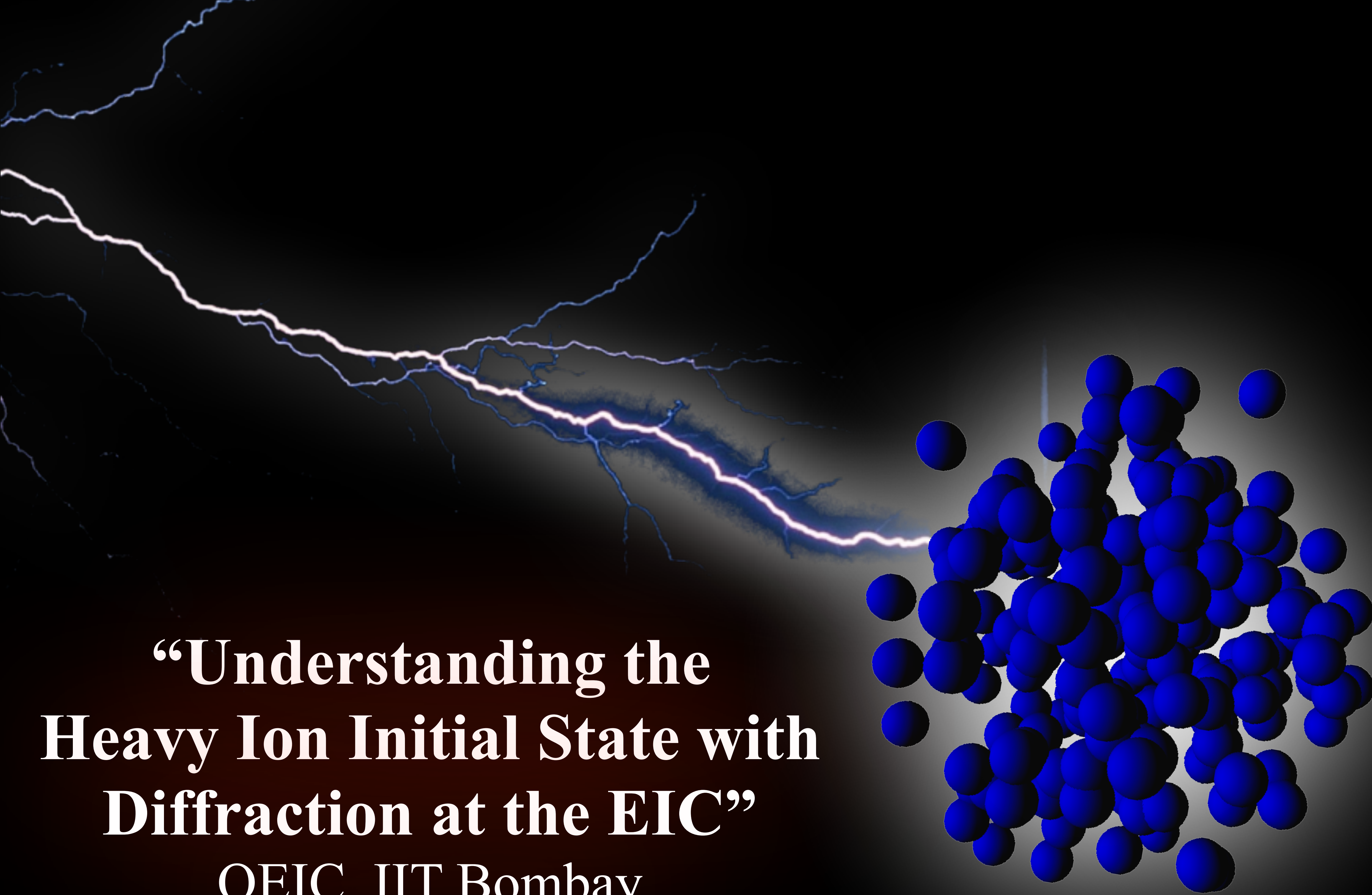


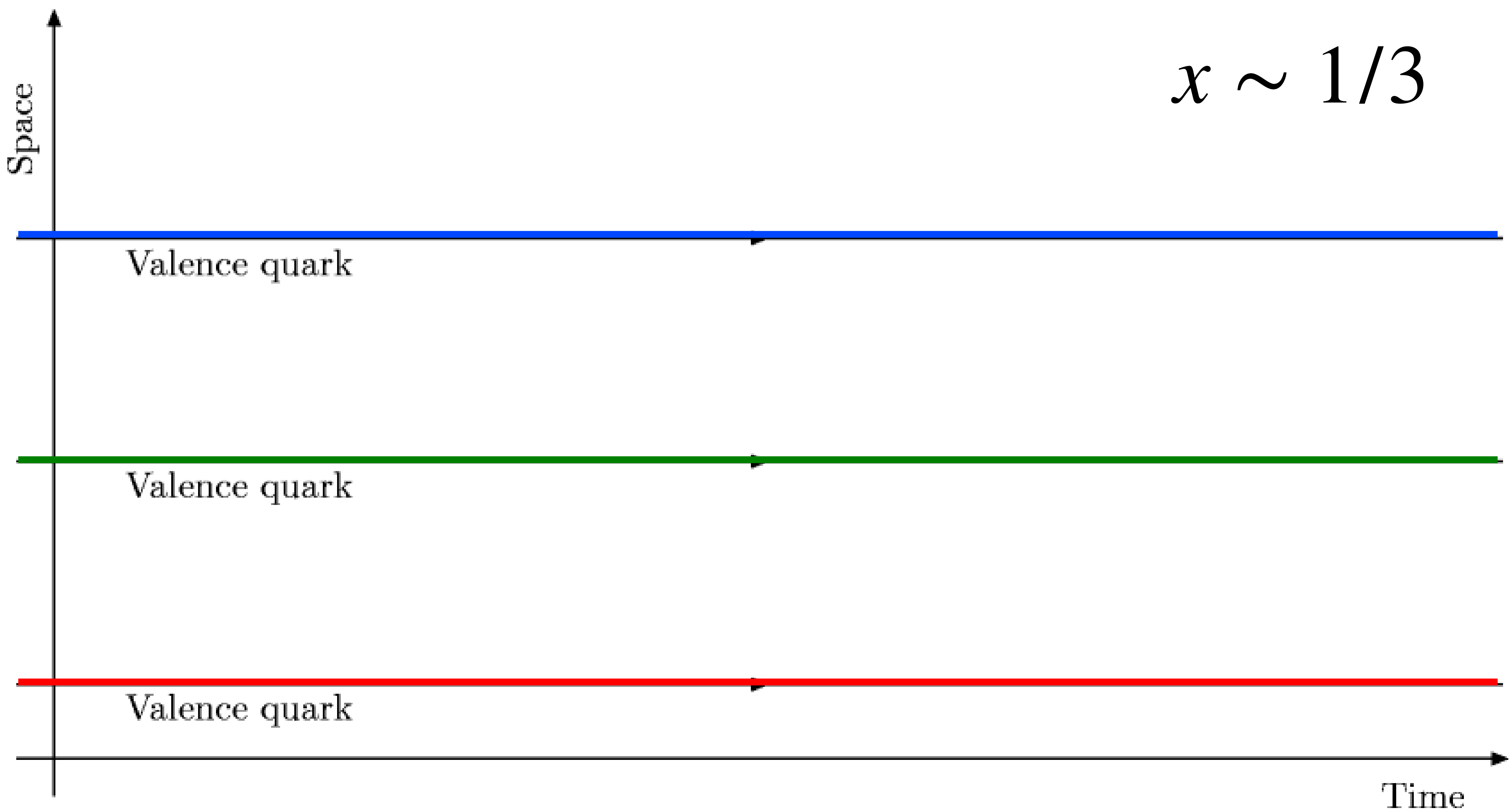
“Understanding the Heavy Ion Initial State with Diffraction at the EIC”

QEIC, IIT Bombay

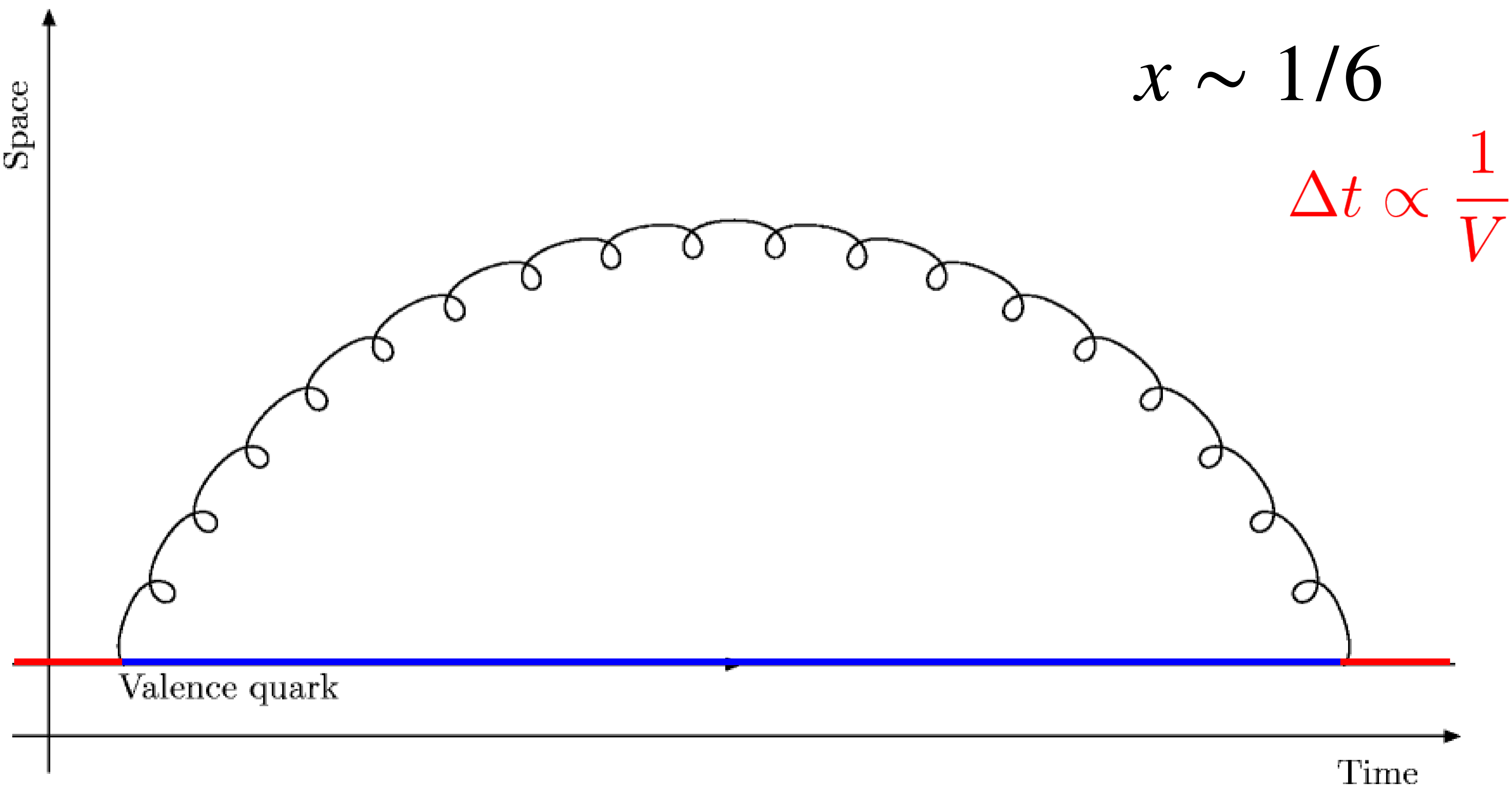
January 5, 2020

Tobias Toll
IIT Delhi

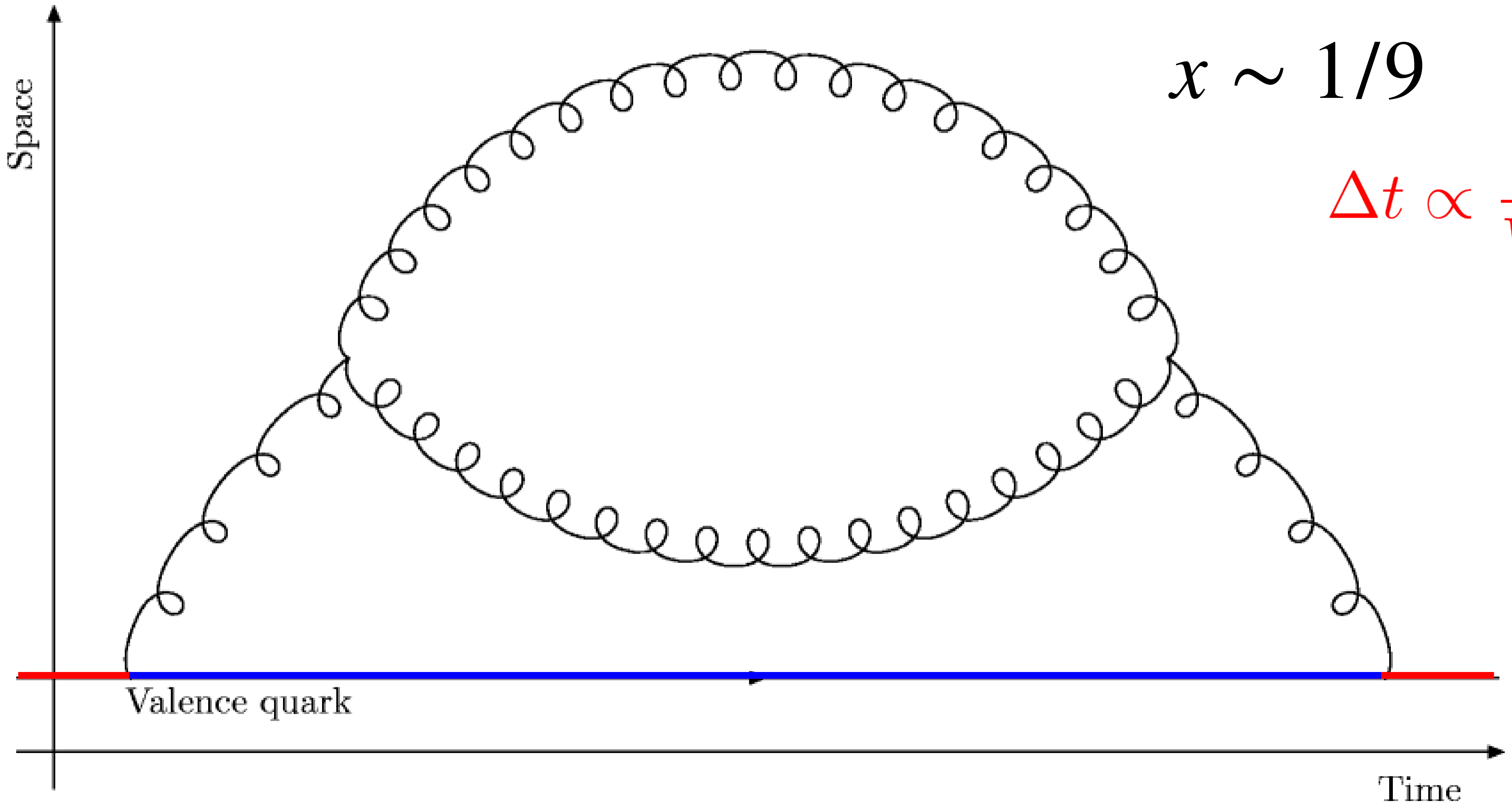
Our Understanding of Gluons



Our Understanding of Gluons



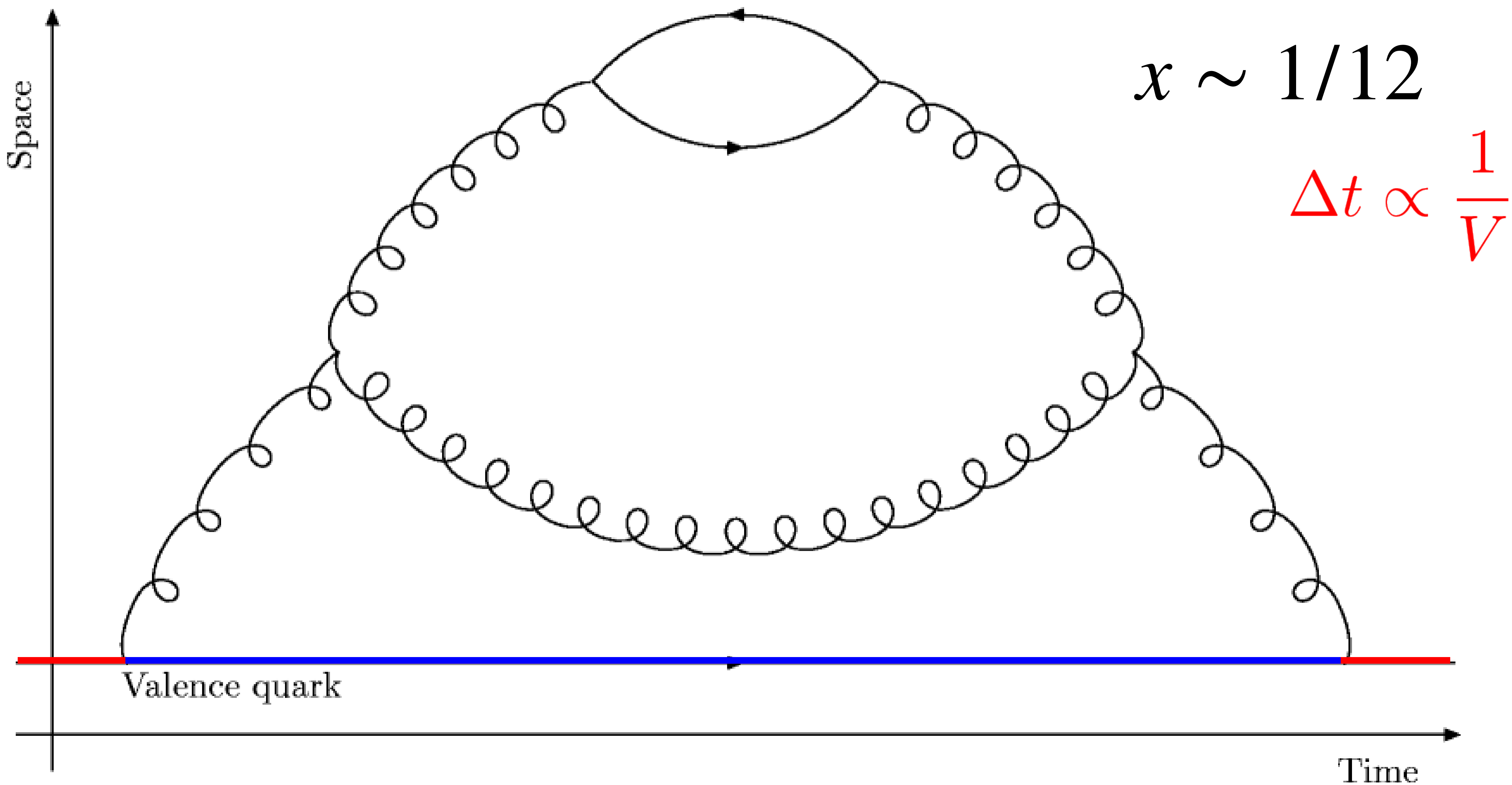
Our Understanding of Gluons



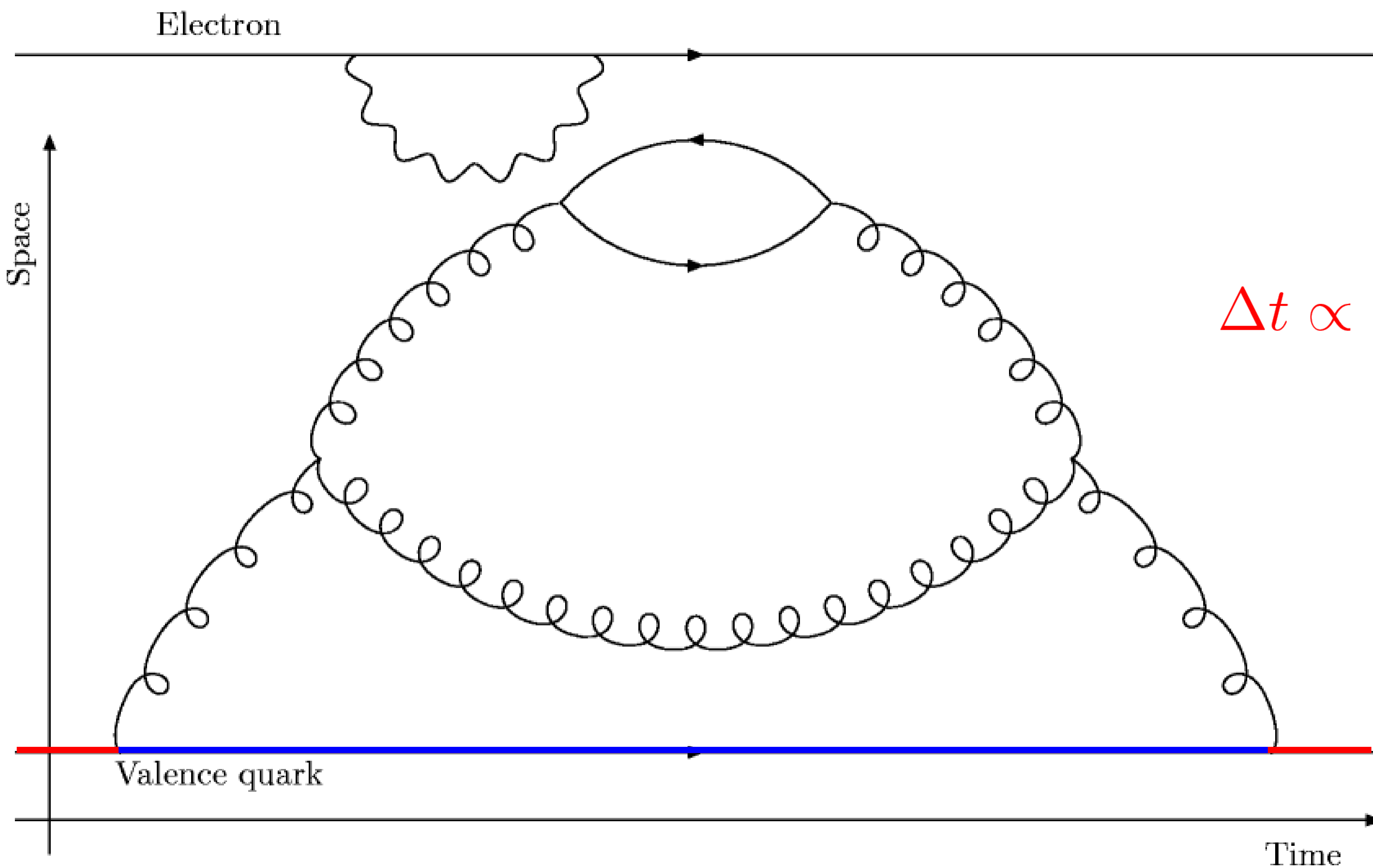
$x \sim 1/9$

$\Delta t \propto \frac{1}{V}$

Our Understanding of Gluons

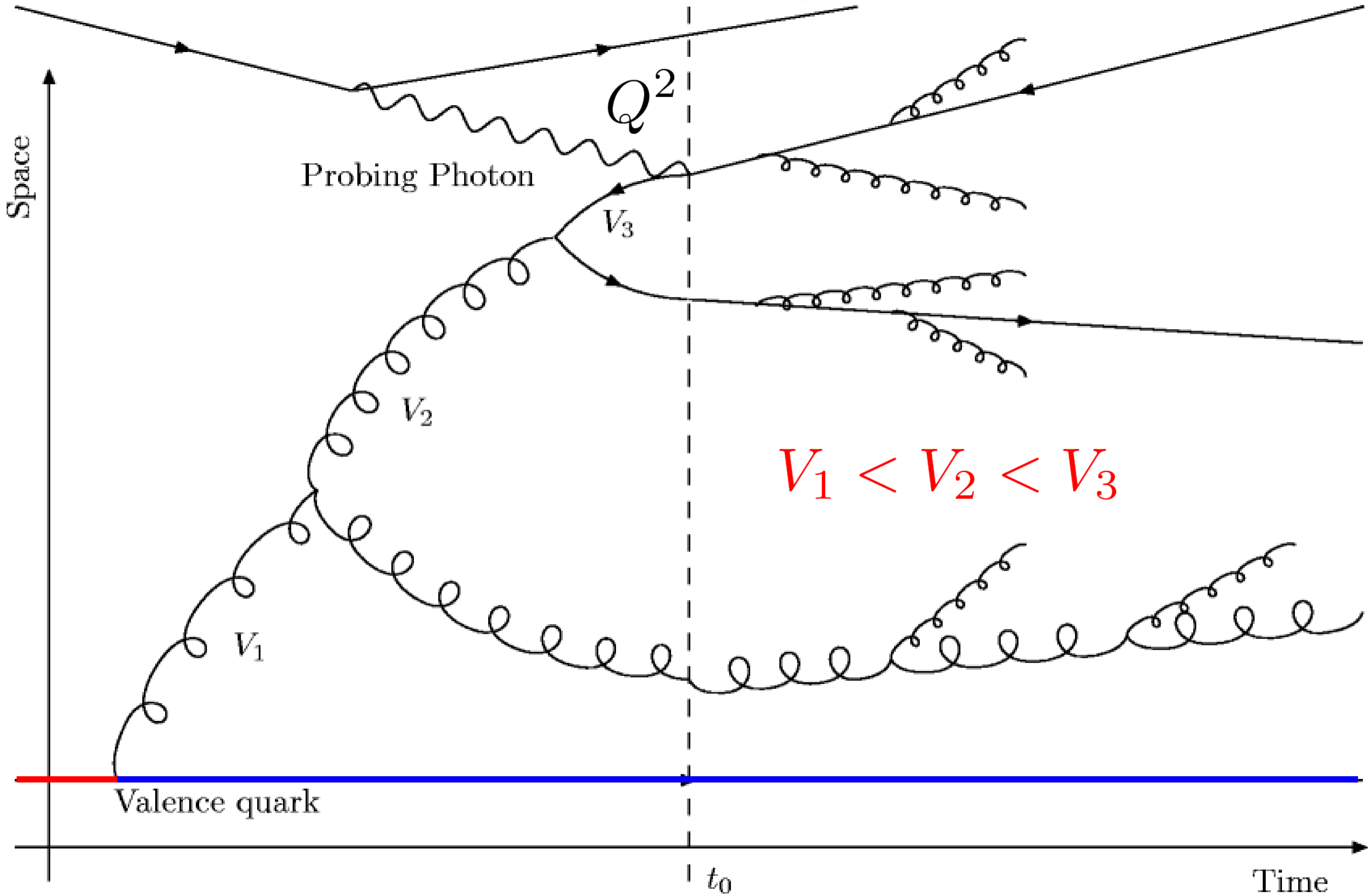


Our Understanding of Gluons



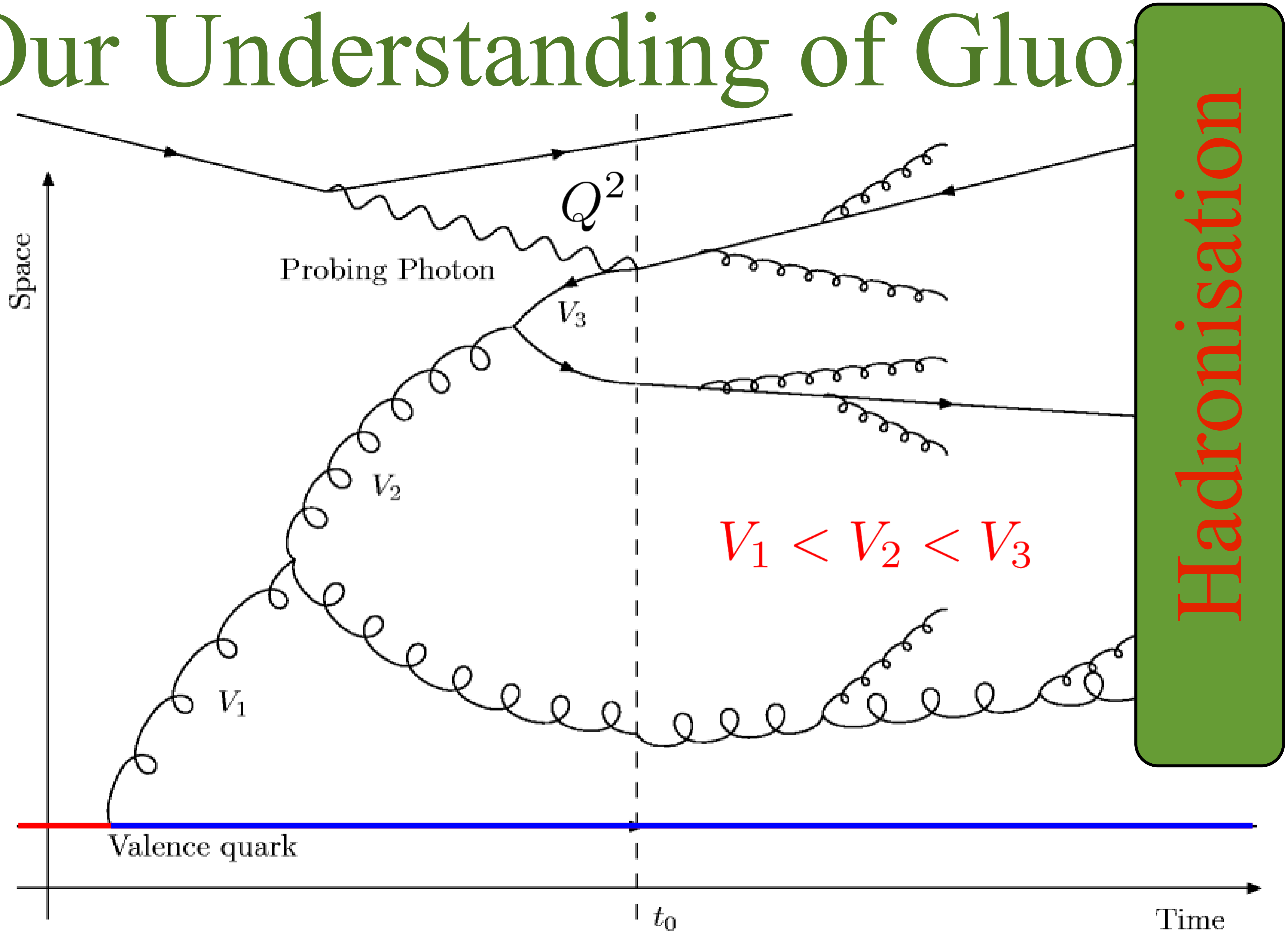
$$\Delta t \propto \frac{1}{V}$$

Our Understanding of Gluons



***D**okshitzer **G**ribov **L**ipatov **A**ltarelli **P**arisi* **DGLAP**

Our Understanding of Gluo



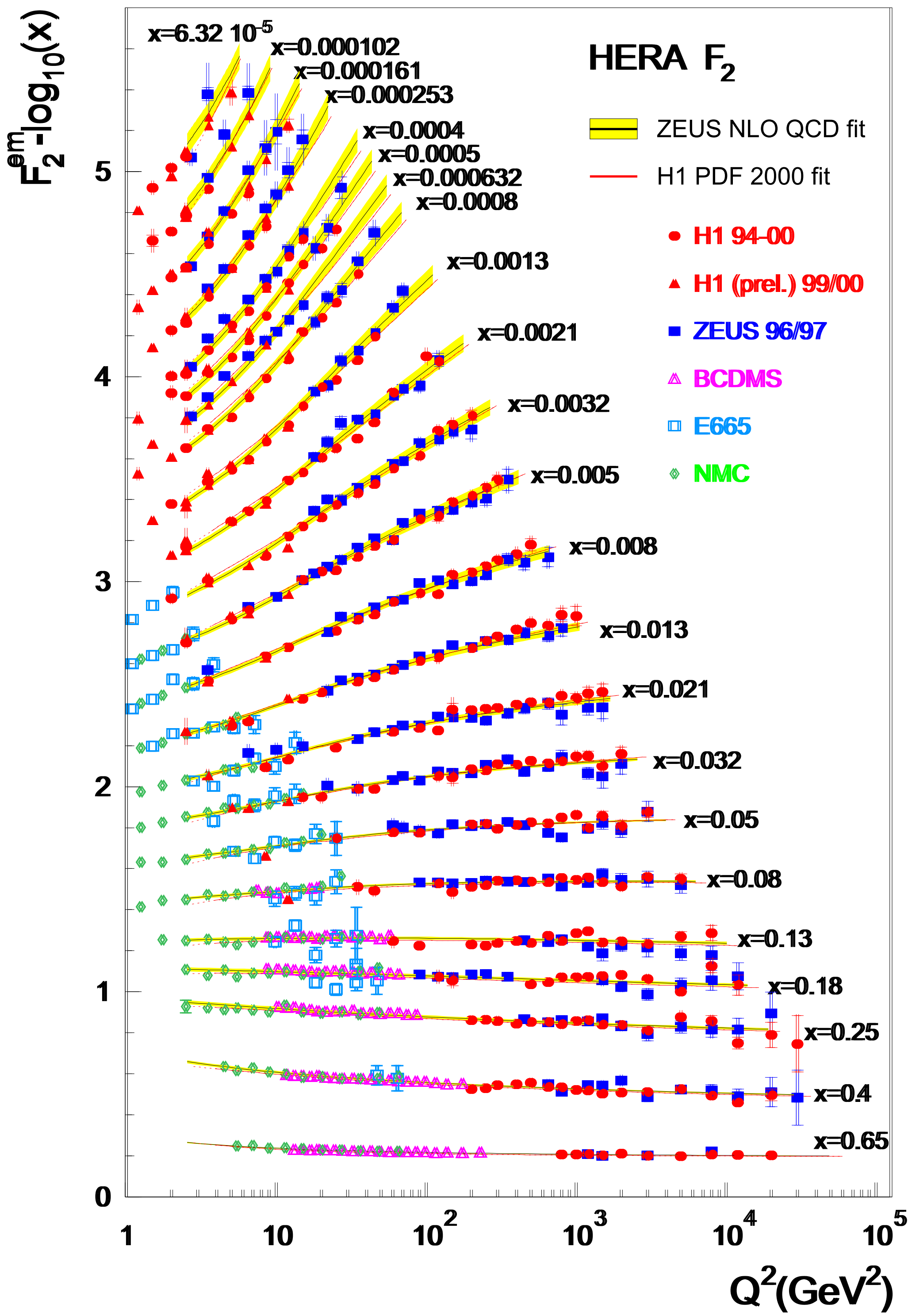
***D**okshitzer **G**ribov **L**ipatov **A**ltarelli **P**arisi* **DGLAP**

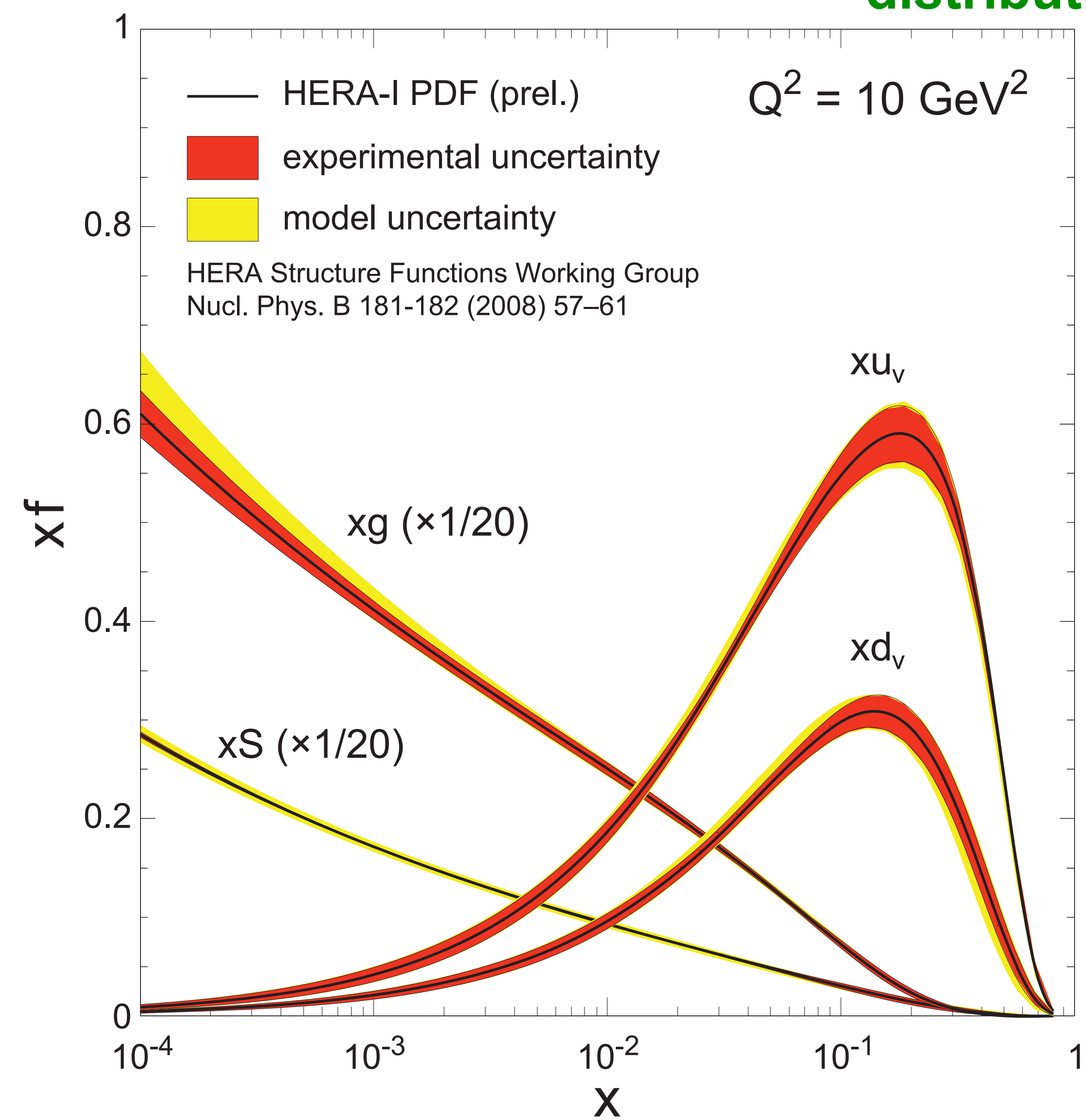
DGLAP in e+p collisions at HERA?

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

quark+anti-quark momentum distributions

gluon momentum distribution



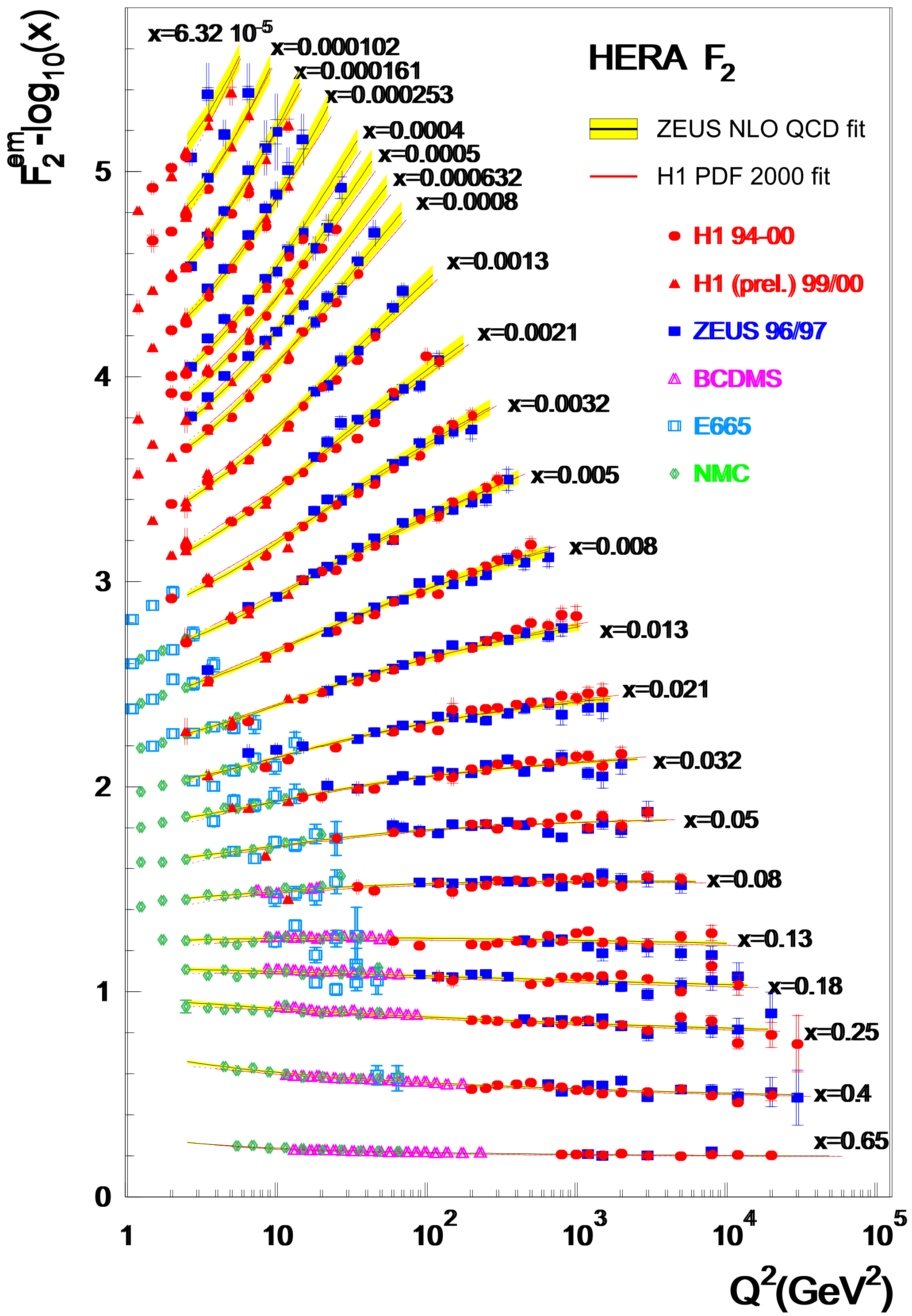


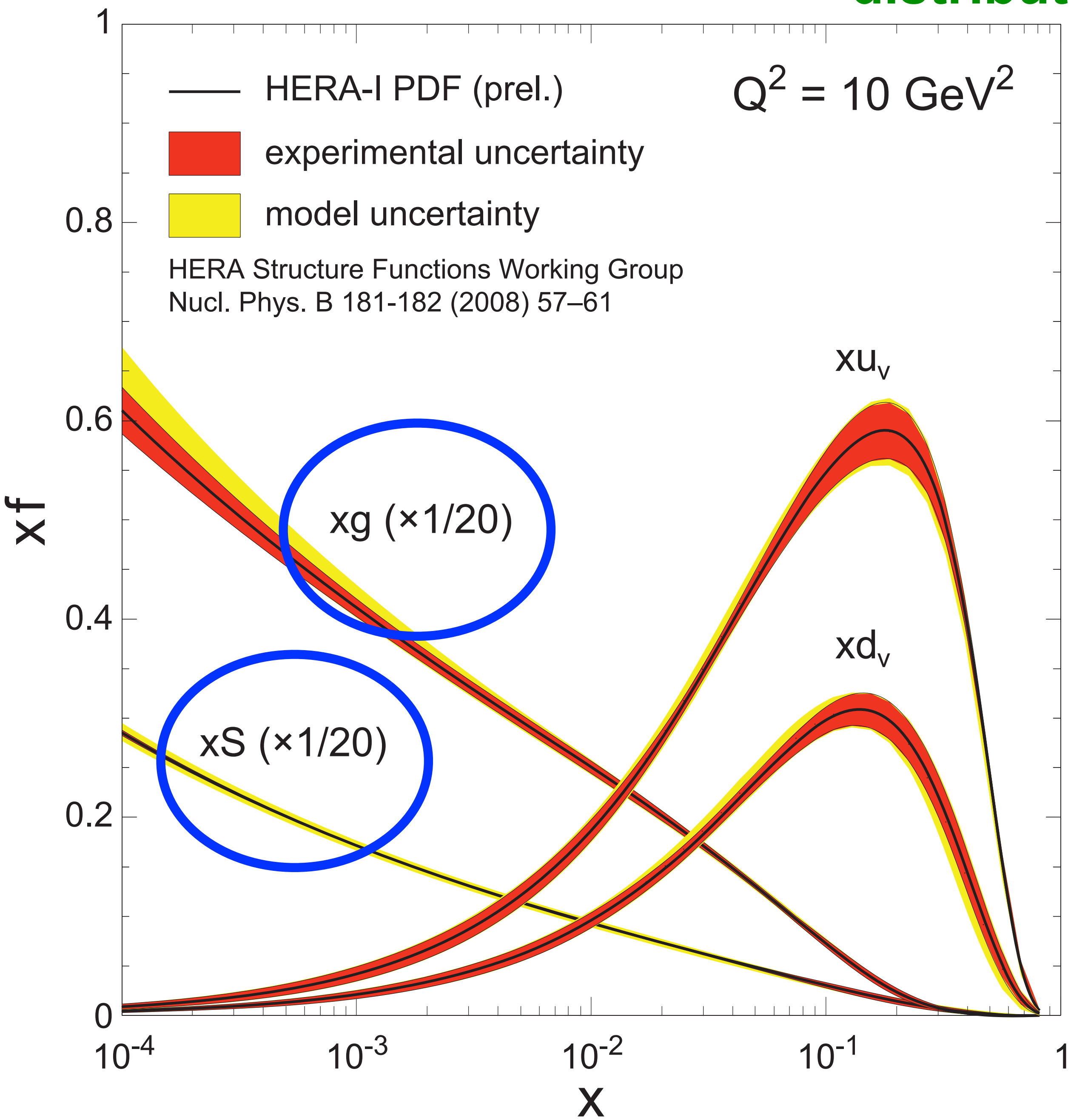
DGLAP in e+p collisions at HERA?

