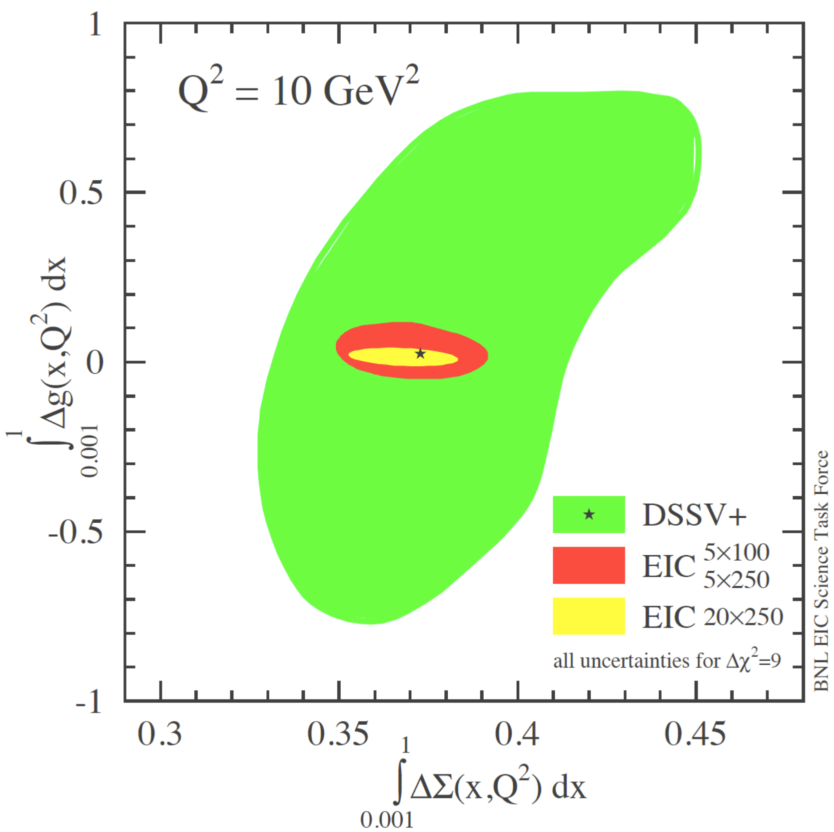
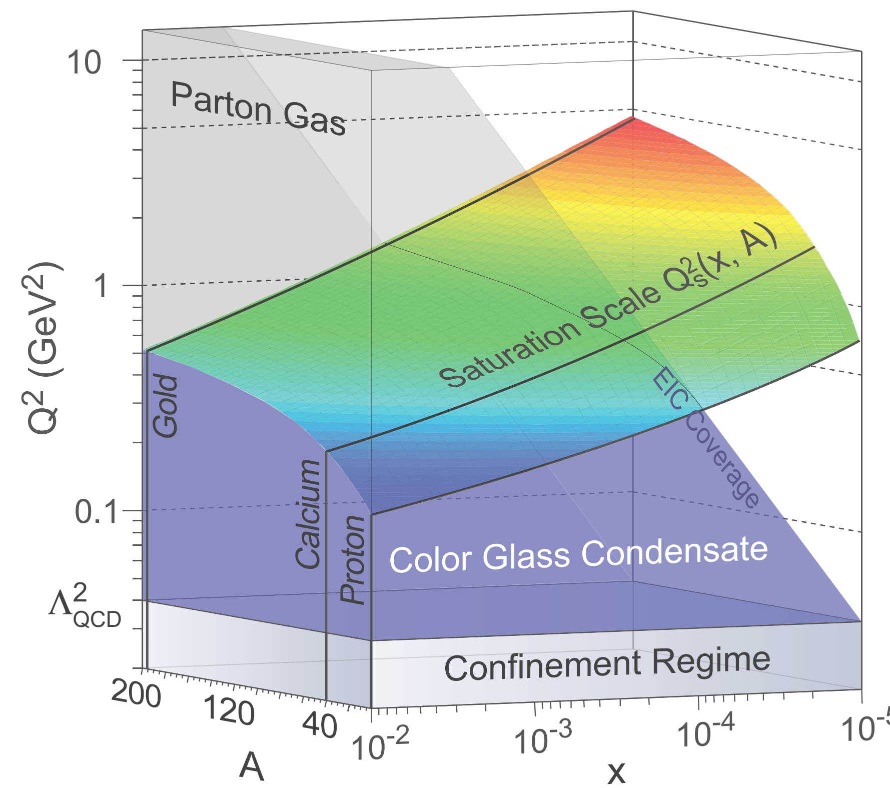
Physics highlights at eRHIC





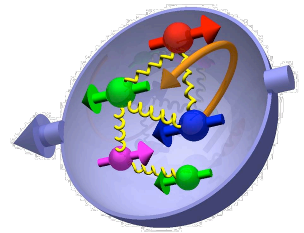
Matthew A. C. Lamont
Brookhaven National Lab

On behalf of the
BNL EIC Science Task Force

BROOKHAVEN NATIONAL LABORATORY

Most compelling physics questions

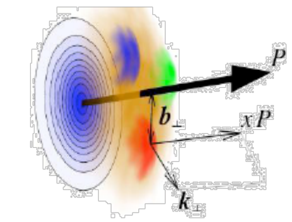
Spin physics



- 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!!

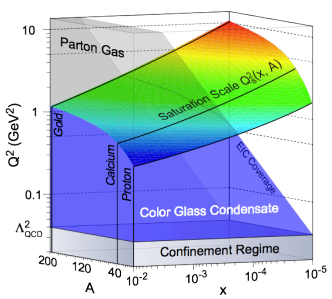
Imaging

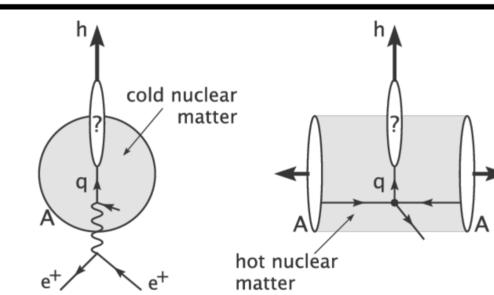


- What is the spatial distribution of quarks/gluons in nucleons AND nuclei?
- Understand deep aspects of gauge theories revealed by k_T dependent distributions

Possible window to orbital angular momentum

Strong Colour Fields and Hadronisation



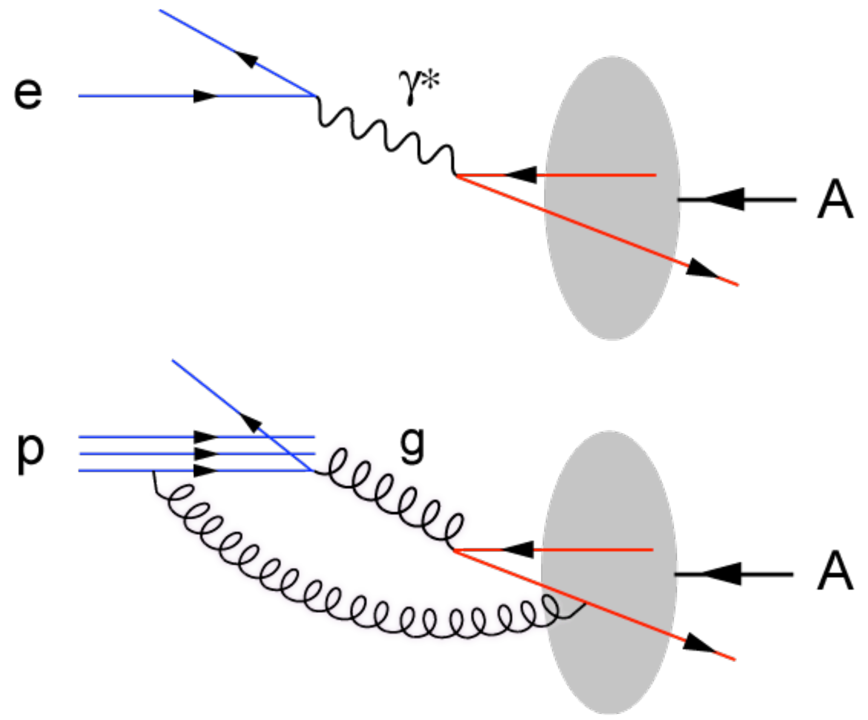


- Quantitatively probe the universality of strong colour fields in A+A, p+A and e+A
- Understand in detail the transition to the non-linear regime of strong gluon fields and the physics of saturation
- How do hard probes in e+A interact with the medium?

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

Why e+A collisions and not p+A?

- e+A and p+A provide excellent information on properties of gluons in the nuclear wave functions
- Both are complementary and offer the opportunity to perform stringent checks of factorization/universality
- Issues:
  - ➡ p+A combines initial and final state effects
  - ➡ multiple colour interactions in p+A
  - ➡ p+A lacks the direct access to x, Q^2



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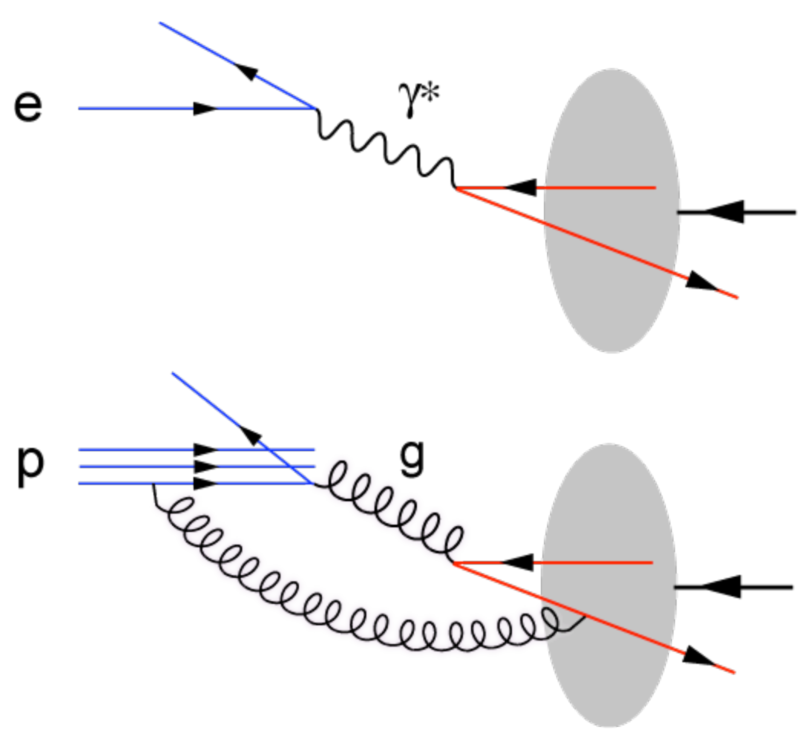

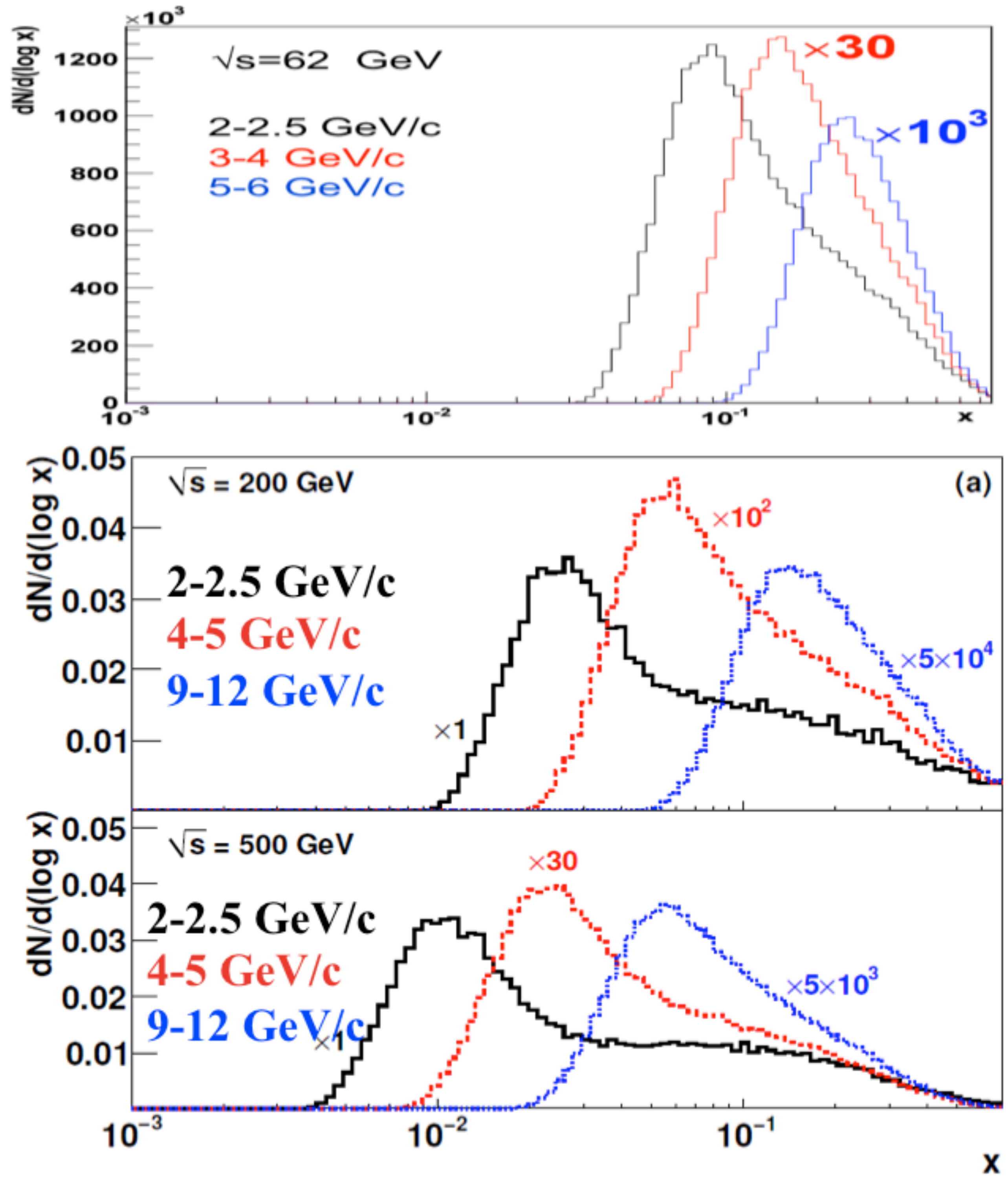

p_T - x correlation in p+p

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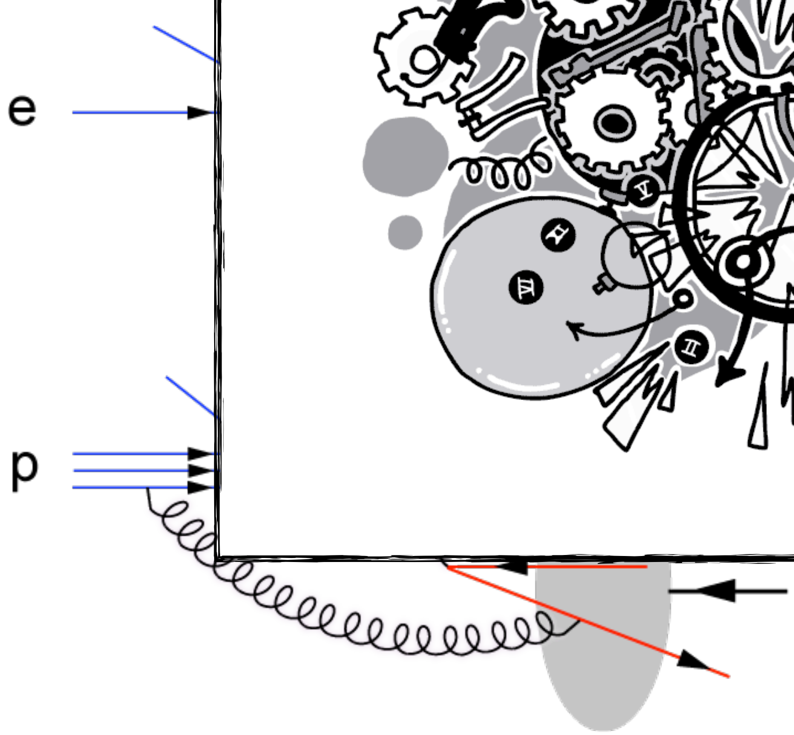
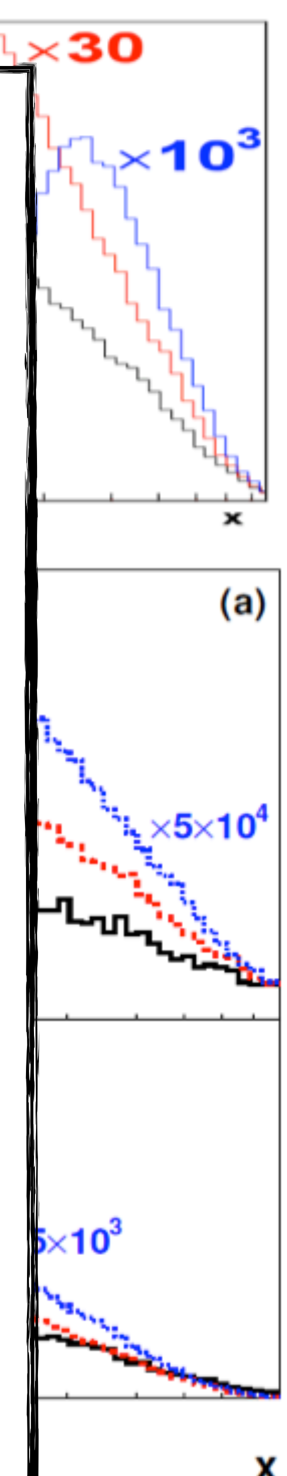
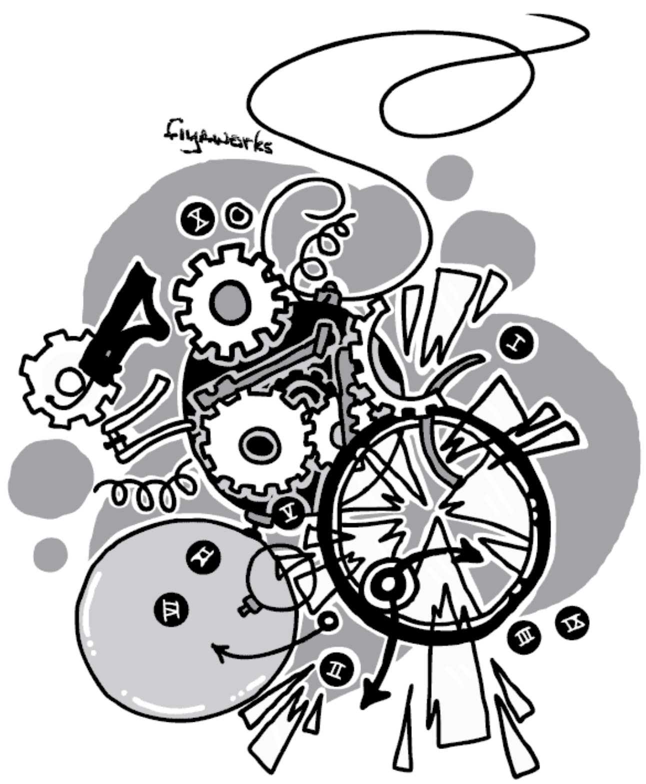


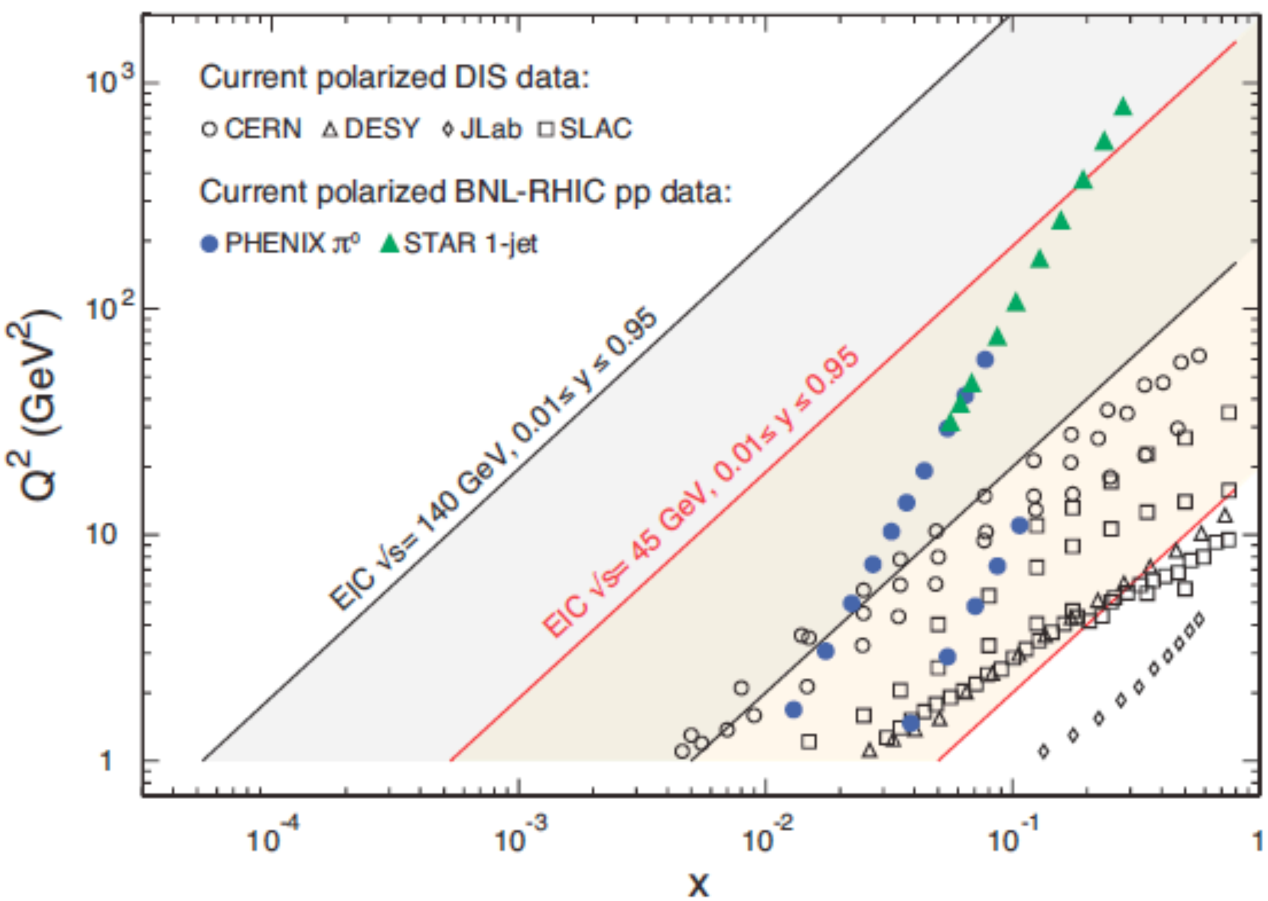


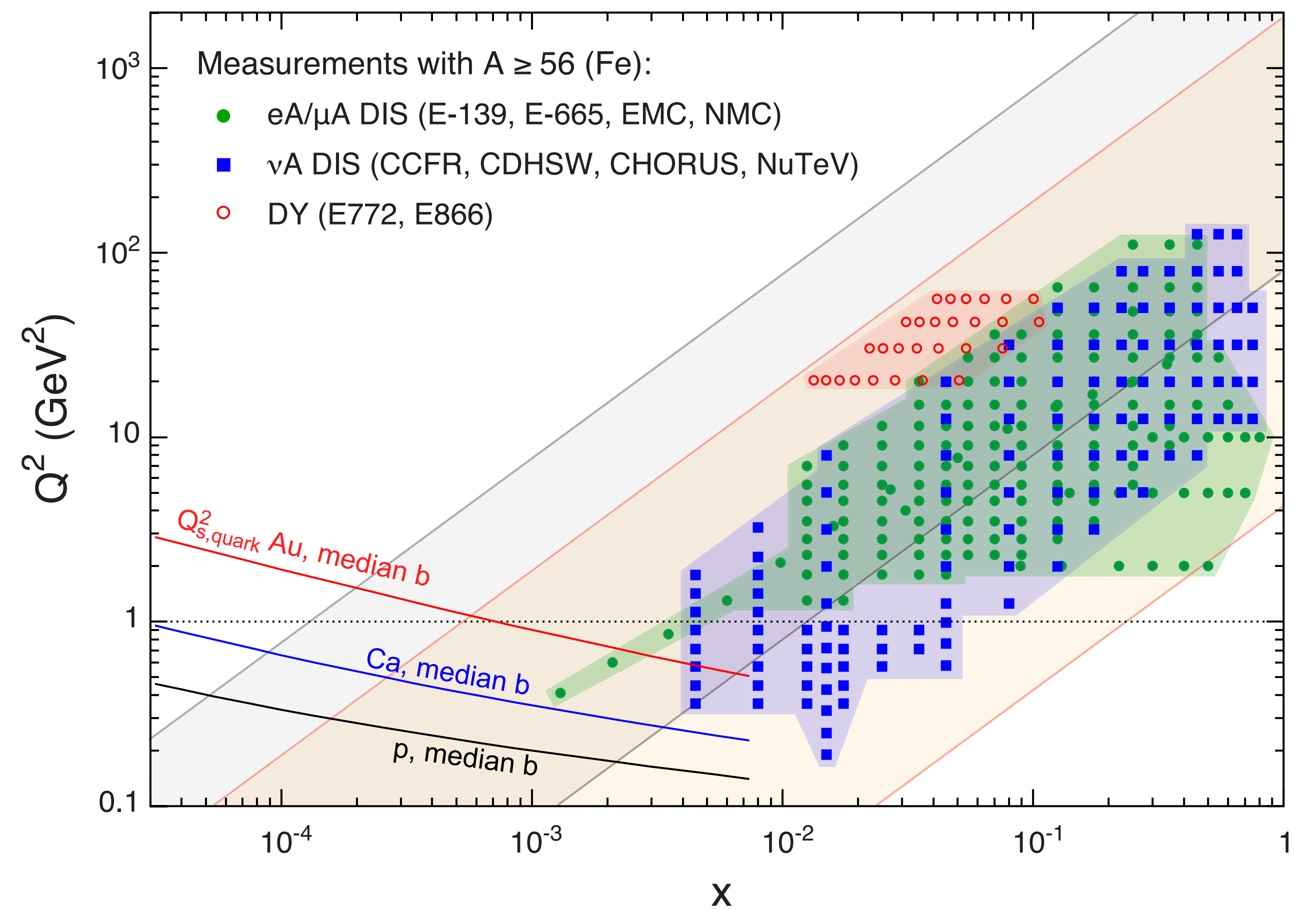
Scattering of protons on protons
is like colliding Swiss watches to find out how they are built.

