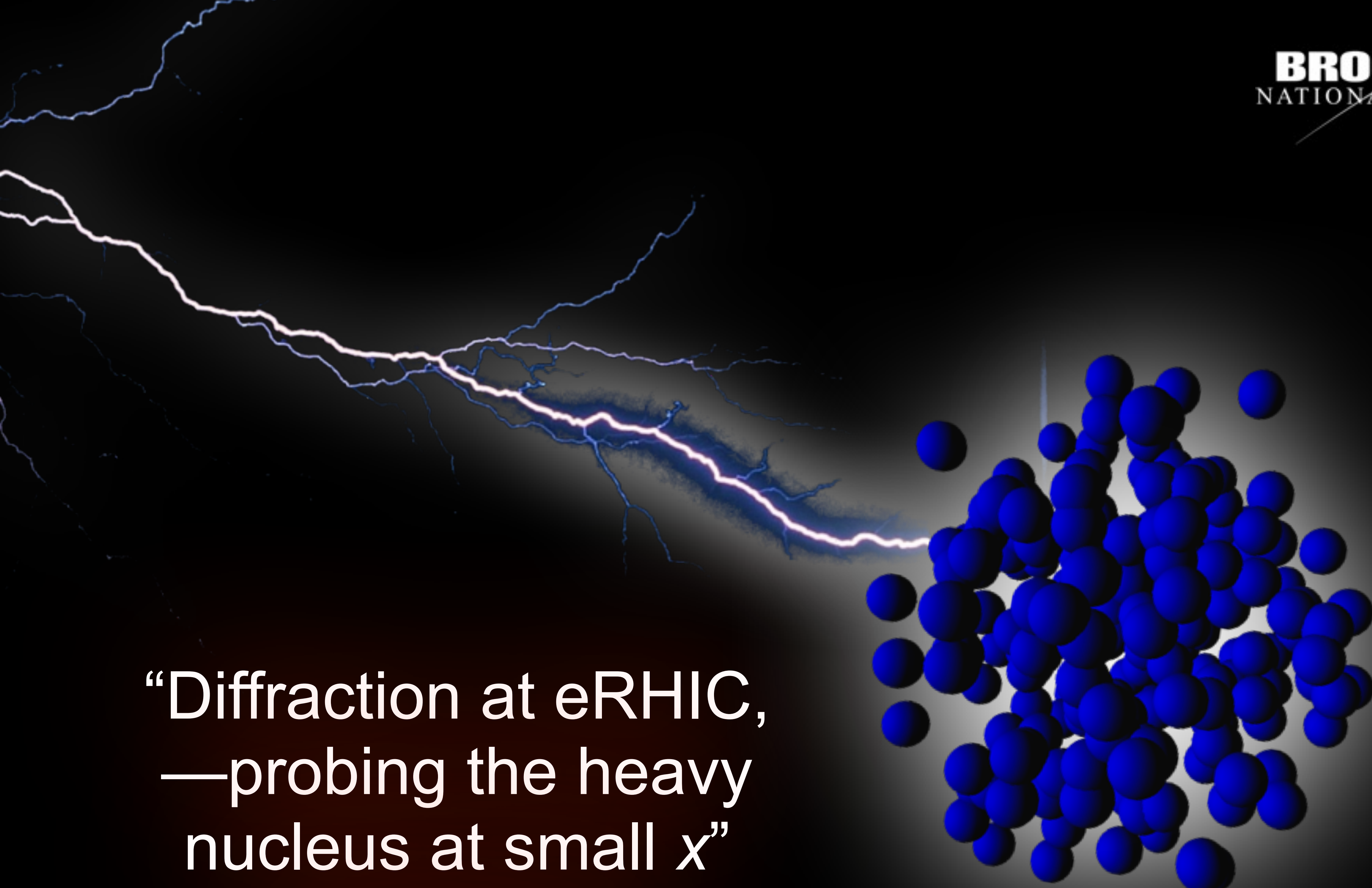


“Diffraction at eRHIC, —probing the heavy nucleus at small *x*”

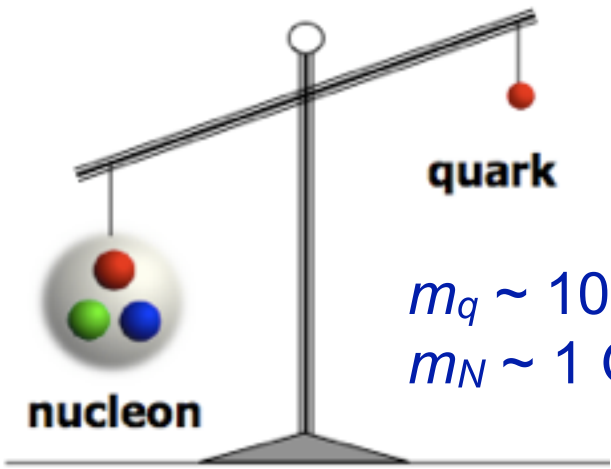
POETIC 2013

Tobias Toll
BNL

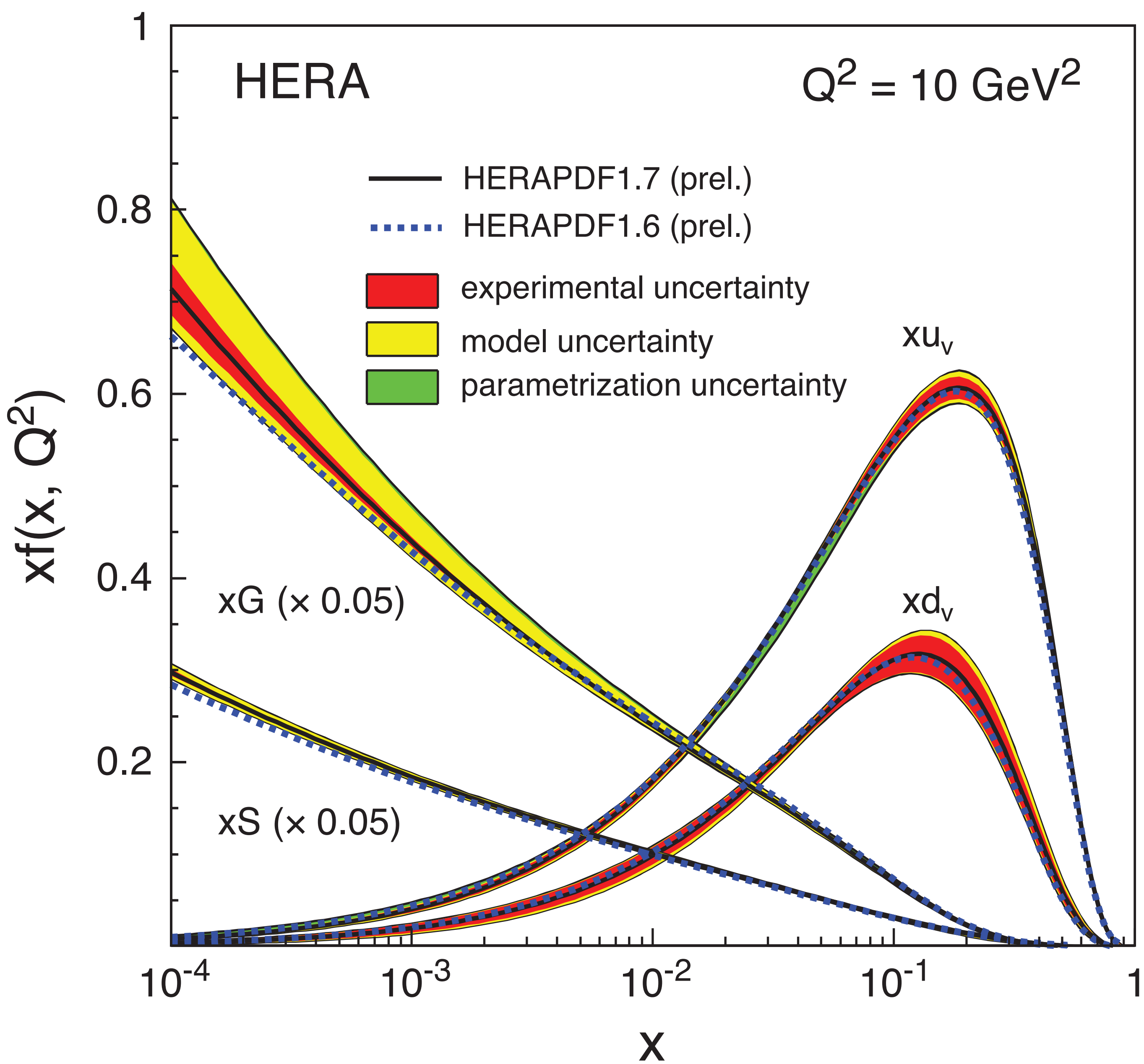
3 conundrums for the small-*x* nucleus

1. how saturated is the initial state of the nucleus?
2. how are gluons distributed in space?
3. how much does the spatial distribution fluctuate?

Importance of gluons

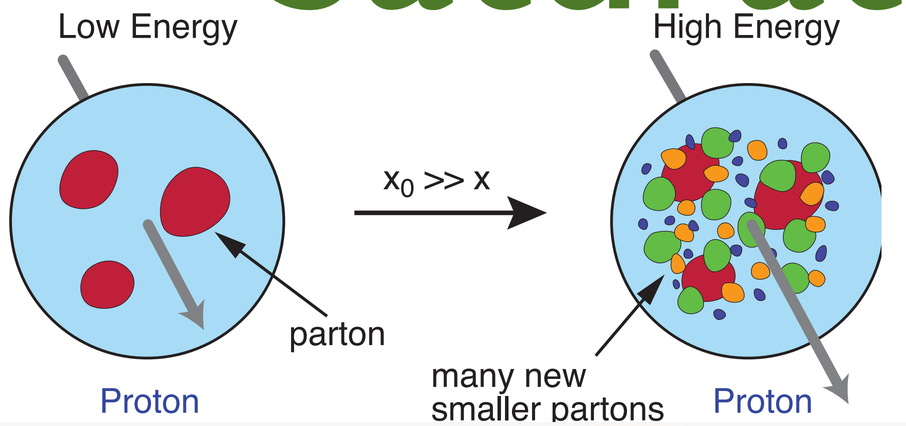


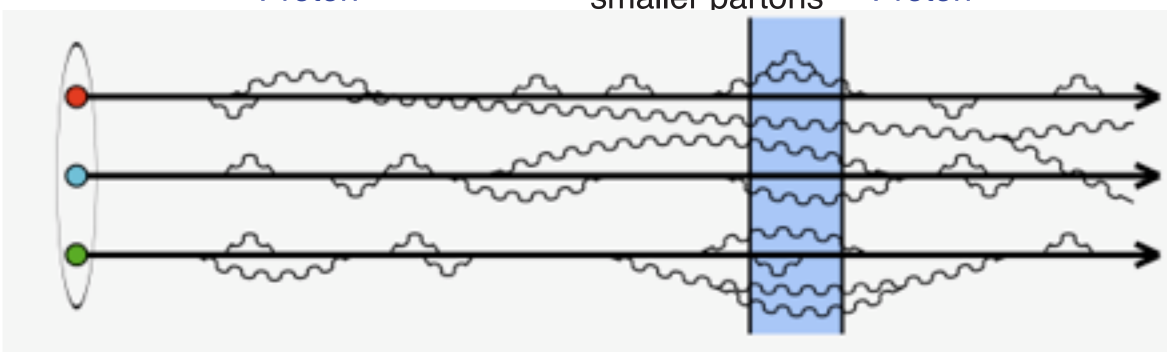
$m_q \sim 10$ MeV
$m_N \sim 1$ GeV

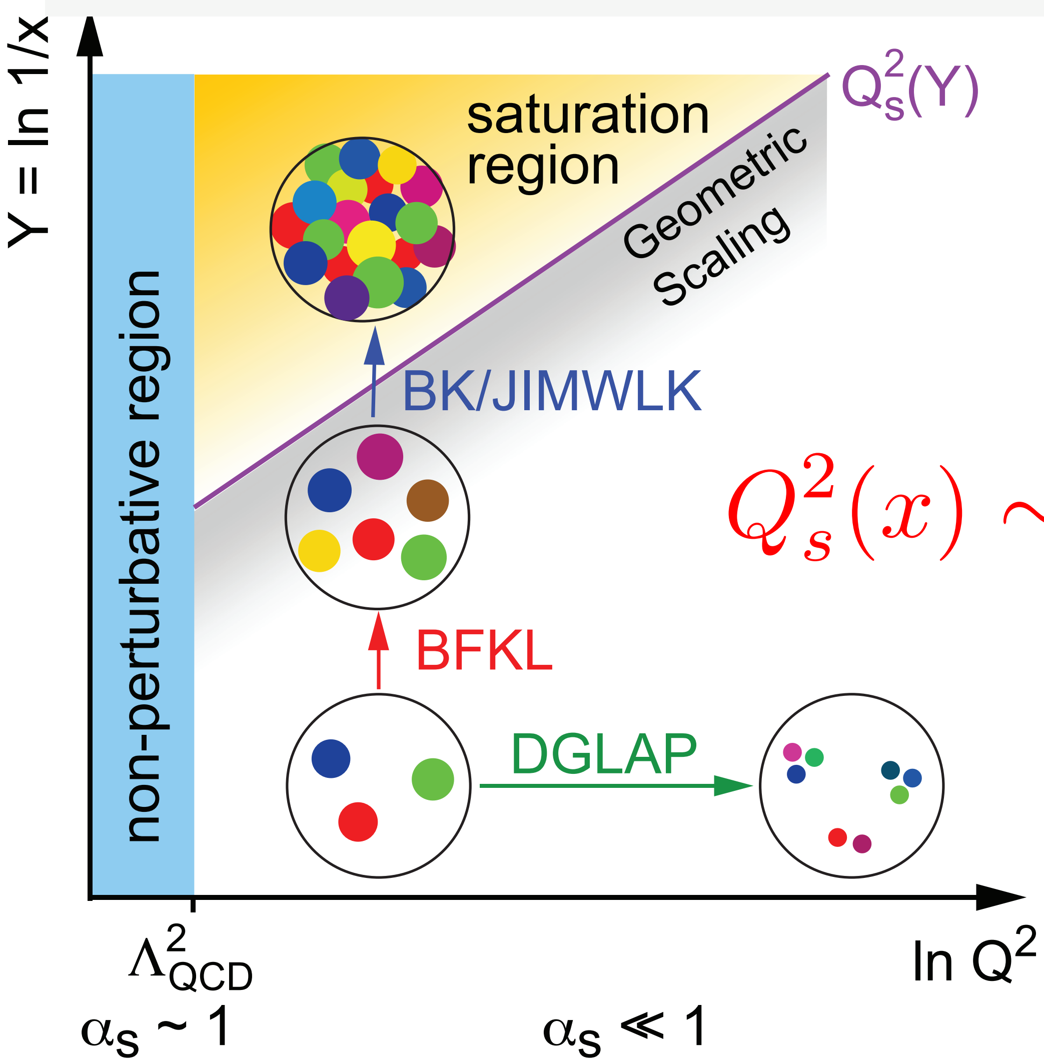



Don't trust the gluons
they make up everything!
nucleon
Q² = 10 GeV²
xu_v
xd_v
10⁻⁴
10⁻³
10⁻²
10⁻¹
1
x

Saturation at eRHIC

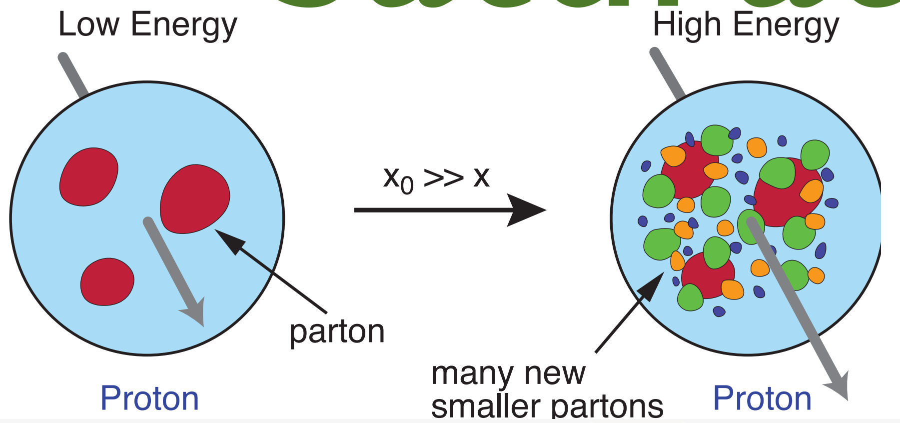


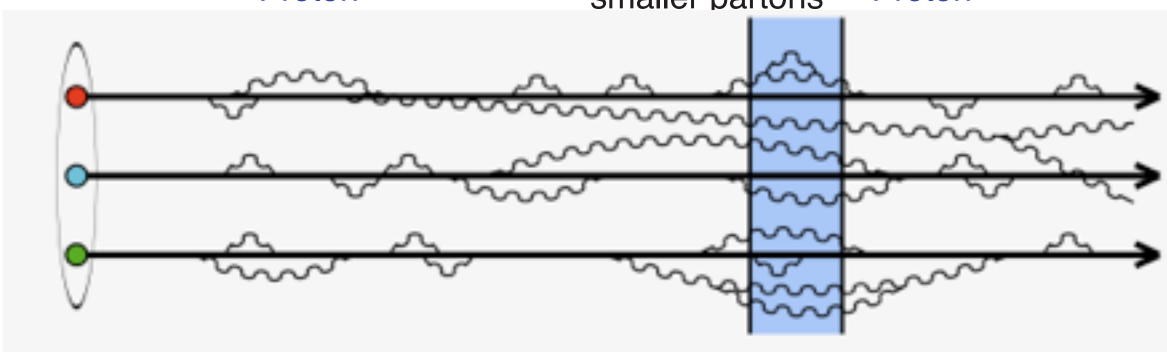


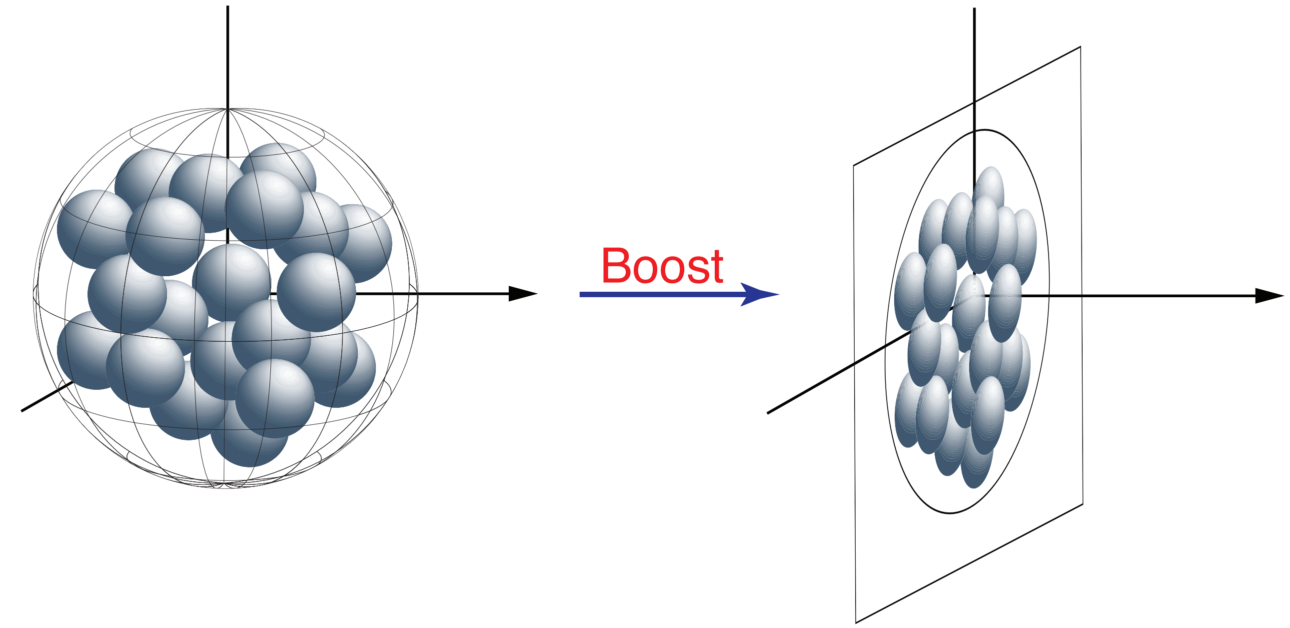


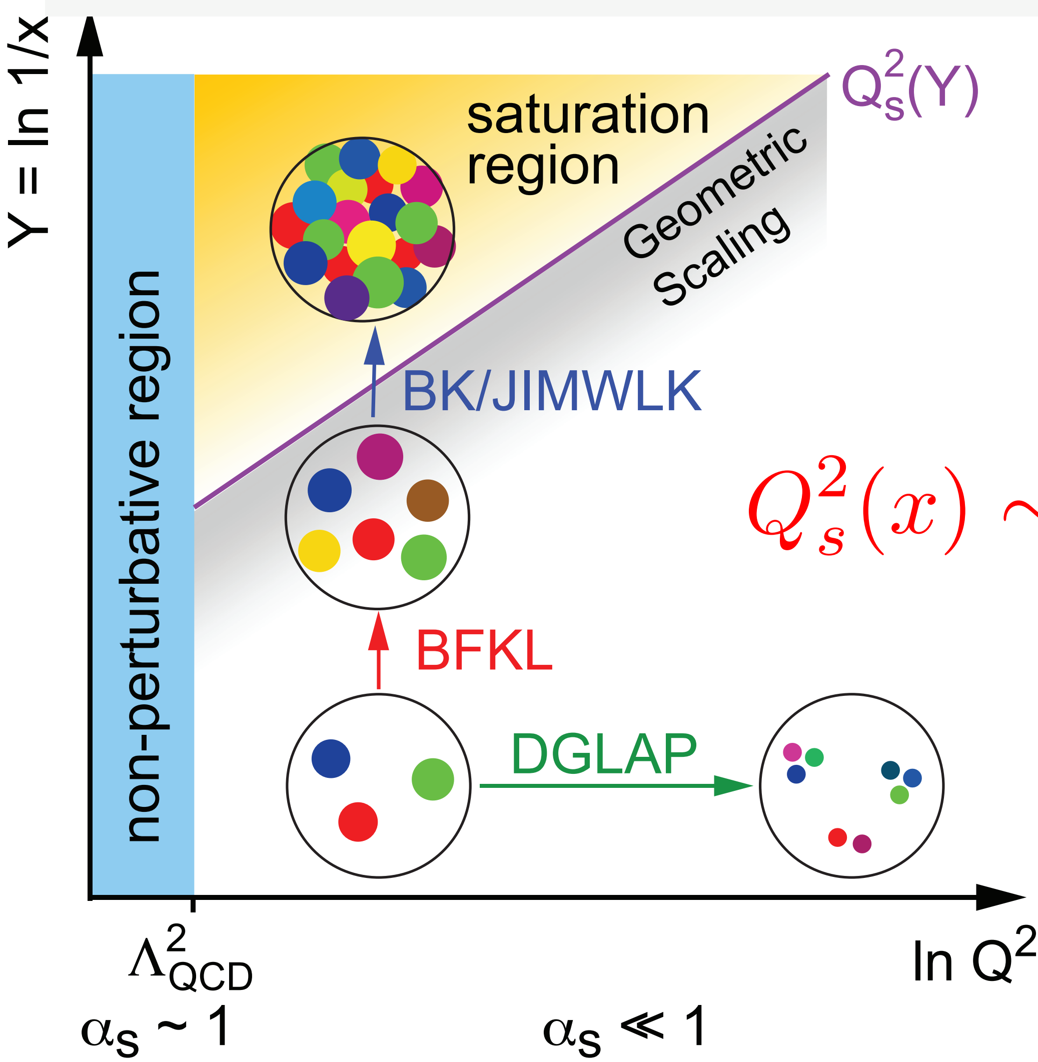
$$Q_s^2(x) \sim \left(\frac{1}{x}\right)^{\lambda}$$

Saturation at eRHIC

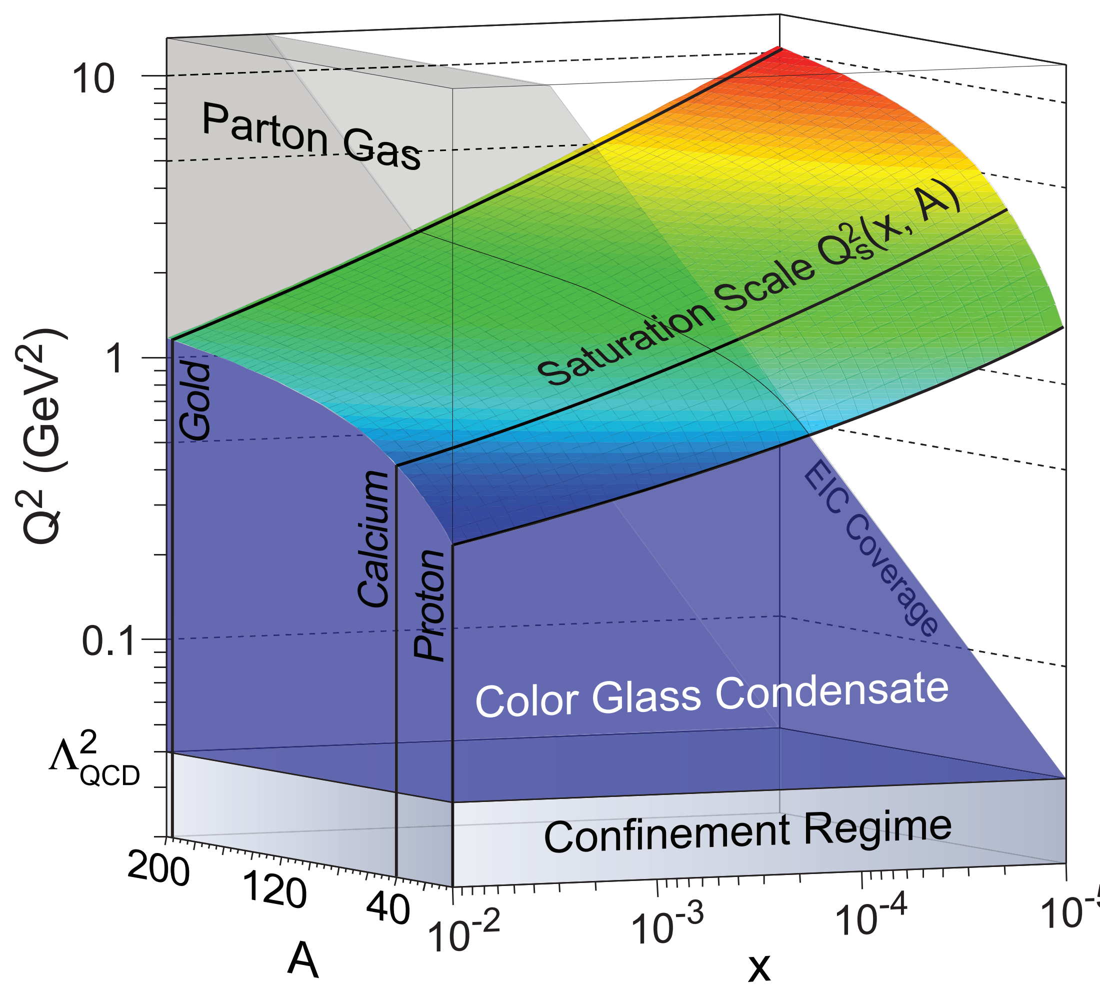








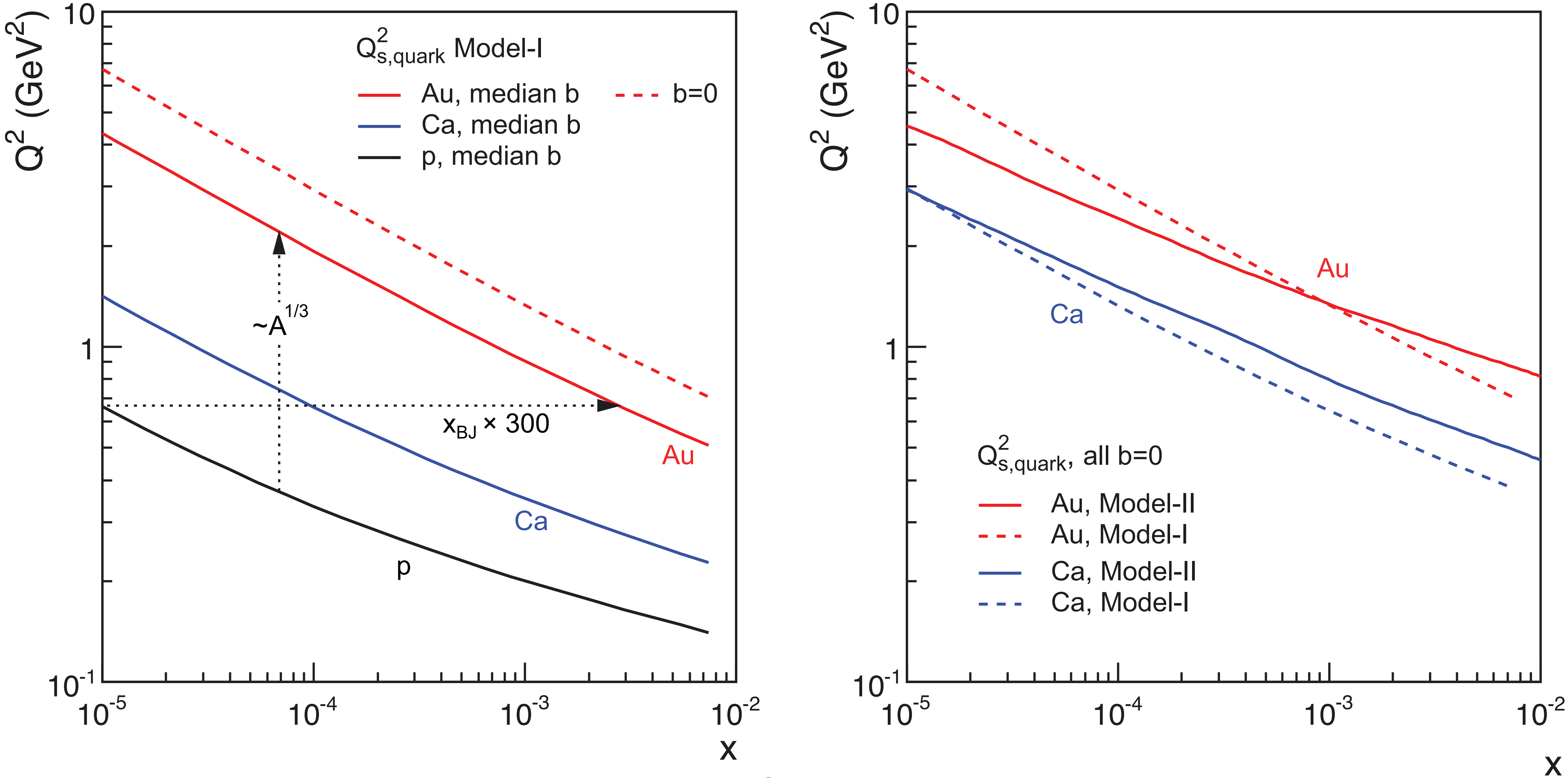
$$Q_s^2(x) \sim A^{1/3}\left(\frac{1}{x}\right)^{\lambda}$$



Saturation at eRHIC

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

Gold: A=197, *x* 197 times smaller!



