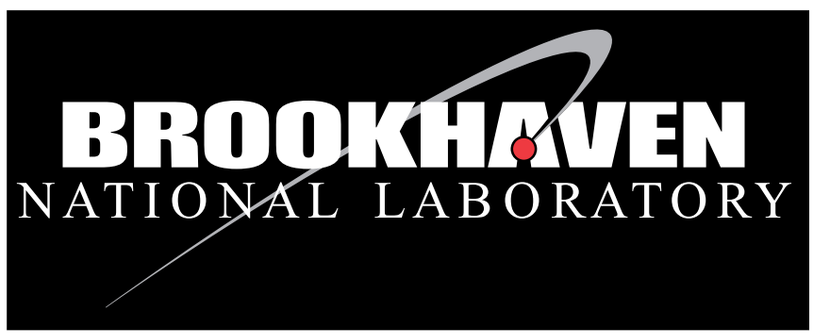
eRHIC

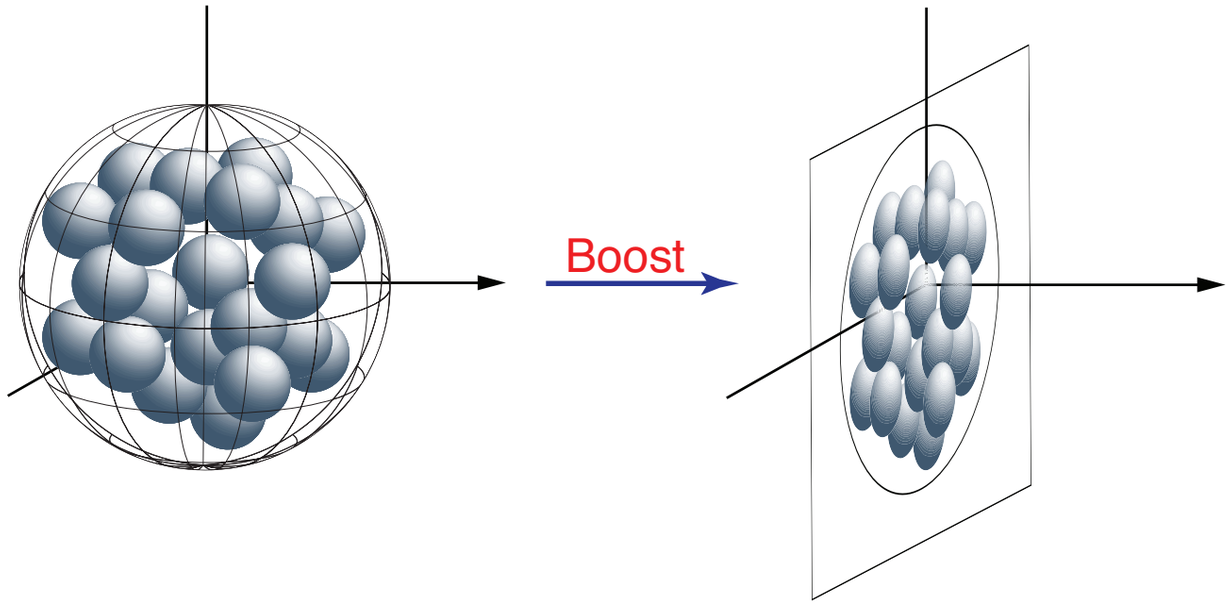
A Precision Tool for Studying Nuclear Structure

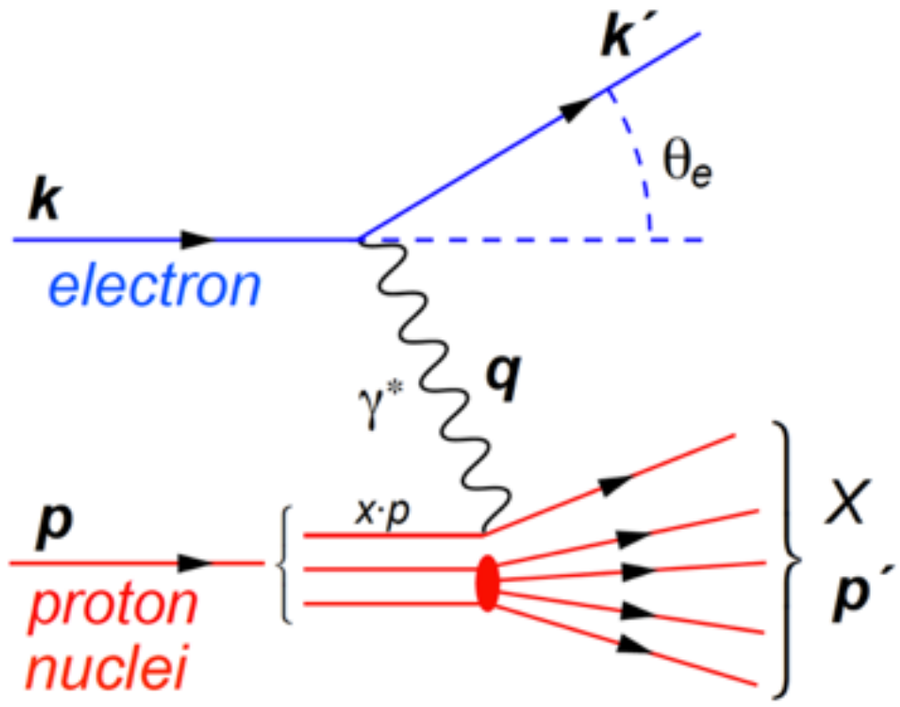
Thomas Burton
On behalf of the EIC Science Task Force

SQM
18th July 2013

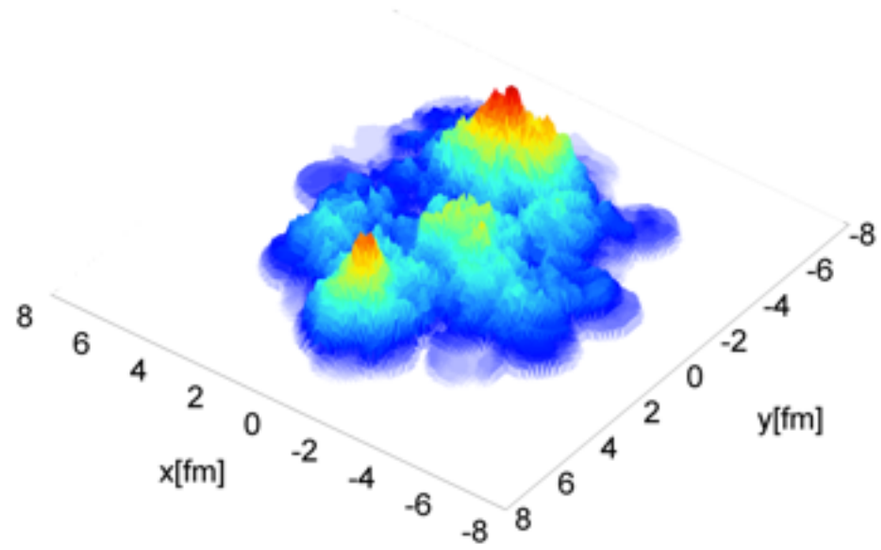


Introduction





- eRHIC and DIS overview
- Key eA measurements
- Detector concept
- Machine design



What is eRHIC?

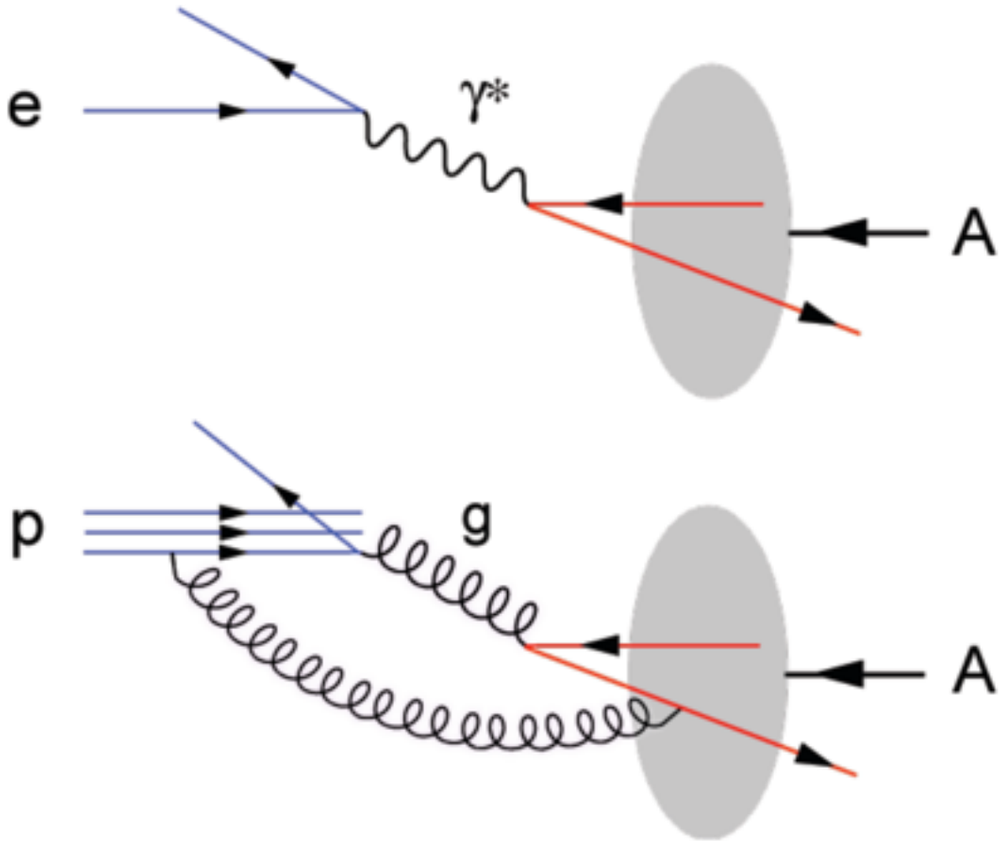
Electron-Ion Collider (**EIC**)
situated at BNL

Relativistic **H**eavy **I**on **C**ollider
+
Electron beam/linac

- Adds **ep** and **eA** capability to RHIC
- Utilises much current investment
- Builds on successes of both RHIC and HERA

Why eA collisions?

- RHIC is a successful hadronic machine
  - so why bother with **electrons**?
    - Electrons give **three** advantages



  - *Clean*: no "spectator" background
  - *Clear*: distinguish initial/final-state effects
  - ***Precise***: direct access to parton-level kinematics via deeply inelastic scattering

(an aside on DIS kinematics)

$$s = (p + k)^2 = 4 \cdot E_p \cdot E_e$$

$$Q^2 = -q^2 = -(k - k')^2$$

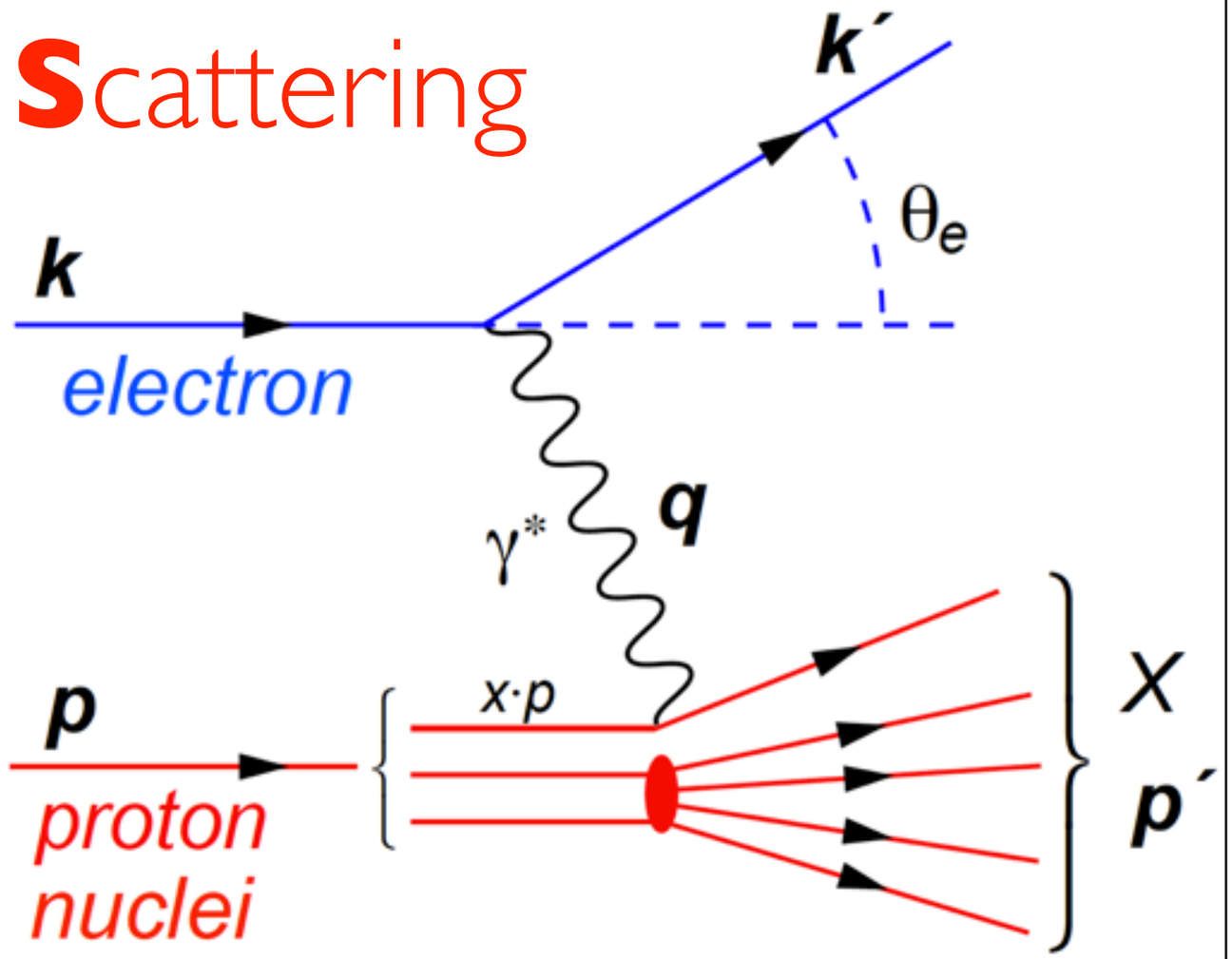
$$x_B = \frac{Q^2}{2 \cdot p \cdot q}$$

"resolution"

$$y = \frac{q \cdot p}{k \cdot p}$$

"inelasticity"

Deeply
Inelastic
Scattering

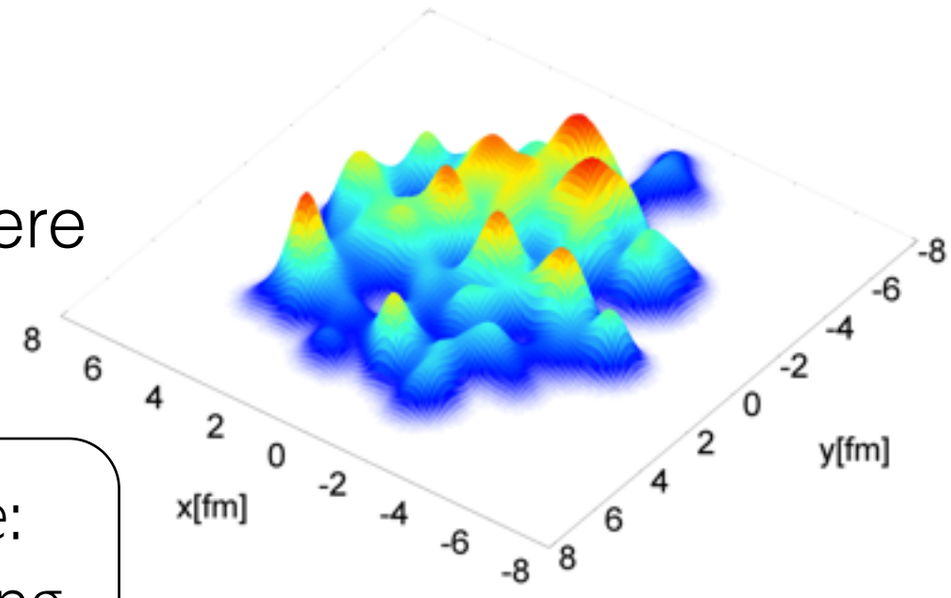


- Kinematics **entirely defined** by scattered electron

Overview

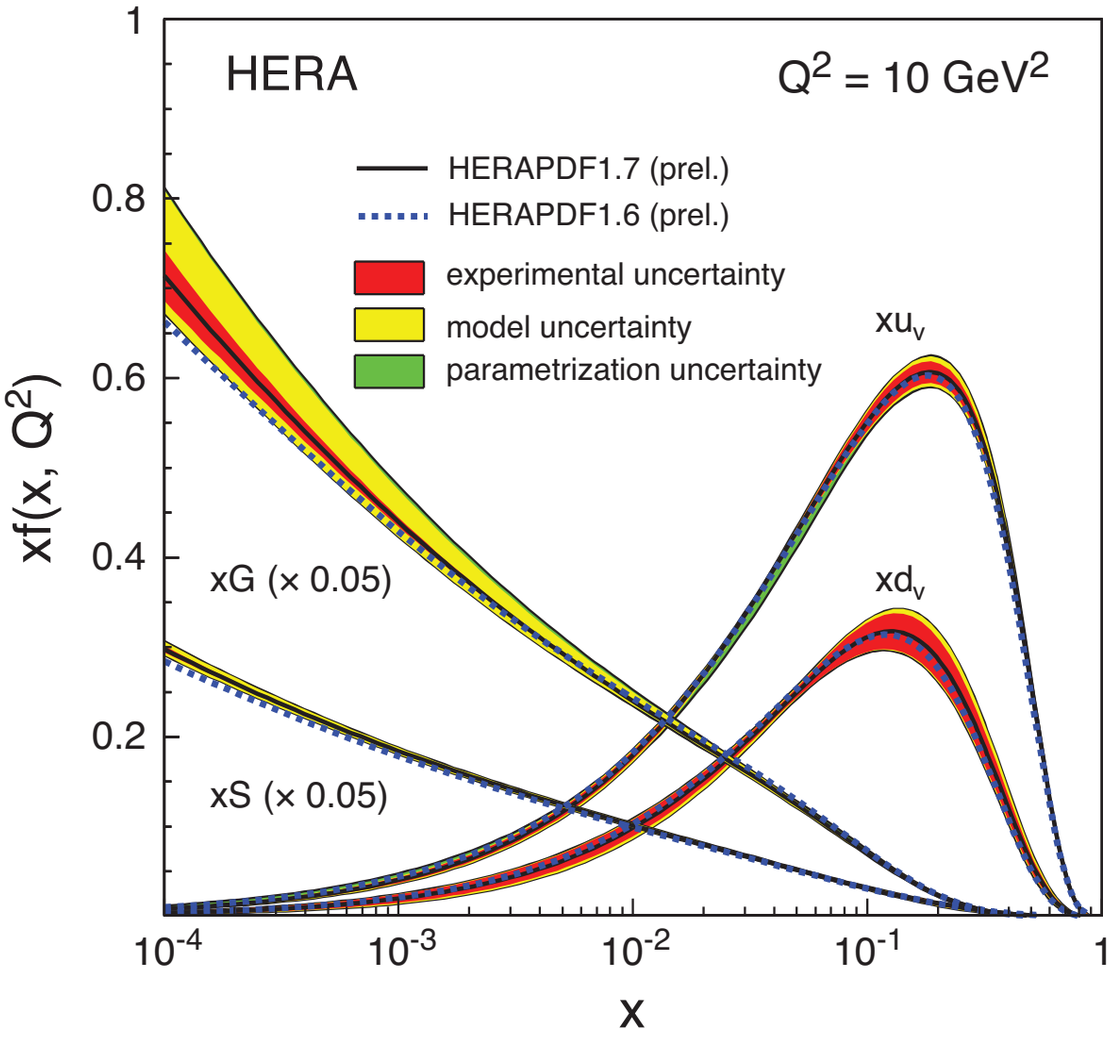
- eRHIC physics goals
  - impossible to give more than a taste here
  - eA
    - Saturation
    - Imaging
    - Nuclear PDFs
    - Hadronisation in strongly interacting medium
  - ep (not covered here)
    - nucleon imaging (impact parameter dependence)
    - unintegrated PDFs (pT-dependence)
    - spin sum rule (origin of spin-1/2 proton/neutron)

Nuclear initial state: vital to understanding nuclear collisions



Gluons at small x

- QCD interaction accounts for 99% of proton mass
  - c.f. 1% Higgs mass of quarks
- Gluon PDFs from DIS show explosive growth at small x
  - must be tamed at some point
- non-linear evolution e.g. BK alternative to DGLAP, BFKL, account for **gluon recombination**