R. Feynman



Extension of x,Q^2 coverage with an EIC





- Increase reach in x by a factor of 100 in both polarised e+p and e+A - into the range where gluons dominate
  - ➡ e+p: constrain the helicity sum rules?
  - ➡ e+A: saturation effects become visible?
- Increase in Q^2 coverage
  - ➡ study scaling violations

Saturation effects in the proton and nucleus

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

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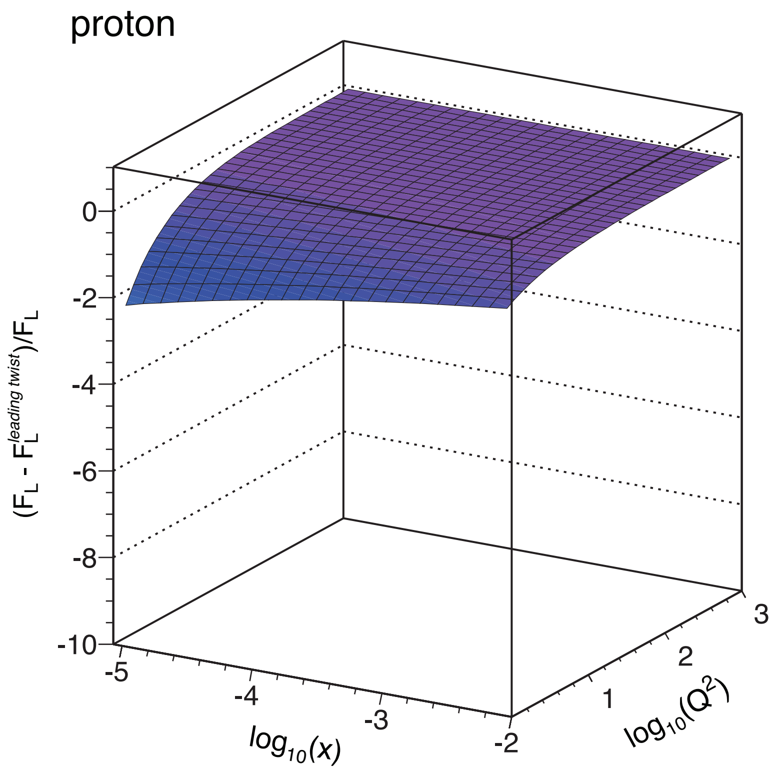
Measure of non-linear effects in the F_L structure function



- Plotting this distribution coming out of saturation inspired GBW model
  - ➡ p: small effect only starting to come in at small-x and small Q^2

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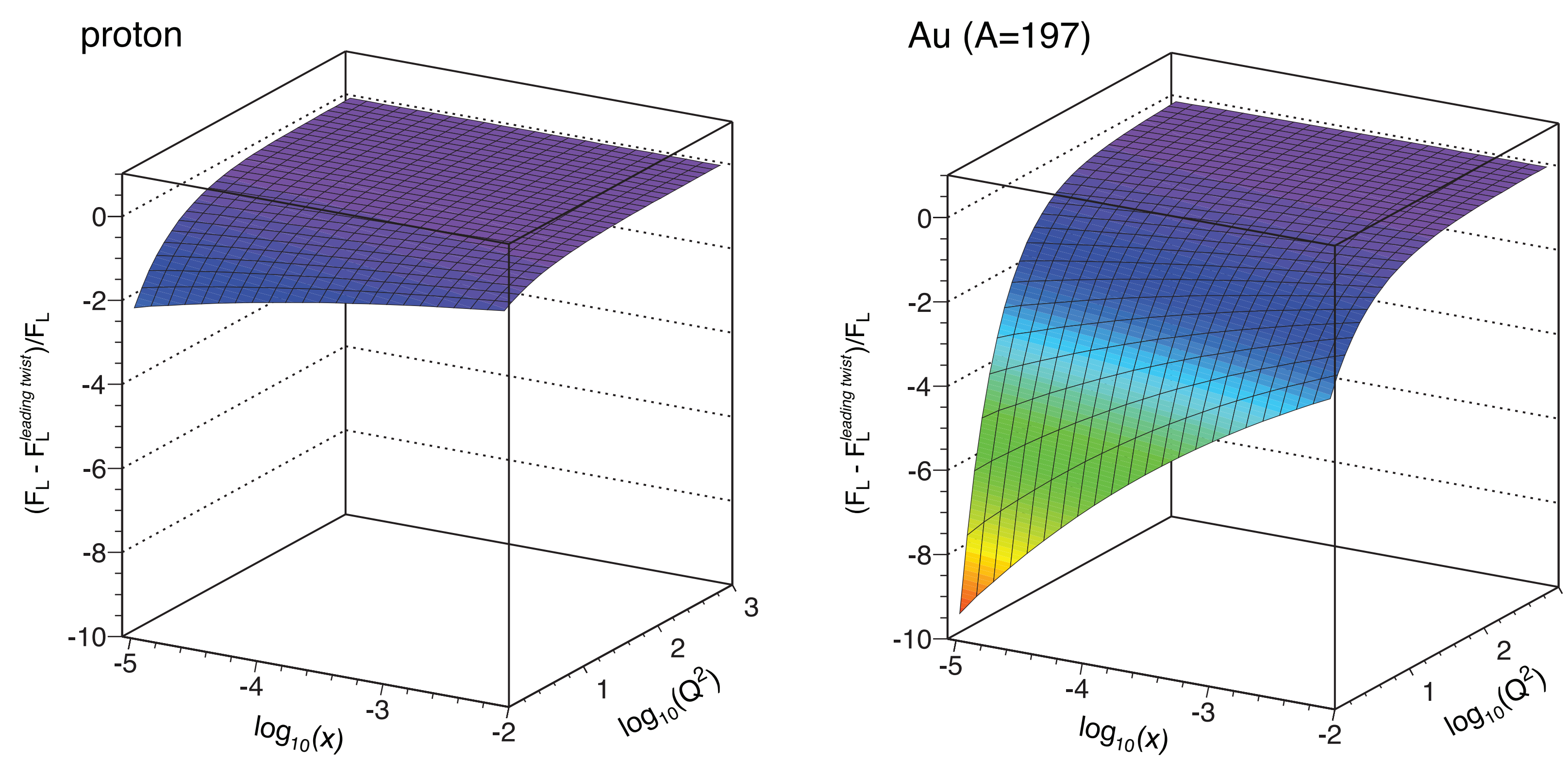

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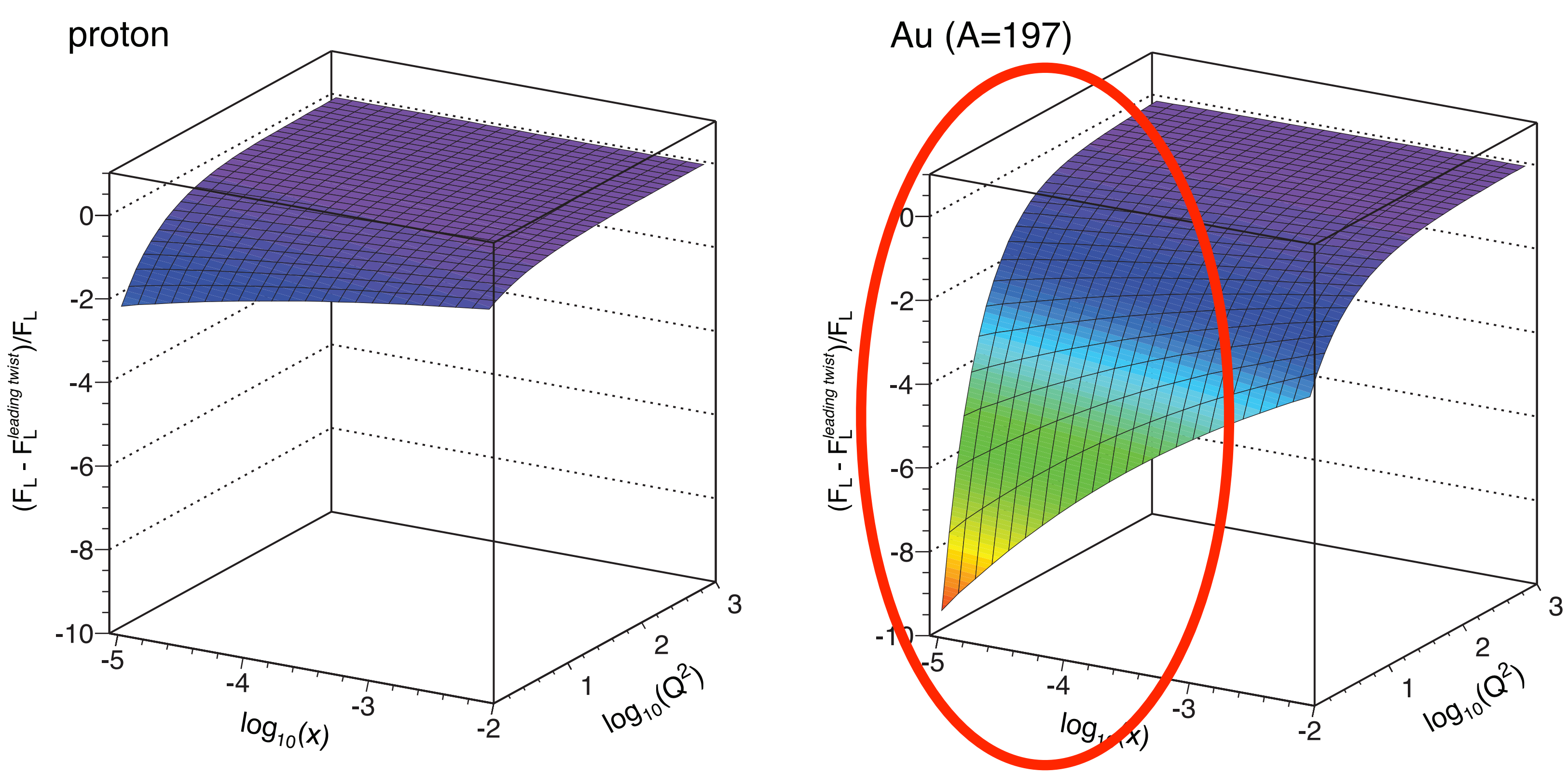

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Nuclear DIS → Structure Functions

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Strategies:

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

e+Au: 1st stage

5x50 - A∫Ldt = 2 fb^{-1}

5x75 - A∫Ldt = 4 fb^{-1}

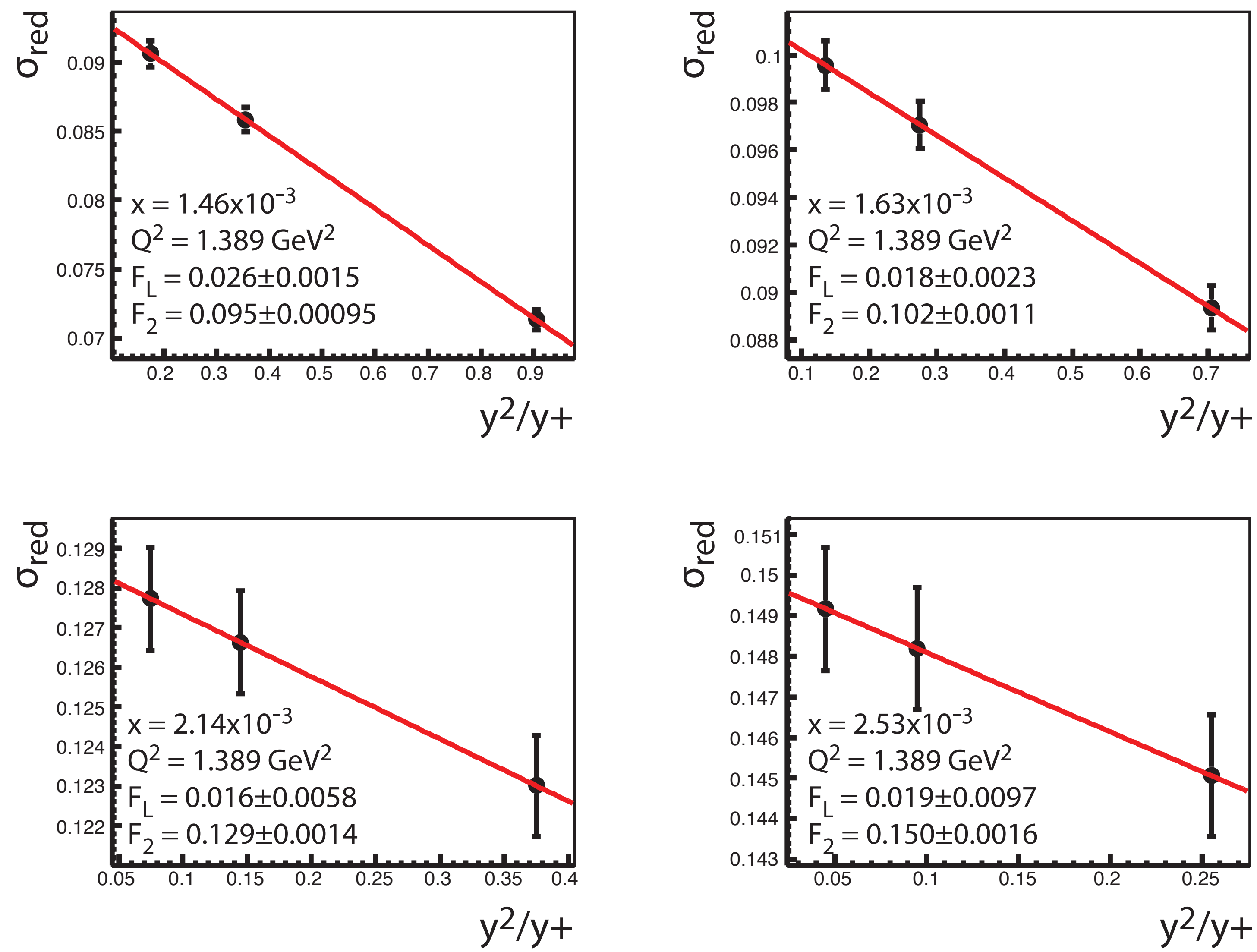
5x100 - A∫Ldt = 4 fb^{-1}

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



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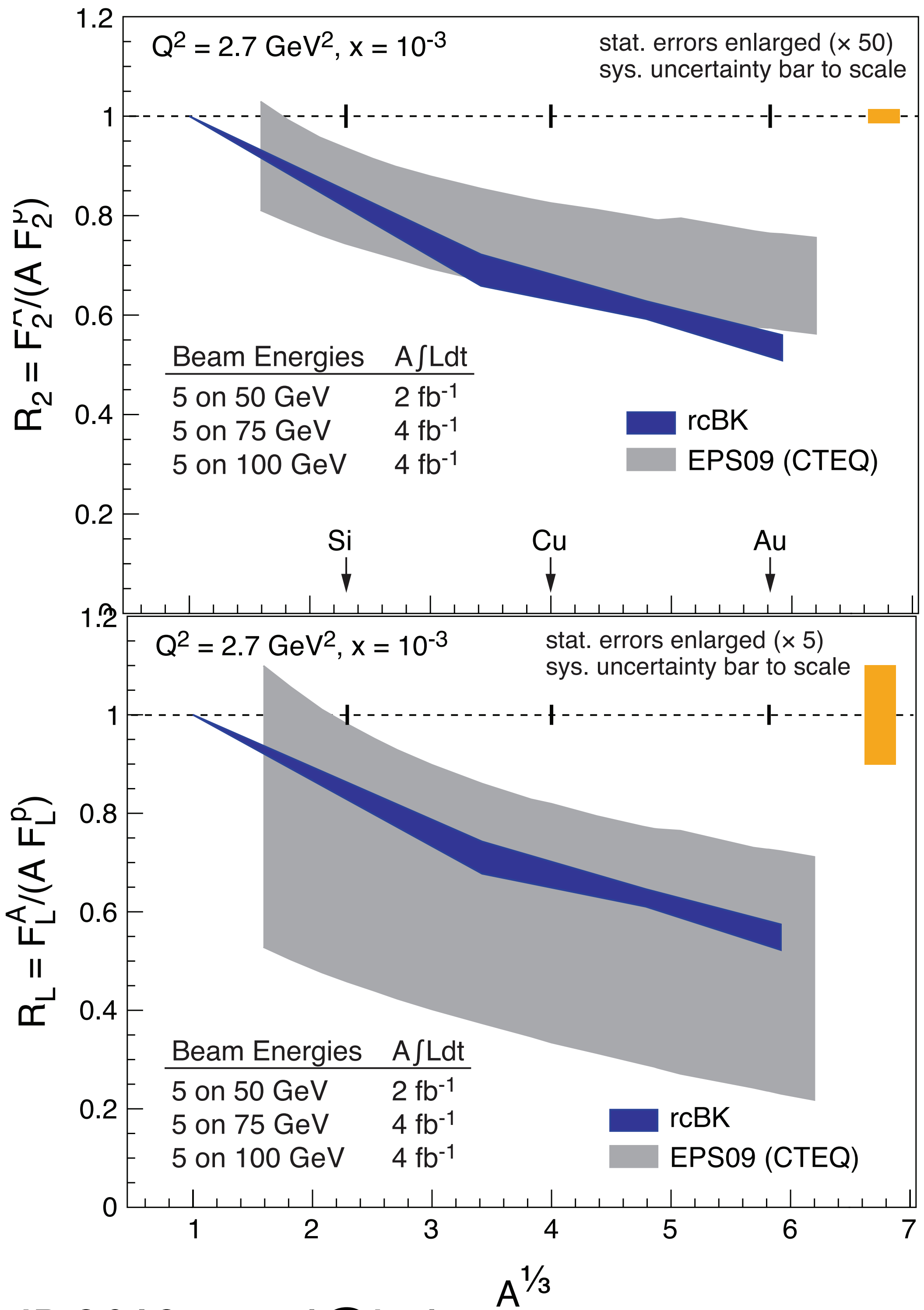
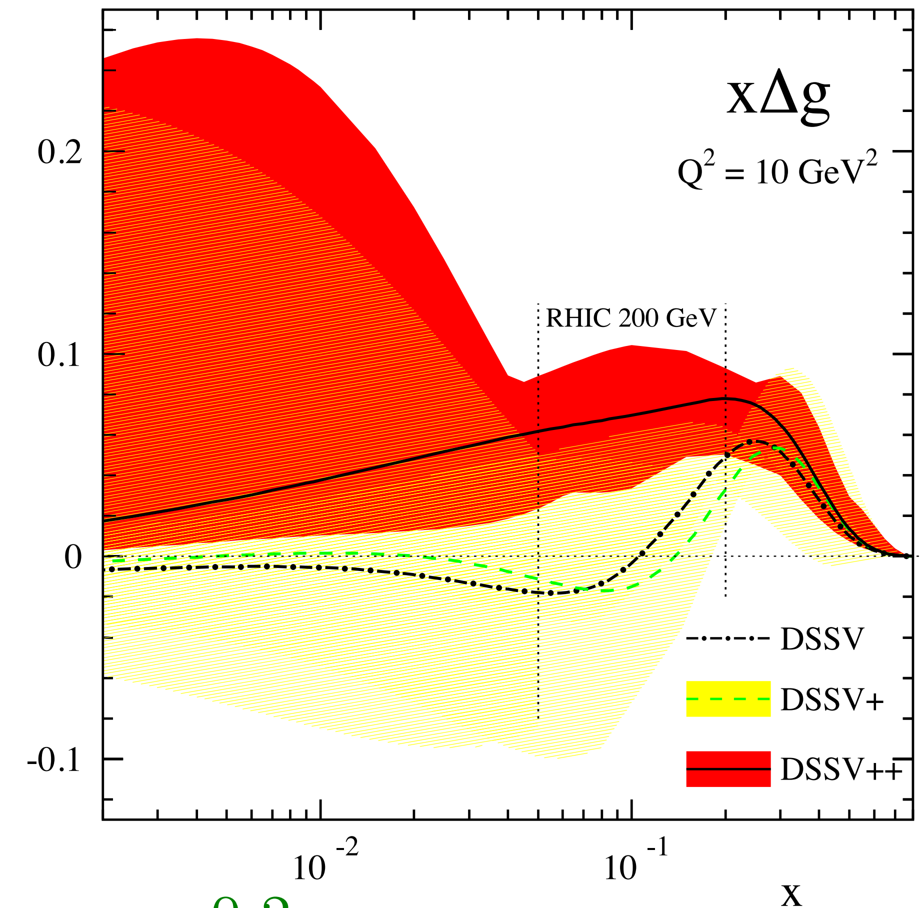


Constraining Δg(x) at RHIC, EIC



$$\int_{0.05}^{0.2} \Delta g(x) = 0.1 \pm^{0.06}_{0.07}$$

- RHIC data can constrain Δg(x) down to a few x 10^{-2}
  - ➡ Latest RHIC data show non-zero Δg(x) in measured range
  - ➡ Large unmeasured region still exists

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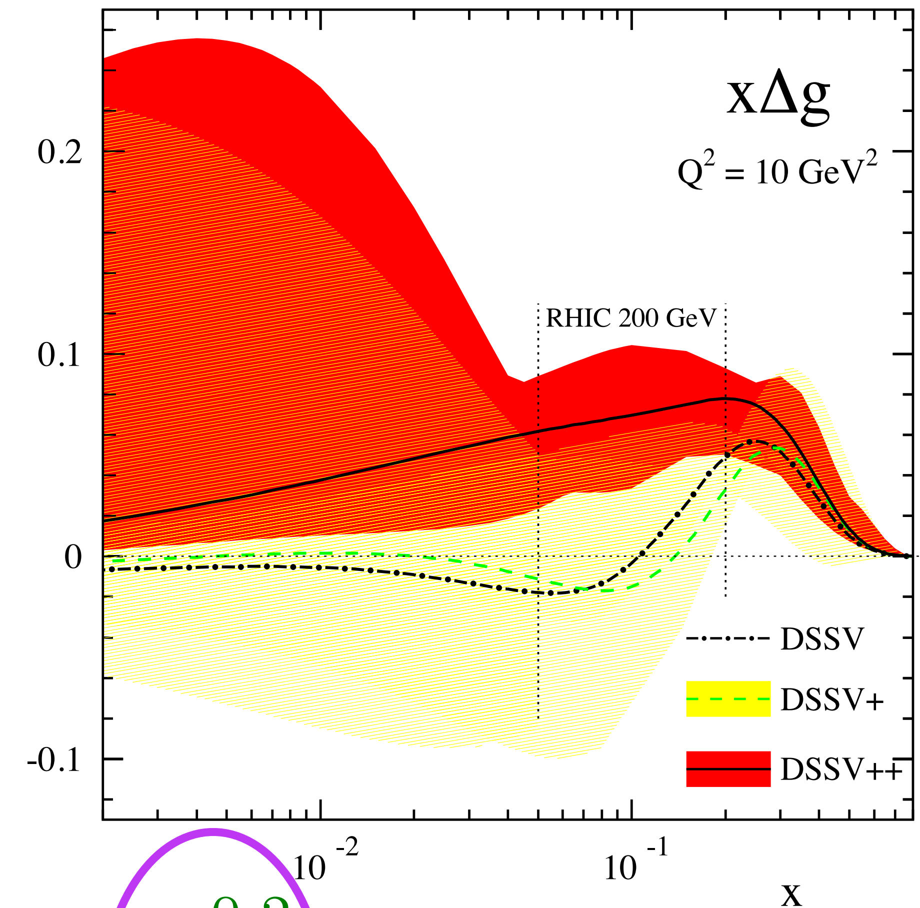

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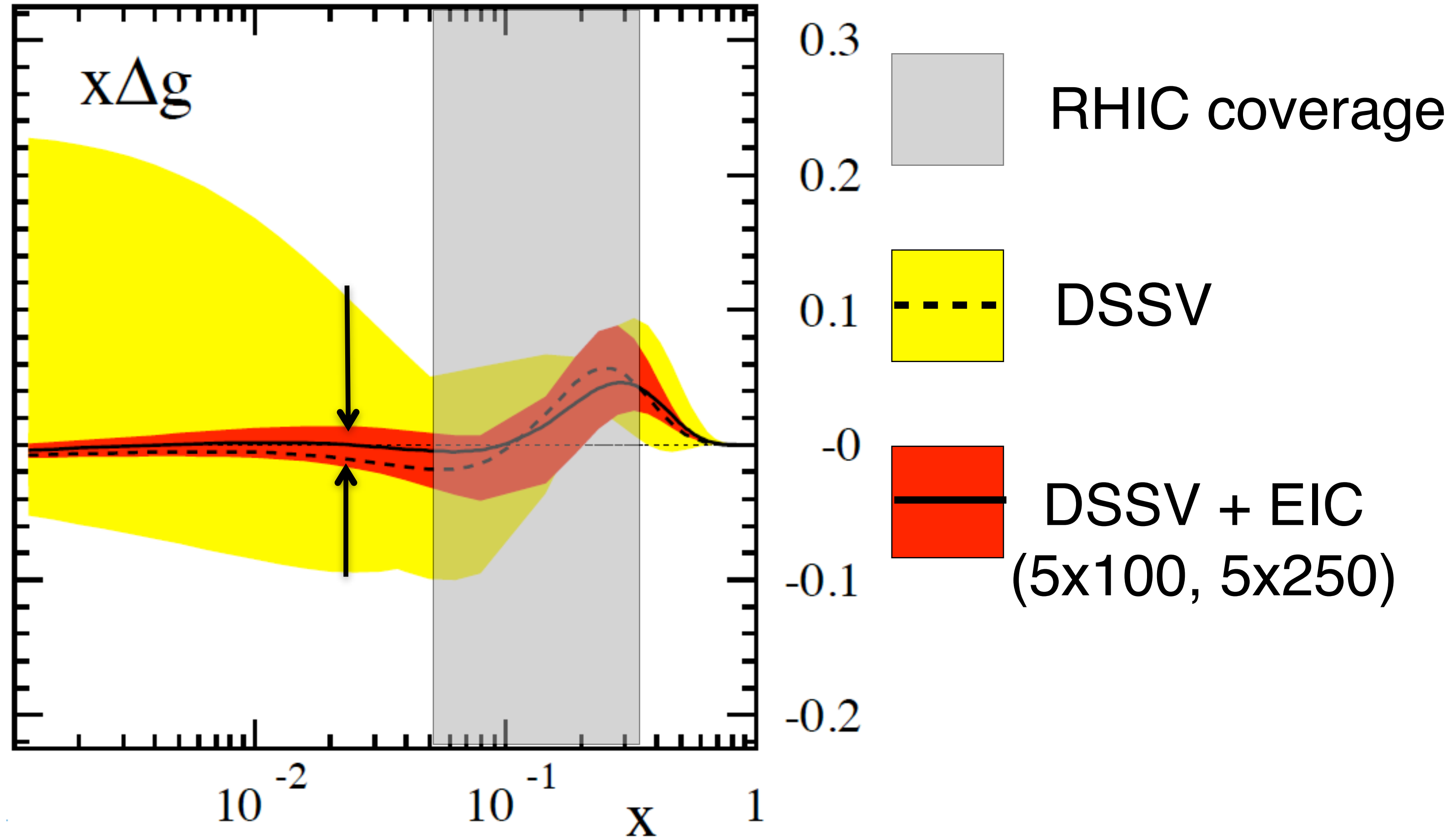

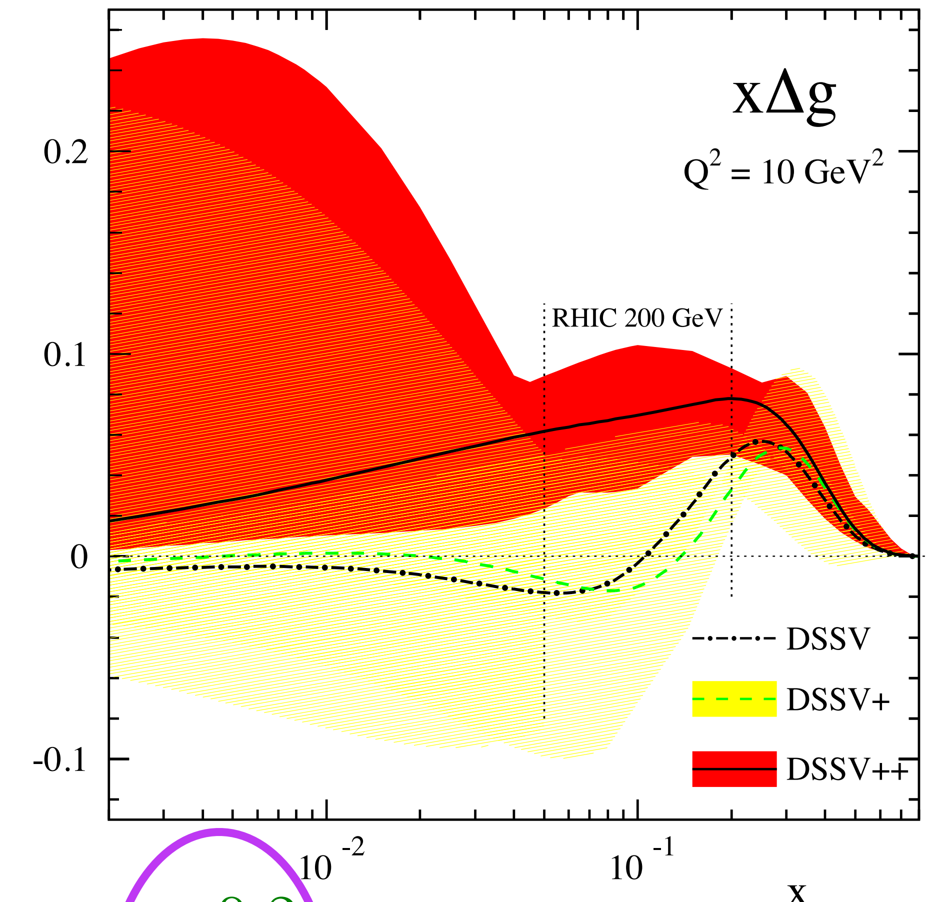

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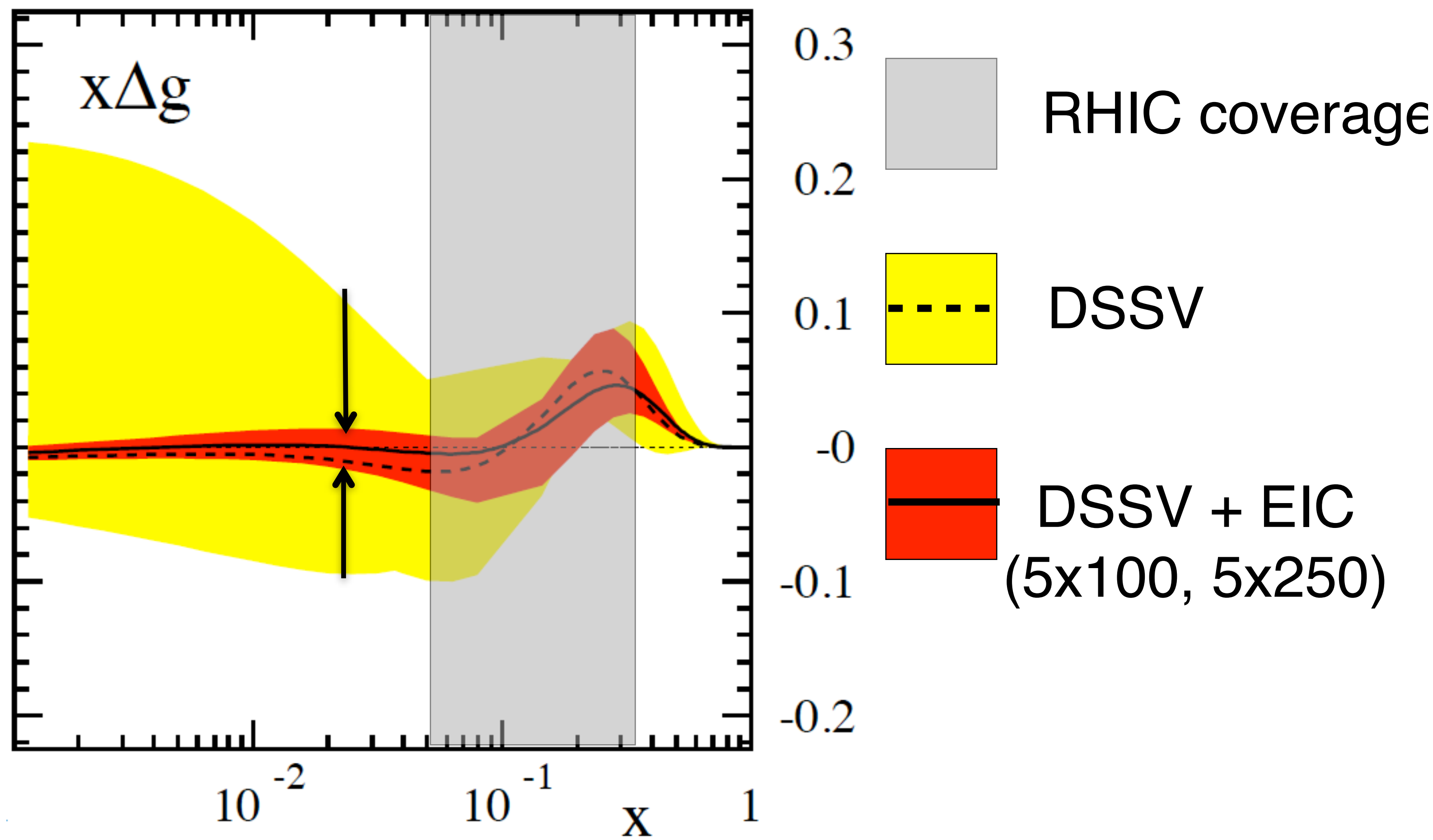

