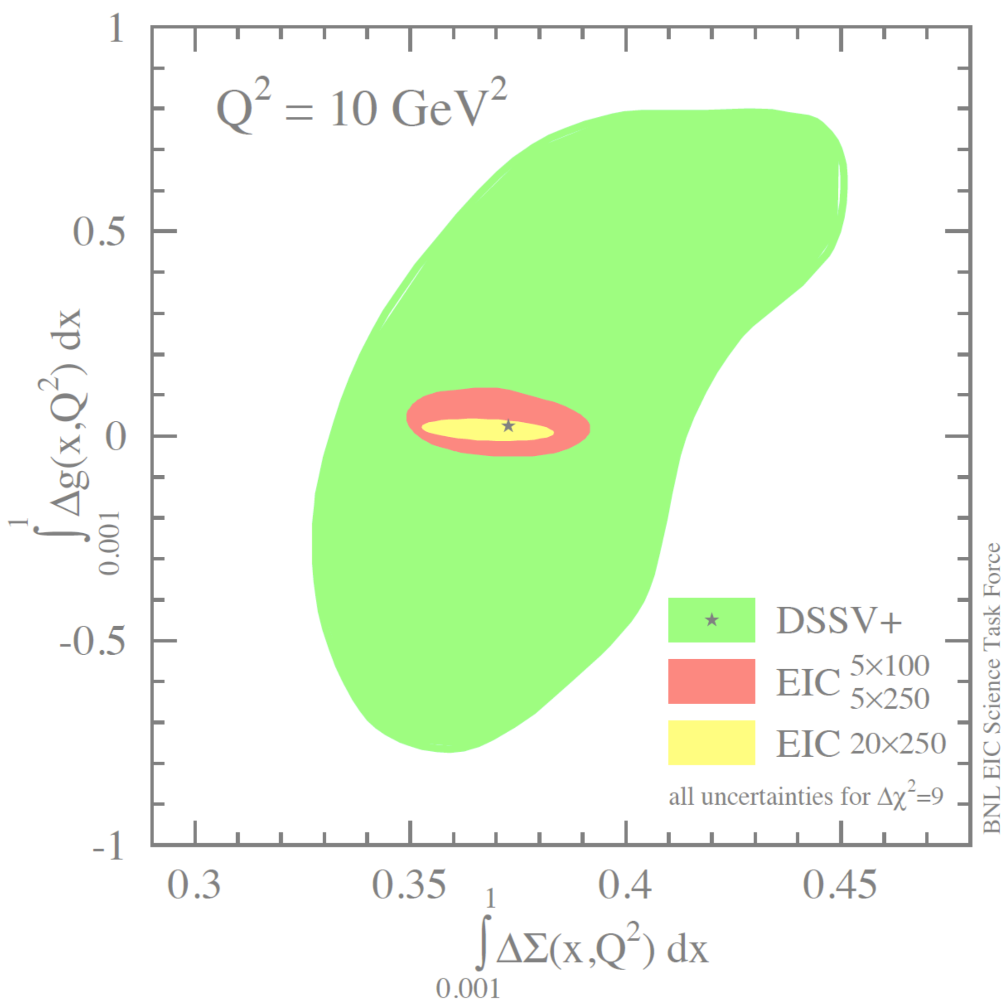
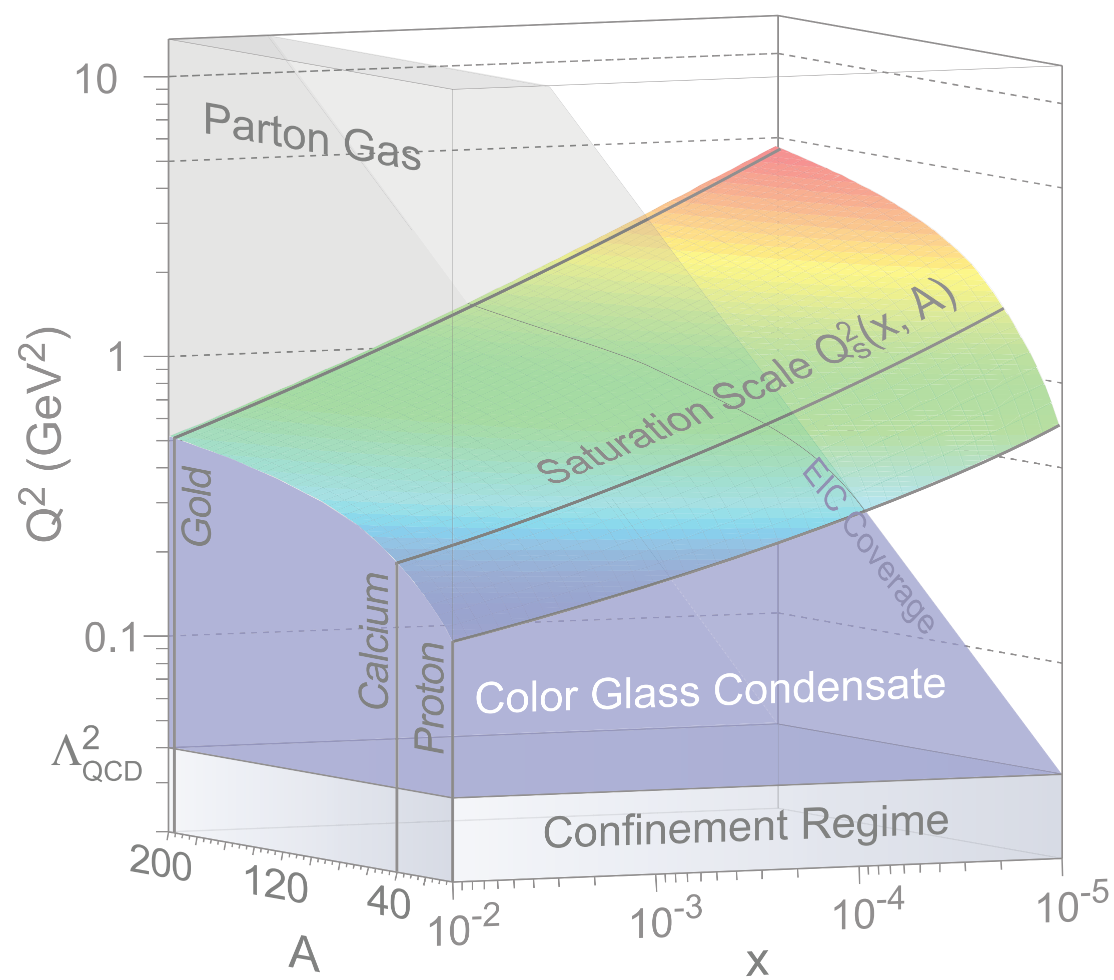
RHIC and the road to an EIC

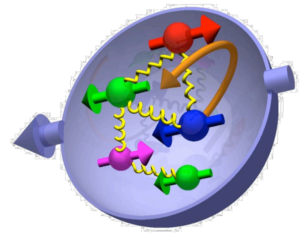




Matthew A. C. Lamont
Brookhaven National Lab

Most compelling physics questions

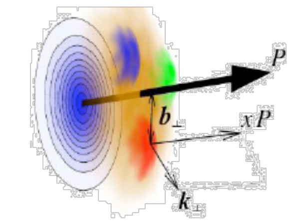
Spin physics



- 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!!

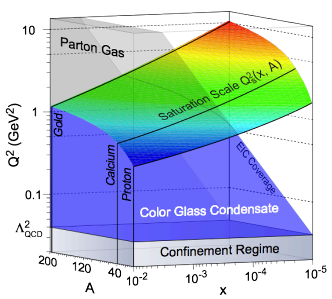
Imaging

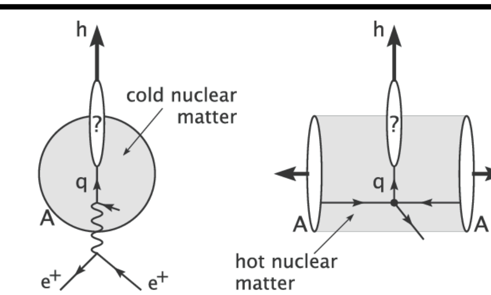


- What is the spatial distribution of quarks/ gluons in nucleons AND nuclei?
- Understand deep aspects of gauge theories revealed by k_T dependent distributions

Possible window to orbital angular momentum

Strong Colour Fields and Hadronisation

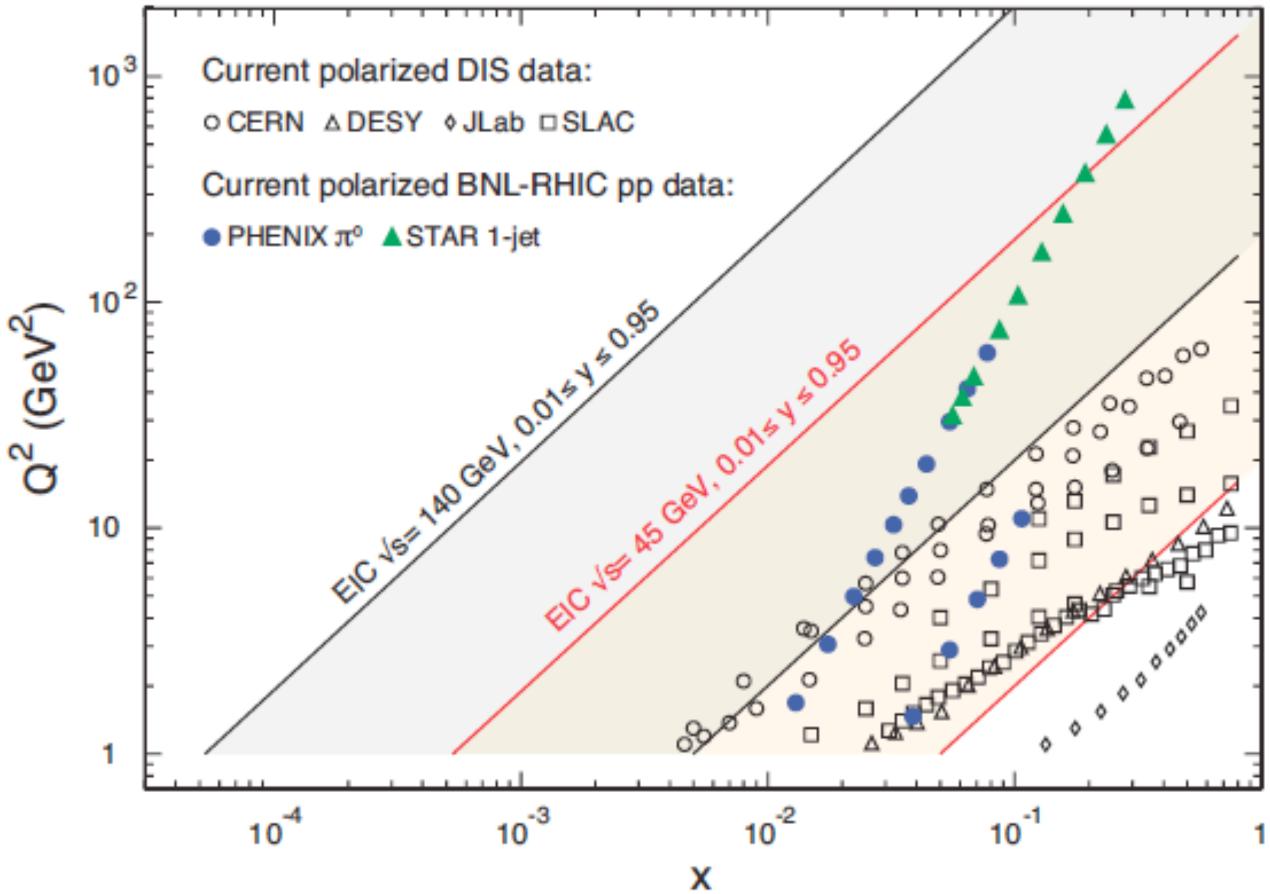




- Quantitatively probe the universality of strong colour fields in A+A, p+A and e+A
- Understand in detail the transition to the non-linear regime of strong gluon fields and the physics of saturation
- How do hard probes in e+A interact with the medium?

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

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

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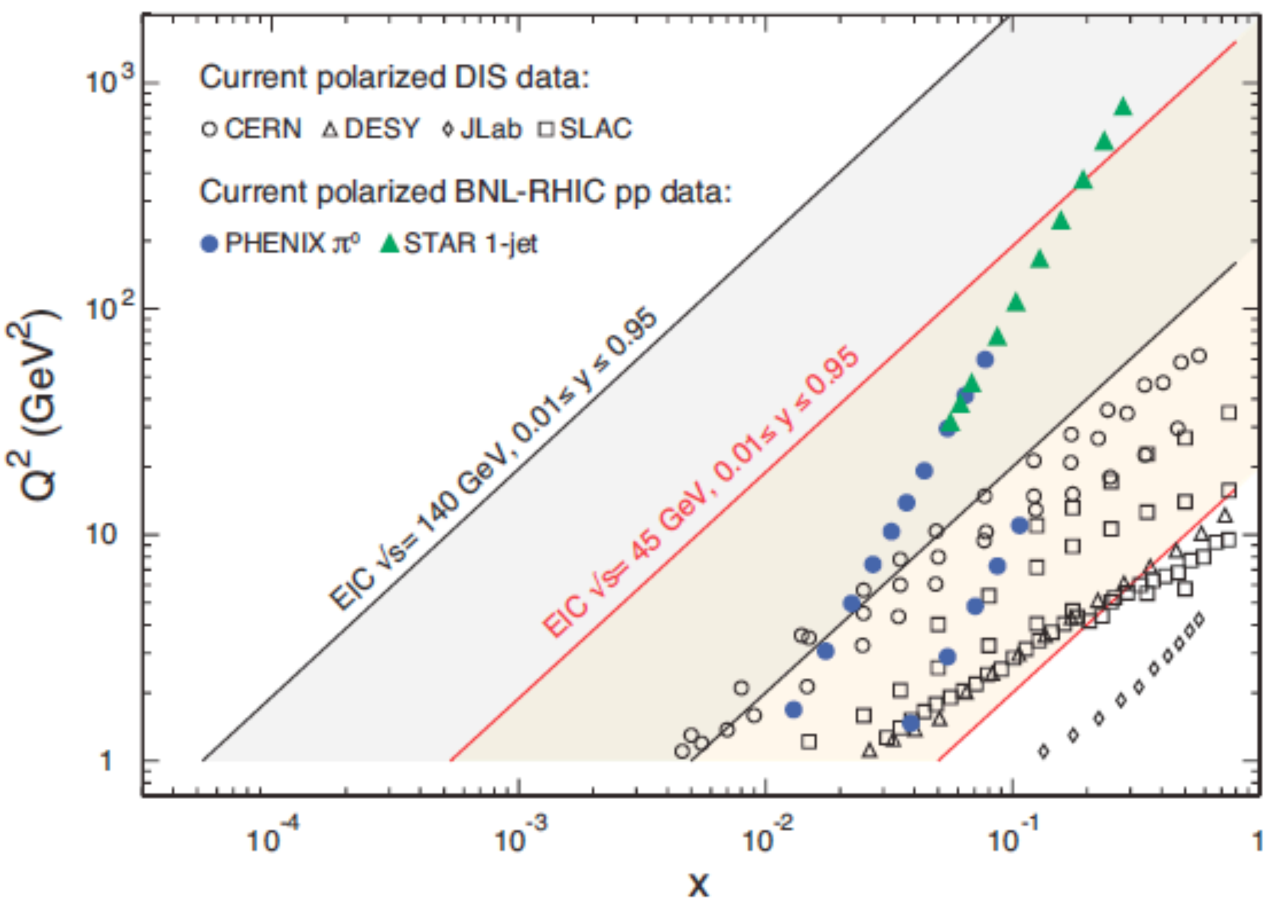

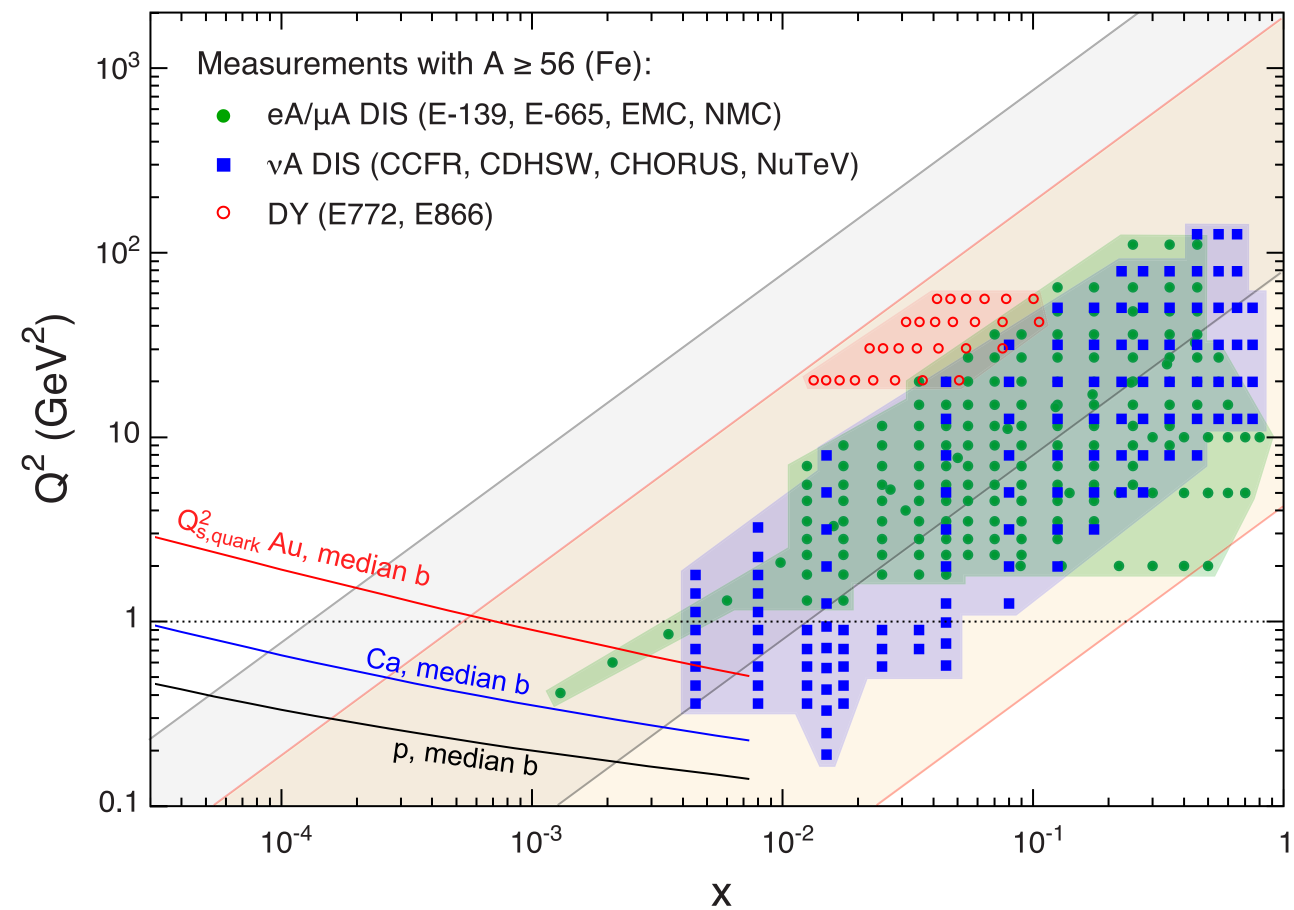

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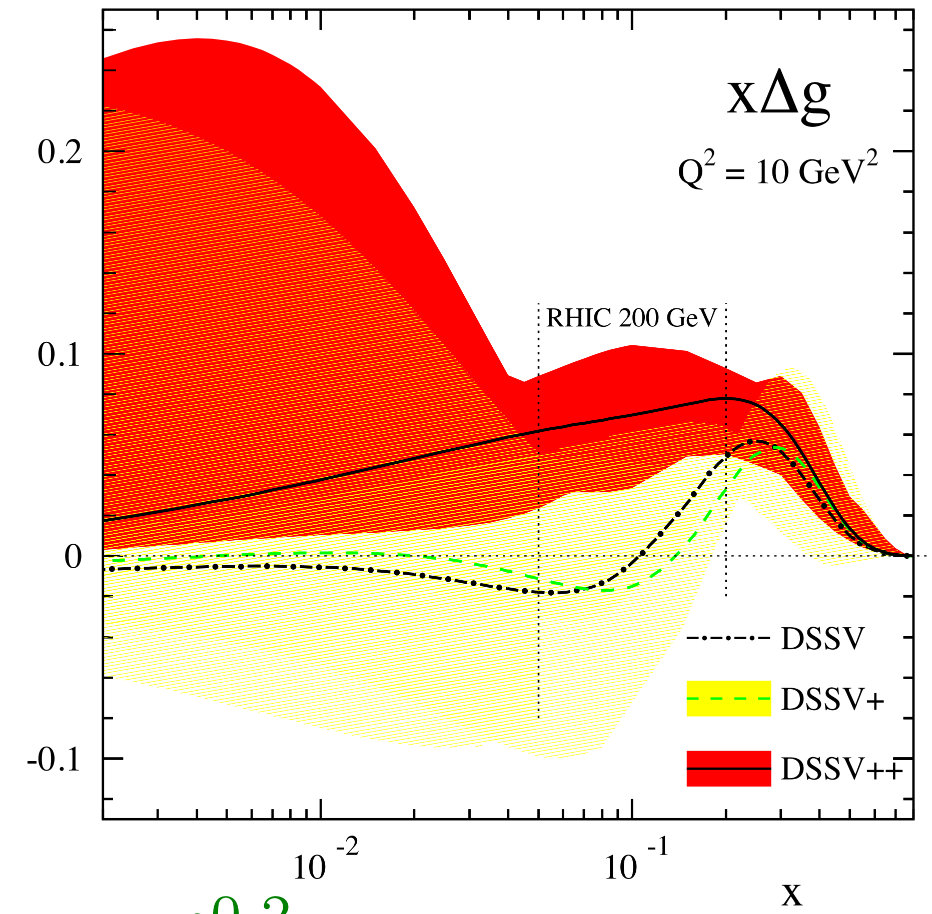
Constraining Δg(x) at RHIC, EIC



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

- 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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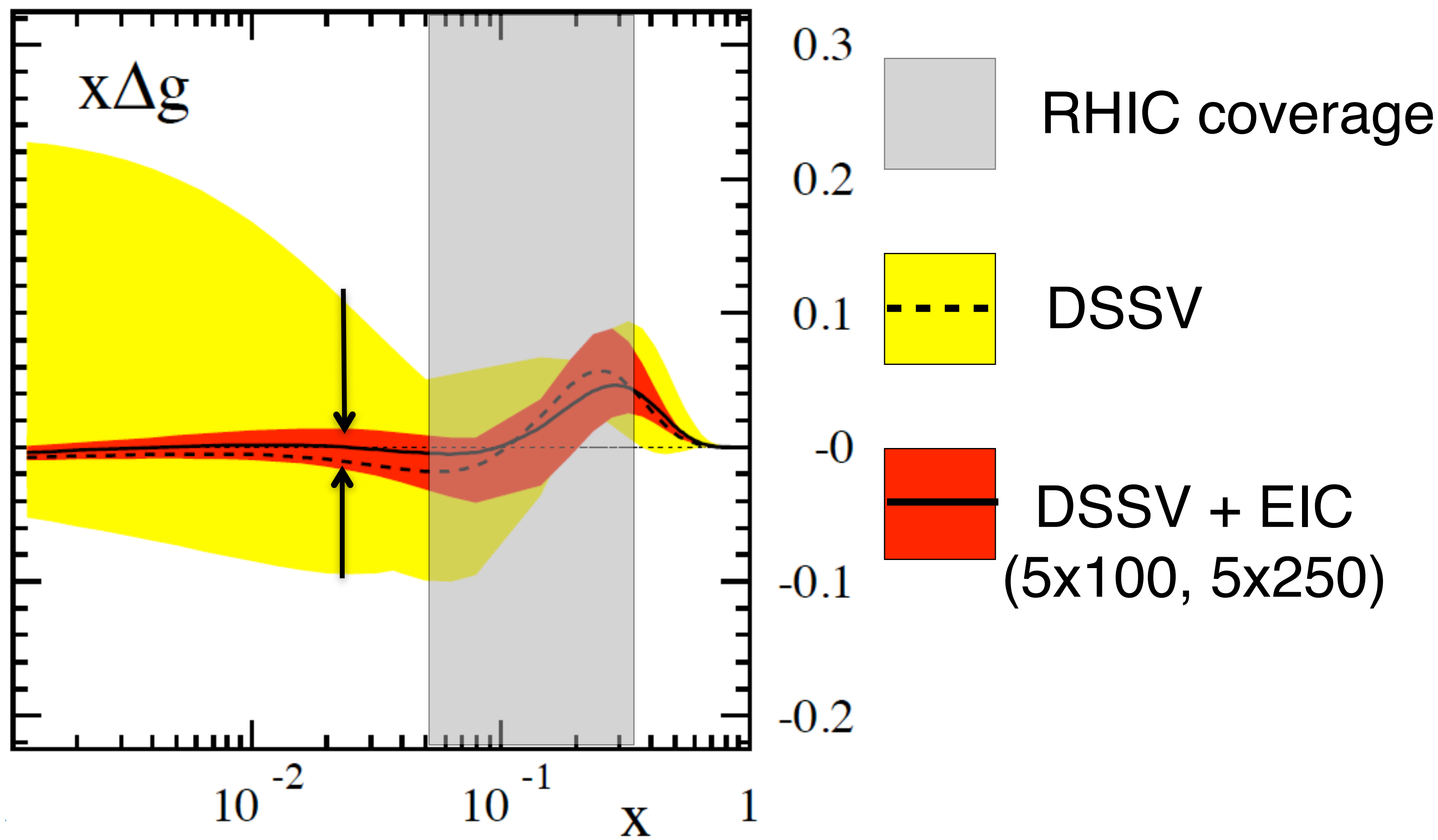