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

quark+anti-quark momentum distributions

gluon momentum distribution



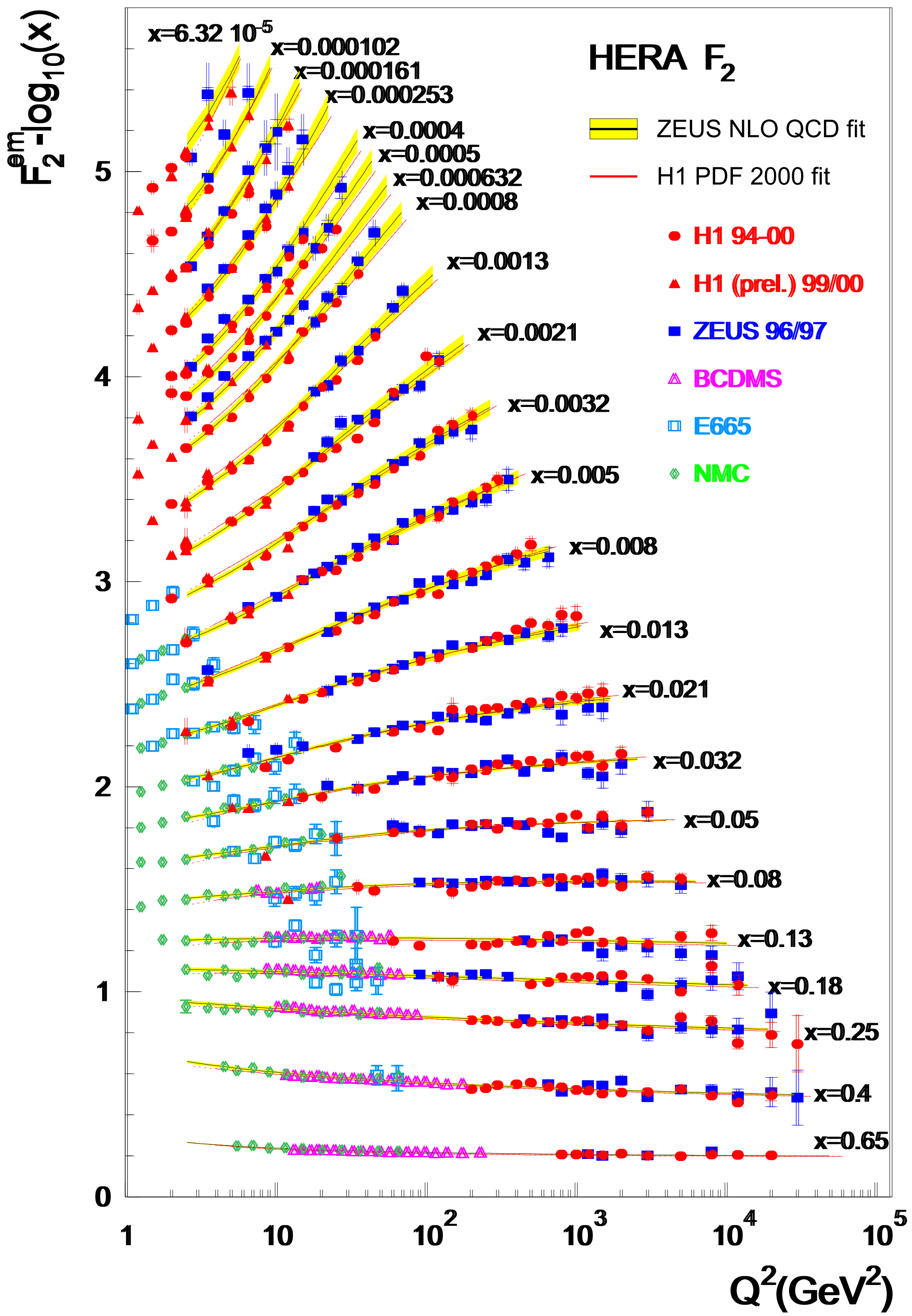


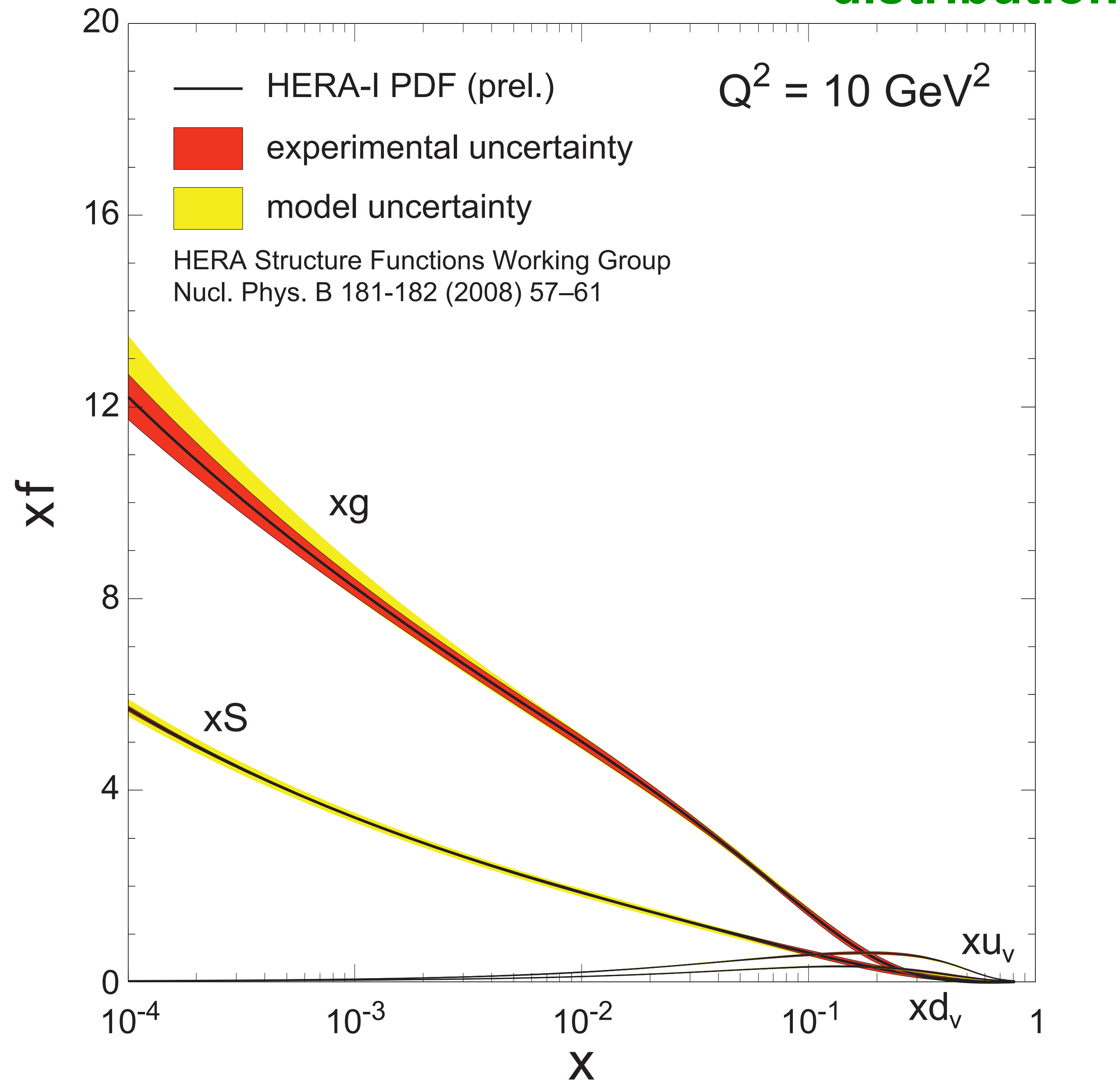
DGLAP in e+p collisions at HERA?

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

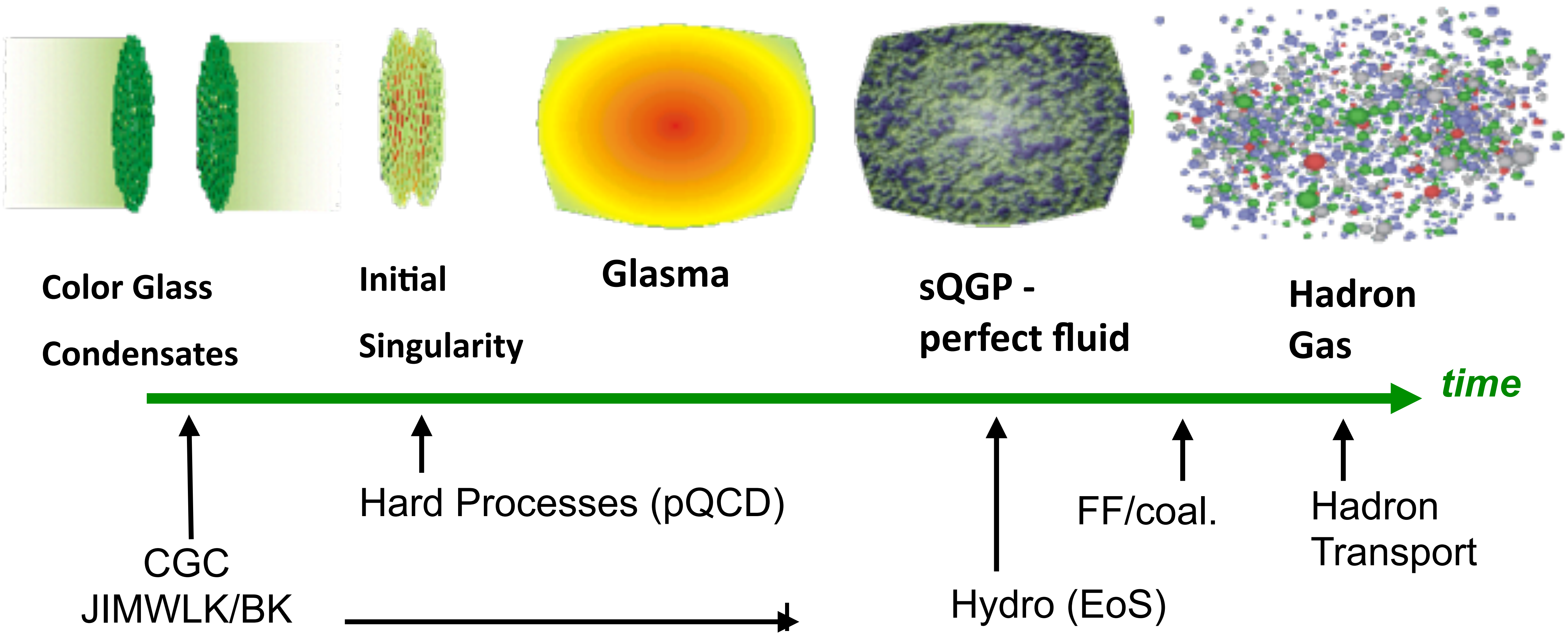
quark+anti-quark momentum distributions

gluon momentum distribution



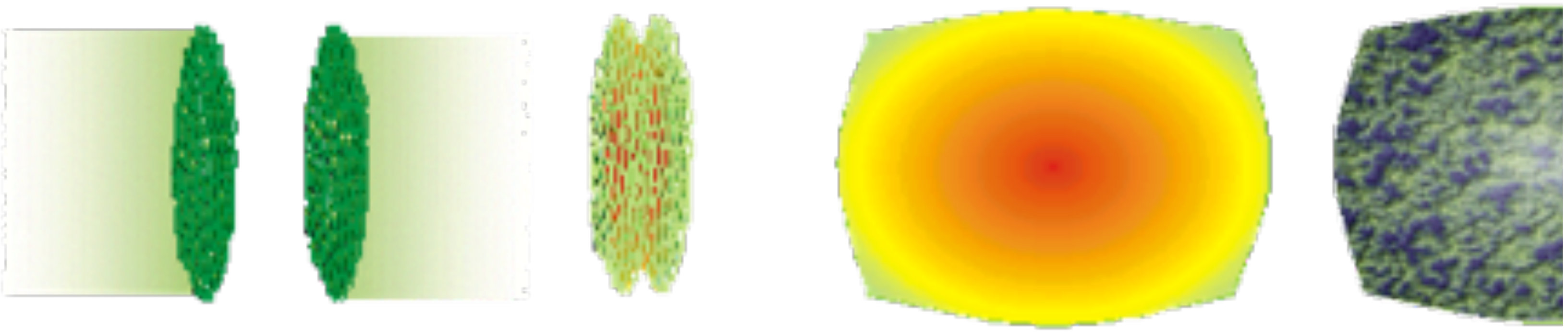


“Standard model of Heavy Ion Collisions”

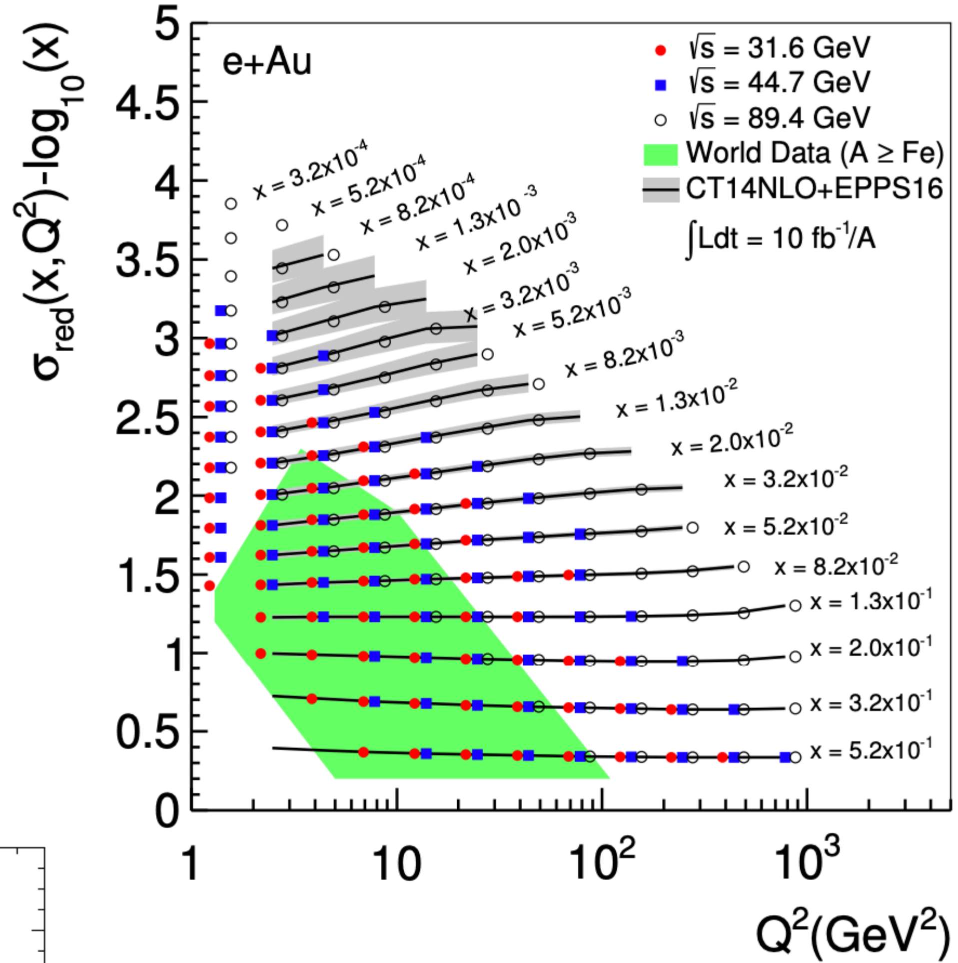


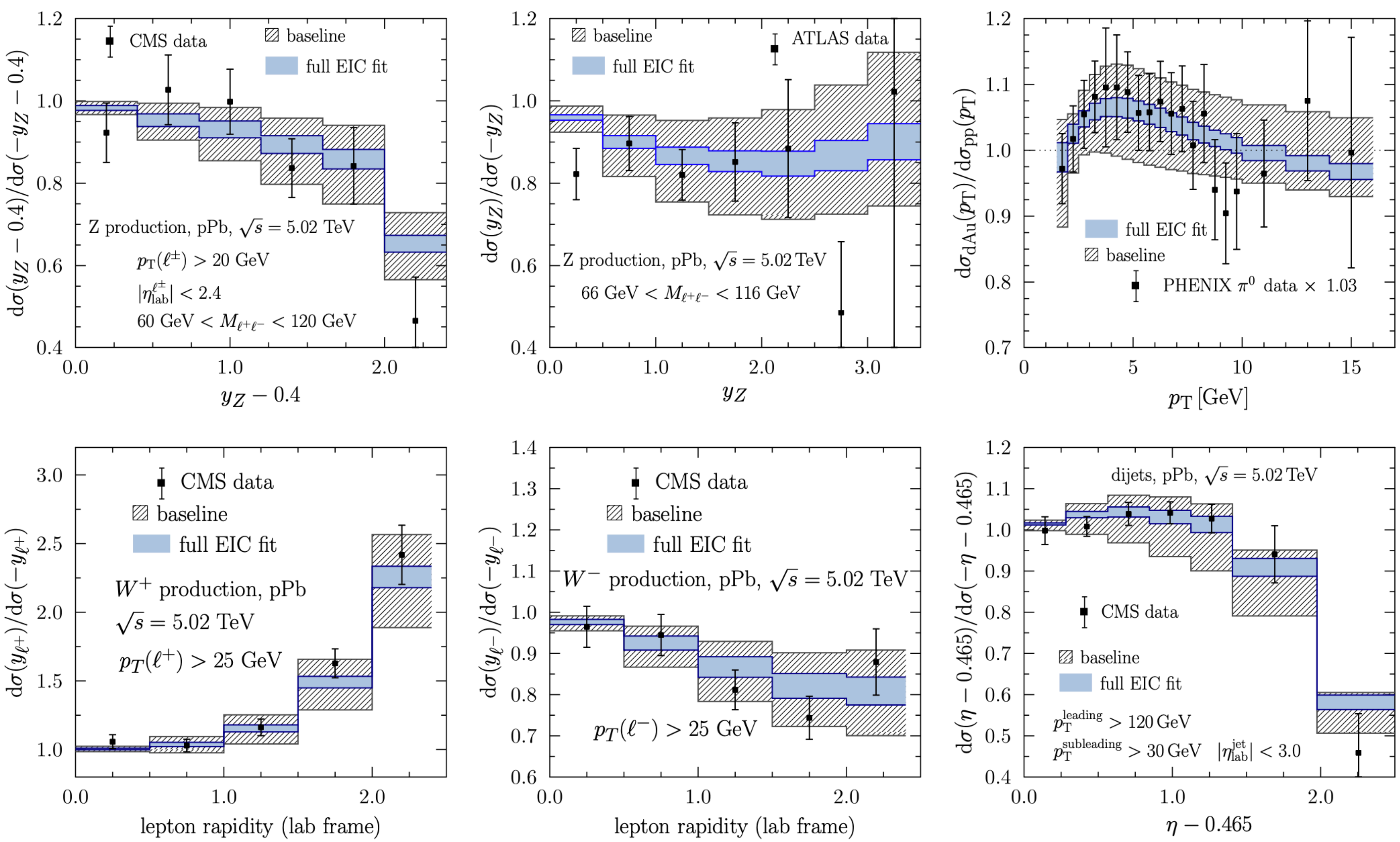
Our understanding of some fundamental properties of the Glasma, sQGP and Hadron Gas depend strongly on our knowledge of the initial state!

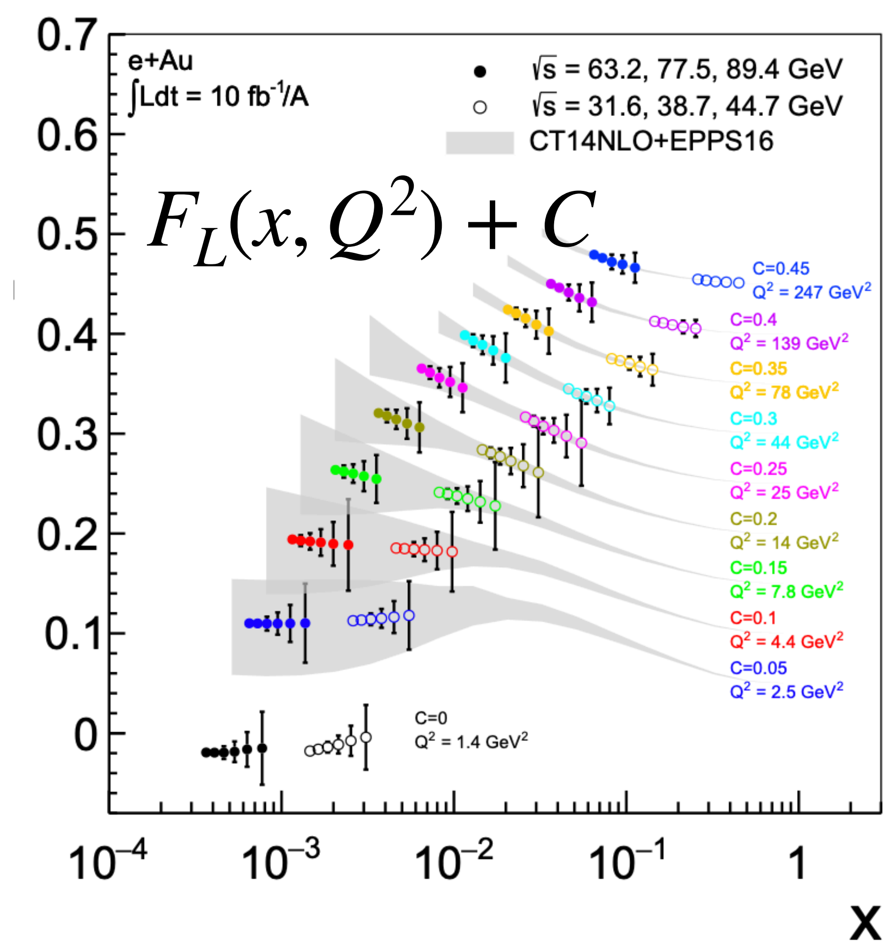
“Standard model of Heavy I



Color Glass Condensates | **Initial Singularity** | **Glasma** | **sQGP perfe**

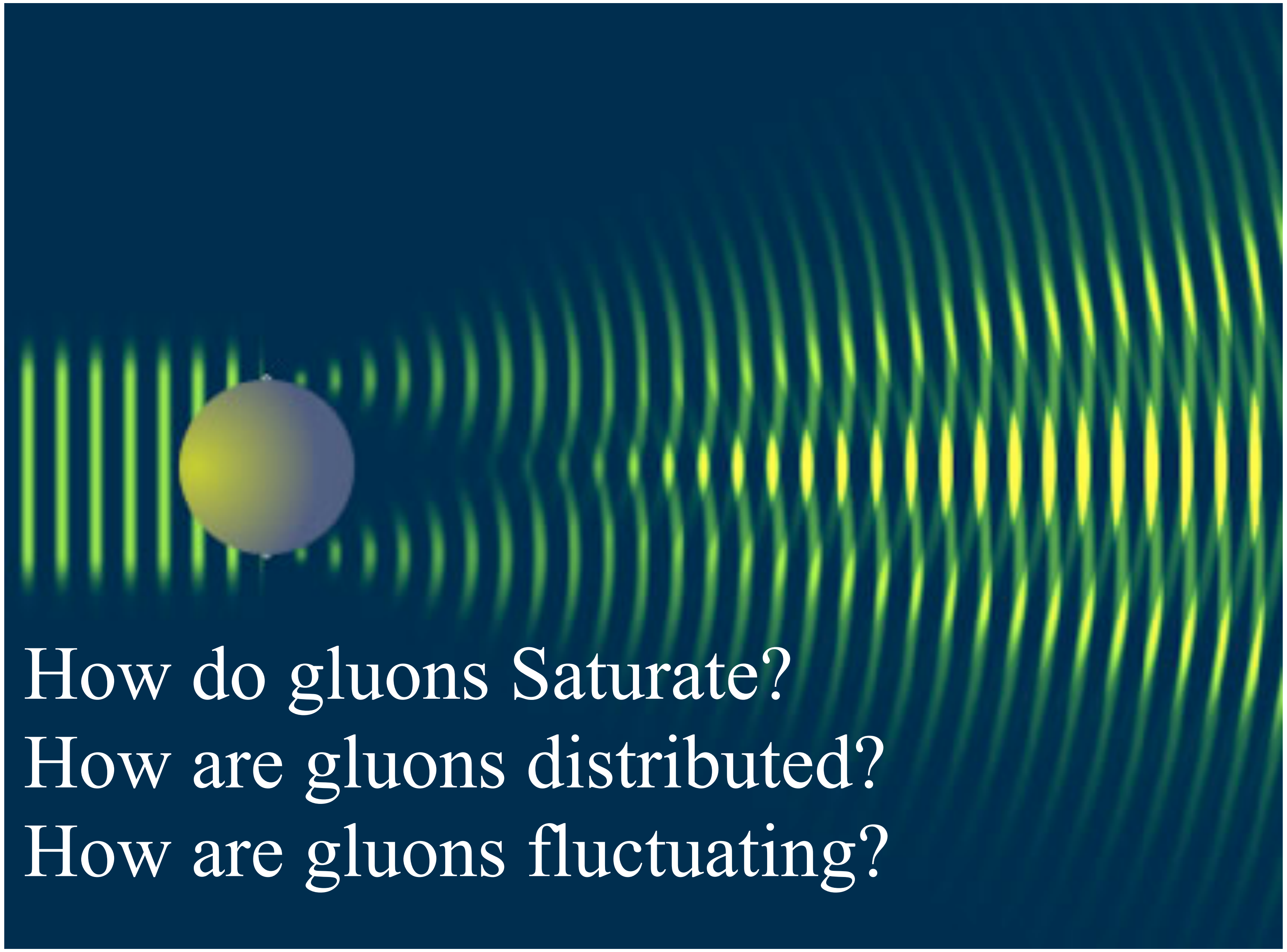




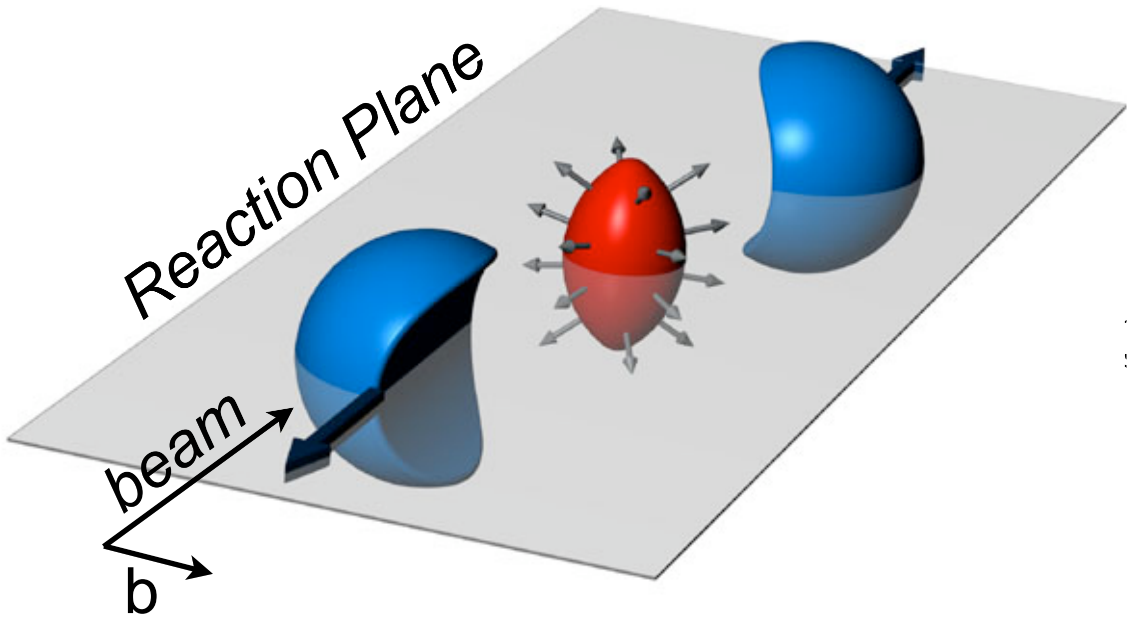


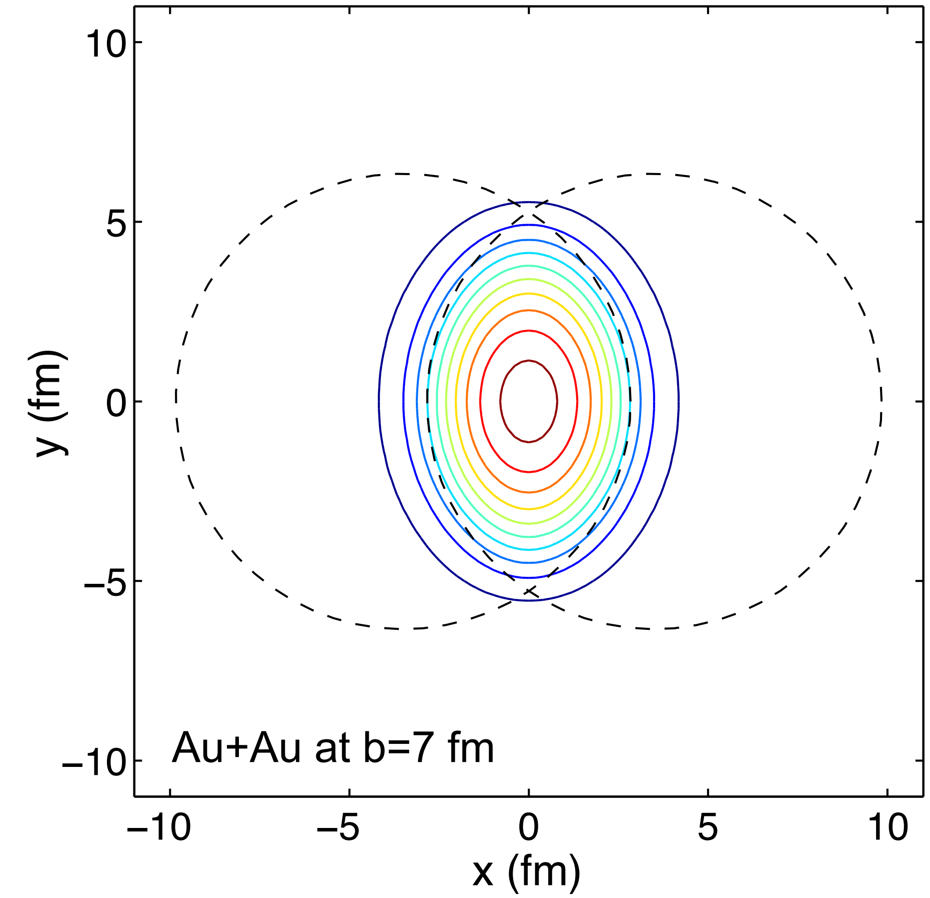
E.C. Aschenauer, S. Fazio, M.A.C. Lamont (Brookhaven), H. Paukkunen (Jyvaskyla U. & Helsinki Inst. of Phys.), Pia Zurita (Brookhaven) Phys.Rev. D96 (2017) no.11, 114005

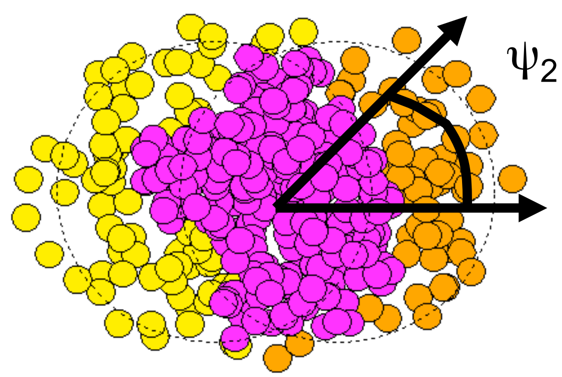
3 Questions best answered by (Exclusive) Diffraction



In Protons and Nuclei







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

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

Sensitive to early interactions and pressure gradients

In ideal hydrodynamics $v_2 \propto$ spatial eccentricity ε_2: $\epsilon_2 = \frac{\langle y^2 - x^2 \rangle}{\langle y^2 + x^2 \rangle}$

v_2/ε versus particle density is sensitive test of ideal hydrodynamic:

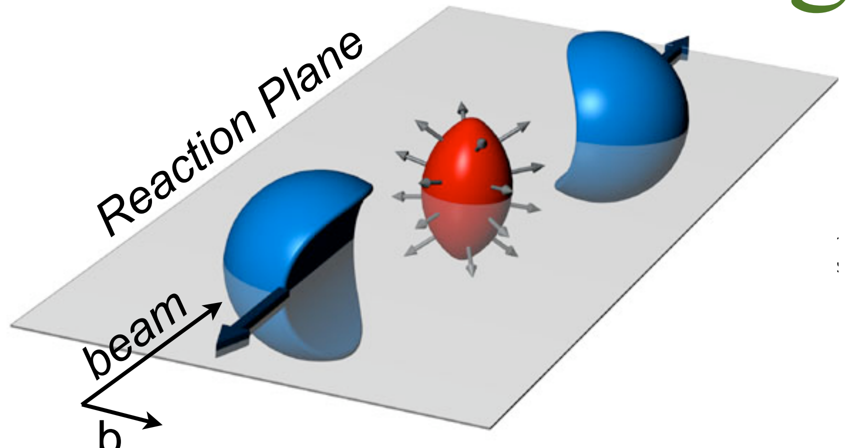
$$\frac{v_2}{\epsilon_2} = \frac{h}{1 + B/\left(\frac{1}{S}\frac{\mathrm{d}N}{\mathrm{d}y}\right)}$$

S= transverse area,

h = hydro limit of v_2/ε and B $\propto$ η/s

Different initial distributions gives different flows!

$$\epsilon_2 = \frac{\langle y^2 - x^2 \rangle}{\langle y^2 + x^2 \rangle}$$



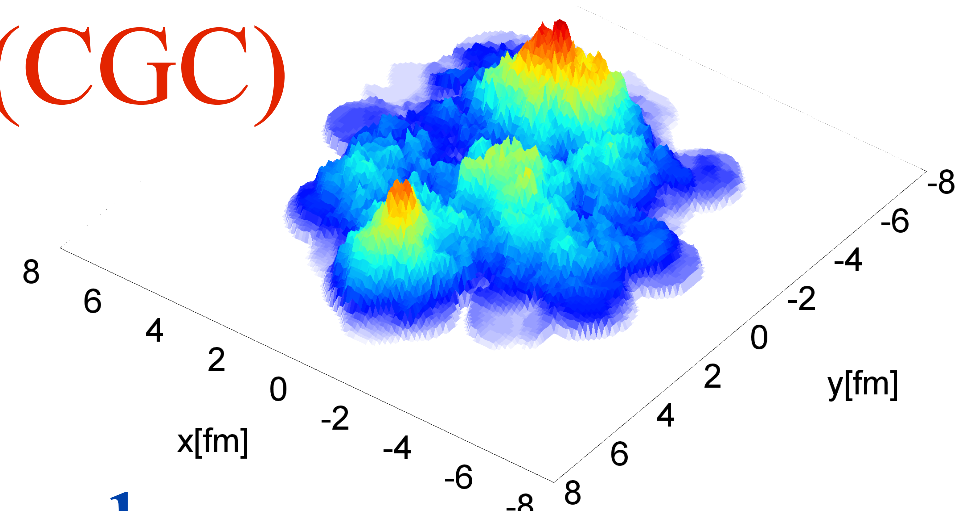
The question is what is ε?

RHIC & LHC: low-p_T realm driven almost entirely by glue ⇒ spatial distribution of glue in nuclei?

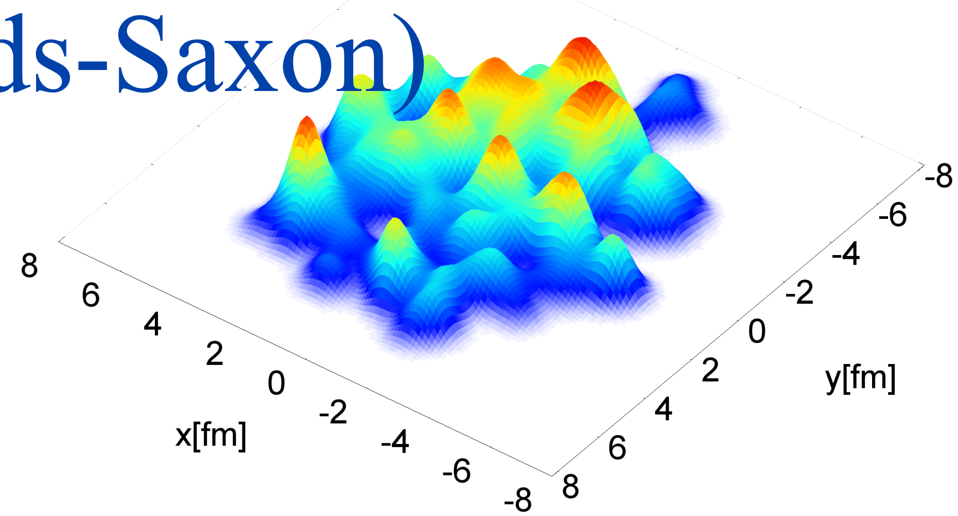
Two methods for ε:

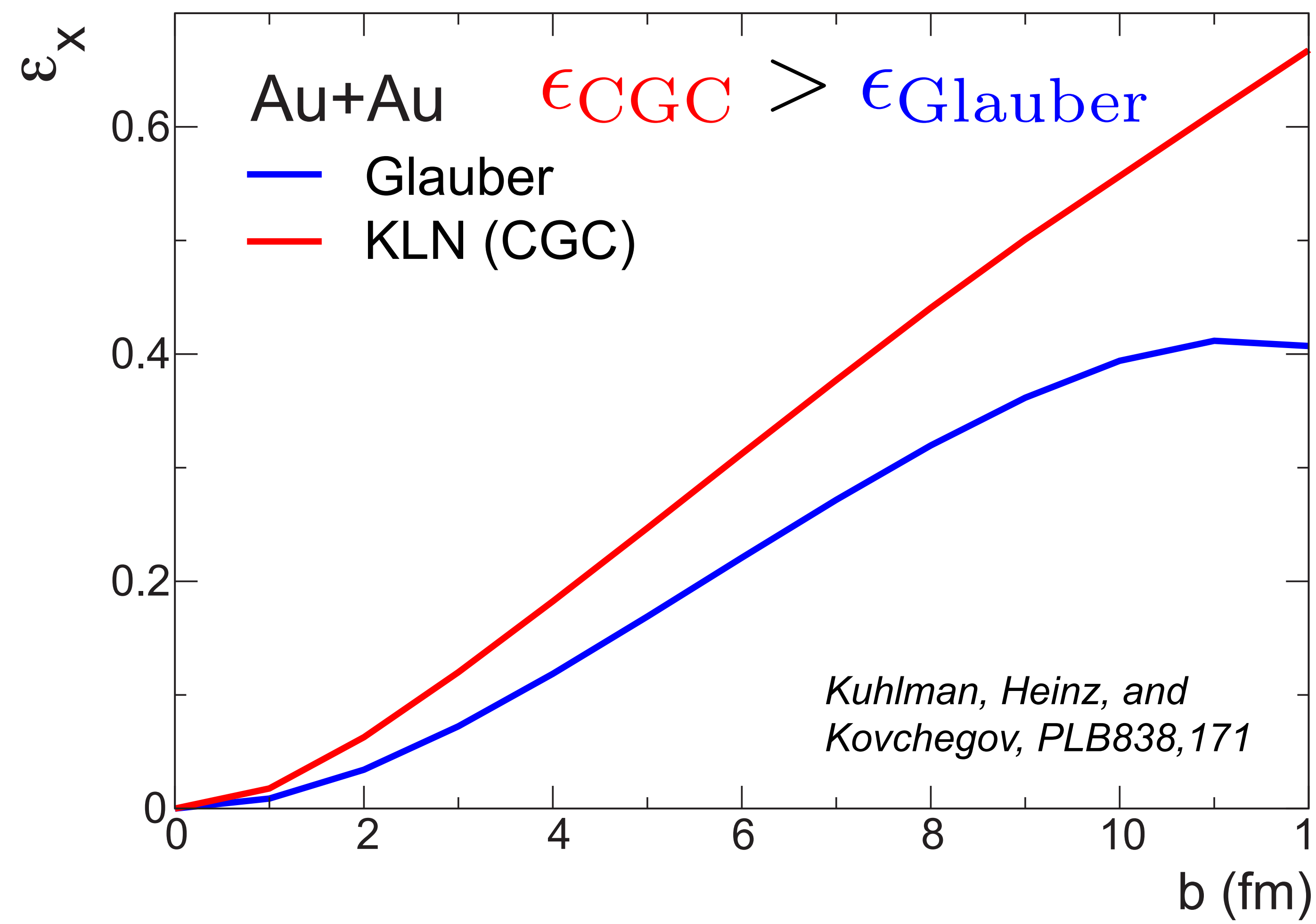
- Glauber (non-saturated)?
- CGC (saturated)?

KLN(CGC)



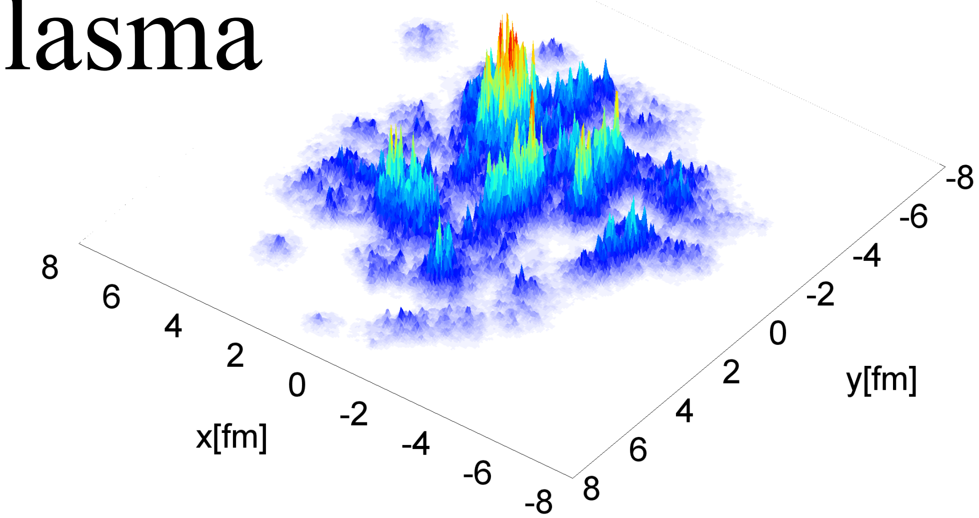
Glauber (Woods-Saxon)



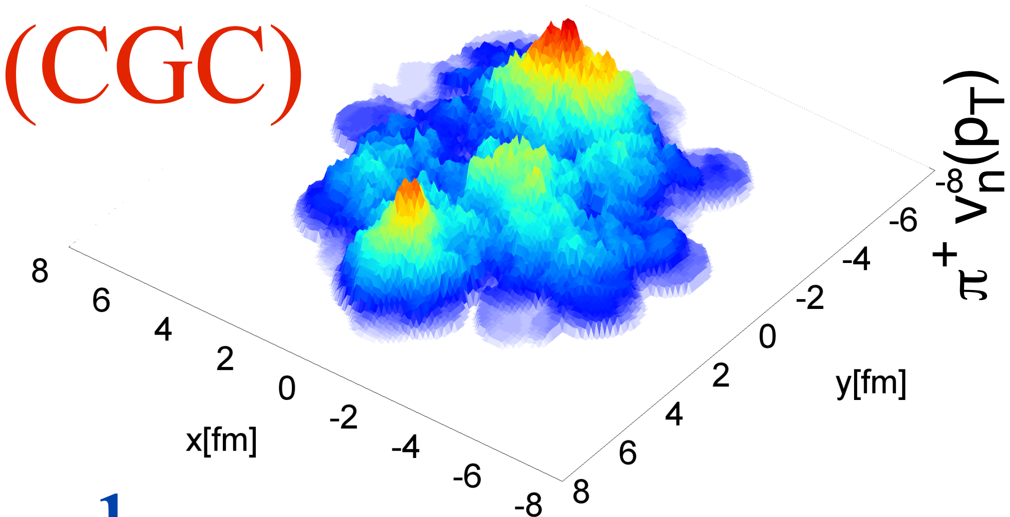


What is η/s?