Model-I: bSat, Model-II: rcBK

Saturation at eRHIC

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

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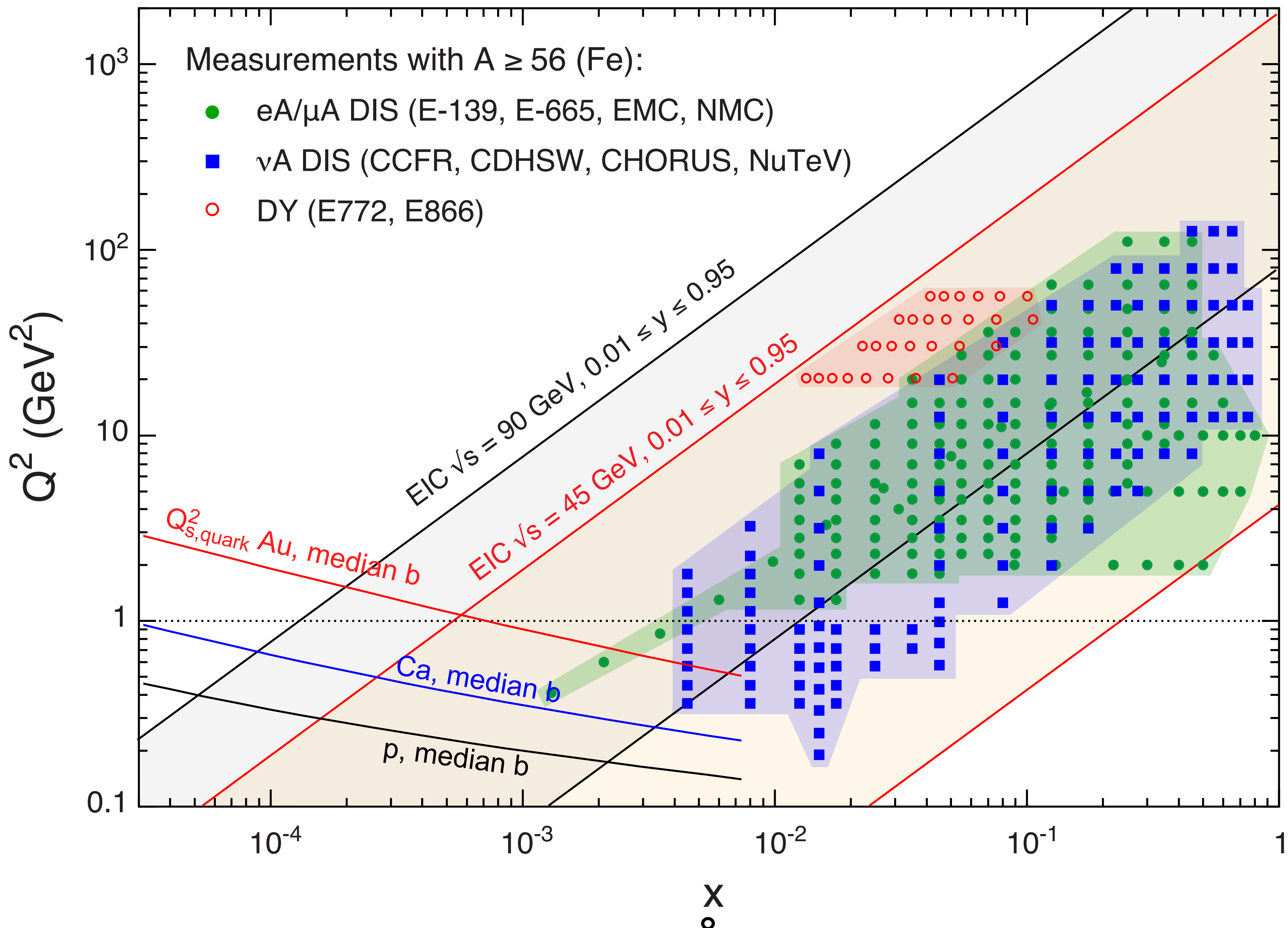
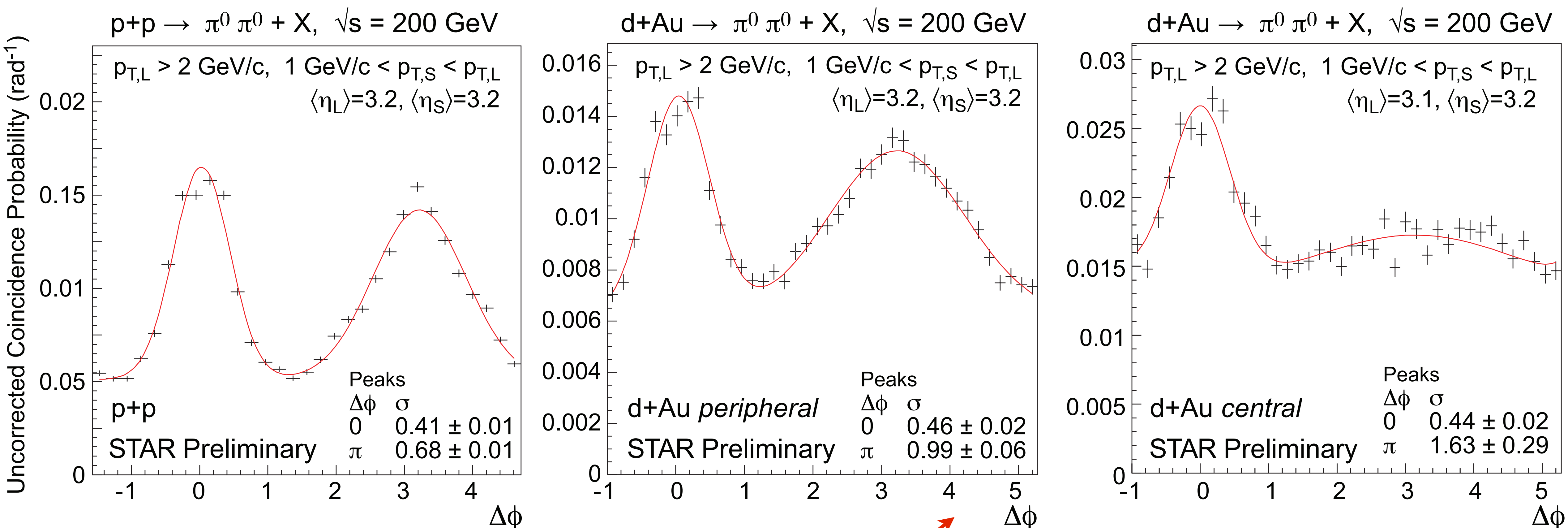
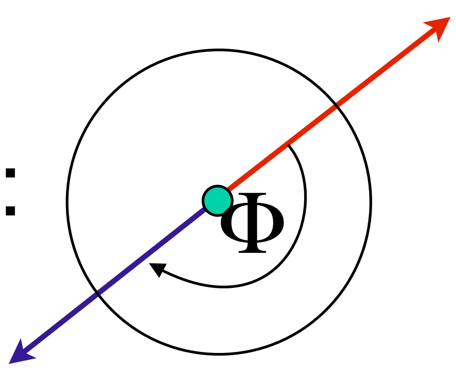


π^0-π^0 forward correlation in *pp* and *dA* at RHIC



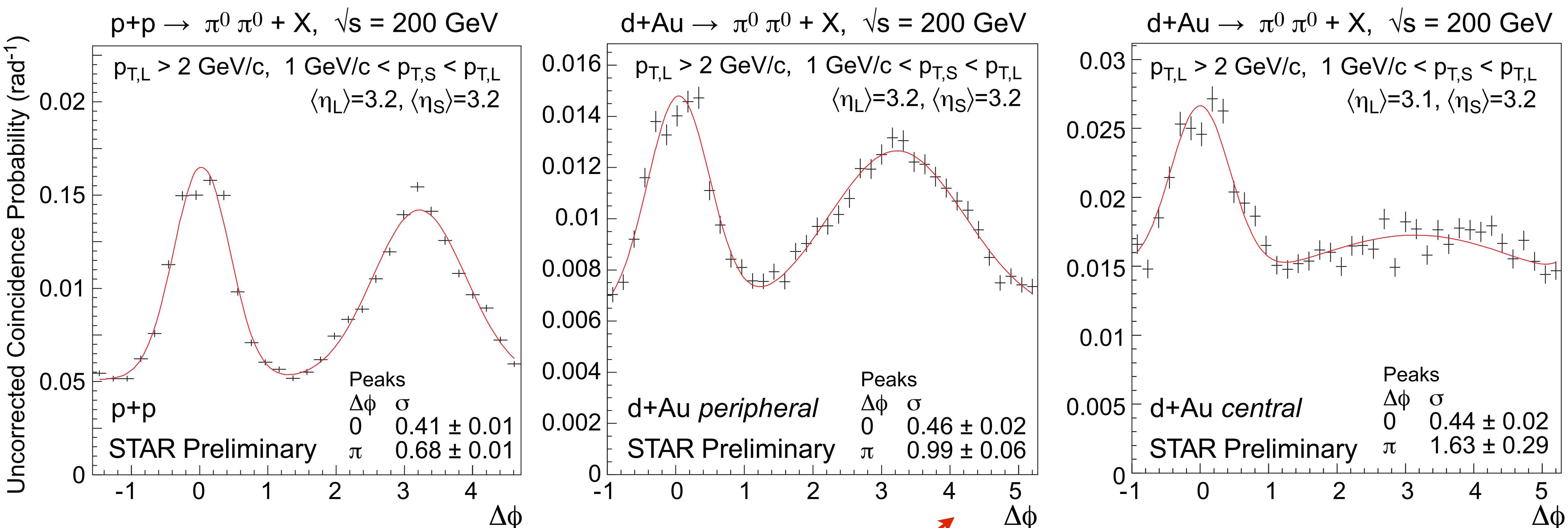
arXiv:1008.3989v1

beam-view:



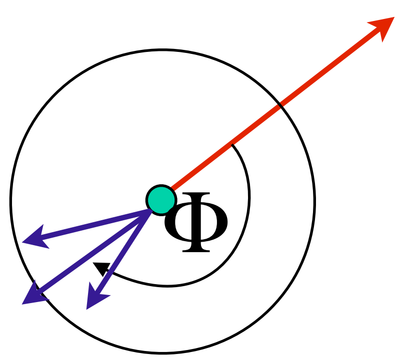
Striking broadening of away side peak in central *dA* compared to *pp* and peripheral *dA*!

π^0-π^0 forward correlation in *pp* and *dA* at RHIC



arXiv:1008.3989v1

beam-view:



Striking broadening of away side peak in central *dA* compared to *pp* and peripheral *dA*!

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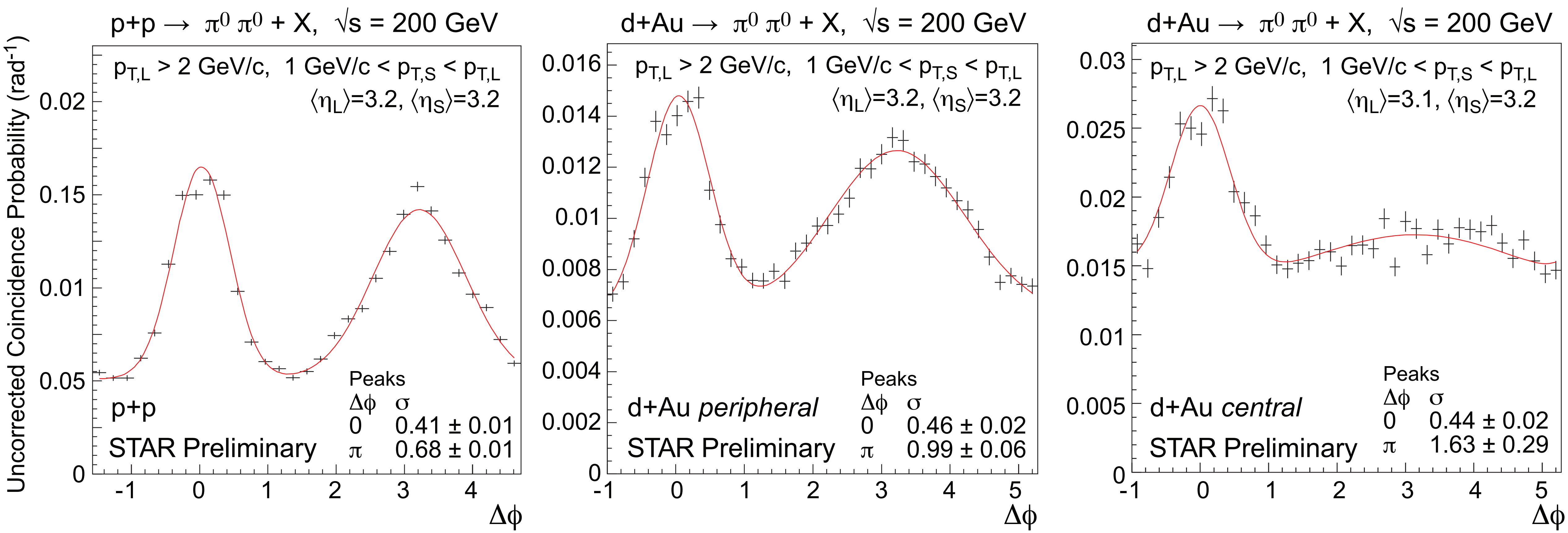

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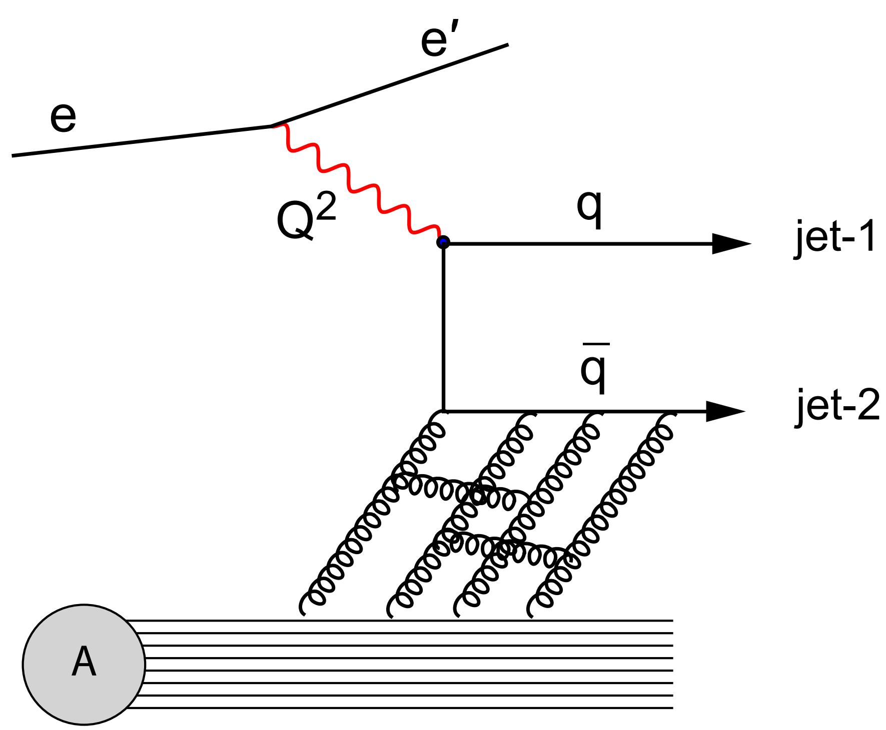
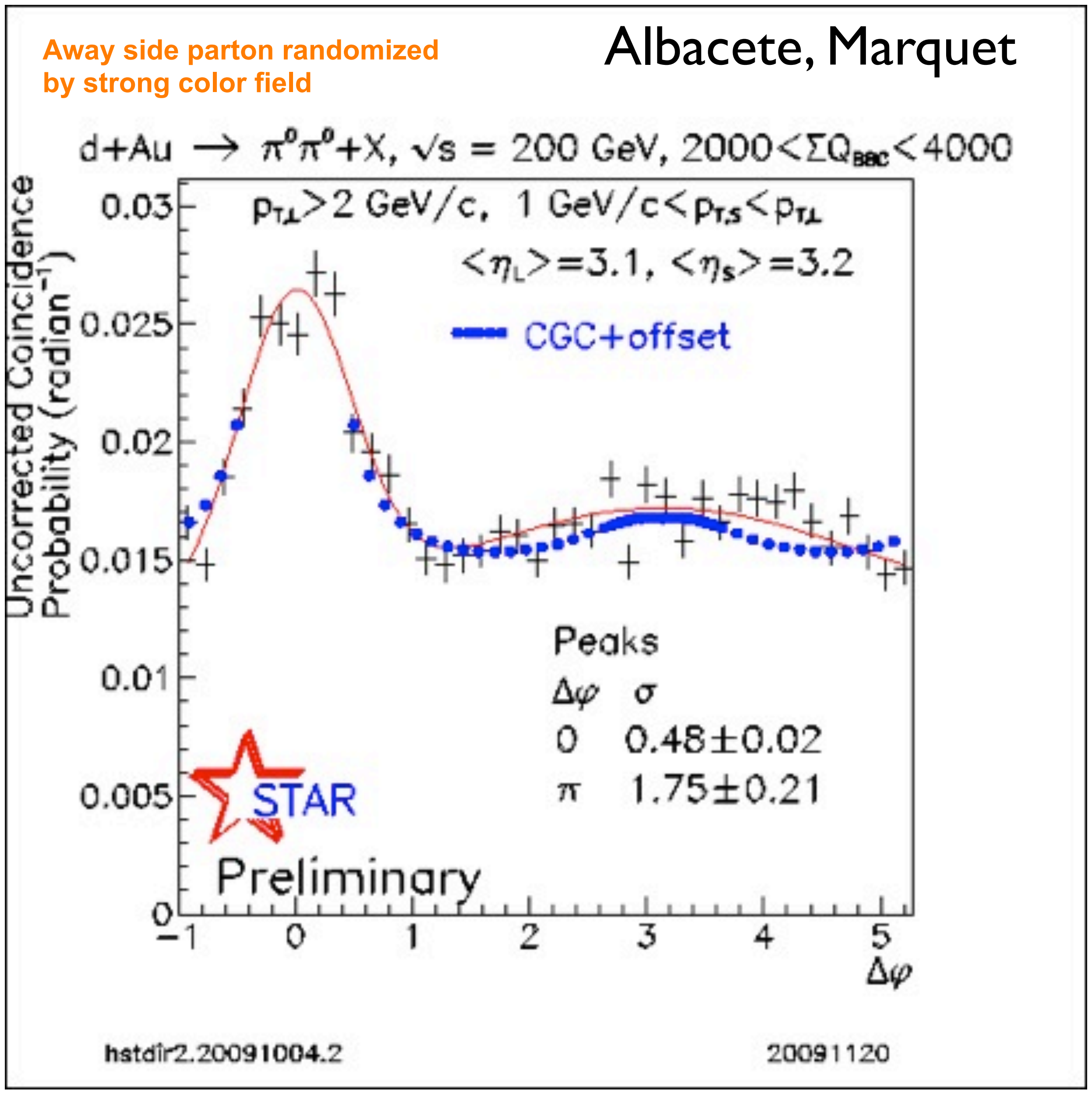


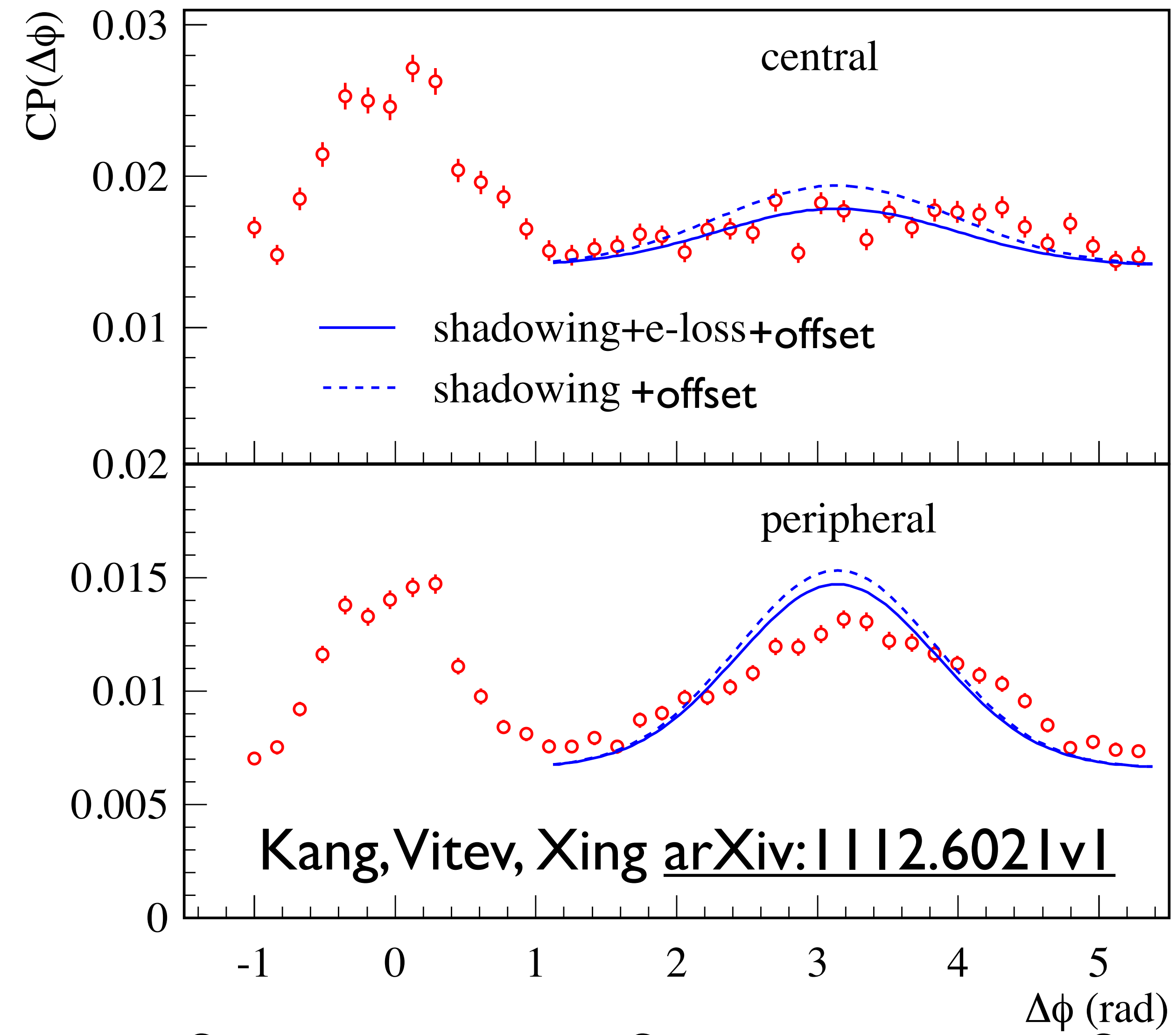
Perfect saturation signature

1 question, 2 answers

Initial state saturation model



Initial and final state multiple scattering



$$\langle q_\perp^2 \rangle_{dAu} = \langle q_\perp^2 \rangle_{pp} + \Delta \langle q_\perp^2 \rangle$$

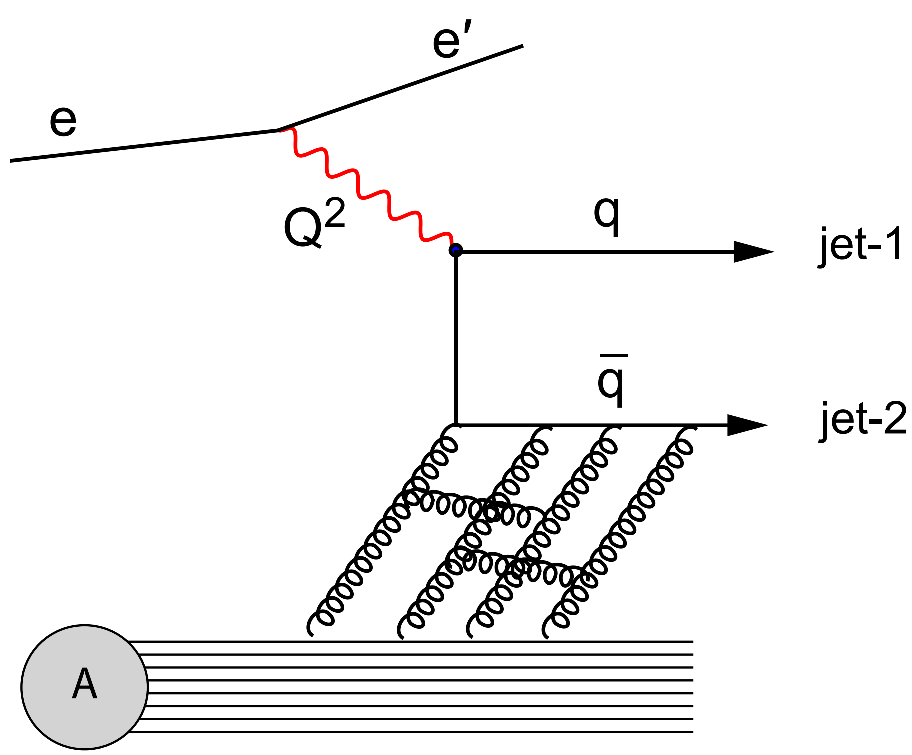
How saturated is the initial state?

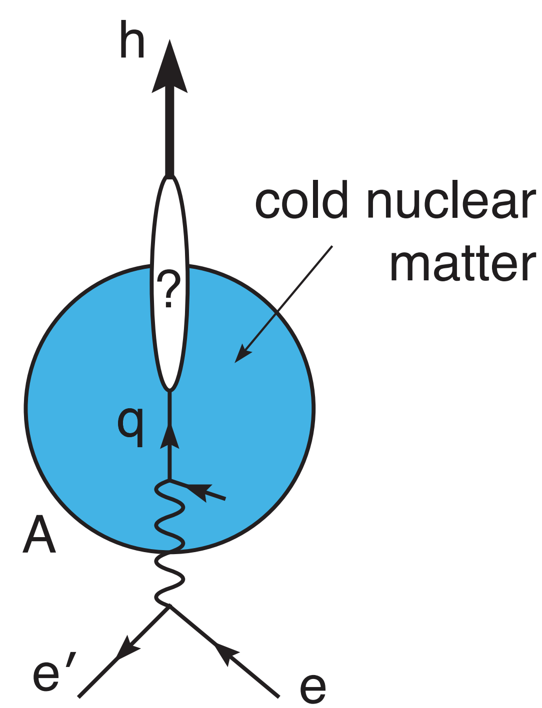
Dihadron correlations at eRHIC

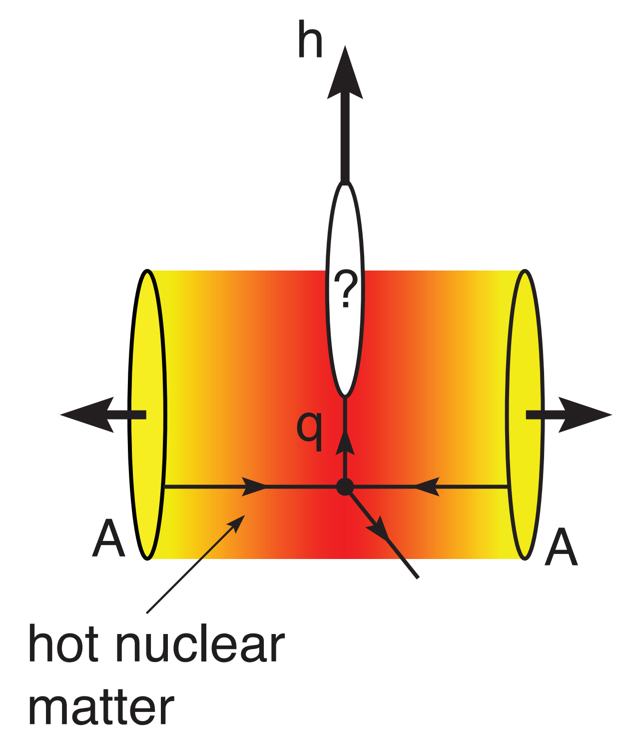
eA vs. $p(d)$A:

eA experimentally much cleaner,
no "spectator" background to extract

Access to the exact kinematics of the DIS process (x, Q^2)





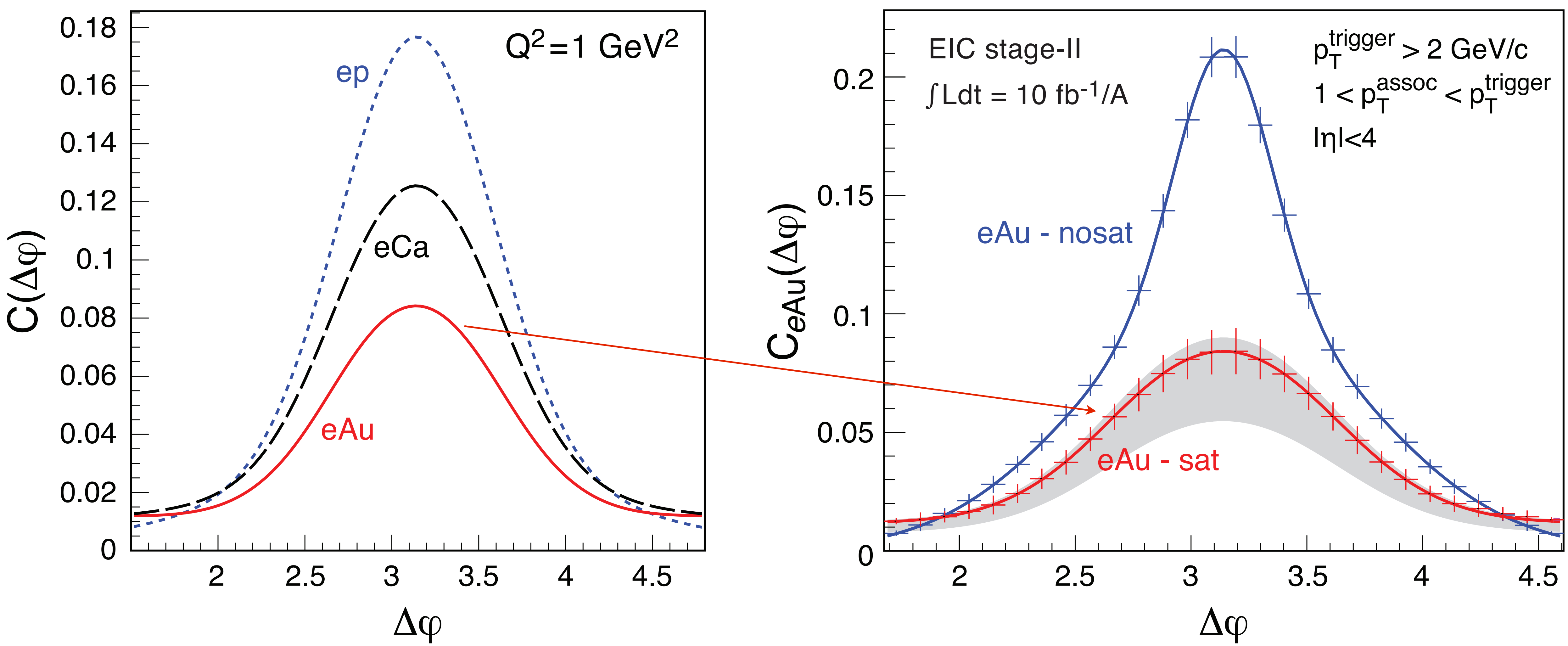


Dihadron correlations at eRHIC

Dominguez, Xiao, Yuan, Lee, Zheng '11/12

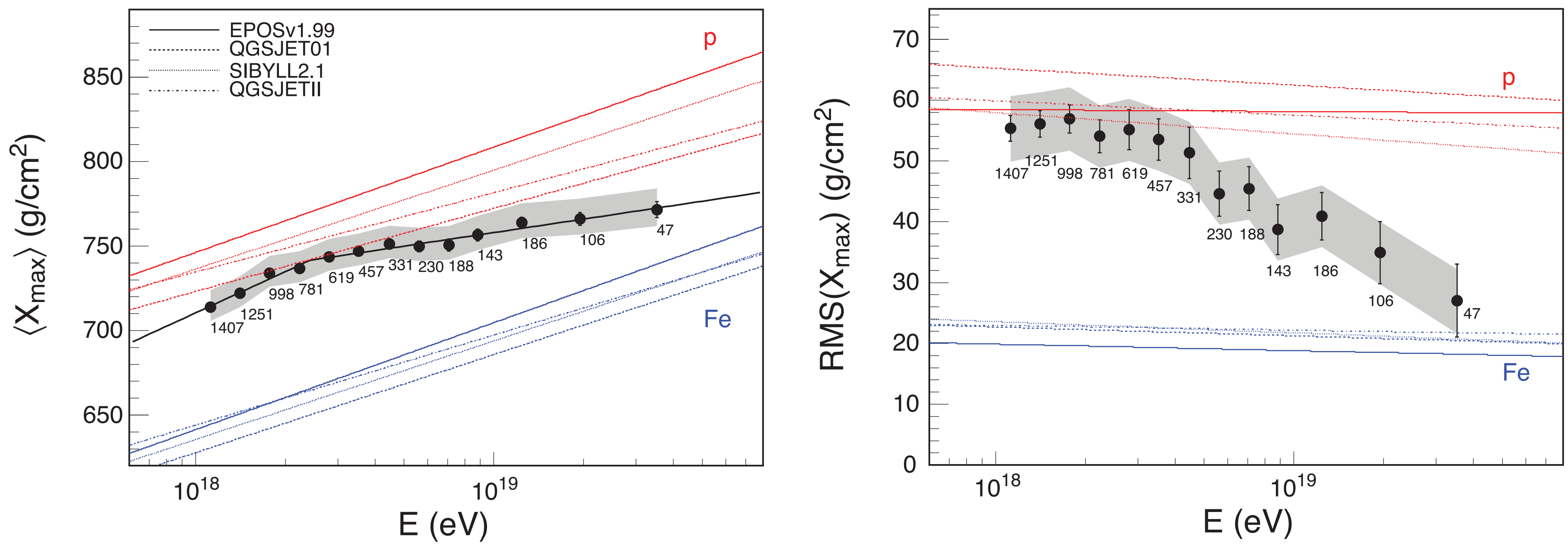
Theory: Saturation

Exp: Saturation vs. no saturation



Non-sat.: Pythia+nPDF(EPS09) w. nuclear geometry from DPMJET-III

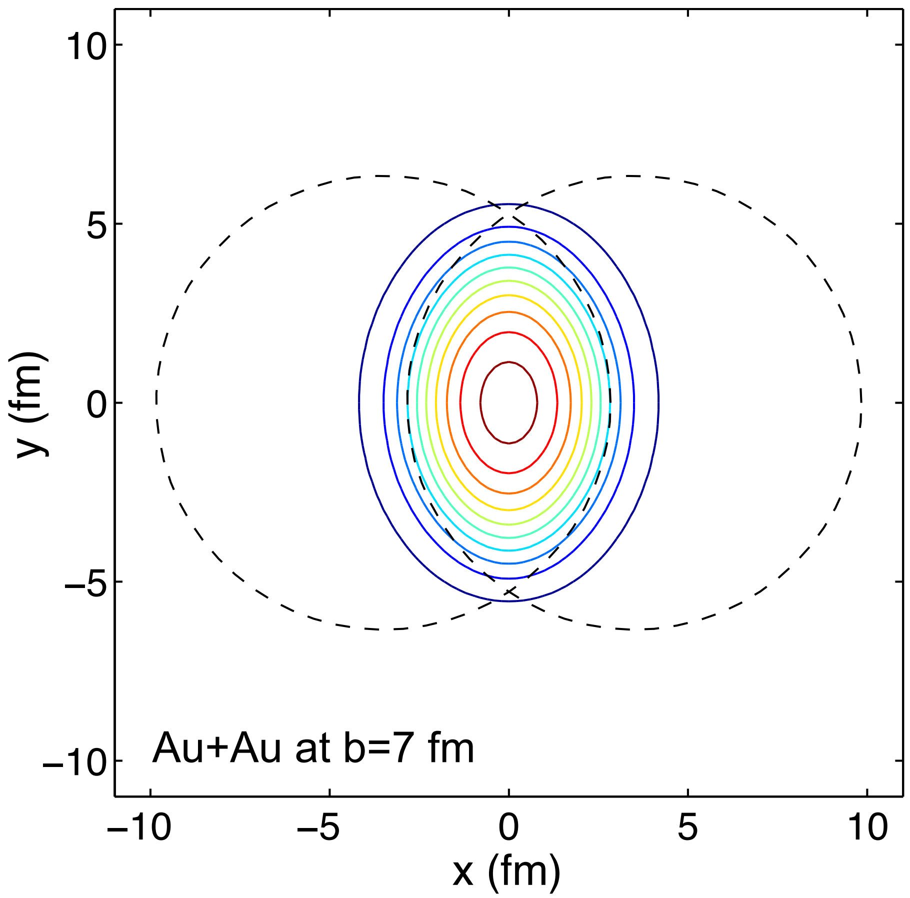
Connection between cosmic rays and saturation



3 conundrums of the small-*x* nucleus

1. how saturated is the initial state of the nucleus?
2. how are gluons distributed in space?
3. how much does the spatial distribution fluctuate? lumpiness, hot-spots etc.