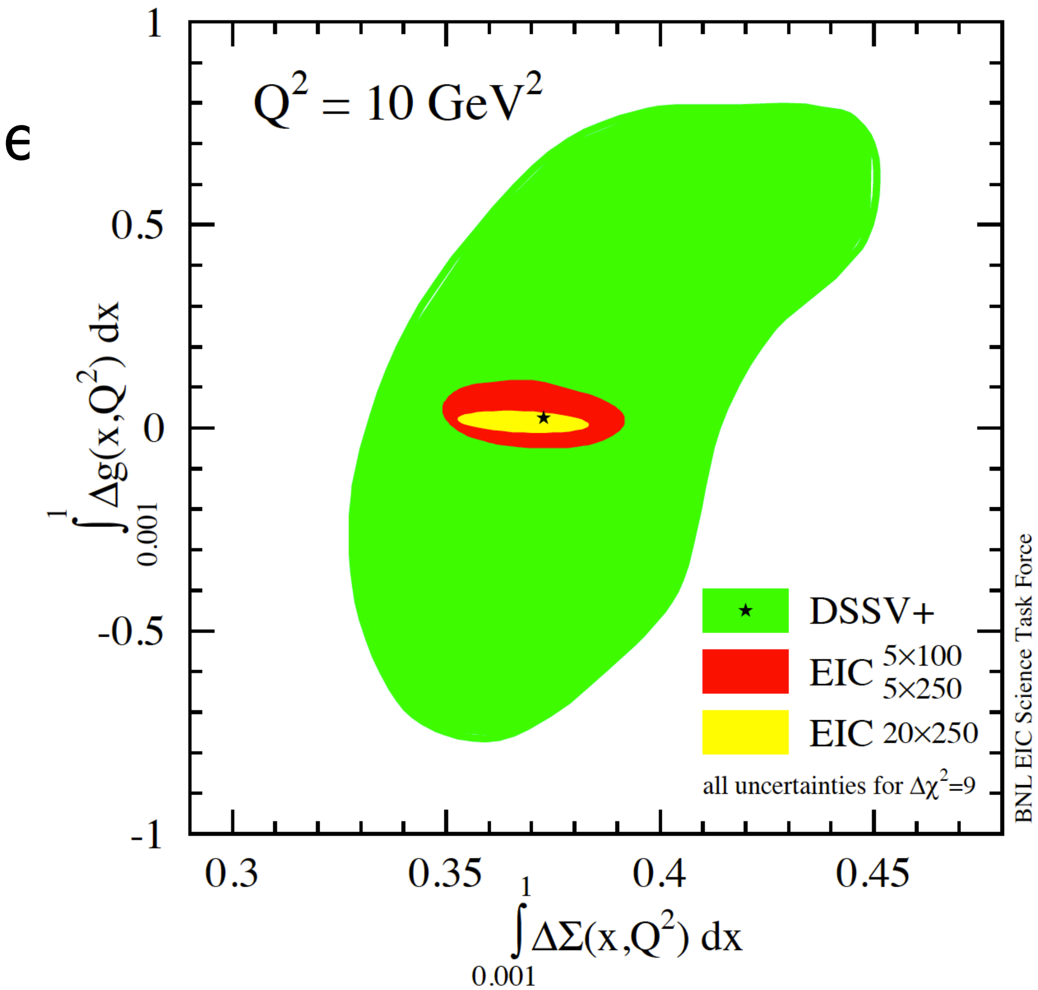

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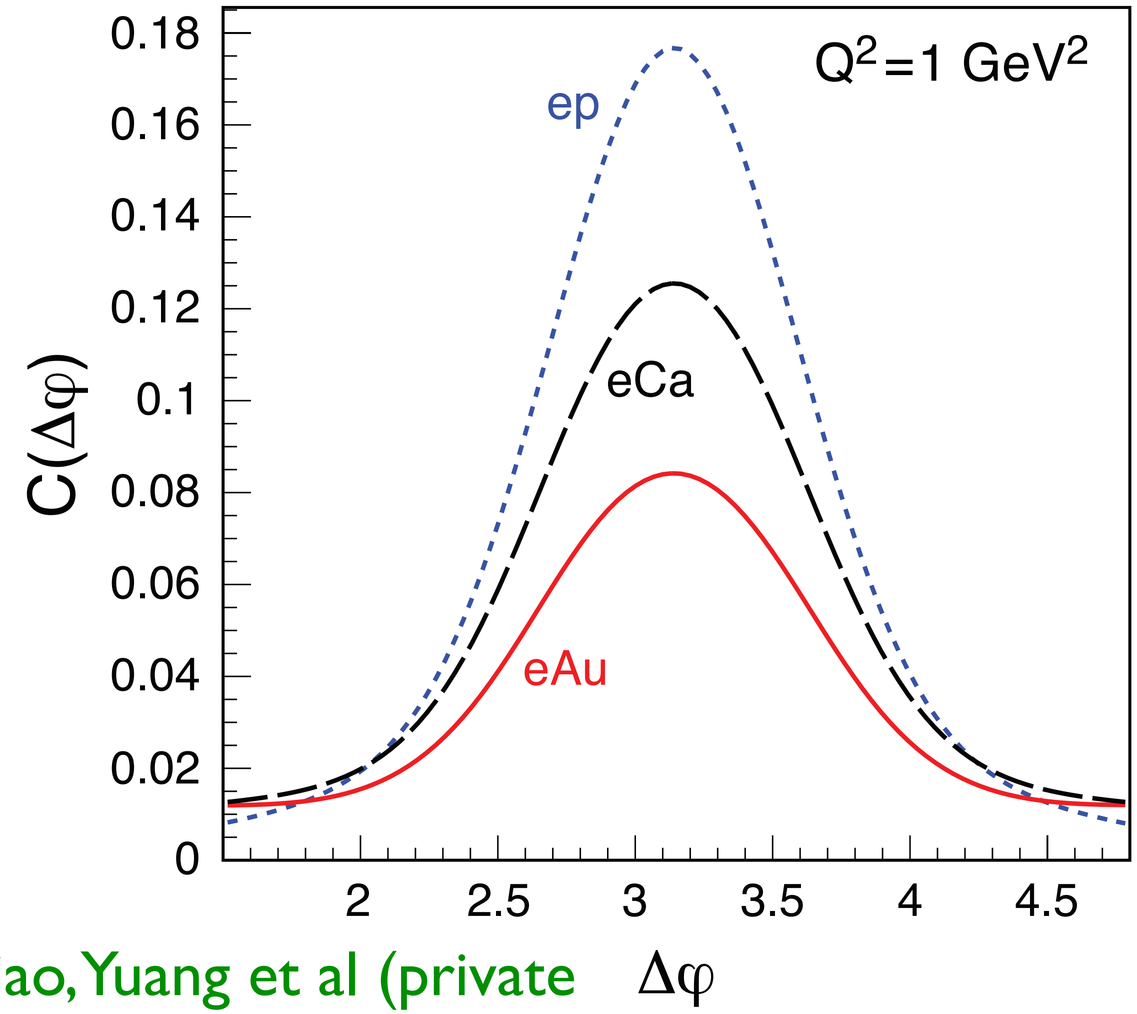
SIDIS in e+A → di-hadron correlations



Xiao, Yuang et al (private communication)

- Predictions from a saturation model show an ordered attenuation of the away-side with increasing nuclear mass

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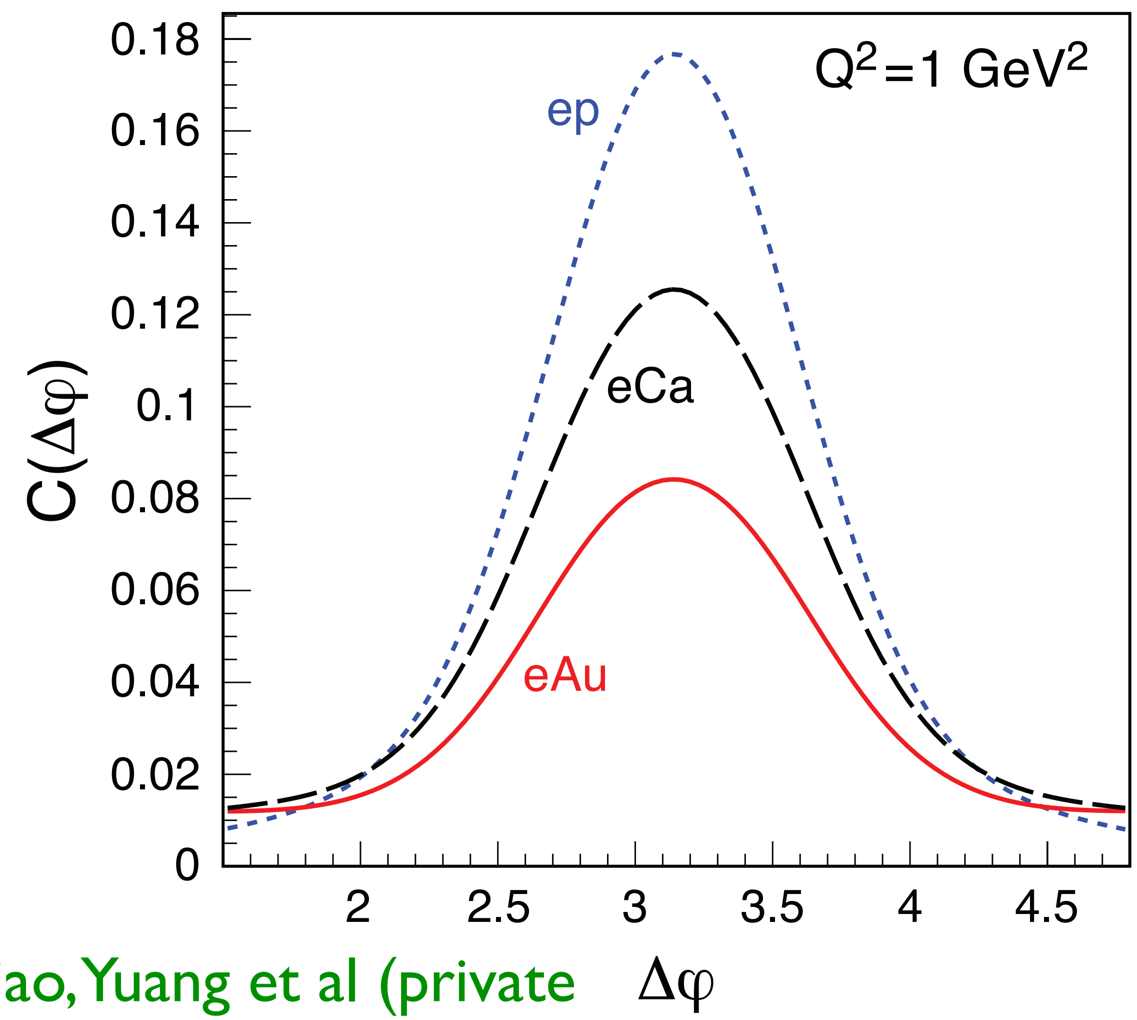
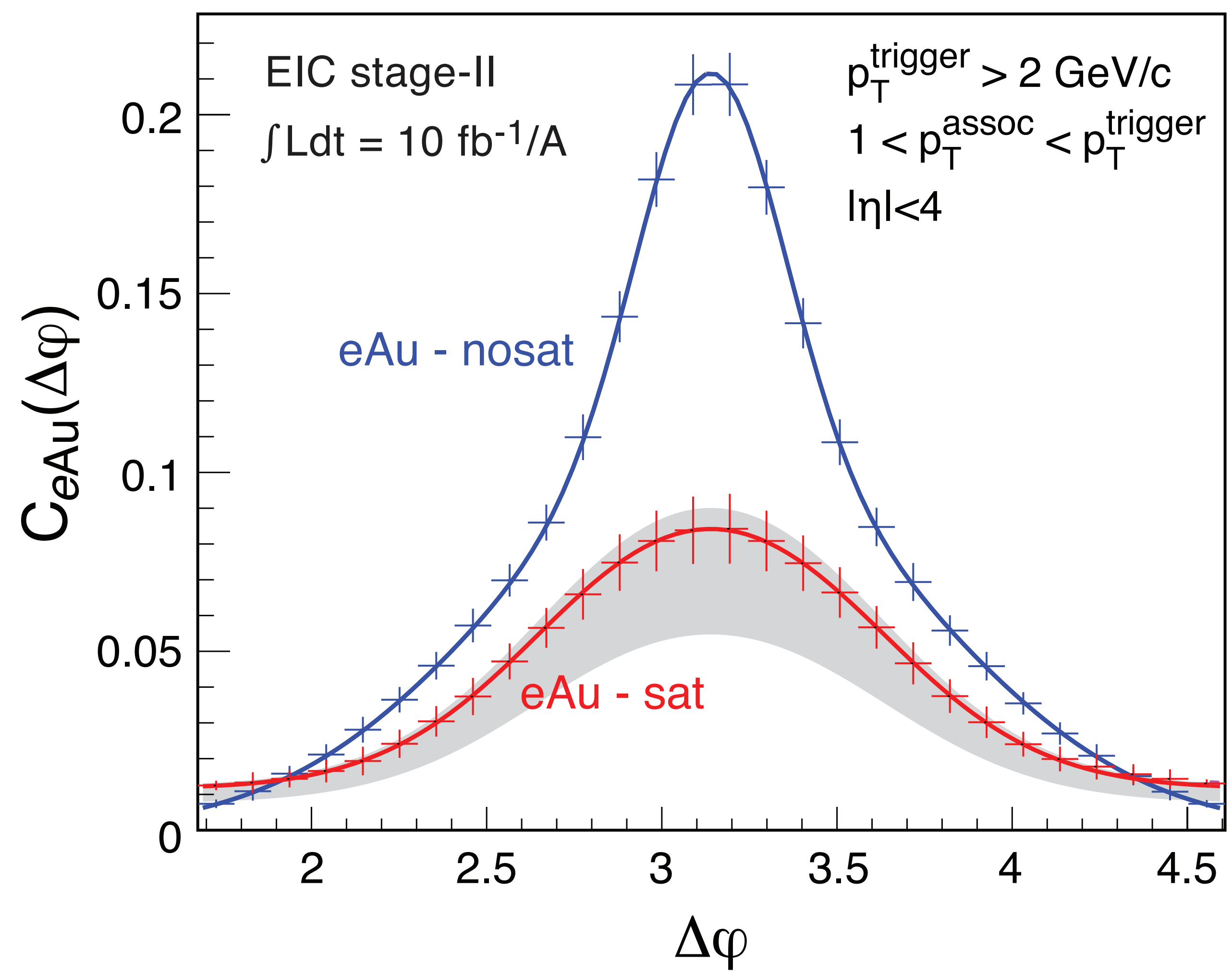


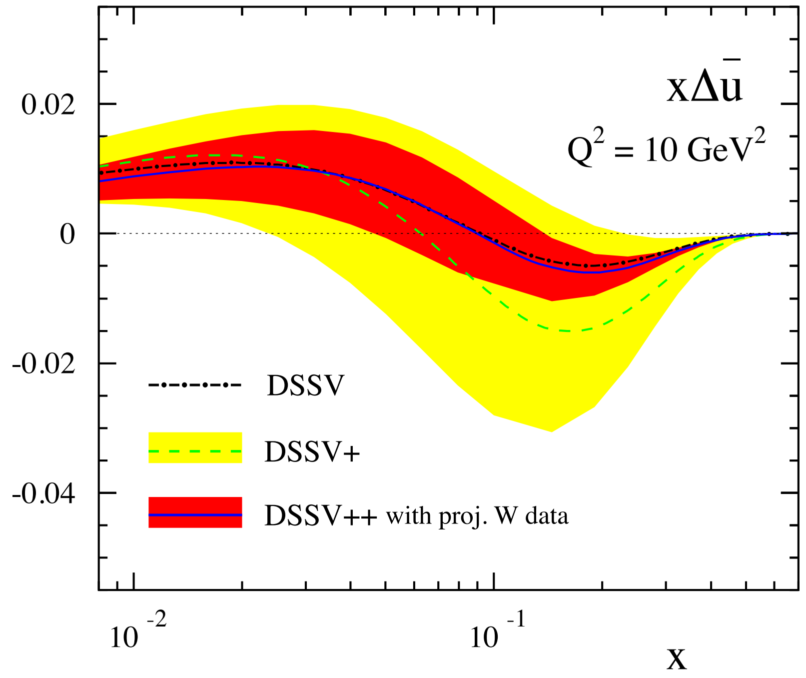


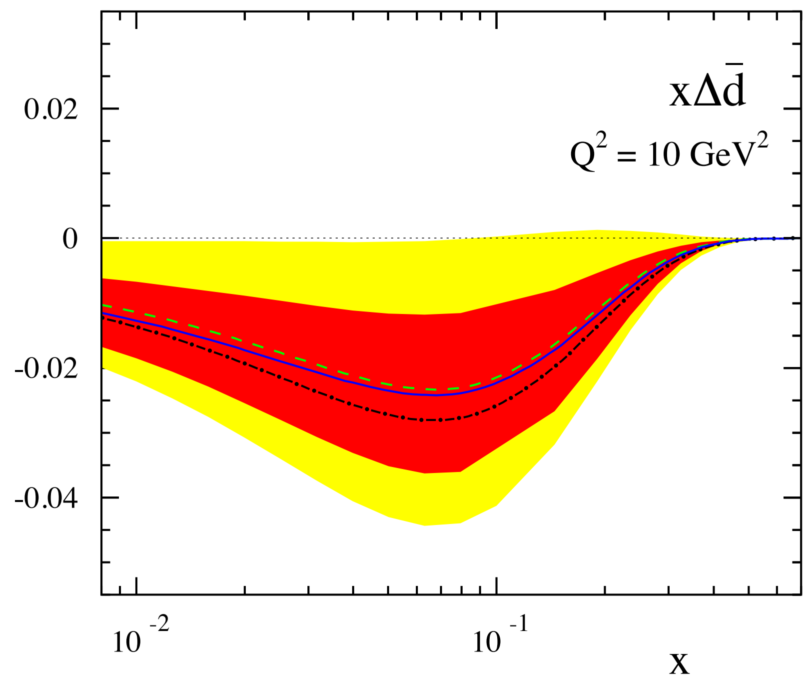
Xiao, Yuang et al (private communication)

- Predictions from a saturation model show an ordered attenuation of the away-side with increasing nuclear mass
- Simulations (PYTHIA + DPMJETIII) for e+Au show that the sat/no-sat scenarios can be distinguished within errors
  - ➡ Gives a handle on multi-gluon distributions

SIDIS in e+p → flavour-separated helicity PDFs

- SIDIS measurements with identified π, k lead to much reduced uncertainties in the flavour-separated helicity PDFs as in Δg(x)





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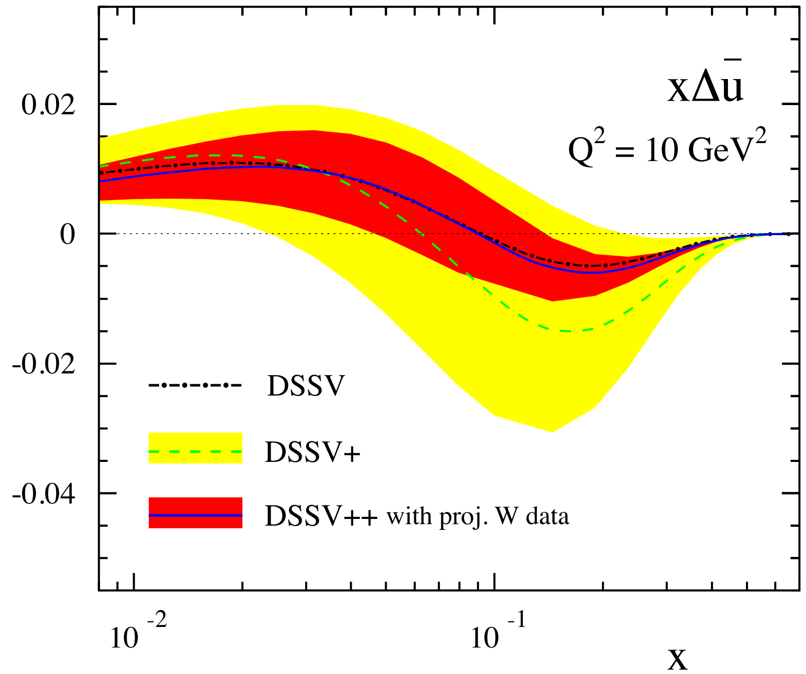
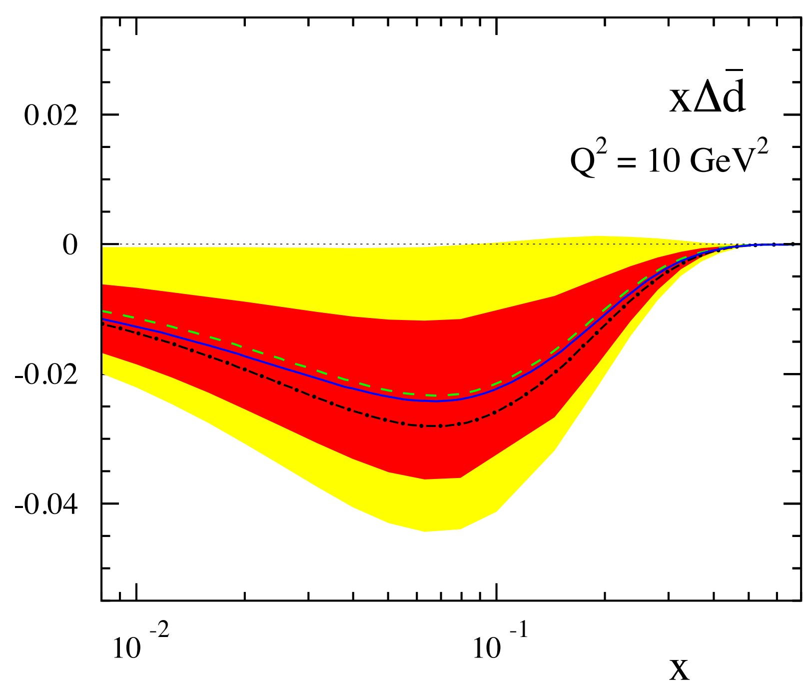
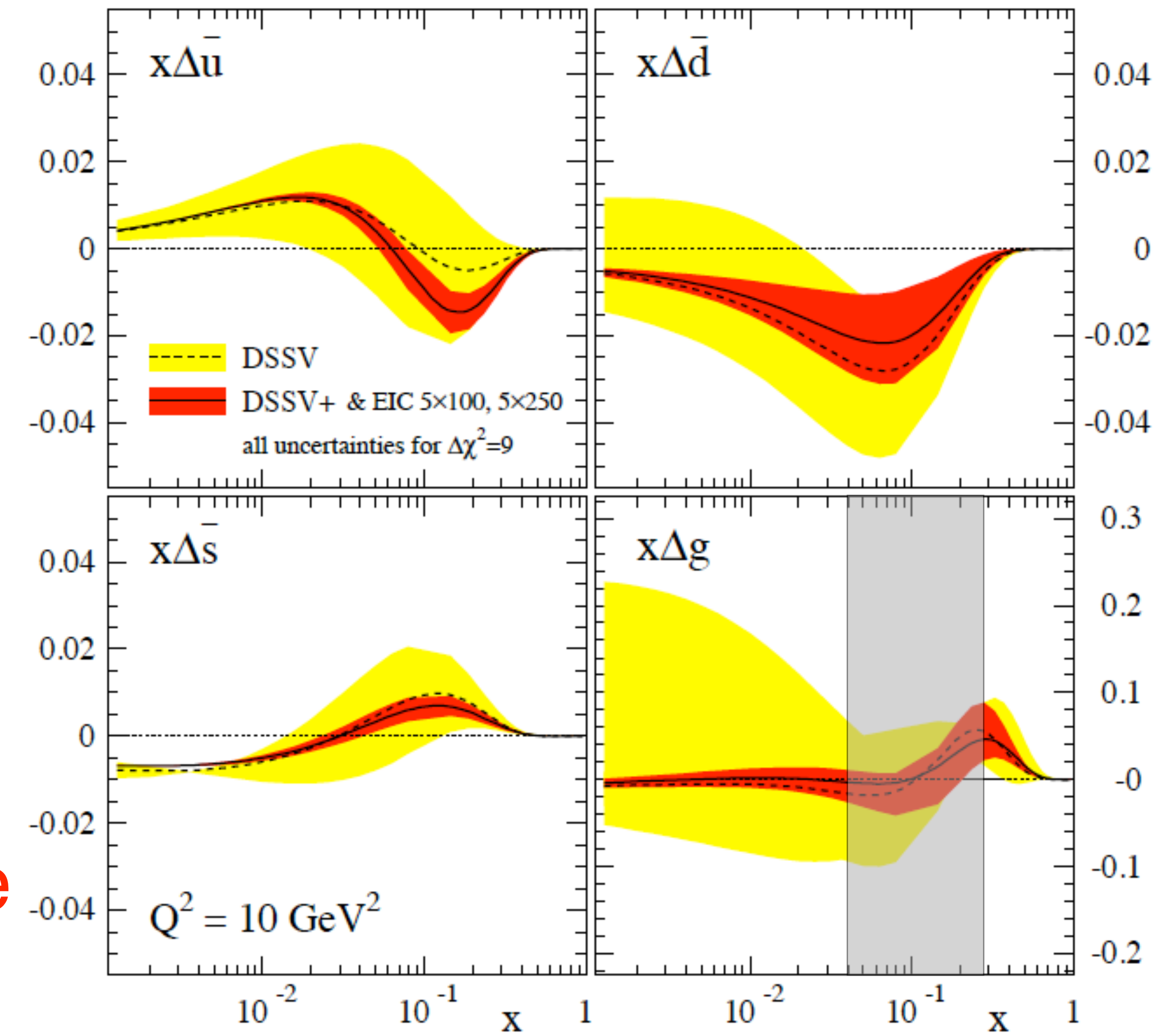