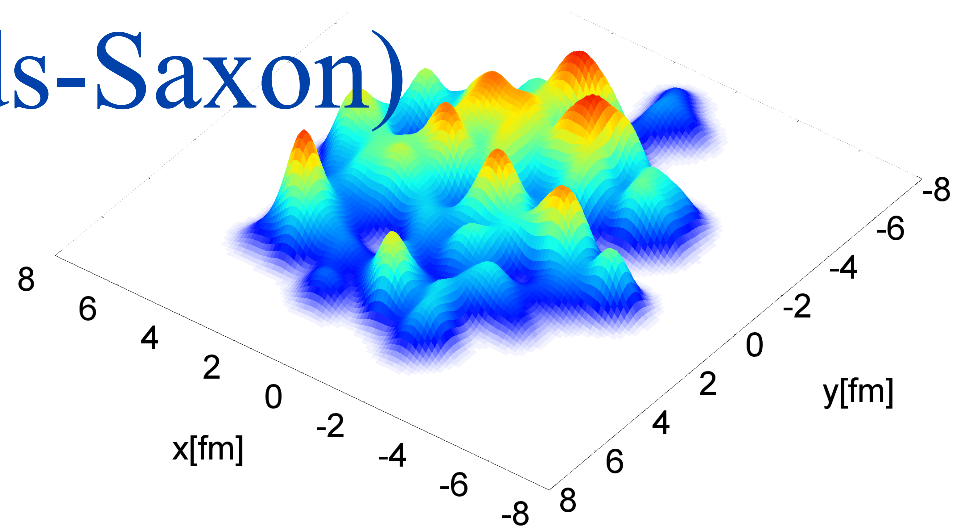
IP-Glasma



KLN(CGC)

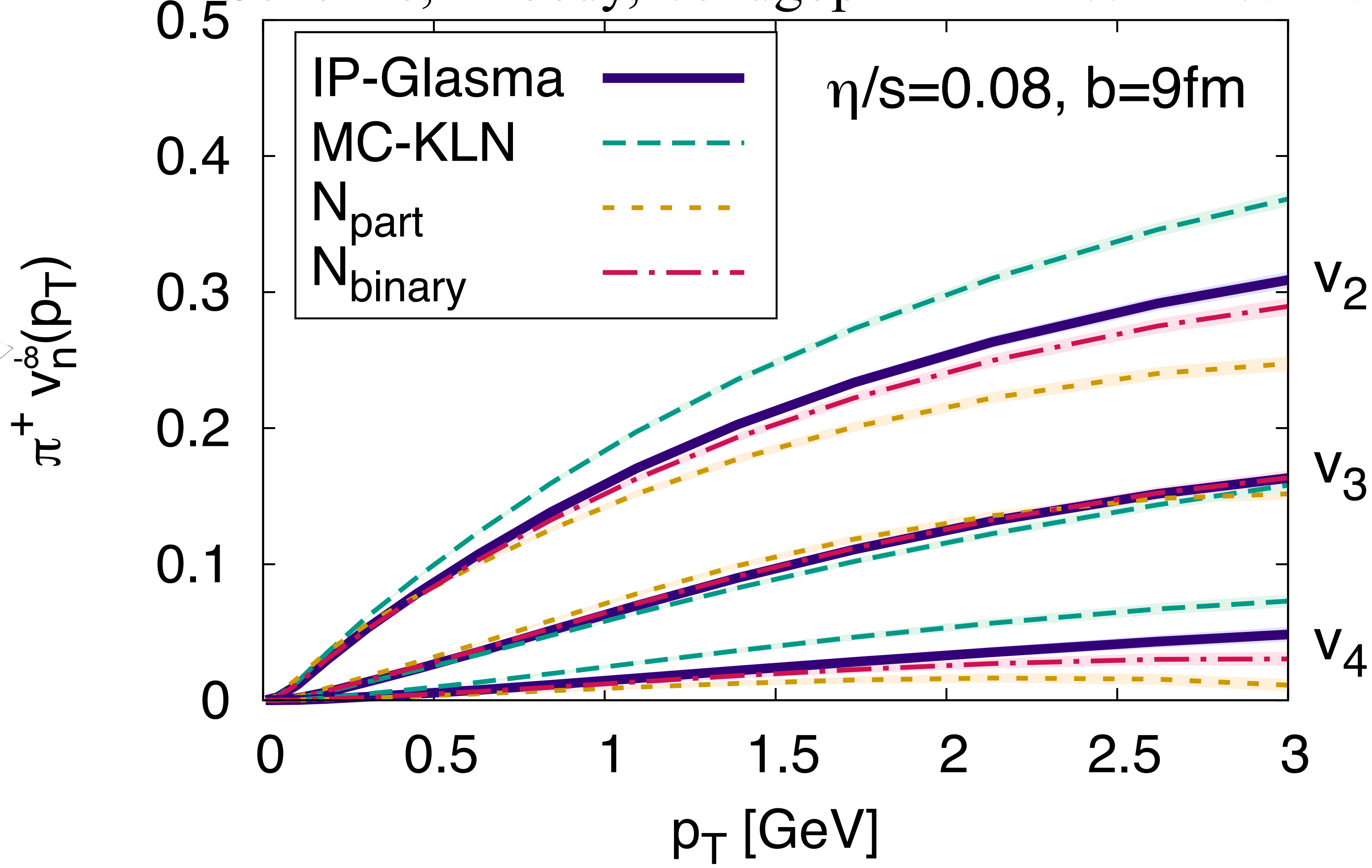


Glauber
(Woods-Saxon)



$1/(4\pi) \sim 0.08$

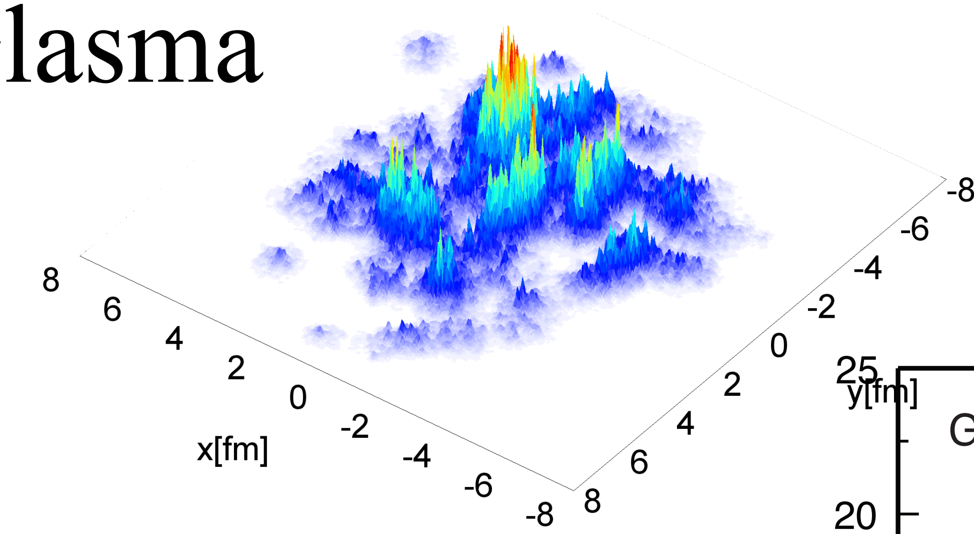
Schenke, Tribedy, Venugopalan arXiv:1202.6646



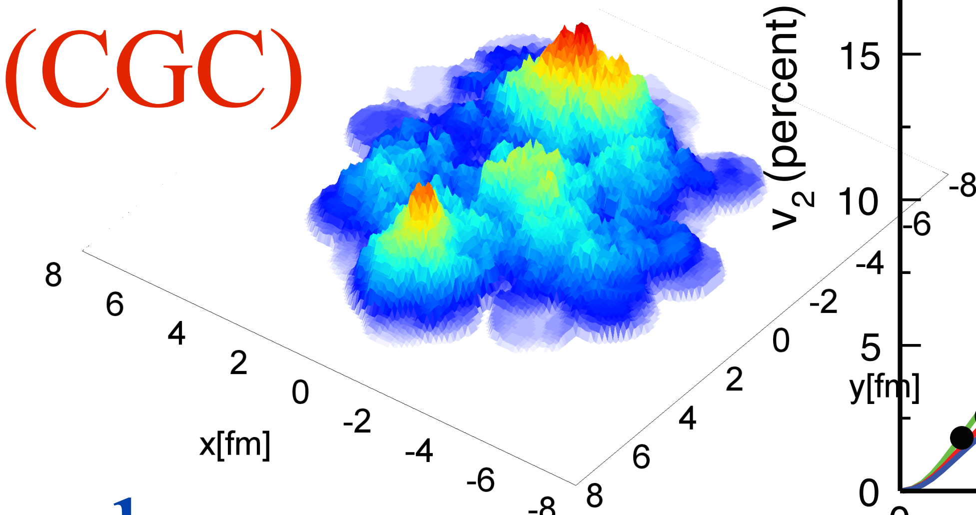
Different initial states=
different fluctuation scales

What is η/s?

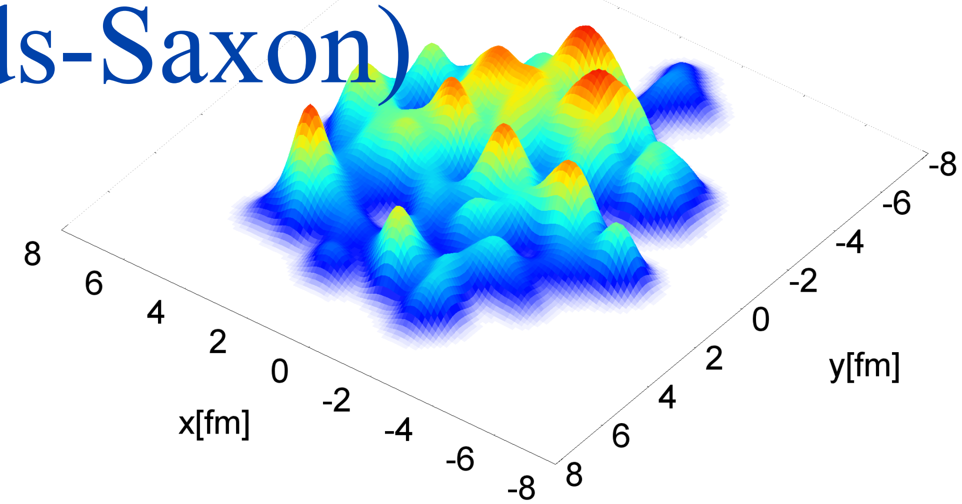
IP-Glasma



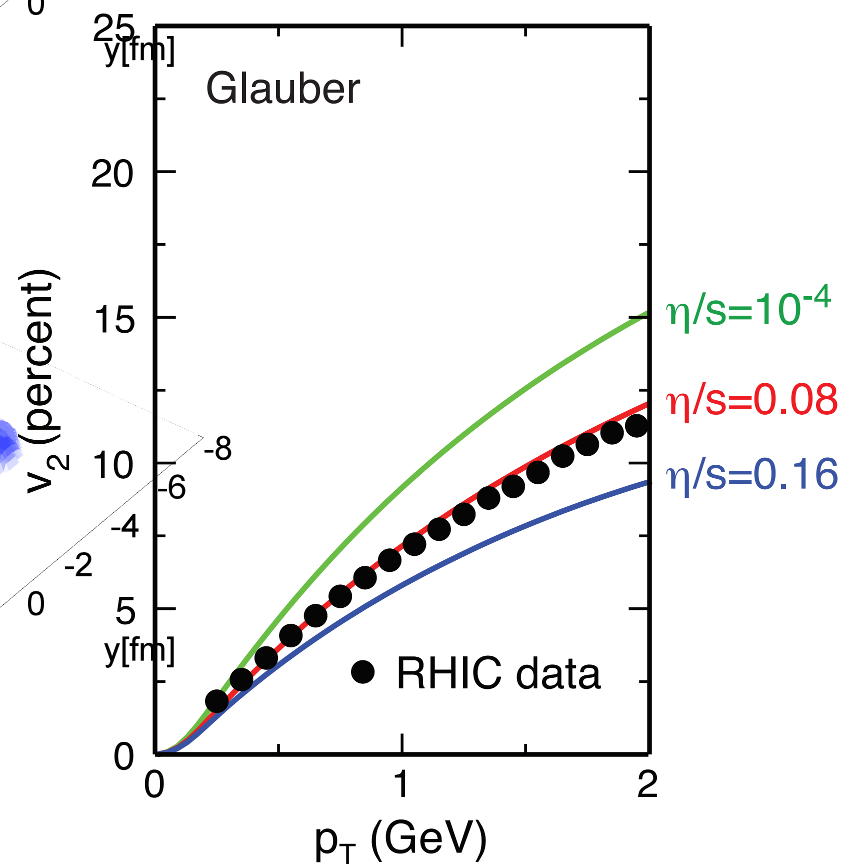
KLN(CGC)

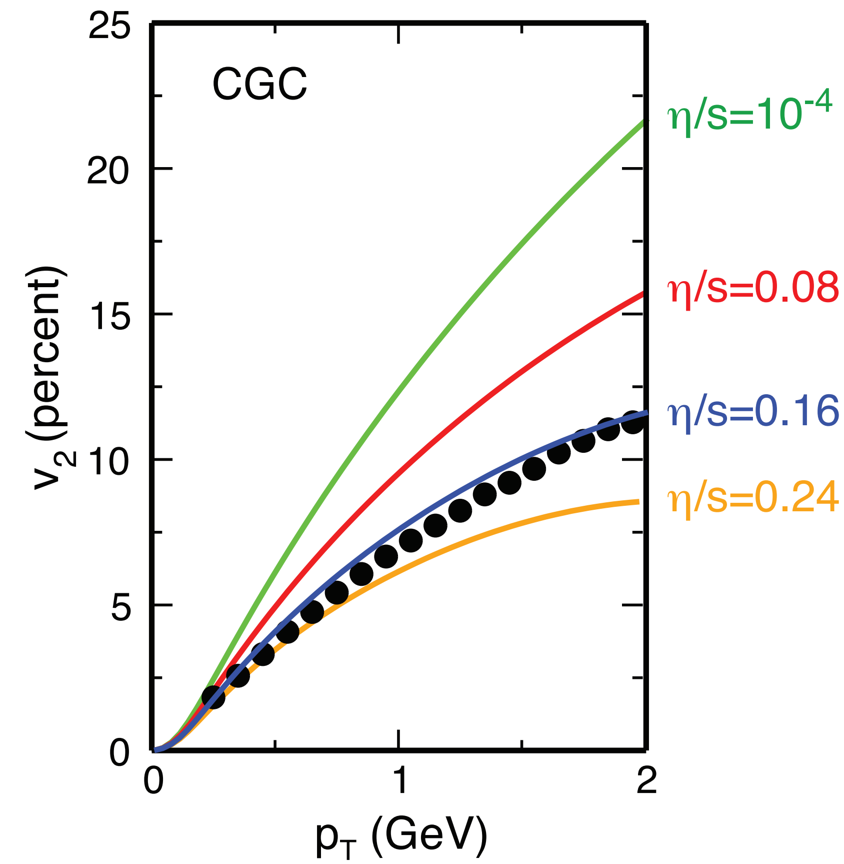


Glauber
(Woods-Saxon)



$1/(4\pi) \sim 0.08$

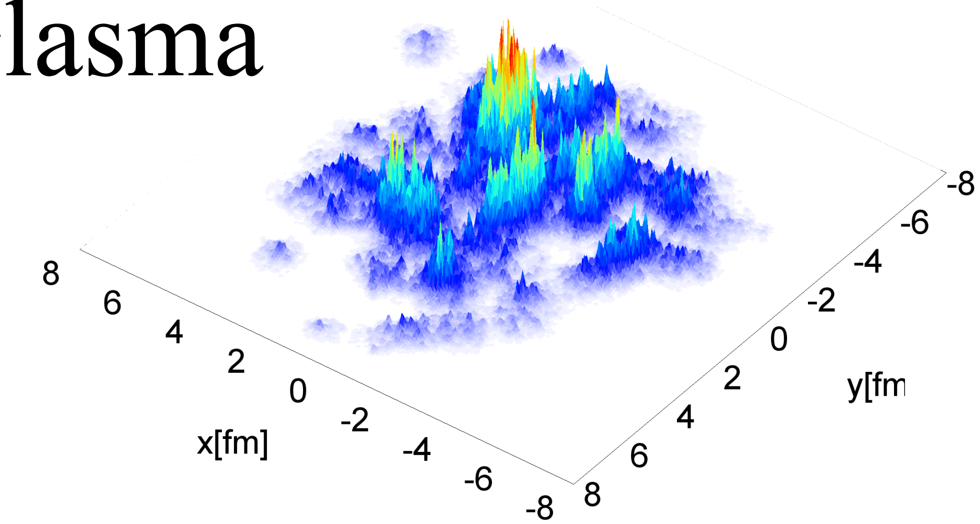




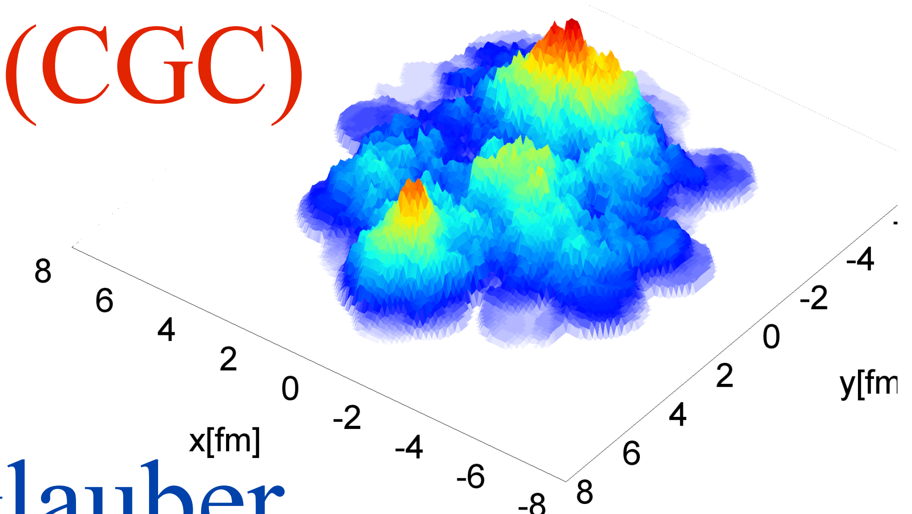
Different initial states=
different fluctuation scales

What is η/s?

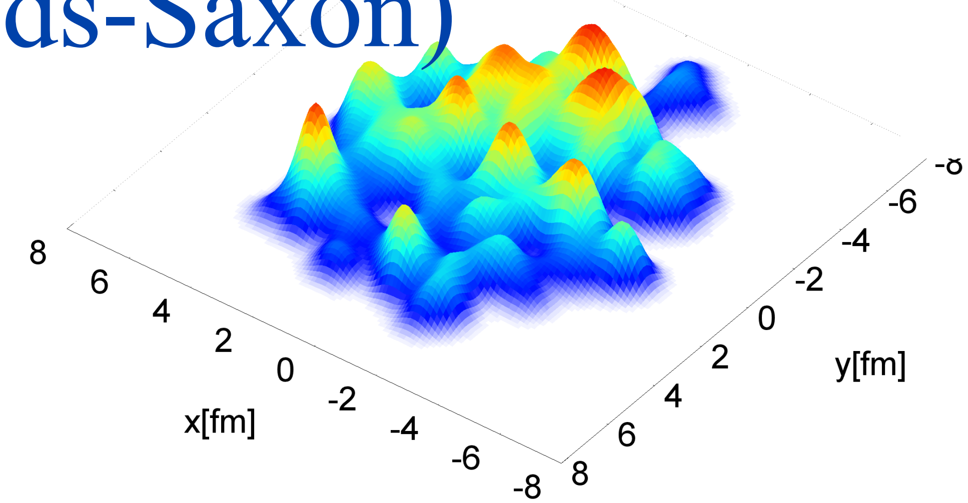
IP-Glasma



KLN(CGC)

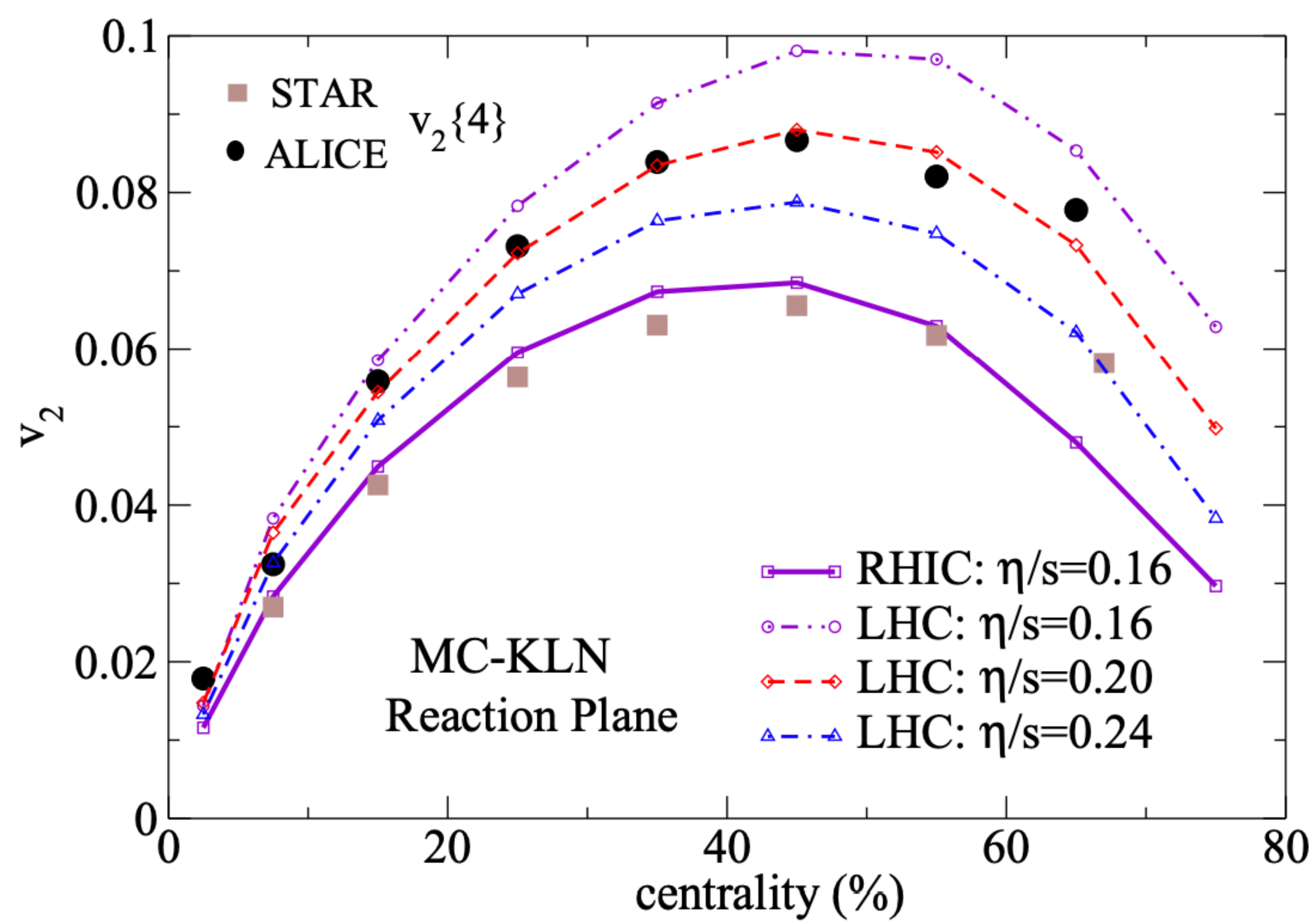


Glauber
(Woods-Saxon)



$1/(4\pi) \sim 0.08$

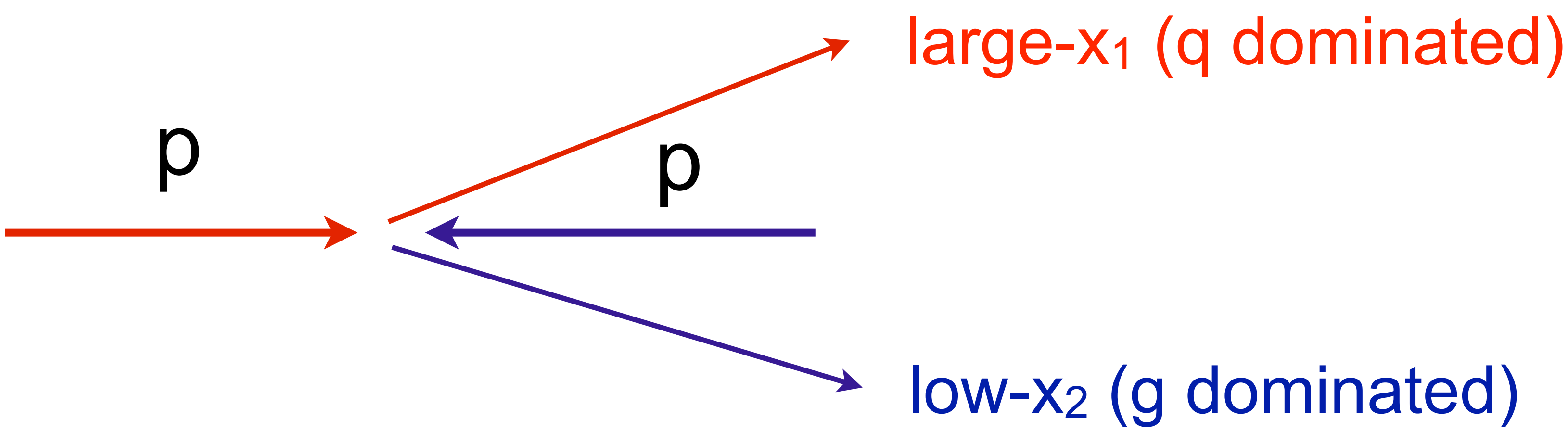
U. Heinz, C. Shen, H. Song, AIP Conf.Proc. 1441 (2012) no.1, 766-770



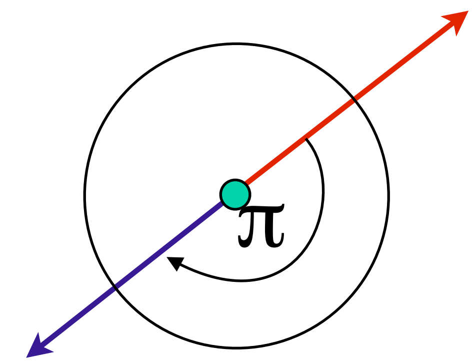
Different initial states=
different fluctuation scales

h-h Forward Correlation in p(d)A at RHIC

side-view



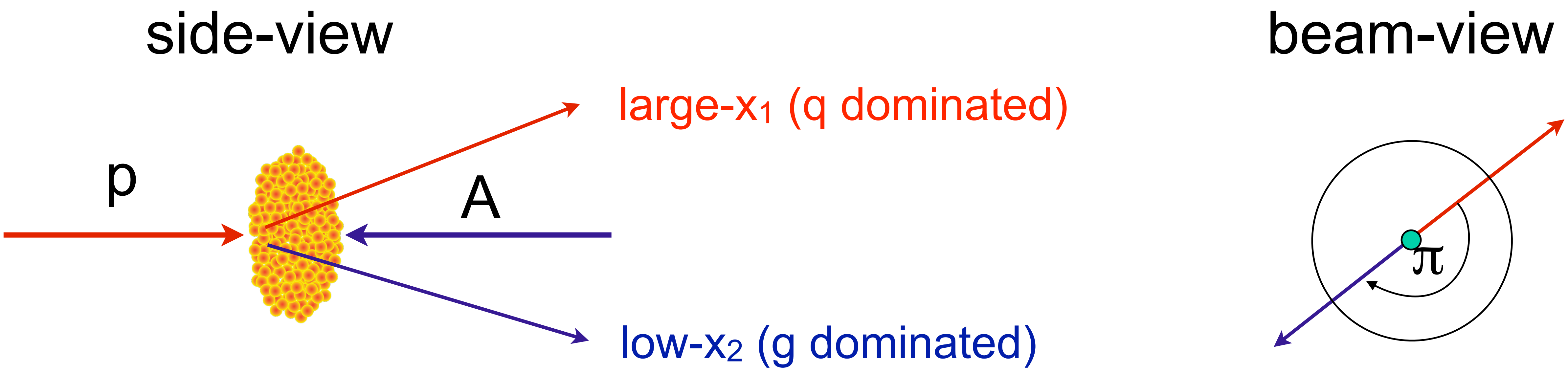
beam-view



Low gluon density (pp):

pQCD predicts 2→2 process ⇒
back-to-back di-jet

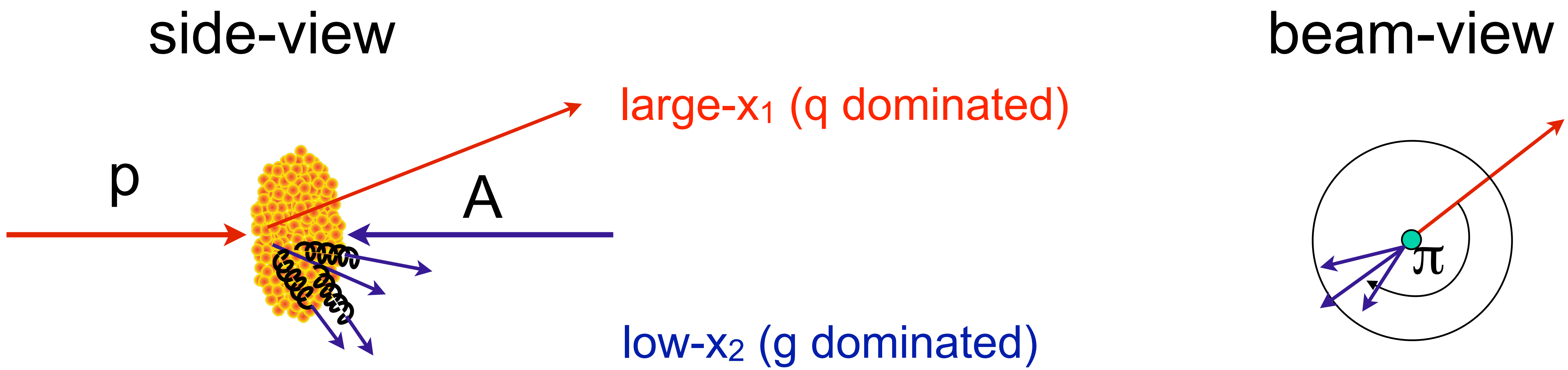
h-h Forward Correlation in p(d)A at RHIC



Low gluon density (pp):

pQCD predicts 2→2 process ⇒
back-to-back di-jet

h-h Forward Correlation in p(d)A at RHIC



Low gluon density (pp):

pQCD predicts 2→2 process ⇒ back-to-back di-jet

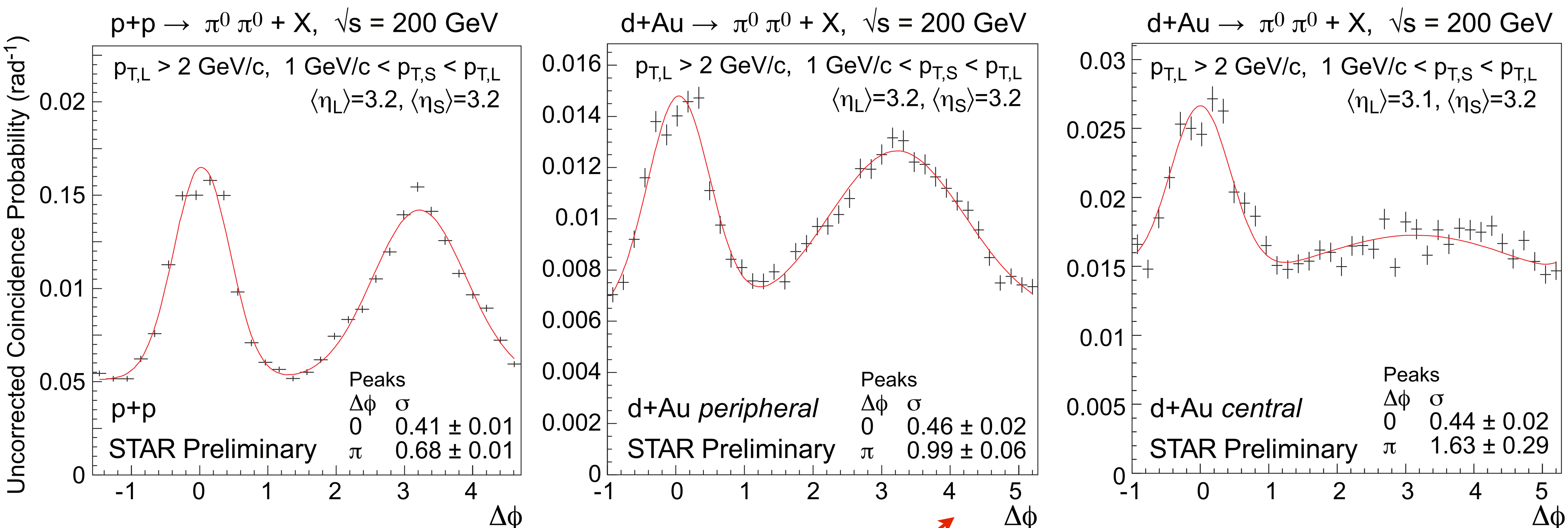
High gluon density (pA):

2→many process
⇒ expect broadening of away-side

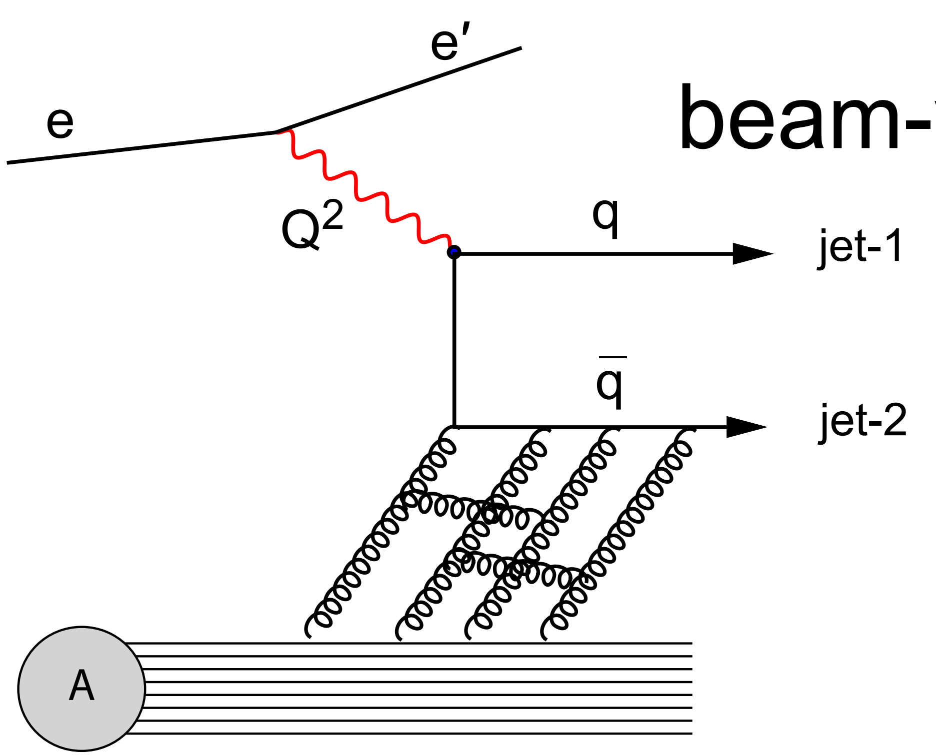
- Small-x evolution ↔ multiple emissions
- Multiple emissions → broadening
- Back-to-back jets (here leading hadrons) may get broadening in p_T with a spread of the order of Q_S

First prediction by: C. Marquet ('07)
Latest review: Giuliano Giacalone, Cyrille Marquet, Nucl.Phys. A982 (2019) 291-294

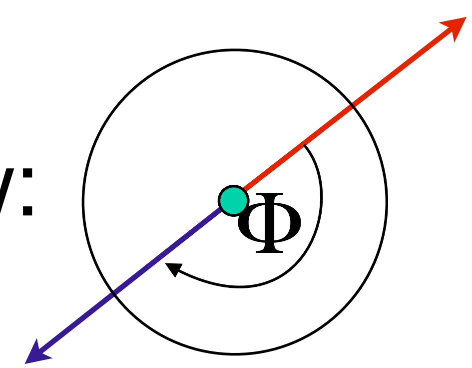
π^0-π^0 forward correlation in *pp* and *d*A at RHIC



arXiv:1008.3989v1

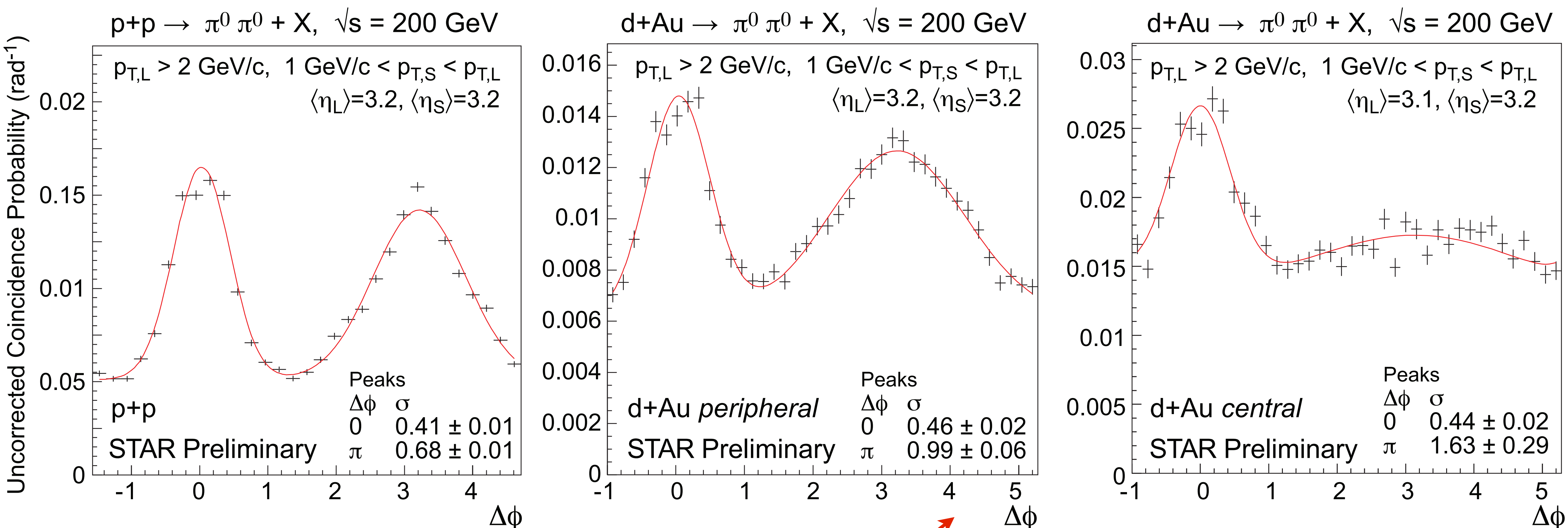


beam-view:

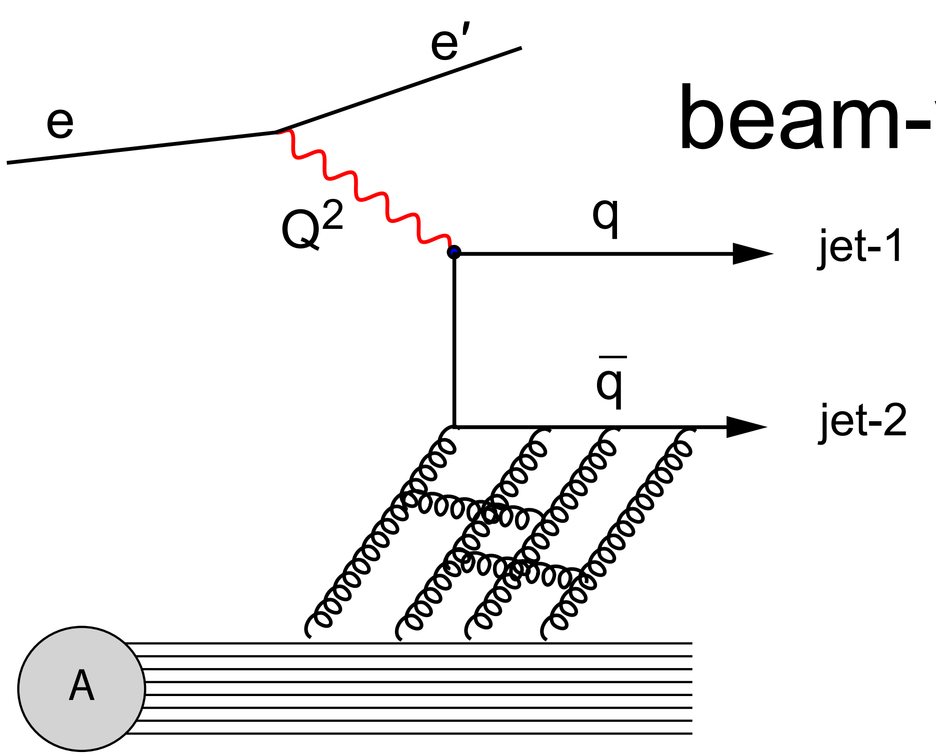


Striking broadening of away side peak in central *d*A compared to *pp* and peripheral *d*A!

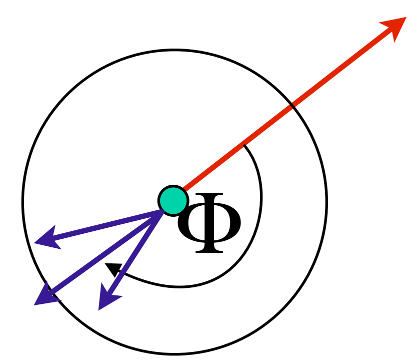
π^0-π^0 forward correlation in *pp* and *d*A at RHIC



arXiv:1008.3989v1



beam-view:

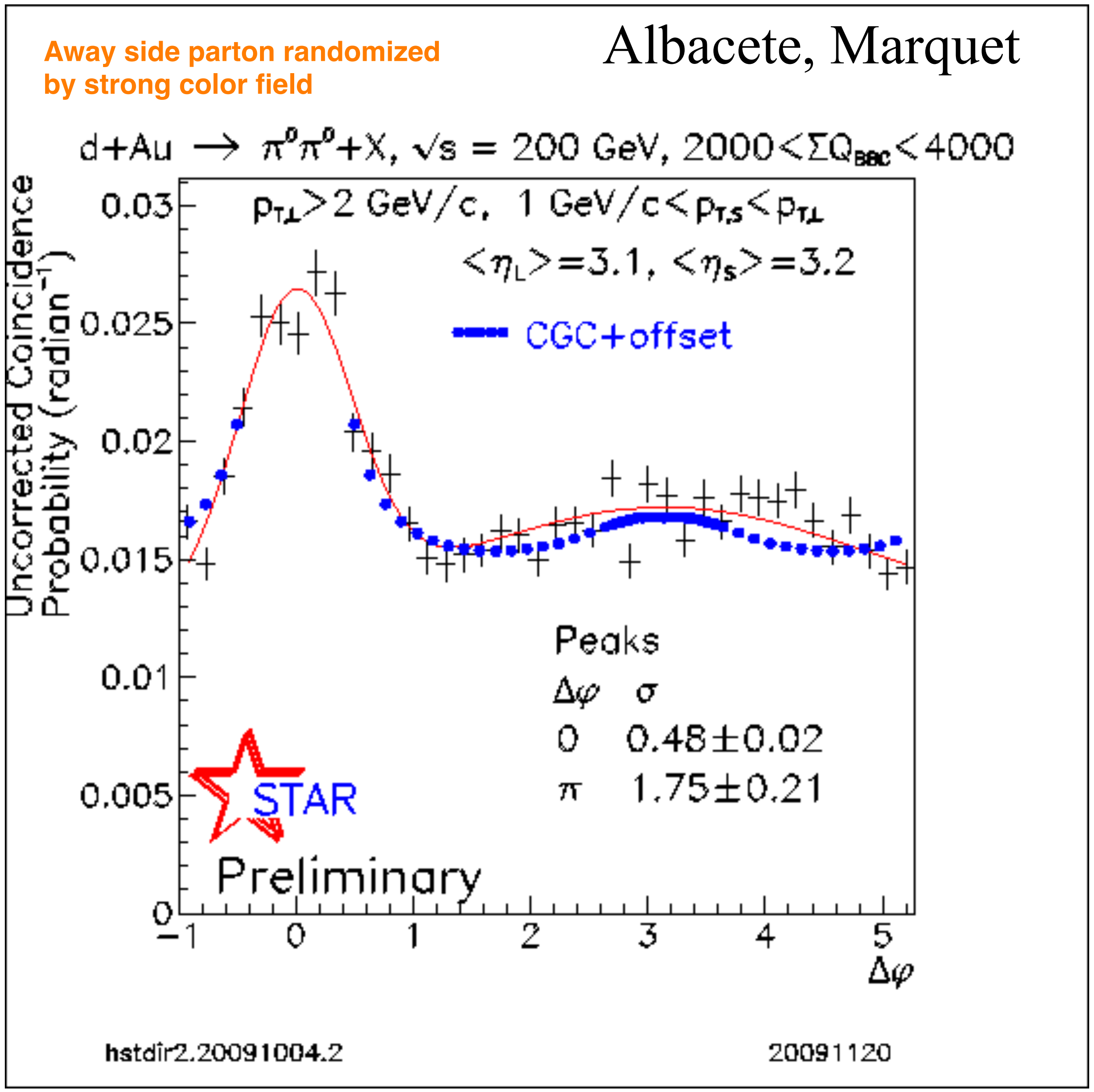


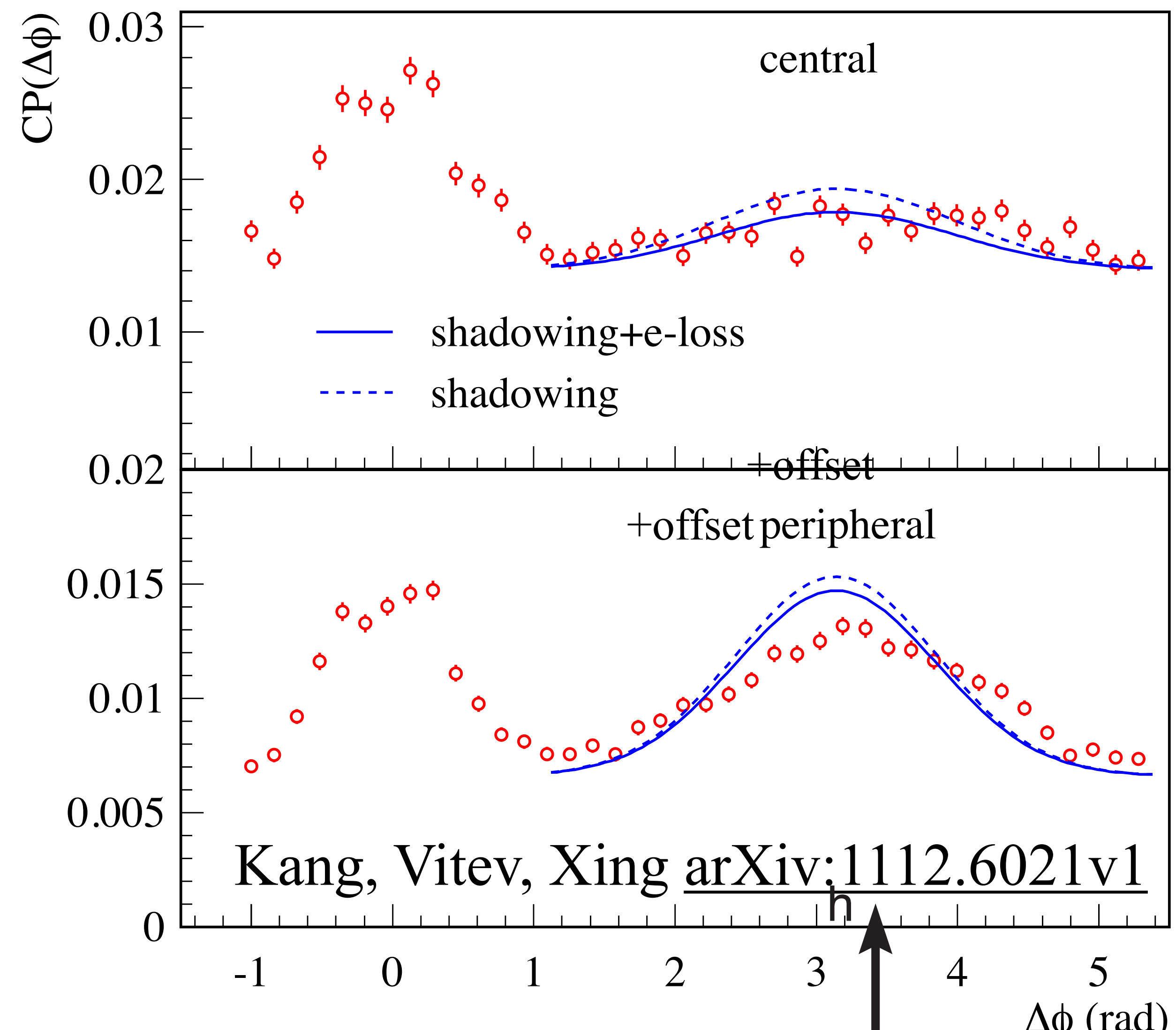
Striking broadening of away side peak in central *d*A compared to *pp* and peripheral *d*A!

