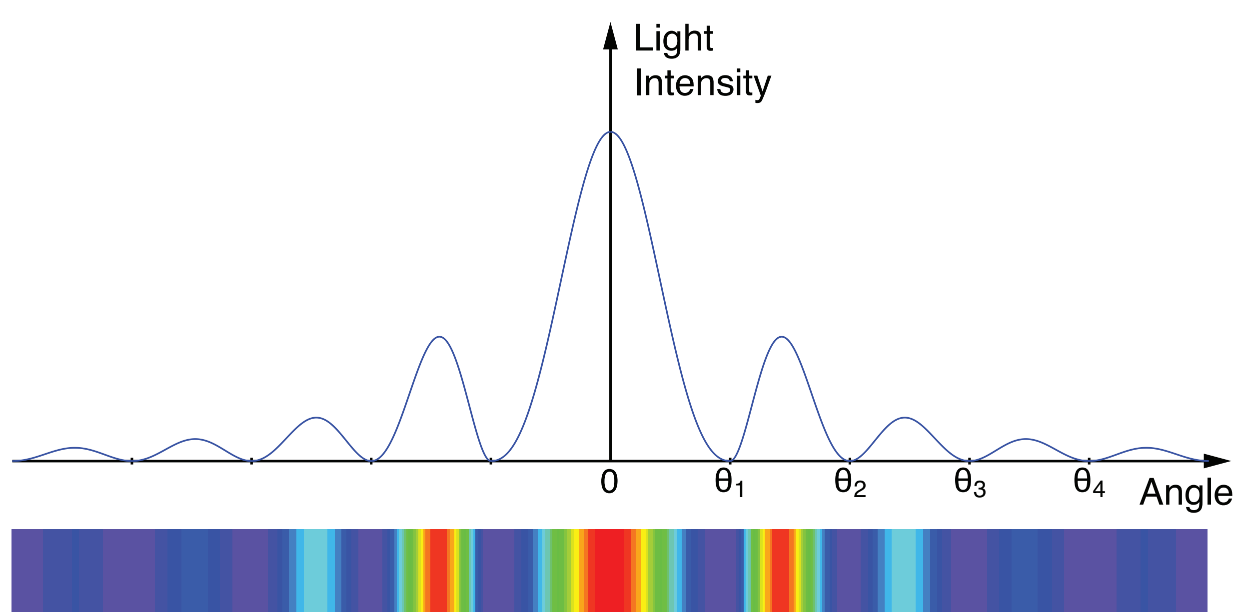
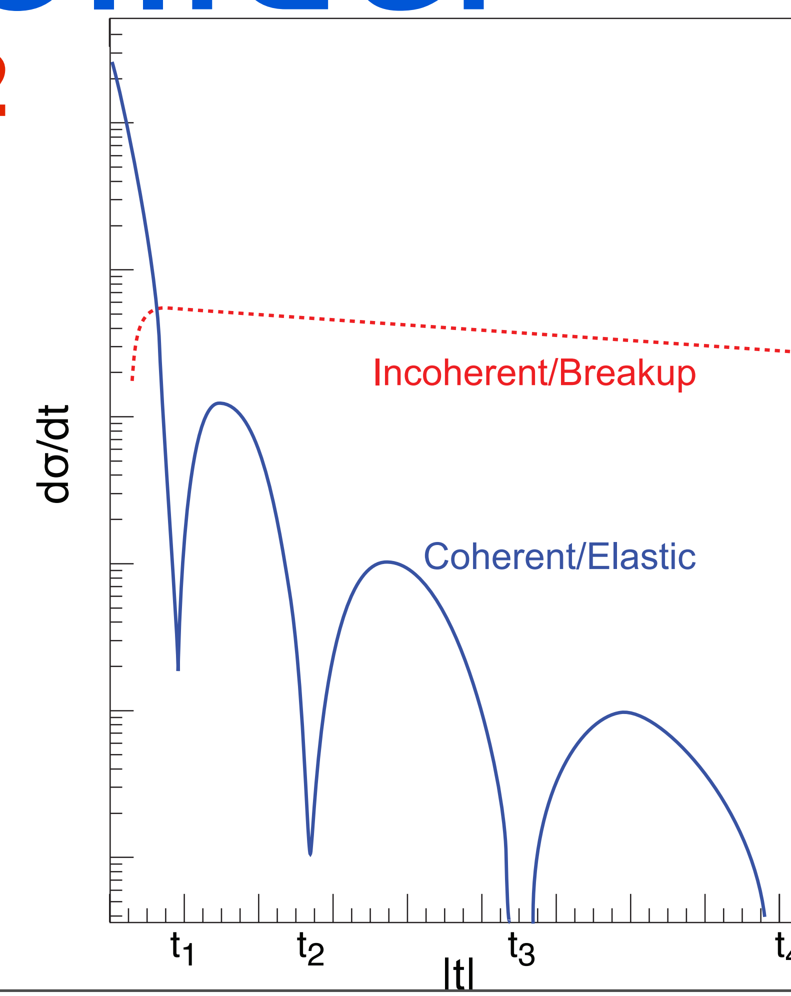
eRHIC

understanding the nuclear initial state with an electron ion collider

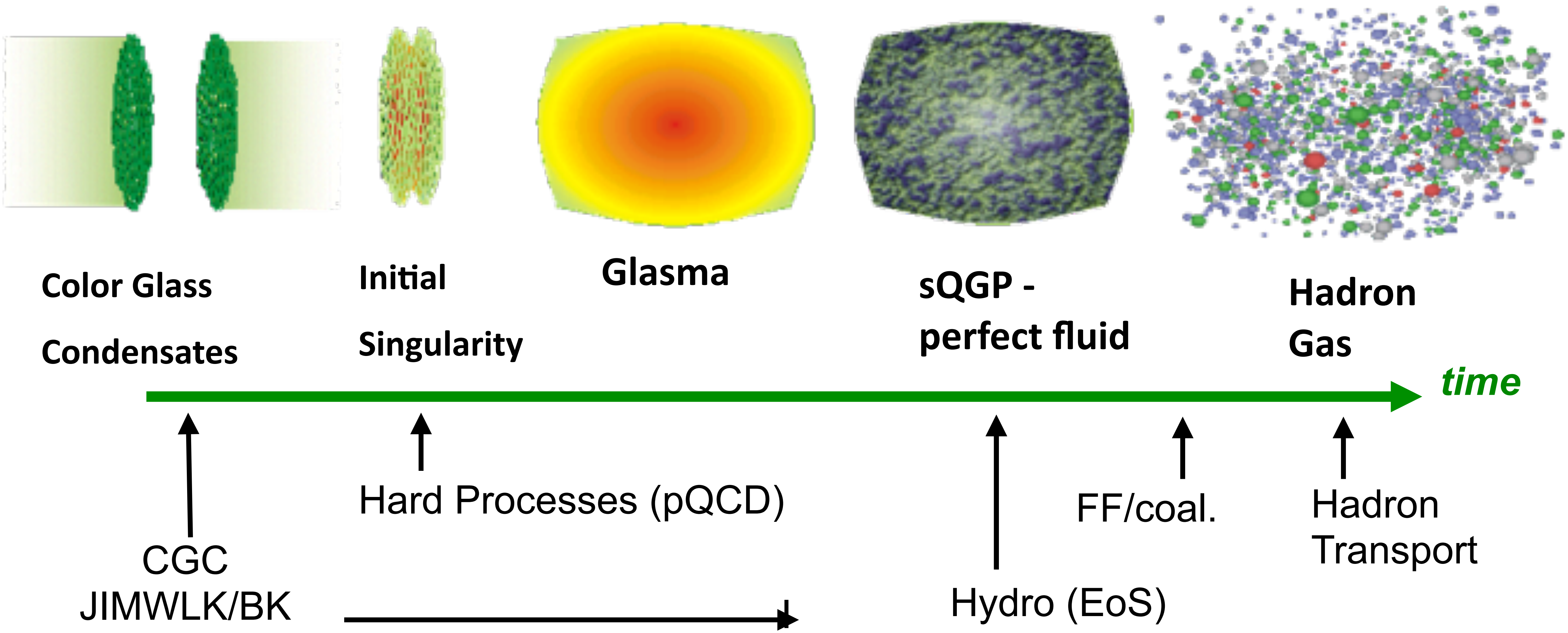
hot quarks 2012

tobias toll





“standard model of heavy ion collisions”



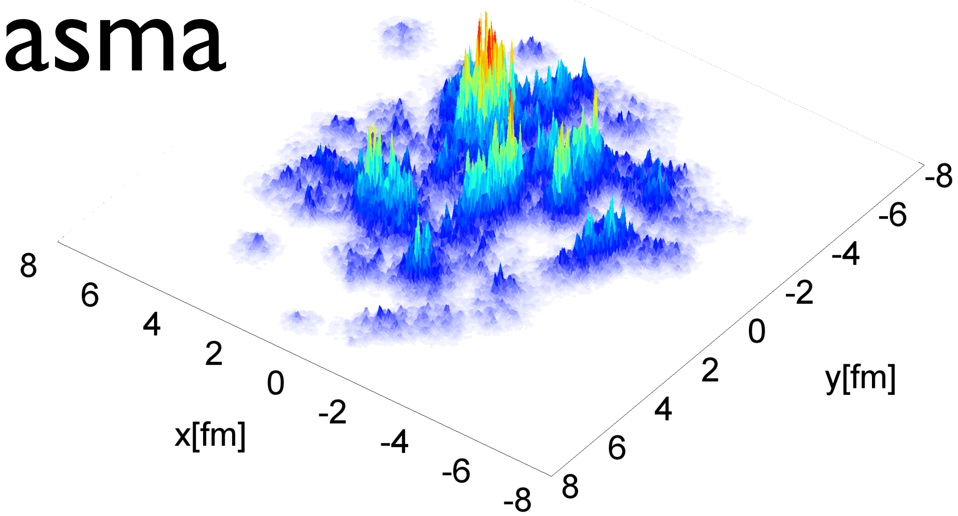
our understanding of some fundamental properties of the glasma, sQGP, and hadron gas depend strongly on our knowledge of the initial state!

3 conundrums of the initial state:

1. what is the spatial transverse distributions of gluons?
2. how much does the spatial distribution fluctuate? lumpiness, hot-spots etc.
3. how saturated is the initial state of the nucleus?

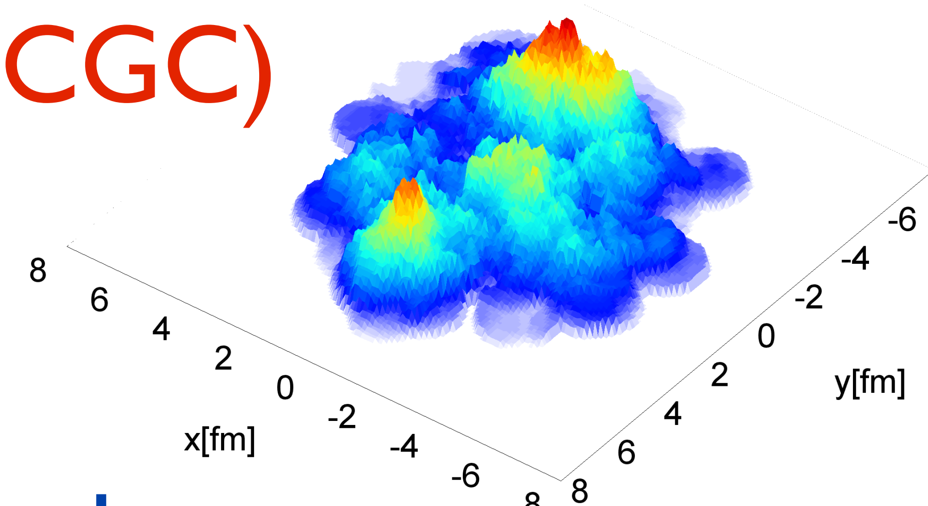
is the sQGP a perfect fluid?

IP-Glasma

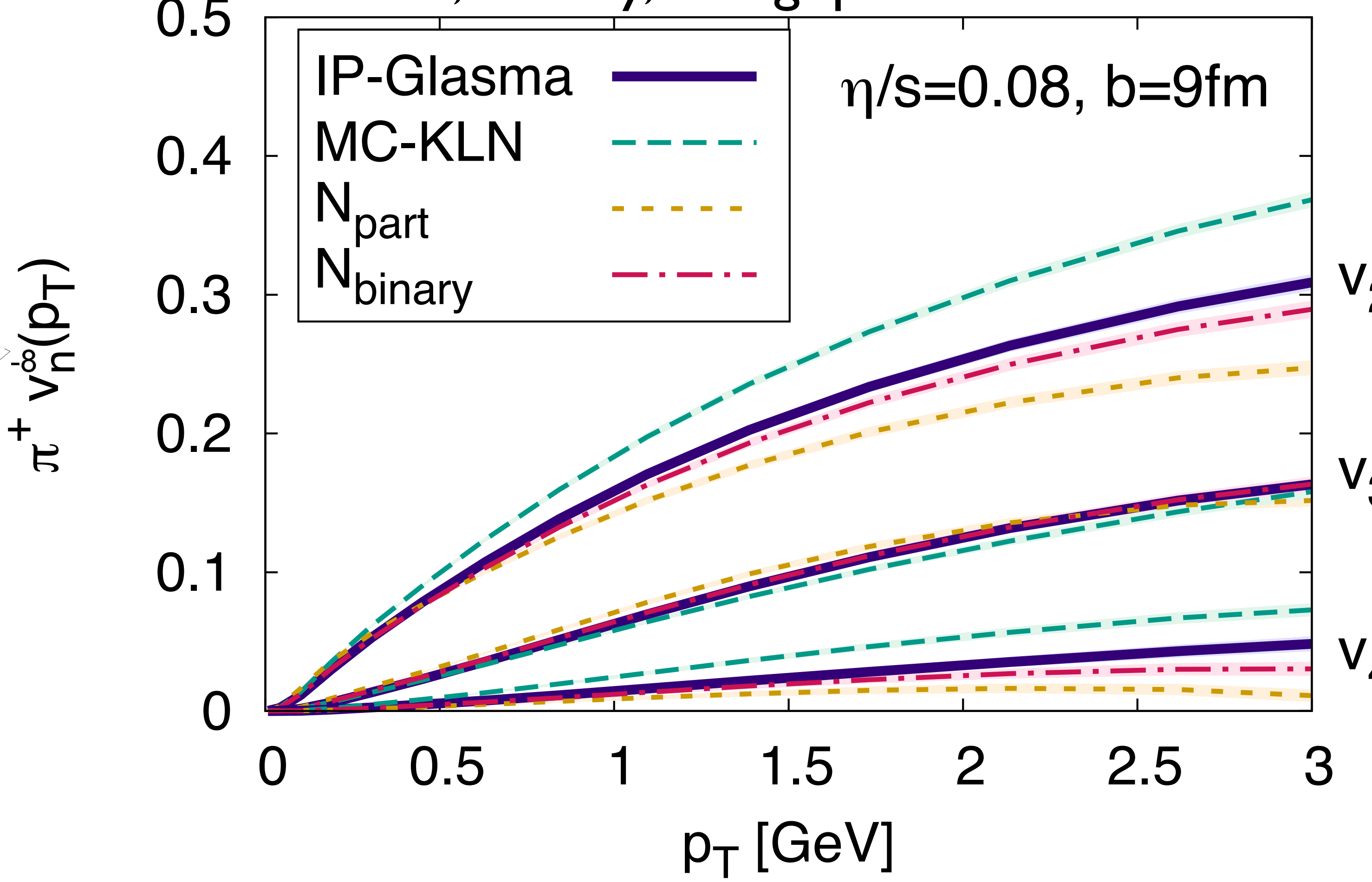


different initial states,
different fluctuation scales

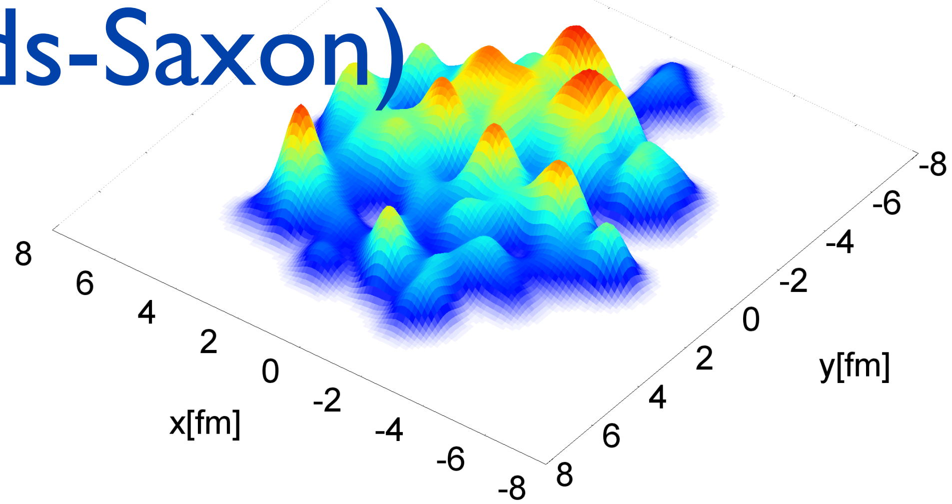
KLN(CGC)



Schenke, Tribedy, Venugopalan arXiv:1202.6646



Glauber
(Woods-Saxon)

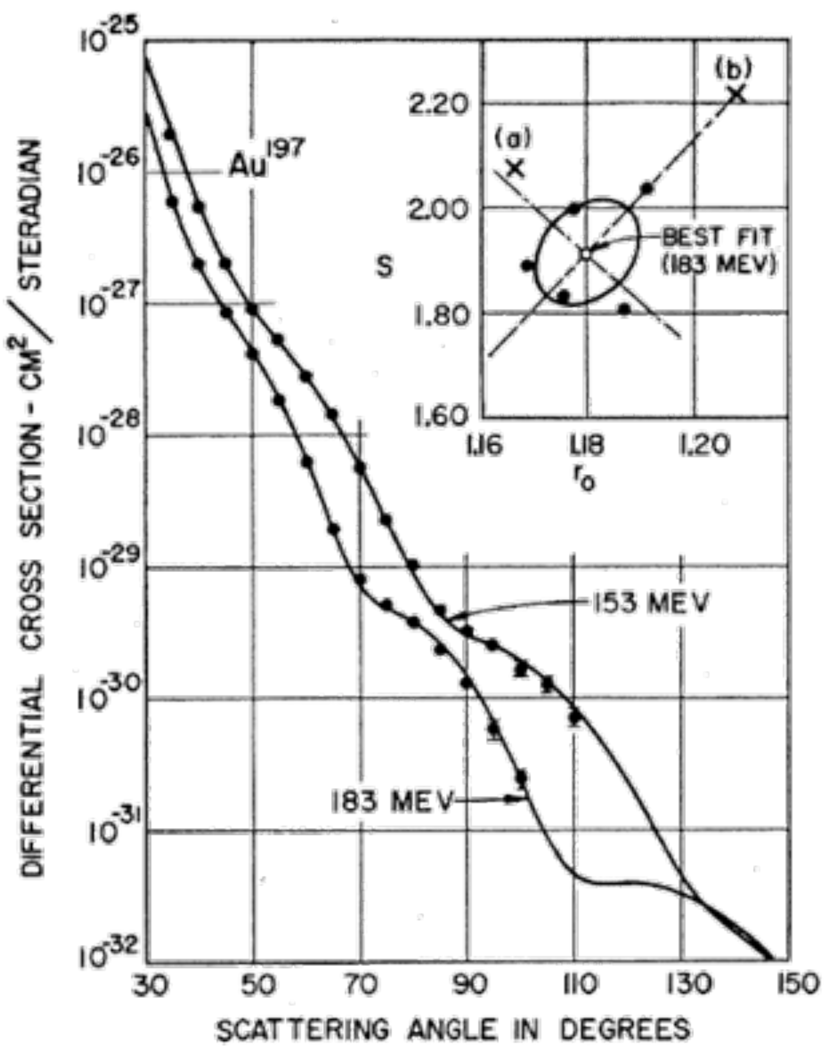


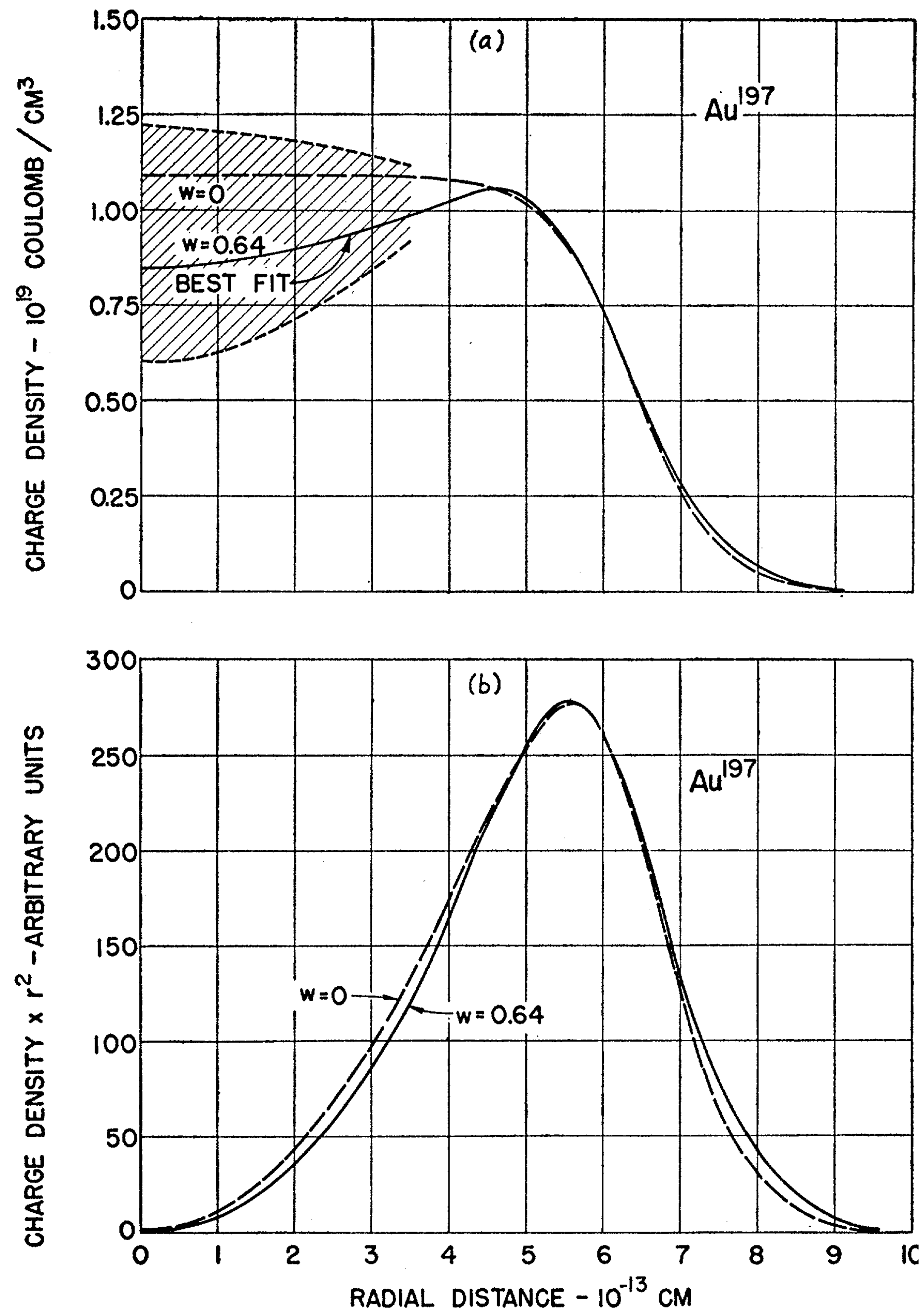
AdS/CFT predicts for a perfect fluid: $\eta/s = 1/(4\pi) \sim 0.08$

wouldn't it be nice if we could measure the initial state directly?

what has been measured?

