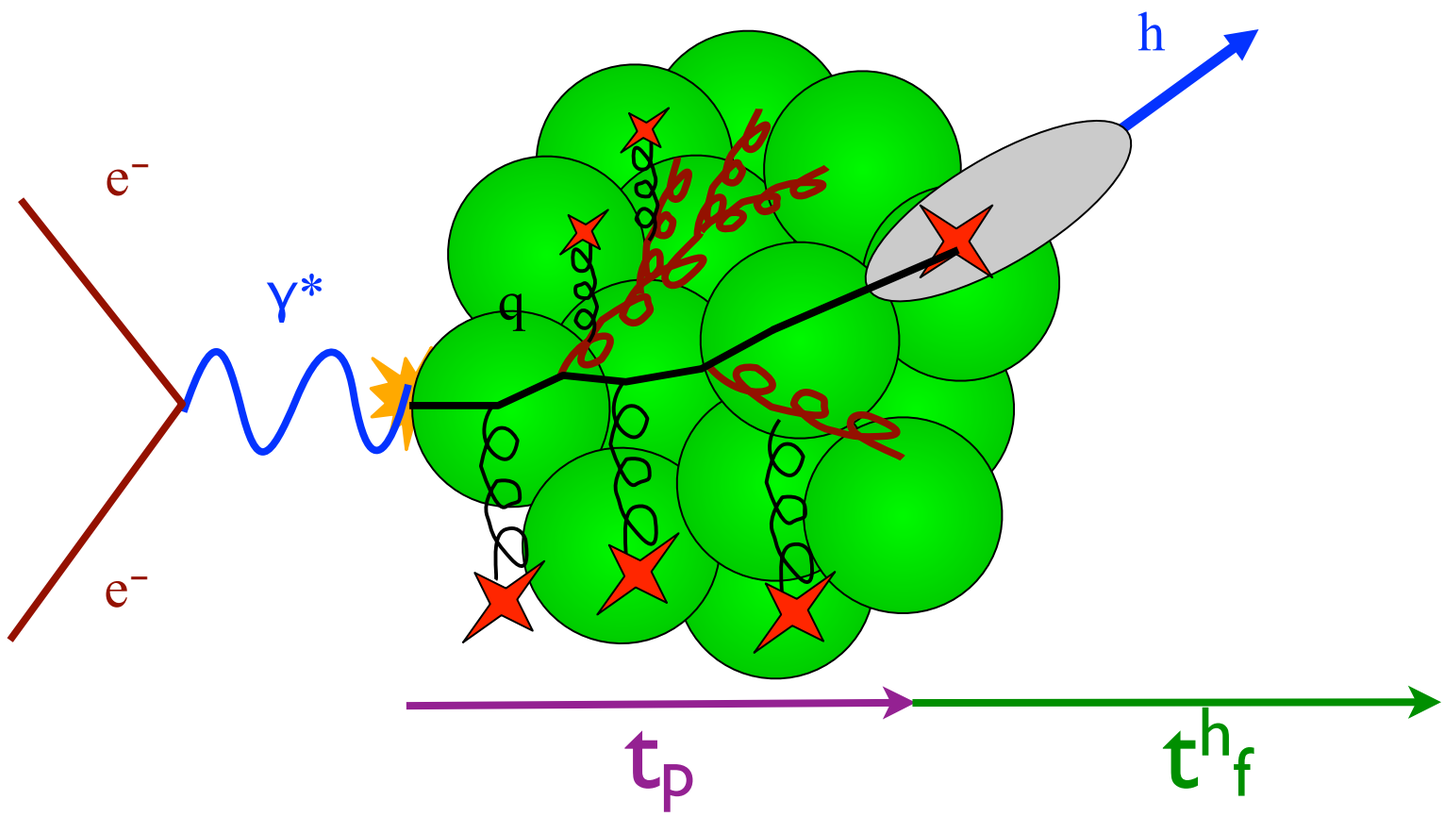
Observables:

Broadening: $\Delta p_T^2 = \langle p_T^2 \rangle_A - \langle p_T^2 \rangle_p$: direct link to saturation scale

# Jets and hadronization

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# Jets and hadronization

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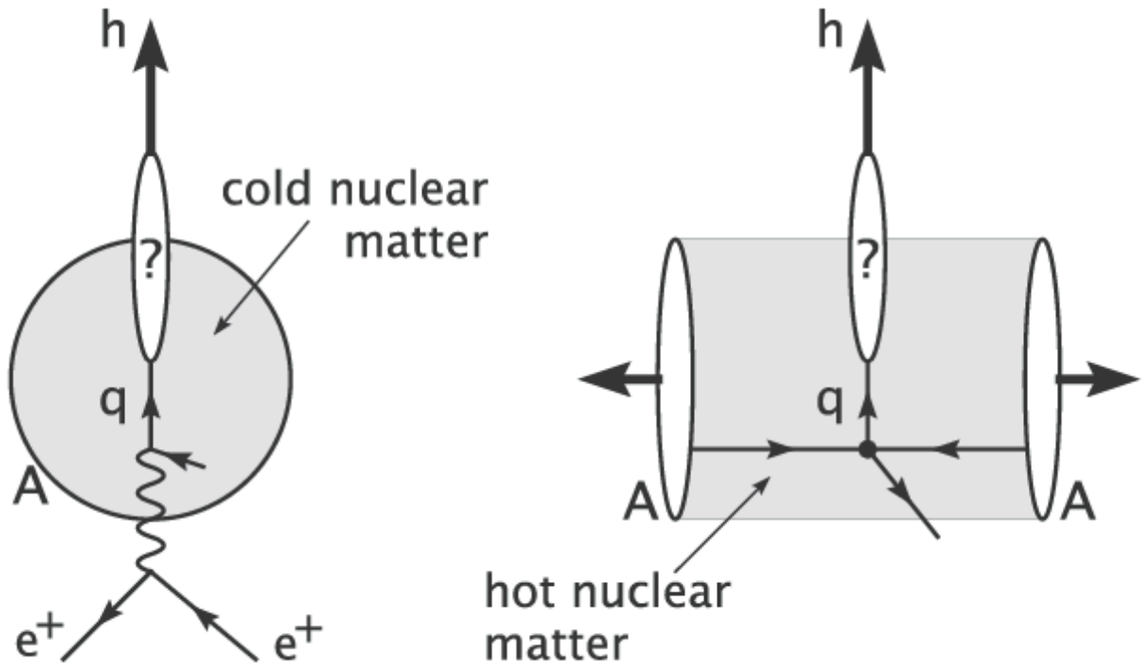