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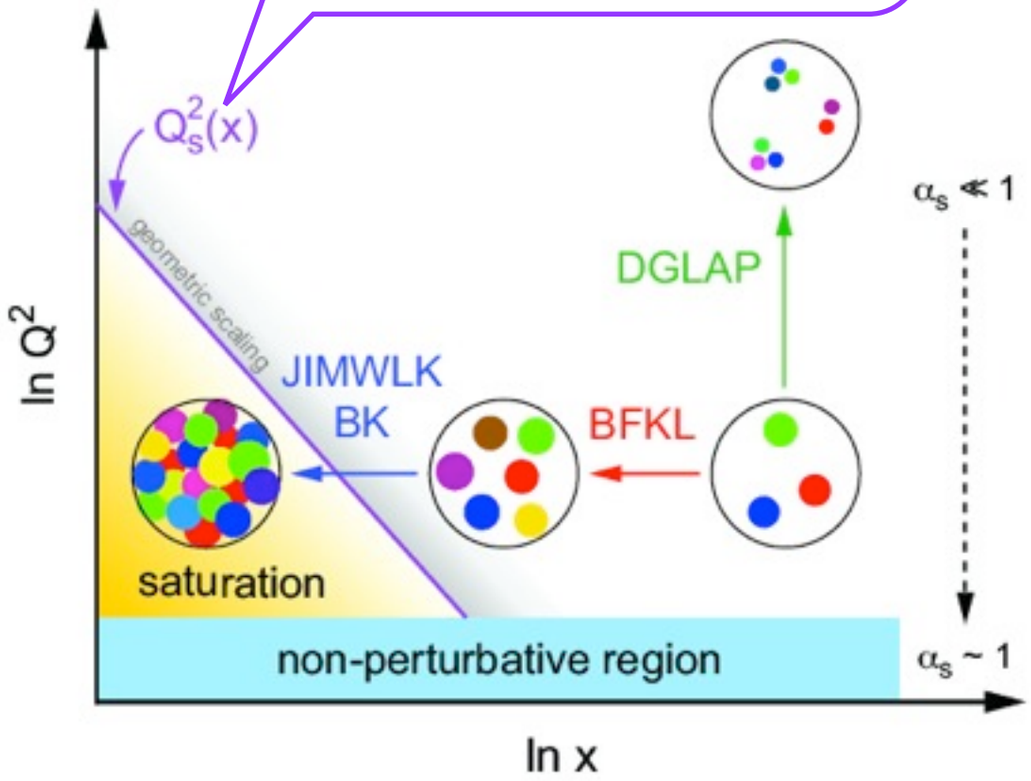
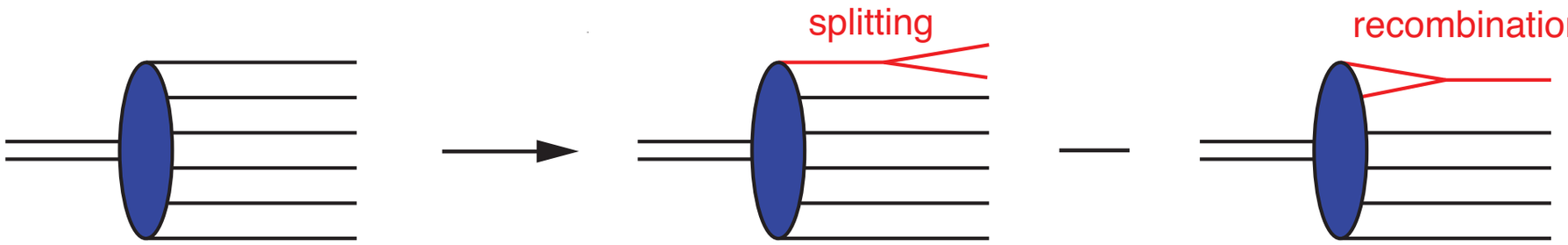
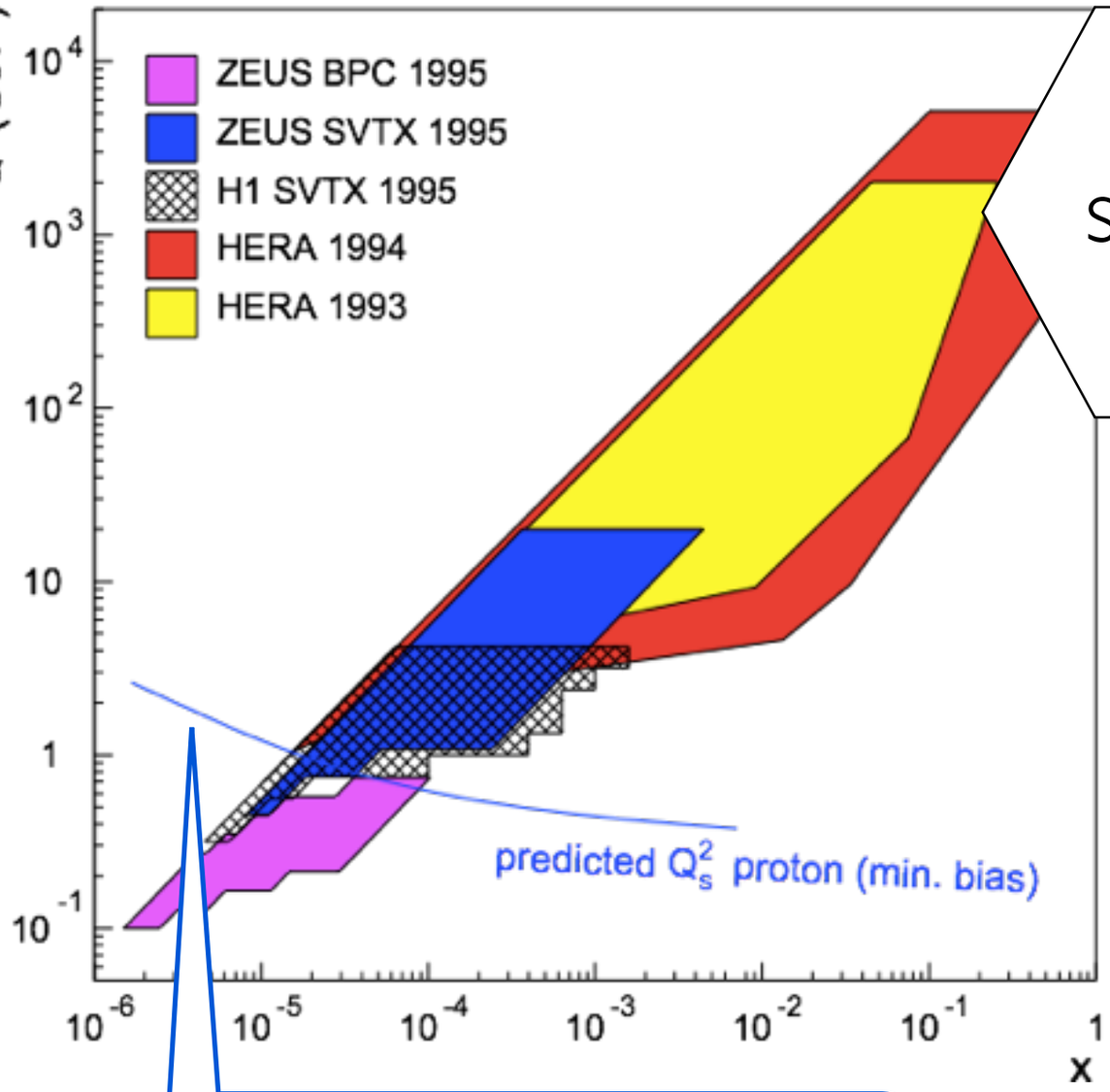
"**Saturation scale**" at which phenomena manifest





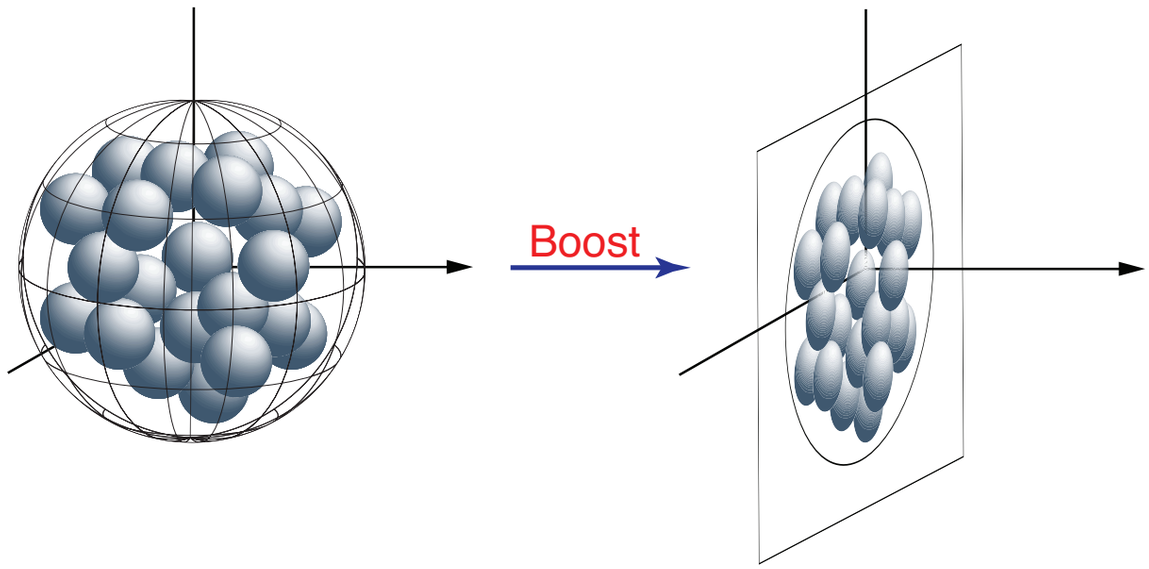
An e**A** collider: why use nuclei?



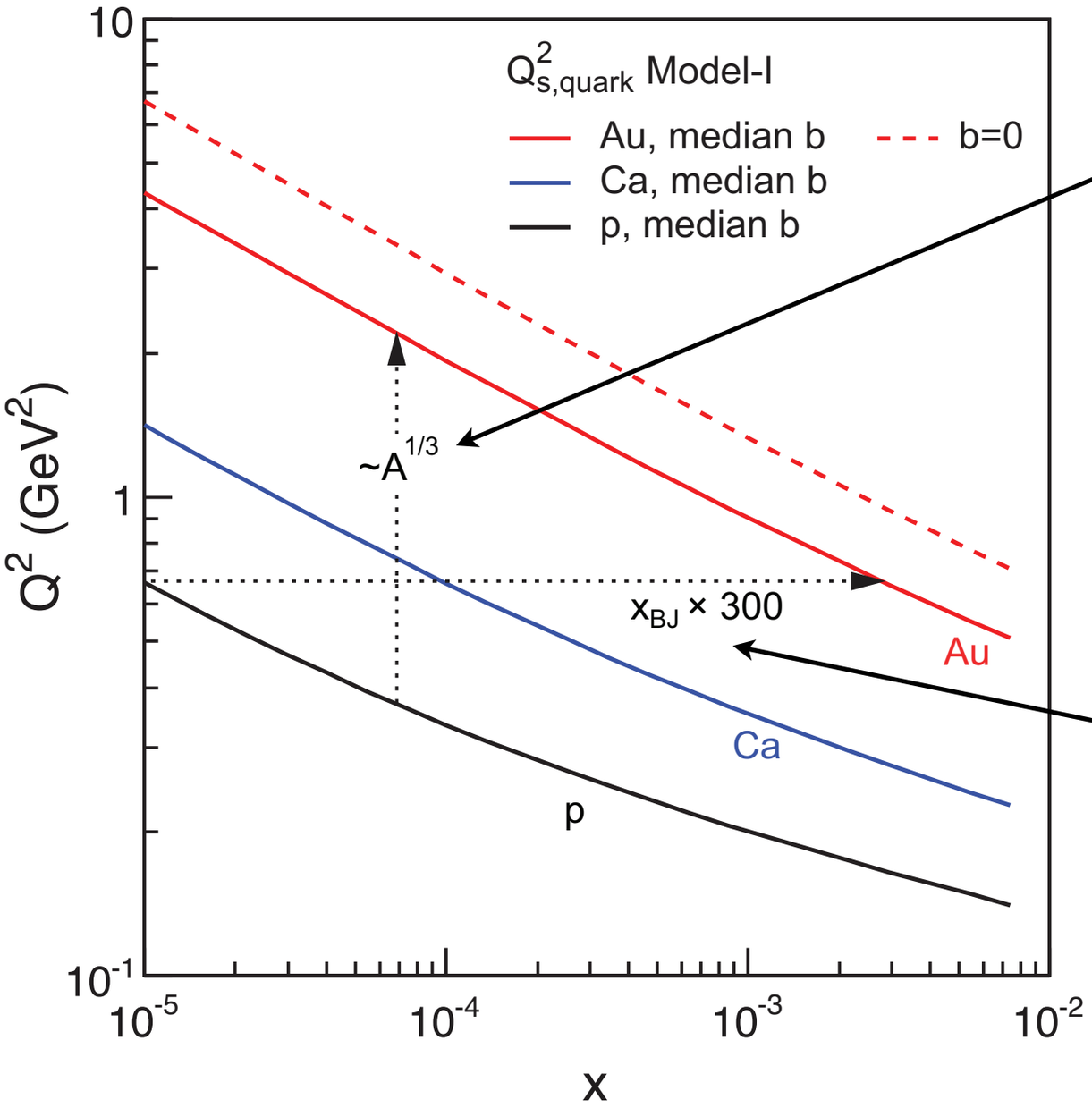
Need even lower x than HERA accessed

Reaching predicted saturation scale in e-p needs **very low x** **→ 1-2 TeV machine**

But...
in a high-E collision gluon density scales ~ nuclear radius



Nuclear amplification



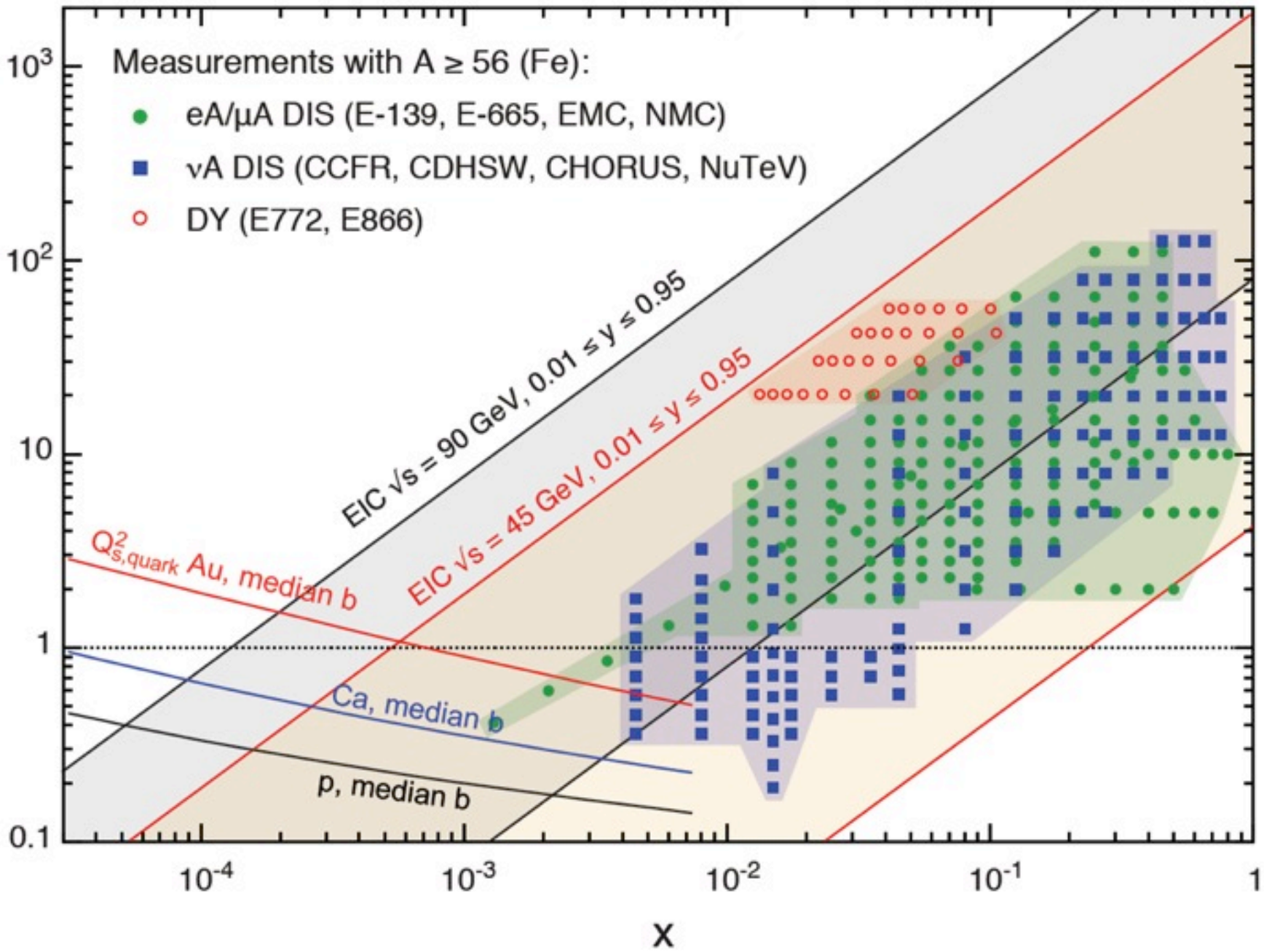
- Nuclear **amplification** of saturation scale

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

- "Effective x" is much smaller in nuclei

→Access saturation with ~100 **G**eV eA machine

eRHIC eA kinematics



Extend reach far beyond existing data

- Access saturated regime
- Precise studies of nuclear structure

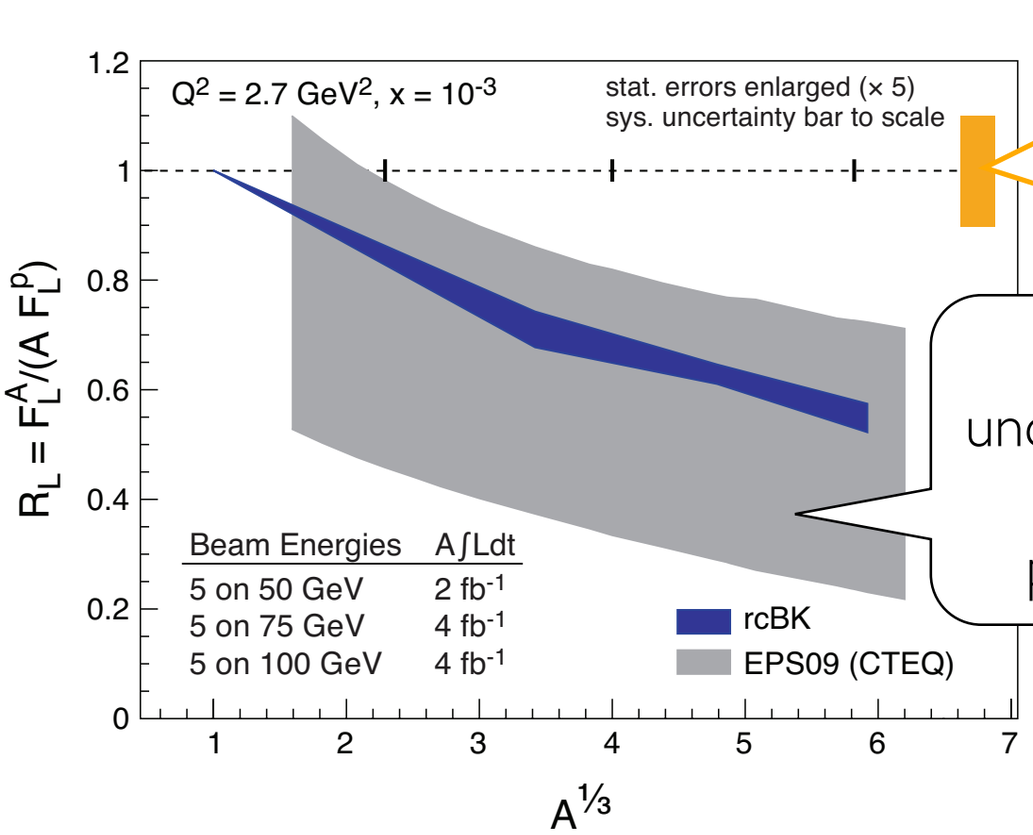
Key measurements

Structure functions

$$\sigma_r = F_2(x, Q^2) - \frac{y^2}{1 + (1 - y)^2} F_L(x, Q^2)$$

F_2 sensitive to quarks
F_L sensitive to gluons
Separation requires
variable energy

- precision **nuclear PDFs**
- indications of **saturation/non-linearity**



Systematics-dominated

large uncertainties on DGLAP predictions

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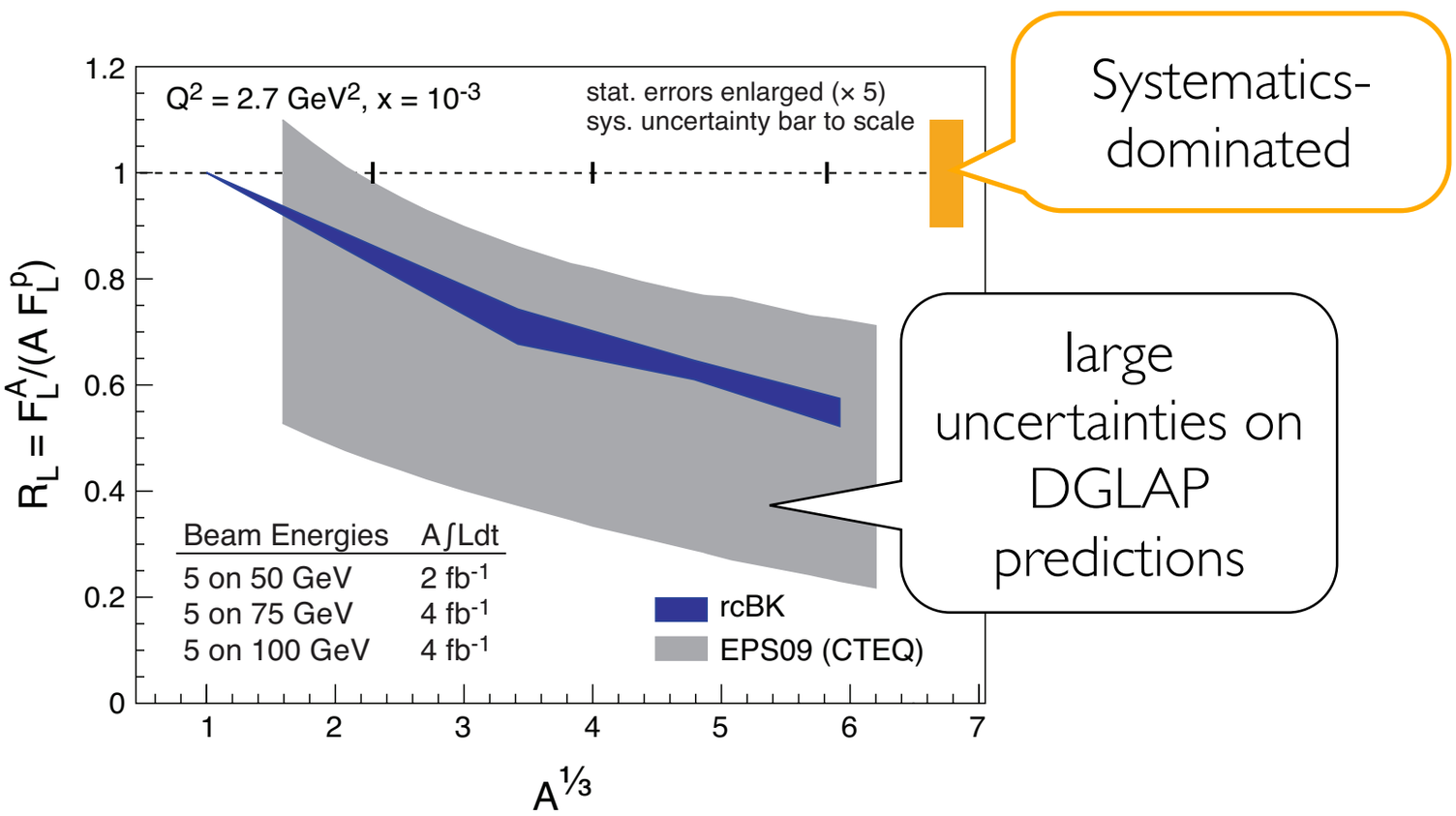