1 question, 2 answers

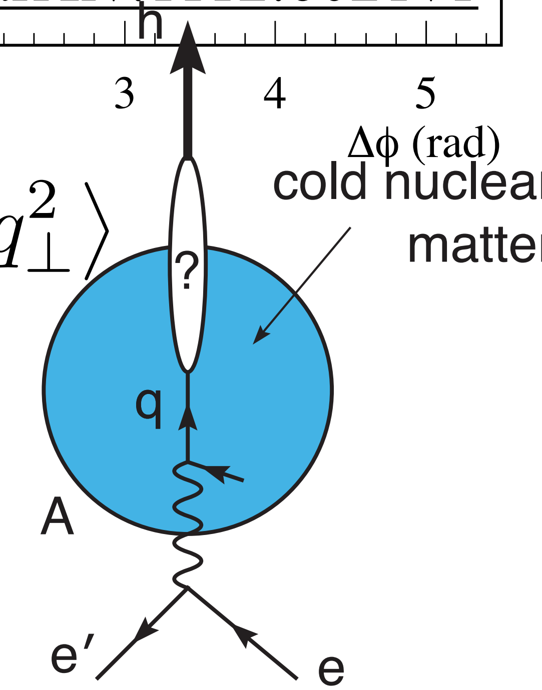
Initial and final state multiple scattering

Initial state saturation model



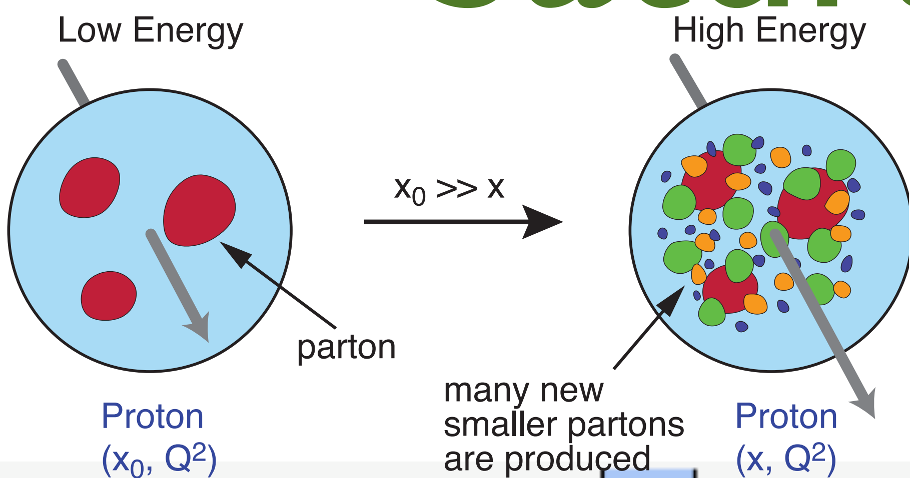


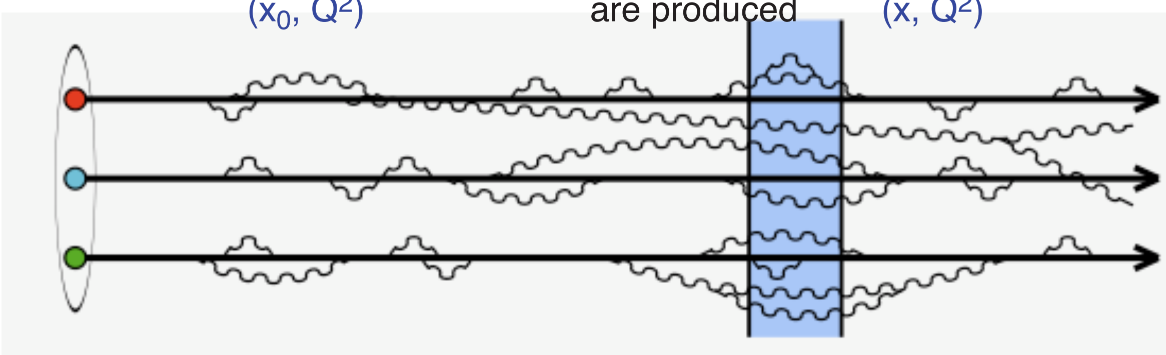
$$\left\langle q_\perp^2 \right\rangle_{dAu} = \left\langle q_\perp^2 \right\rangle_{pp} + \Delta \left\langle q_\perp^2 \right\rangle$$



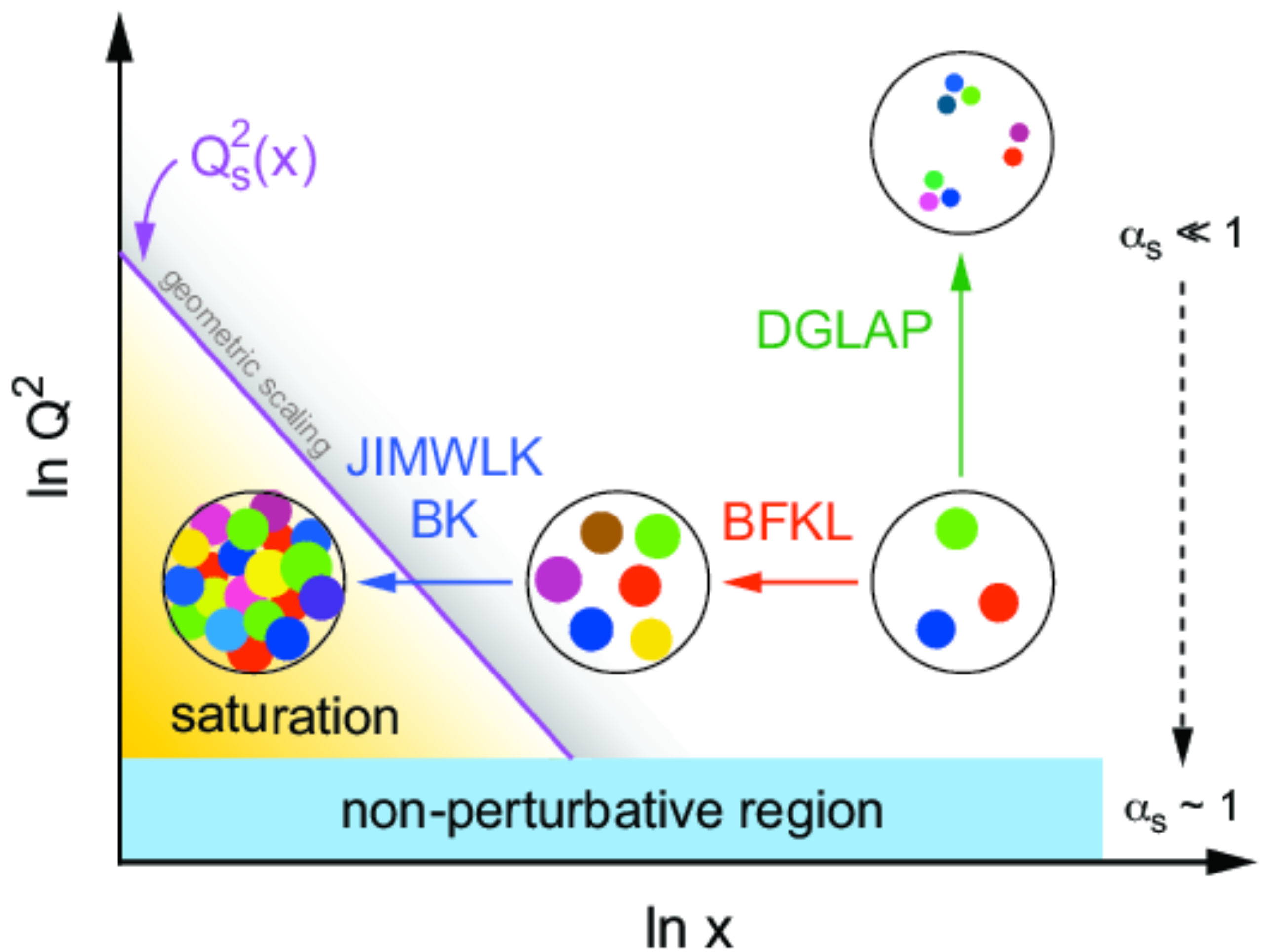
How saturated is the initial state?

Saturation at EIC

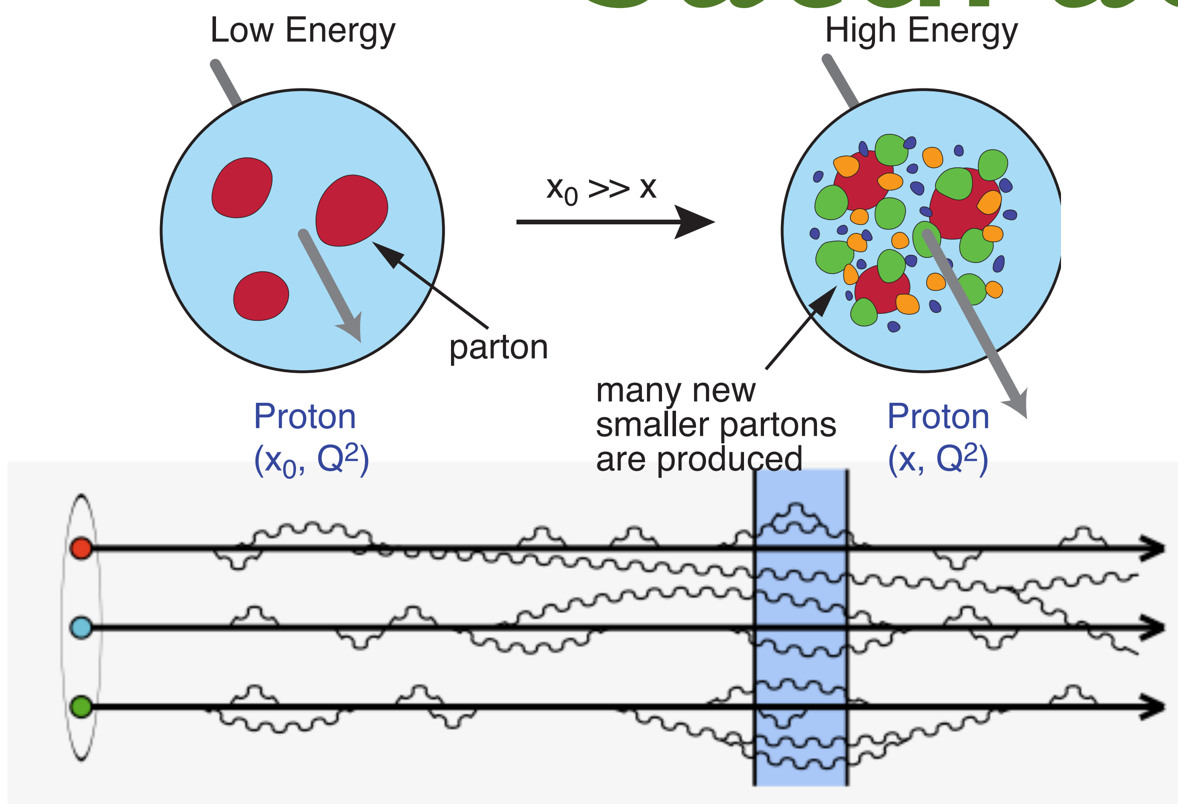


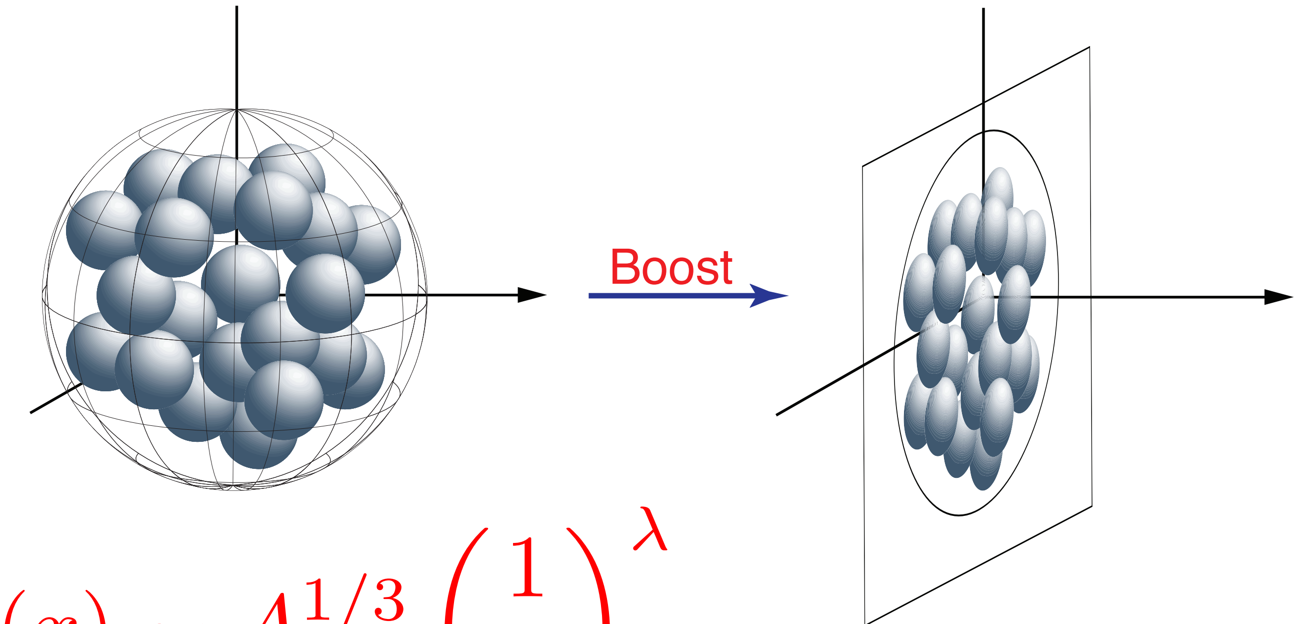


$$Q_s^2(x) \sim \left(\frac{1}{x}\right)^{\lambda}$$

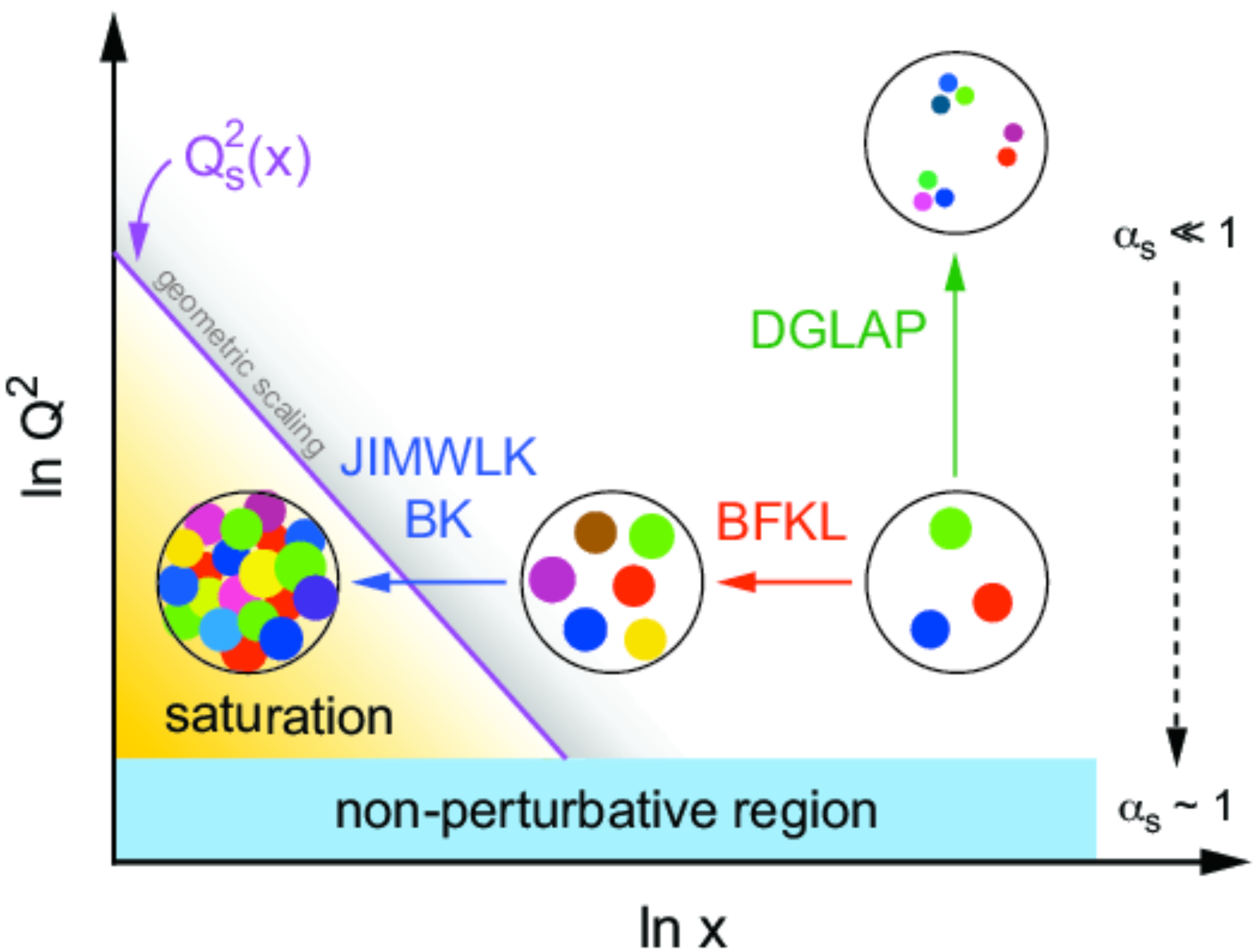


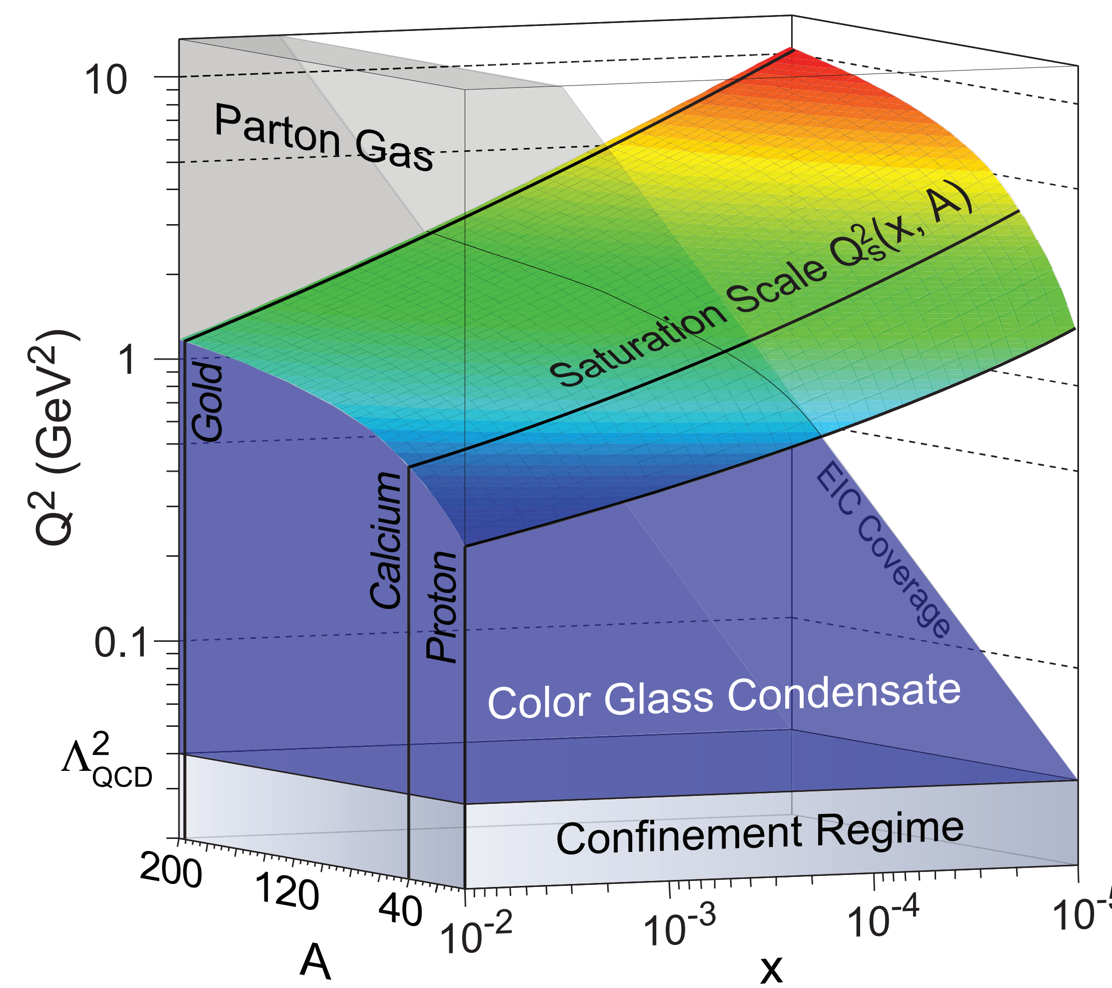
Saturation at EIC





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

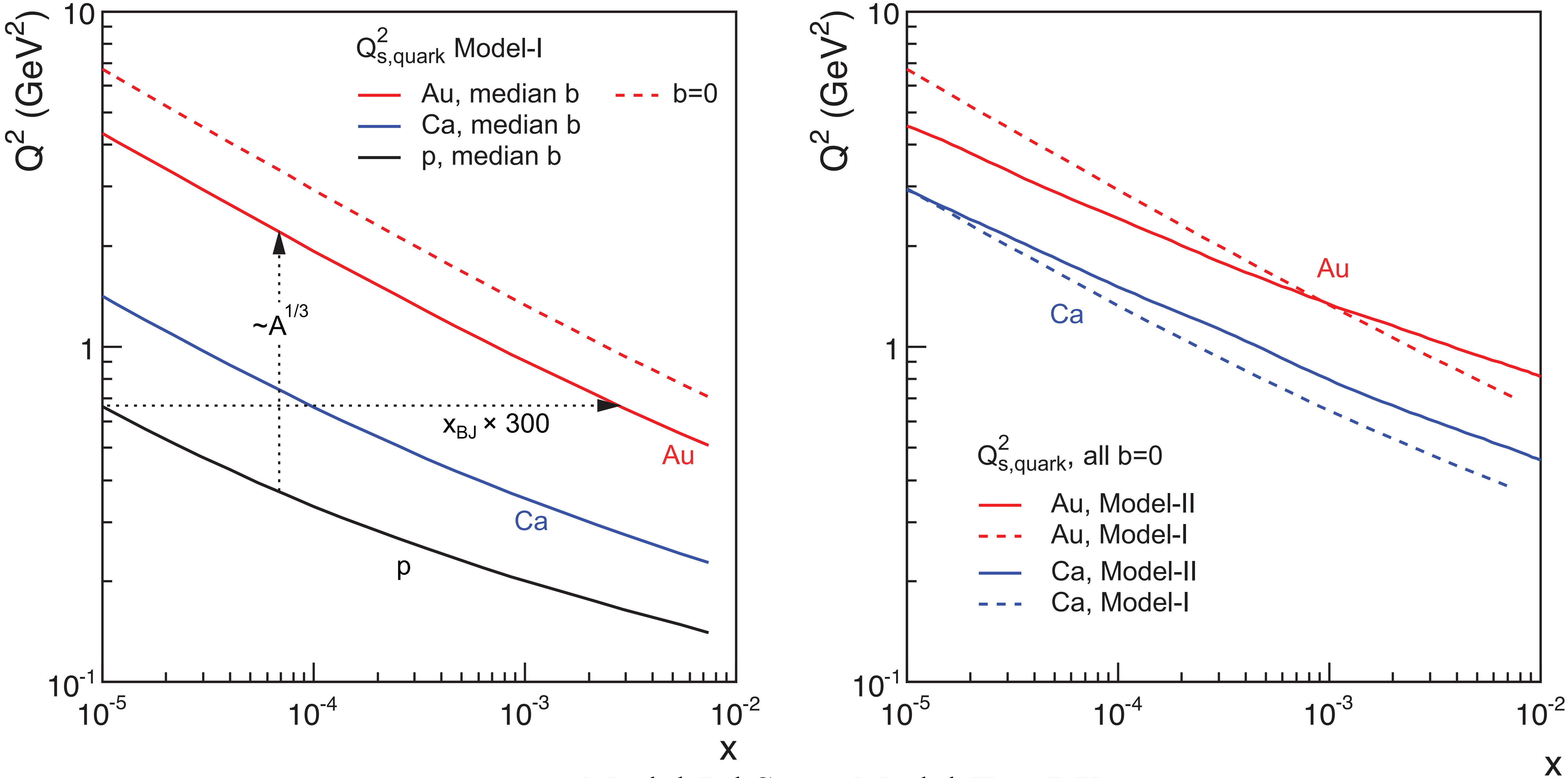




Saturation at eRHIC

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!

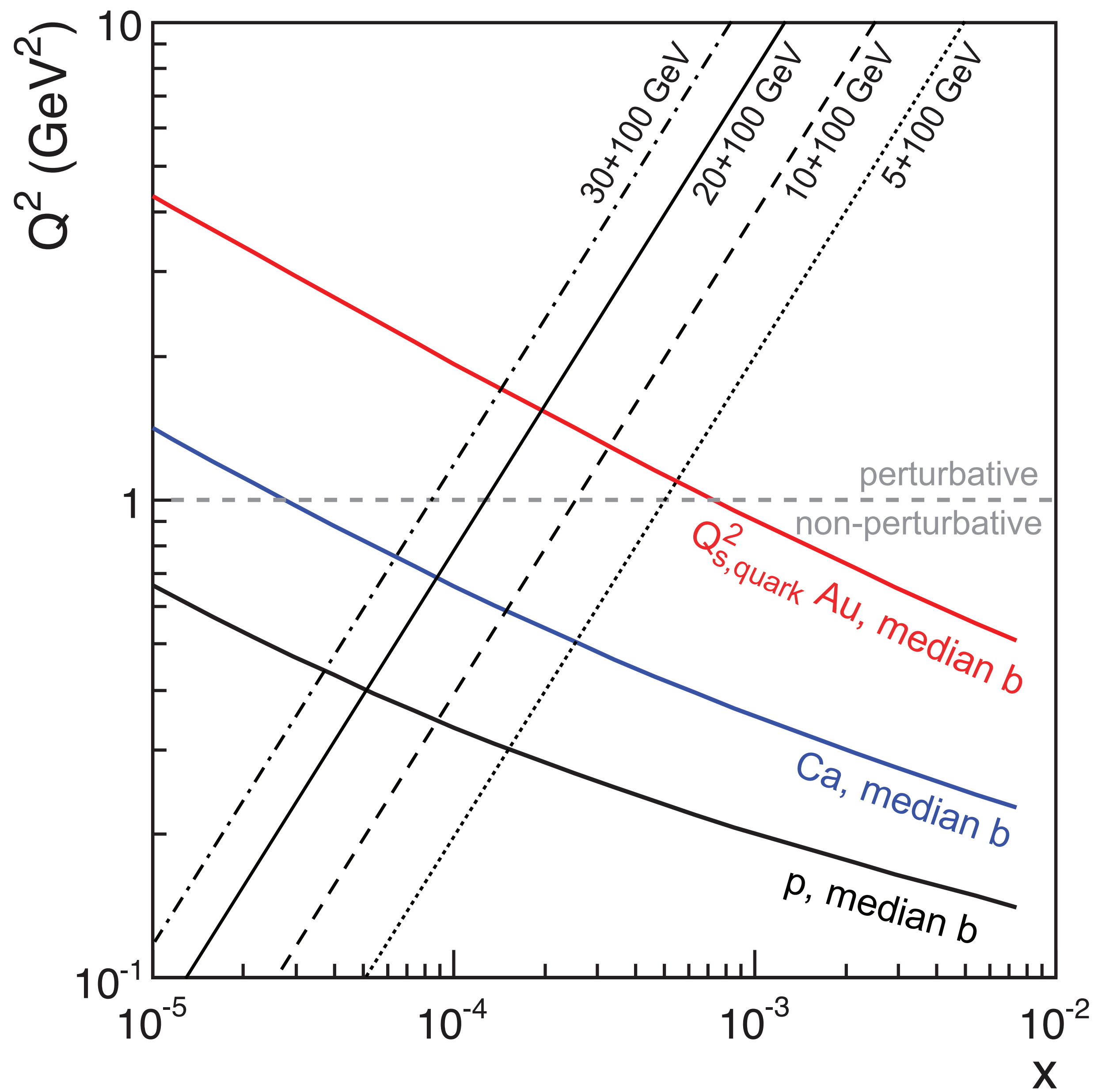


Model-I: bSat, Model-II: rcBK

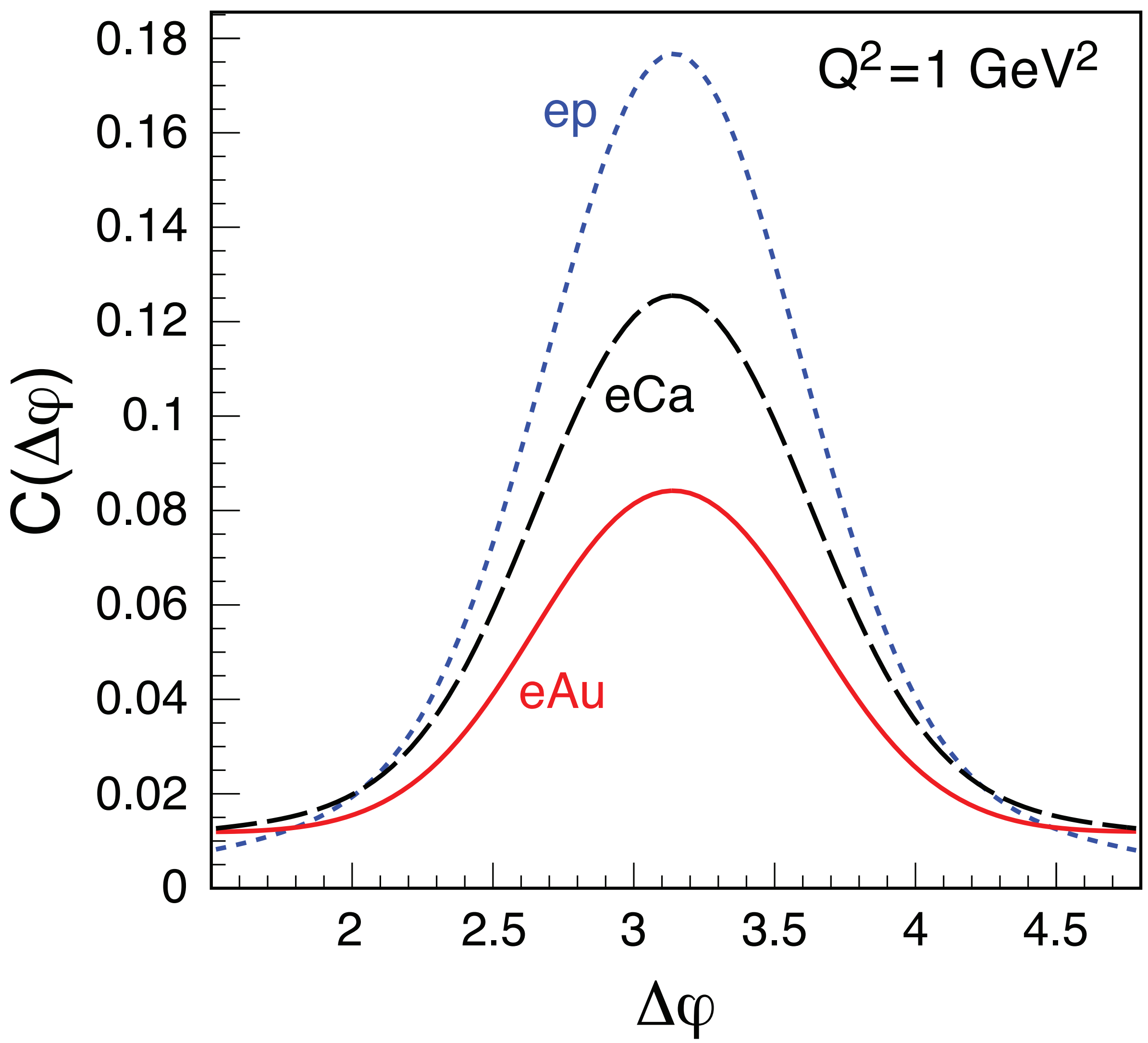
Saturation at eRHIC

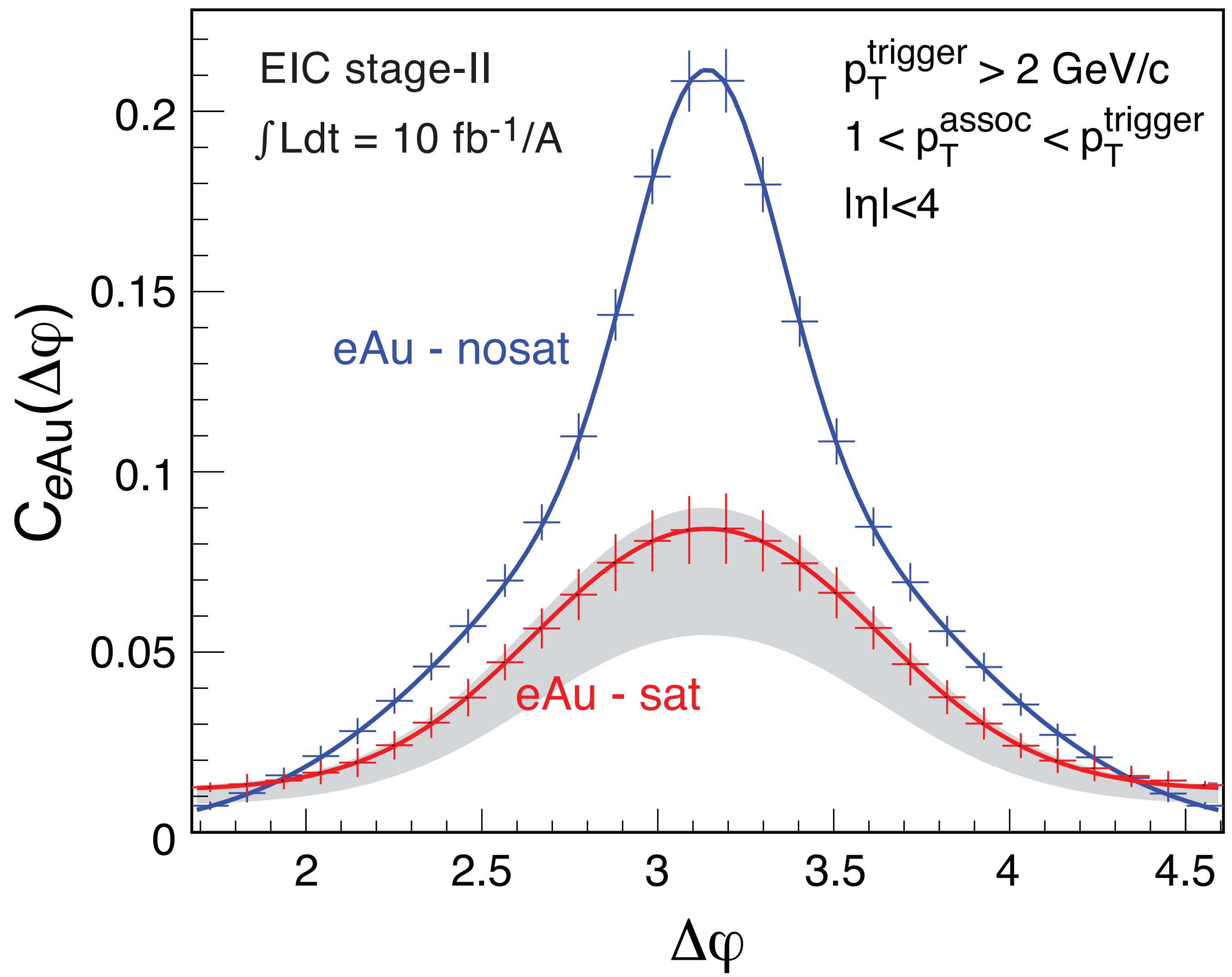
Pocket formula: $Q_s^2(x) \sim A^{1/3}\left(\frac{1}{x}\right)^{\lambda} \sim \left(\frac{A}{x}\right)^{1/3}$

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



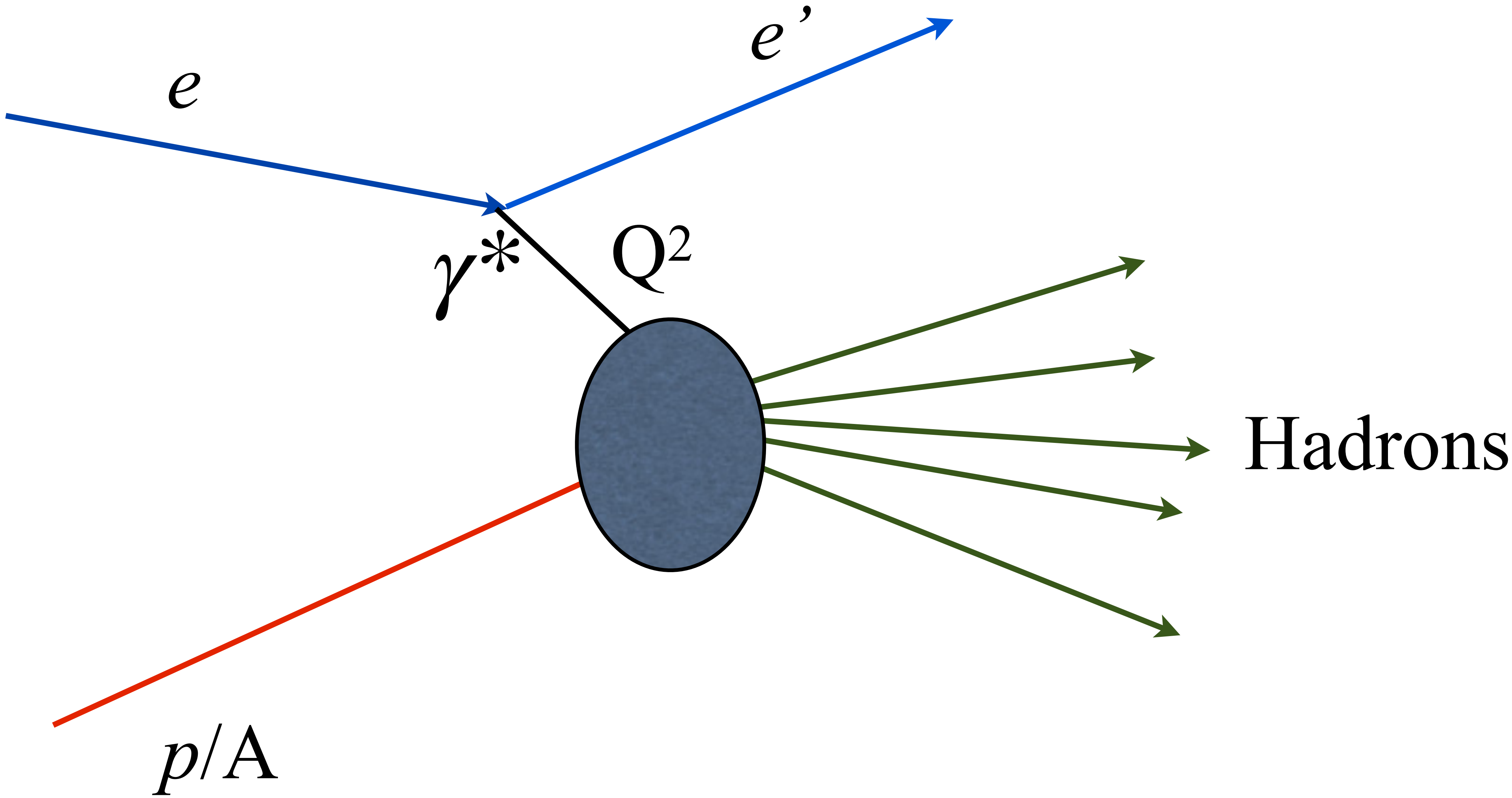
eRHIC predictions: Dihadron correlations, away peak



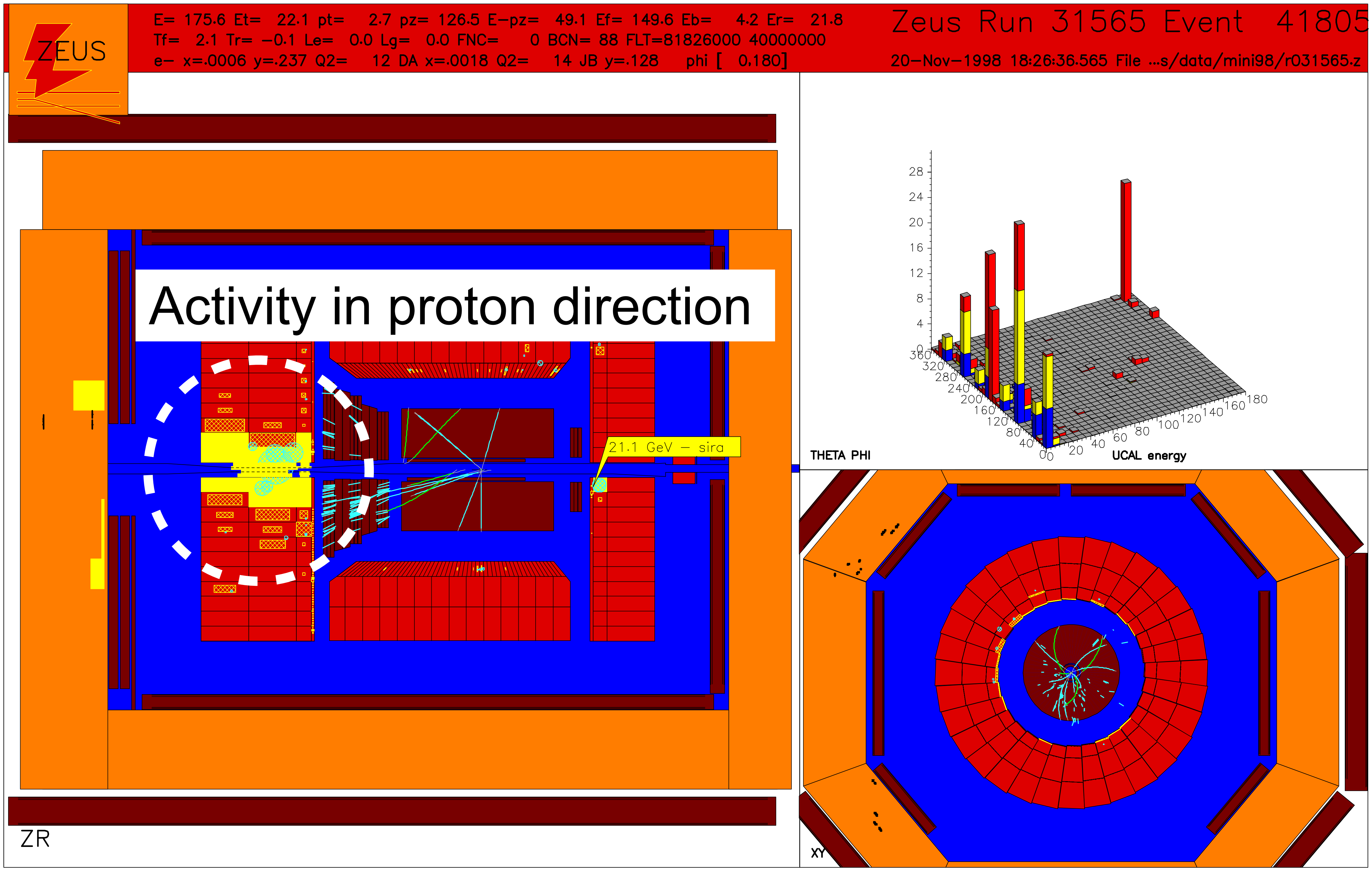


Can constrain models a lot with a few months of running!