Eccentricity and the spatial distr.



$$\frac{dN}{d\varphi} \propto 1 + 2v_2 \cos[2(\varphi - \psi_R)] + \ldots$$

$$v_2 = \langle \cos[2(\varphi - \psi_R)] \rangle$$

sensitive to **early** interactions and pressure gradients

Ideal hydrodynamics, $v_2 \propto$ spatial eccentricity ε: $\epsilon = \frac{\langle y^2 - x^2 \rangle}{\langle y^2 + x^2 \rangle}$

v_2/ε versus particle density is sensitive gauge to test if system approaches ideal hydrodynamic

$$\frac{v_2}{\epsilon} = \frac{h}{1 + B/(\frac{1}{S}\frac{dN}{dy})}$$

Bhalerao, Blaizot, Borghini and Ollitrault, Phys. Lett. B 627 (2005) 49
Luzum and Romatschke, Phys. Rev. C 78, 034915

S= transverse area, h = hydro limit of v_2/ε and B $\propto$ η/s

Eccentricity and the spatial distr.

The question is what is ε?

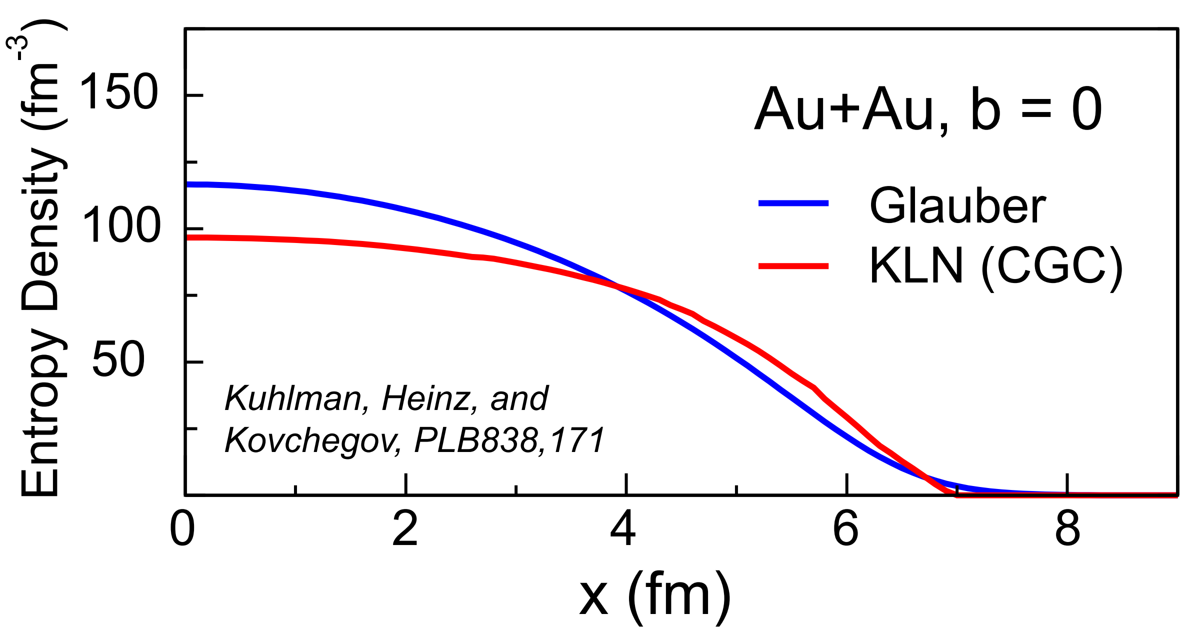
RHIC & LHC: low-p_T realm driven almost entirely by glue

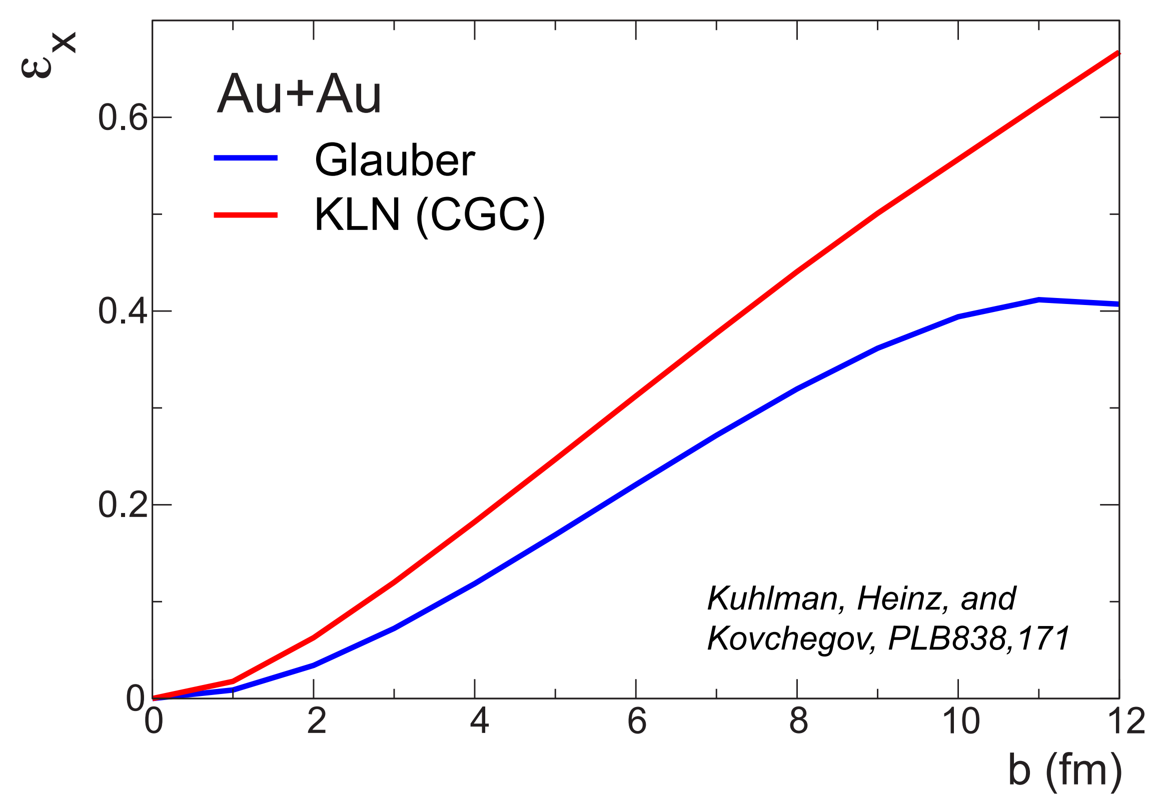
⇒ spatial distribution of glue in nuclei?

Two methods for ε:

- Glauber (non-saturated)?
- CGC (saturated)?

$\varepsilon_{CGC} > \varepsilon_{Glauber}$





Eccentricity and the spatial distr.

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RHIC & LHC: low-p_T realm driven almost entirely by glue

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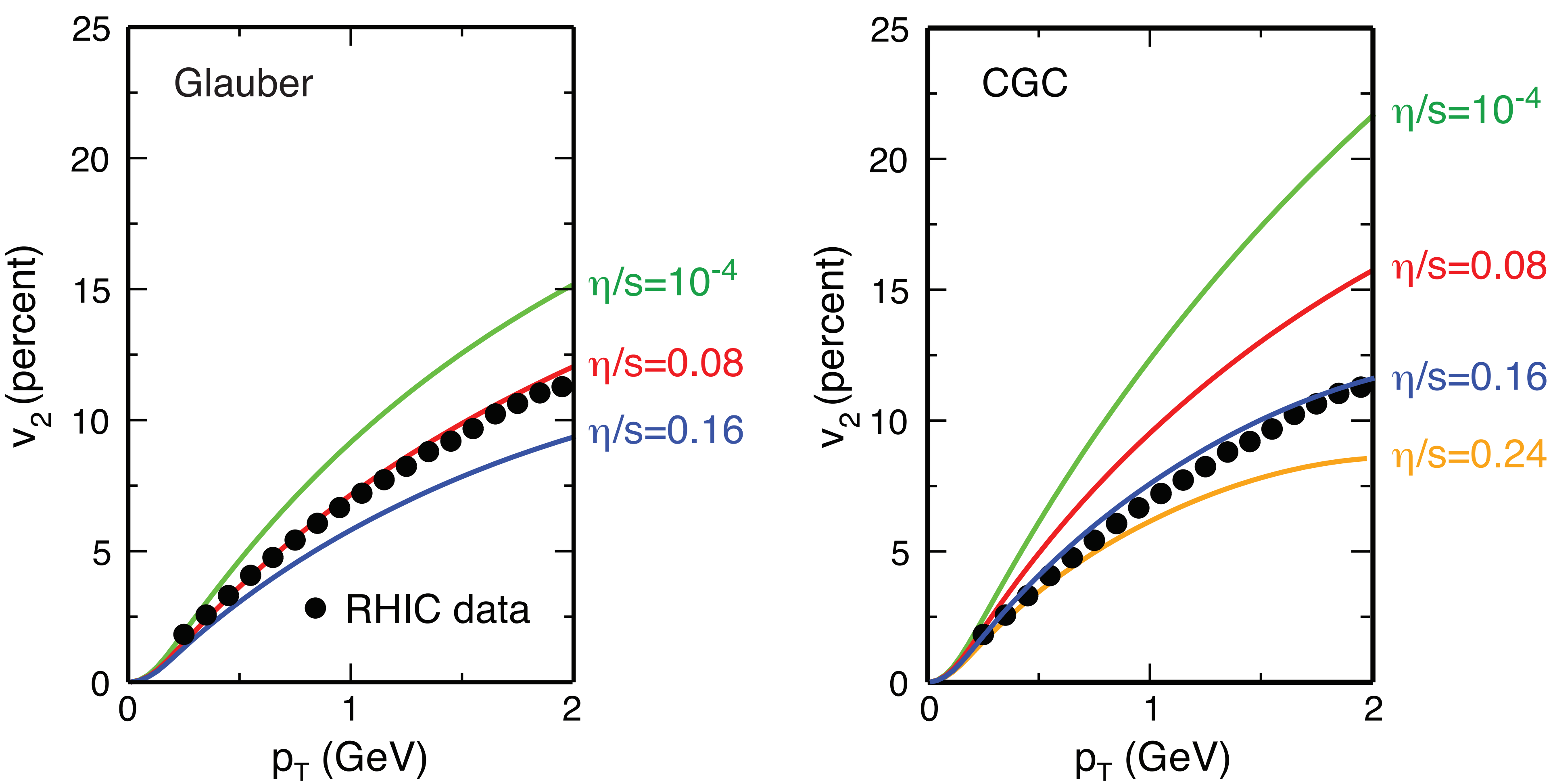
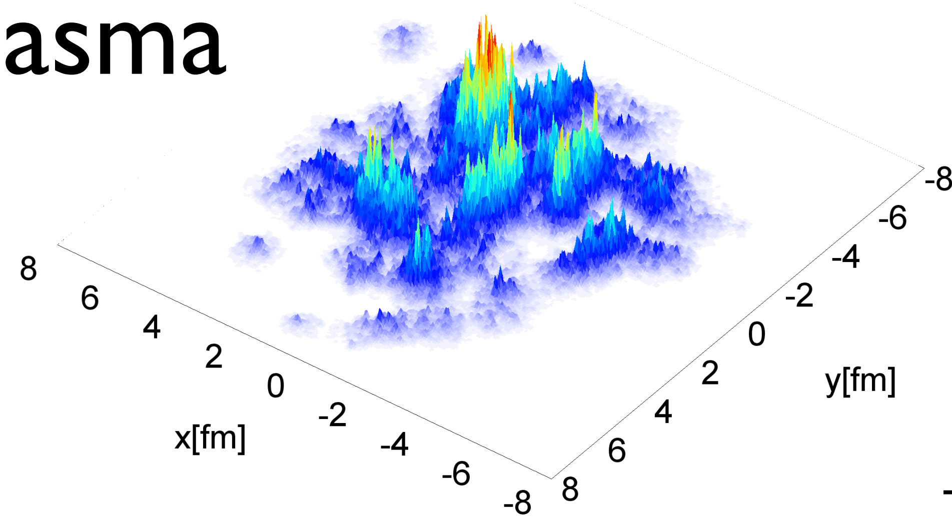
Impact on η/*s*

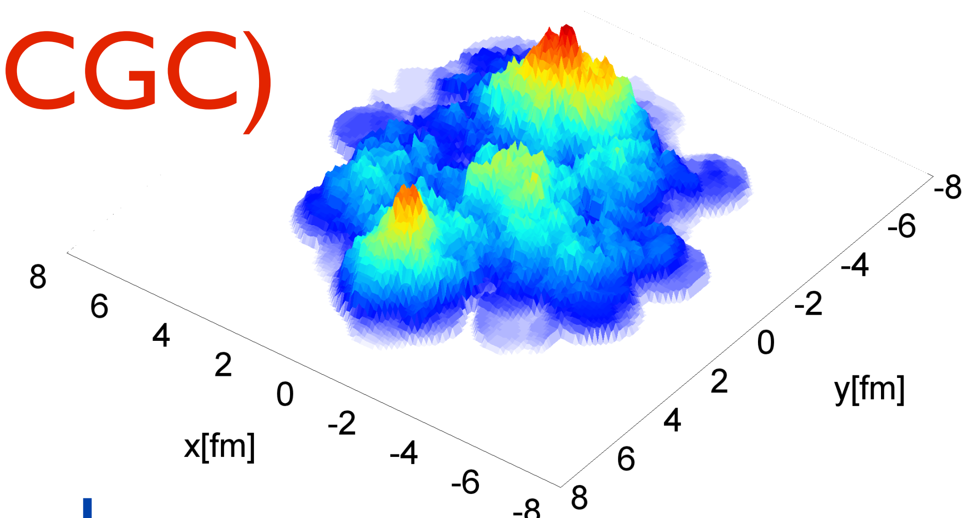


Fluctuations

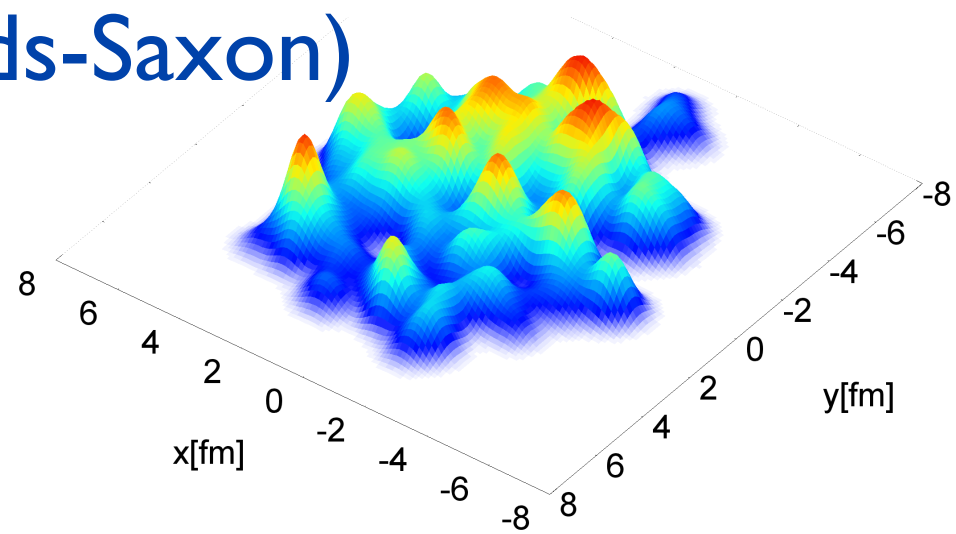
IP-Glasma

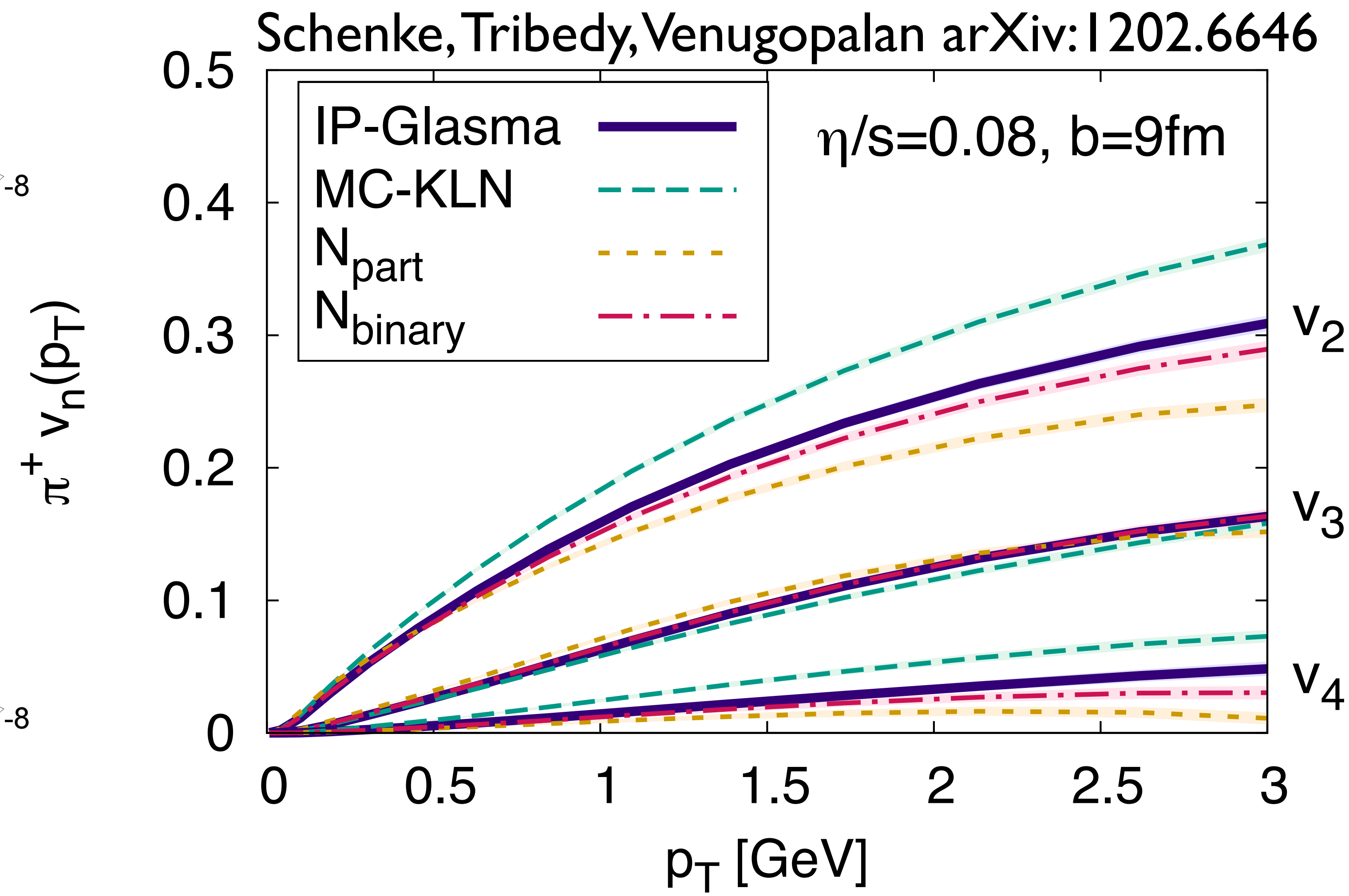


KLN(CGC)



Glauber
(Woods-Saxon)

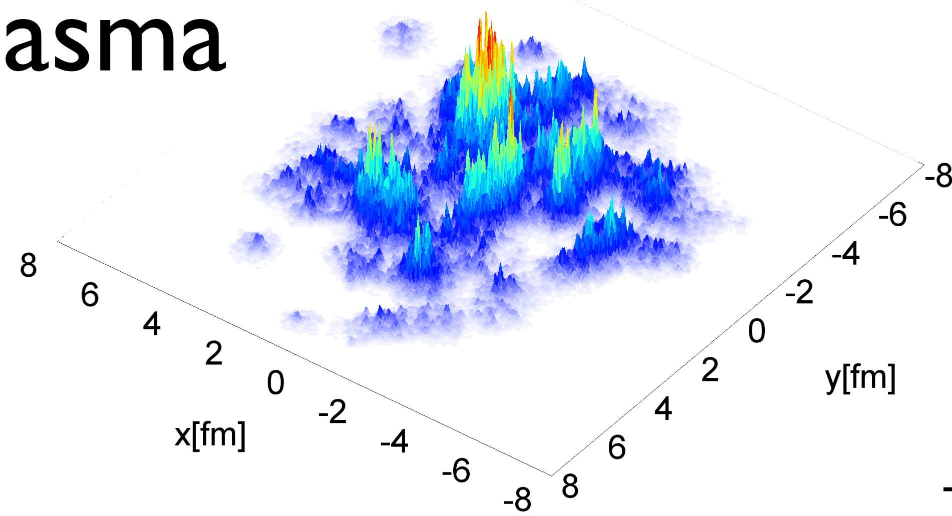




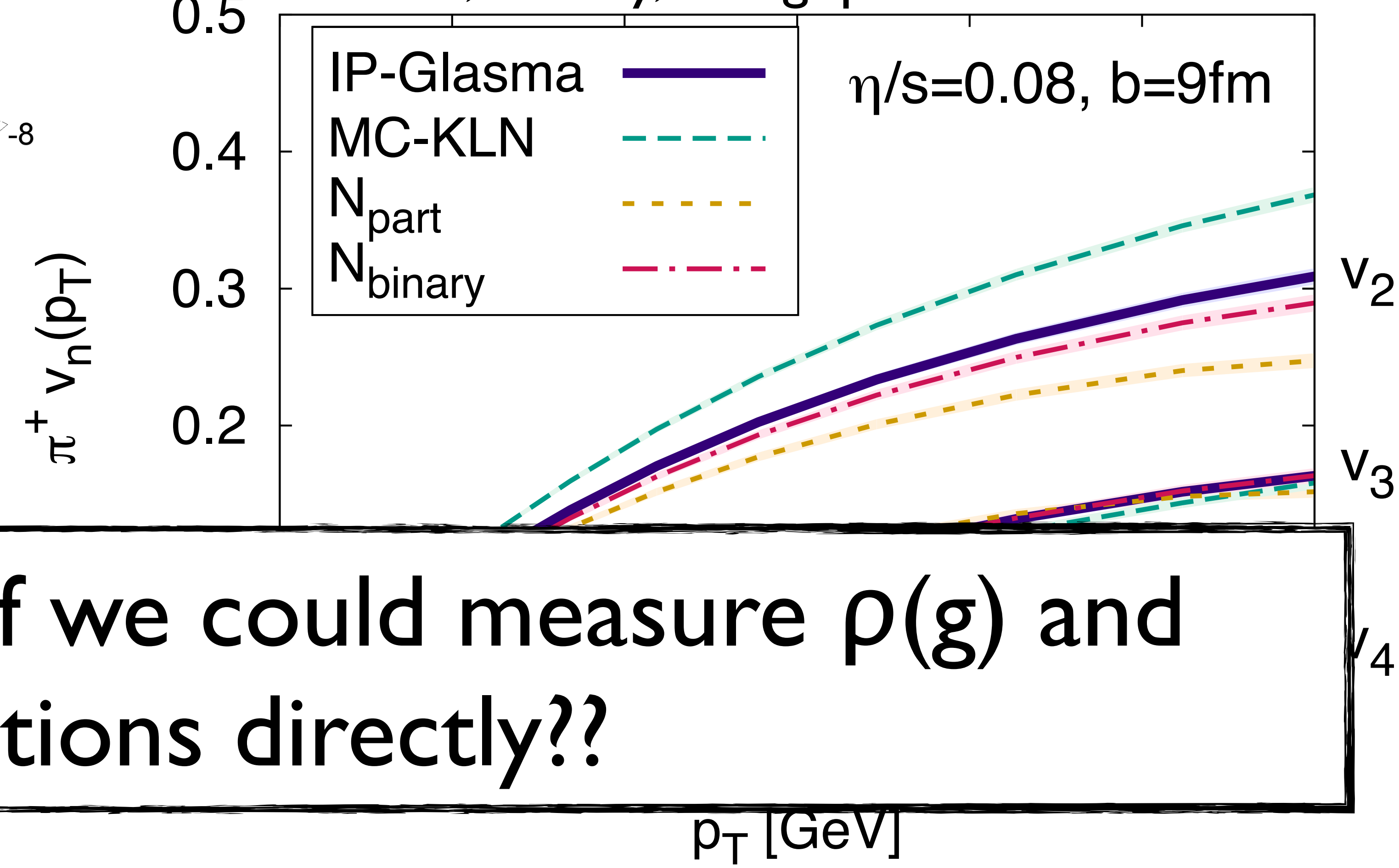
Different initial states=
different fluctuation scales

Fluctuations

IP-Glasma

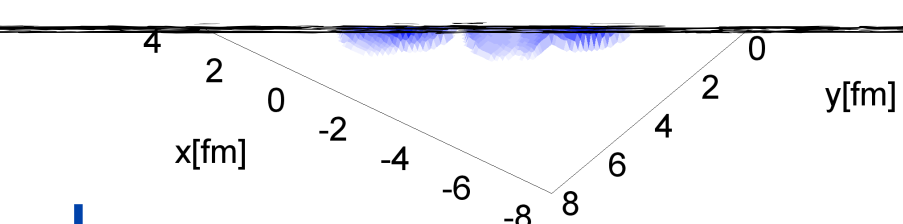


Schenke, Tribedy, Venugopalan arXiv:1202.6646

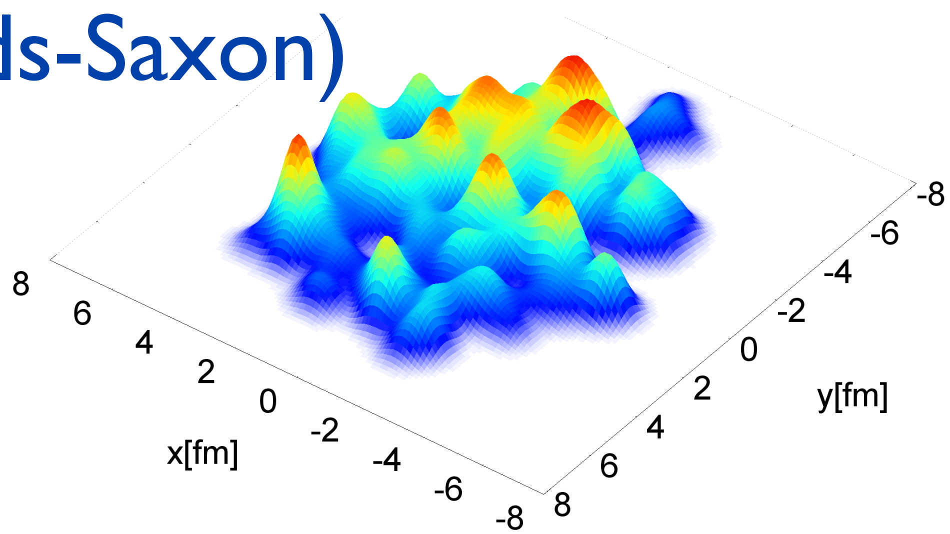


K

Wouldn't it be nice if we could measure ρ(g) and fluctuations directly??