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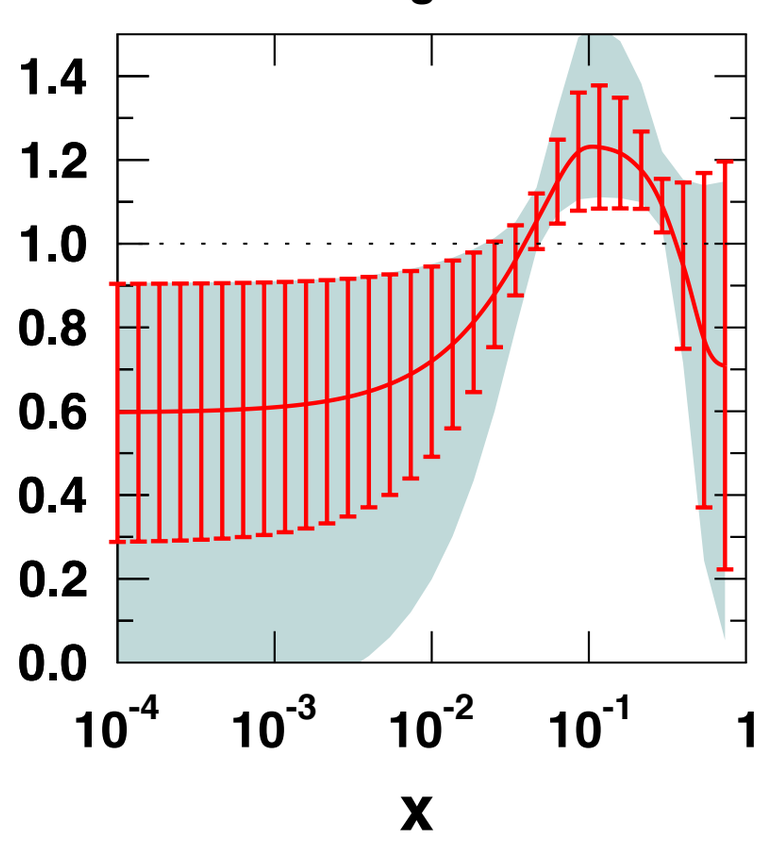
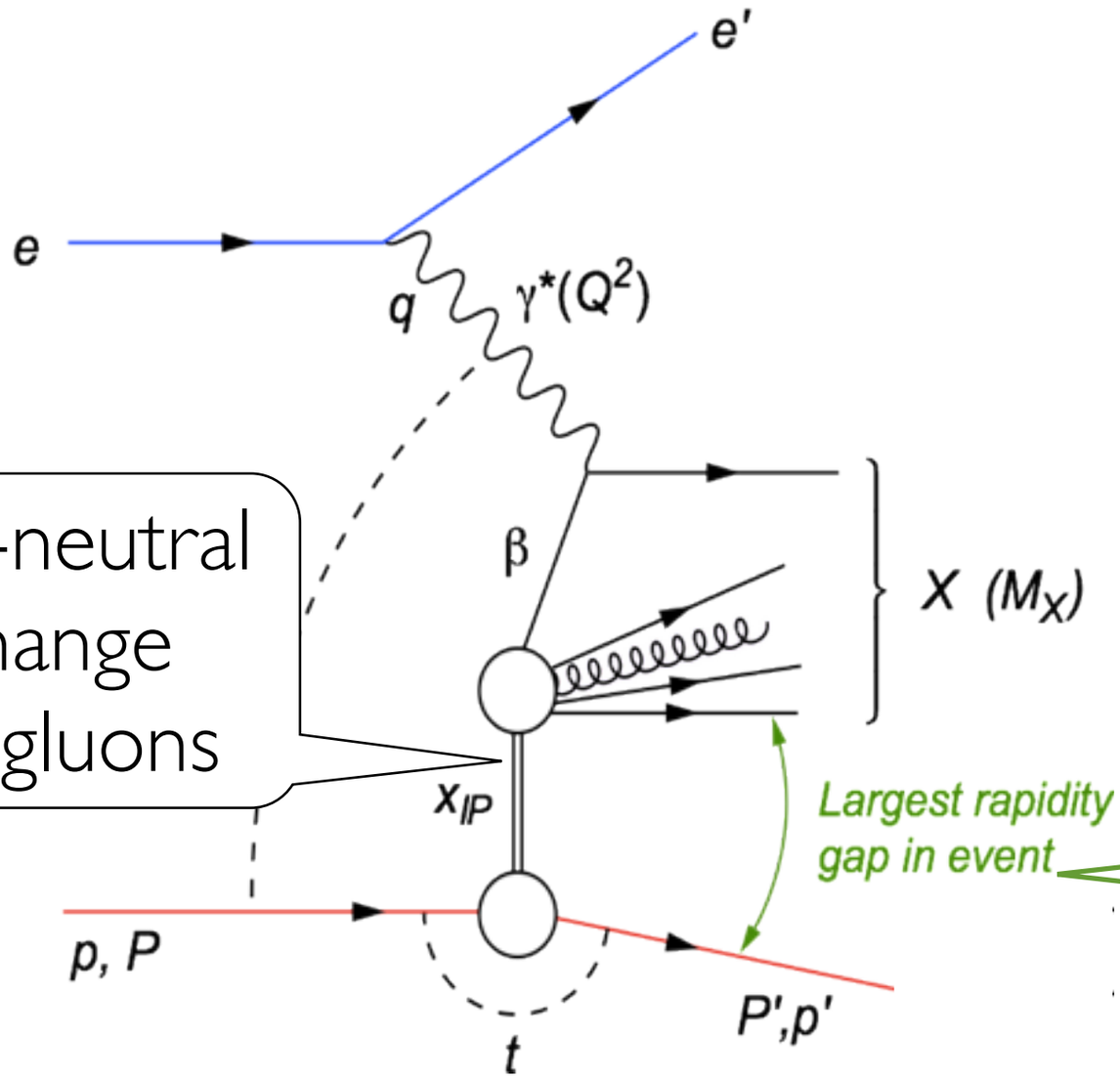


Diffraction



15% of HERA cross section **25-40%** in eA!

colour-neutral exchange e.g. 2 gluons

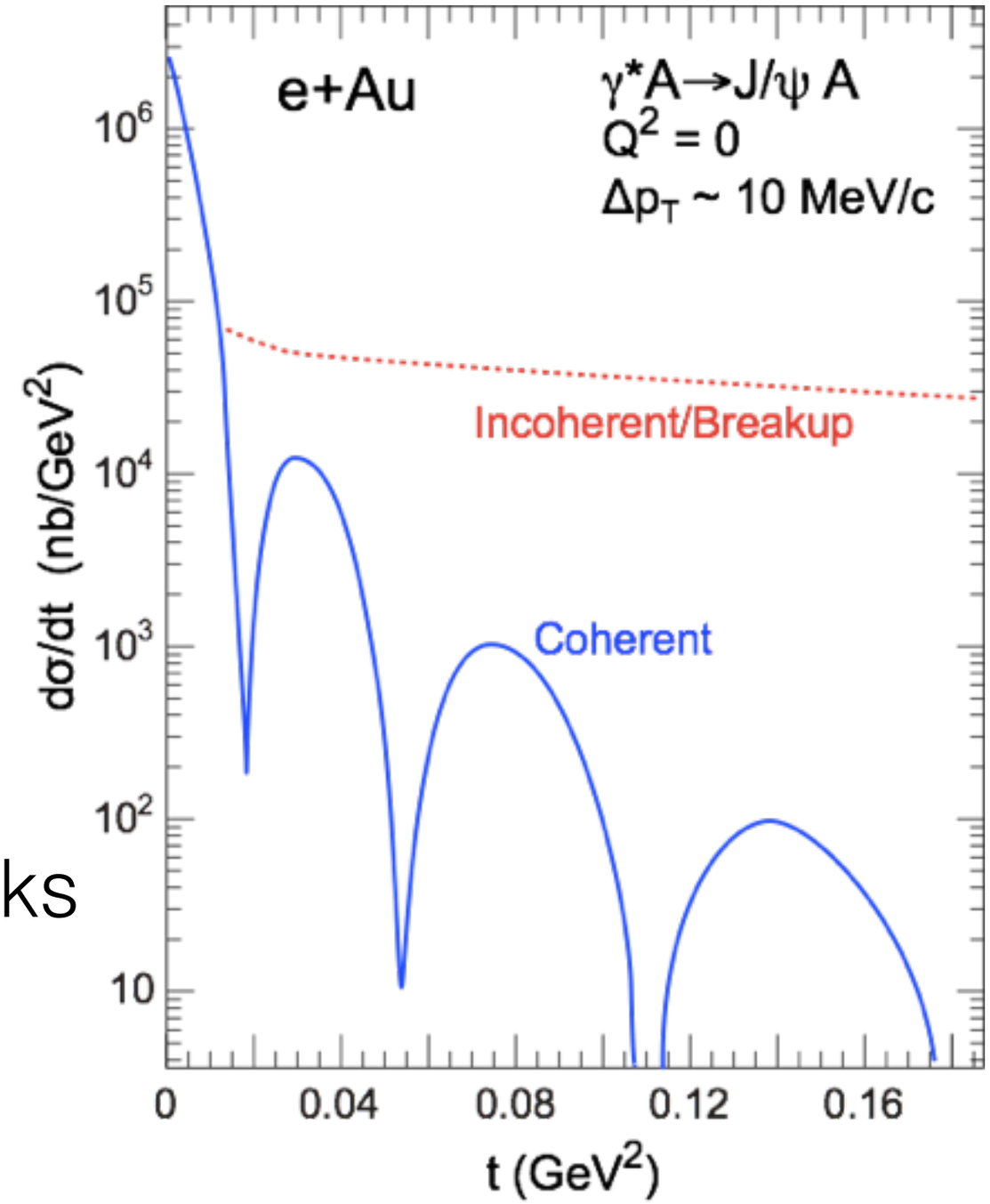
Signature: absence of activity in detector over wide rapidity

Measure additional variable: 4-momentum transfer $t = p - p`$

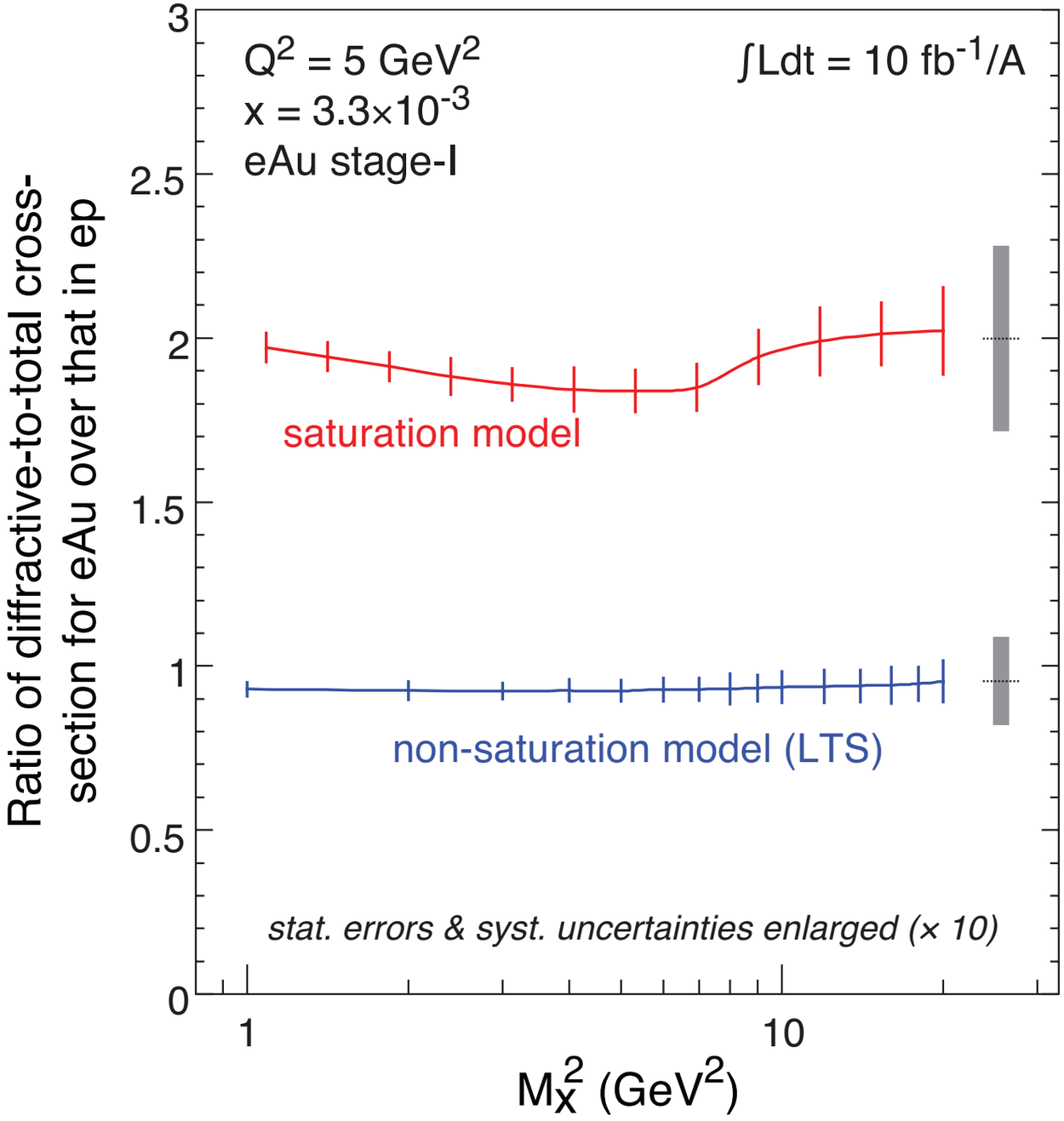
Ideal for studying gluons: $\sigma \sim g(x, Q^2)^2$

Diffraction

- Ideal tool for both
  - studying saturation
  - imaging gluons
- "**Coherent**": nucleus intact
- "**Incoherent**": nucleus breaks up (no diffraction pattern)



Diffraction: saturation

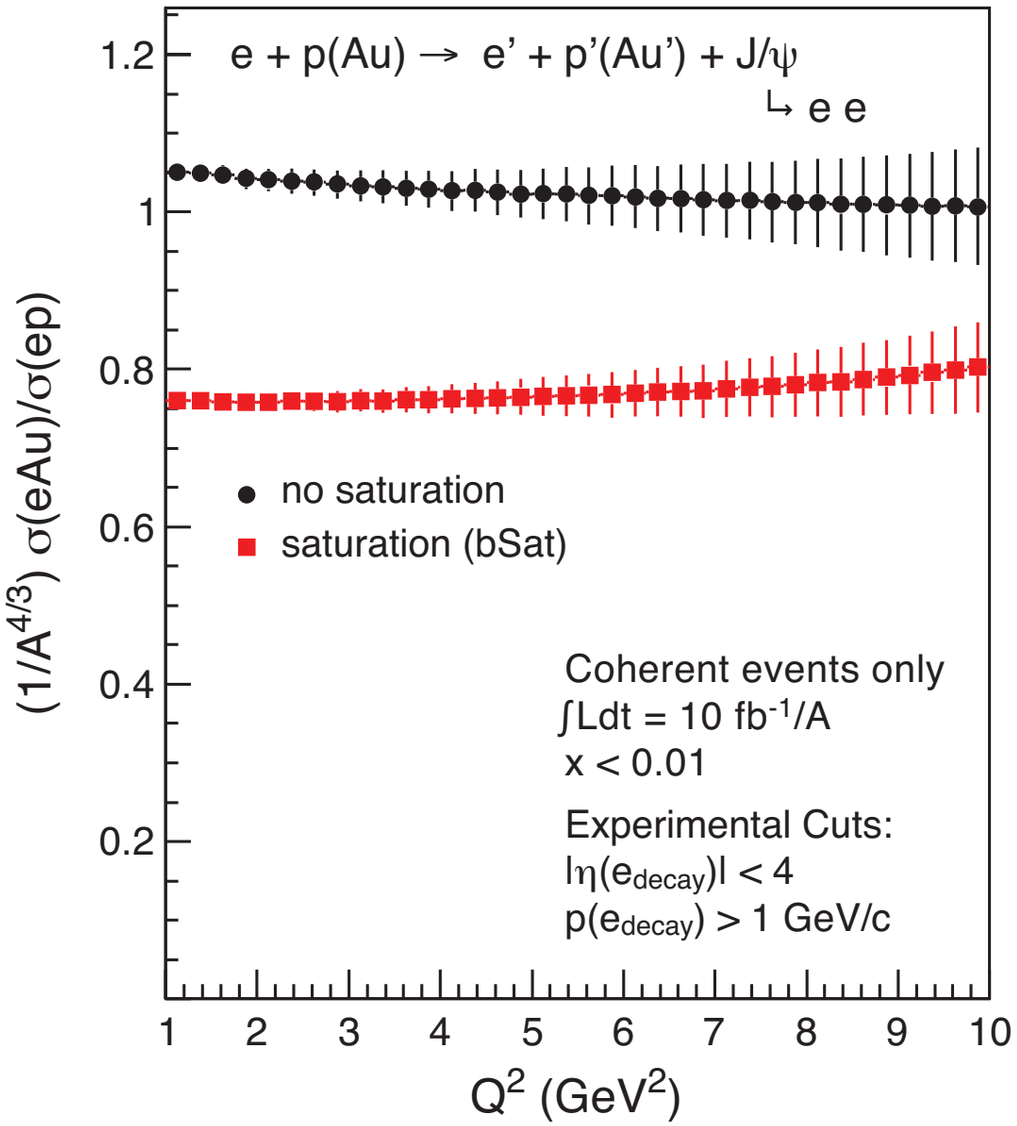


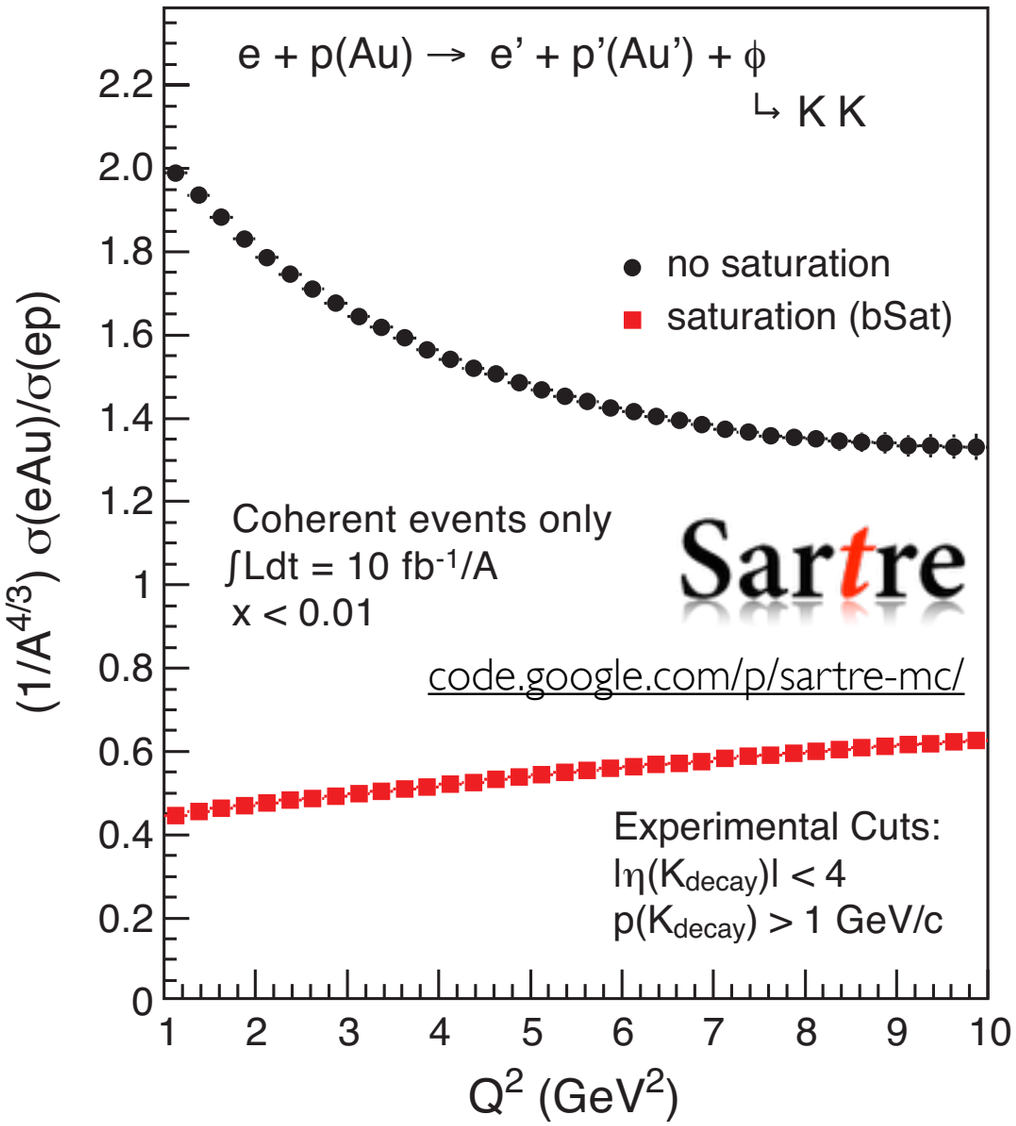
- No saturation: eA/ep ratio ~ 1
- Saturation: enhances σ_{diff} in eA vs. ep
  - strong distinguishing power at eRHIC