DIS *ep* and *eA*

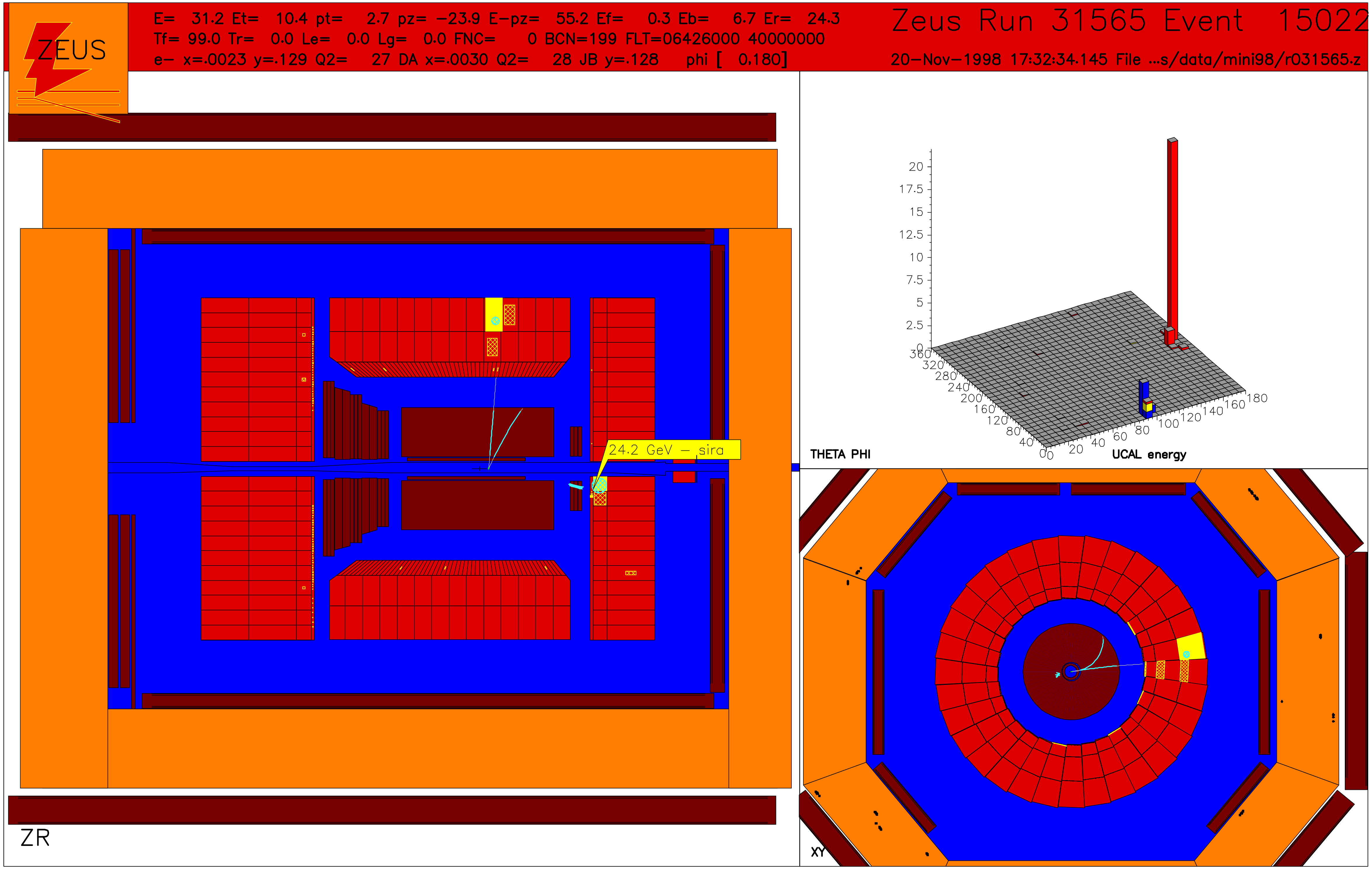


DIS *ep* and *eA*

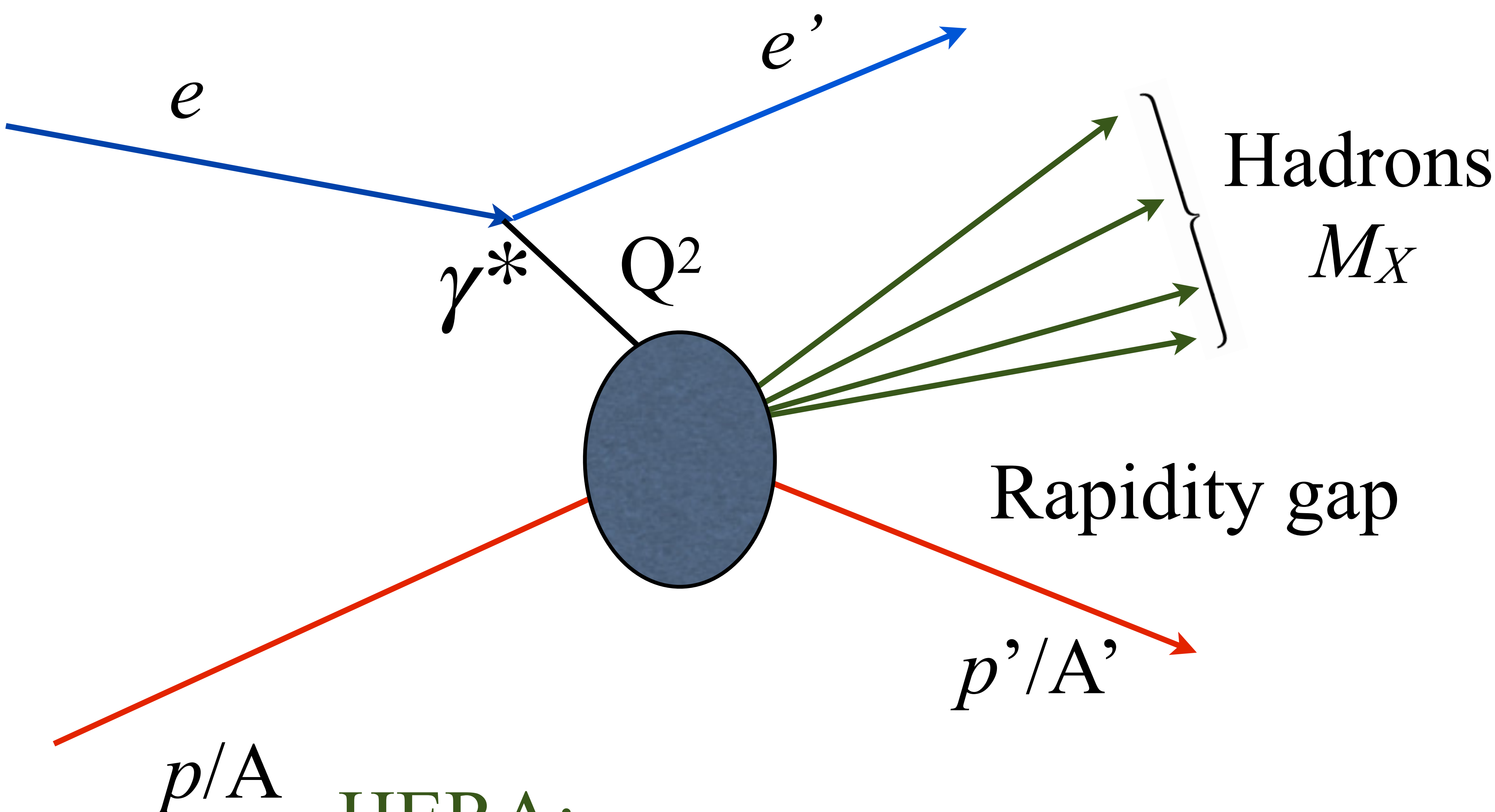


E= 175.6 Et= 22.1 pt= 2.7 pz= 126.5 E−pz= 49.1 Ef= 149.6 Eb= 4.2 Er= 21.8
Tf= 2.1 Tr= −0.1 Le= 0.0 Lg= 0.0 FNC= 0 BCN= 88 FLT=81826000 40000000
e− x=.0006 y=.237 Q2= 12 DA x=.0018 Q2= 14 JB y=.128 phi [0,180]
Zeus Run 31565 Event 41805
20−Nov−1998 18:26:36.565 File ...s/data/mini98/r031565.z
ZEUS
Activity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

diffraction *ep* and *eA*



Diffraction *ep* and *eA*

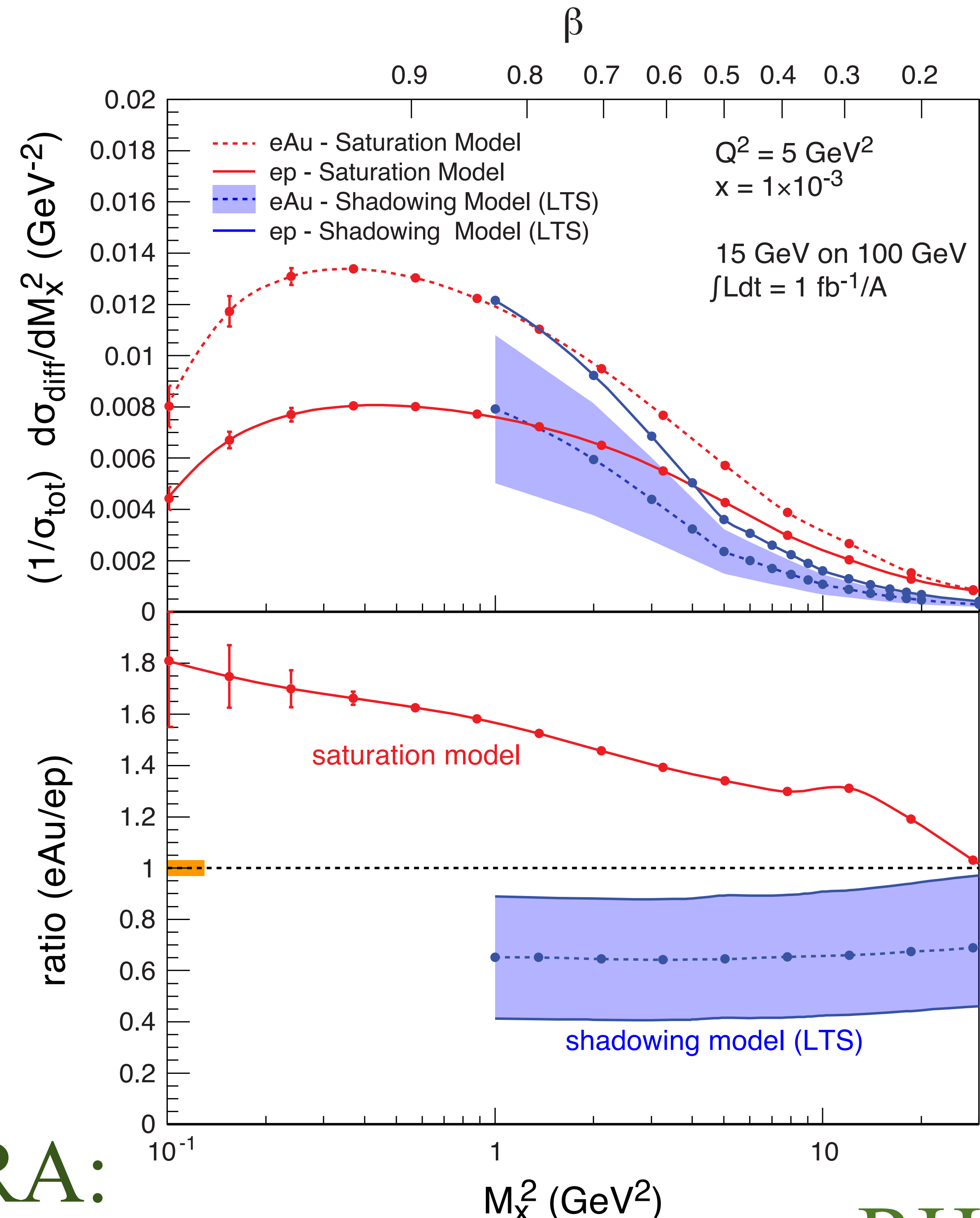


HERA:

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!



HERA:

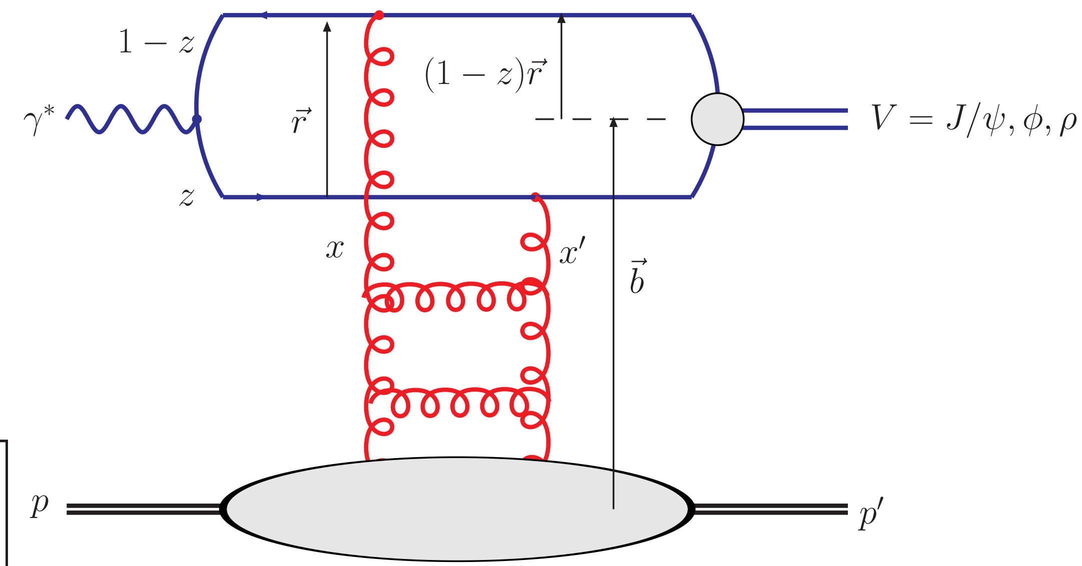
Proton collides with electron at CMS energy ~300m_p.
In ~15% of measured collisions proton stays intact!

eRHIC *e*+A:

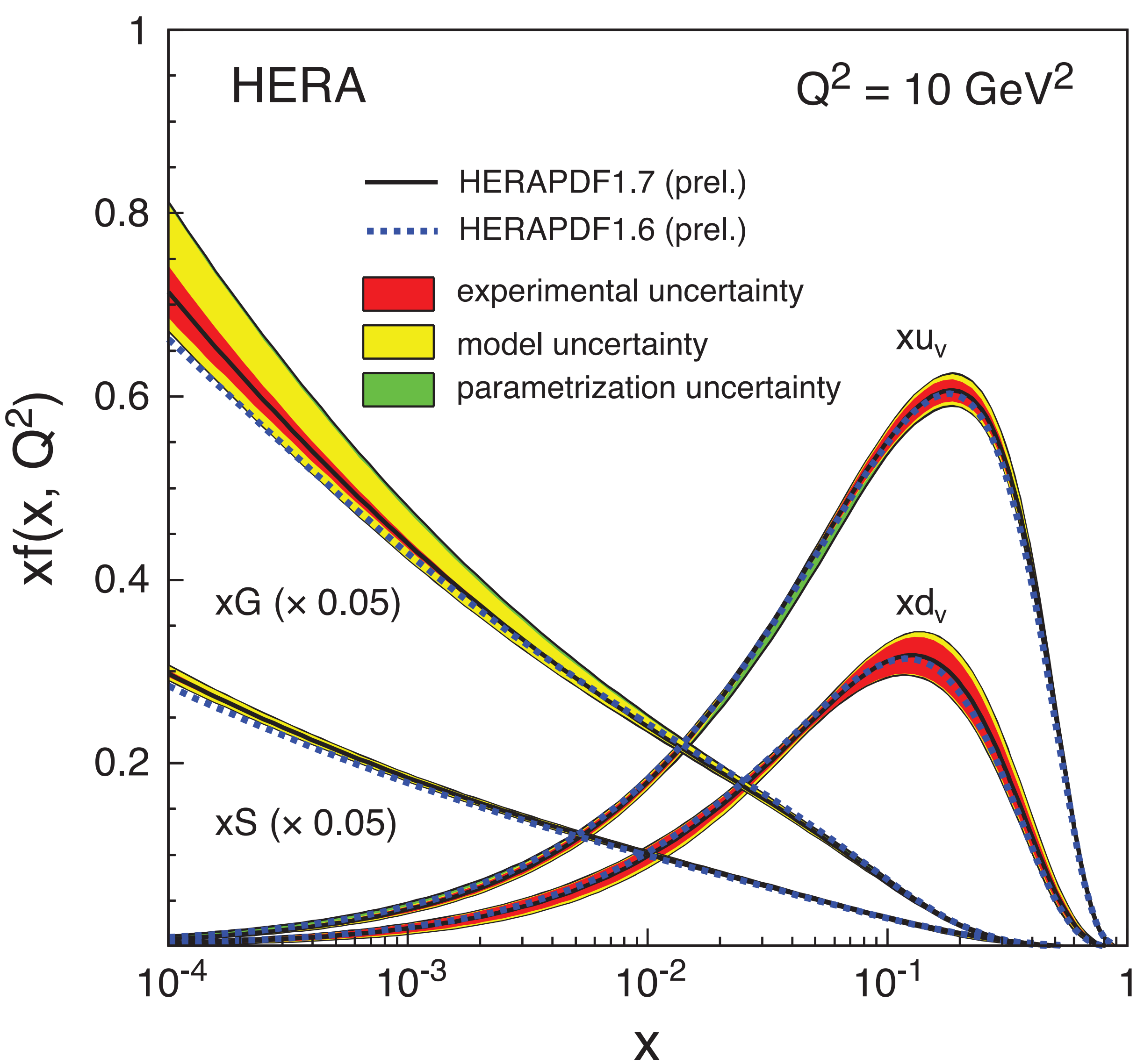
Ion predicted to stay intact in 25%-40% of events!

Why is diffraction so great? Pt. 1

Diffraction sensitive to gluon momentum distributions²:

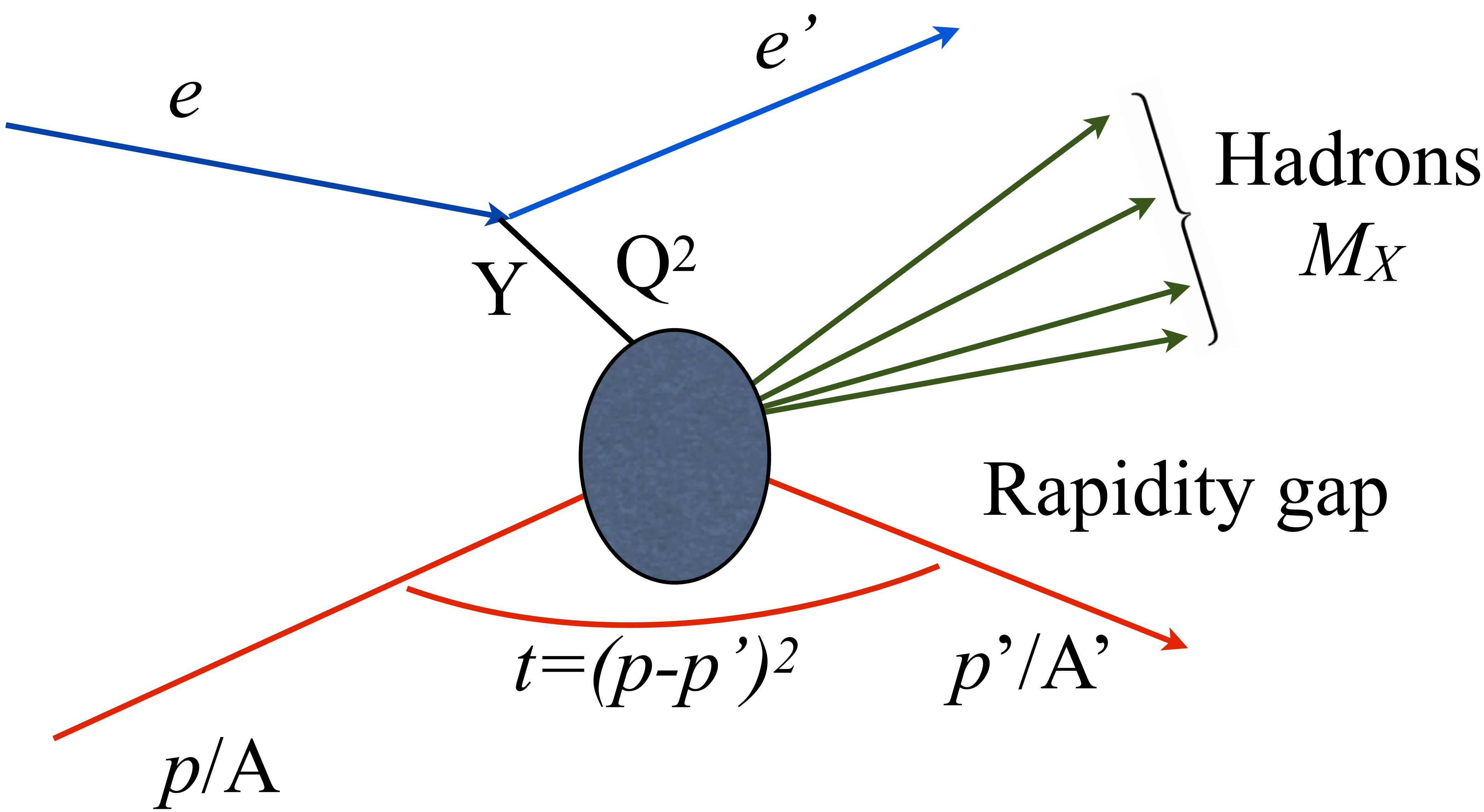


$$\sigma \propto g(x,Q^2)^2$$



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

Diffraction *ep* and *eA*



Depend on *t*, momentum transfer to proton/ion.

Fourier transform of t-distribution

=

transverse spatial distribution

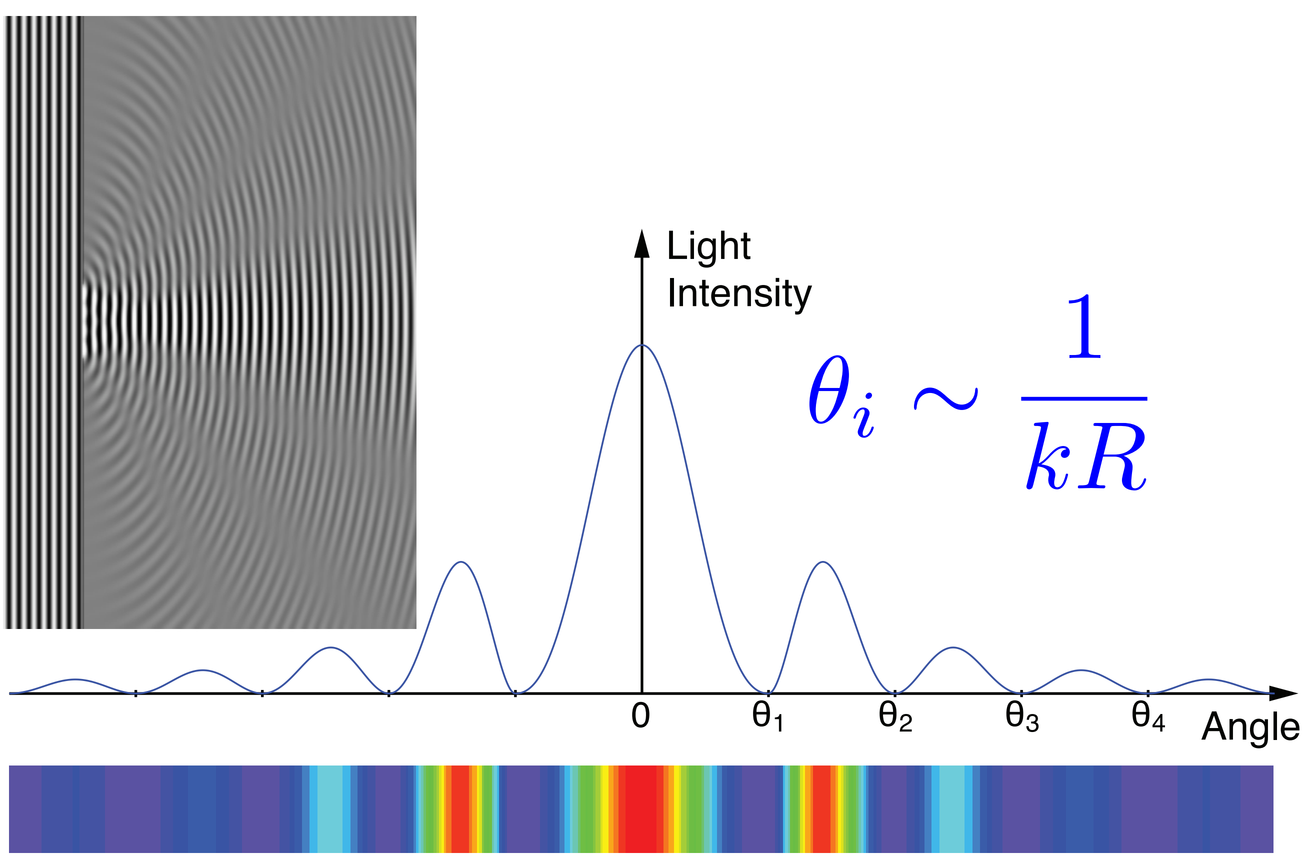
Spatial imaging!

Why is diffraction so great? Pt. 2

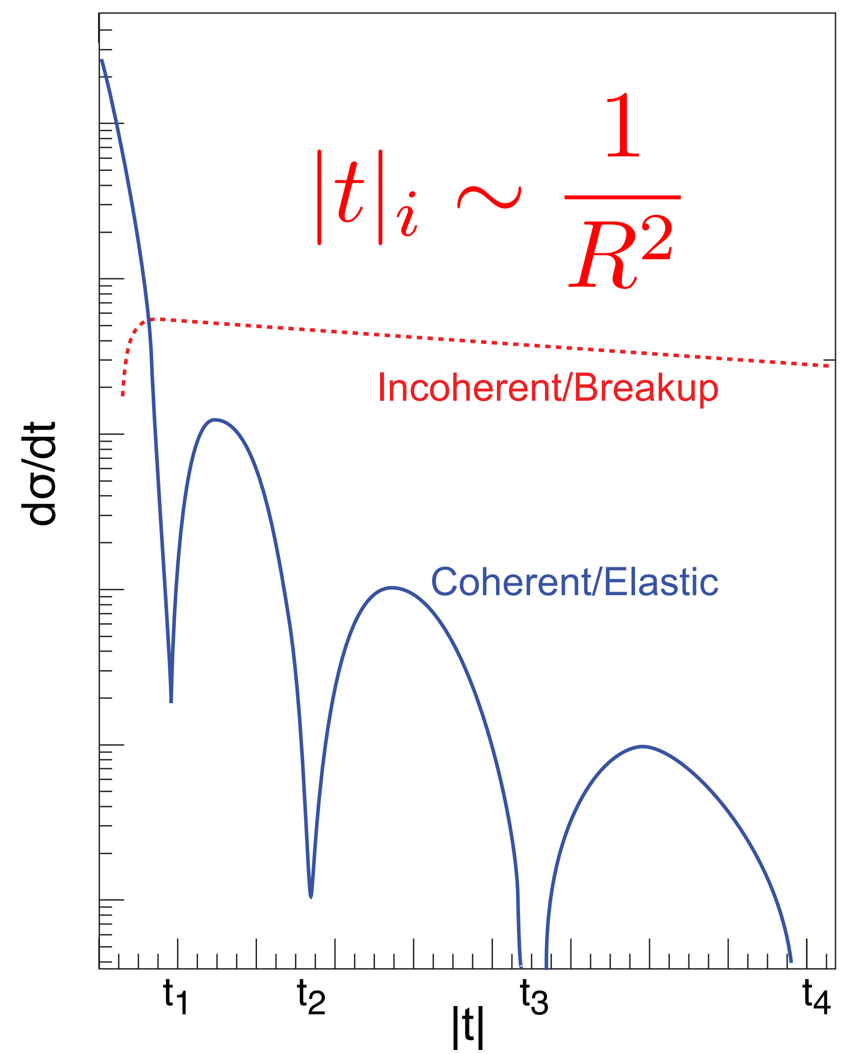
Sensitive to spatial gluon distributions

A projectile scattering off a nucleus of radius R
-not a ‘black disk’, edge effects
-target may break up

Light scattering off a circular screen of radius R

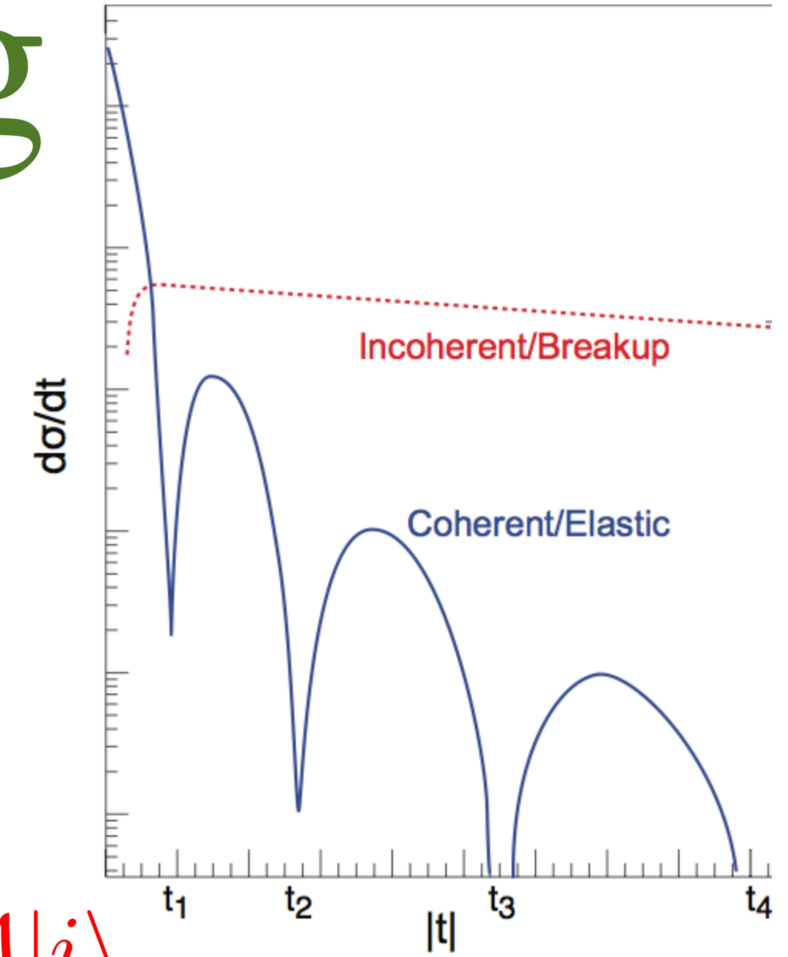


$$\theta_i \sim \frac{1}{kR}$$



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

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!!

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

How to measure $t=(P_A\text{-}P_A')^2$

Need to measure $P_{A'}$

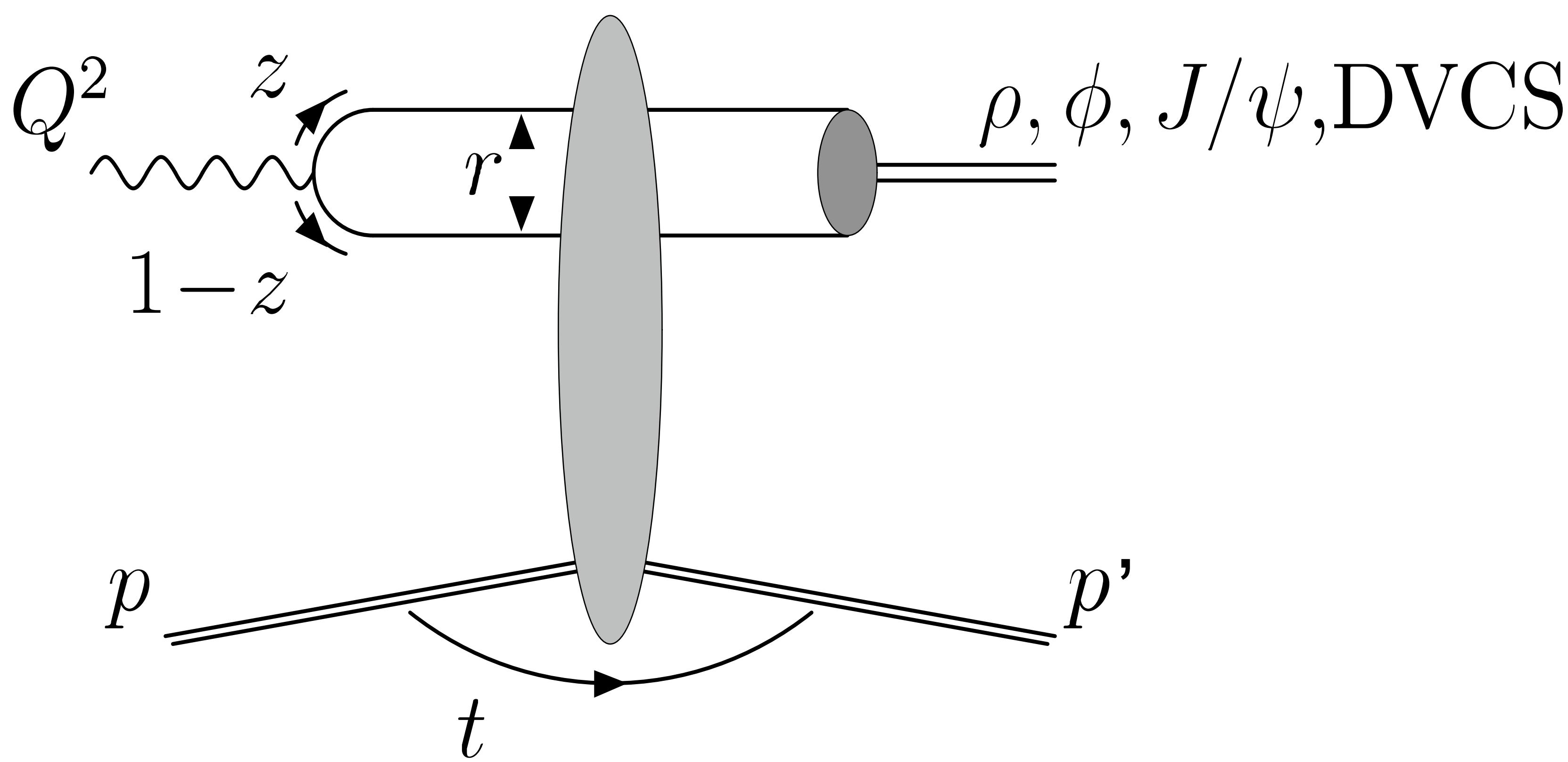
Coherent case: A' disappears down beampipe

Incoherent case: Cannot measure all beam remnants

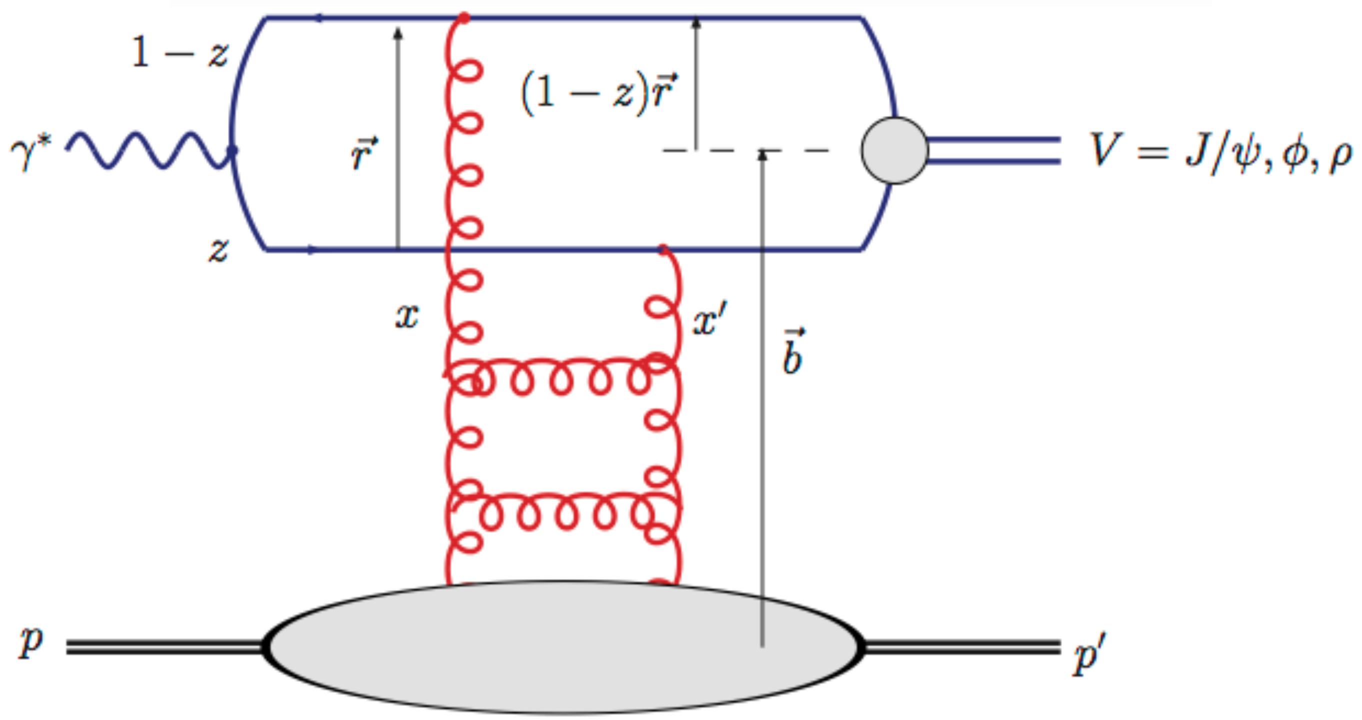
Only possibility: Exclusive diffraction

$e+\mathrm{A} \rightarrow e'+\mathrm{VM}+\mathrm{A}'$

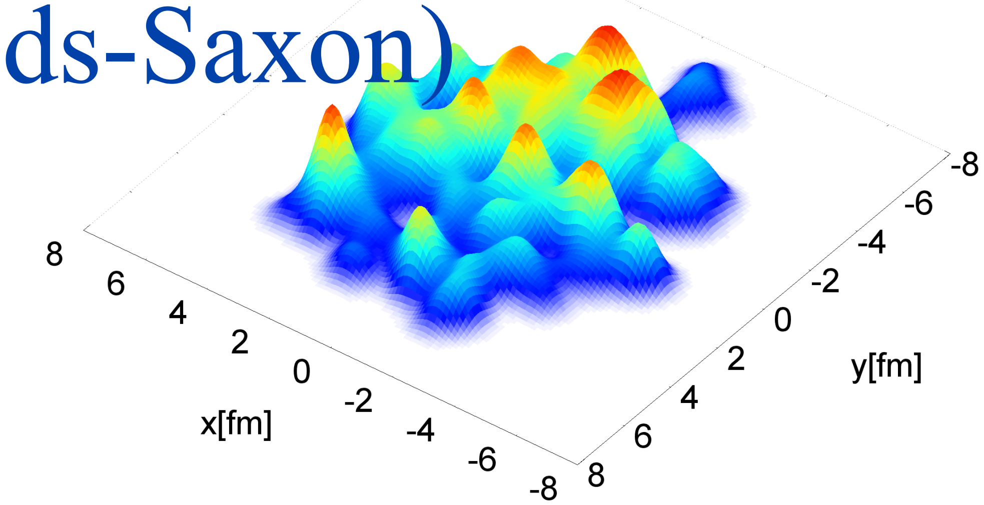
$t=(P_{VM}+P_{e'}\text{-}P_e)^2$

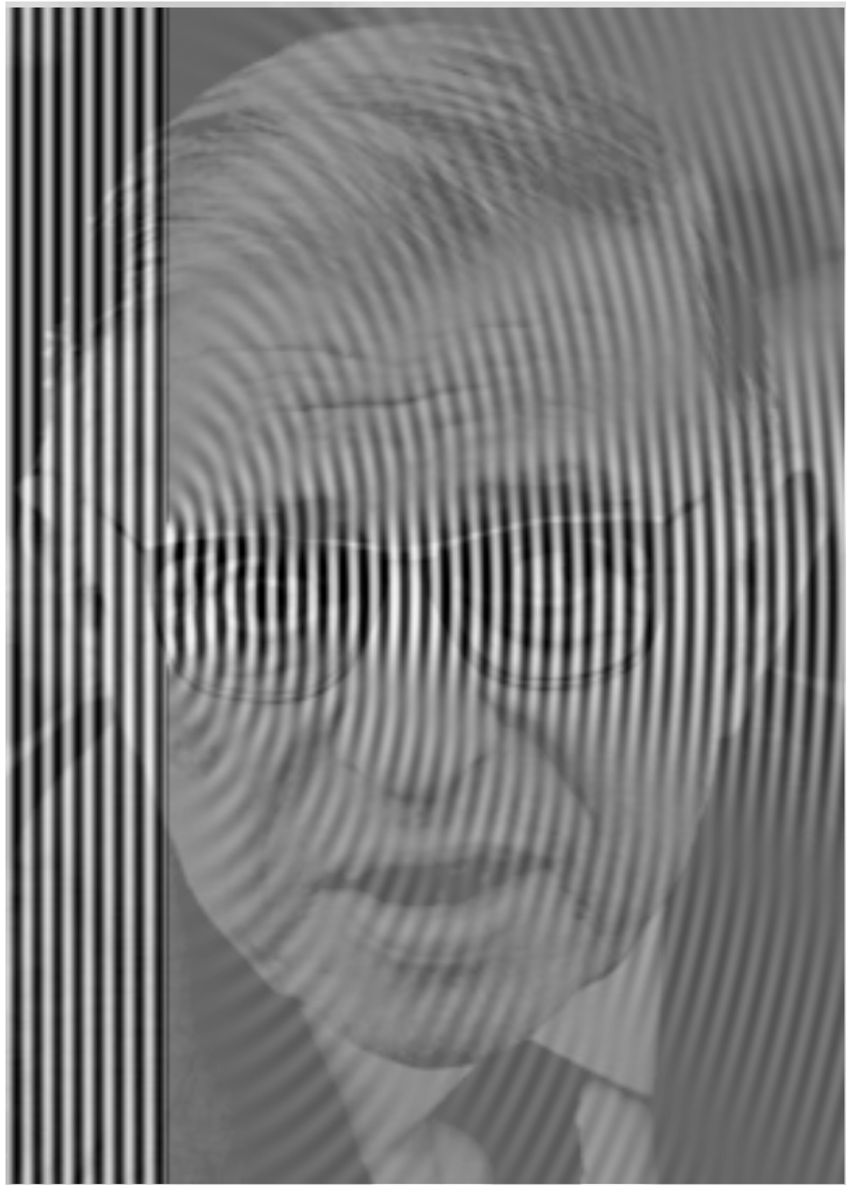


eRHIC predictions: Exclusive diffraction Sartre



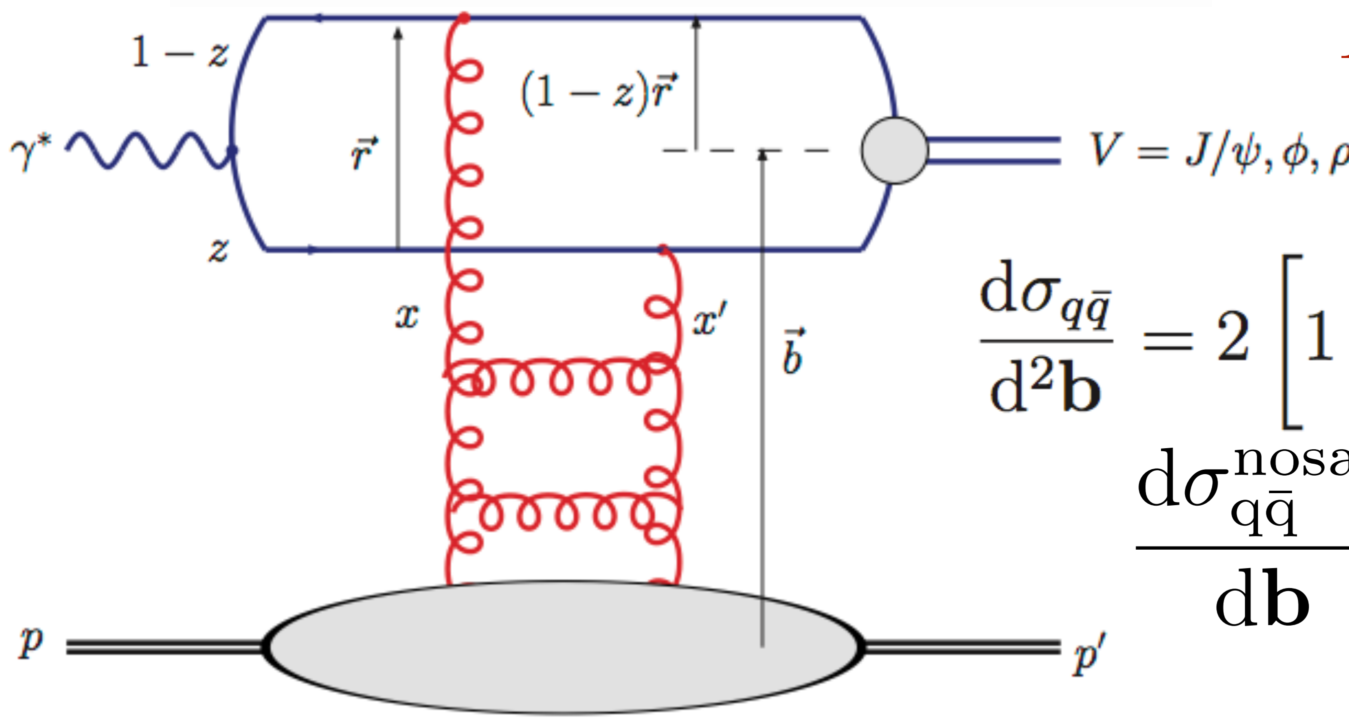
Glauber (Woods-Saxon)





