

# Summary of the EIC White Paper

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Snyder Auditorium, BNL

# The writing committee

Put together by BNL and JLab managements last summer

## ❑ Overall editors:

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## ❑ Advisors:

Holt, Mueller

## ❑ Charge:

- ✧ Aiming at non experts, and the rest of nuclear physics community
- ✧ Laying out the goals, importance and uniqueness of the facility
- ✧ Answering the basic questions raised about EIC at 2007 LRP meeting
- ✧ All in clear, concise, compelling, jargon-free language, in < 100 pages

## ❑ INT “Yellow Book” on EIC:

arXiv: 1108.1713

# The White Paper's structure

## ❑ Introduction:

One-page introduction to EIC for congressional staffers

## ❑ Executive Summary:

Nuclear science in a big picture, and the overarching questions

The EIC, its goals and uniqueness, and what it can deliver

## ❑ The first polarized electron-proton collider:

The spin and flavor structure of the nucleon

Three-dimensional motion of quarks and gluons

The tomography of the nucleon – spatial imaging of quarks and gluons

## ❑ The first electron-ion collider:

The internal landscape of the nucleus in terms of quarks and gluons

QCD at an extremely high gluon density

## ❑ The realization of EIC:

The machine designs, and the detector requirements

# The big picture

## ❑ The universe:

Dark energy, dark matter, and the visible world

## ❑ Dark energy:

The universe's accelerating expansion requires a massive amount of dark energy (~70% of the universe's energy budget)

## ❑ Dark matter:

The motion of stars and galaxies needs a lot of dark matter (~25% of the universe's energy budget)

## ❑ The visible world:

Everything that we can see by our eyes, and telescopes  
~ only 5% of the universe's energy budget

Has the most impact on our life, and

Has been mostly investigated in generations!

# “Mass without mass”

– John Wheeler

## □ What makes up the mass of the visible world?

Nuclear mass makes up 99.9% mass of atoms, hence of the visible world

Nucleon mass (proton and neutron) makes up all nuclear mass

But, nucleon mass itself is believed to be made of the energy of massless gluons and almost massless up and down quarks

## □ What determines the properties of the visible world?

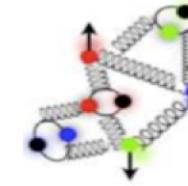
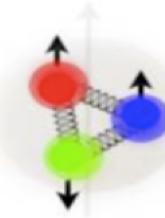
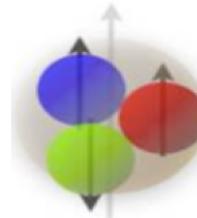
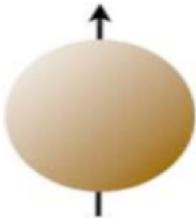
Nuclear properties determine the fundamental properties of atoms, hence of the visible world

Critical importance of nuclear science!

# Nuclear science and QCD

## □ Nuclear science and hadron physics in last 40 years:

Nucleon:



Resolution  
→

Success of QCD dynamics at 1/10 fm and less – Asymptotic freedom

Success of lattice calculation of hadron masses, magnetic moments, ...

Discovery of a huge density of soft gluons and a nontrivial sea, ...

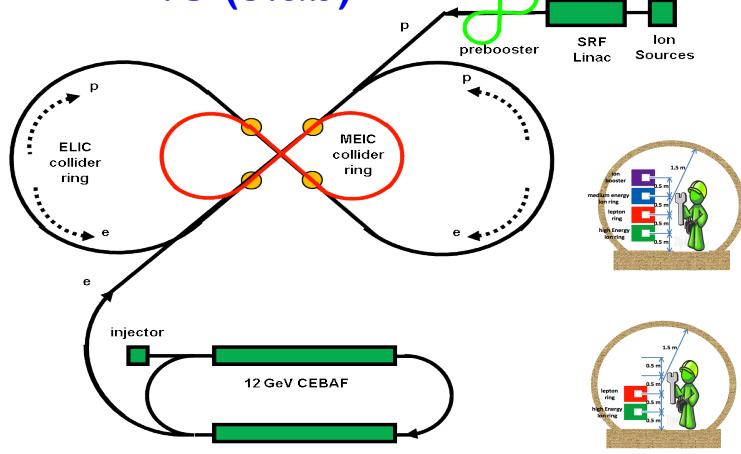
## □ The overarching questions:

- ✧ How quarks and gluons distributed in nucleons and in nuclei
  - in momentum, in space, in spin, in flavor – in the sea-quarks and gluons dominated regime?
- ✧ How hadron properties, such as spin, are determined by the motion and the intrinsic properties of quarks and gluons?
- ✧ What governs the transition of quarks and gluons into hadrons?
- ✧ Does the gluon self-interaction saturates gluon density, producing a gluonic matter of universal properties in nucleons and in nuclei?
- ✧ ...

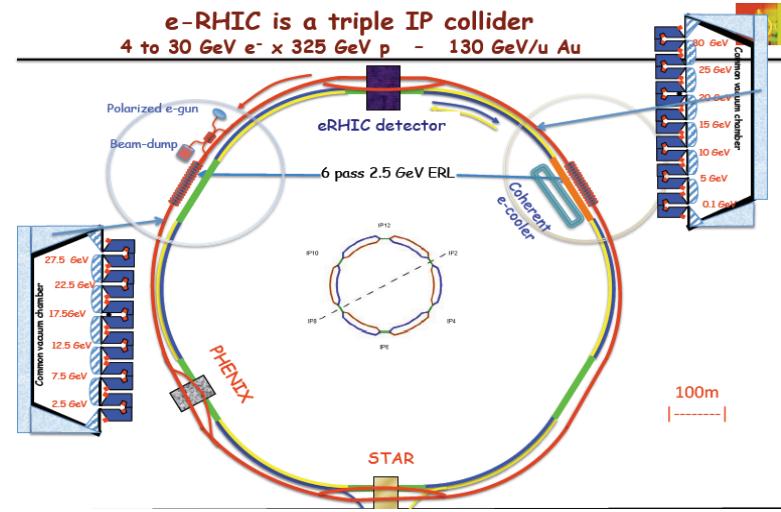
# The Electron-Ion Collider (EIC)