Exclusive vector mesons

$$e + A \rightarrow e` + A` + \mathbf{VM}$$

- Measure t via exclusive final state
- Clear difference between **saturated** and **unsaturated**





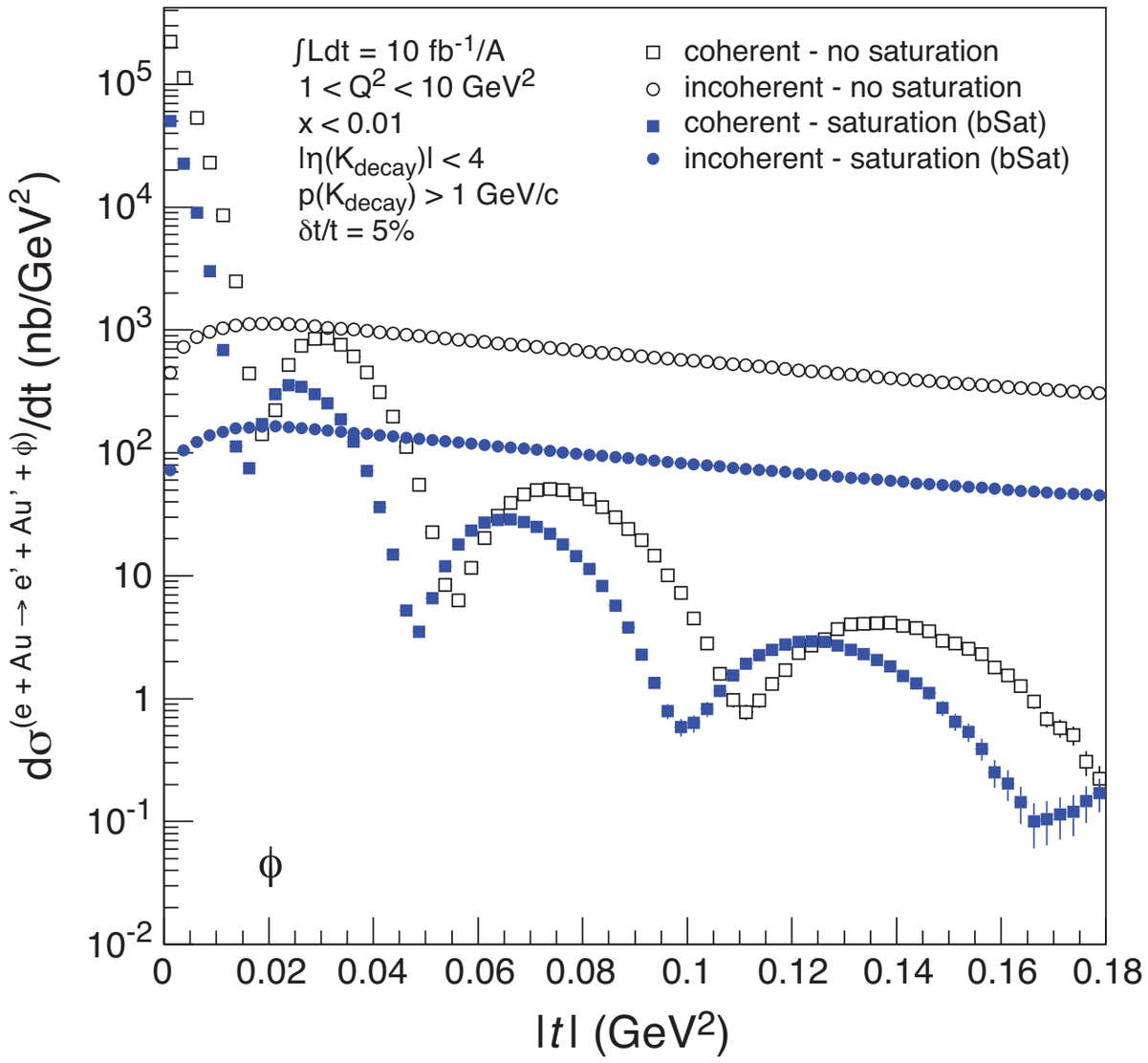
Diffraction: imaging

- t is conjugate of impact parameter, b

$d\sigma/dt \xleftrightarrow[\text{Transform}]{\text{Fourier}} F(b)$

➡ gluon imaging

- Strict detector demands



PRC 87 024913 (2013)

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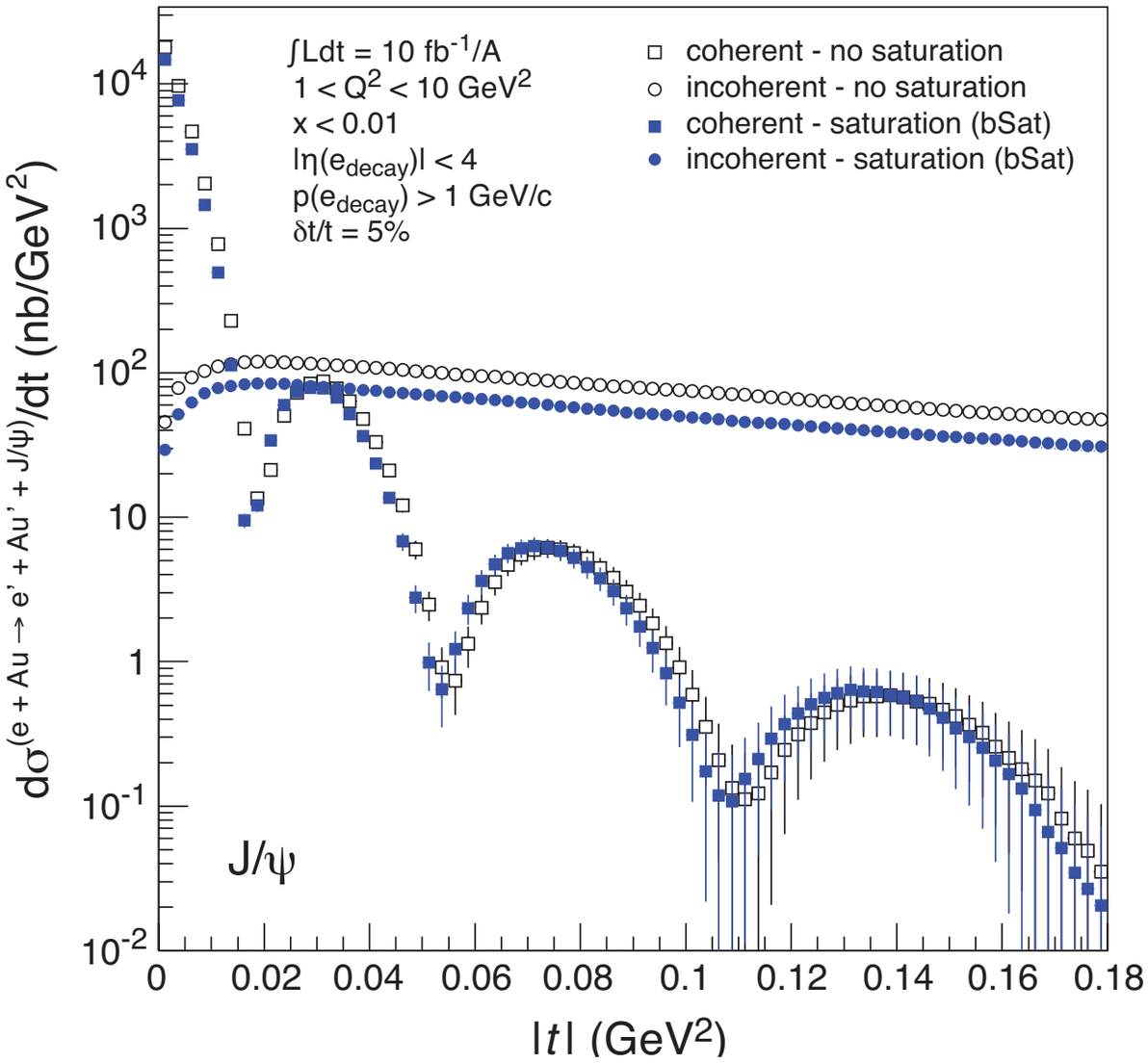

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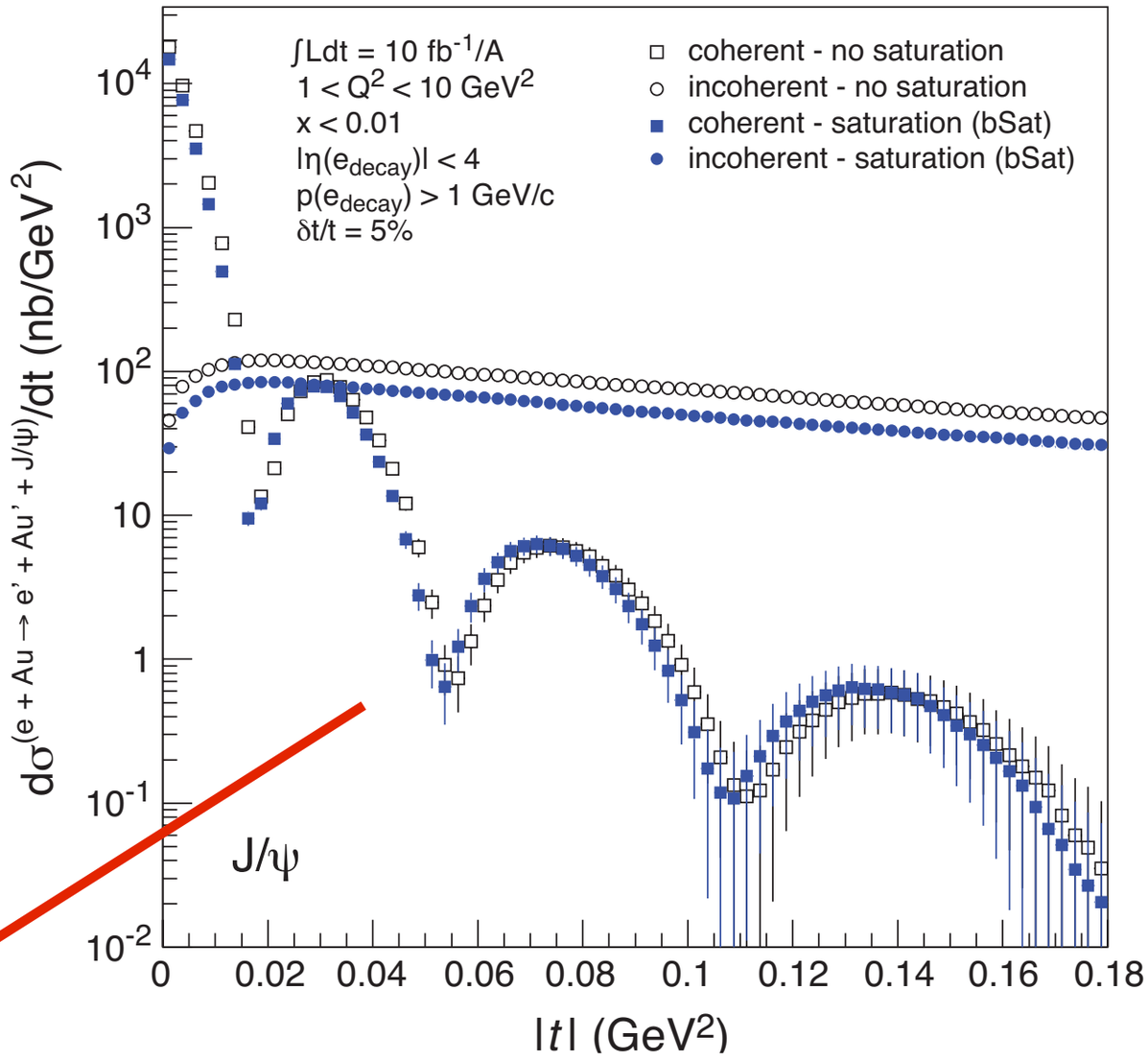

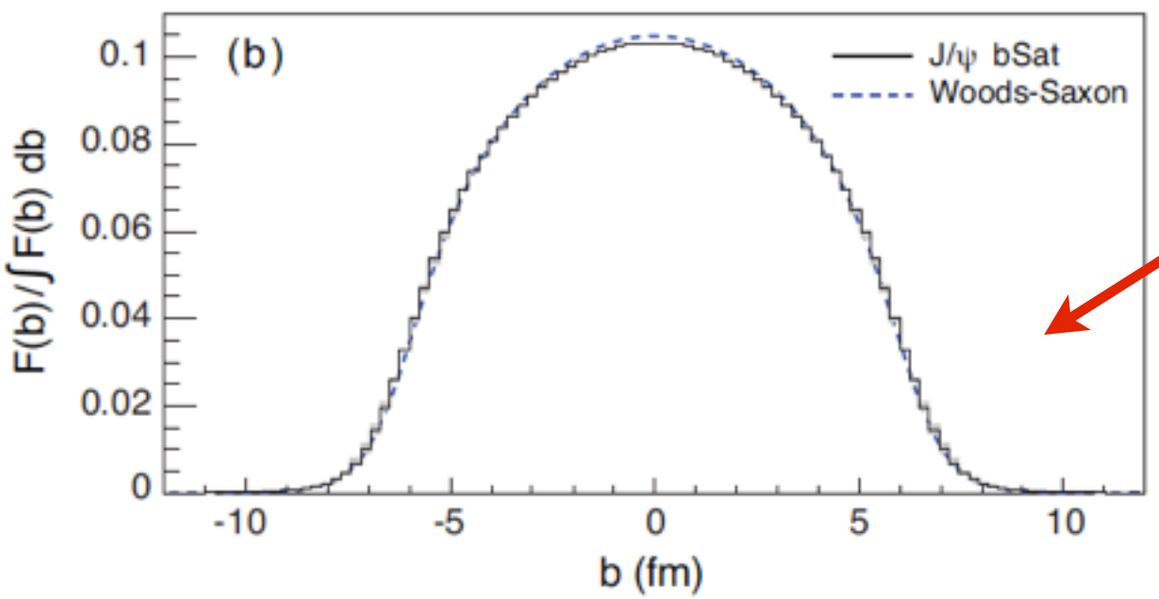

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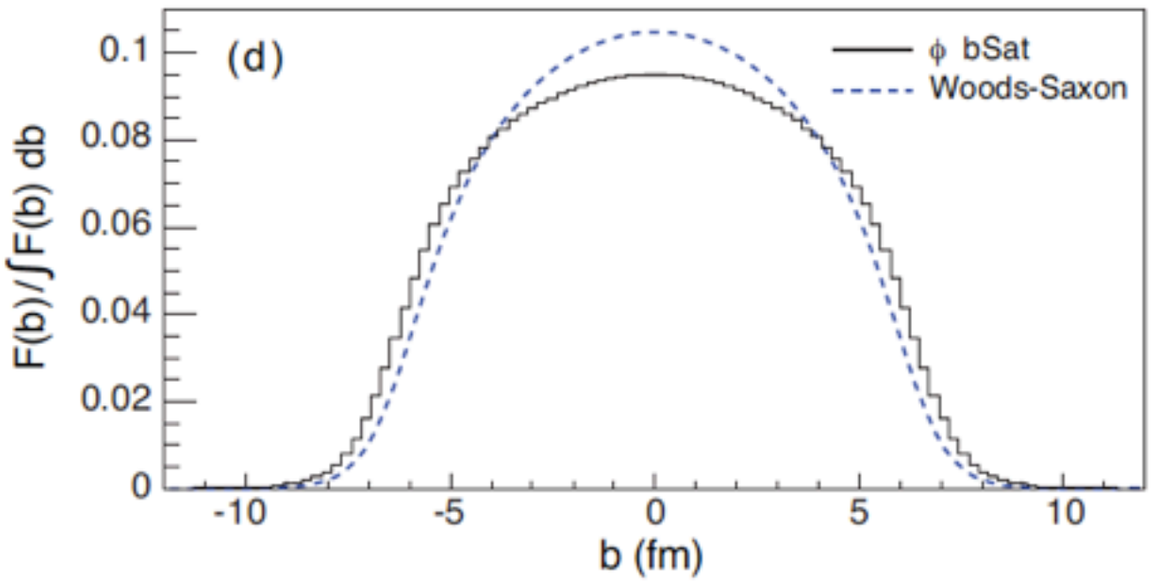

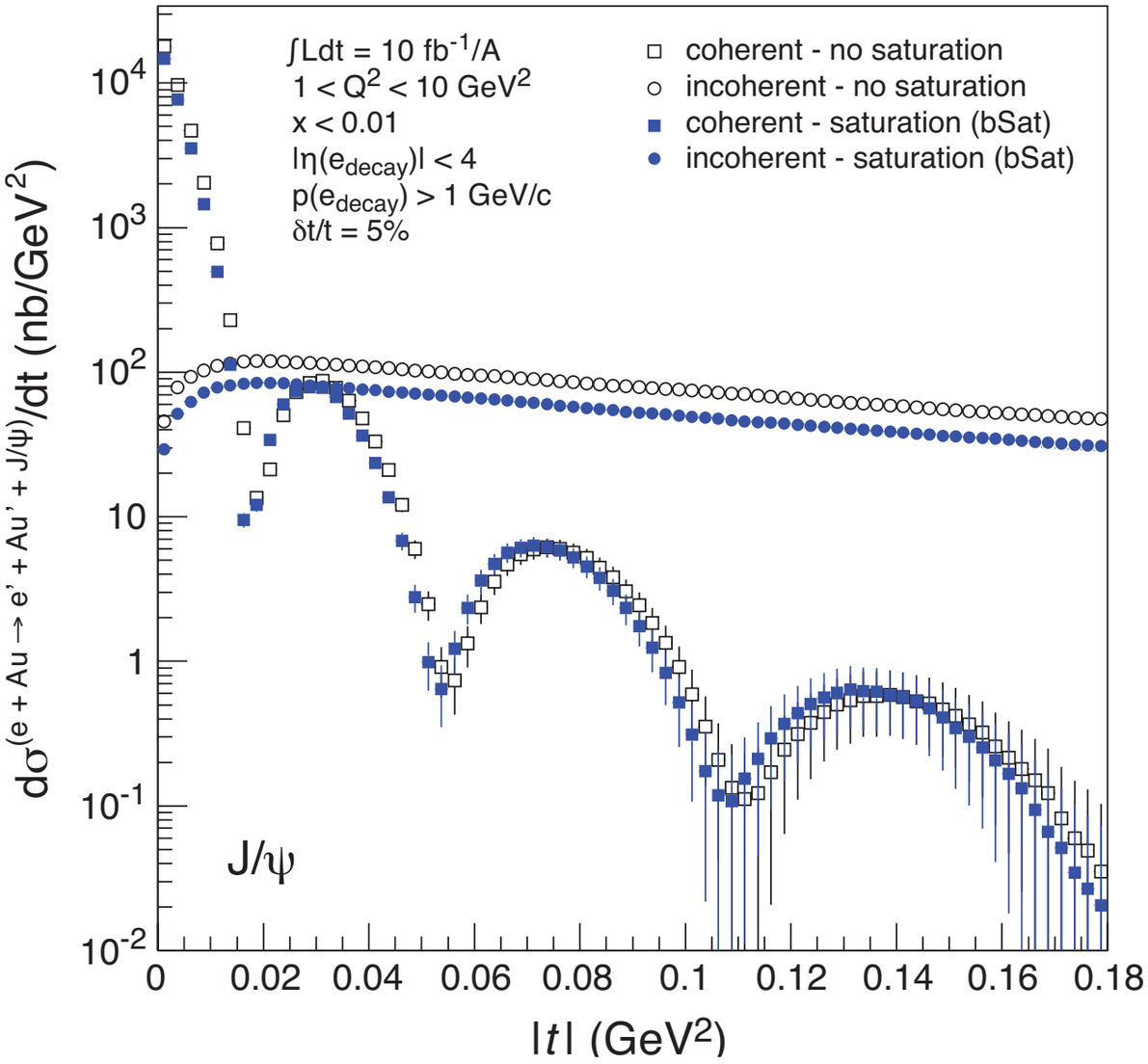

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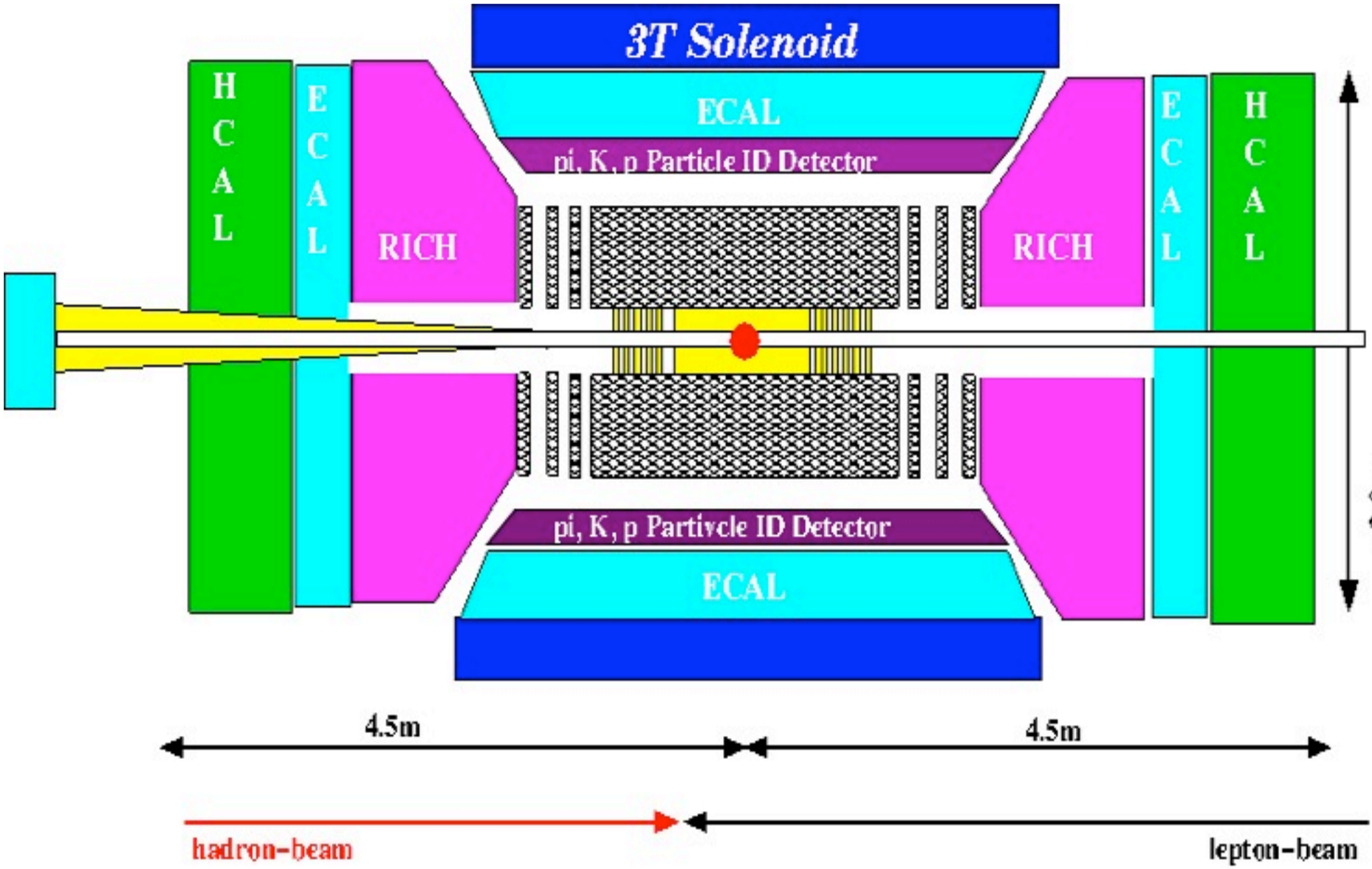
Detector and machine

