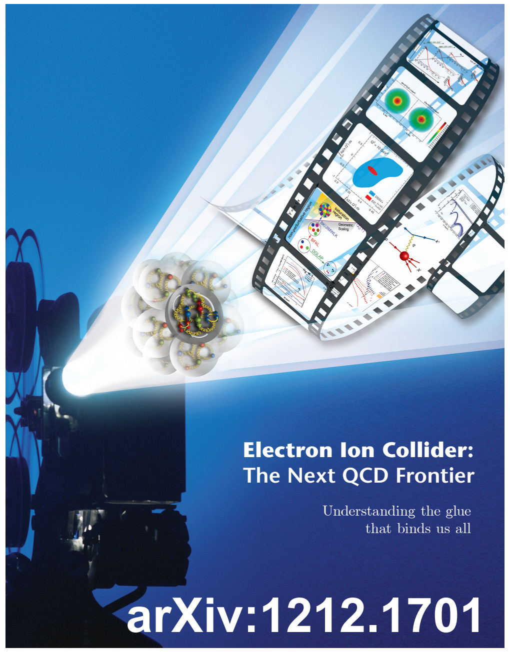
Photoproduction prospects at the EIC

Heikki Mäntysaari (BNL)



PHOTON 2017
CERN, Geneva
May 24, 2017

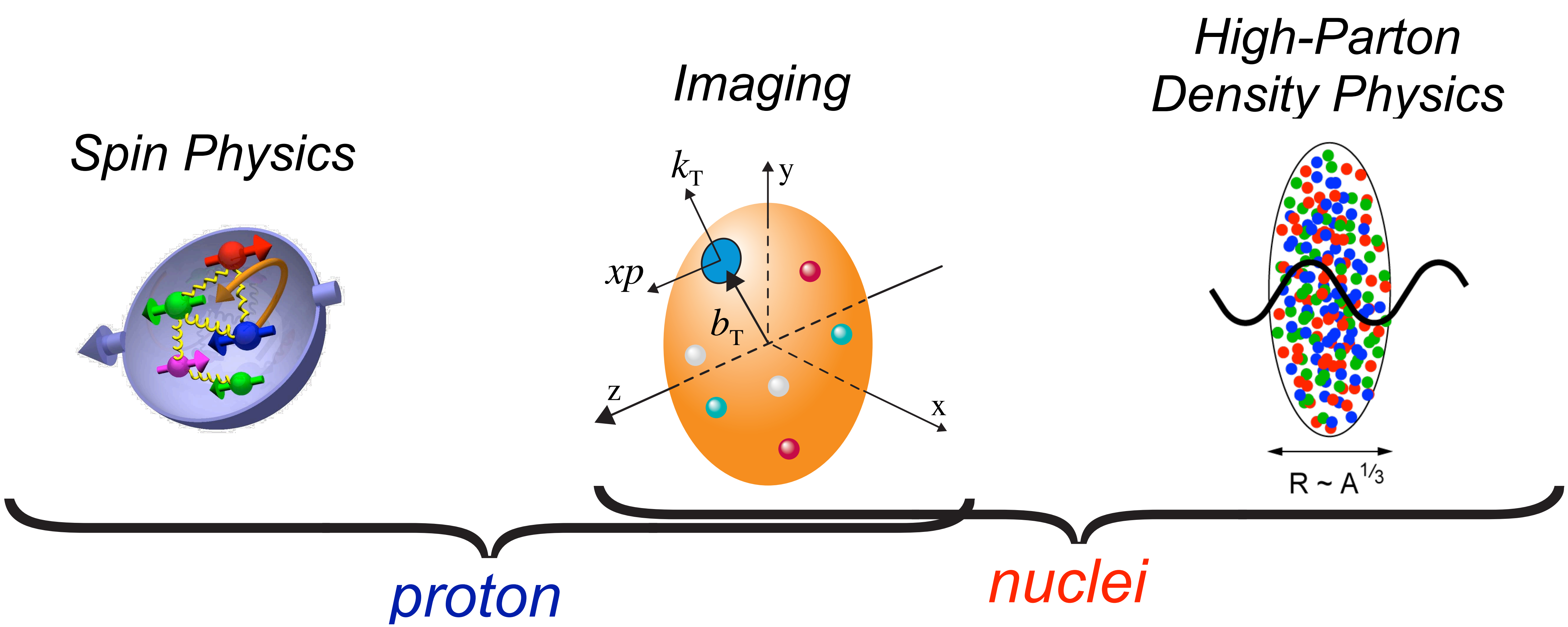
Many thanks to T. Ullrich and the BNL EIC Task Force for providing material to this talk!

Electron-Ion Collider

Investigate with precision the structure of nuclei (and p)

Central themes:

- Probe the gluon densities and the onset of saturation in nucleons and nuclei
- Map the transverse spatial and spin distributions of partons in the gluon-dominated regime



Electron-Ion Collider

Investigate with precision the structure of nuclei (and p)

Central themes:

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- Map the transverse spatial and spin distributions of partons in the gluon-dominated regime

Requirements:

- Collider ⇒ Kinematic reach well into gluon-dominated regime
- Electron beams ⇒ Precision of the electromagnetic interaction
- Polarized e&p beams ⇒ Correlations of gluon distributions with the nucleon spin
- Heavy ion beams ⇒ Amplification, access large gluon densities

EIC science

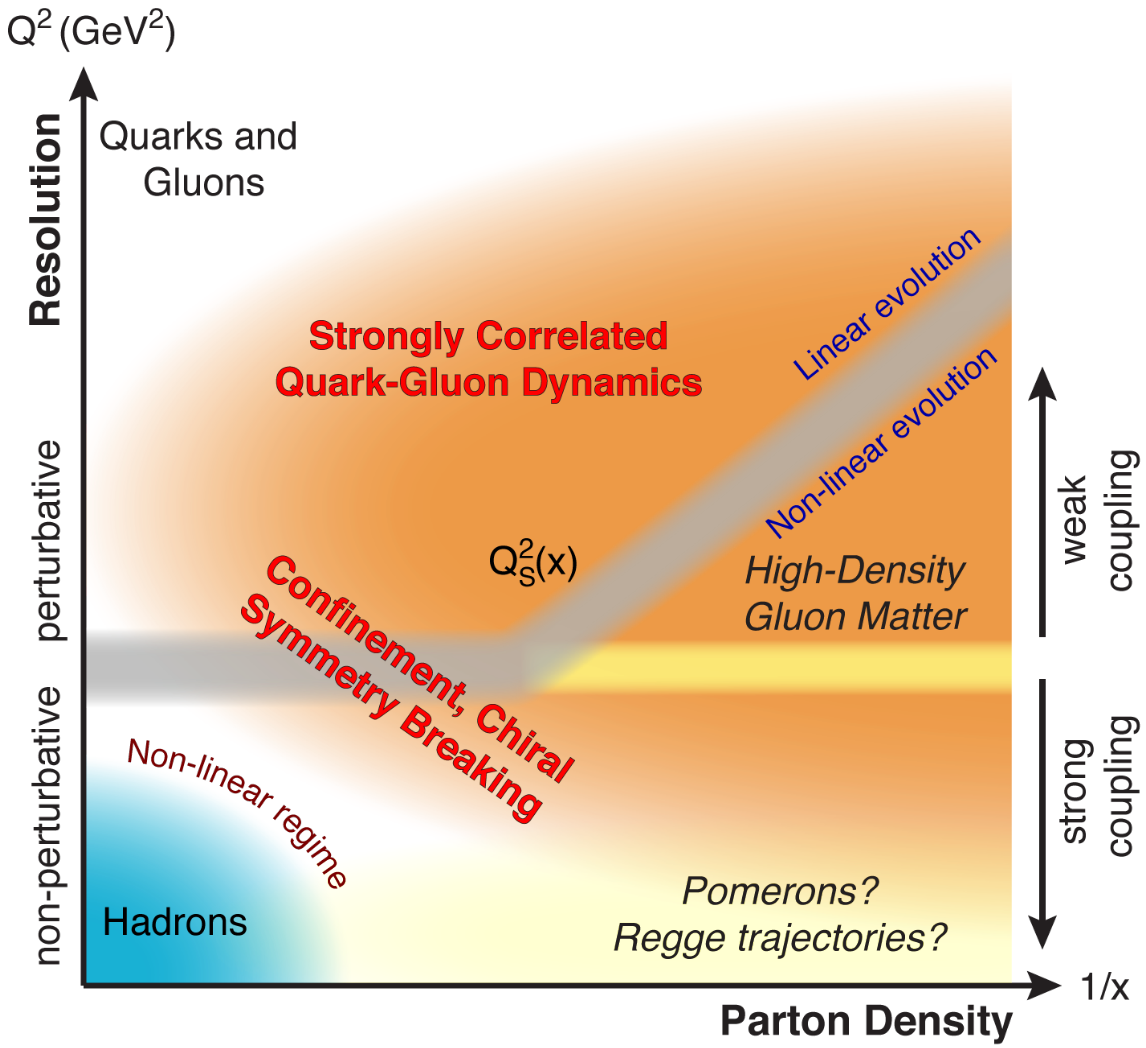
EIC Will be the the Ultimate QCD machine:

- The world's first polarized electron-polarized proton collider
- The world's first electron-heavy ion collider
- Luminosities: a hundred to up to a thousand times HERA

Some important questions

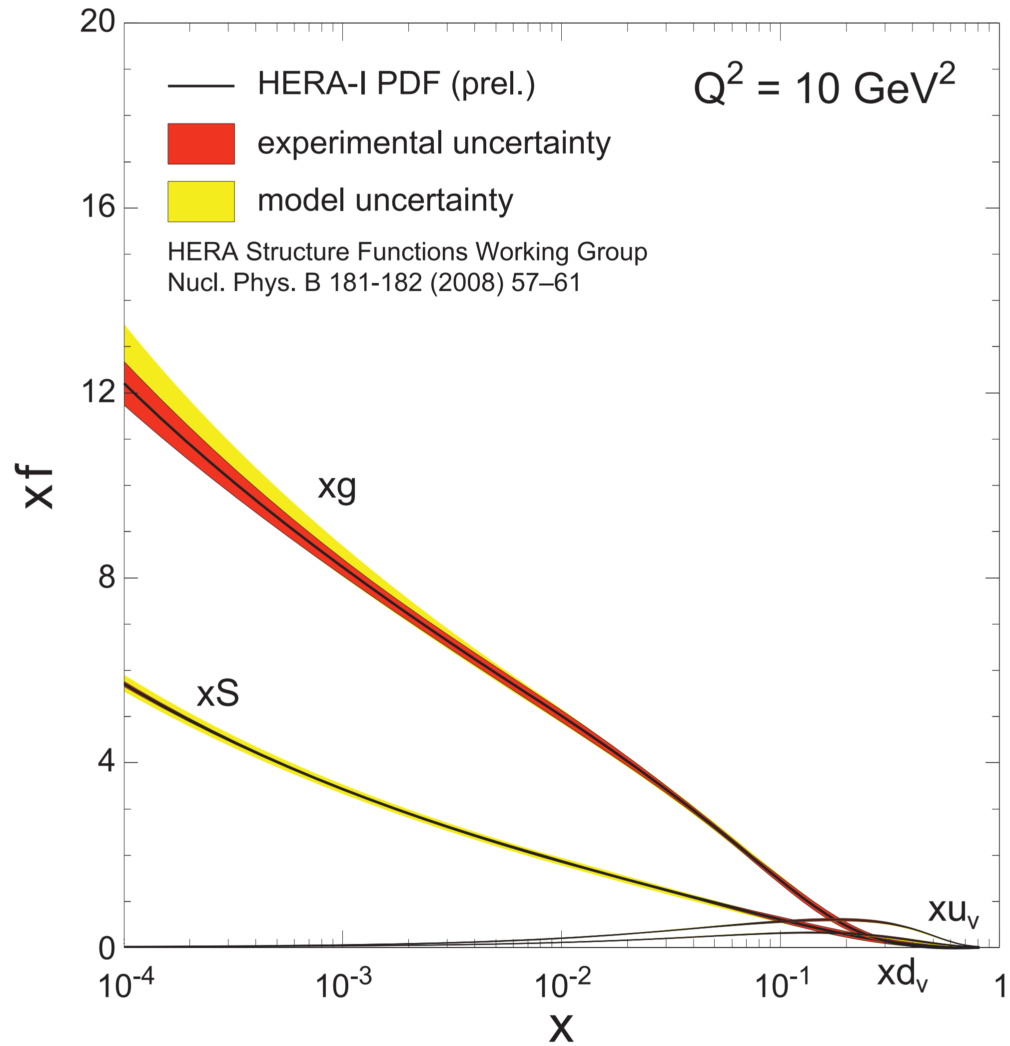
- What is the fundamental quark-gluon structure of light and heavy nuclei?
- What is the role of saturated strong gluon fields
- How does the proton spin add up to 1/2
- How do partons hadronize, how does the nucleus affect this? Study confinement.