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

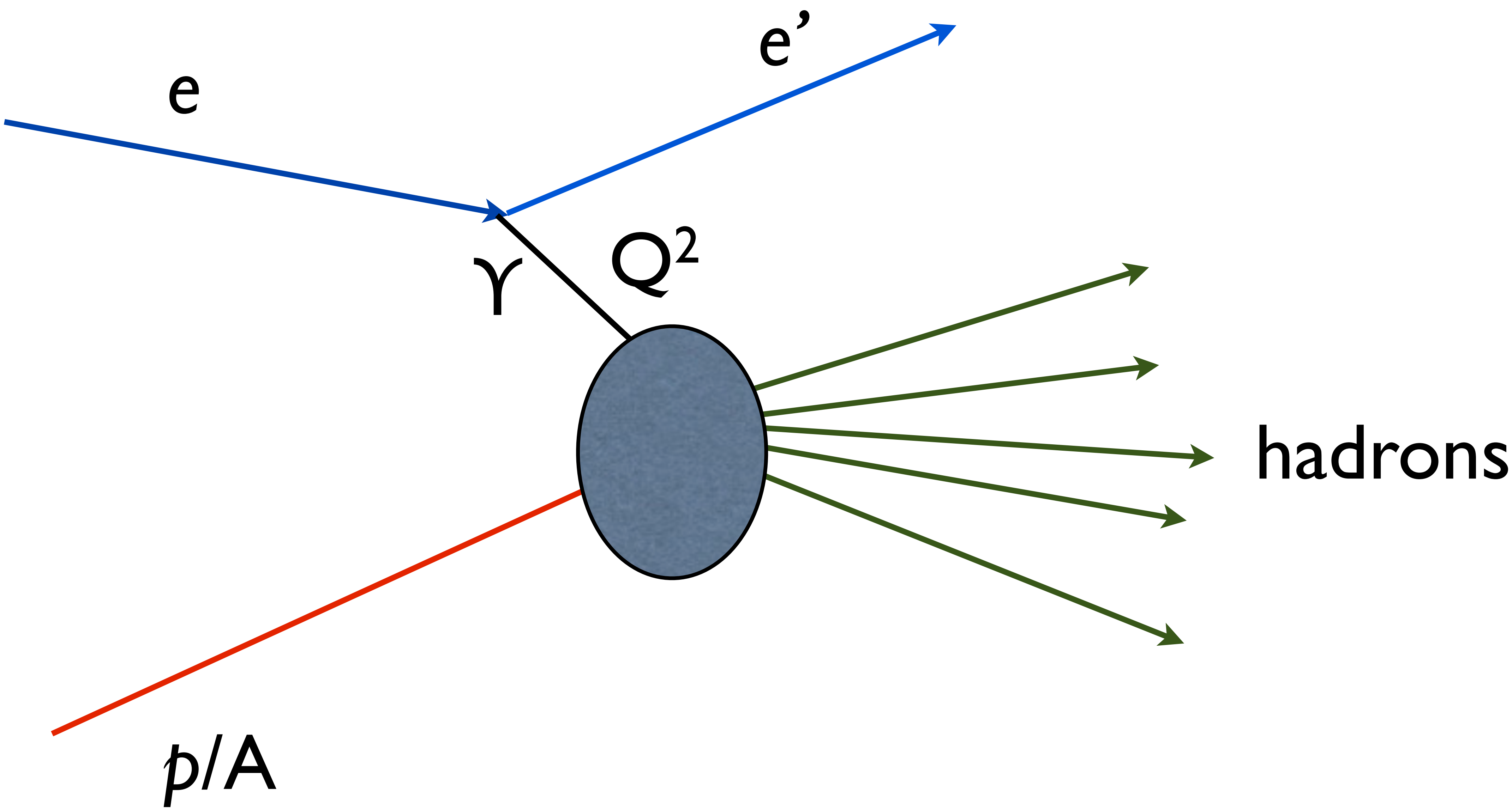




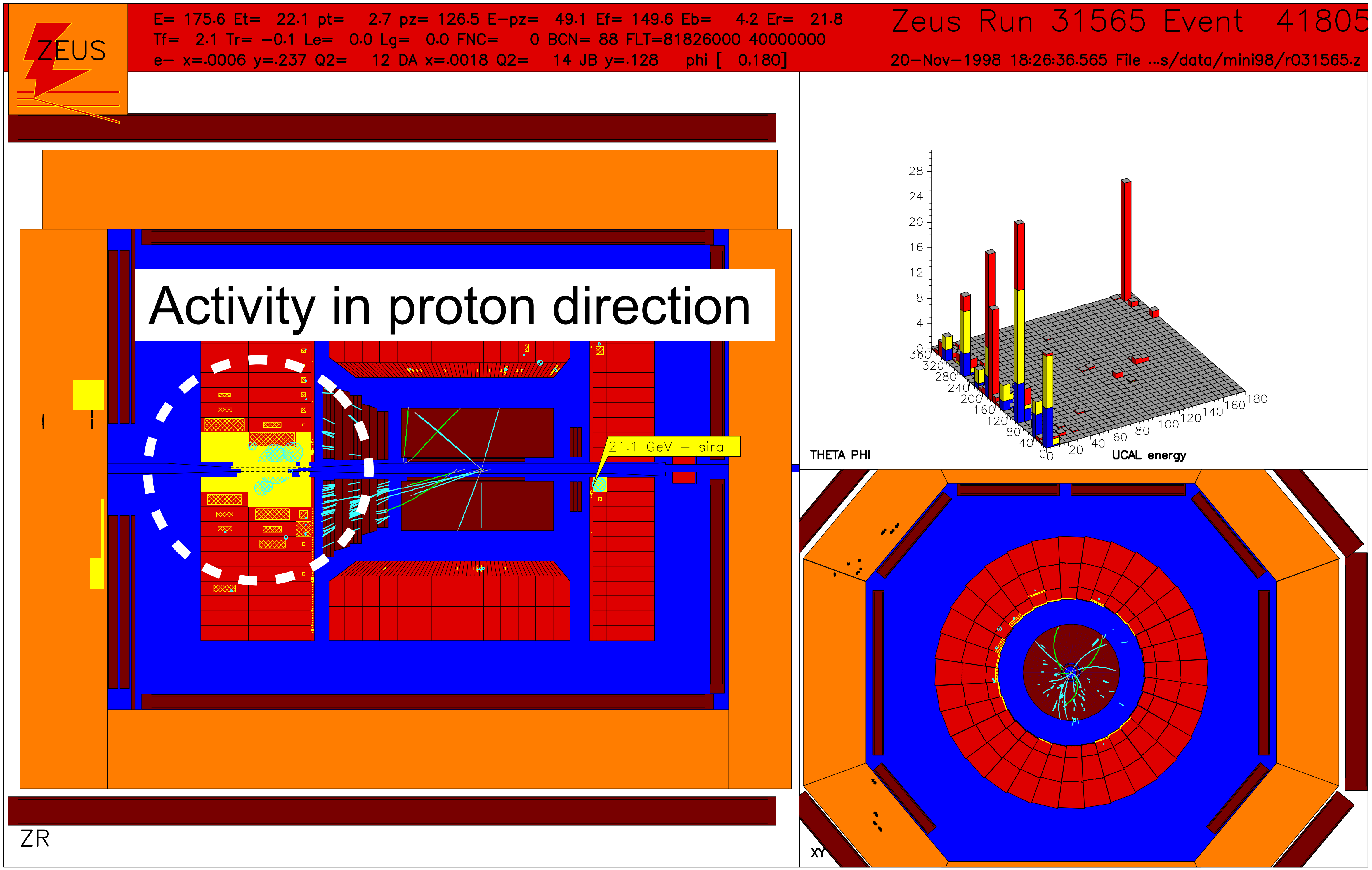
electron colliding with fixed ion target,
large *x* charge distribution - no gluons!

what can eRHIC do?

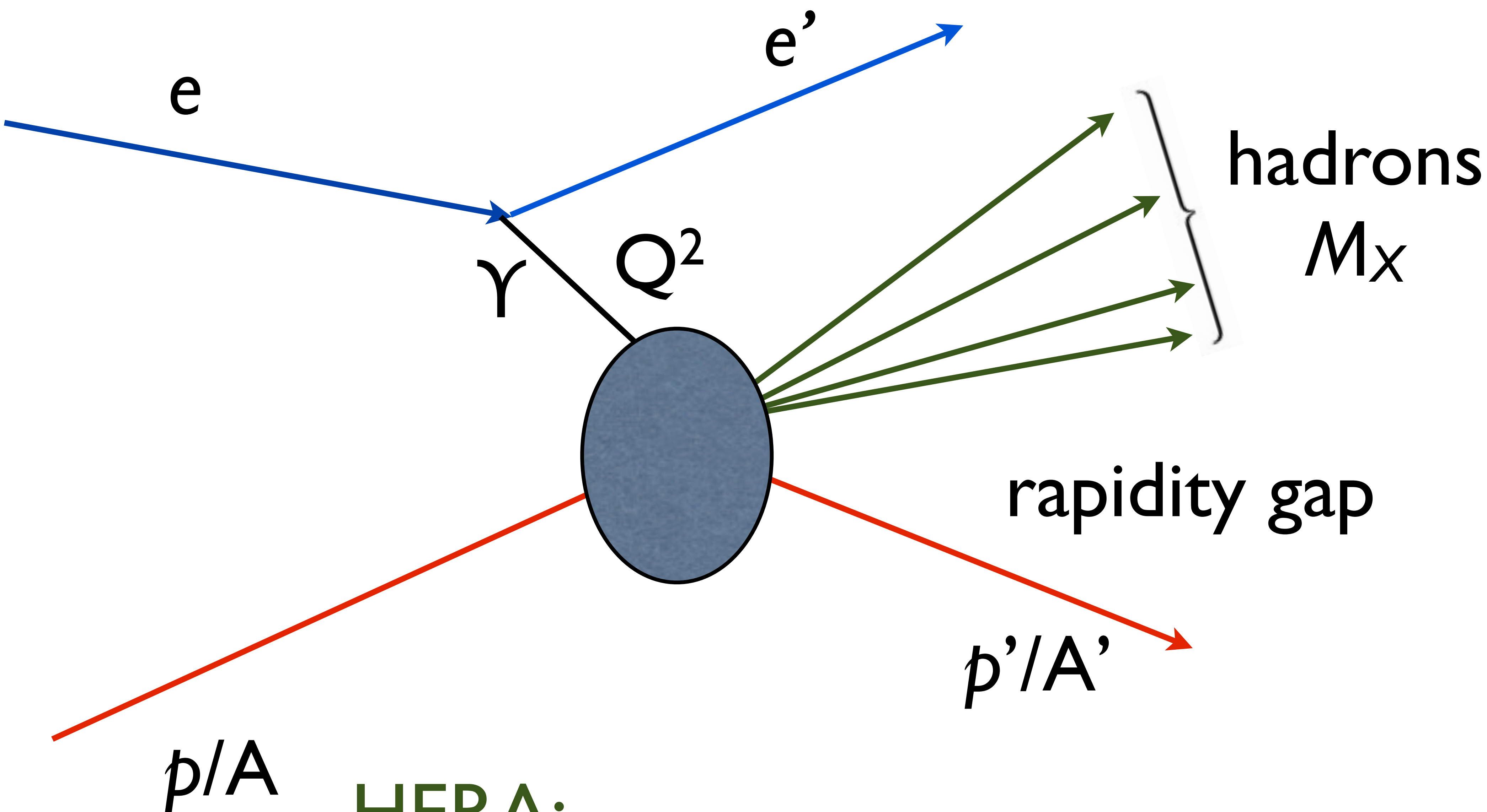
DIS *ep* and eA



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:

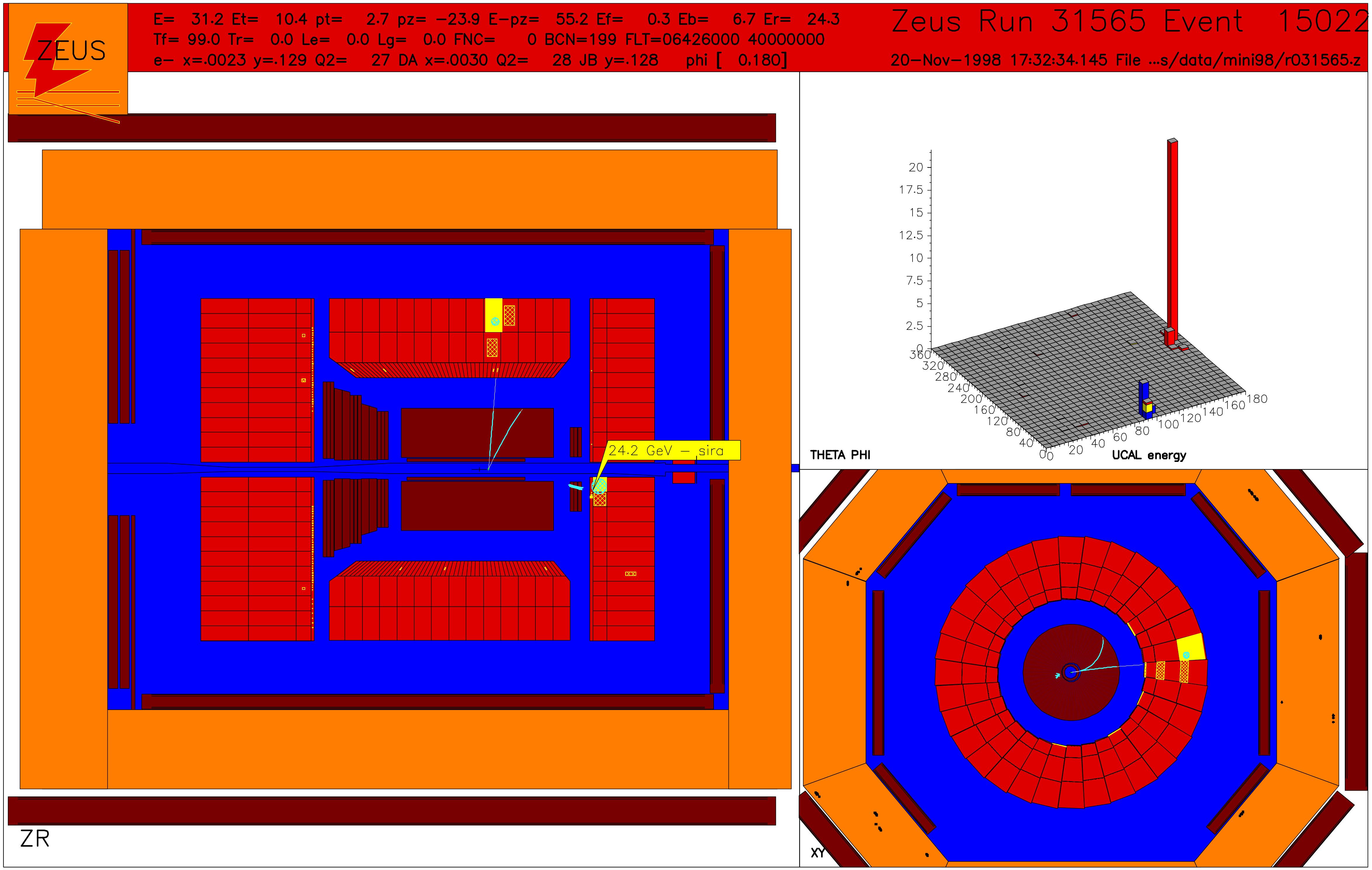
proton collides with electron at CMS energy ~300m_p.

in ~15% of measured collisions proton stays intact!

eRHIC e+A:

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

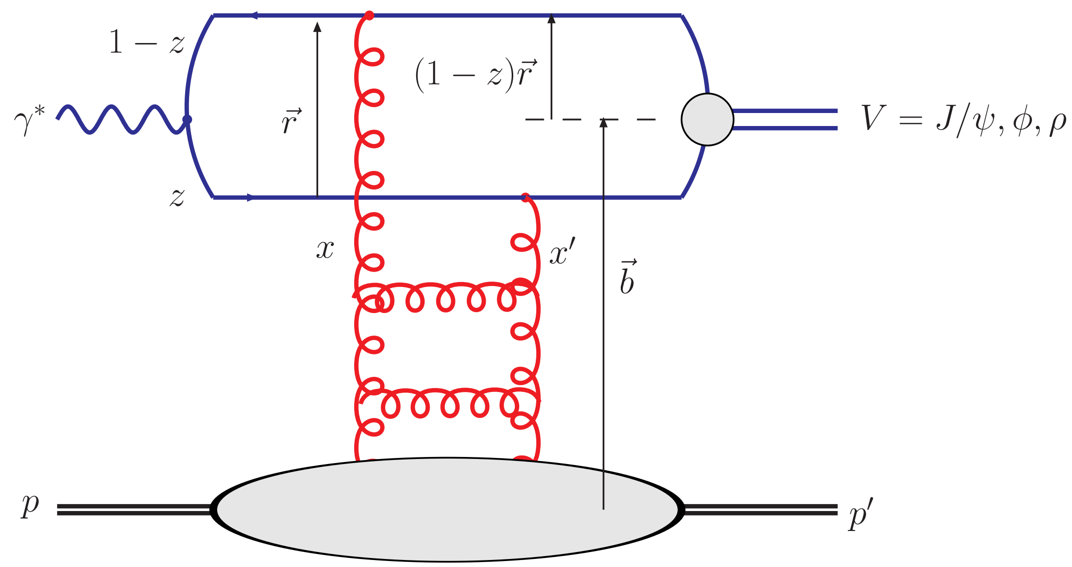
diffraction *ep* and eA

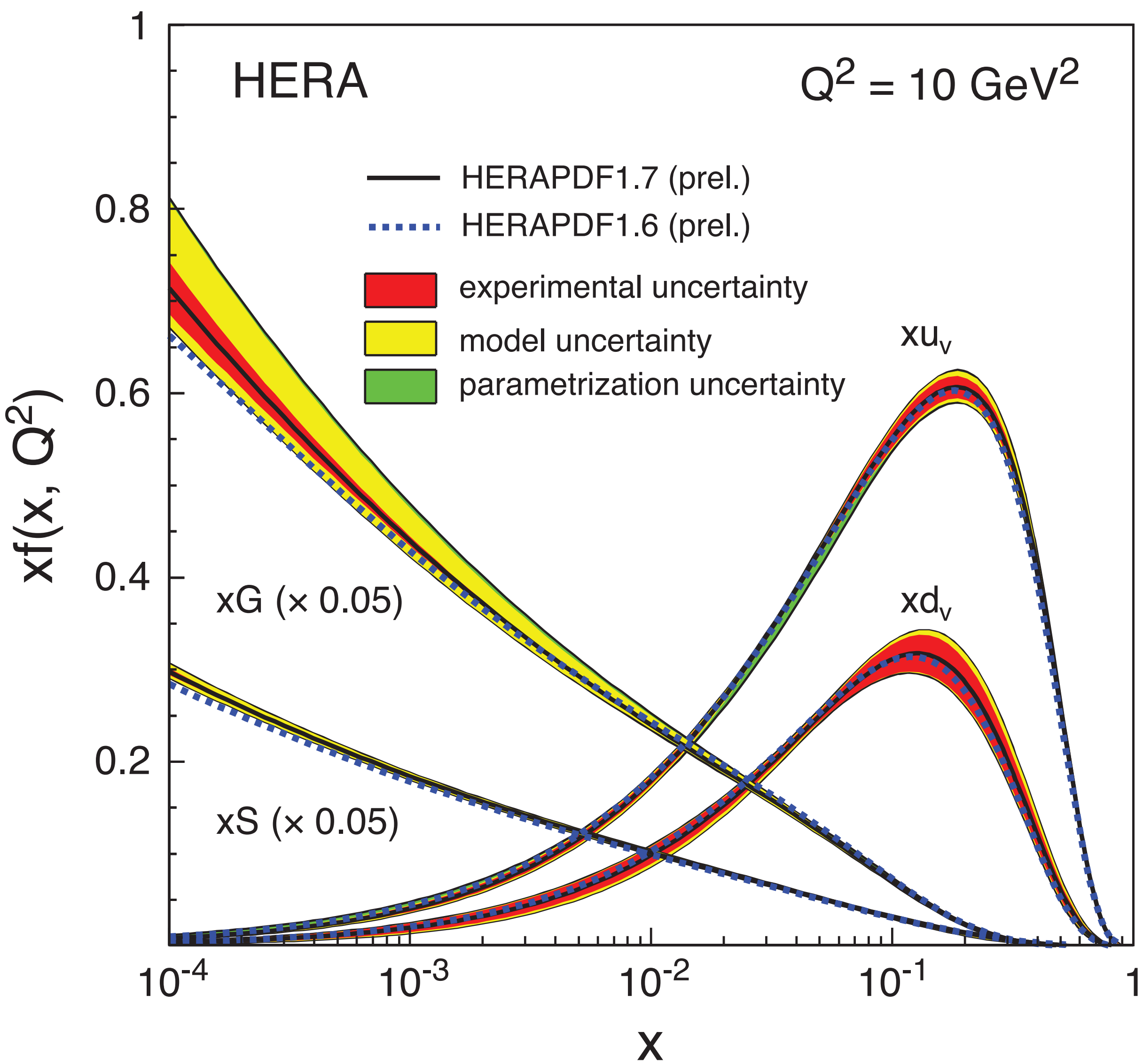


why is diffraction so great?

diffraction sensitive to gluon momentum distributions²:

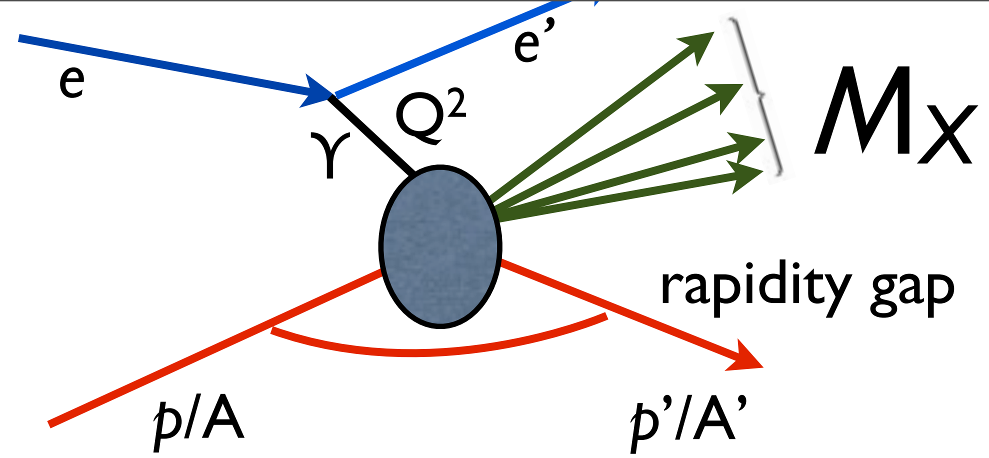
$$\sigma \propto g(x,Q^2)^2$$

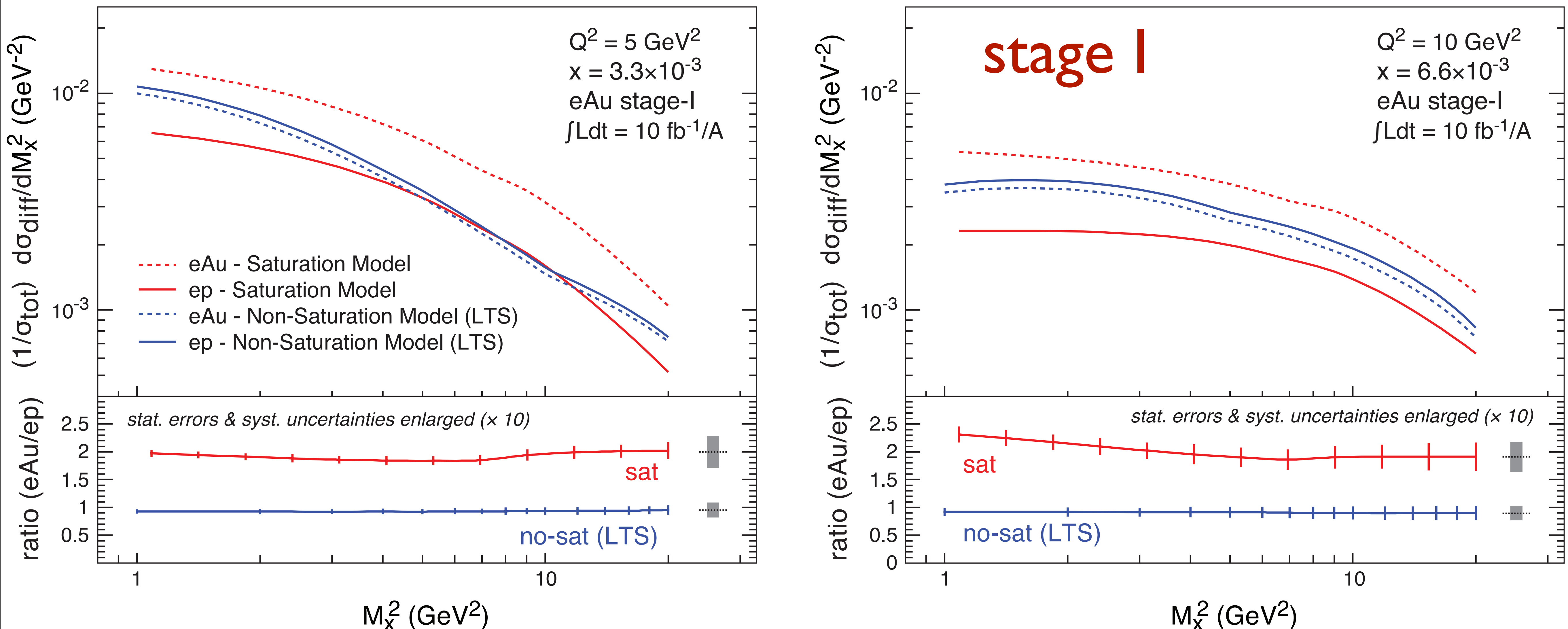




how does the gluon distribution saturate at small *x*?