T. Ullrich & T.T.

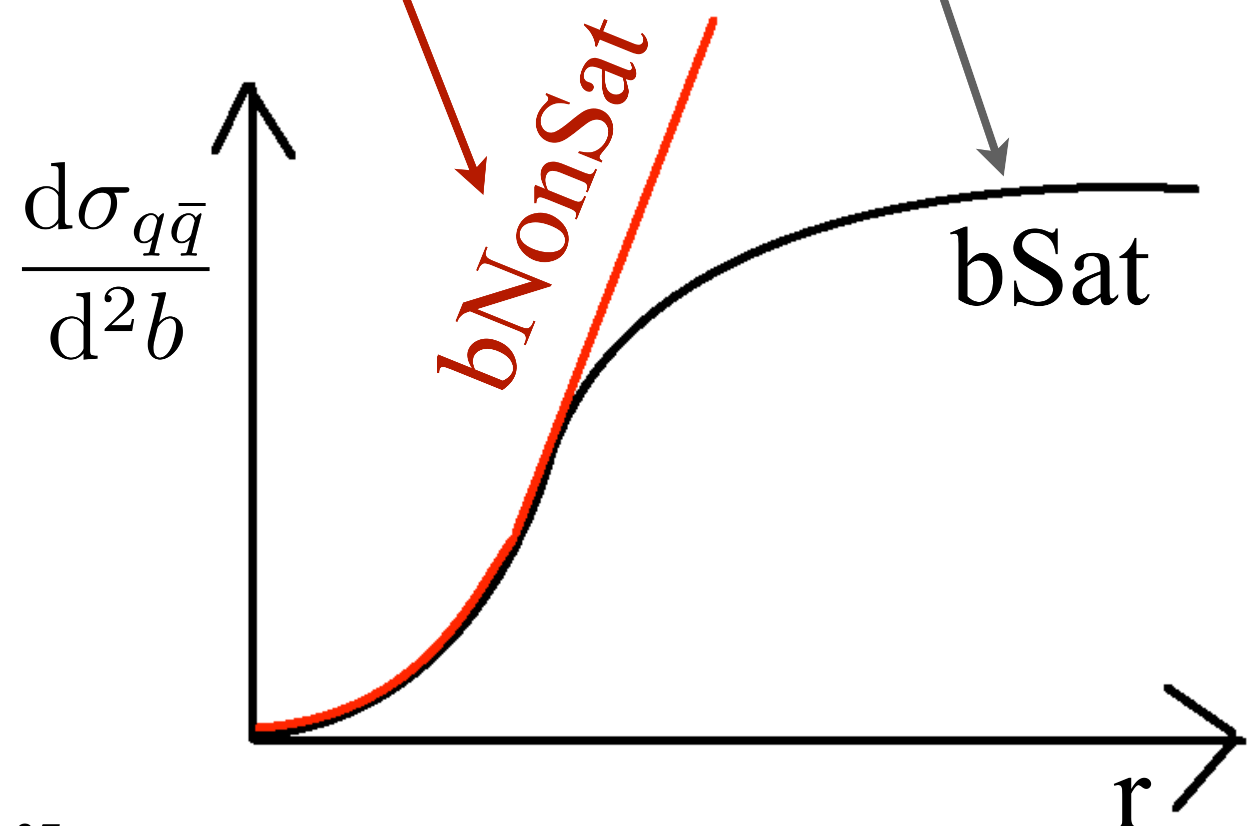
Exclusive diffraction Sartre



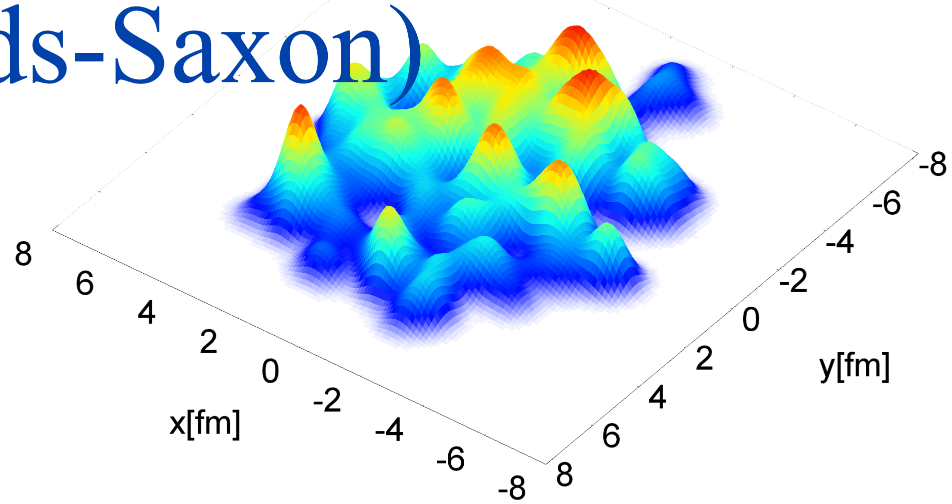
Dipole model with Glauber bSat and bNonSat

$$\frac{d\sigma_{q\bar{q}}}{d^2\mathbf{b}} = 2\left[1-\exp\left(-\frac{\pi^2}{2N_c}r^2\alpha_s(\mu^2)xg(x,\mu^2)T(b)\right)\right]$$

$$\frac{d\sigma^{\mathrm{nosat}}_{\mathrm{q\bar{q}}}}{d\mathbf{b}} = \frac{\pi^2}{N_C}r^2\alpha_S(\mu^2)xg(x,\mu^2)T(b)$$

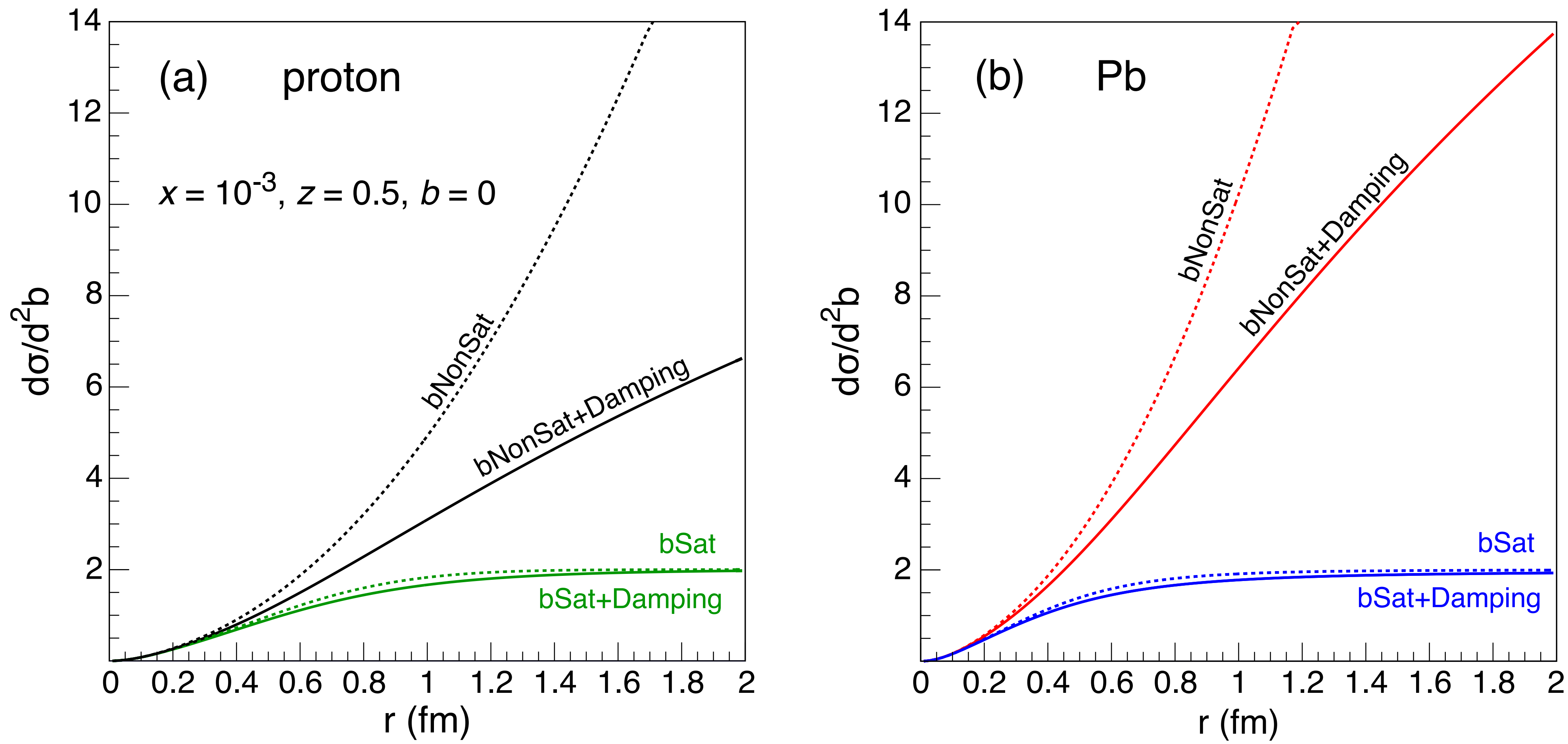


Glauber (Woods-Saxon)



Exclusive diffraction Sartre

B. Sambasivam, TT, T. Ullrich, e-Print: arXiv:1910.02899

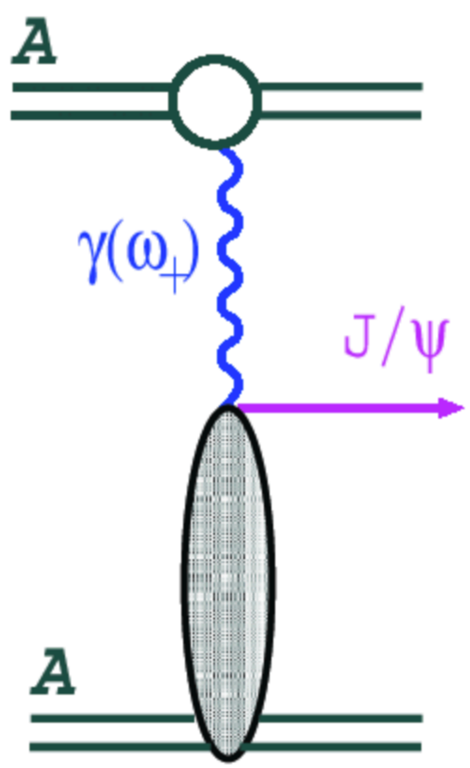


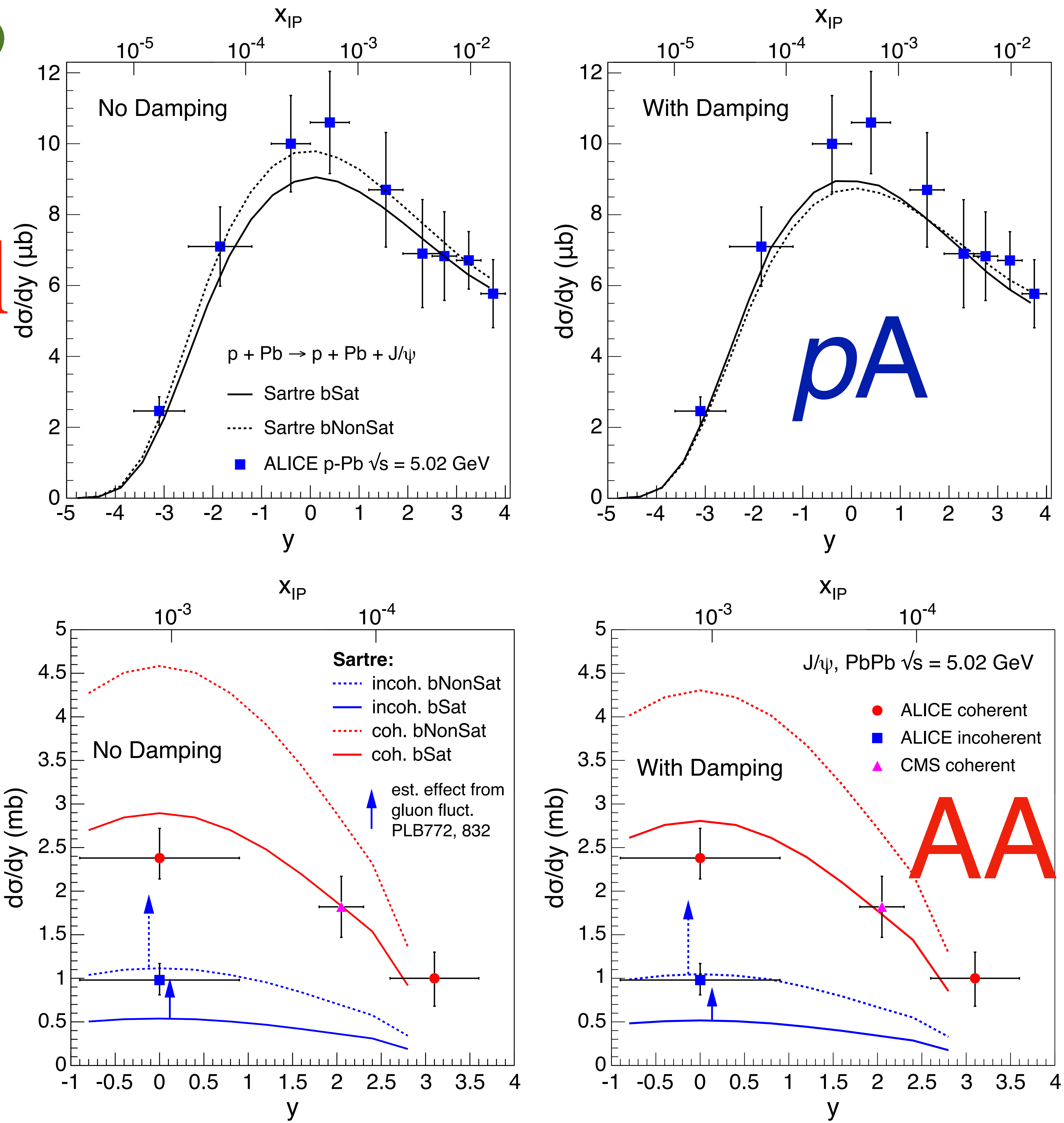
Model	χ^2/Ndf	N	m_l (GeV)	m_c (GeV)	C	A_g	λ_g	R_{shrink} (fm)
bNonSat (damped)	**1.108**	409+34	0.05116	1.3446	1.7076	2.3938	0.06581	0.9025
bSat (damped)	**1.270**	409+34	0.004	1.4280	1.9724	2.1945	0.09593	1.1889
bNonSat [6]	**1.317**	410+33	0.1497	1.3180	3.5445	2.8460	0.008336	
bSat [6]	**1.290**	410+33	0.03	1.3210	1.8178	2.0670	0.09575	

[6] Heikki Mäntysaari, Pia Zurita. Phys.Rev. D98 (2018) 036002

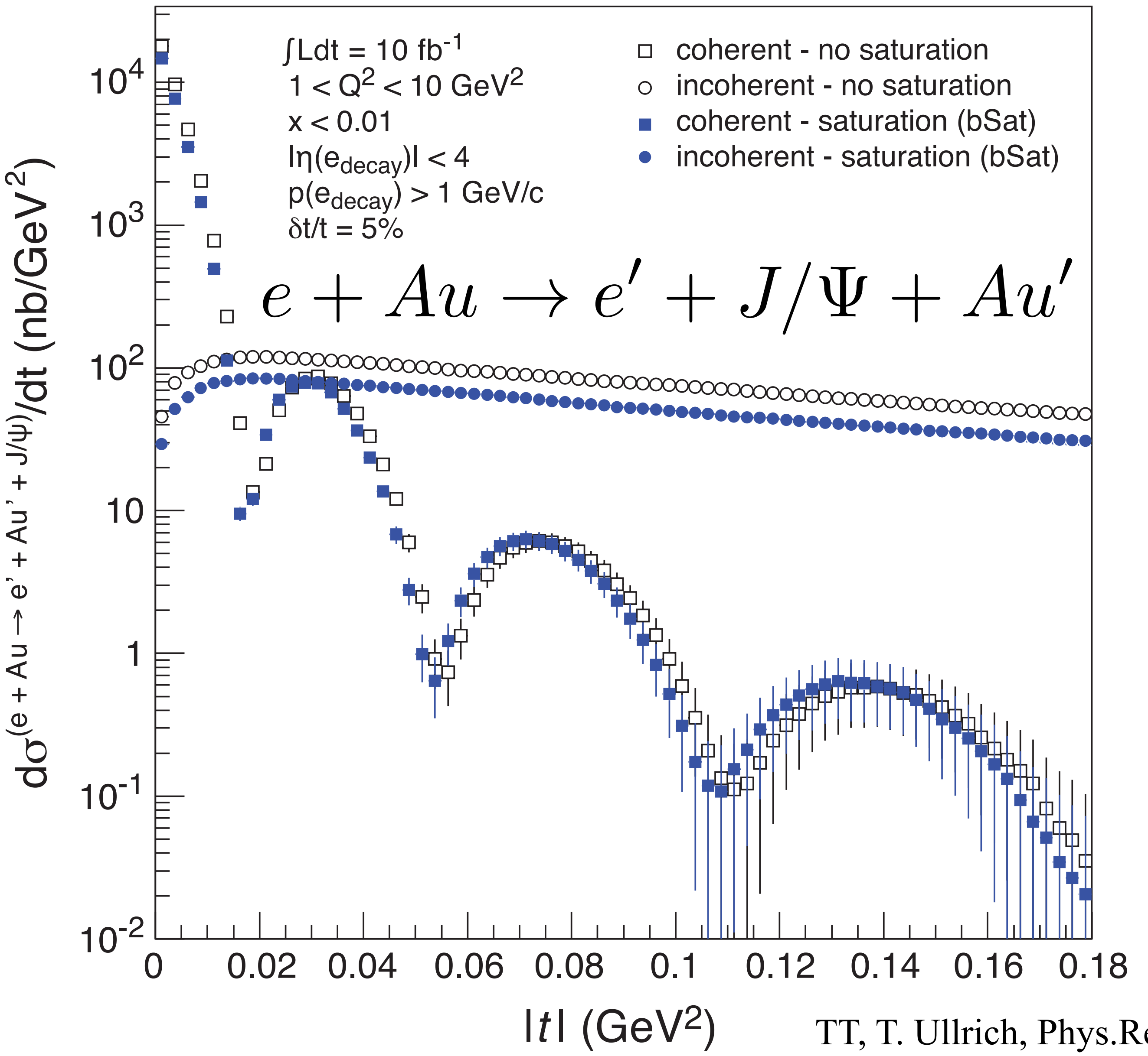
B. Sambasivam, TT, T. Ullrich, e-Print: arXiv:1910.02899

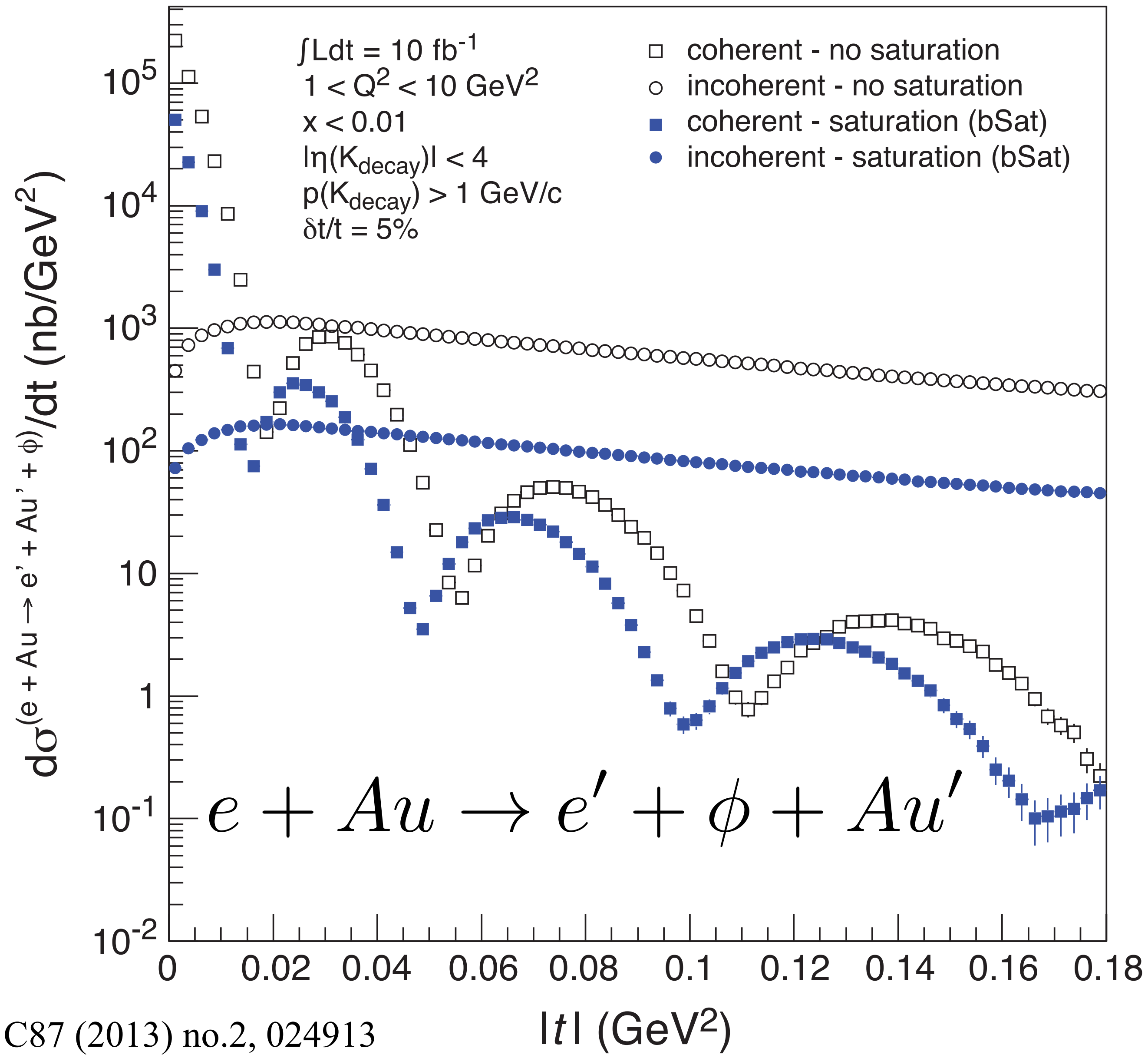
Comparing to Ultra-Peripheral Collisions





EIC predictions:
Exclusive diffraction Sartre



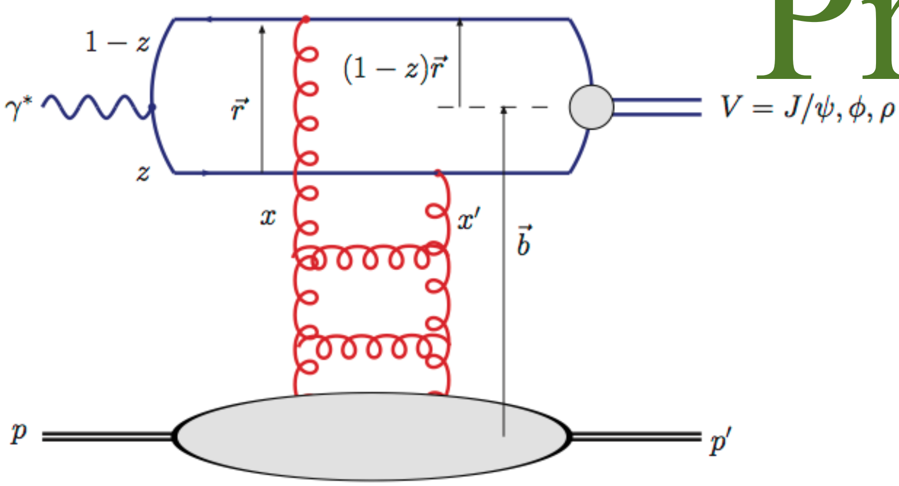


TT, T. Ullrich, Phys.Rev. C87 (2013) no.2, 024913

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

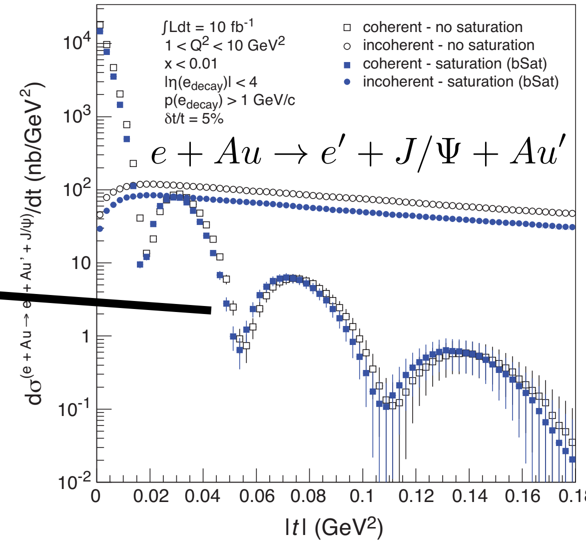
First 4 dips obtainable.

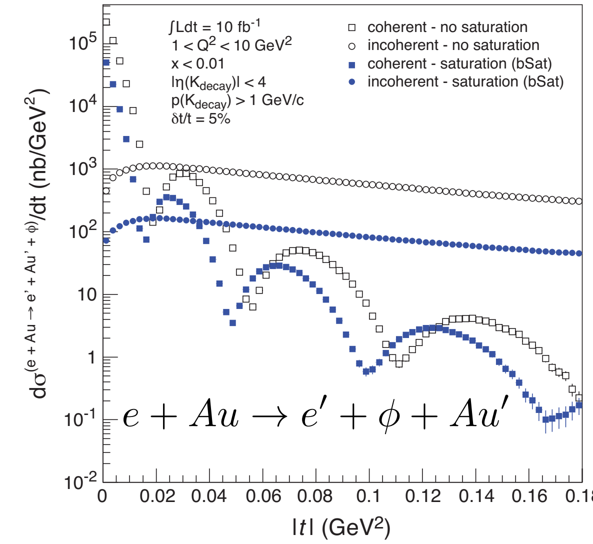
Probing the spatial gluon distribution at EIC



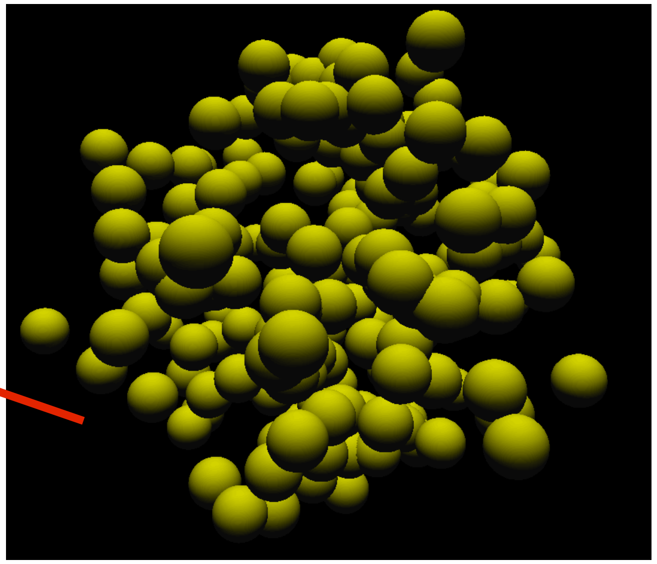
$$\frac{\mathrm{d}\sigma}{\mathrm{d}t} = \frac{1}{16\pi} \left|\mathcal{A}(\Delta)\right|^2$$

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





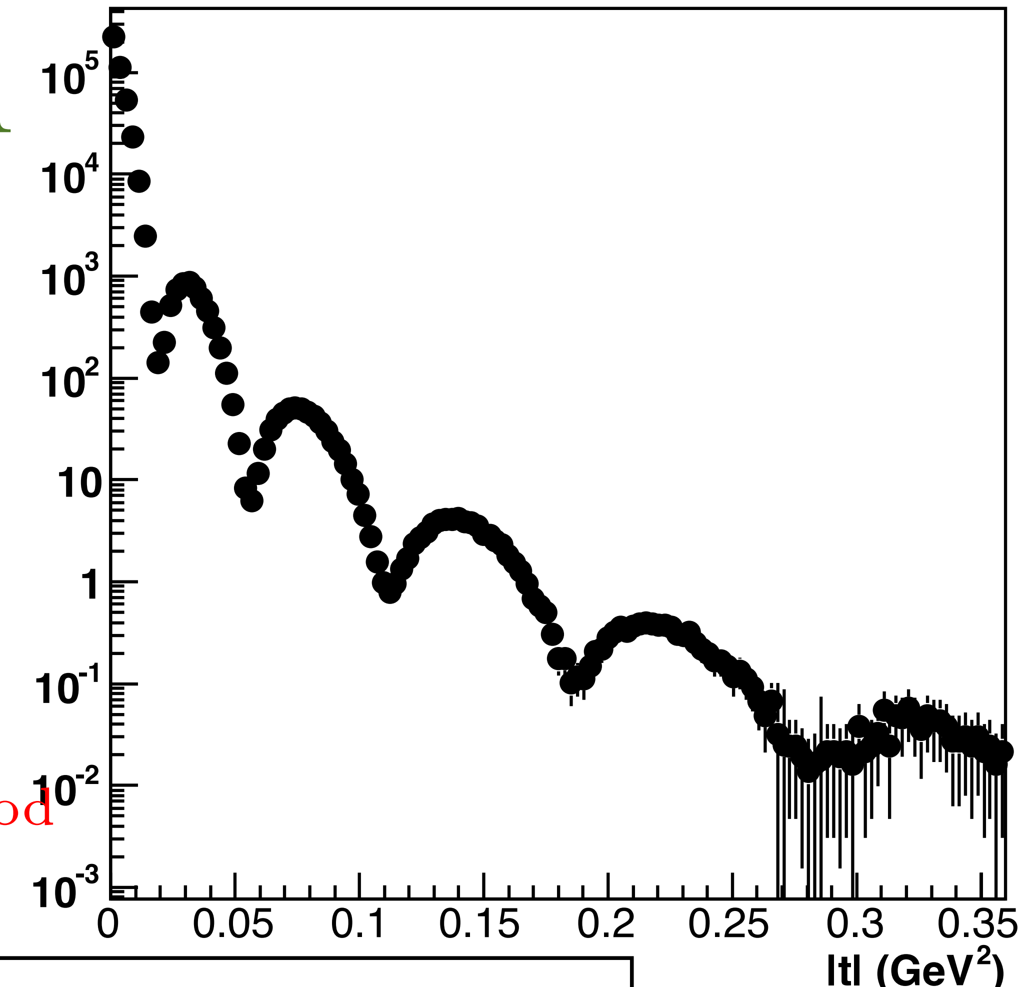
$$\mathcal{A}(\Delta) \sim \mathcal{F}ourier(\text{Wave Overlap} \cdot \text{Dipole Model}(b))$$



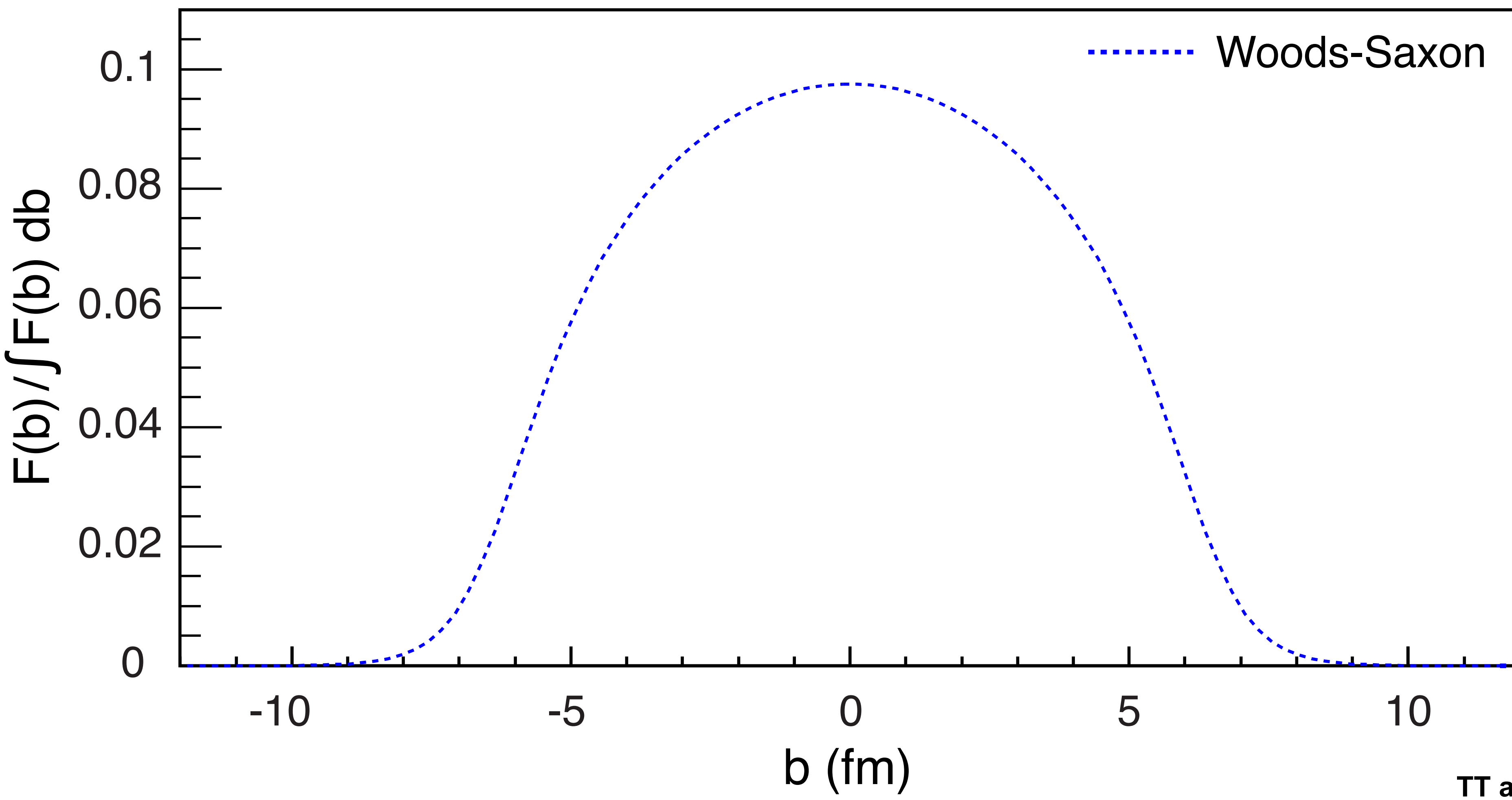
Fourier transform again to retain spatial distribution:

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

Probing the spatial gluon distribution at EIC

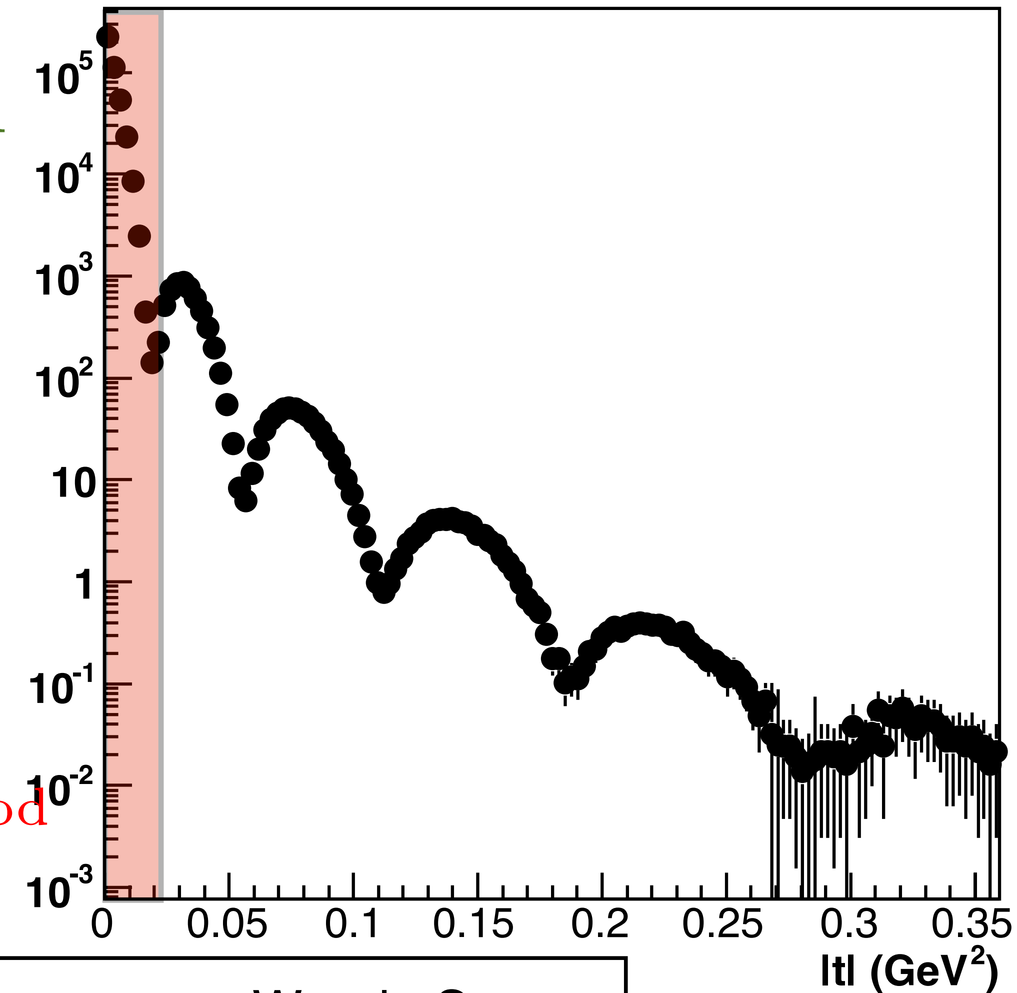


$$F(b) = \frac{1}{2\pi}\int_0^\infty \mathrm{d}\Delta\Delta J_0(\Delta b)\sqrt{\frac{\mathrm{d}\sigma_{\mathrm{coherent}}}{\mathrm{d}t}(\Delta)}\Bigg|_{\mathrm{mod}}$$

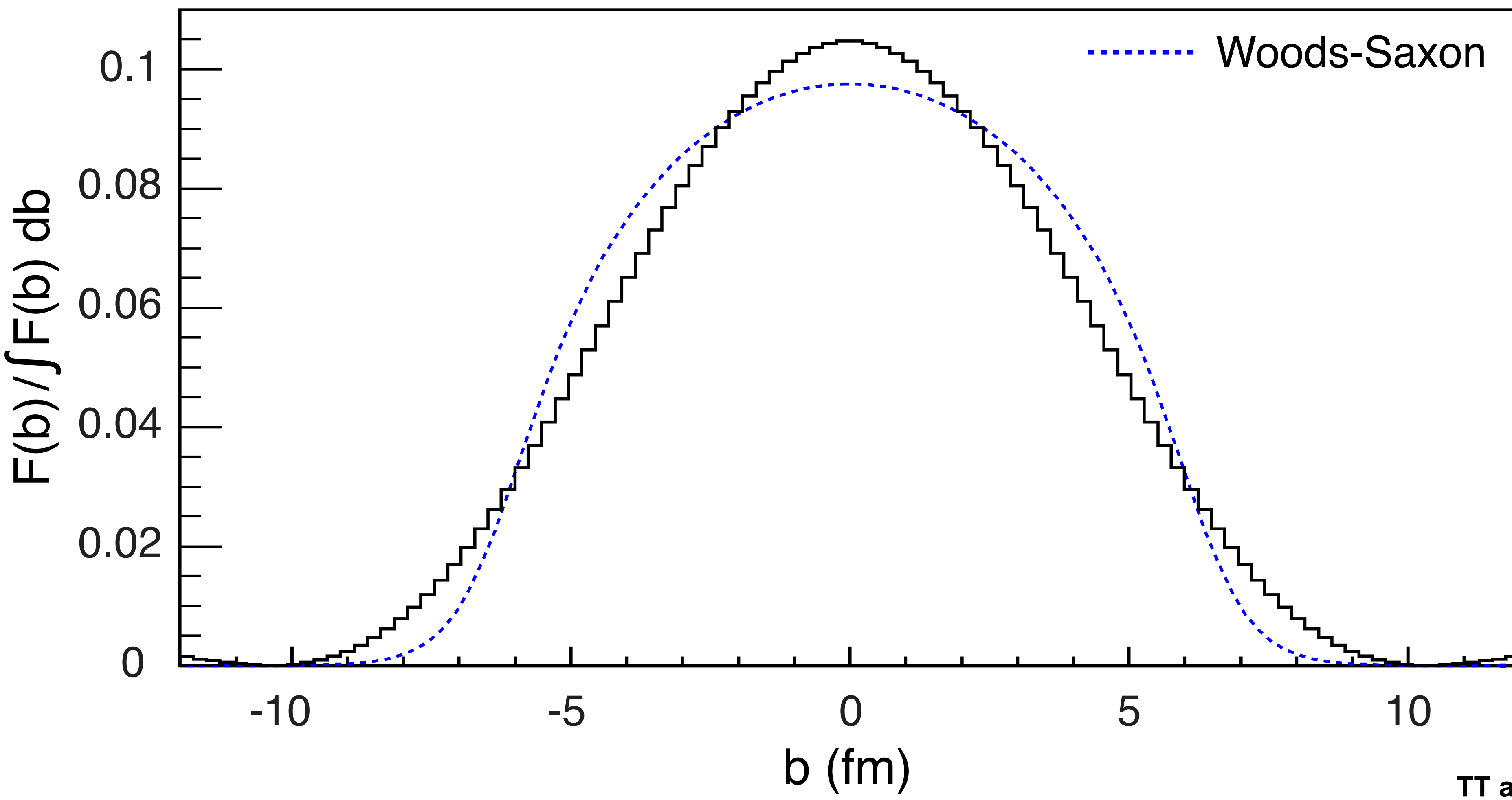


TT and T. Ullrich,
Phys. Rev. C 87, 024913 (2013)
arXiv:1211.3048

Probing the spatial gluon distribution at EIC



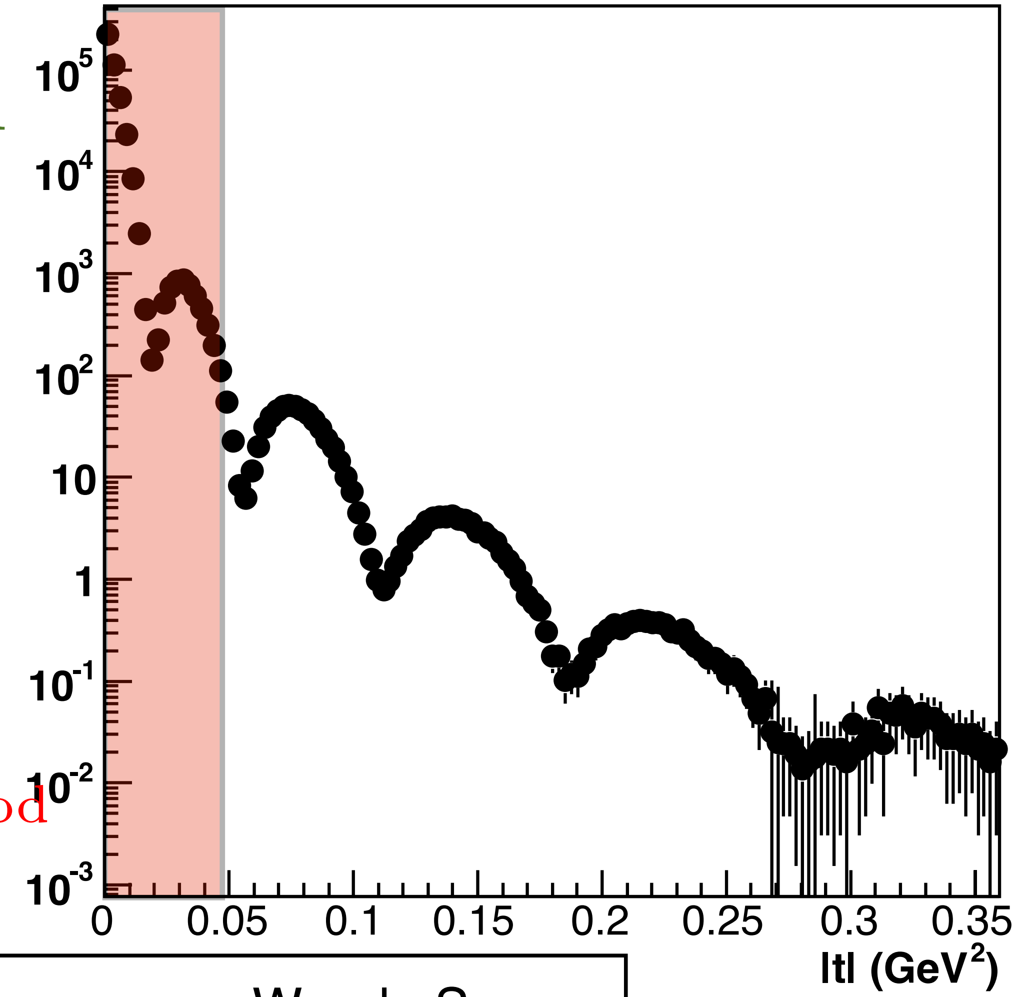
$$F(b) = \frac{1}{2\pi}\int_0^\infty \mathrm{d}\Delta\Delta J_0(\Delta b)\sqrt{\frac{\mathrm{d}\sigma_{\mathrm{coherent}}}{\mathrm{d}t}(\Delta)}\Bigg|_{\mathrm{mod}}$$