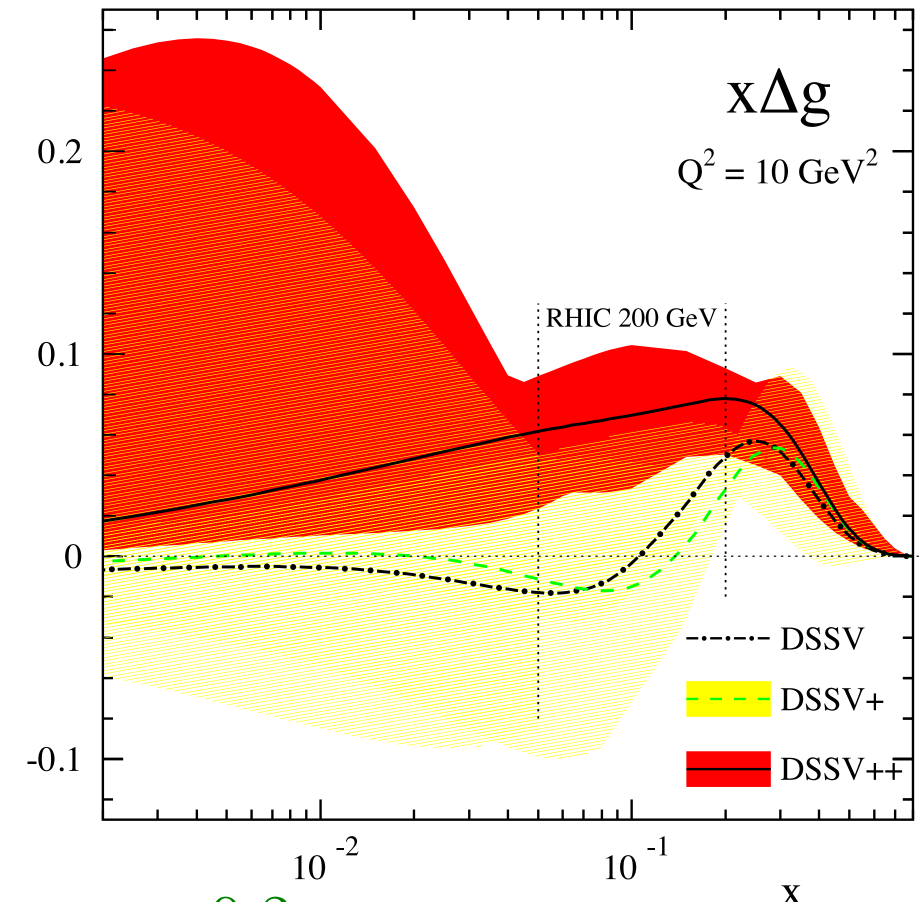

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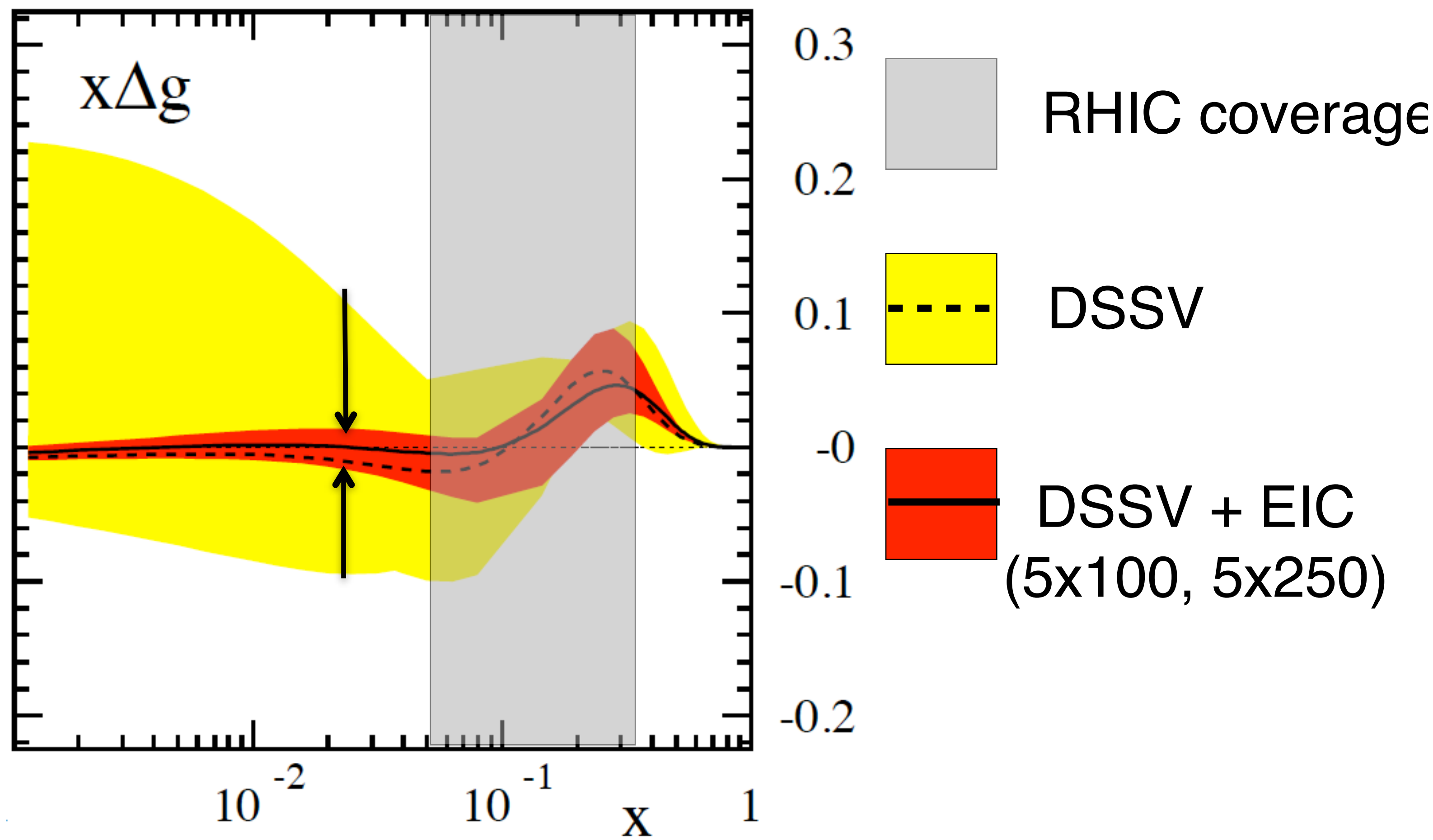

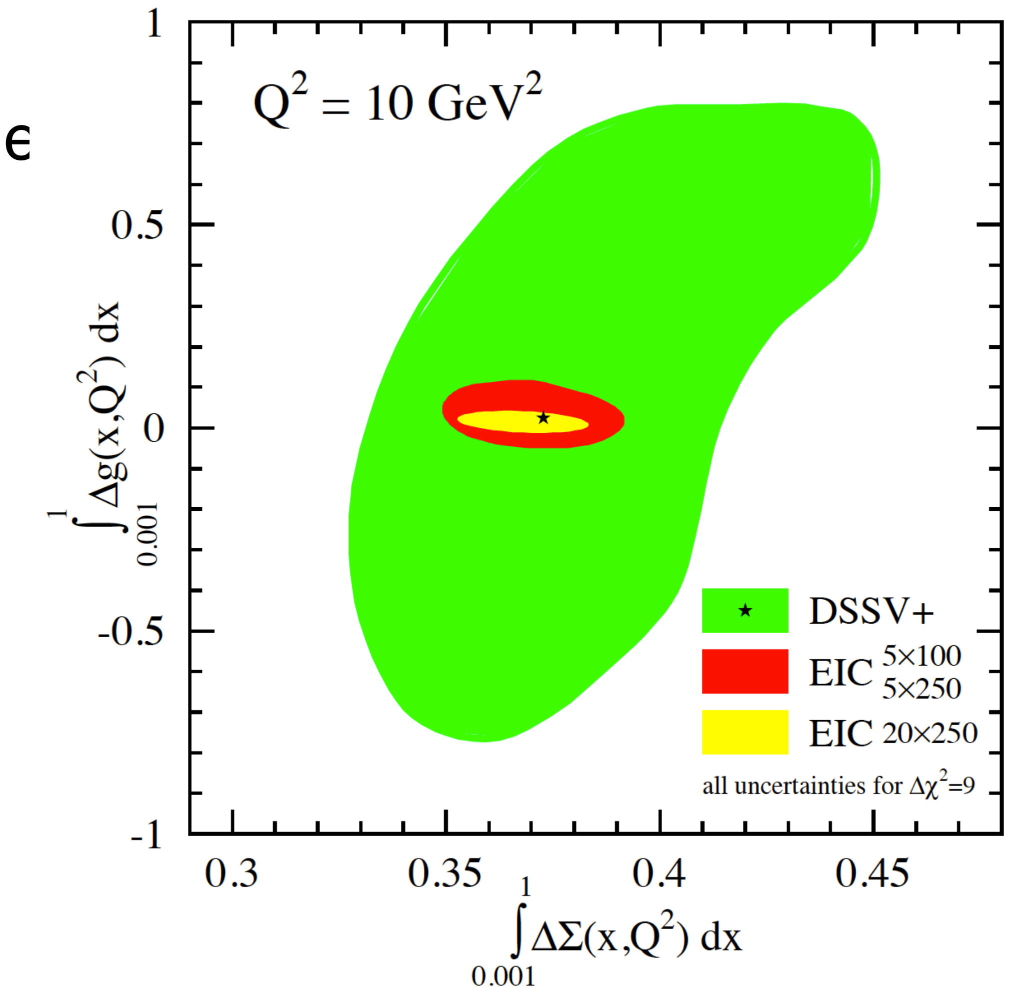

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Nuclear DIS → Structure Functions

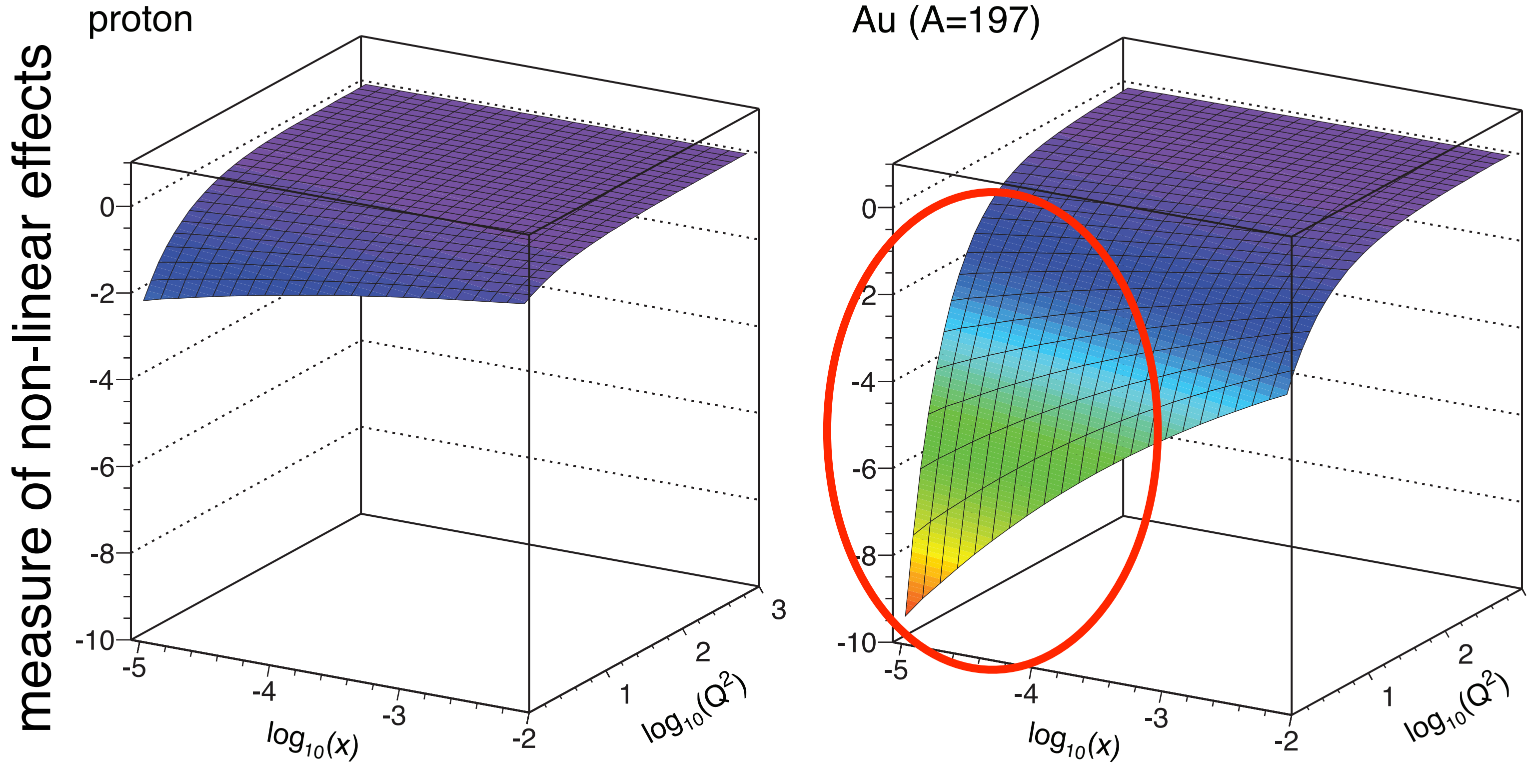
$$\sigma_r(x,Q^2) = F_2^A(x,Q^2) - \frac{y^2}{Y+}F_L^A(x,Q^2) \qquad x = \frac{Q^2}{2pq} = \frac{Q^2}{sy}$$

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



Region with non-linear effects should be seen at at EIC!!

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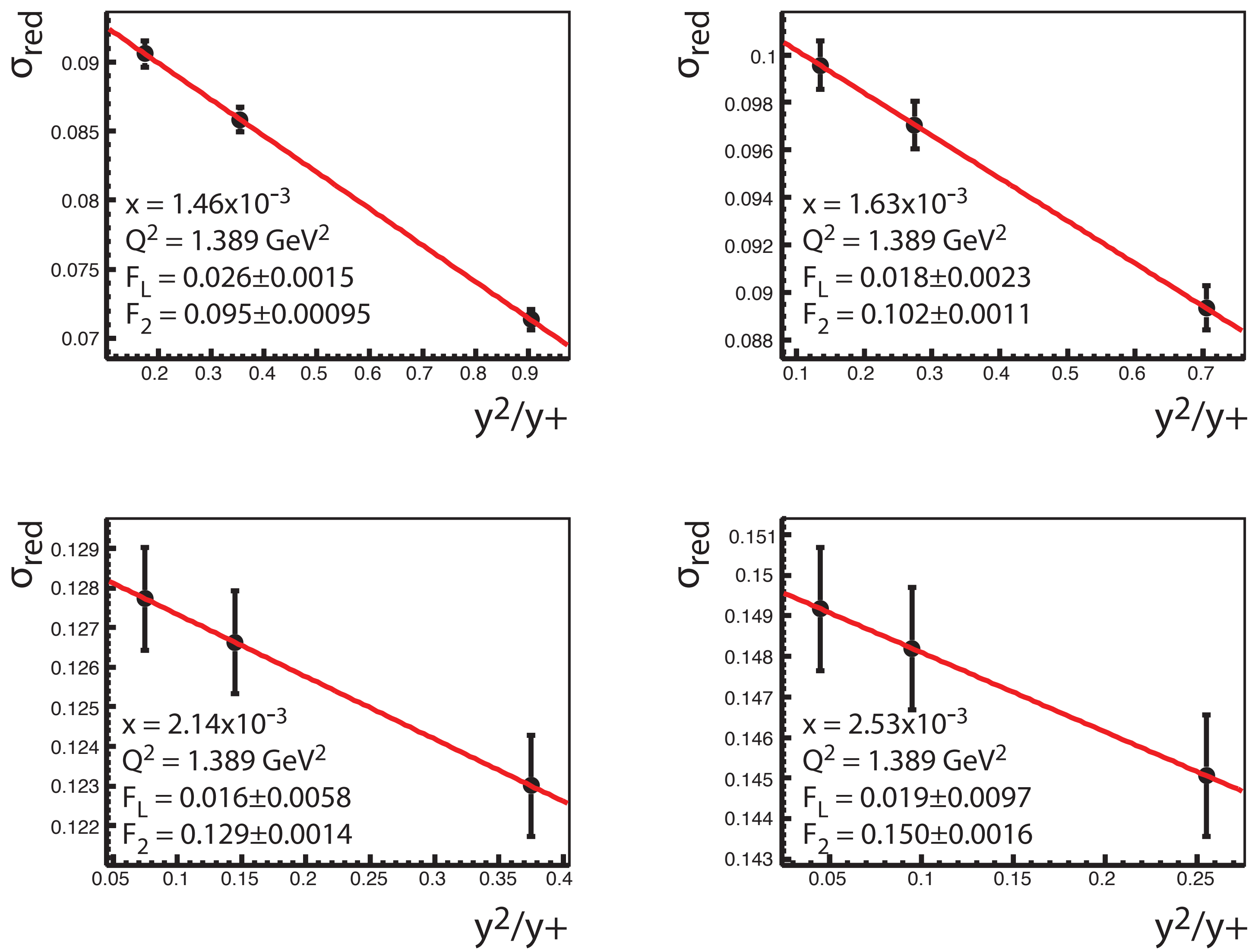

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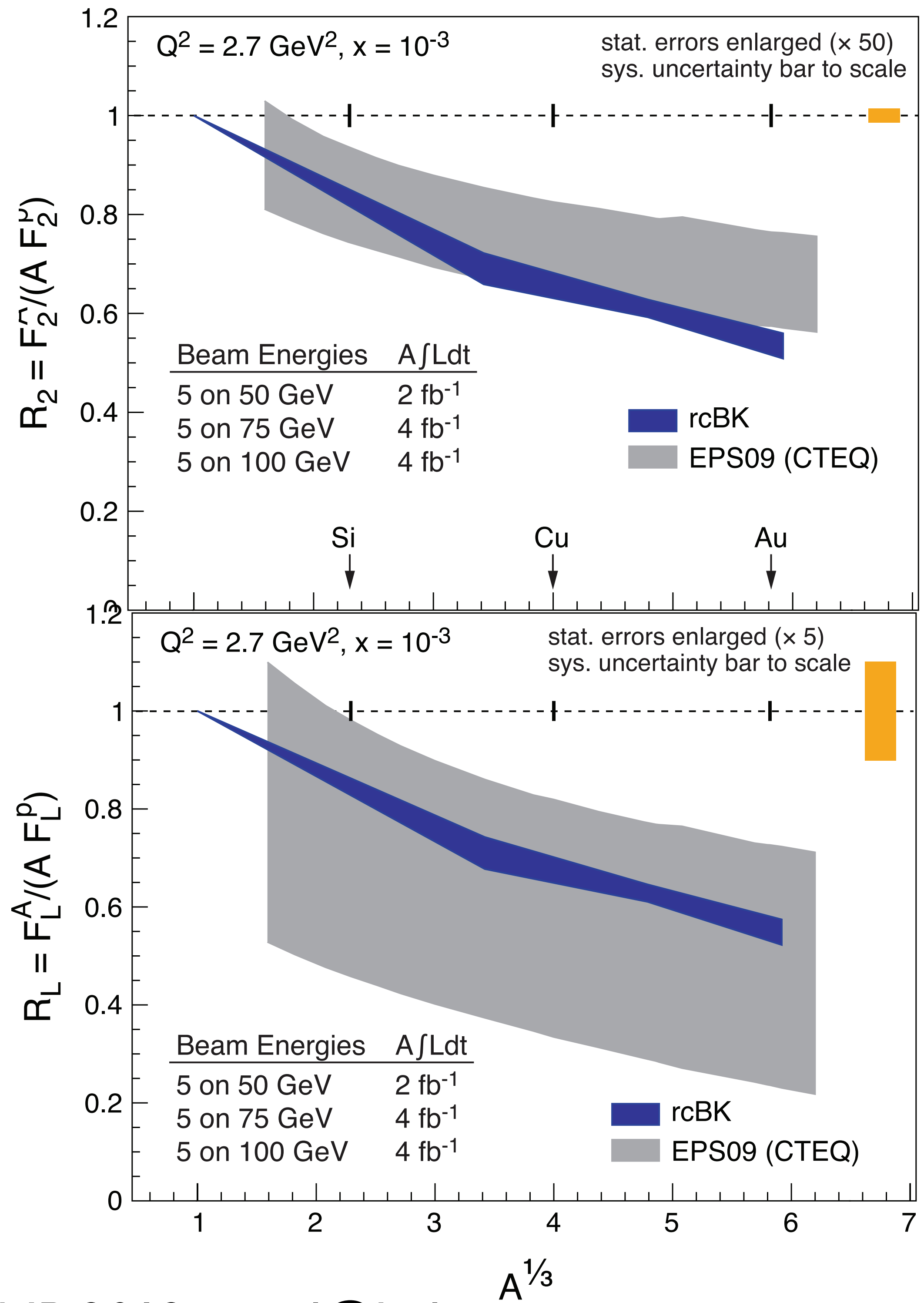
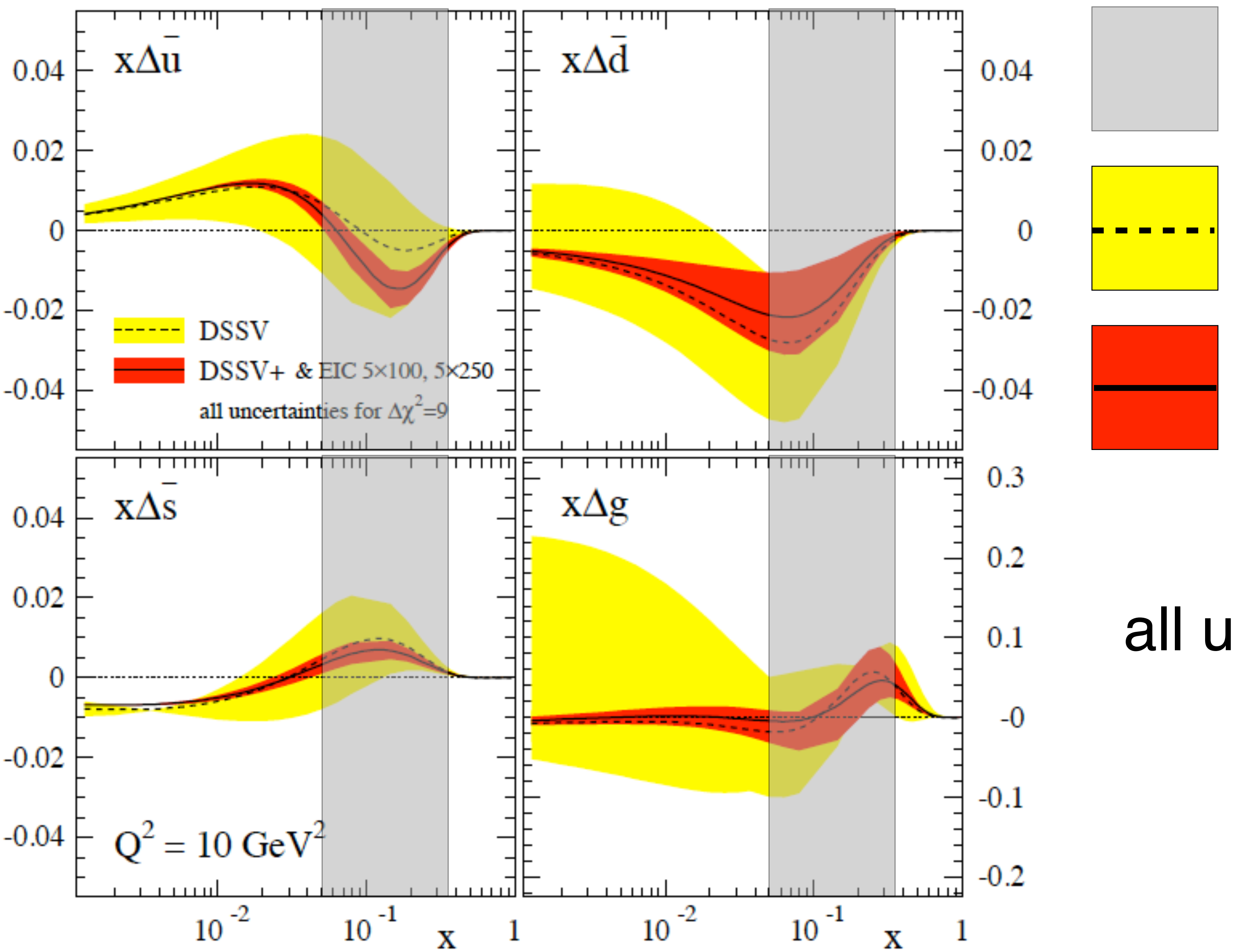


SIDIS in e+p → flavour-separated helicity PDFs

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



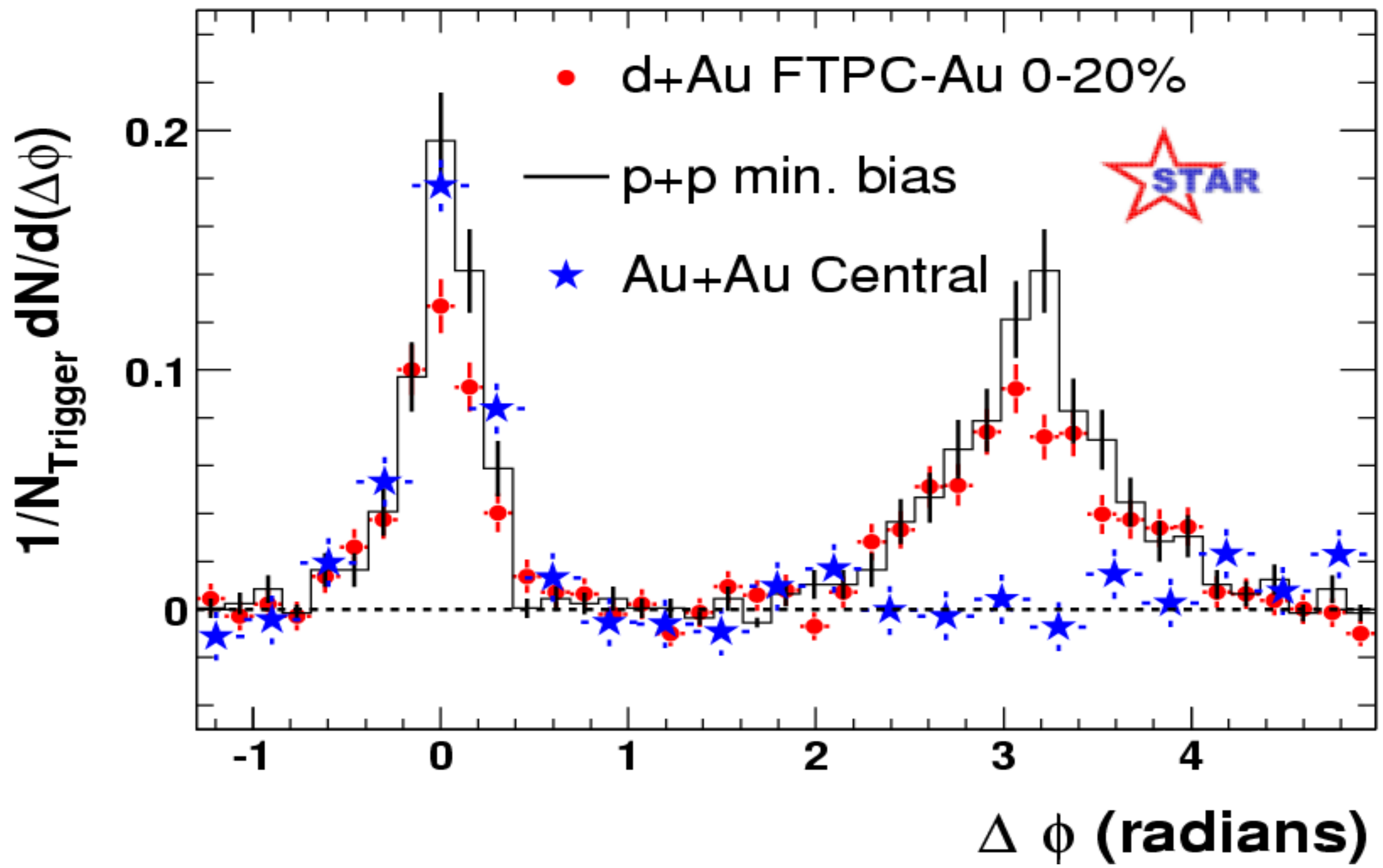
RHIC coverage

DSSV

DSSV + EIC (5x100, 5x250)

all uncertainties for $\Delta\chi^2$=9

SIDIS in e+A → di-hadron correlations



- Long history of di-hadron correlation measurements in p+p, d+A and A +A collisions
  - ➡ central rapidity show attenuation of away-side correlation in A+A but not p +p nor d+A collisions
    - ‣ Final state effect