RHIC to eRHIC

smaller x;
need integral from 0 to 1 for spin sum rule

$\Delta s(\bar{s})$ cannot be accessed at existing facilities

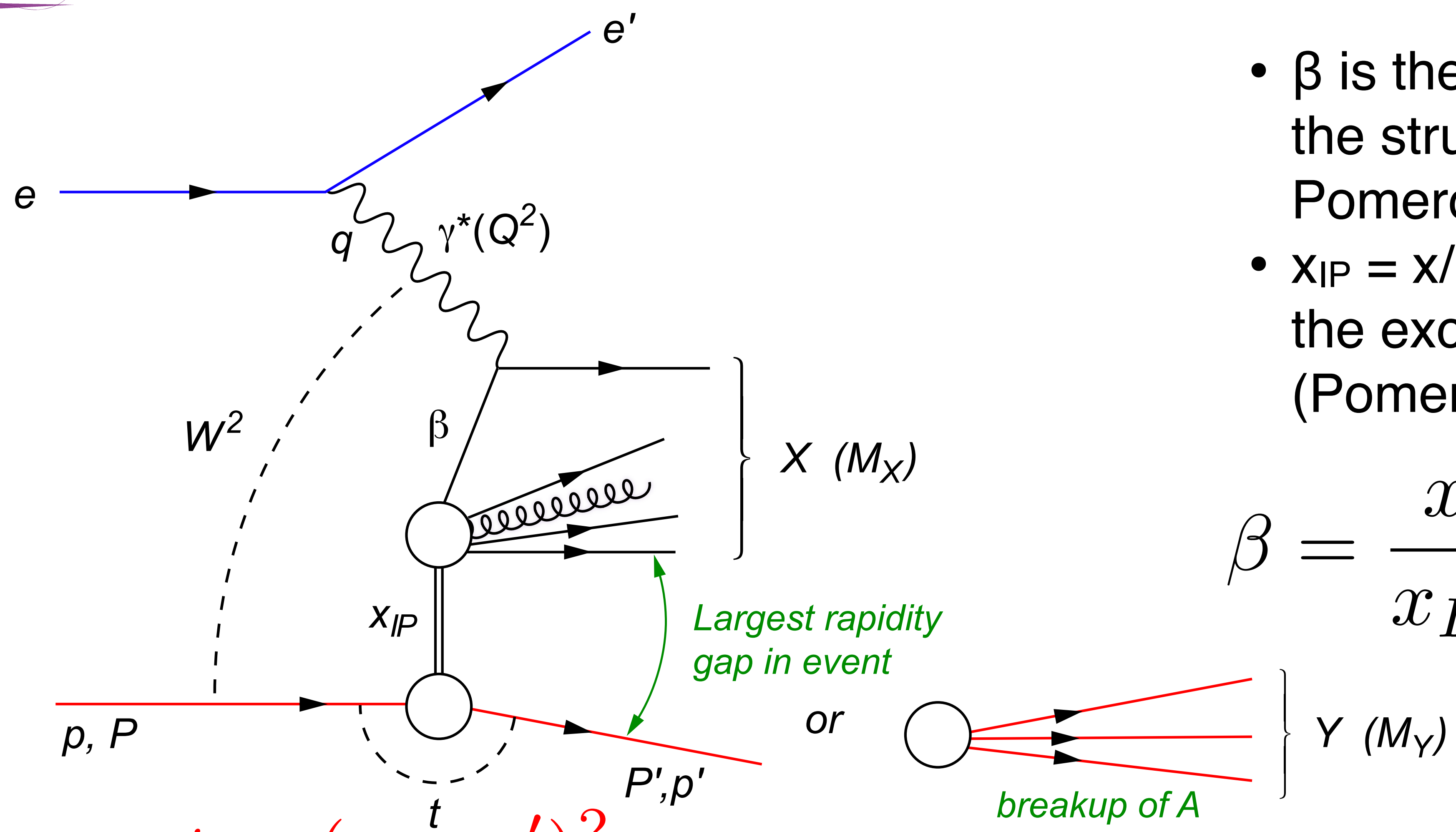


DSSV

DSSV + EIC (5x100, 5x250)

RHIC coverage

Exclusive processes in e+A - diffraction



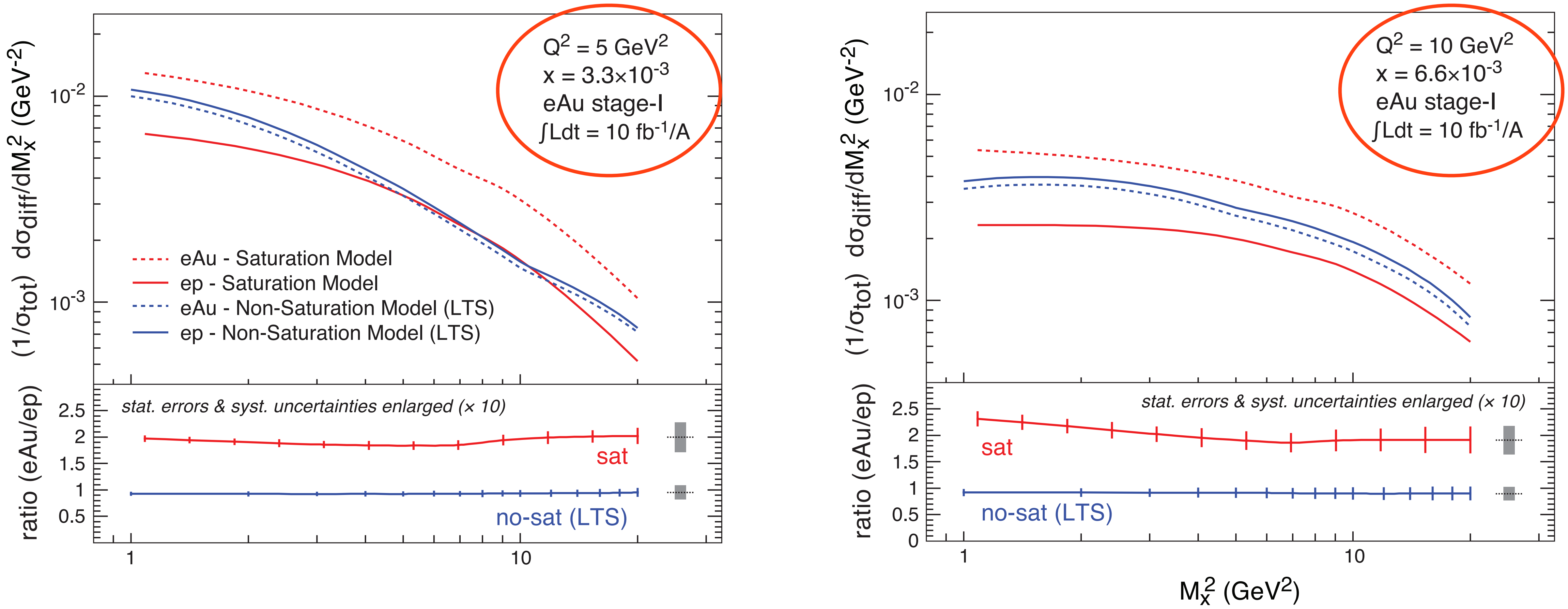
$$t = (p - p')^2$$

- β is the momentum fraction of the struck parton w.r.t. the Pomeron
- $x_{IP} = x/\beta$: momentum fraction of the exchanged object (Pomeron) w.r.t. the hadron

$$\beta = \frac{x}{x_{I\!P}} = \frac{Q^2}{Q^2 + M_X^2 - t}$$

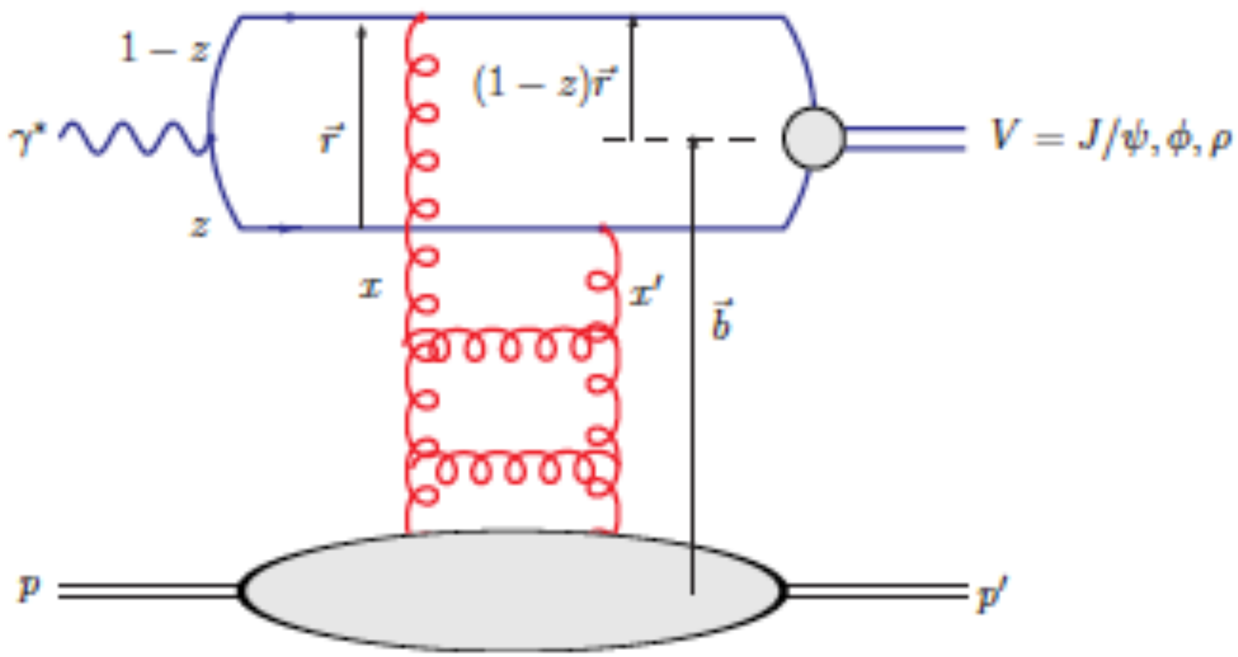
- Diffraction in e+p:
  - ➡ HERA: 15% of all events are diffractive
- Diffraction in e+A:
  - ➡ Predictions: $\sigma_{diff}/\sigma_{tot}$ in e+A ~25-40%
  - ➡ Coherent diffraction (nuclei intact)
  - ➡ Incoherent diffraction: breakup into nucleons (nucleons intact)

Day 1: Diffractive Cross-sections

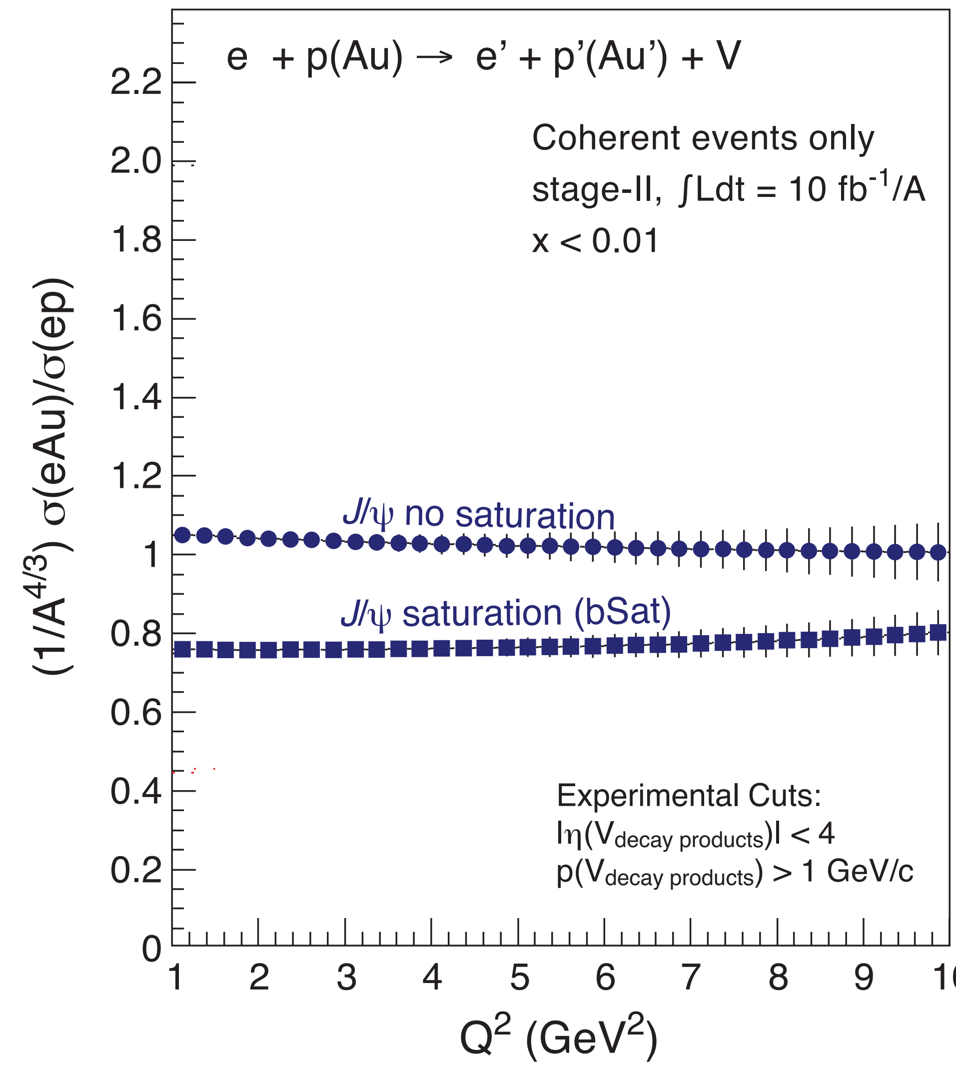


- Ratio of diffractive-to-total cross-section drastically different between saturation (Marquet) and non-saturation (Frankfurt, Guzey, Strikman) models
- Expected experimental error bars (simulated for 10 fb^{-1} of data for a stage-I eRHIC) can distinguish between the two scenarios

Exclusive vector meson production



$$d\sigma \propto g(x)^2$$



- Exclusive vector meson production is most sensitive to the gluon distribution
  - ➡ colour-neutral exchange of gluons
- J/ψ shows some difference between saturation and no-saturation

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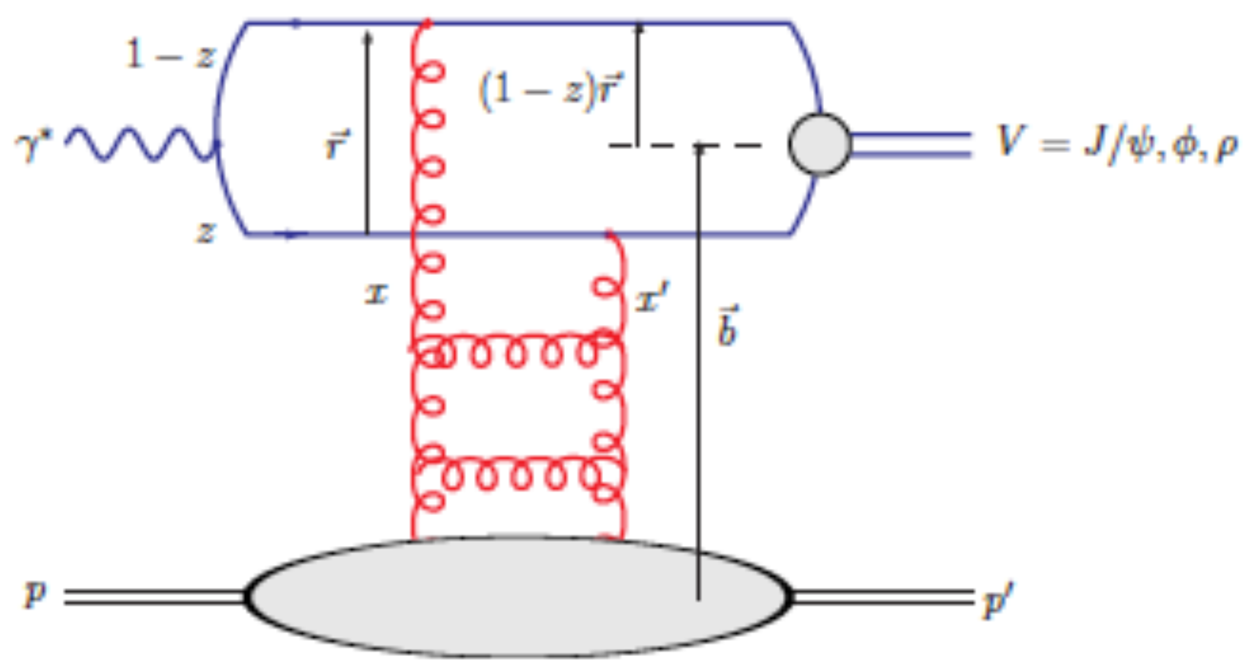

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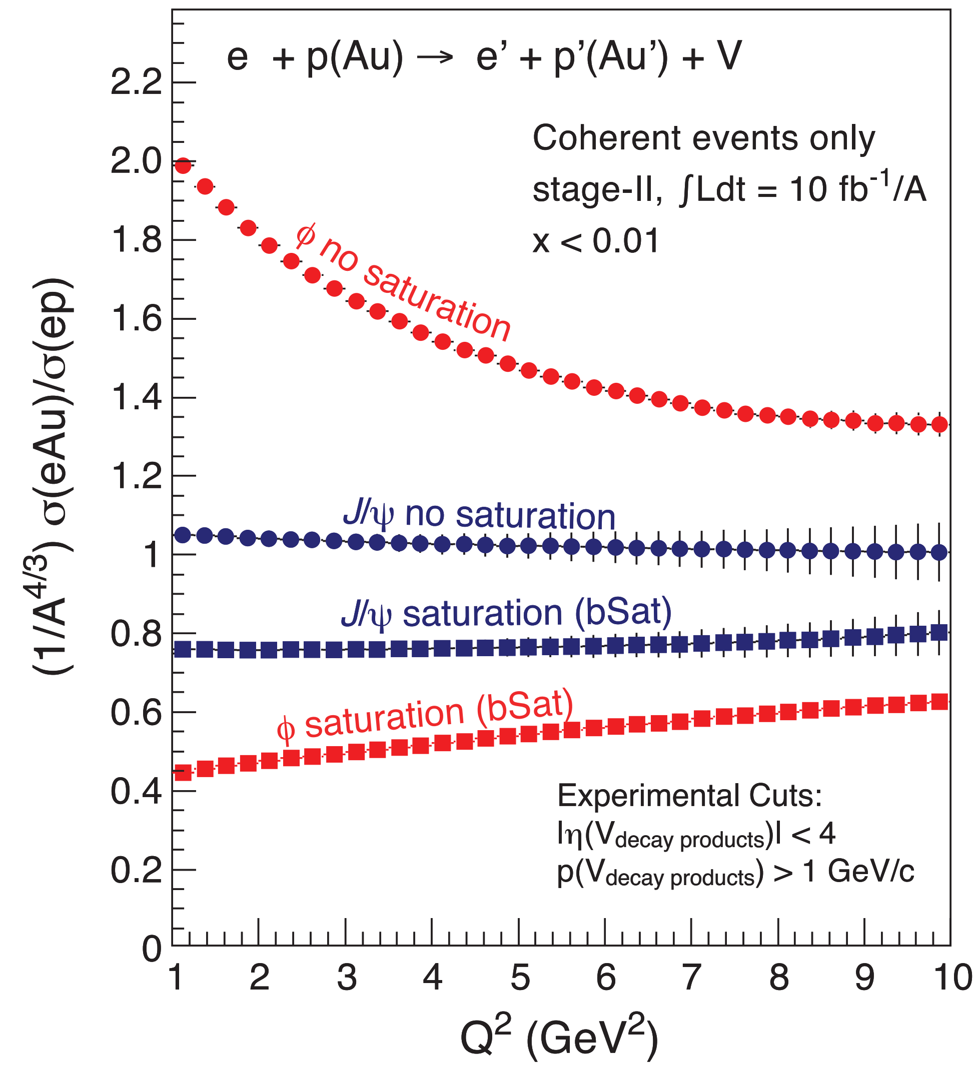
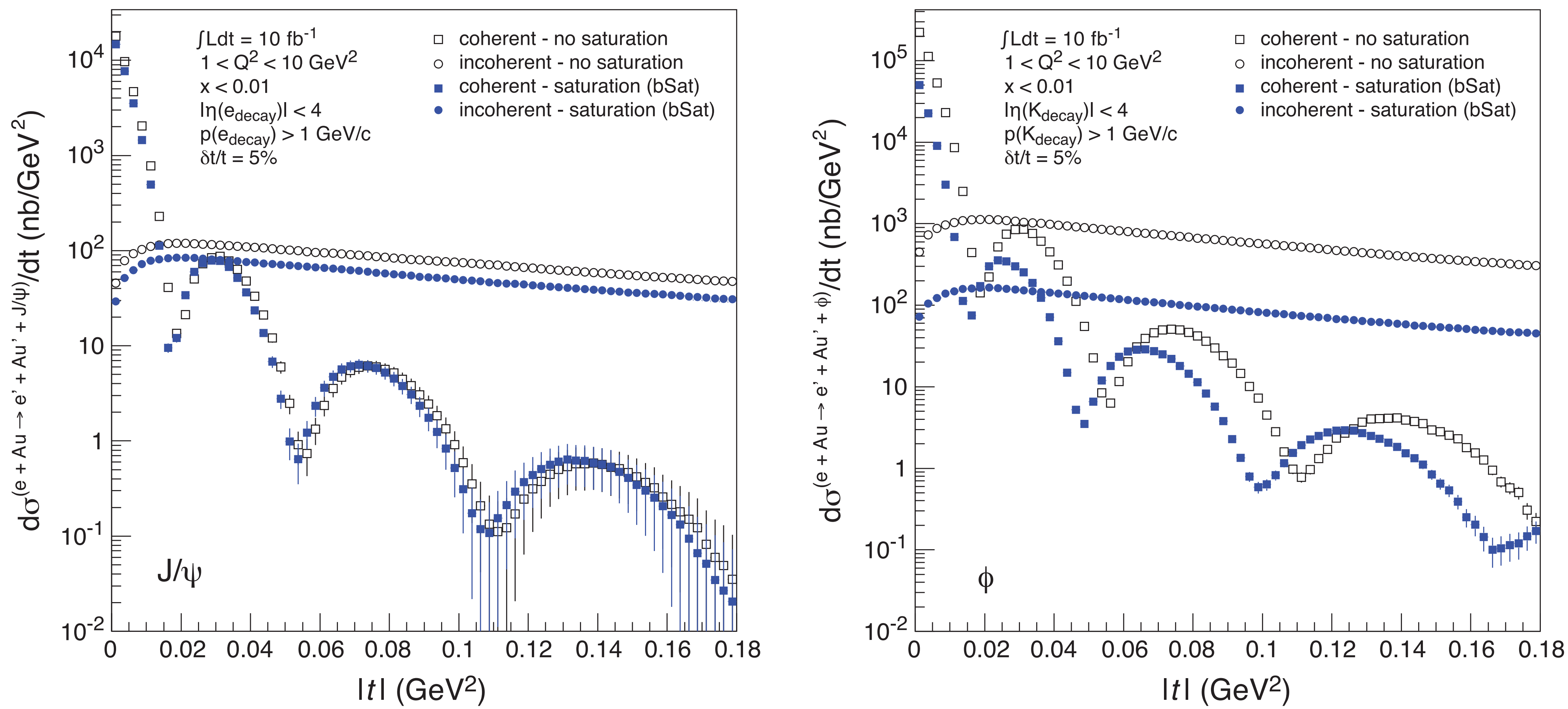


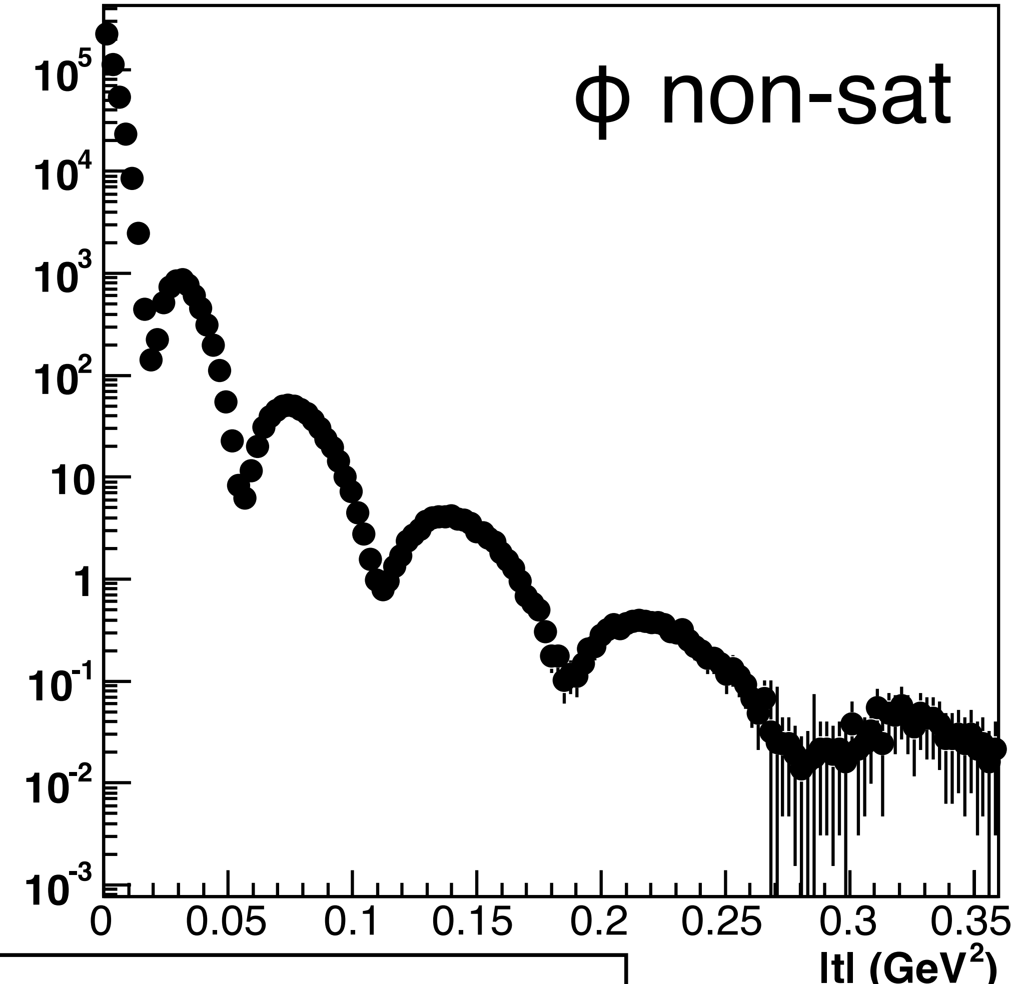
- Exclusive vector meson production is most sensitive to the gluon distribution
  - ➡ colour-neutral exchange of gluons
- J/ψ shows some difference between saturation and no-saturation
- ϕ shows a much larger difference
  - ➡ wave function for ϕ is larger and hence more sensitive to saturation effects

Exclusive Vector Meson Production in e+A



- Low-t: coherent diffraction dominates - gluon density
- High-t: incoherent diffraction dominates - gluon correlations
  - ➡ Need good breakup detection efficiency to discriminate between the two scenarios
    - unlike protons, forward spectrometer won't work for heavy ions
      - measure emitted neutrons in a ZDC
    - rapidity gap with absence of break-up fragments sufficient to identify coherent events

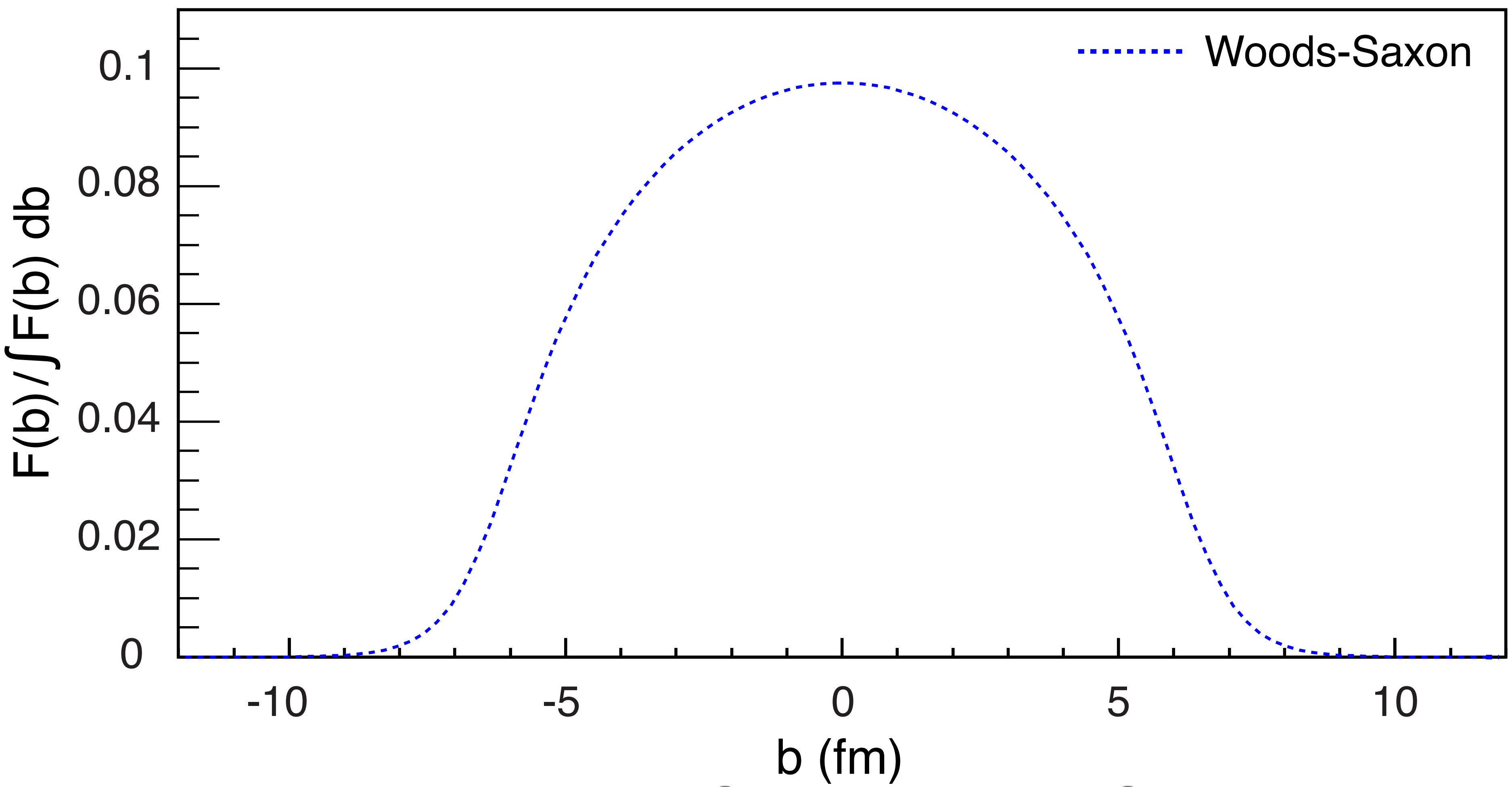
Finding the source...