eRHIC predictions: inclusive diffraction

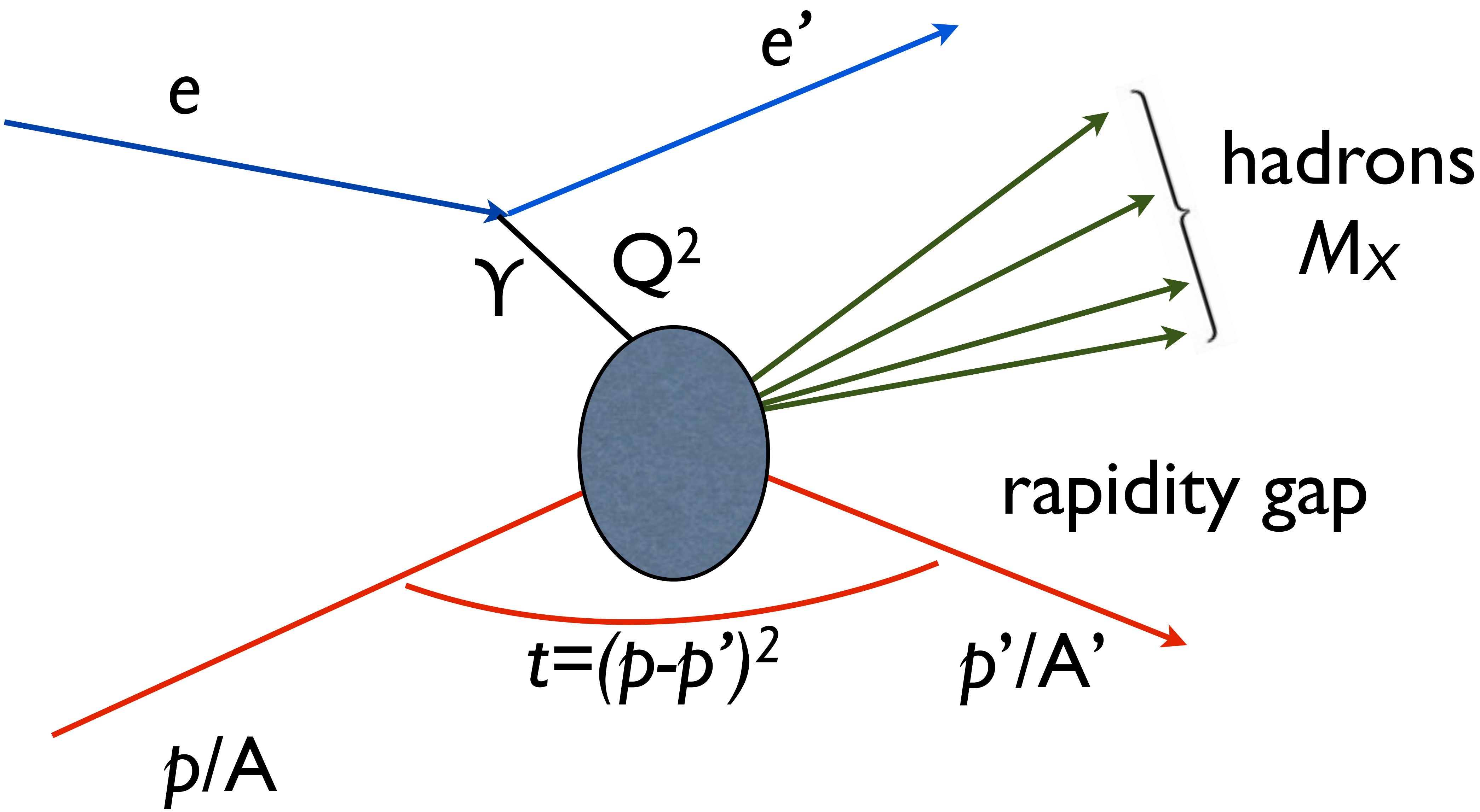




can constrain models a lot with a few months of running!

already in Stage 1!

why is diffraction so great?



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

Fourier transform of t-distribution

=

transverse spatial distribution

spatial imaging!

why is diffraction so great?

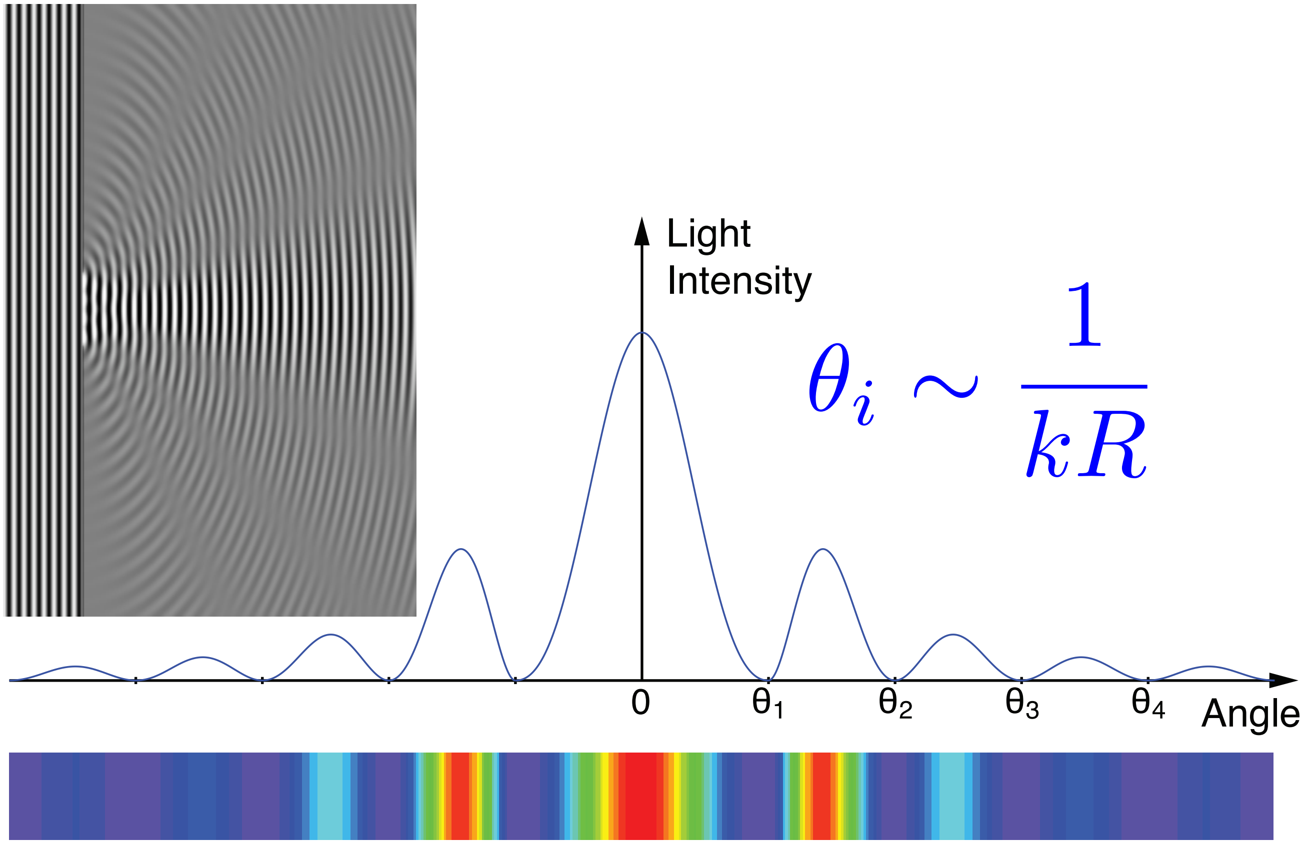
sensitive to spatial gluon distributions

light scattering elastically off a circular screen of radius R

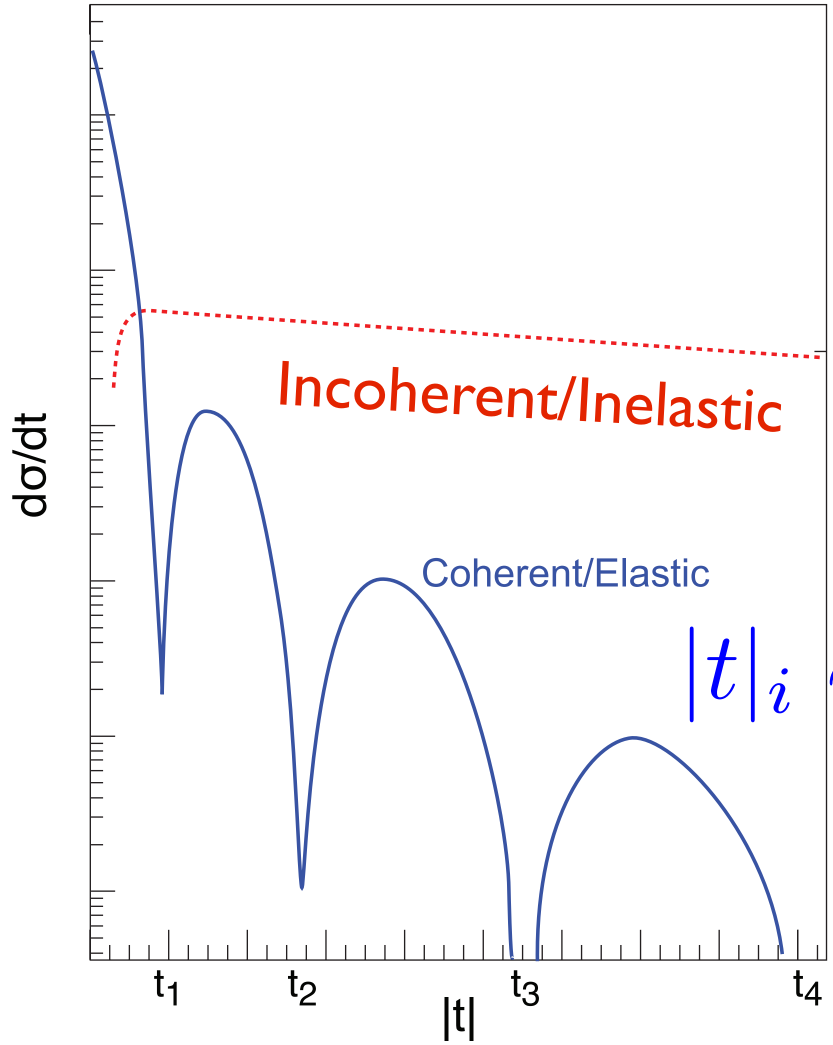
a projectile scattering off a nucleus of radius R

-not a 'black disk', edge effects

-inelastic scattering

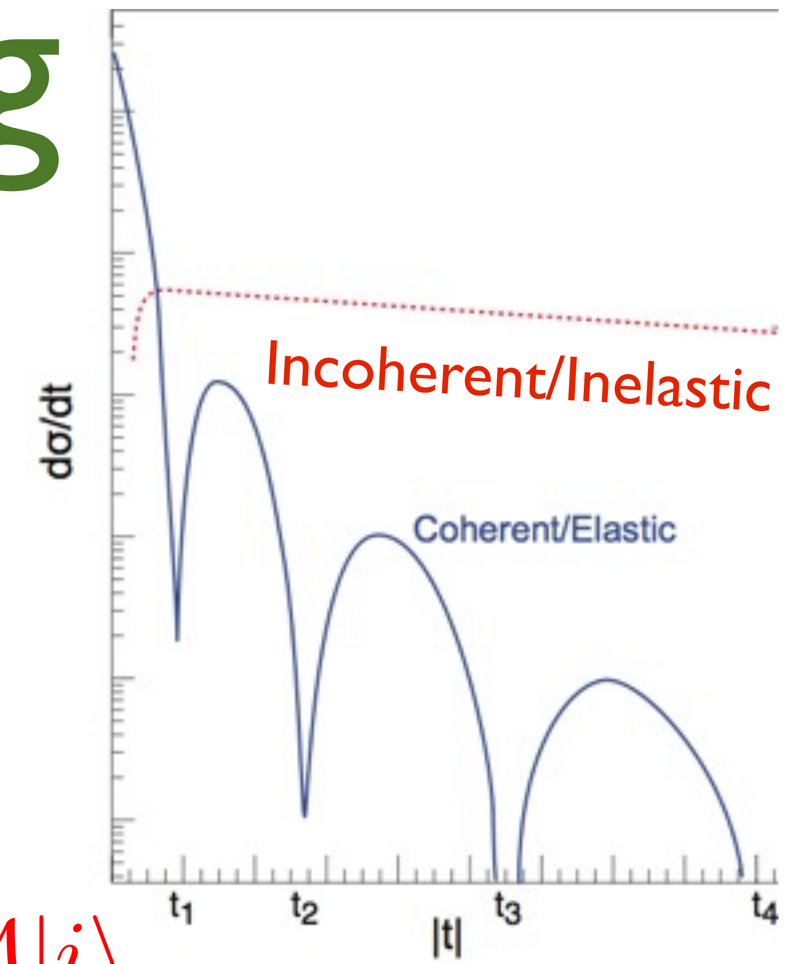


$$\theta_i \sim \frac{1}{kR}$$



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

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

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

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

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

need to measure $P_{A'}$

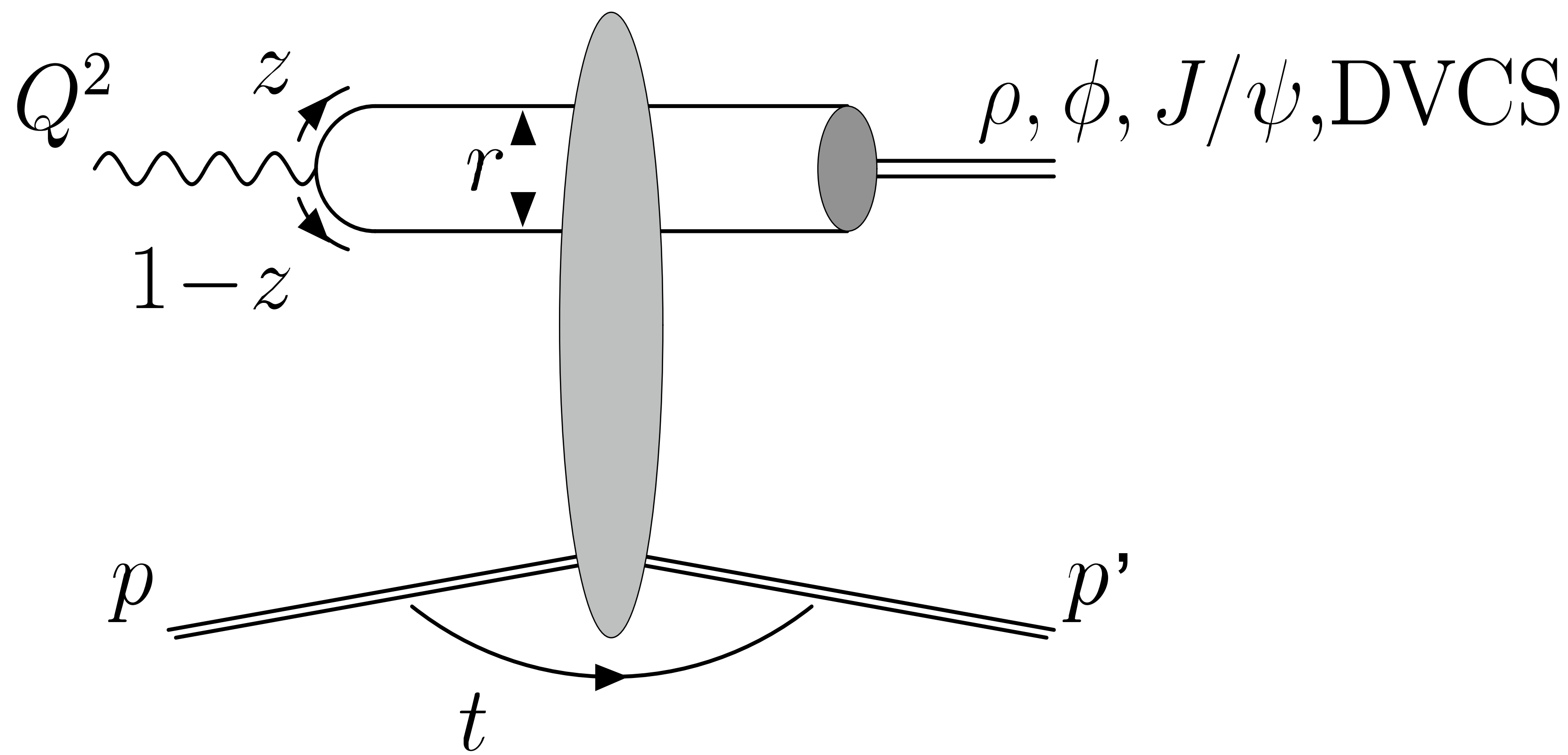
coherent case: A' disappears down beam pipe

incoherent case: cannot measure all beam remnants

only possibility: Exclusive diffraction

e+A → e'+VM+A'

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



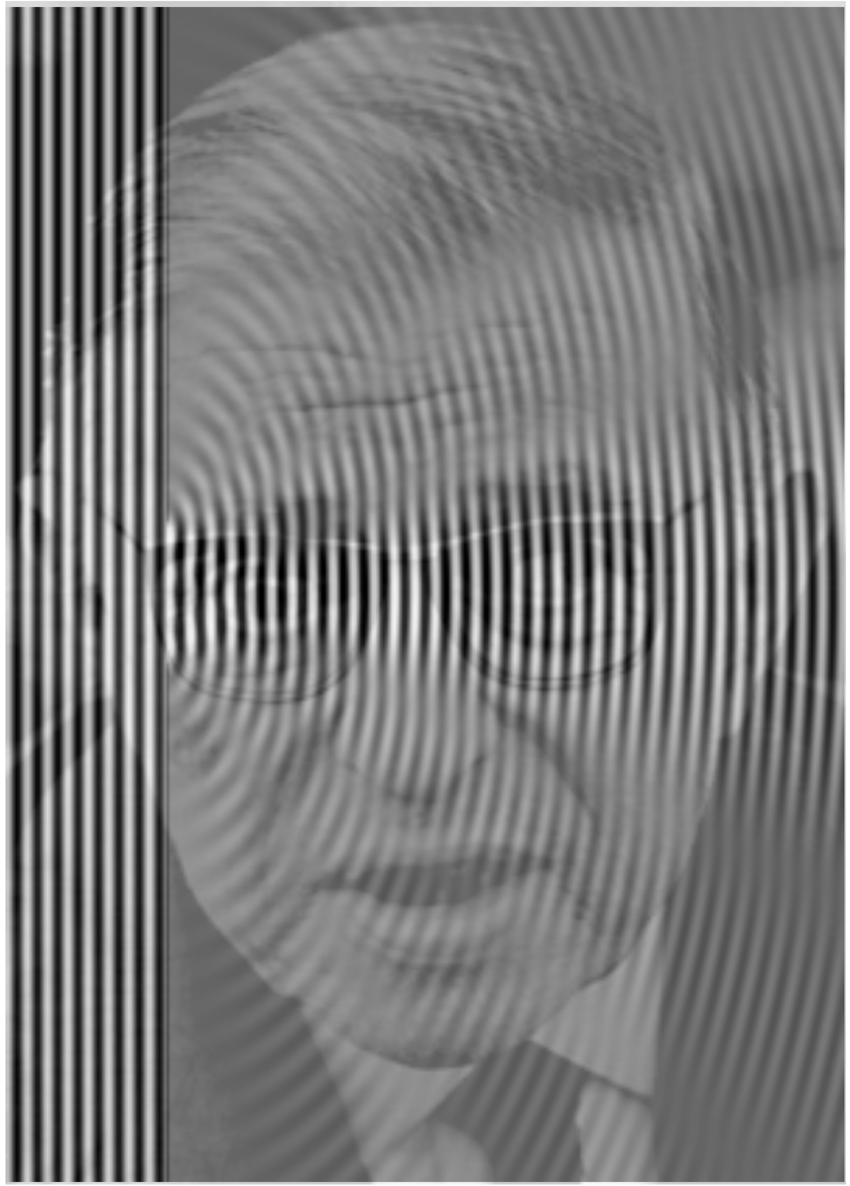
eRHIC predictions:

new physics event generator

sartre

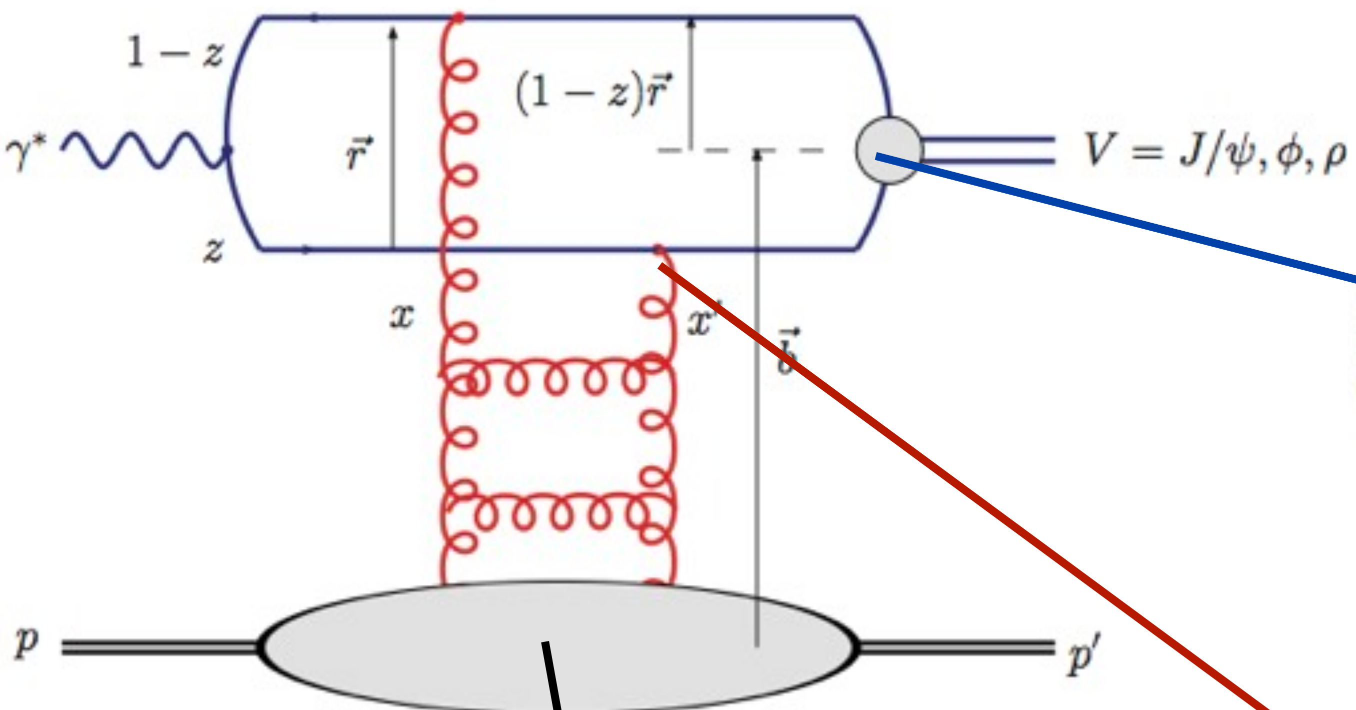
exclusive diffractive vector meson and DVCS production in