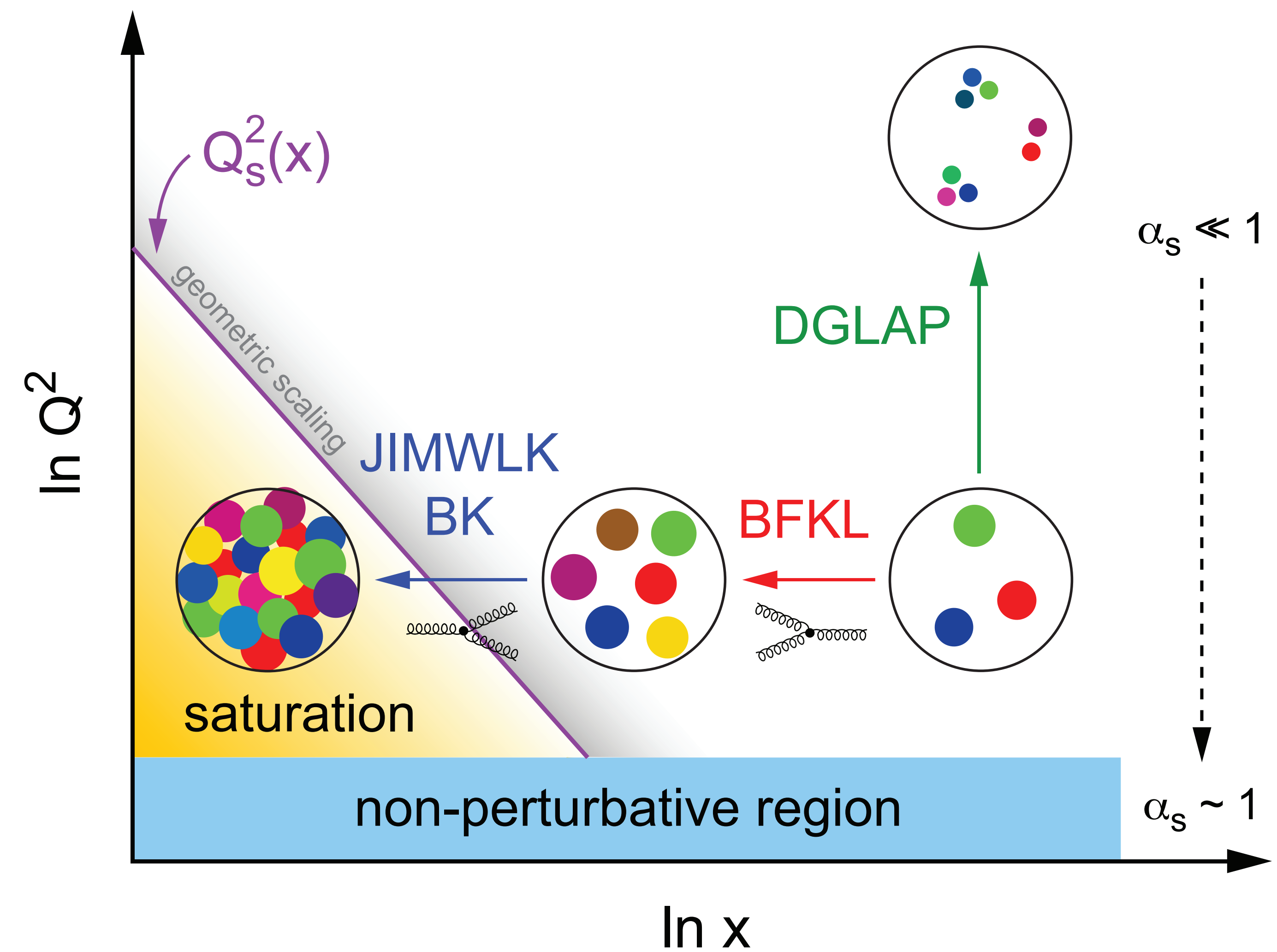
Photo- (and electro)production is a powerful tool to study hadron structure!



One key task: access the small-x gluon

Ever growing $G(x,Q^2)$?



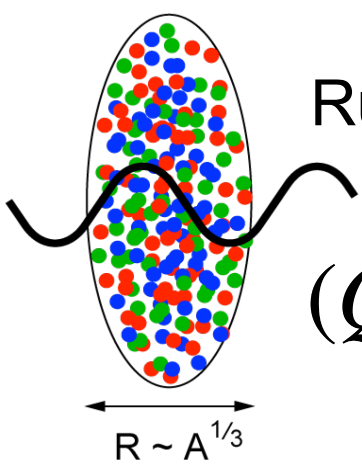


Avoid violating unitarity: Non-Linear Evolution

- *Recombination* compensates gluon splitting
- New evolution equations at low-x & low to moderate Q^2
- Saturation of gluon densities characterized by scale $Q_s(x)$
  - Color Glass Condensate effective theory of QCD

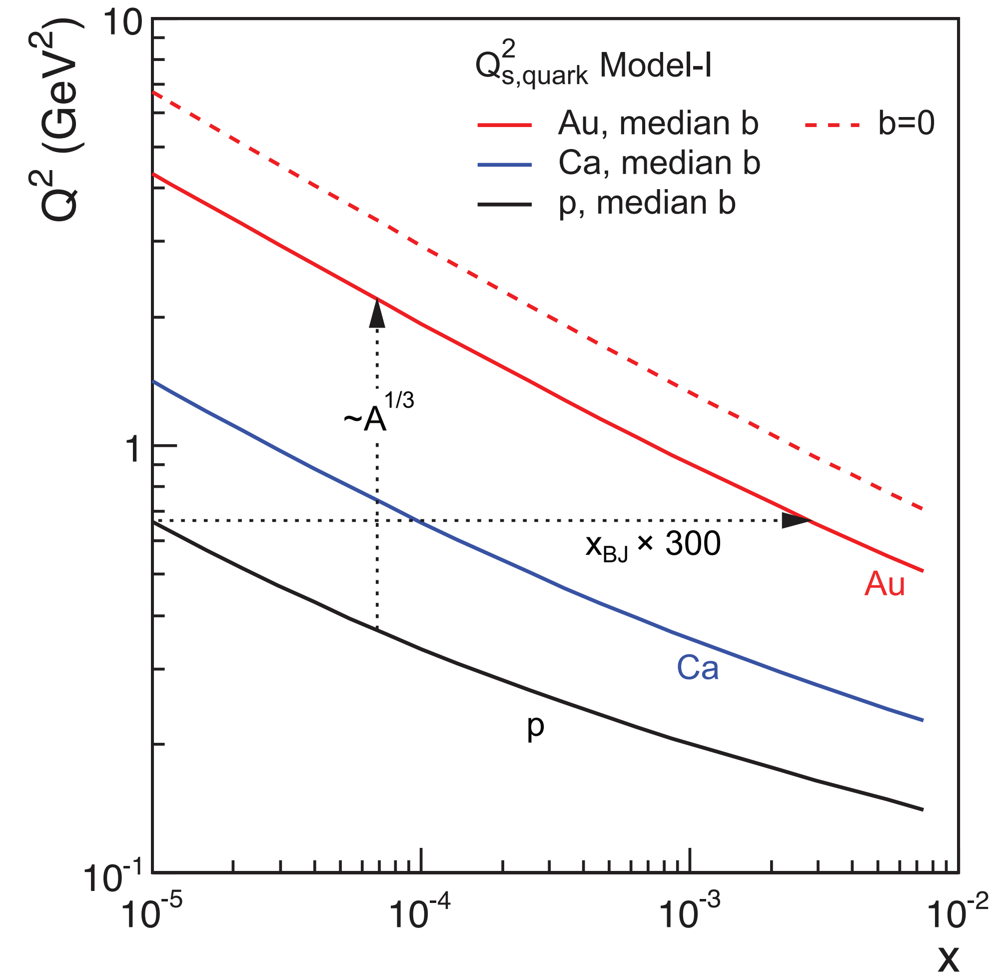
Large gluon densities at the EIC

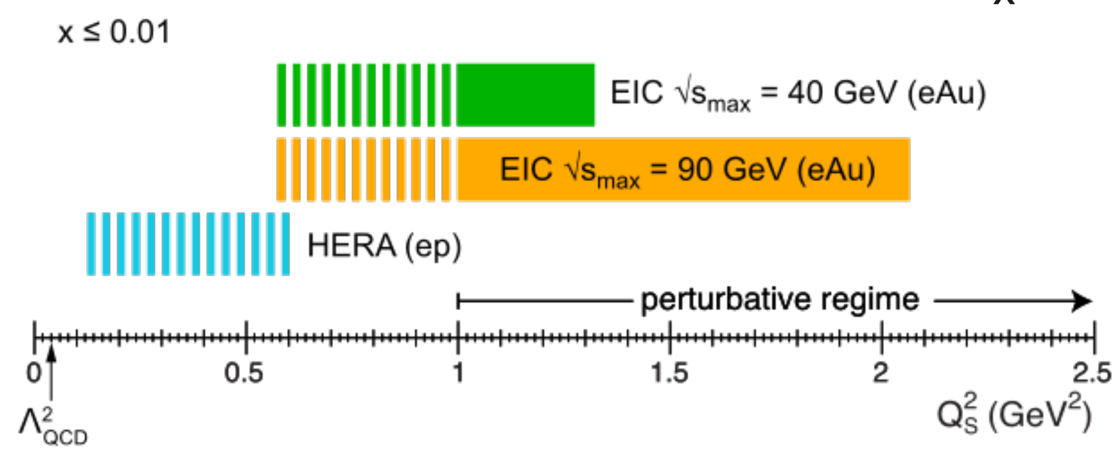
Enhancement of Q_S with A ⇒ saturation regime reached at significantly lower energy (and cost) in nuclei



Rule of Thumb:

$$(Q_s^A)^2 \approx c Q_0^2 \left(\frac{A}{x} \right)^{1/3}$$

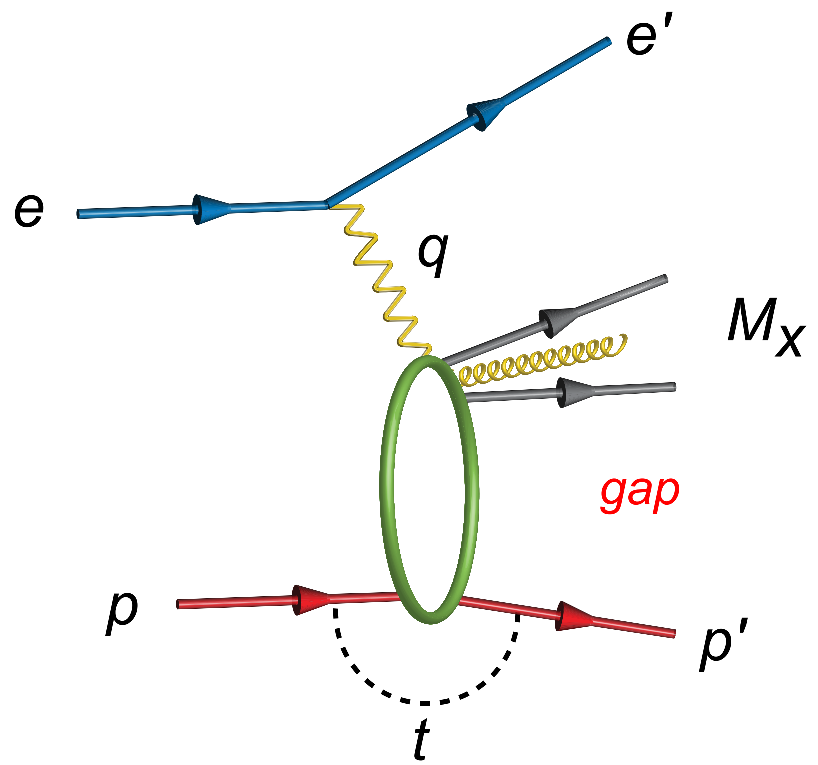




EIC can go deep inside the saturation region

Key Measurements - Diffraction

Diffractive physics will play a major role in the EIC
Especially in eA



t : momentum transfer squared
M_X : mass of diffractive final-state

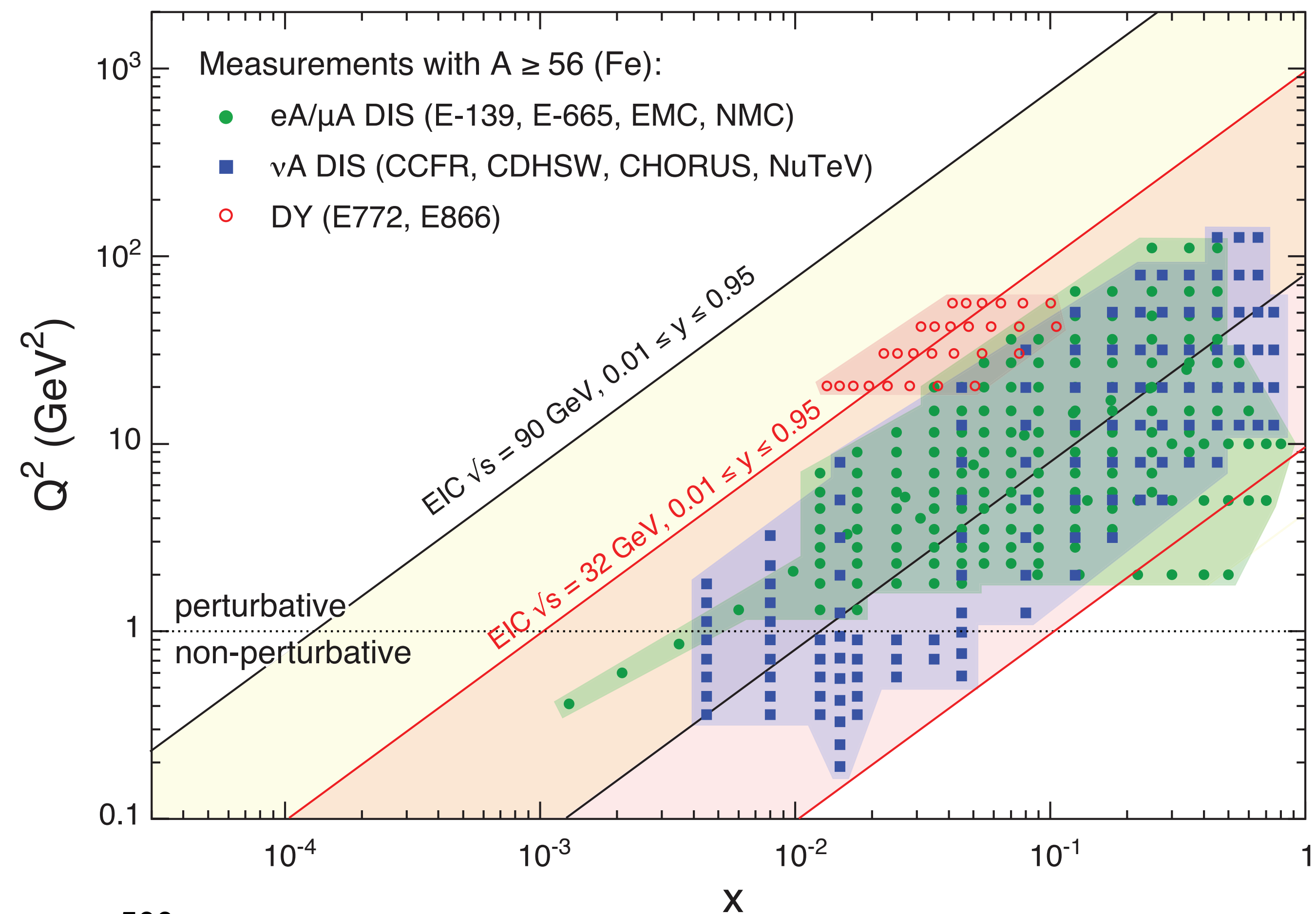
- HERA surprise: ~15% of the DIS events are diffractive!
- Sensitive to gluons, at LO two-gluon exchange $\sigma \sim [g(x,Q^2)]^2$

t can be measured only in exclusive processes (e.g. X=J/ψ)