## □ Two options:

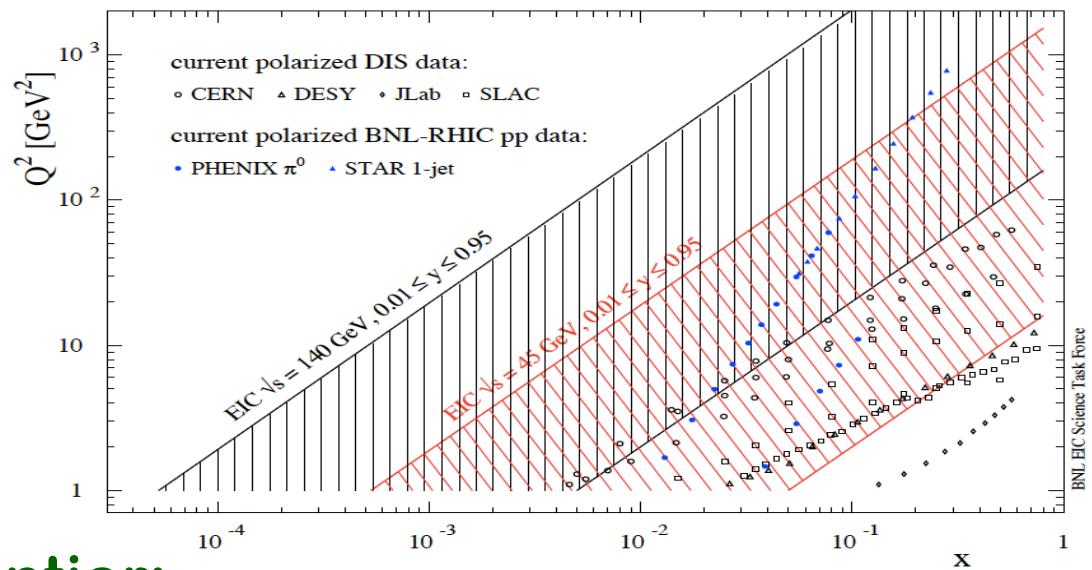
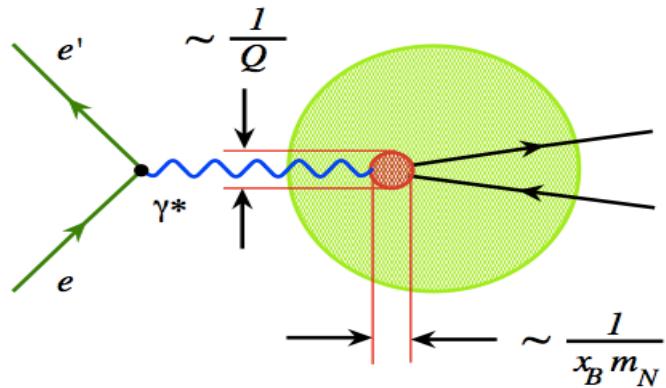
ELIC (Jlab)



eRHIC (BNL)



## □ Resolution:

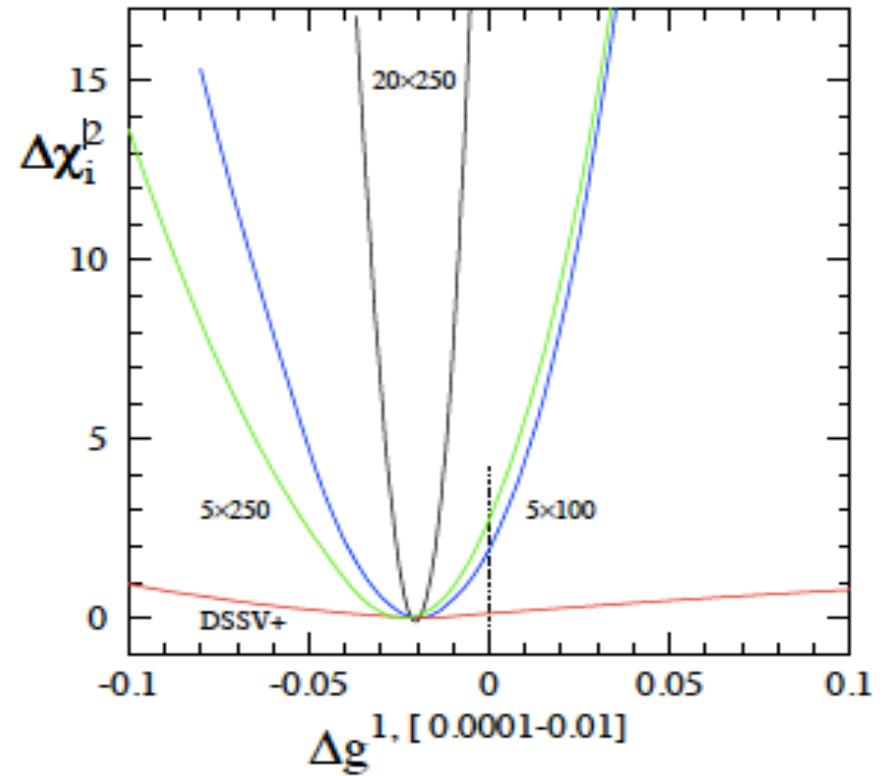
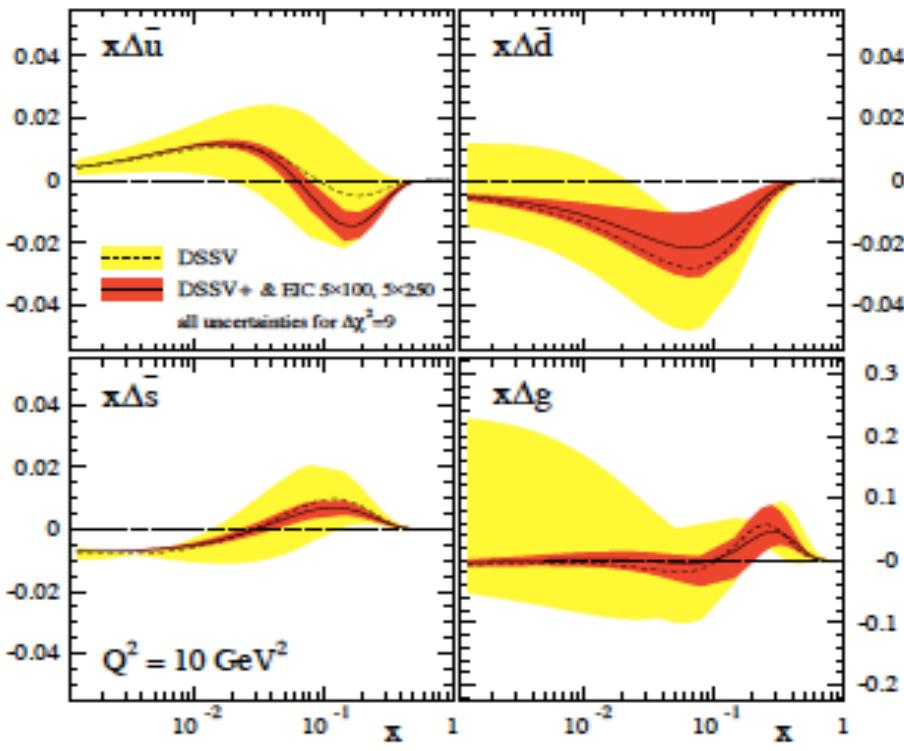


