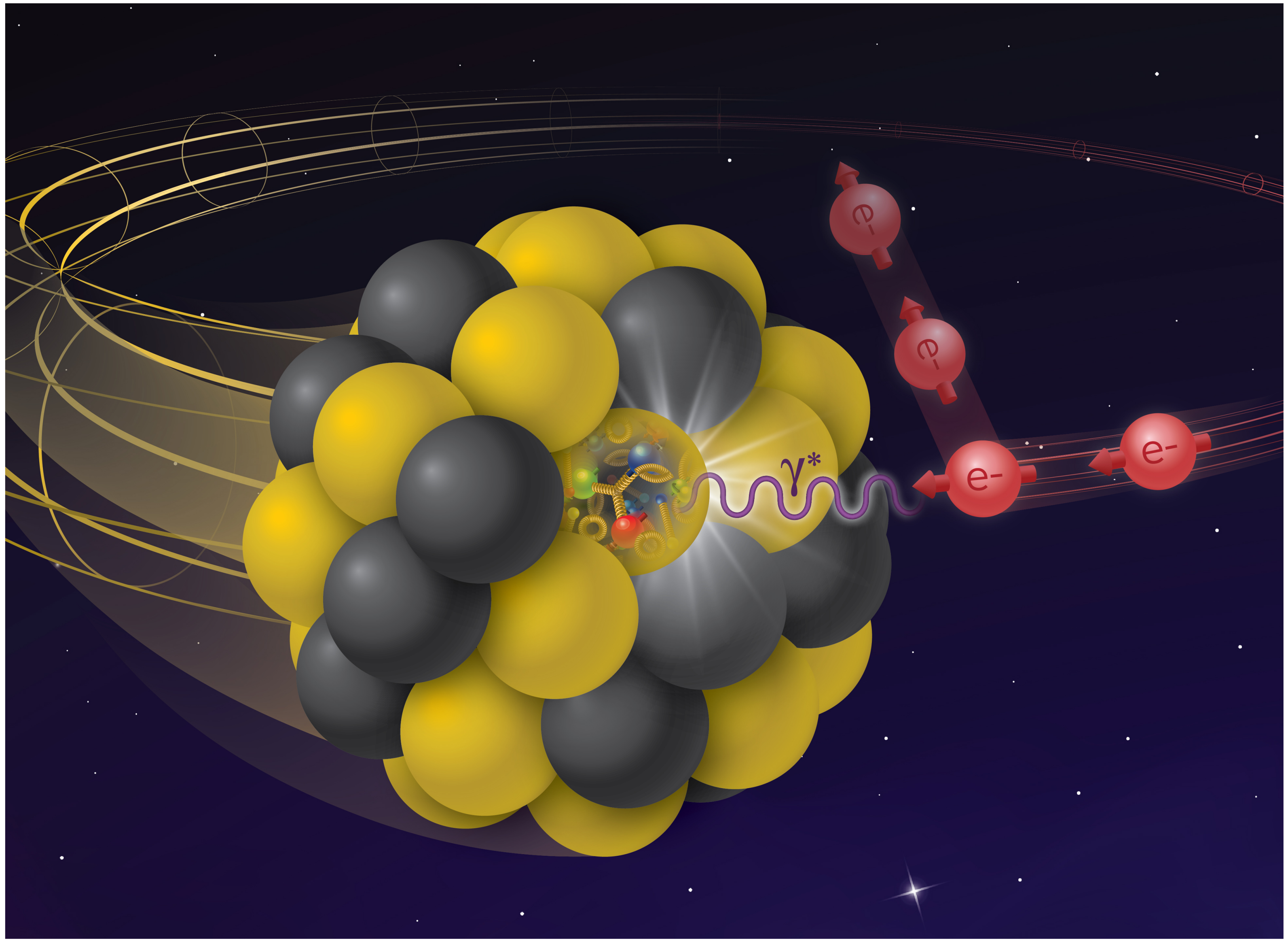


Overview of the EIC

Anna Staśto

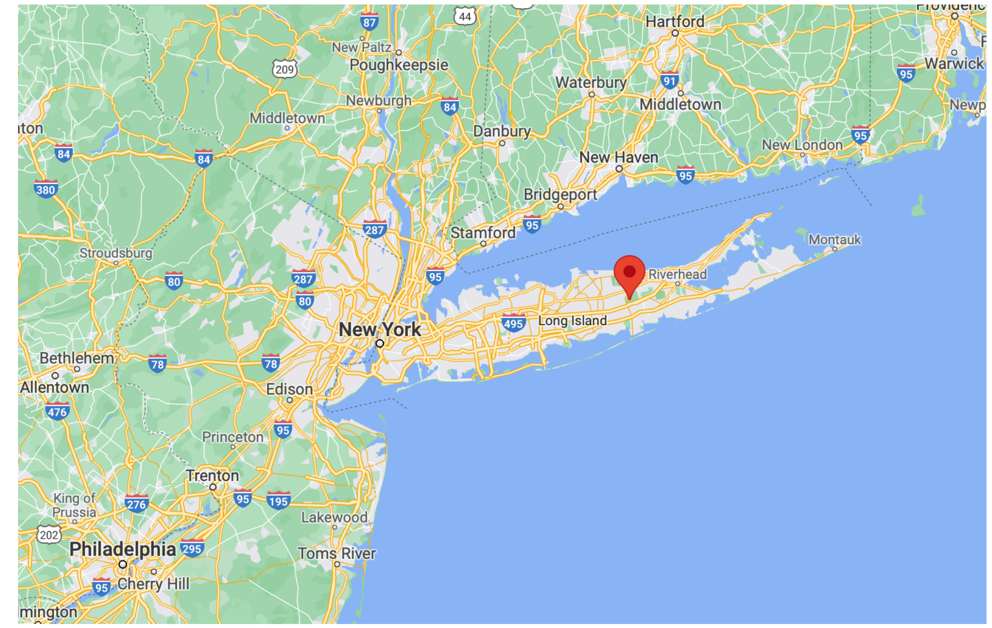
Penn State University

UPC 2023, Students Day, Playa del Carmen, December 10, 2023

What is EIC ?

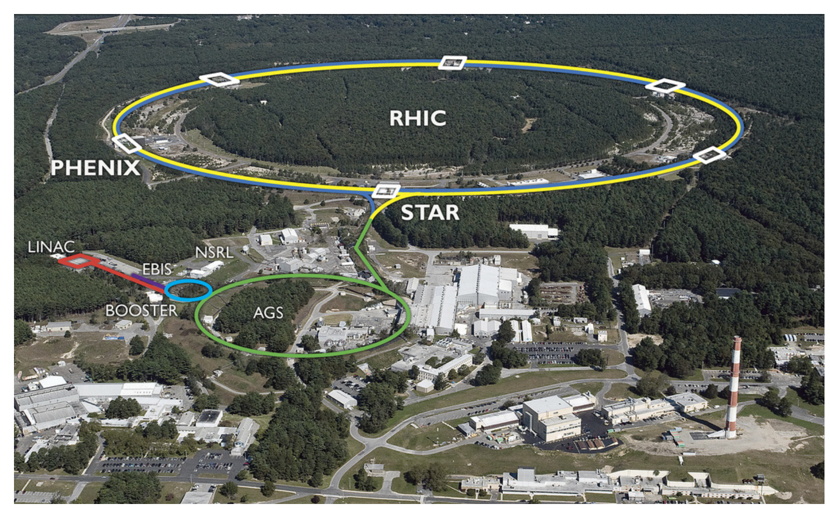
EIC: **E**lectron-**I**on **C**ollider facility that will be built at Brookhaven National Laboratory using and upgrading existing RHIC complex.

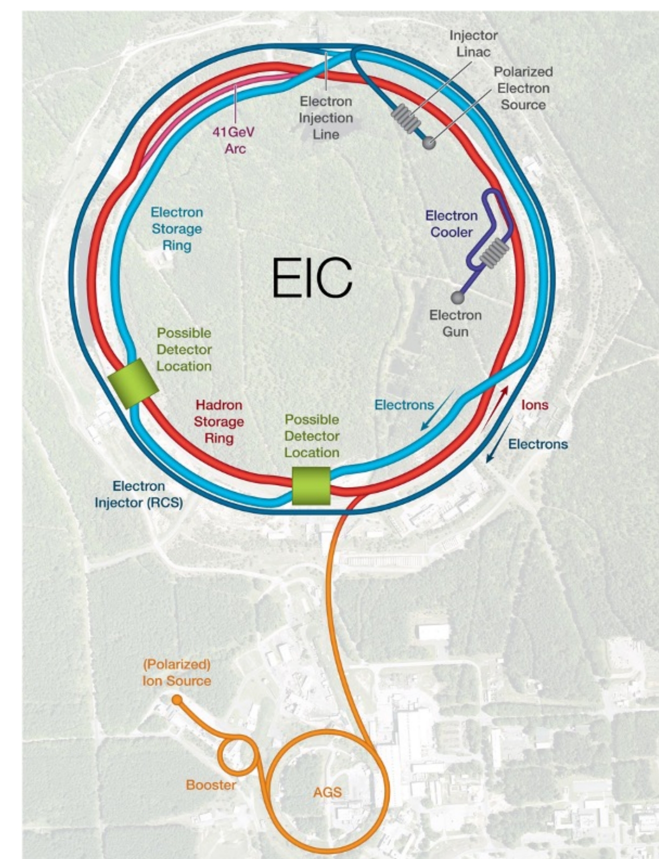
Partnership between BNL and Jefferson Lab.



Capabilities of EIC

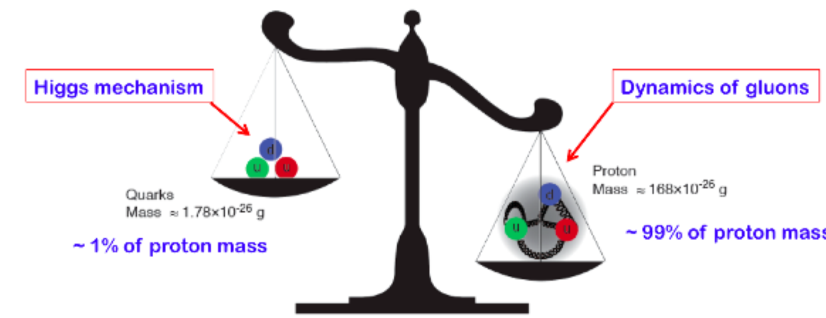
- **High luminosity** $10^{33} - 10^{34} cm^{-2}s^{-1}$ (100-1000 times more than HERA)
- **Variable** center of mass energies 20 -140 GeV
- Beams with different A: from **light nuclei (proton)** to the **heaviest nuclei (uranium)**
- **Polarized** electron and proton beams. Possibility of polarized light ions.
- Up to **two interaction** regions

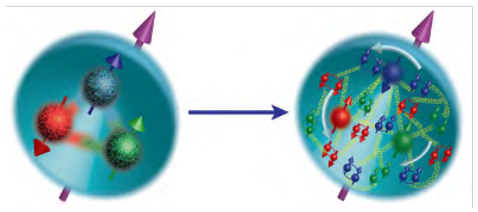


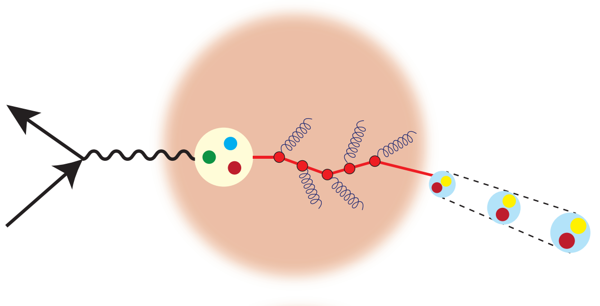


Core physics program of the EIC

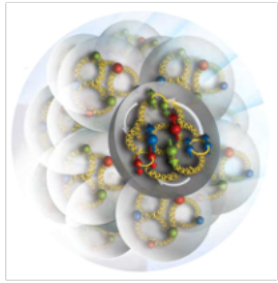
How are the sea quarks and gluons, and their spins, **distributed in space and momentum** inside the nucleon? How do the **nucleon properties (mass & spin) emerge** from their interactions?





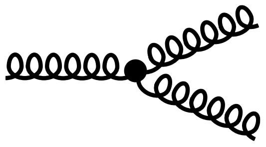


How do color-charged quarks and gluons, and colorless jets, **interact with a nuclear medium**? How do the **confined hadronic states emerge** from these quarks and gluons? How do the quark-gluon **interactions create nuclear binding?**

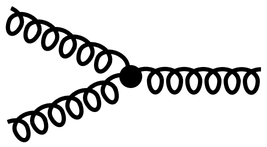


How does a **dense nuclear environment affect** the quark- and gluon- distributions? What happens to the **gluon density in nuclei**? Does it **saturate at high energy**, giving rise to a **gluonic matter with universal properties** in all nuclei, even the proton?

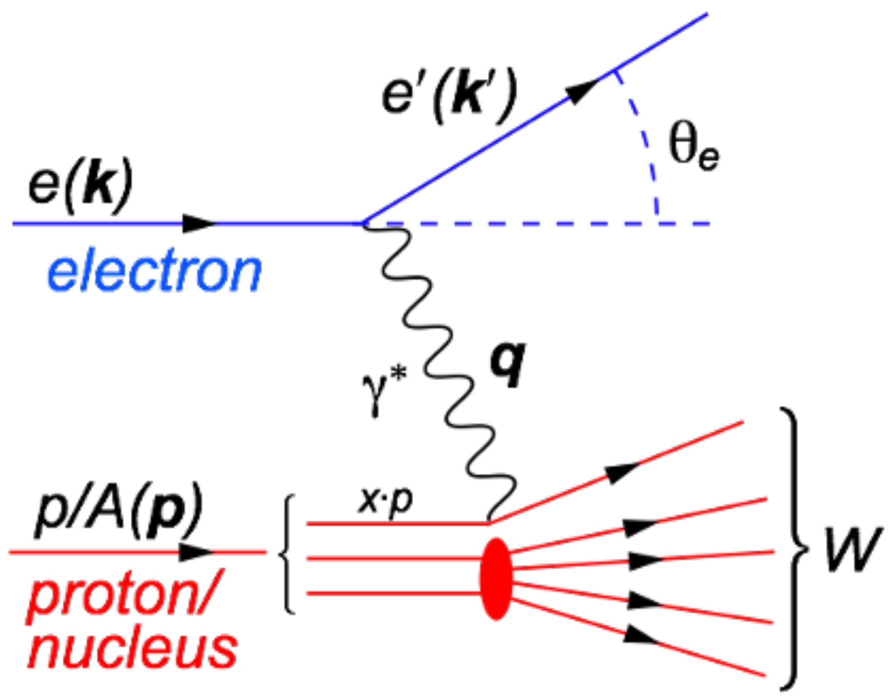
gluon emission



gluon recombination



Deep Inelastic Scattering



DIS: Deep Inelastic e/p(A) scattering

- **Electromagnetic probe** allows for very **precise** exploration of hadron structure: excellent **microscope**
- **Control** over kinematics of the process

electron-proton cms energy squared:

$$s = (k+p)^2$$

(minus) photon virtuality resolution power

$$Q^2 = -q^2$$

inelasticity

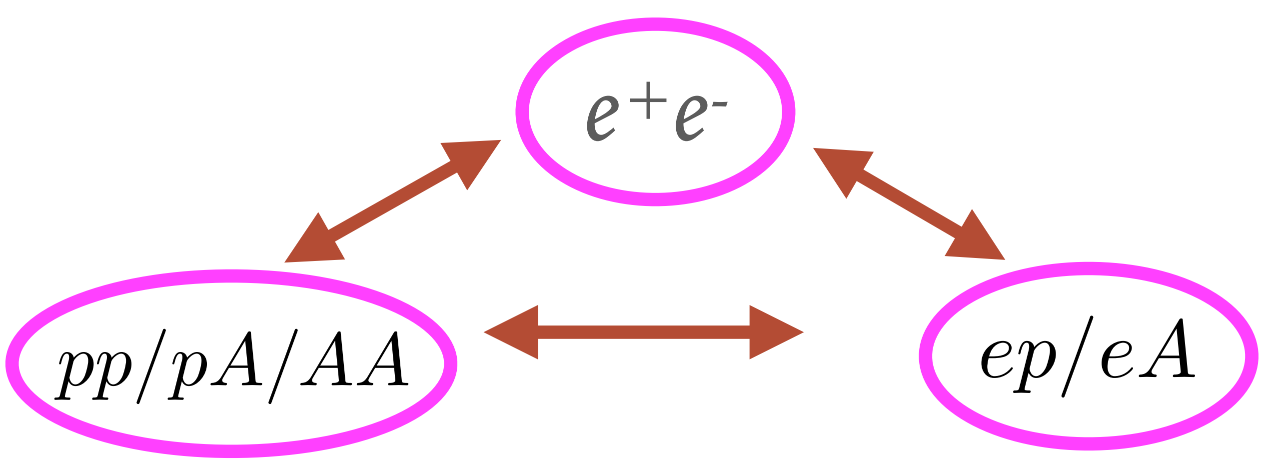
$$y = \frac{p \cdot q}{p \cdot k}$$

Bjorken x: momentum fraction of struck quark

$$x = \frac{-q^2}{2p \cdot q}$$

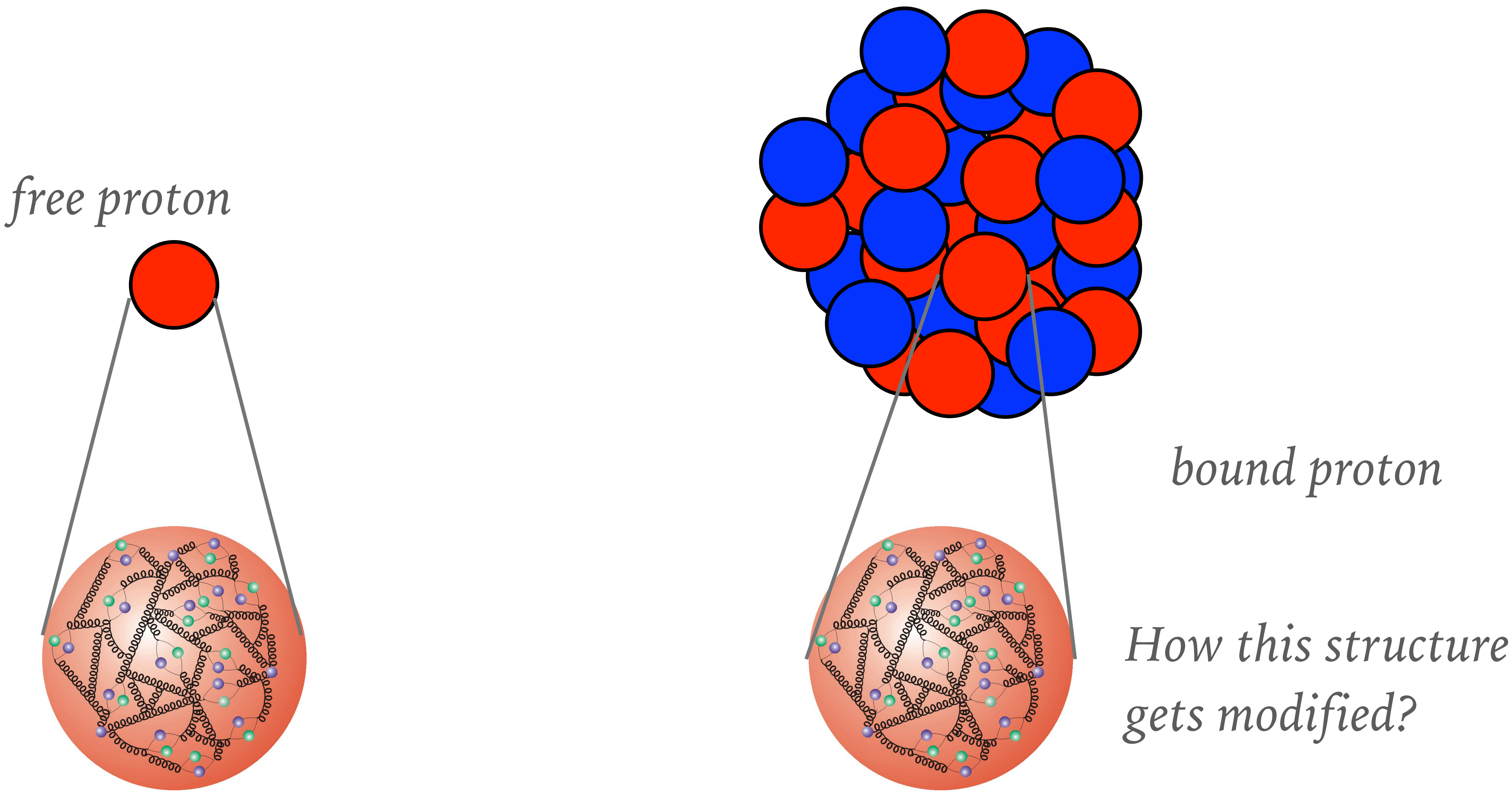
Complementarity:

For full understanding of QCD and EW need to run various experiments with 0,1,2 initial state hadrons



Nuclear structure

How quarks and gluon distributions get modified in nuclei? How this interaction creates nuclear binding?