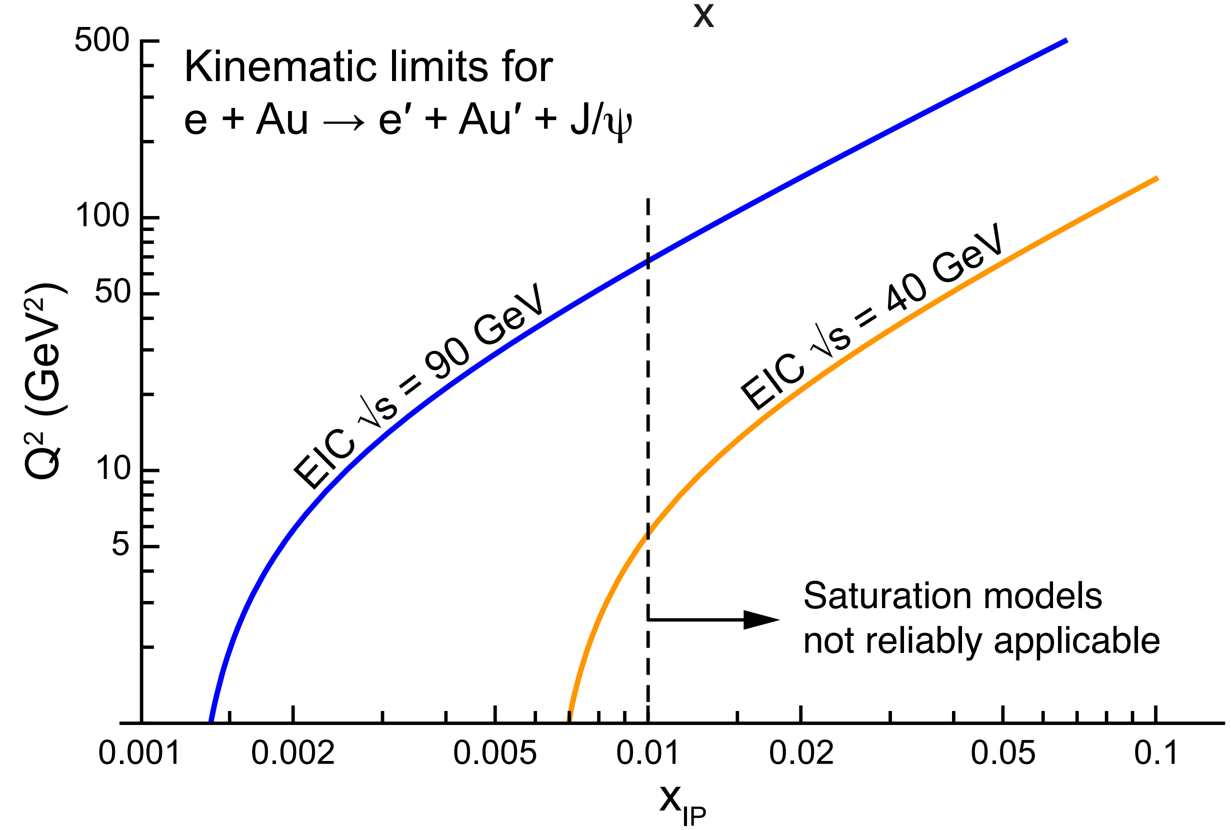
- Access spatial gluon distribution (Fourier conjugate to b)

EIC capabilities

Explore nuclear structure in a new kinematical domain



Coverage for exclusive processes in the small-x region



What do the diffractive cross sections tell us

Coherent: target remains intact

~ average density

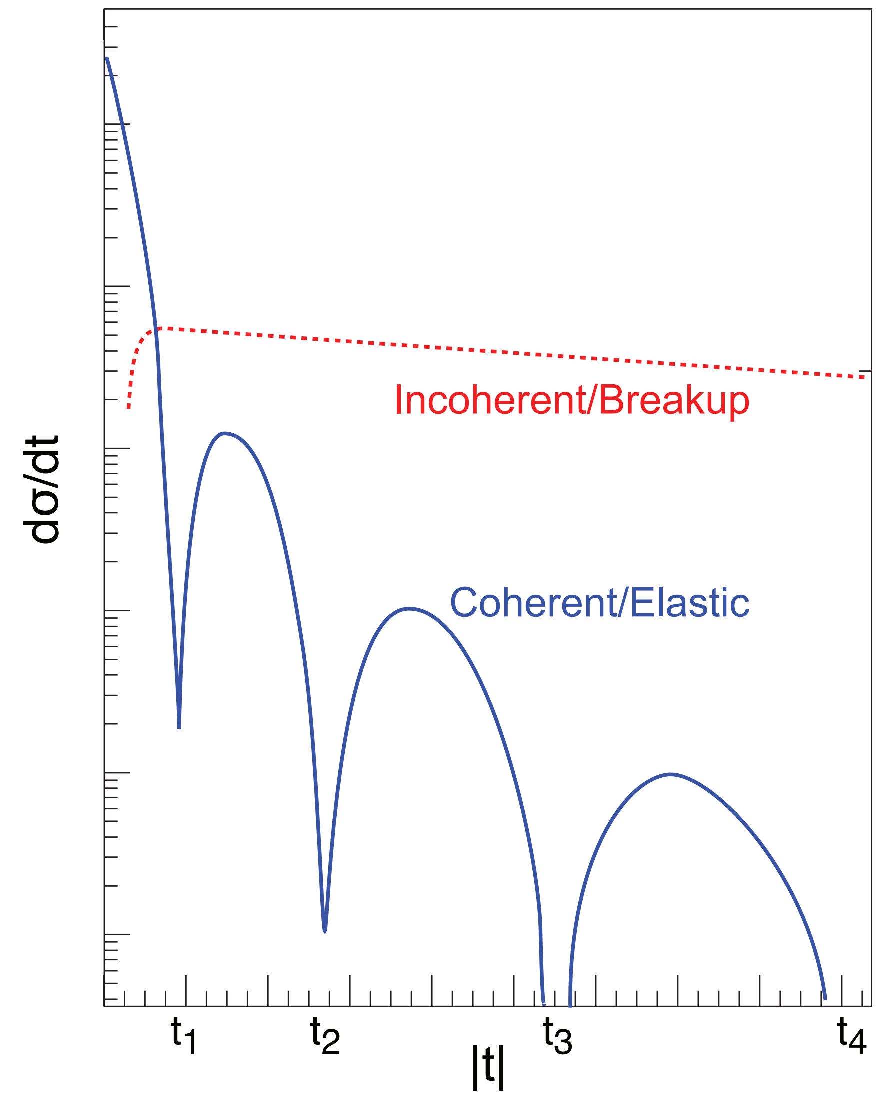
$$\frac{\mathrm{d}\sigma_{\mathrm{coh}}}{\mathrm{d}t} = \frac{1}{16\pi} \left|\langle \mathcal{A} \rangle\right|^2$$

Incoherent: target dissociation ($f \neq i$)

$$\begin{aligned} \sigma_{\mathrm{incoh}} &\propto \sum_{f \neq i} \langle i|\mathcal{A}|f\rangle^\dagger \langle f|\mathcal{A}|i\rangle \\ &= \sum_{f} \langle i|\mathcal{A}|f\rangle^\dagger \langle f|\mathcal{A}|i\rangle - \langle i|A|i\rangle^\dagger \langle i|A|i\rangle \\ &= \langle i|\,|\mathcal{A}|^2|i\rangle - \left|\langle i|\mathcal{A}|i\rangle\right|^2 = \langle|\mathcal{A}|^2\rangle - \left|\langle \mathcal{A}\rangle\right|^2 \end{aligned}$$

Variance of amplitude $\mathcal{A}$

⇒ measure of fluctuating source density



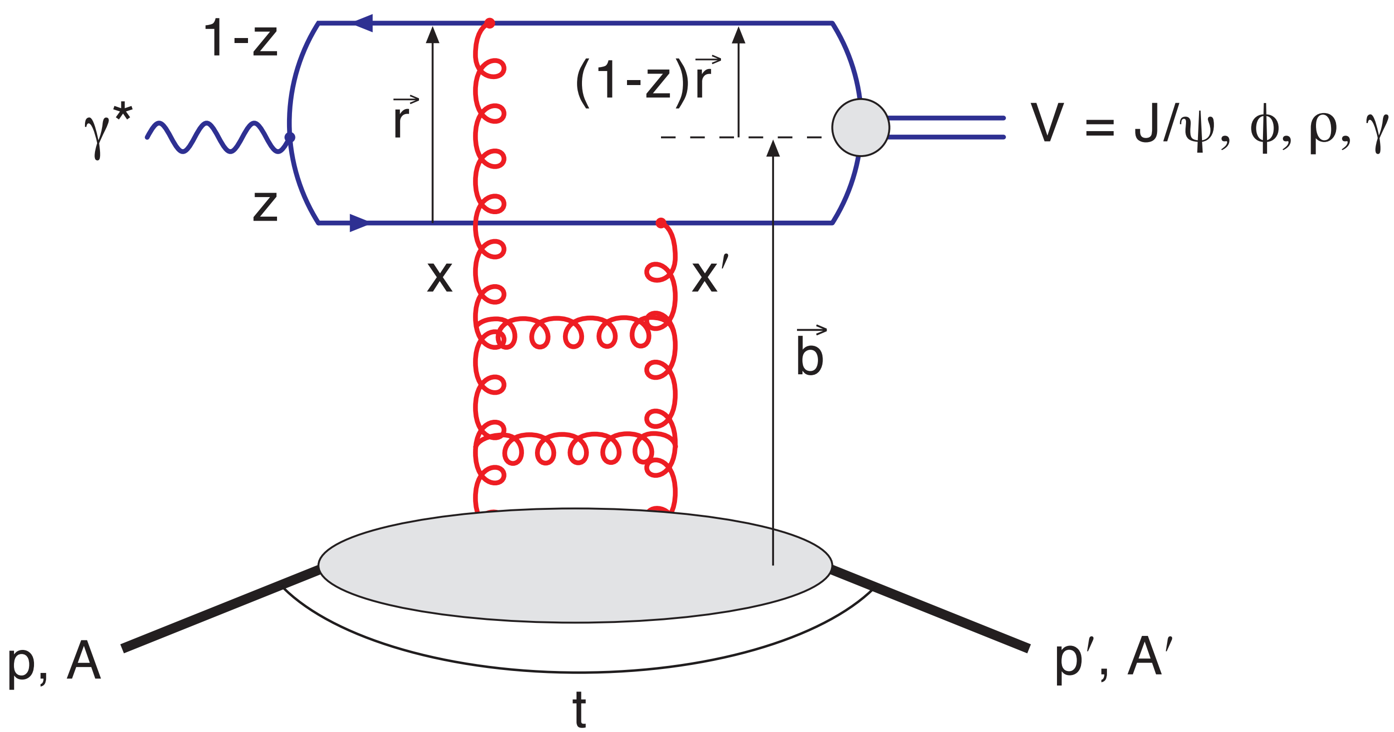
$$\mathbf{t_i \sim 1/R^2}$$

H. I. MIETTINEN
AND J. PUMPLIN
PHYS. REV. D18 (1978) 1696

Exclusive Vector Meson Production

Describing diffractive scattering at high energy: dipole picture

$$\mathcal{A} = \int \mathrm{d}^2 b \mathrm{d}^2 r \mathrm{d}z e^{-ib\cdot\Delta} \Psi_\gamma(r,z,Q^2)\sigma_{\mathrm{dip}}(r,b,x)\Psi^*_{\mathrm{VM}}(r,z,M^2)$$