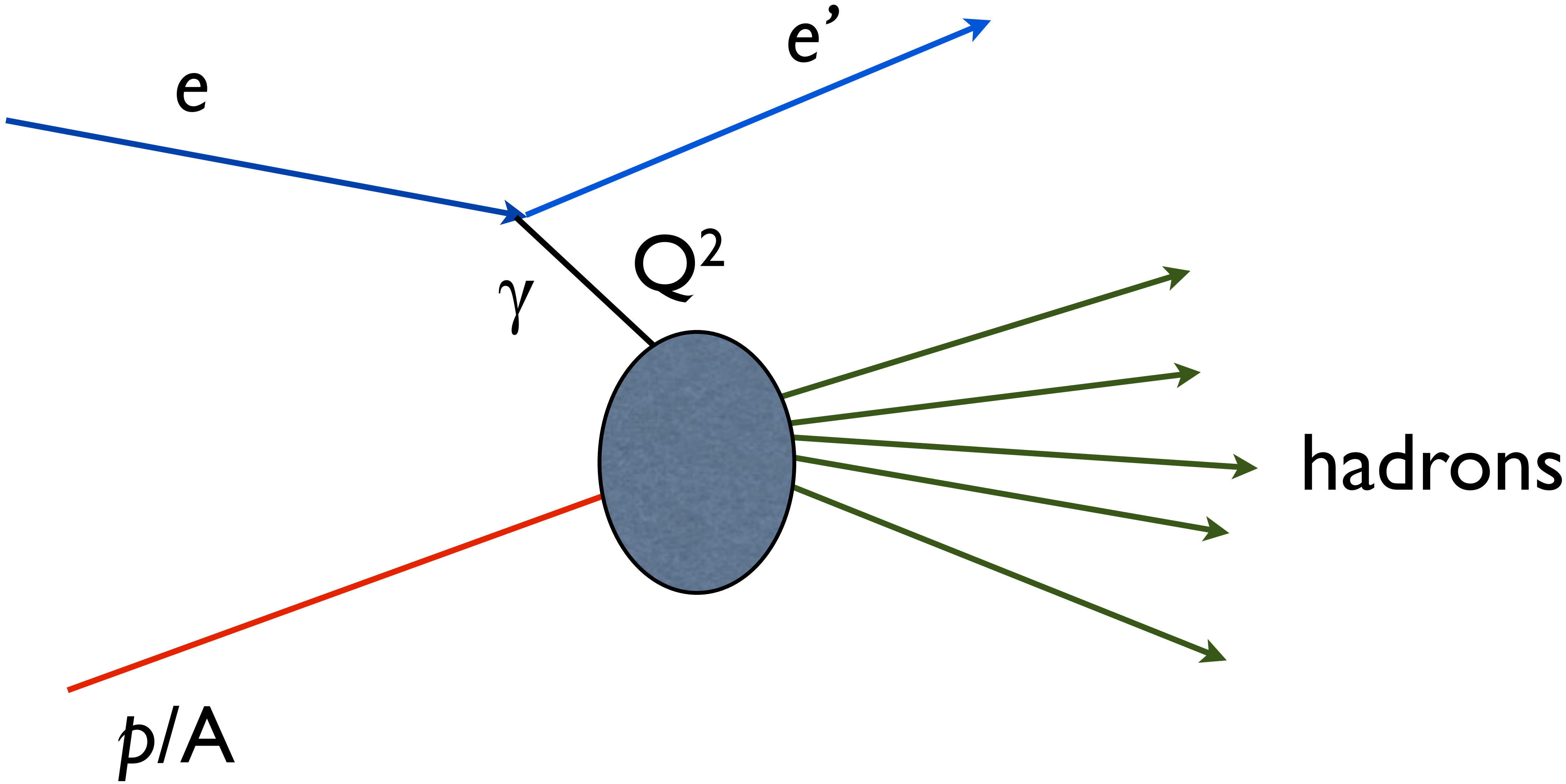
Glauber (Woods-Saxon)



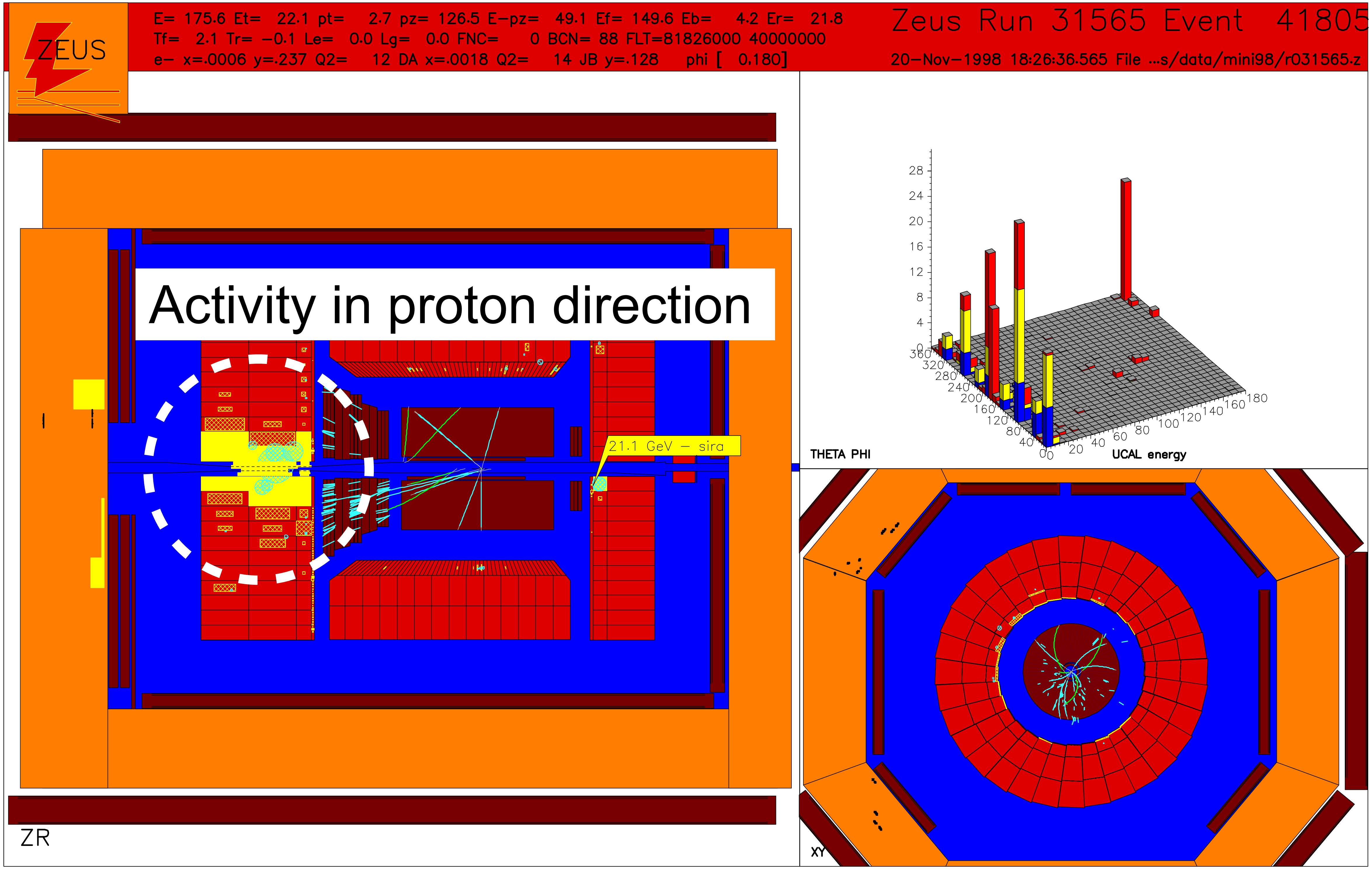
Different initial states= different fluctuation scales

Diffraction at eRHIC

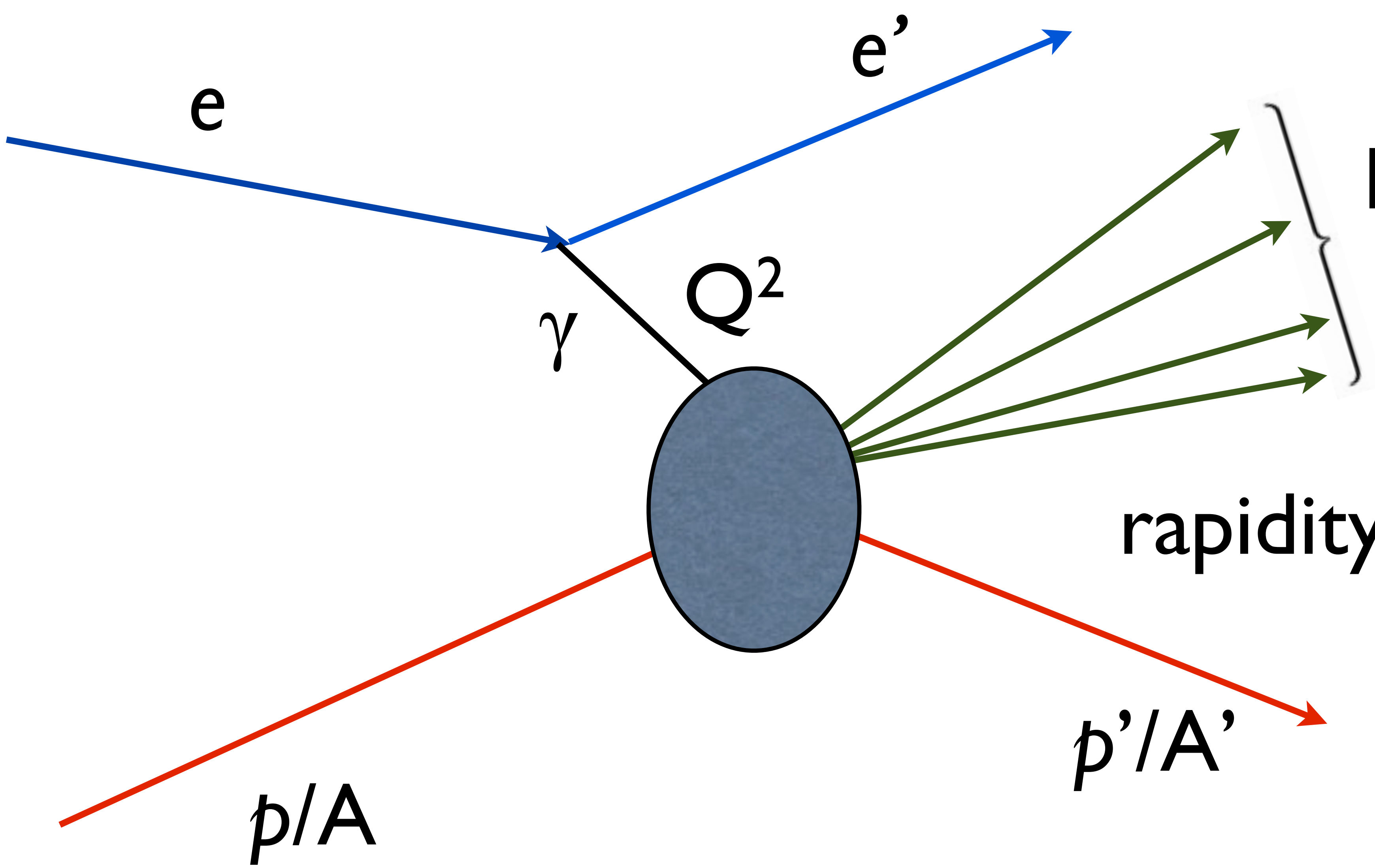
DIS *ep* and eA



DIS *ep* and eA


E= 175.6 Et= 22.1 pt= 2.7 pz= 126.5 E−pz= 49.1 Ef= 149.6 Eb= 4.2 Er= 21.8
Tf= 2.1 Tr= −0.1 Le= 0.0 Lg= 0.0 FNC= 0 BCN= 88 FLT=81826000 40000000
e− x=.0006 y=.237 Q2= 12 DA x=.0018 Q2= 14 JB y=.128 phi [0,180]
Zeus Run 31565 Event 41805
20−Nov−1998 18:26:36.565 File ...s/data/mini98/r031565.z
ZEUS
Activity in proton direction
21.1 GeV − sira
ZR
THETA PHI
UCAL energy
XY

diffraction *ep* and eA



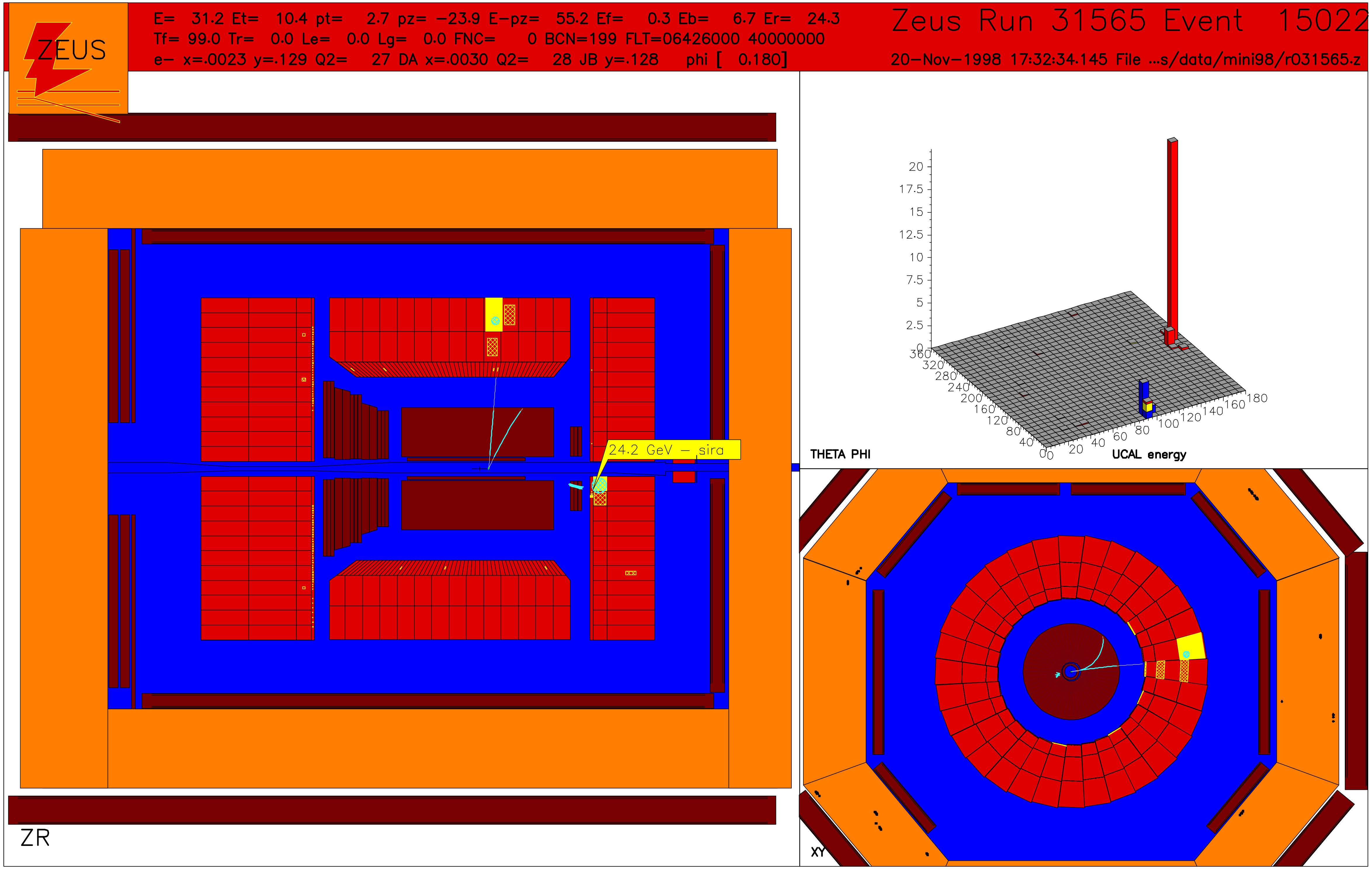
HERA:

proton collides with electron at CMS energy ~300m_p.
in ~15% of measured collisions proton stays intact!

eRHIC e+A:

ion predicted to stay intact in 25%-40% of events w. saturation!

diffraction *ep* and eA



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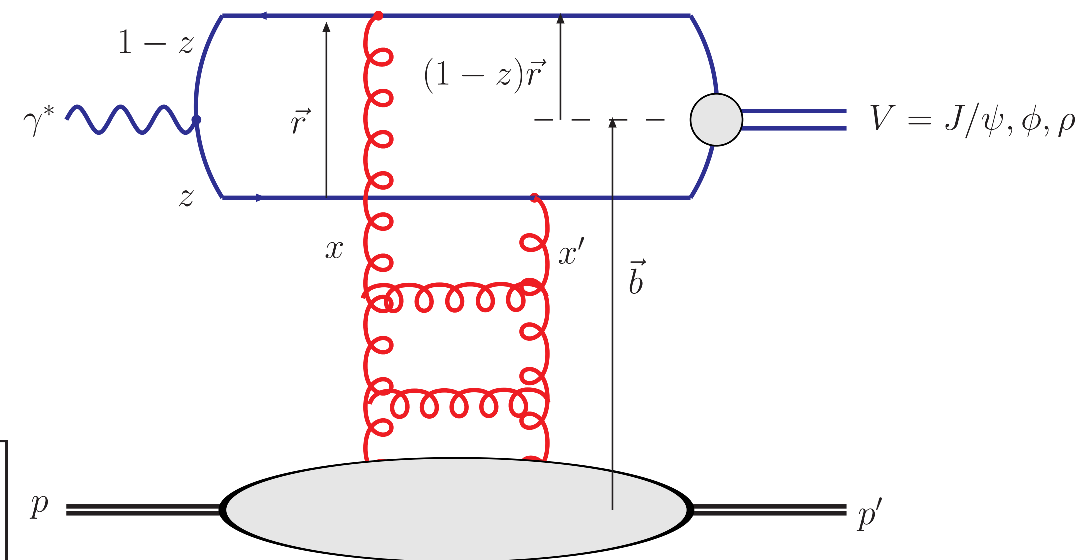
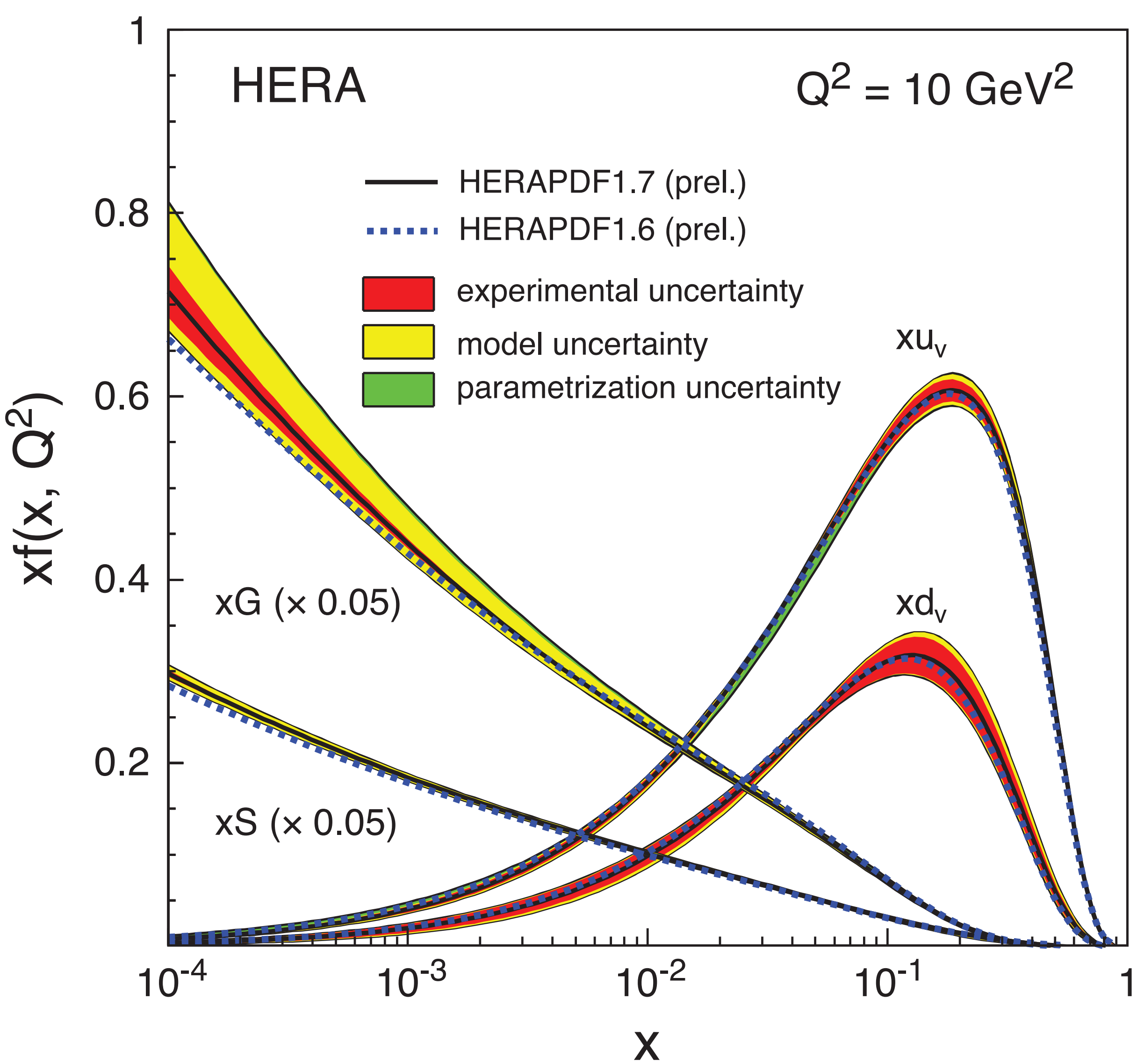
why is diffraction so great, part I?

diffraction sensitive to gluon momentum distributions[2]:

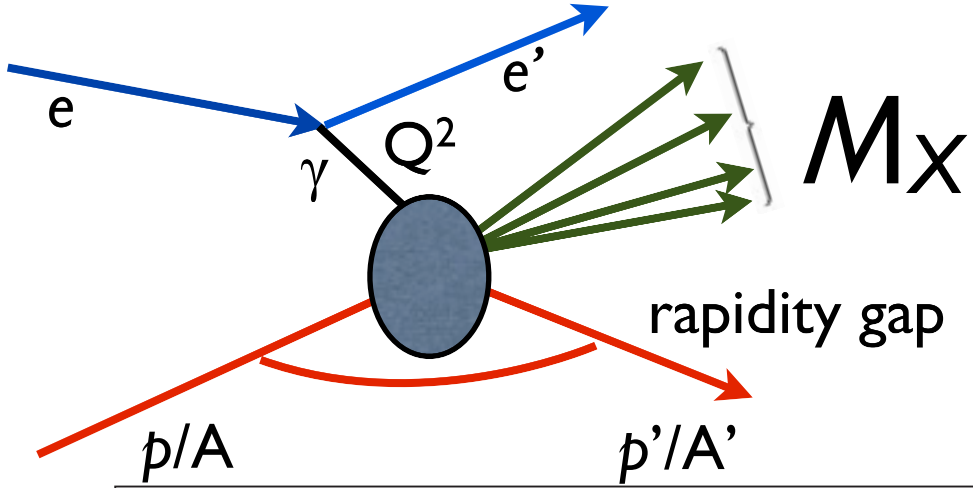


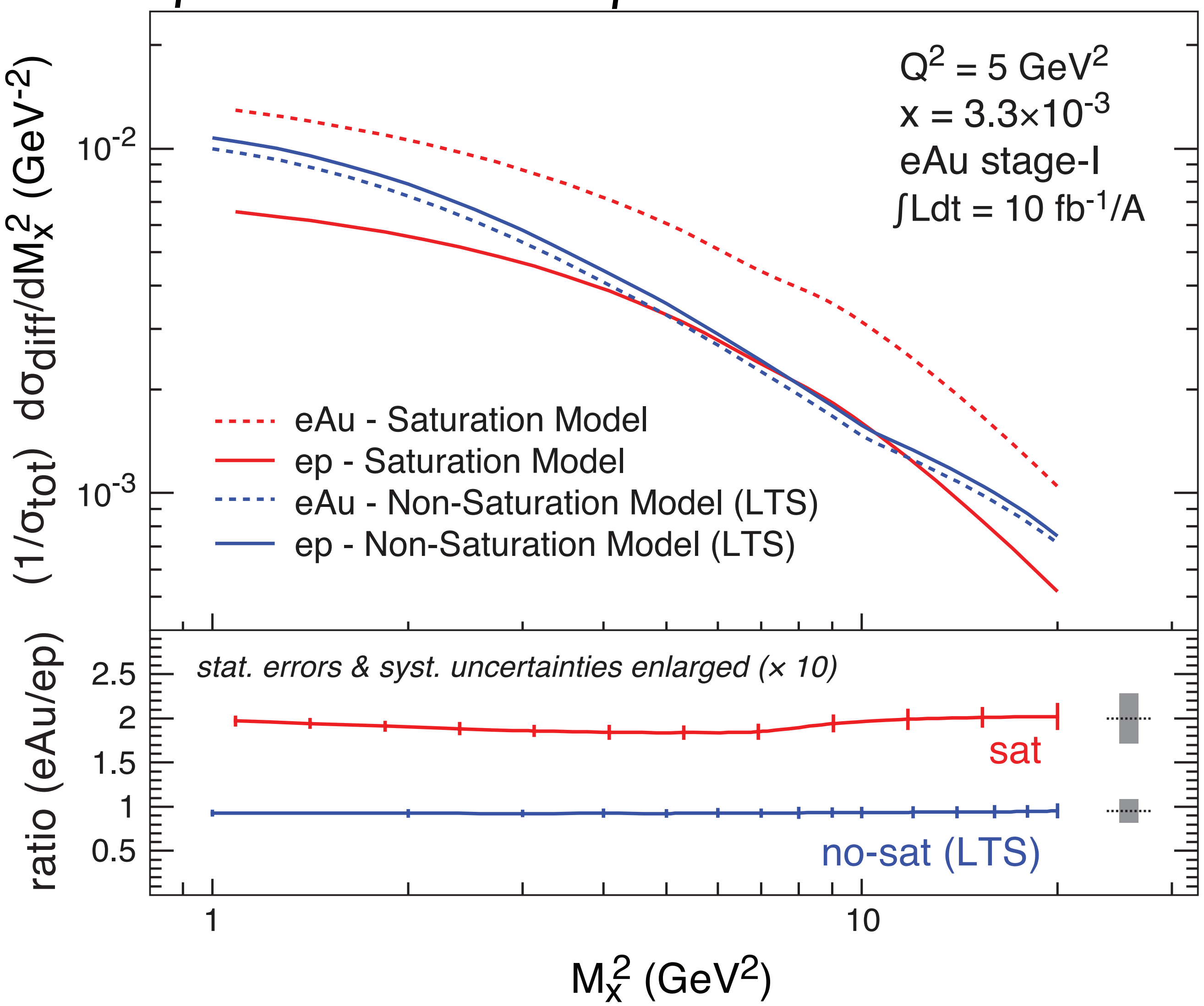
$$\sigma \propto g(x,Q^2)^2$$

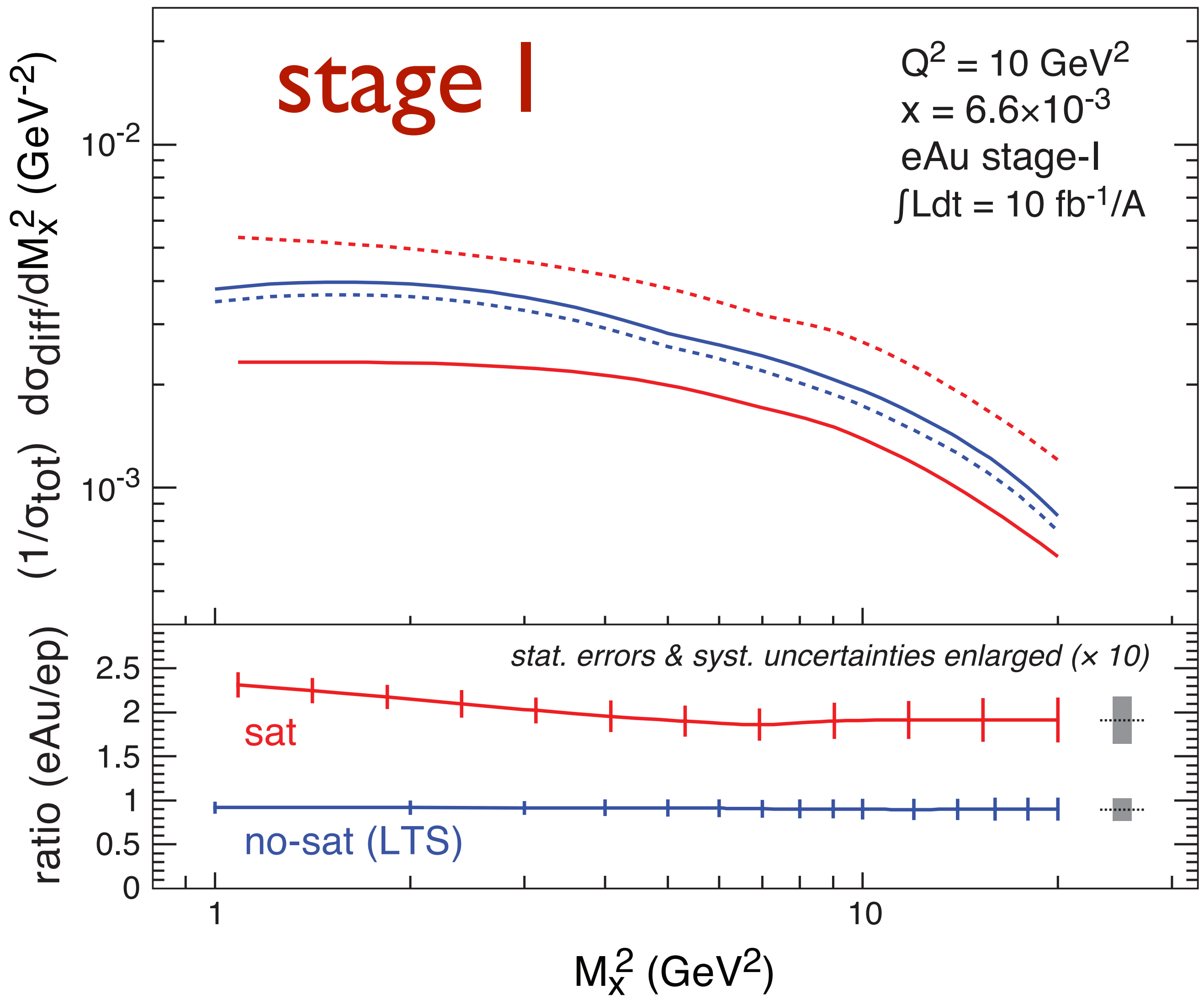


how does the gluon distribution saturate at small *x*?

eRHIC predictions: inclusive diffraction

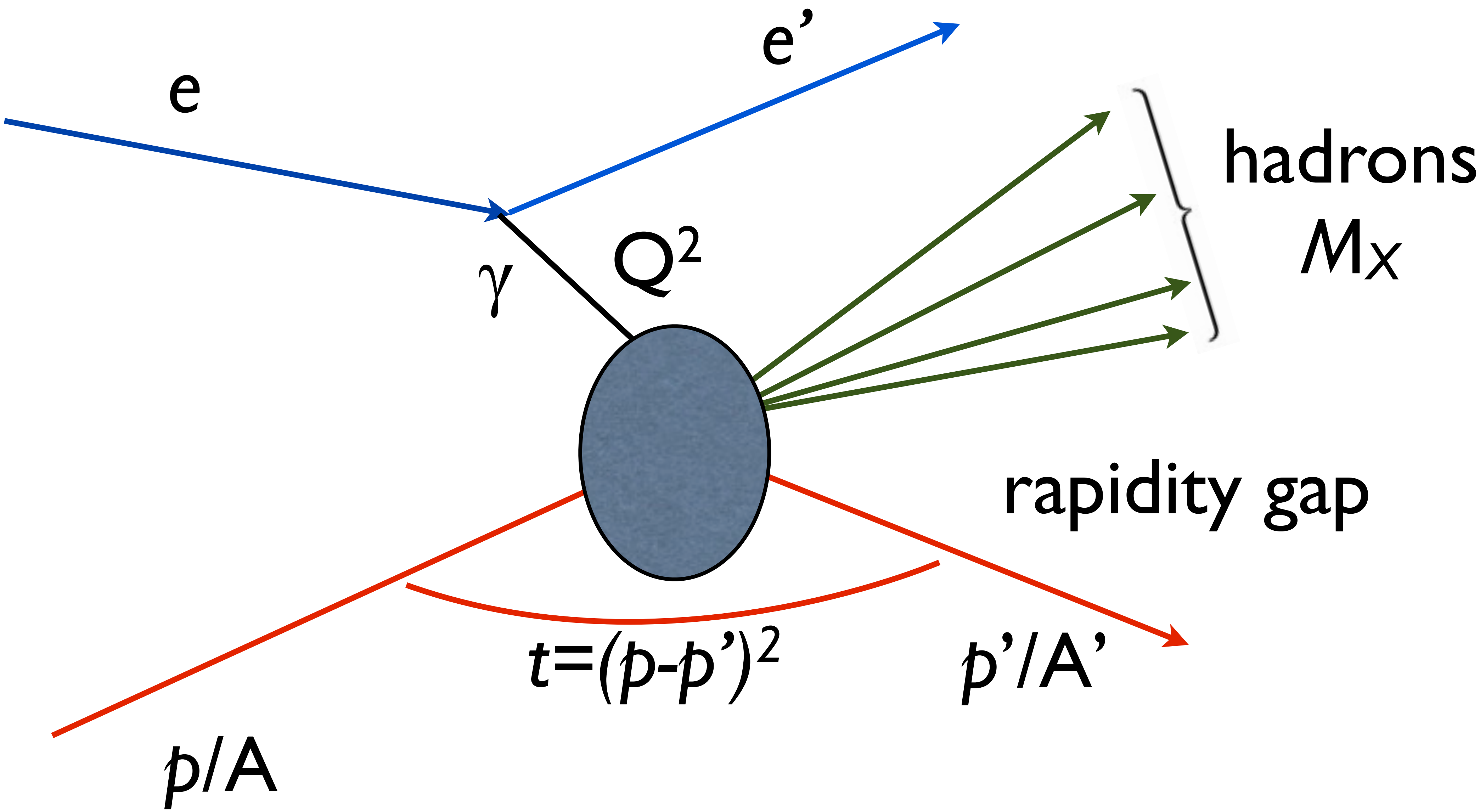






can constrain models a lot with a few months of running!
already in Stage I!

why is diffraction so great, part II?



depend on t, momentum transfer to proton/ion.