Nuclear structure

Nuclear ratio:

$$R^A_{F_2}(x,Q^2) = \frac{F_2^A(x,Q^2)}{A\,F_2^{\mathrm{nucleon}}(x,Q^2)}$$

Ratio of cross section on a nucleus to the proton (scaled by mass number A)

Nuclear effects: $R^A \neq 1$

Nuclear structure

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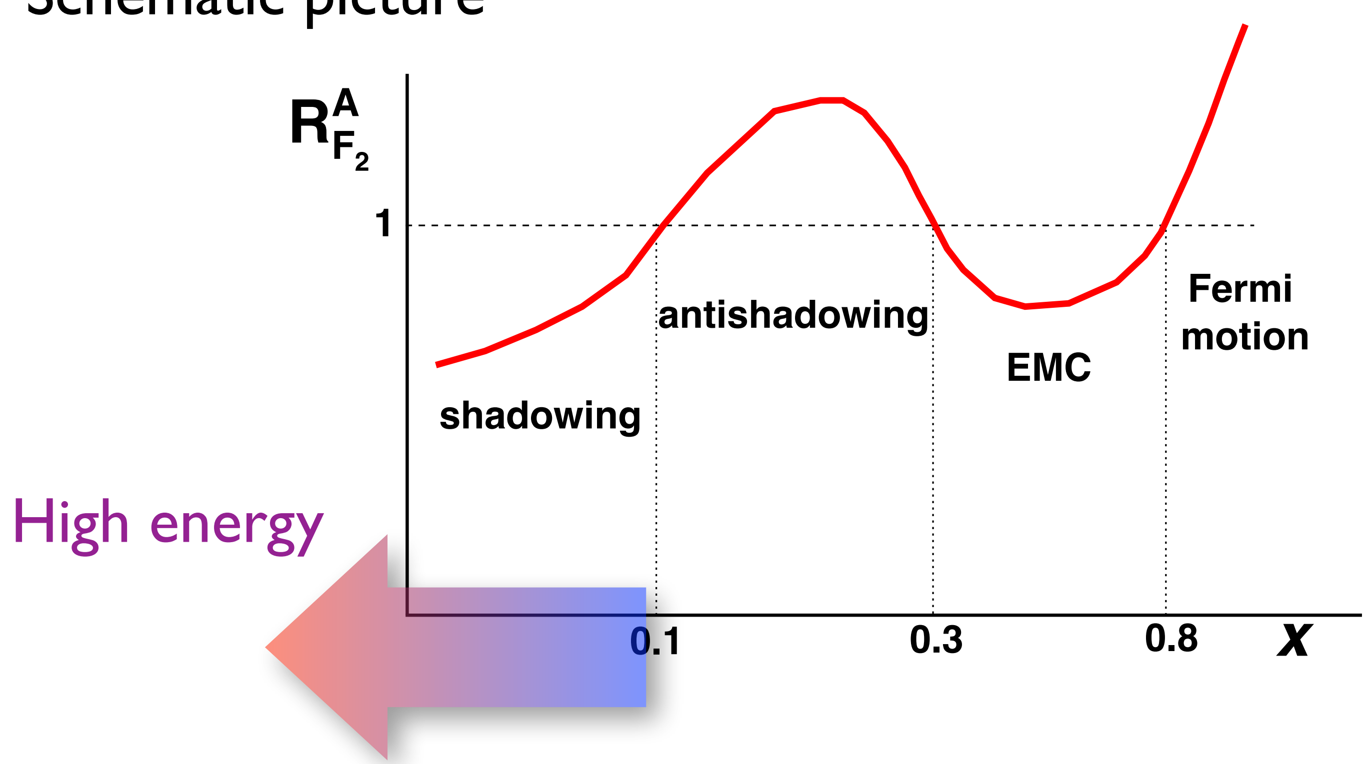
Schematic picture



Nuclear structure

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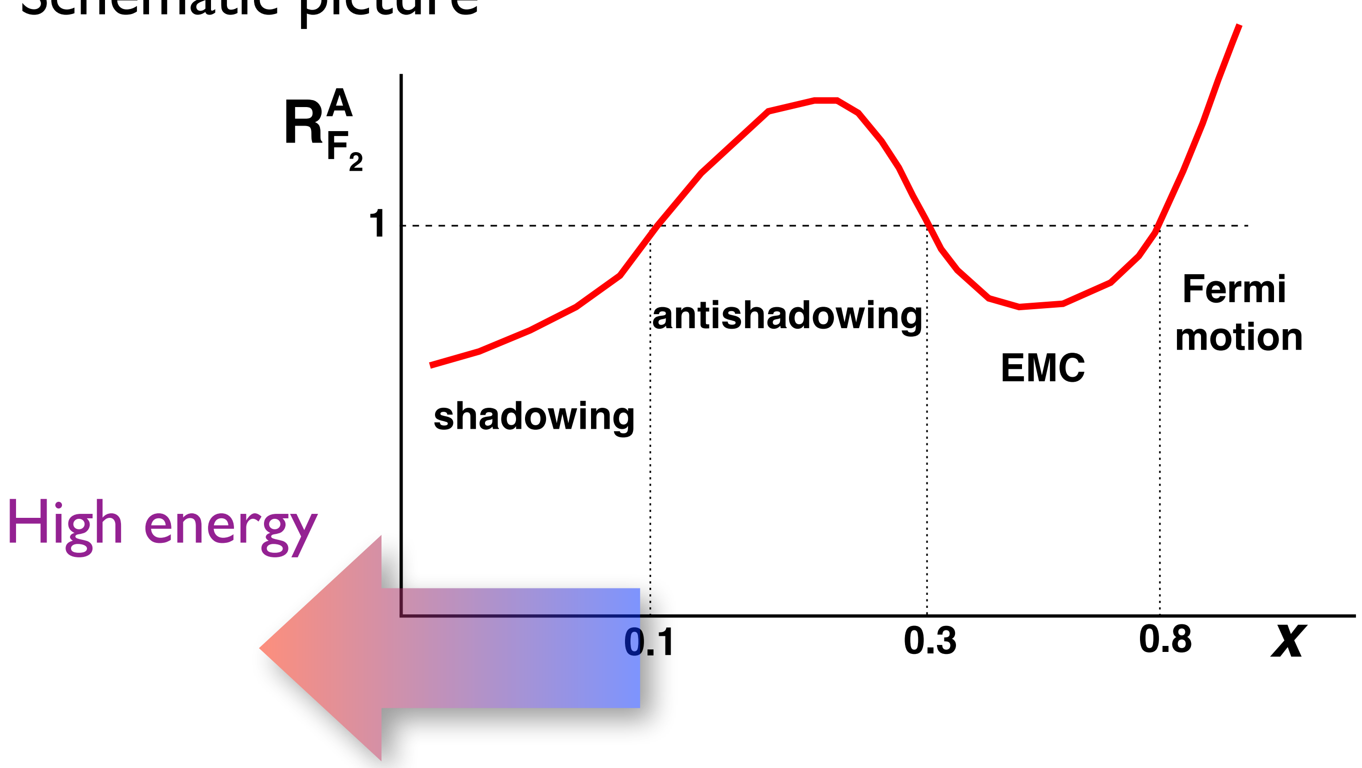
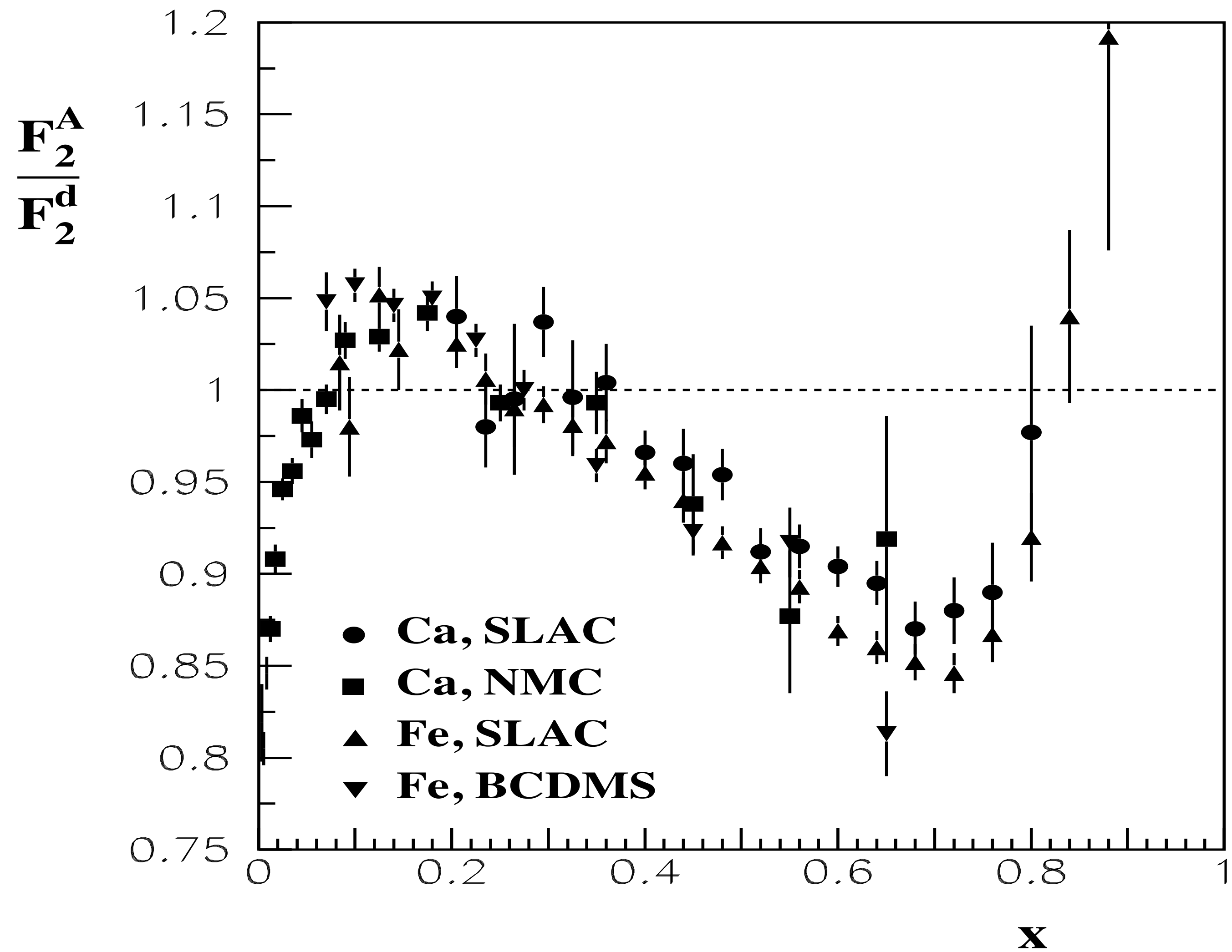


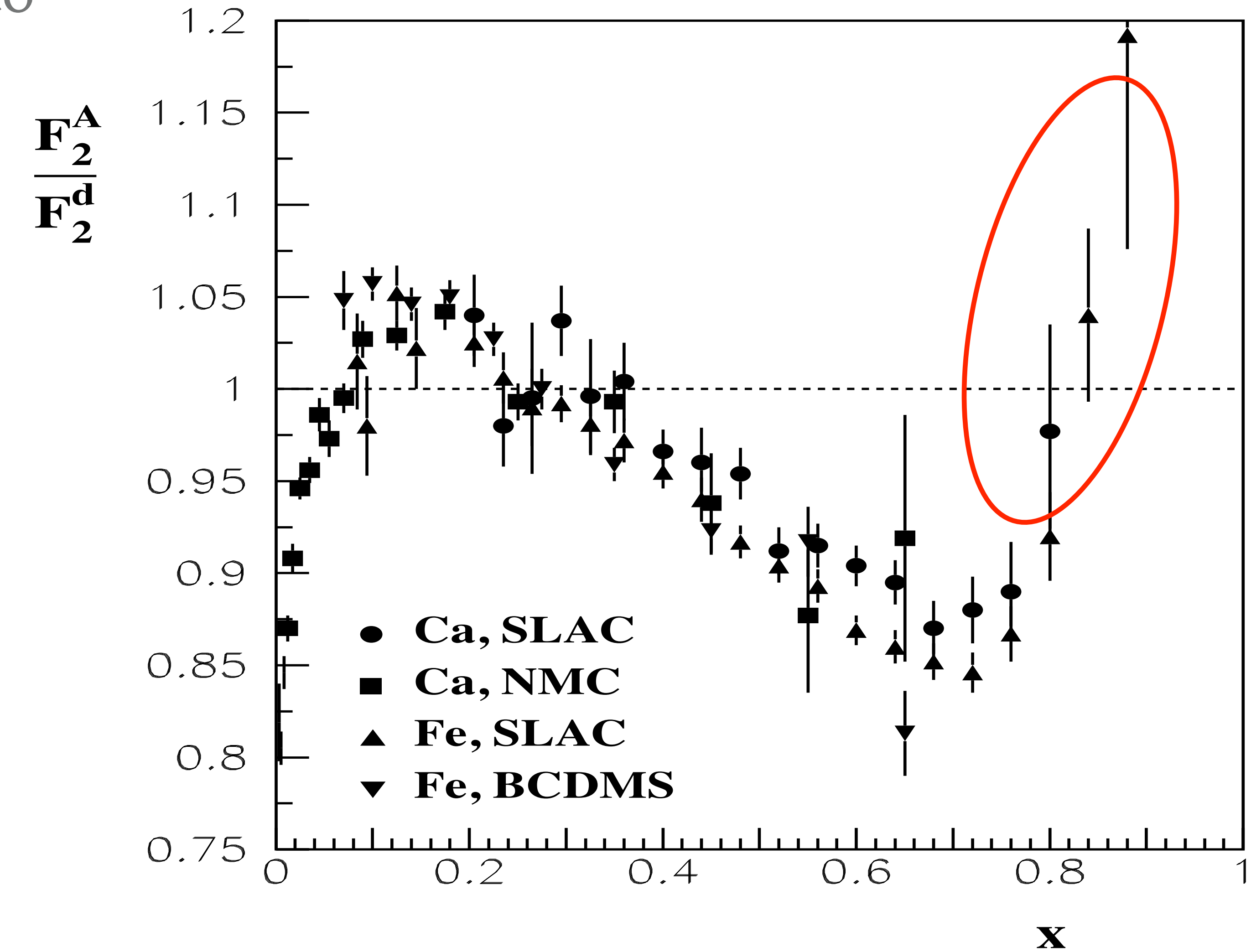
- Fermi motion $x \geq 0.8$
- EMC region $0.25 - 0.3 \leq x \leq 0.8$
- Antishadowing region $0.1 \leq x \leq 0.25 - 0.3$
- Shadowing region $x \leq 0.1$

Nuclear structure



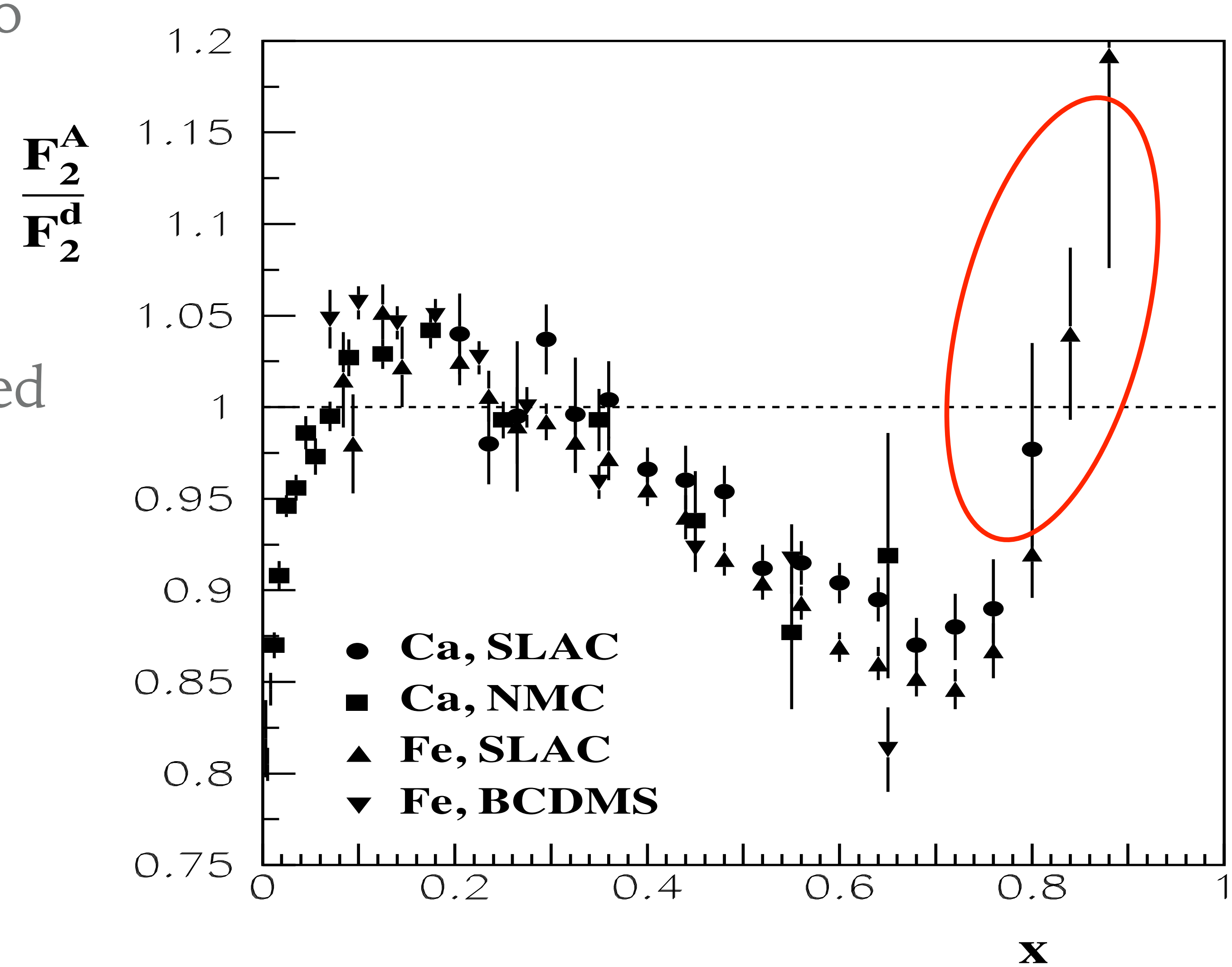
Nuclear structure

- Fermi motion: ratio >1 for x>0.8. Due to motion of bound nucleons inside the nucleus.



Nuclear structure

- Fermi motion: ratio >1 for x>0.8. Due to motion of bound nucleons inside the nucleus.
- EMC region: EMC collaboration discovered large deviation of the ratio from 1 in the region of 0.3<x<0.8. Usually referred as the EMC effect.



Nuclear structure

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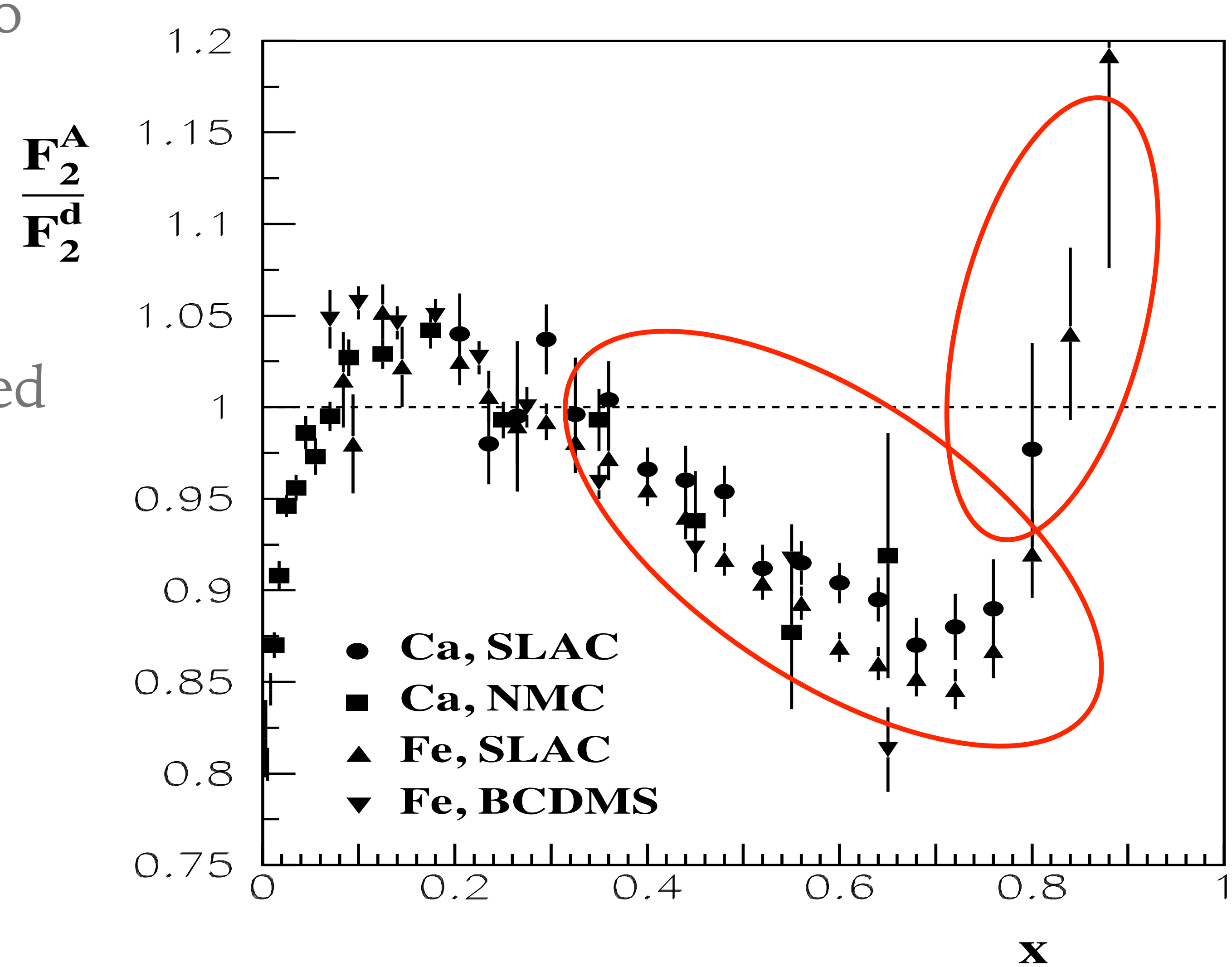
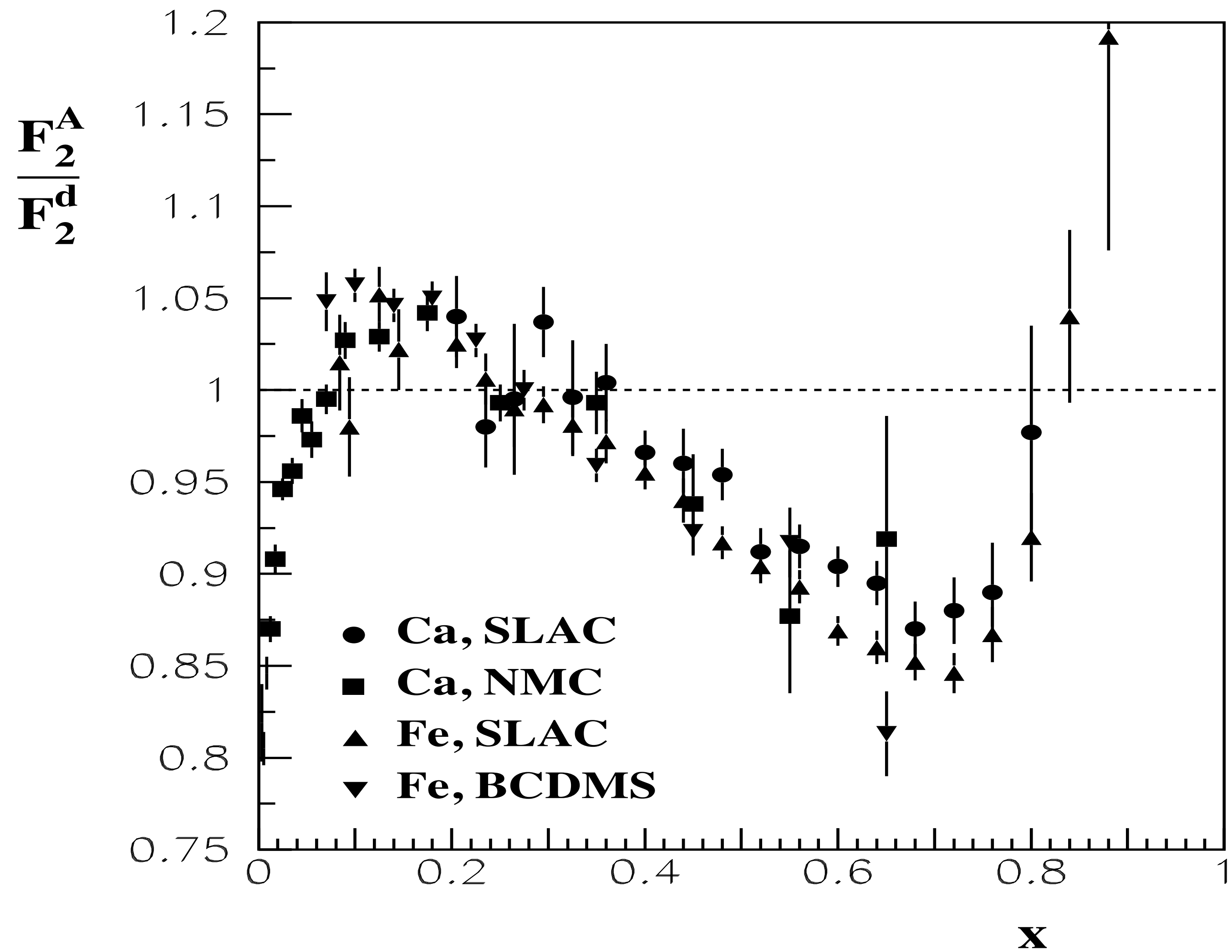
- Possible explanation: Short range correlations between nucleons, most nucleons are not modified but some experiencing SRC are modified (about 20%).