## □ Intensity and versatility frontier:

Near a 1000 times higher luminosity than HERA with polarization of both electron and proton beams and energy variability

# The spin and flavor structure of the nucleon

## □ The decisive measurement (two months running):



No other machine in the world can achieve this!

## □ The proton spin:

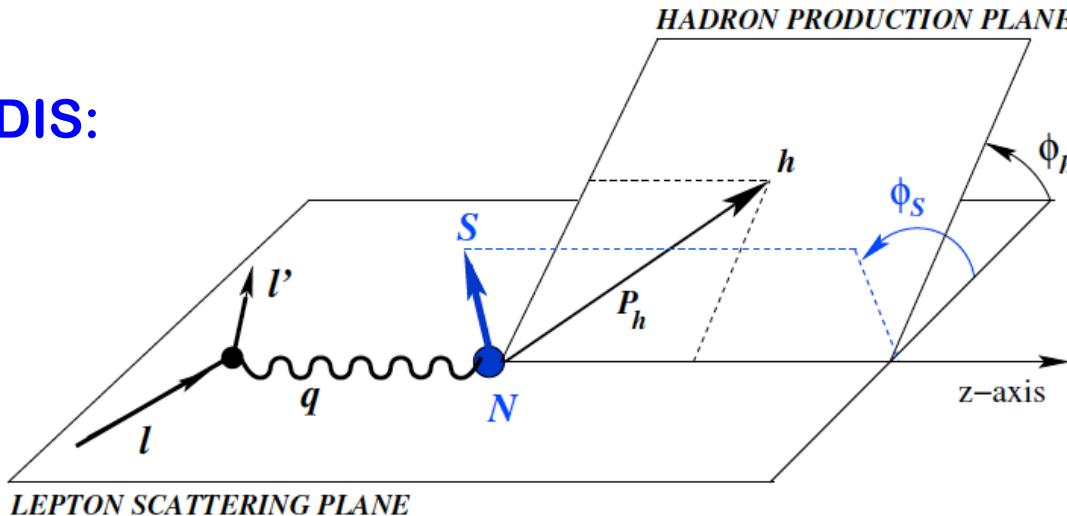
Adding the  $\Delta g$ , is there still a deficit to the proton spin?

If yes, we will have to investigate the orbital motion of quarks and gluons  
– the motion transverse to the proton's momentum

# Momentum tomography of the nucleon

- Going beyond the PDFs – 3D motion of quarks and gluons:  
High resolution scattering, but, still sensitive to parton's transverse motion