Fourier transform of t-distribution

=

transverse spatial distribution

spatial imaging!

why is diffraction so great, part II?

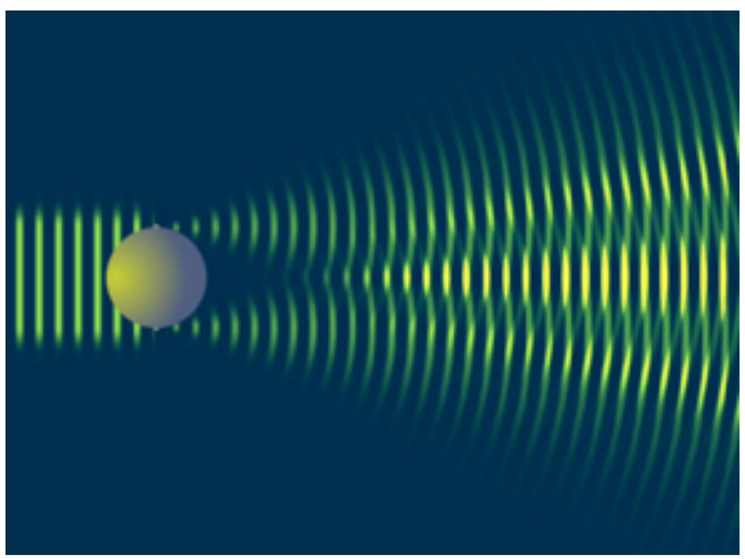
sensitive to spatial gluon distributions

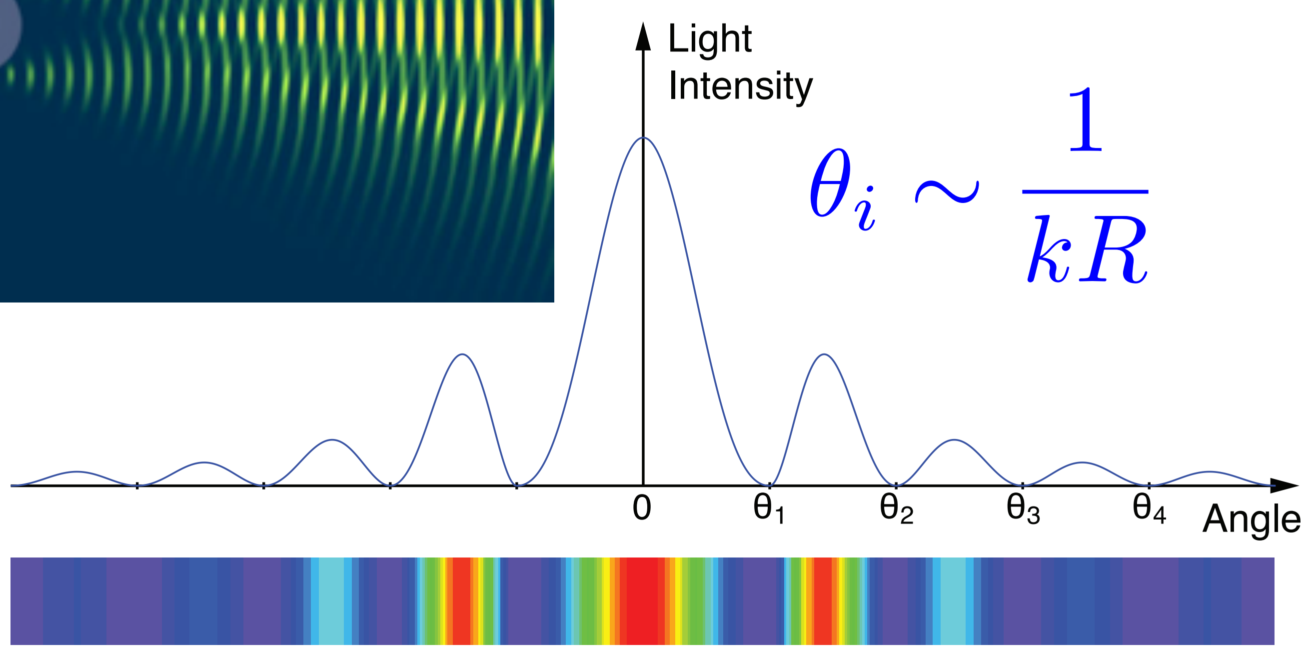
a projectile scattering off a nucleus of radius R

-not a 'black disk', edge effects

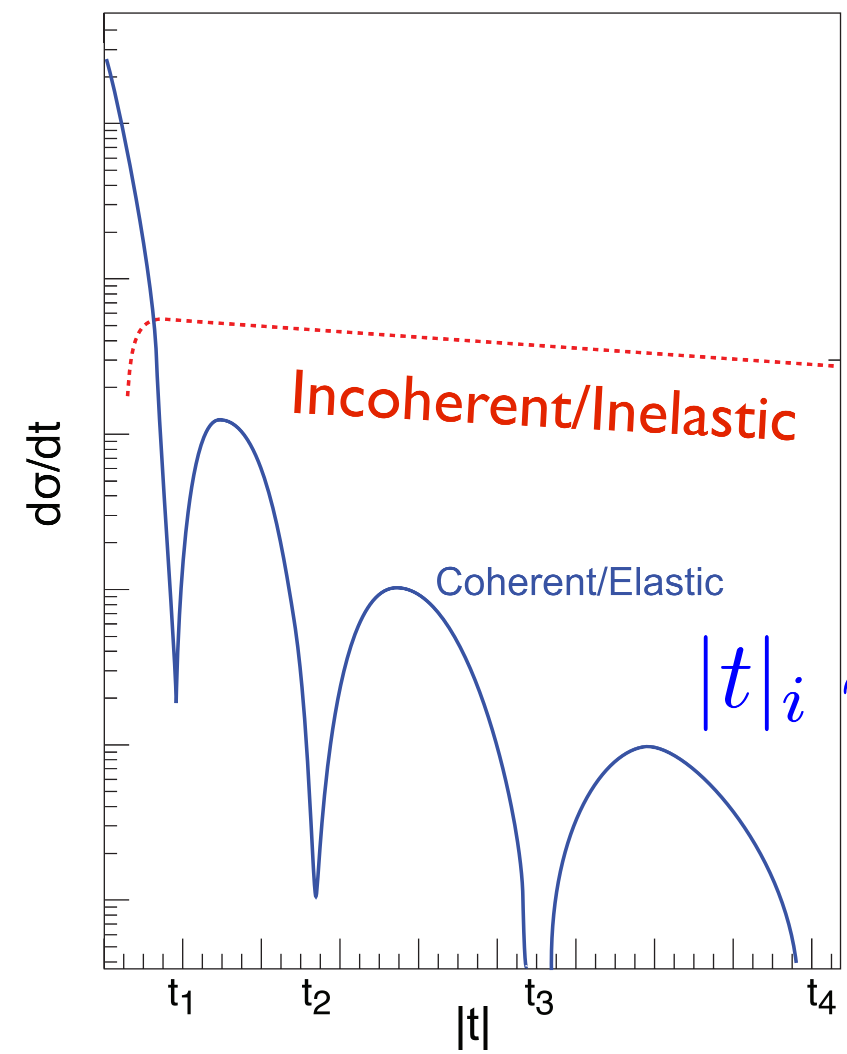
-inelastic scattering

light scattering elastically off a circular screen of radius R



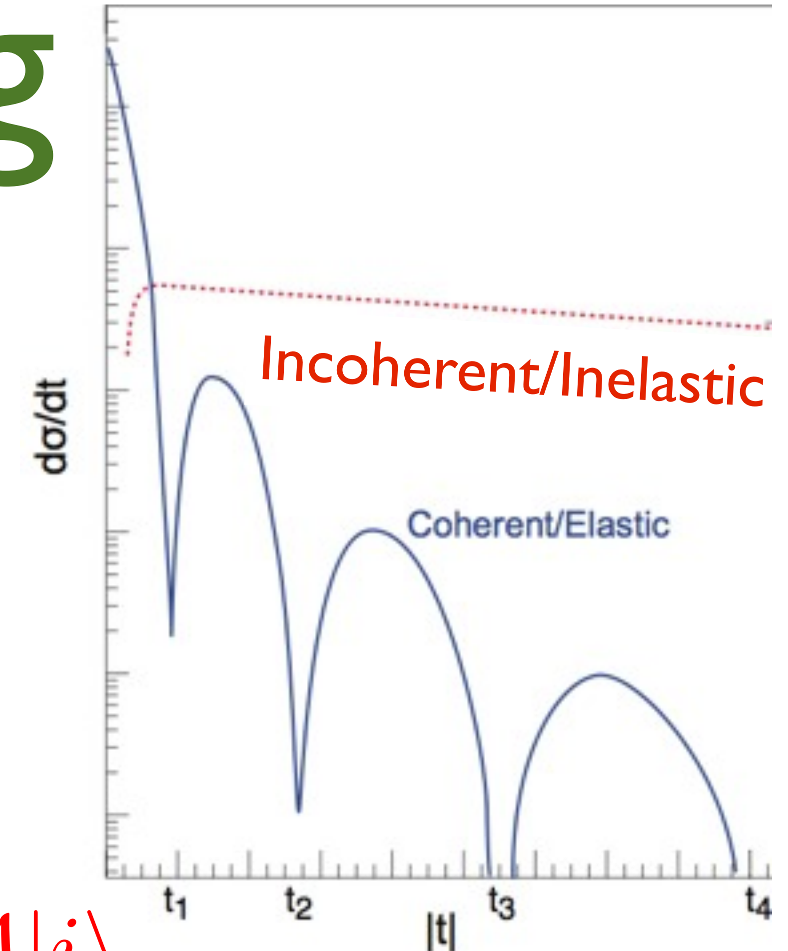


$$\theta_i \sim \frac{1}{kR}$$



$$|t|_i \sim \frac{1}{R^2}$$

incoherent Scattering



Good, Walker:

nucleus dissociates ($f \neq i$):

$$\sigma_{\text{incoherent}} \propto \sum_{f \neq i} \langle i|\mathcal{A}|f\rangle^\dagger \langle f|\mathcal{A}|i\rangle$$

complete set

$$= \sum_f \langle i|\mathcal{A}\overbrace{|f\rangle^\dagger \langle f|}\mathcal{A}|i\rangle - \langle i|\mathcal{A}|i\rangle^\dagger \langle i|\mathcal{A}|i\rangle$$

$$= \langle i \left| |\mathcal{A}|^2 \right| i\rangle - |\langle i|\mathcal{A}|i\rangle|^2 = \left\langle |\mathcal{A}|^2 \right\rangle - |\langle \mathcal{A}\rangle|^2$$

the incoherent CS is the variance of the amplitude!!

$$\frac{d\sigma_{\text{total}}}{dt} = \frac{1}{16\pi} \left\langle |\mathcal{A}|^2 \right\rangle \qquad \frac{d\sigma_{\text{coherent}}}{dt} = \frac{1}{16\pi} |\langle \mathcal{A}\rangle|^2$$

how to measure $t=(P_A-P_A')^2$

need to measure $P_{A'}$

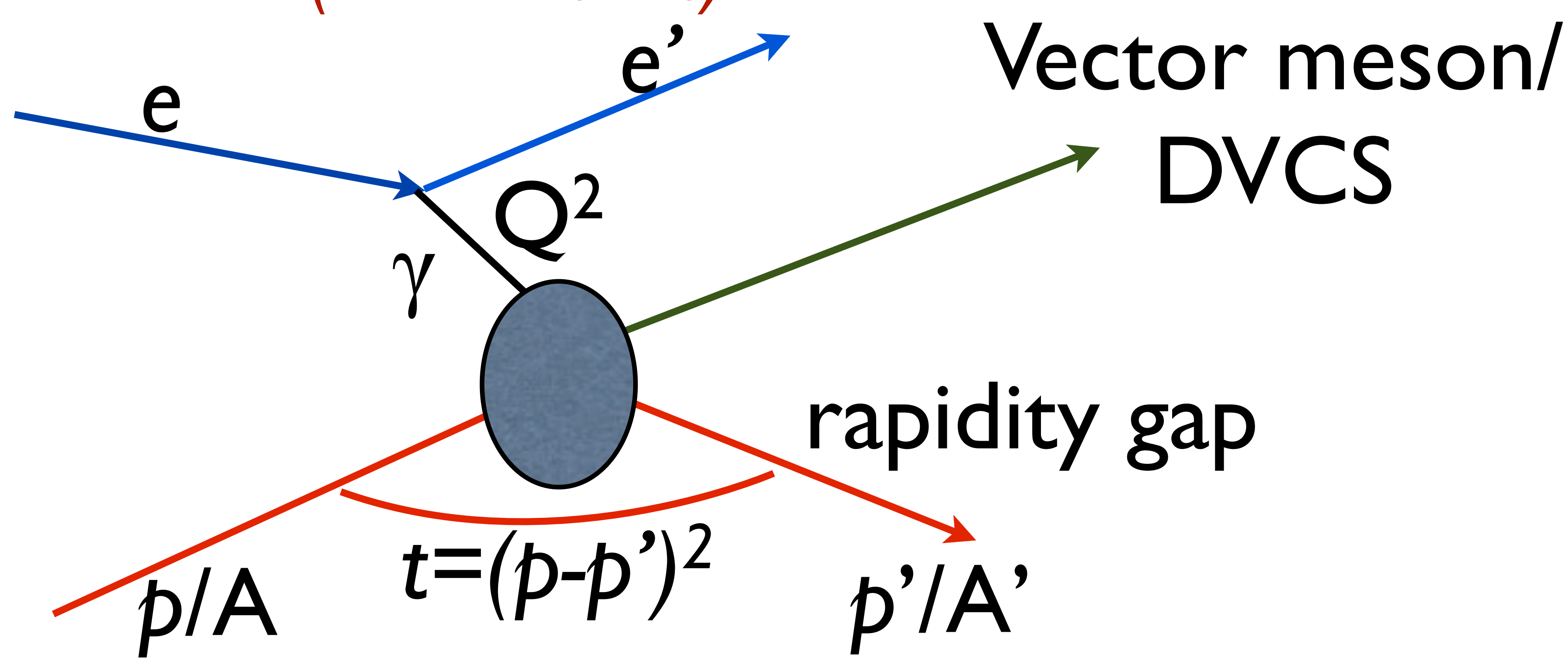
coherent case: A' disappears down beam pipe

incoherent case: cannot measure all beam remnants

only possibility: Exclusive diffraction

$e+A \longrightarrow e'+VM+A'$

$t=(P_{VM}+P_{e'}-P_e)^2$



TT and T. Ullrich,
Phys. Rev. C 87, 024913 (2013)
arXiv:1211.3048

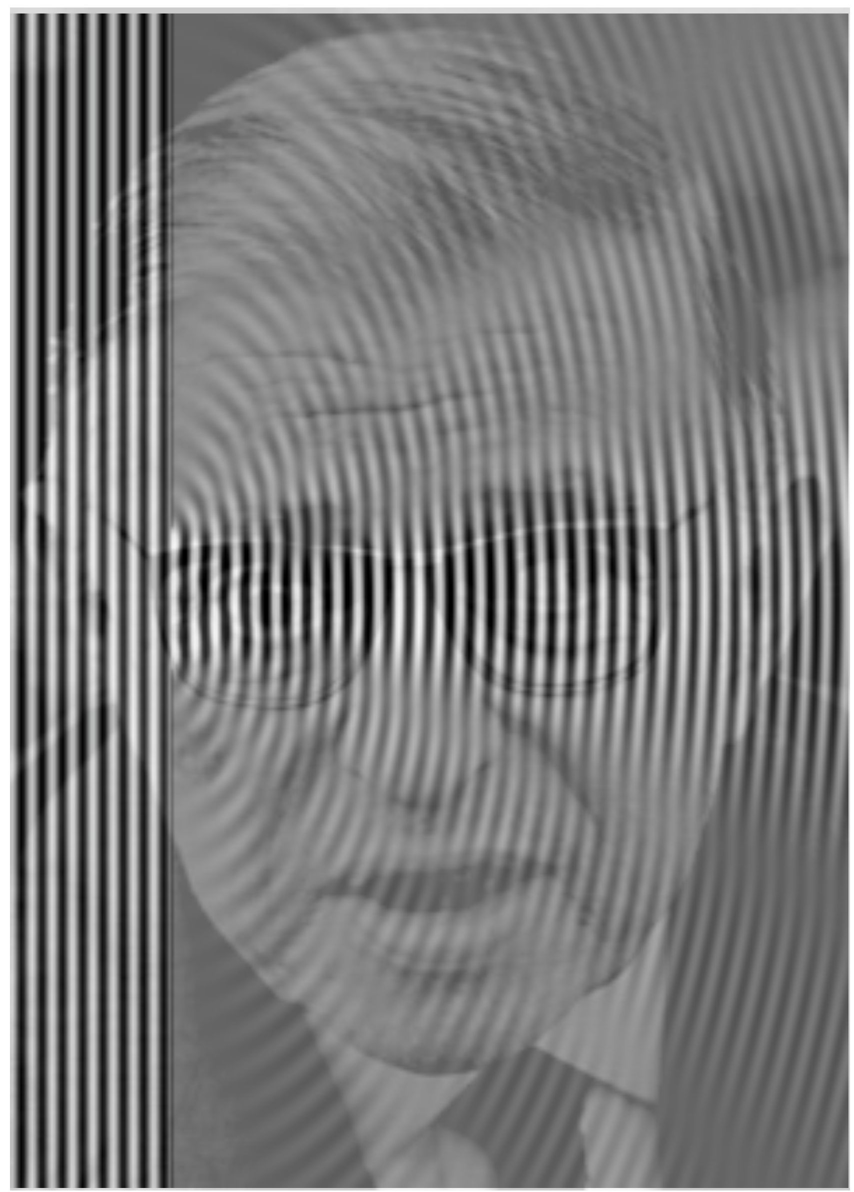
eRHIC predictions:

new physics event generator

Sartre

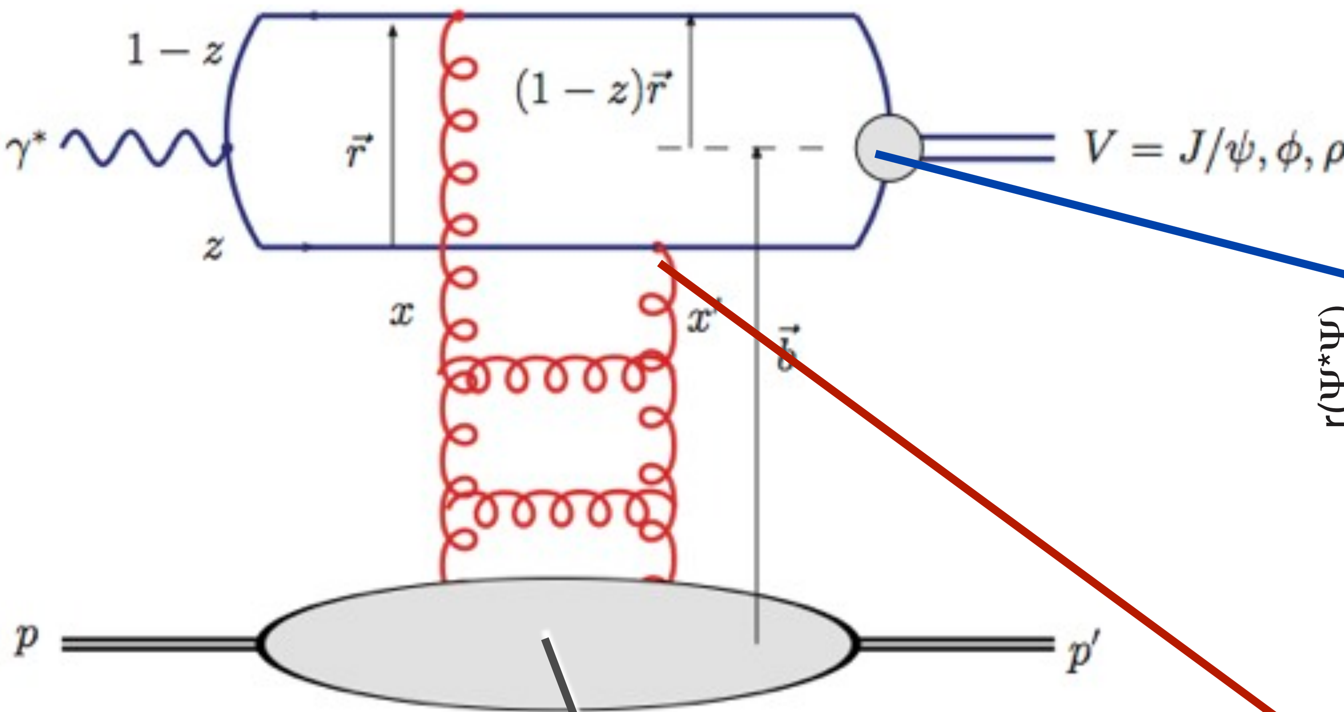
exclusive diffractive vector meson and DVCS production in

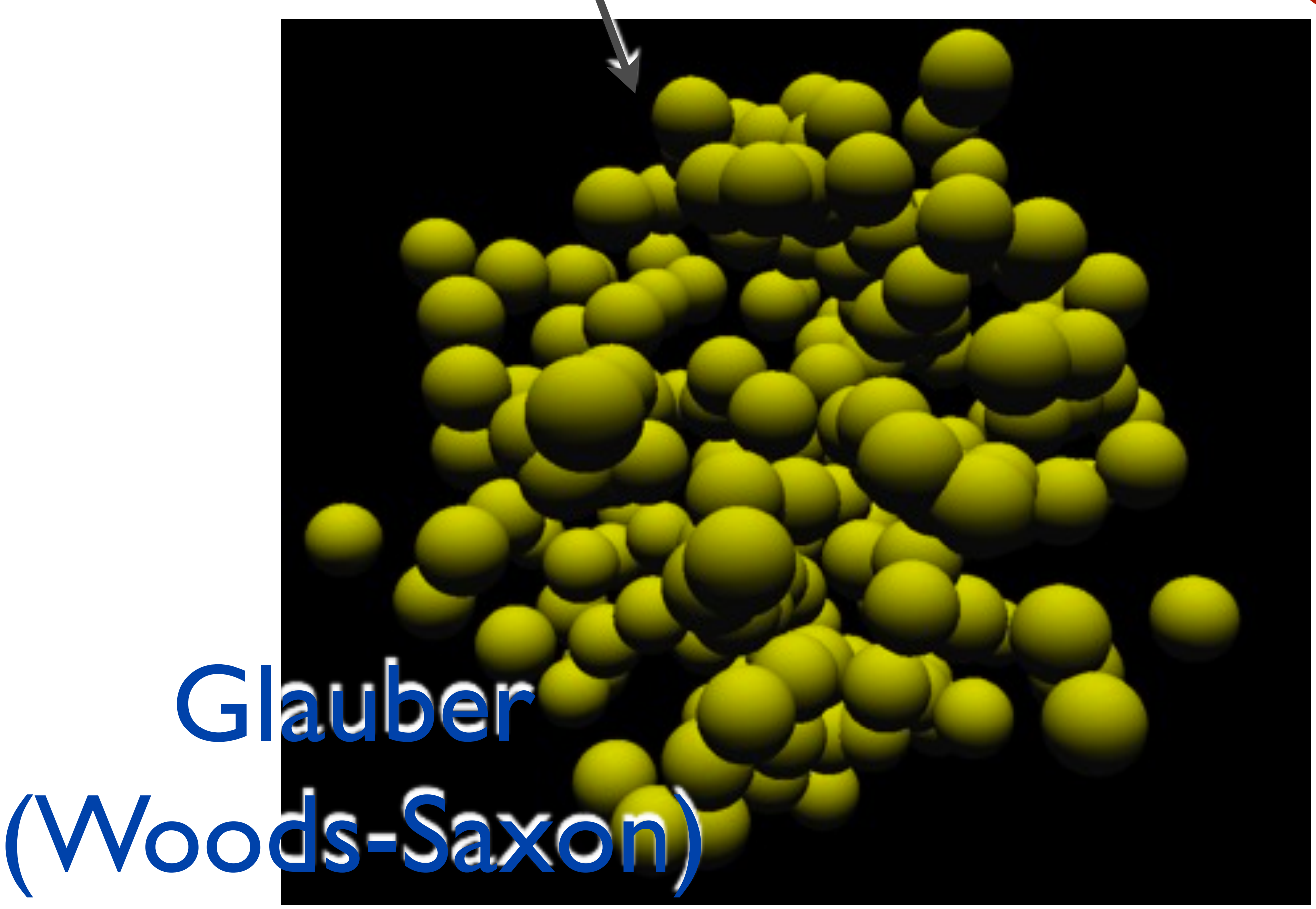
eA

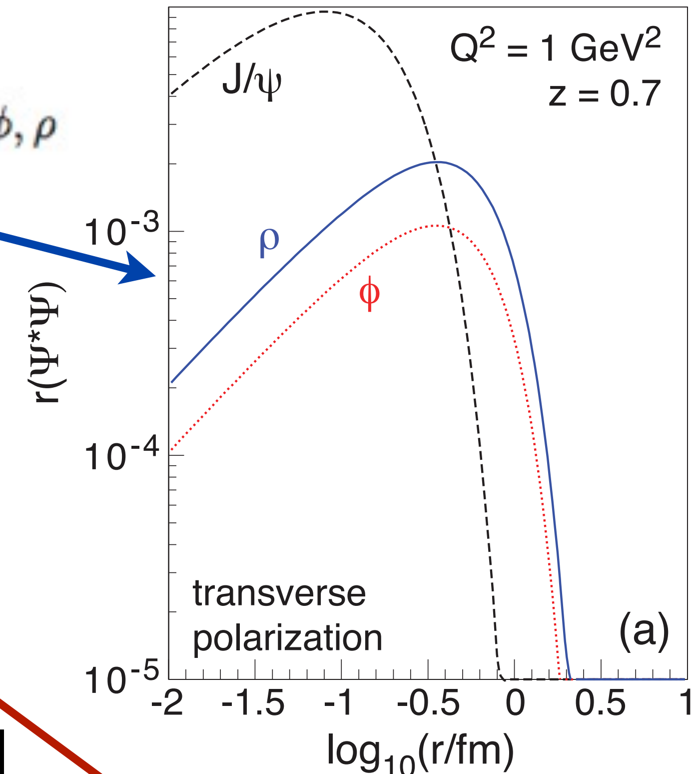


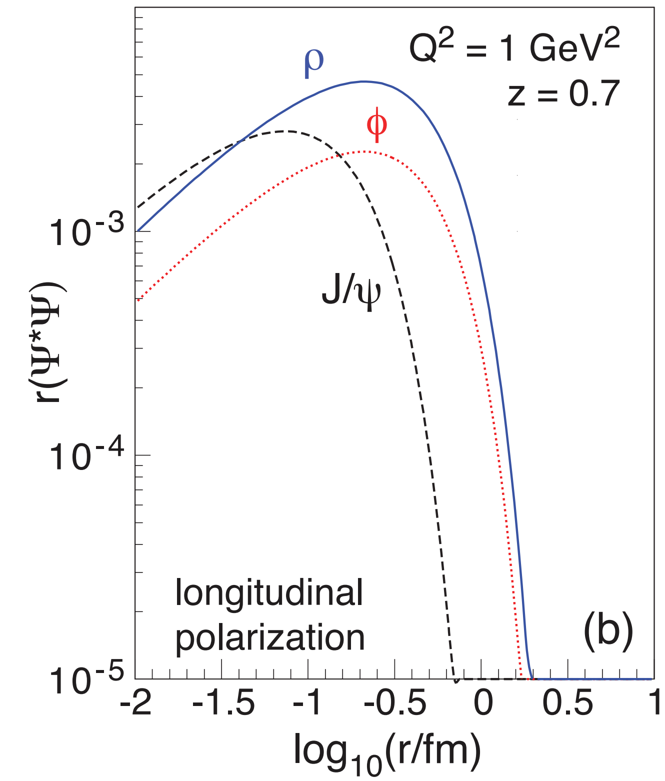
T. Ullrich & TT

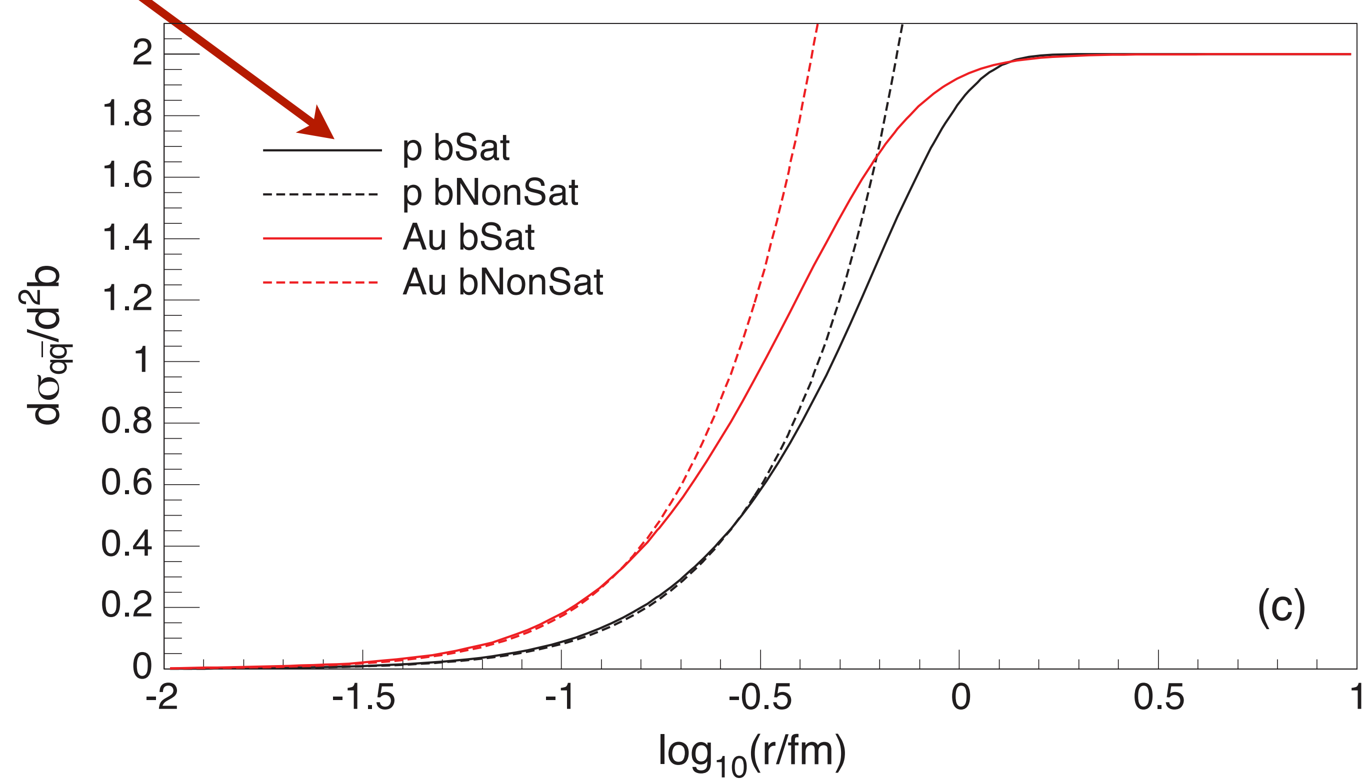
eRHIC predictions:
Sartre dipole model with glauber bSat and bNonSat