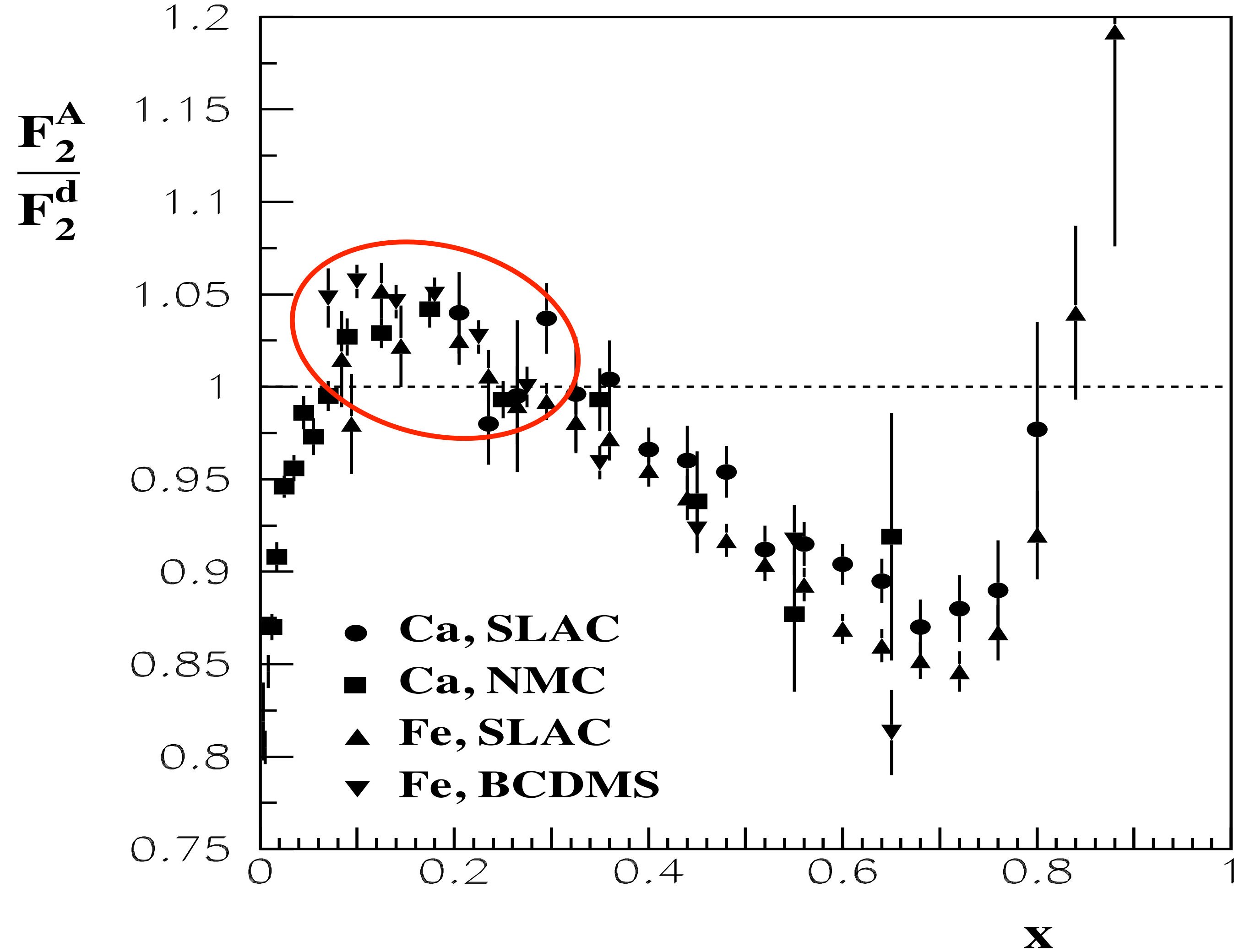


Nuclear structure



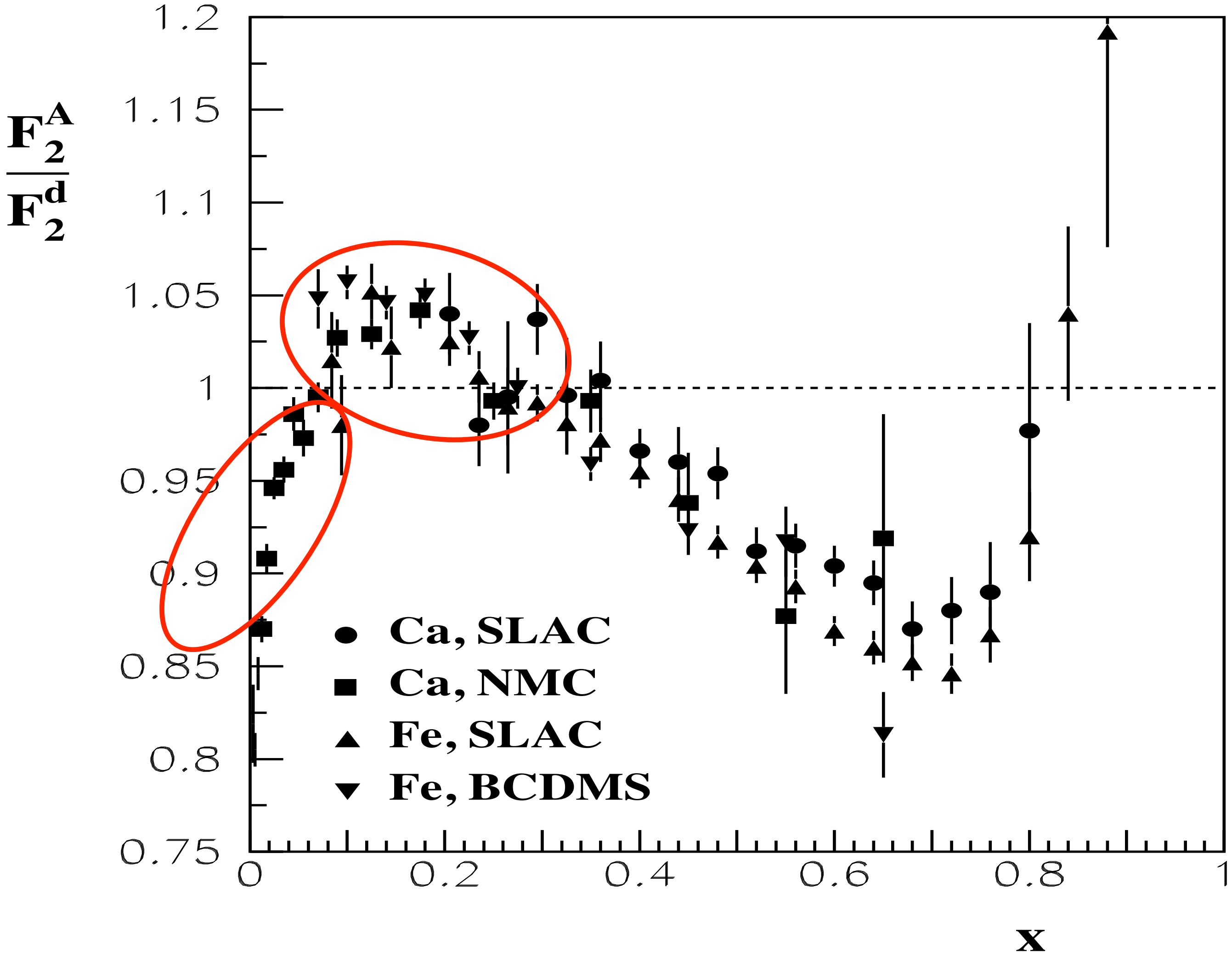
Nuclear structure

- Antishadowing: Ratio > 1 for 0.1<x<0.3. Momentum sum rule (?)



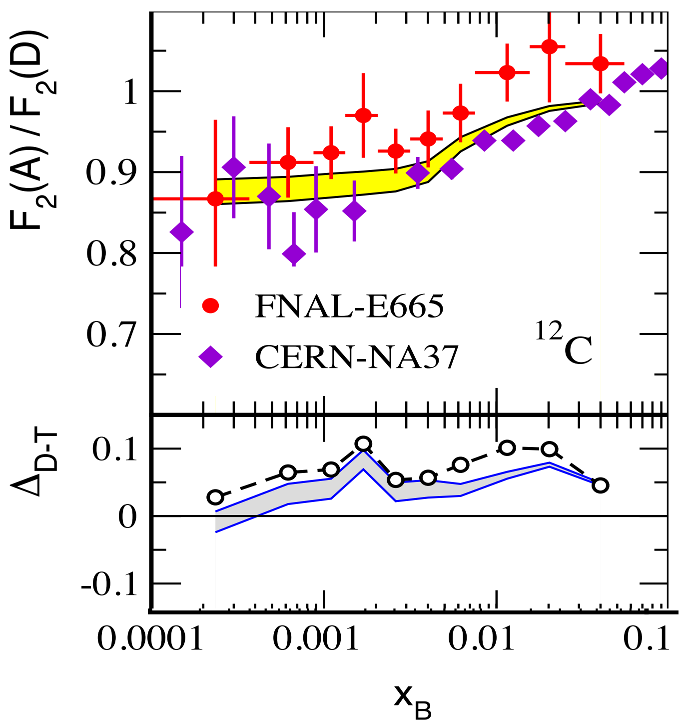
Nuclear structure

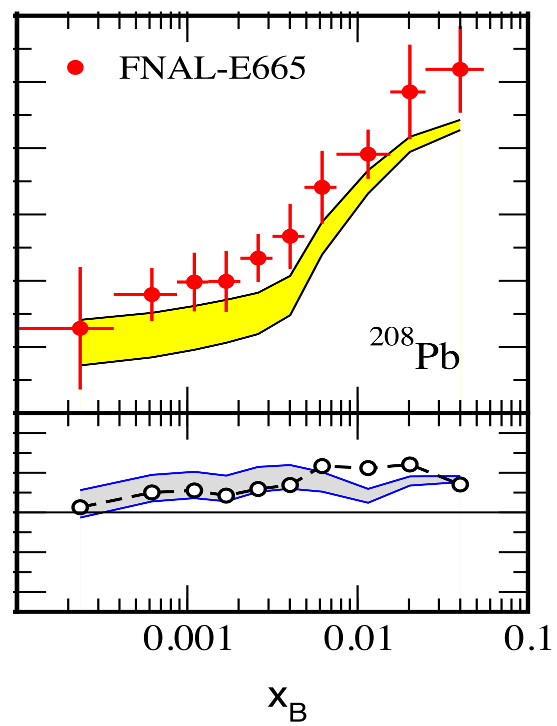
- Antishadowing: Ratio > 1 for 0.1<x<0.3. Momentum sum rule (?)
- Shadowing: ratio < 1 for small x, x<0.1.

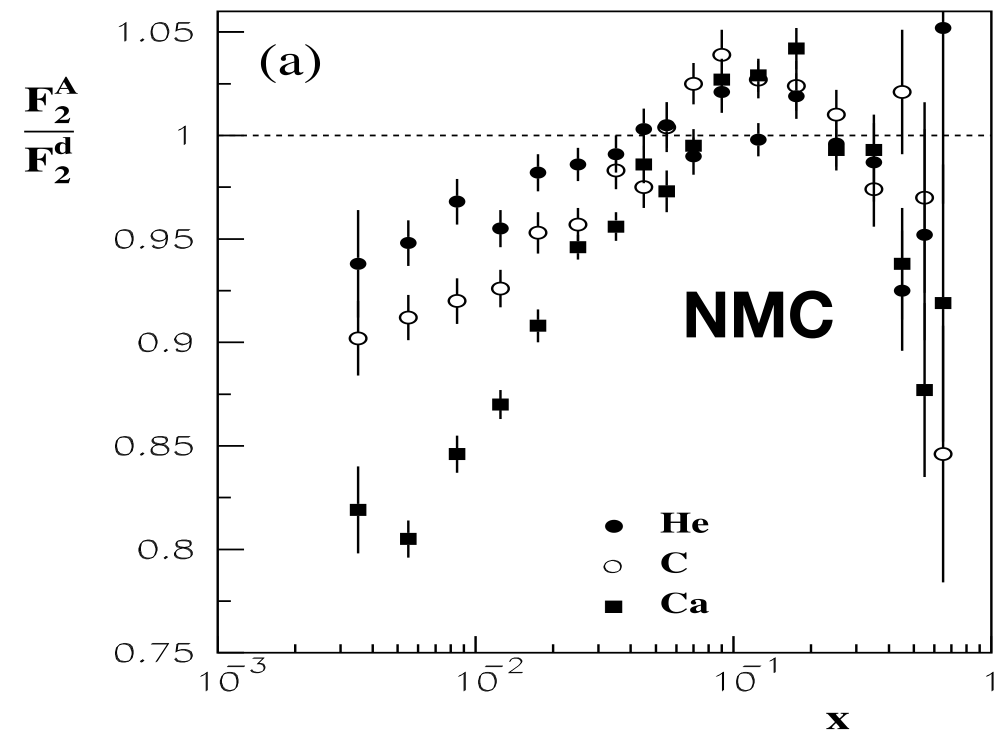


Nuclear structure: nuclear shadowing

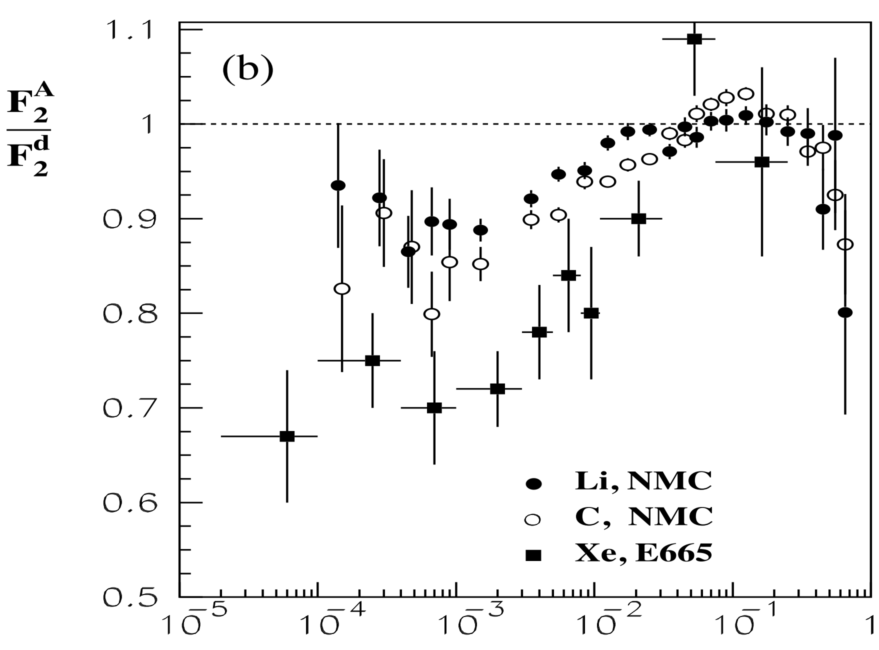
Shadowing increases with A and increases with decreasing x

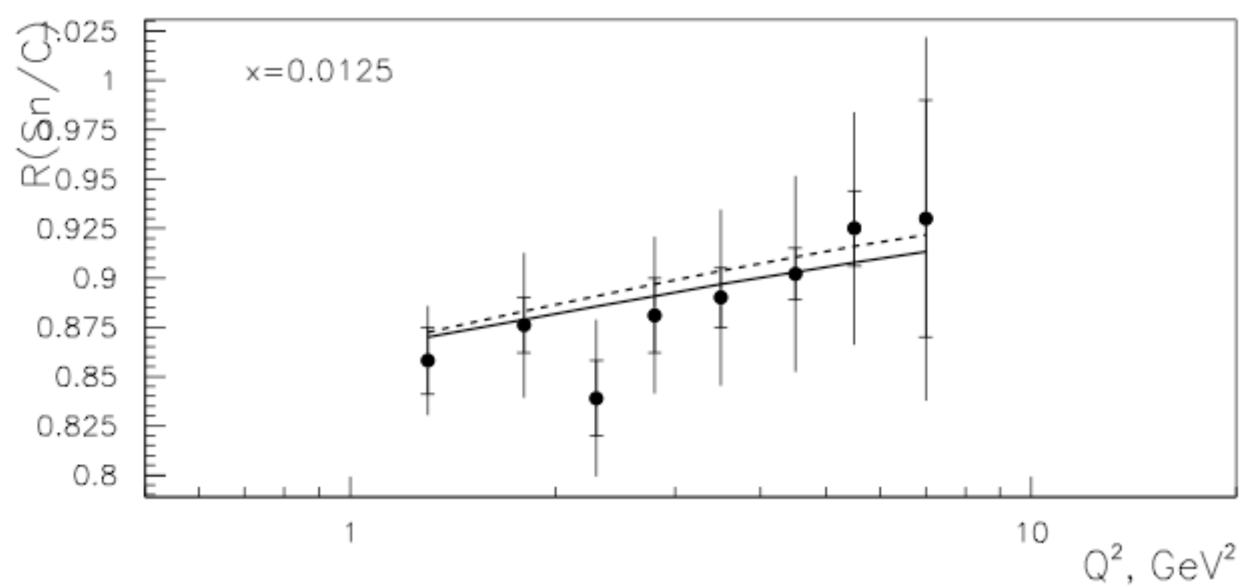






Shadowing decreases with increasing Q

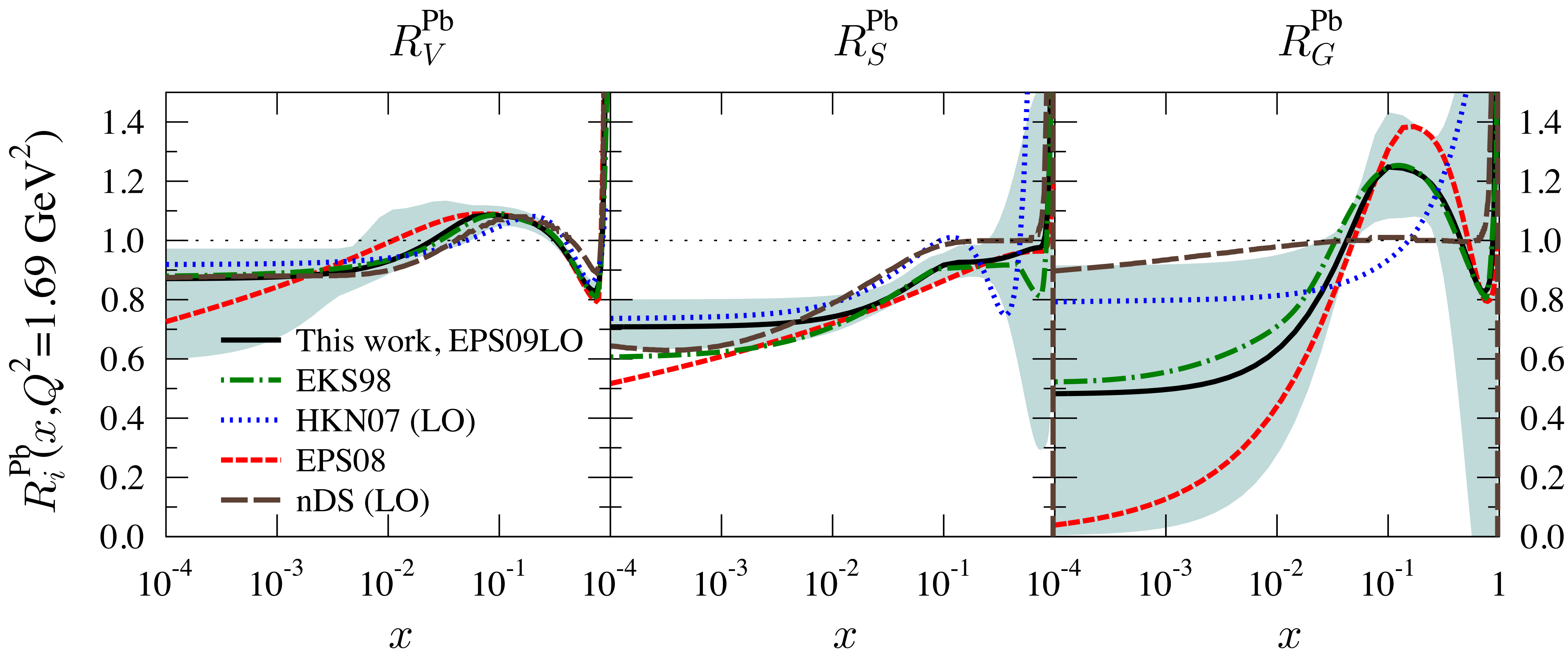




Nuclear structure

Ratio for parton densities

$$R_f^A(x, Q^2) = \frac{f^A(x, Q^2)}{A f^p(x, Q^2)}$$



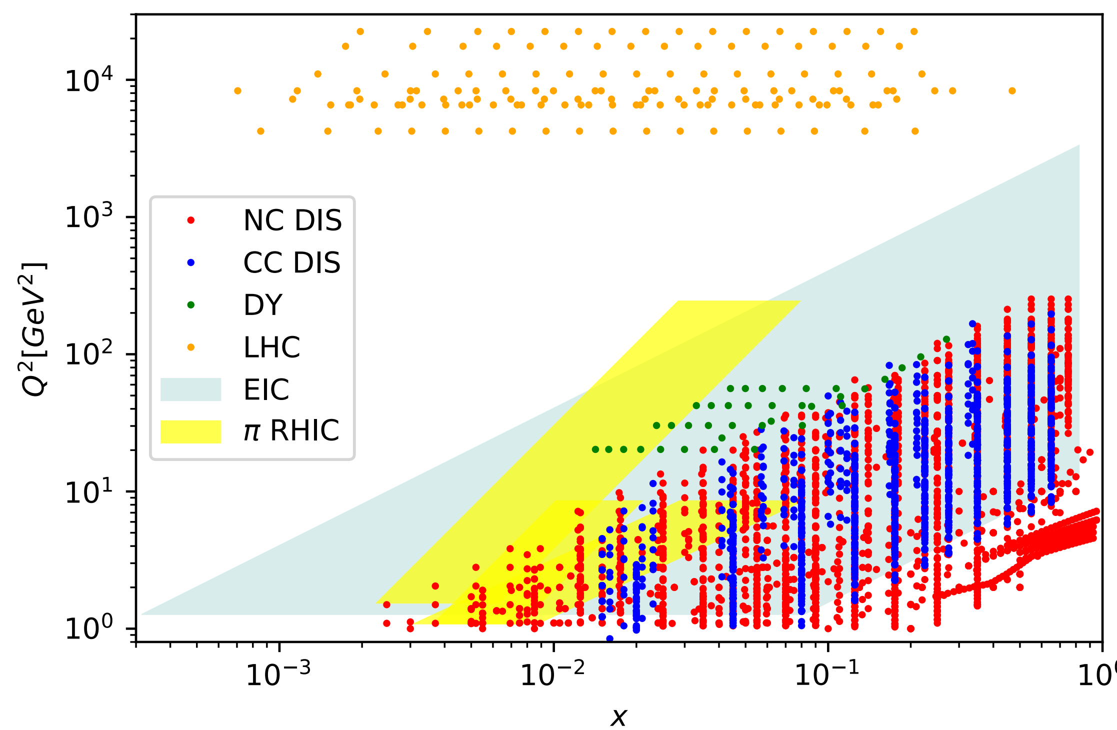
Large uncertainties, particularly at low x: need more accurate data

Global structure of nuclei

$$Y_+ = 1 + (1-y)^2$$

$$\frac{d^2\sigma}{dxdQ^2} = \frac{2\pi\alpha_{\rm em}^2}{xQ^4}\, Y_+\, \sigma_{\rm r}(x,Q^2)$$

$$\sigma_{\rm r}(x,Q^2) = F_2(x,Q^2) - \frac{y^2}{Y_+} F_L(x,Q^2)$$



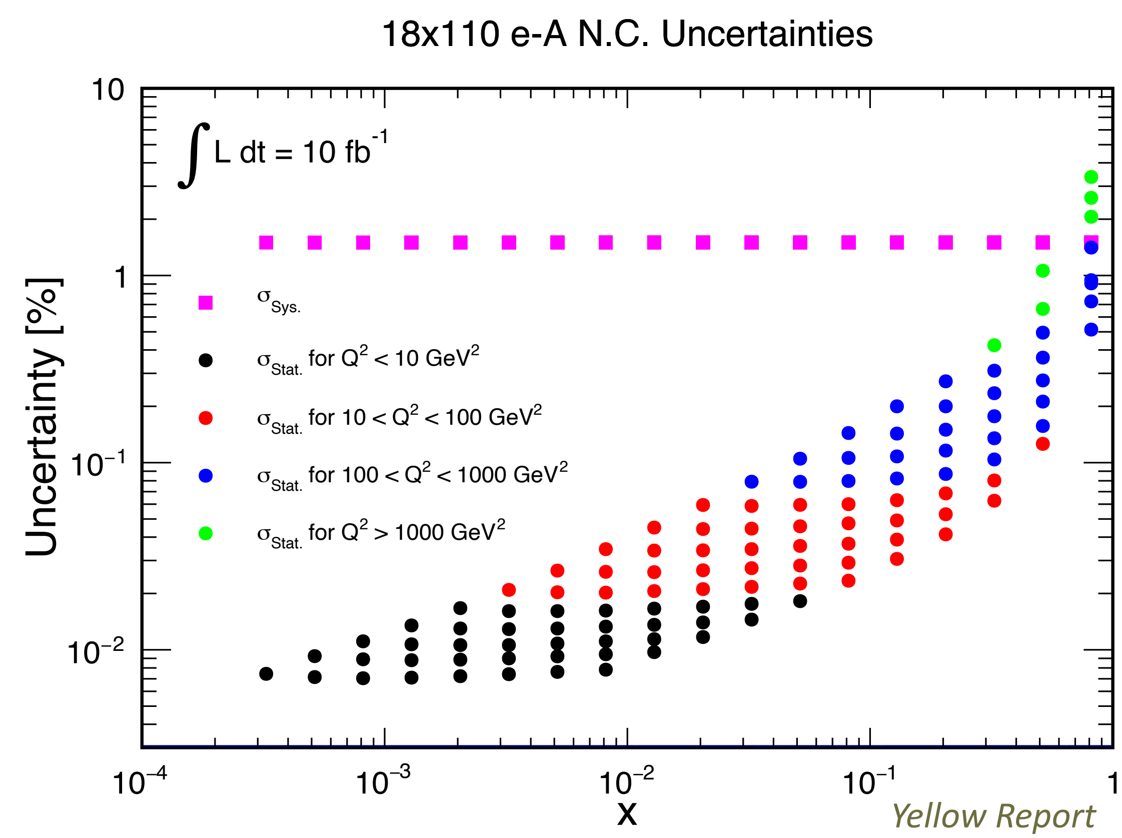
- Precise measurement of **nuclear structure functions** for wide range of nuclei and **wide kinematic range**