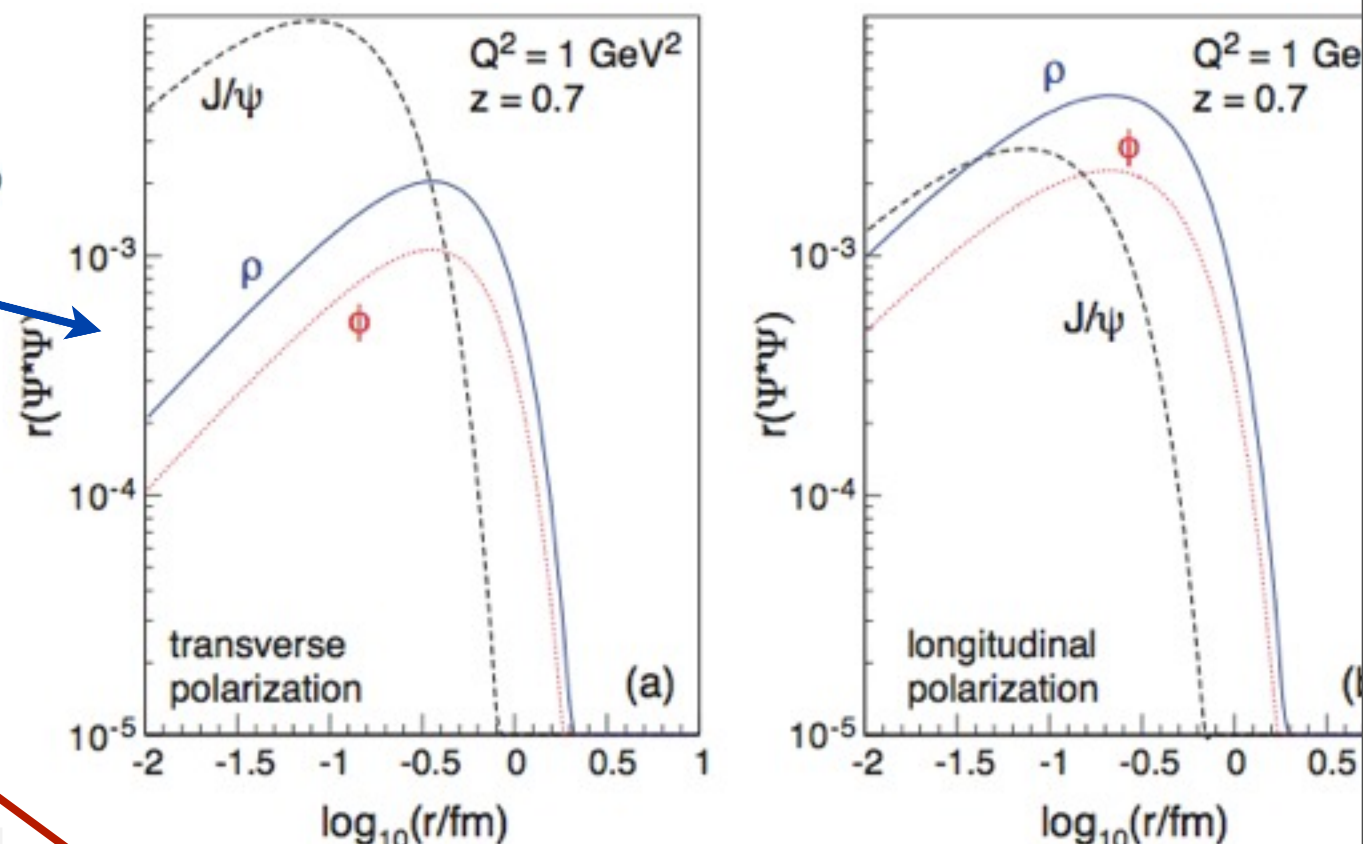
eA

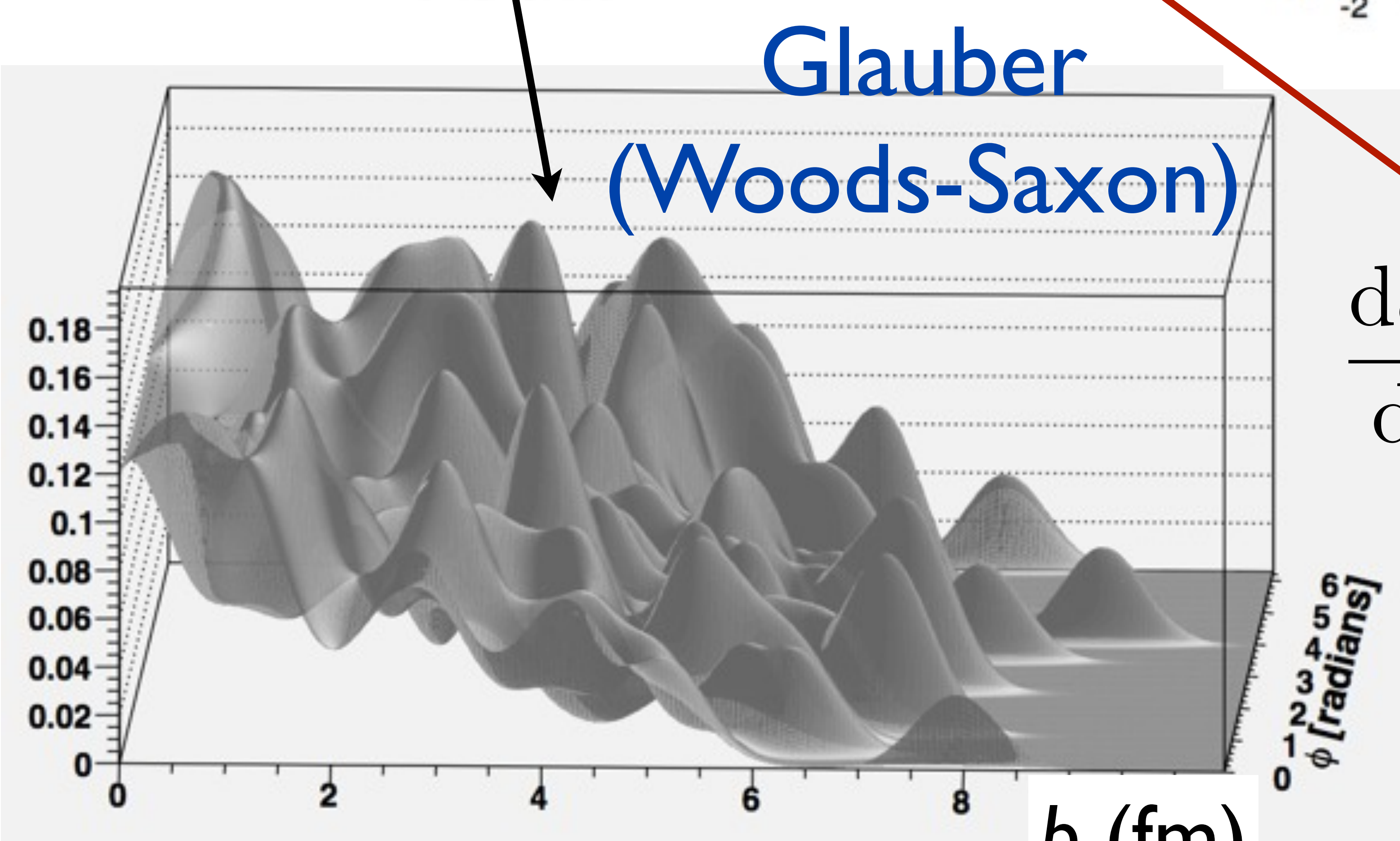


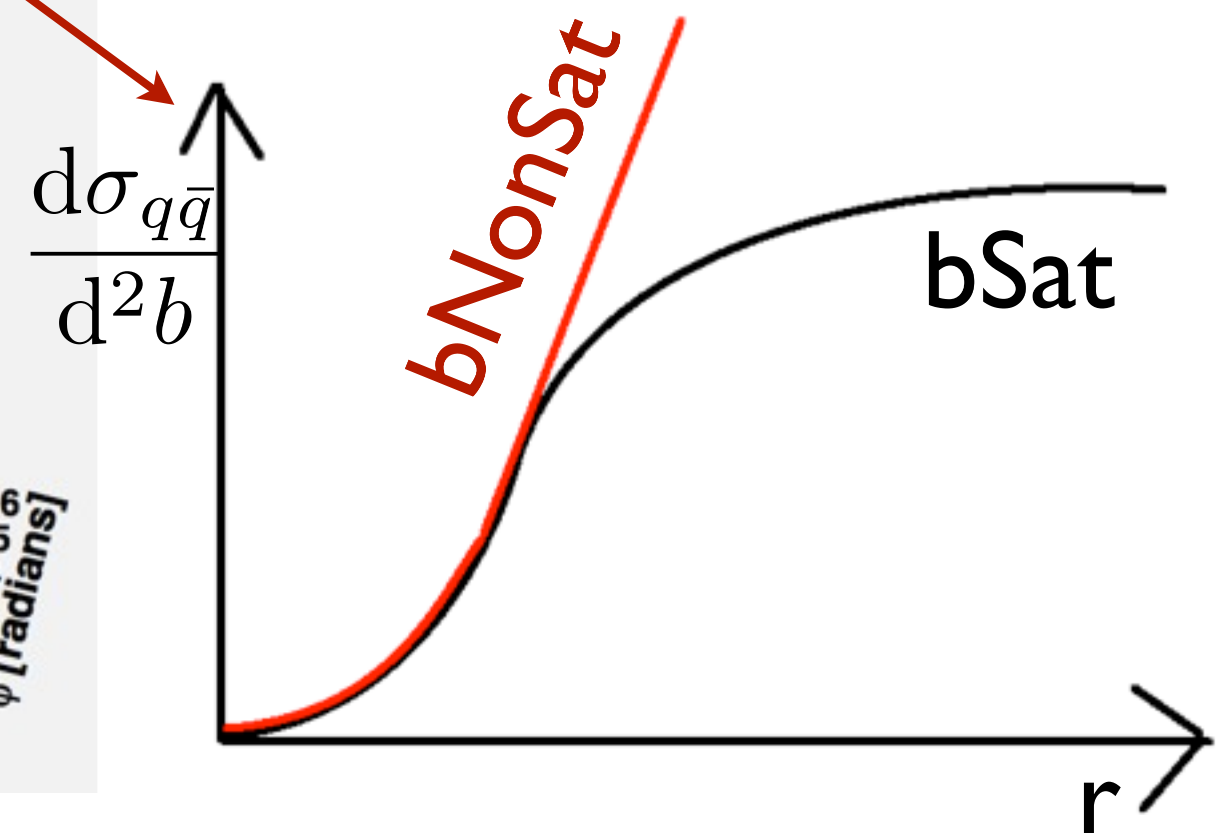
t. ullrich & t.t.

eRHIC predictions:
sartre dipole model with glauber bSat and bNonSat

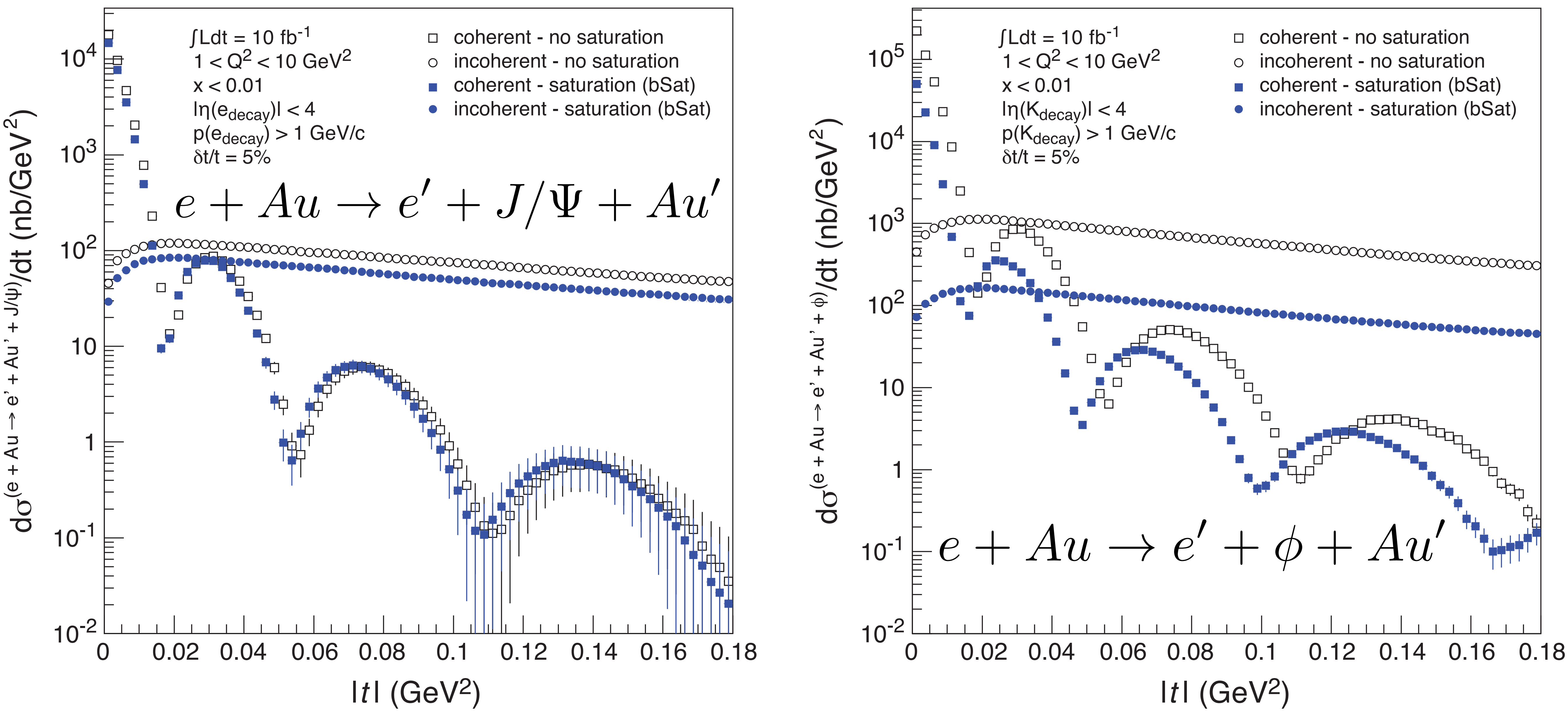








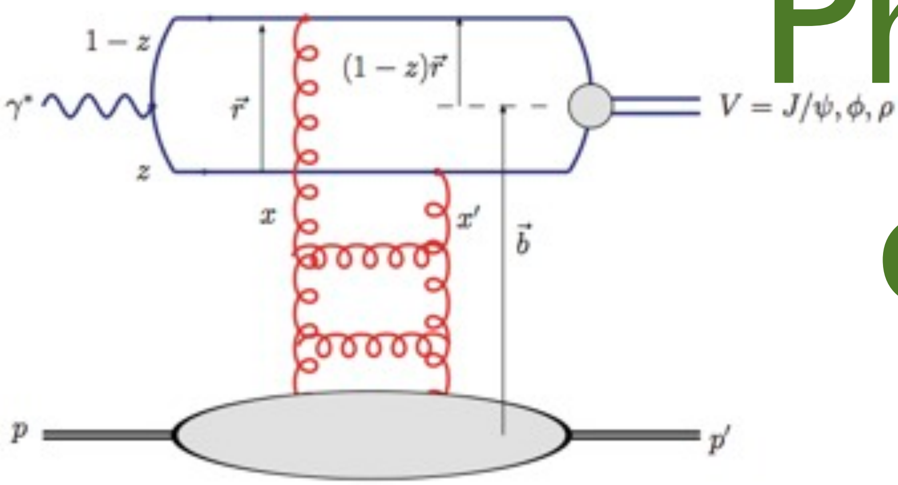
eRHIC predictions: exclusive diffraction with Sartre



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

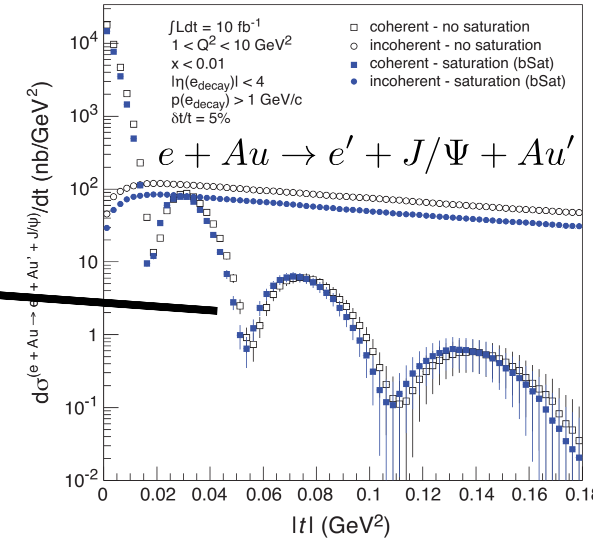
First 4 dips obtainable.

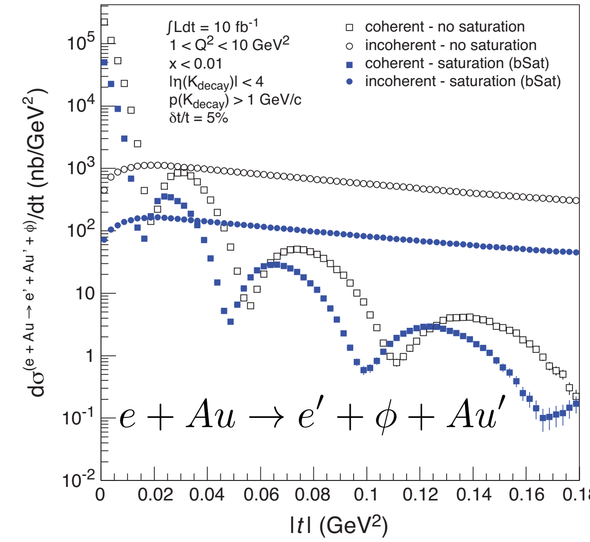
Probing the spatial gluon distribution at eRHIC



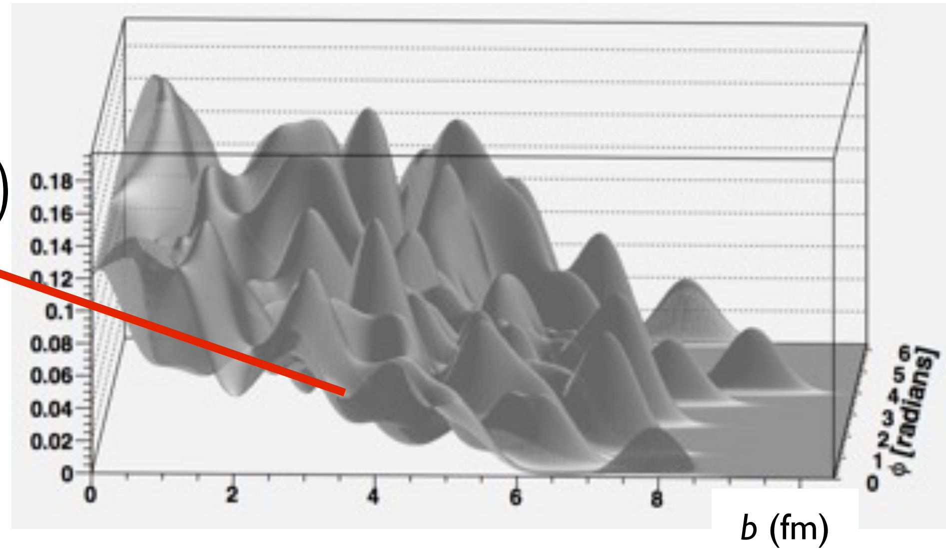
$$\frac{\mathrm{d}\sigma}{\mathrm{d}t} = \frac{1}{16\pi}\left|\mathcal{A}(\Delta)\right|^2$$

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





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



Fourier transform again to retain spatial distribution:

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

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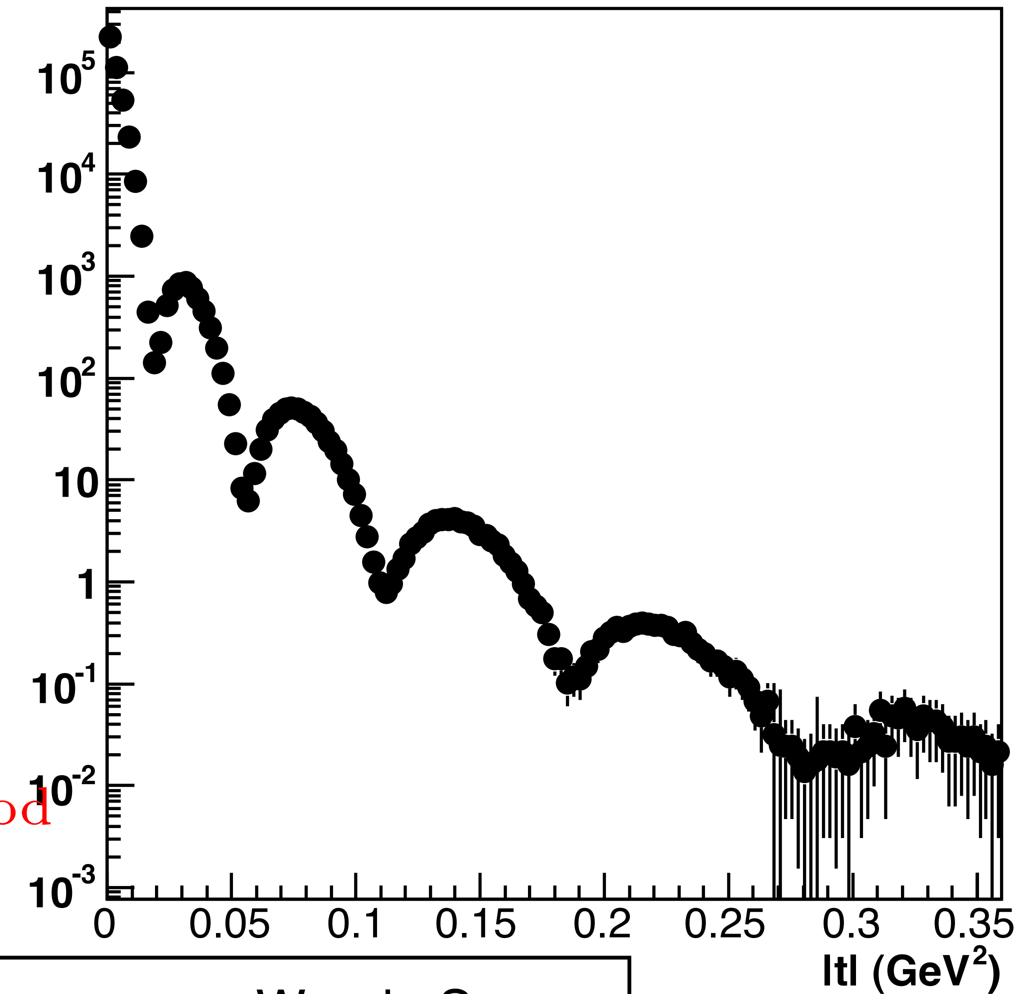