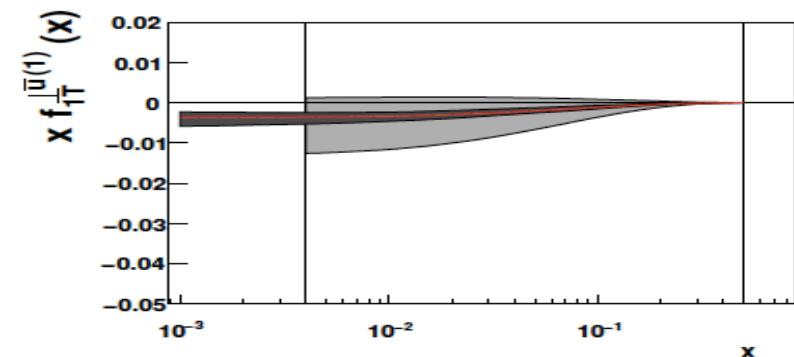
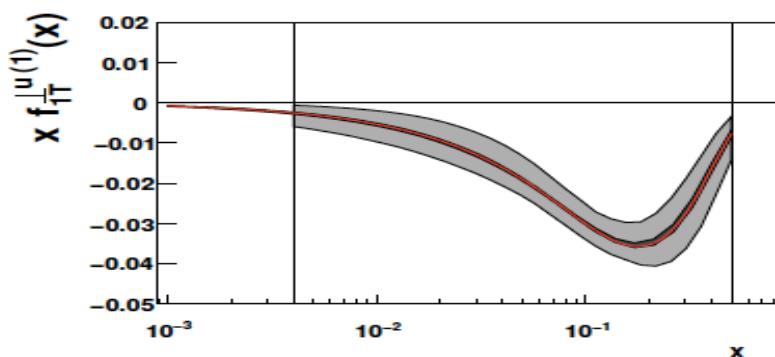
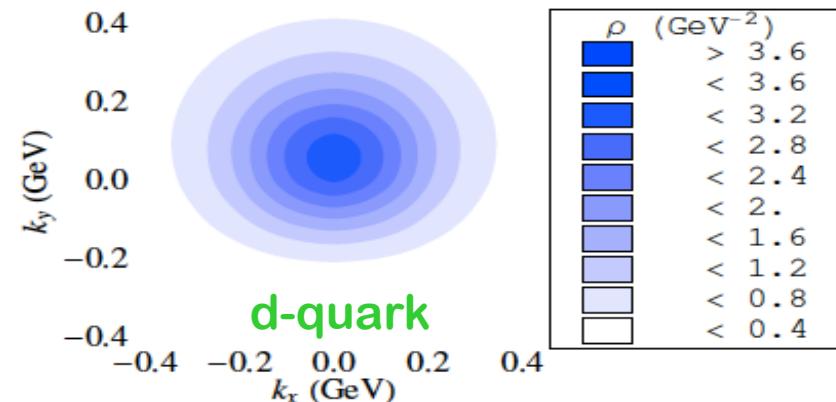
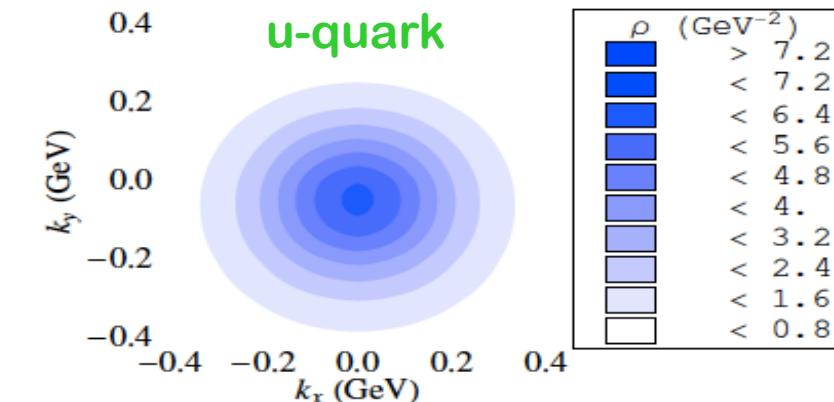
Semi-inclusive DIS:



$$Q \gg P_T$$

# Momentum tomography of the nucleon

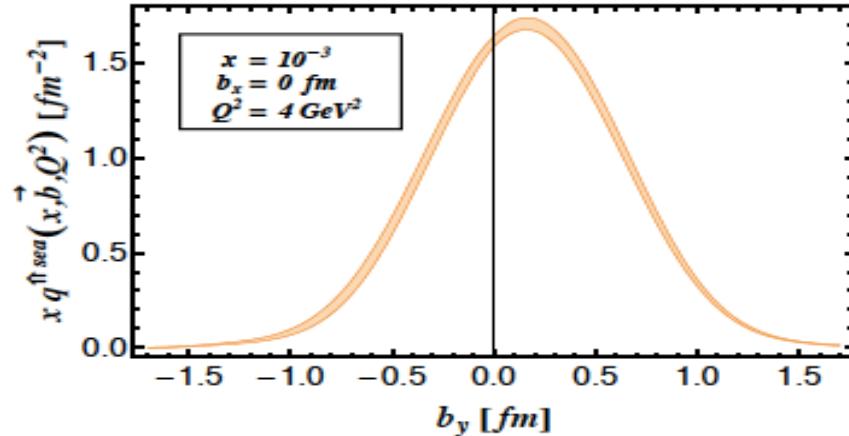
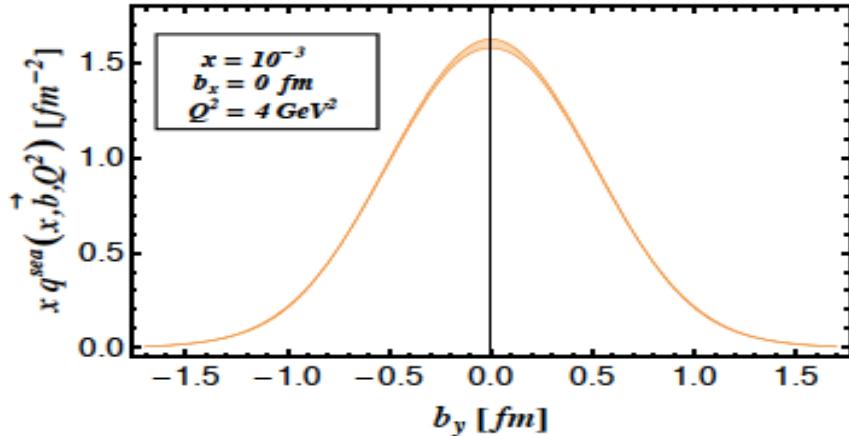
- Going beyond the PDFs – 3D motion of quarks and gluons:
  - High resolution scattering, but, still sensitive to parton's transverse motion
- QCD quantum correlations:
  - Sivers effect – correlations of hadron spin and parton transverse motion
  - Collins effect – influence of parton spin on direction of produced hadrons
  - ...
- Momentum tomography – wide range of  $x$  and  $Q^2$ :