- Extraction of **nuclear PDFs** which are essential for understanding **nuclear structure**

- **Initial conditions for Quark-Gluon Plasma**

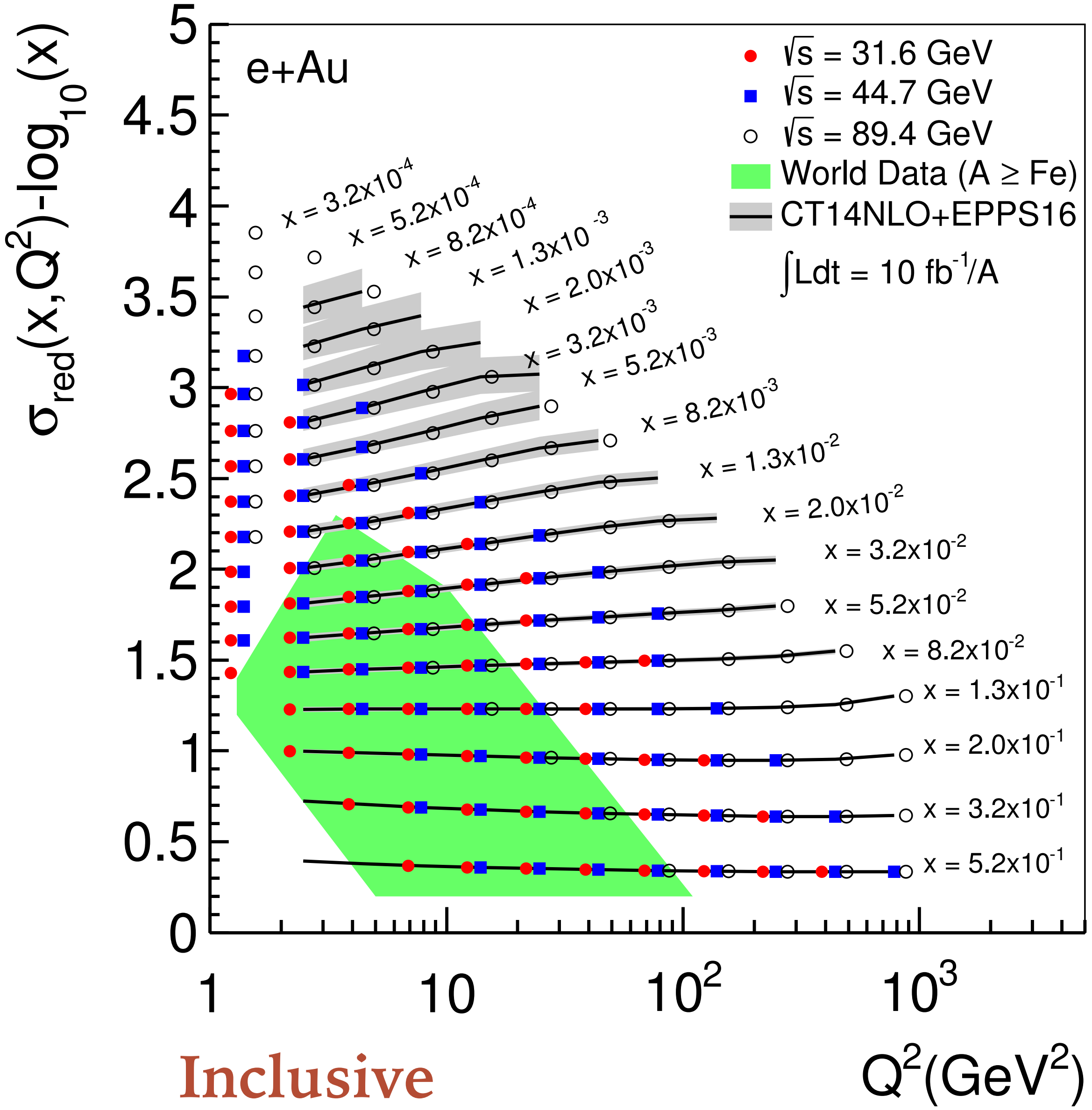
- Sys. uncertainties at most few %, stat. negligible

- Proton, deuteron and wide range nuclei structure function within **one facility:** reduction of uncertainties

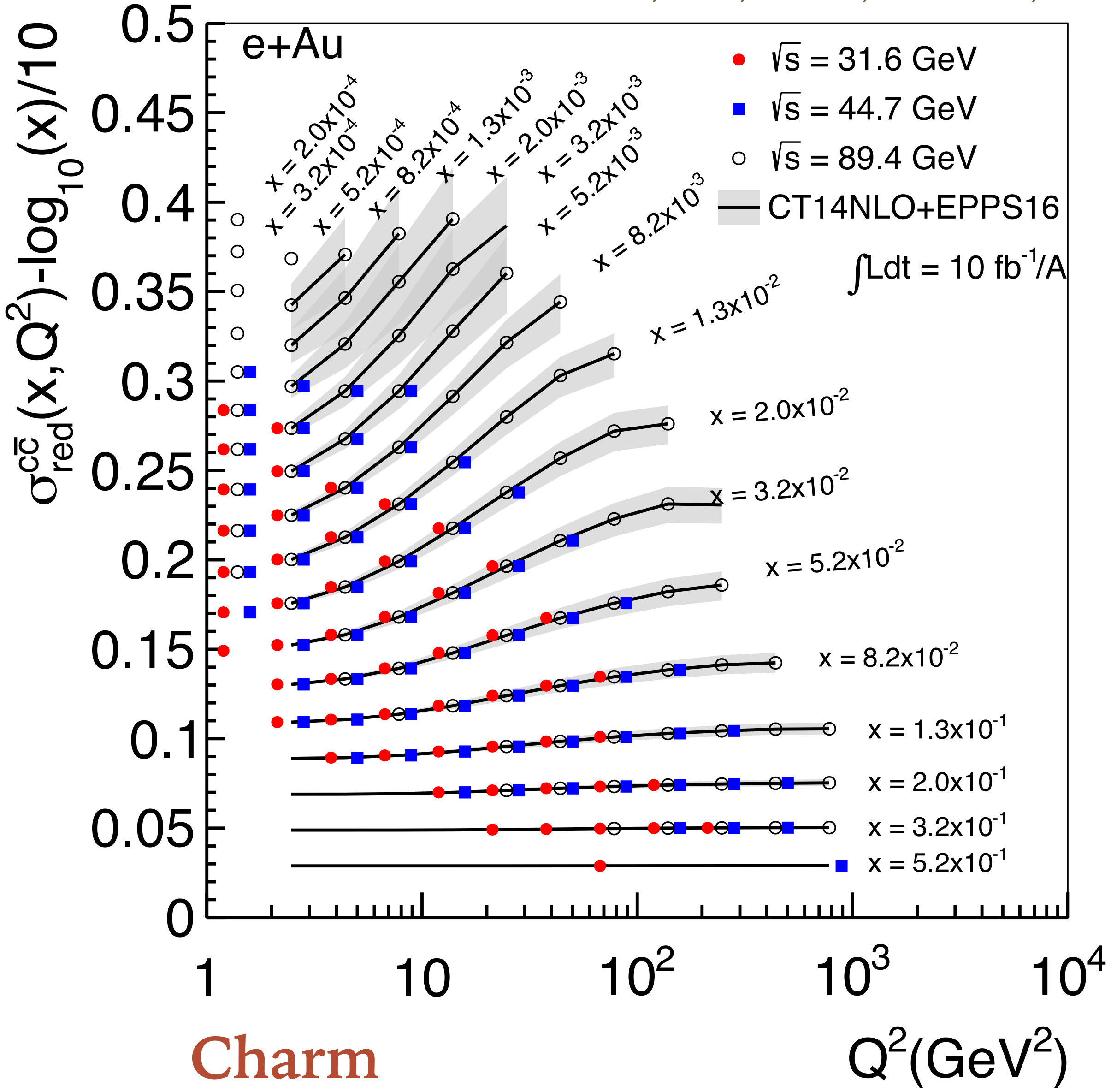


Global nuclear structure: structure functions

Aschenauer, Fazio, Lamont, Paukkunen, Zurita



Inclusive



Charm

- Precision measurements of the reduced cross section
- Charm component in nuclei
- Errors much smaller than the uncertainties of QCD predictions

Impact of EIC on nuclear PDFs

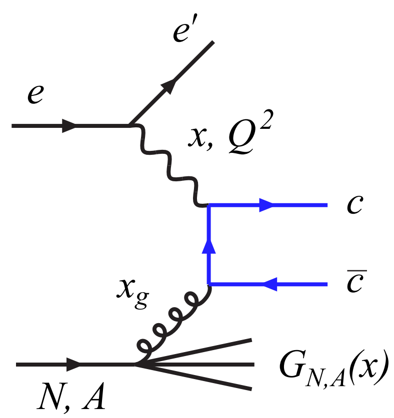
Collinear factorization

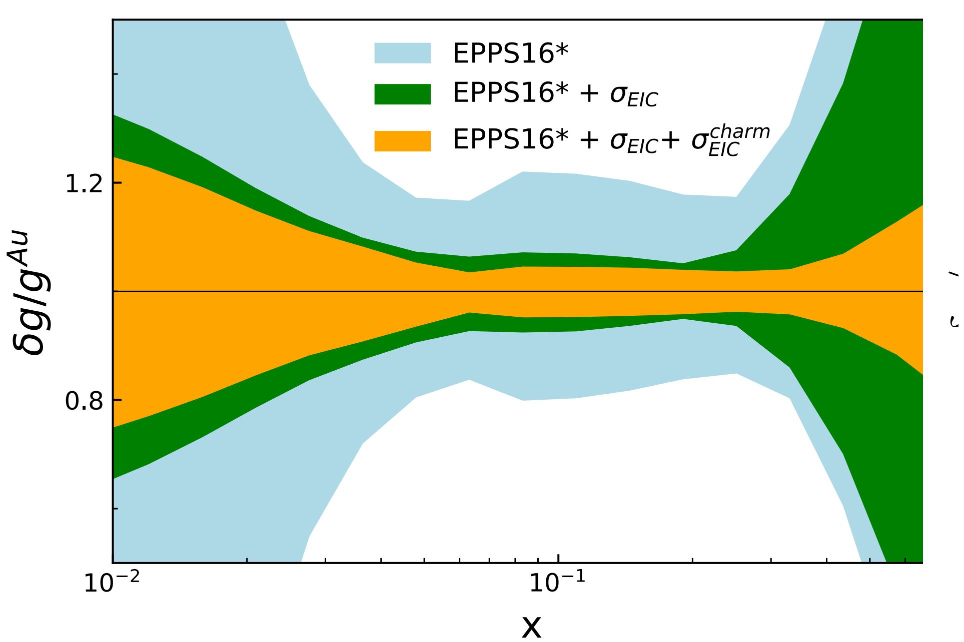
$$F_{2,L}(x,Q^2) = \sum_j \int_x^1 dz\, C_{2,L}(Q/\mu, x/z; \alpha_s)\, f_j(z,\mu) + \ldots$$

Nuclear modification in this framework:

initial condition at low scales, **linear evolution with scale**

- Impact of **charm cross section** on the gluon PDF at high x
- Charm is produced mainly in the photon-gluon fusion process
- Further constraints: $\mathbf{F_L}$

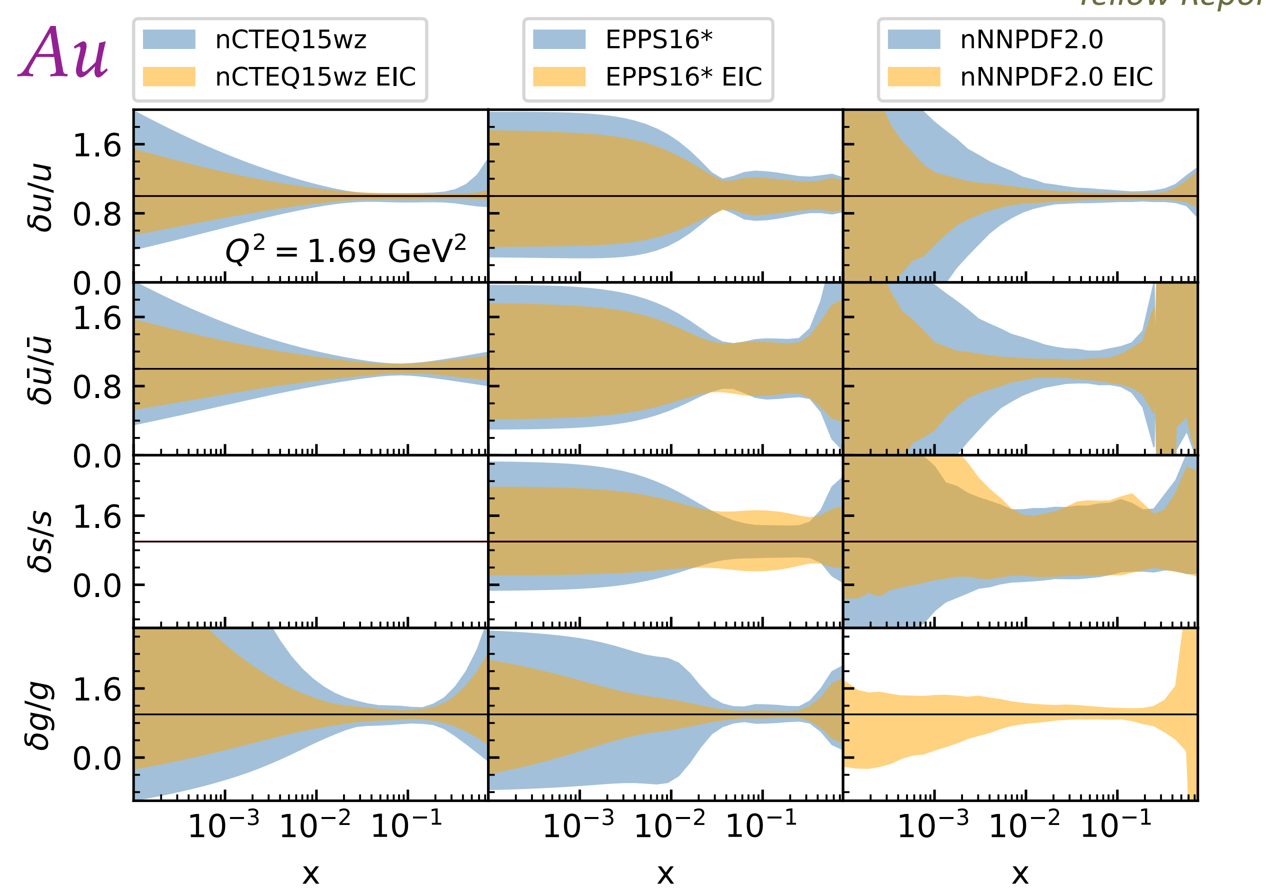




DGLAP : linear evolution

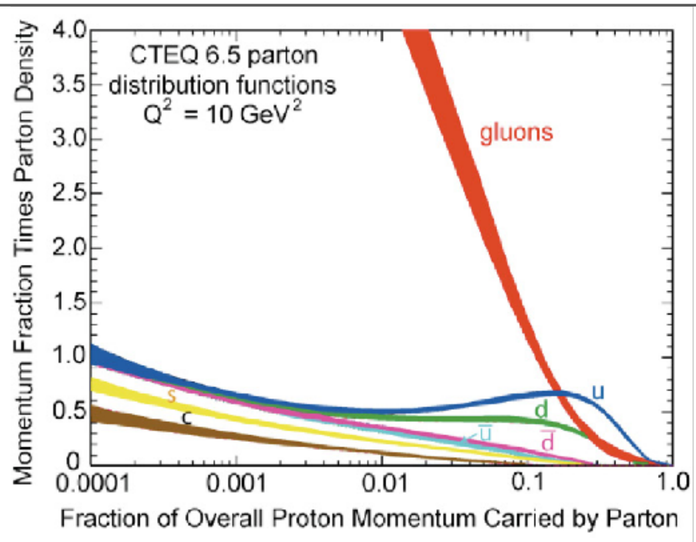
$$\frac{d}{d\ln\mu^2} f_j(z,\mu) = \sum_k \int \frac{d\xi}{\xi} P_{jk}(\xi,\alpha_s) f_k(z/\xi,\mu)$$

Yellow Report



Significant impact of EIC measurements on nuclear PDFs

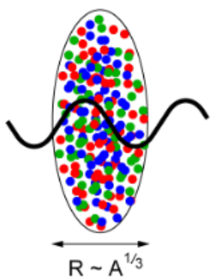
Studying saturation at EIC with nuclei



Does the rise of **gluon** $xg(x, Q^2)$ get **tamed**?

Important to understand for initial conditions in heavy ion collisions

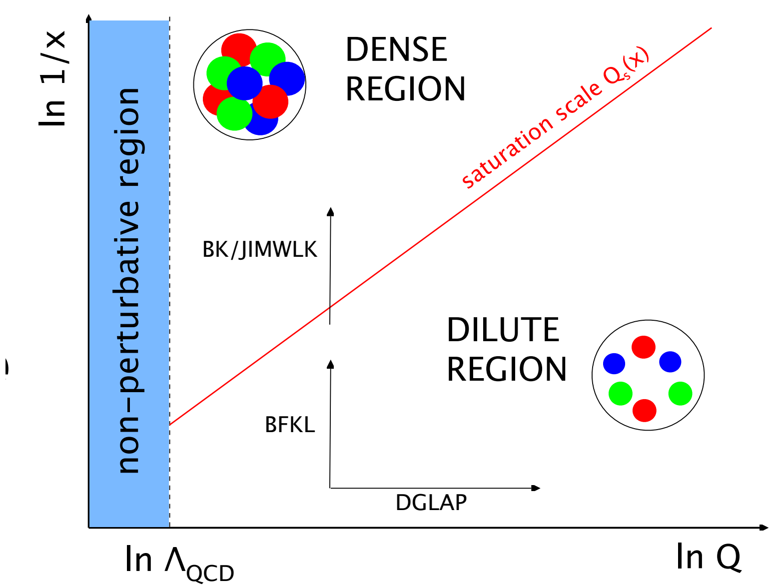
Probe interacts **coherently** with nucleons

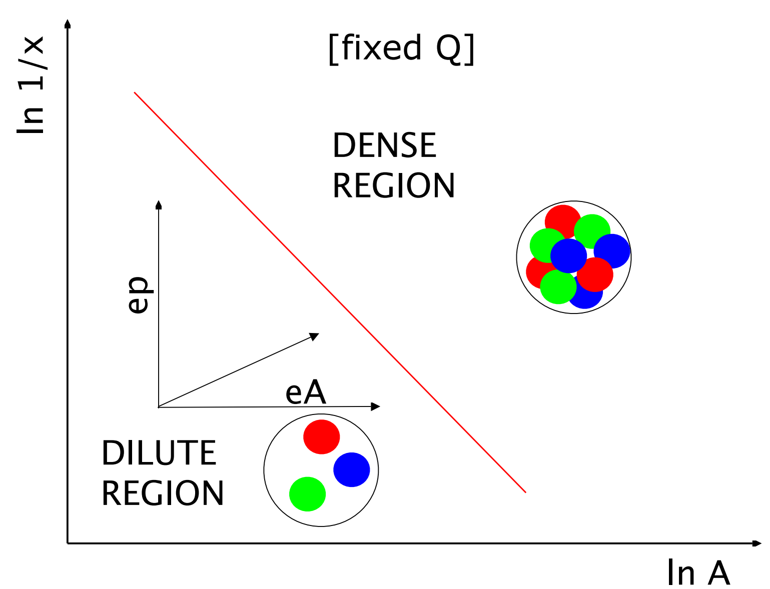


QCD at high energy (low x) and/or high density (large A) predicts **saturation** of gluons

Effective theory of QCD at high energy/density:
Color Glass Condensate CGC *McLerran, Venugopalan,...*

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





Nuclei provide enhancement of the density : opportunities to test saturation at EIC

Testing saturation through inclusive structure functions at EIC

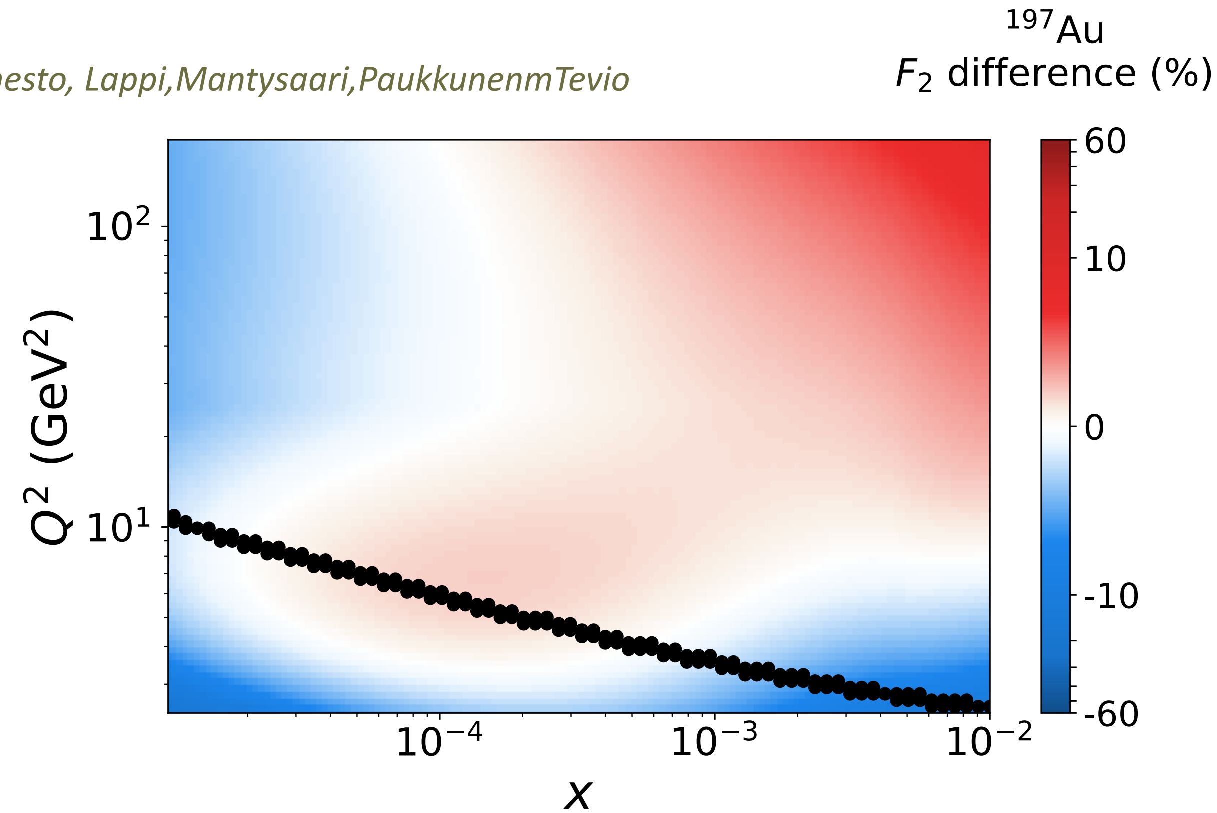
Study differences in evolution between **linear DGLAP** evolution and **nonlinear** evolution with **saturation**