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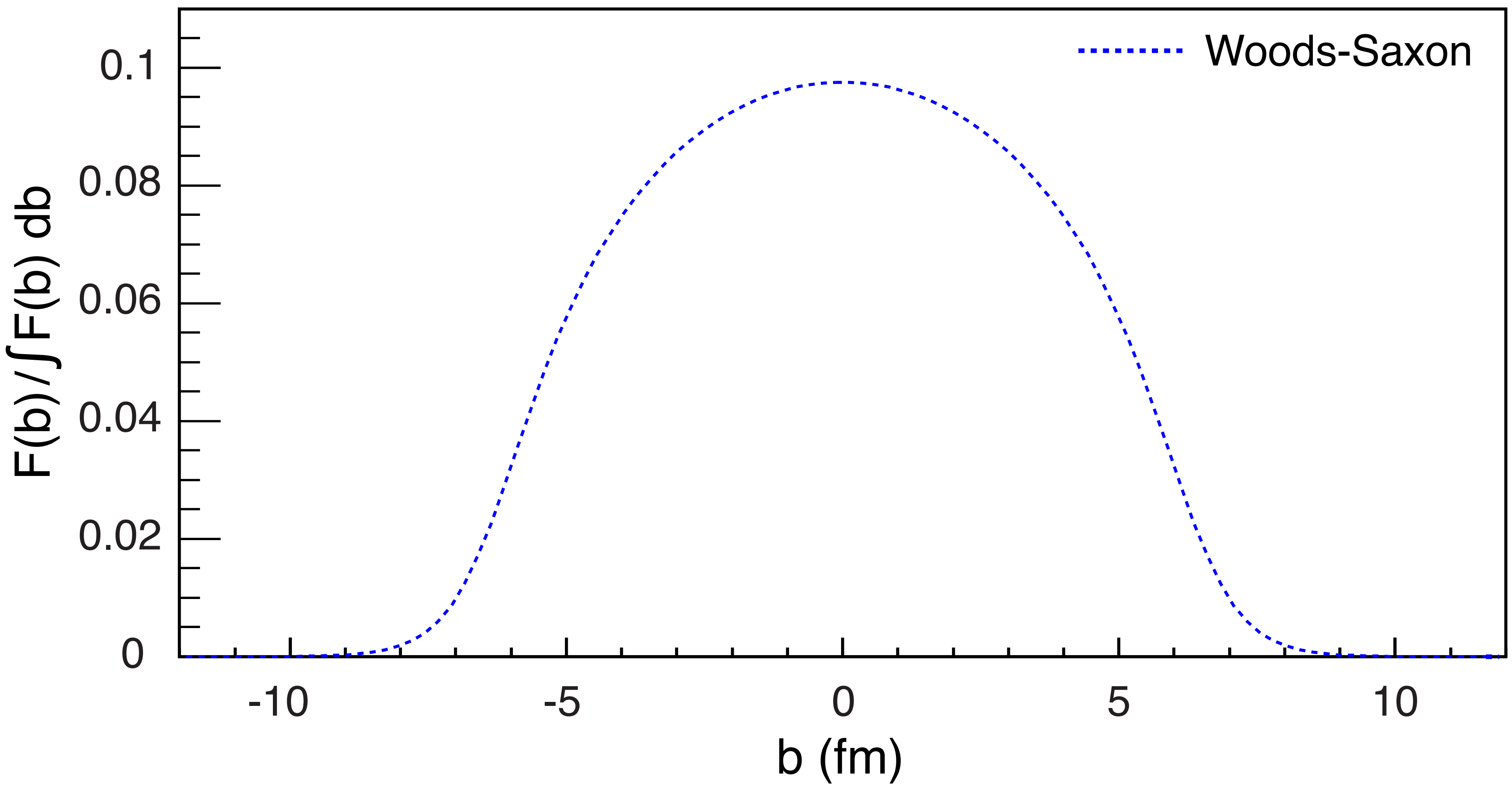

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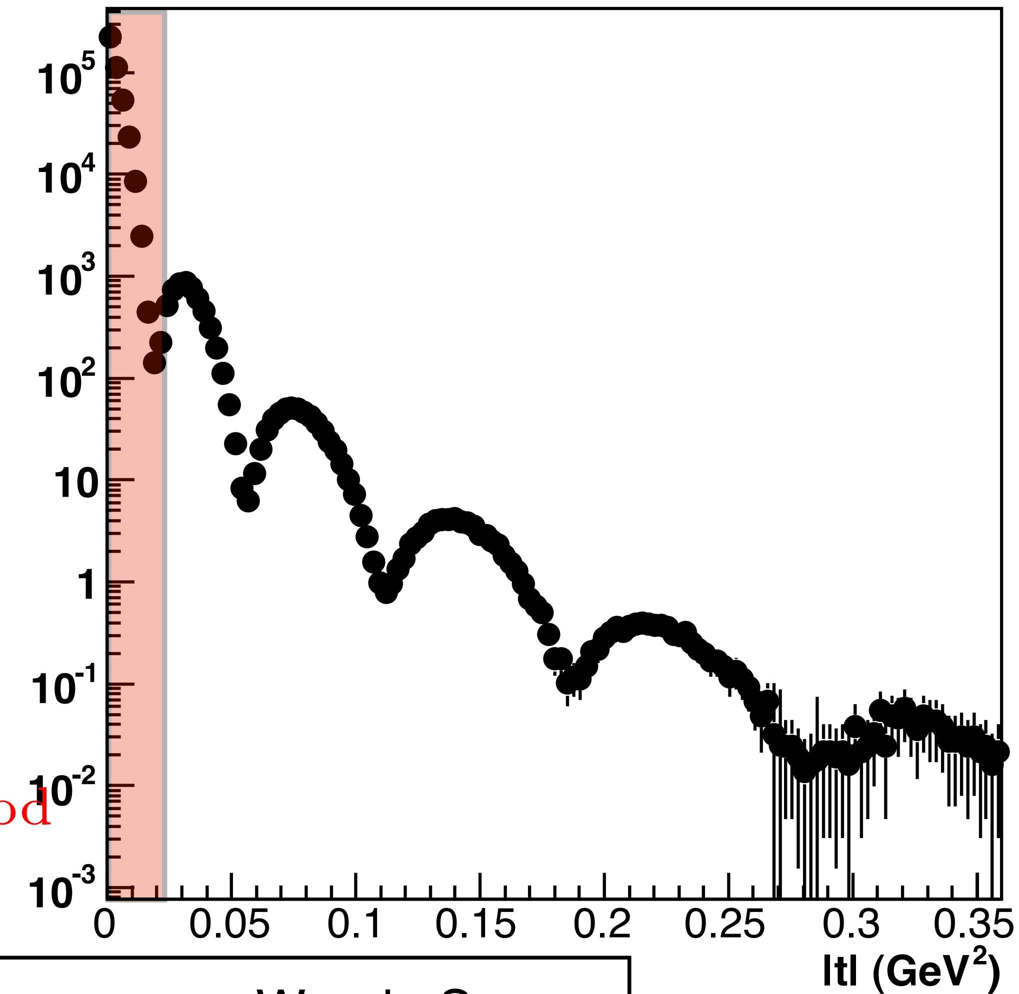

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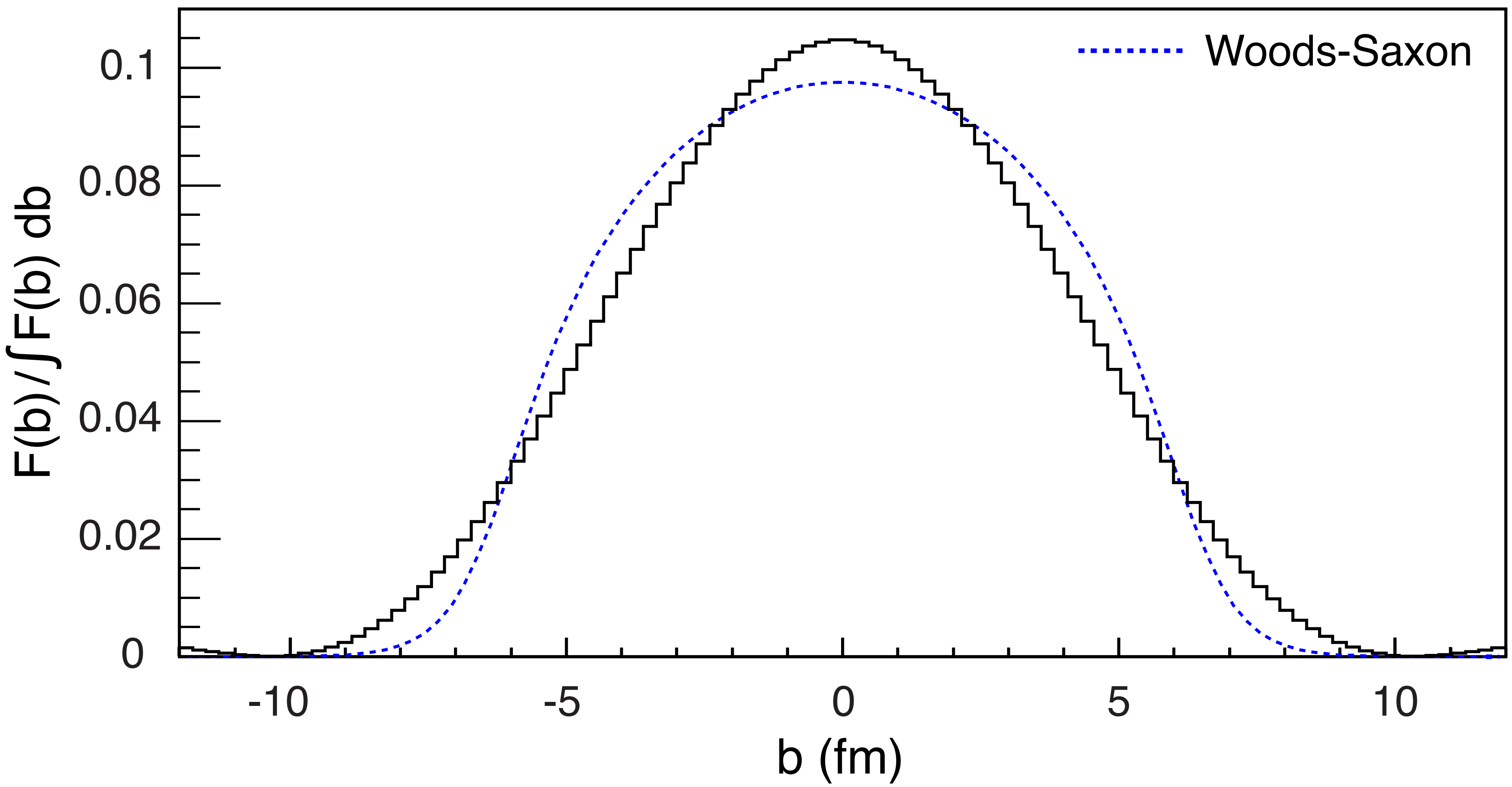

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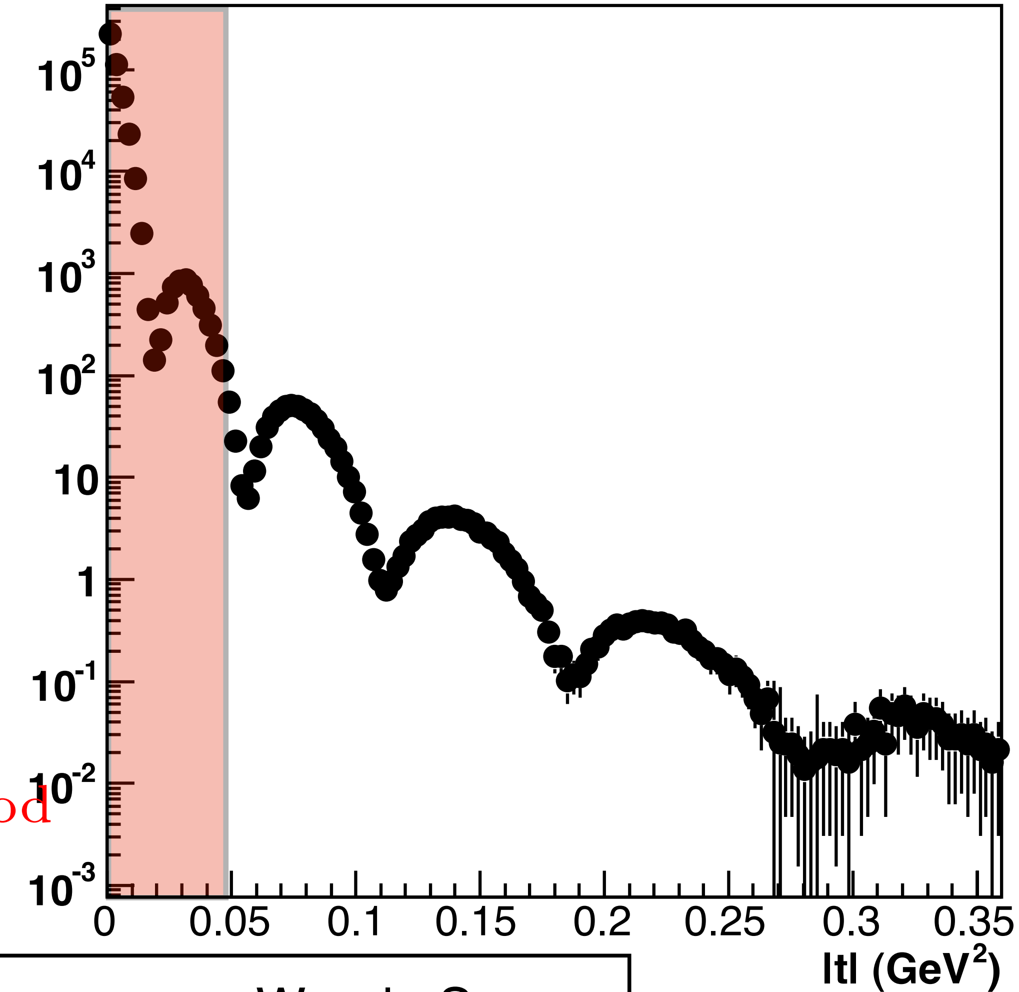

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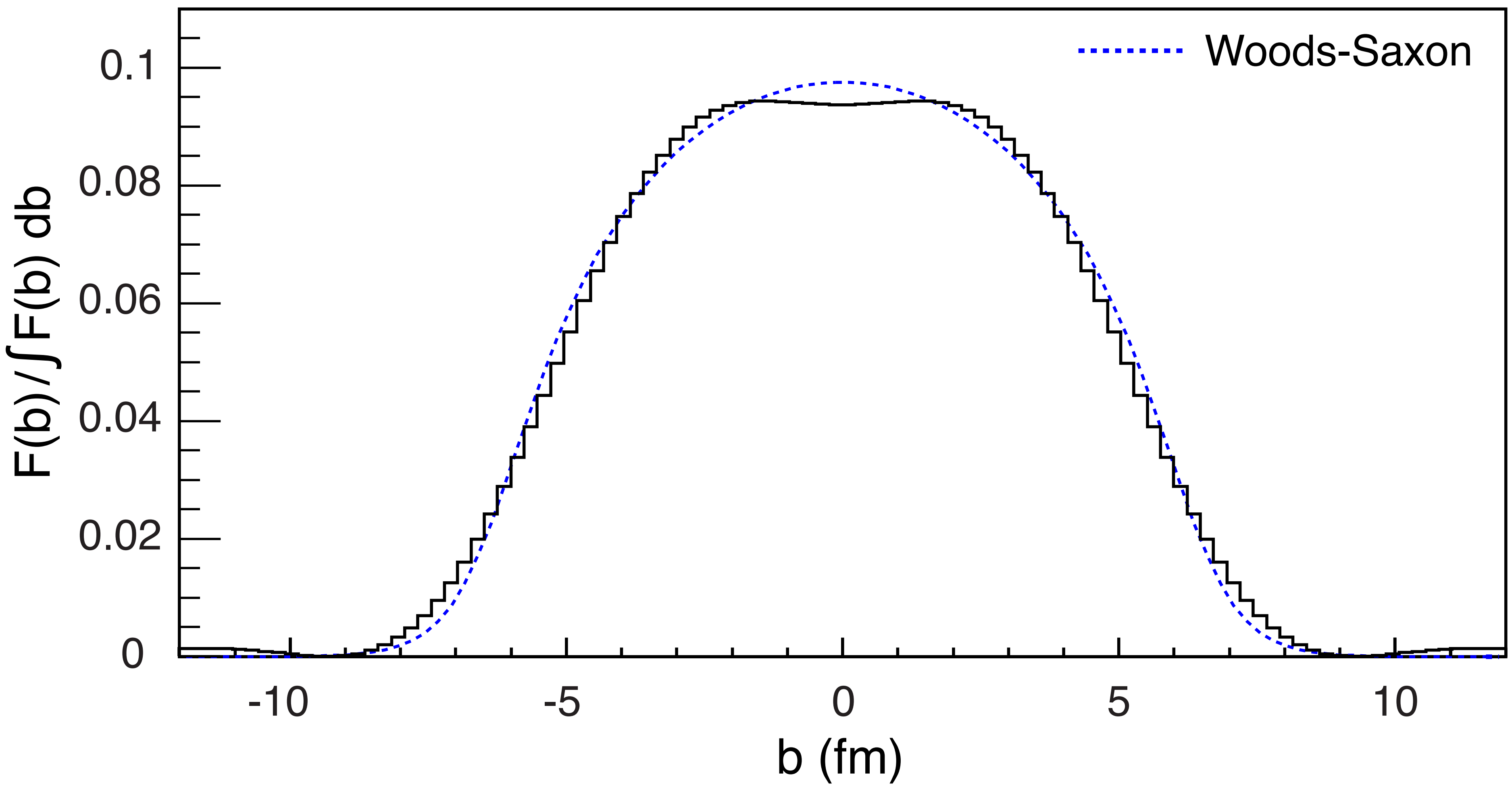

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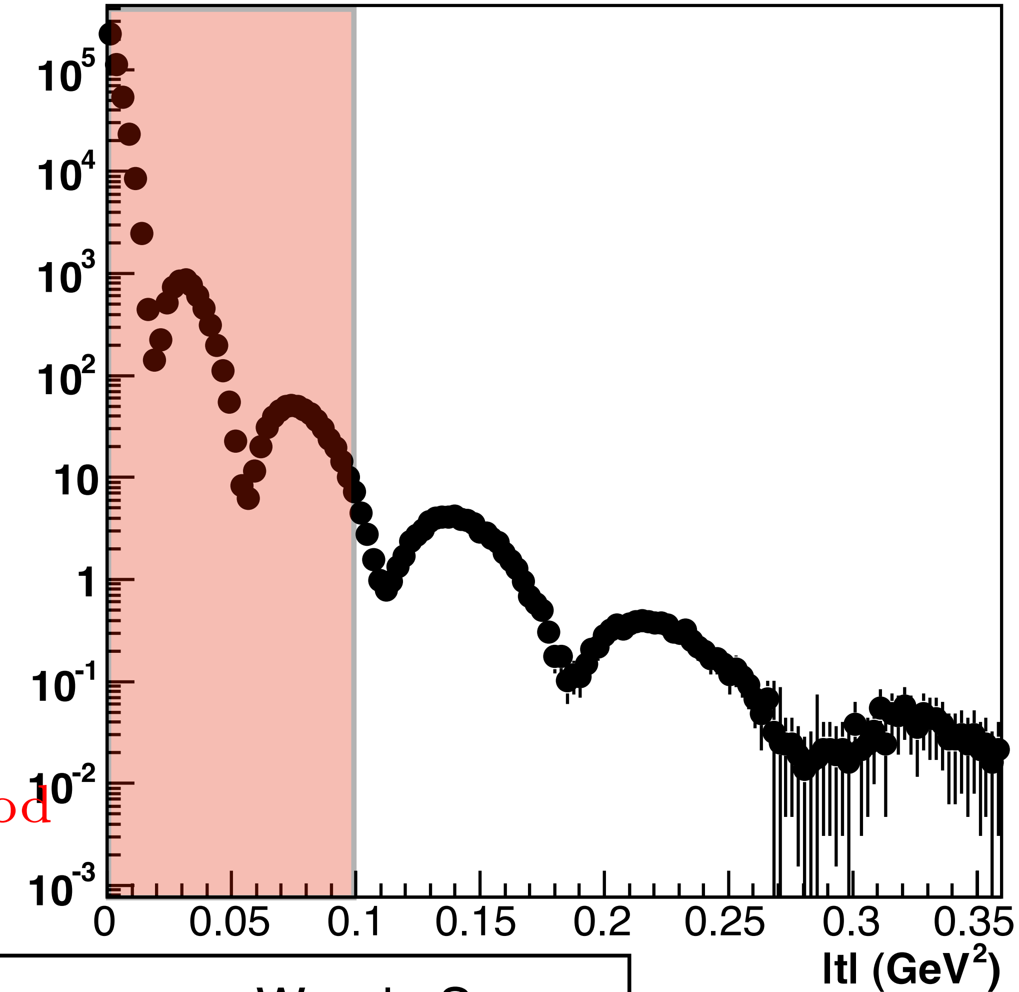

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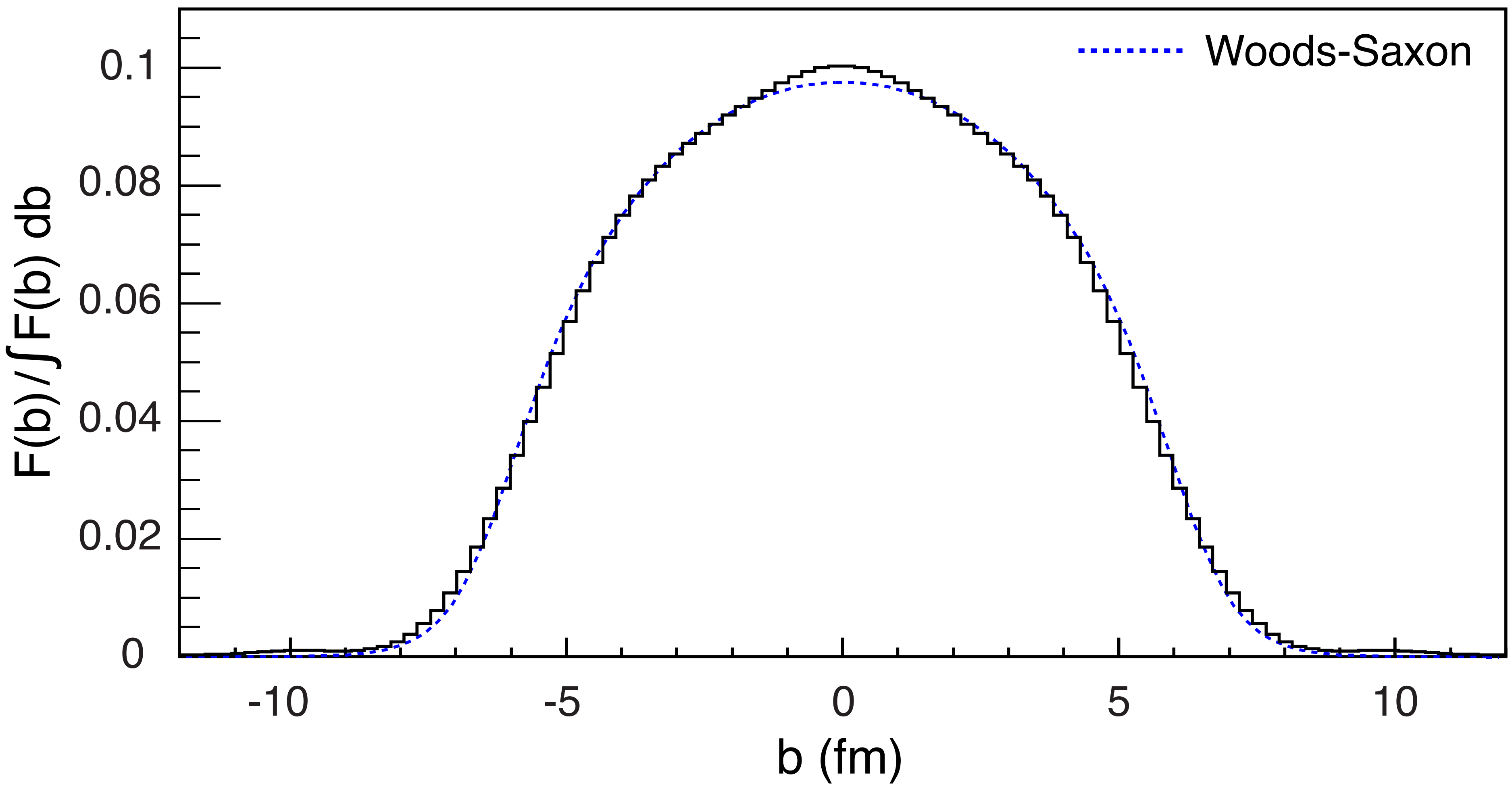