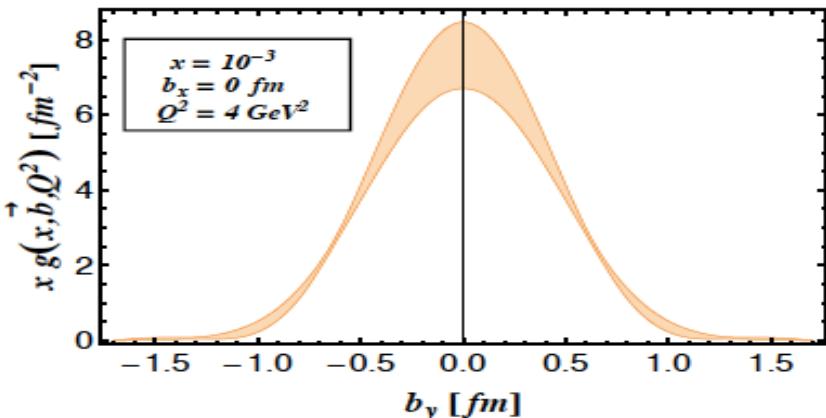
# The tomography of the nucleon

## □ Spatial imaging – effect of transverse polarization:

Transverse  
spin



## □ QCD quantum evolution in probing scale – Q:



Cross check with diffractive  
 $J/\psi$  production @ EIC

No QCD factorization for  
diffractive scattering in pp

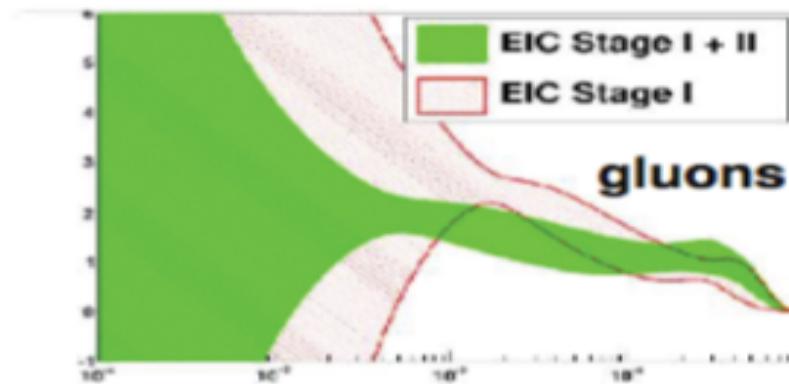
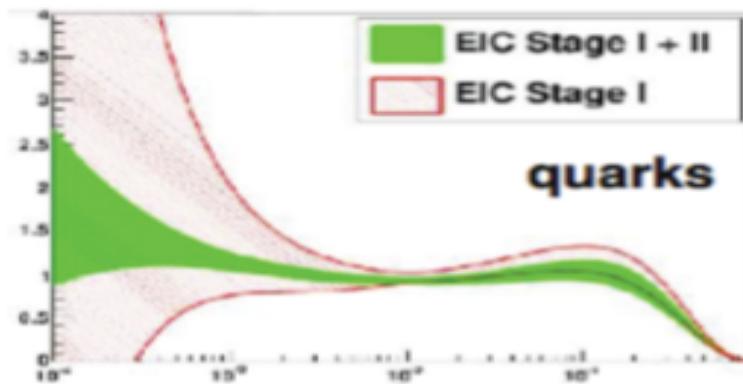
## □ Total quark's orbital contribution to proton's spin:

$$J_q = \frac{1}{2} \lim_{t \rightarrow 0} \int dx x [H_q(x, \xi, t) + E_q(x, \xi, t)] = \frac{1}{2} \Delta q + L_q$$

Should this be consistent  
with Lattice QCD?

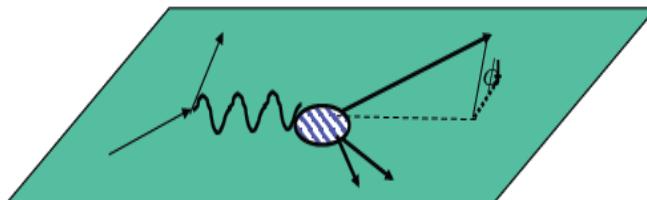
# The internal landscape of the nucleus

- How a nucleus look like if we only see quarks and gluons?  
What is the nature of nuclear force? ...
- EIC can map out nuclear distributions of quarks and gluons:



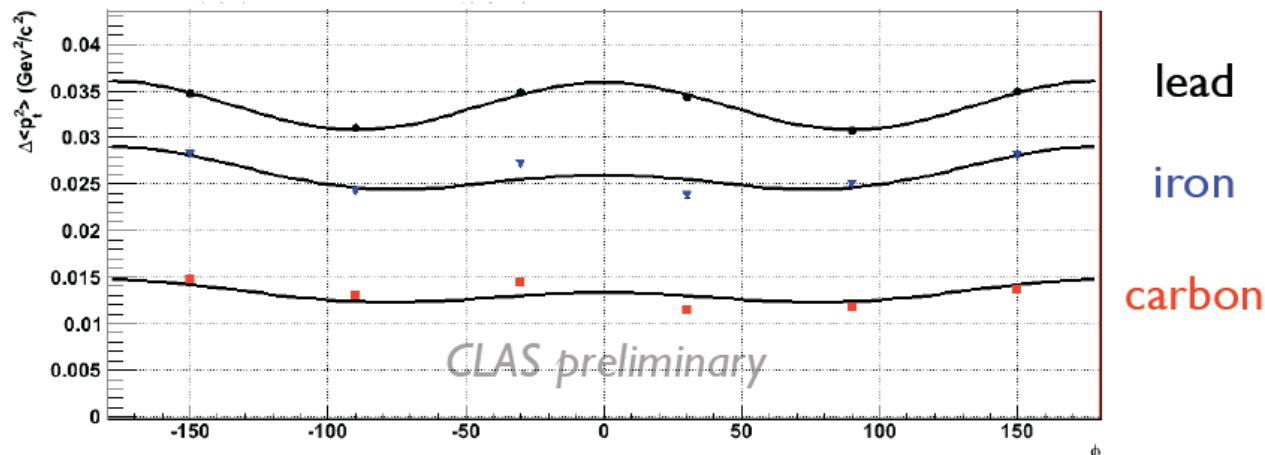
EIC has the constraining power to nuclei as HERA to the proton

- Parton density fluctuation in a large nucleus:



Transverse momentum  
broadening

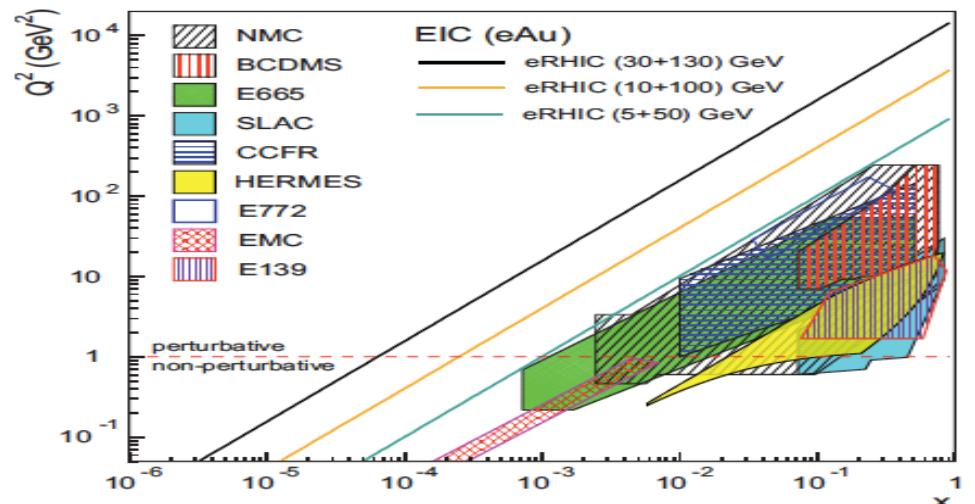
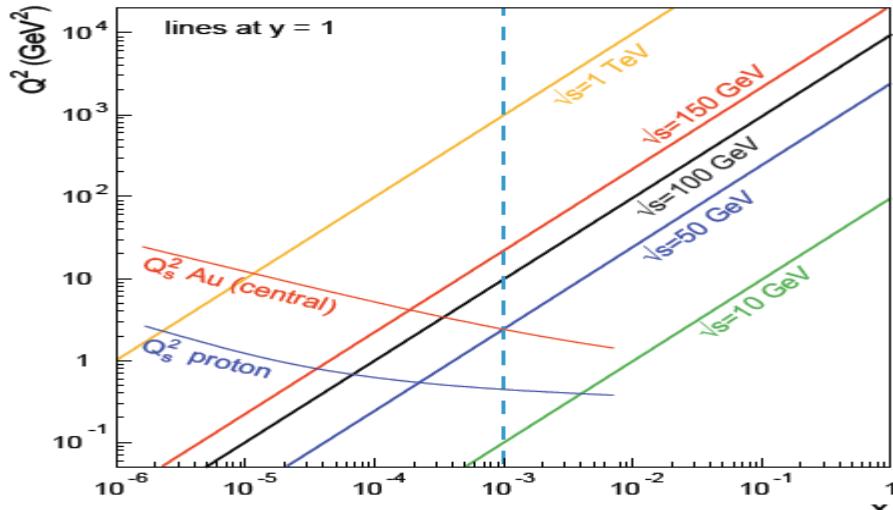
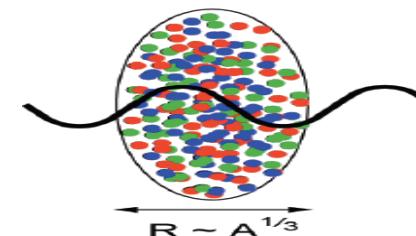
$$\langle \Delta p_T^2 \rangle_{AN} = \langle p_T^2 \rangle_A - \langle p_T^2 \rangle_N$$



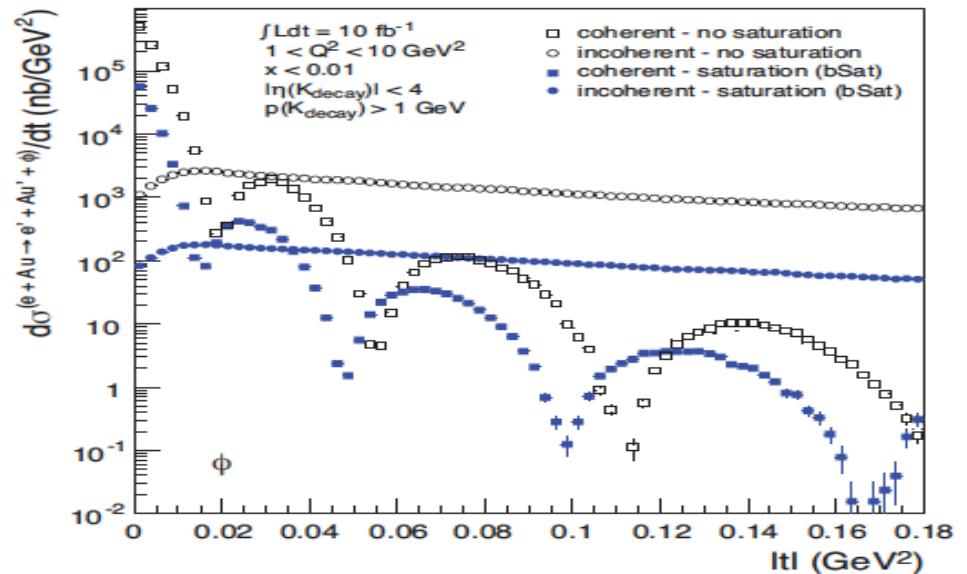
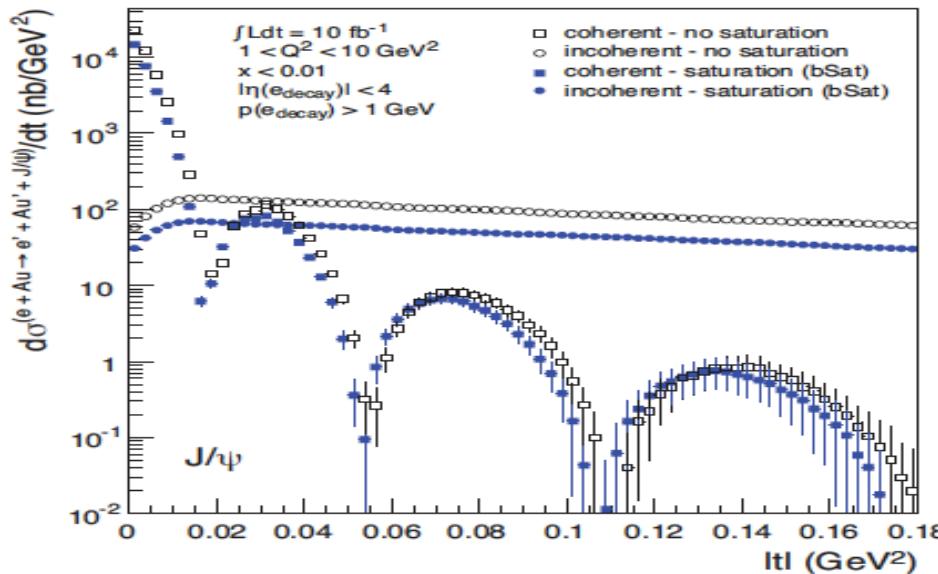
# QCD at an extremely high gluon density