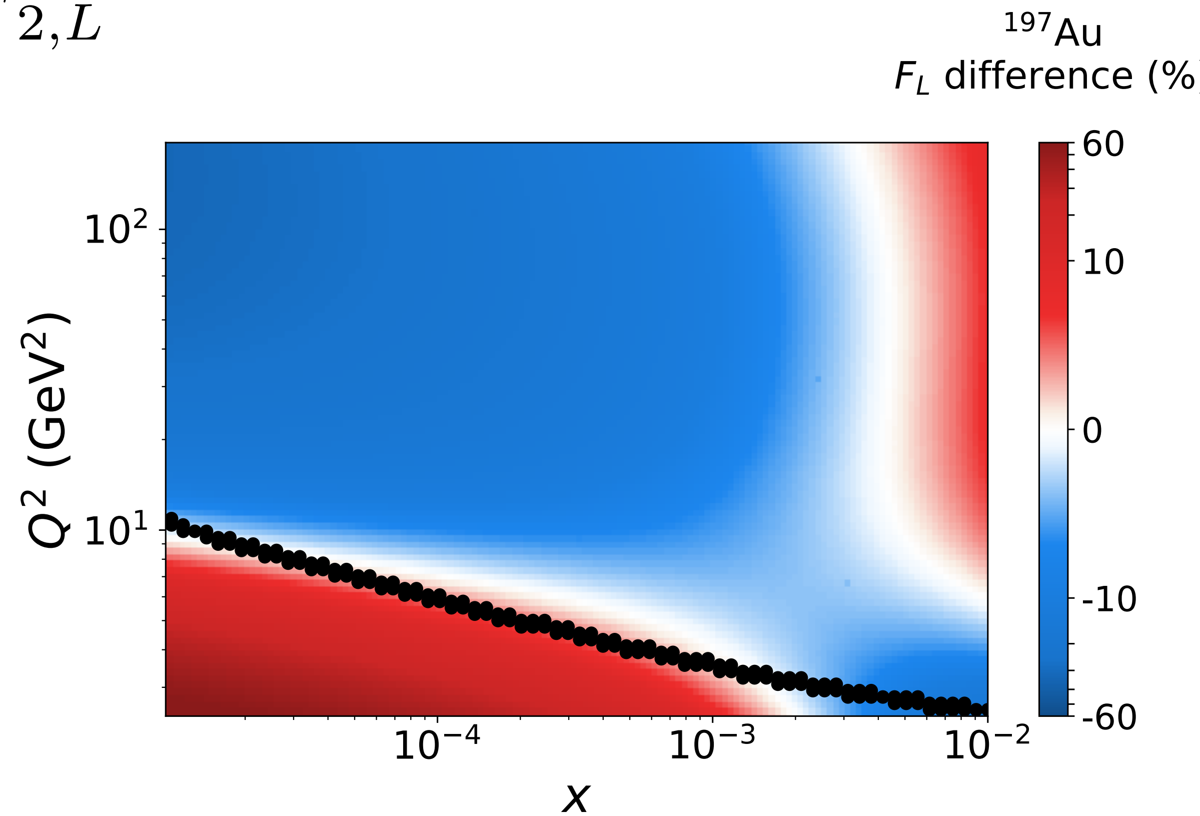
Matching of both approaches in the region where saturation effects expected to be small

Quantify differences away from the matching region: **differences in evolution dynamics**

$$\frac{F_{2,L}^{\rm BK} - F_{2,L}^{\rm Rew}}{F_{2,L}^{\rm BK}}$$

Armesto, Lappi,Mantysaari,PaukkunenmTevio





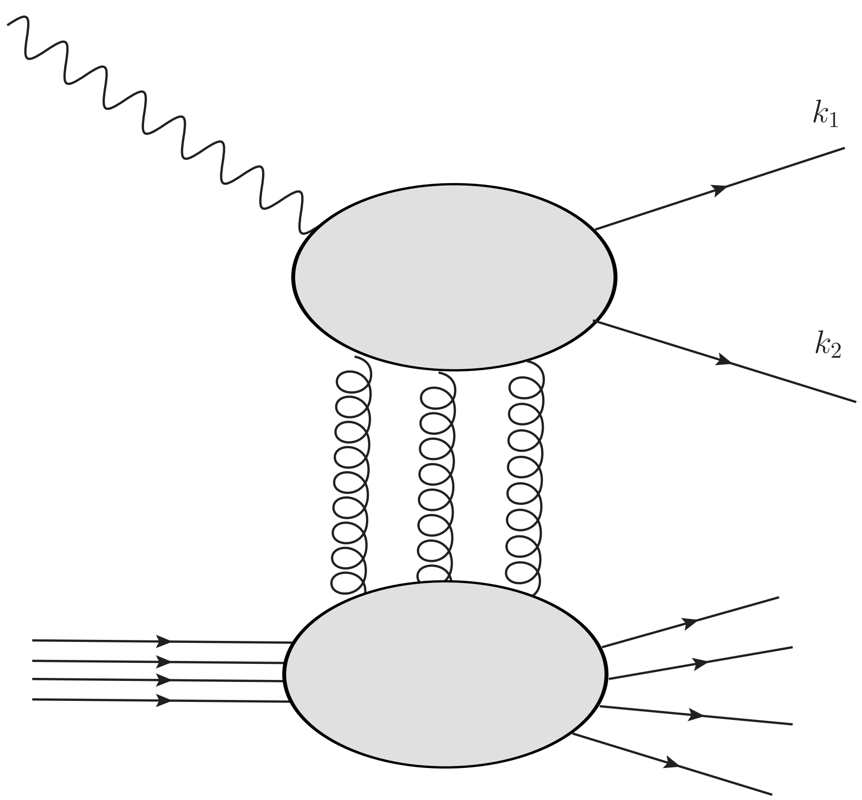
Heavy nucleus: difference between DGLAP and nonlinear are few % for F_2^A and up to 20% for F_L^A.

Longitudinal structure function can provide good sensitivity at EIC

Testing small x and saturation in (de)correlations of hadrons at EIC

Azimuthal **(de)correlations of two hadrons** (dijets) in DIS in eA: direct test of the **unintegrated gluon distribution**

Instead of looking for two jets separated by large rapidity, look for two hadrons/dijets at small x



Two partons. Can look at the decorrelation of jets or hadrons

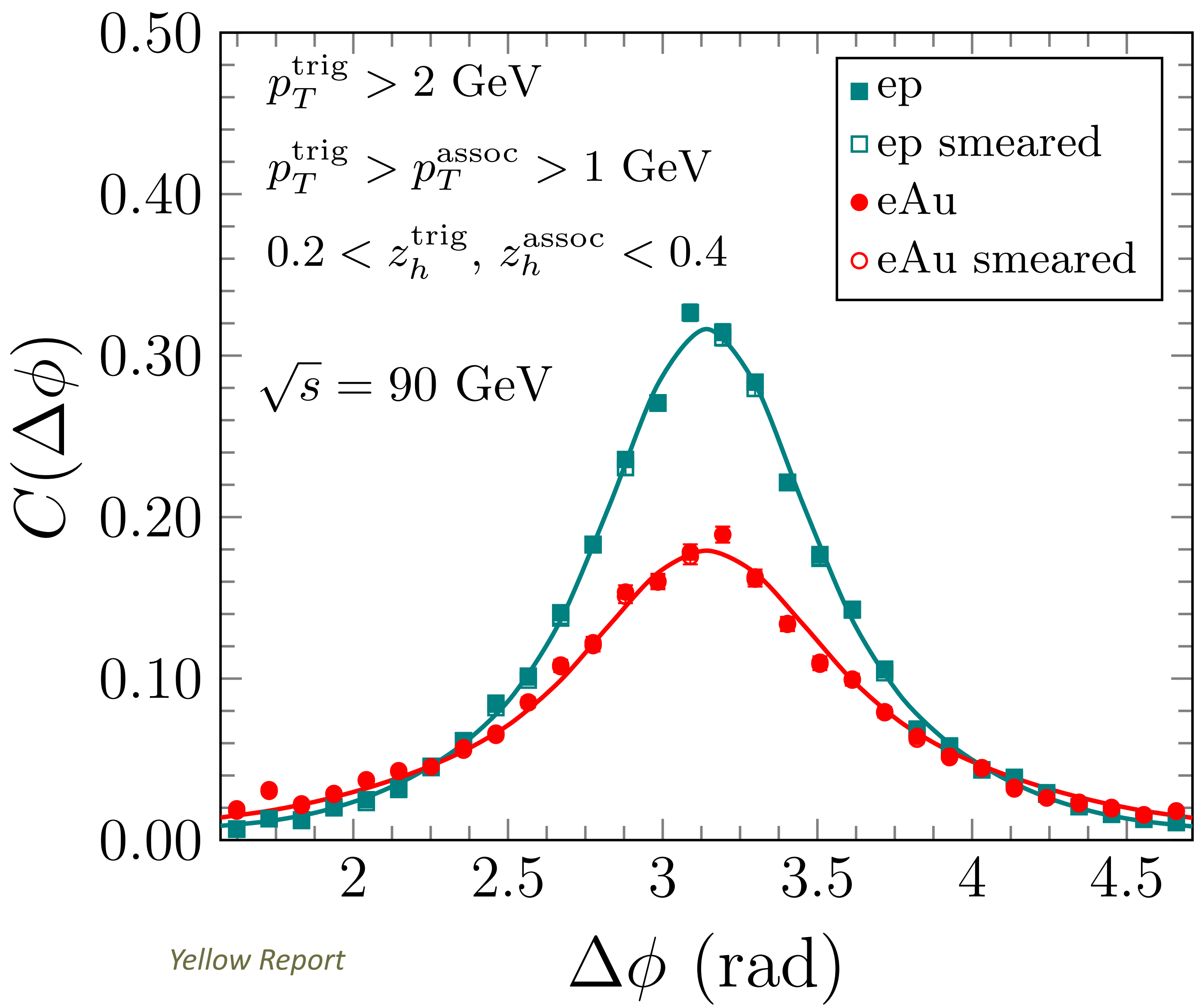
$$C(\Delta\phi) = \frac{1}{\frac{d\sigma_{\rm SIDIS}^{\gamma^*+A\to h_1+X}}{dz_{h1}}} \frac{d\sigma_{\rm tot}^{\gamma^*+A\to h_1+h_2+X}}{dz_{h1}dz_{h2}d\Delta\phi}$$

$$\frac{d\sigma^{\gamma^*+A\to h_1+h_2+X}}{dz_{h1}dz_{h2}d^2p_{h1T}d^2p_{h2T}} \sim \mathcal{F}(x_g,q_T)\otimes\mathcal{H}(z_q,k_{1T},k_{2T})\otimes D_q(z_{h1}/z_q,p_{1T})\otimes D_q(z_{h2}/z_q,p_{2T})$$

Testing small x and saturation in (de)correlations of hadrons at EIC

Clear differences between the ep and eA: **suppression** of the correlation peak in **eA** due to **saturation** effects (including the **Sudakov resummation)**

Further observables: azimuthal correlations of dihadrons/dijets in diffraction, photon+jet/dijet. These processes will allow to test various **CGC correlators**



Spin

Fundamental **quantum** property of particles: intrinsic angular momentum

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Proton: spin 1/2 Quarks: spin 1/2

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Proton has complex structure. How does its spin emerge?

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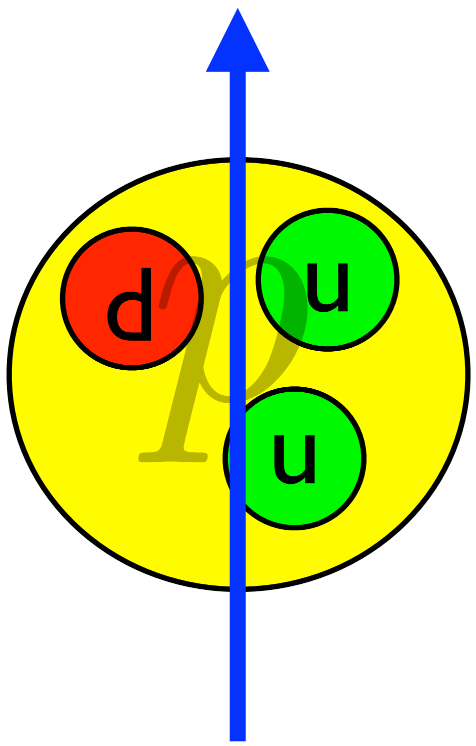

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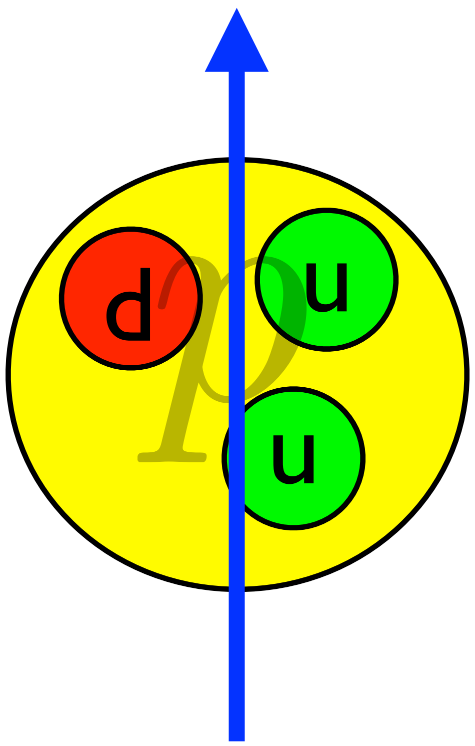

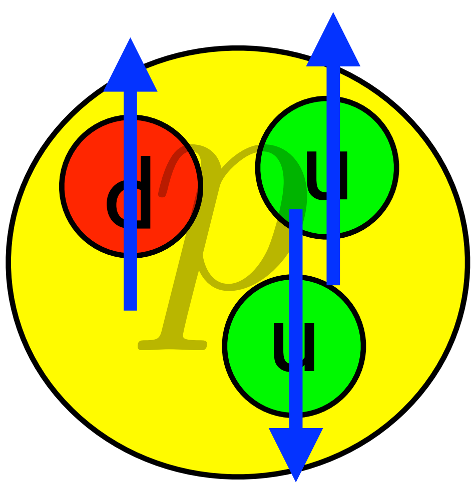

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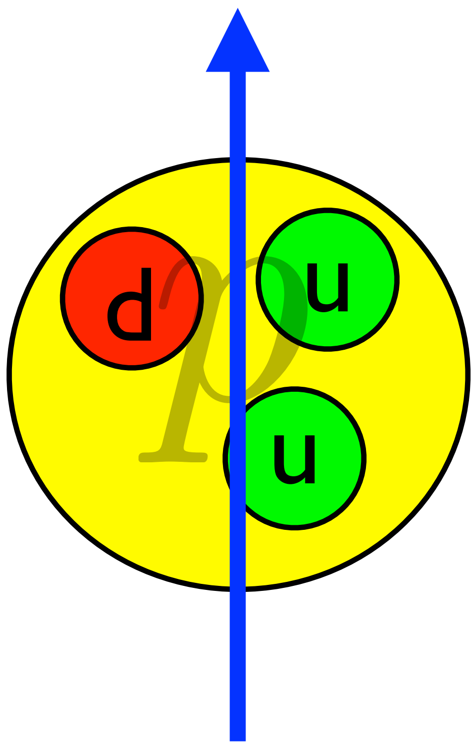
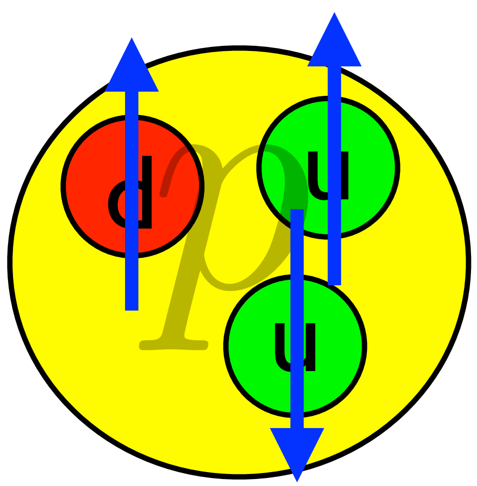




Does the proton spin come from spin of quarks?

Spin

Fundamental **quantum** property of particles: intrinsic angular momentum

Proton: spin 1/2   Quarks: spin 1/2

Proton has complex structure. How does its spin emerge?

Does the proton spin come from spin of quarks?

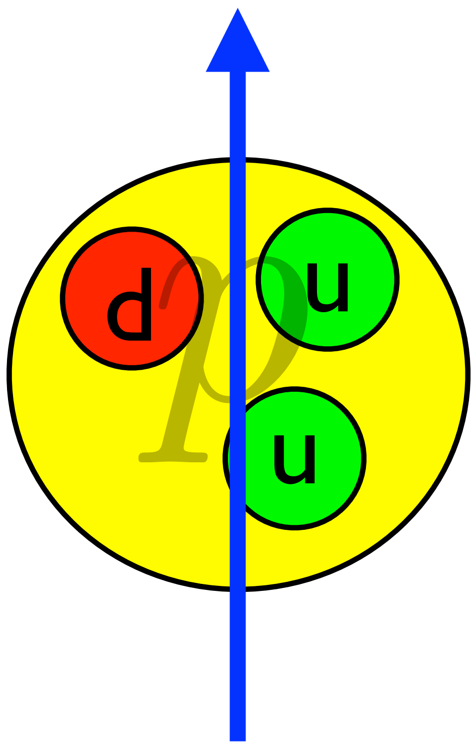
Hypothesis: two quarks spin parallel, one quark spin anti-parallel

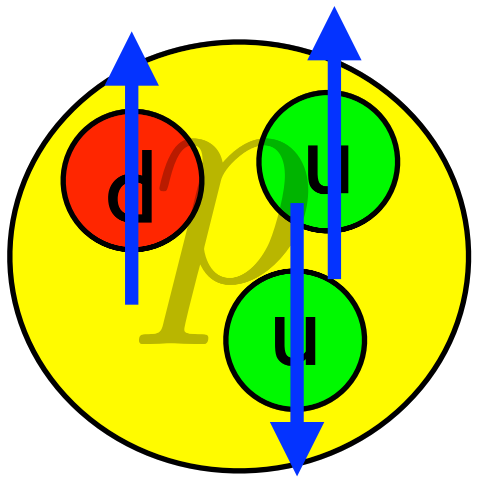
Spin

Fundamental **quantum** property of particles: intrinsic angular momentum

Proton: spin 1/2 Quarks: spin 1/2

Proton has complex structure. How does its spin emerge?





Does the proton spin come from spin of quarks?

Hypothesis: two quarks spin parallel, one quark spin anti-parallel

Problem solved….Is it ? Not so fast…

EMC and spin crisis

Volume 206, number 2 PHYSICS LETTERS B 19 May 1988

A MEASUREMENT OF THE SPIN ASYMMETRY AND DETERMINATION OF THE STRUCTURE FUNCTION g_1 IN DEEP INELASTIC MUON–PROTON SCATTERING

European Muon Collaboration

Aachen, CERN, Freiburg, Heidelberg, Lancaster, LAPP (Annecy), Liverpool, Marseille, Mons, Oxford, Rutherford, Sheffield, Turin, Uppsala, Warsaw, Wuppertal, Yale

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EMC and spin crisis

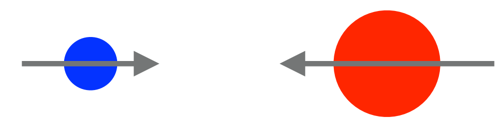
Polarized muon - proton scattering

Measuring asymmetry (difference between cross sections of parallel and antiparallel orientations of projectile and target spins divided by the sum)

$$A = \frac{\sigma^{\uparrow\downarrow} - \sigma^{\uparrow\uparrow}}{\sigma^{\uparrow\downarrow} + \sigma^{\uparrow\uparrow}}$$

EMC and spin crisis

Polarized muon - proton scattering



Measuring asymmetry (difference between cross sections of parallel and antiparallel orientations of projectile and target spins divided by the sum)

$$A = \frac{\sigma^{\uparrow\downarrow} - \sigma^{\uparrow\uparrow}}{\sigma^{\uparrow\downarrow} + \sigma^{\uparrow\uparrow}}$$

Result:

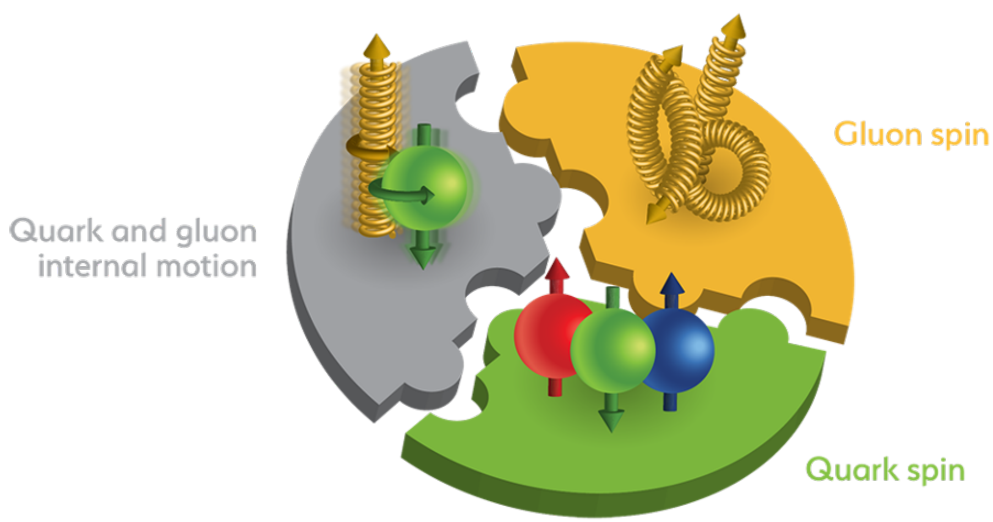
In addition, the result implies that, in the scaling limit, a rather small fraction of the spin of the proton is carried by the spin of the quarks.

!