Detector concept

- Largely hermetic
  - needed e.g. to detect rapidity gap



To Roman pots, ZDCs

ZDC: breakup neutrons give ~100% efficiency to detect incoherent eA

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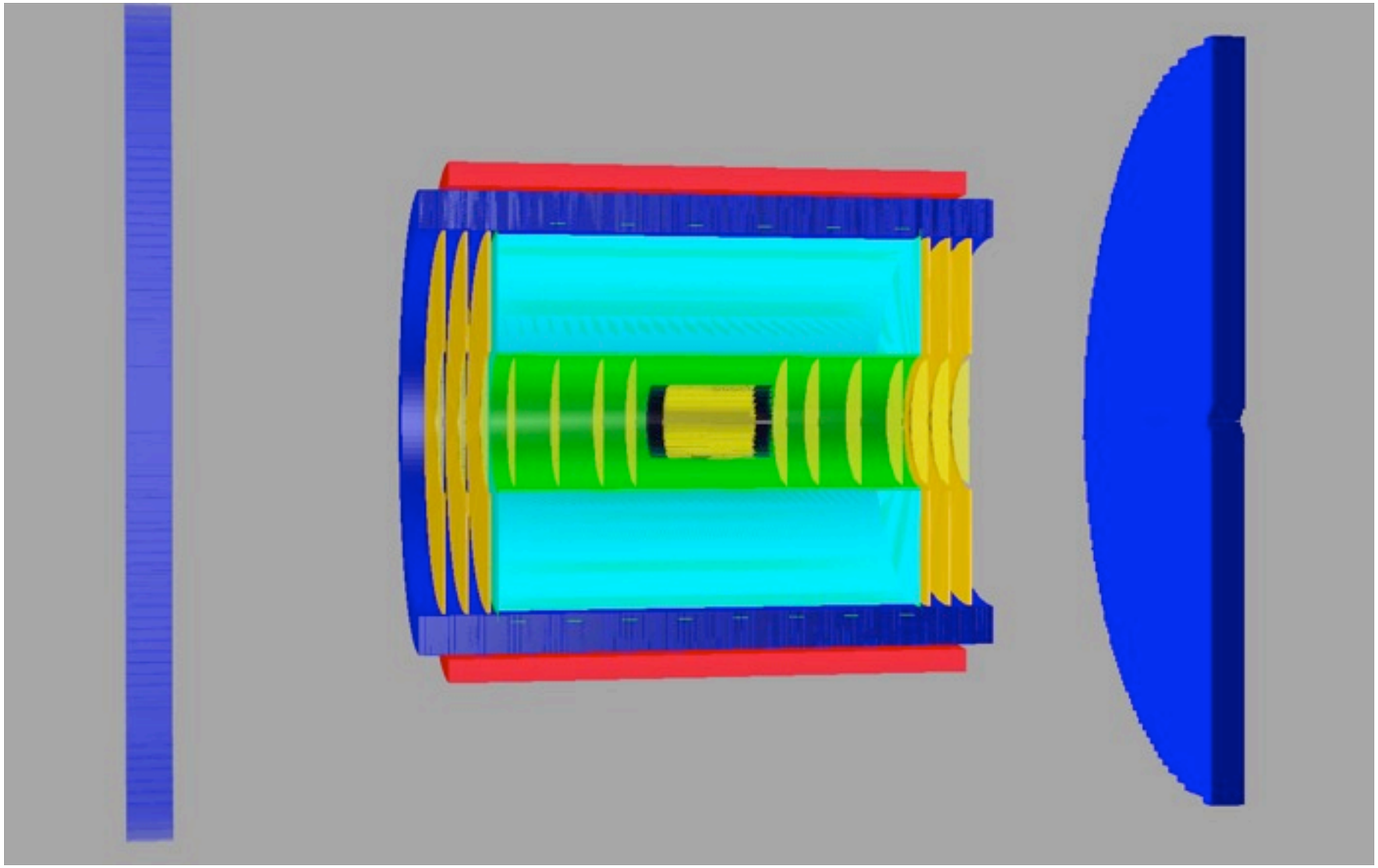
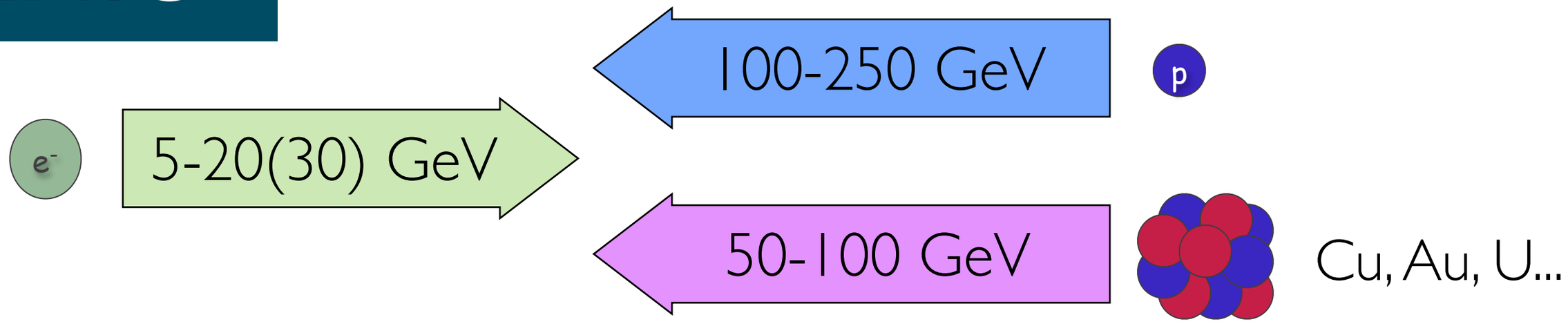


Geant simulations under way

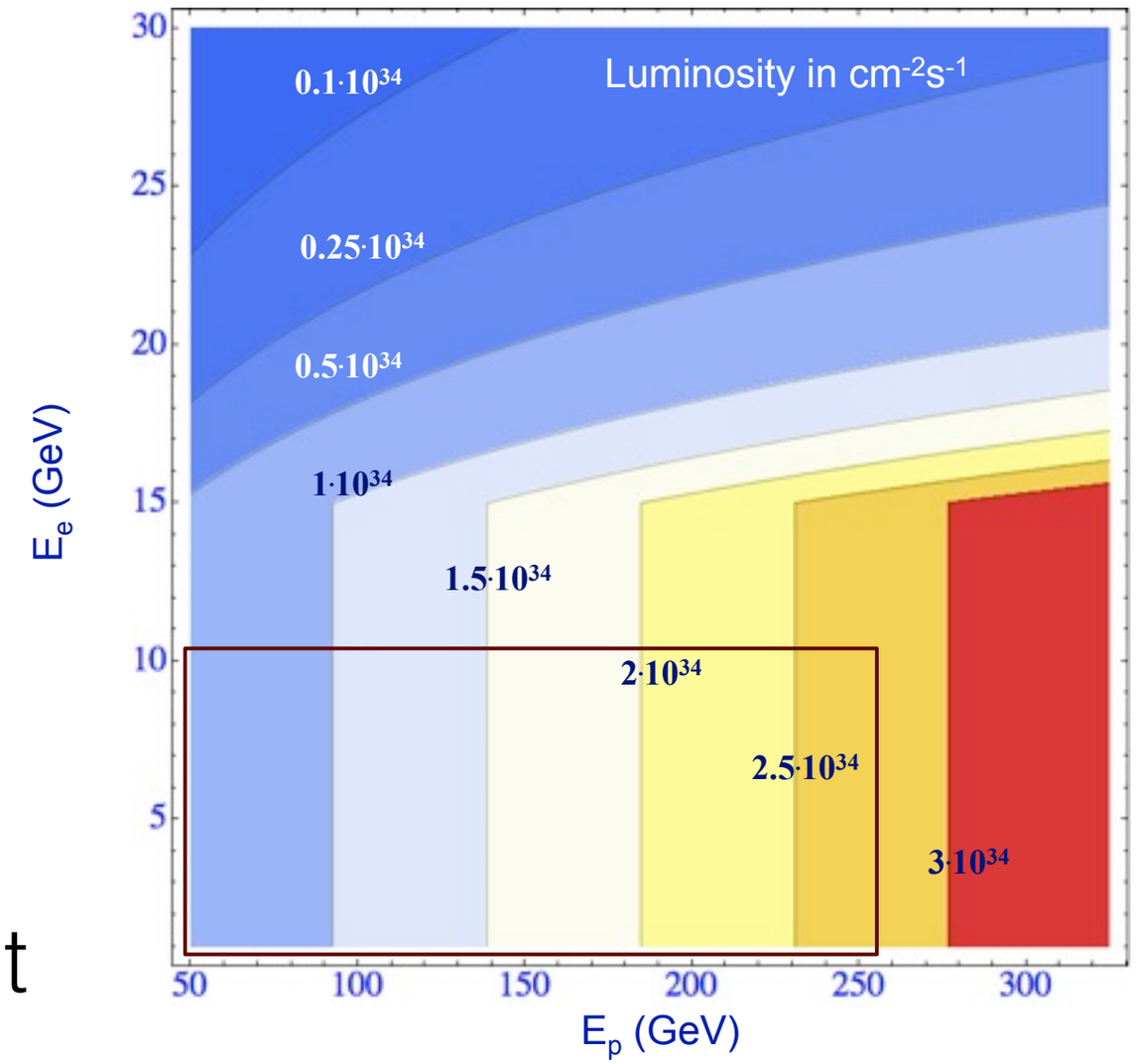
To Roman pots, ZDCs

ZDC: breakup neutrons give ~100% efficiency to detect incoherent eA

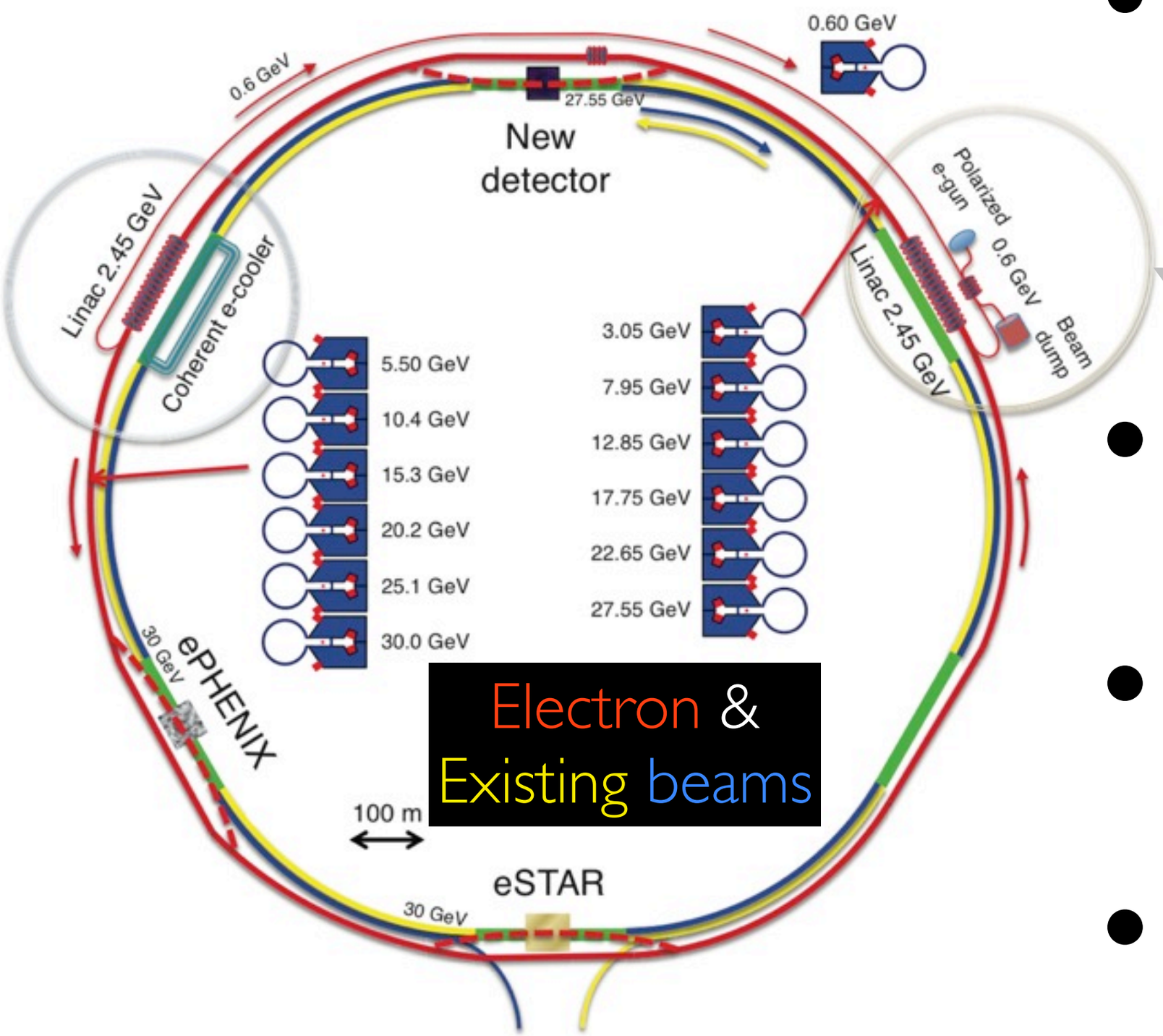
eRHIC



- **4 goals** of machine design:
  1. Variable beams **species**
  2. Variable beam **energies**
  3. High **luminosity** ~10^{34}
  4. e^- **polarisation** ~80%
- Maximise use of existing infrastructure and investment



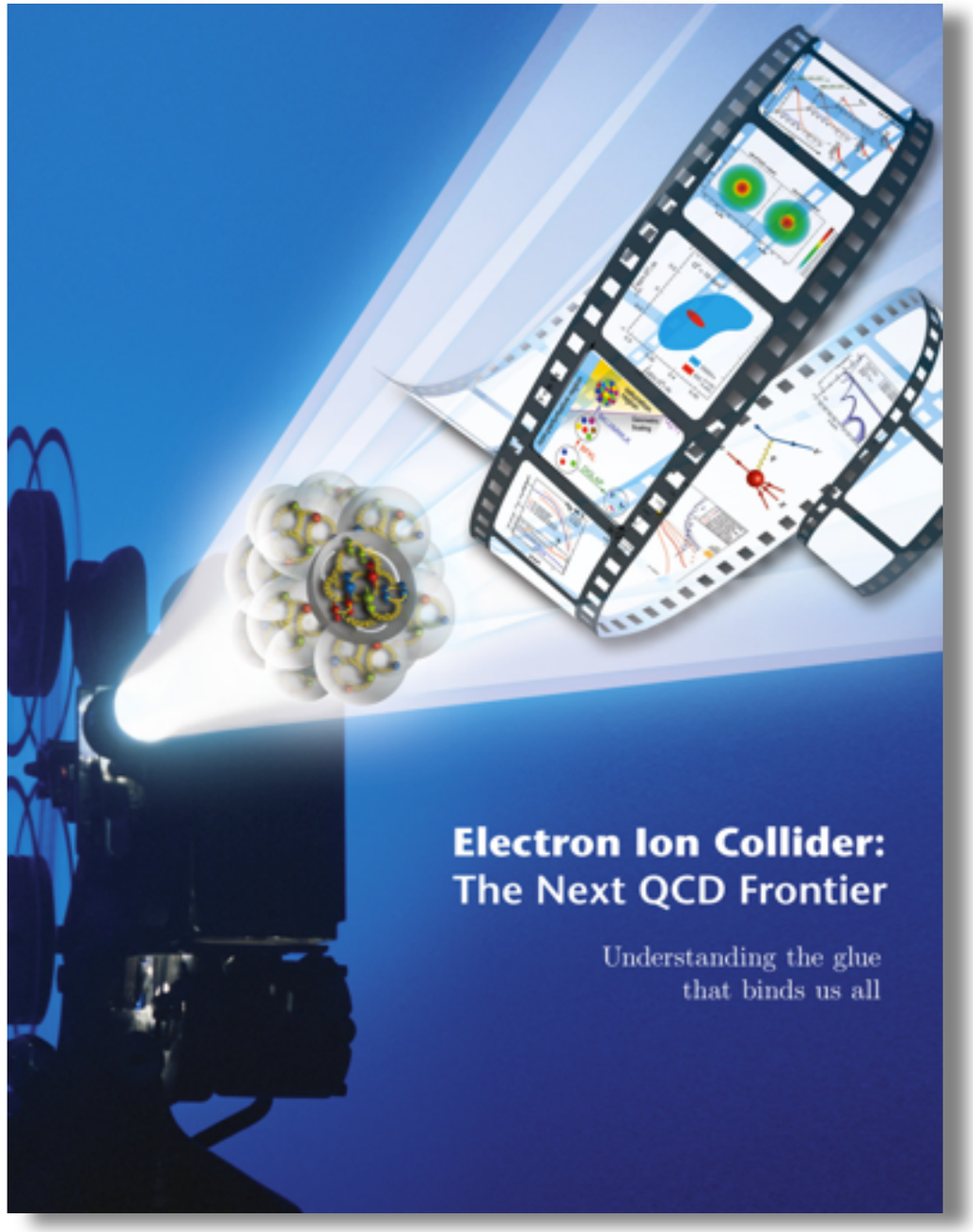
eRHIC



- Re-use of existing infrastructure
- Two **linacs**
  - multiple passes
- Stageable energy
  - add RF cavities
- New high-intensity polarised e^- source

Conclusions

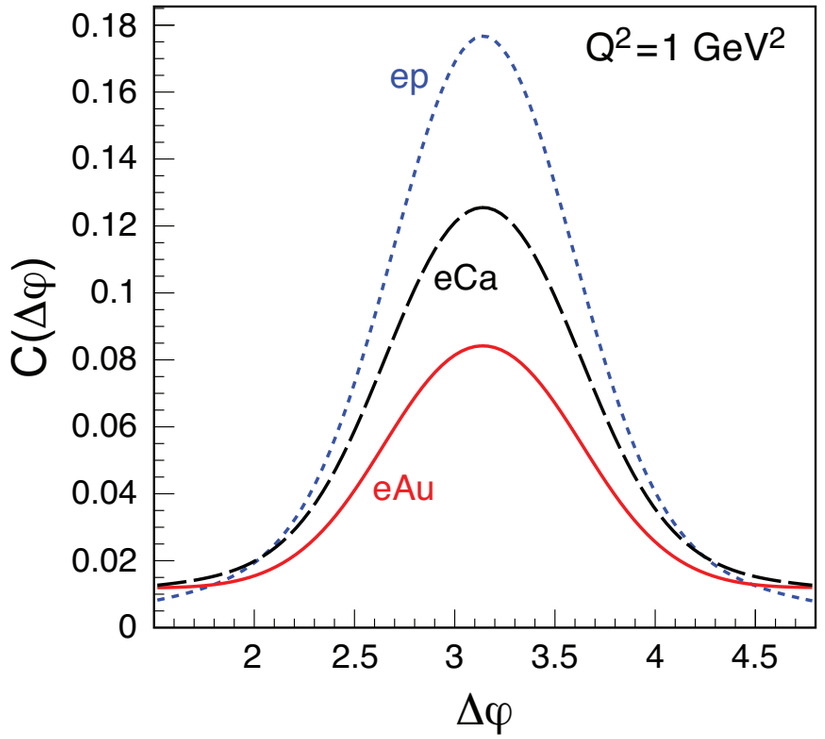
- eRHIC: ep/A collider at BNL
- Rich programme of eA (and ep physics)