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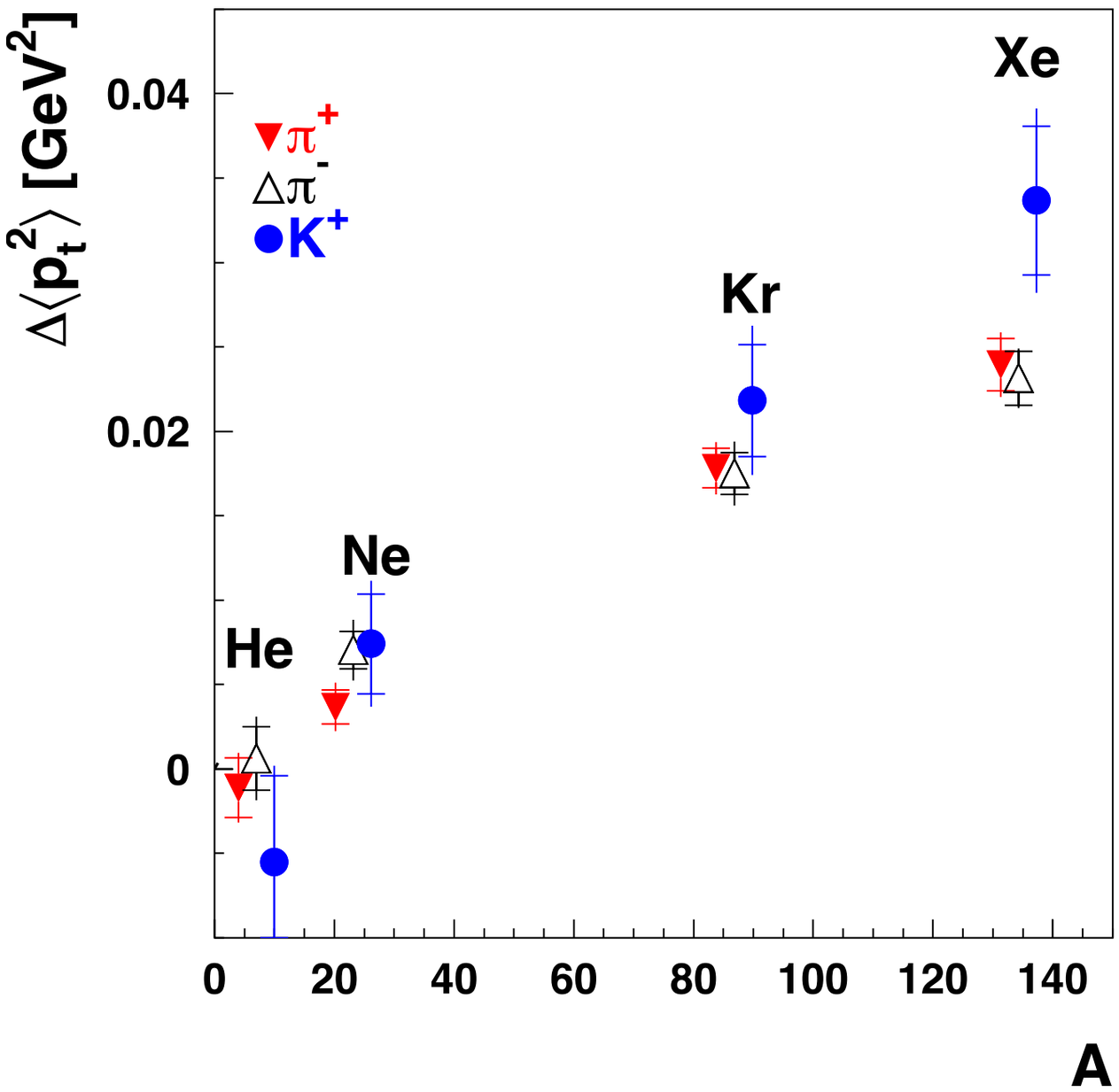
# $p_T$ broadening - how can the EIC contribute?

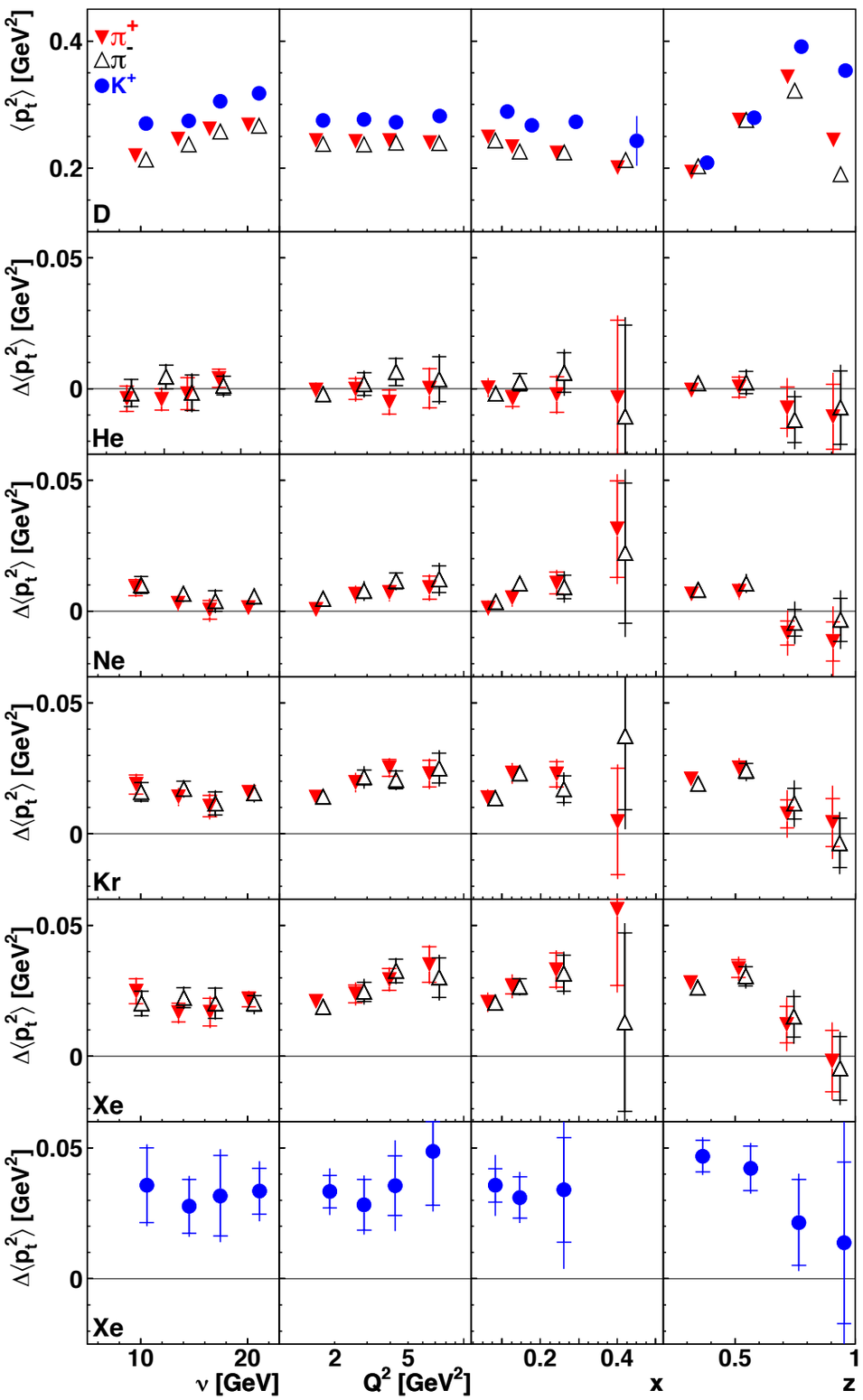
HERMES:




Increase of $p_T$ broadening seen with increasing nuclear size - integrated over all variables

# $p_T$ broadening - how can the EIC contribute?

HERMES:



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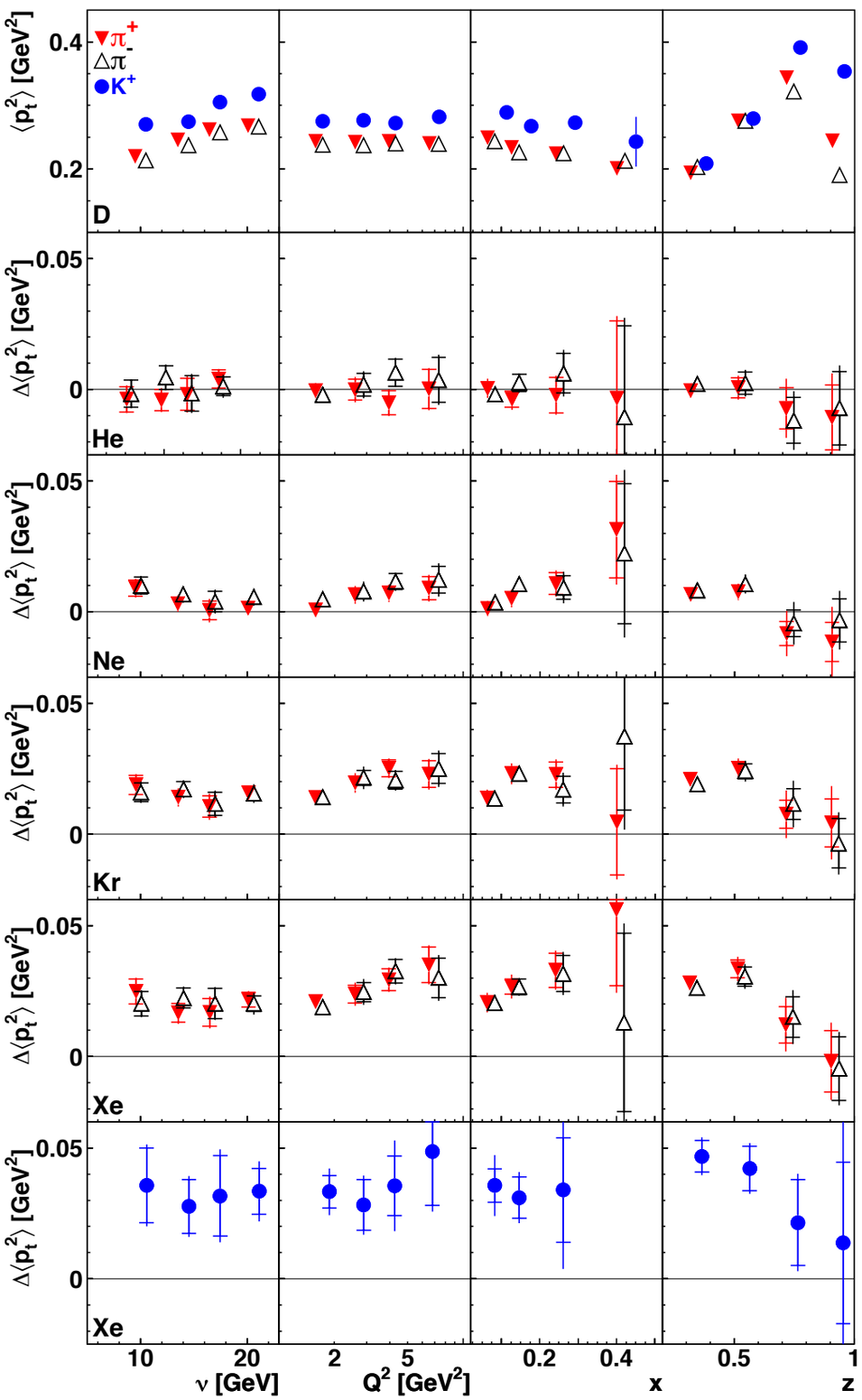
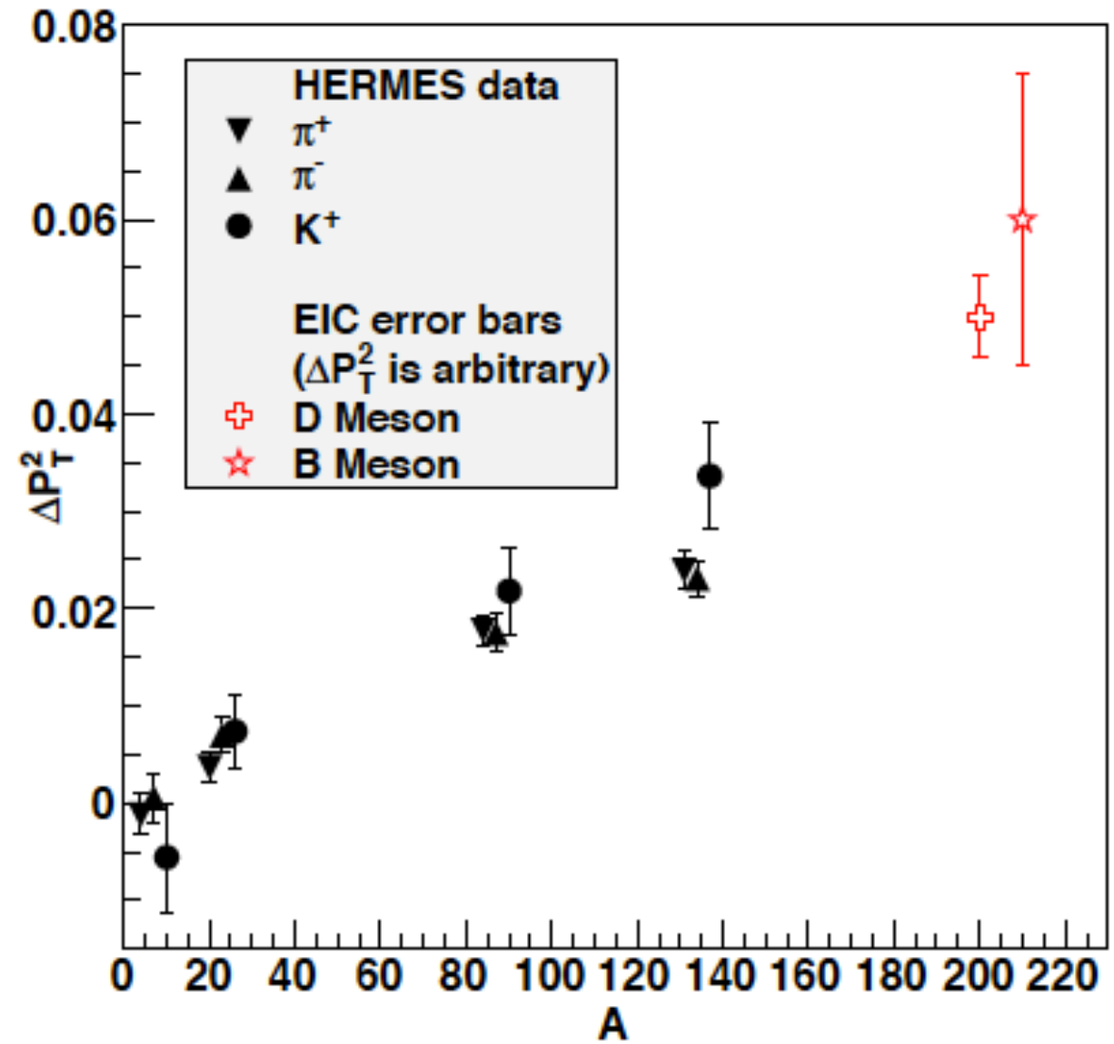



EIC:



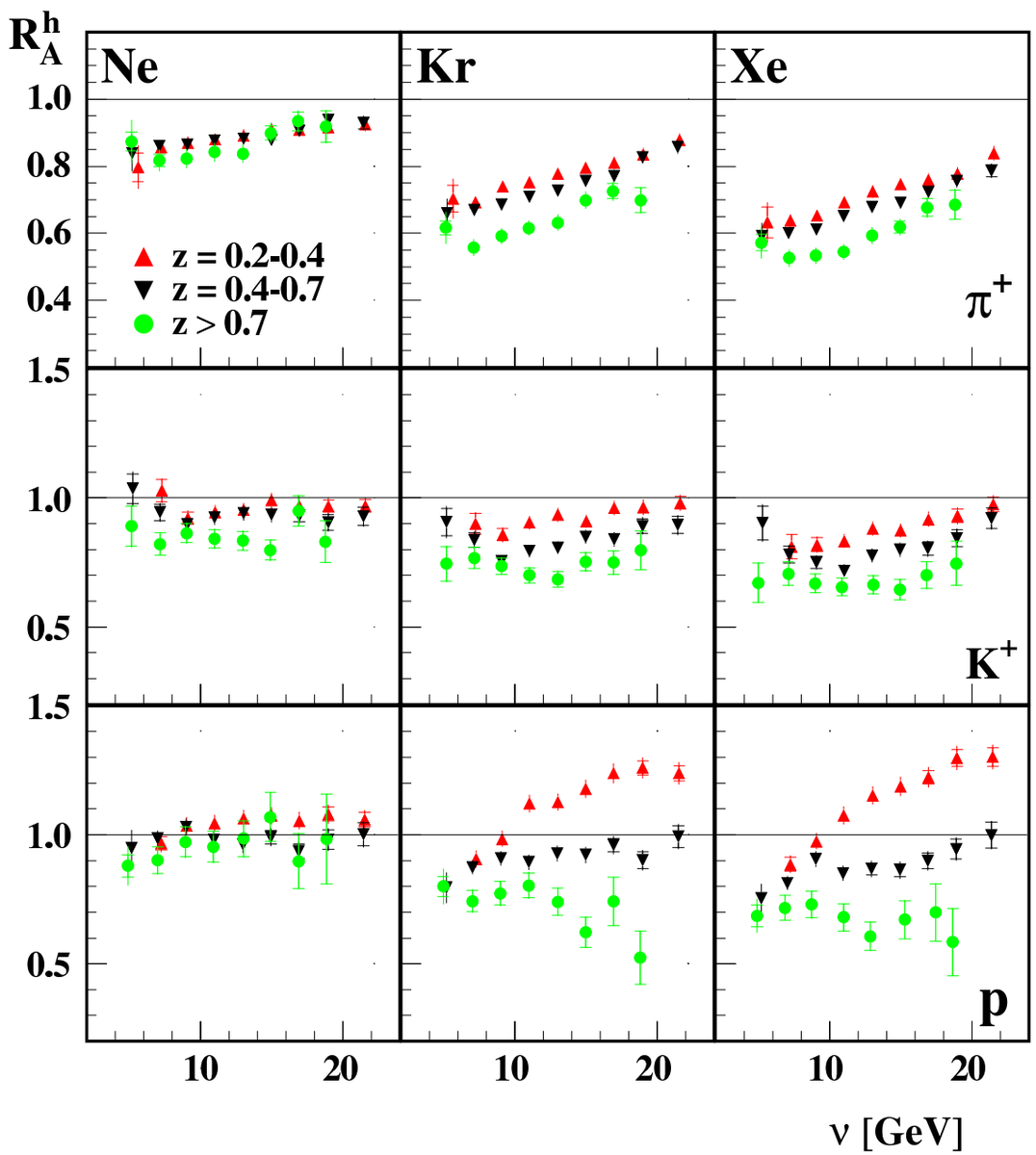

Measurements from HERMES can be repeated, with the addition of heavy quarks

# Attenuation - how can the EIC contribute?

HERMES:

$E_e$ = 27 GeV → $\sqrt{s}$ = 7.2 GeV

$E_h$ = 2-15 GeV




ν = virtual photon energy

$Z_h = E_h/\nu$

# Attenuation - how can the EIC contribute?

HERMES:

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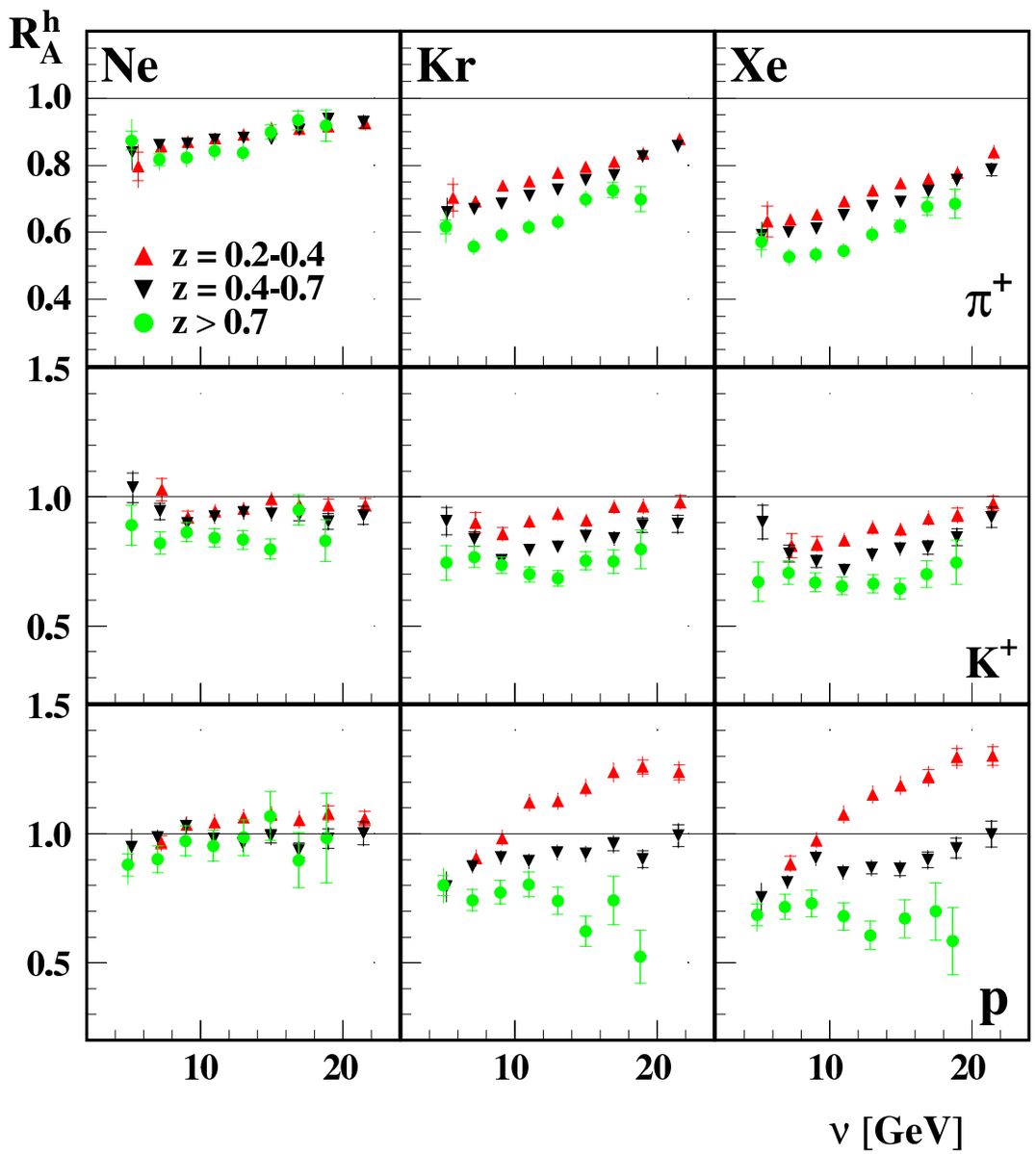
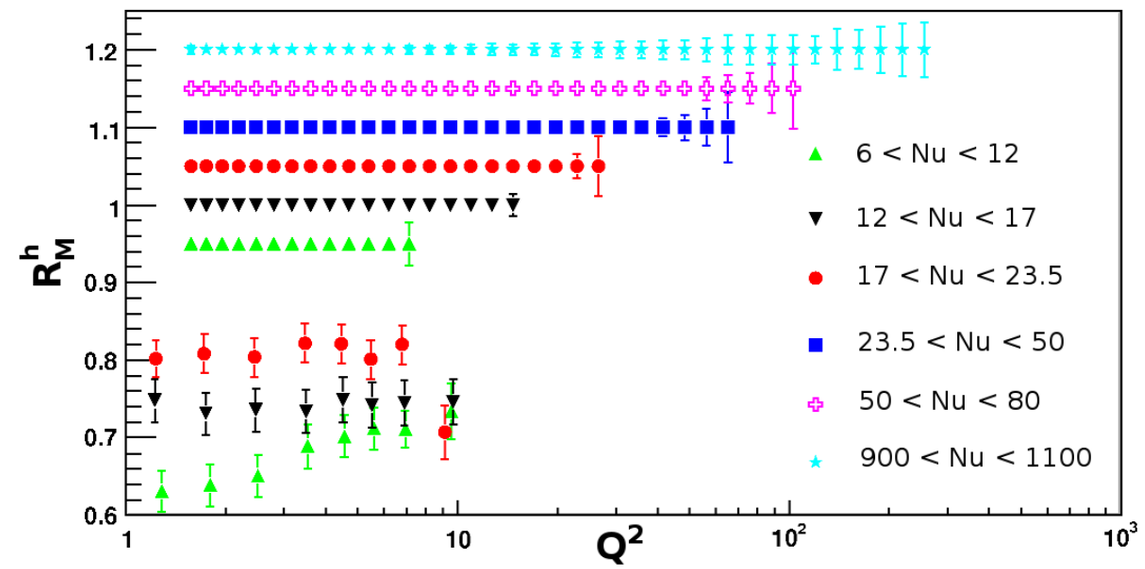
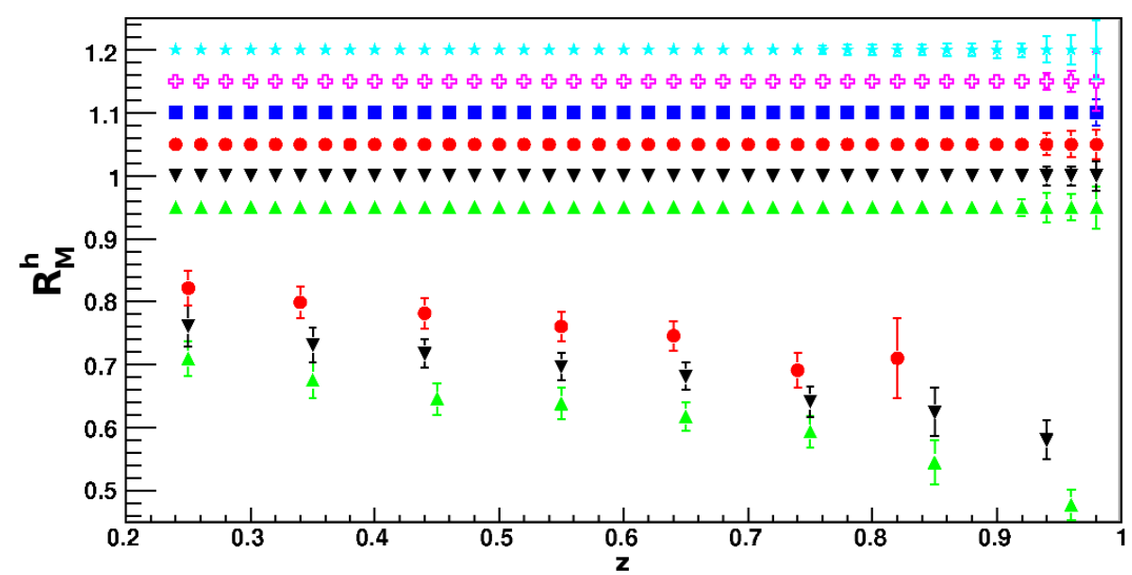