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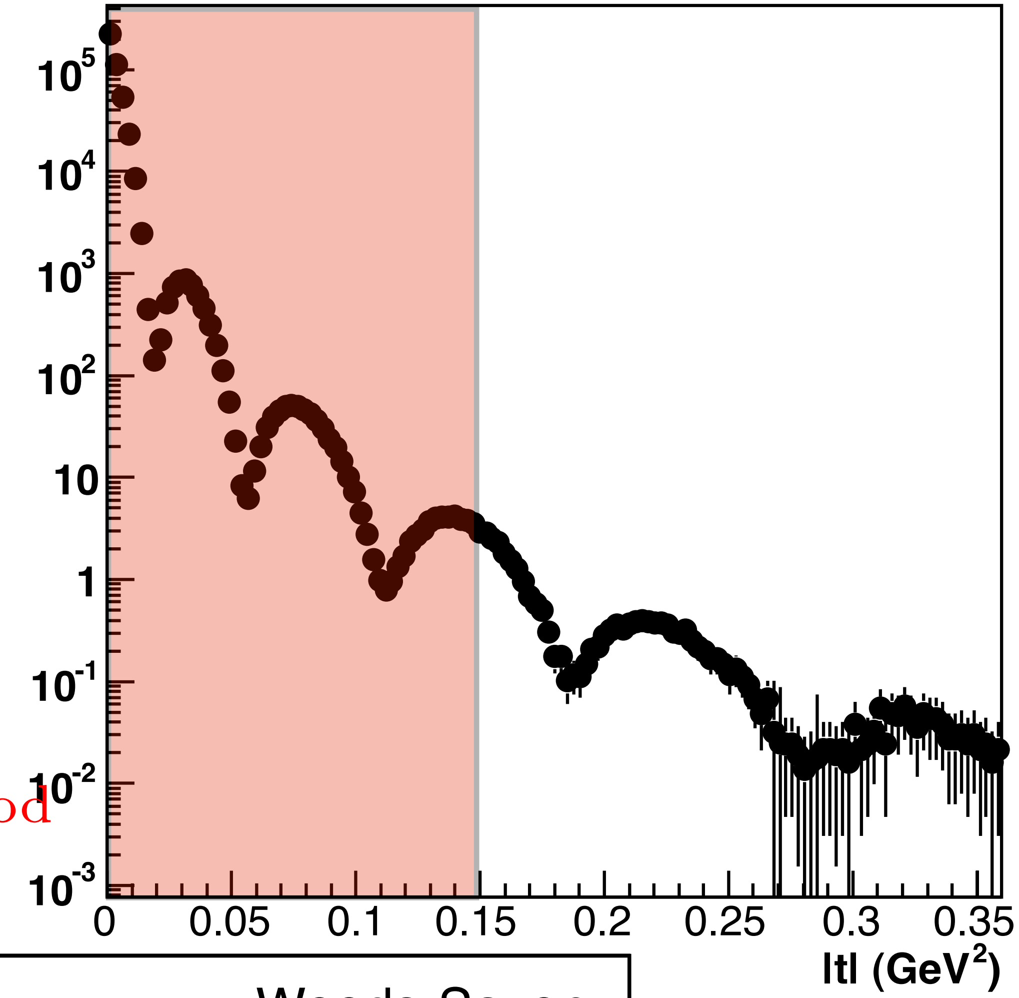

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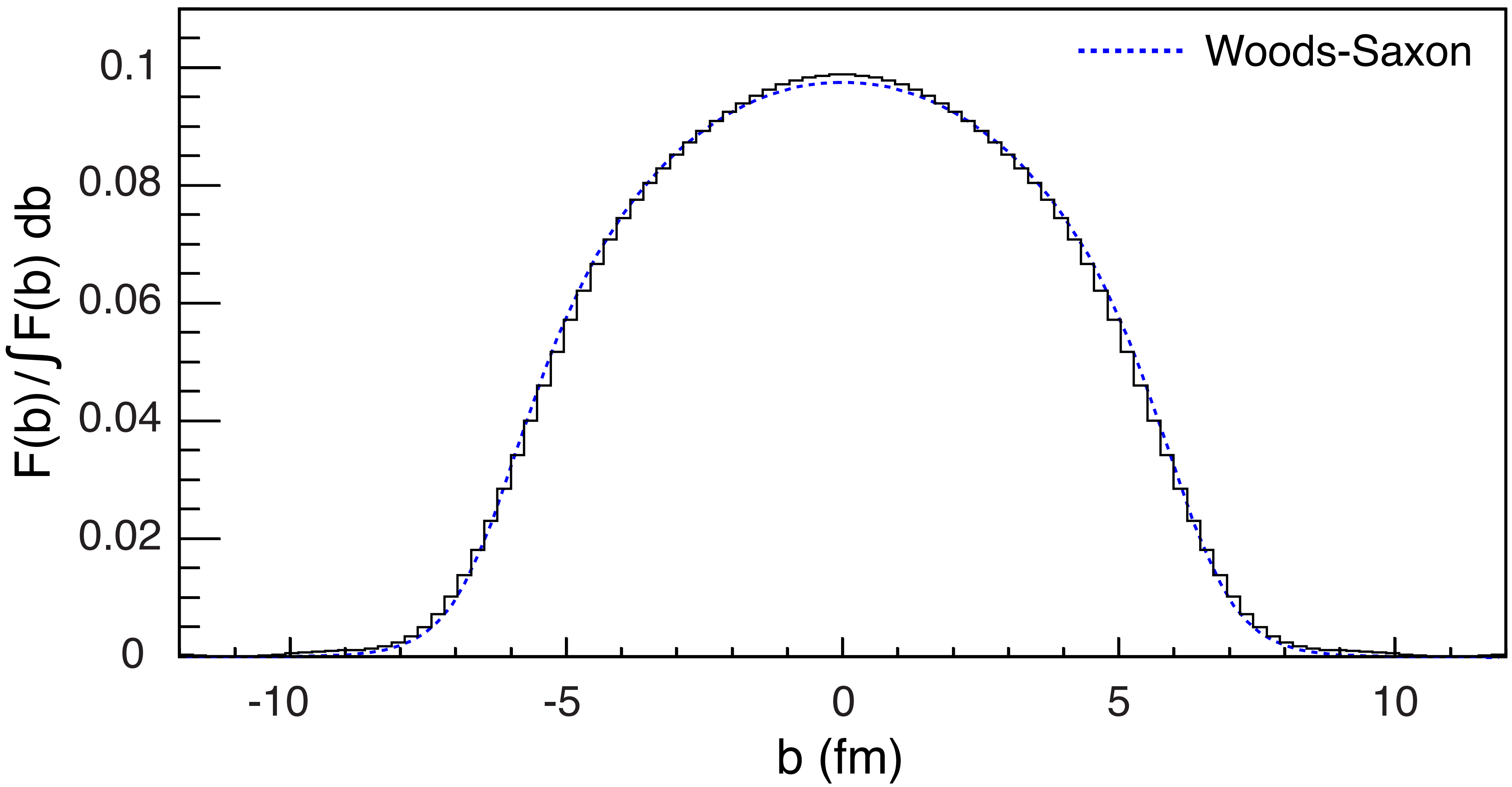

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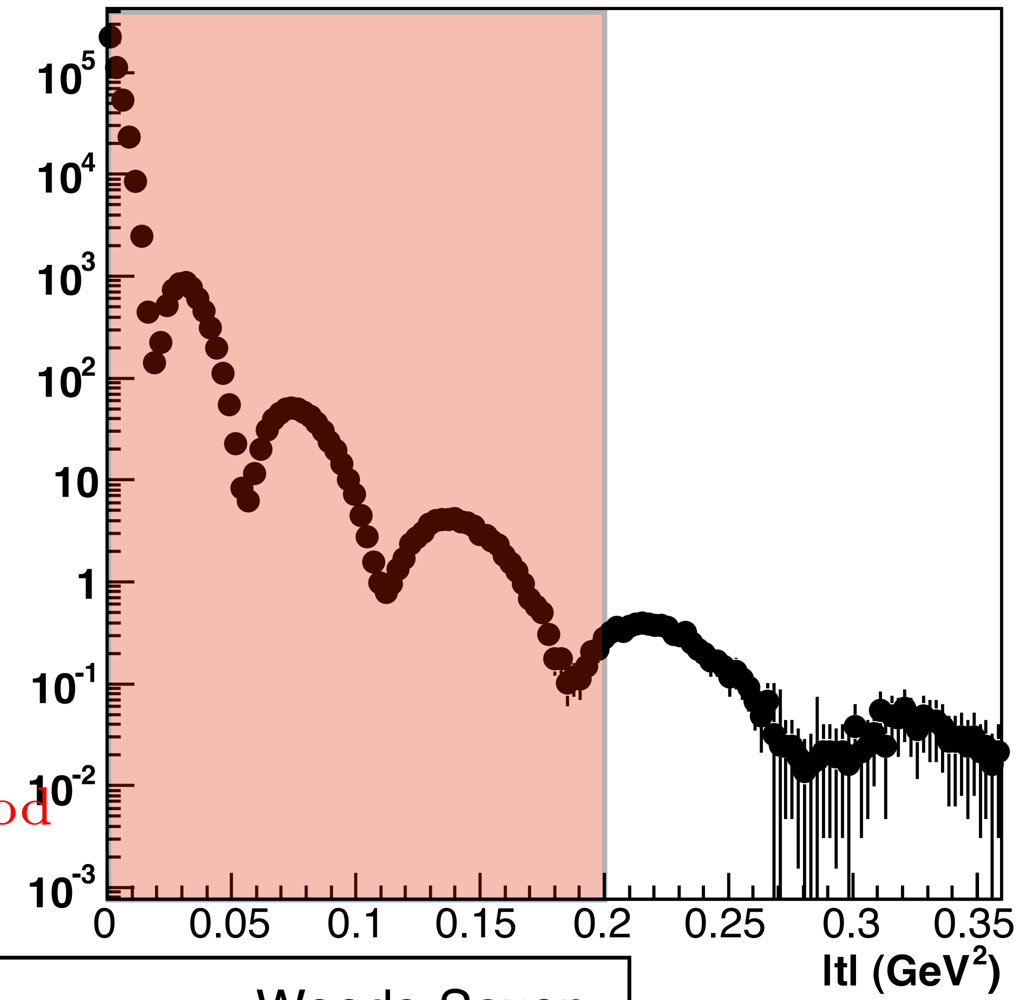

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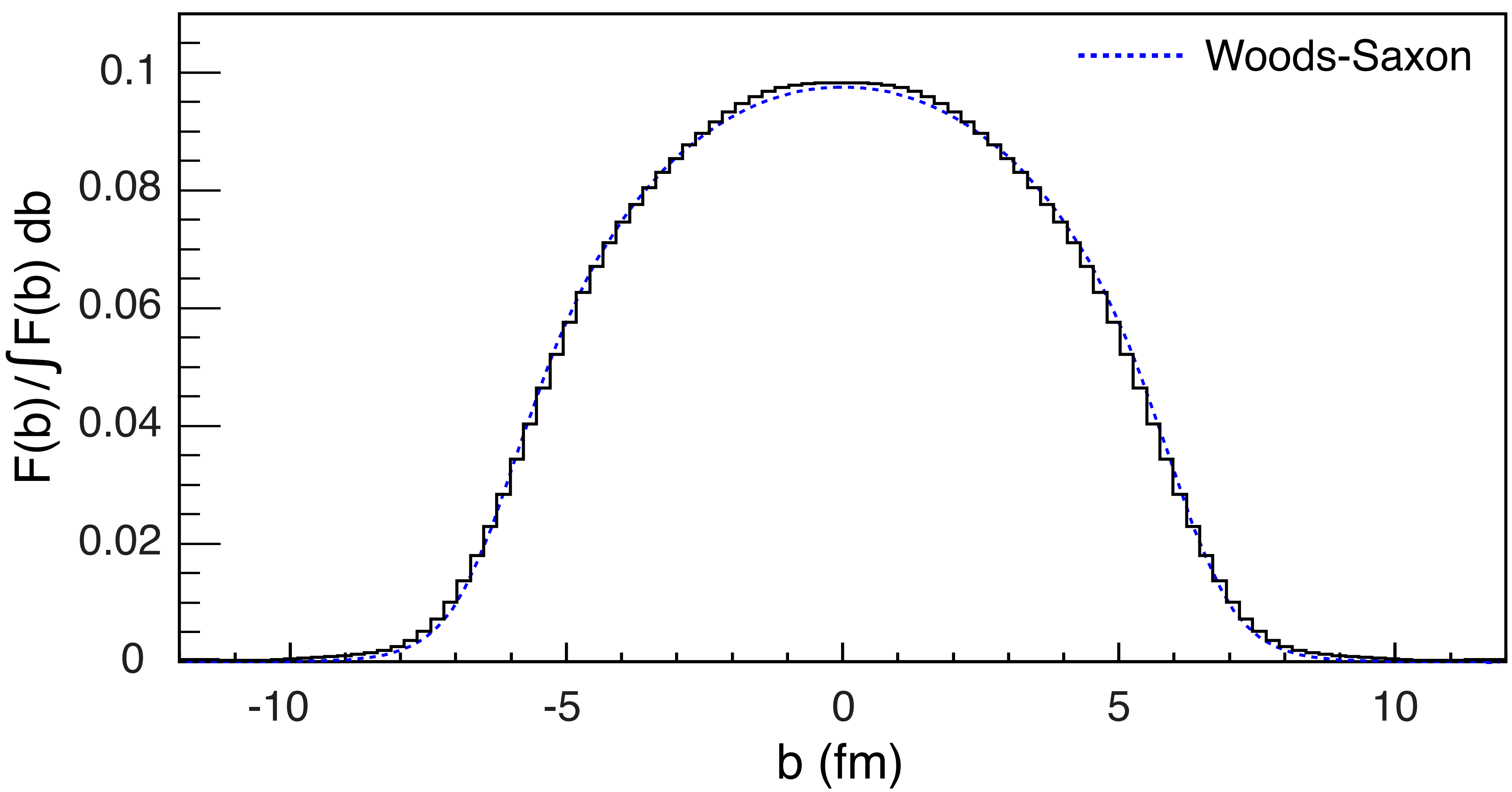

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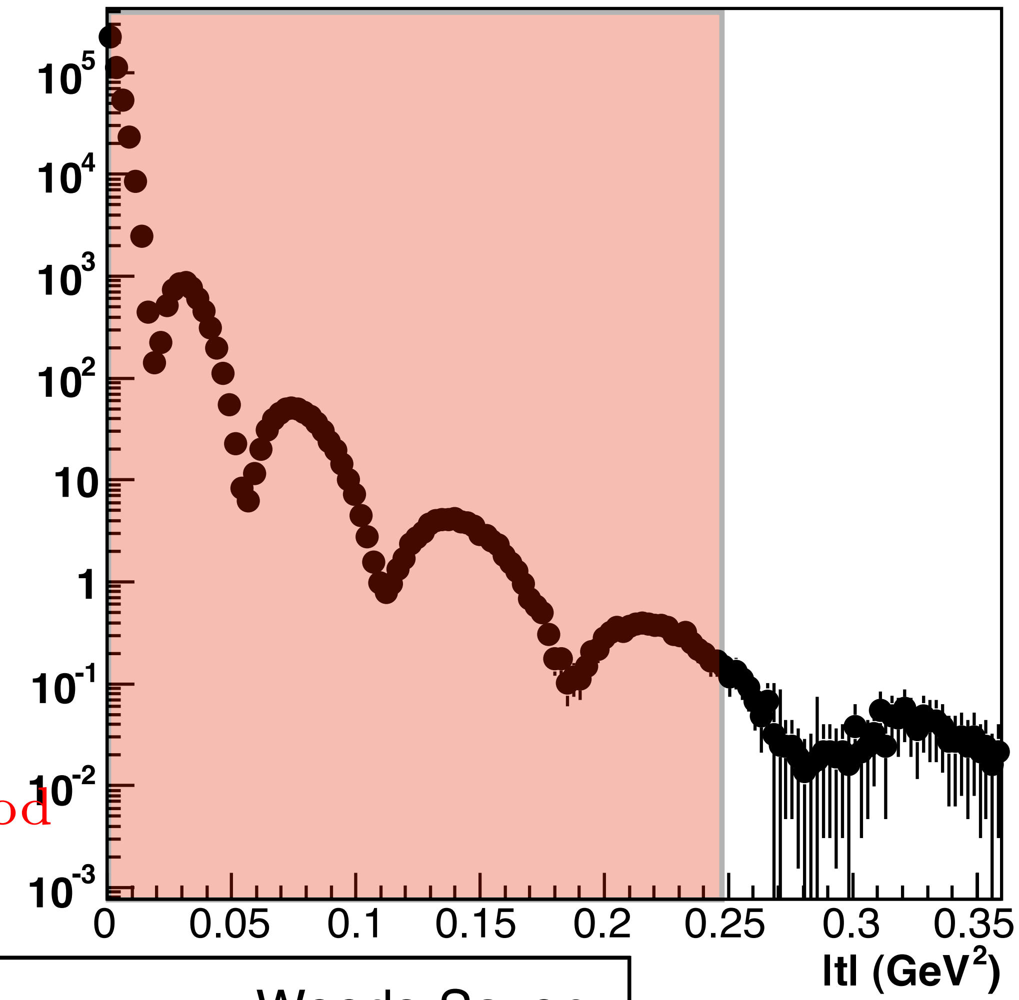

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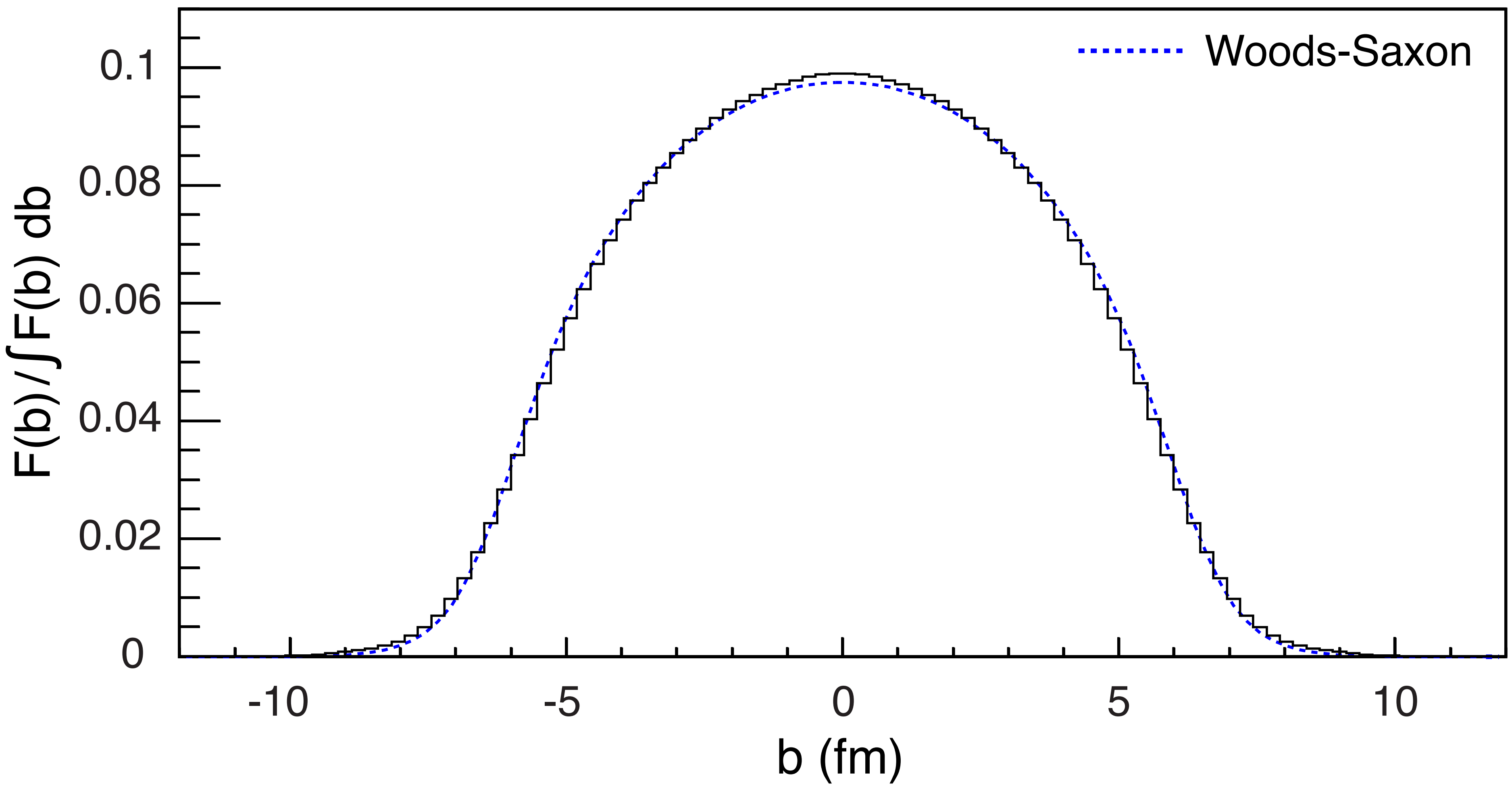

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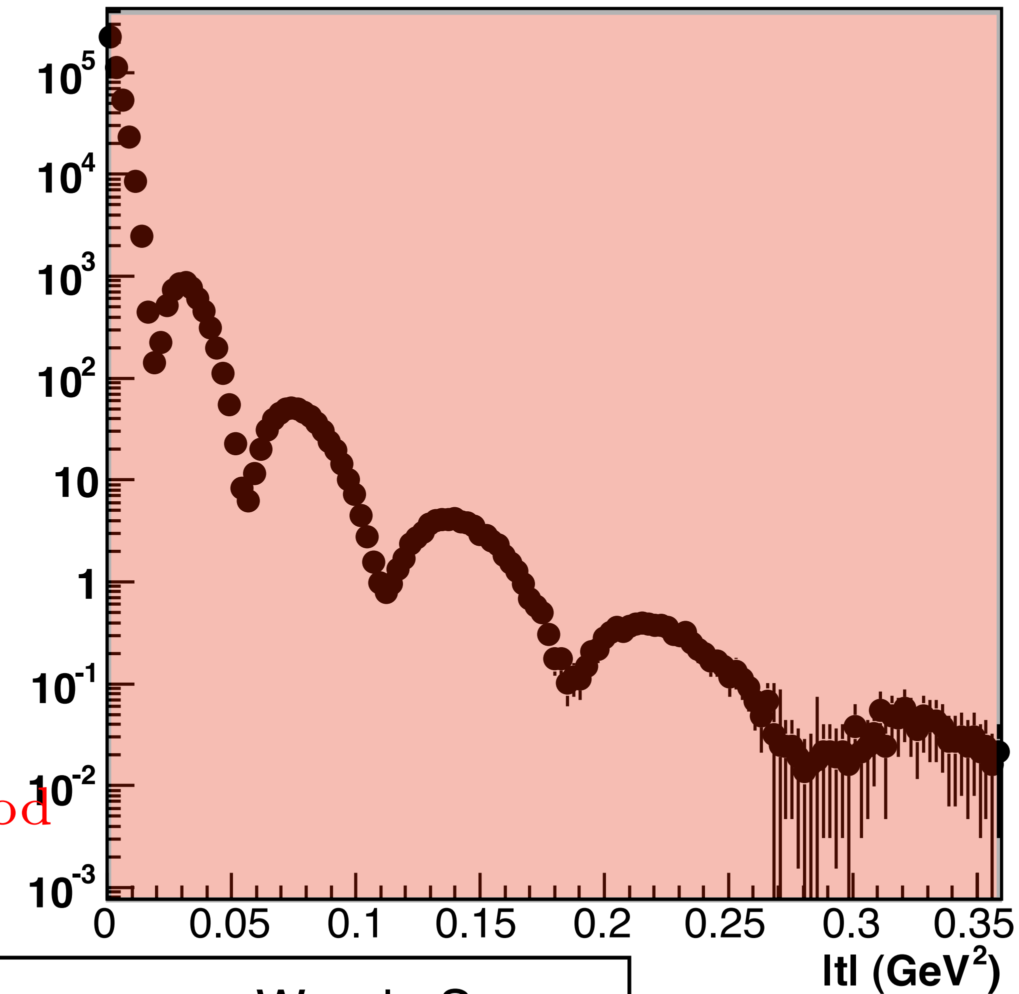