- Take the dσ/dt distribution and perform a Fourier Transform to extract the b-distribution of the gluons

$$F(b) \sim \frac{1}{2\pi} \int_0^\infty d\Delta\, \Delta\, J_0(\Delta b) \sqrt{\frac{d\sigma}{dt}}$$

$t = \Delta^2/(1-x) \approx \Delta^2$ (for small x)



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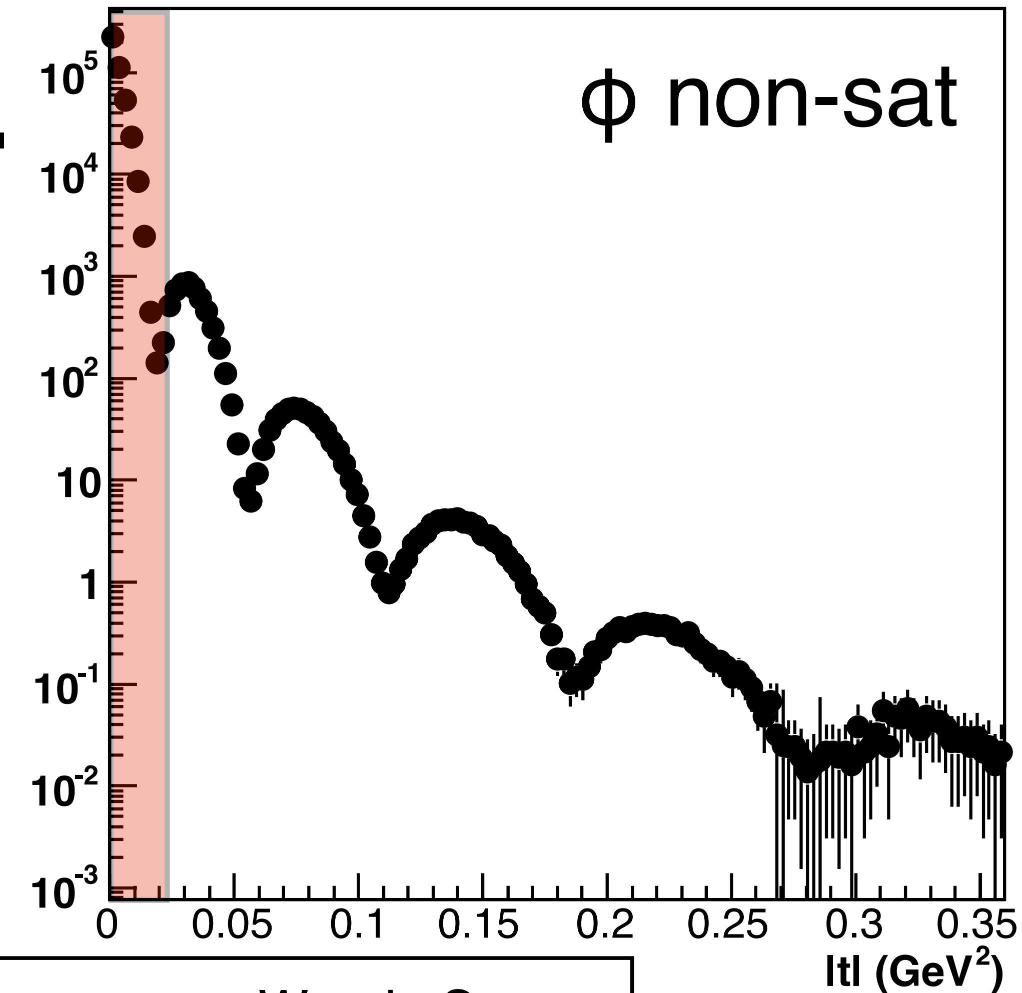

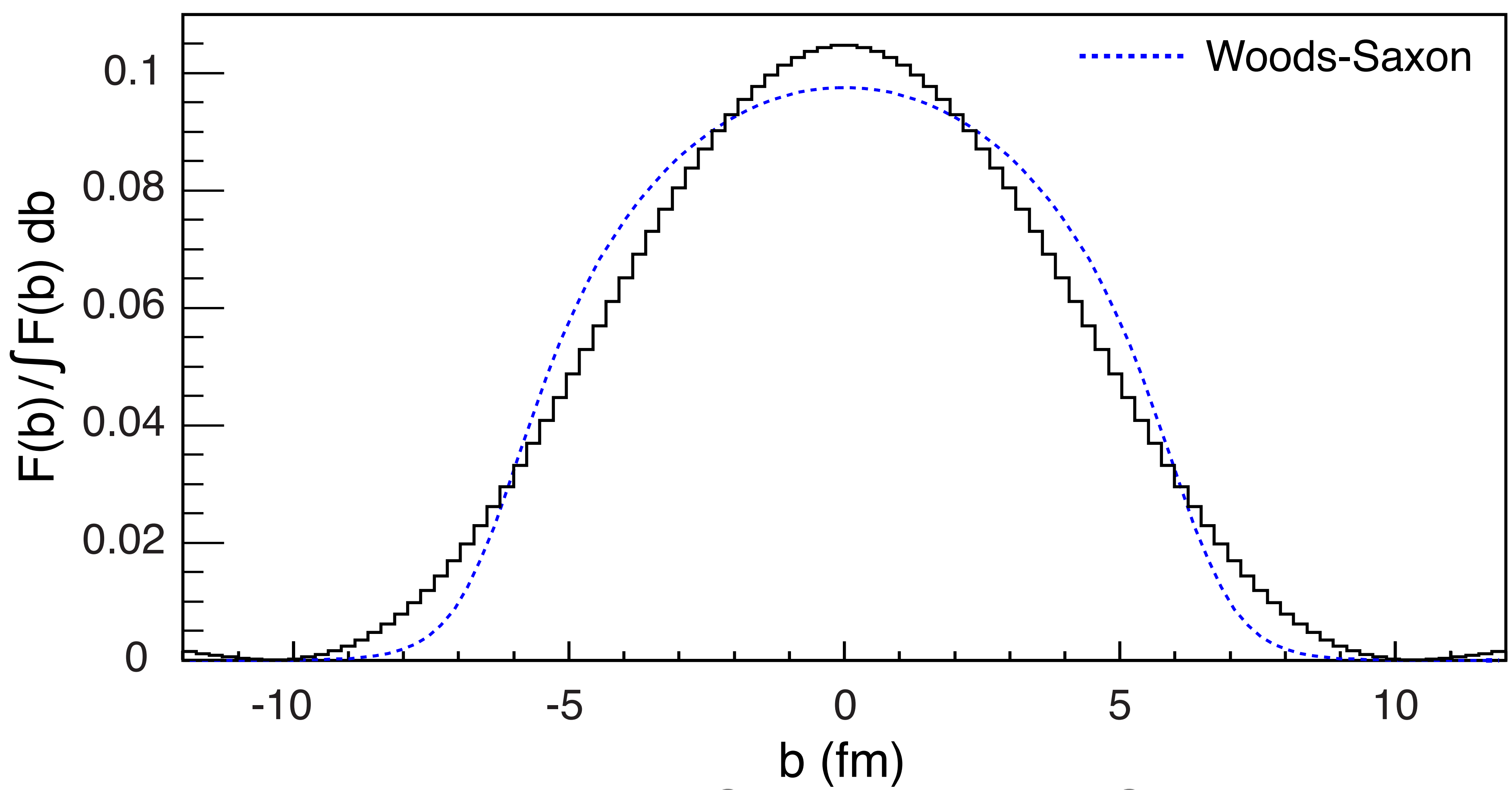

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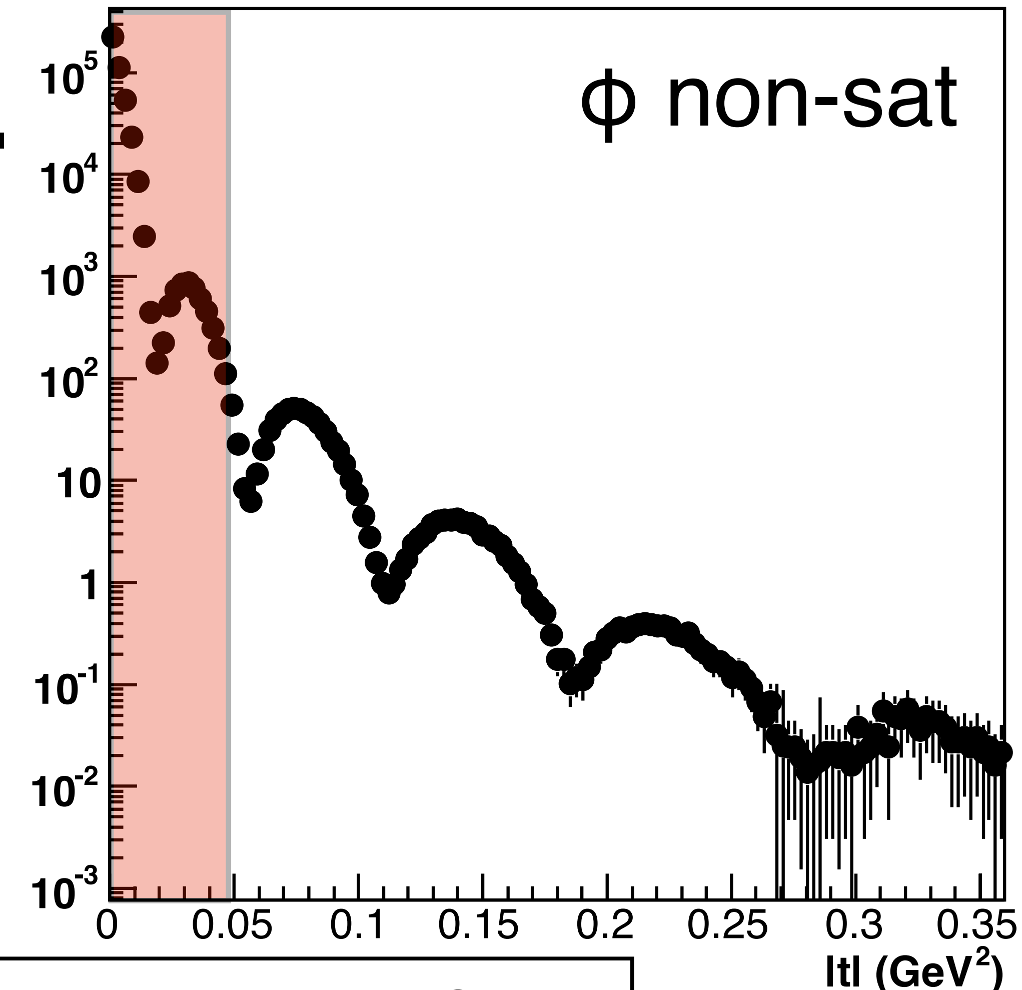

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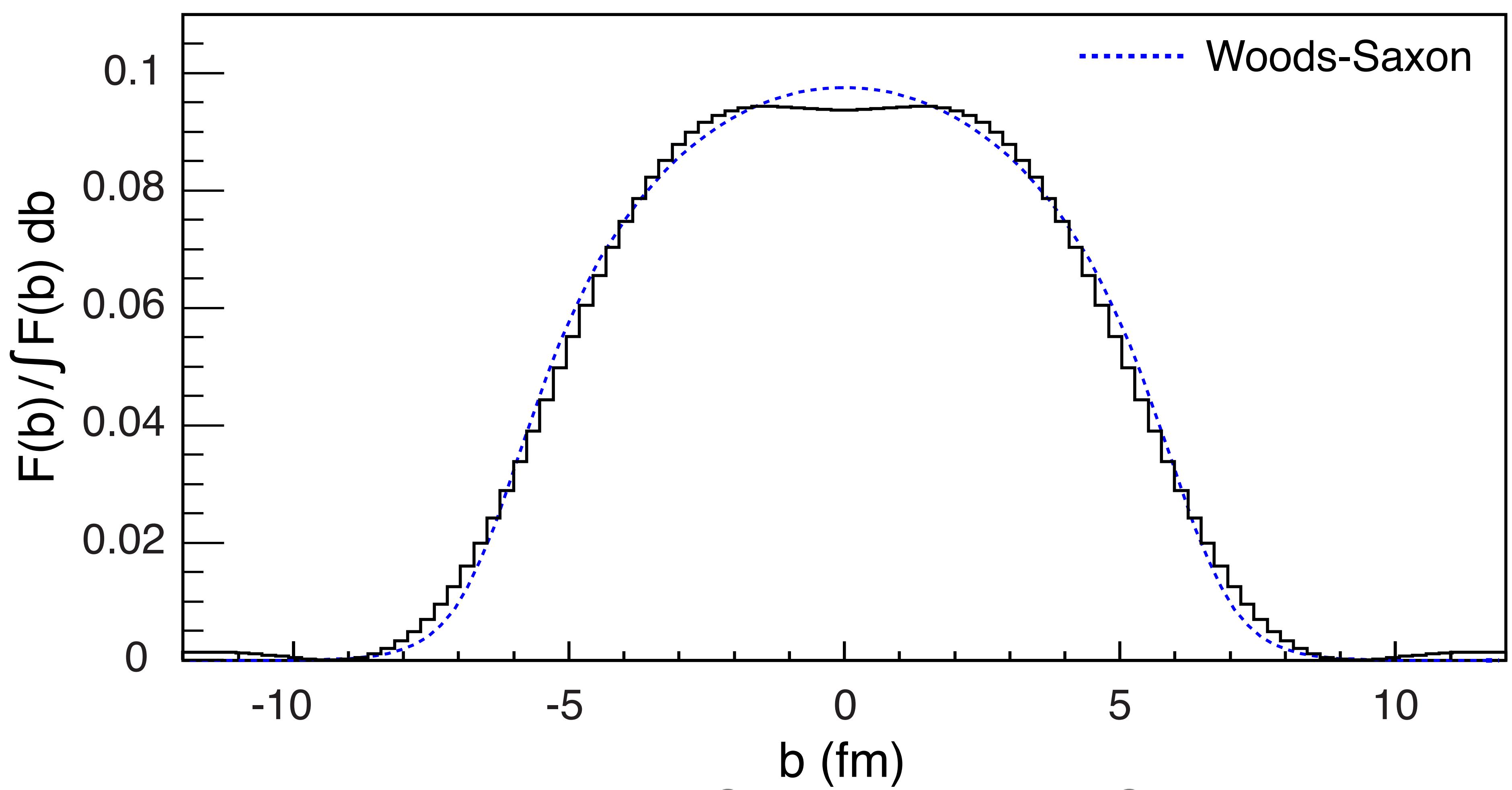

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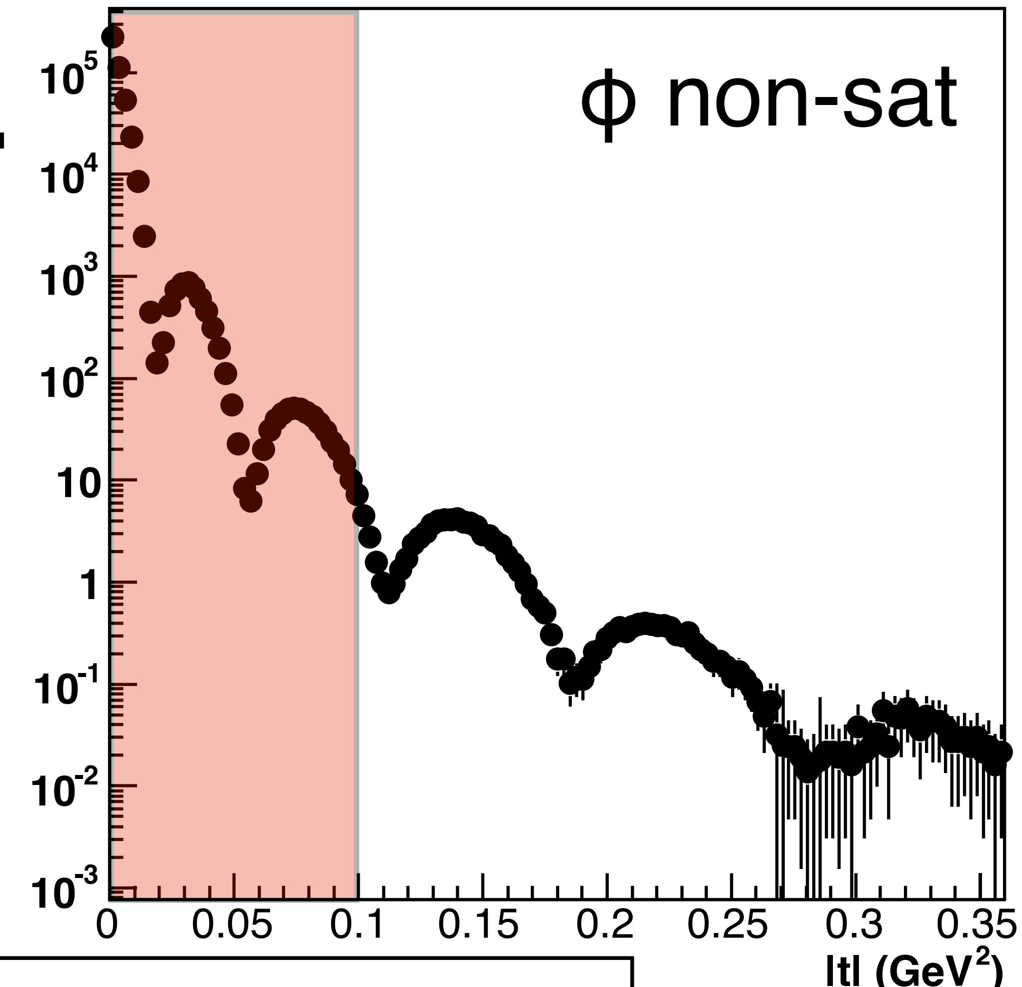
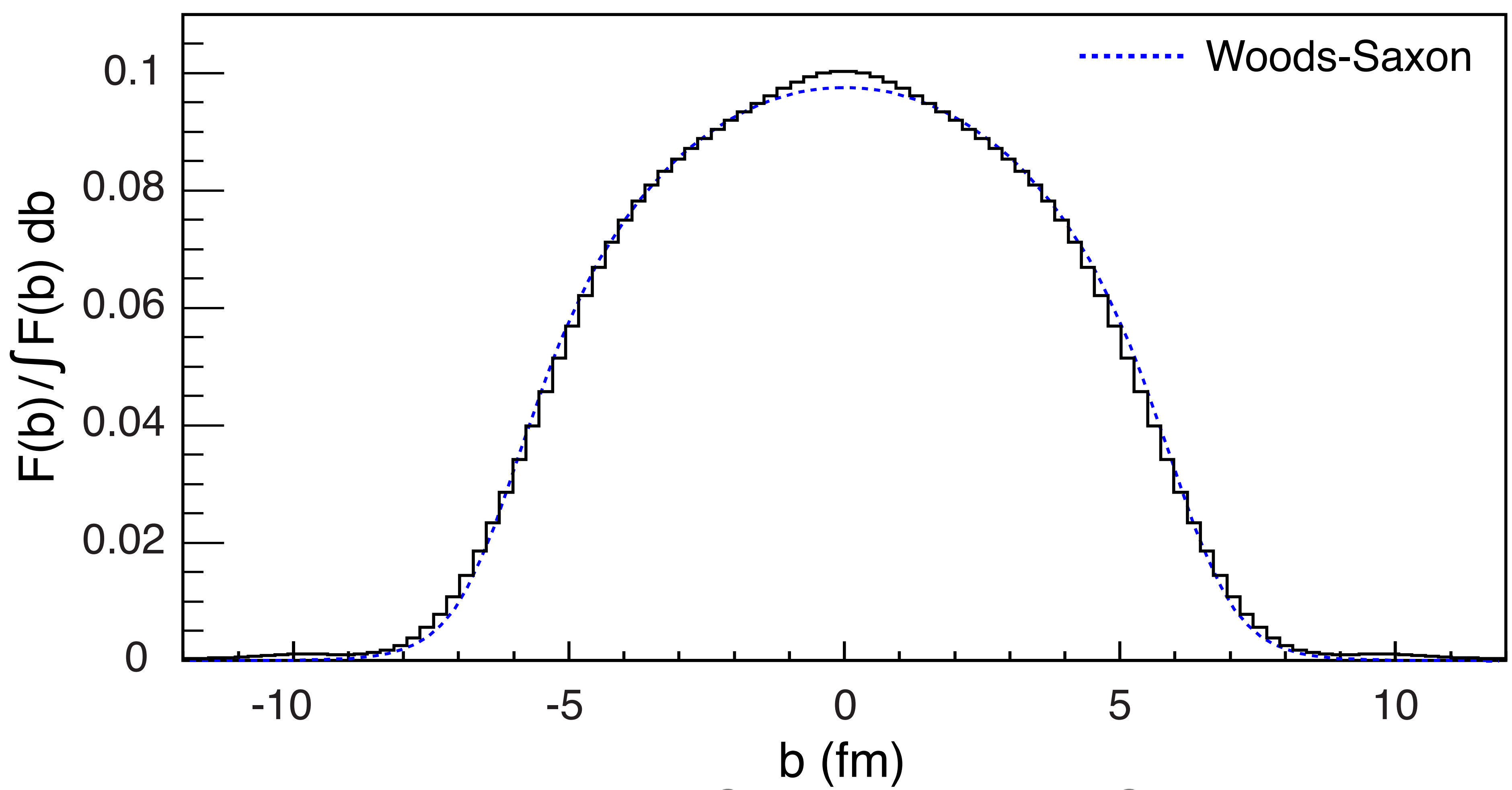


$$F(b) \sim \frac{1}{2\pi} \int_0^\infty d\Delta\, \Delta\, J_0(\Delta b) \sqrt{\frac{d\sigma}{dt}}$$

$t = \Delta^2/(1-x) \approx \Delta^2$ (for small x)



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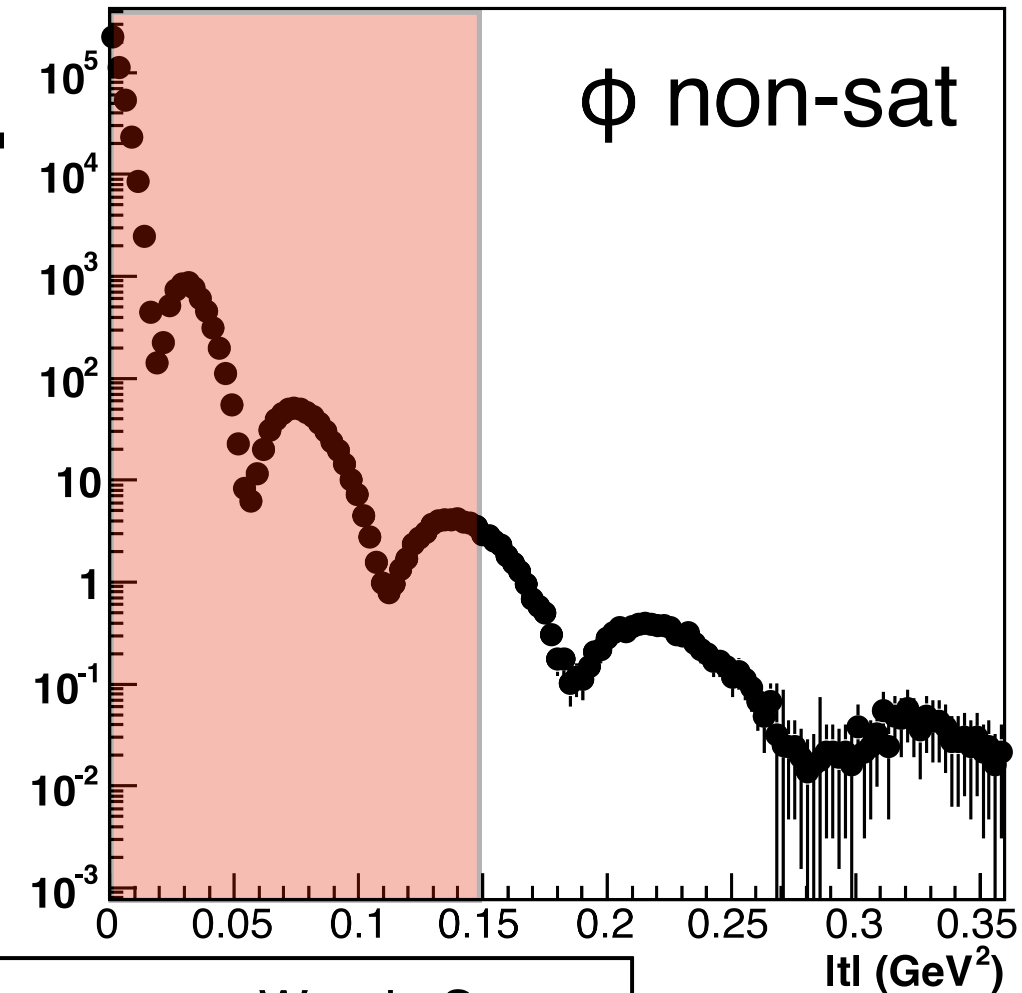

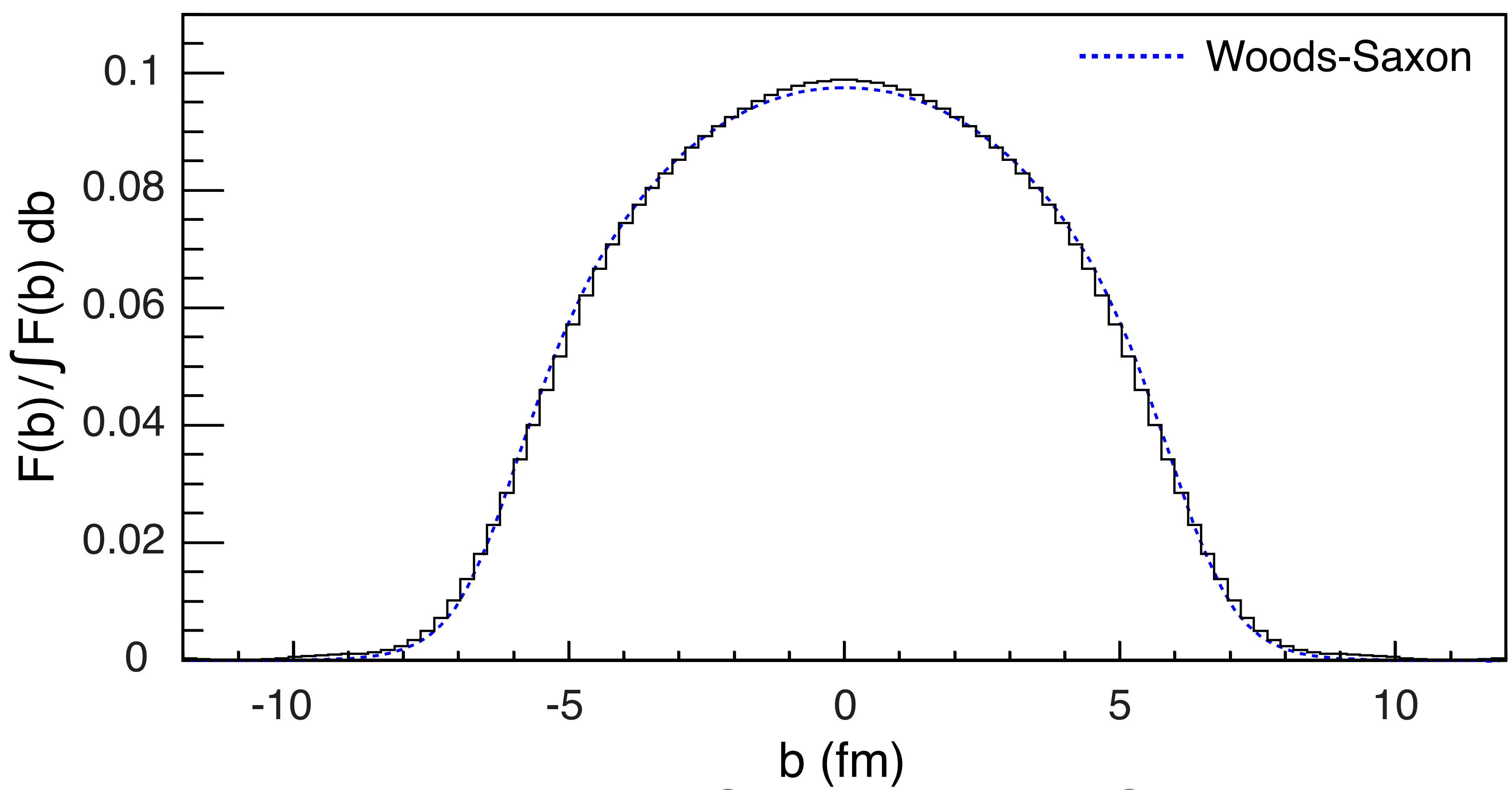

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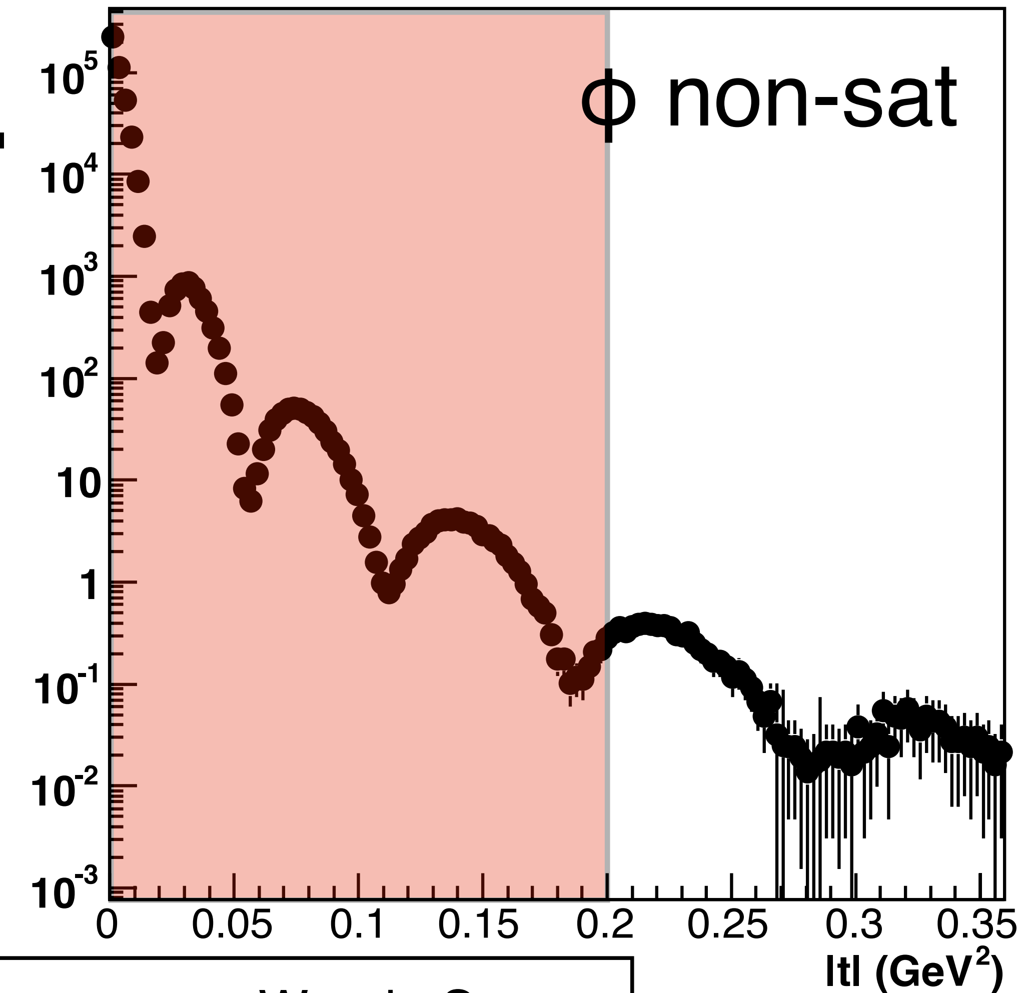