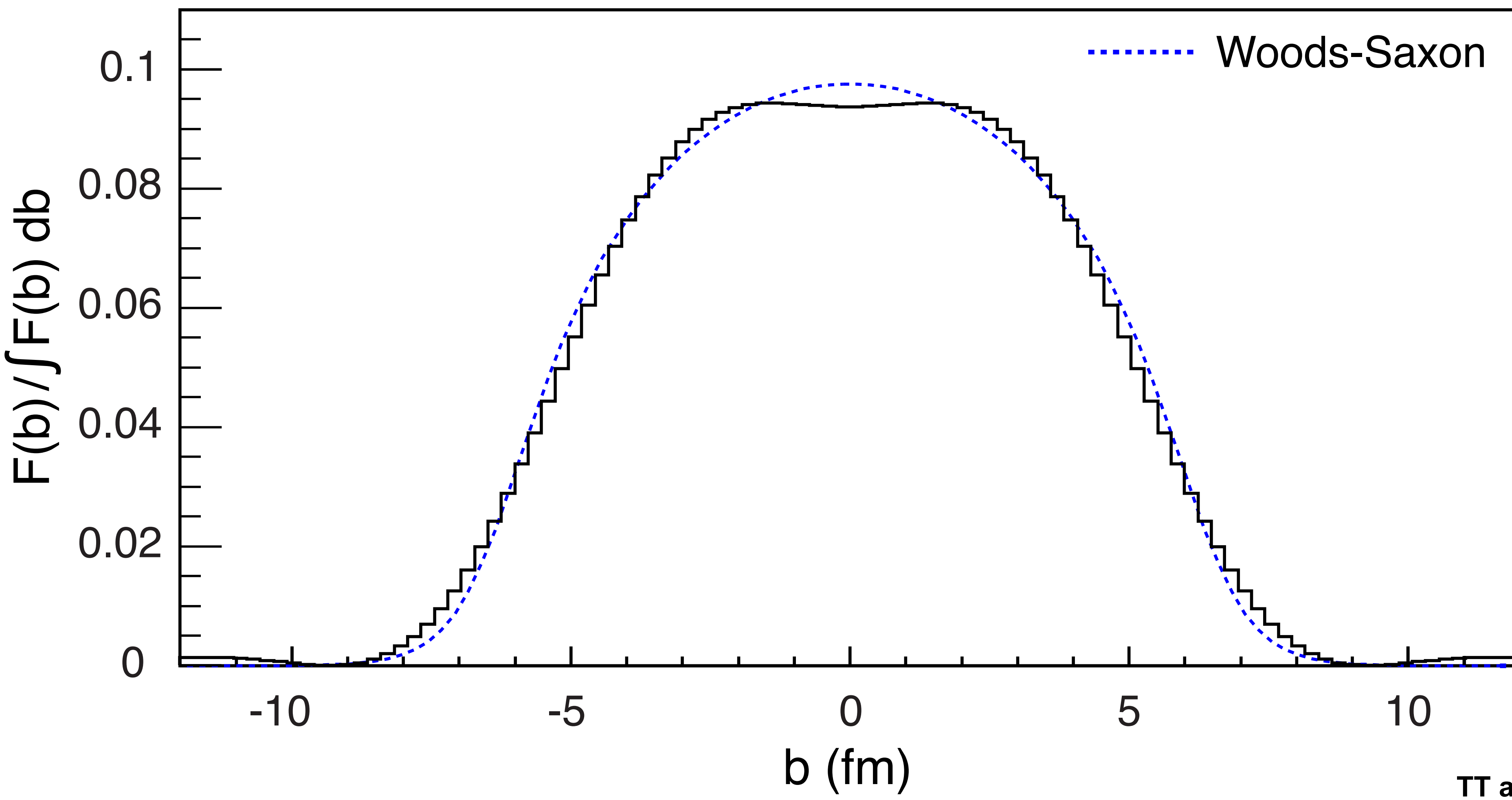


TT and T. Ullrich,
Phys. Rev. C 87, 024913 (2013)
arXiv:1211.3048

Probing the spatial gluon distribution at EIC

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

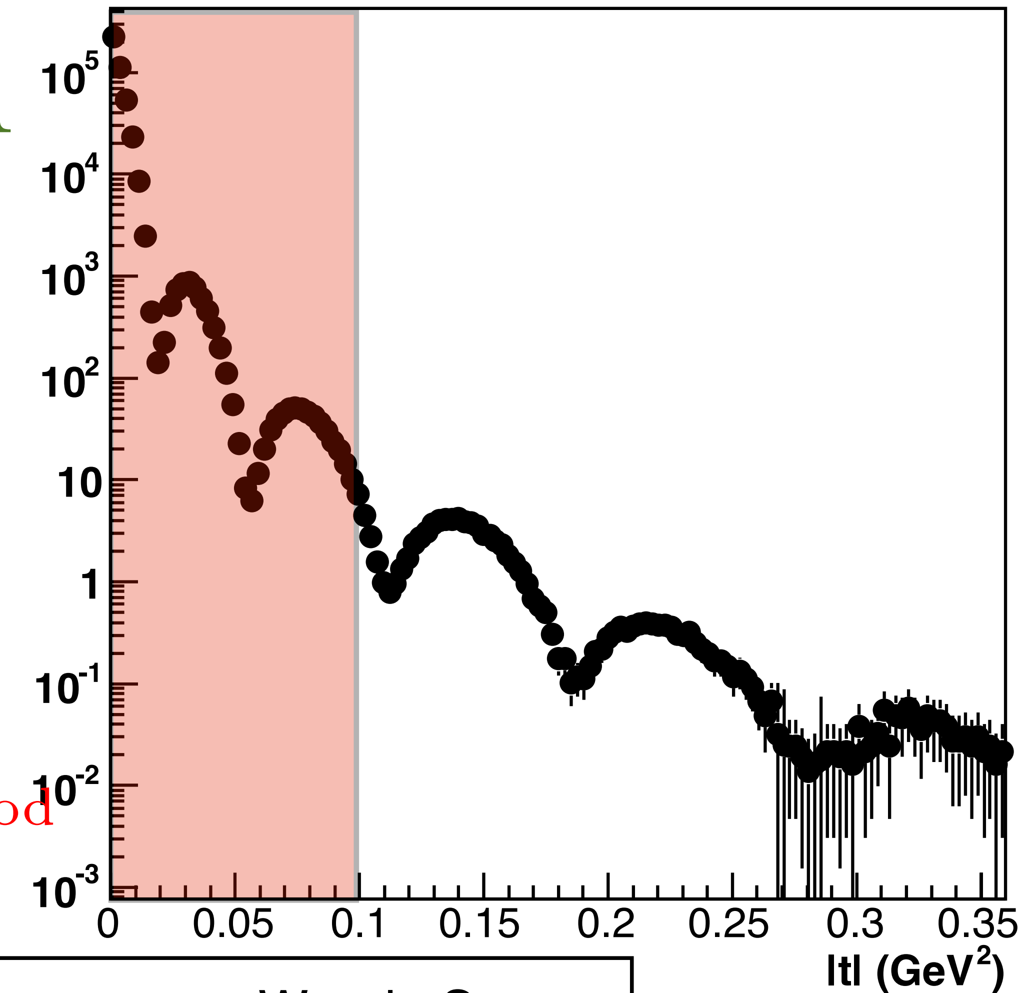


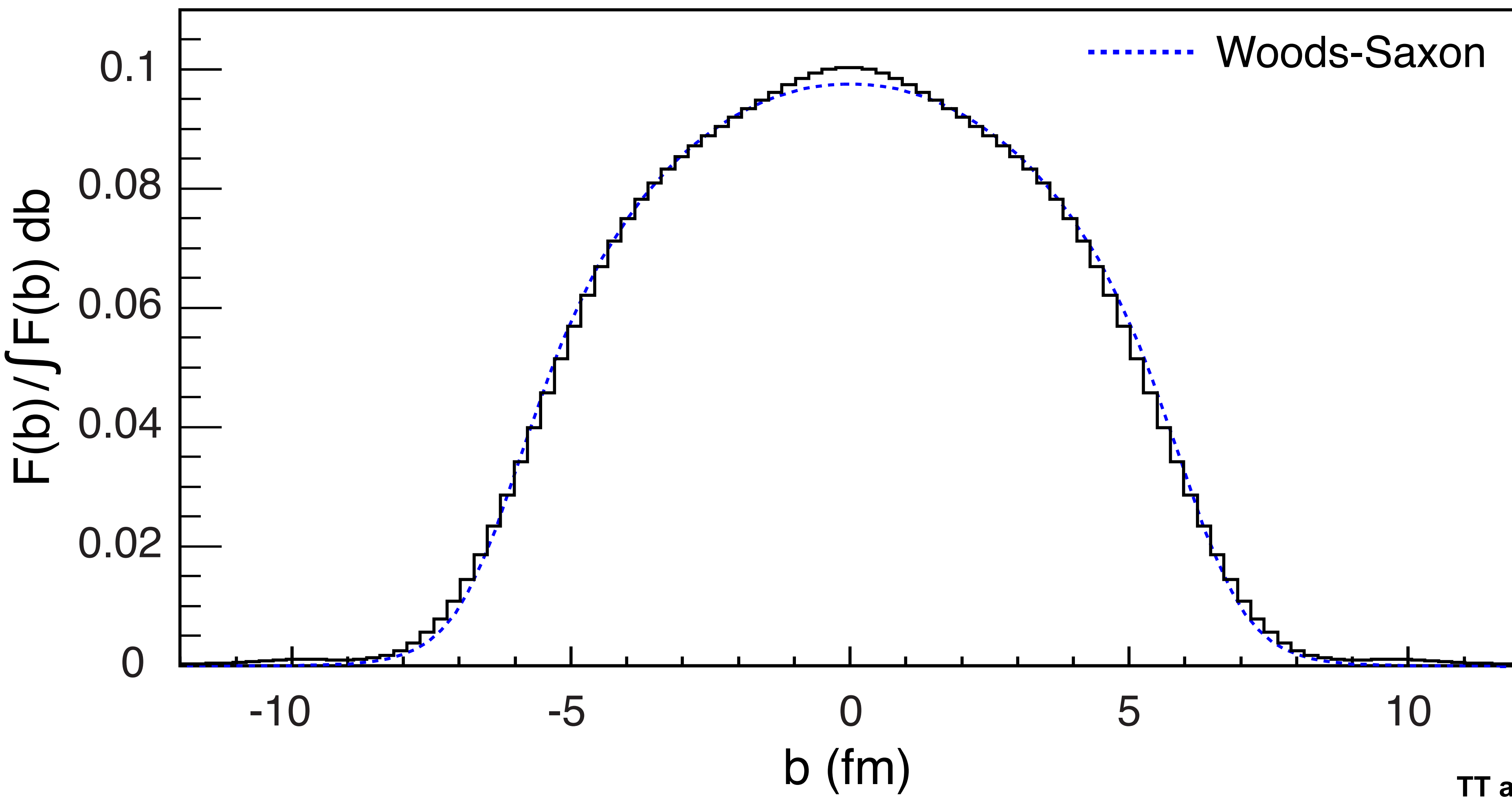


TT and T. Ullrich,
Phys. Rev. C 87, 024913 (2013)
arXiv:1211.3048

Probing the spatial gluon distribution at EIC

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

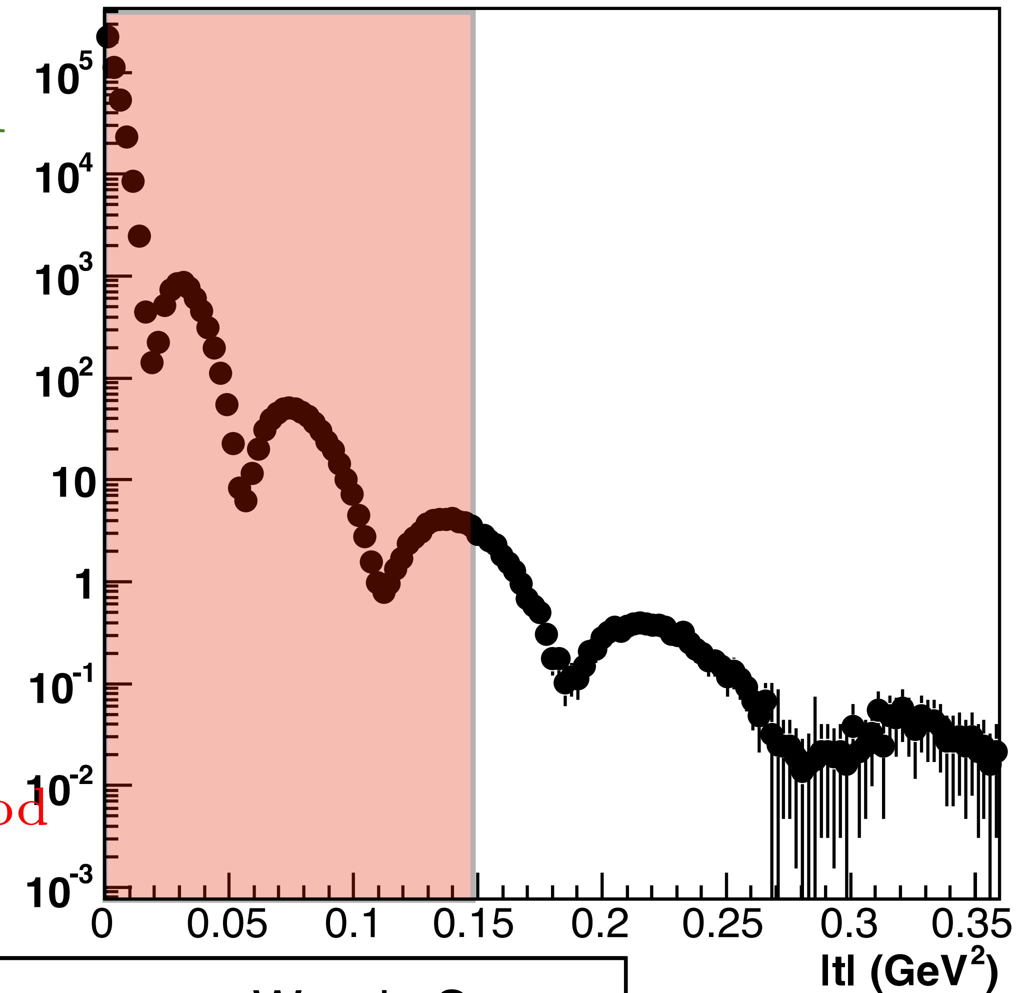


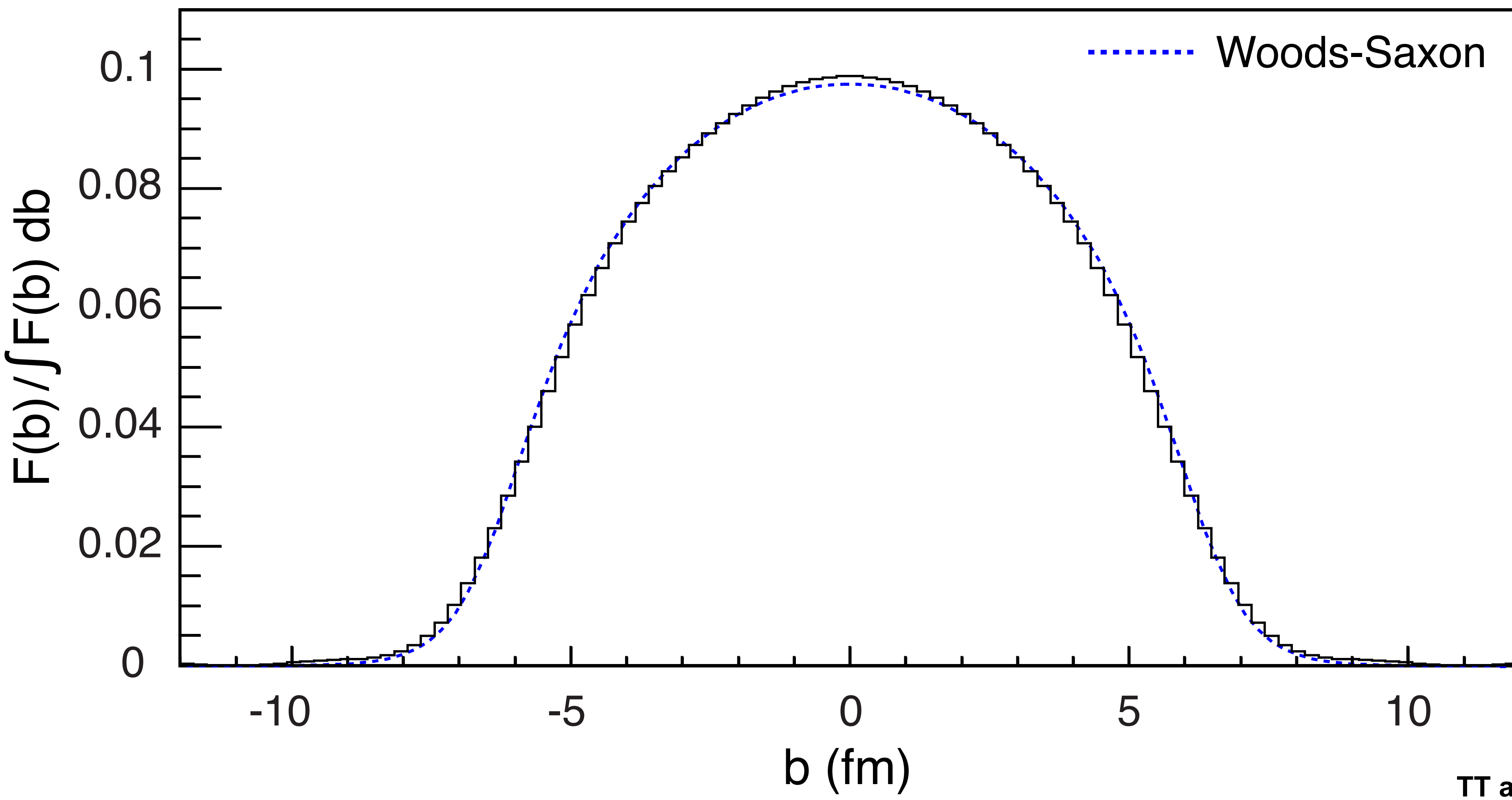


TT and T. Ullrich,
Phys. Rev. C 87, 024913 (2013)
arXiv:1211.3048

Probing the spatial gluon distribution at EIC

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

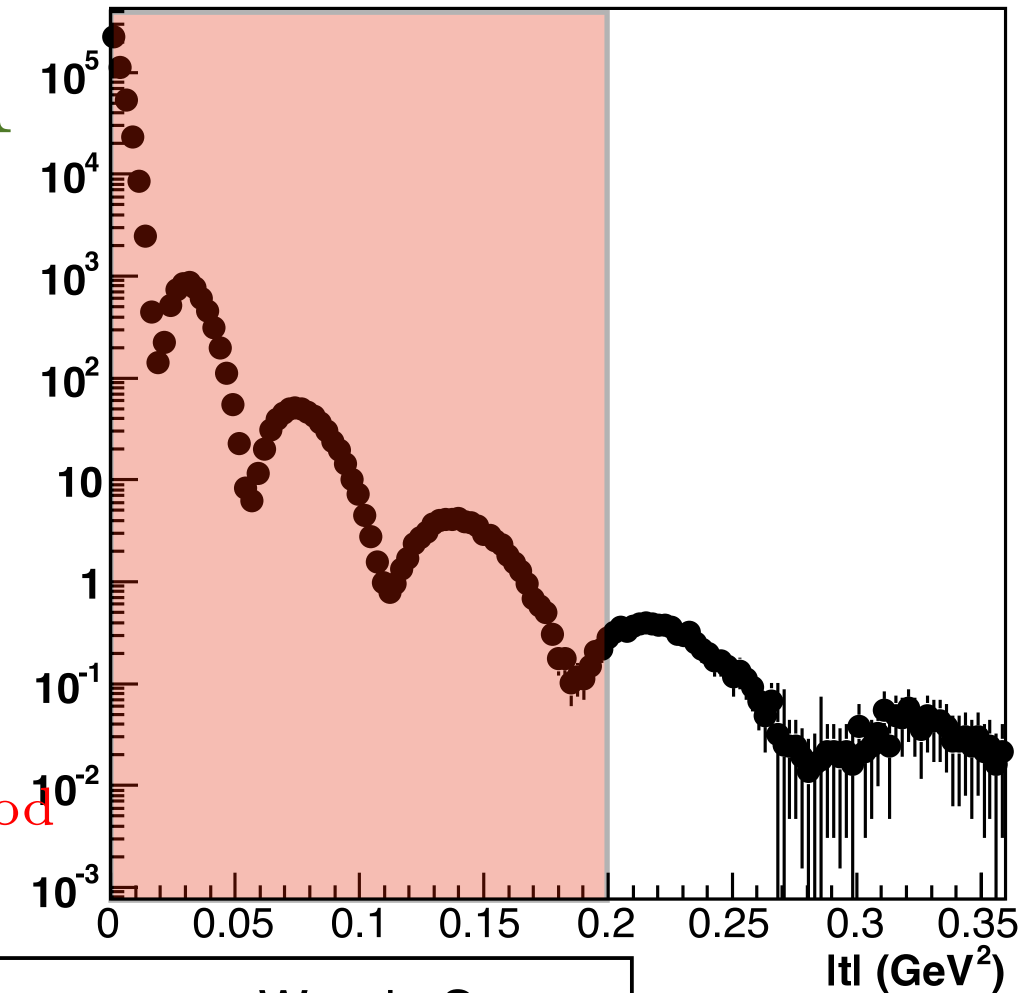


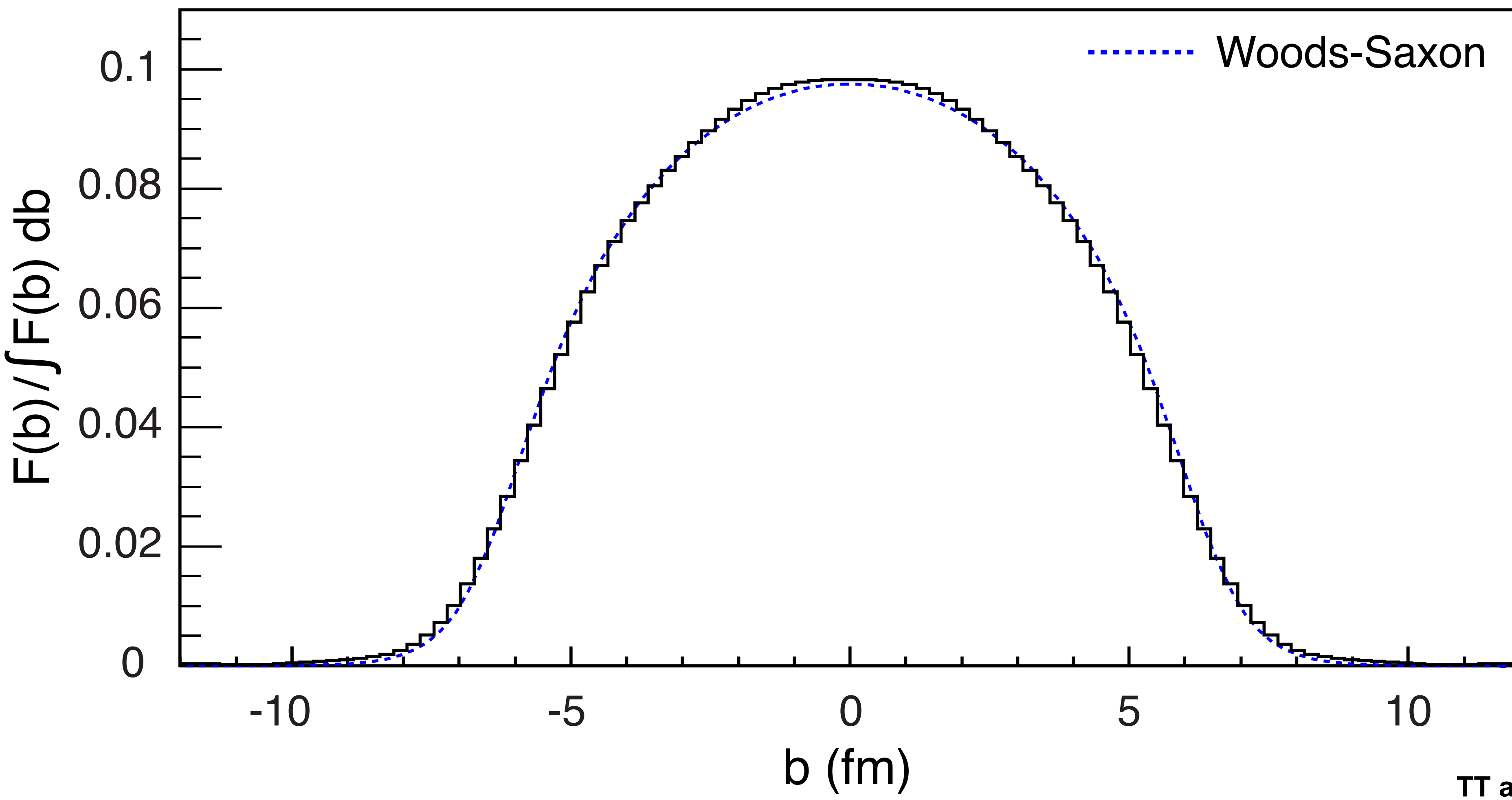


TT and T. Ullrich,
Phys. Rev. C 87, 024913 (2013)
arXiv:1211.3048

Probing the spatial gluon distribution at EIC

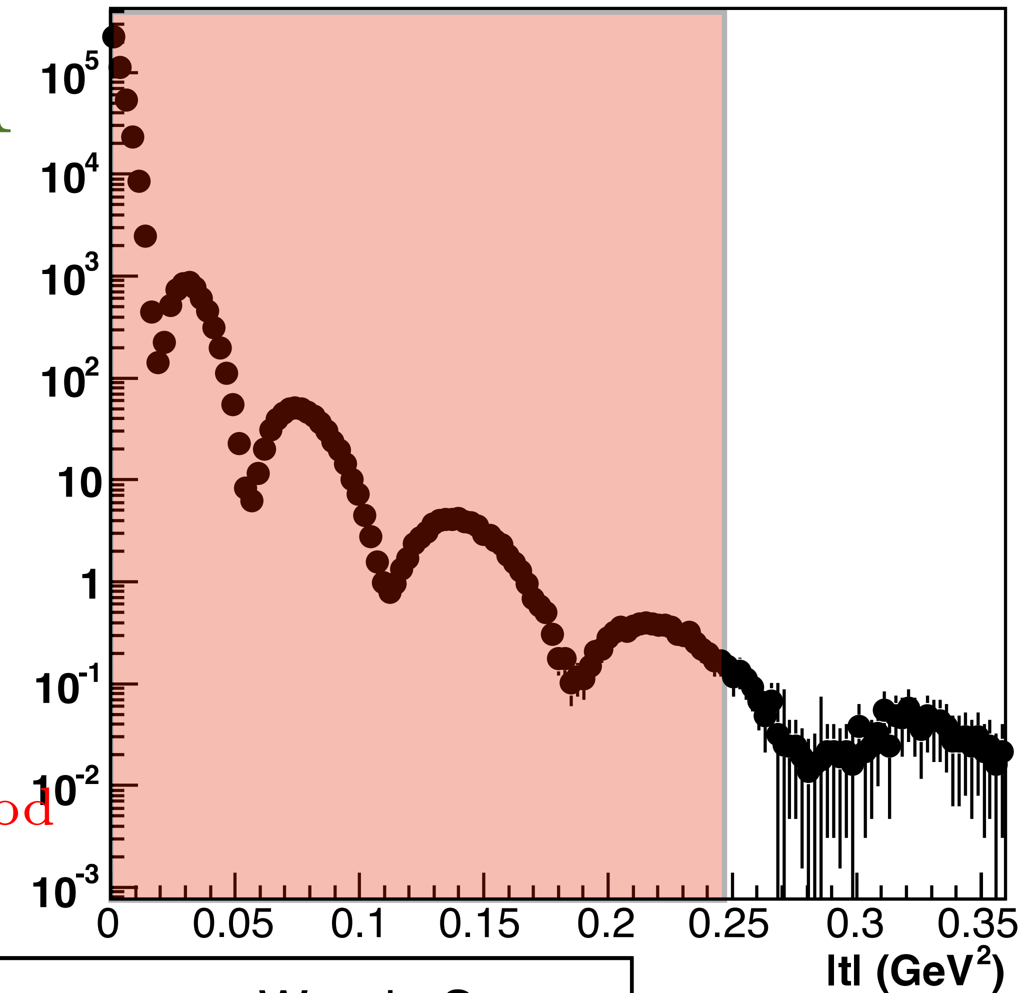
$$F(b) = \frac{1}{2\pi}\int_0^\infty \mathrm{d}\Delta\Delta J_0(\Delta b)\sqrt{\frac{\mathrm{d}\sigma_{\mathrm{coherent}}}{\mathrm{d}t}(\Delta)}\Bigg|_{\mathrm{mod}}$$



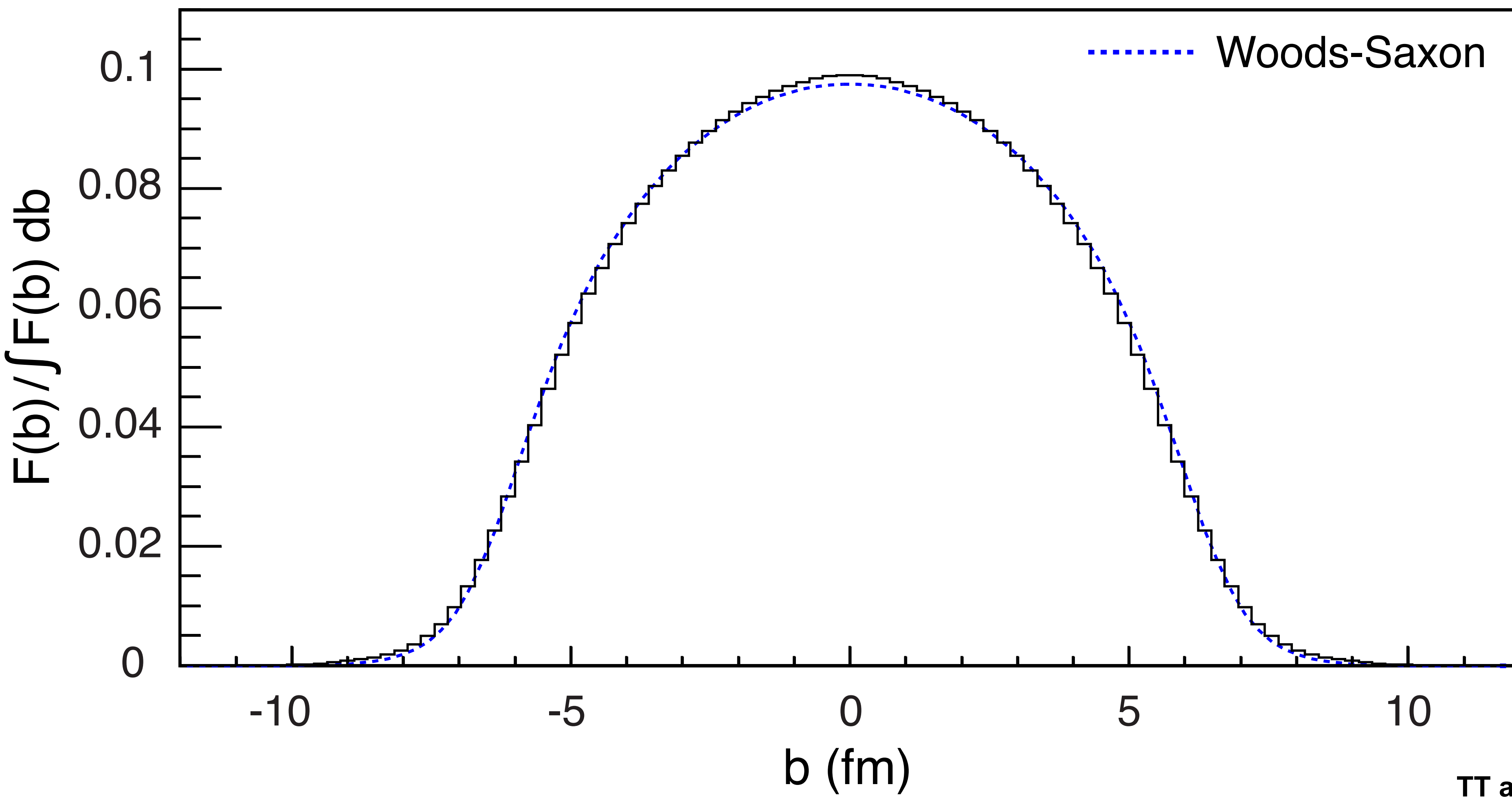


TT and T. Ullrich,
Phys. Rev. C 87, 024913 (2013)
arXiv:1211.3048

Probing the spatial gluon distribution at EIC

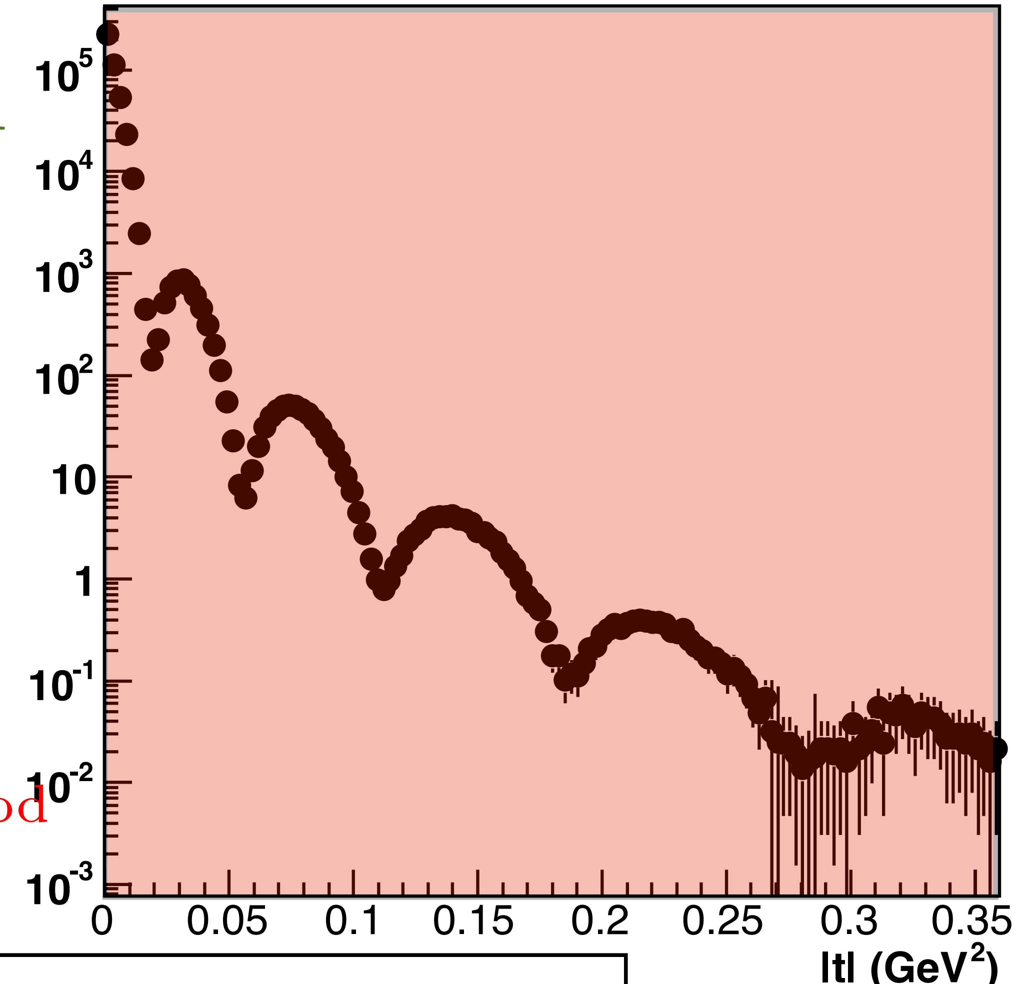


$$F(b) = \frac{1}{2\pi}\int_0^\infty \mathrm{d}\Delta\Delta J_0(\Delta b)\sqrt{\frac{\mathrm{d}\sigma_{\mathrm{coherent}}}{\mathrm{d}t}(\Delta)}\Bigg|_{\mathrm{mod}}$$

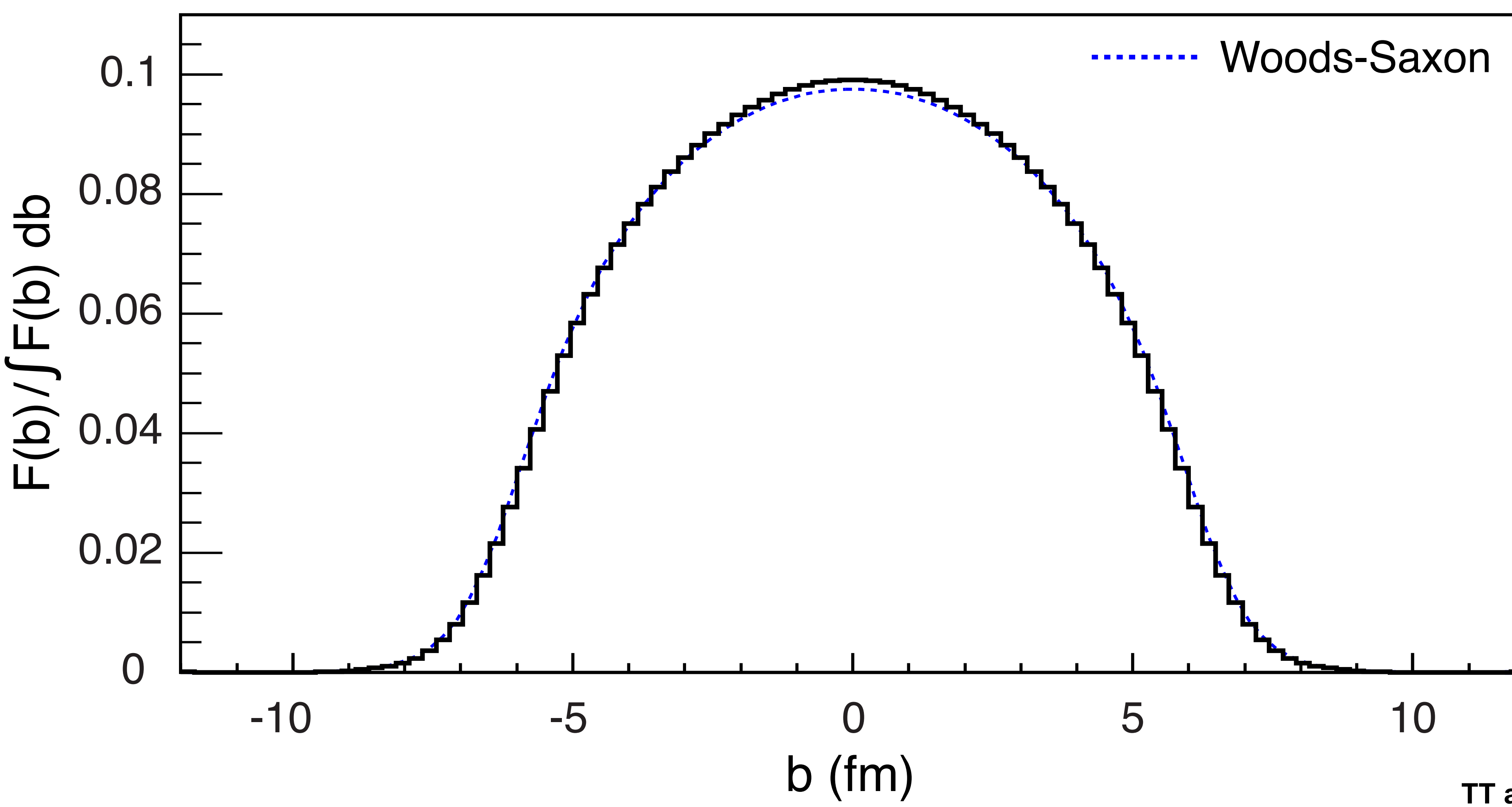


TT and T. Ullrich,
Phys. Rev. C 87, 024913 (2013)
arXiv:1211.3048

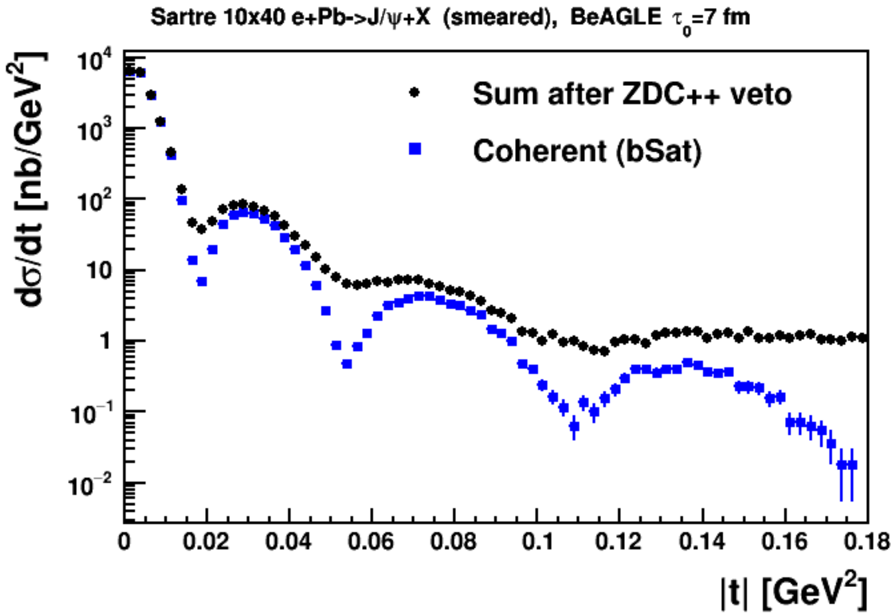
Probing the spatial gluon distribution at EIC



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



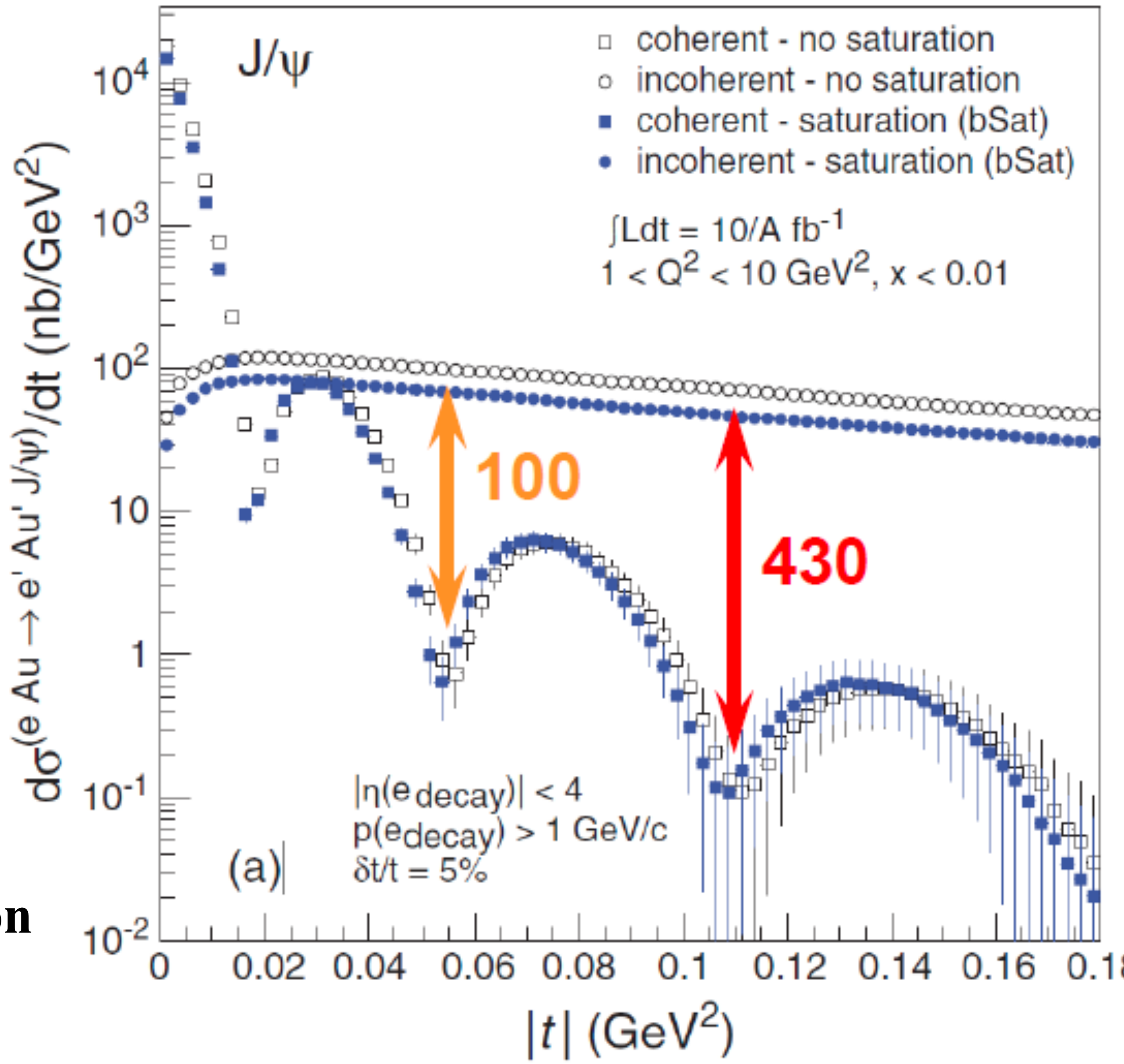
TT and T. Ullrich,
Phys. Rev. C 87, 024913 (2013)
arXiv:1211.3048