- Coherent interaction at a given impact parameter:

$$Q_s^2(eA) \propto Q_s^2(ep) A^{1/3}$$

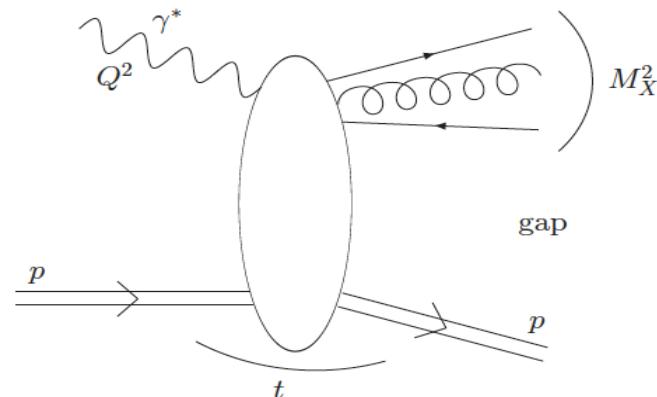


- Diffractive production of mesons:

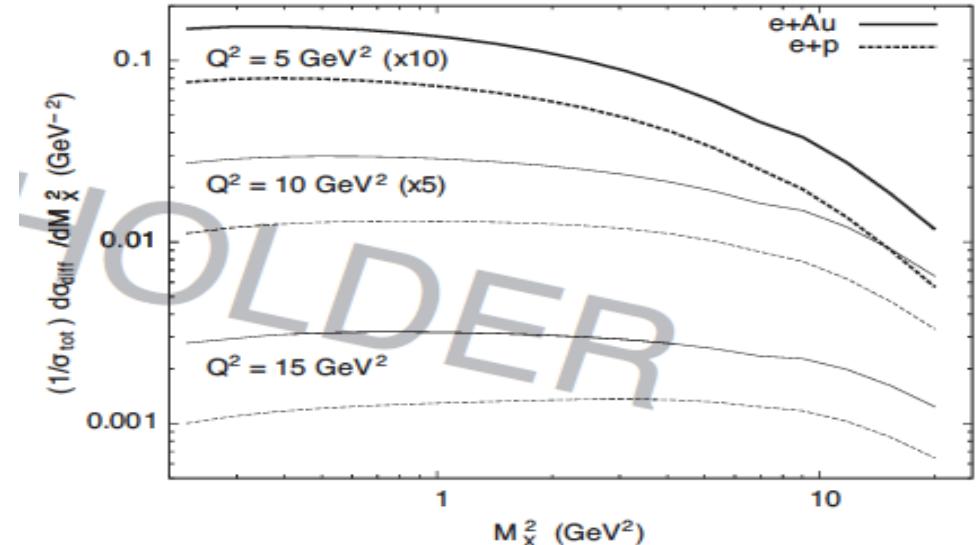


# QCD at an extremely high gluon density

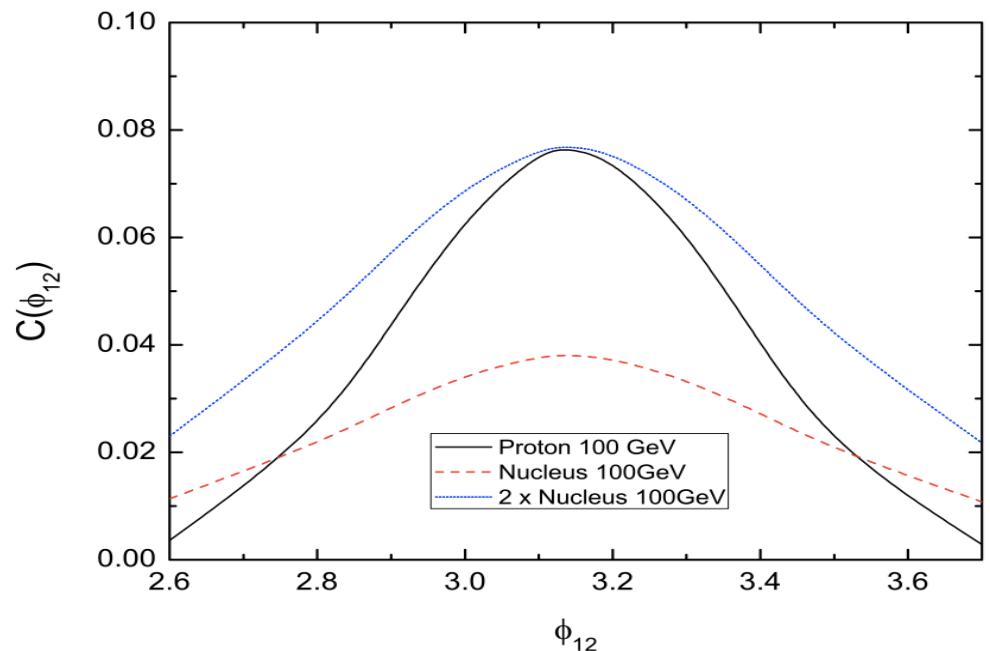
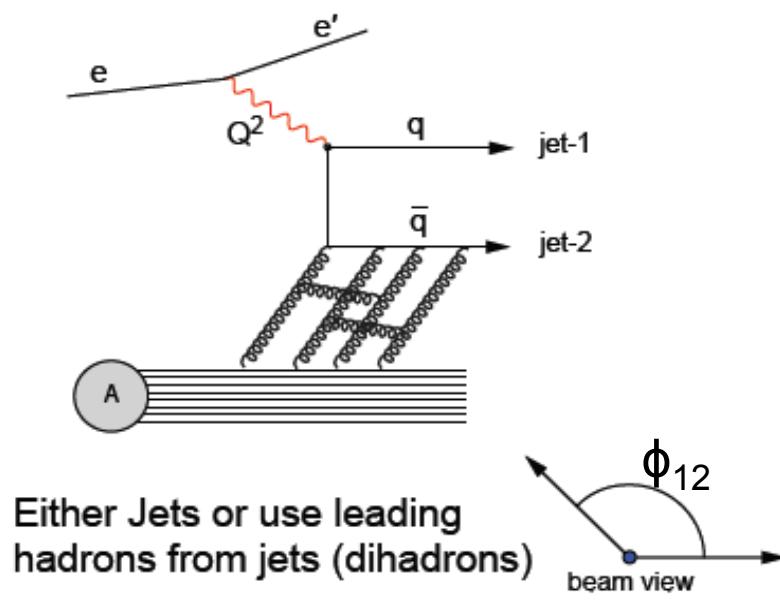
- Strong enhancement of diffractive structure functions:



$$\beta = Q^2 / (Q^2 + M_X^2)$$

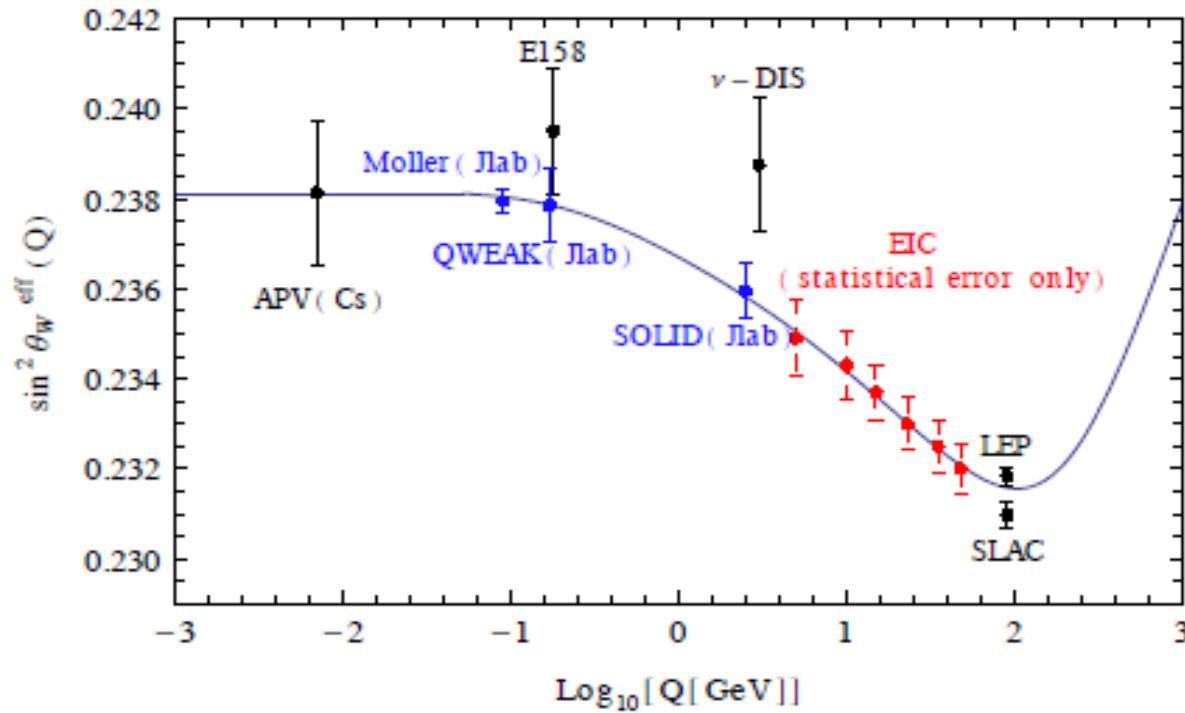


- Strong suppression of di-hadron correlations:



# Opportunities at the luminosity frontier

- Mixing angle of weak interaction – high luminosity:



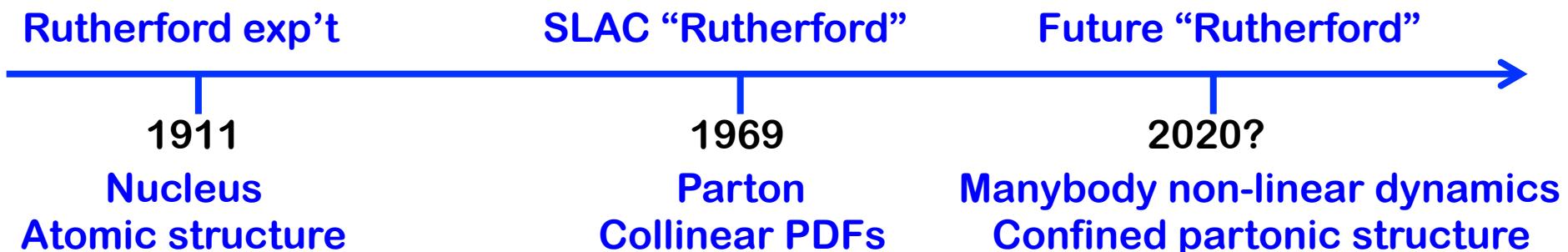
Fill the region  
never  
be measured

Test the running  
of  
weak force

- Explorations at high  $x$  with polarization, and possibility of searches for lepto-quarks, and new physics

# Summary

- After almost 40 years, we have learned a lot of QCD dynamics, but, only in its most trivial asymptotic regime (less than 0.1 fm), and very limited information on nucleon/nuclear structure
- Many aspects of hadron's partonic structure can be naturally studied at the EIC, but, not other machines: e+e-, pp, pA, AA
- EIC with polarization might be the only dedicated QCD machine for sea-quarks and gluons for generations
- EIC can provide a new program to explore new frontier research of QCD dynamics – key to the visible matter



- The EIC White Paper is due by end of May