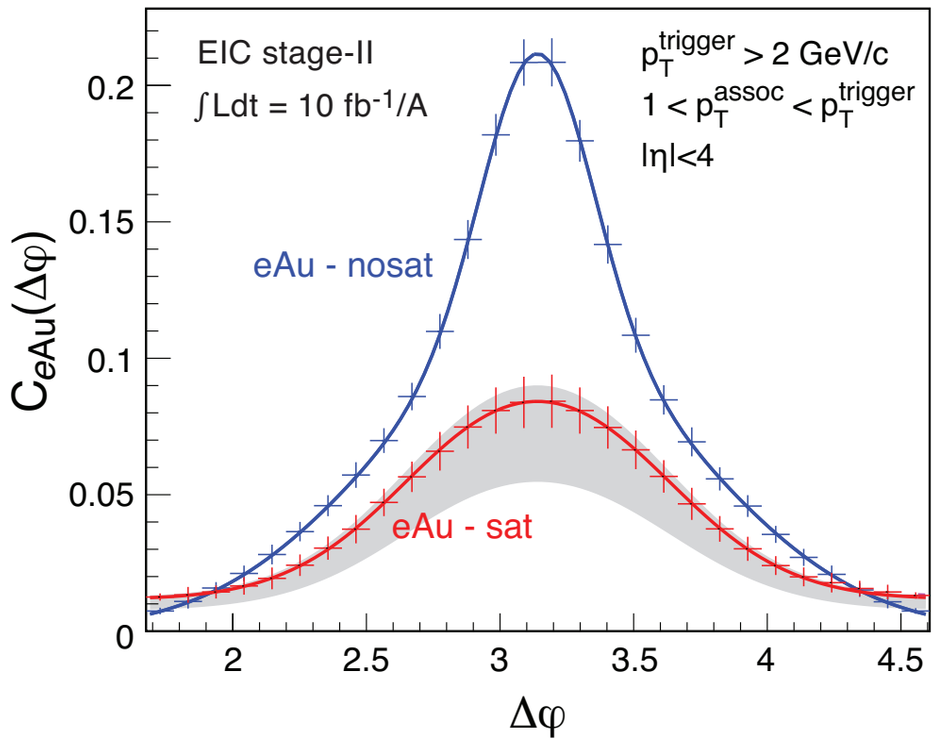


- Further reading
  - arXiv:1212.1701
  - arXiv:1108.1713
  - wiki.bnl.gov/eic/index.php/Main_Page

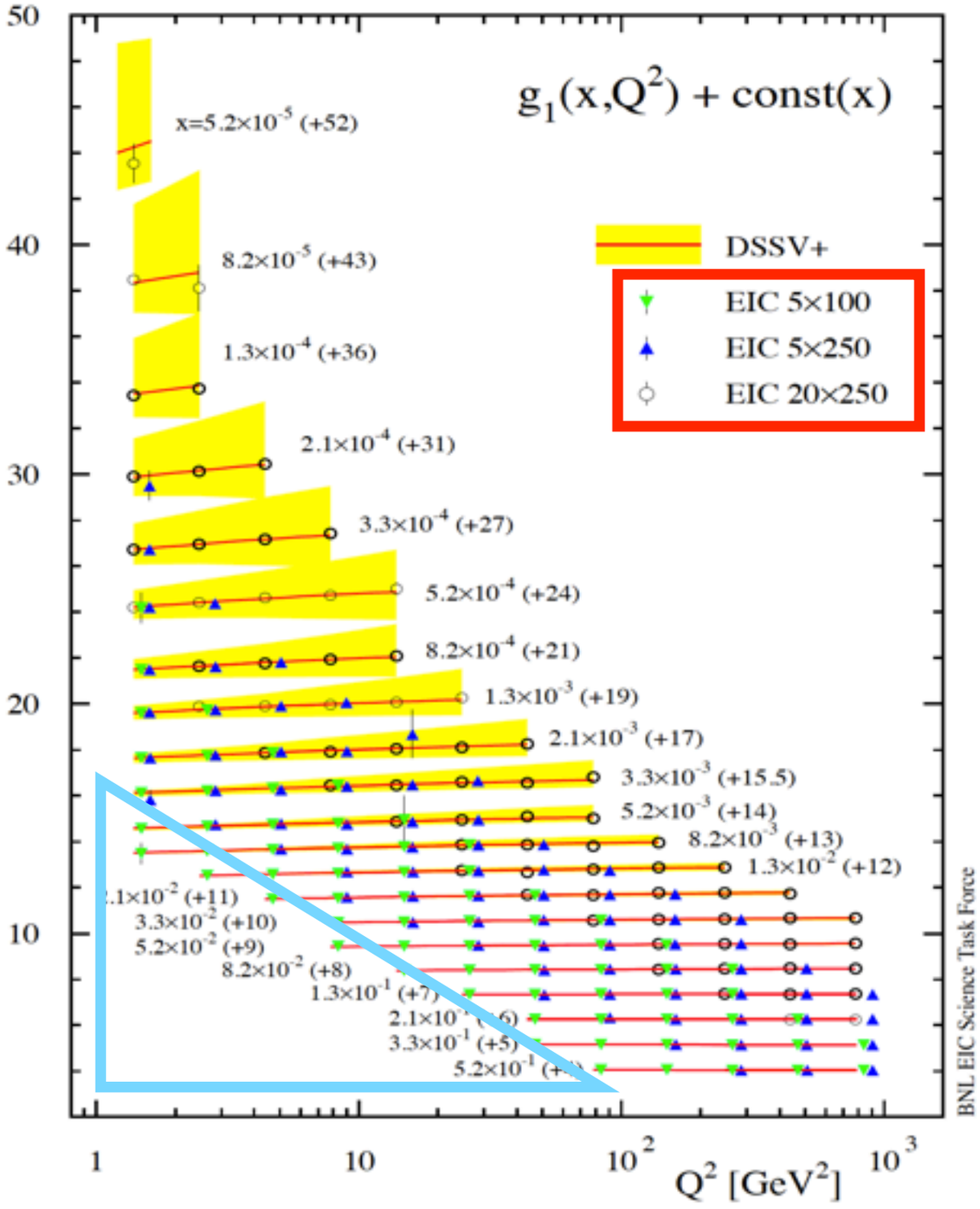
Dihadron correlations

- "Semi-inclusive" DIS
- Multiple gluon re-scattering, emission in saturation framework washes out correlation
- Ratio = 1 in absence of collective nuclear effects
- Shaded: uncertainties in knowledge of saturation scale
- ep baseline needed, but cancels various uncertainties

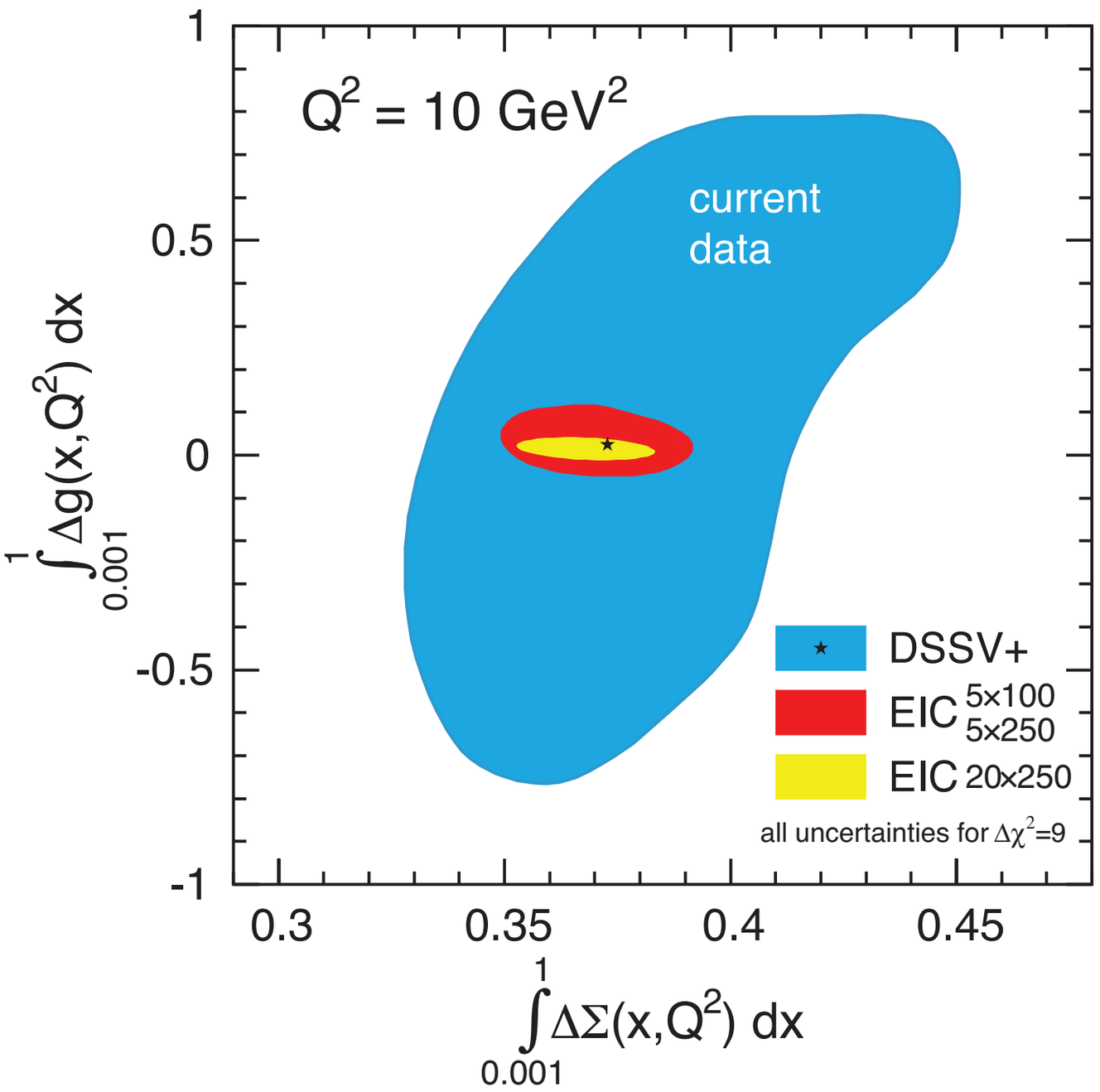




DIS with polarised beams



Measure quark/gluon helicity

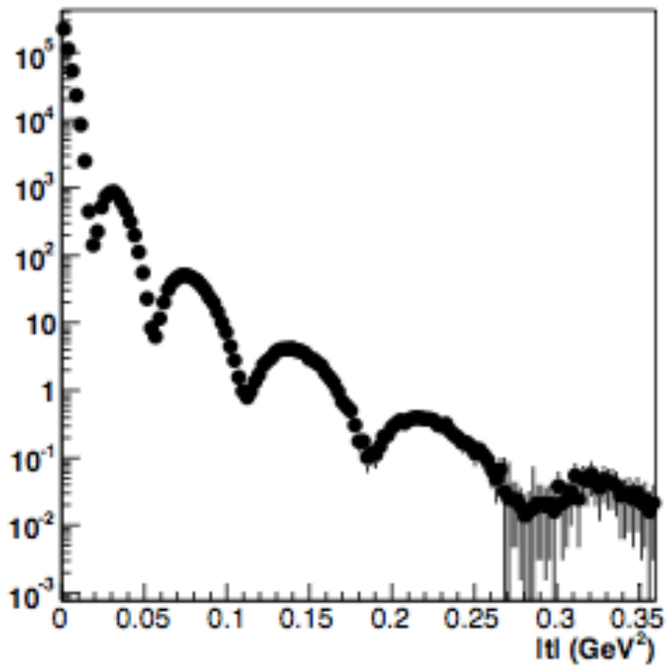


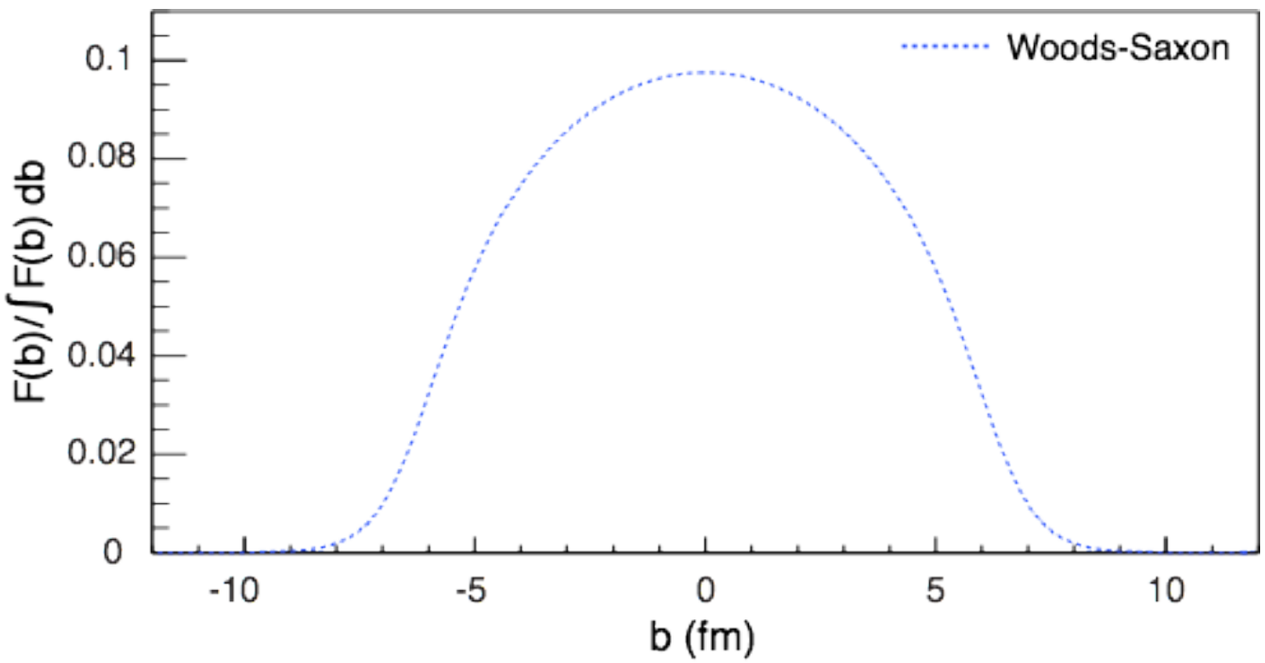
Fourier transform

Measure more minima

↓

Better measure of b-dependence





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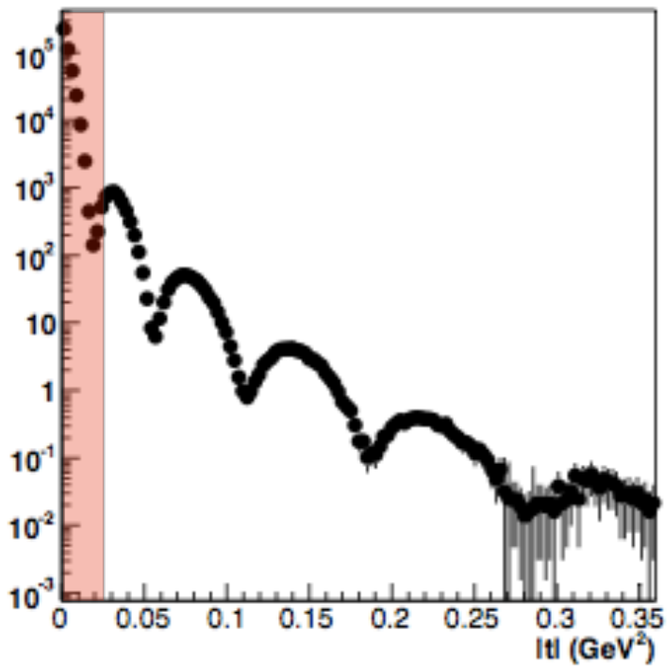

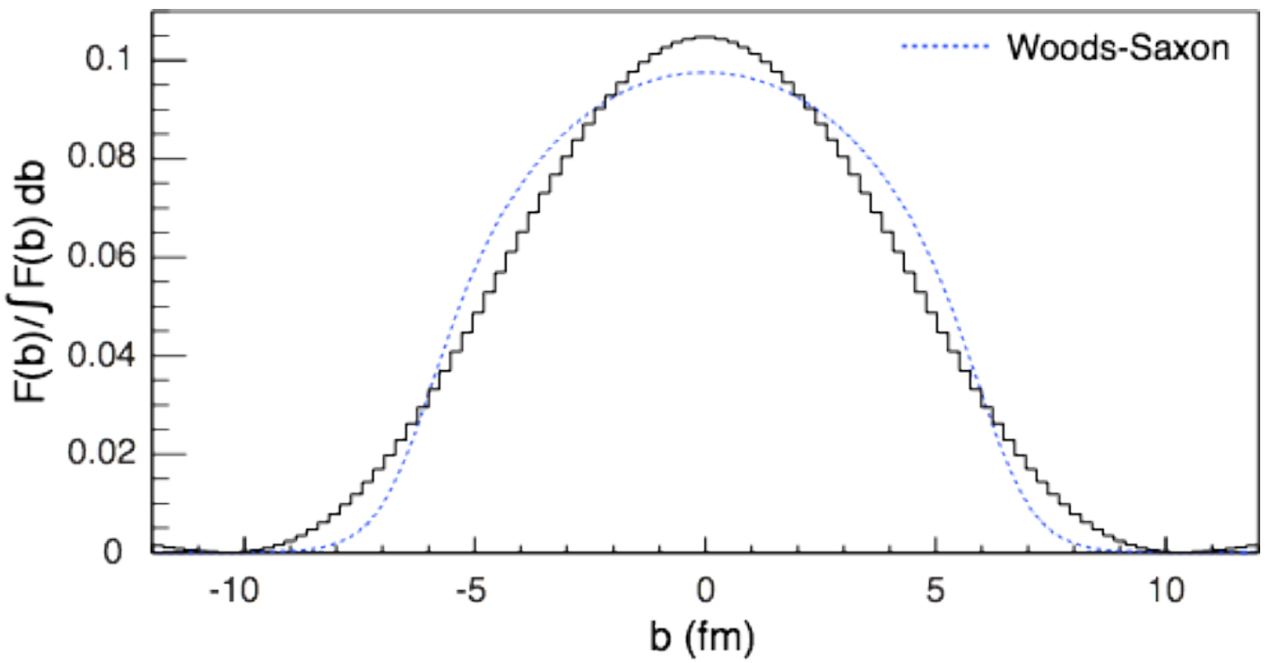

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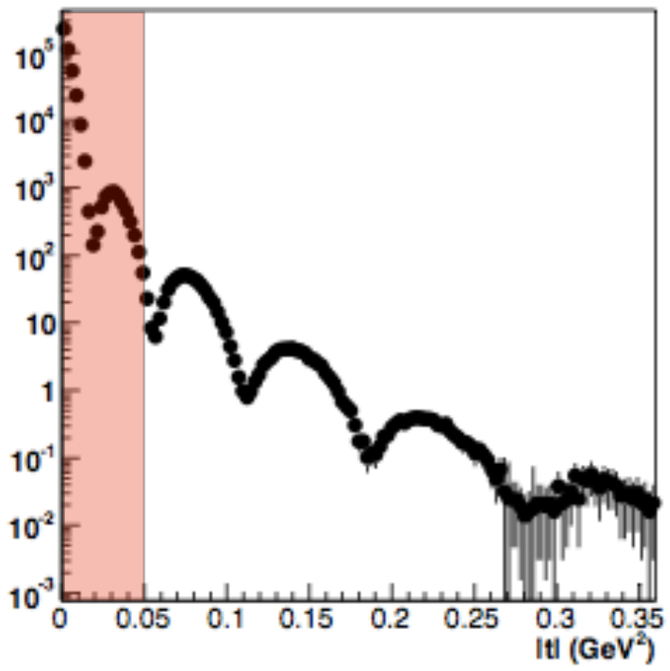

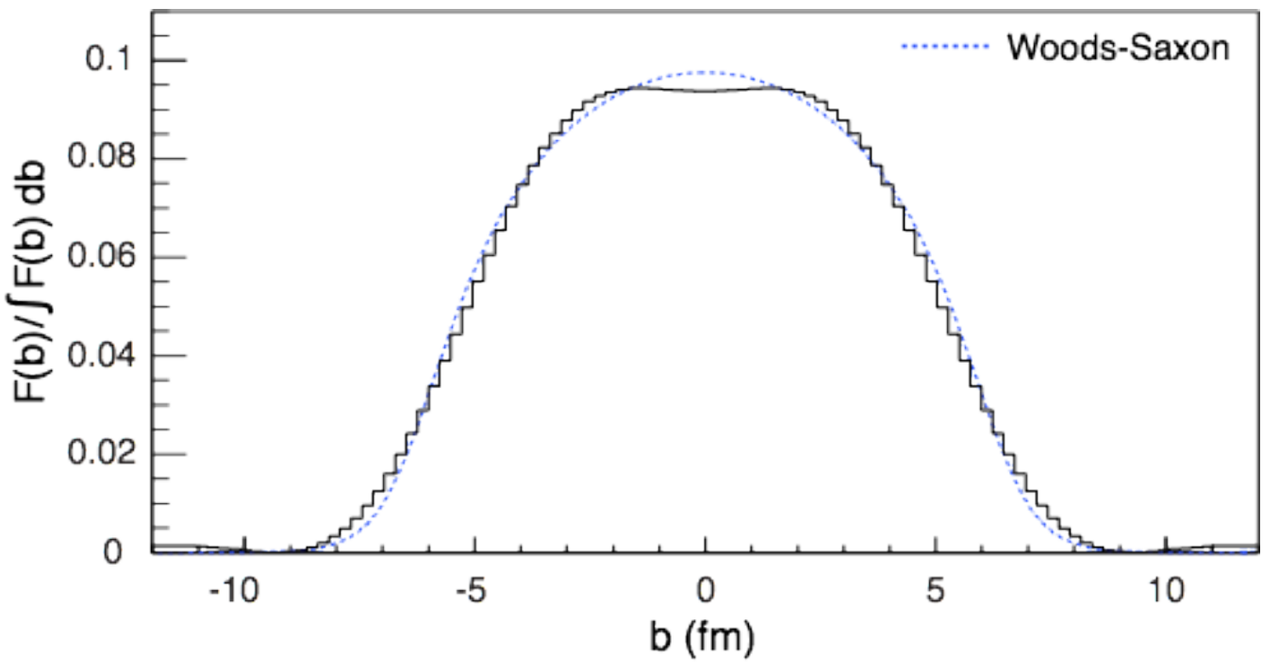

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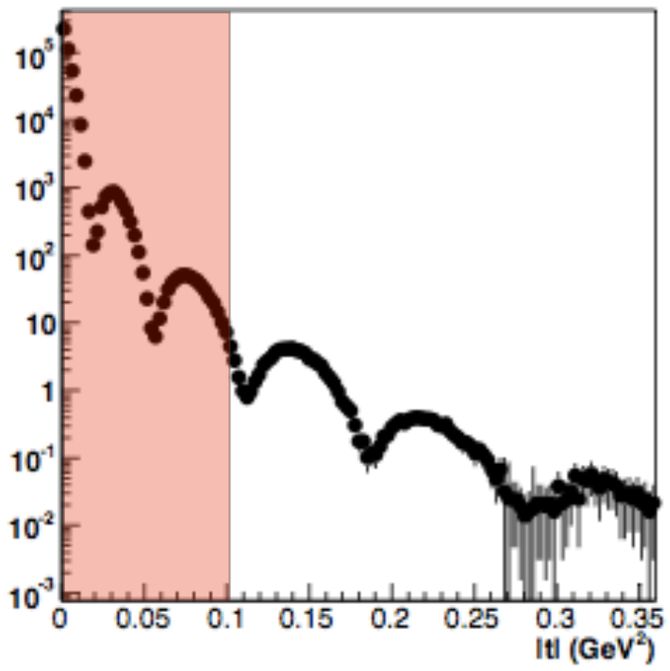