$$-t = (p_A - p_{A'})^2 \approx \Delta^2 = p_T^{VM,2}$$

Diffractive amplitude:
FT coordinate space
→ momentum space

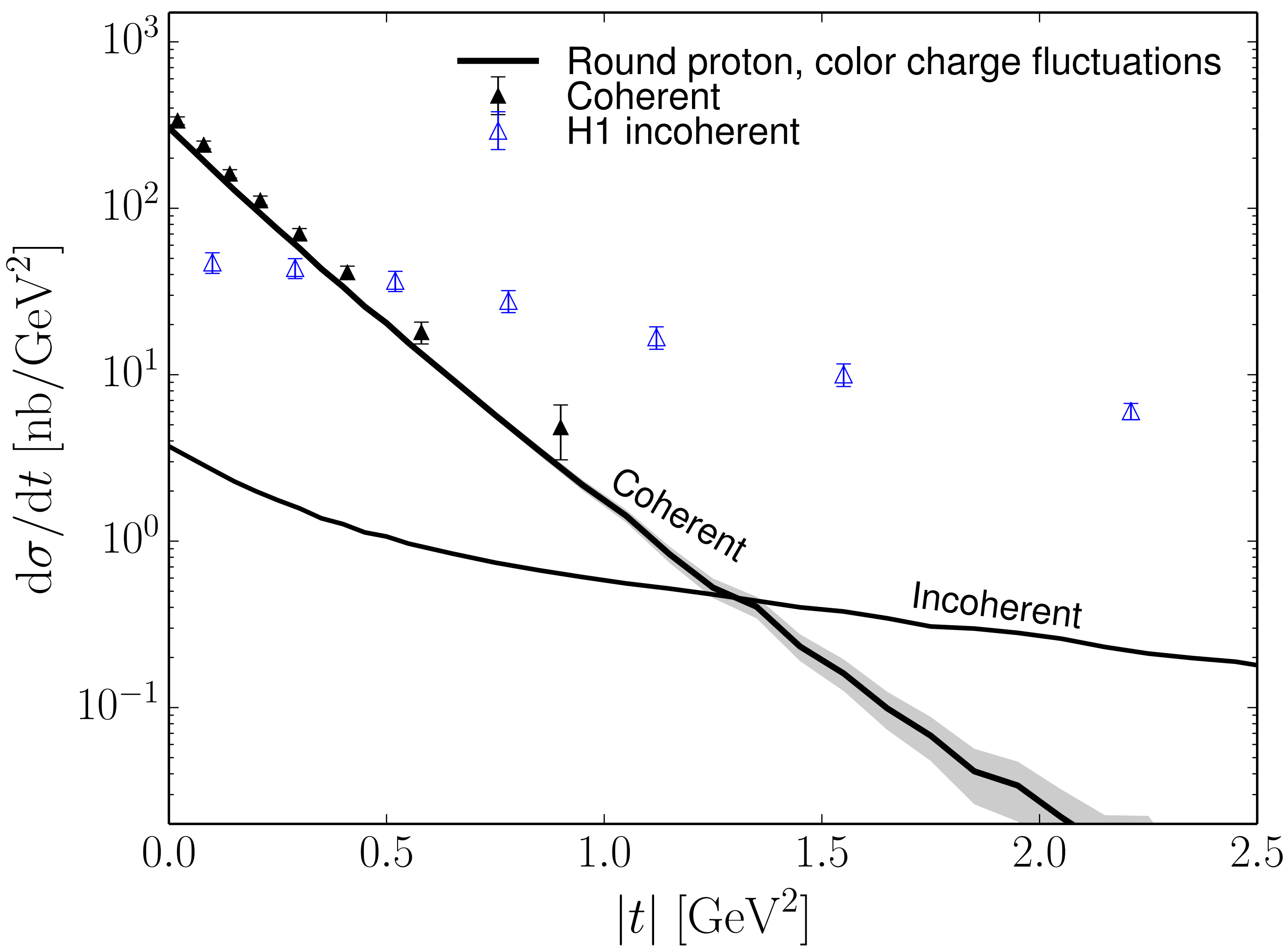
➡ Sensitive to geometry

See talk by B. Schenke

Proton structure

$\gamma p \to J/\Psi p, W = 75\,\mathrm{GeV}$

Recall: incoherent cross section ~ fluctuations
coherent cross section ~ average density



Incoherent cross section clearly underestimated with only color charge fluctuations

See talk by B. Schenke

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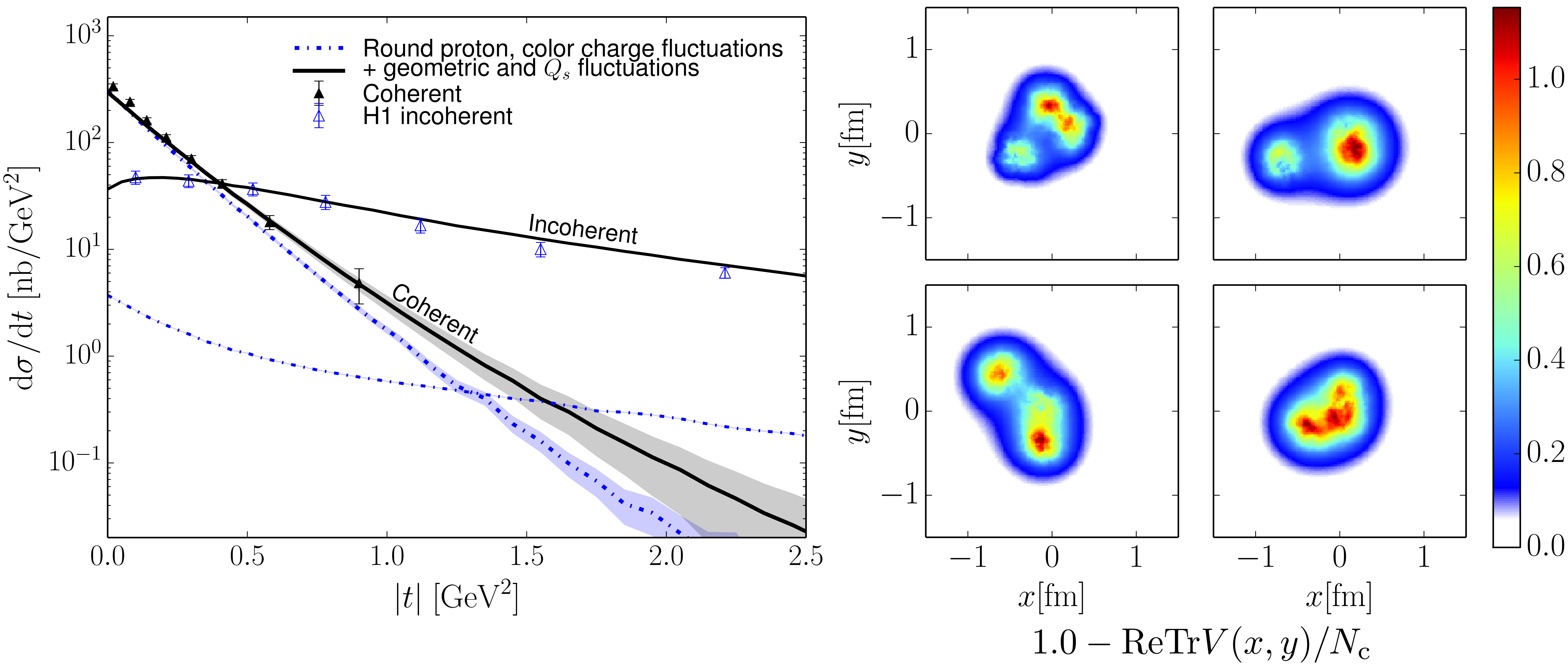
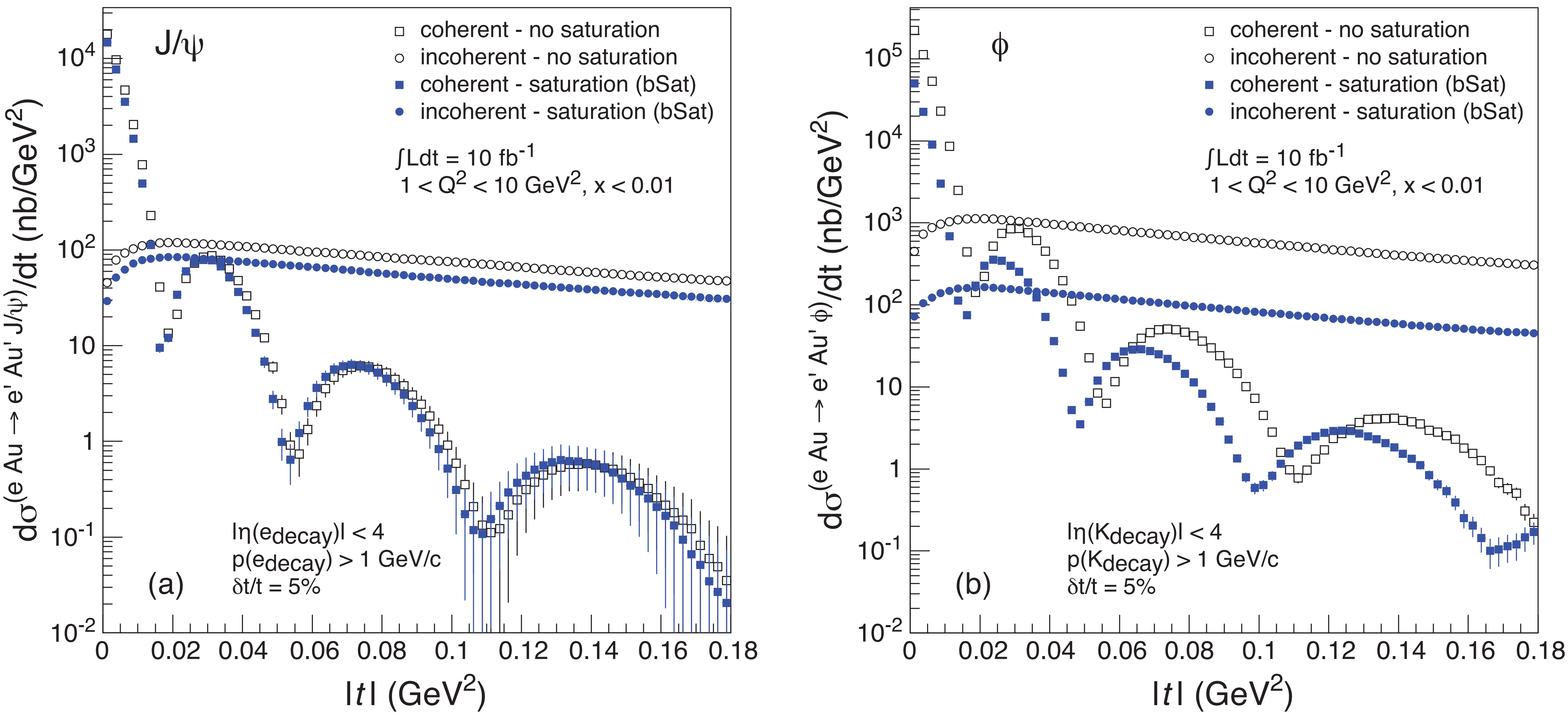


HERA data requires large geometric fluctuations

See talk by B. Schenke

Vector Meson Production in eA



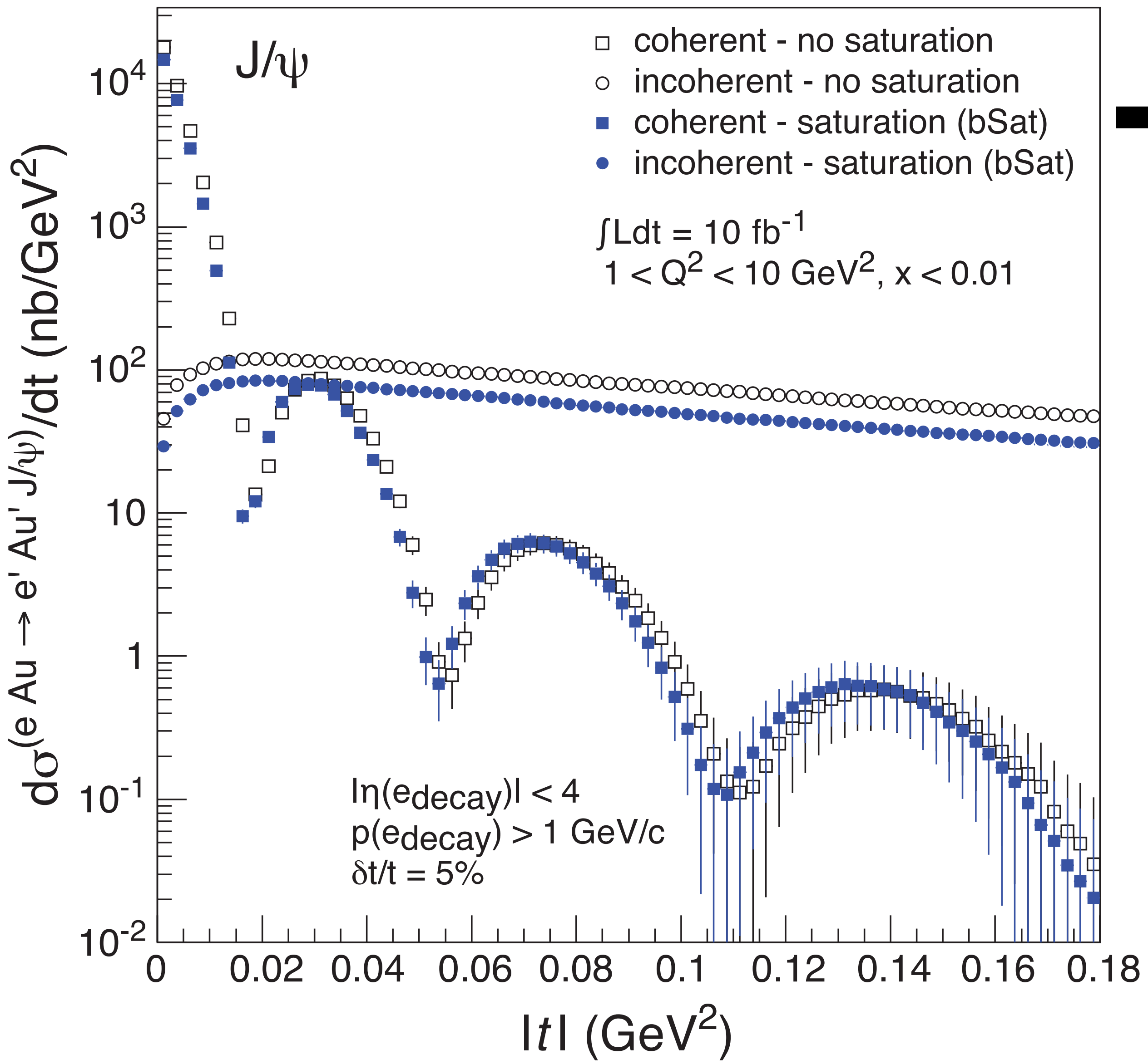
- Diffractive pattern for coherent (non-breakup) part
- Saturation effects seen especially in light meson production
- Need: t resolution, kinematical reach, luminosity for x binning