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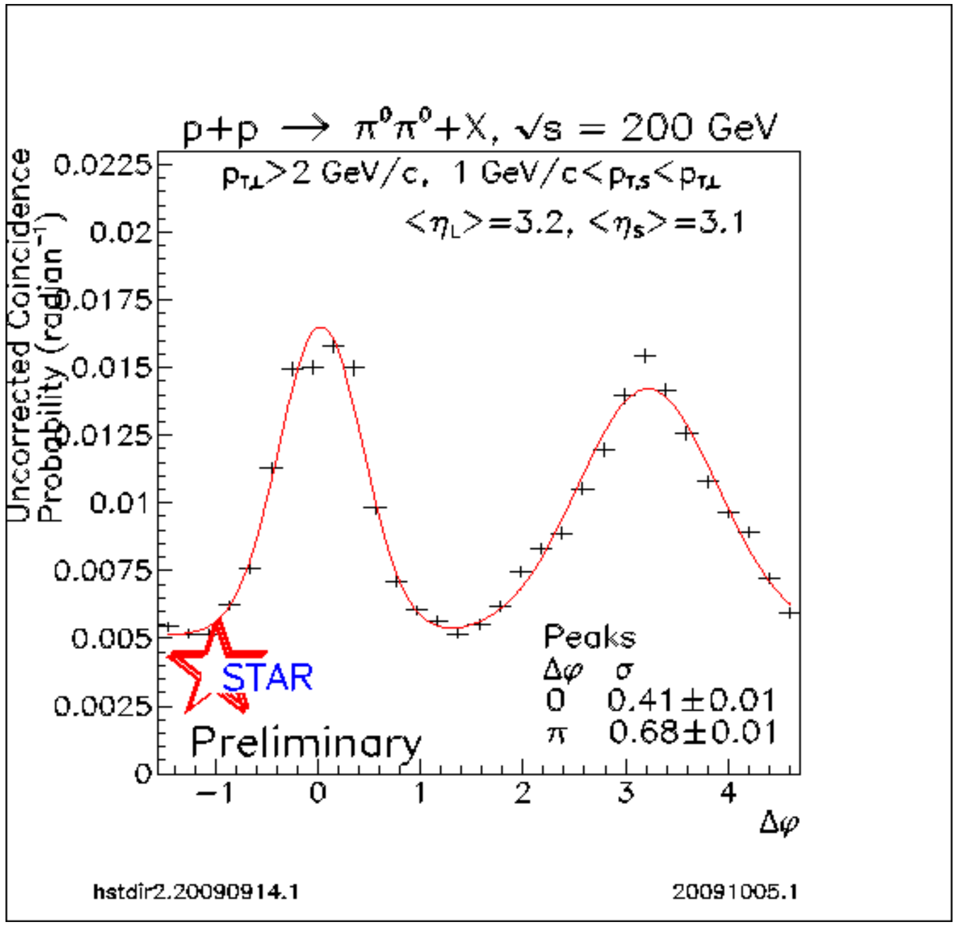

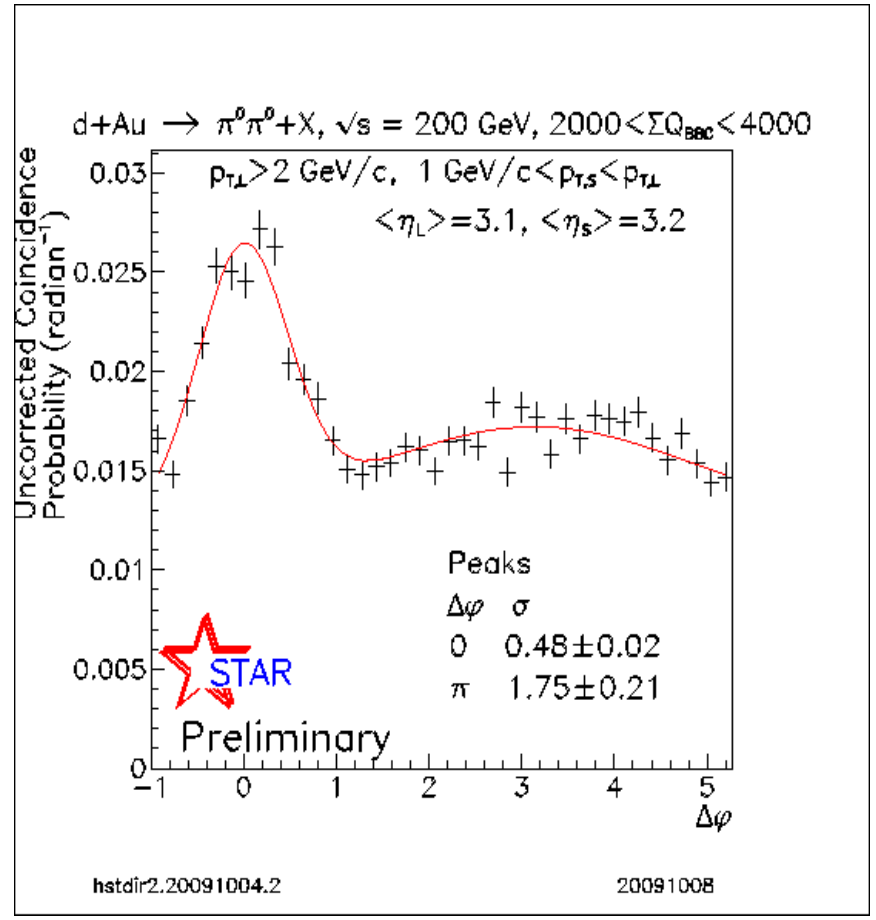

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    - Best evidence so far for manifestation of saturation effects

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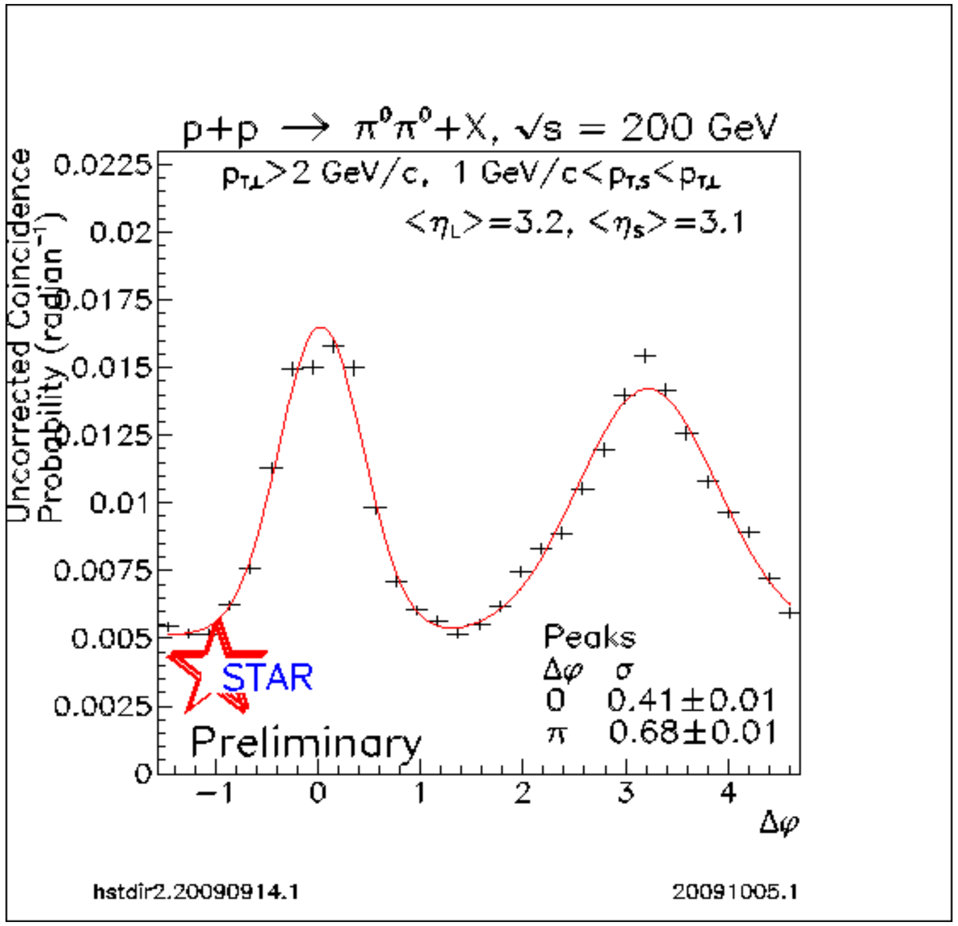

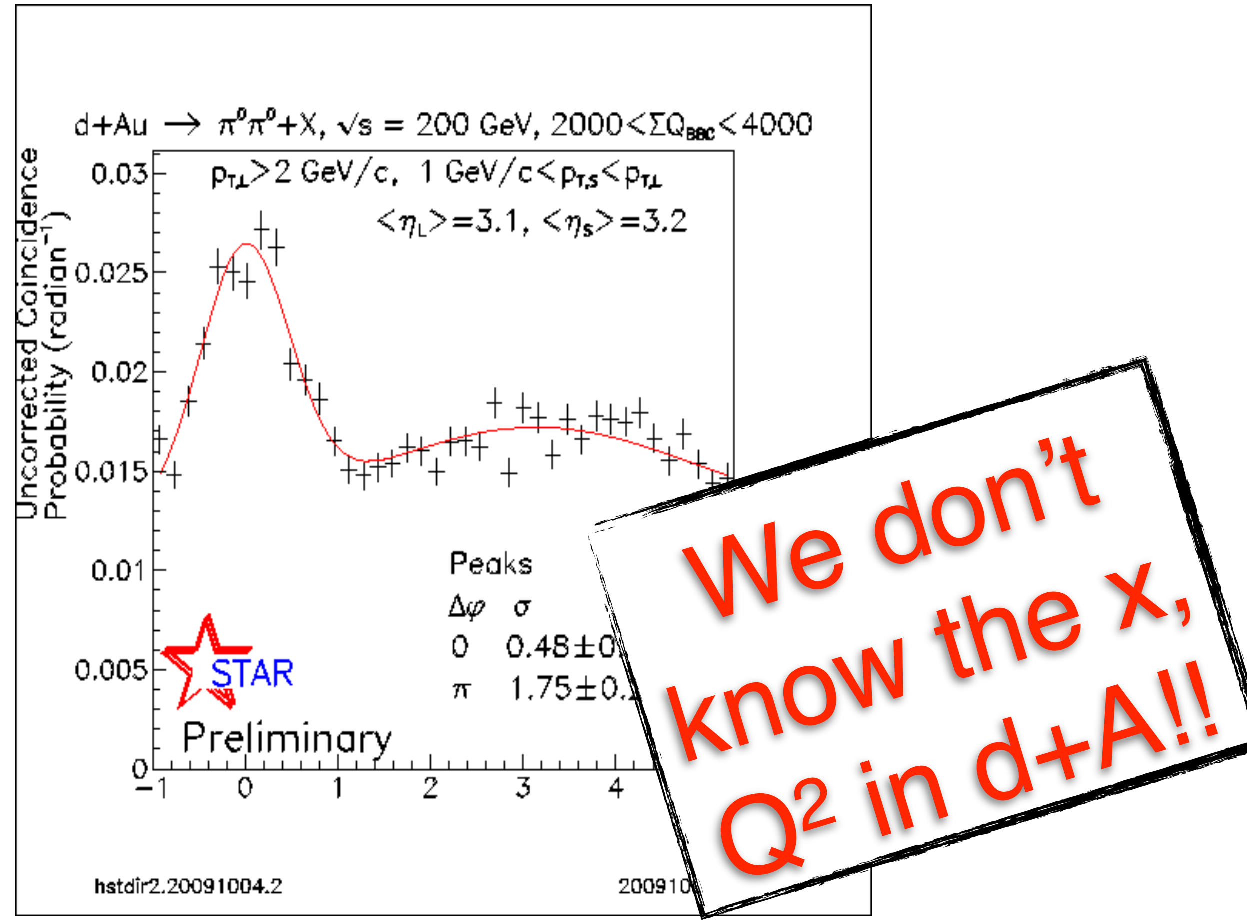

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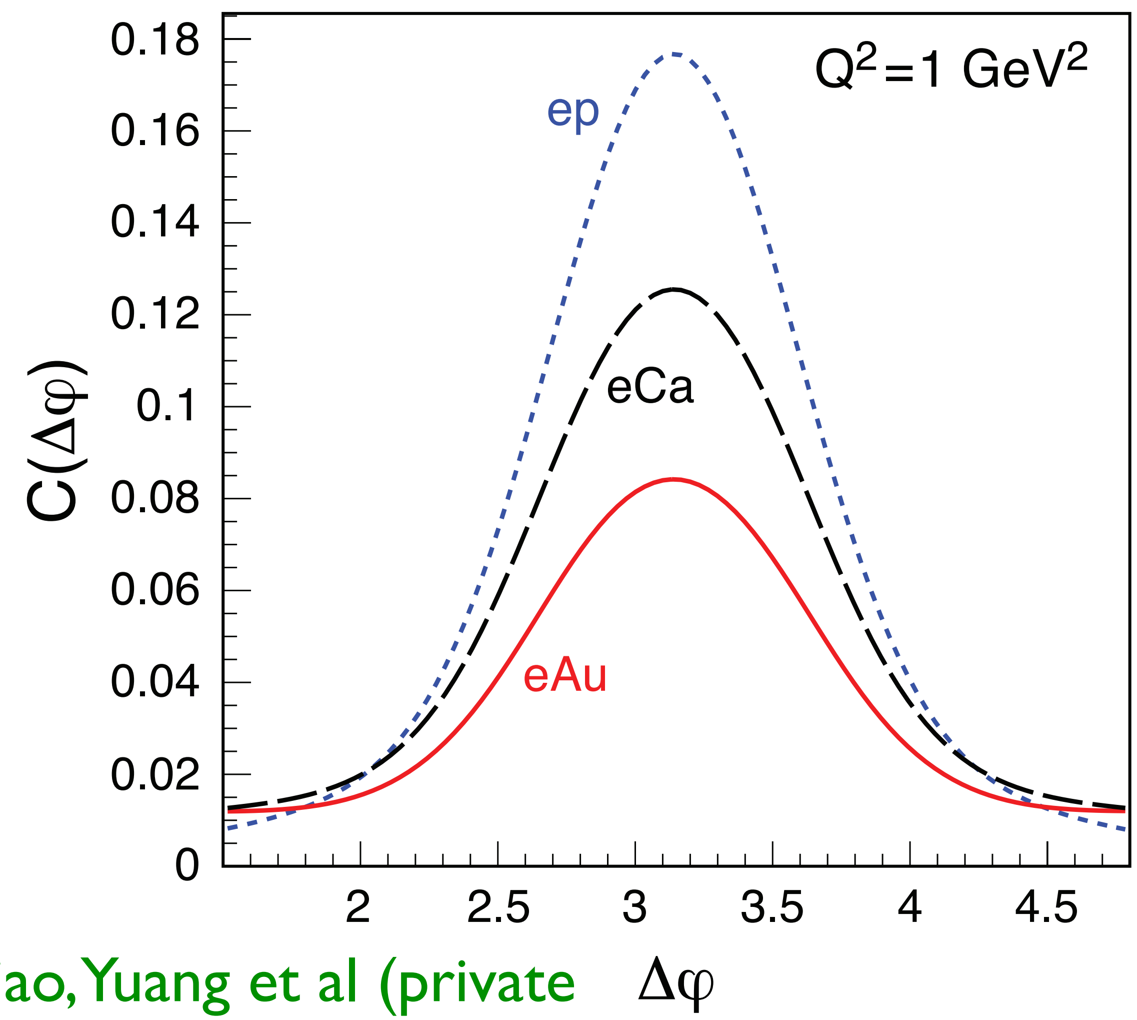

Xiao, Yuang et al (private communication)

- 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

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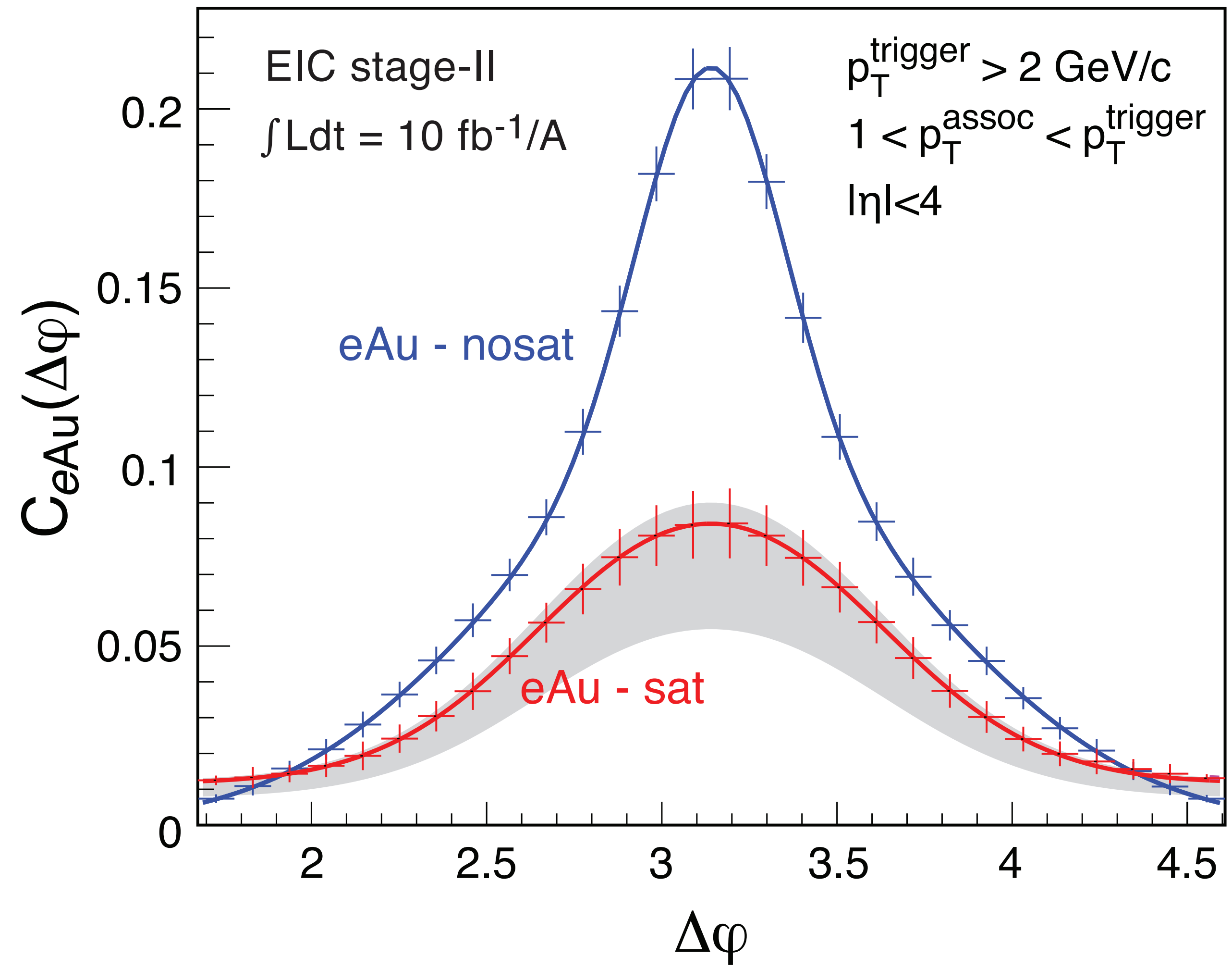

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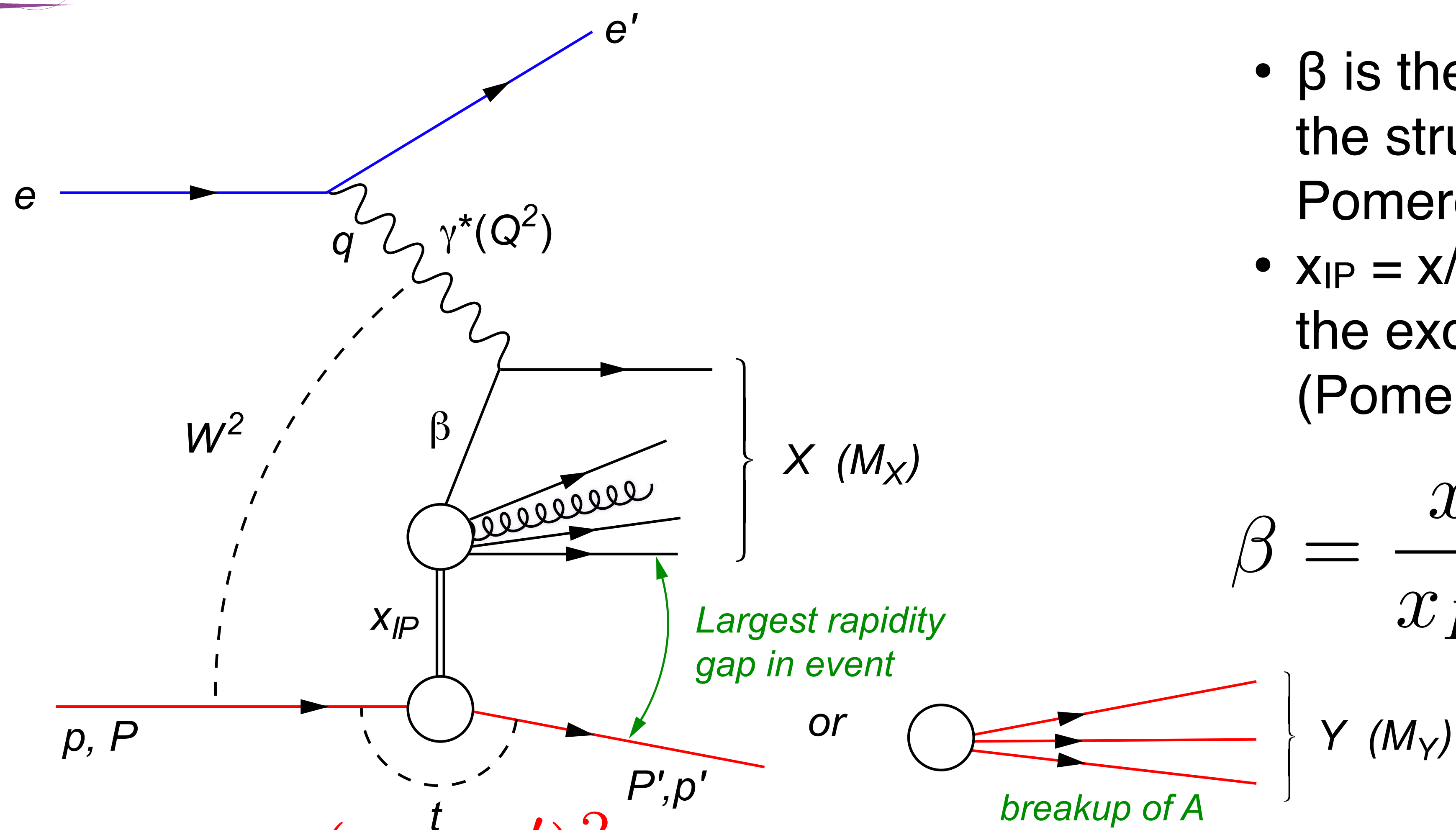
Exclusive processes in e+A - diffraction