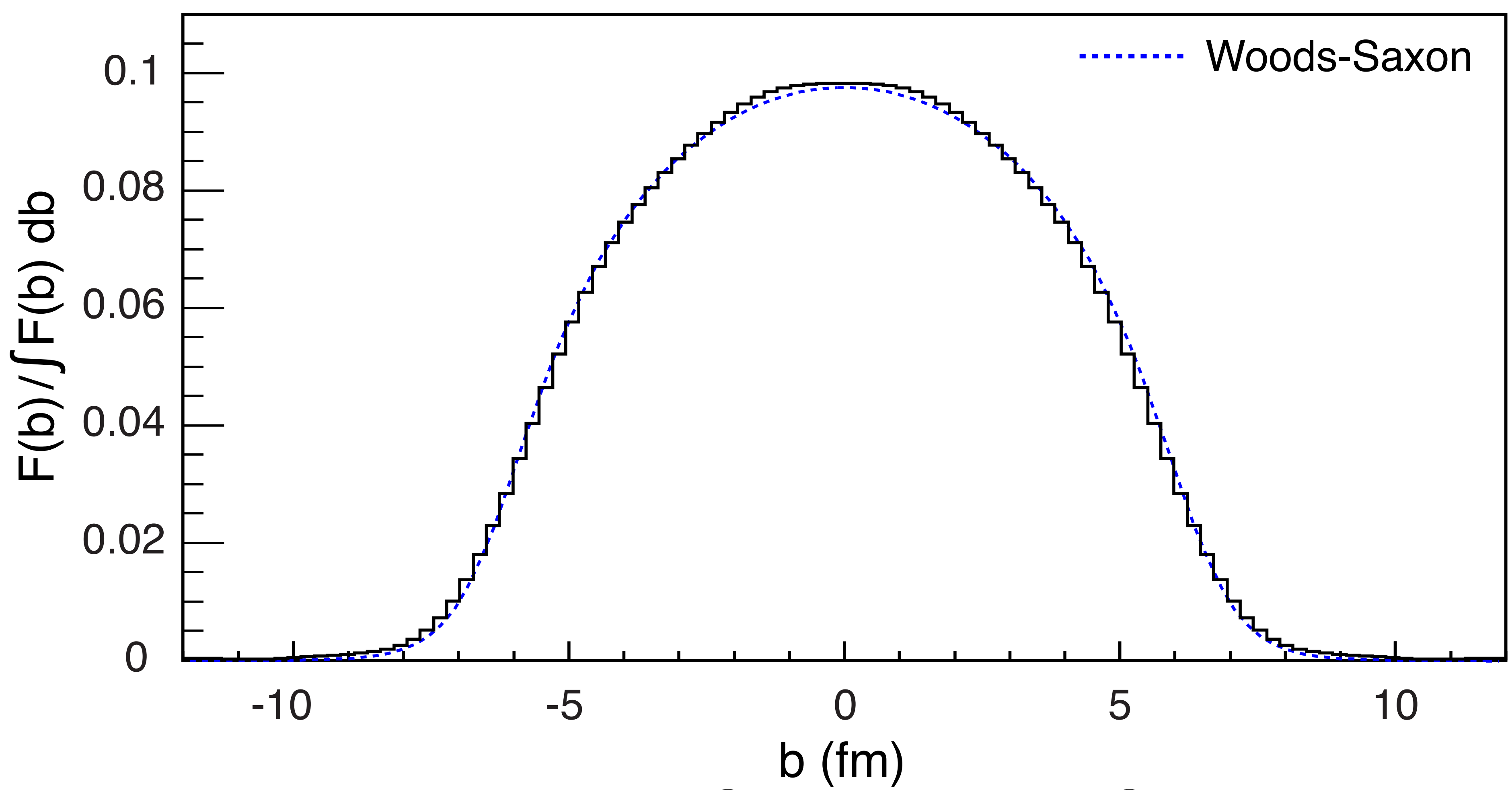

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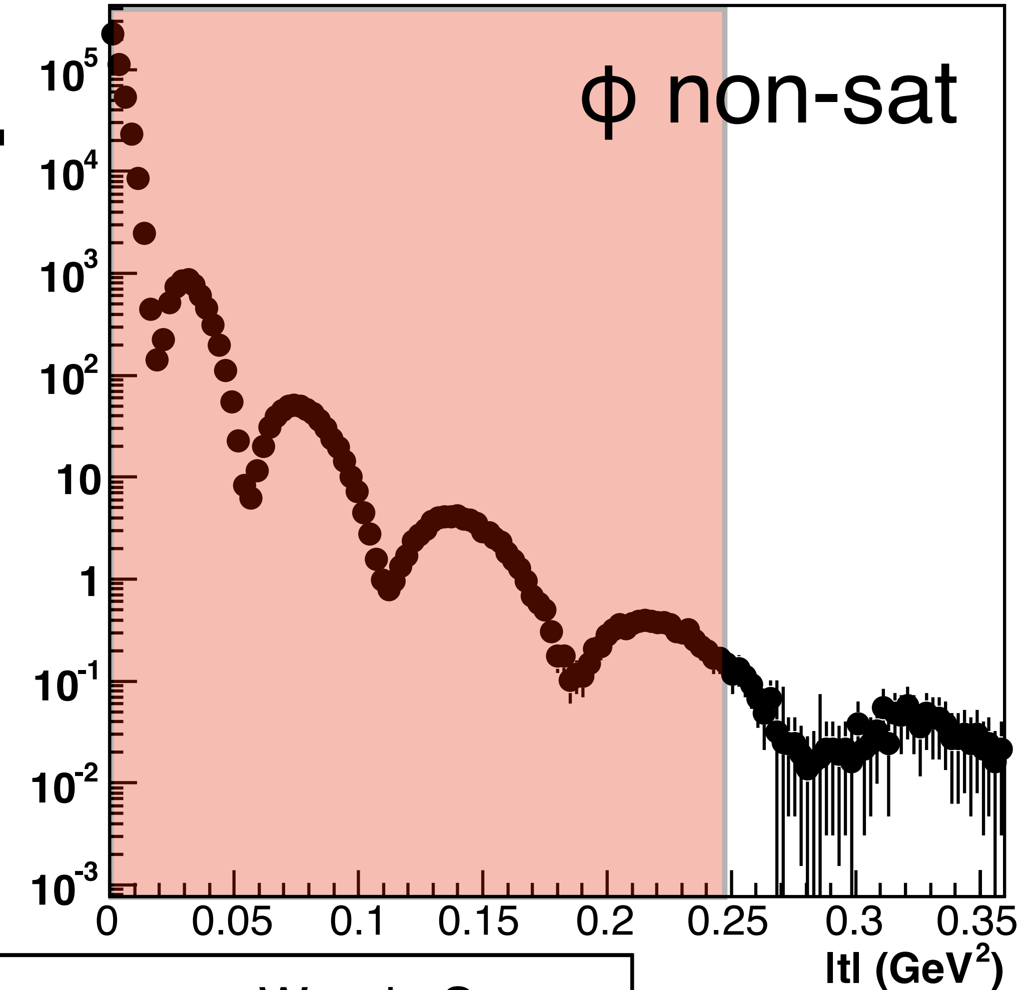

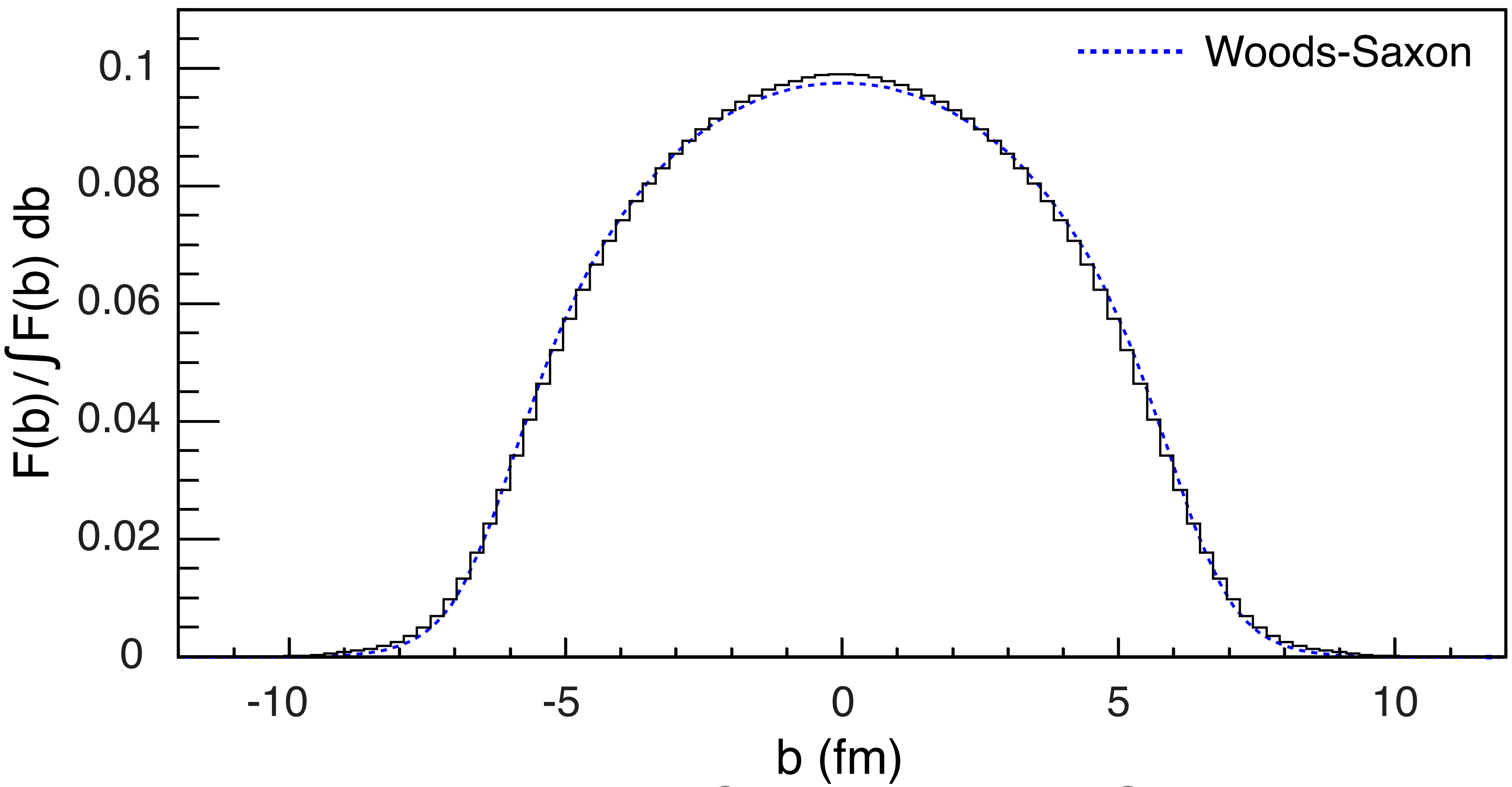

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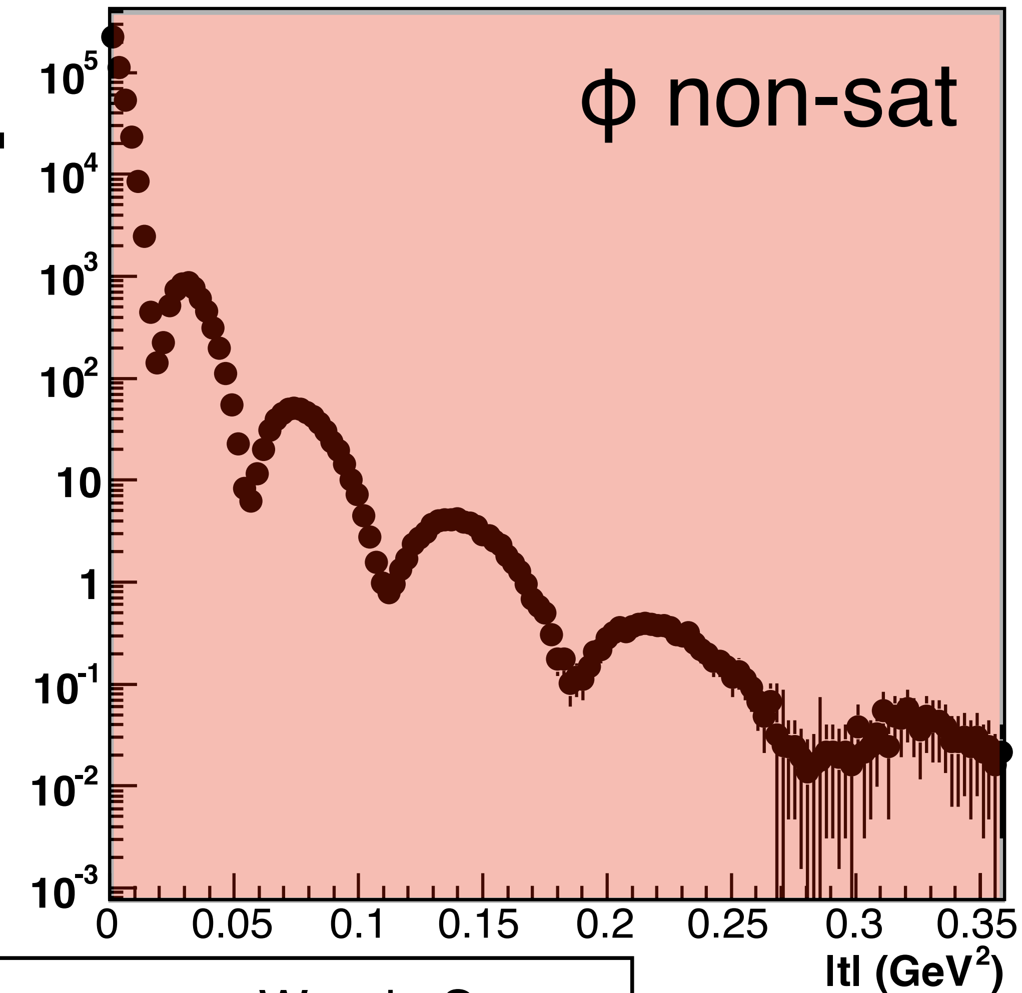

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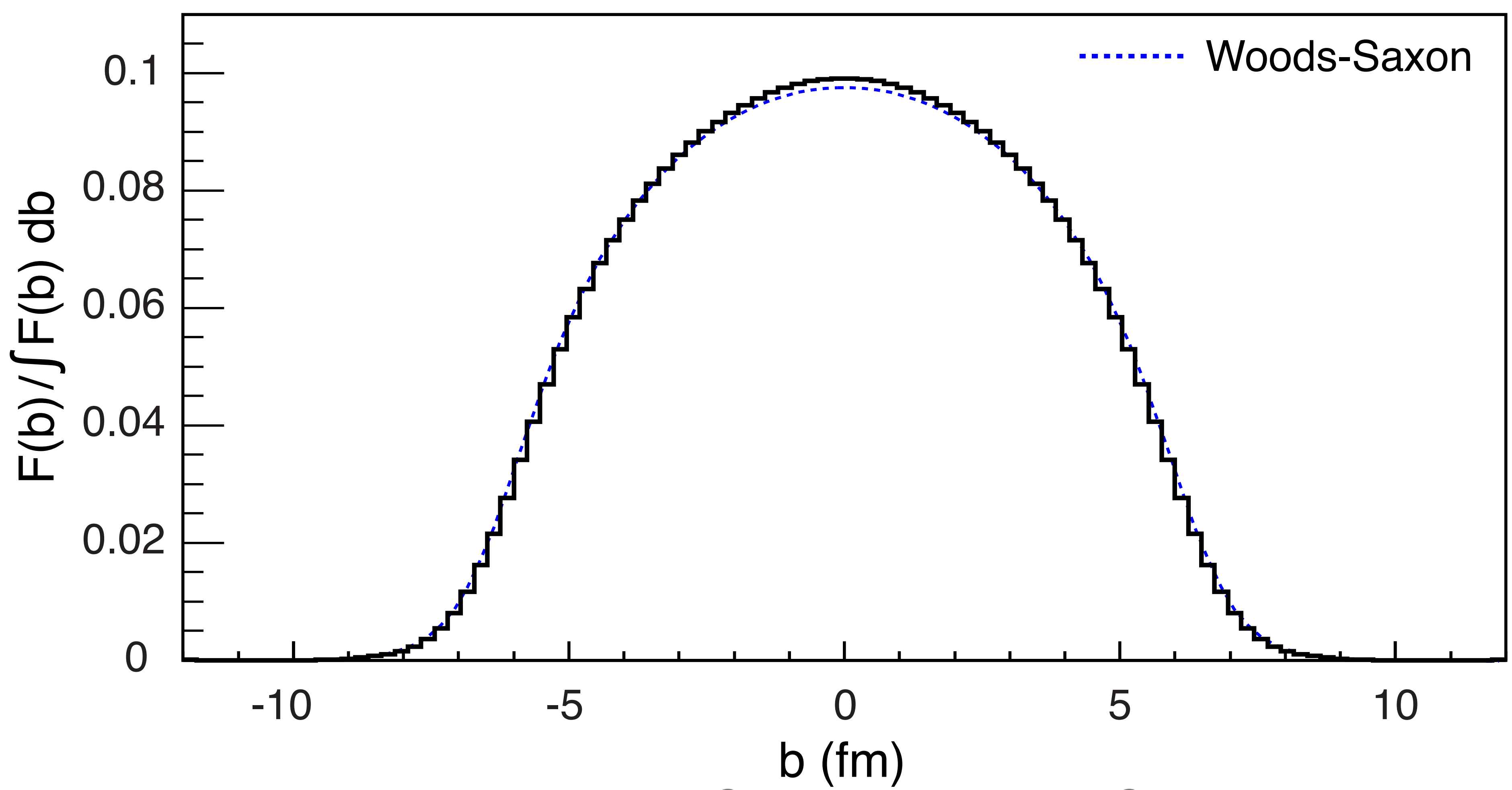
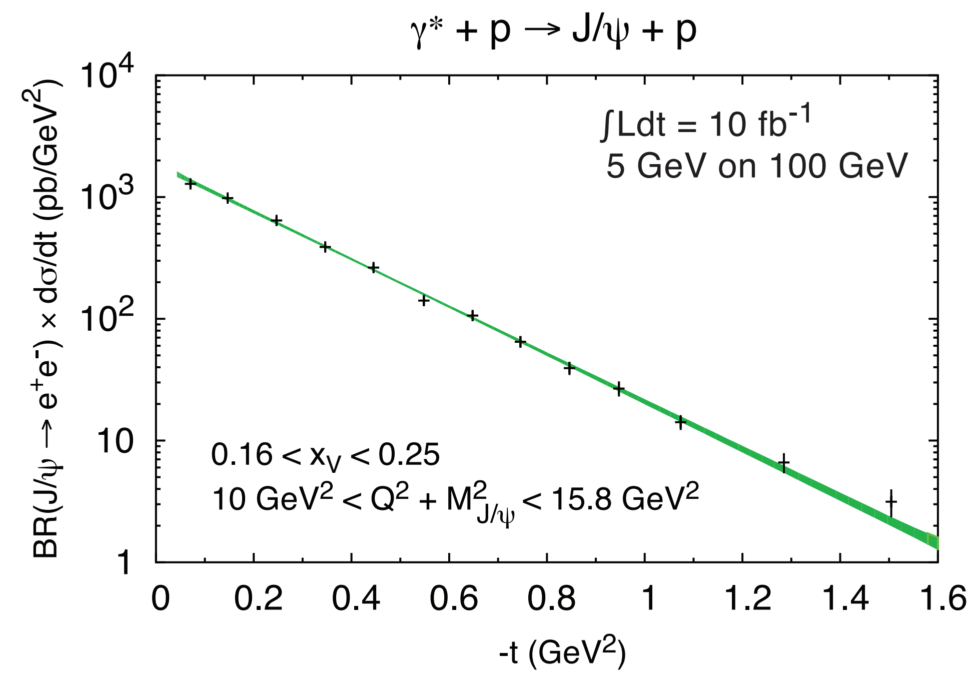


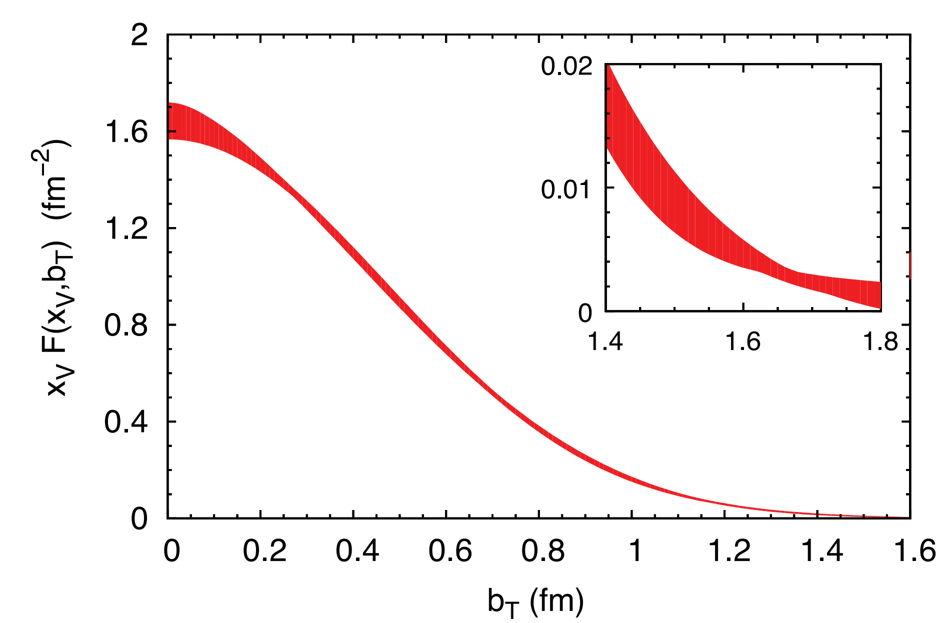
Imaging in e+p

- As with e+A, exclusive measurements can be used to image momentum space (TMDs) or position space (GPDs)



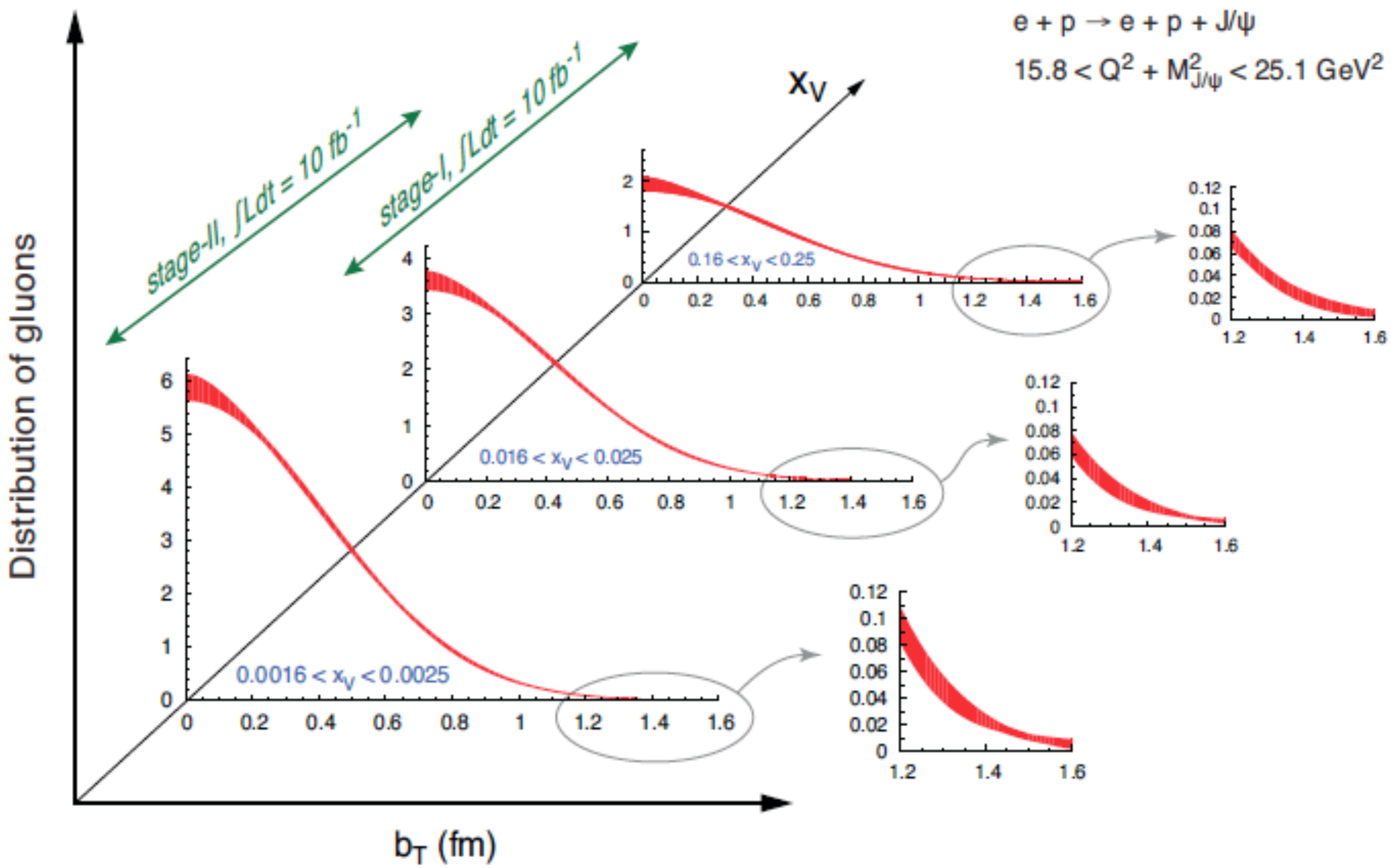
- Fine binning in (x,Q^2,t) space
  - ➡ Small statistical error bars in ~ 1 years running

- Fourier transform the momentum distribution to get the b-dependent gluon distribution



Imaging in e+p

- As with e+A, exclusive measurements can be used to image momentum space (TMDs) or position space (GPDs)
- Map out the x-dependence of the gluon distribution



Summary and Conclusions

- Both the e+A the e+p physics programmes at an EIC will give us a unique opportunity for precision studies of gluons in nuclei and nucleons
- e+A:
  - ➡ 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
- e+p:
  - ➡ Constrain $\Delta g(x)$ at small x along with the flavour-separated helicity PDFs
  - ➡ Imaging of the spatial and momentum gluon distributions in nucleons

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entire science program uniquely tied to a
future high-energy electron-ion collider
never been measured before & never without

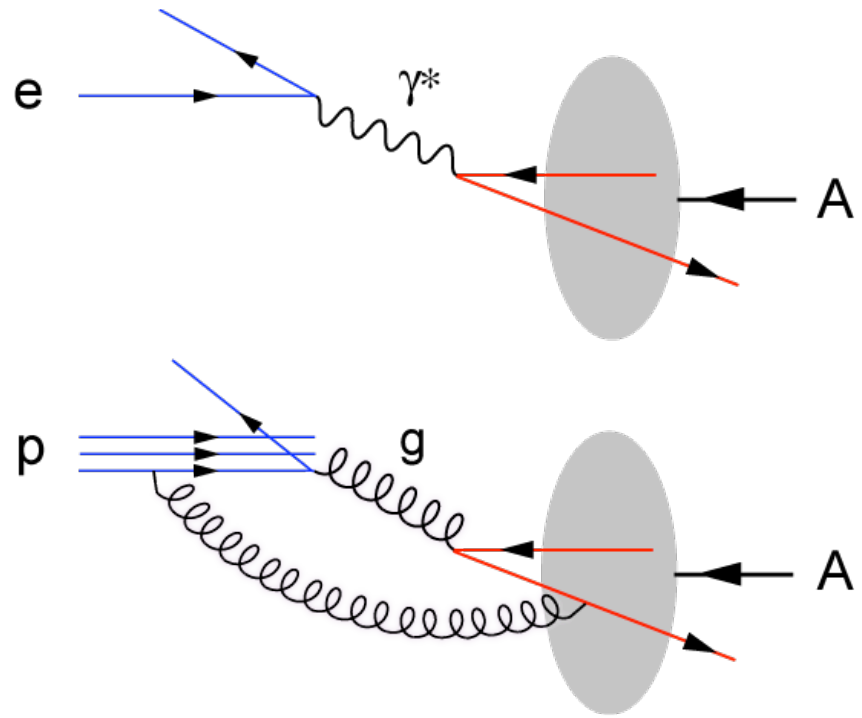
EIC White Paper

- 2010: Ten week INT programme on "Gluons and the quark sea at high energies"
  - ➡ 550 page proceedings on the ArXiv: http://arxiv.org/abs/1108.1713
- 2012: White paper released to community
  - ➡ ~150 page document, recently released to the community
  - ➡ http://www.bnl.gov/rhic/eicrev/ch/ch-files/c1-c6.pdf
    - Simulations and other tasks identified in INT programme were performed for this document and presented in this talk
- Community input and comments requested by October 31st

BACKUP

Why e+A collisions and not p+A?