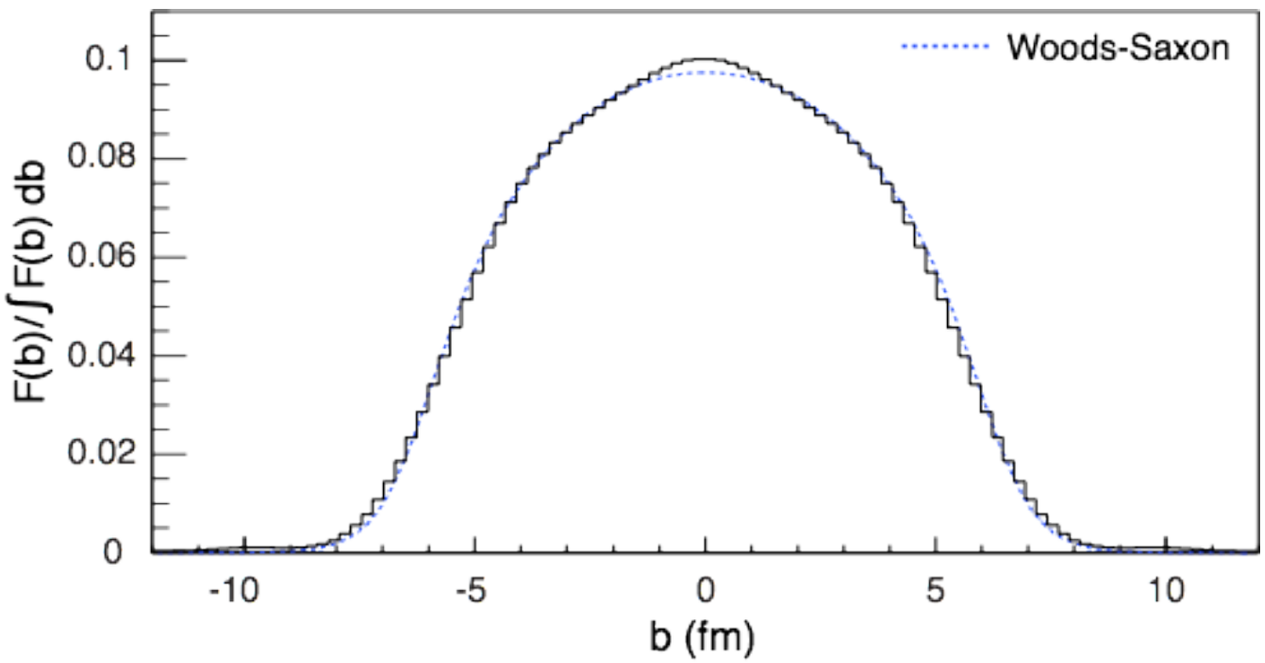

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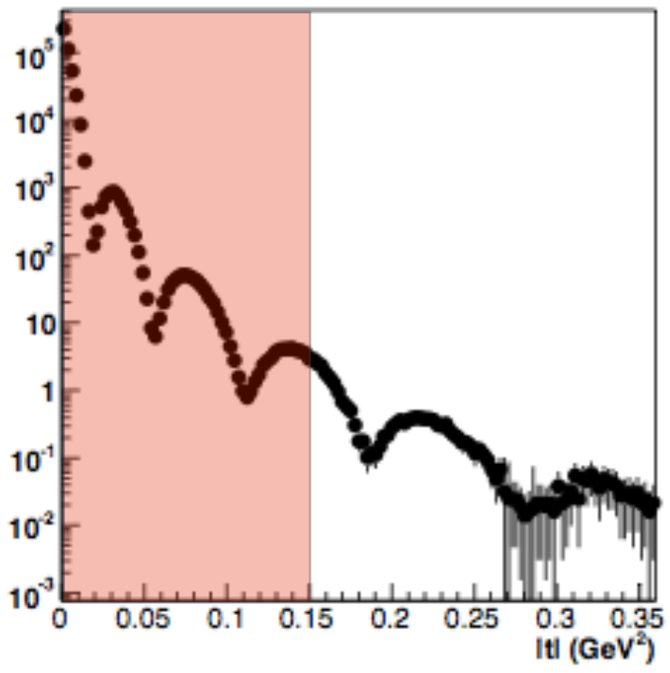
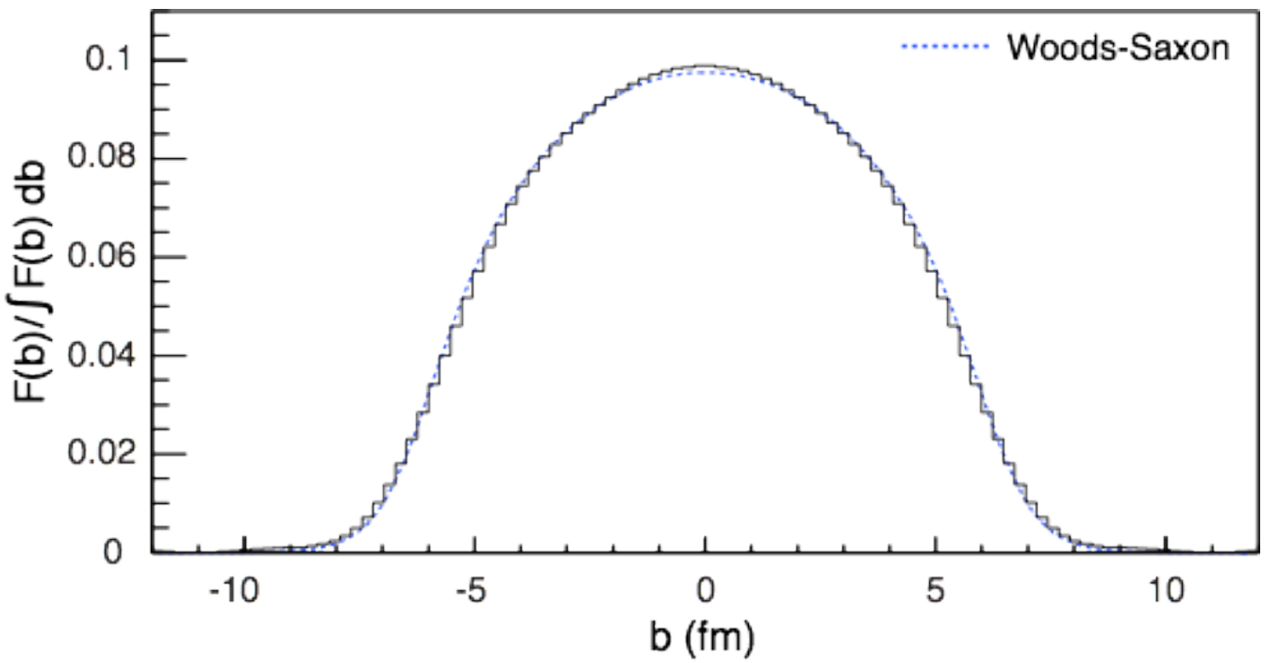
↓