EIC:

light hadrons:

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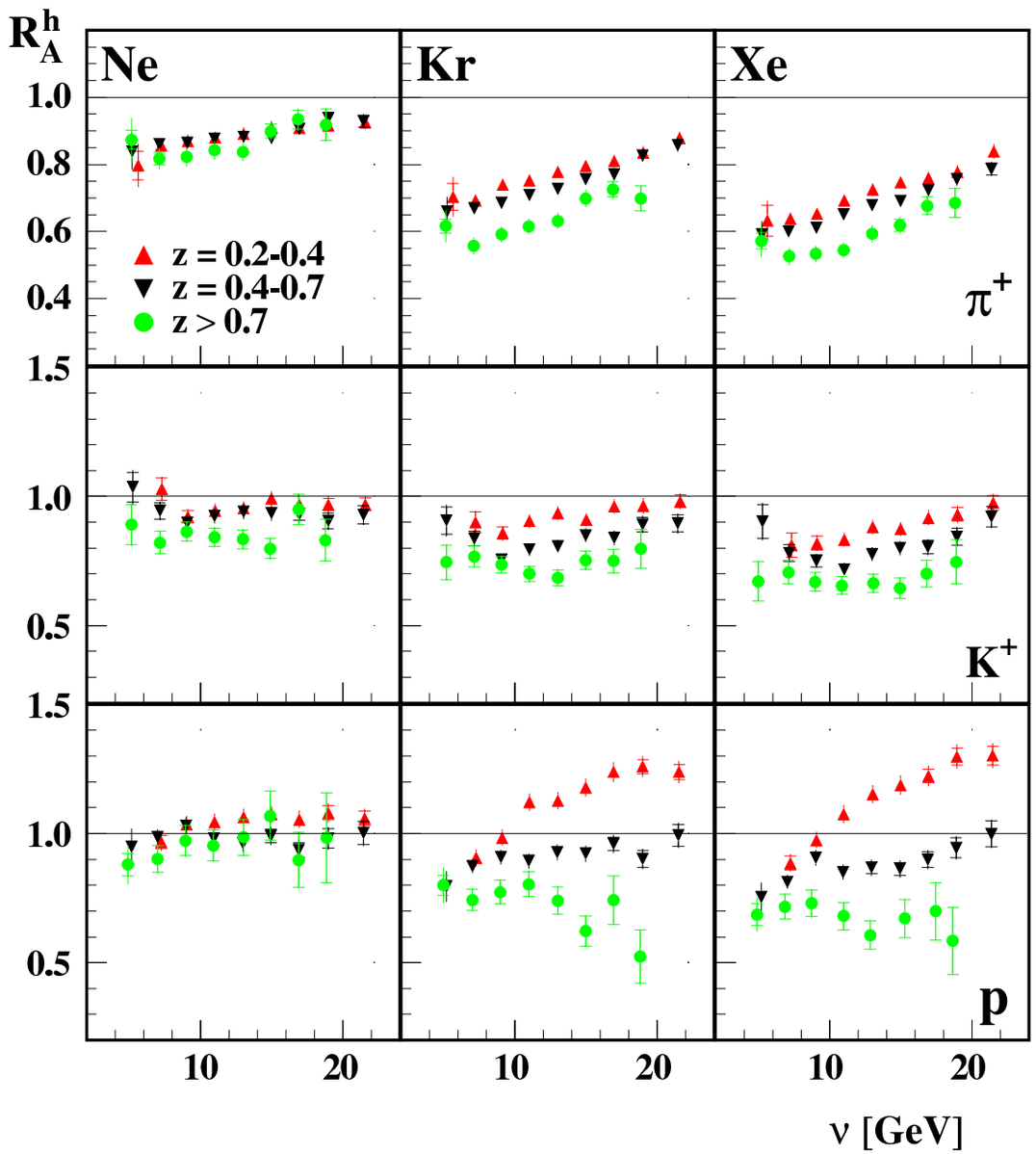
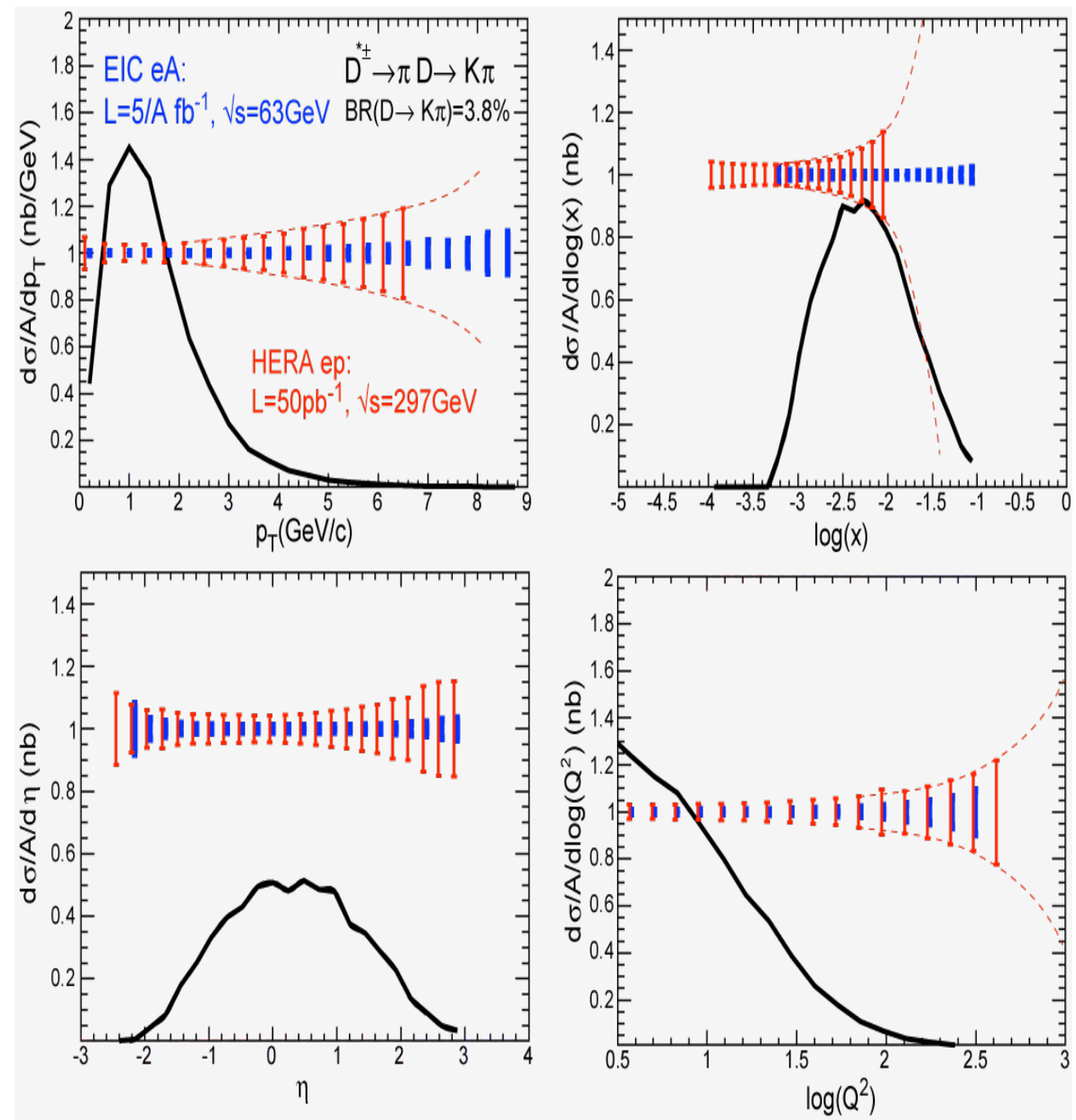