T. Toll and TU,
PRC 87 (2013) 024913

Spatial Gluon Distribution from $d\sigma/dt$

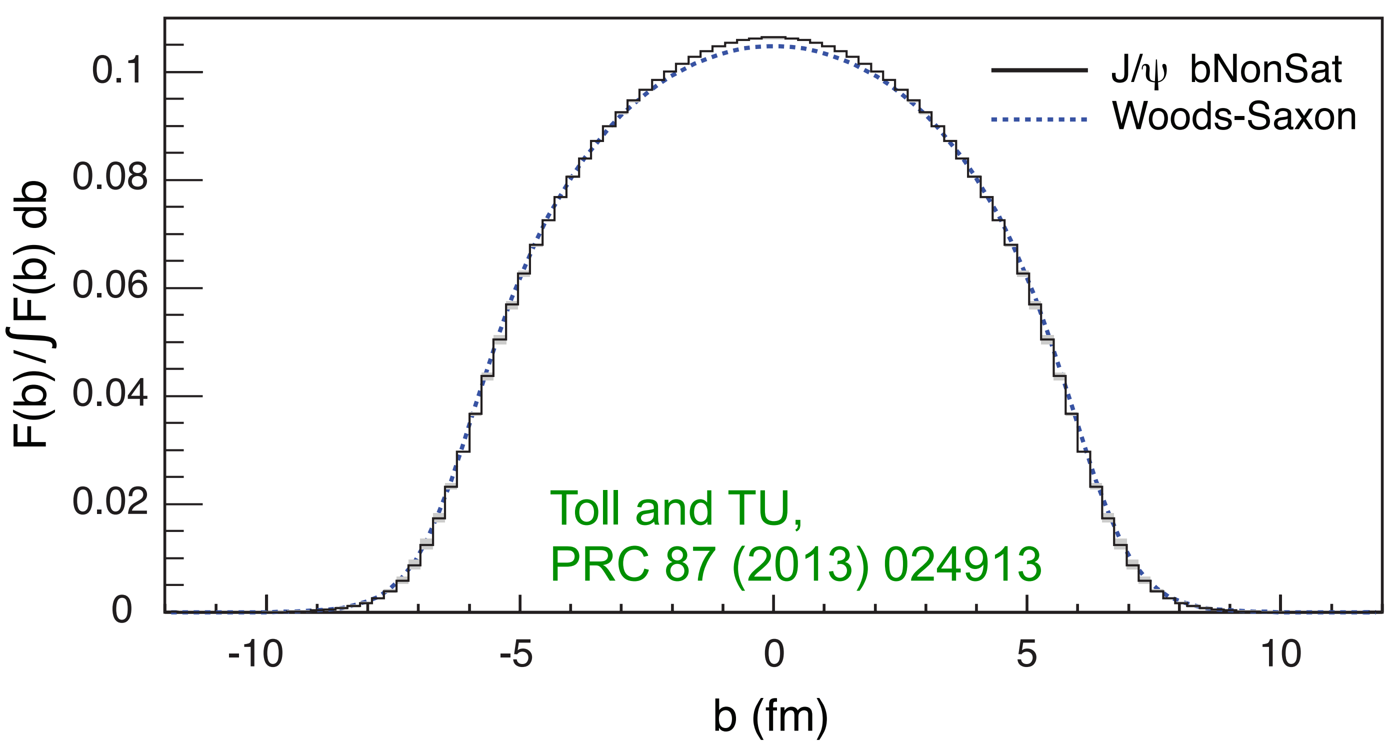
Diffractive vector meson production: $e + Au \rightarrow e' + Au' + J/\psi$

- Momentum transfer $t = |p_{Au} - p_{Au'}|^2$ conjugate to b_T



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

$t \approx \Delta^2$

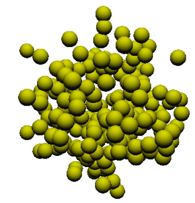


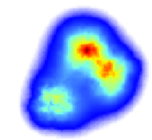
Can extract transverse profile of small-x gluons!

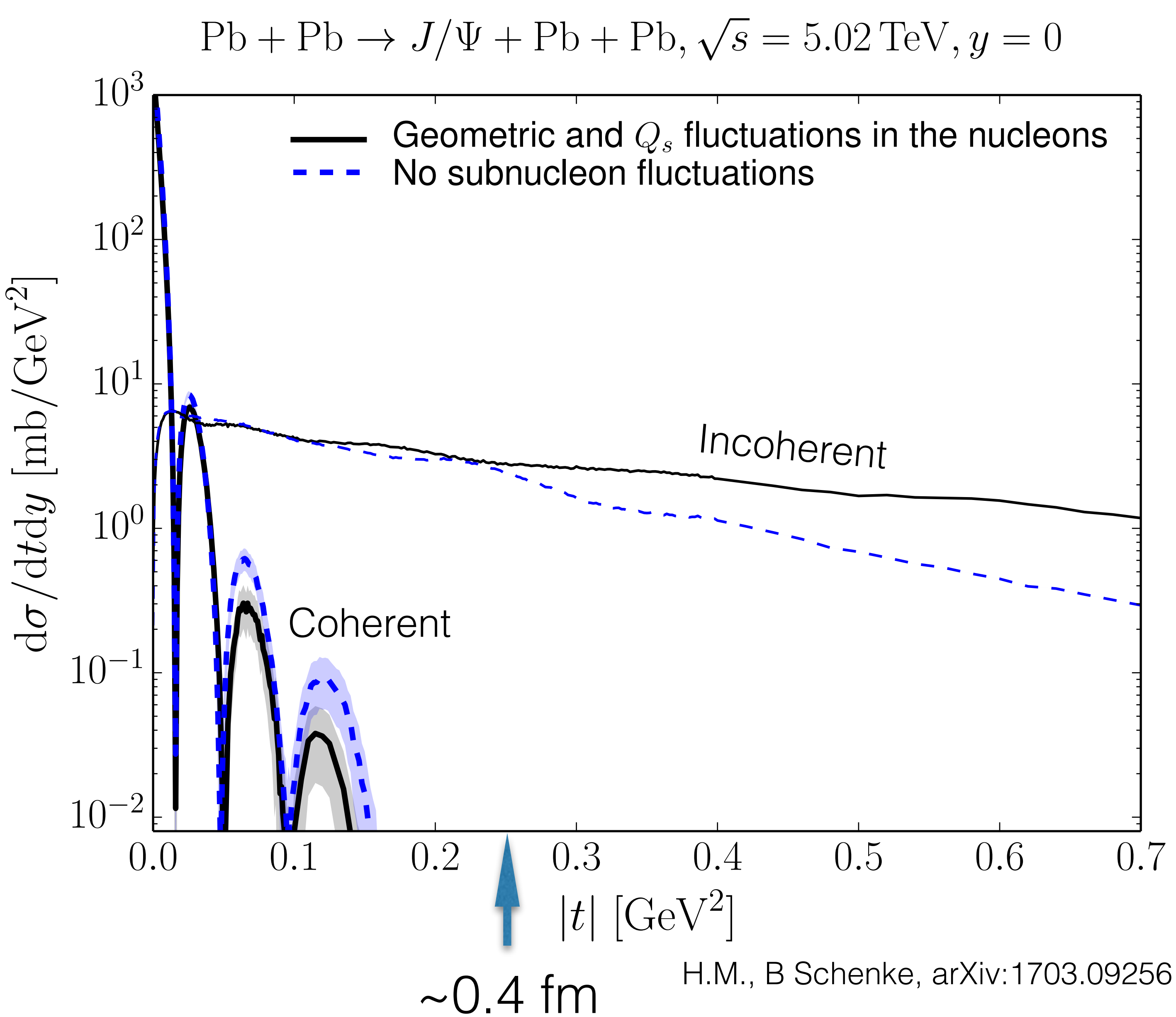
Fluctuations in the nuclear structure

For nuclear targets, two sources of fluctuations

- Nucleon positions
- Sub-nucleon fluctuations







H.M., B Schenke, arXiv:1703.09256

J/ψ photoproduction in γ+Pb sensitive to small-scale fluctuations

EIC can study
- Q^2 dependence
- **A dependence**

In a more clean environment

See talk by B. Schenke

Access rare configurations

In incoherent diffraction a largish p_T kick is localized in a nucleon-size area

One nucleon receives a large kick

- Scatters off other nucleons on its path out
- More "ballistic nucleons" in the central events

T. Lappi, H.M., R. Venugopalan Phys.Rev.Lett. 114 (2015) no.8, 082301

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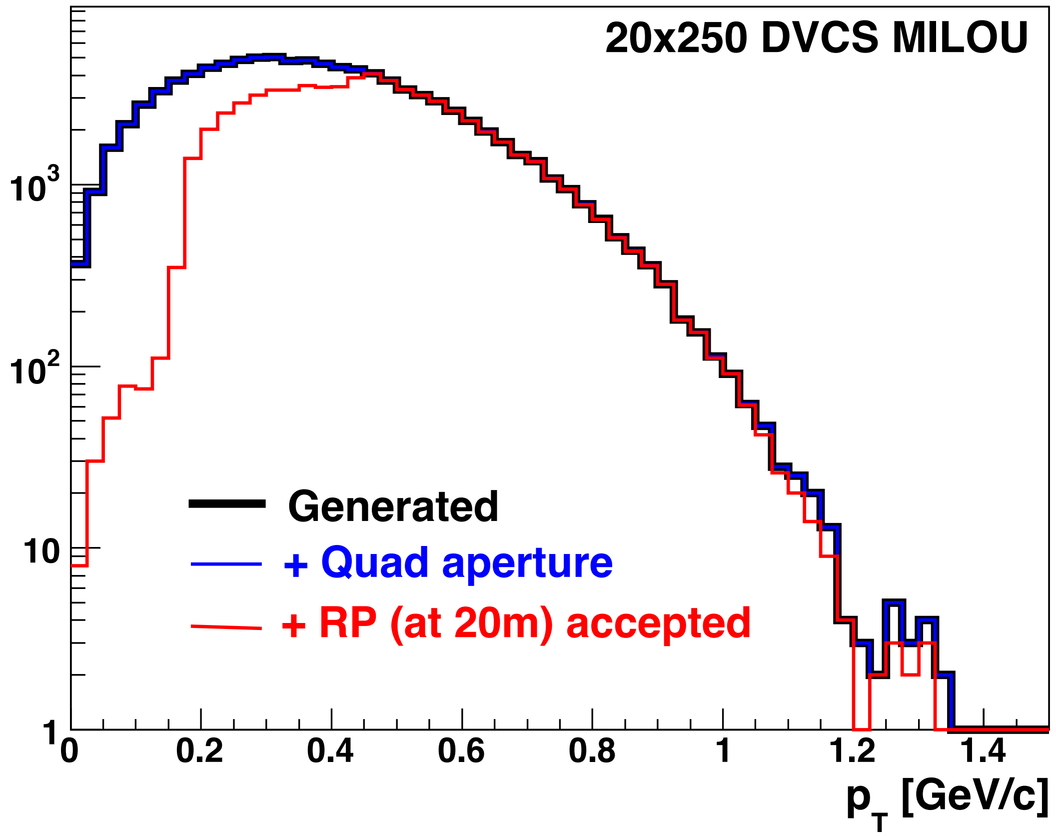
2nd component of nucleons:

- Thermal spectra in the rest frame
- Different p_T!