Better measure of b-dependence



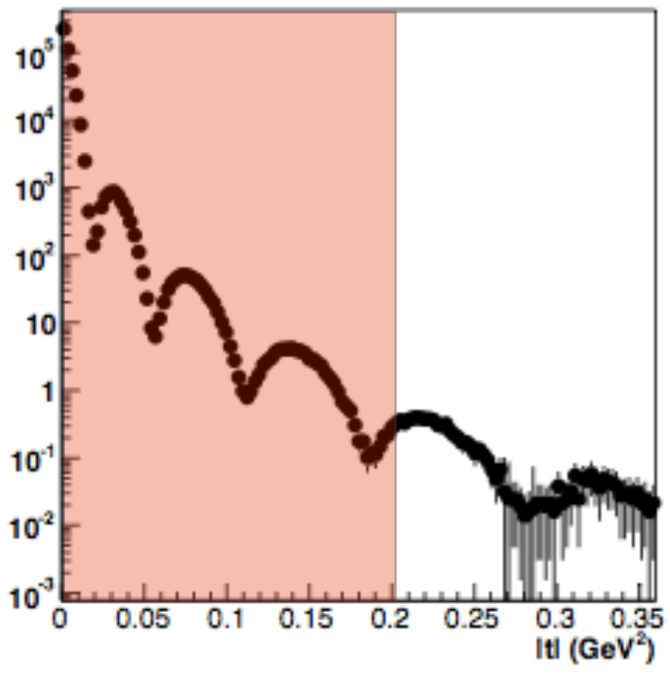


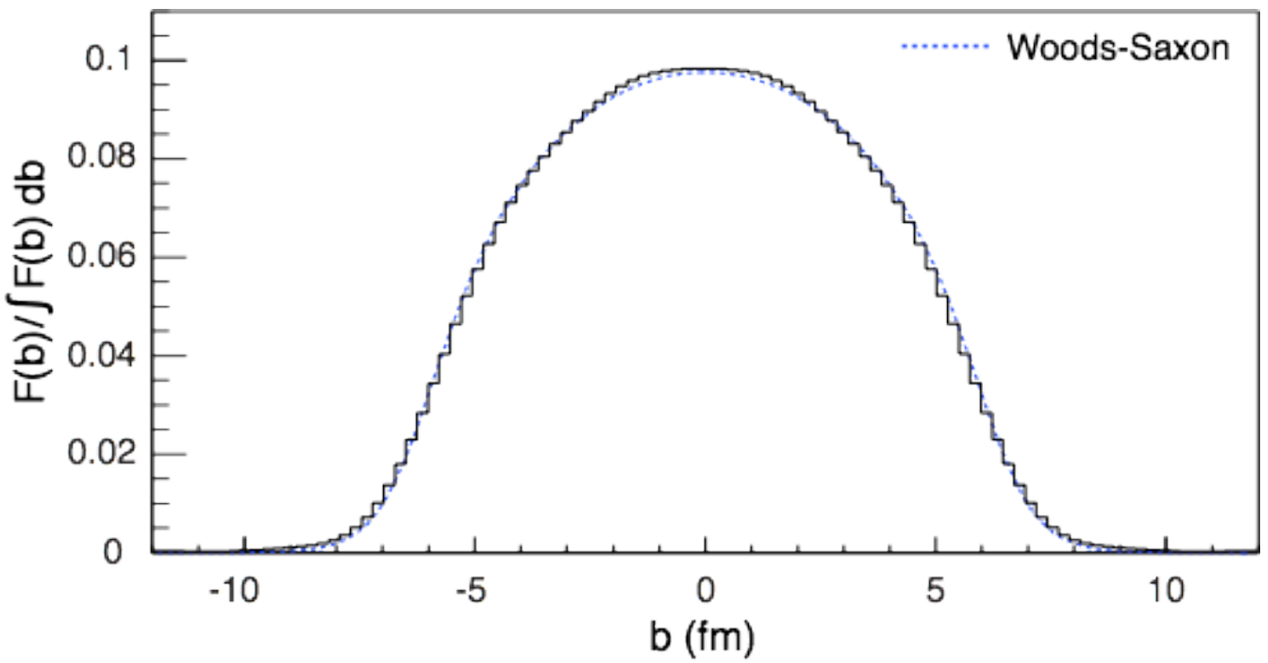
Fourier transform

Measure more minima

↓

Better measure of b-dependence



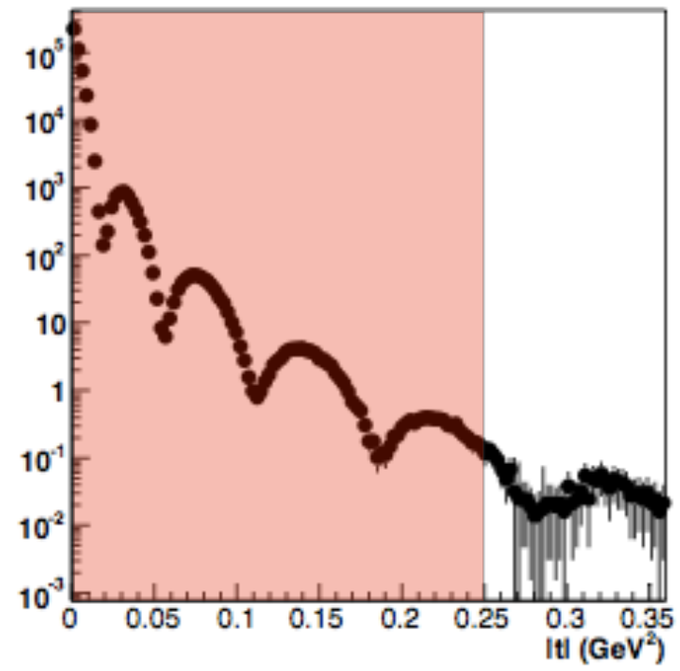


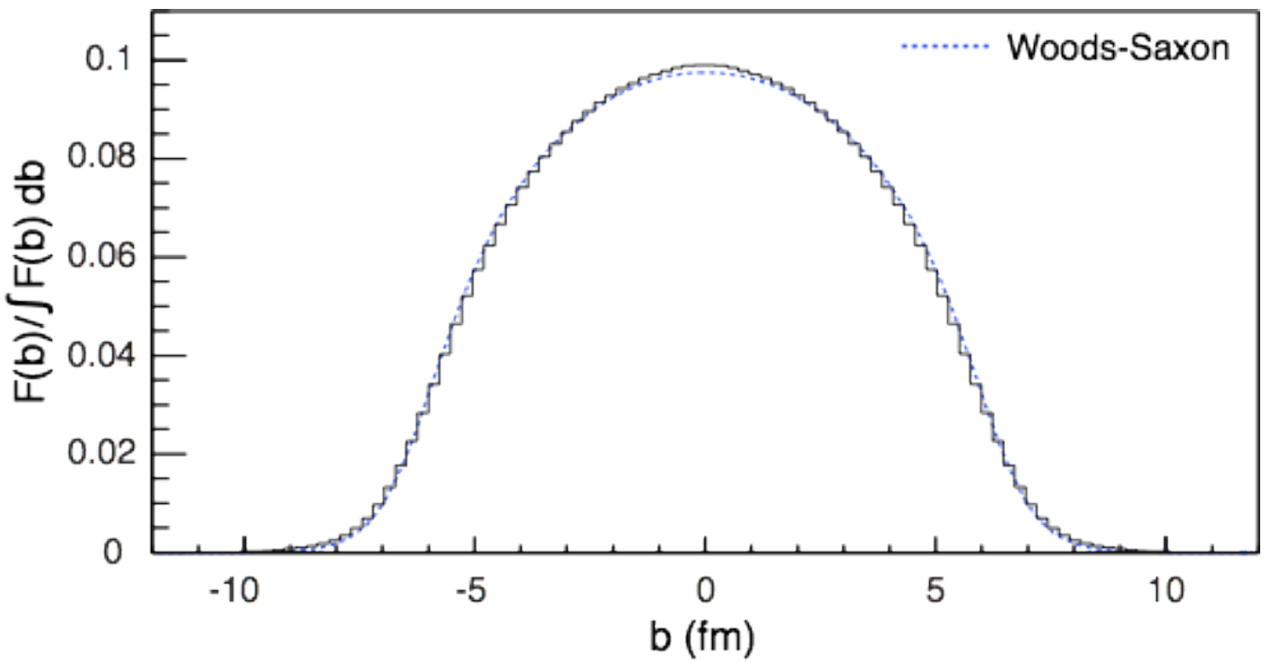
Fourier transform

Measure more minima

↓

Better measure of b-dependence



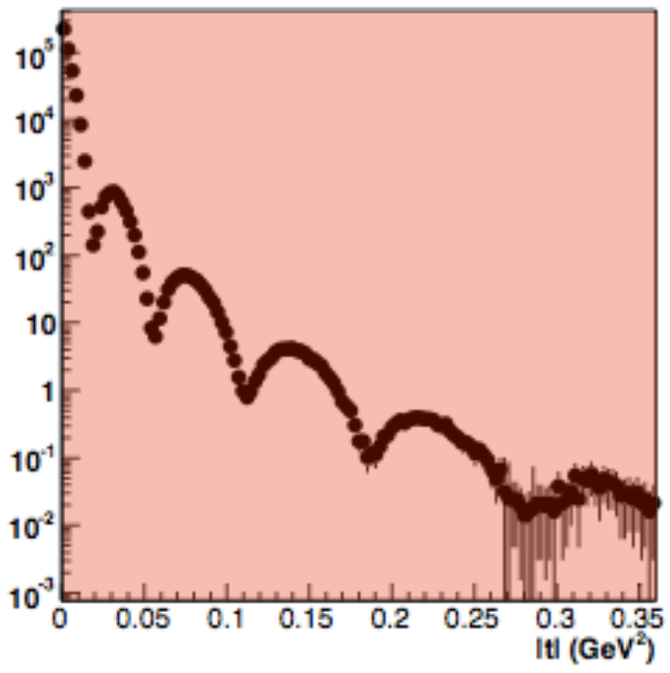


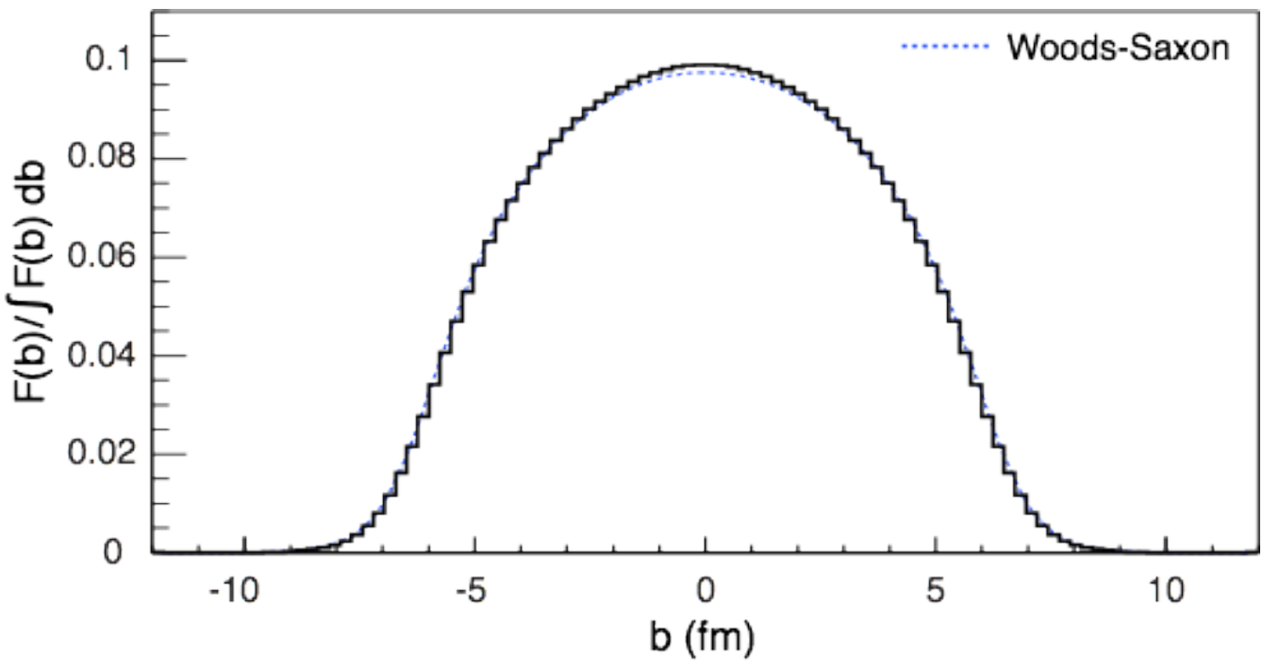
Fourier transform

Measure more minima

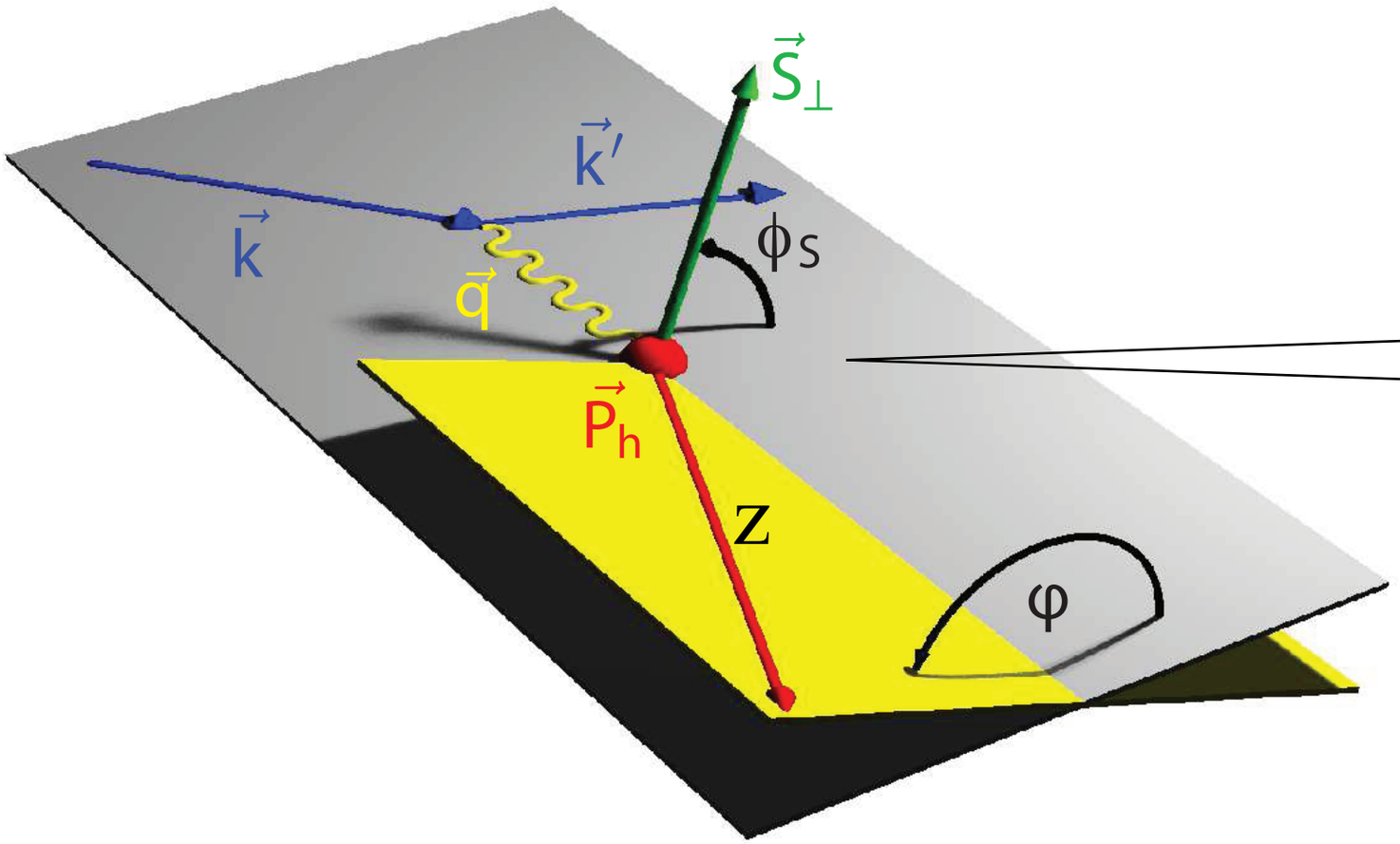
↓

Better measure of b-dependence





SIDIS



Semi-**I**nclusive
Deeply **I**nelastic
Scattering

Measure the electron + a single hadron

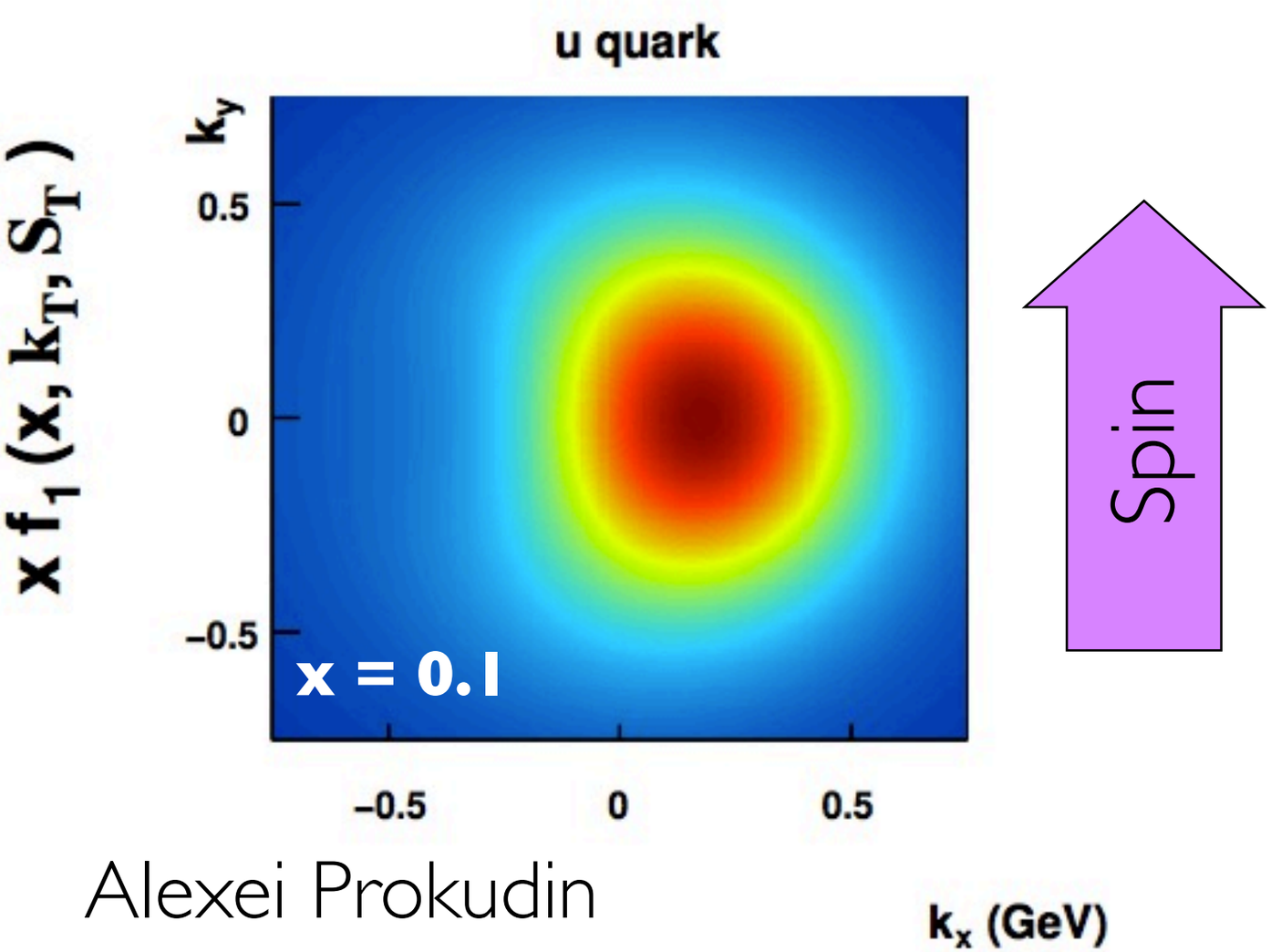
⇓

characterised via (z, p_T)

DIS x, Q^2 + semi-inclusive z, p_T (+ spin ϕ) ⇒ Multi-dimensional

SIDIS

- Gives additional hadron information
  - extract "*transverse-momentum-dependent distributions*": **TMD**s

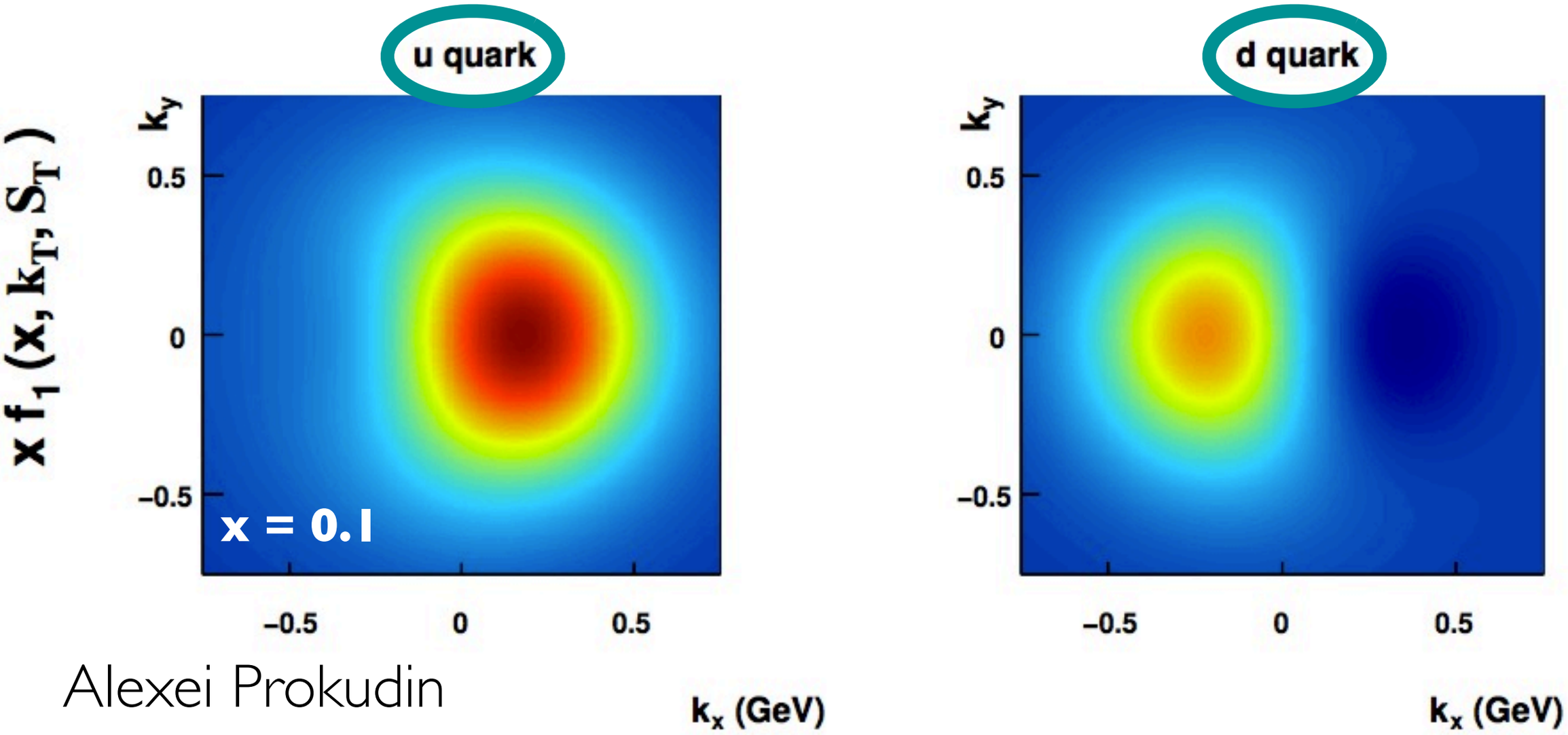


Alexei Prokudin

1) Spin-dependence: see deformation of parton distribution e.g. **Sivers** function

SIDIS

- Gives additional hadron information
  - extract "*transverse-momentum-dependent distributions*": **TMD**s



Alexei Prokudin

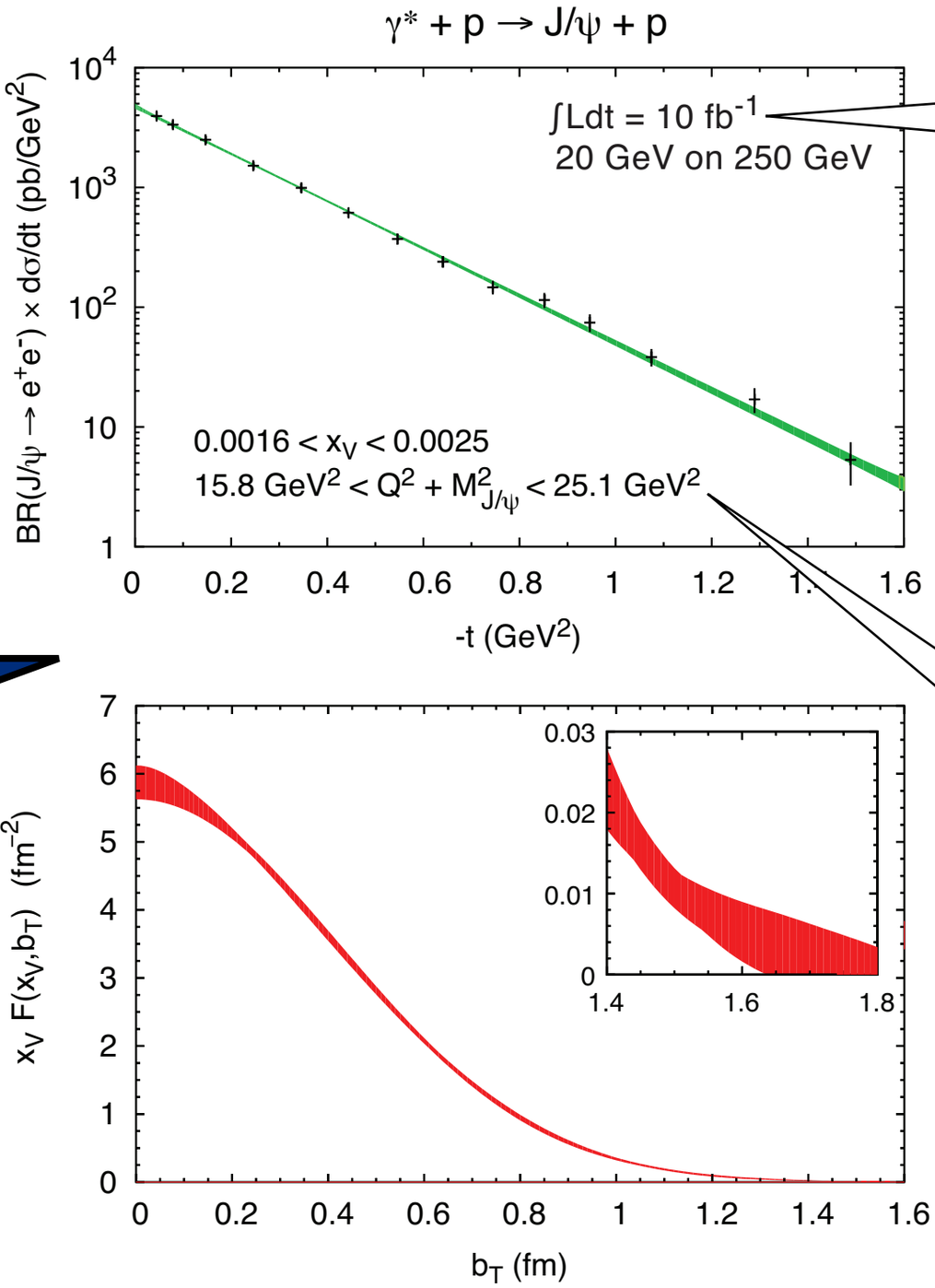
2) Identify hadrons: decompose **flavour** dependence

J/psi production

t

Fourier transform

b

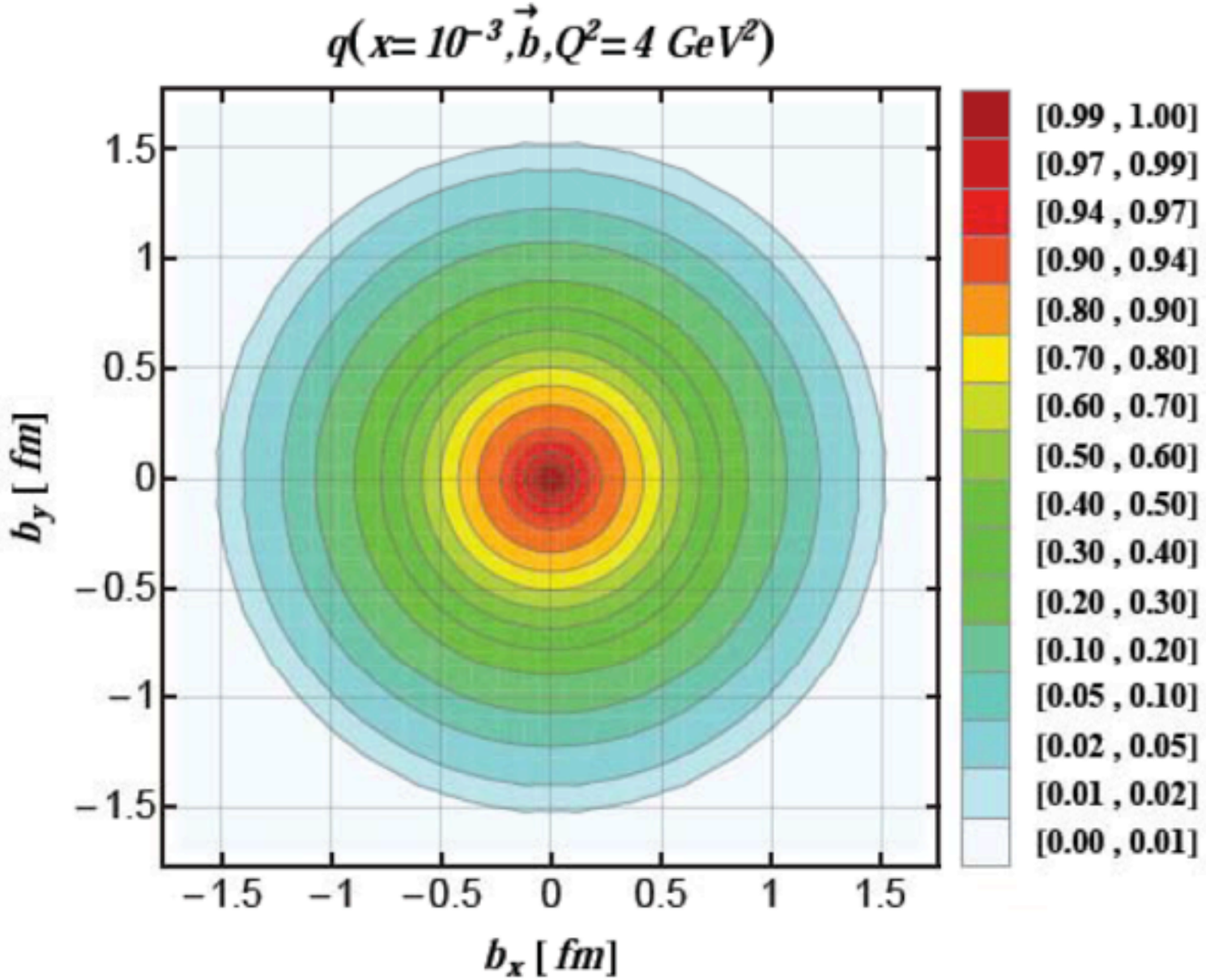


Tiny statistical errors in < 1 year running

Fine binning in (x, Q^2, t)

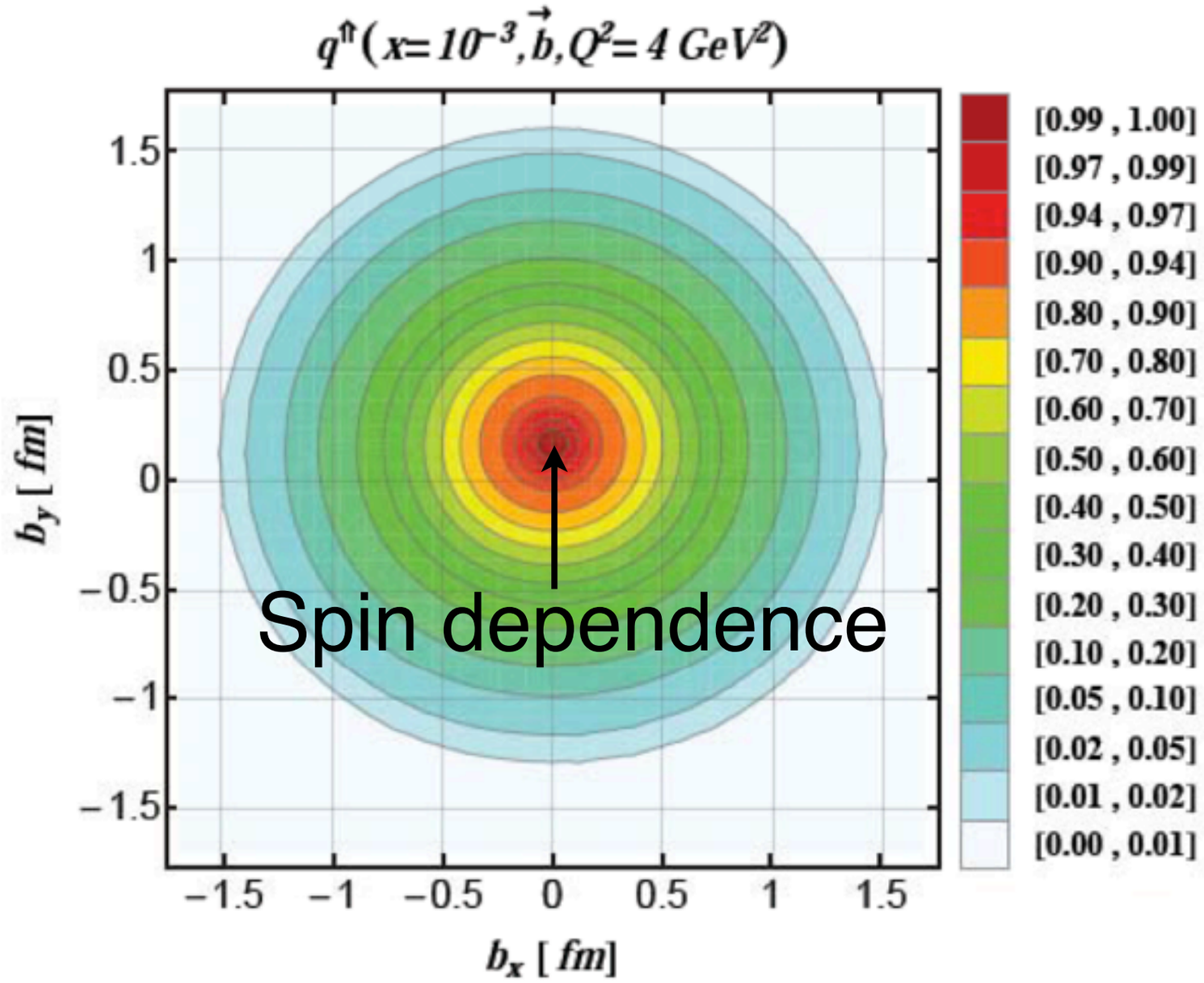
Nucleon **tomography**

Generalised **P**arton **D**istributions → b-dependence



Nucleon **tomography**

Generalised **P**arton **D**istributions → b-dependence



Nucleon **tomography**

Generalised **P**arton **D**istributions → b-dependence