EIC:

charm hadrons:

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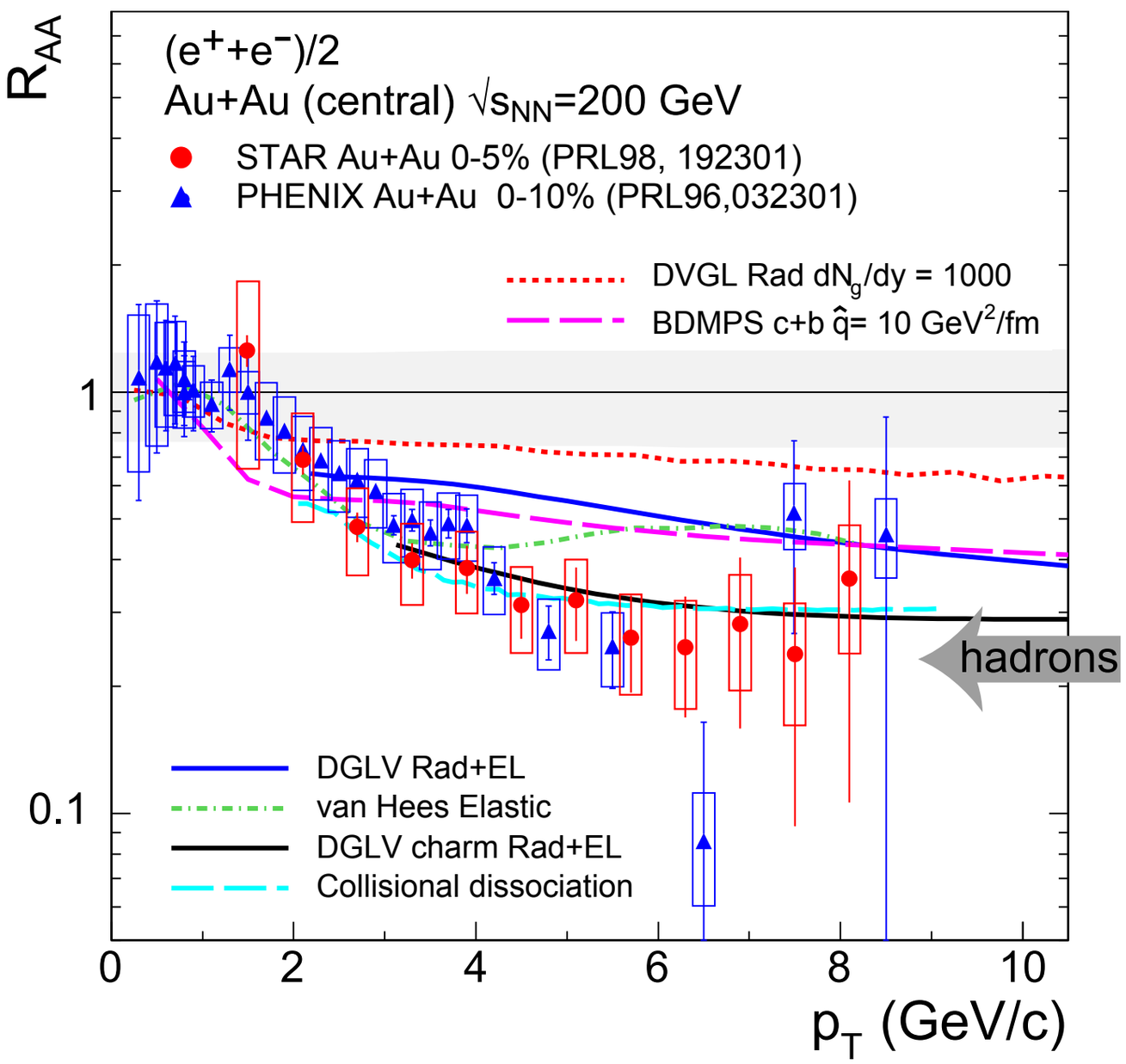
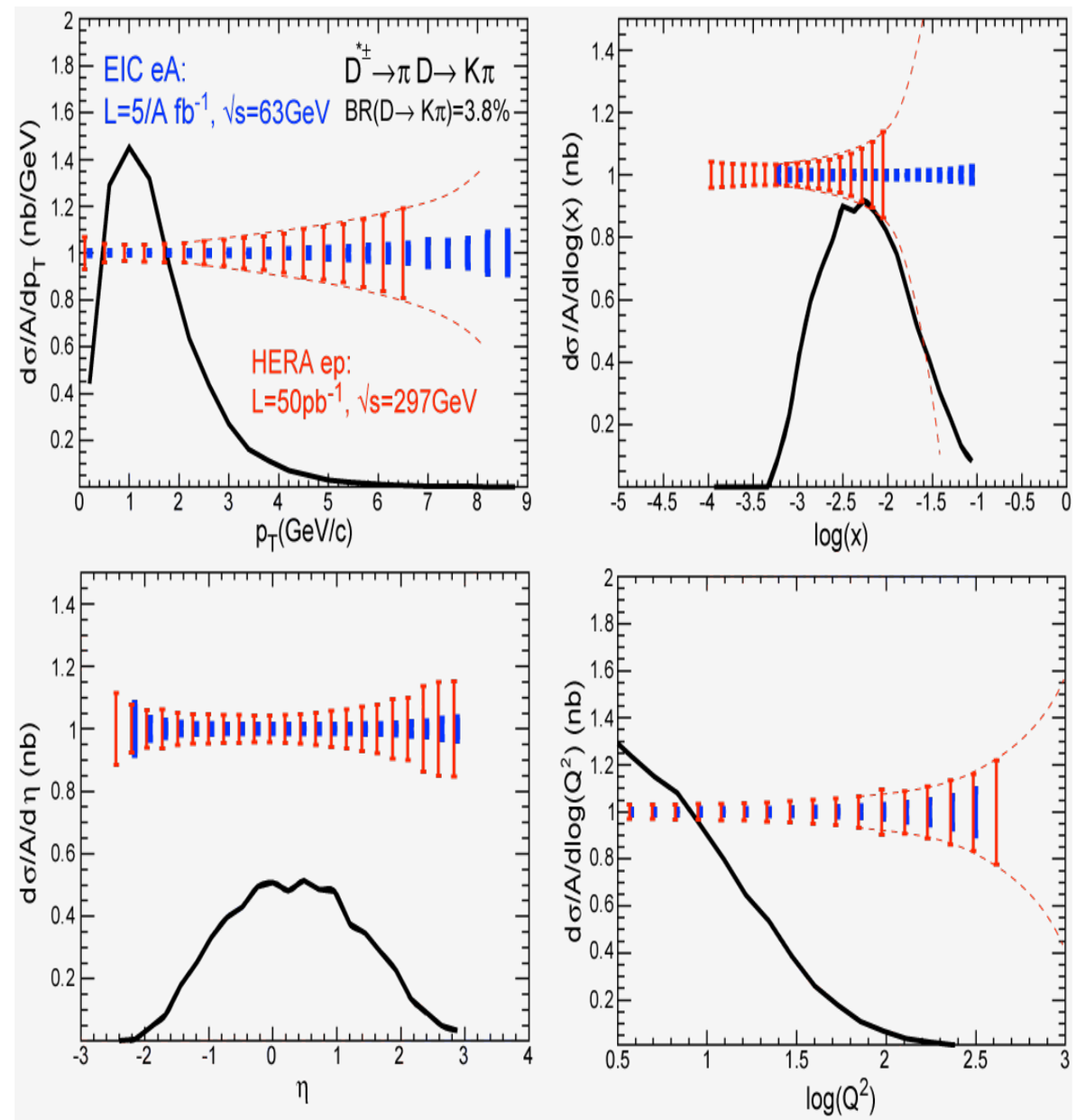
RHIC:




EIC:

charm hadrons:

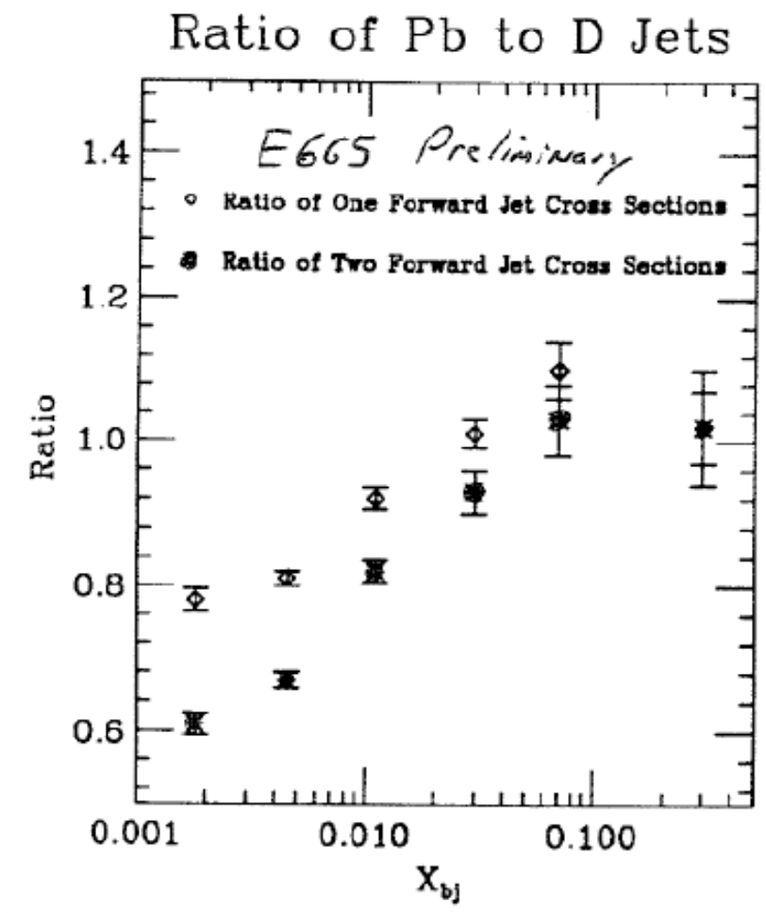



$\nu$ = virtual photon energy  large $\nu$ range → boost

$Z_h = E_h/\nu$  hadronization in and out of nucleus

# Jets at an EIC

- E665 at FNAL have measured jets in μ+A at $\sqrt{s} \sim 30$ GeV
  - ➡ Feasible to start a jet programme in phase 1
  - ➡ caveat that collider kinematics are different to fixed target



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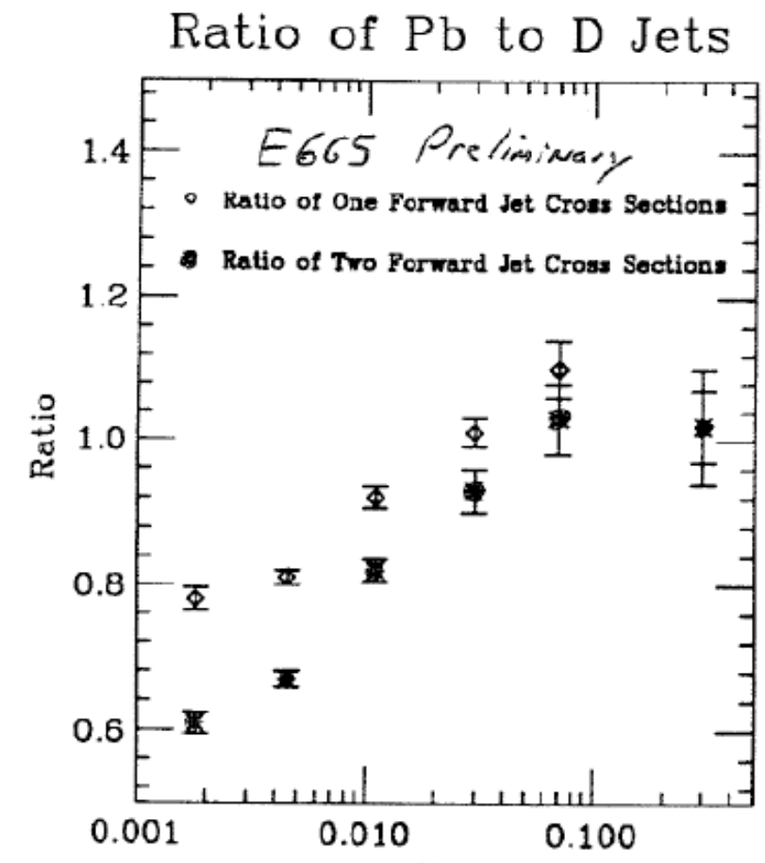
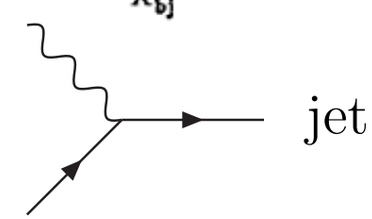



1+1 jets, dominated by q processes → allow study of parton propagation through cold nuclear matter



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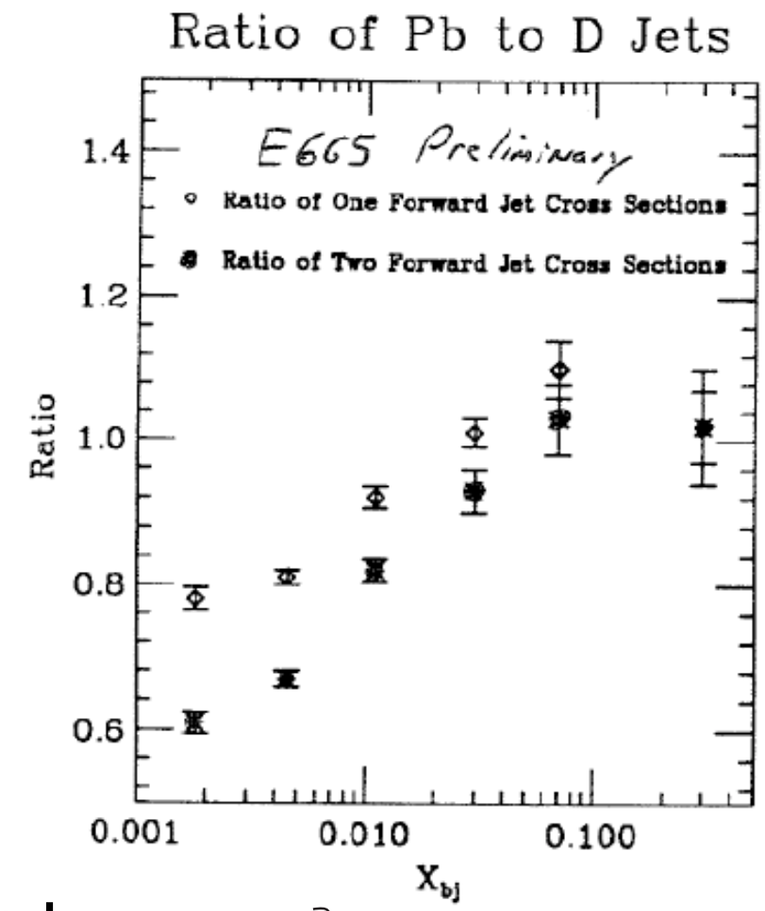