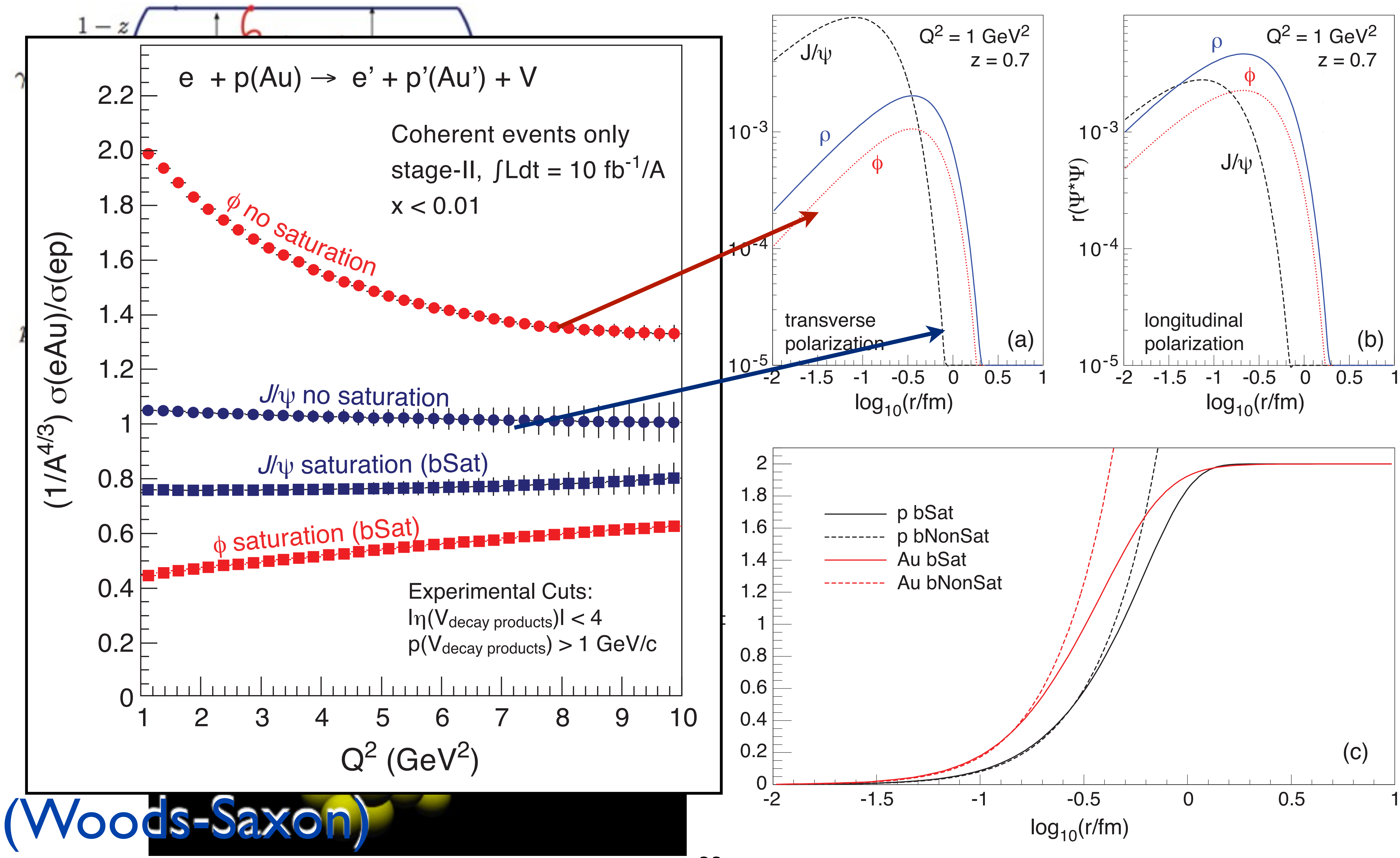




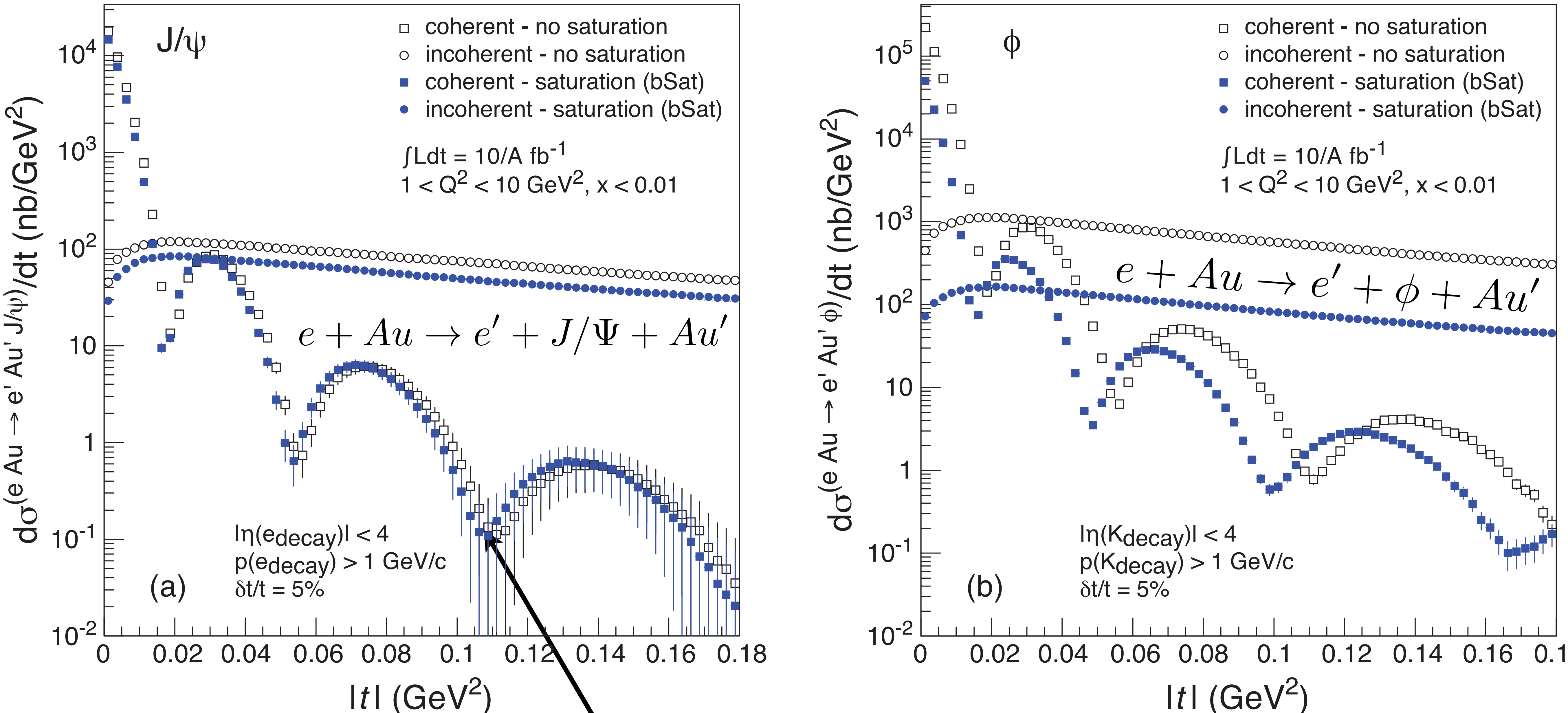




eRHIC predictions:
Sartre dipole model with glauber bSat and bNonSat



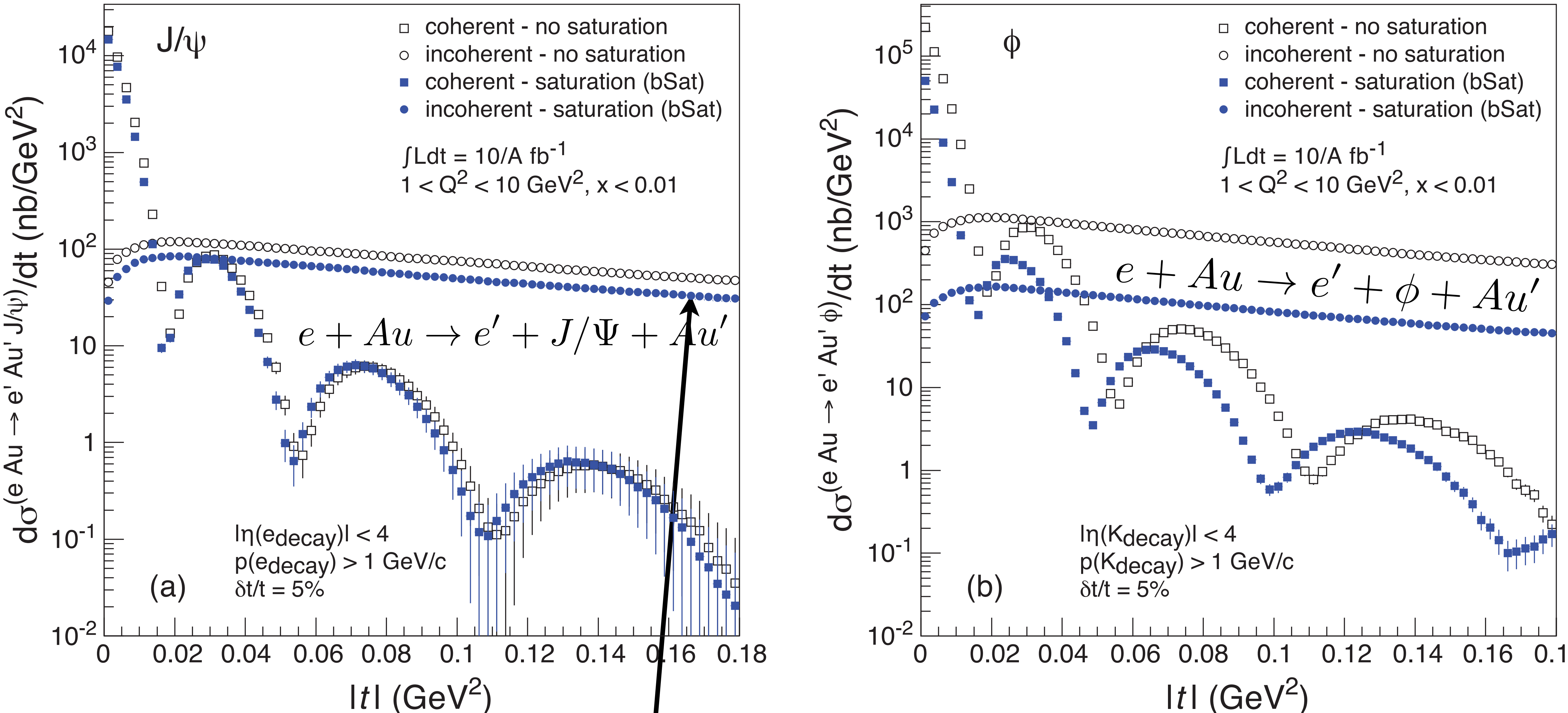
eRHIC predictions: exclusive diffraction with Sartre



Can constrain models a lot with a few months of running!

First 4 dips obtainable.

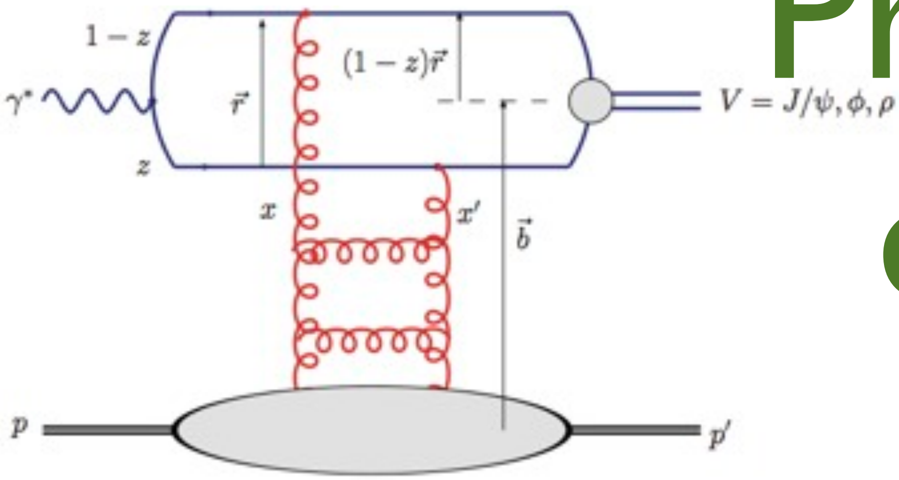
eRHIC predictions: exclusive diffraction with Sartre



Can constrain models a lot with a few months of running!

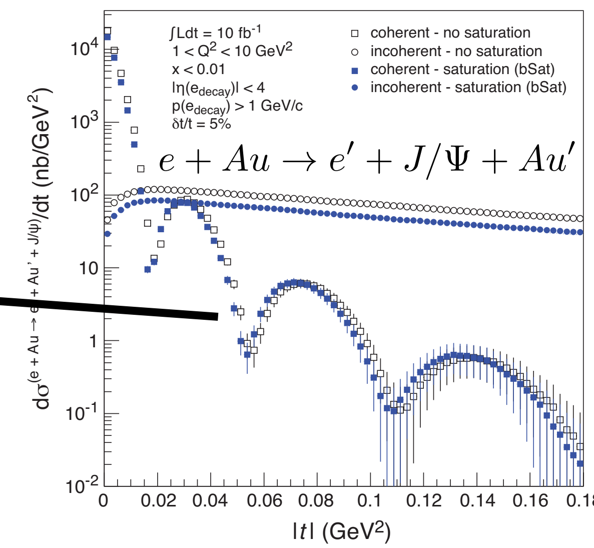
Can measure incoherent (lumpiness) to great precisions!

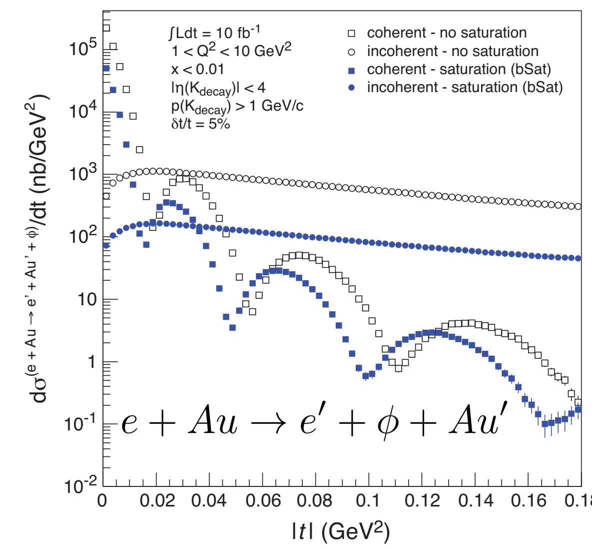
Probing the spatial gluon distribution at eRHIC



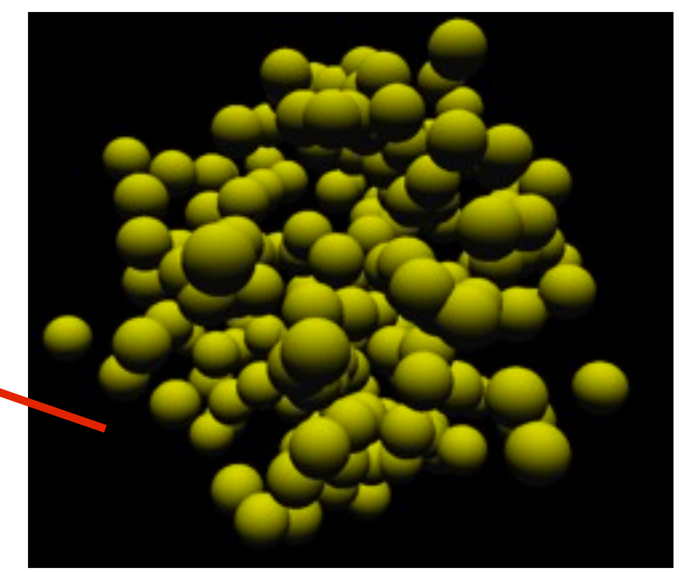
$$\frac{\mathrm{d}\sigma}{\mathrm{d}t} = \frac{1}{16\pi}\left|\mathcal{A}(\Delta)\right|^2$$

$$\Delta \simeq \sqrt{-t}$$





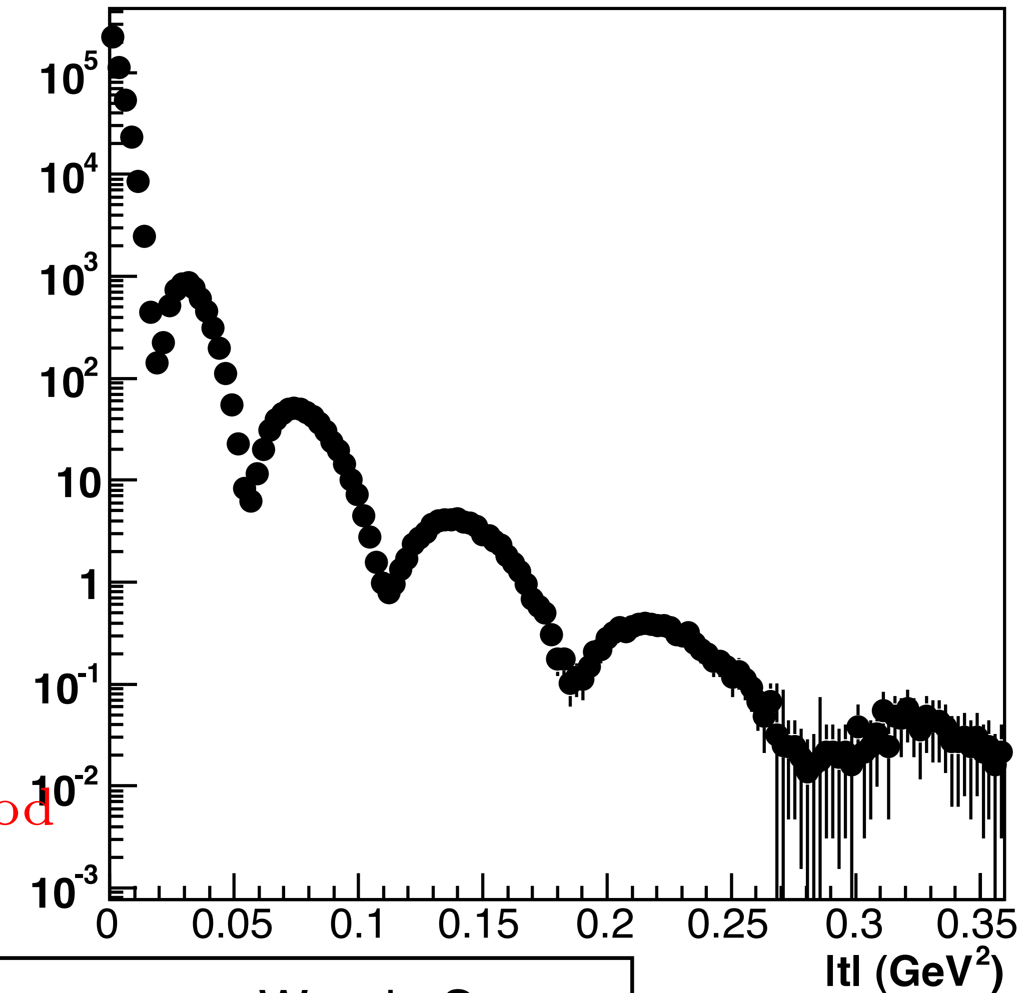
$$\mathcal{A}(\Delta) \sim \mathcal{F}ourier(\text{Wave Overlap} \cdot \text{Dipole Model}(b))$$



Fourier transform again to retain spatial distribution:

$$F(b) = \frac{1}{2\pi}\int_0^\infty \mathrm{d}\Delta \Delta J_0(\Delta b)\sqrt{\frac{\mathrm{d}\sigma_{\text{coherent}}}{\mathrm{d}t}(\Delta)}\Bigg|_{\text{mod}}$$

Probing the spatial gluon distribution at eRHIC



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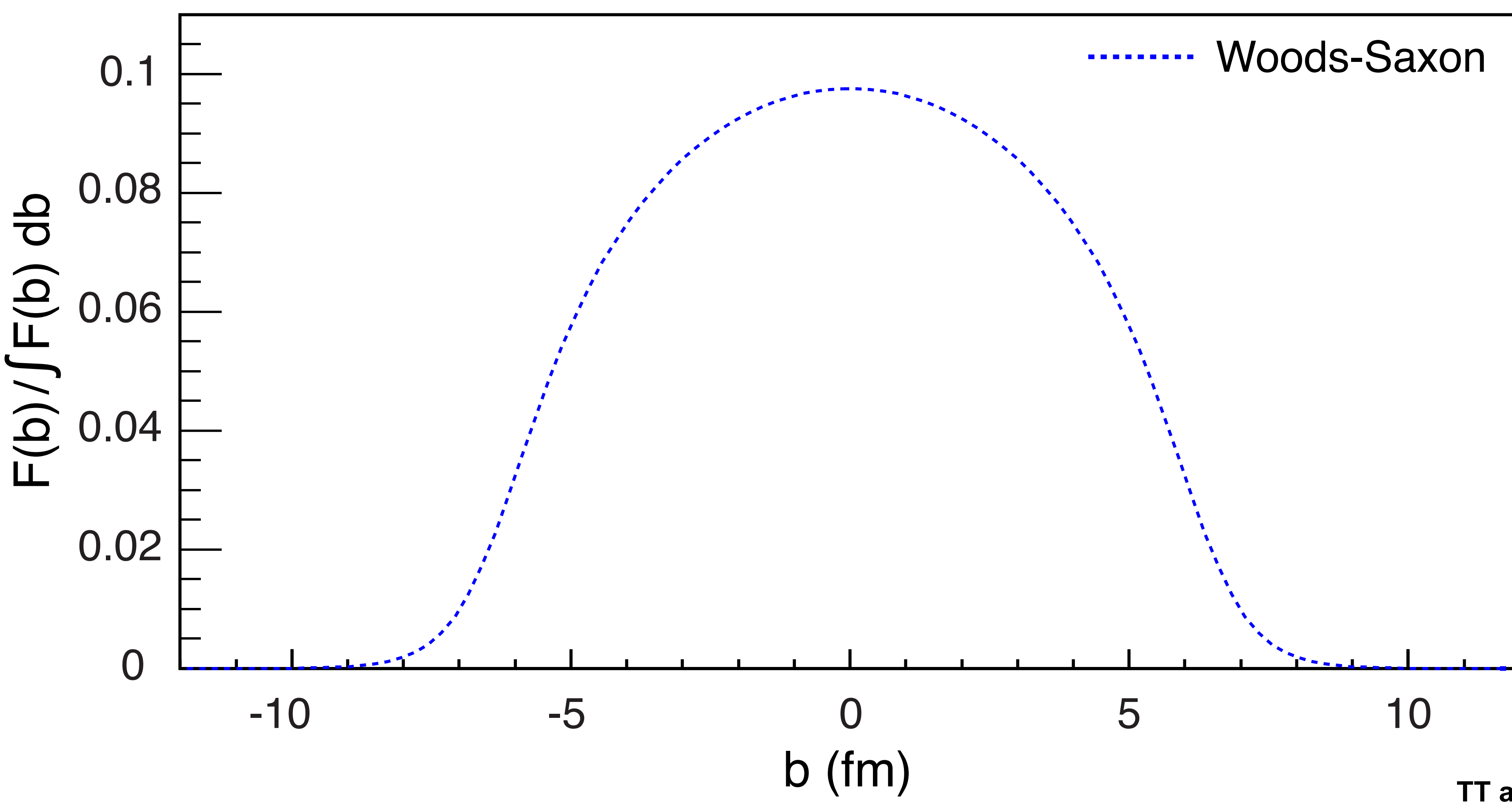

TT and T. Ullrich,
Phys. Rev. C 87, 024913 (2013)
arXiv:1211.3048

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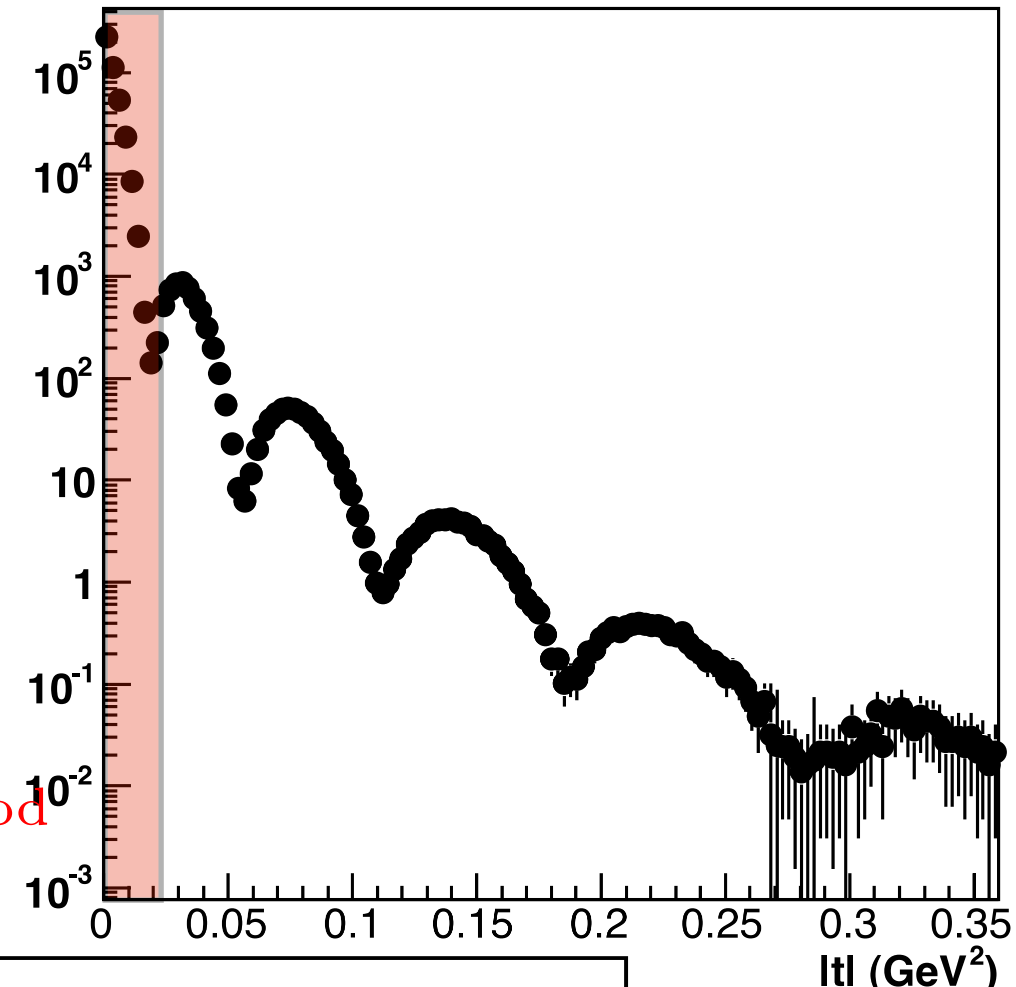

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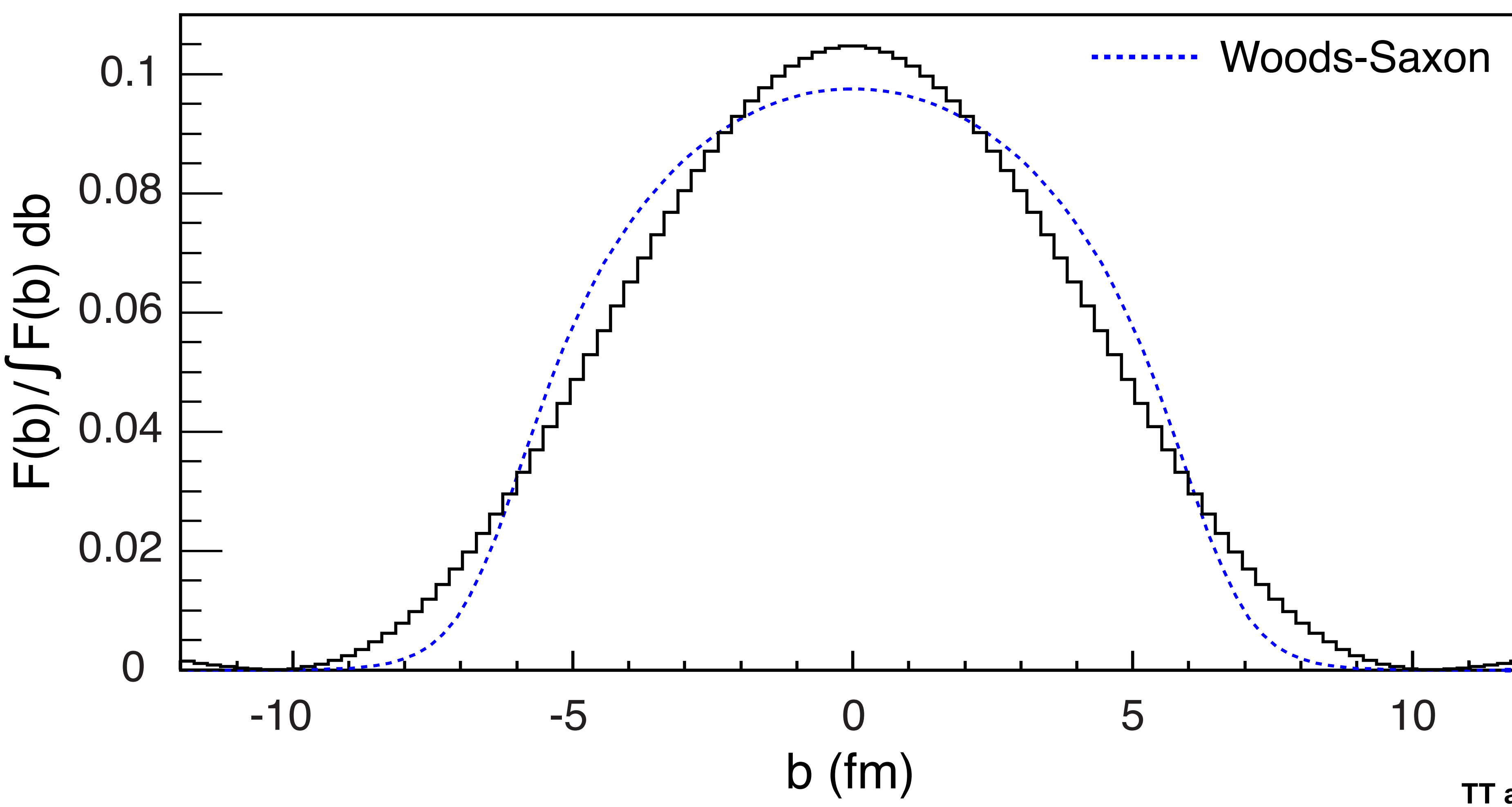