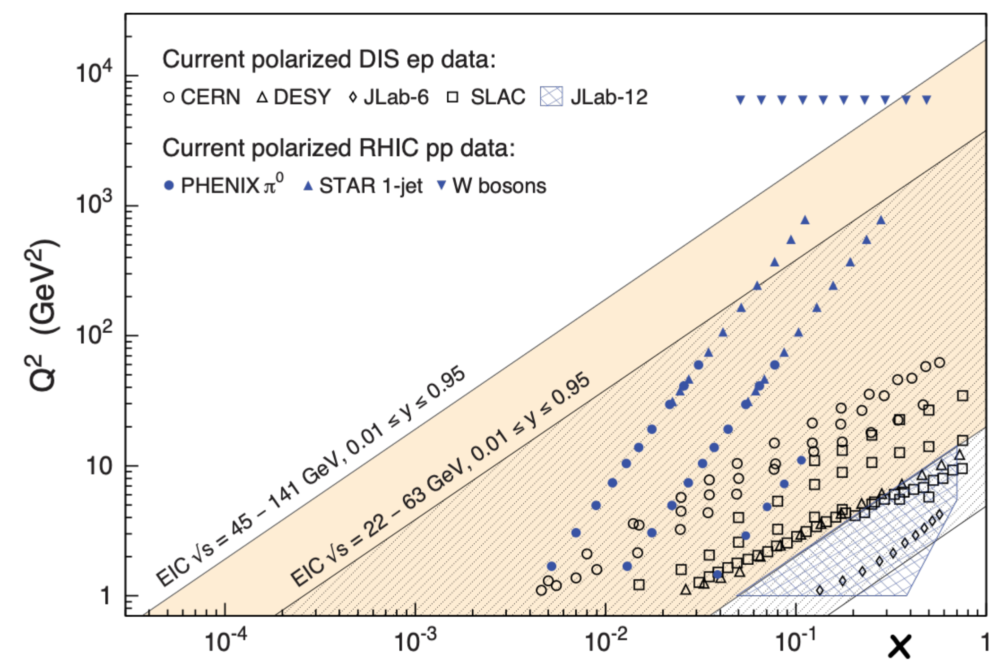
Proton spin at EIC

$$\frac{1}{2} = \frac{1}{2}\int_0^1 dx\,\Delta\Sigma(x,Q^2) + \int_0^1 dx\,\Delta G(x,Q^2) + \int_0^1 dx\,\Big(\sum_q L_q + L_g\Big)$$

quark spin — *gluon spin* — *orbital angular momentum*



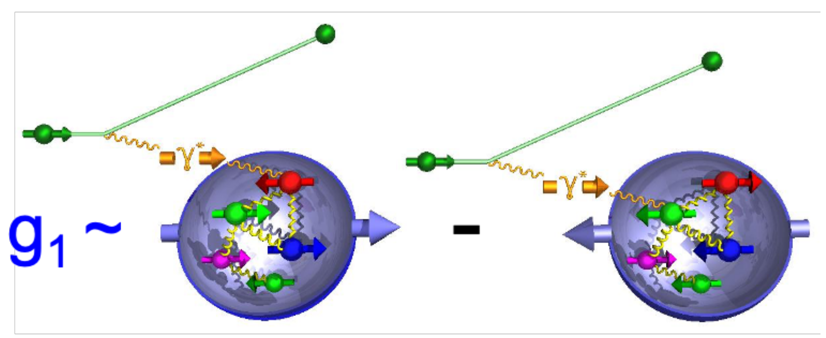
EIC kinematic plane vs current polarized data



- EIC extends range in (x,Q^2) by 1-2 orders of magnitude for polarized measurements.
- Possibilities for precision measurement of **structure function g1, gluon** contribution to proton spin, **quark** contribution, **strange** quark contribution also accessible, **polarized deuterons** allow for measurement of g_1 in a neutron

Proton spin

$$\frac{1}{2}\left[\frac{d^2\sigma^{\rightleftarrows}}{dx\,dQ^2} - \frac{d^2\sigma^{\rightrightarrows}}{dx\,dQ^2}\right] \simeq \frac{4\pi\,\alpha^2}{Q^4} y\,(2-y)\,g_1(x,Q^2)$$



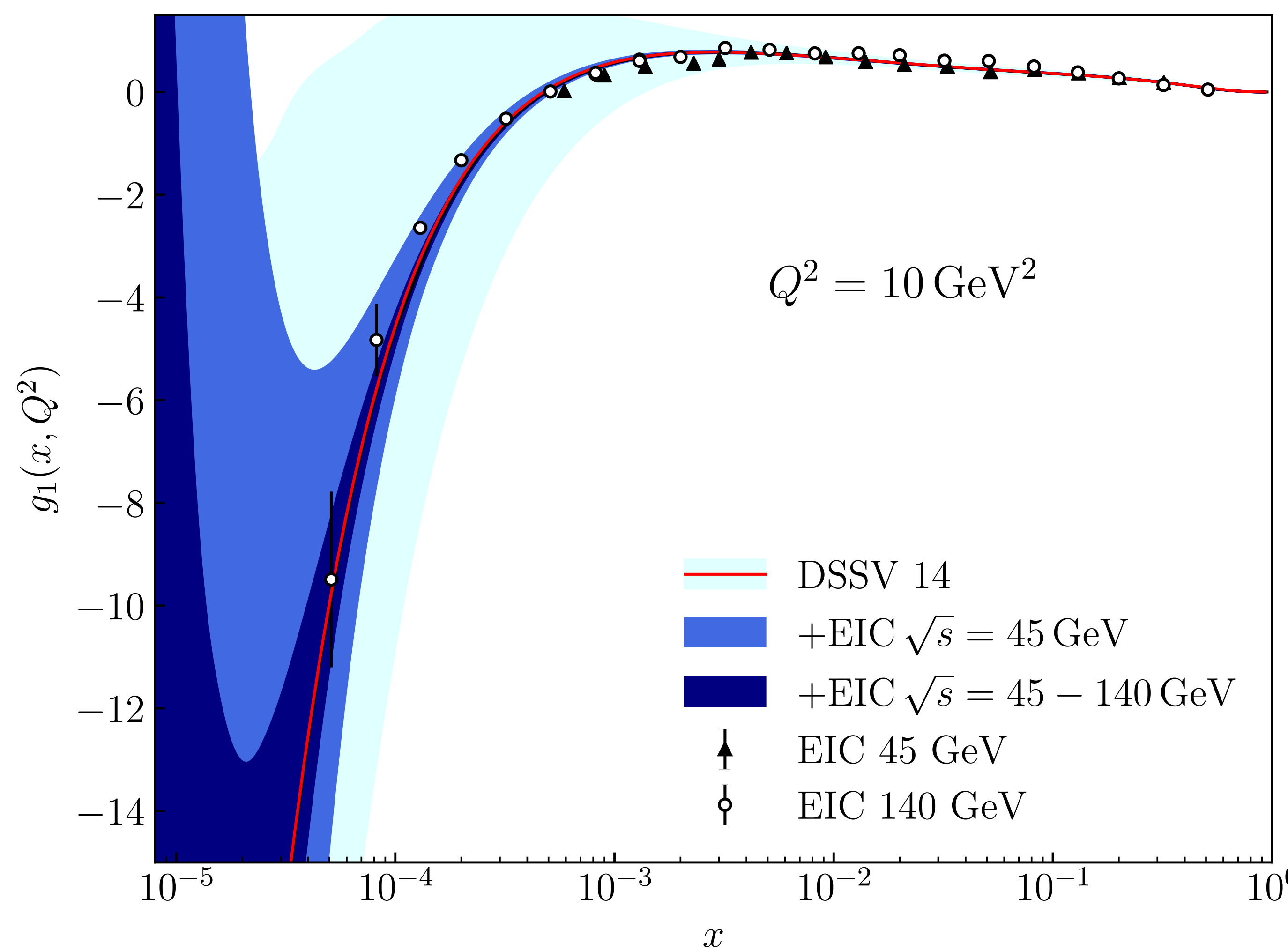
Quark contribution: integral over of g_1 over x from 0 to 1

Sensitive to **gluon** contribution Δg at higher orders: drive the scaling violations.

$$\frac{dg_1(x,Q^2)}{d\log Q^2} \sim \Delta g$$

Current uncertainties for g_1 as a function of x for fixed Q^2

EIC projections leads to greatly reduced uncertainties



Borsa, Lucero, Sassot, Aschenauer, Nunes

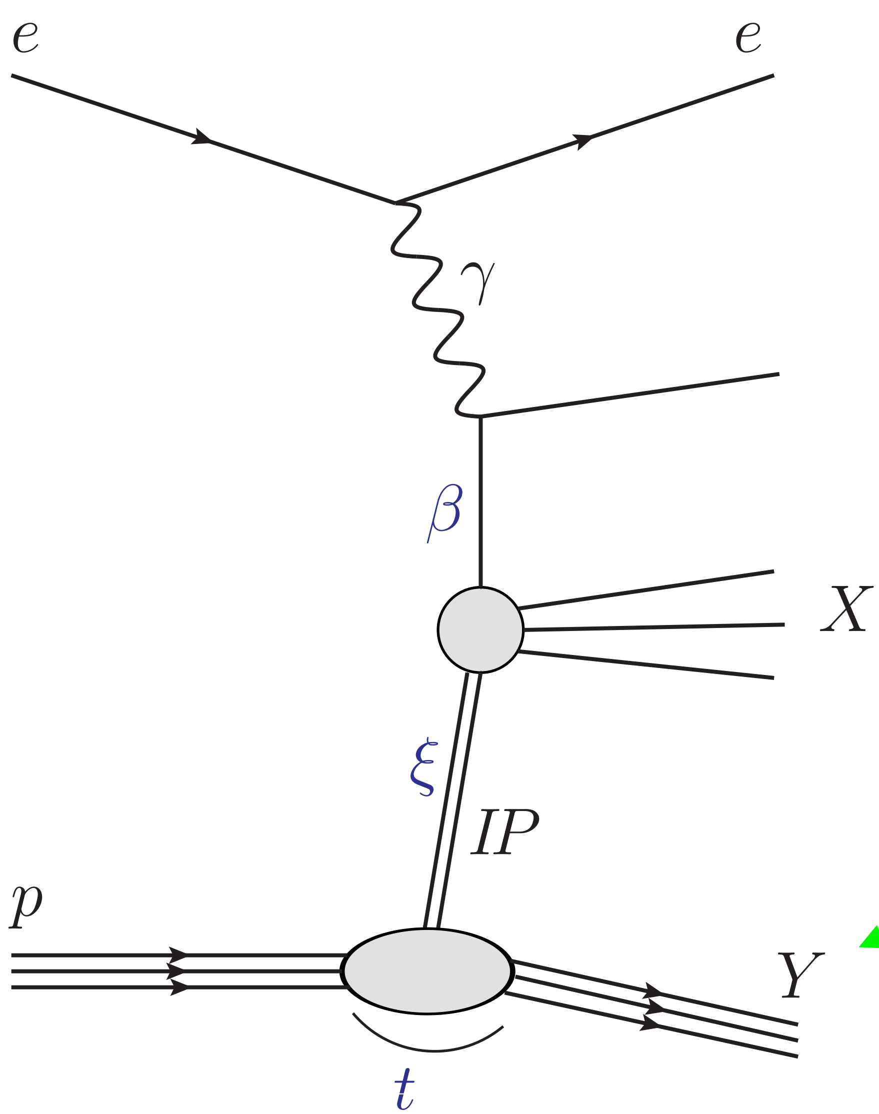
Diffraction

Diffraction : occurs when a wave (for example light) encounters an obstacle or an opening.

Source: Wikipedia
Author: Verbcatcher

Water waves passing through small entrance

Diffraction in DIS



Y Final state: elastically scattered proton, or the system with the same quantum numbers

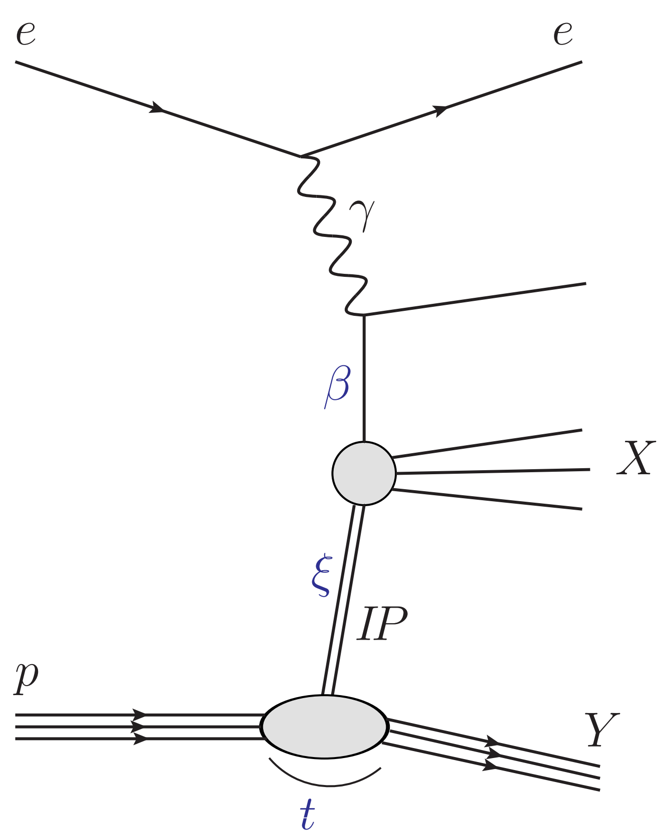
X Diffractive system with mass M_x

Rapidity gap

In order for the rapidity gap to exist it needs to be mediated by the **colorless** exchange

Diffraction: a reaction characterized by a **rapidity** gap in the final state

Diffractive kinematics in DIS



Standard DIS variables:

electron-proton
cms energy squared:

$$s = (k+p)^2$$

photon-proton
cms energy squared:

$$W^2 = (q+p)^2$$

inelasticity

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

Bjorken x

$$x = \frac{-q^2}{2p \cdot q}$$

(minus) photon virtuality

$$Q^2 = -q^2$$

Target is scattered elastically: elastic scattering

It can also dissociate into a state Y with the same quantum numbers, but still separated from the rest of particles

Diffractive DIS variables:

$$x = \xi\beta$$

$$\xi \equiv x_{IP} = \frac{Q^2 + M_X^2 - t}{Q^2 + W^2}$$

momentum fraction of the Pomeron w.r.t hadron

$$\beta = \frac{Q^2}{Q^2 + M_X^2 - t}$$

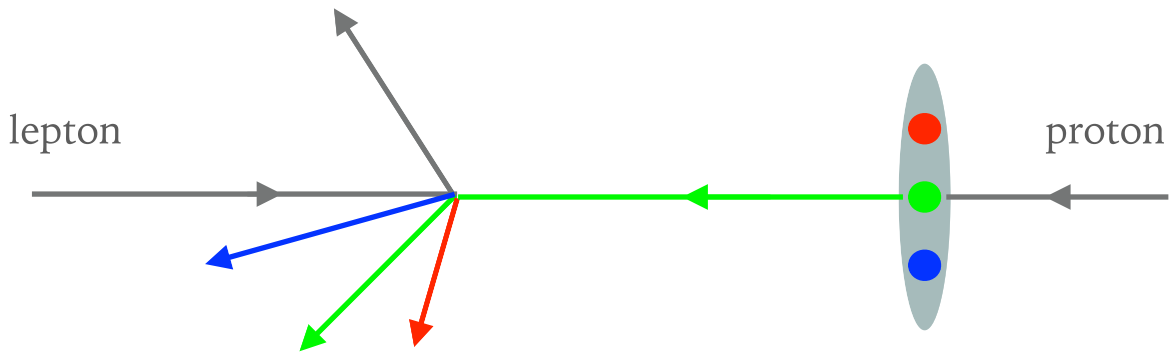
momentum fraction of parton w.r.t Pomeron

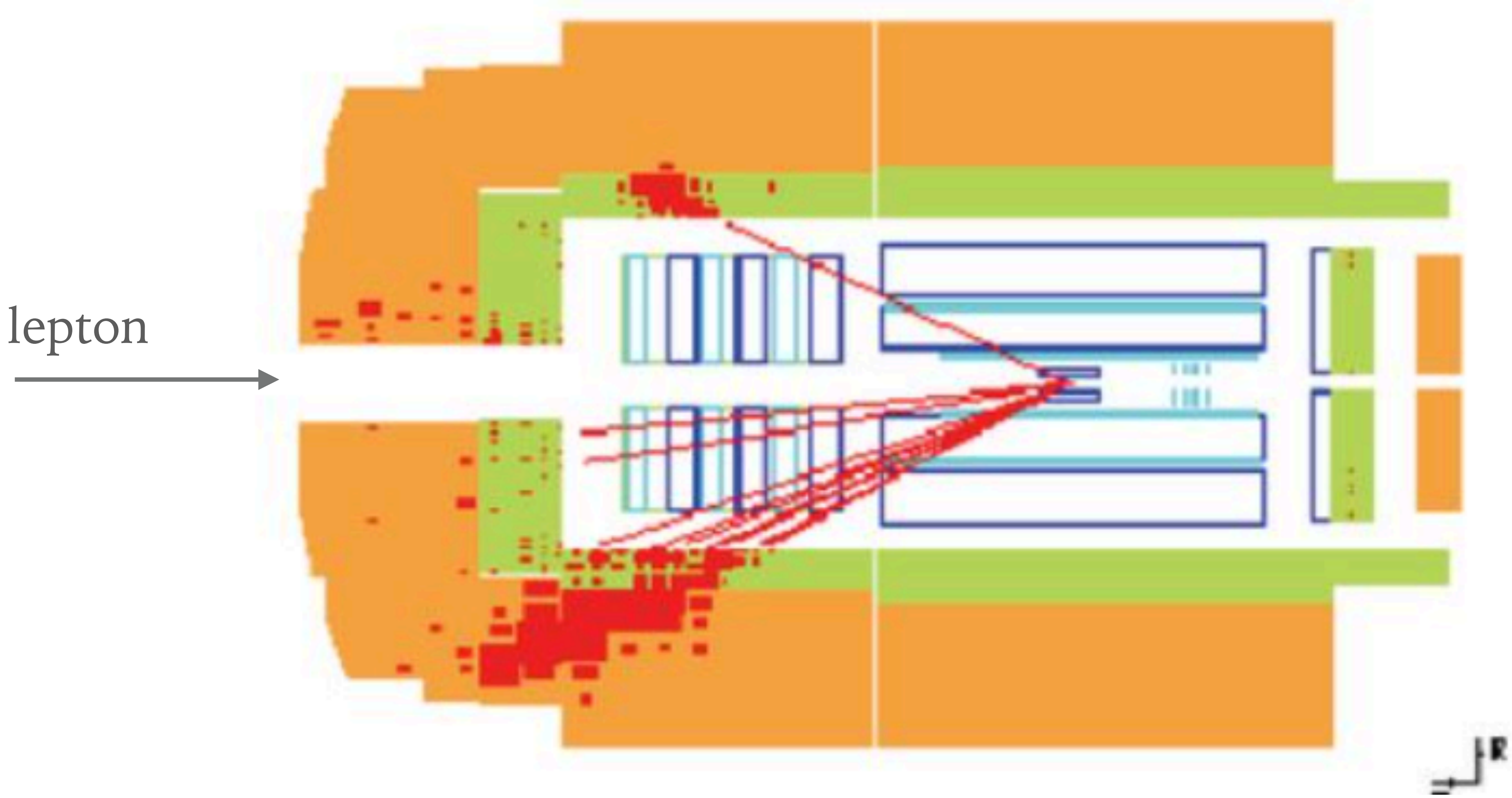
$$t = (p - p')^2$$

4-momentum transfer squared

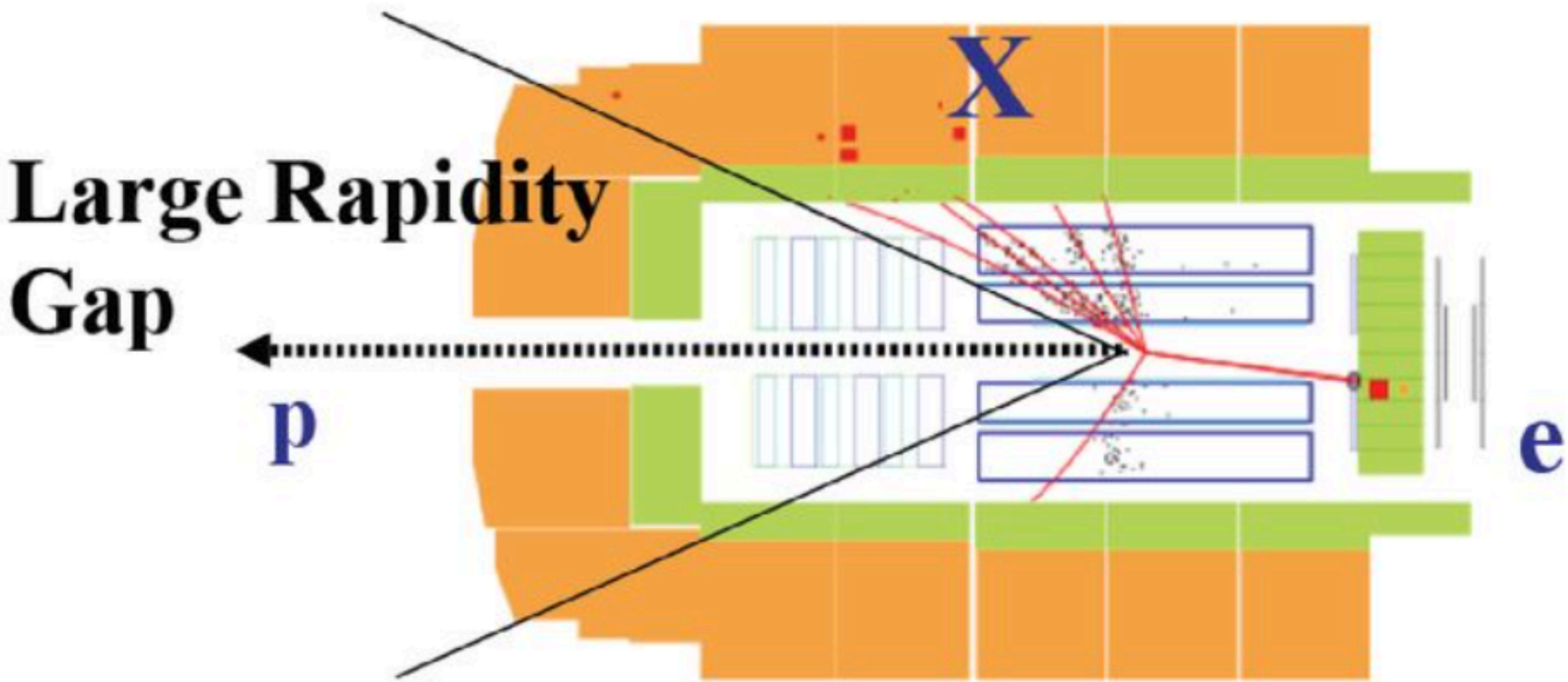
Deep Inelastic Scattering : non-diffractive

Non-diffractive DIS event





Diffraction at HERA

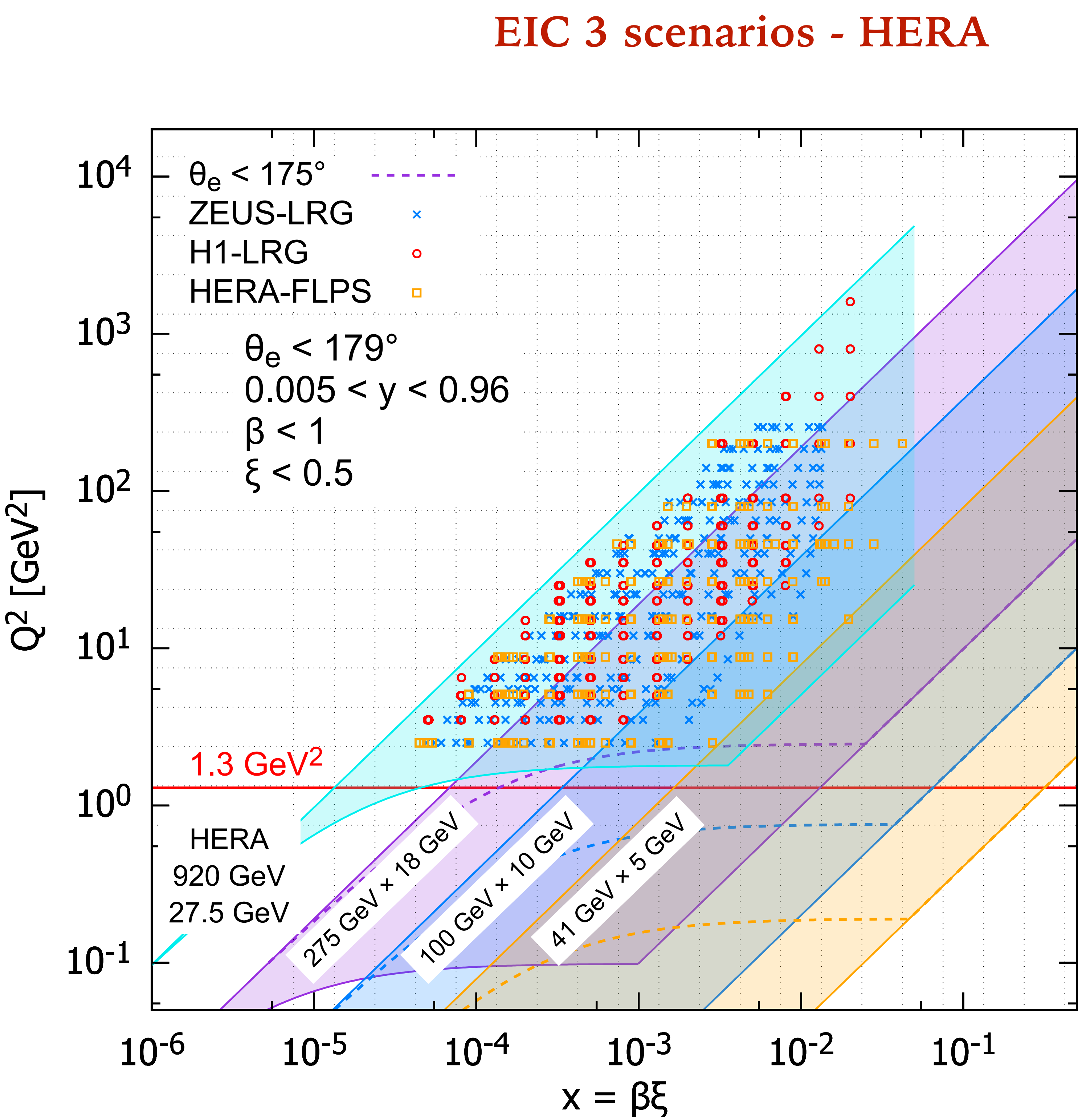


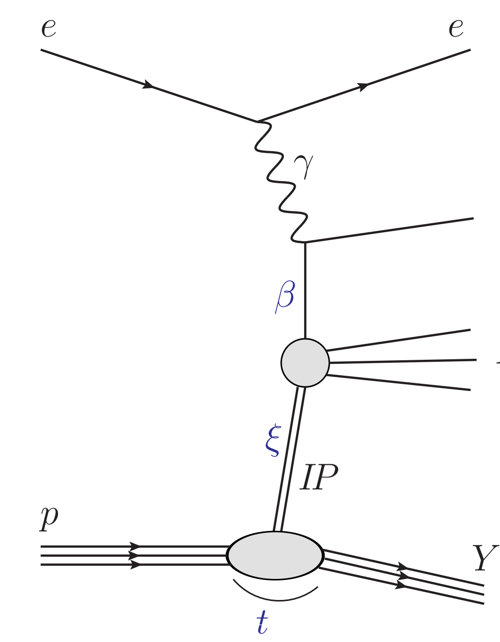
10% events at HERA were of diffractive type

Large portion of the detector void of any particle activity: **rapidity gap**

Proton stays intact despite undergoing violent collision with a 50 TeV electron (in its rest frame)

Phase space (x,Q²) EIC-HERA in diffraction





$$\xi \equiv x_{IP} = \frac{Q^2 + M_X^2 - t}{Q^2 + W^2}$$

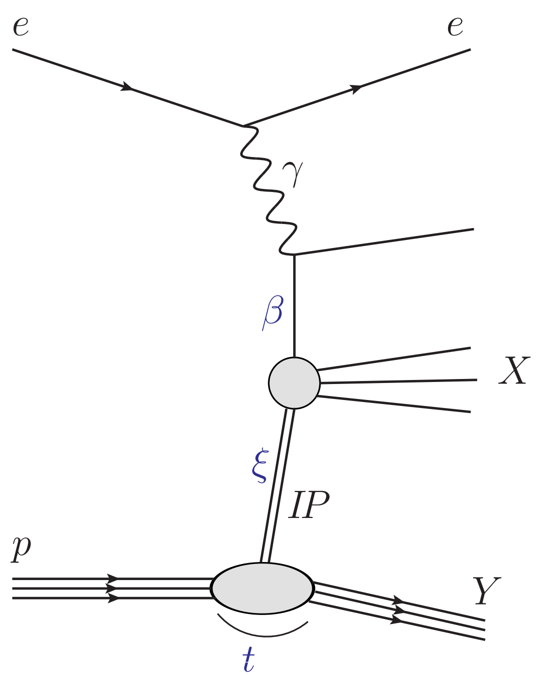
$$\beta = \frac{Q^2}{Q^2 + M_X^2 - t}$$

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

Diffraction in DIS

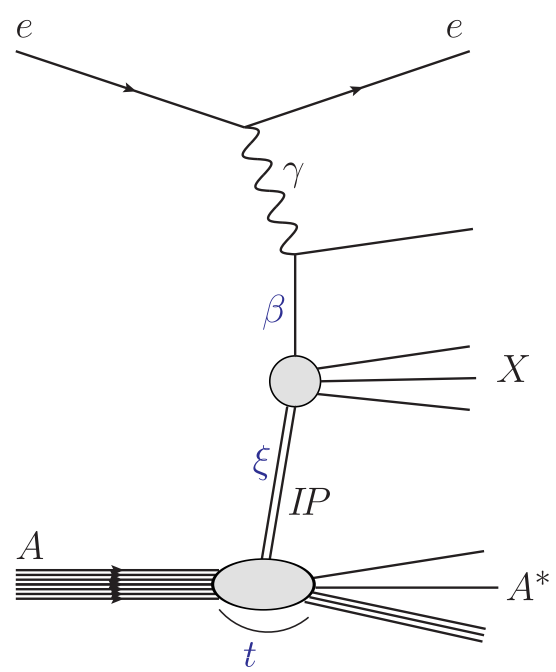
Why diffraction ?