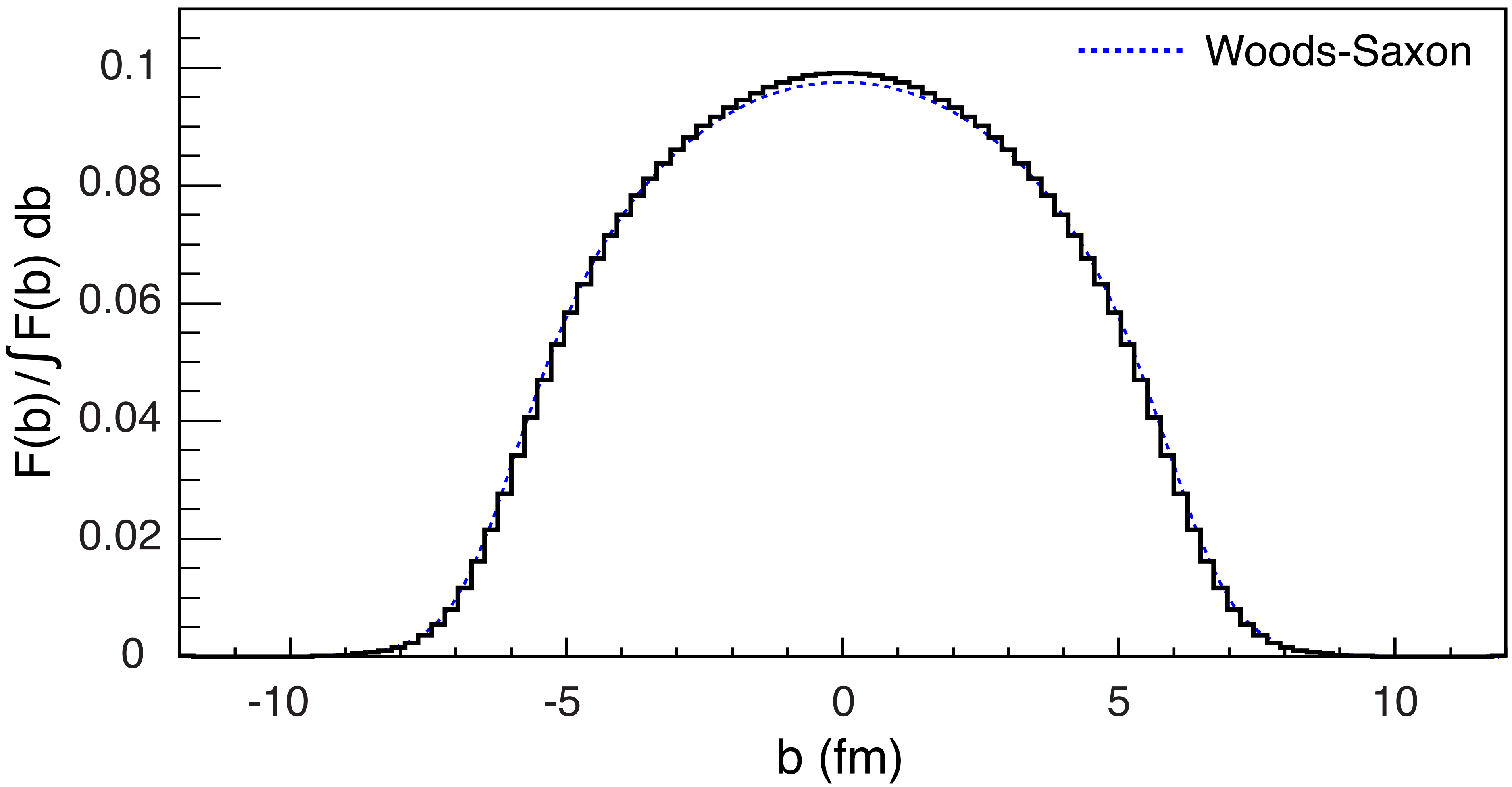

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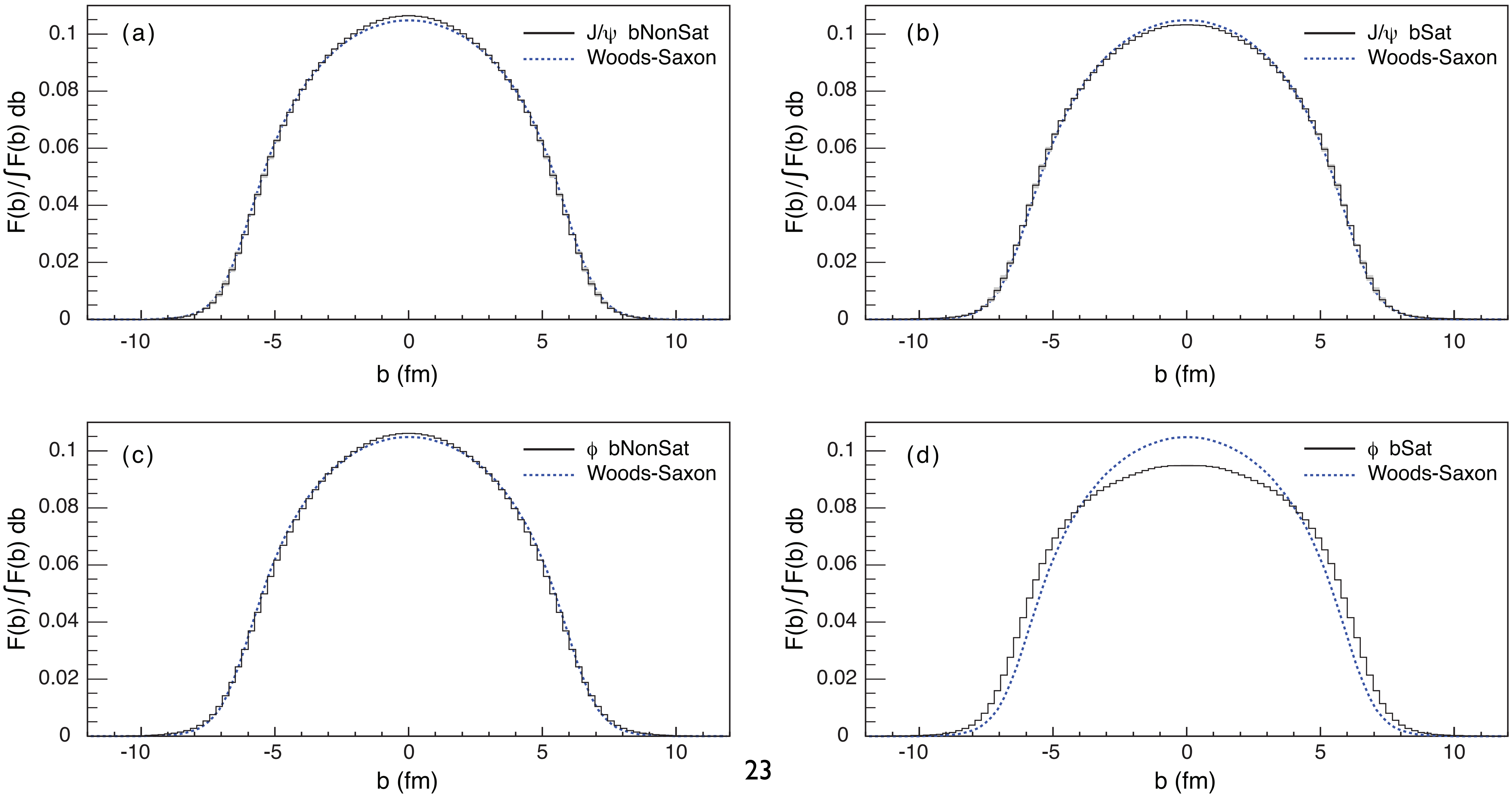
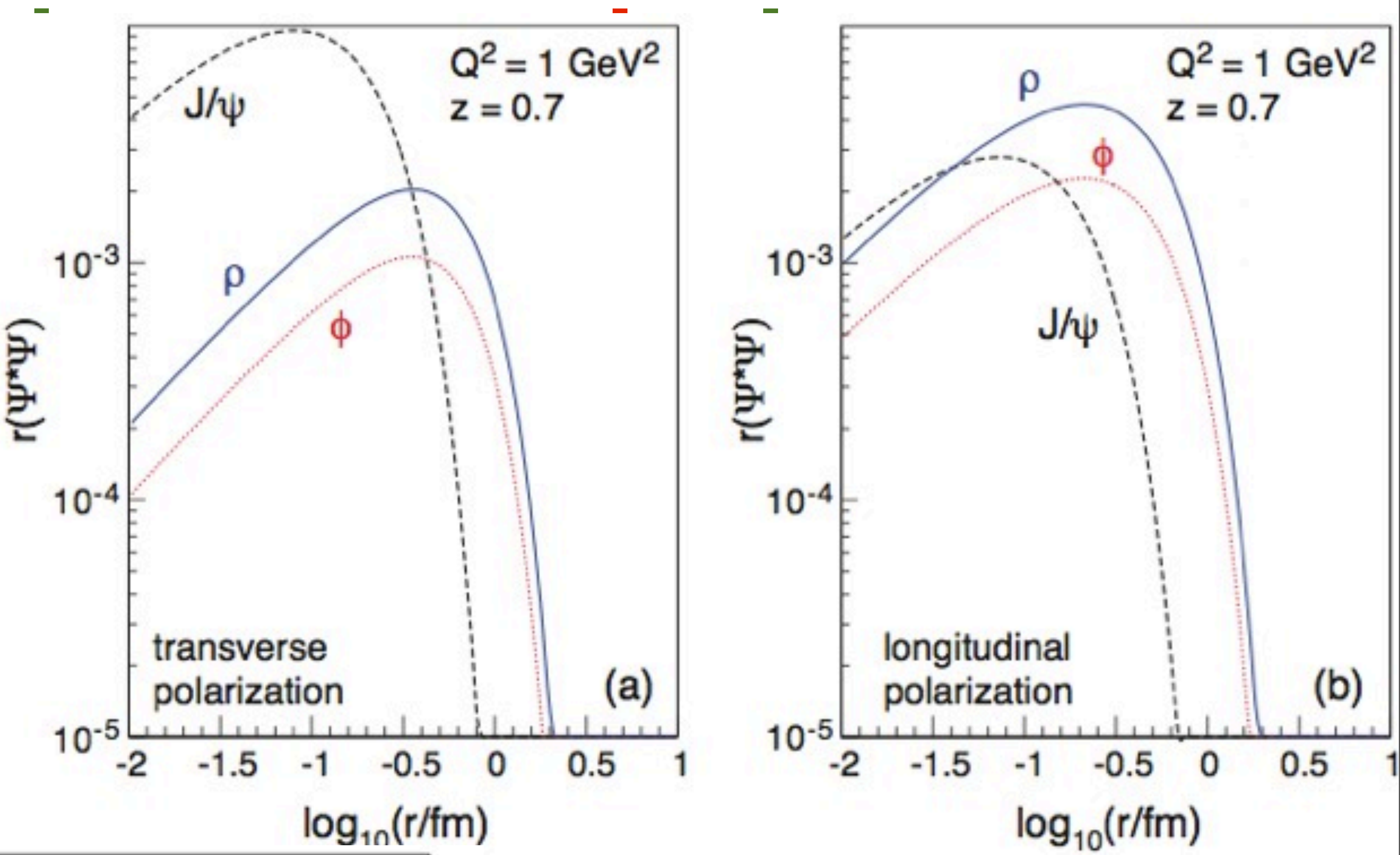
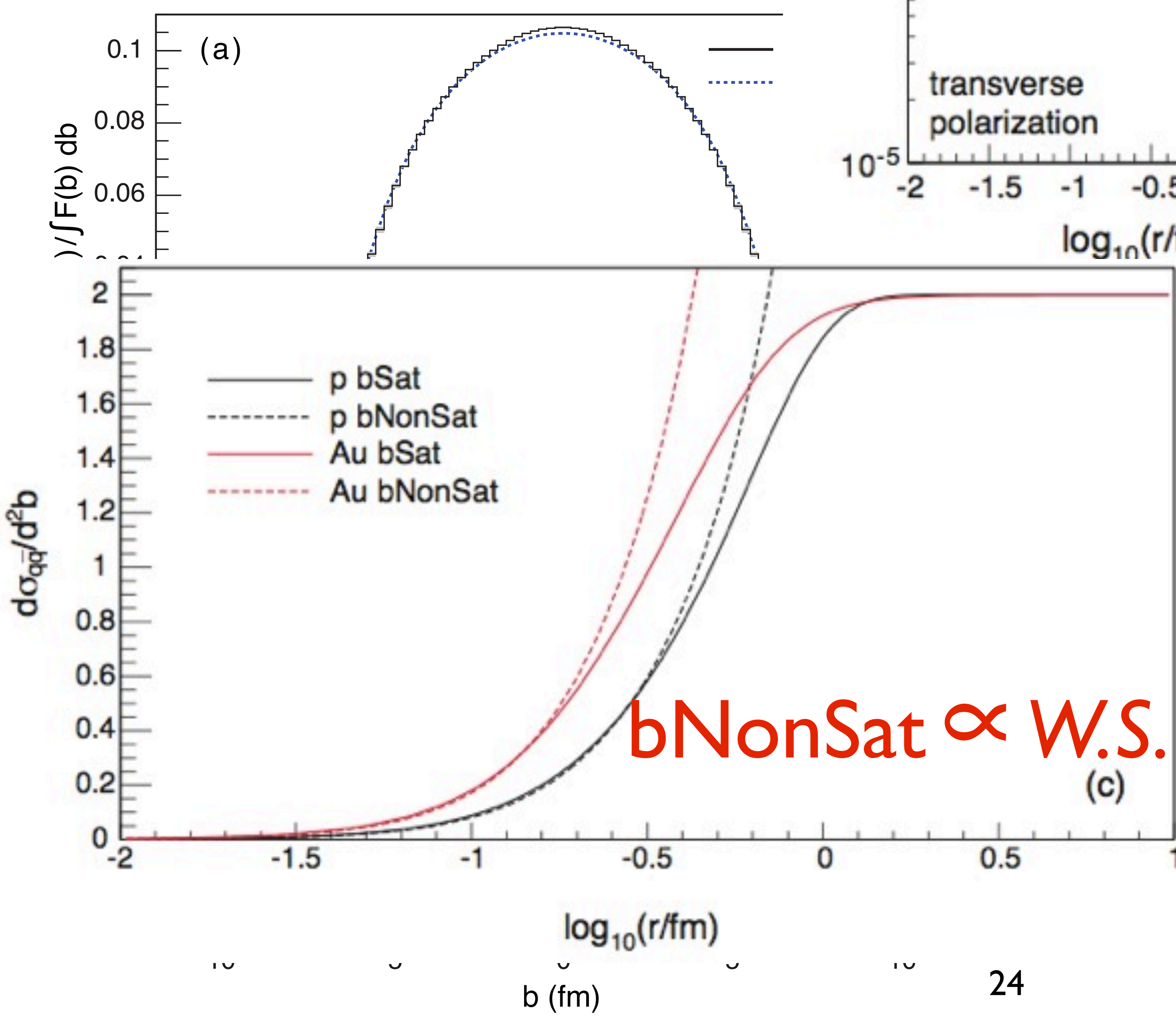


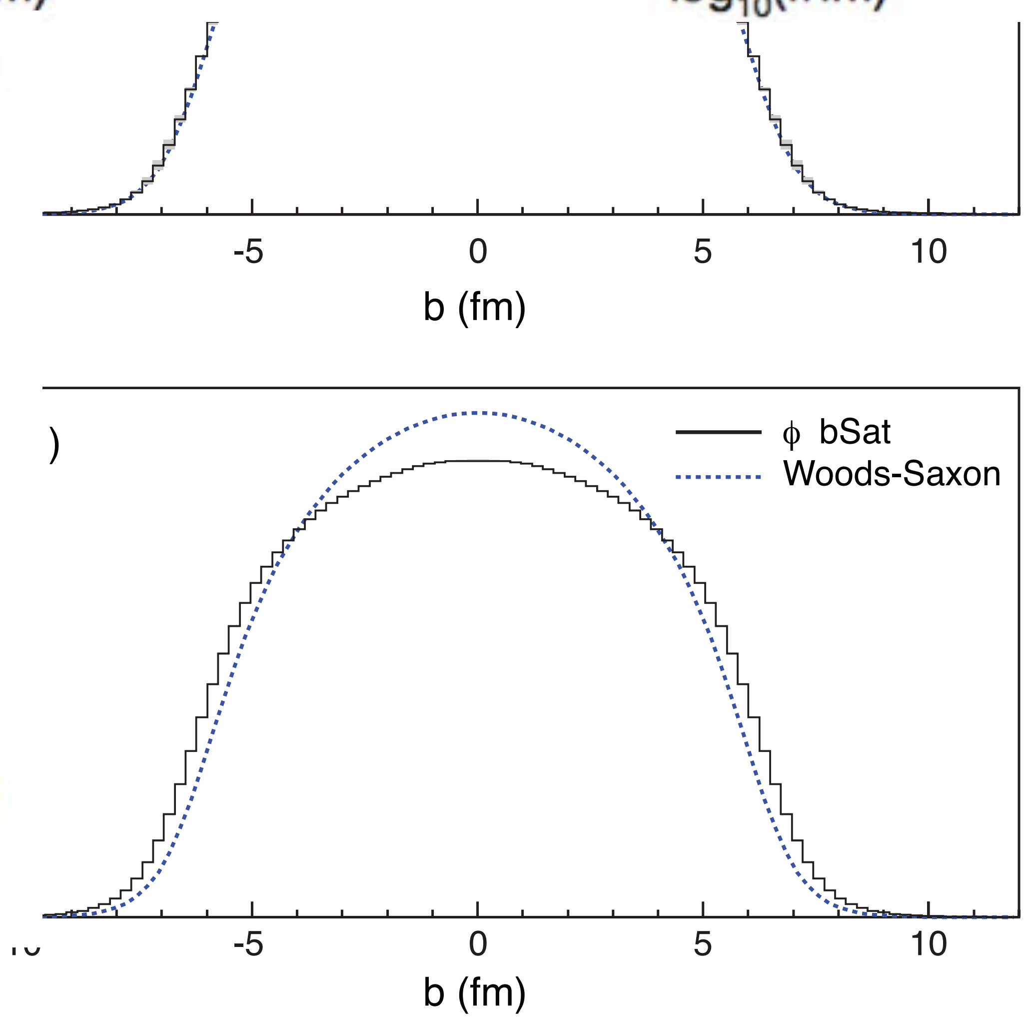
Probing t...
distribu...

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





bNonSat ∝ W.S.



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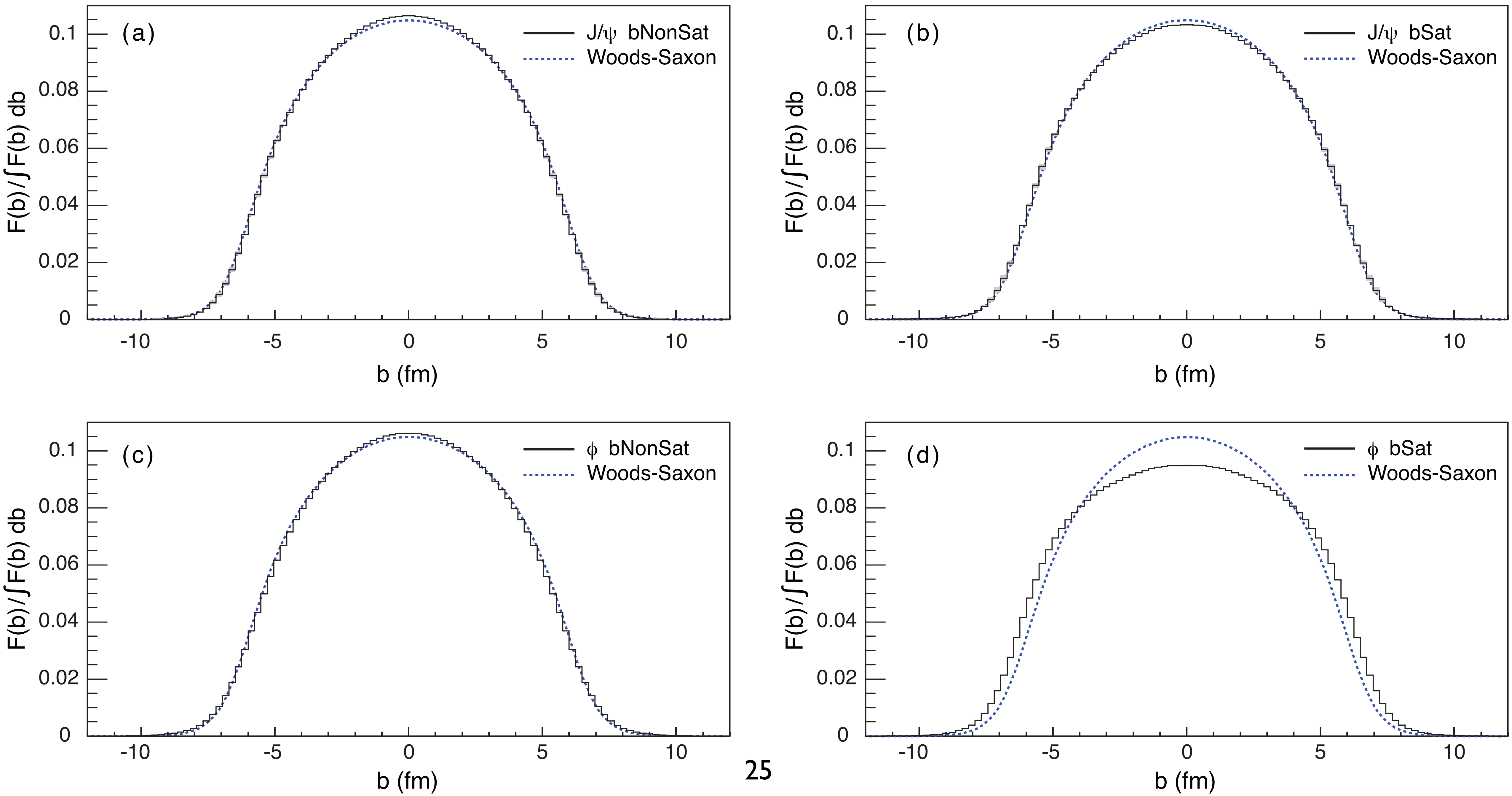

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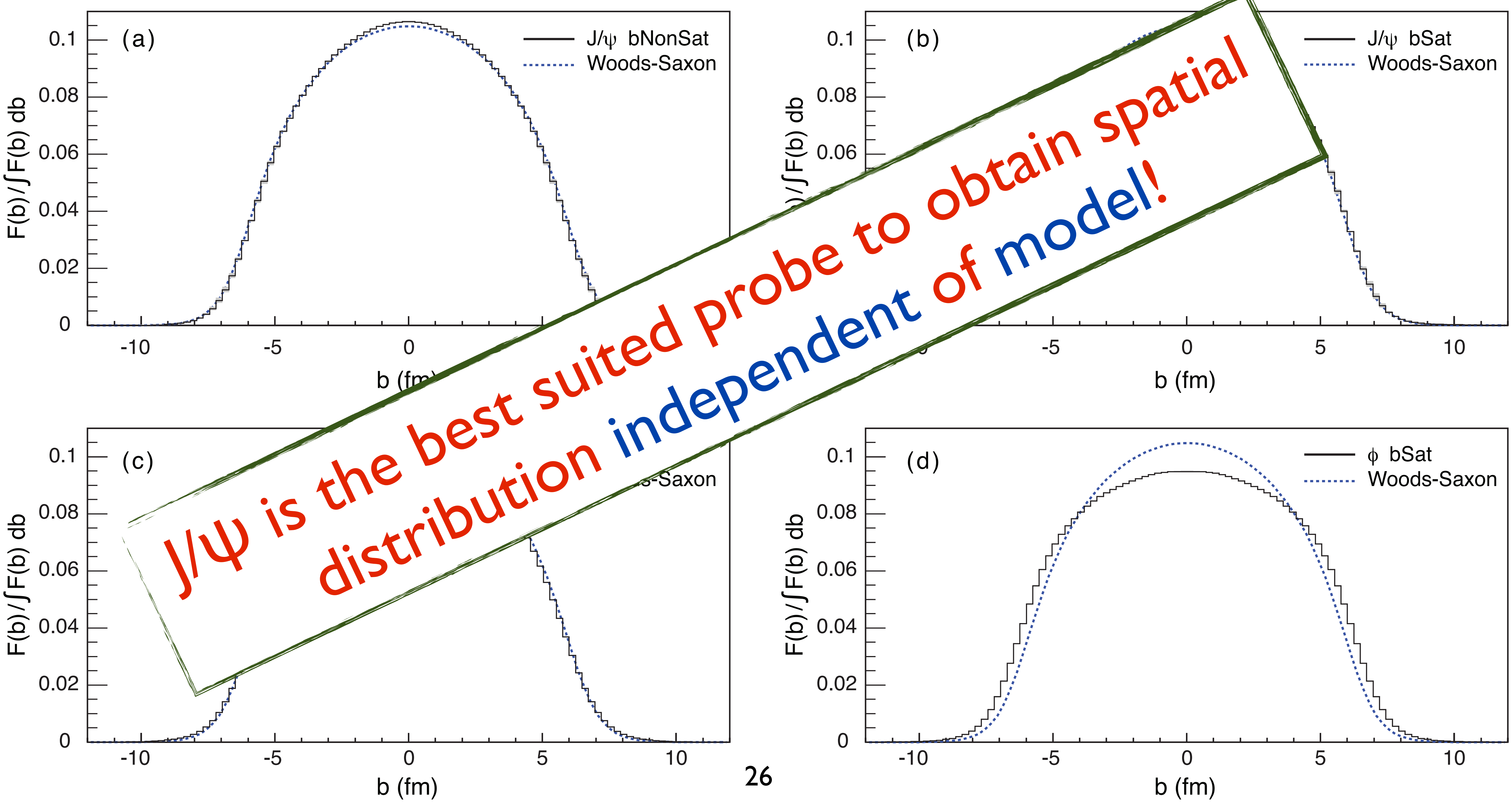


summary

diffraction in eA is a great tool for measuring:

1. a signal for gluon saturation
2. gluon spatial distribution in nuclei

saturation signal, day 1 measurement via diffractive/total ratio

gluon spatial distributions in nuclei available in a model independent way via exclusive heavy vector mesons, s.a. J/φ

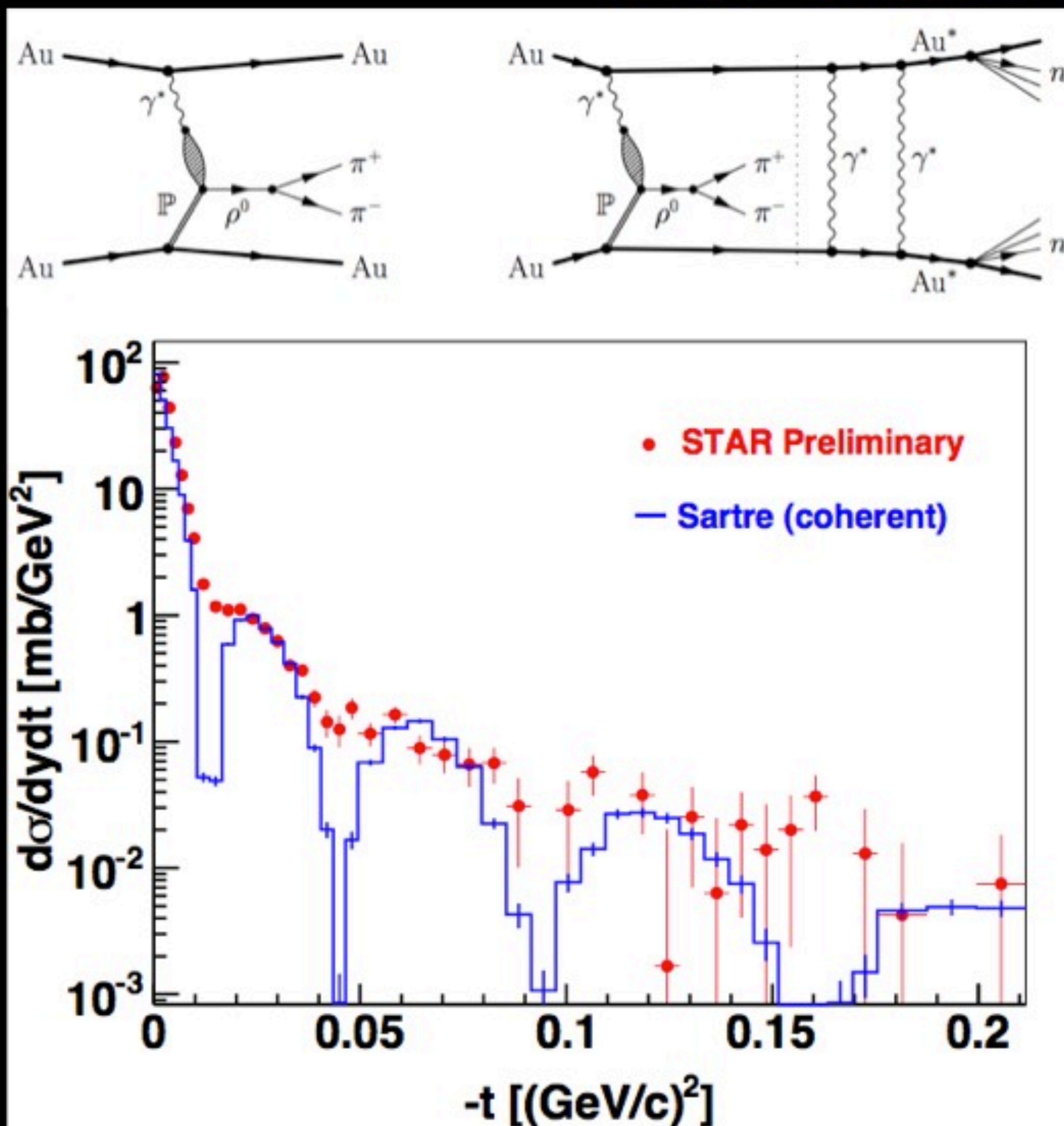
eRHIC truly an ultra high resolution femtoscope for probing the initial state of nuclei

back up

What is being measured?

Slide from J.H. Lee,
Analysis: R. Debbe

Coherent Diffraction (γ*+IP) in UPC at RHIC



- Coherent diffractive ρ production in Au+Au at $\sqrt{s_{NN}}$=200 GeV
- Data: STAR/RHIC Ultra-peripheral AuAu Collision
- Simulation: Sartre

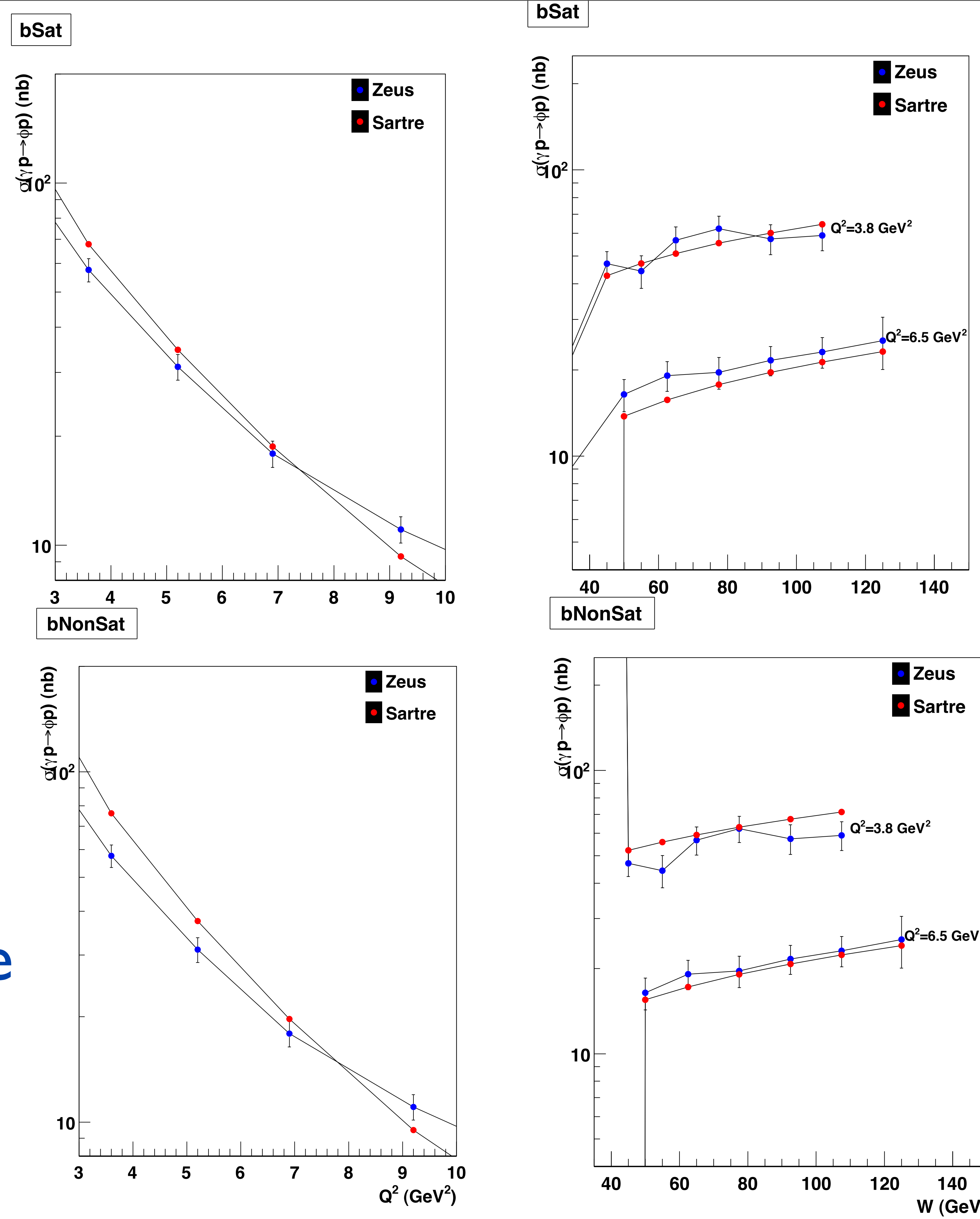
No t-smearing in Sartre

bSat vs. bNonSat at HERA

$\phi - \text{mesons}$

No distinguishing power!

eRHIC can probe the difference!



Probing the spatial gluon distribution at eRHIC

Amplitude is a Fourier transform from position to momentum space:

$$\langle \mathcal{A}_{T,L}(Q^2,\Delta,x_{I\!P})\rangle_\Omega = \int \pi r \mathrm{d}r \mathrm{d}z b \mathrm{d}b (\Psi_V^* \Psi)_{T,L}(Q^2,r,z)$$

$$J_0([1-z]r\Delta) J_0(b\Delta) \left\langle \frac{\mathrm{d}\sigma_{q\bar{q}}}{\mathrm{d}^2\mathbf{b}} \right\rangle_\Omega (x_{I\!P},r,b)$$

Cross-section:

$$\frac{\mathrm{d}\sigma}{\mathrm{d}t} = \frac{1}{16\pi} \left| \langle \mathcal{A}_{T,L}(Q^2,\Delta,x_{I\!P})\rangle_\Omega \right|^2$$

Fourier transform again to retain spatial distribution:

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

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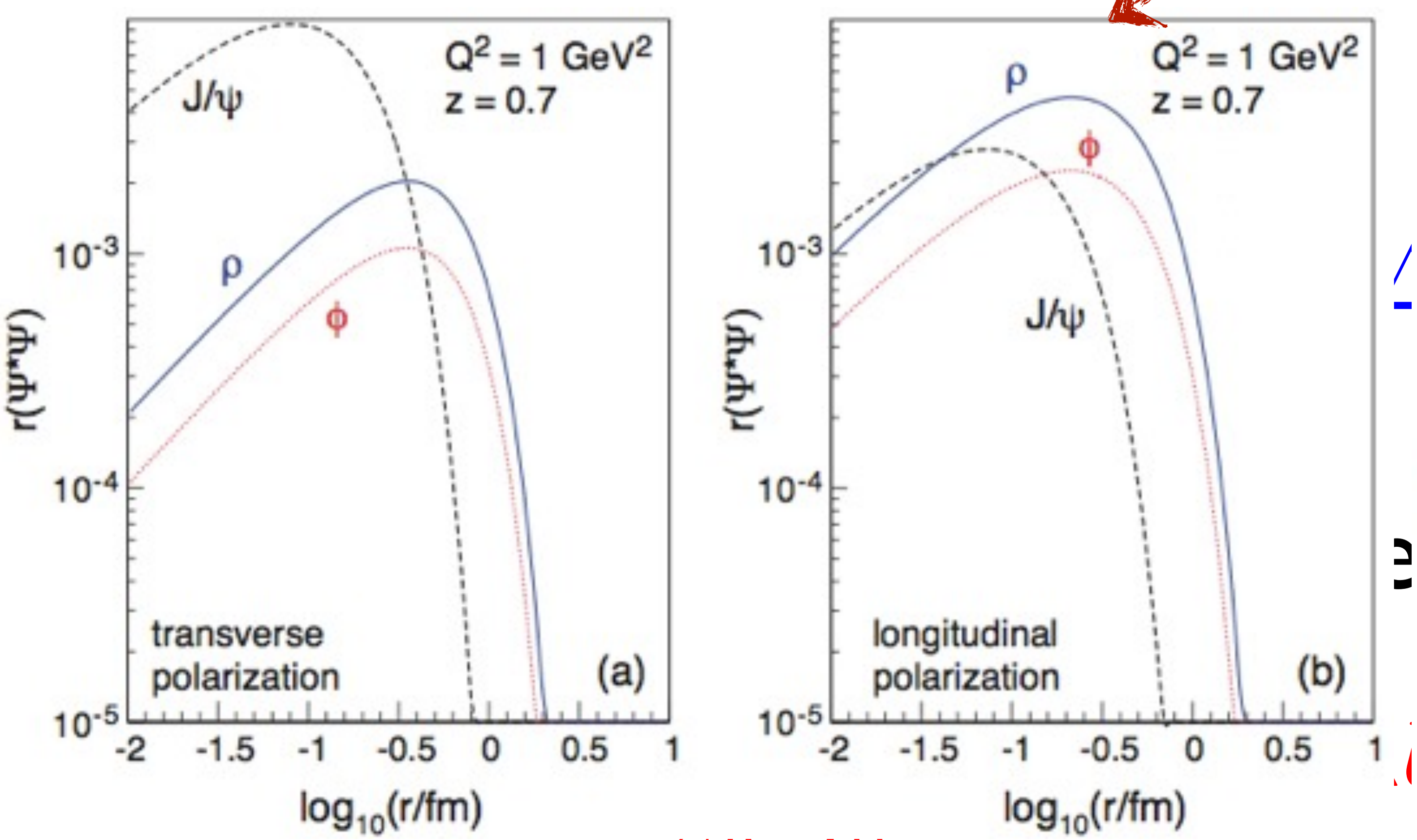
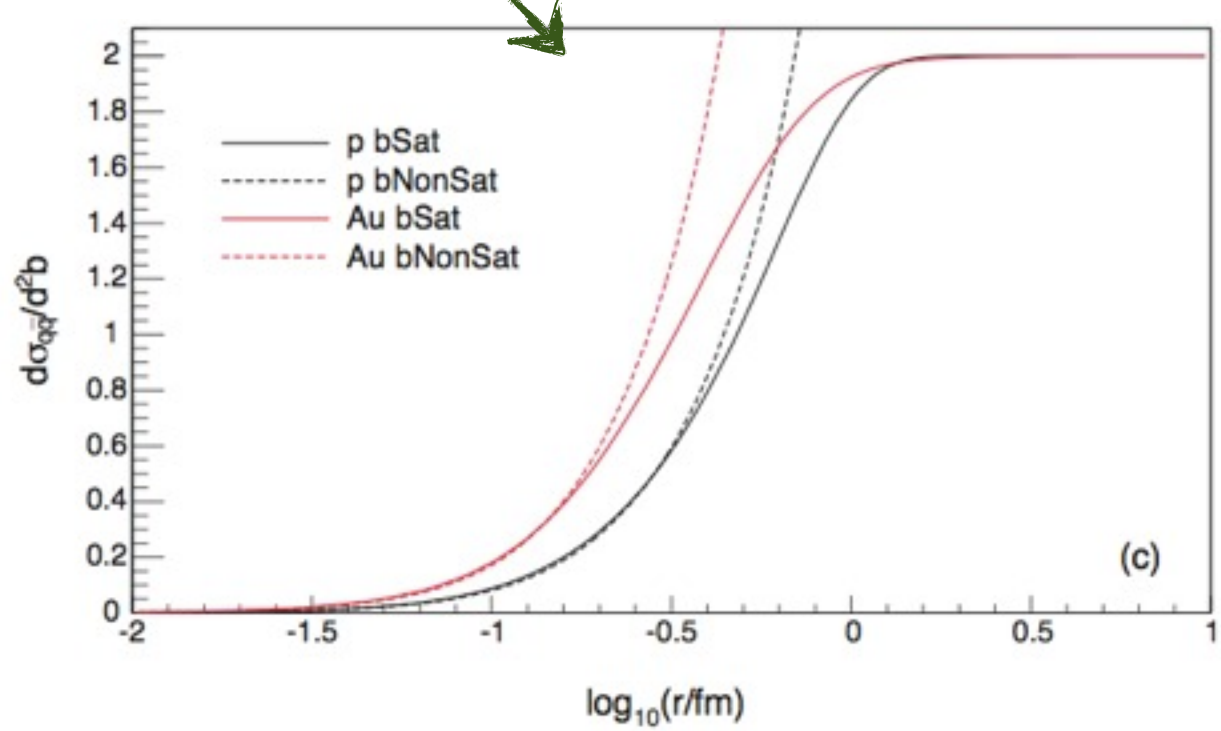
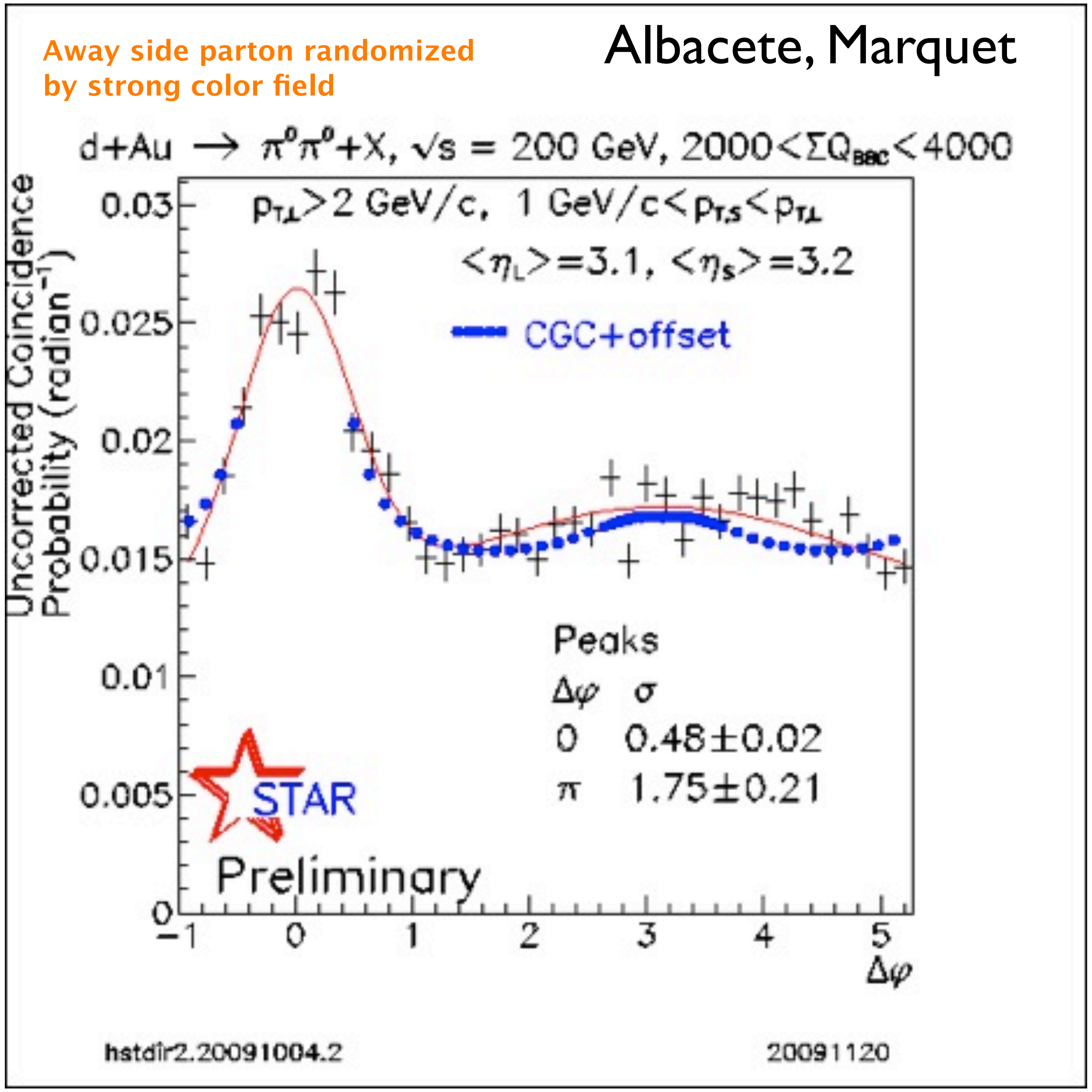


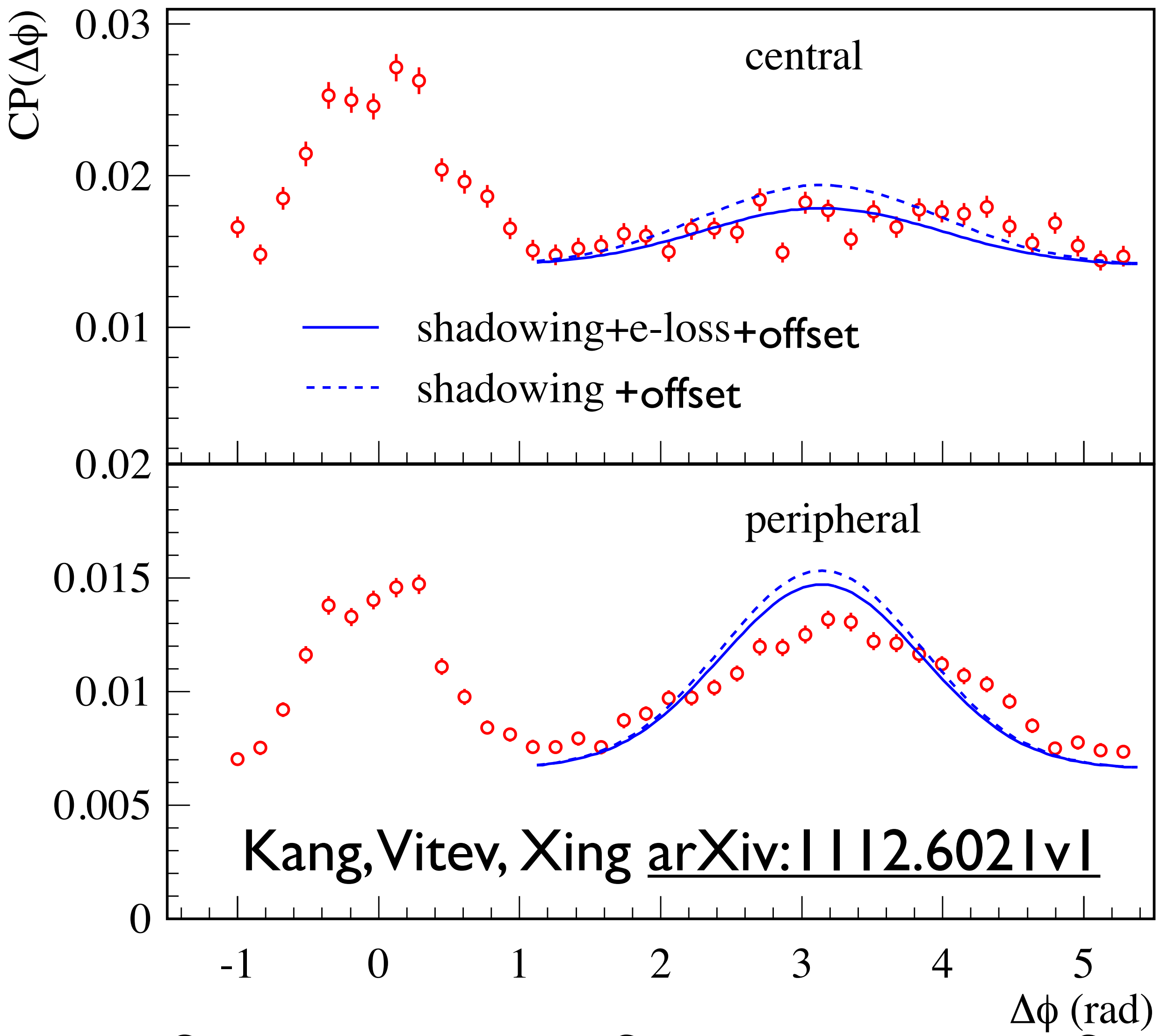


1 question, 2 answers

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?