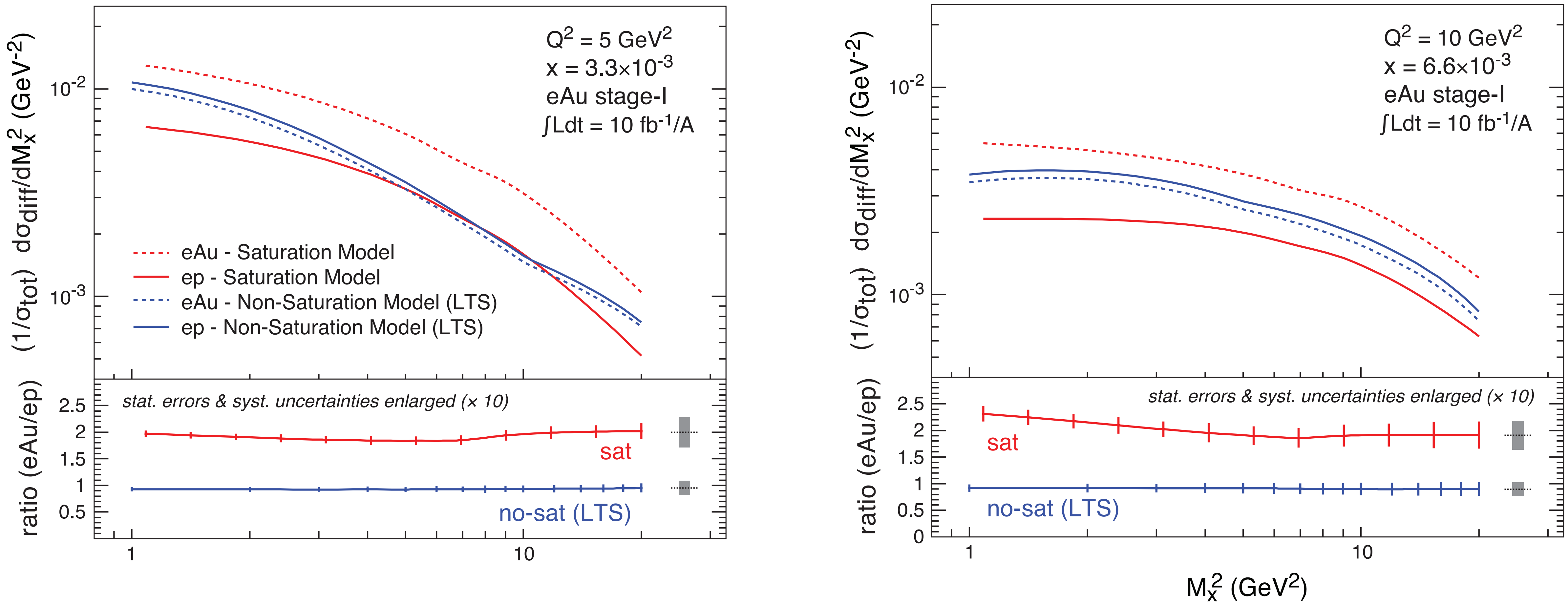
$$t = (p - p')^2$$

- 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

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

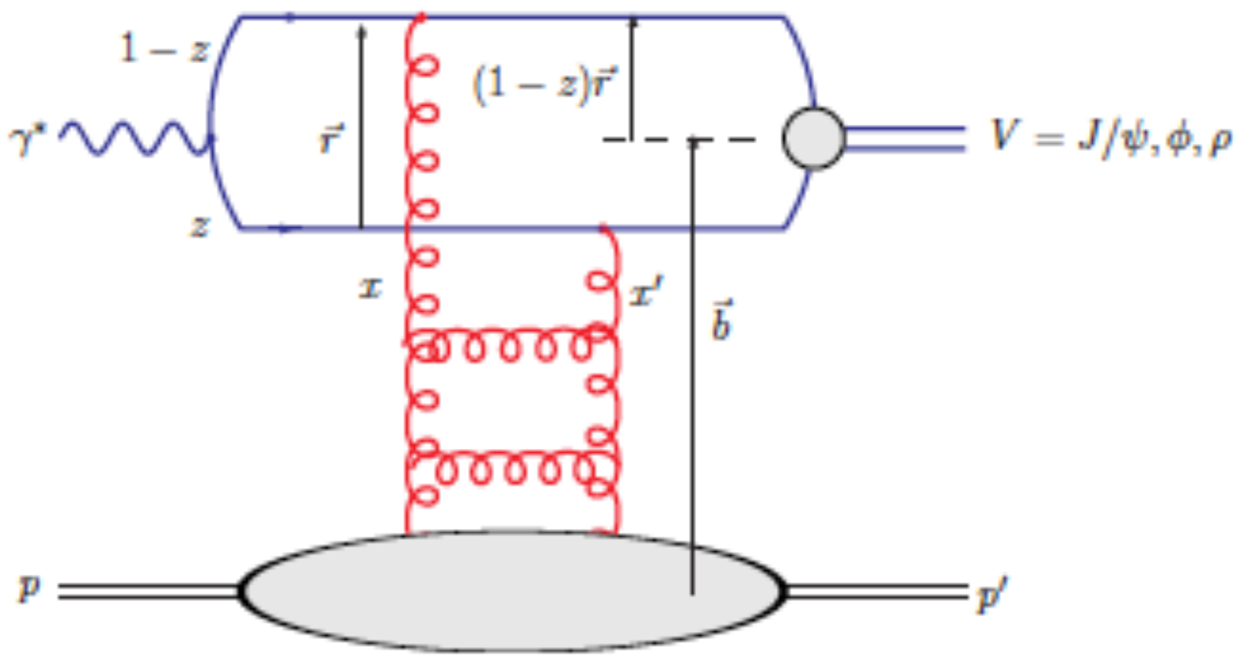
- Diffraction in e+p:
  - ➡ HERA: 15% of all events are diffractive
- Diffraction in e+A:
  - ➡ Predictions: $\sigma_{diff}/\sigma_{tot}$ in e+A ~25-40%
  - ➡ Coherent diffraction (nuclei intact)
  - ➡ Incoherent diffraction: breakup into nucleons (nucleons intact)

Day 1: Diffractive Cross-sections

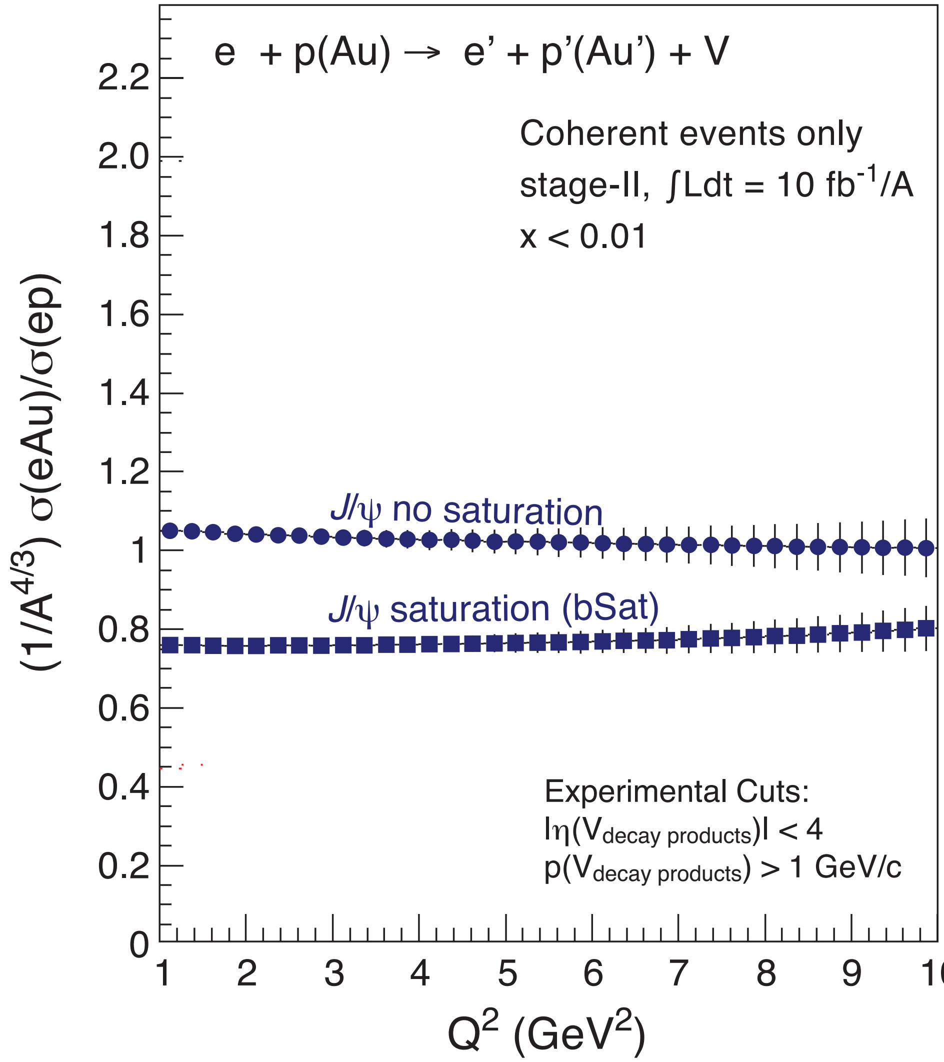


- Ratio of diffractive-to-total cross-section drastically different between saturation (Marquet) and non-saturation (Frankfurt, Guzey, Strikman) models
- Expected experimental error bars (simulated for 10 fb^{-1} of data) can distinguish between the two scenarios

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
- ϕ shows a much larger difference
  - ➡ wave function for ϕ is larger and hence more sensitive to saturation effects

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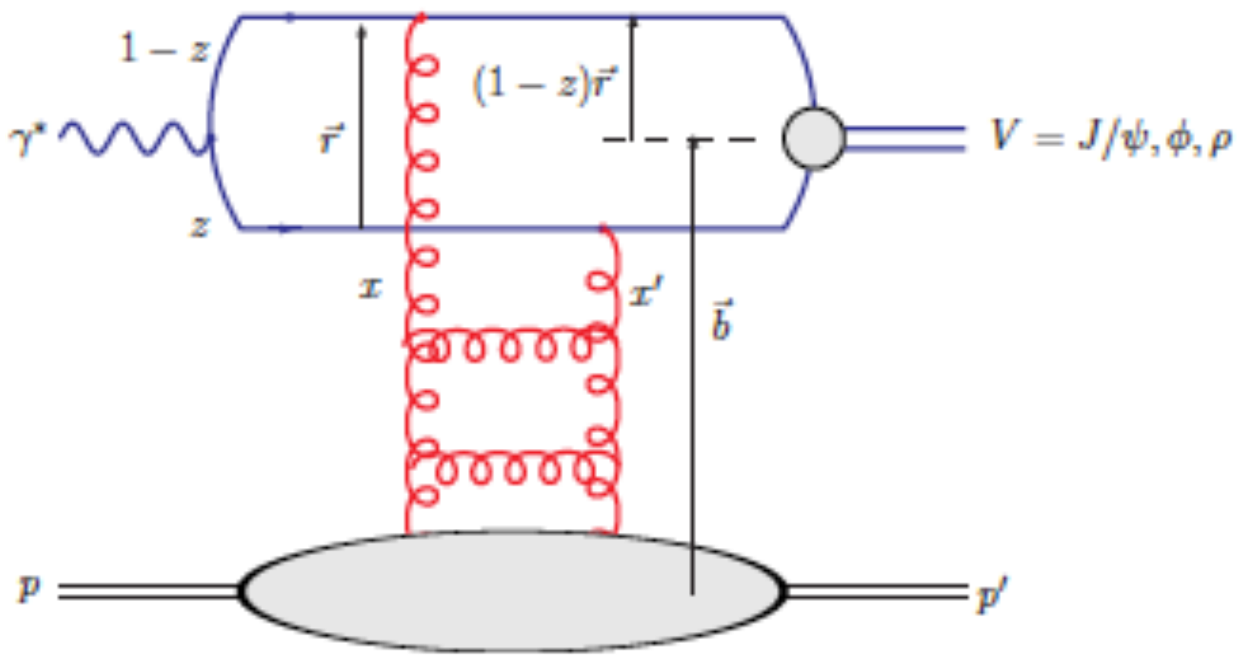

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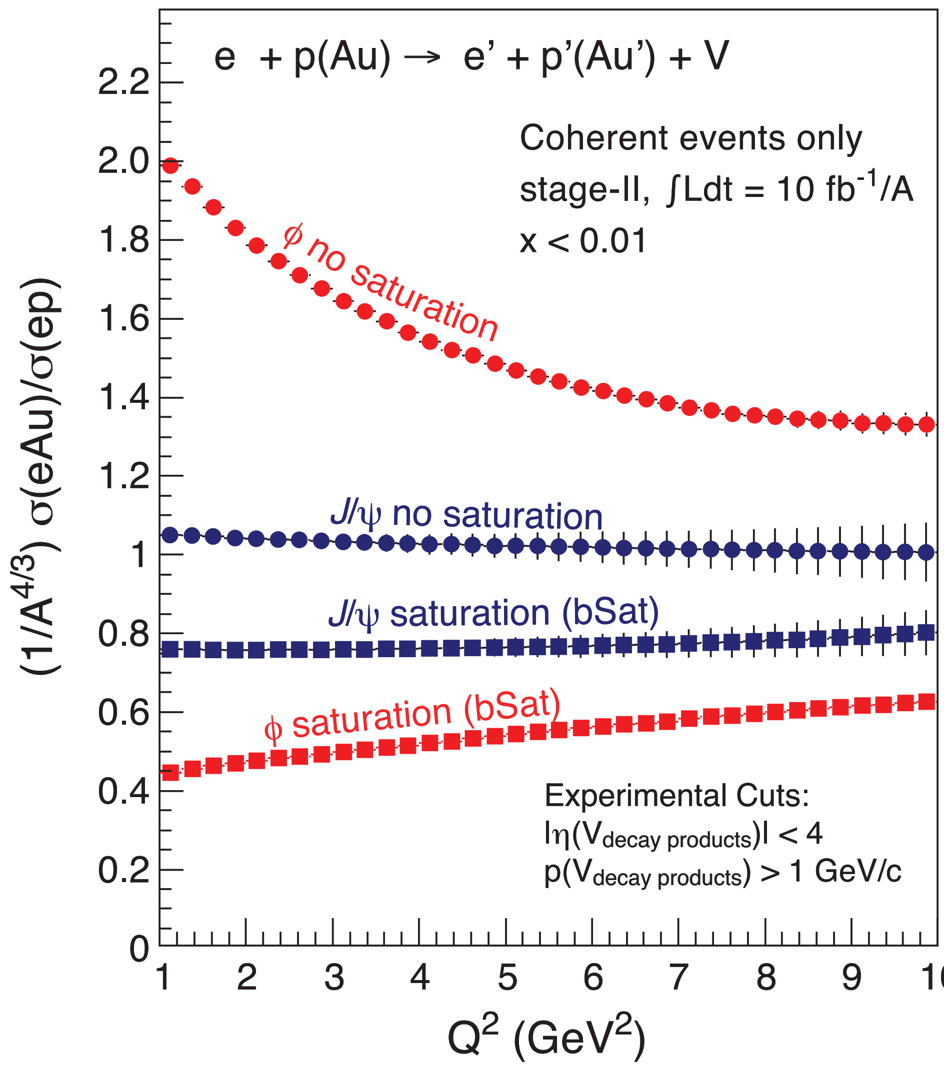

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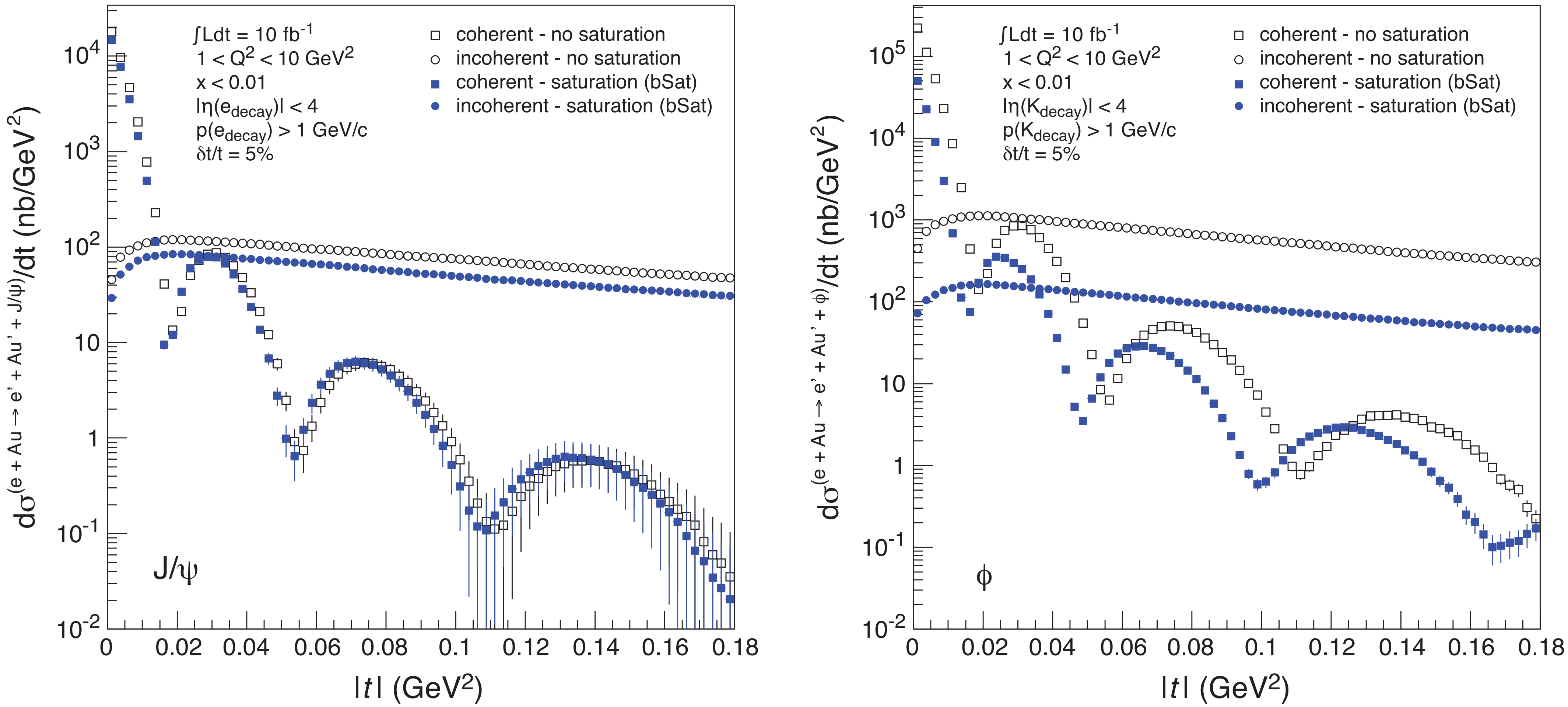
Exclusive Vector Meson Production in e+A



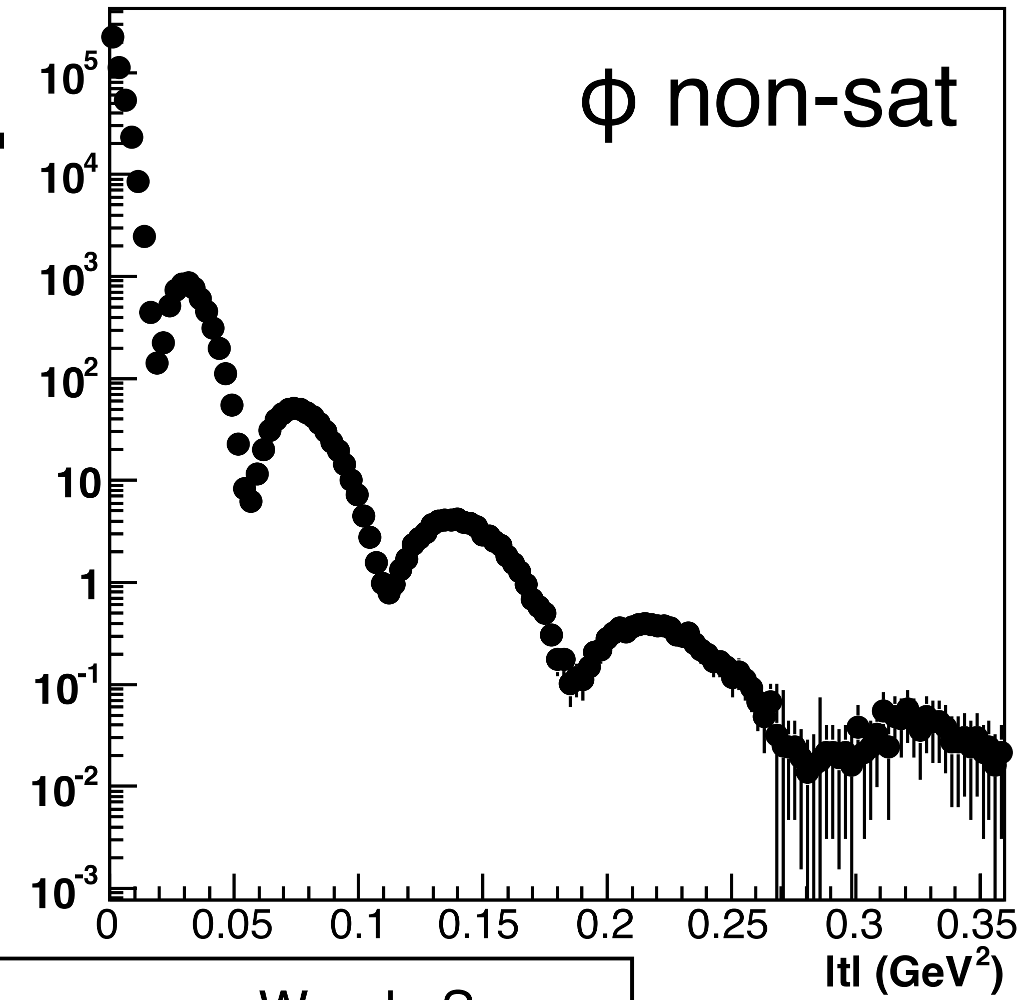
- Low-t: coherent diffraction dominates - gluon density
- High-t: incoherent diffraction dominates - gluon correlations
  - ➡ Need good breakup detection efficiency to discriminate between the two scenarios
    - unlike protons, forward spectrometer won't work for heavy ions
      - measure emitted neutrons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

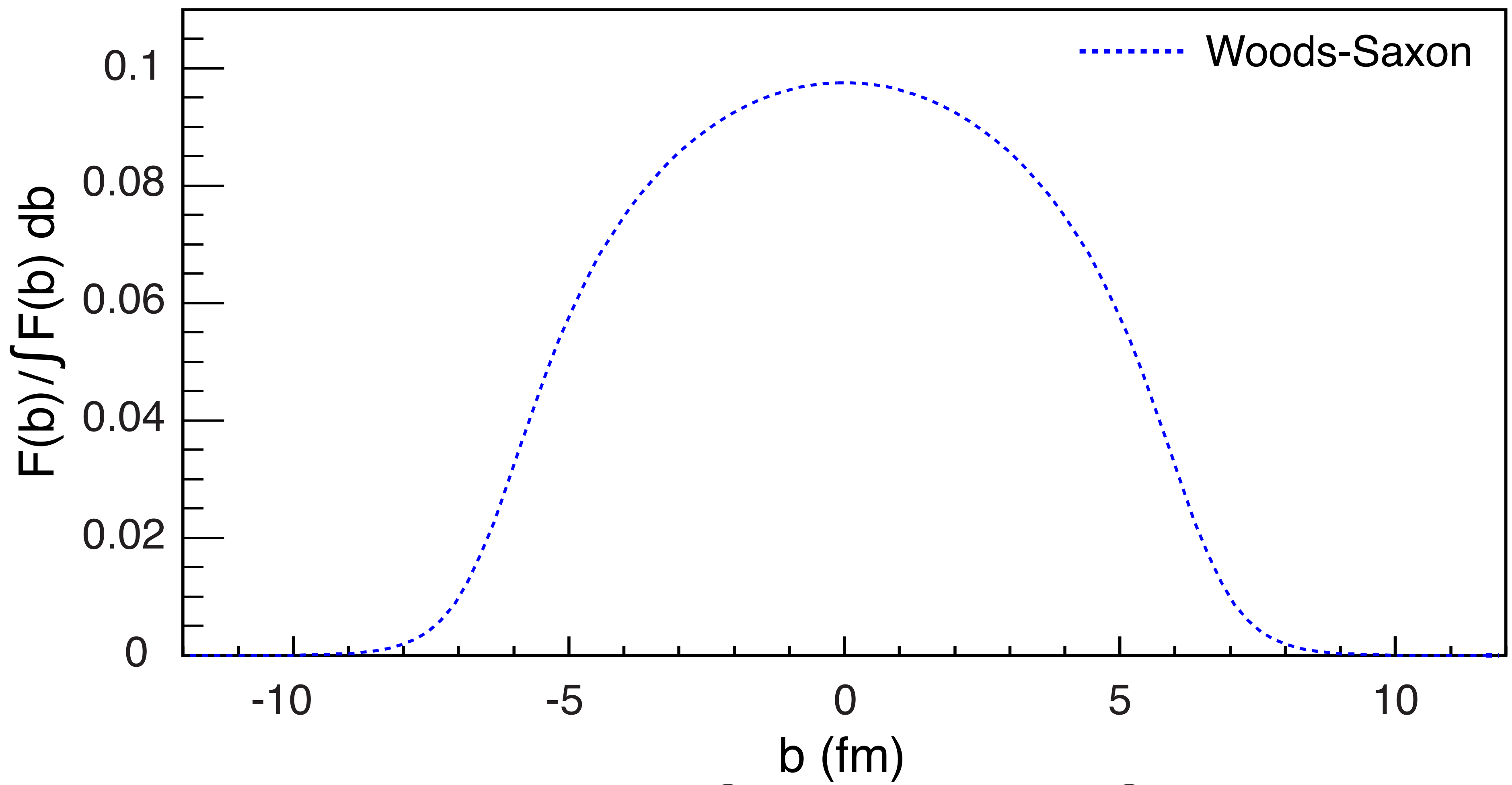
Finding the source...