- Dynamics of **color singlet** object (Pomeron). Relation to confinement
- Sensitivity to **gluon** content, **low x** dynamics and **saturation**
- Relation to **shadowing**
- Limits of **factorization** and **universality** of diffractive PDFs
- Provides information about **spatial** distribution of the gluons in the target



In nuclei, also possible **incoherent** diffraction, when nucleus breaks up, but rapidity gap still present

On protons, one can have **diffractive dissociation** (proton breaks up but there is rapidity gap)



Diffractive cross section, structure functions

Diffractive cross section depends on 4 variables (ξ,β,Q^2,t):

$$\frac{d^4\sigma^D}{d\xi d\beta dQ^2 dt} = \frac{2\pi\alpha_{\rm em}^2}{\beta Q^4} Y_+ \, \sigma_r^{D(4)}(\xi,\beta,Q^2,t)$$

$$Y_+ = 1 + (1-y)^2$$

Reduced cross section depends on two structure functions:

$$\sigma_r^{D(4)}(\xi,\beta,Q^2,t) = F_2^{D(4)}(\xi,\beta,Q^2,t) - \frac{y^2}{Y_+} F_L^{D(4)}(\xi,\beta,Q^2,t)$$

Upon integration over t:

$$F_{2,L}^{D(3)}(\xi,\beta,Q^2) = \int_{-\infty}^{0} dt \, F_{2,L}^{D(4)}(\xi,\beta,Q^2,t)$$

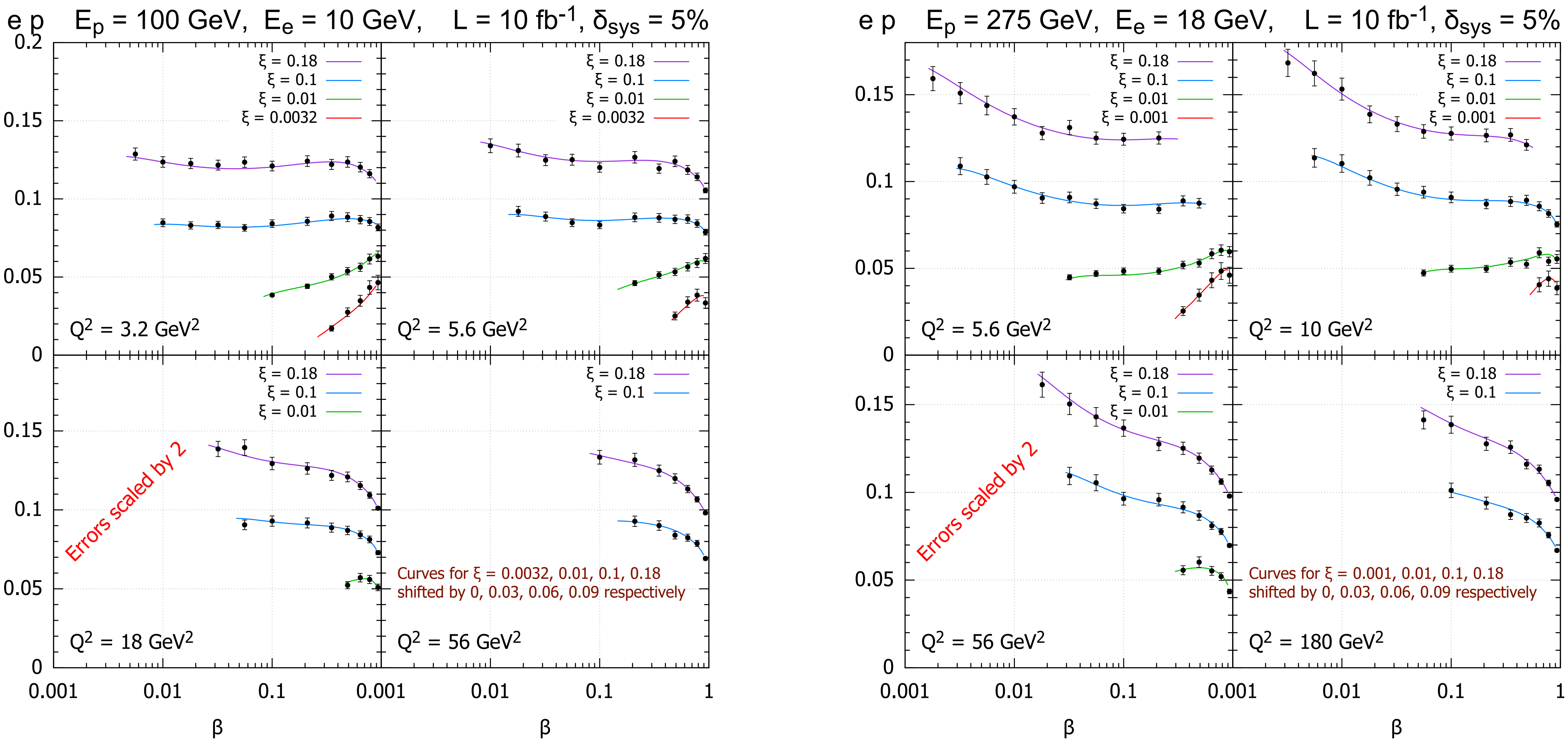
Dimensions:

$[\sigma_r^{D(4)}] = {\rm GeV}^{-2}$

$\sigma_r^{D(3)}$ Dimensionless

Example: pseudodata for $\sigma^{D(3)}$ in ep at EIC

Armesto, Newman, Slominski, Stasto



In total:
482 points for $1.3 < Q^2 < 1330\ \mathrm{GeV}^2$

In total:
792 points for $1.3 < Q^2 < 4220\ \mathrm{GeV}^2$

Possibilities for $F_L^{D(3)}$ at EIC

Why F_L^D is interesting?

$$\sigma_r^{D(3)} = F_2^{D(3)} - \frac{y^2}{Y_+} F_L^{D(3)}$$

F_L^D vanishes in the parton model

Gets non-vanishing contributions in QCD

As in inclusive case, particularly sensitive to the diffractive **gluon density**

Expected large **higher twists,** provides test of the **non-linear, saturation** phenomena

Experimentally challenging…

Measurement requires several beam energies

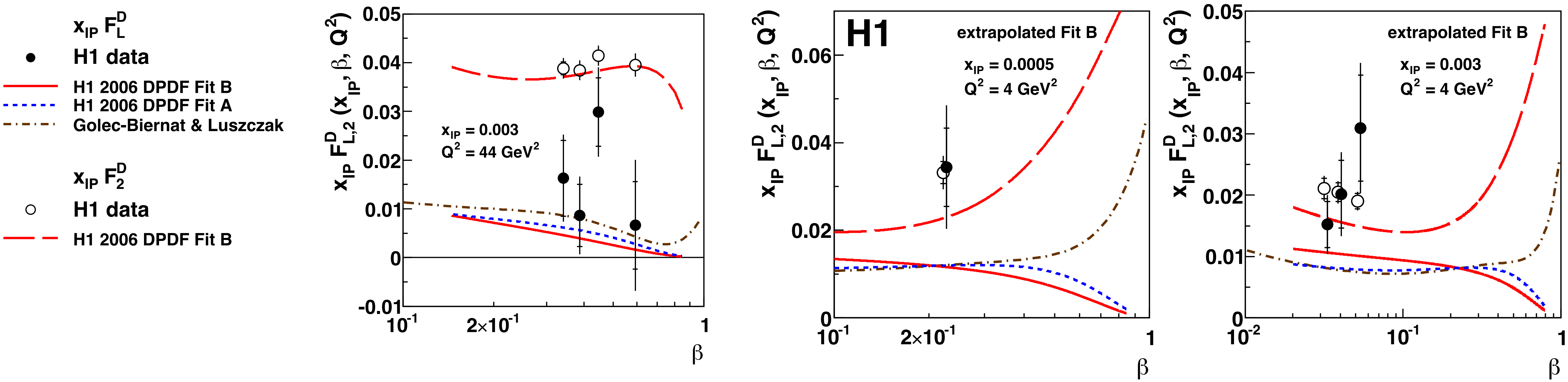
F_L^D strongest when $y \to 1$. Low electron energies

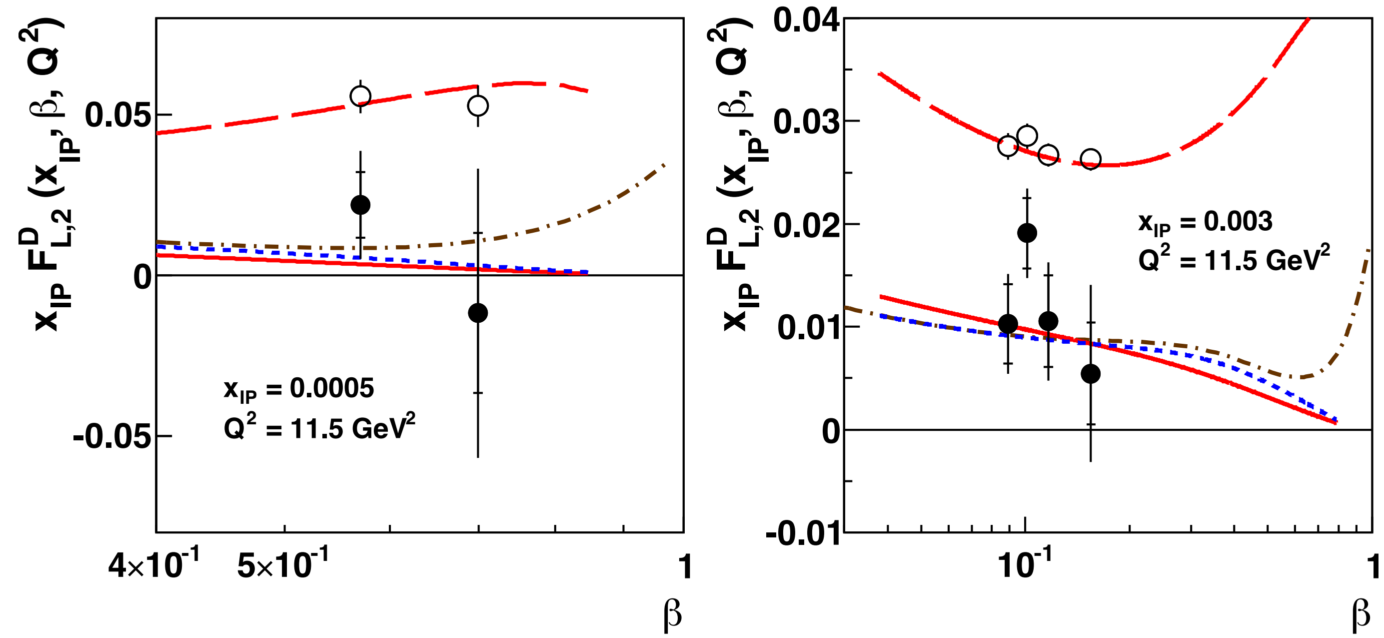
H1 measurement: 4 energies, E_p=920, 820, 575, 460 GeV, electron beam E_e=27.6 GeV

Large errors, limited by statistics at HERA

Careful evaluation of systematics. Best precision 4%, with uncorrelated sources as low as 2%

$F_L^{D(3)}$ at HERA





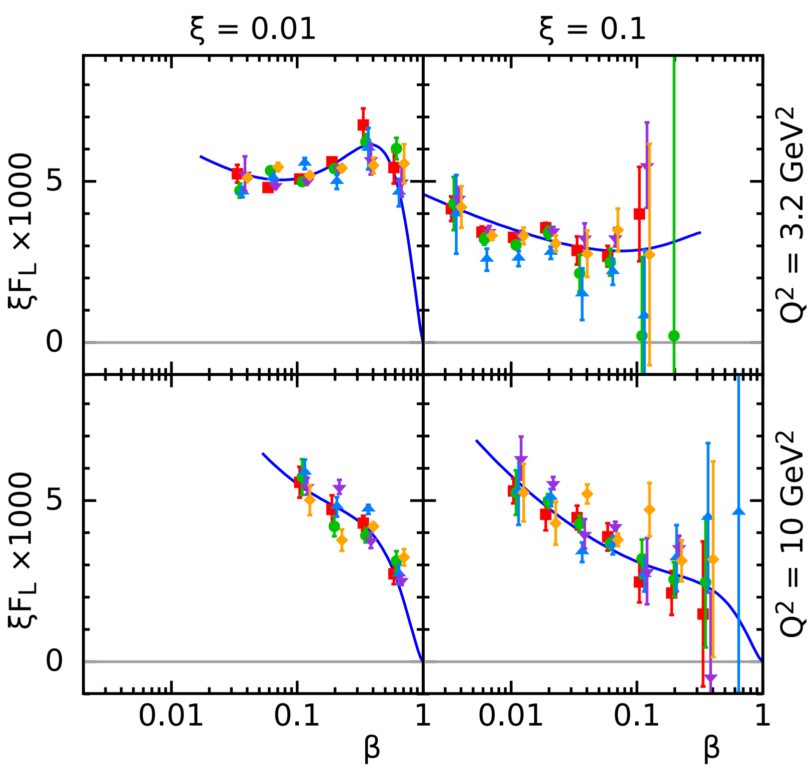
Measurements of σ_r^D consistent with predictions from the models

Extracted F_L^D has a tendency to be higher than the predictions, though compatible with model predictions within errors

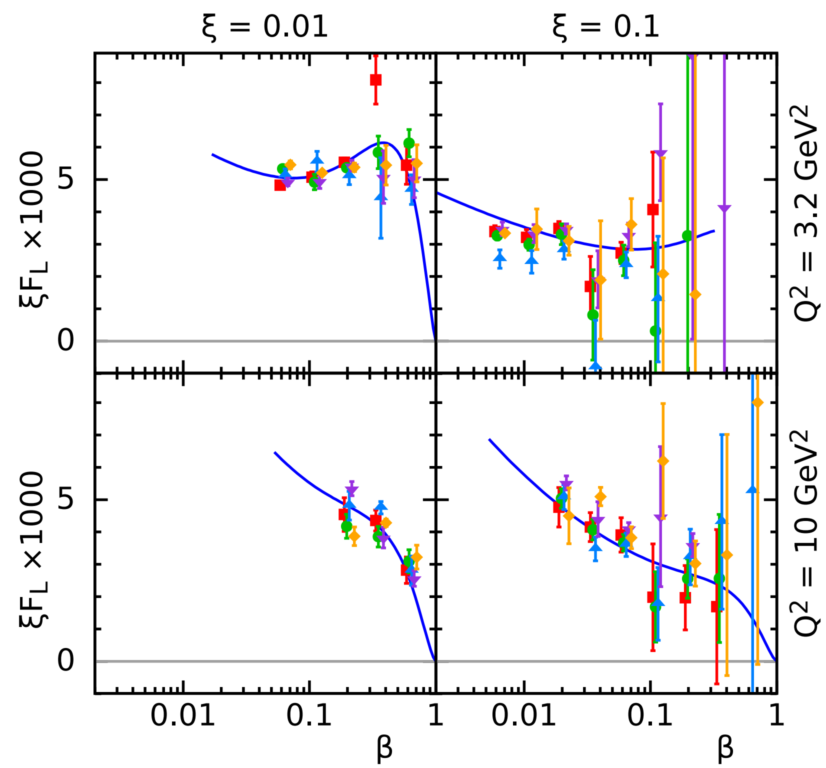
Overall: $0 < F_L^D < F_2^D$

Simulated measurement of $F_L^{D(3)}$ vs β in bins of (ξ, Q^2)

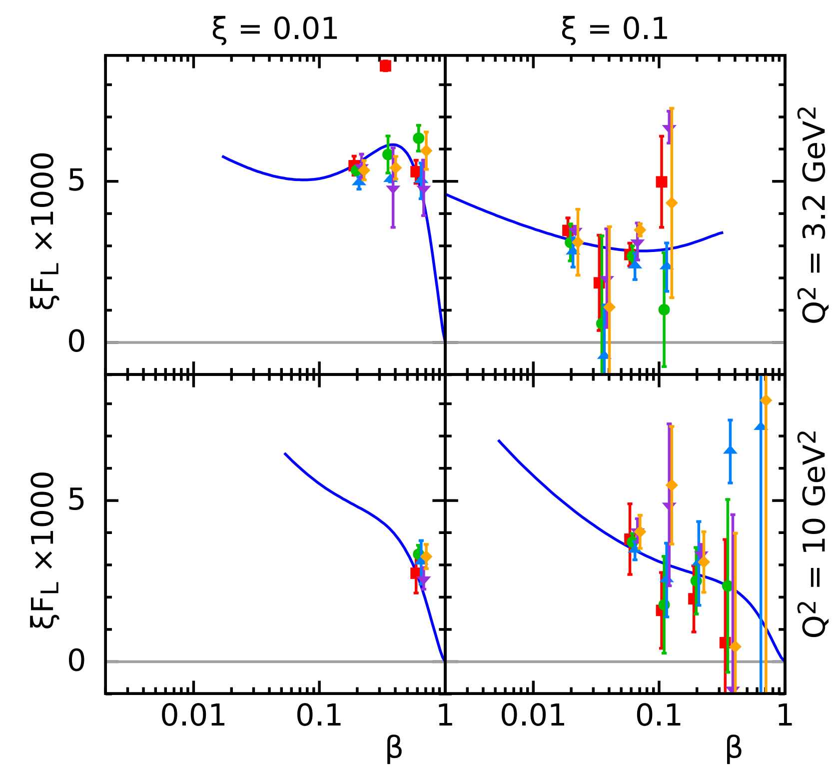
Uncorr. systematic error 1%, 5 MC samples to illustrate fluctuations



17 energies



9 energies



5 energies

Armesto, Newman, Slominski, Stasto

Small differences between S-17 and S-9, small reduction to range and increase in uncertainties.

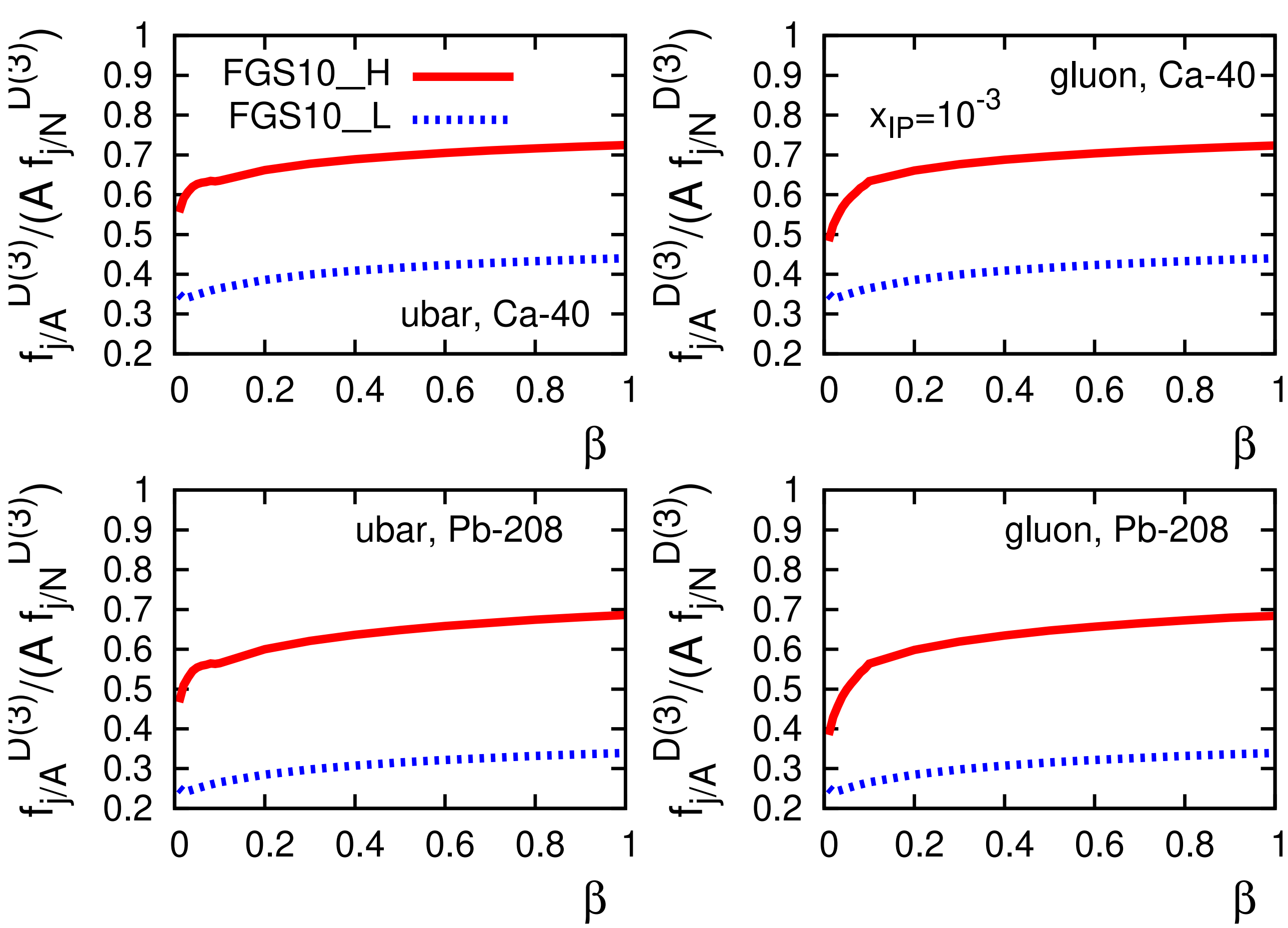
More pronounced reduction in range and higher uncertainties in S-5.