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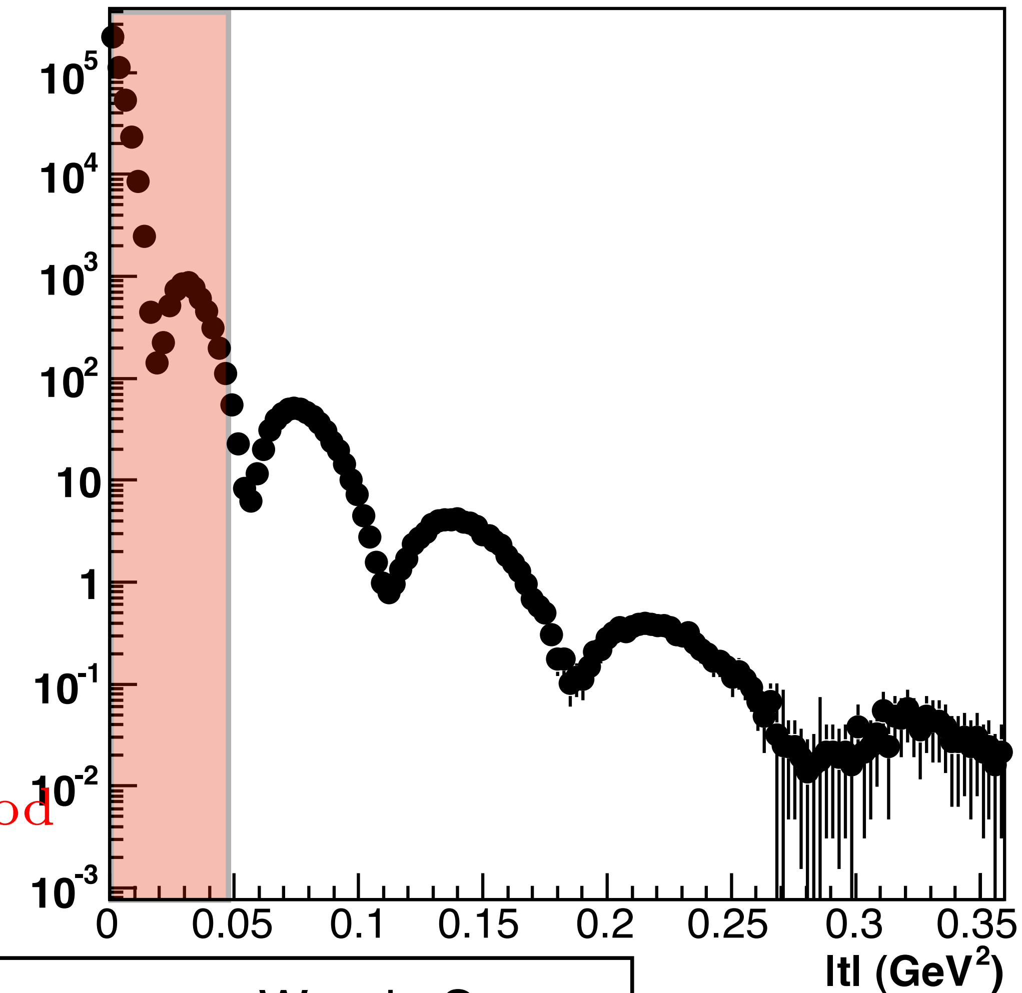

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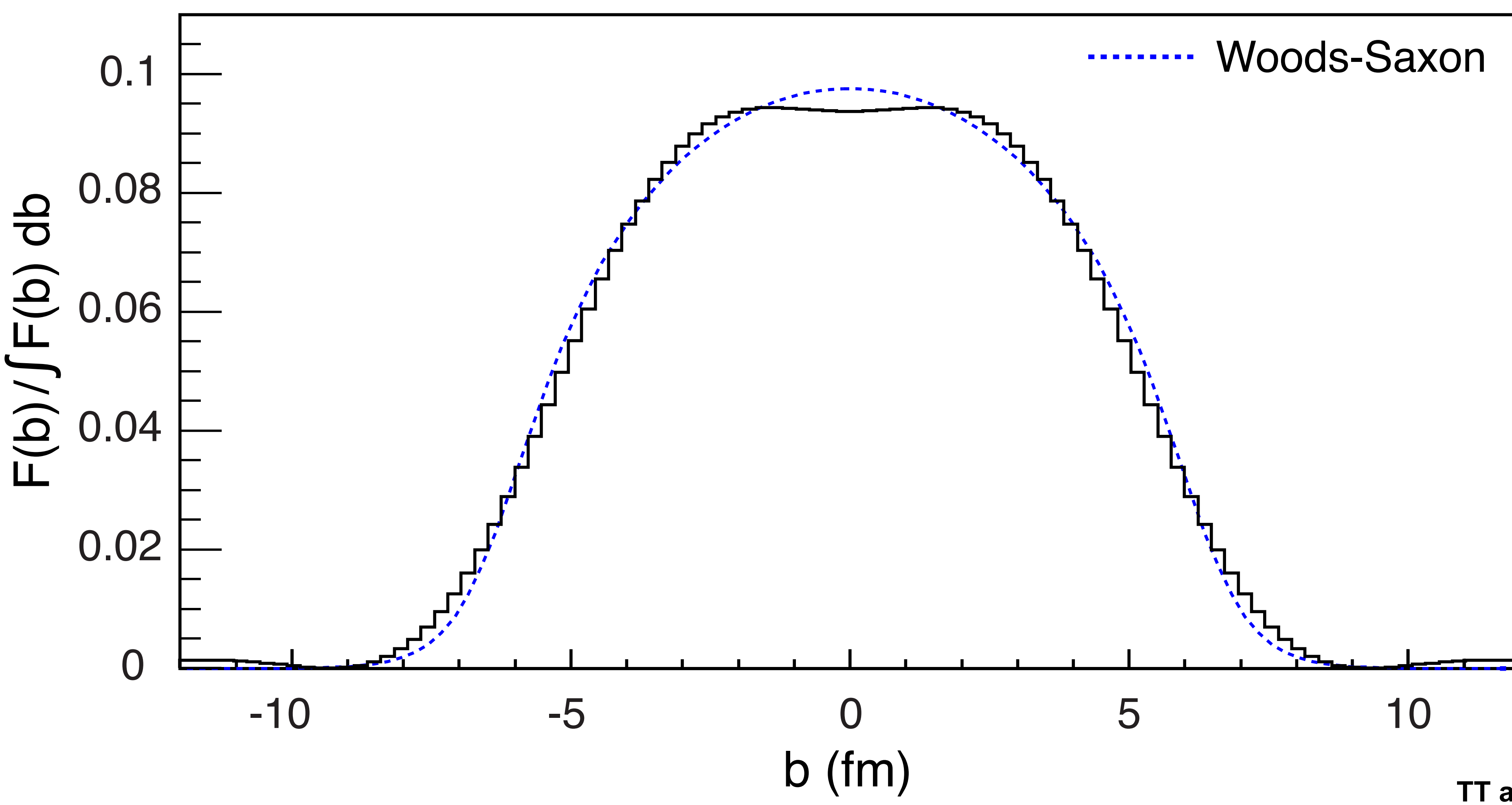

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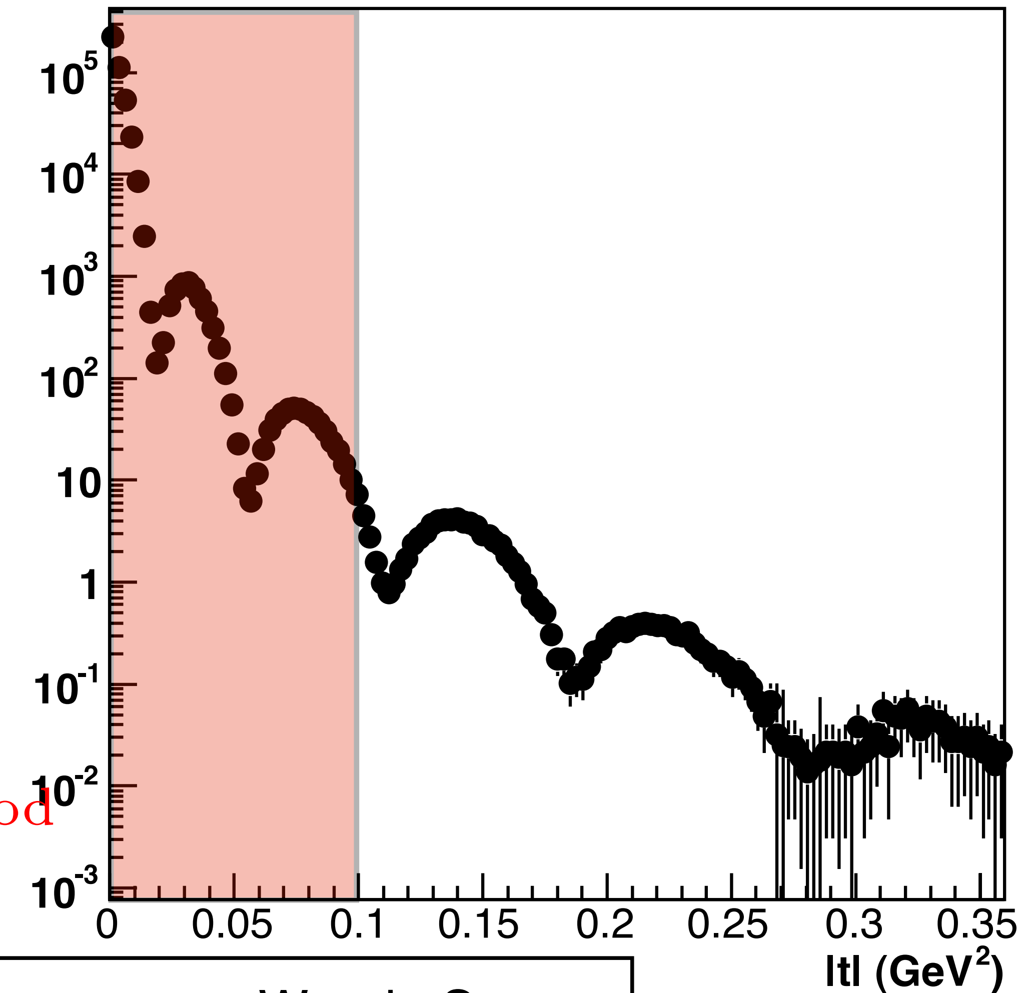

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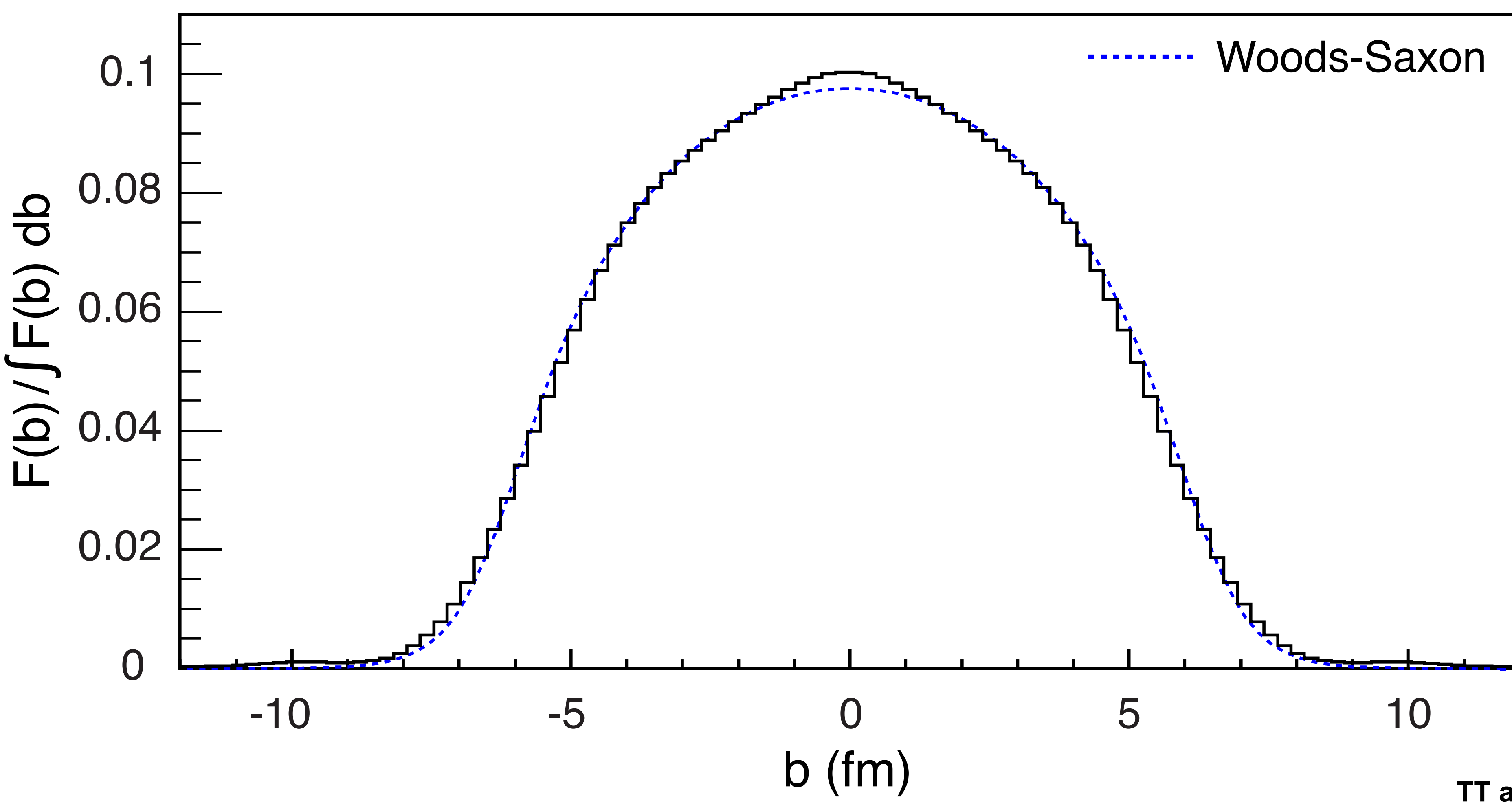

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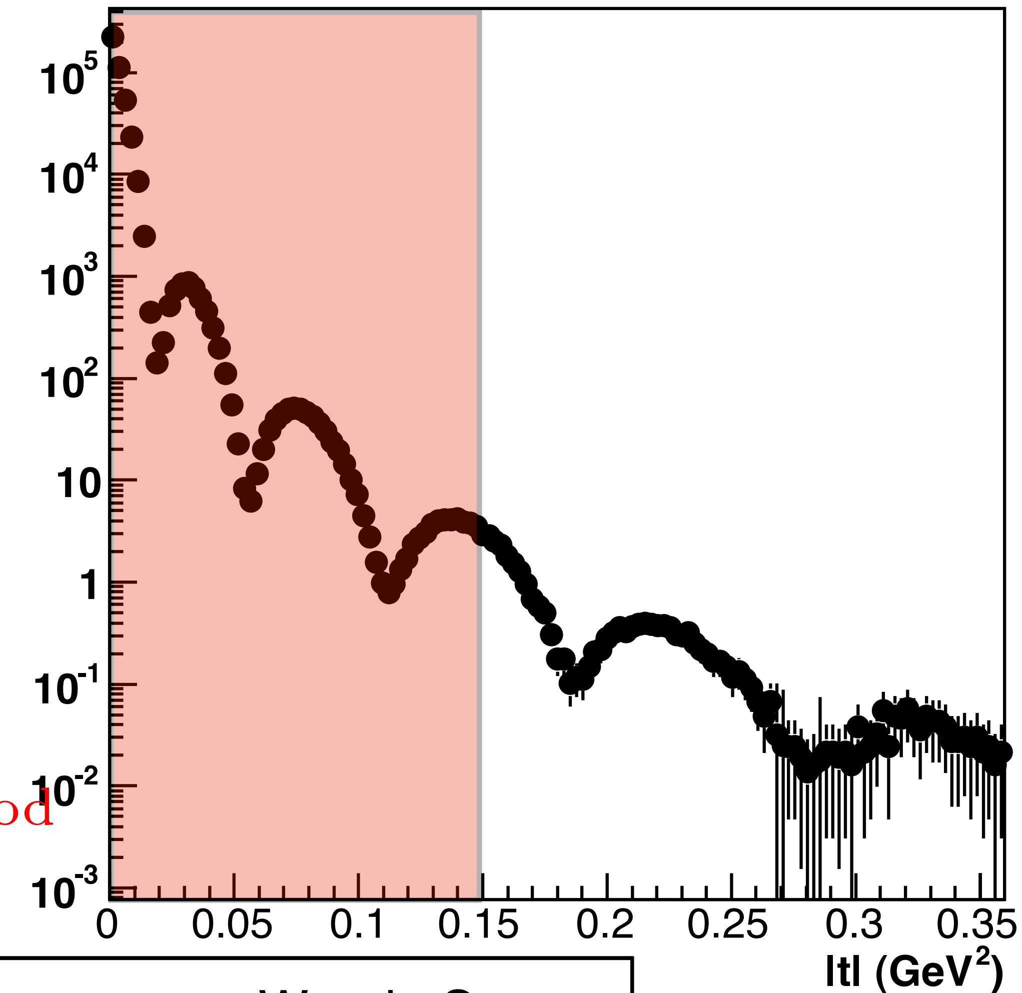

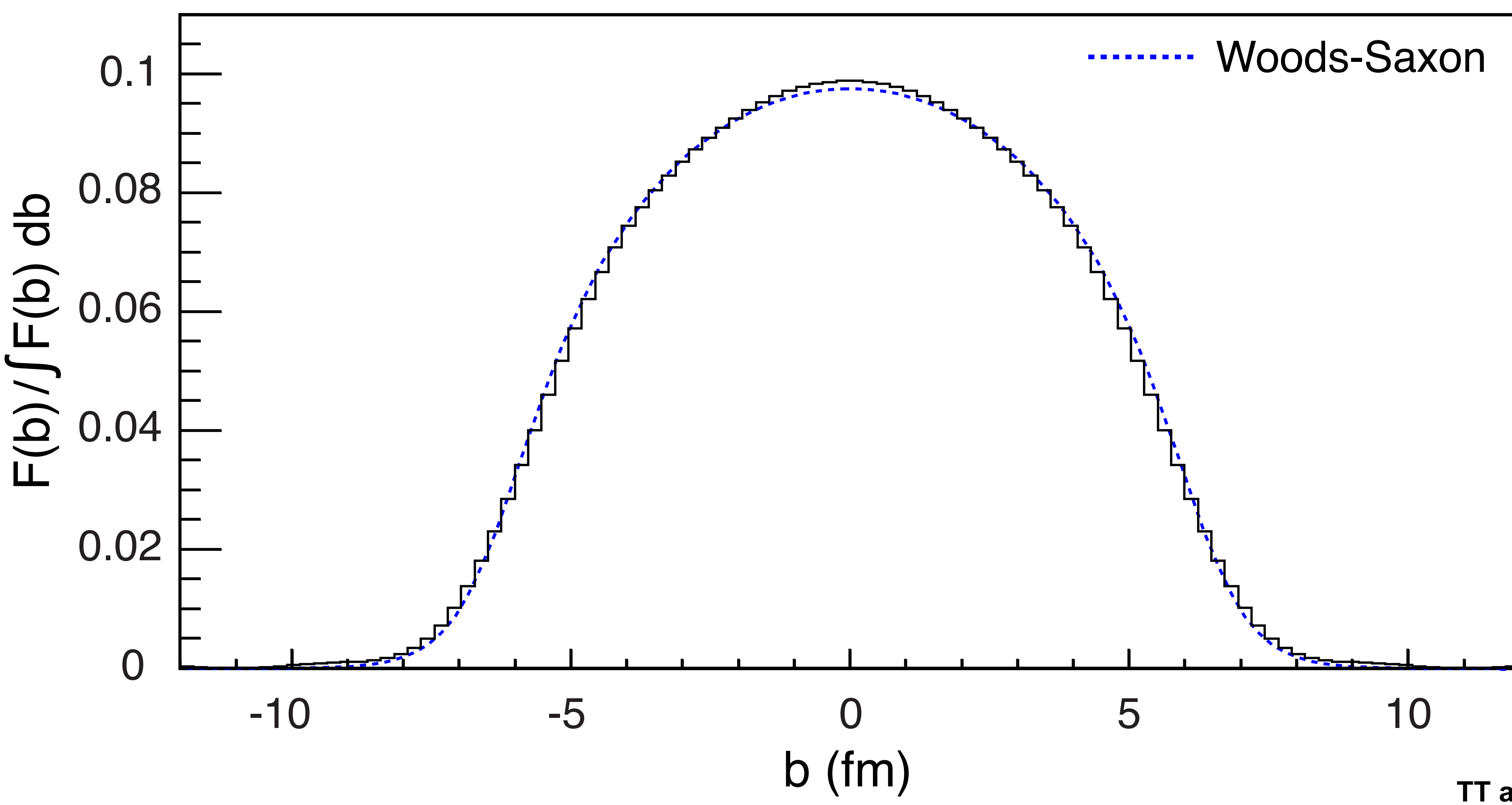

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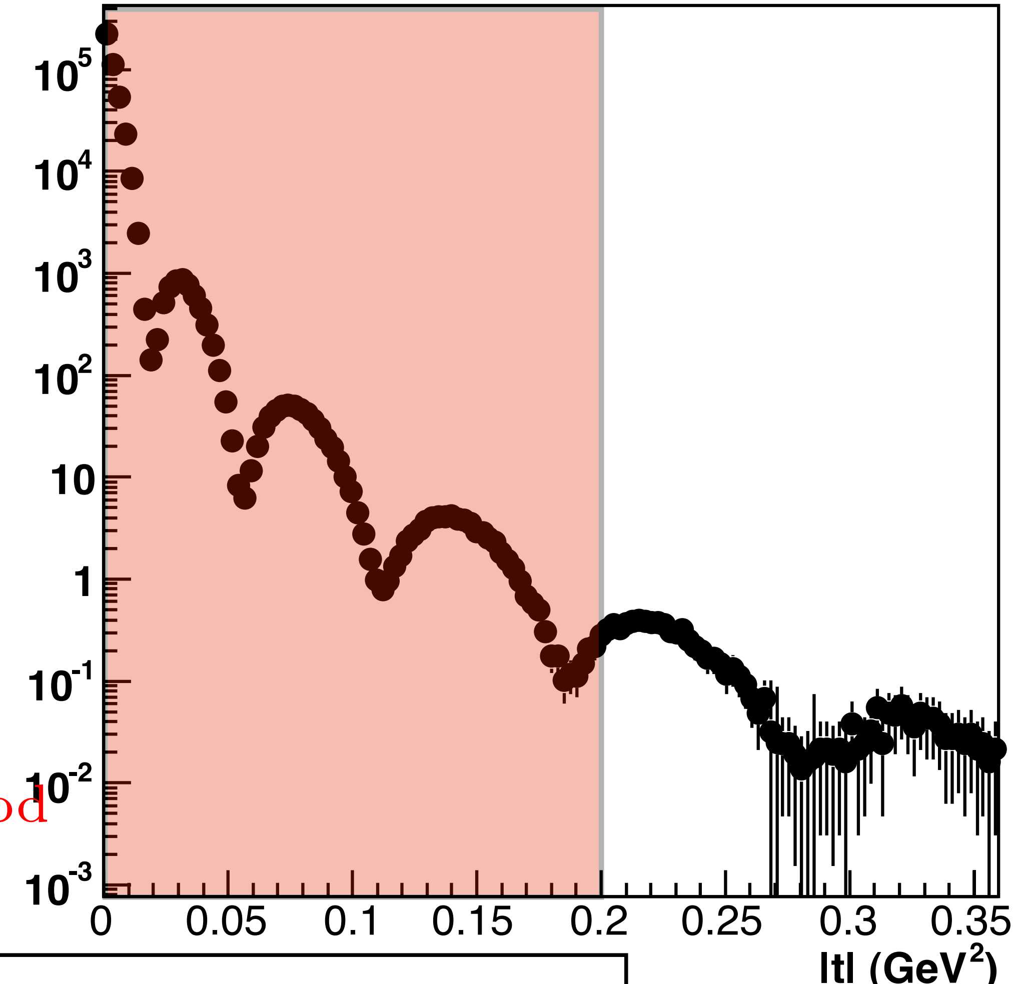

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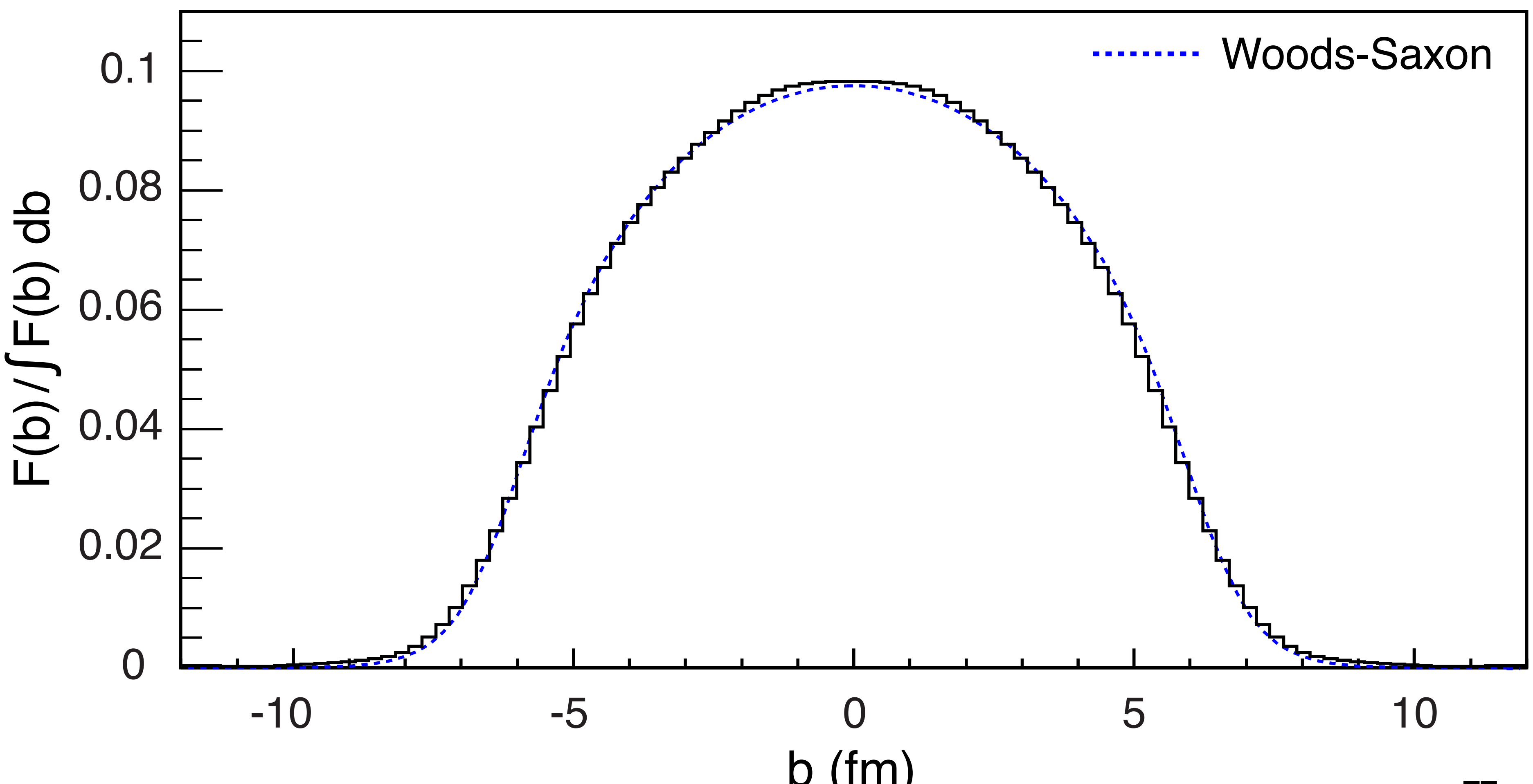

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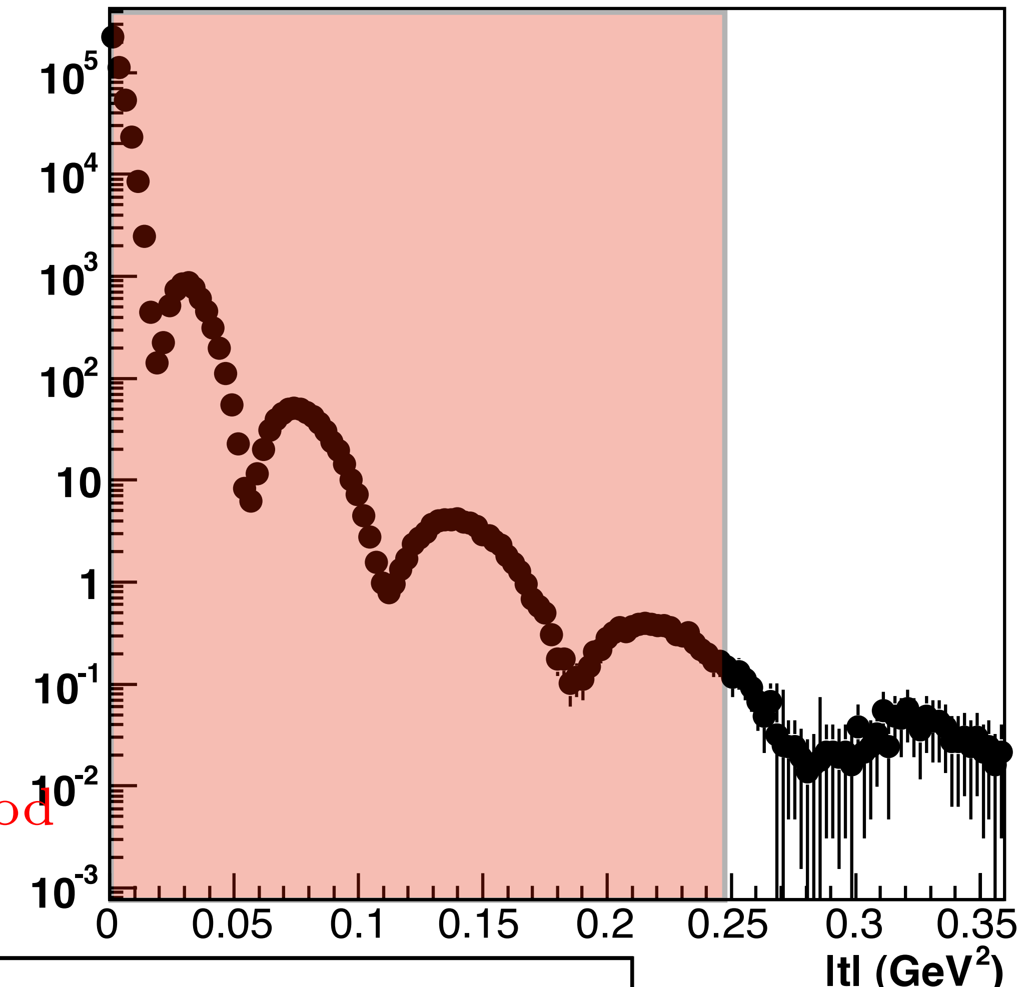