- 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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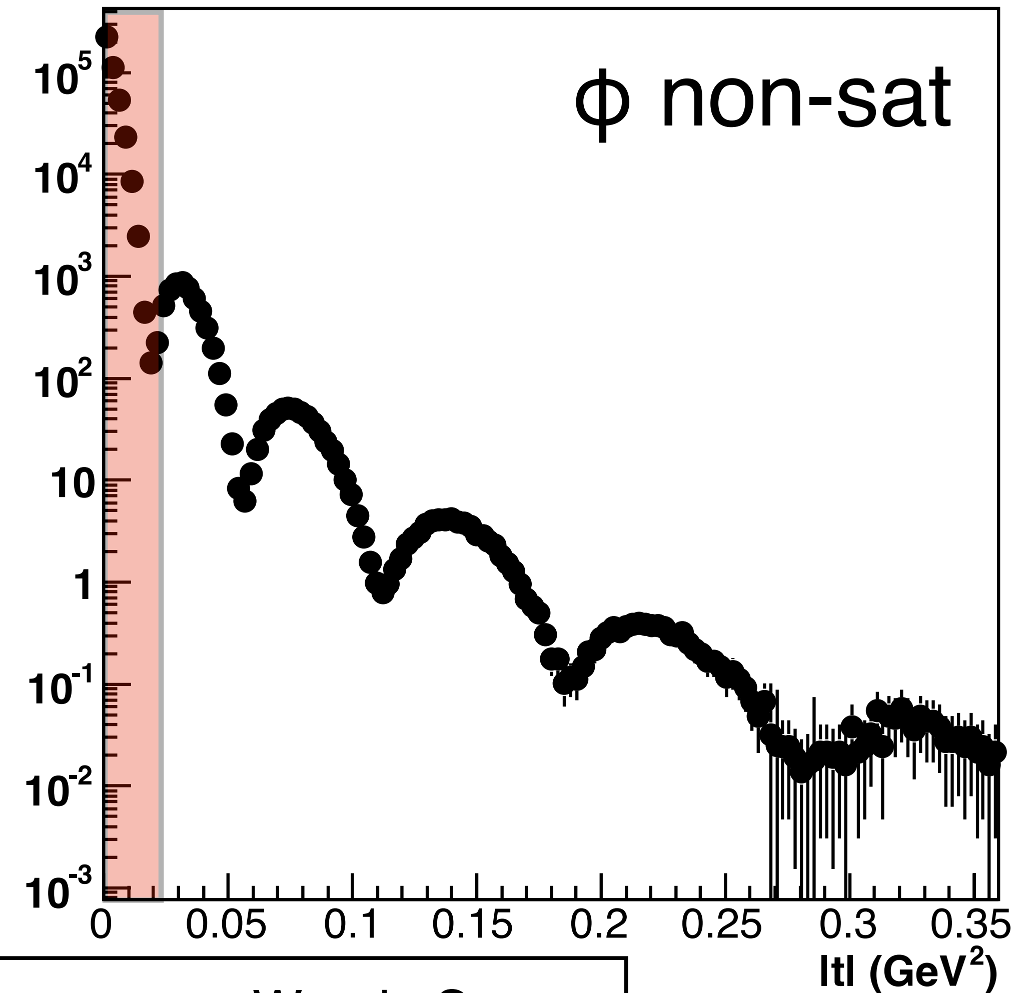

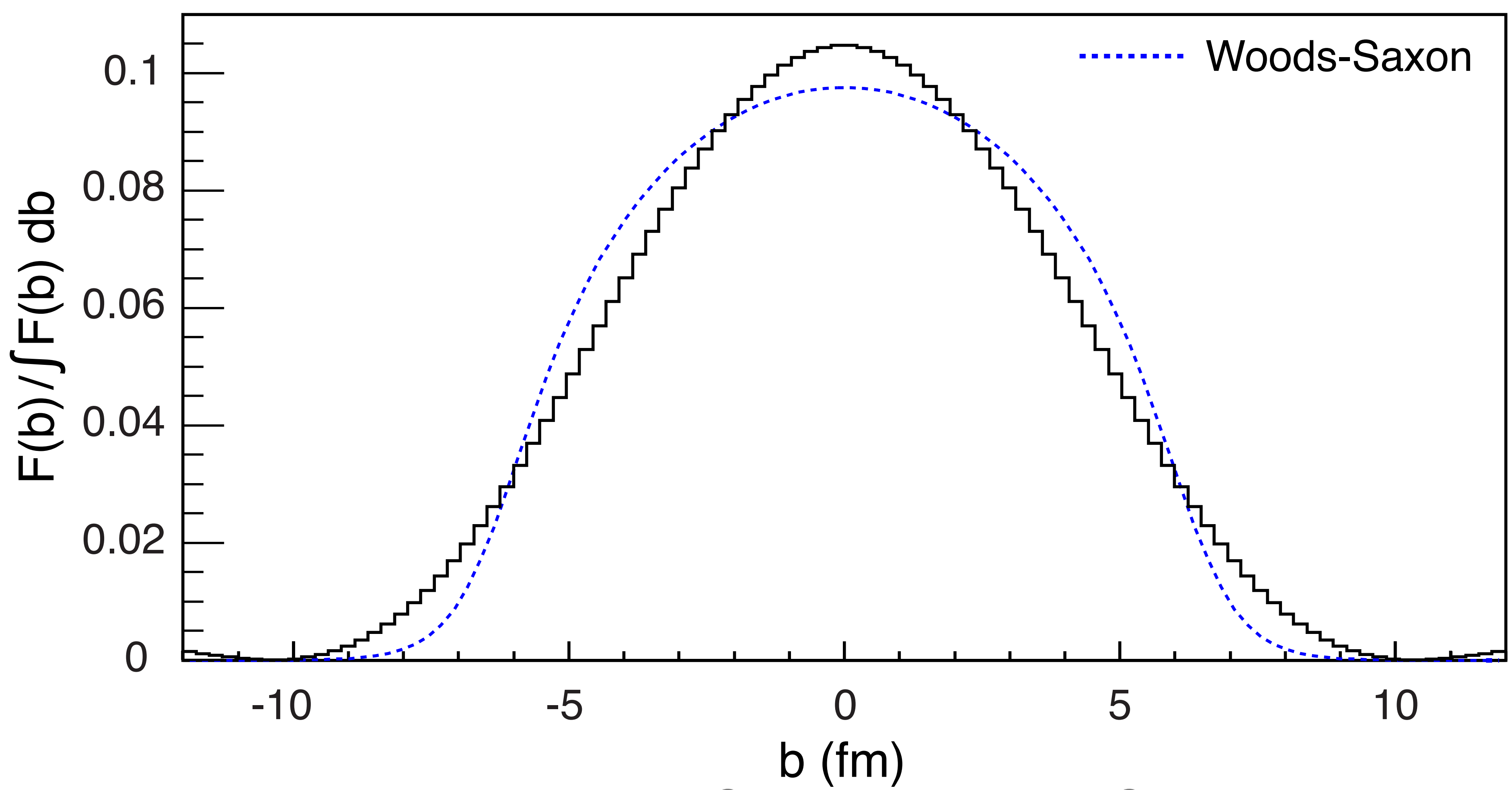

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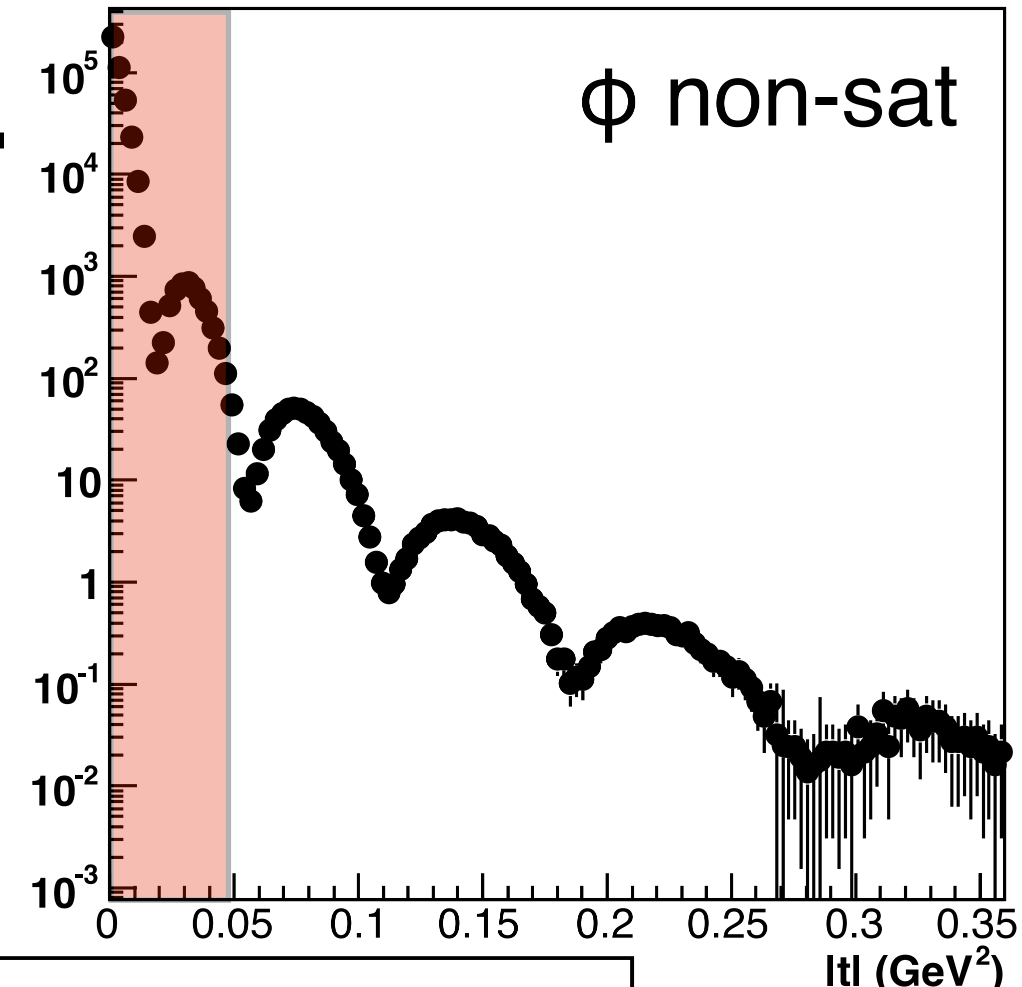

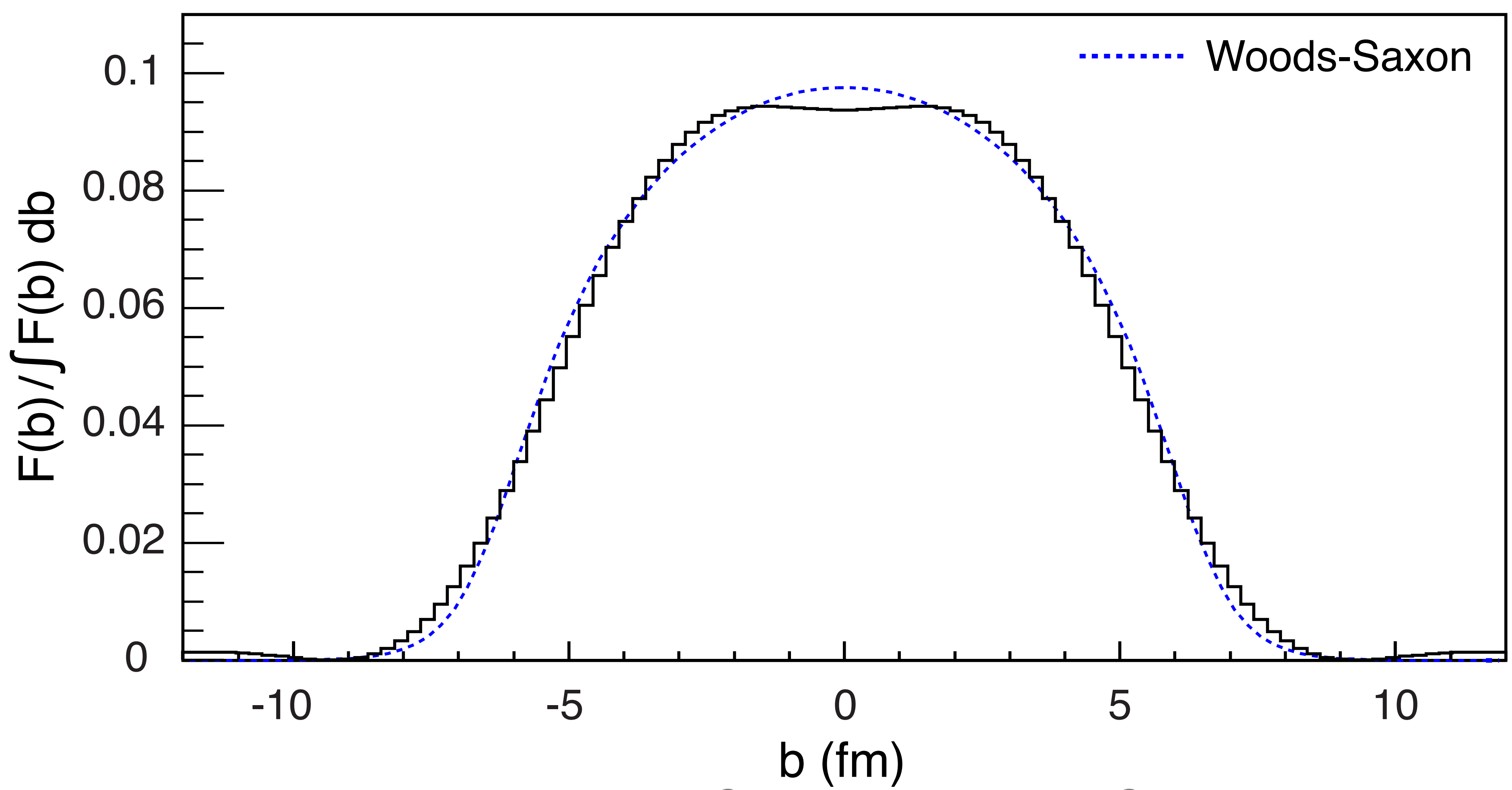

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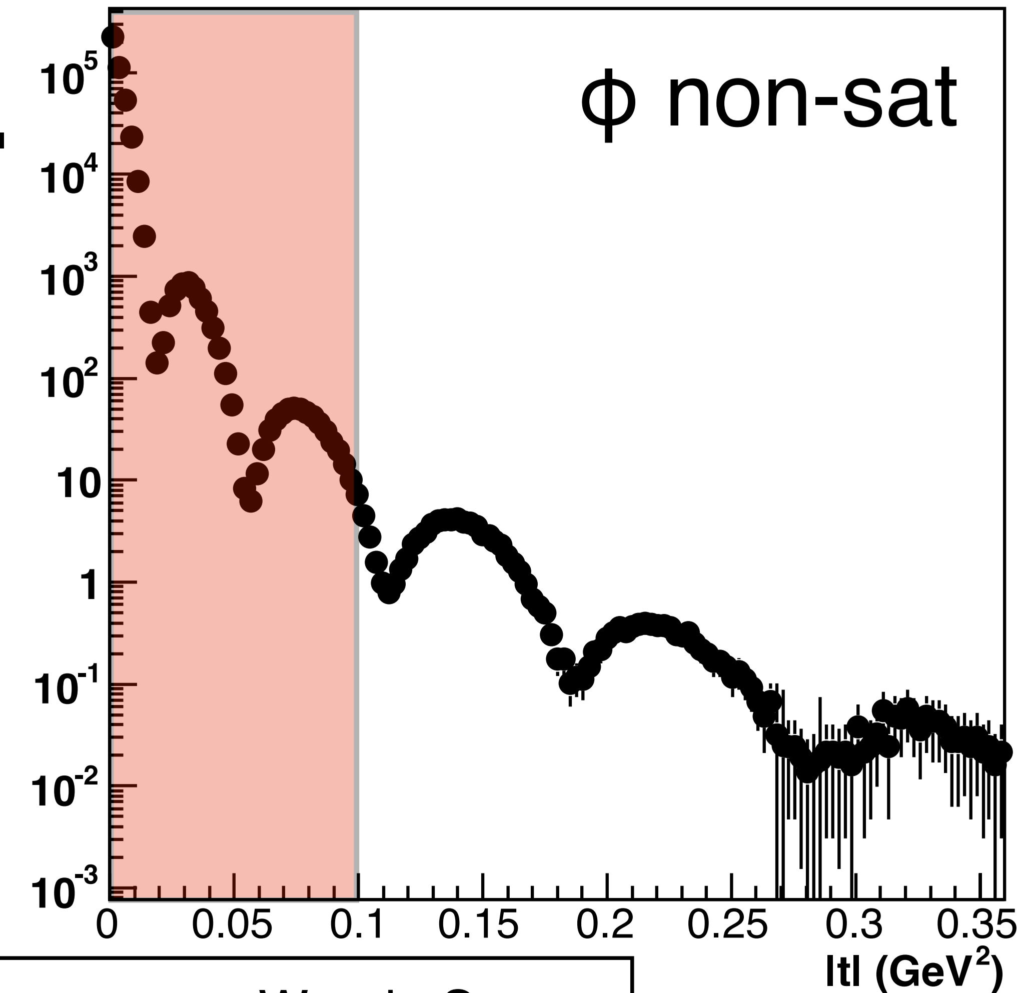

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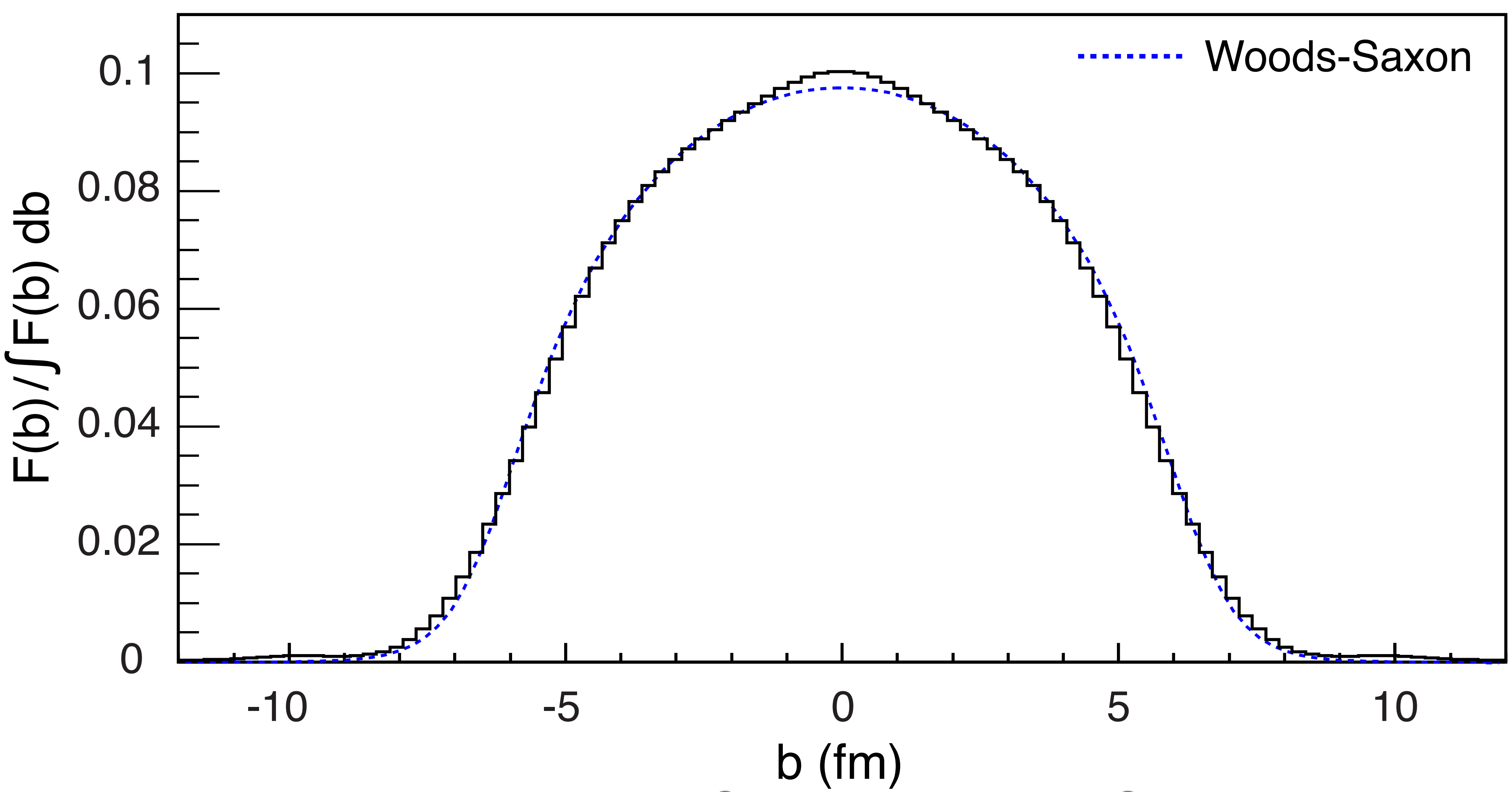

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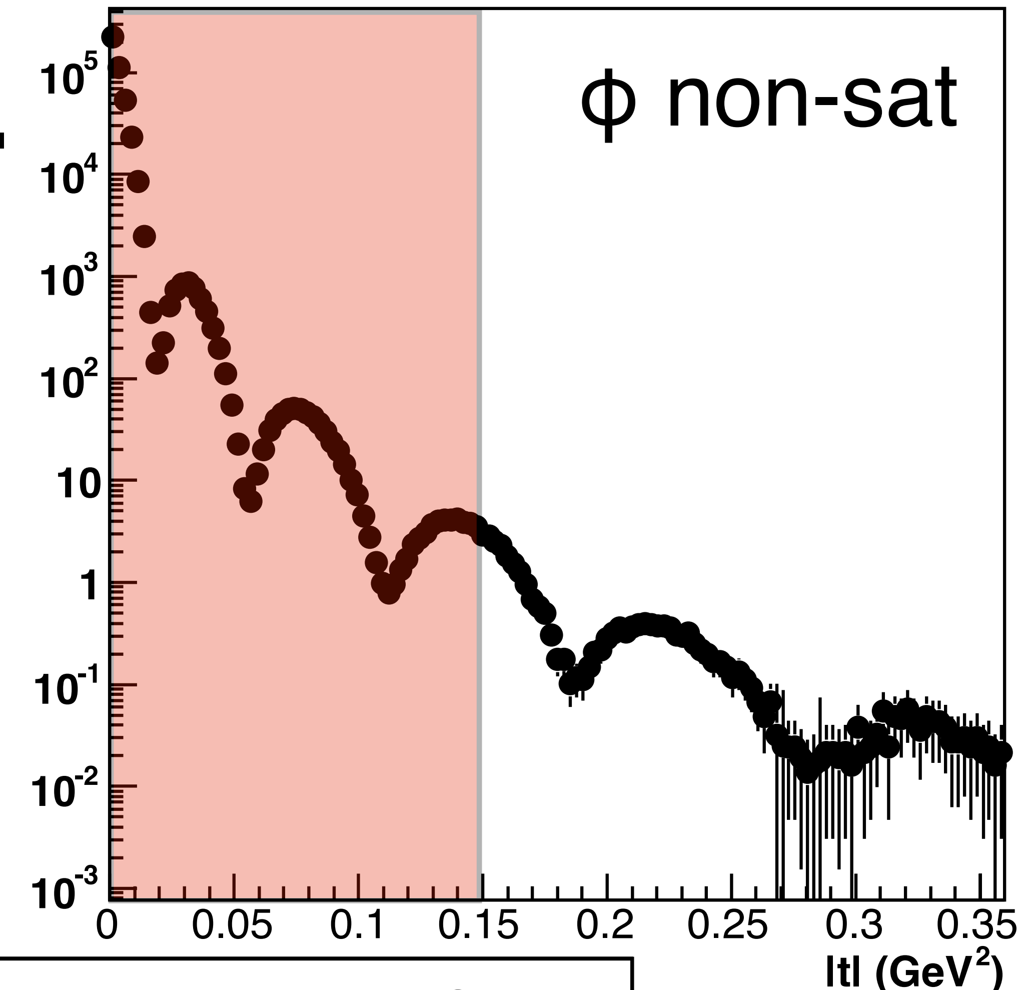

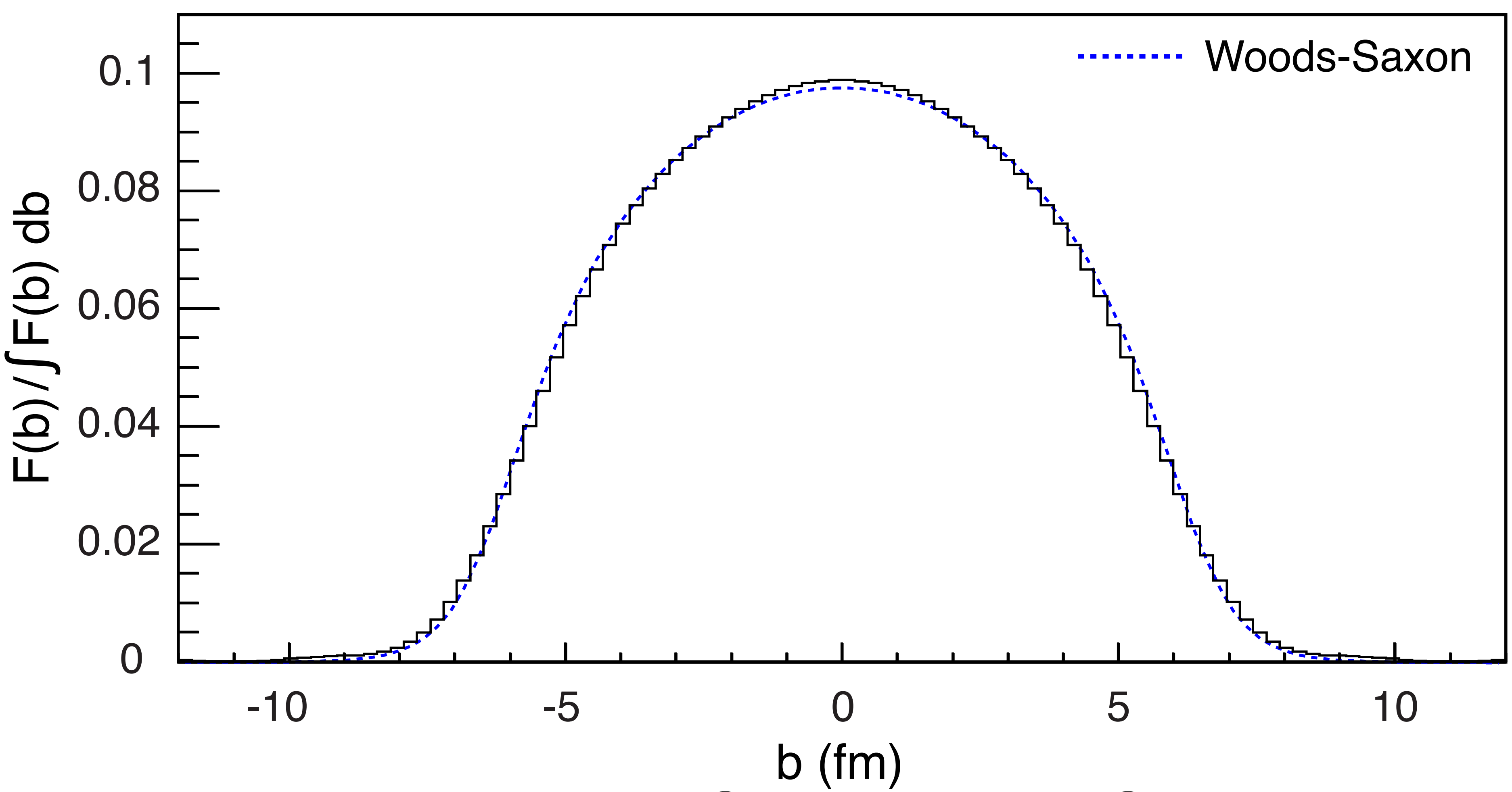

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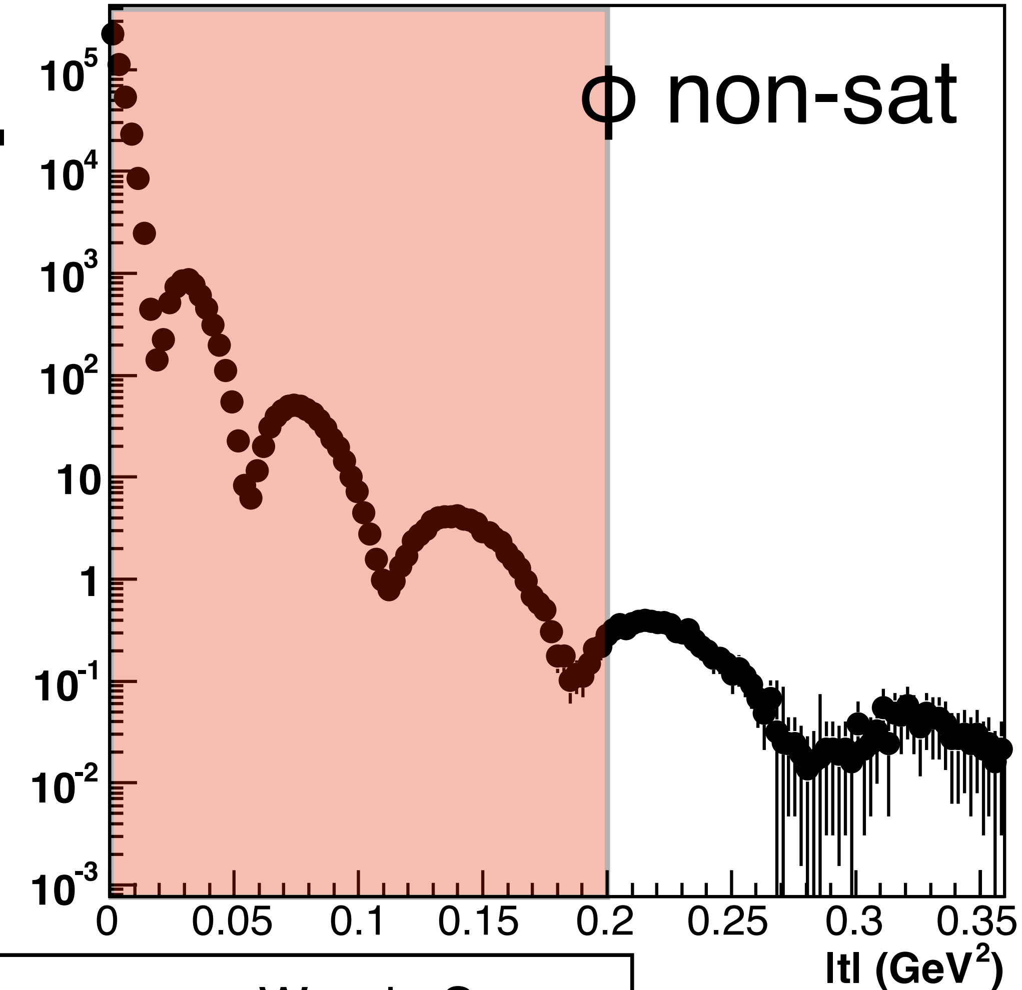