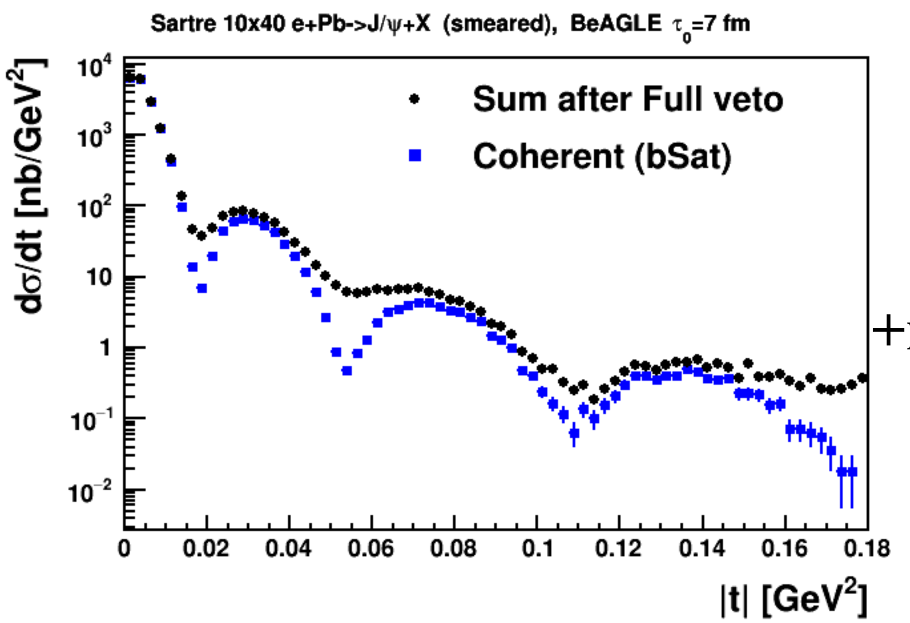


ZDC veto

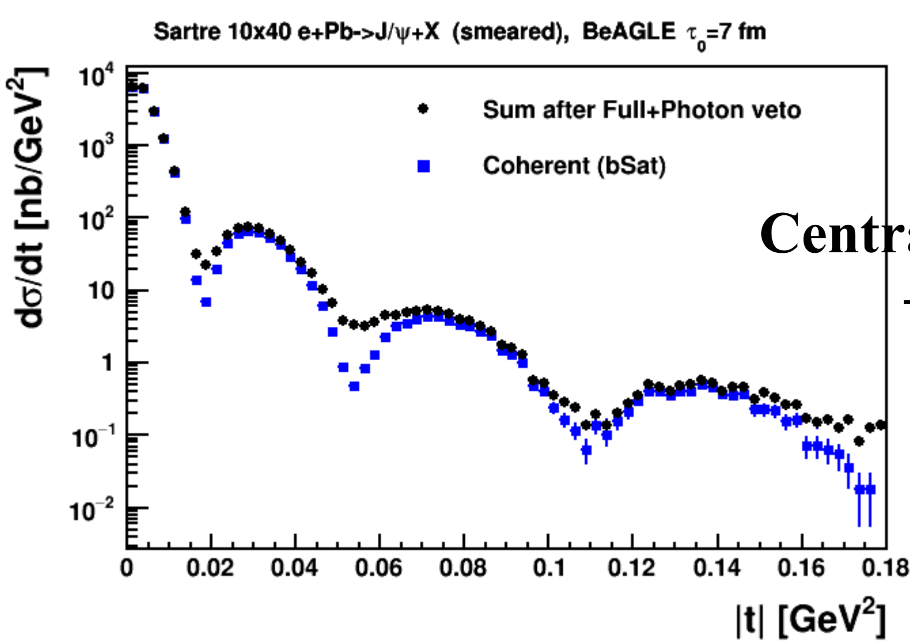
$E_\gamma > 40$ MeV, $\pi^{\pm}, K^{\pm}$,

$p/\bar{p}, n/\bar{n}$

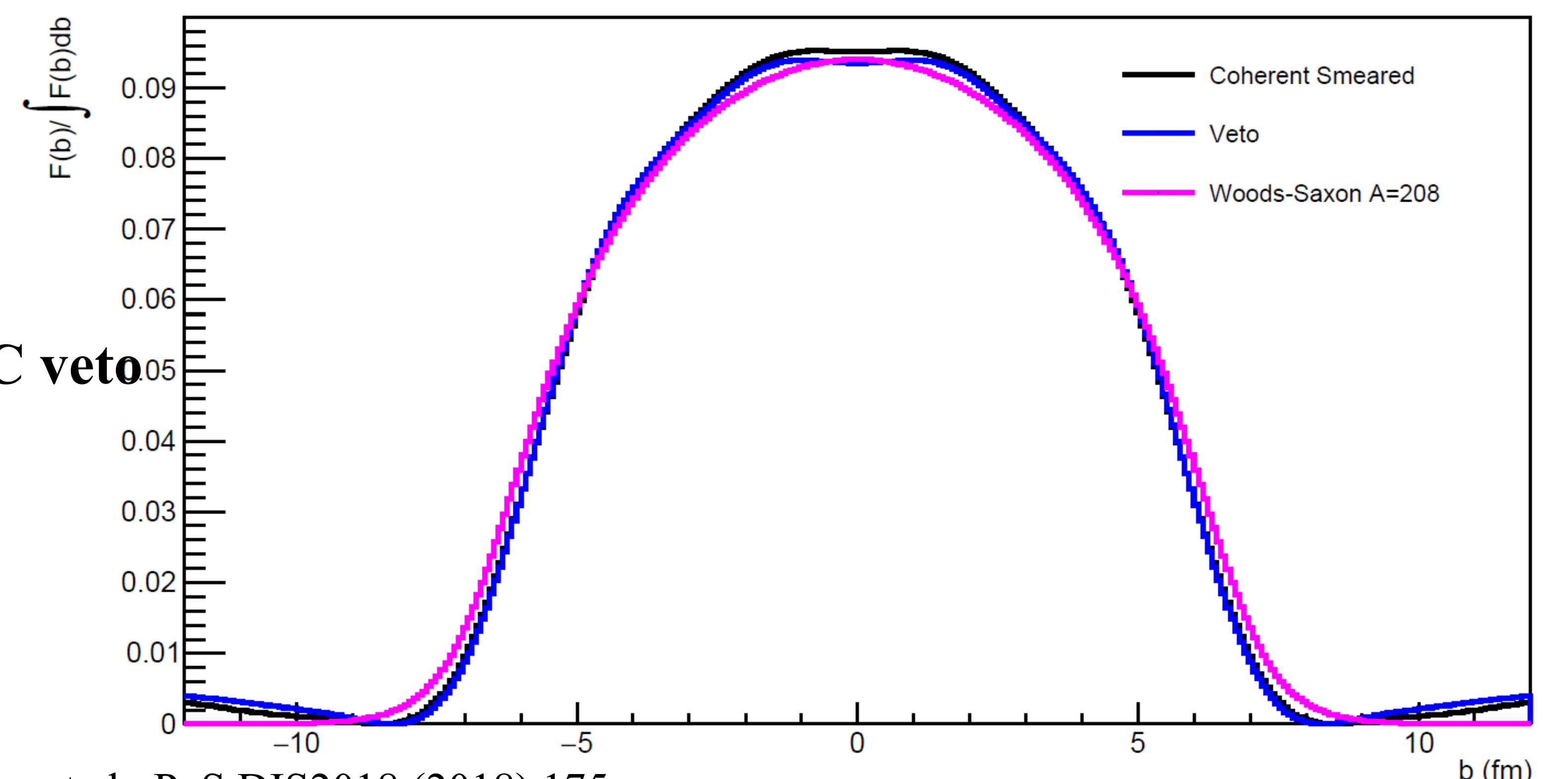




Central + ZDC veto
+nucleon/charged meson
after first dipole



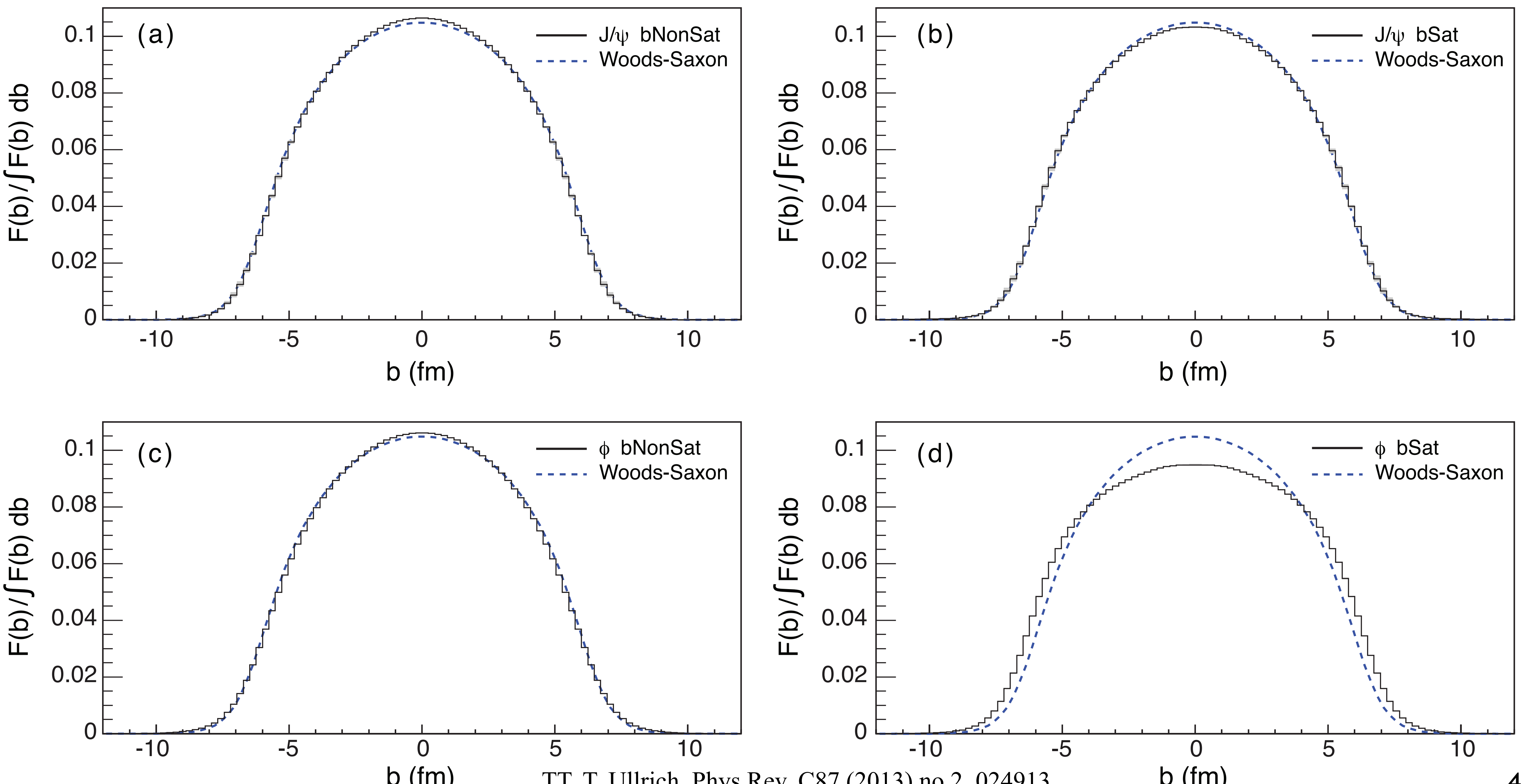
Central + ZDC veto
+photon



V. Morozov et al., PoS DIS2018 (2018) 175

Probing the spatial gluon distribution at EIC

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

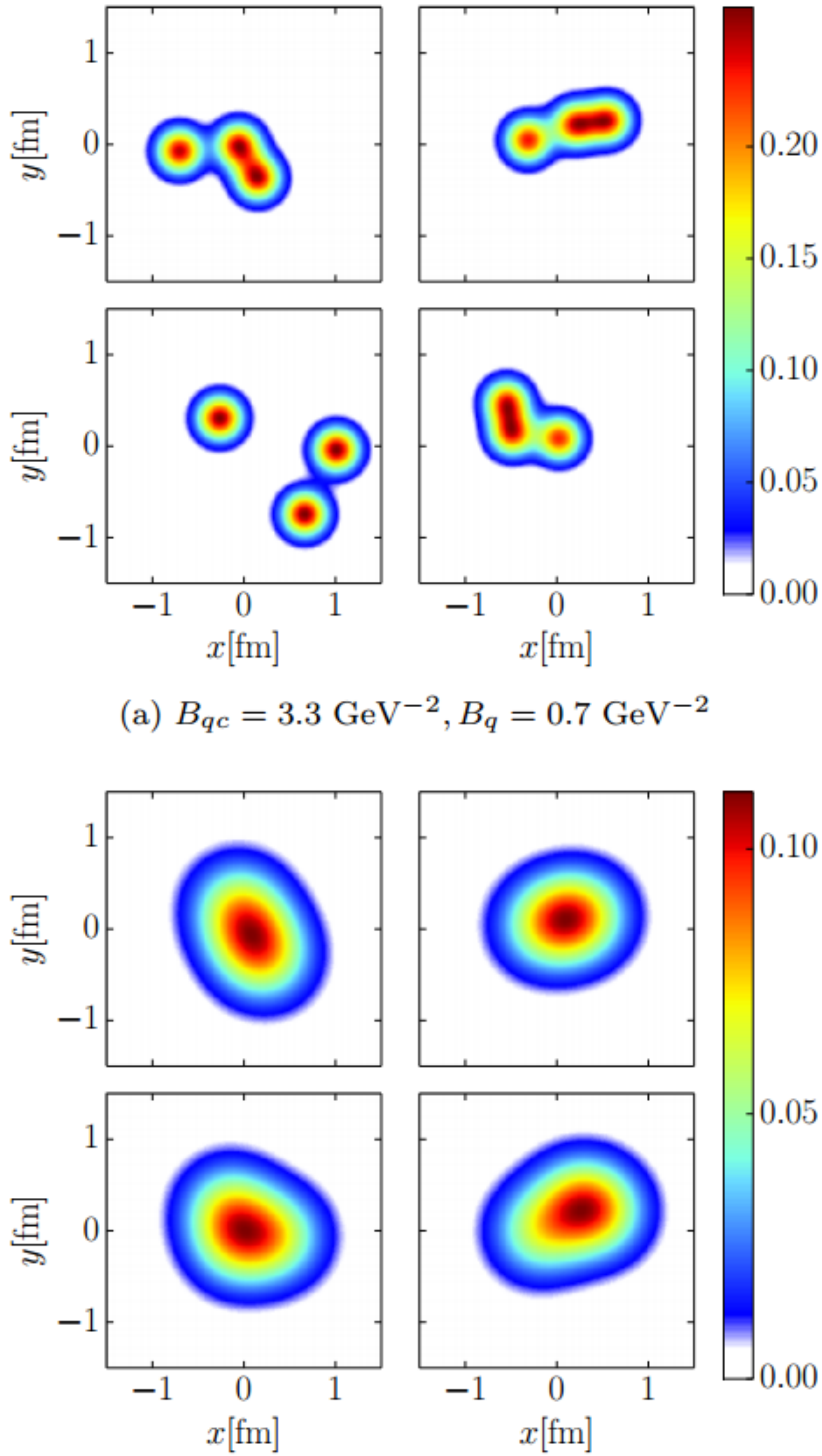


TT, T. Ullrich, Phys.Rev. C87 (2013) no.2, 024913

Fluctuations **inside Nucleons**

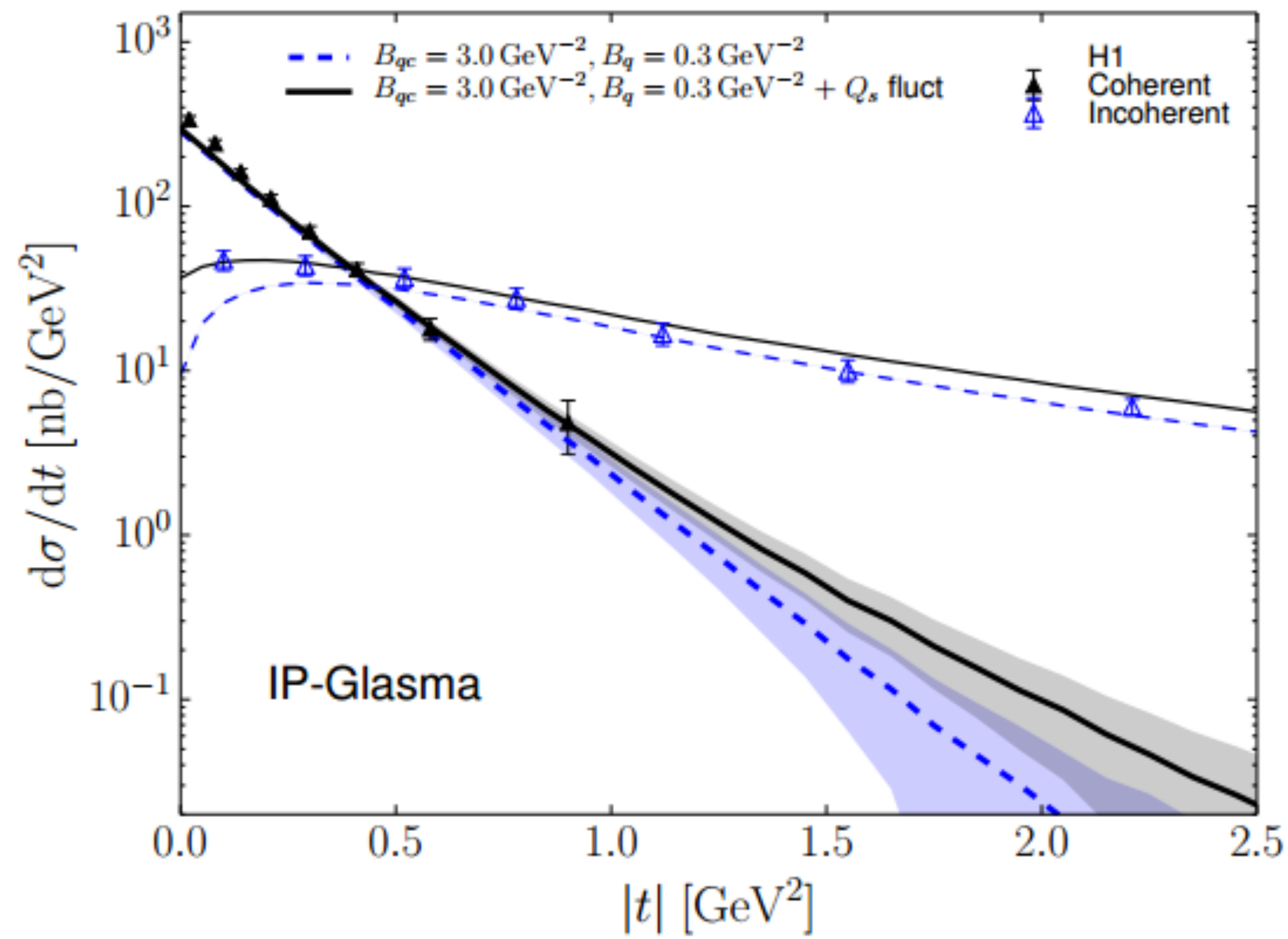
Two different fluctuations:

Around low scale partons + **Saturation Scale**

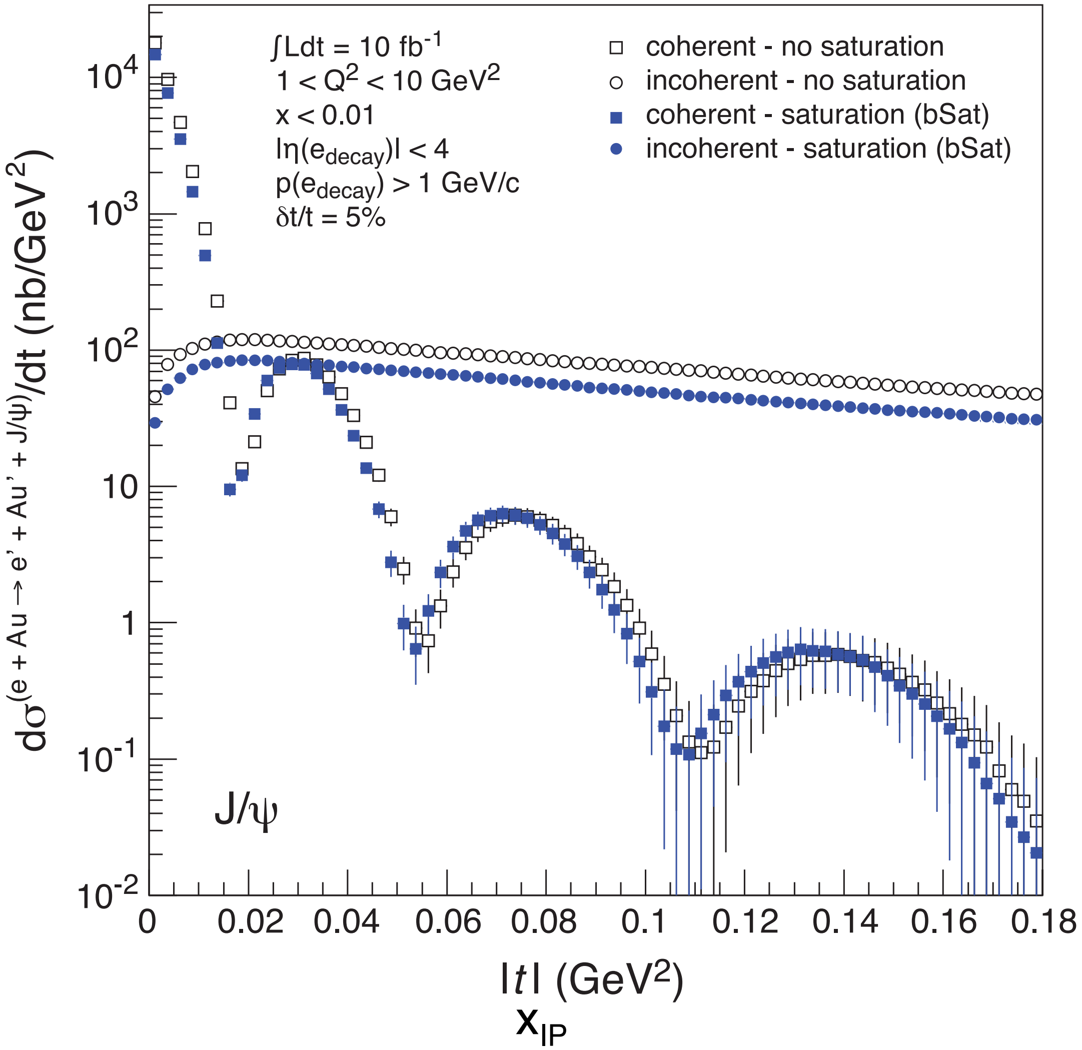


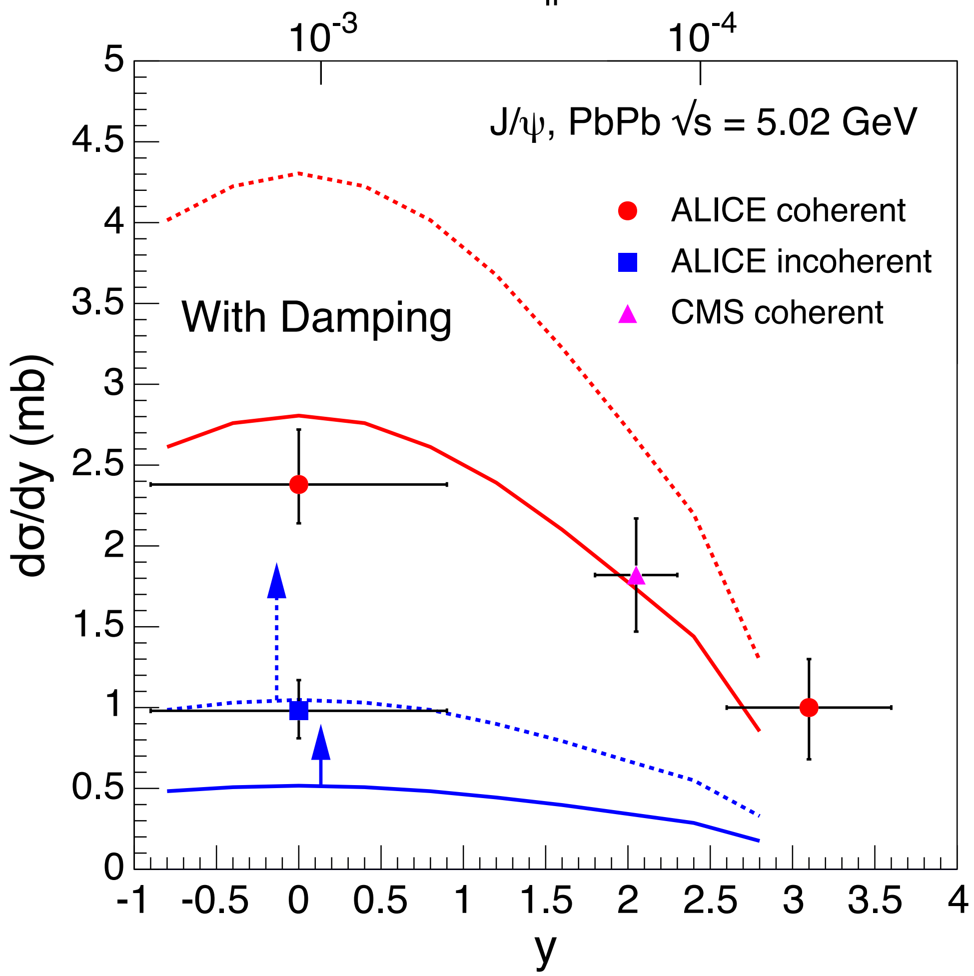
(a) $B_{qc} = 3.3\ \mathrm{GeV}^{-2}, B_q = 0.7\ \mathrm{GeV}^{-2}$

(b) $B_{qc} = 1.0\ \mathrm{GeV}^{-2}, B_q = 3.0\ \mathrm{GeV}^{-2}$



Heikki Mäntysaari, Björn Schenke (Brookhaven Natl. Lab.)Phys.Rev. D94 (2016) no.3, 034042

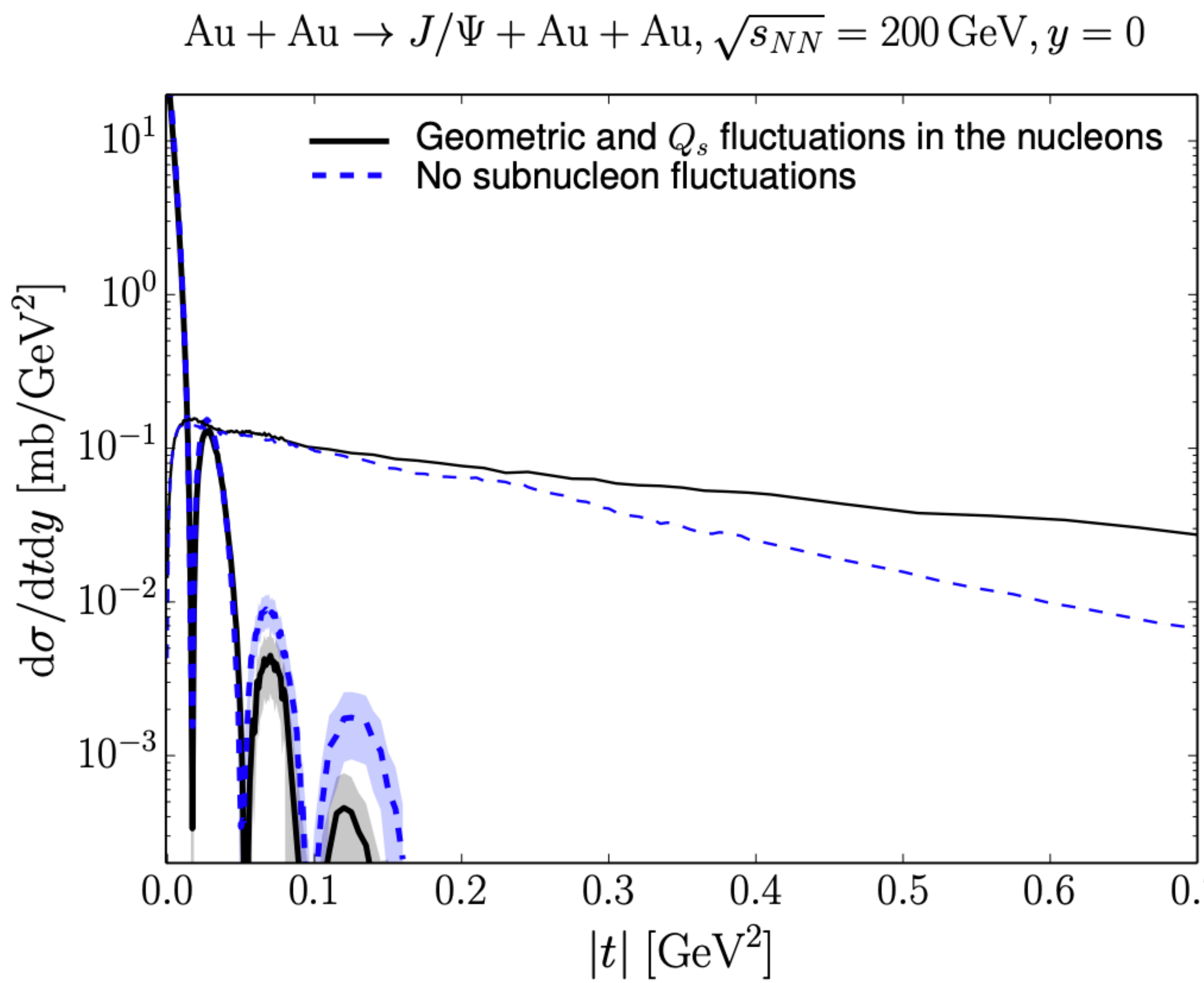




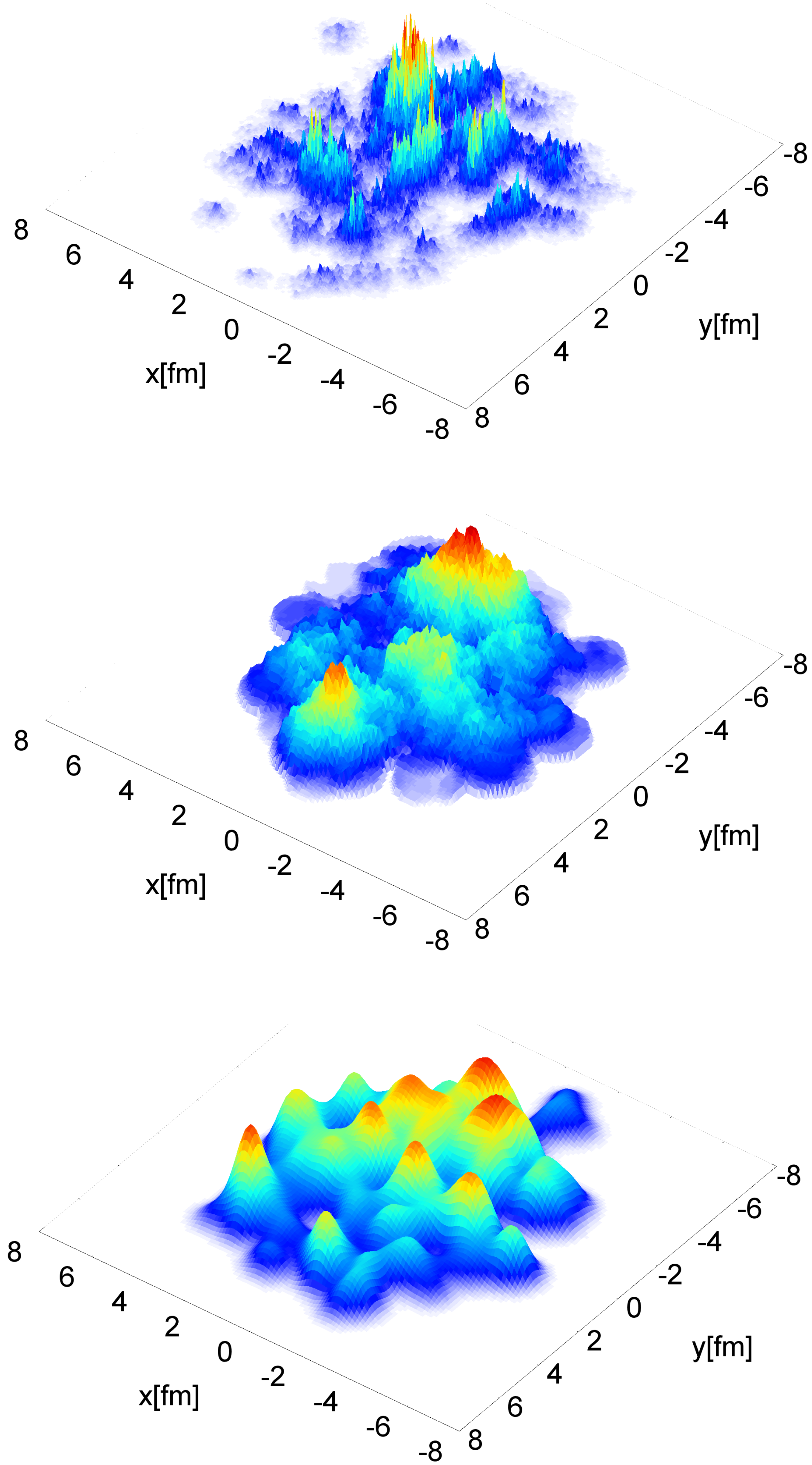
Fluctuations inside Nucleons

Two different fluctuations:

Around low scale partons + **Saturation Scale**



Heikki Mäntysaari, Björn Schenke (Brookhaven Natl. Lab.) Phys.Lett. B772 (2017) 832-838



Summary

The **EIC** provides the only way to measure the **Nuclear Initial State:**

Saturation

Gluon Fluctuations

Nuclear Imaging

Constrict Nuclear PDFs

Essential for limiting major uncertainties in many AA observables

Going from *ep* to eA

ep:

$$\mathrm{Re}(S) = 1 - \mathcal{N}^{(p)}(x, r, \mathbf{b}) = 1 - \frac{1}{2}\frac{\mathrm{d}\sigma^{(p)}_{q\bar{q}}(x, r, \mathbf{b})}{\mathrm{d}^2\mathbf{b}}$$

eA:

Independent scattering approximation

$$1 - \mathcal{N}^{(A)} = \prod_{i=1}^{A}\left(1 - \mathcal{N}^{(p)}(x, r, |\mathbf{b} - \mathbf{b}_i|)\right)$$

Assume the Woods-Saxon distribution

bSat:

$$\frac{\mathrm{d}\sigma^{A}_{q\bar{q}}}{\mathrm{d}^2\mathbf{b}} = 2\left[1 - \exp\left(-\frac{\pi^2}{2N_c} r^2 \alpha_{\mathrm{s}}(\mu^2) x g(x, \mu^2) \sum_{i=1}^{A} T_p(\mathbf{b} - \mathbf{b}_i)\right)\right]$$

What we learn from diffraction:

Obervable	Process	What we learn	Coh./Inc.
$\sigma_{diff}/\sigma_{tot}$	Inclusive	Level of saturation	Coherent
$d\sigma/dt$ No breakup	Exclusive	Spatial gluon density $\rho_G(\mathbf{b})$, important for e.g. η/S	Coherent
$d\sigma/dt$ Breakup	Exclusive	Fluctuations and lumpiness of gluons in ions	Incoherent
$d\sigma/dt$	Exclusive	Level of saturation	Coherent & Incoherent
$\Delta\Phi$ of dihadrons	DIS	Level of saturation vs. shadowing	

Detecting Nuclear Breakup

- Detecting **all** fragments $p_{A'} = \sum p_n + \sum p_p + \sum p_d + \sum p_\alpha$ ... not possible
- Focus on n emission
  - Zero-Degree Calorimeter
  - Requires careful design of IR
- Additional measurements:
  - Fragments via Roman Pots
  - γ via EMC

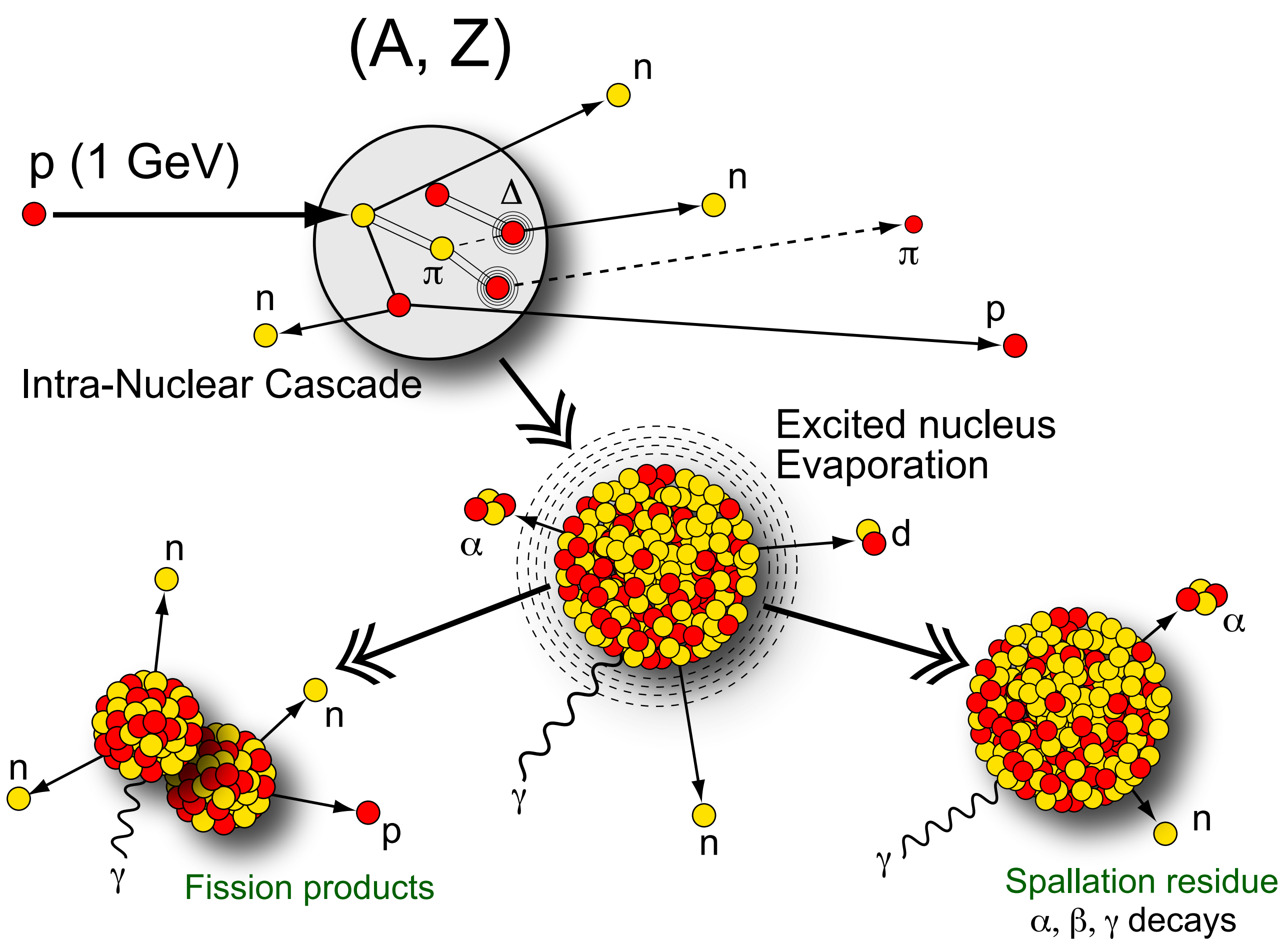
Traditional modeling done in pA:

Intra-Nuclear Cascade

- Particle production
- Remnant Nucleus (A, Z, E*, ...)
- ISABEL, INCL4

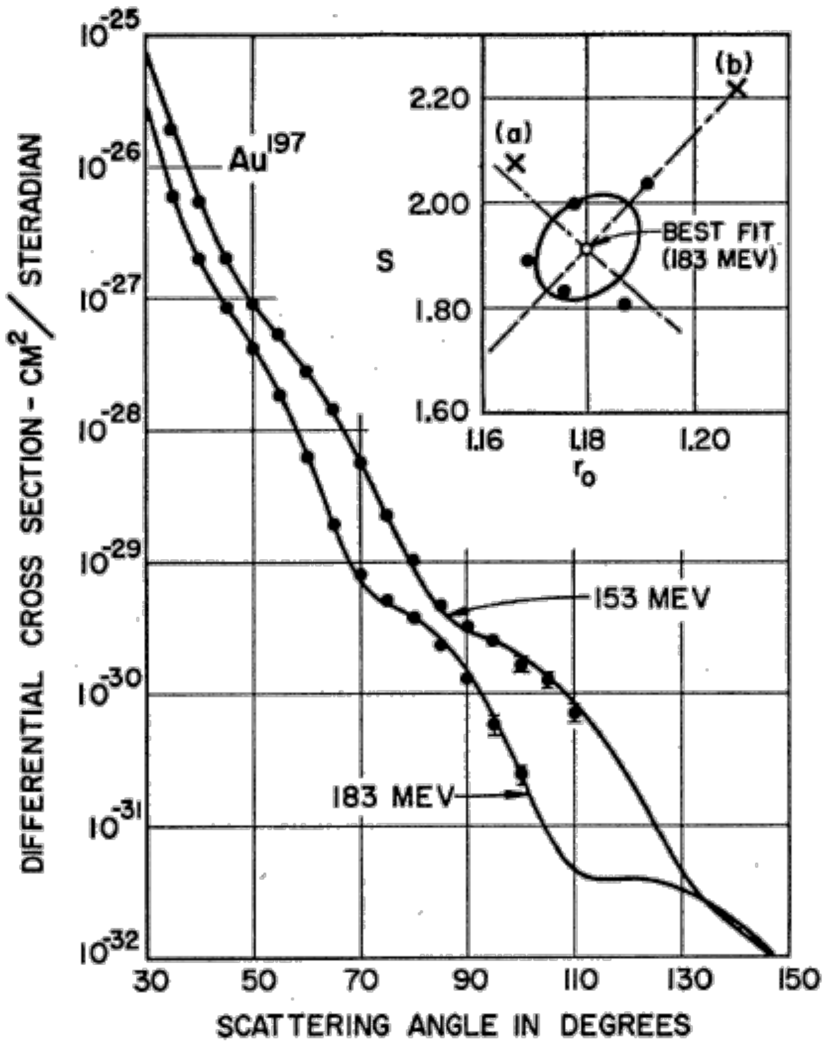
De-Excitation

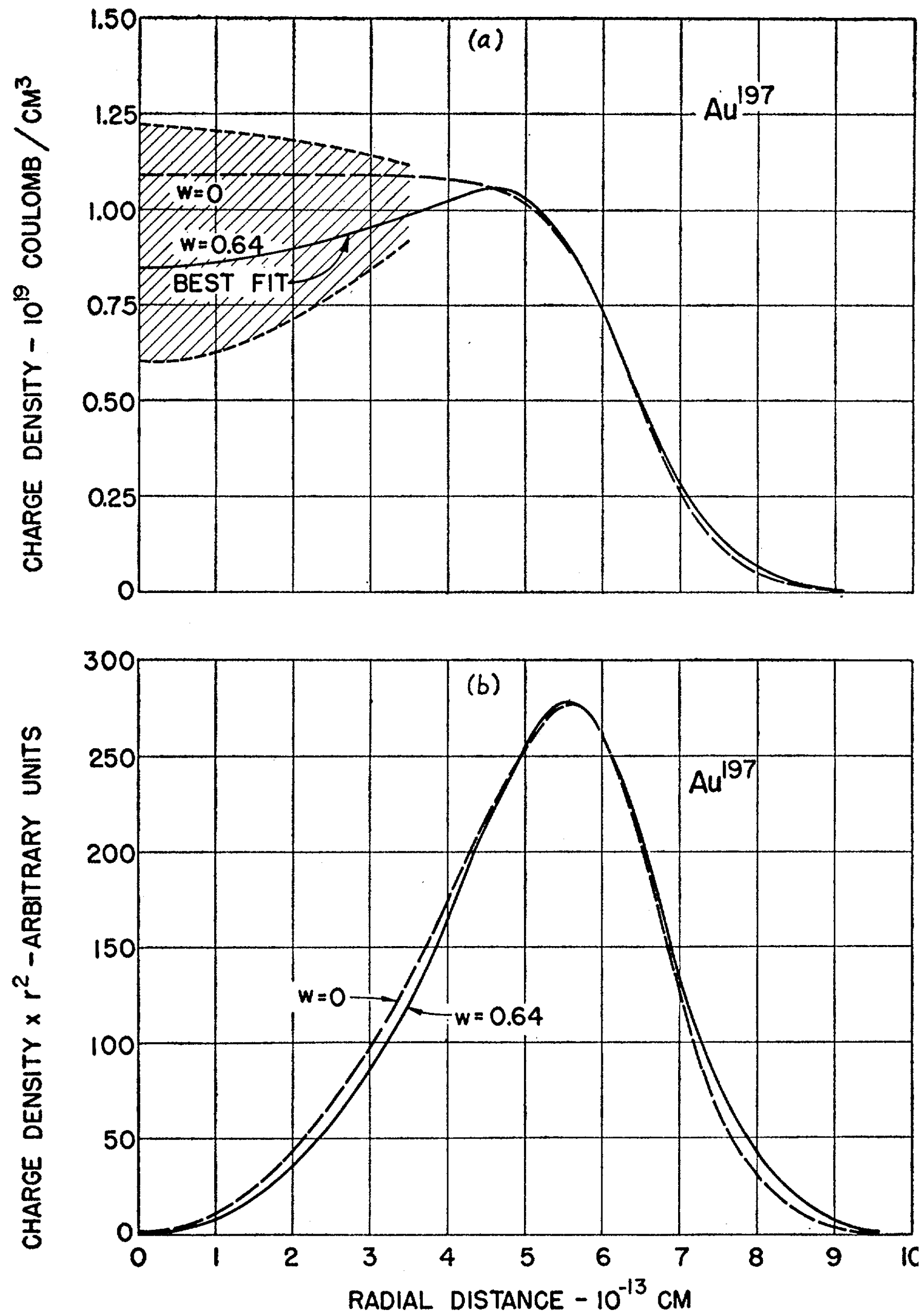
- Evaporation
- Fission
- Residual Nuclei
- Gemini++, SMM, ABLA (all no γ)



What has been measured?

Hahn, Ravenhall, and Hofstadter,
Phys Rev 101 (1956)





Electron colliding with fixed ion target,
large *x* charge distribution - no gluons!