- e+A and p+A provide excellent information on properties of gluons in the nuclear wave functions
- Both are complementary and offer the opportunity to perform stringent checks of factorization/universality
- Issues:
  - ➡ p+A combines initial and final state effects
  - ➡ multiple colour interactions in p+A
  - ➡ p+A lacks the direct access to x, Q^2



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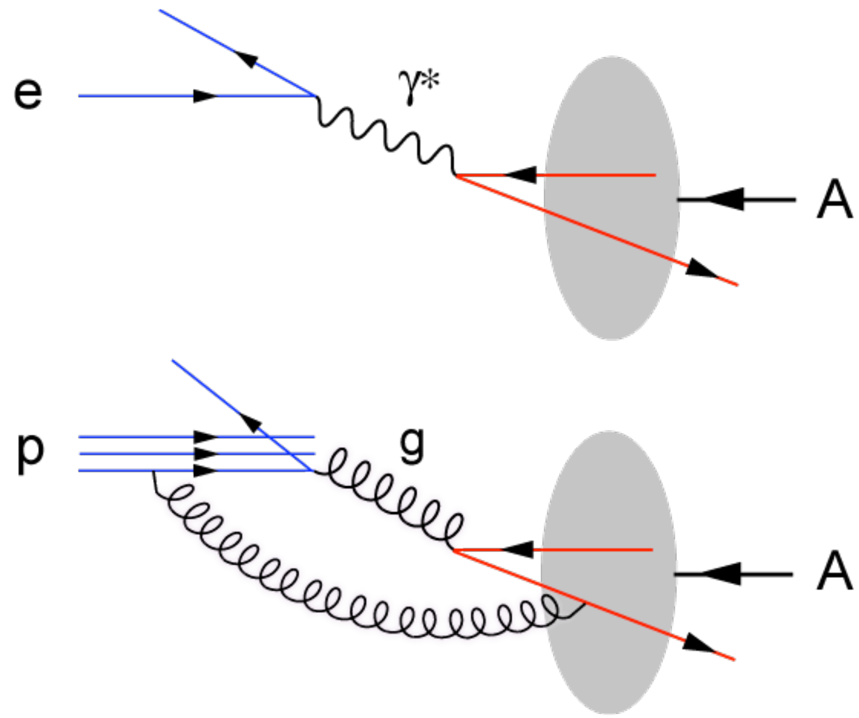
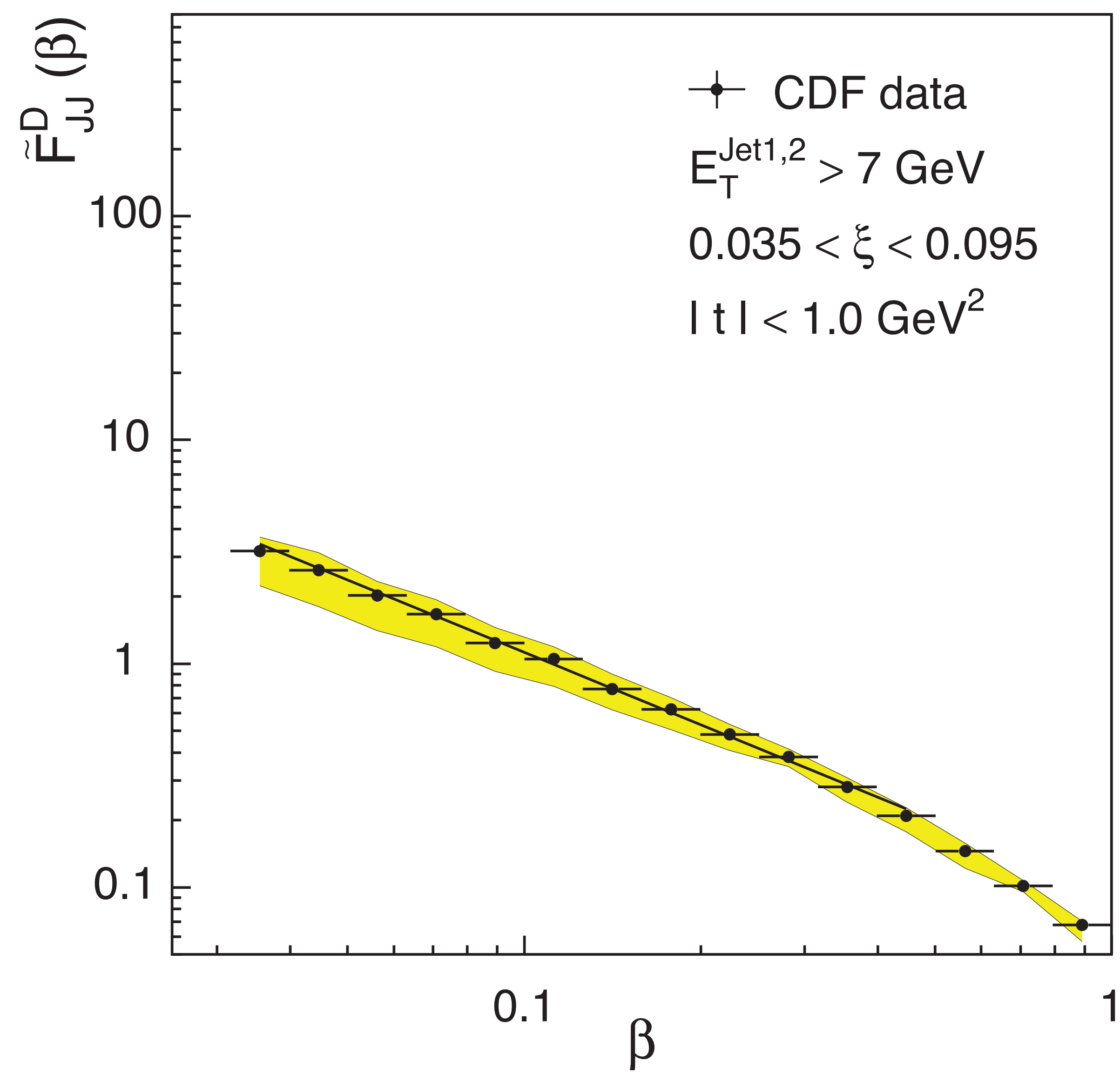


F. Schilling, hep-ex/0209001



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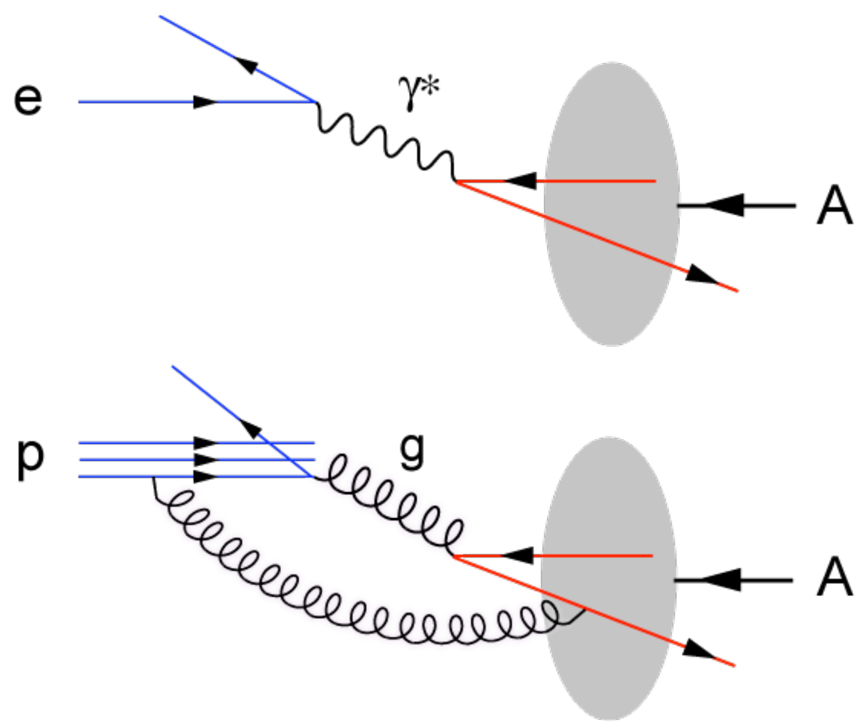

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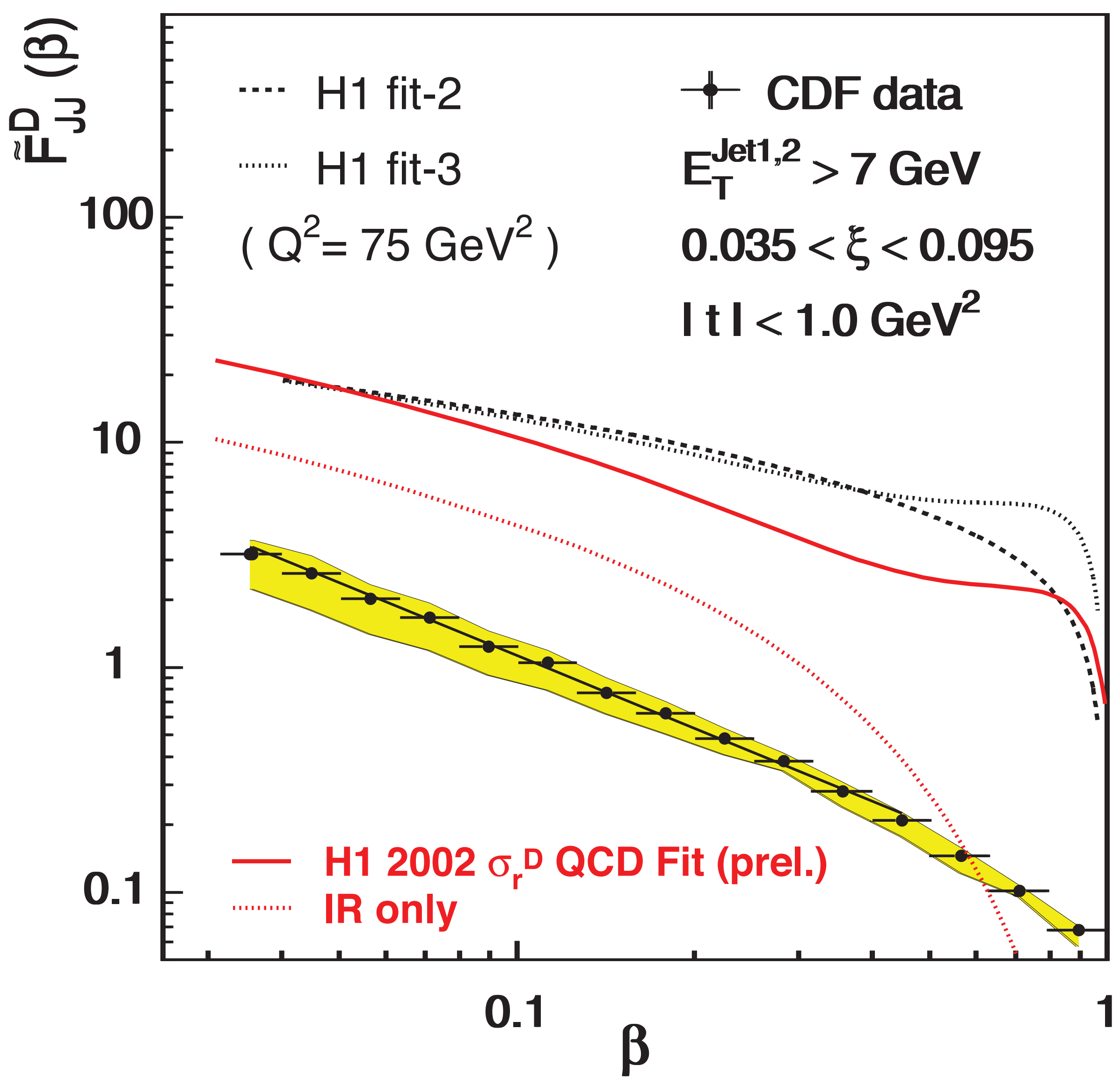

Breakdown of factorization (e+p HERA versus p+p Tevatron) observed for di-jets produced in diffractive collisions

Why *e*+A collisions and not *p*+A?

F. Schilling, hep-ex/0209001

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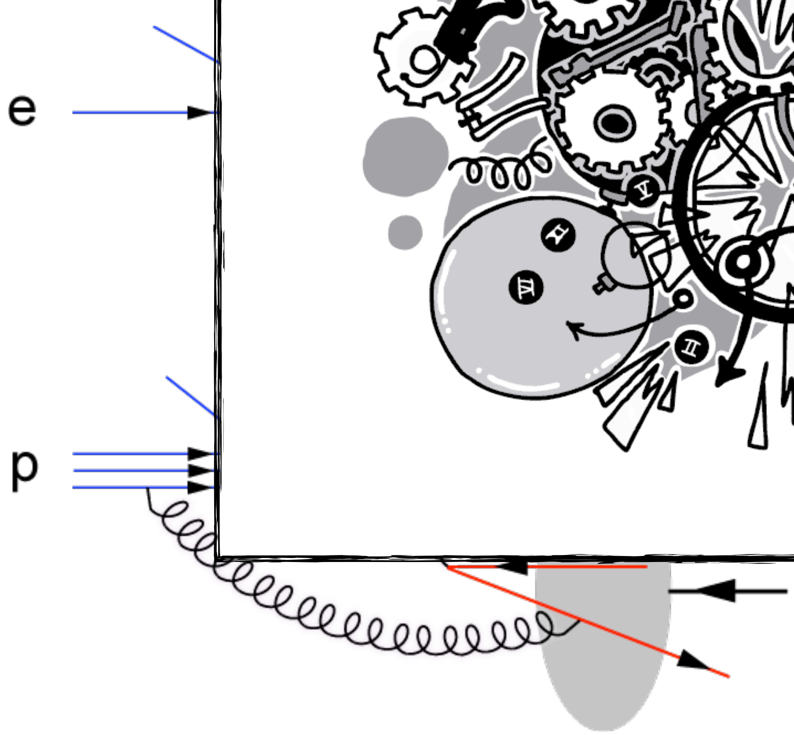
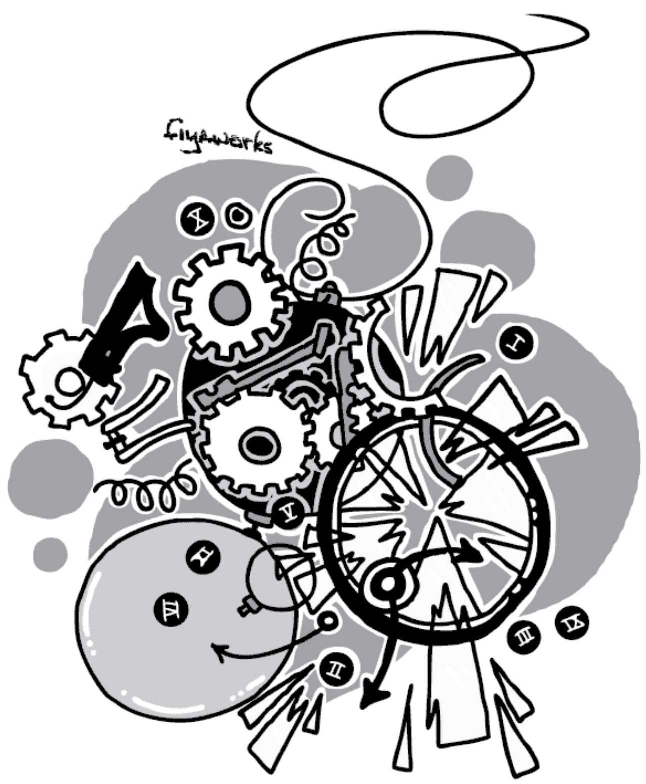
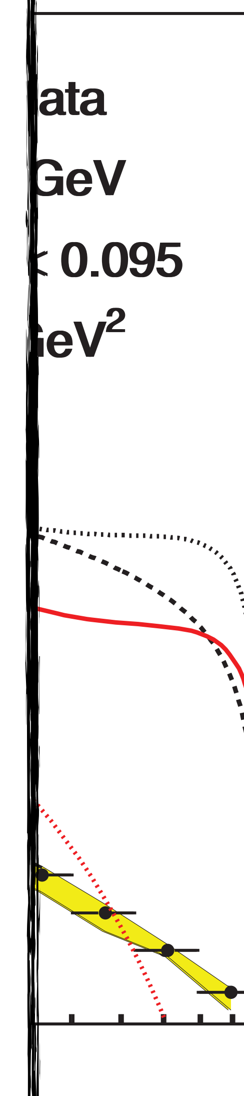


Scattering of protons on protons
is like colliding Swiss watches to find out how they are built.



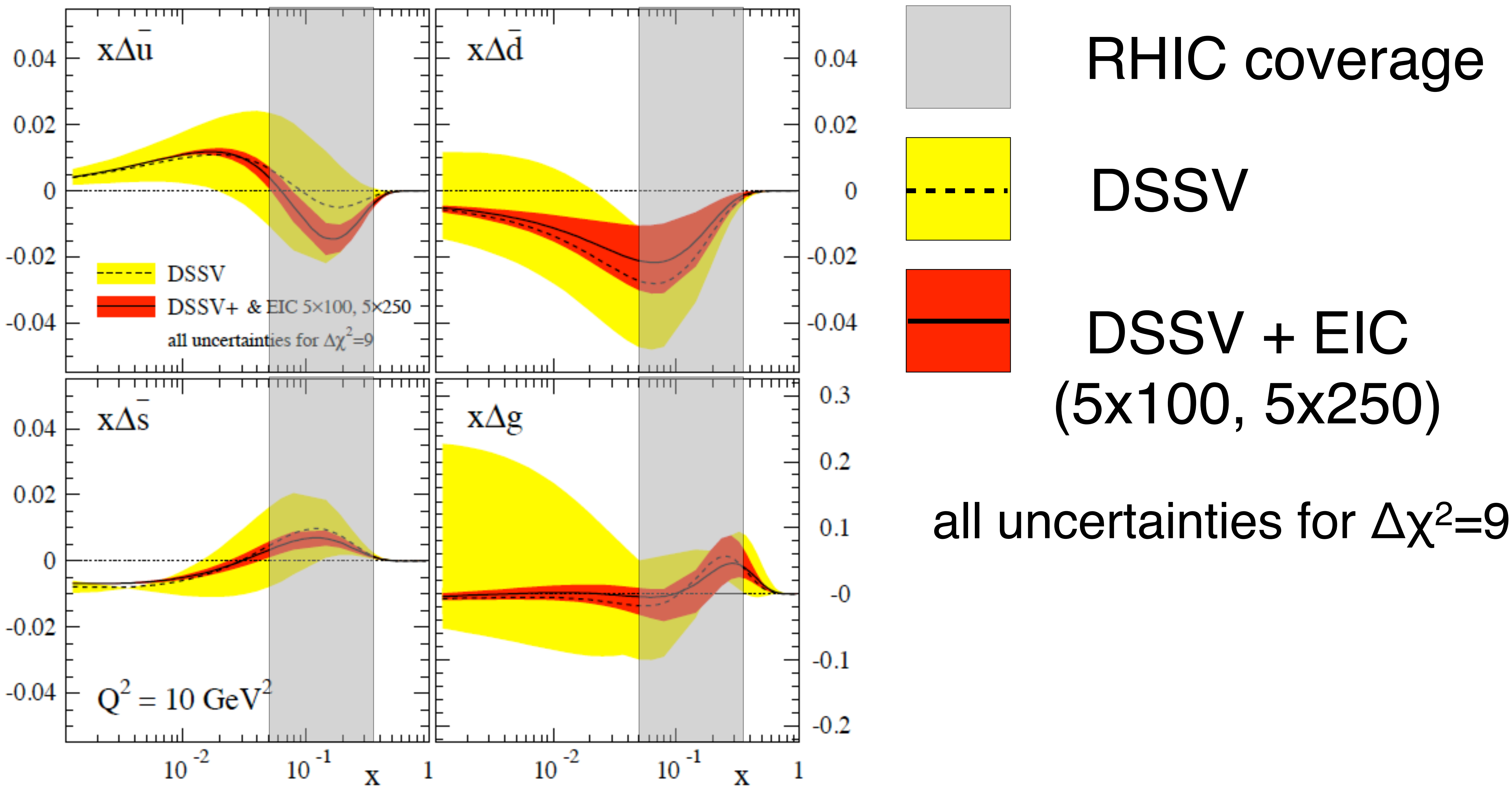
R. Feynman



+*p* HERA
for di-jets
produced in diffractive collisions

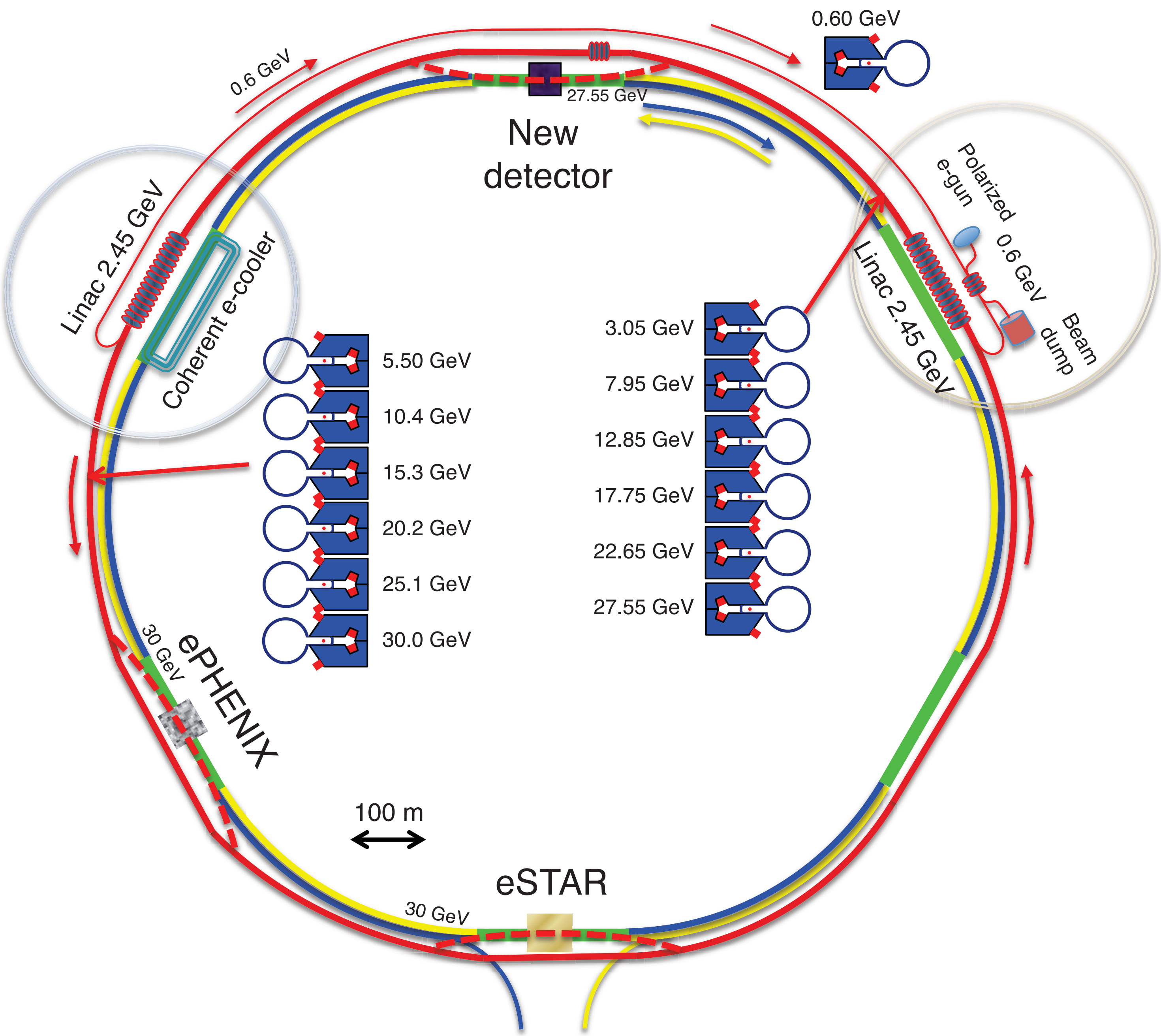
SIDIS in e+p → flavour-separated helicity PDFs

- SIDIS measurements with identified π, k lead to much reduced uncertainties in the flavour-separated helicity PDFs as in Δg(x)



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



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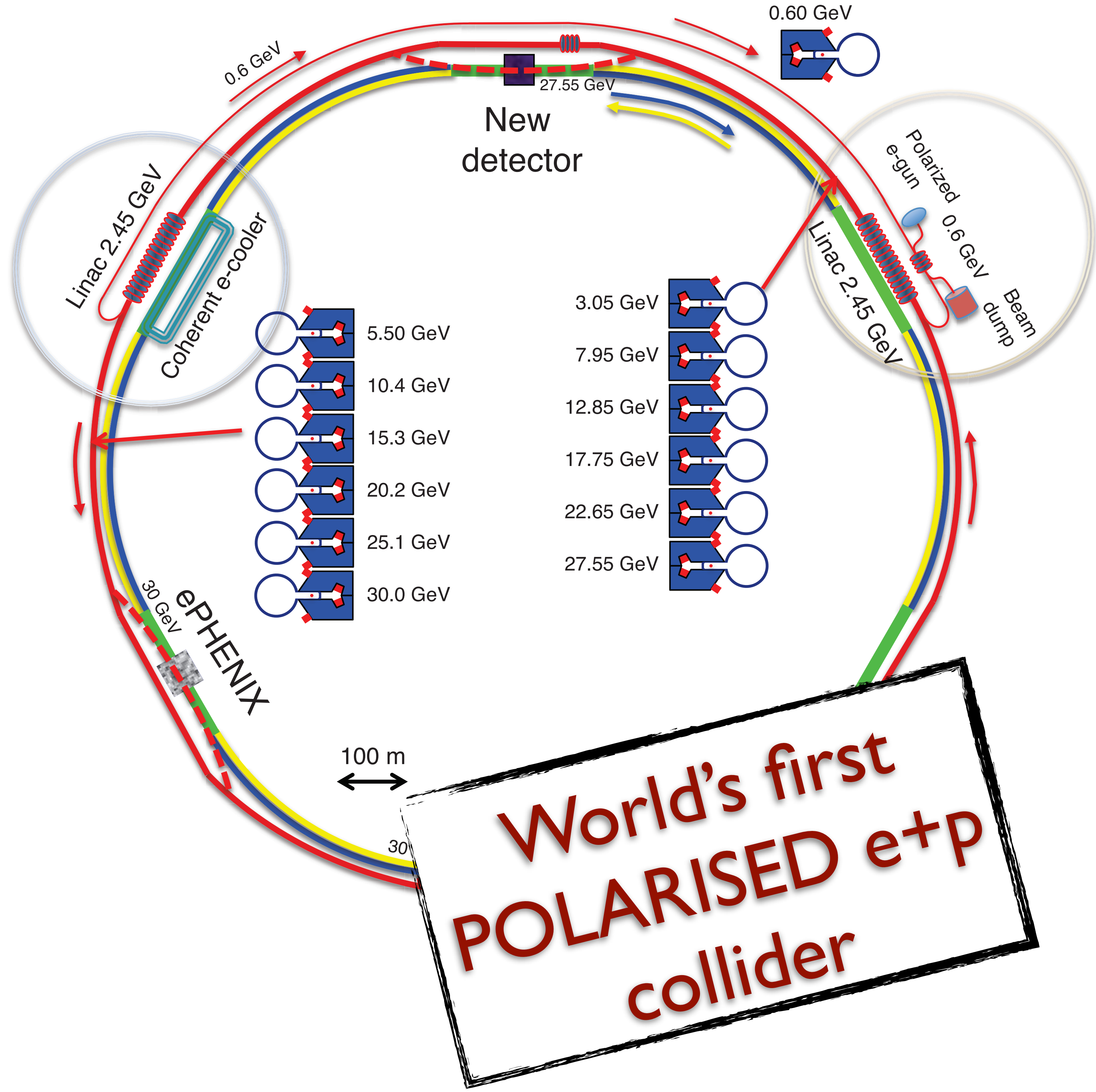