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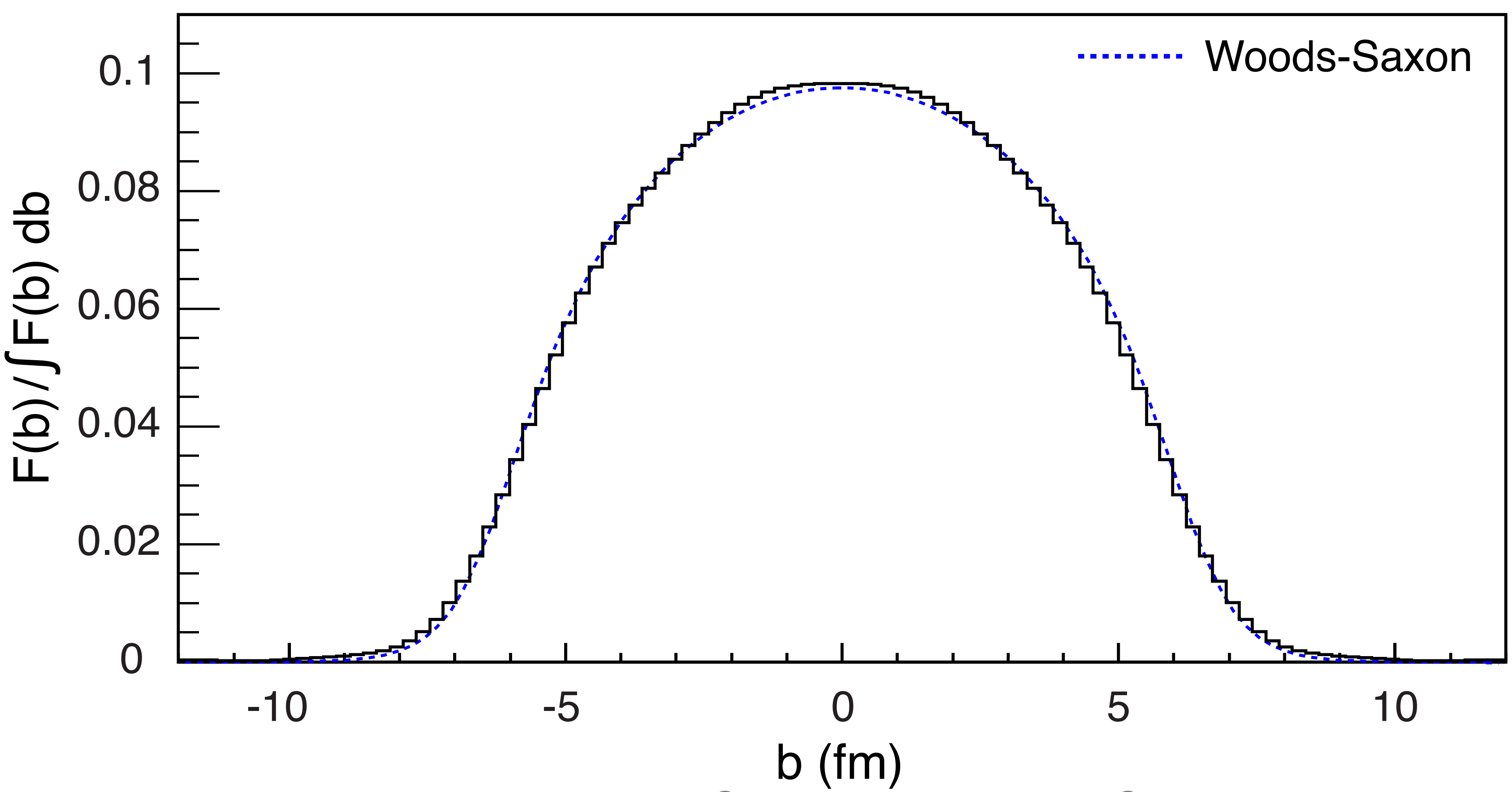

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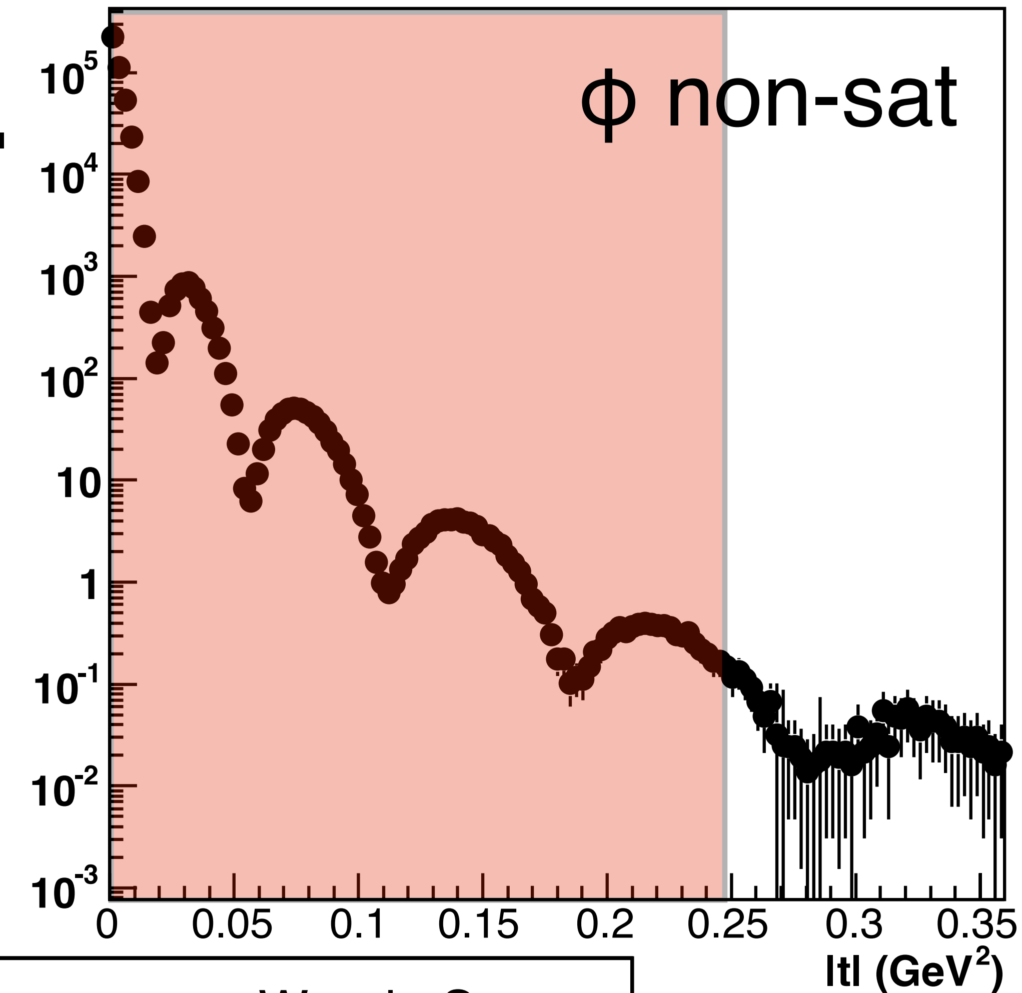

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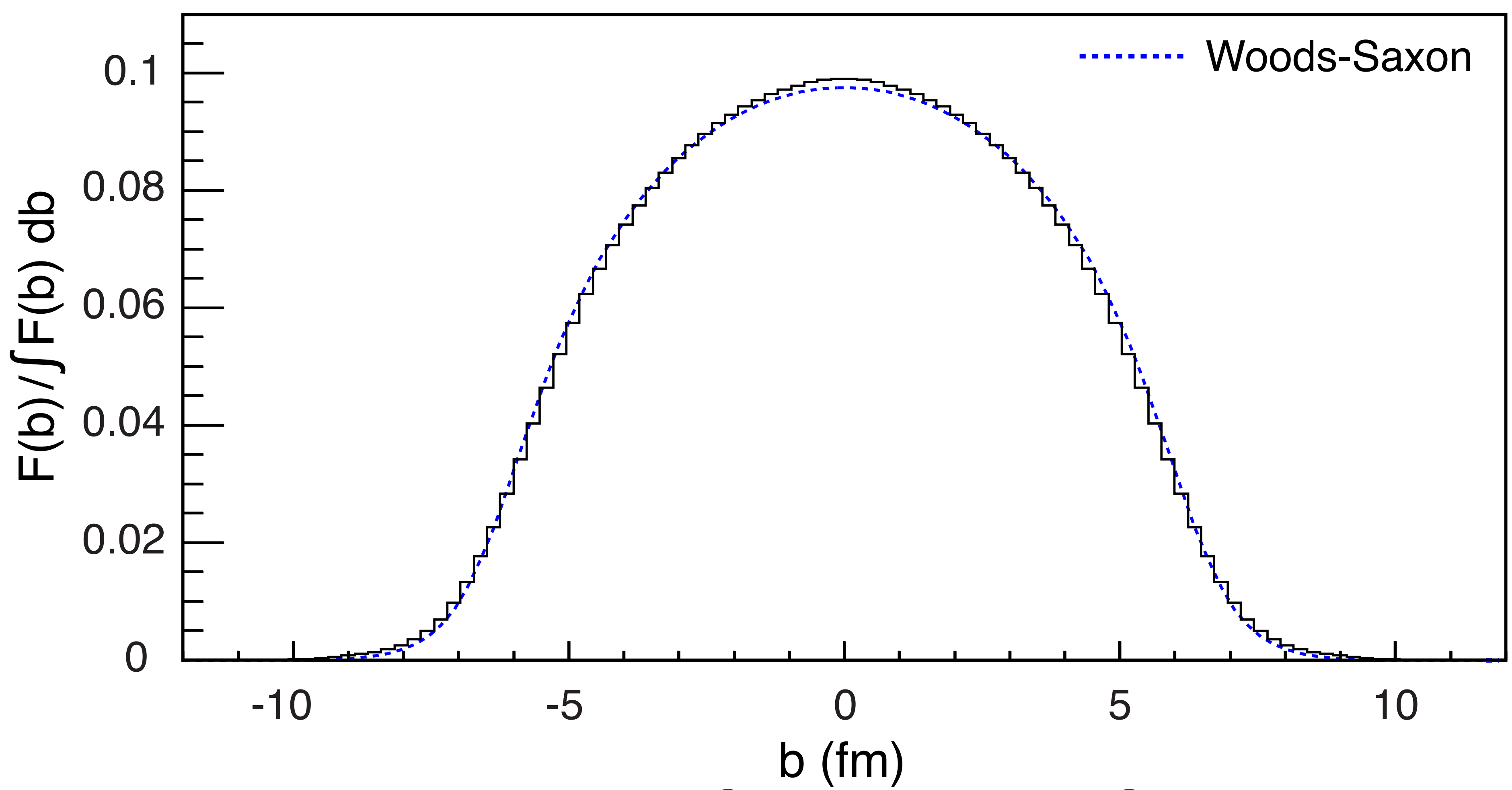

Finding the source...

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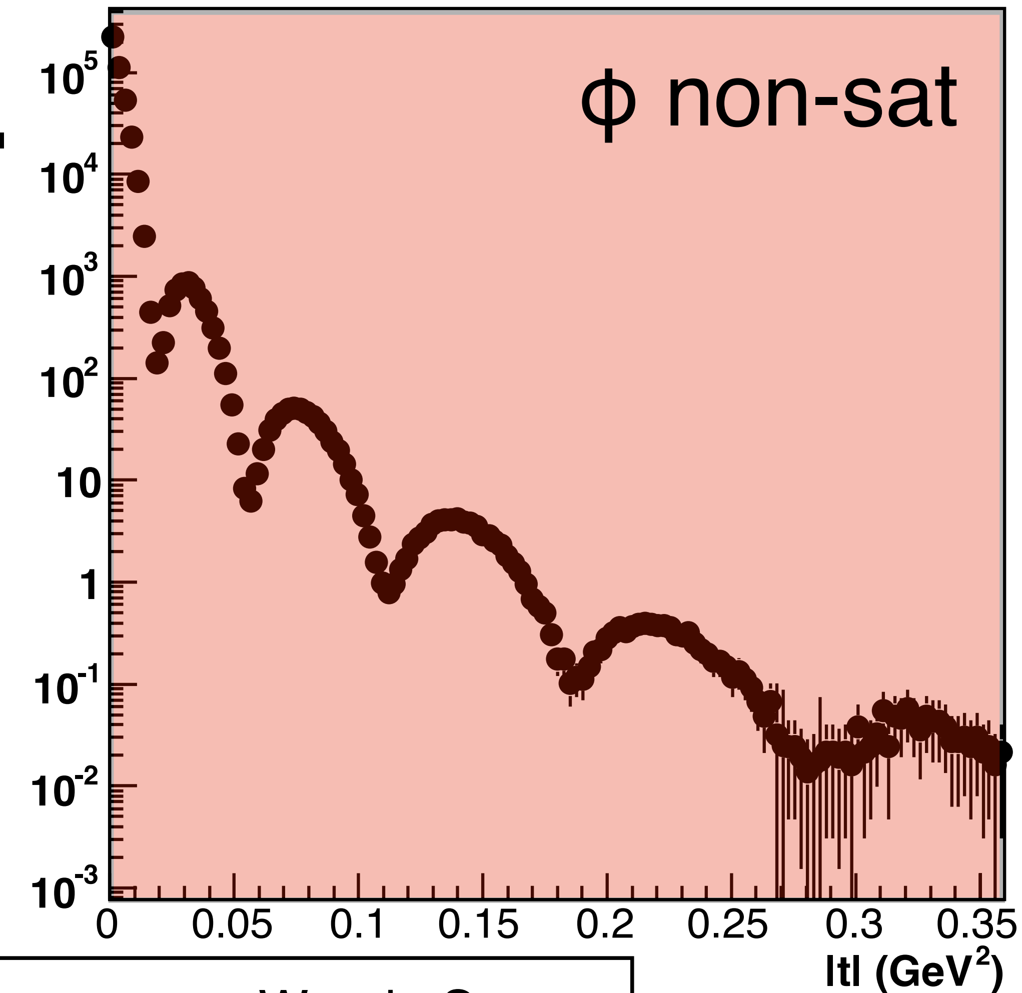
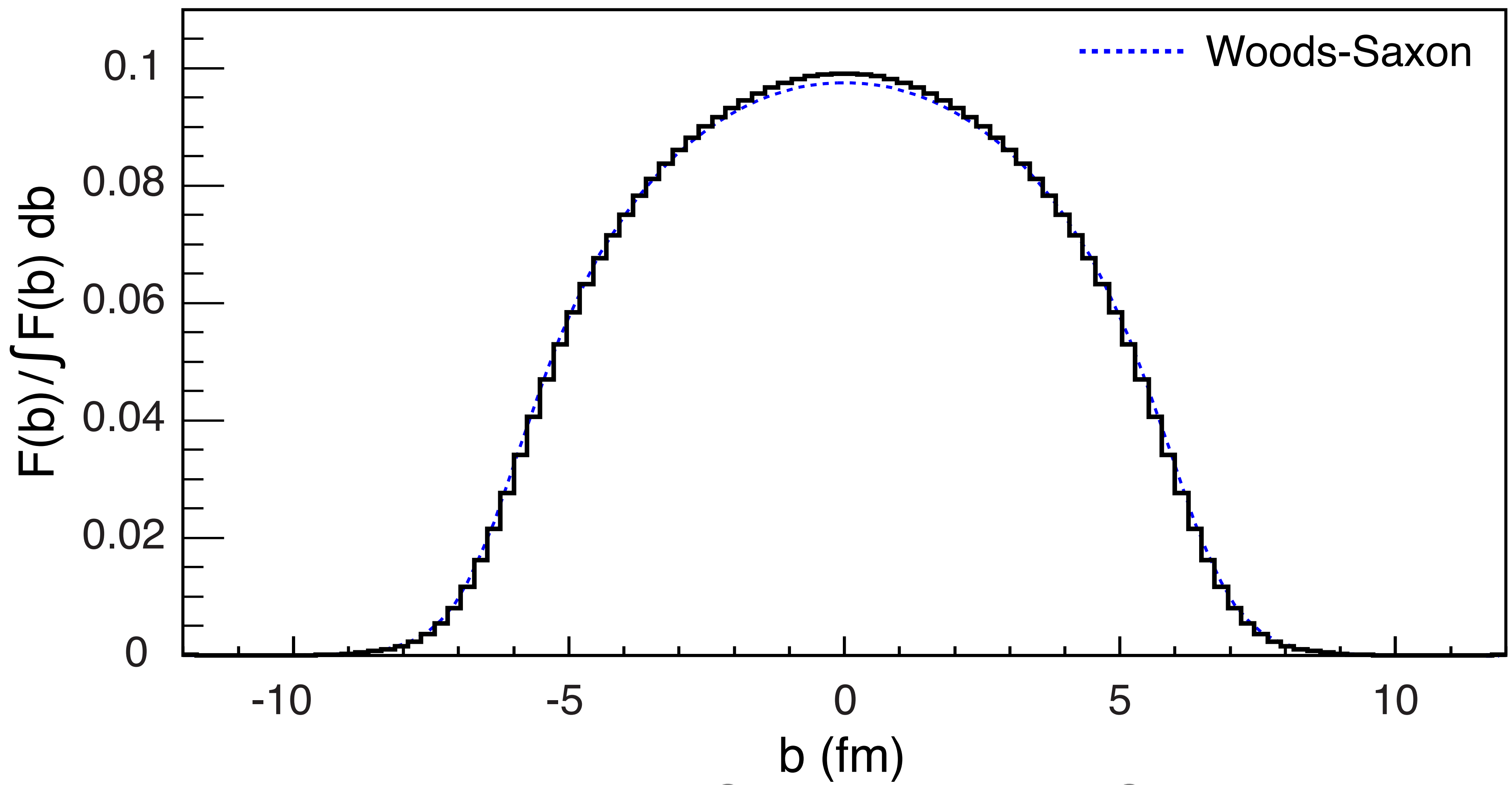
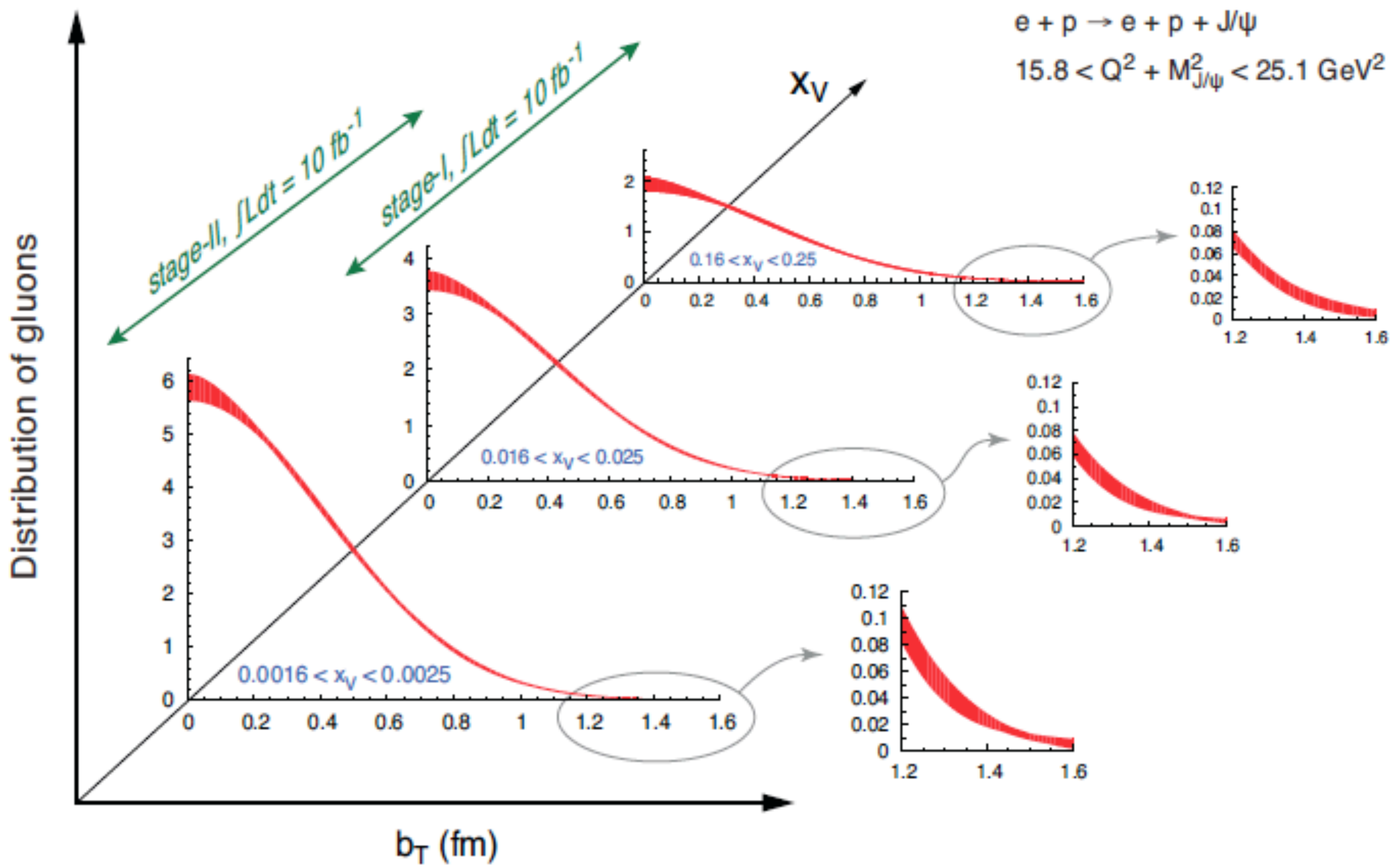
$$F(b) \sim \frac{1}{2\pi}\int_0^\infty d\Delta\,\Delta\,J_0(\Delta b)\sqrt{\frac{d\sigma}{dt}}$$