Ballistic protons seen in Roman pots

- Centrality estimator

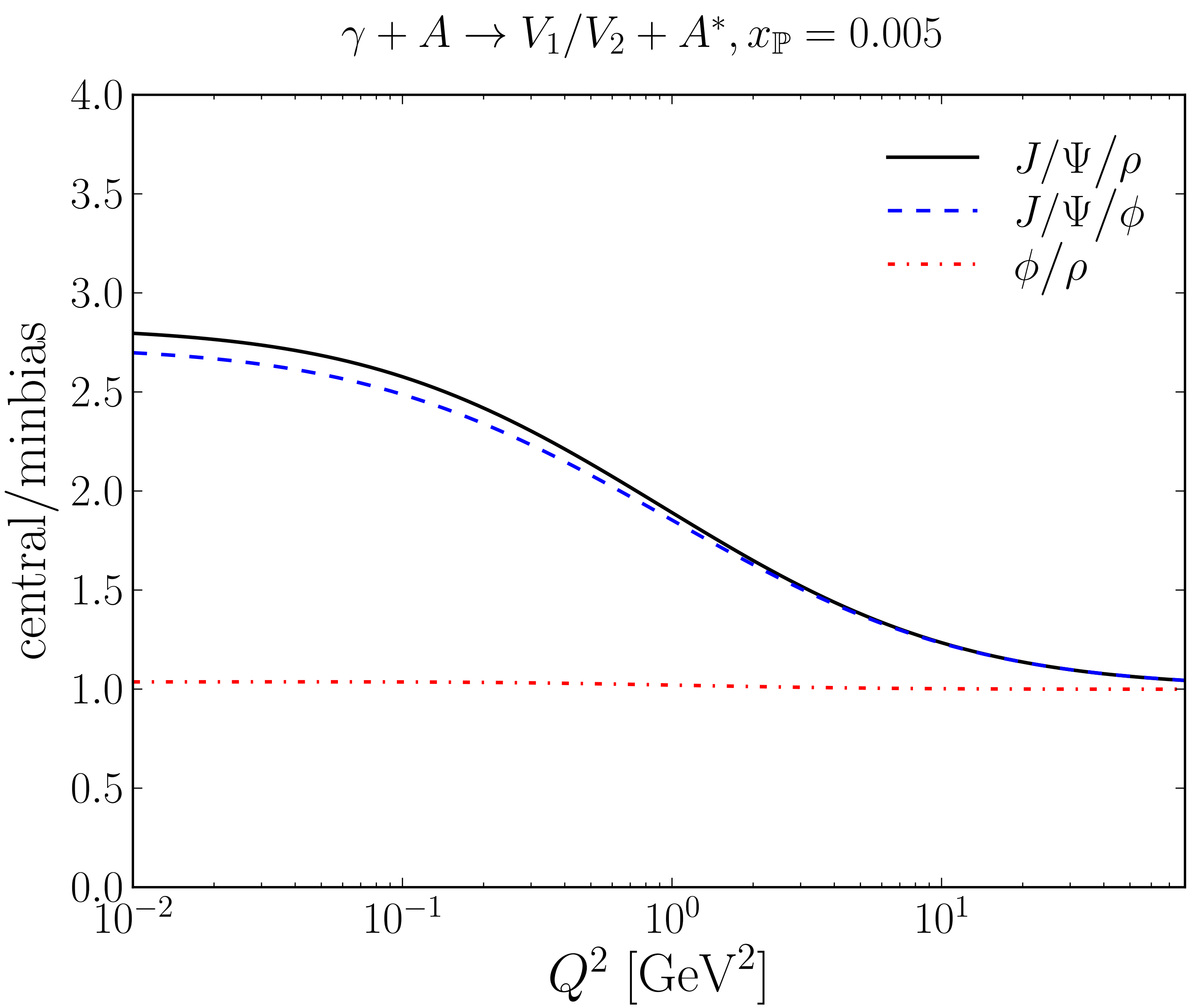


T. Lappi, H.M., R. Venugopalan Phys.Rev.Lett. 114 (2015) no.8, 082301

Access rare configurations

Larger saturation scale in central events

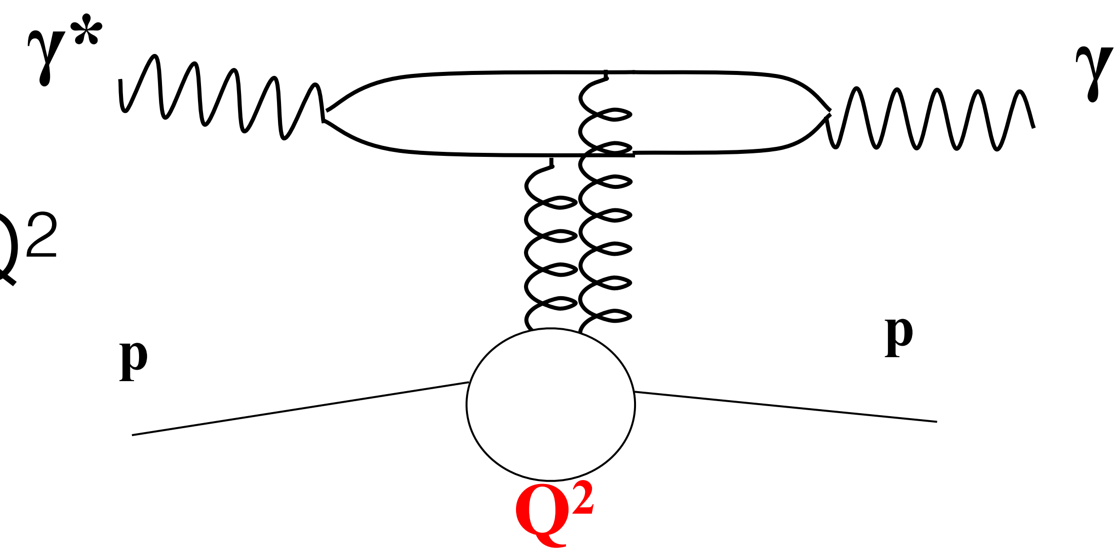
- Expect to see larger suppression for lighter mesons