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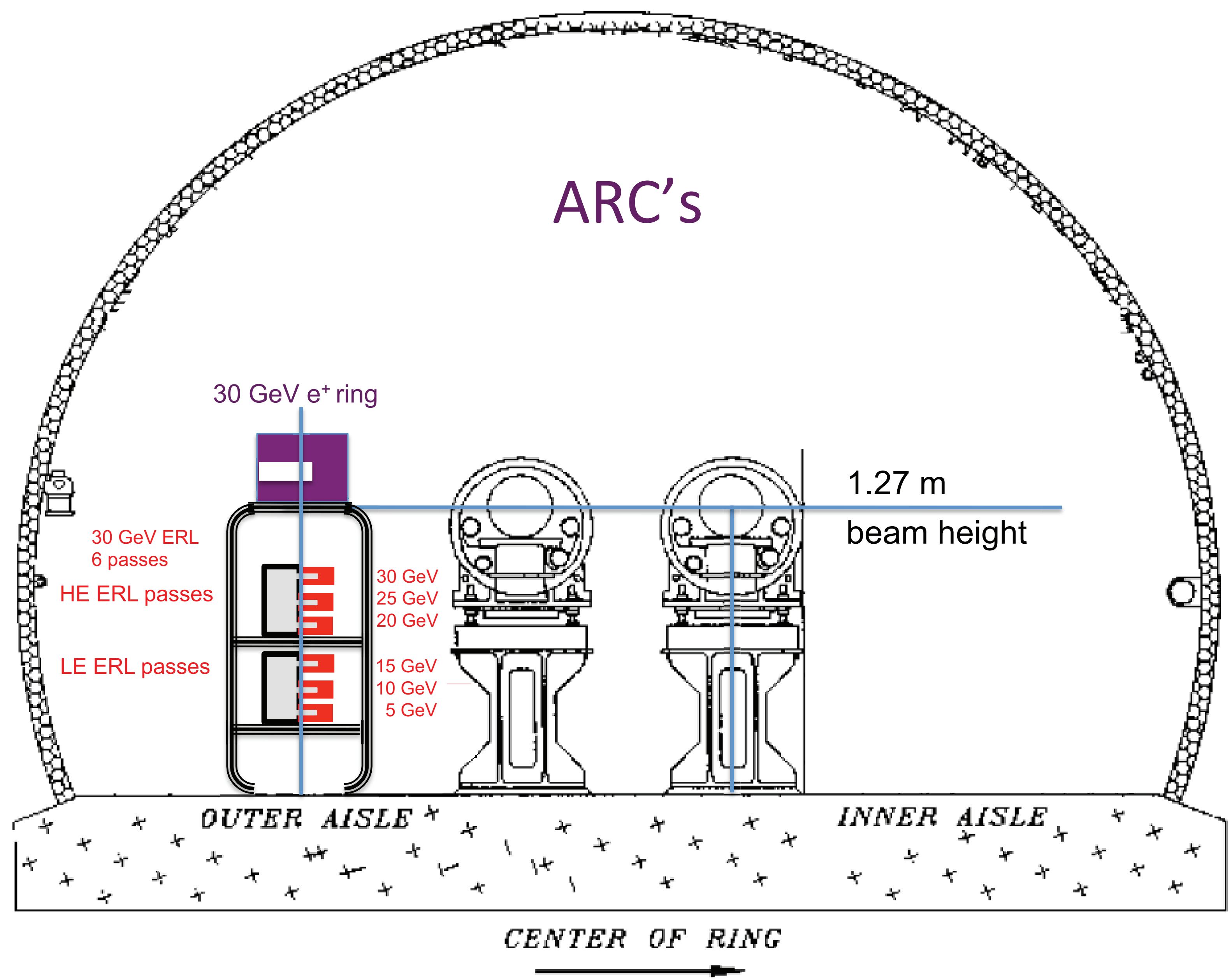
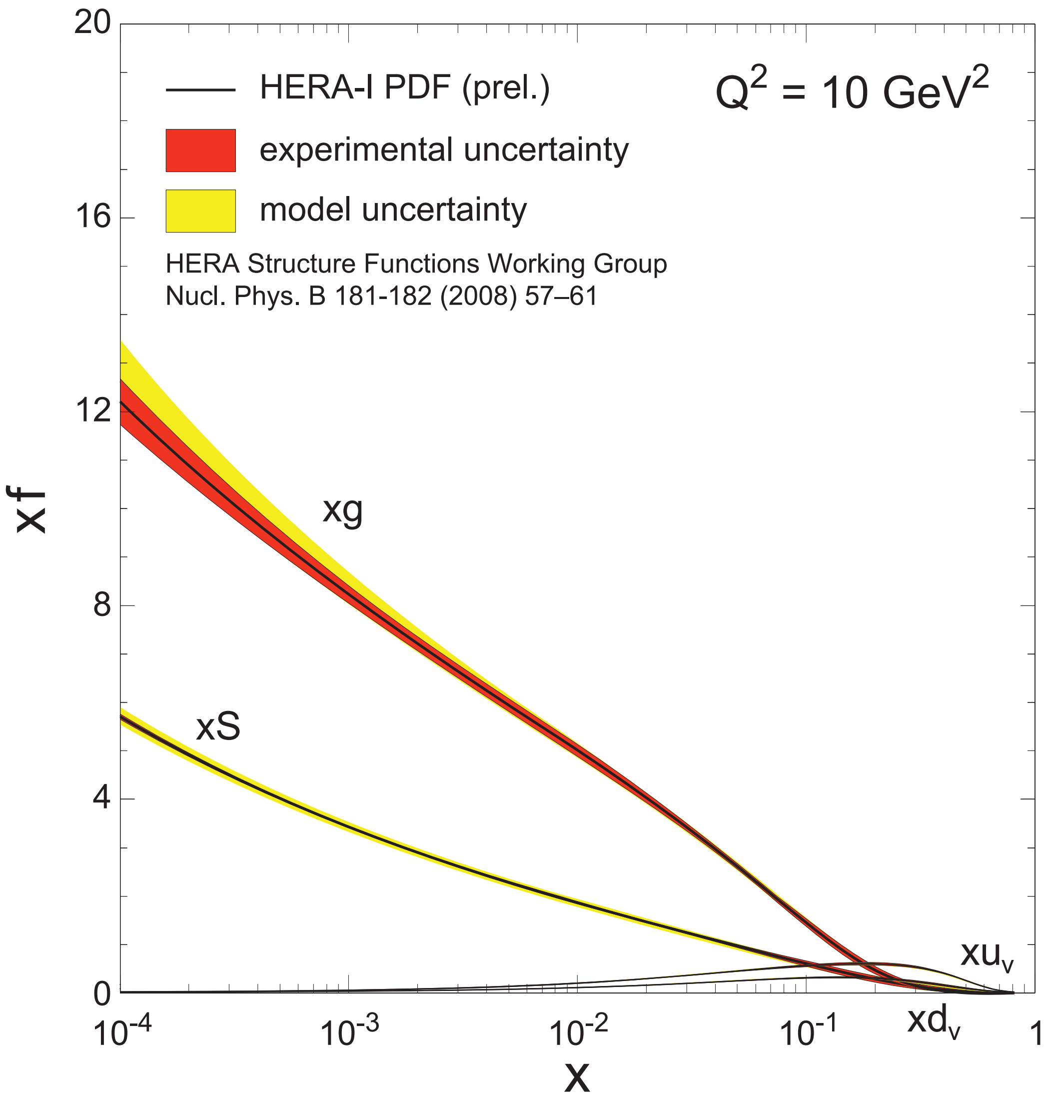


(Very) Brief Recap of Saturation at an EIC



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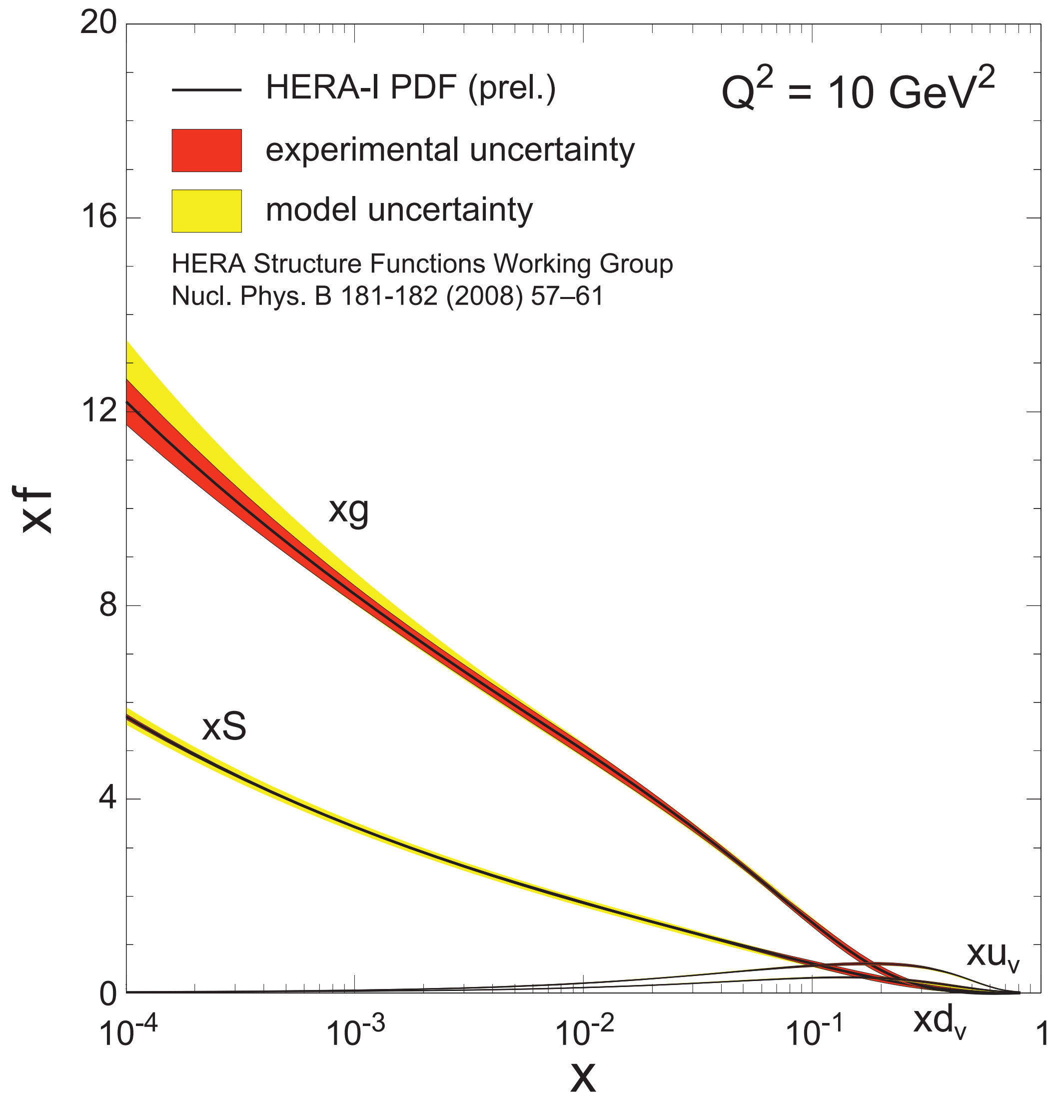

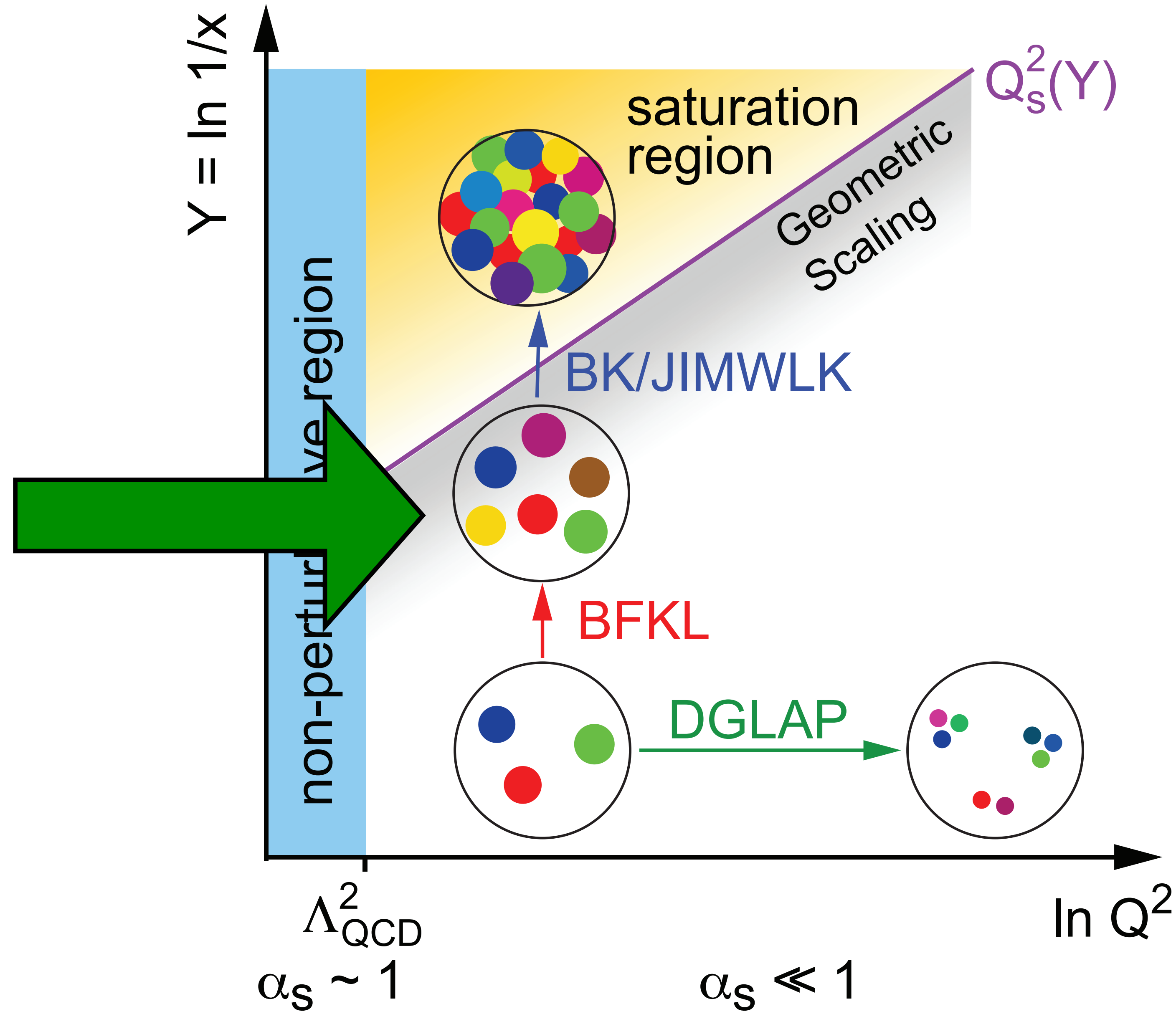

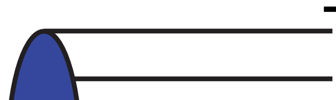

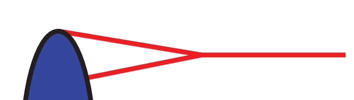

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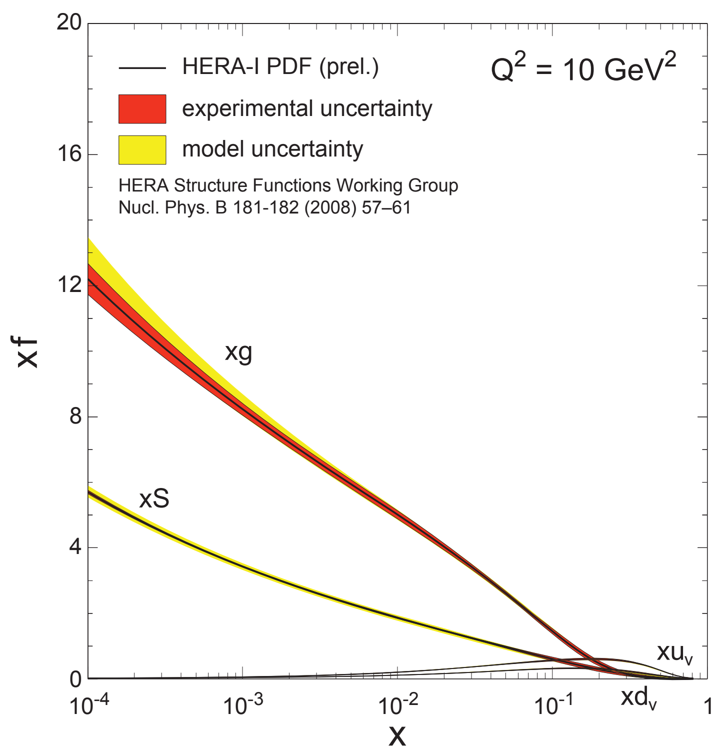
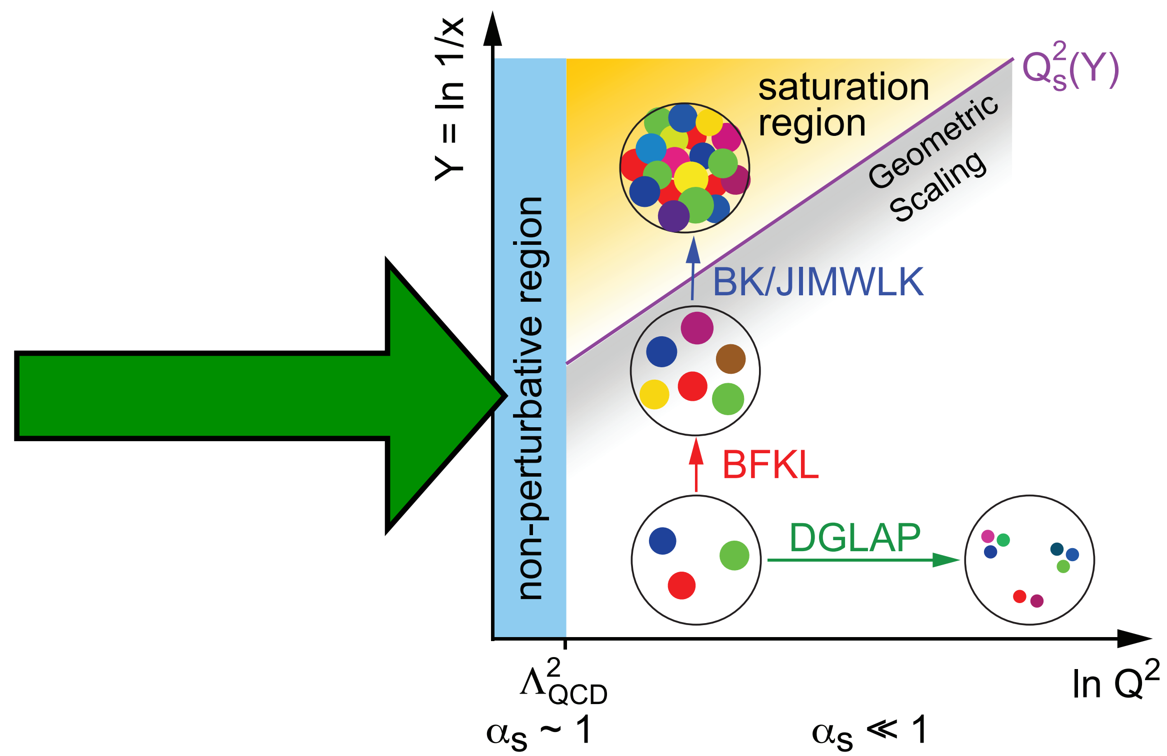
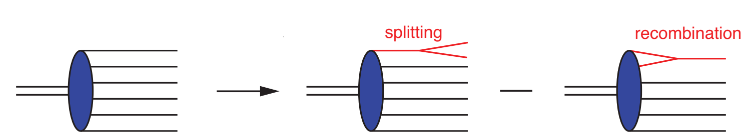
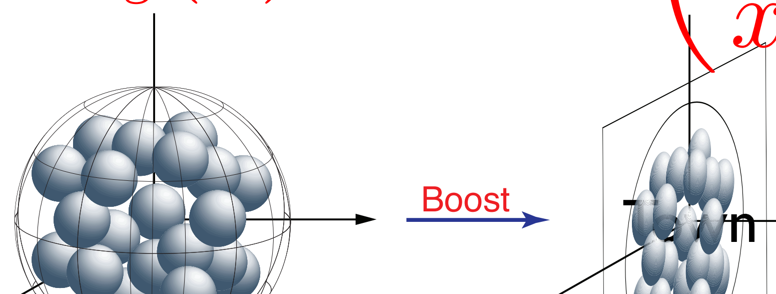






$$Q_s^2(x) \sim A^{1/3} \left(\frac{1}{x}\right)^{\lambda}$$



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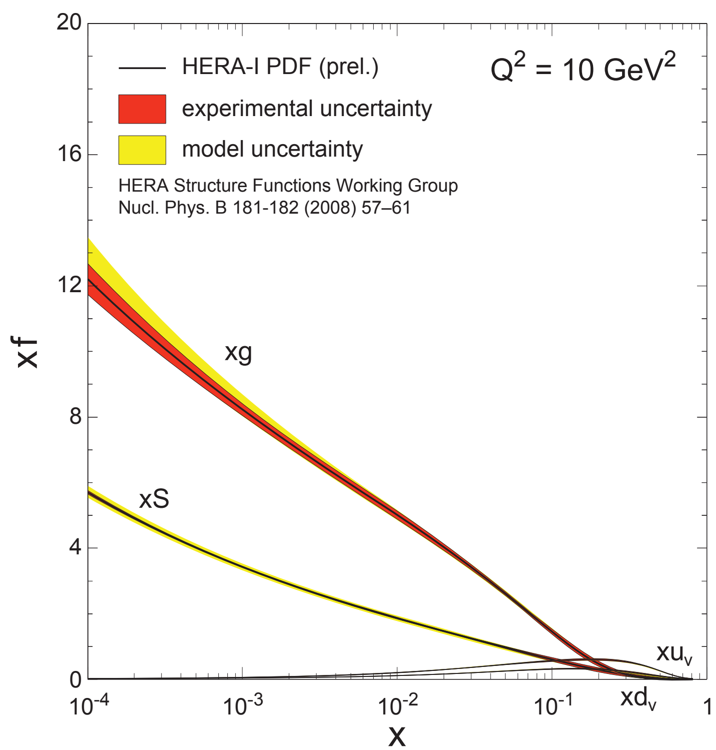

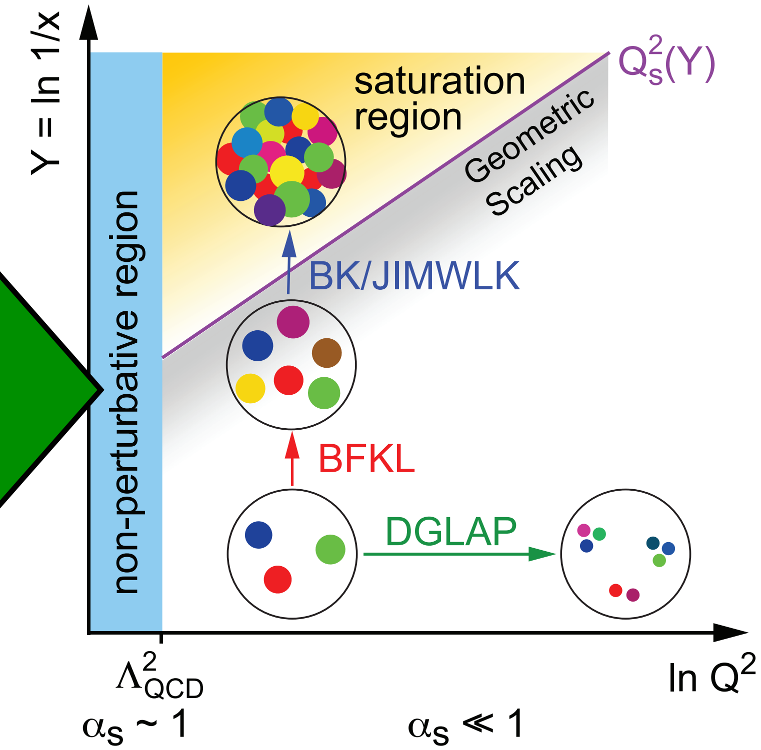

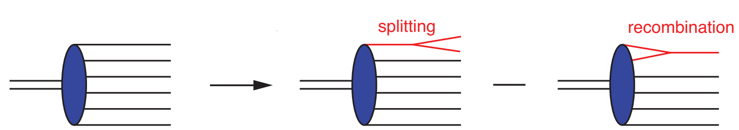

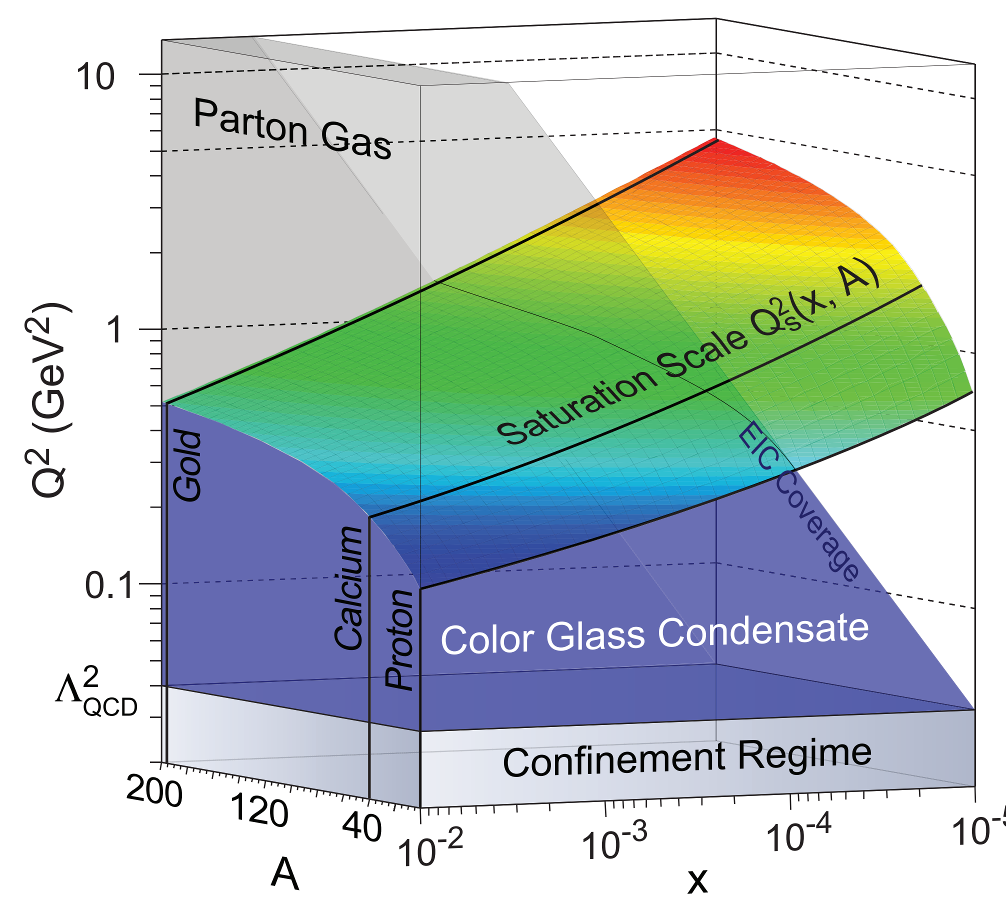

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