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





Imaging in e+p - DVCS



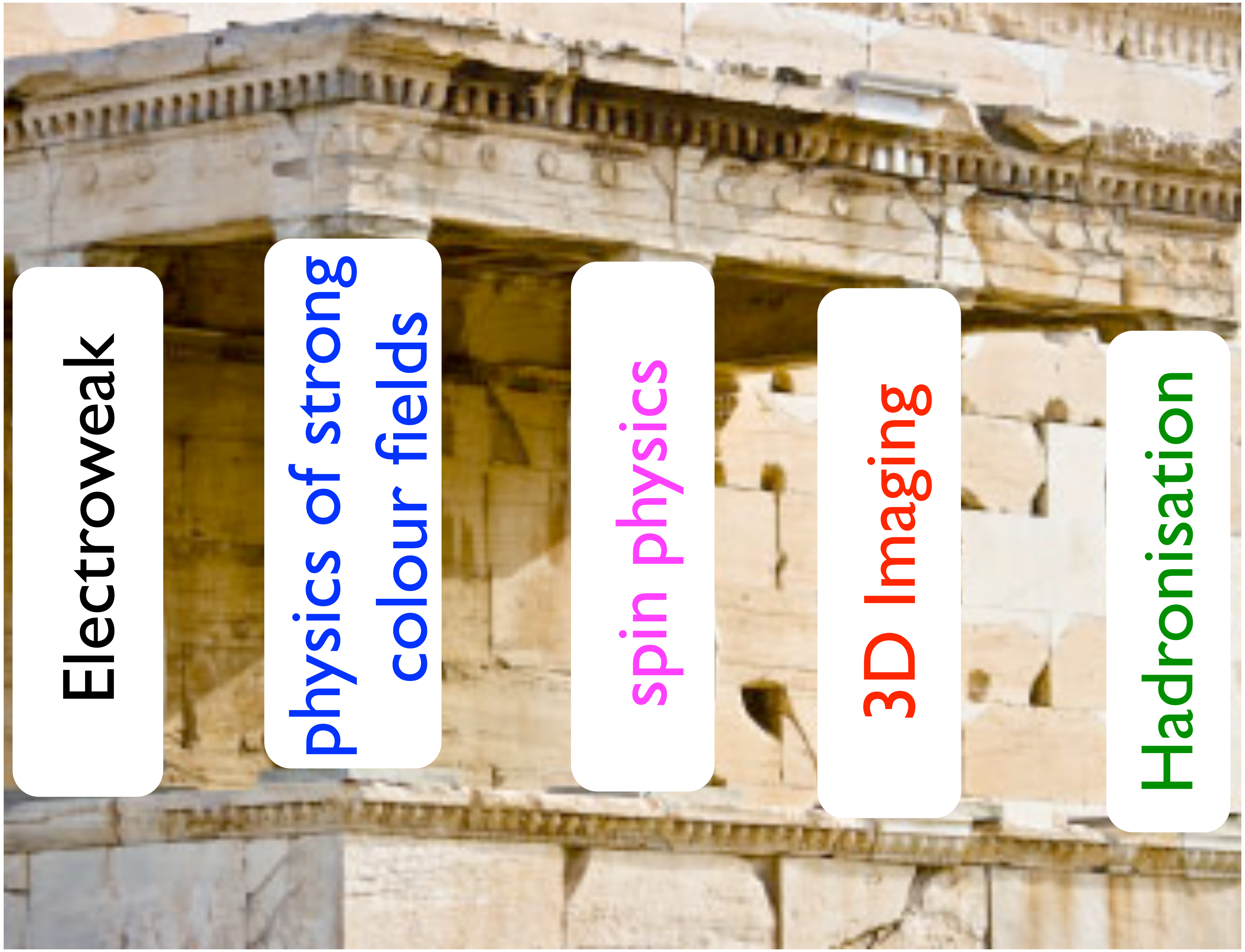
Summary/Conclusions

BACKUP

The pillars of the eRHIC physics programme

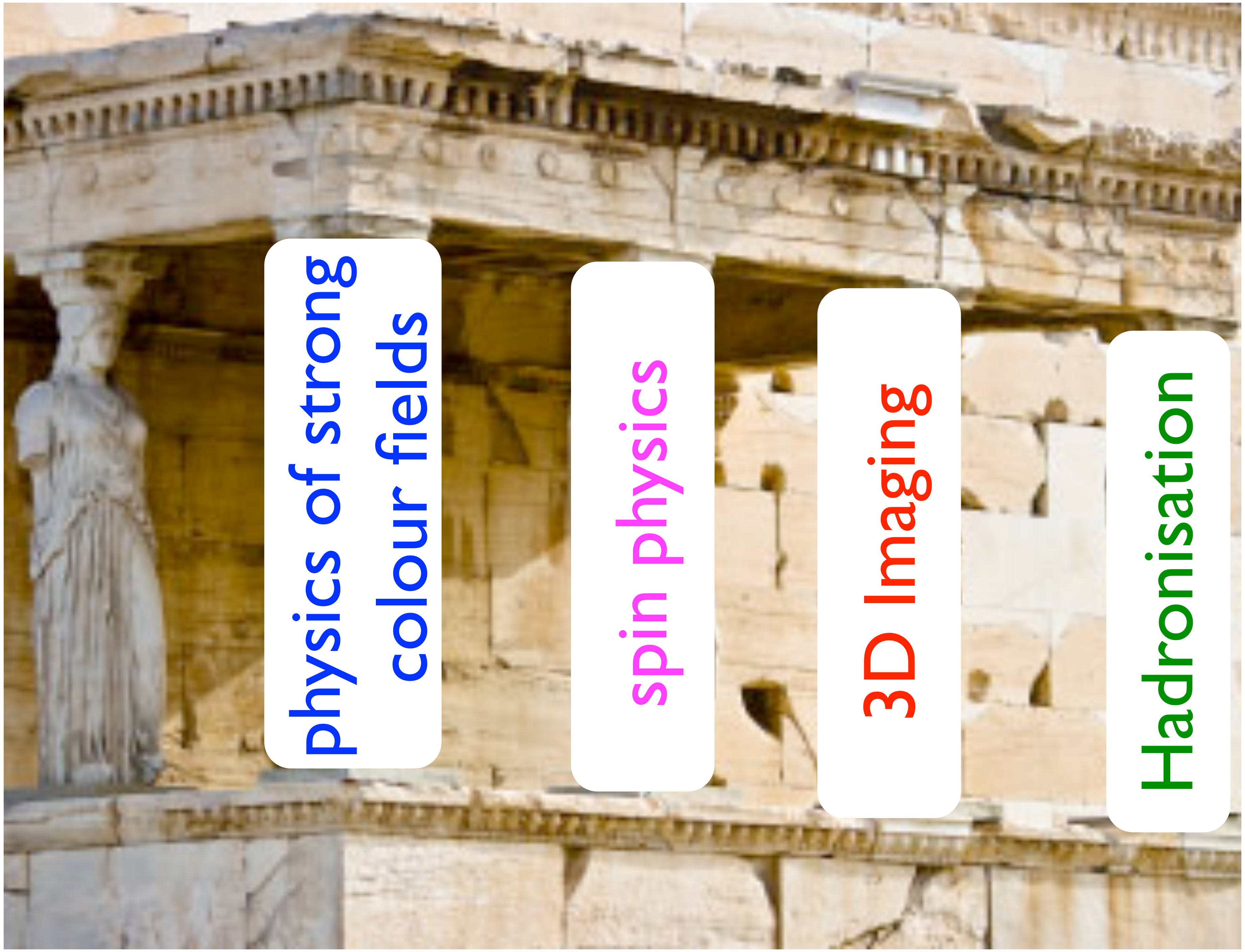
- Wide physics programme with demanding requirements on detector and machine performance

The pillars of the eRHIC physics programme



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

The pillars of the eRHIC physics programme



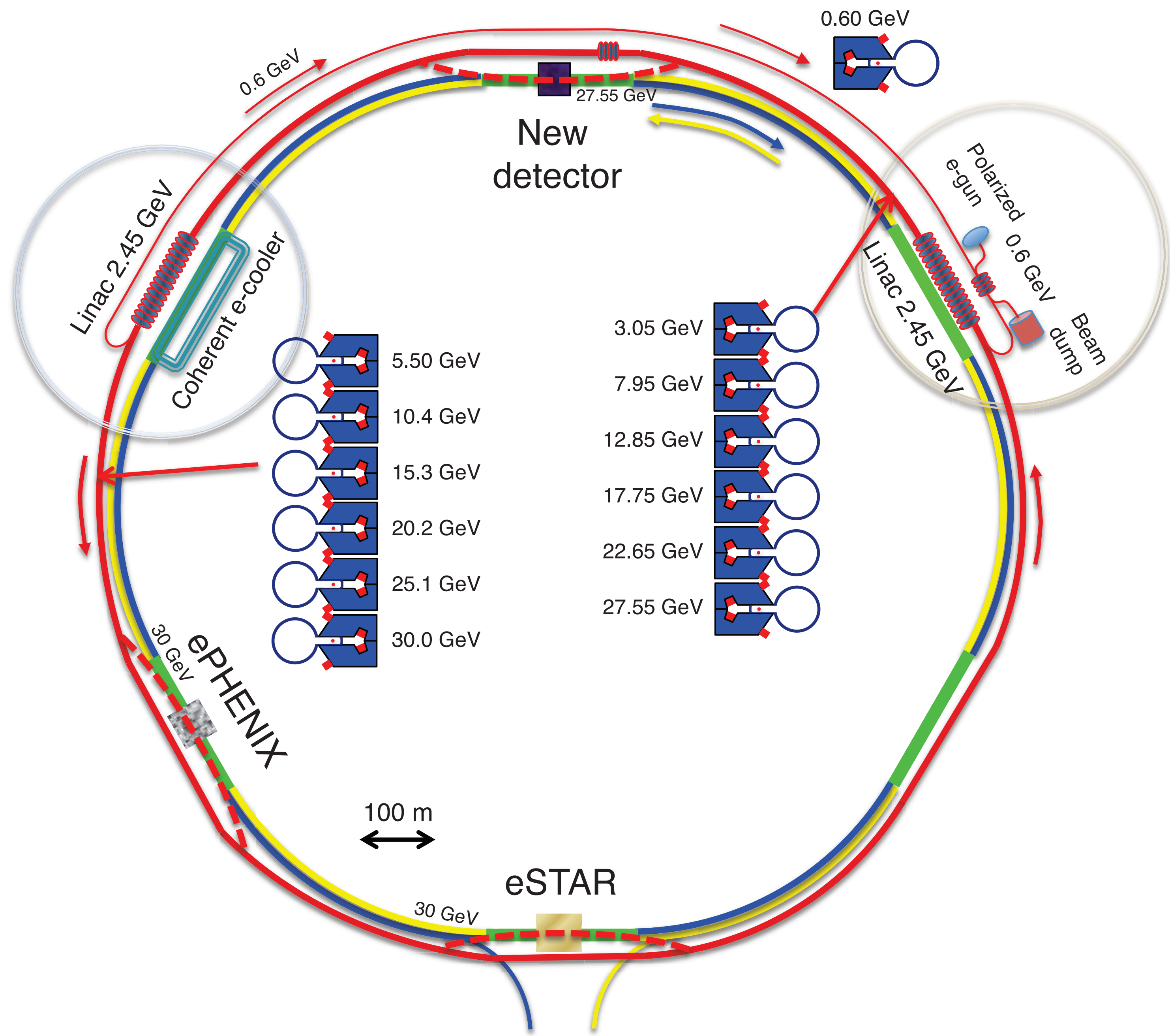
- Wide physics programme with demanding requirements on detector and machine performance

Outline

- Why an EIC?
  - ➡ Spin + e+A
- What is eRHIC?
- What can eRHIC do for you?
- How do we realise eRHIC?

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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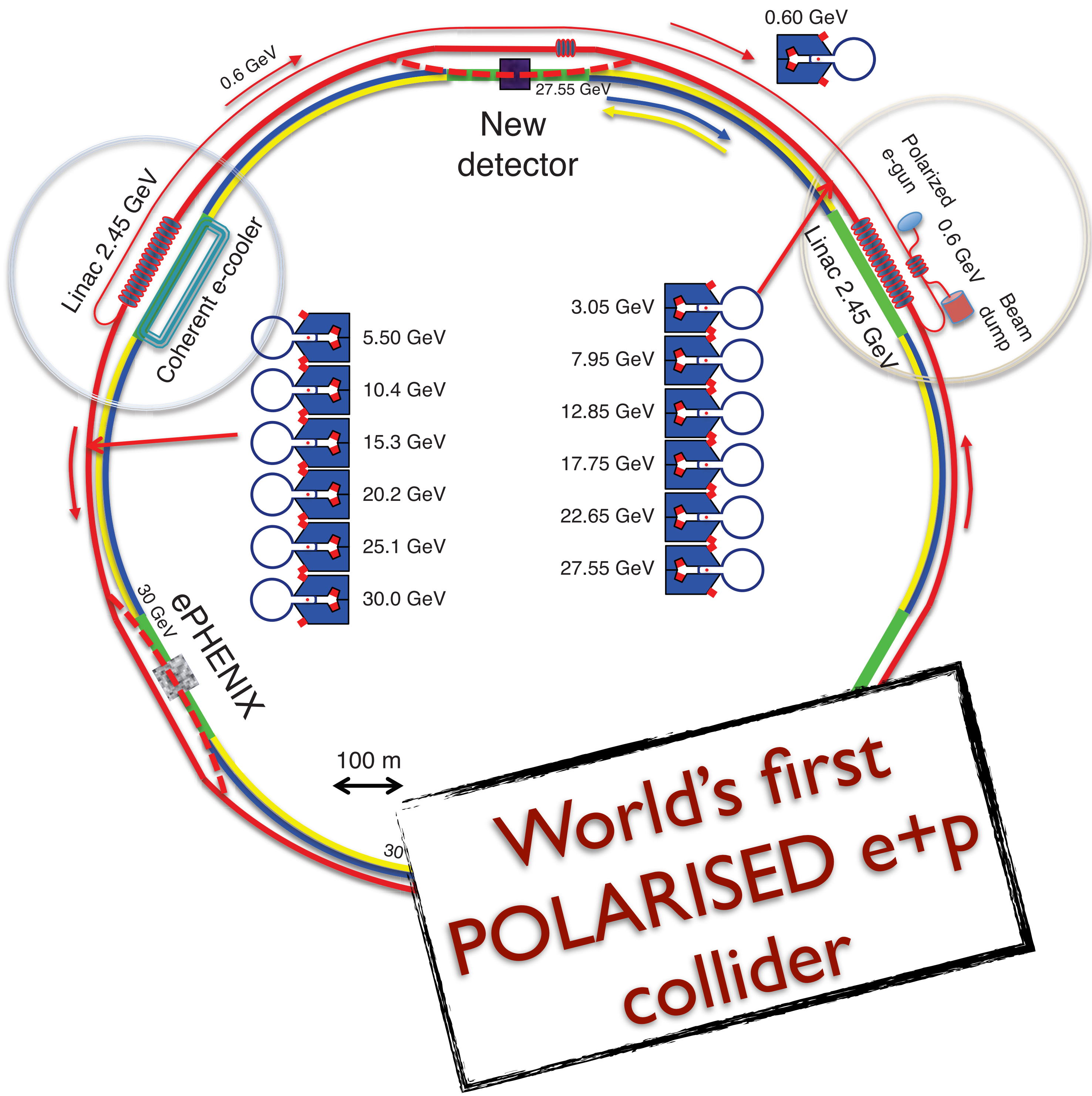

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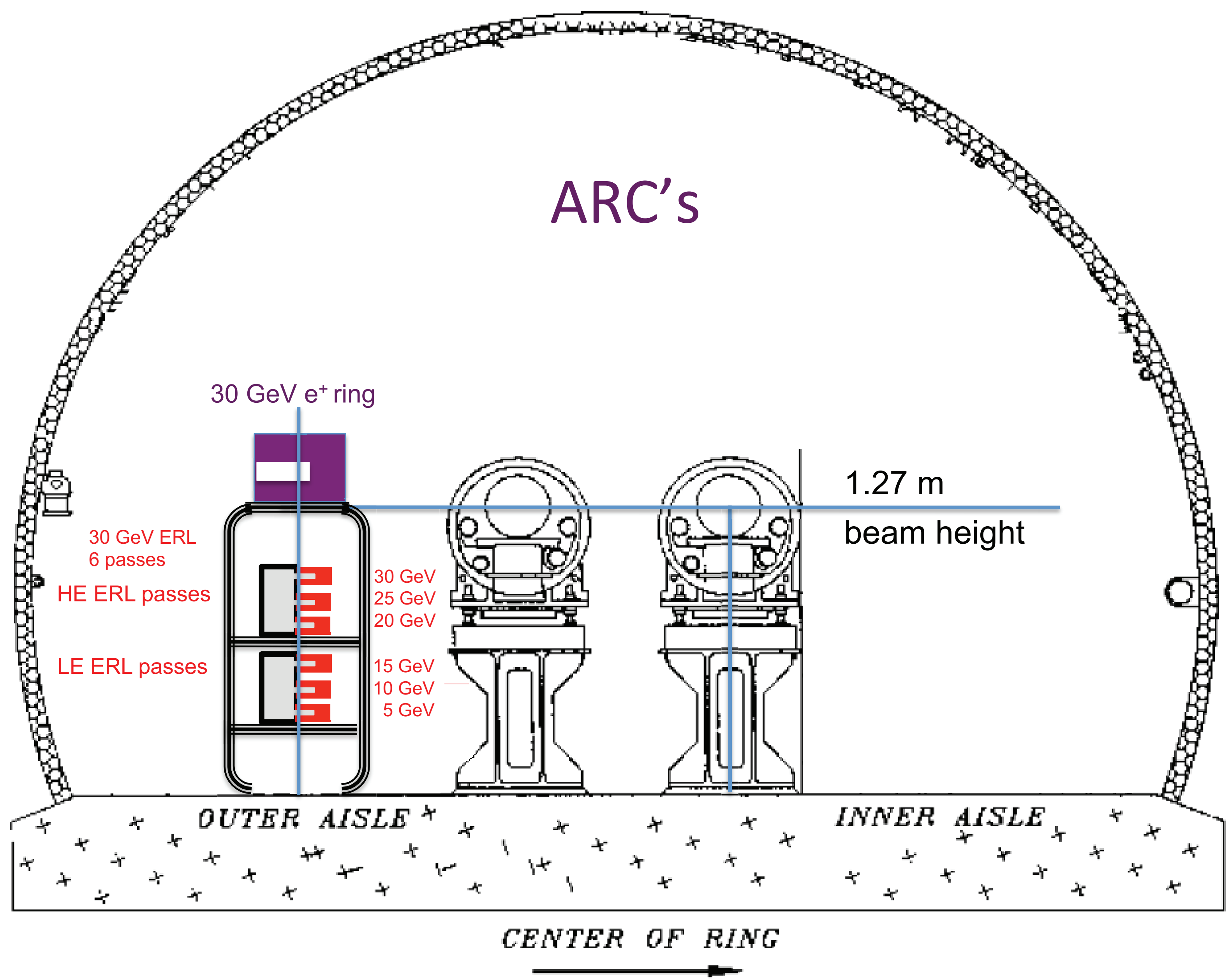

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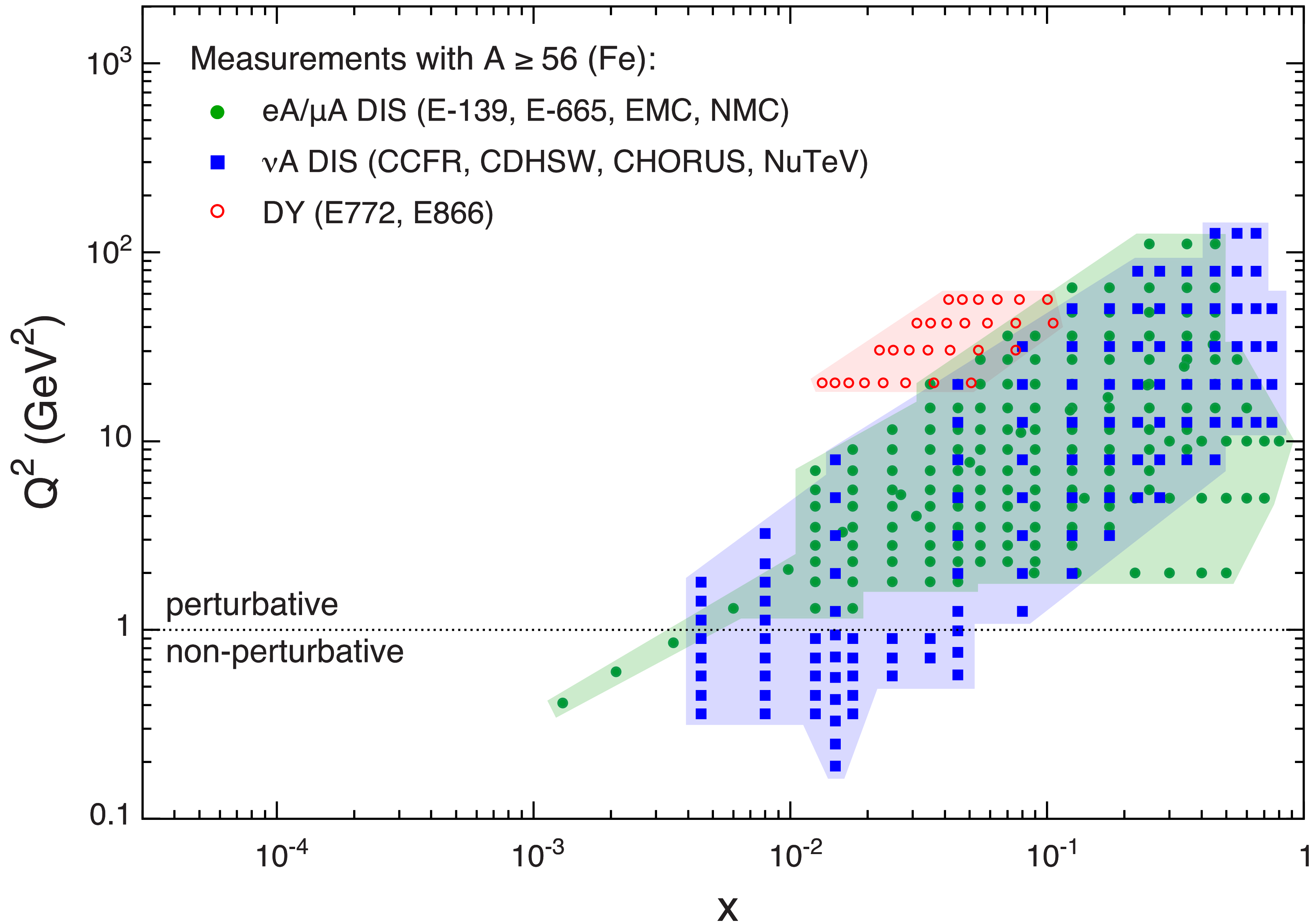

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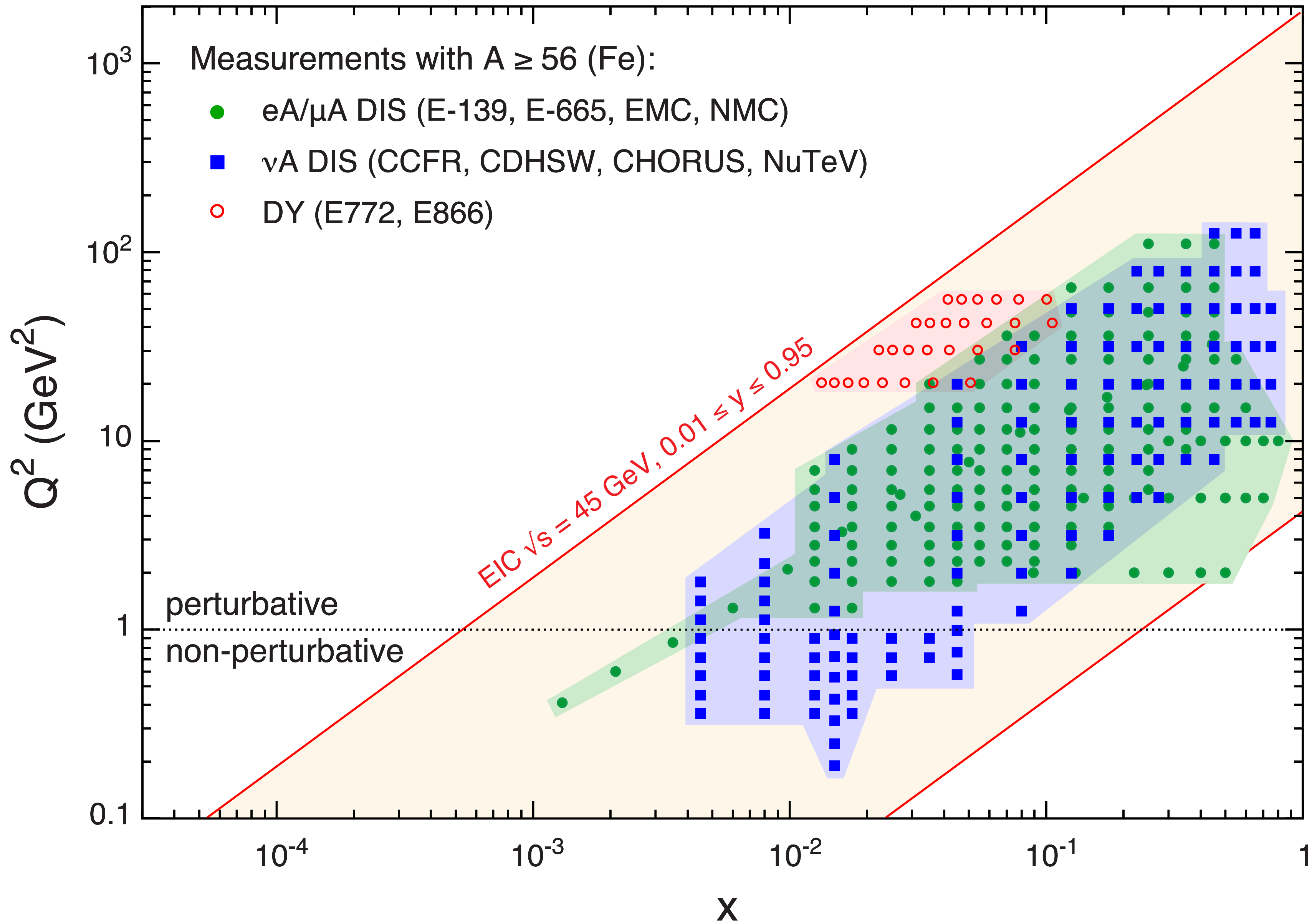

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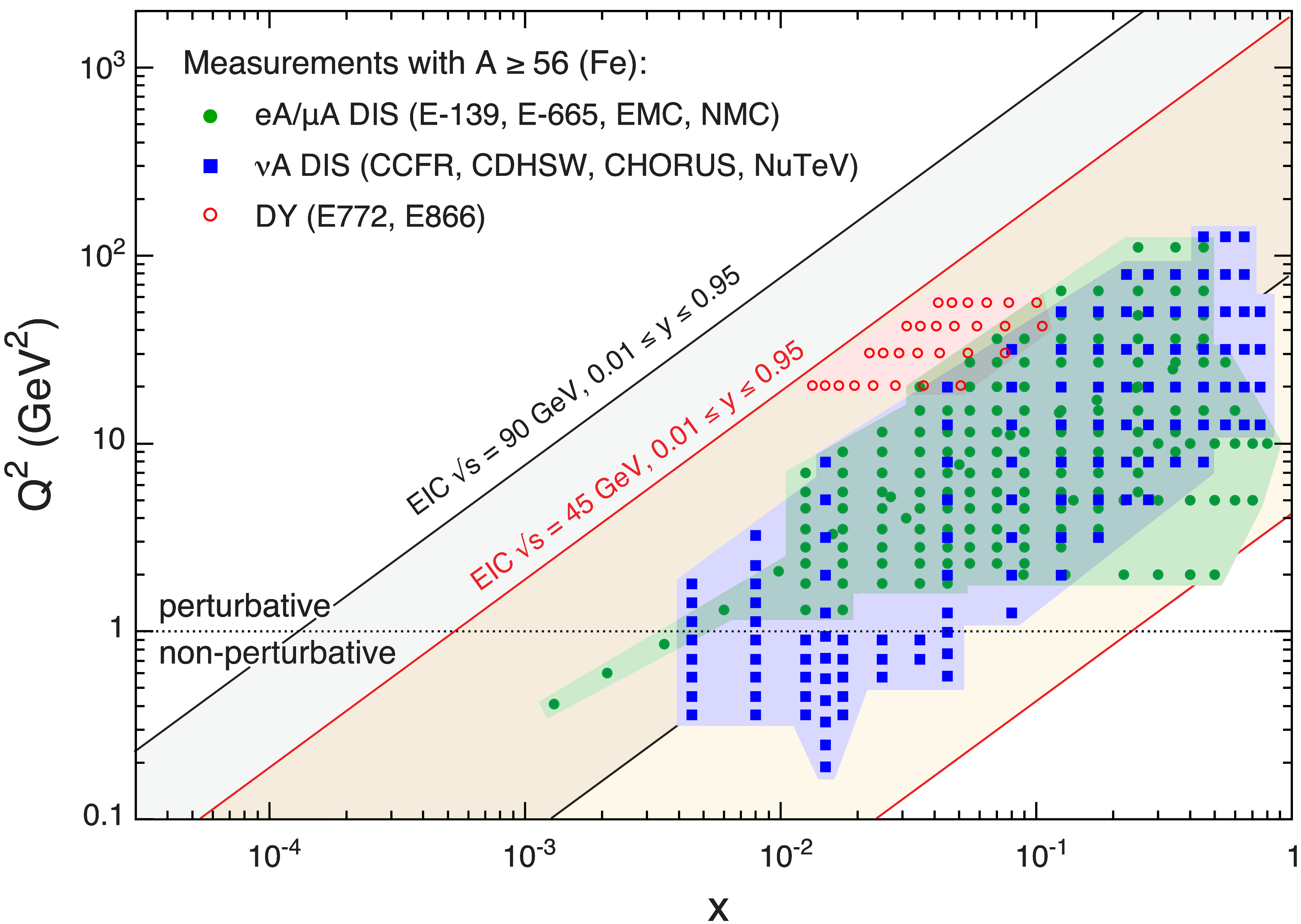