Access centrality dependence of Q_s

T. Lappi, H.M., R. Venugopalan Phys.Rev.Lett. 114 (2015) no.8, 082301

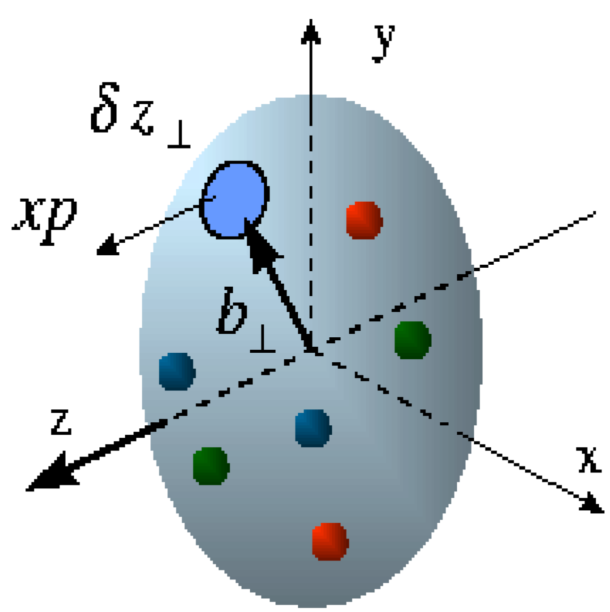
Deeply Virtual Compton Scattering

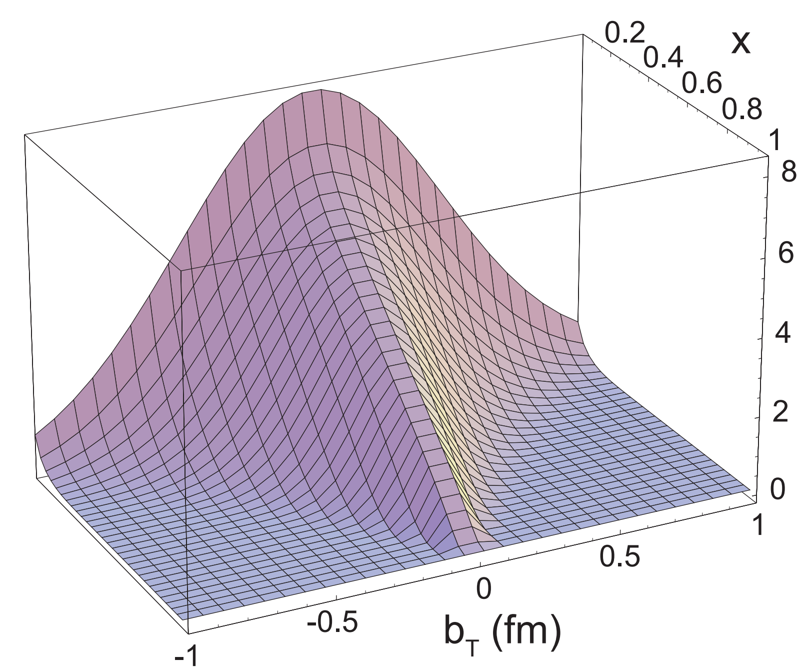


Hard scale provided by virtuality Q^2

- Experimentally very clean
- Not affected by VM wave function uncertainty

Access Generalized Parton Distribution Functions

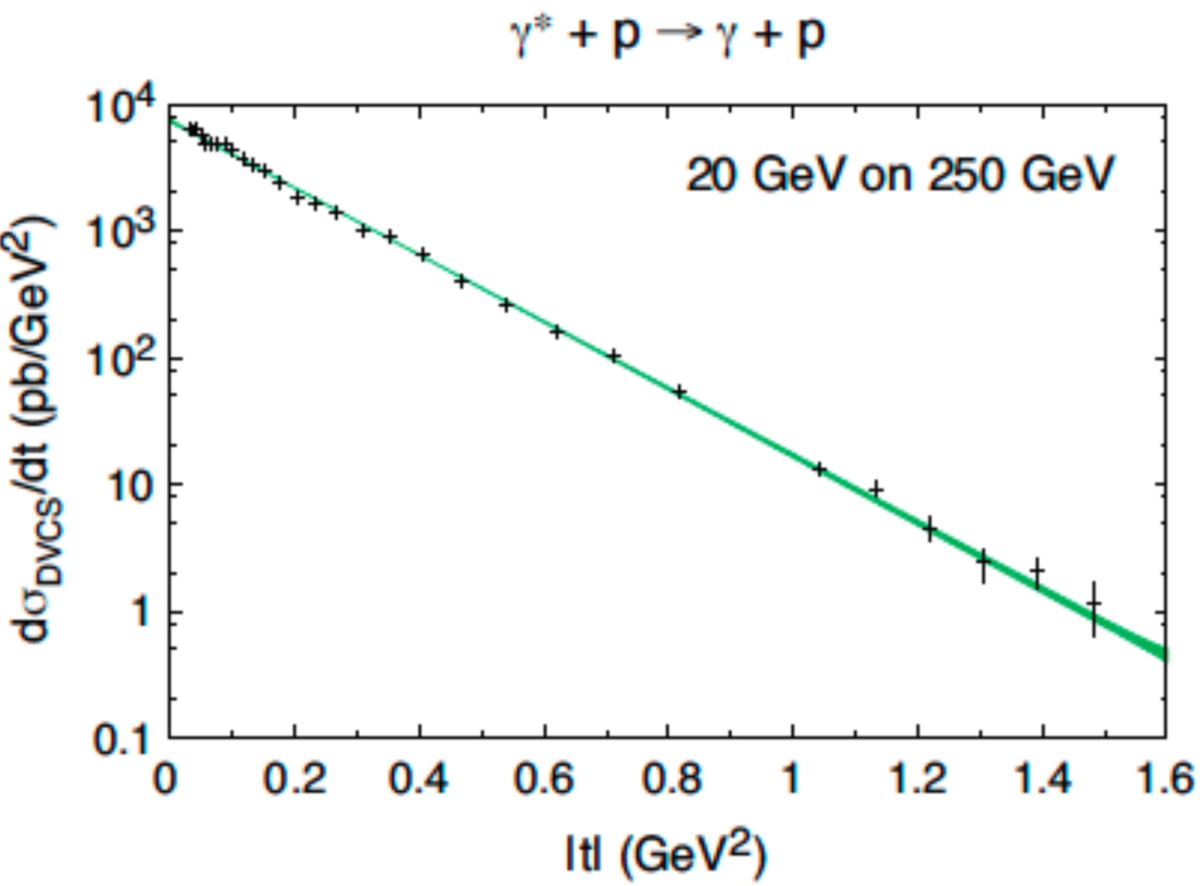




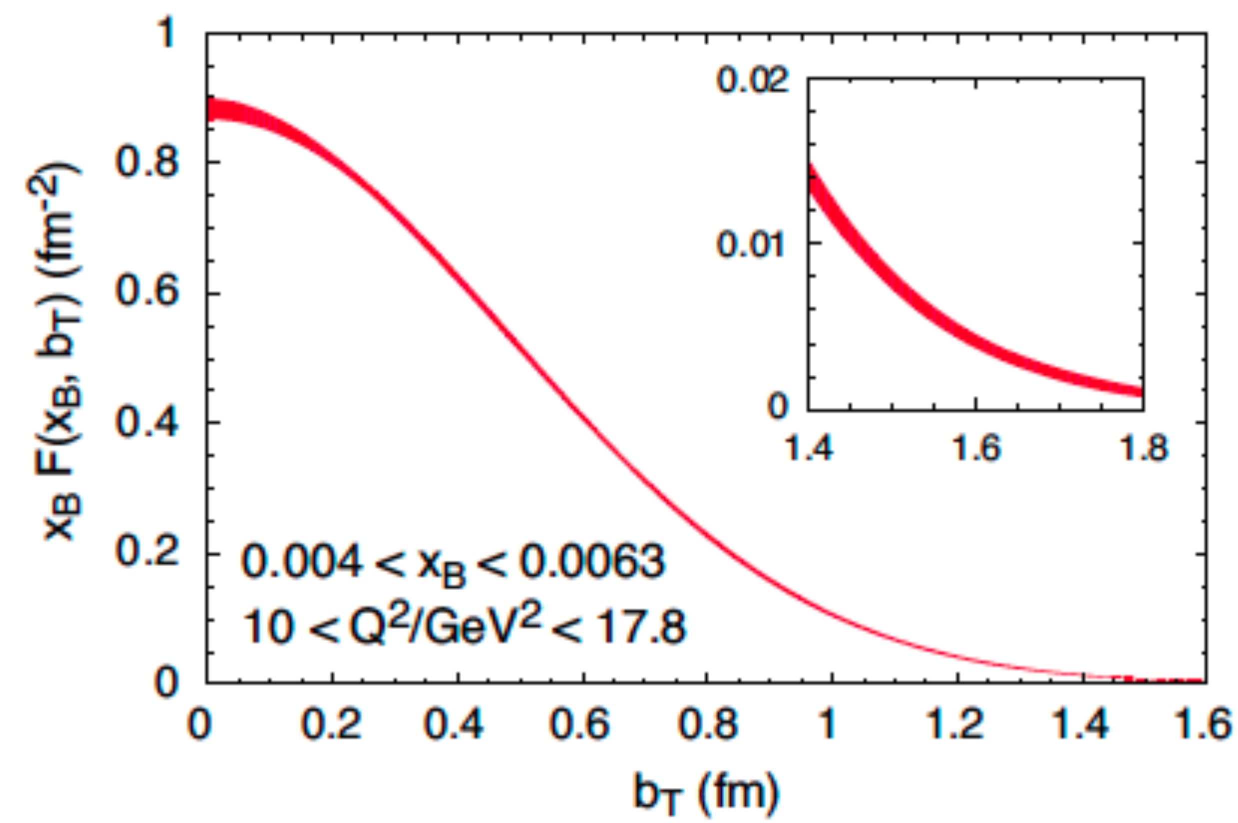
DVCS impact

Provides access to Generalized Parton Distribution Functions

$$\int \mathrm{d}^2 b_T x F(x, b_T, Q^2) \sim xq(x, Q^2)$$



FT

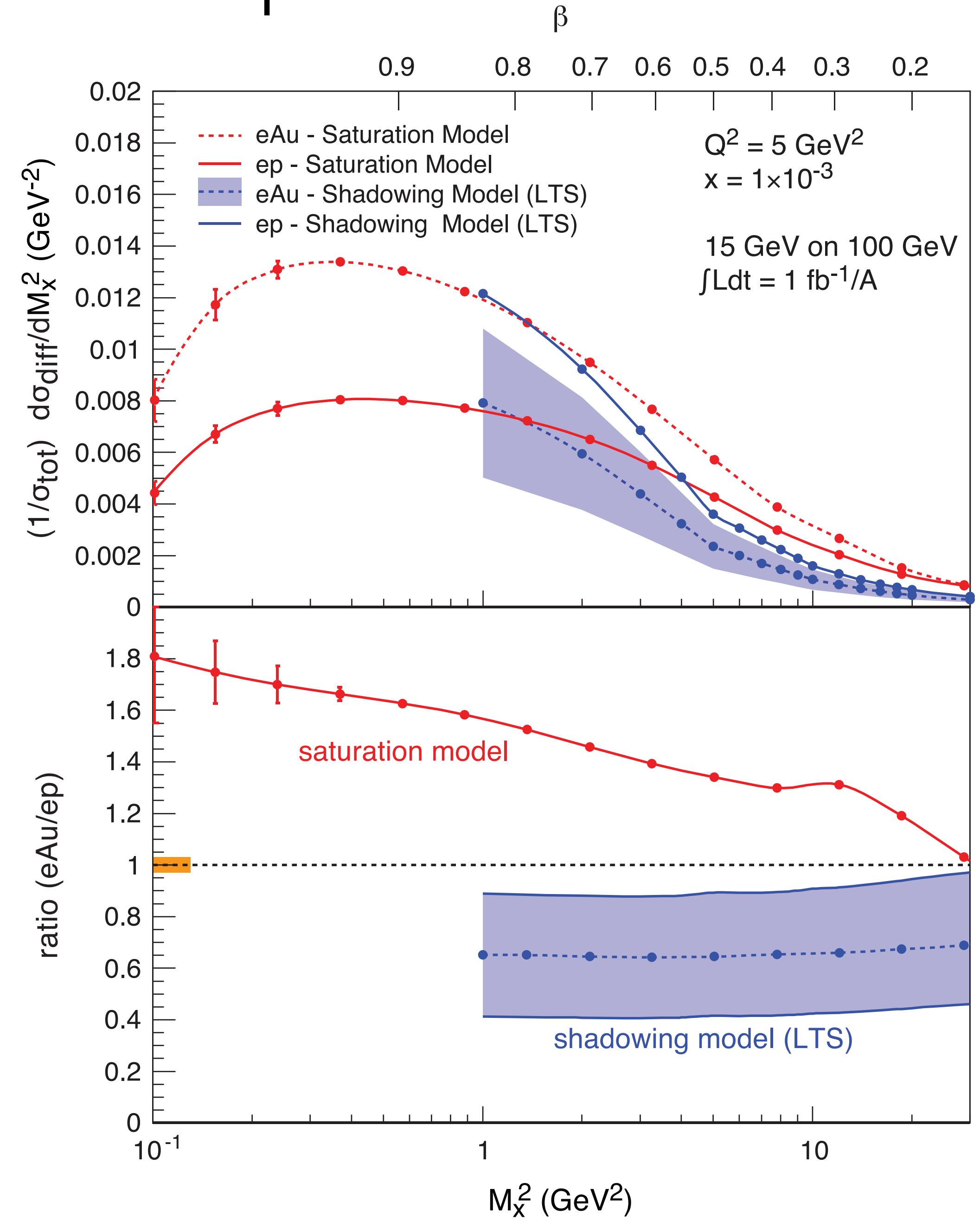


E.C. Aschenauer, S. Fazio, K. Kumerički, D. Müller JHEP09(2013)093

Inclusive diffraction

Diffractive production of a system of particles with mass M_X^2

Saturation models generally predict more diffractive events in eA compared to ep

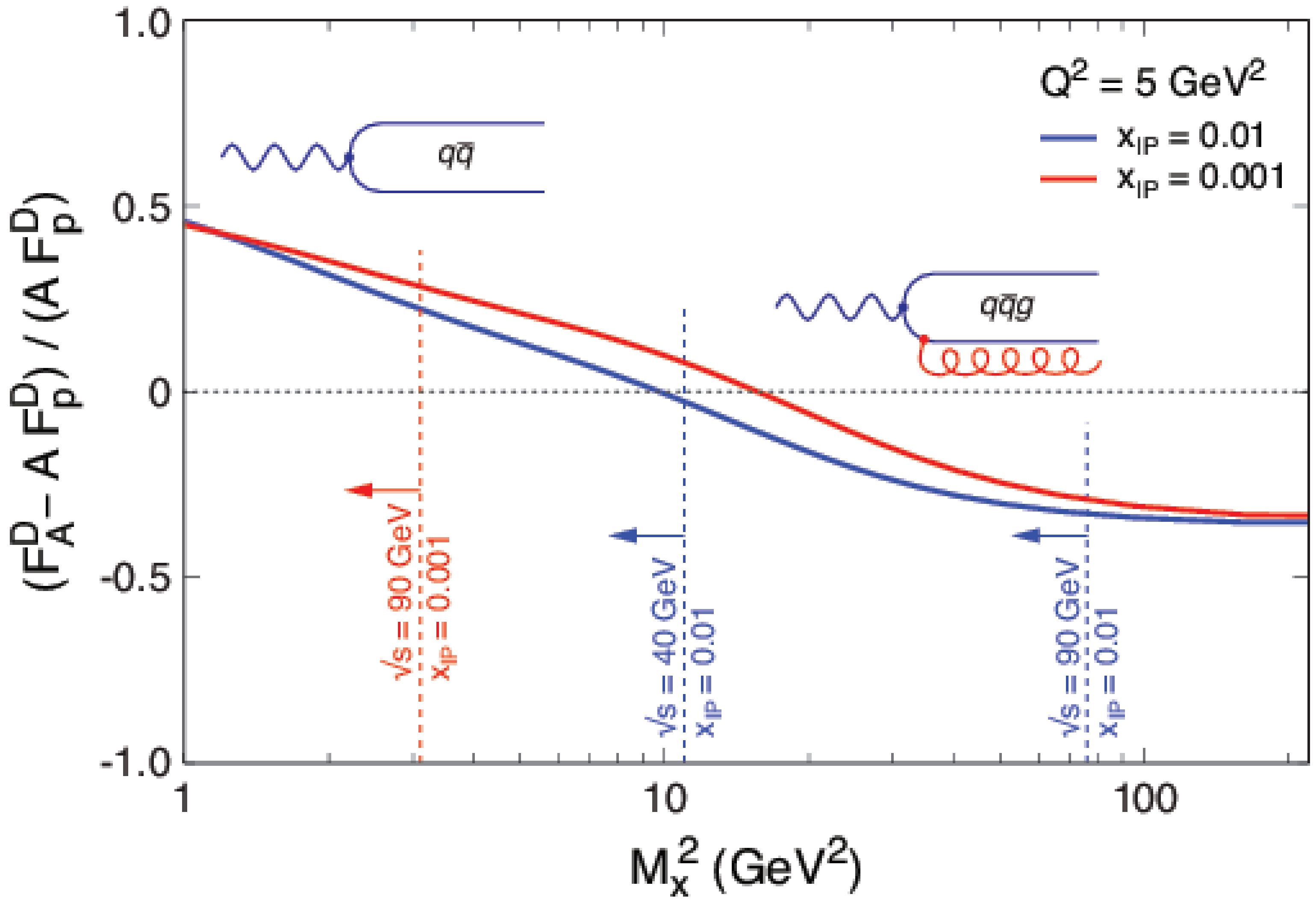


Diffractive/total cross section: clear signature of saturation

"Day-1" measurement

Inclusive diffraction at large mass

Large mass: nuclear suppression (higher Fock states)



Black disk limit approached more quickly with nuclear targets

Need large center-of-mass energies!

EIC realization

DOE Nuclear Physics Long Range Plan 2015:
"Highest priority for new facility construction"

Option 1:
electron beam to RHIC tunnel

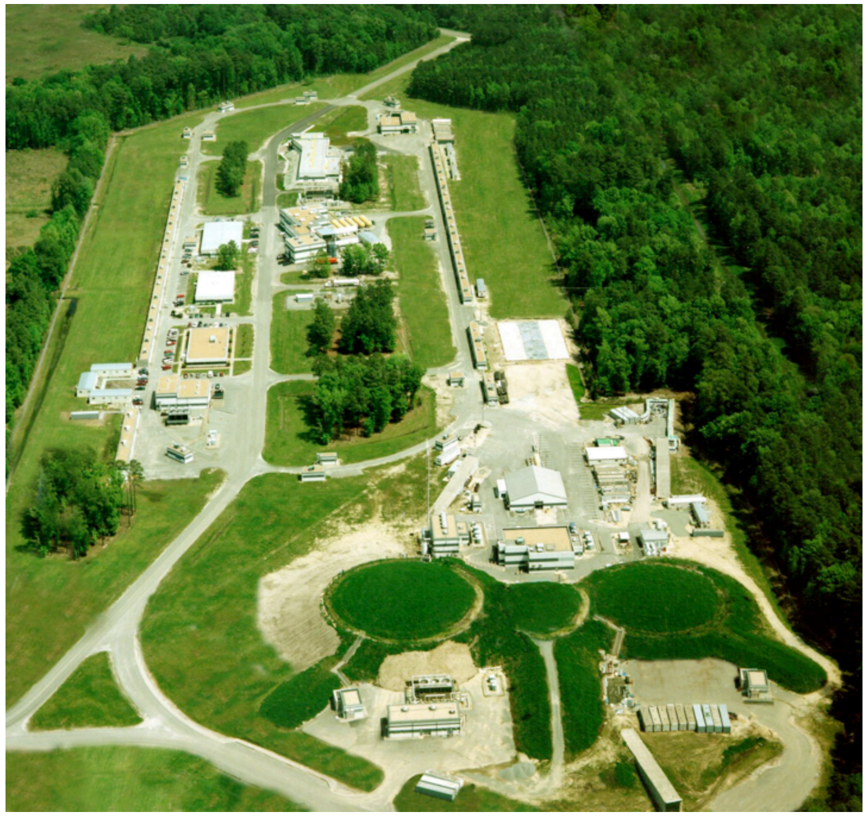
- Focus on energy

eA $\sqrt{s} = 90\,\mathrm{GeV}$

Option 2:
hadron machine to JLAB

- Focus on luminosity

eA $\sqrt{s} \approx 40\,\mathrm{GeV}$



Status now: NAS review in progress until ~early 2018

Conclusions

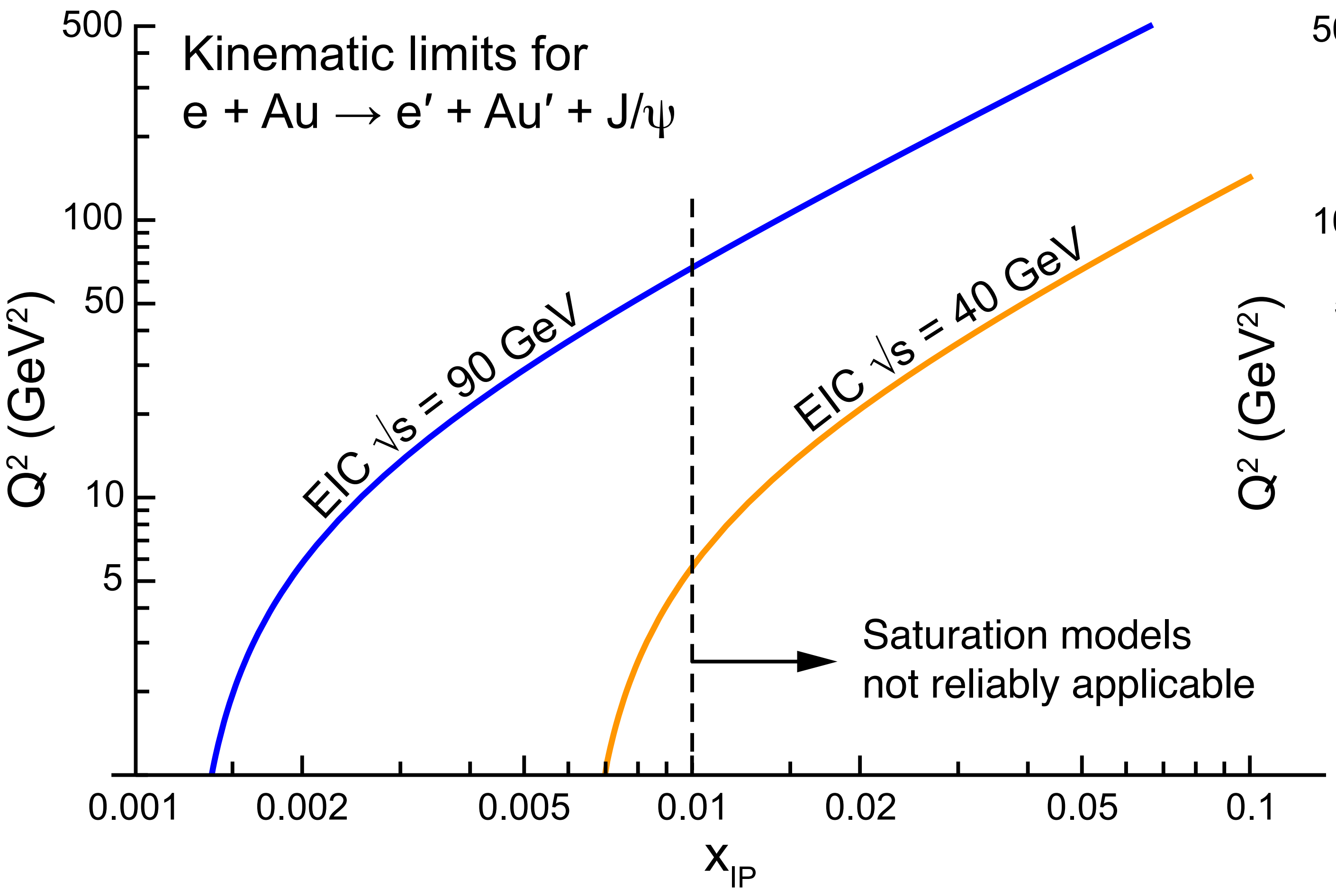
- Diffractive processes at the EIC provide a precise tool to study proton and nuclear structure at small-x
- Access saturation phenomena in nuclei
- Map transverse quark and gluon profile of protons and nuclei