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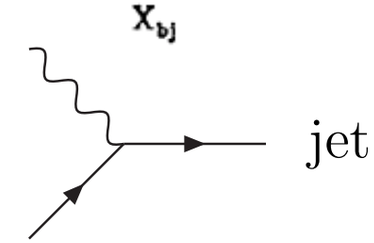
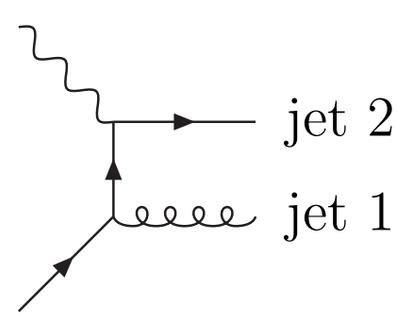
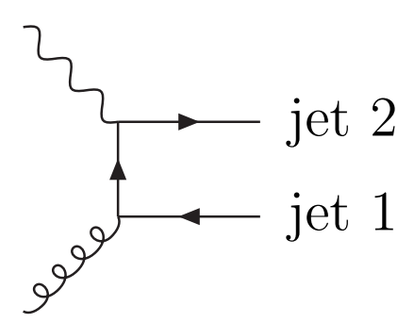



$$\frac{d^2\sigma_{2+1}}{dx dQ^2} = A_q(x,Q^2)q^A(x,Q^2) + A_g(x,Q^2)g_A(x,Q^2)$$

2+1 jets→ sensitive to nuclear gluons




By measuring 1+1 jets, can extract information on gluons

# Jets at an EIC

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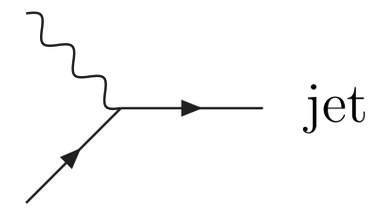


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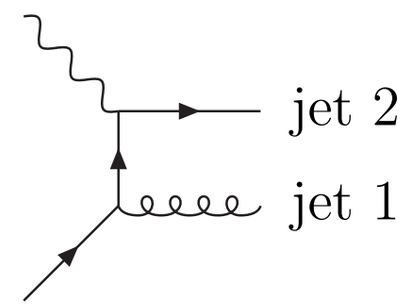


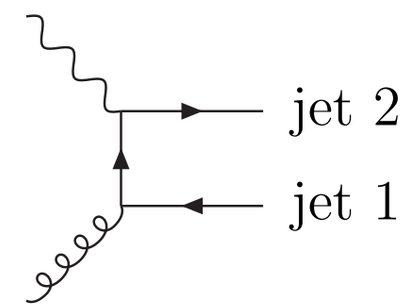


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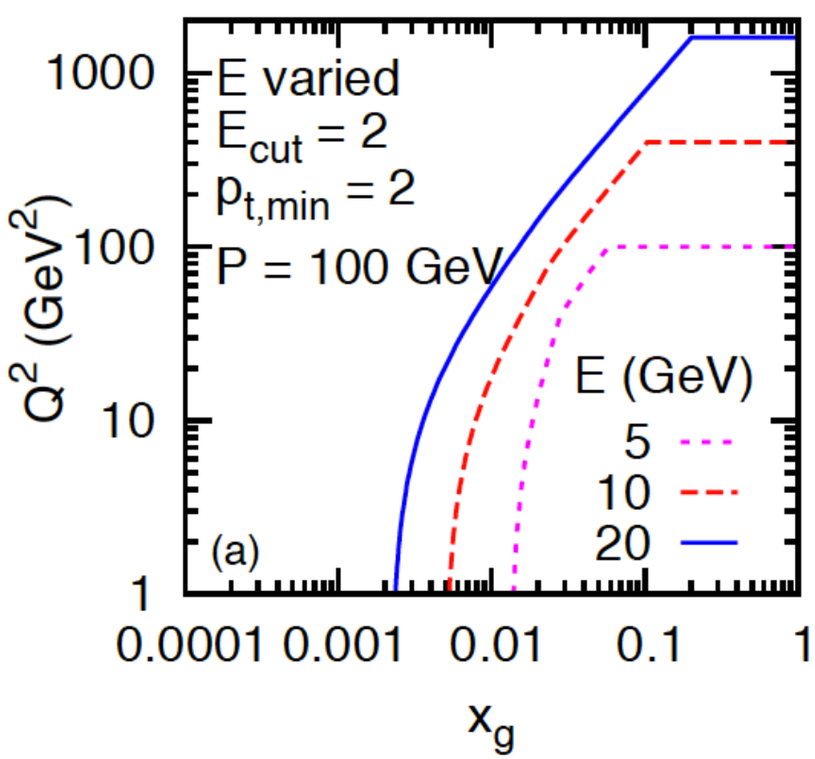


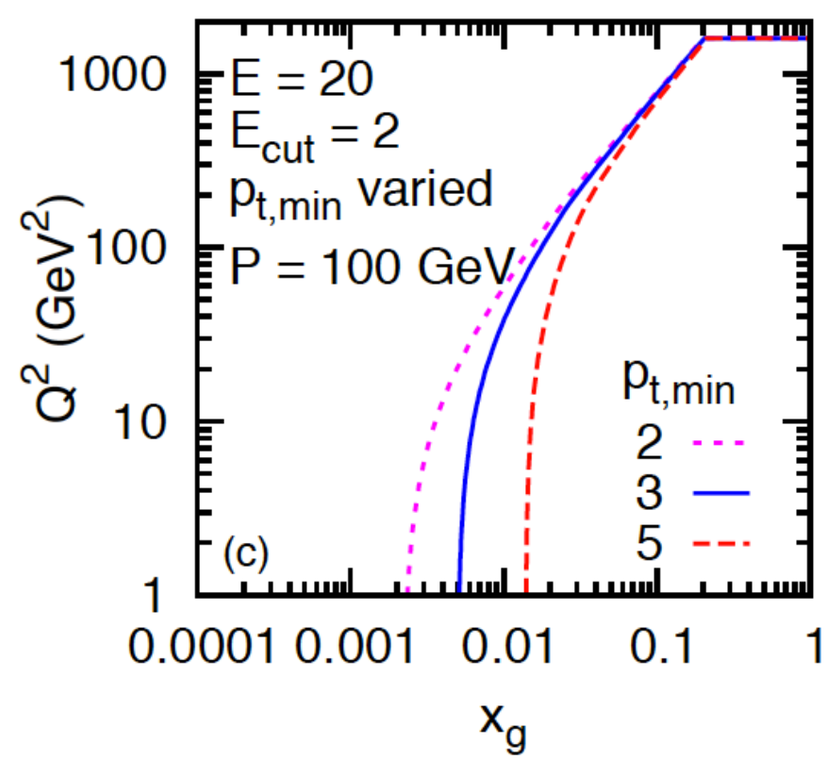

# b dependent gluons, gluon correlations from DVCS and diffractive vector meson production

# Silver Measurements

| Deliverables | Observables | What we learn | Stage-I | Stage-II |
|---|---|---|---|---|
| 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 |

See talk by Tobias Toll on Thursday afternoon

# Summary and Conclusions

- The e+p physics programme at an EIC will allow us to study in detail the spin structure of the proton
  - ➡ Unprecedented coverage down to small-x, provide constraints on $\Delta g$ and $\Delta q$
- 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 (encompassing both e+A and e+p) is now published!!