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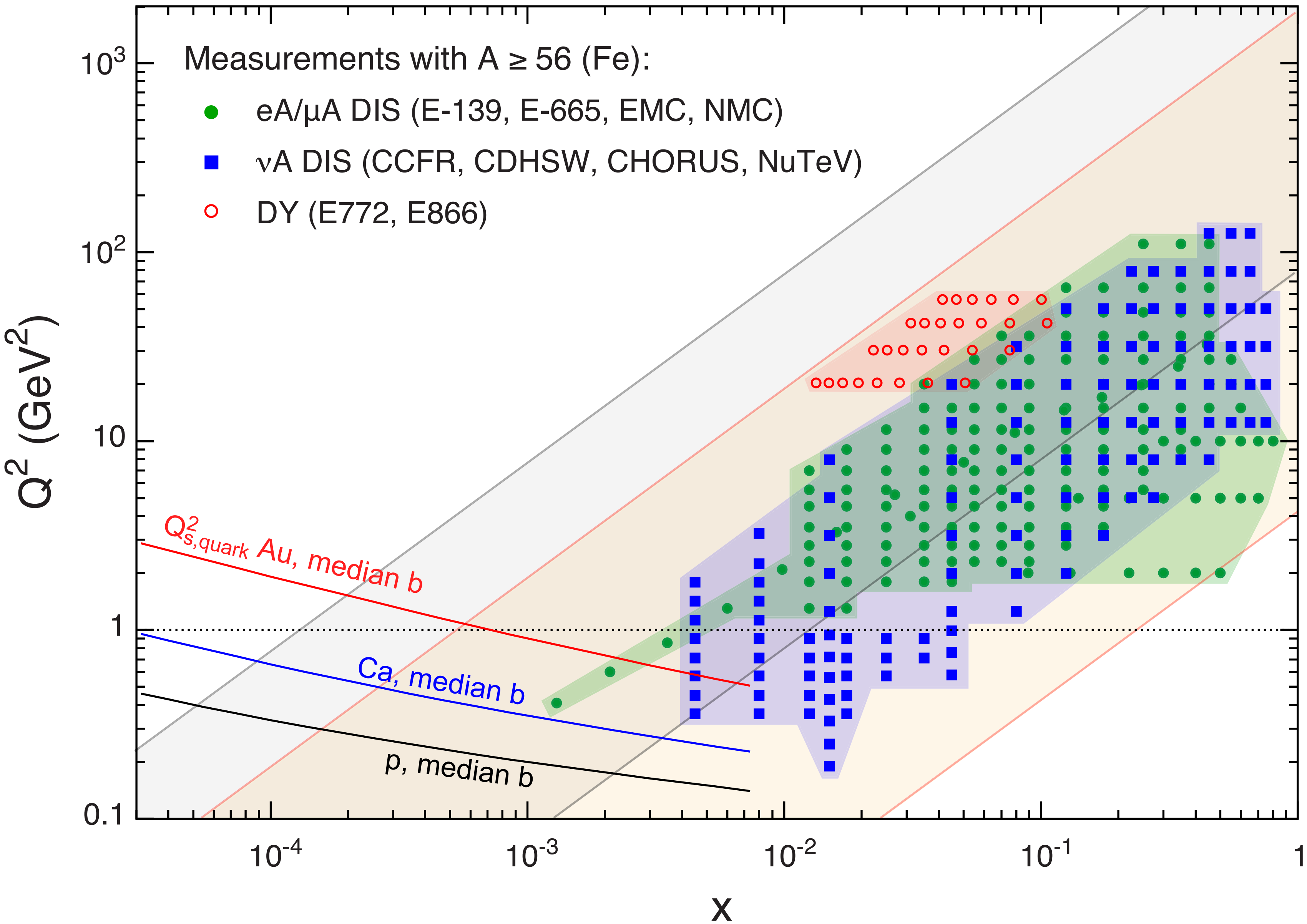
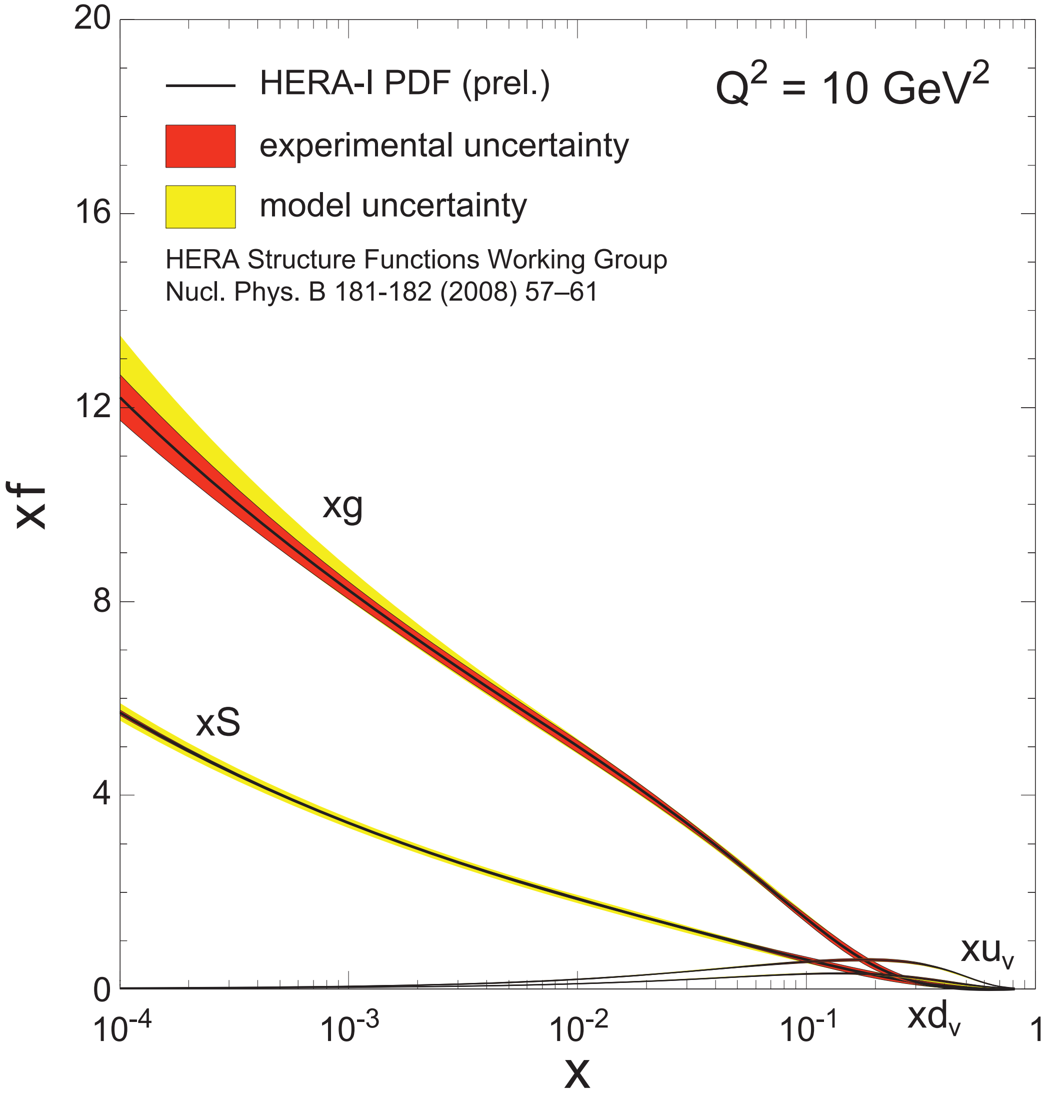


(Very) Brief Recap of Saturation at an EIC



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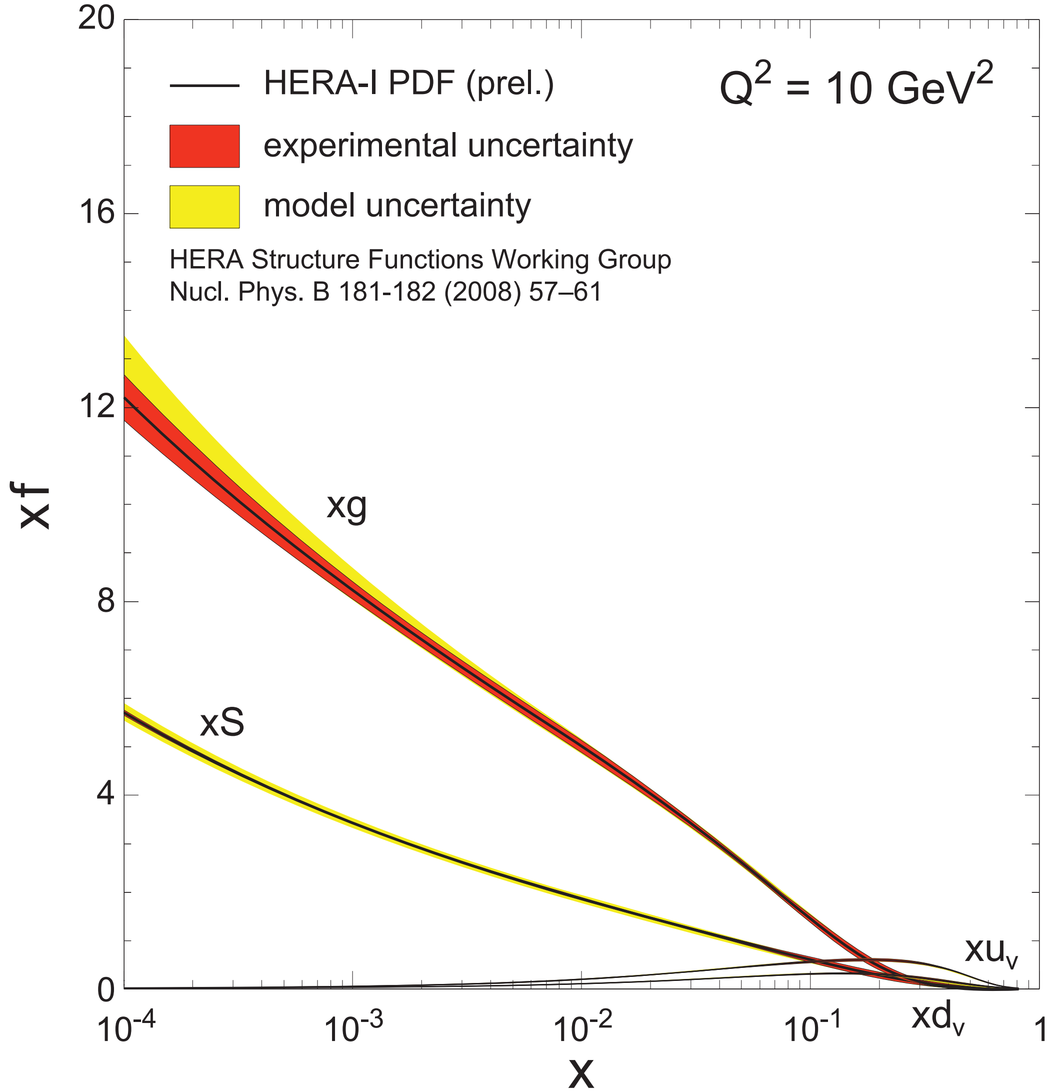

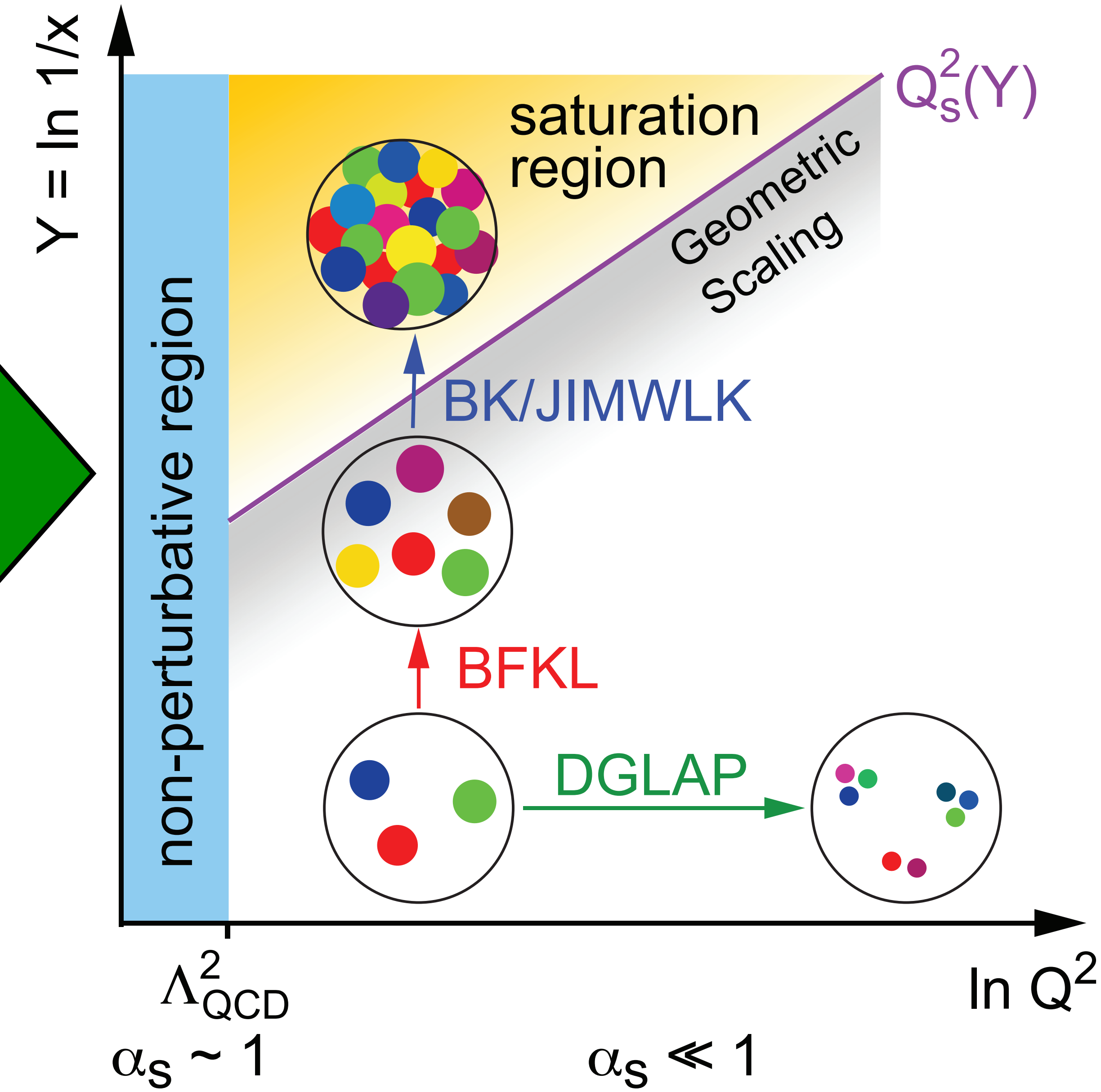

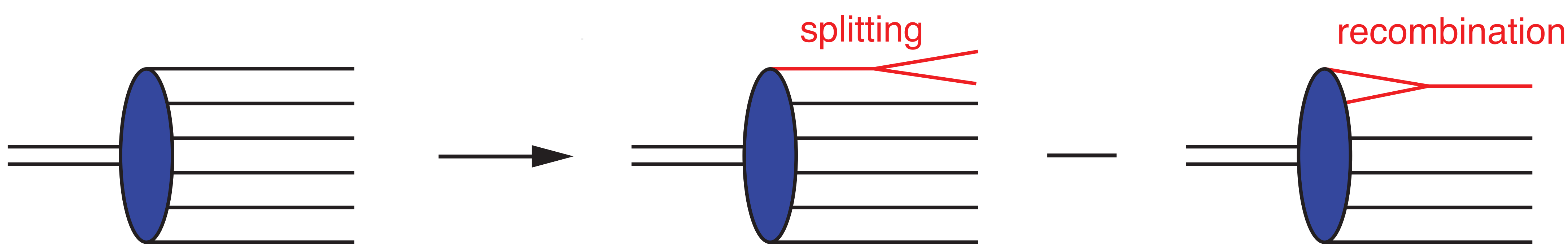

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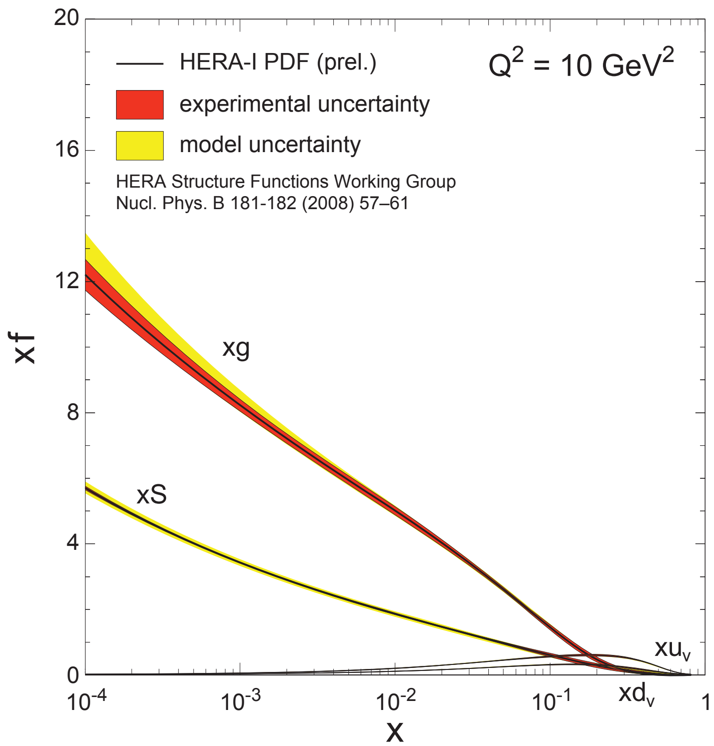
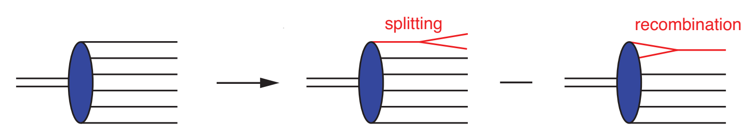
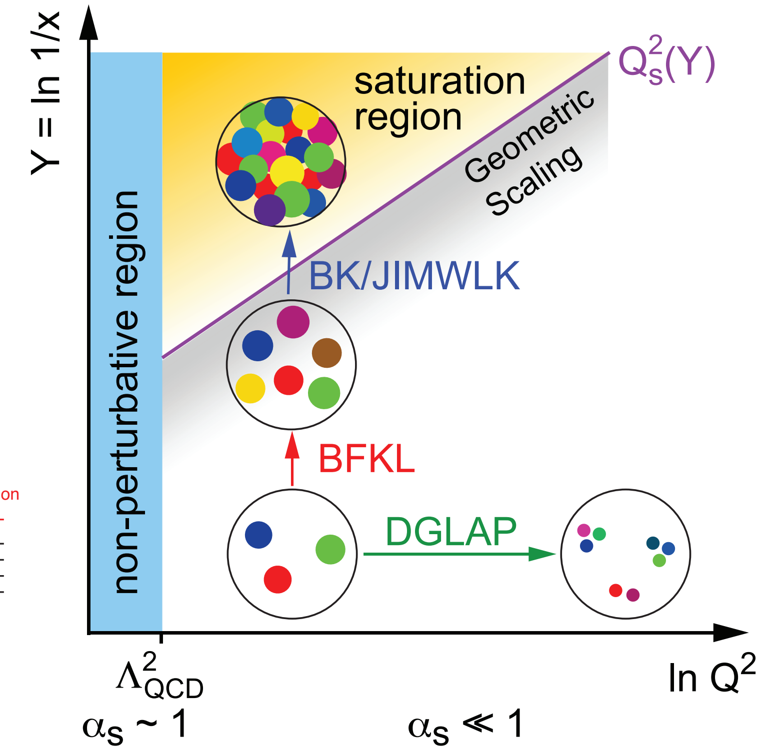
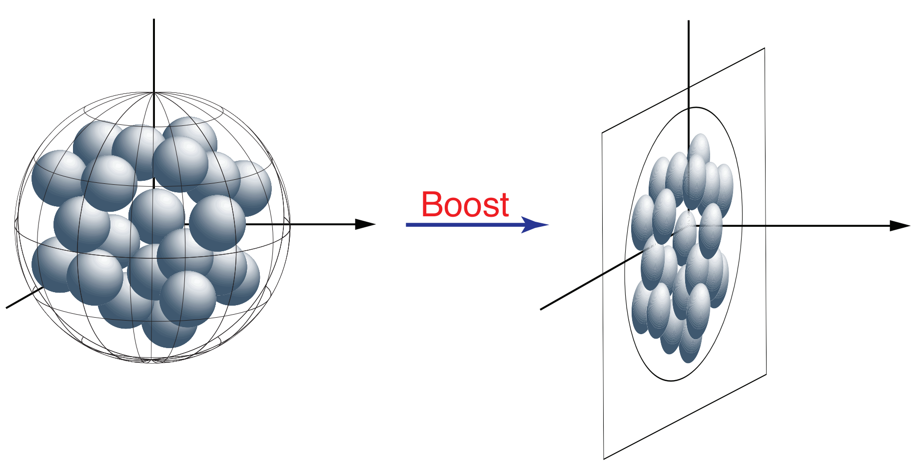






$$Q_s^2(x) \sim A^{1/3} \left(\frac{1}{x}\right)^{\lambda}$$



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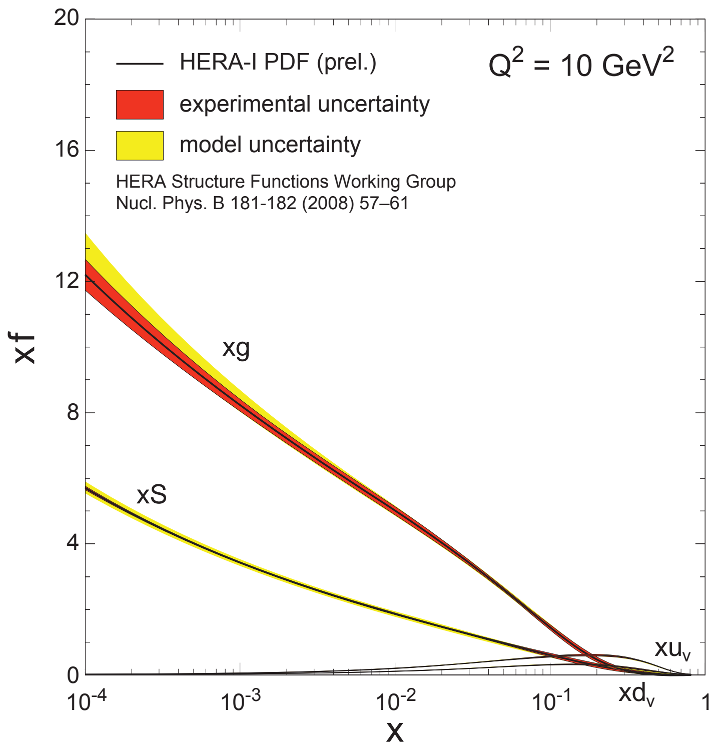

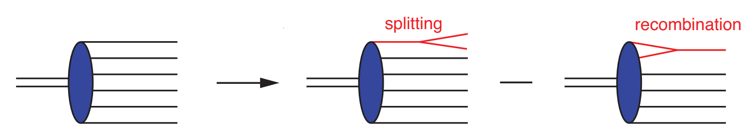

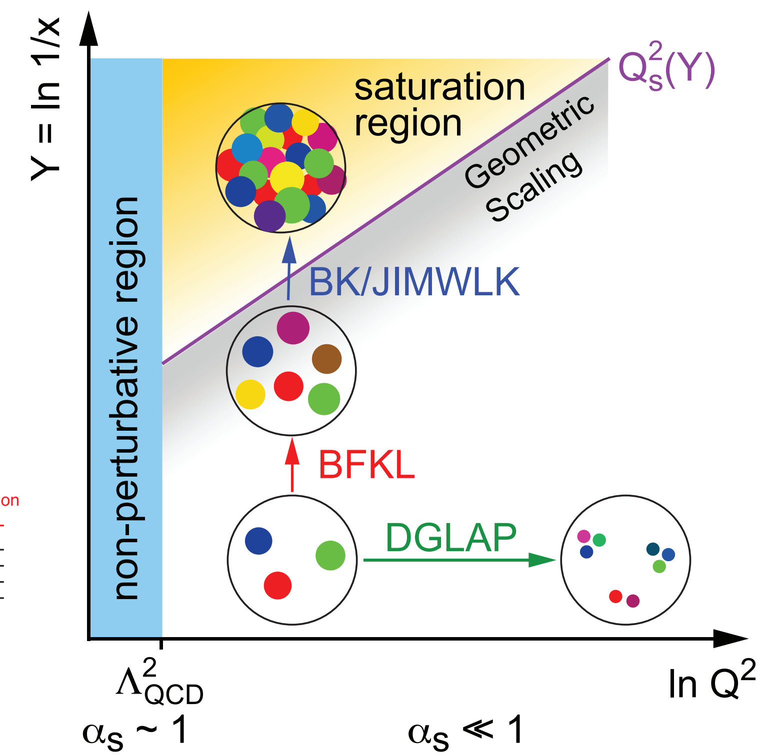

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