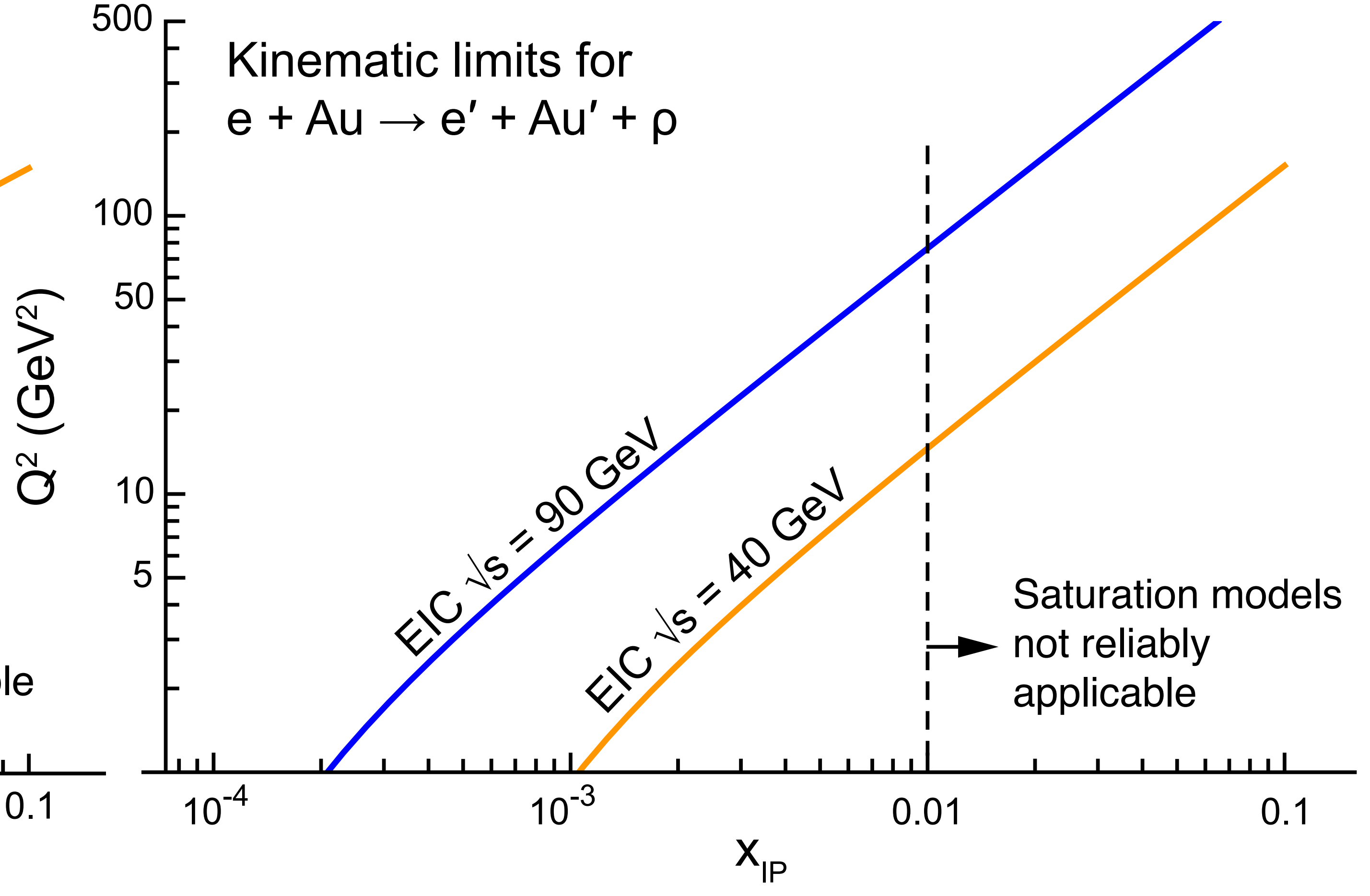
Also many other physics opportunities not discussed here

- Nuclear PDFs
- Polarization and spin structure
- Transverse momentum dependent PDFs
- Hadronization/confinement

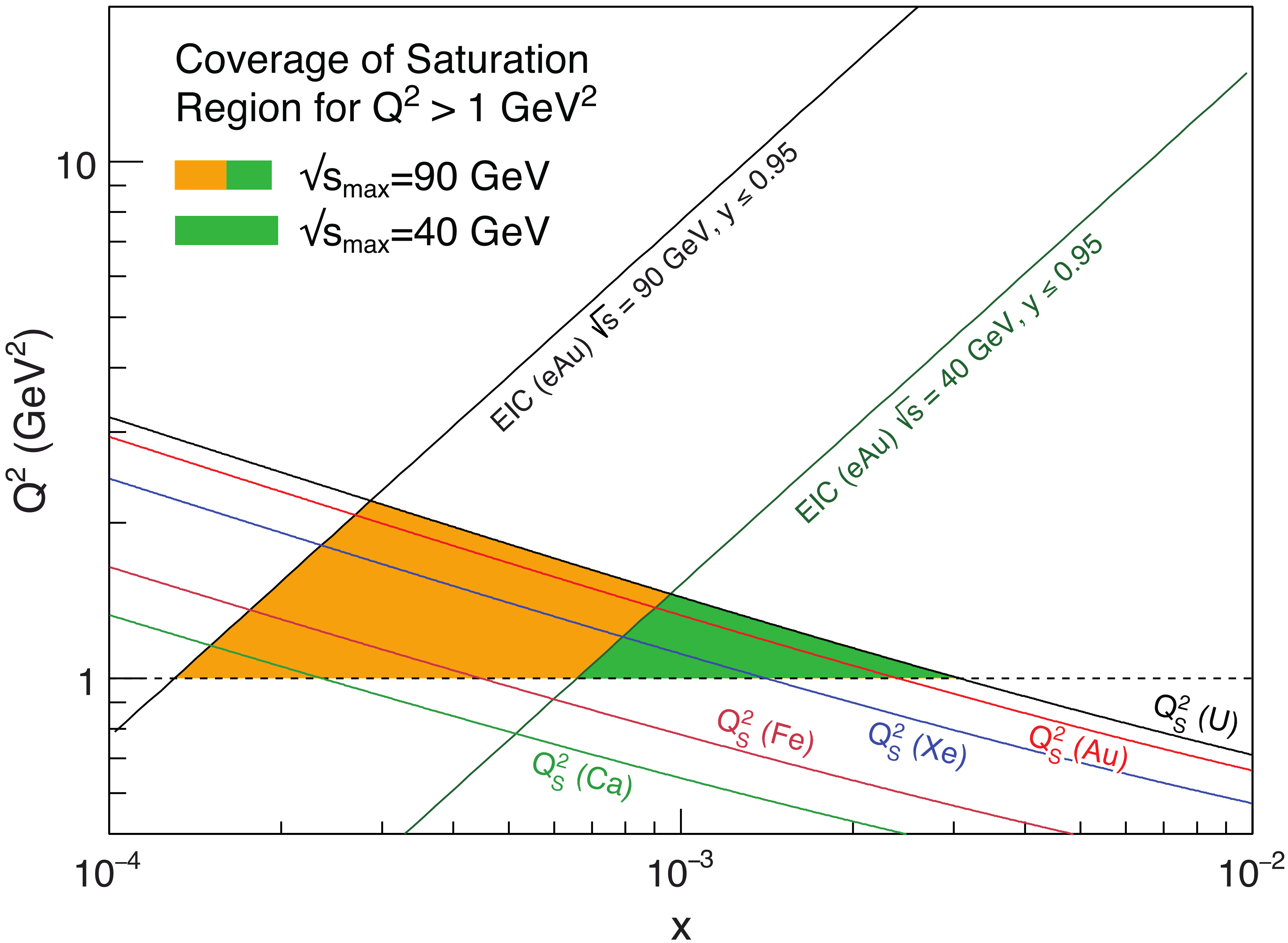
BACKUPS

Kinematical coverage for vector mesons

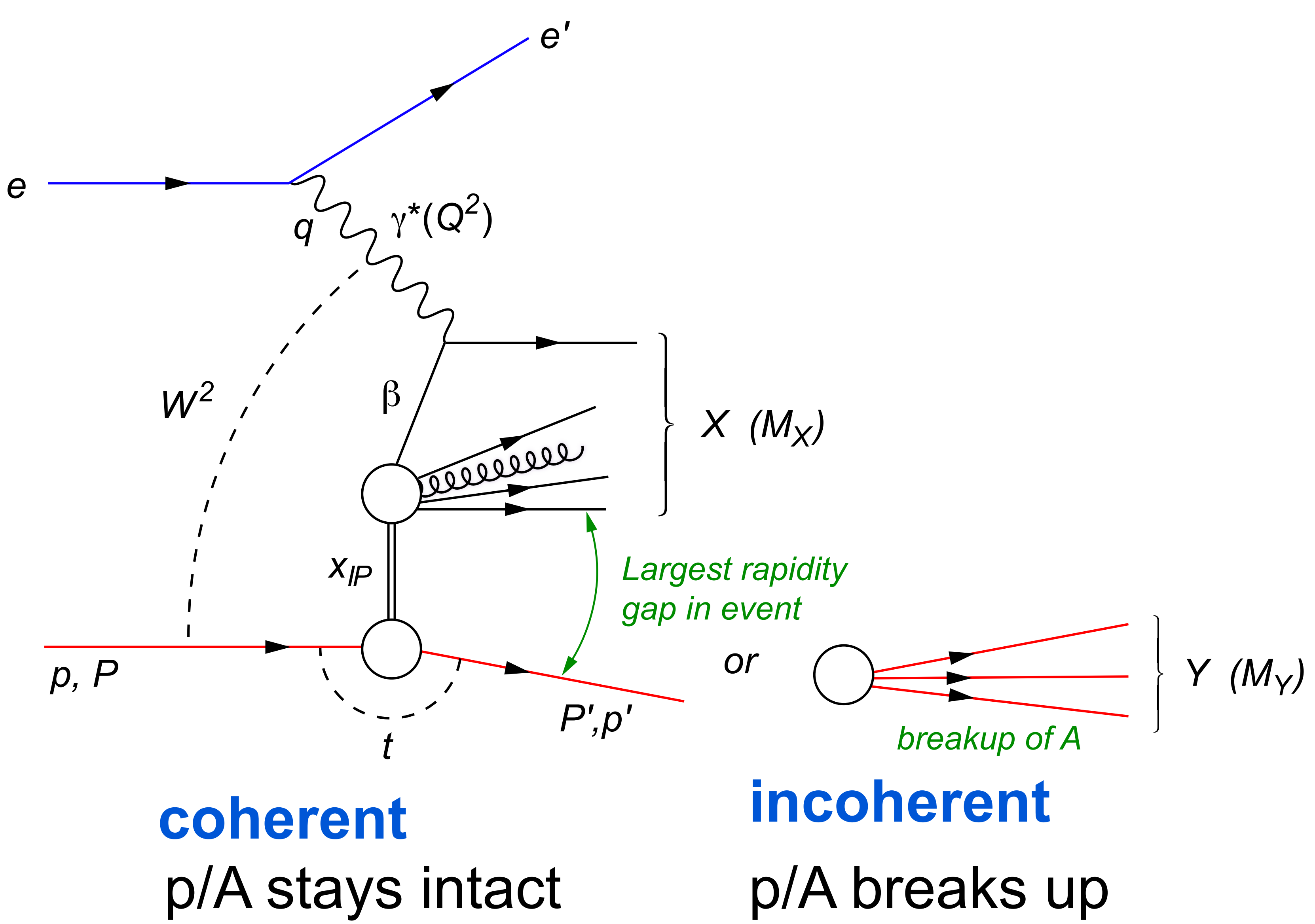




Coverage of the saturation region



Diffractive Events: Experimental Side



t can be measured only in exclusive processes (e.g. X=J/ψ)

- Access spatial gluon distribution (Fourier transform t - b)