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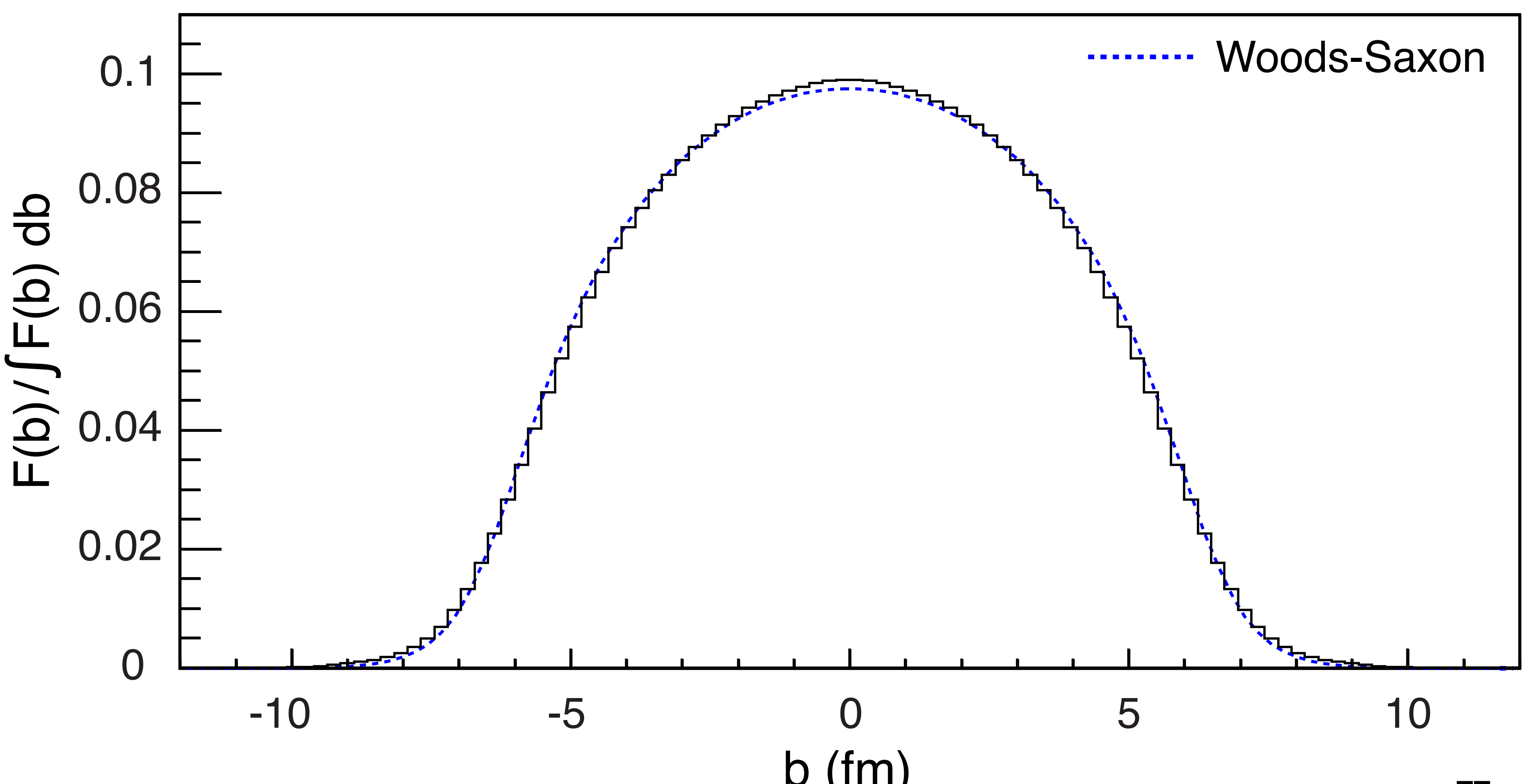

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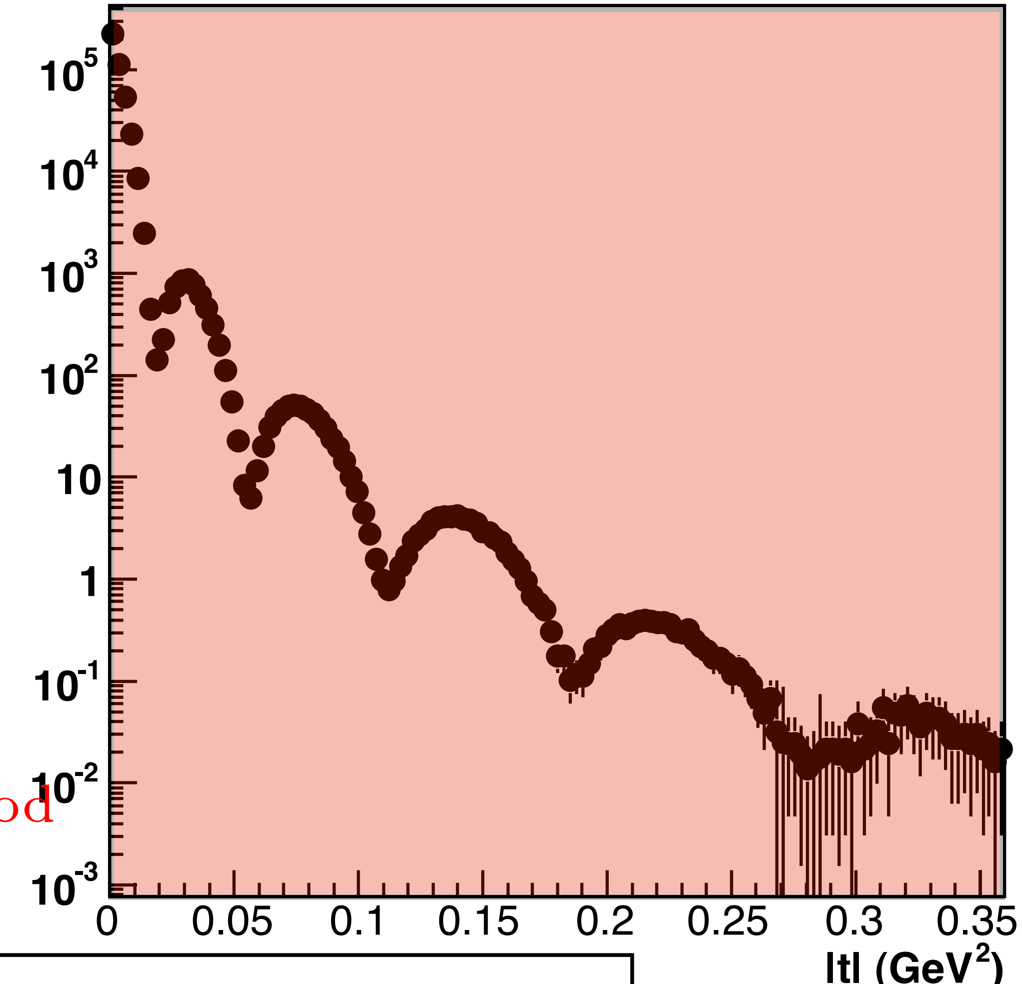

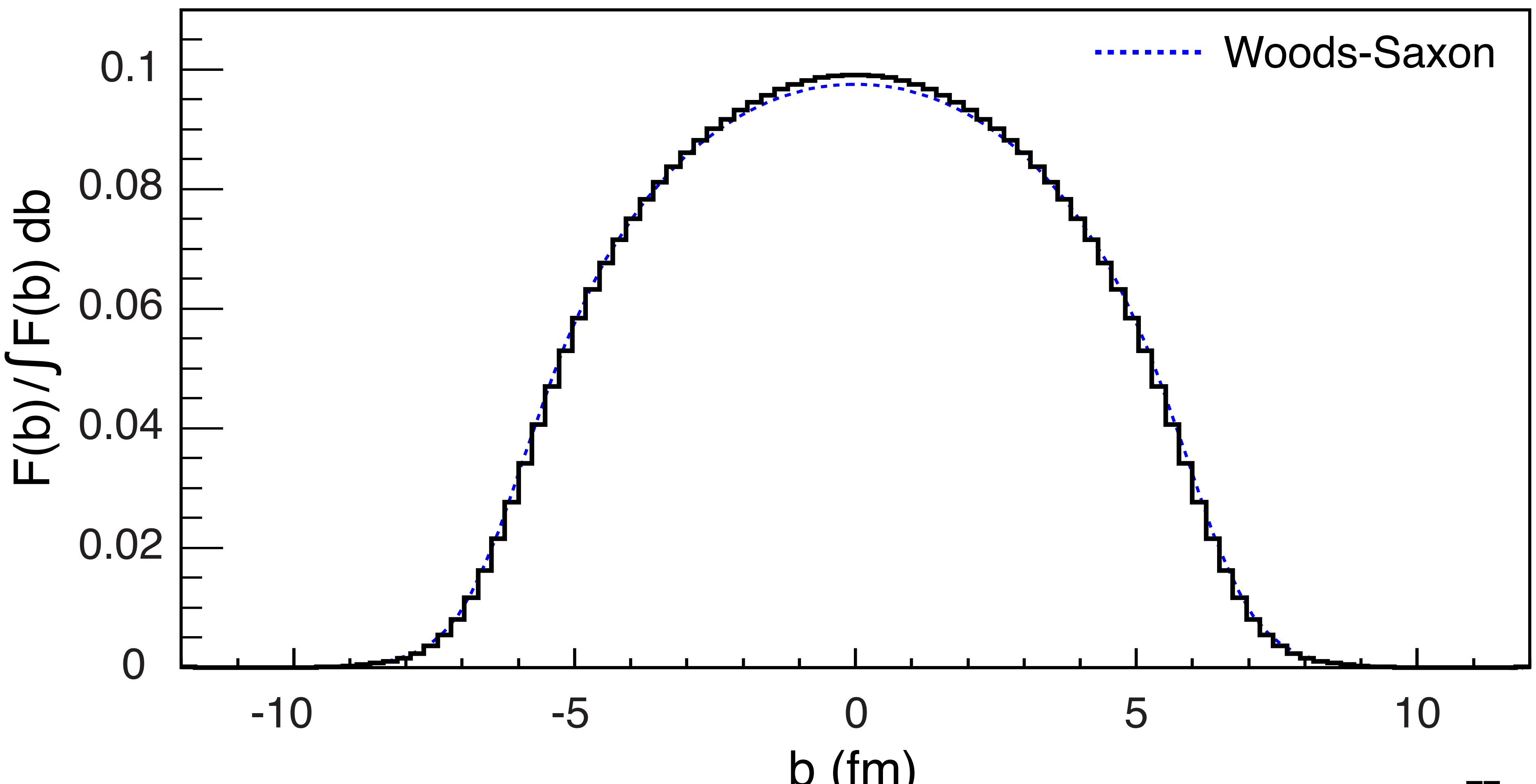

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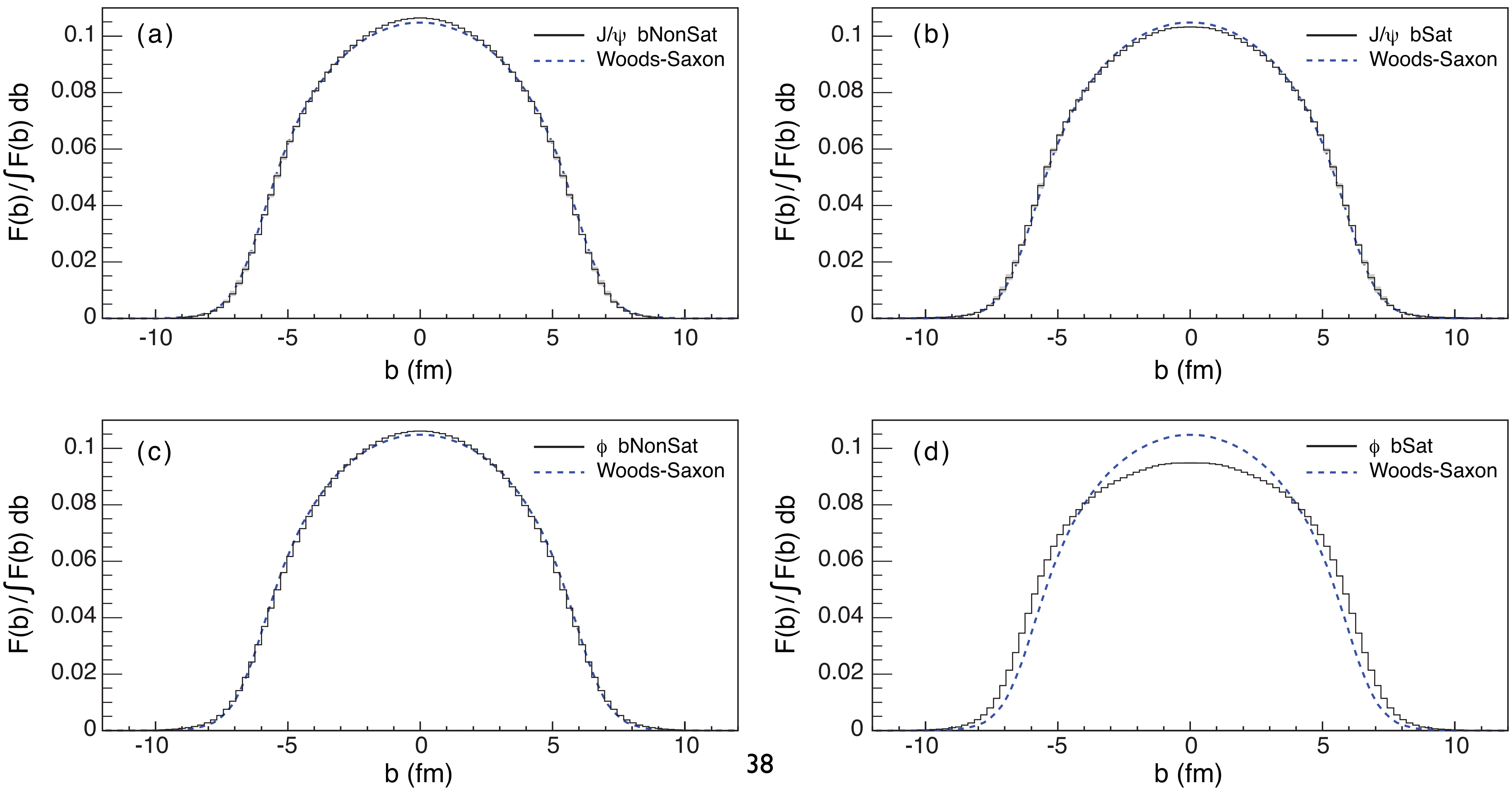
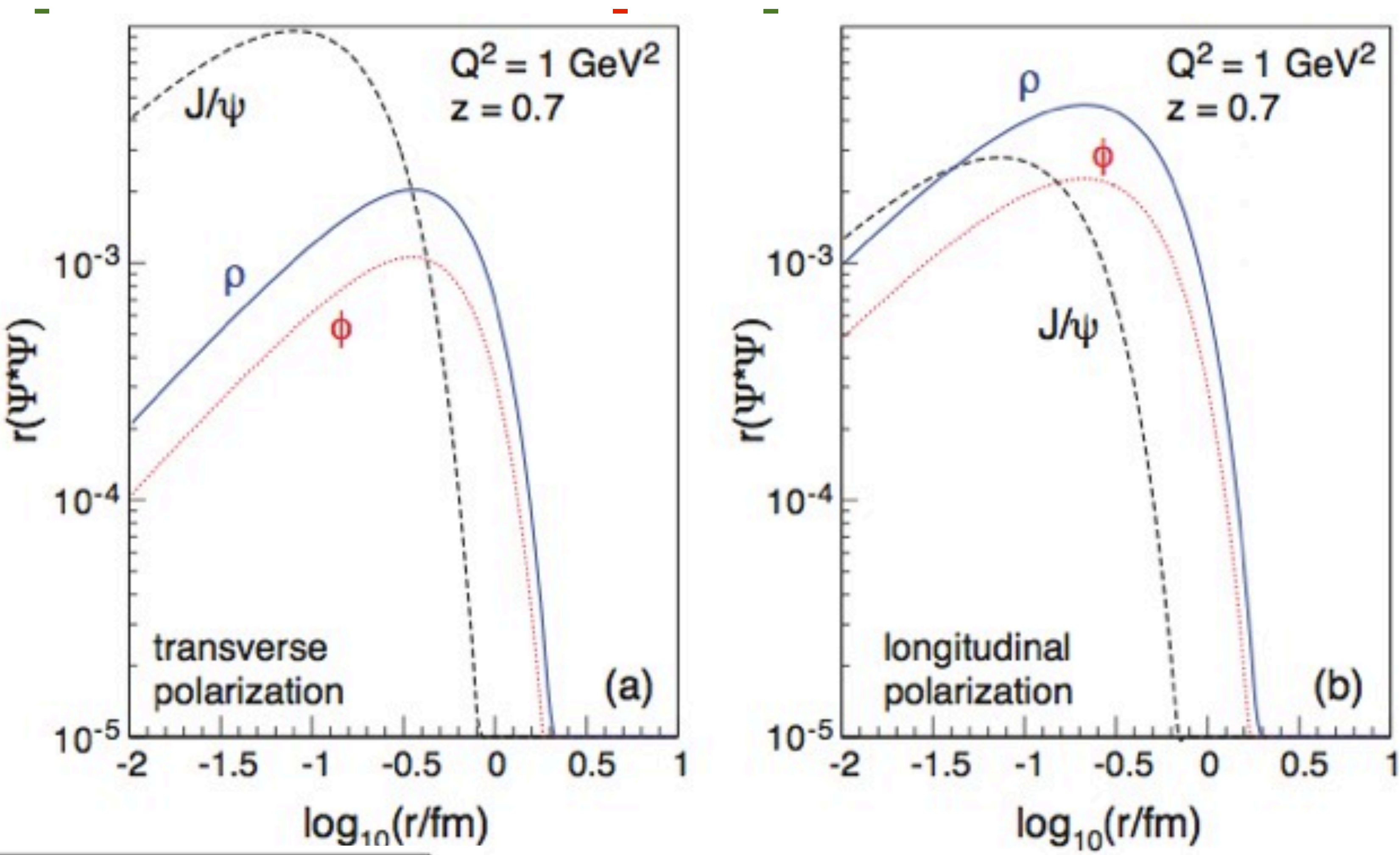
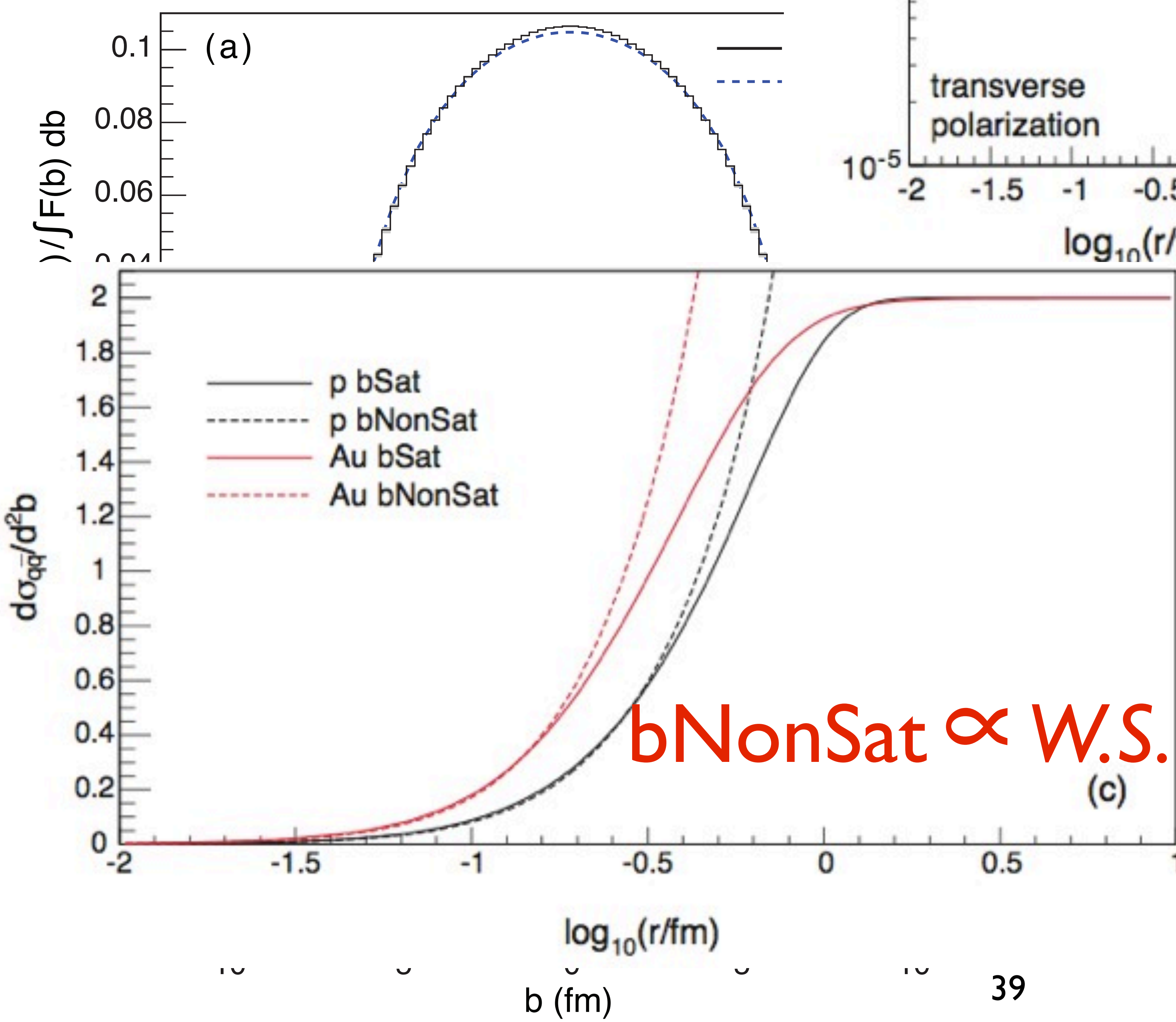


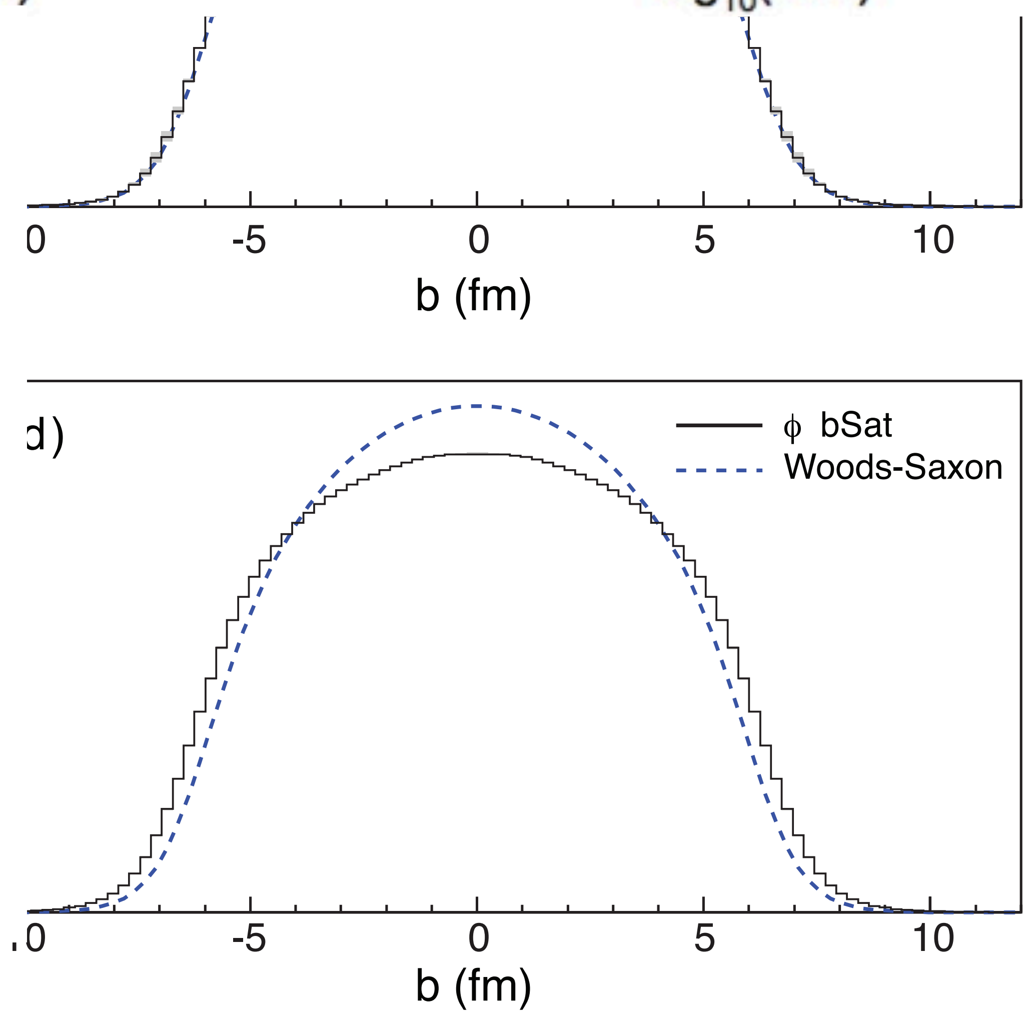
Probing t… distribu…

$$F(b) = \frac{1}{2\pi}\int_0^\infty \mathrm{d}\ldots$$





bNonSat ∝ W.S.



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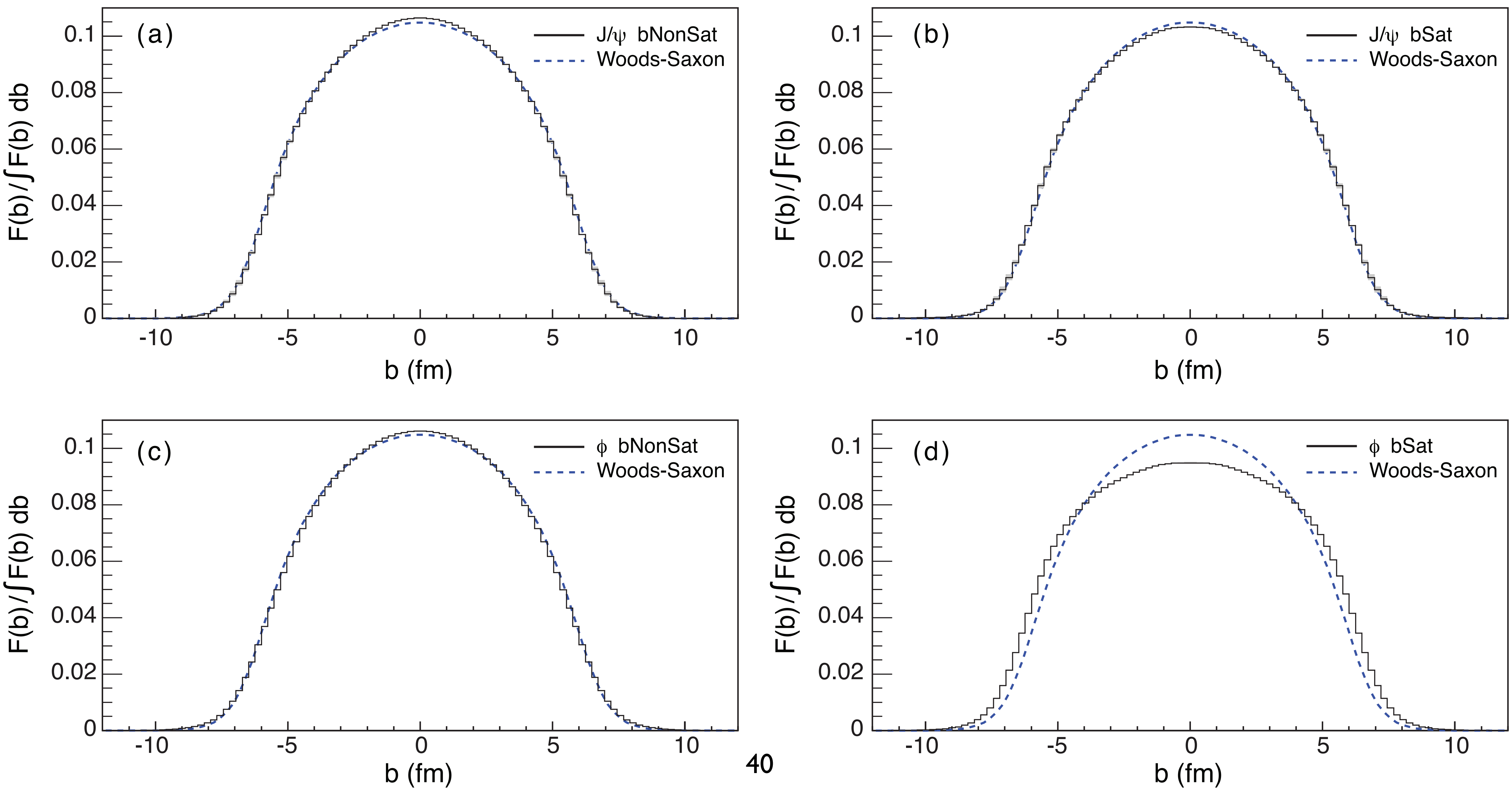

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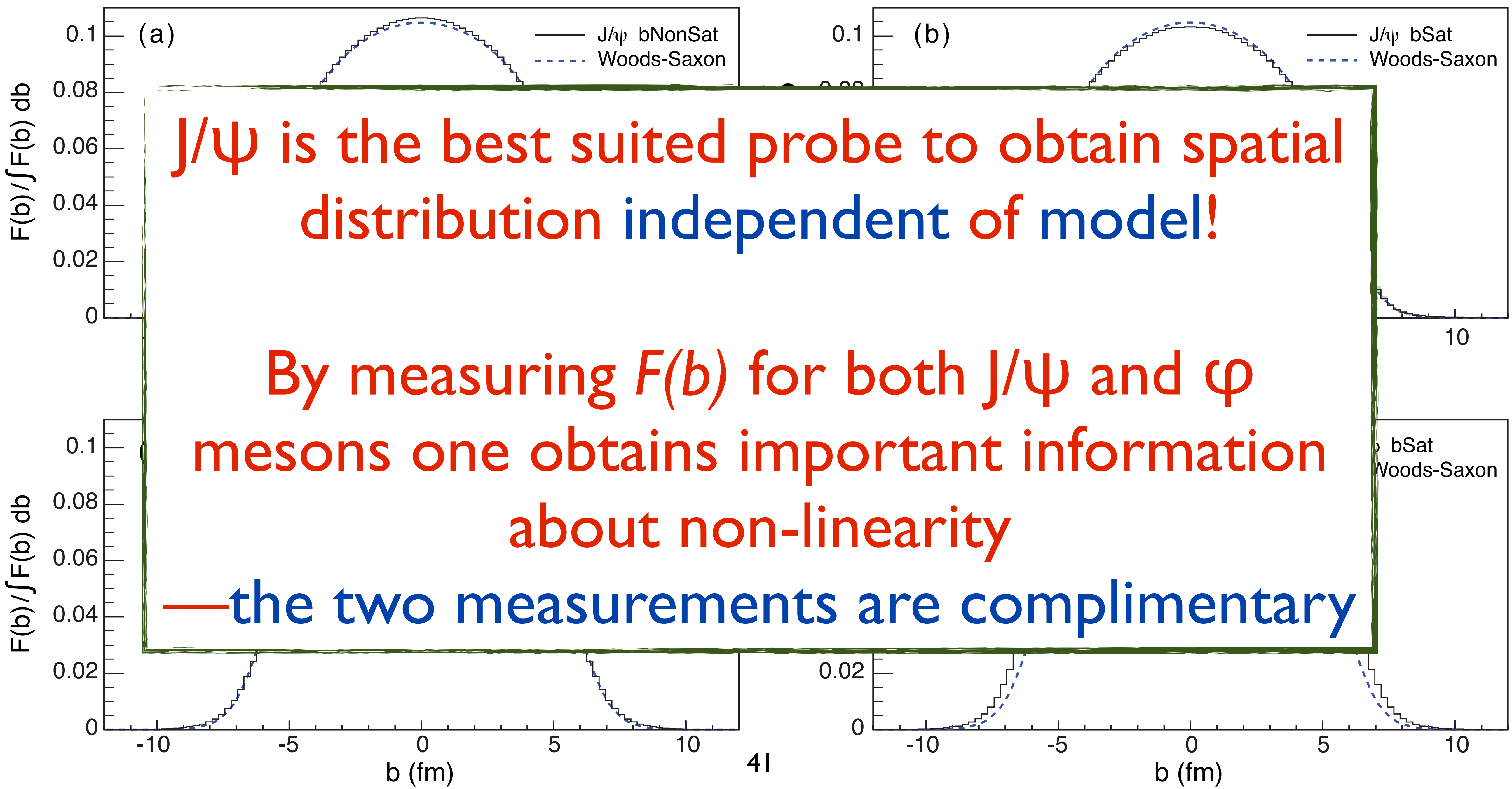

J/ψ is the best suited probe to obtain spatial distribution independent of model!

By measuring *F(b)* for both J/ψ and φ mesons one obtains important information about non-linearity —the two measurements are complimentary

UPC at RHIC with Sartre

PHENIX UPC J/ψ

$$\sqrt{s} = 200\ \mathrm{GeV}$$

$$\frac{\mathrm{d}\sigma}{\mathrm{d}y} = 76 \pm 33(\mathrm{stat.}) \pm 11(\mathrm{syst.})\mu b$$

$$|\eta(J/\psi)| < 0.35$$

Sartre: $$\frac{\mathrm{d}\sigma}{\mathrm{d}y} = 118.5\mu b$$

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Summary

Key diffractive measurements at eRHIC:

Rate of diffractive events vs. total events.
low luminosity "day one" measurement.

Exclusive vector meson production:
Q^2 distributions - medium luminosity,
stunning discriminatory power between models

Coherent t-distributions - high luminosity
can obtain source gluon distribution model
independently with J/ψ, sees non-linear effects with φ.

Incoherent t-distribution - high luminosity
measure of fluctuations in the initial state nucleus