An extraction of F^D_L possible with EIC-favored set of energy combinations

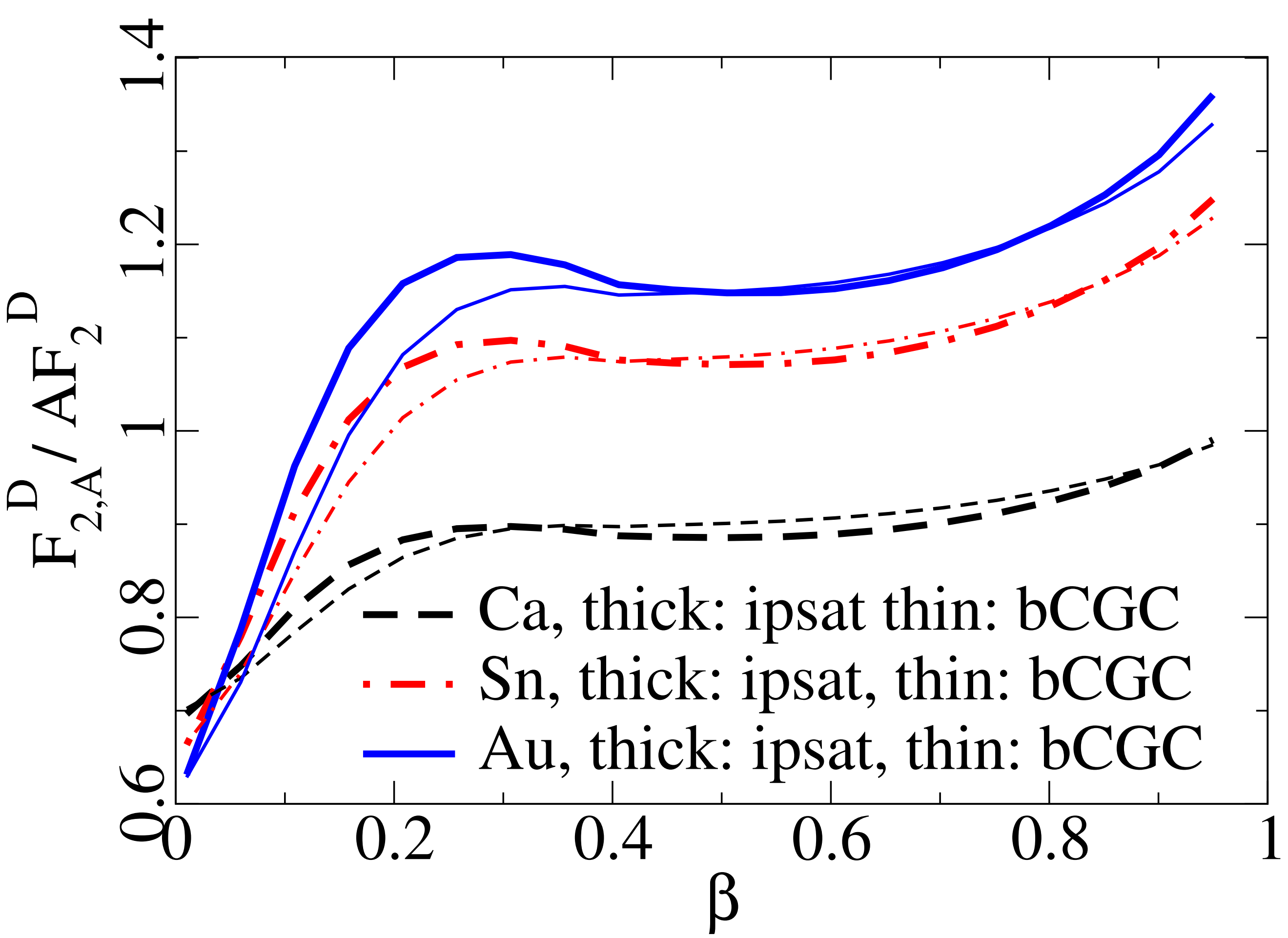
Example : inclusive diffraction in eA DIS

Diffractive to inclusive ratio of cross sections **sensitive probe to different models**

Ratio in LT shadowing : suppression



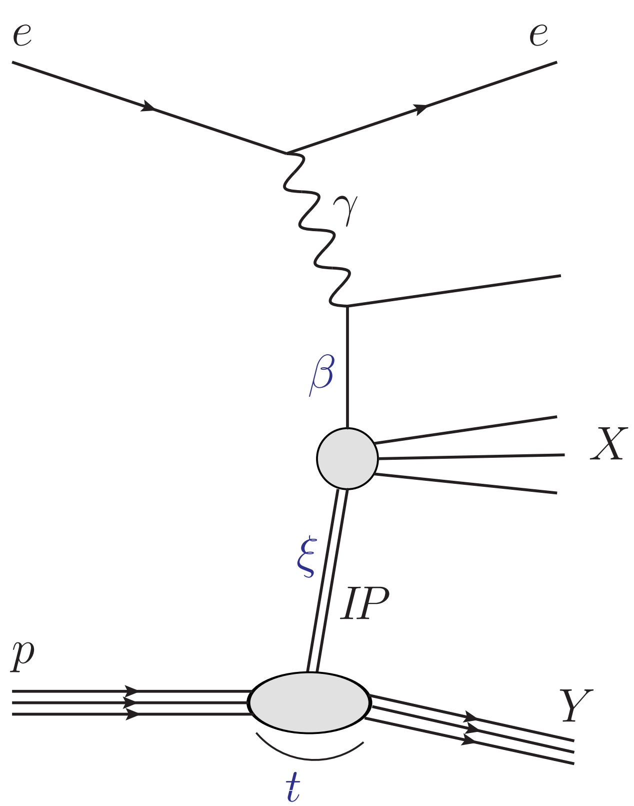
Ratio in saturation model: enhancement



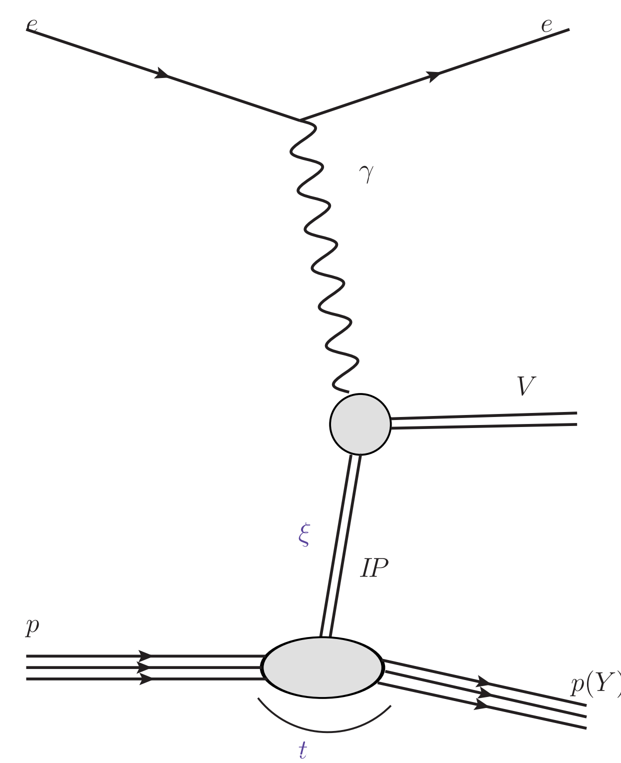
Yellow Report

Example : diffractive elastic vector meson production

Inclusive diffraction



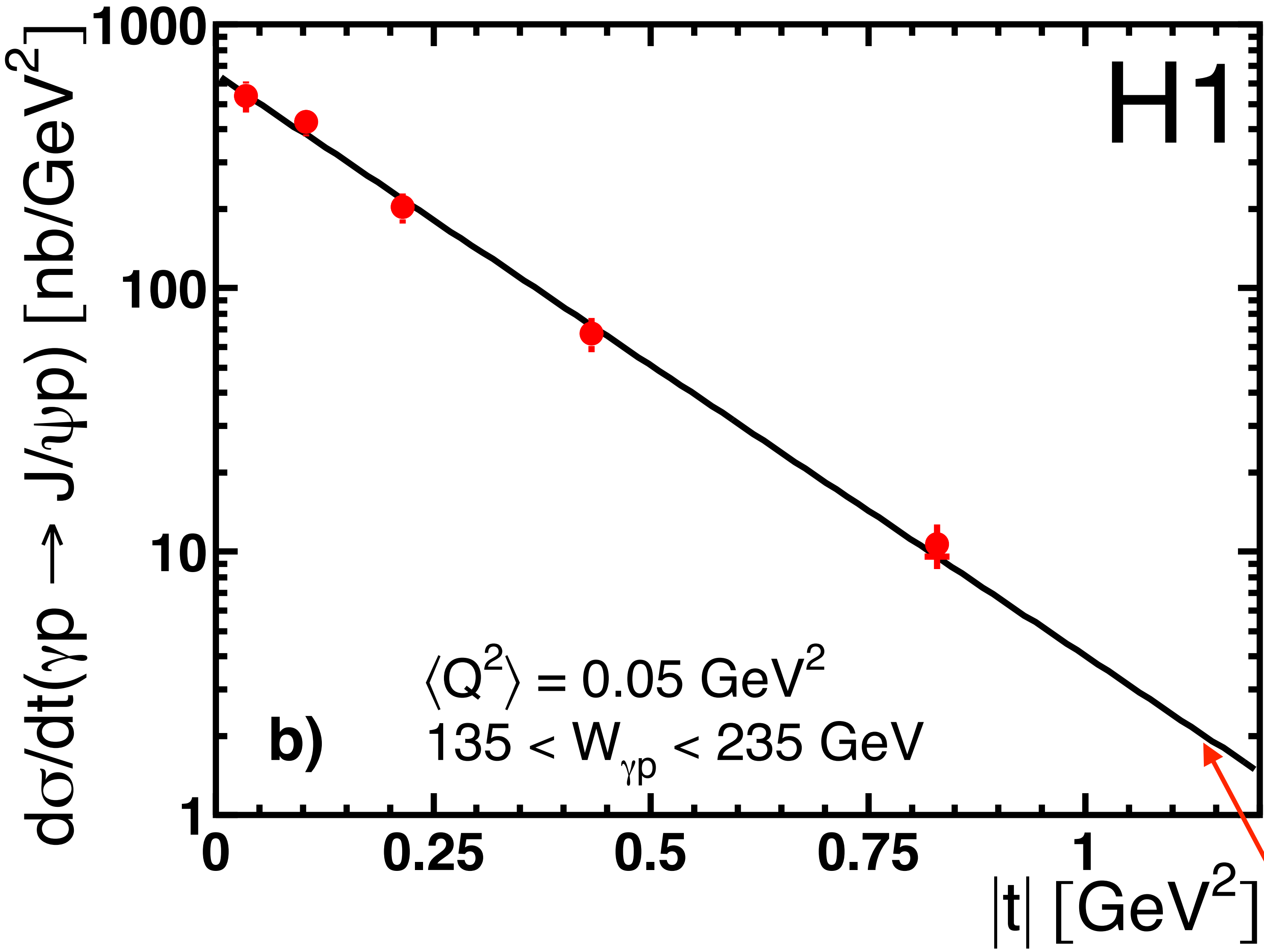
Final state contains only vector meson, scattered lepton and proton

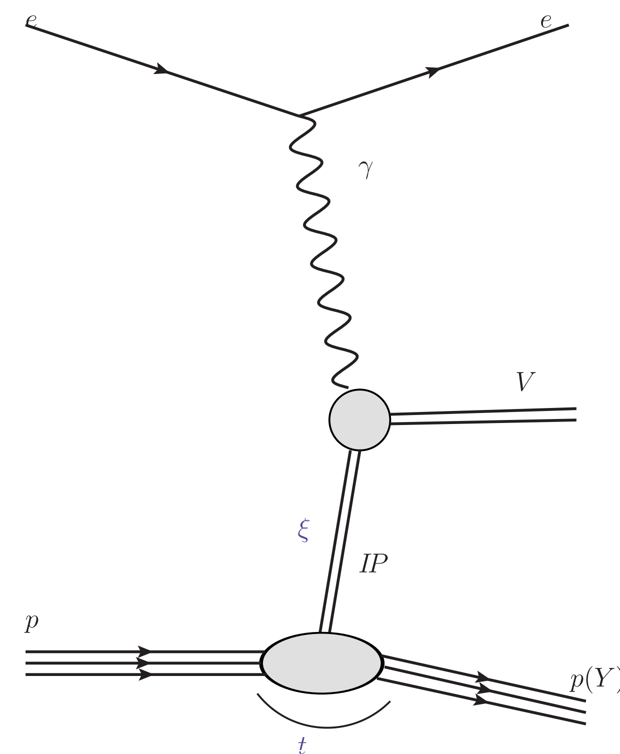


J/ψ vector meson: charm -anti charm system $m = 3.09 \text{ GeV}$

Upsilon vector meson: bottom - anti bottom system $m = 9.46 \text{ GeV}$

Elastic vector meson production





$$t = (p - p')^2 < 0$$

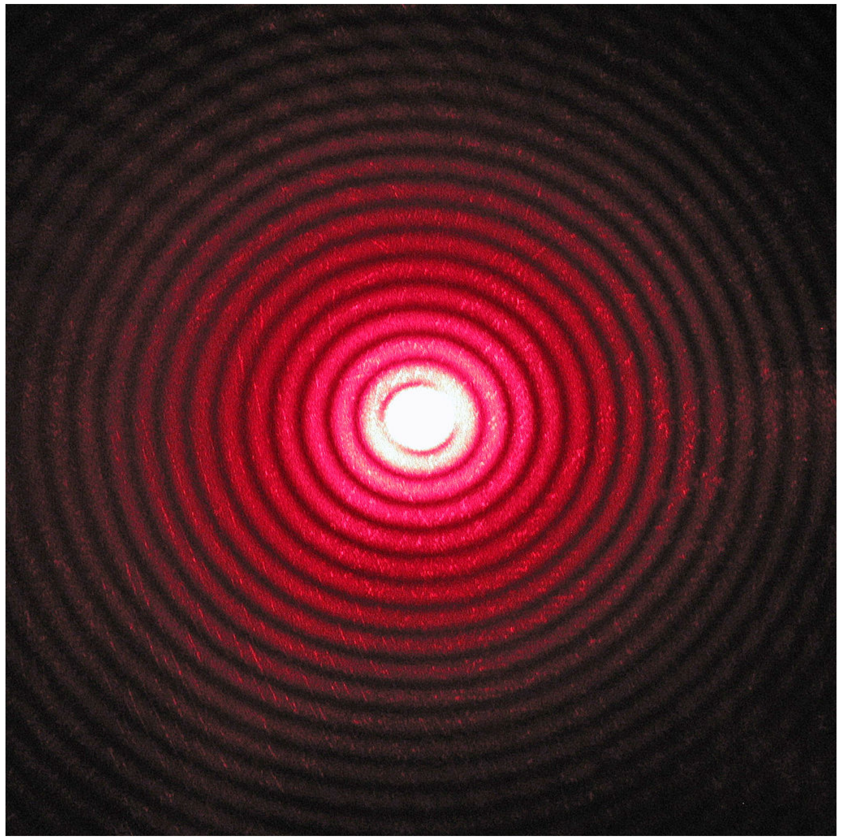
momentum transfer at the proton vertex

$$\frac{d\sigma}{dt} \sim e^{bt}$$

Exponential fit

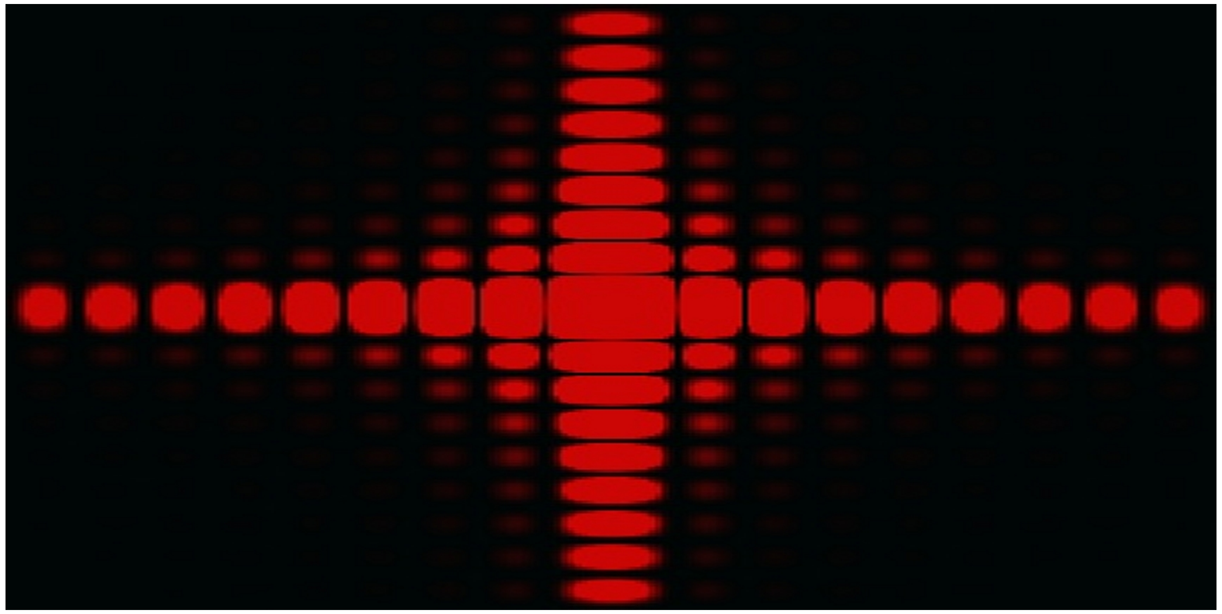
t-dependence of the elastic cross section provides information about the profile of the target

Diffraction in hadronic physics: analogy with optics



Source: Wikipedia
Author: Wisky

Circular aperture



Source: Wikipedia
Author: Epzcaw

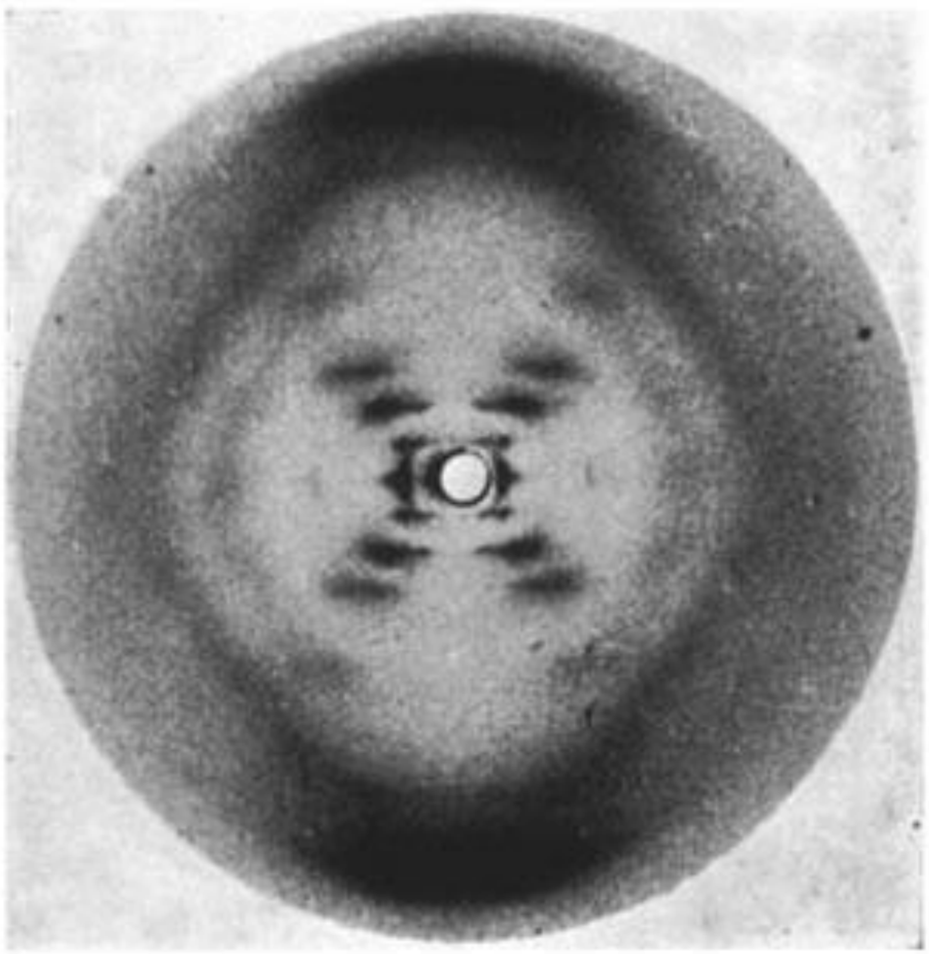
Rectangular aperture

The diffraction pattern (far away from obstacle) is a Fourier transform of the apertured field.

Diffraction pattern

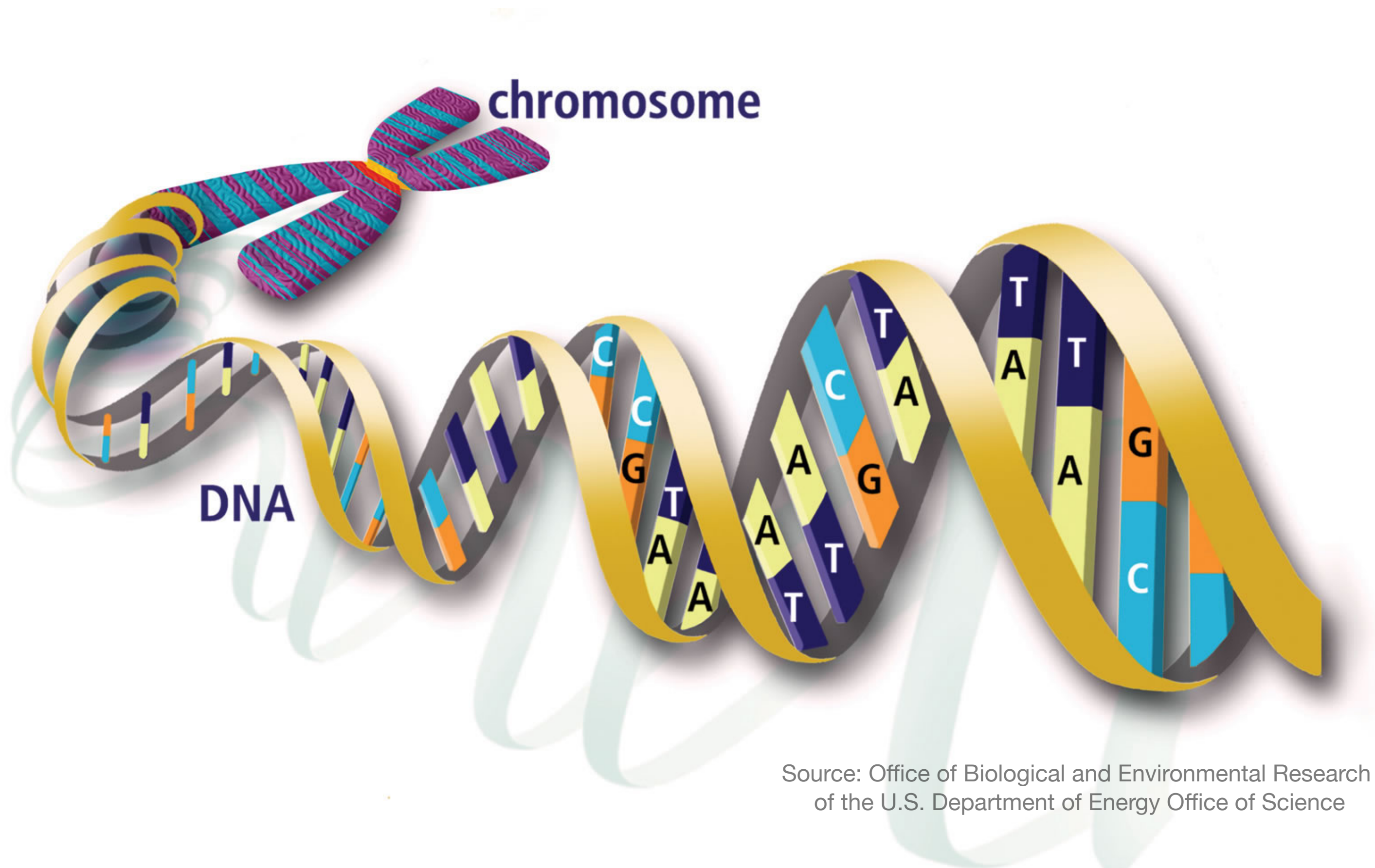
Photo 51

Gosling-Franklin



Source: Wikipedia

Watson-Crick



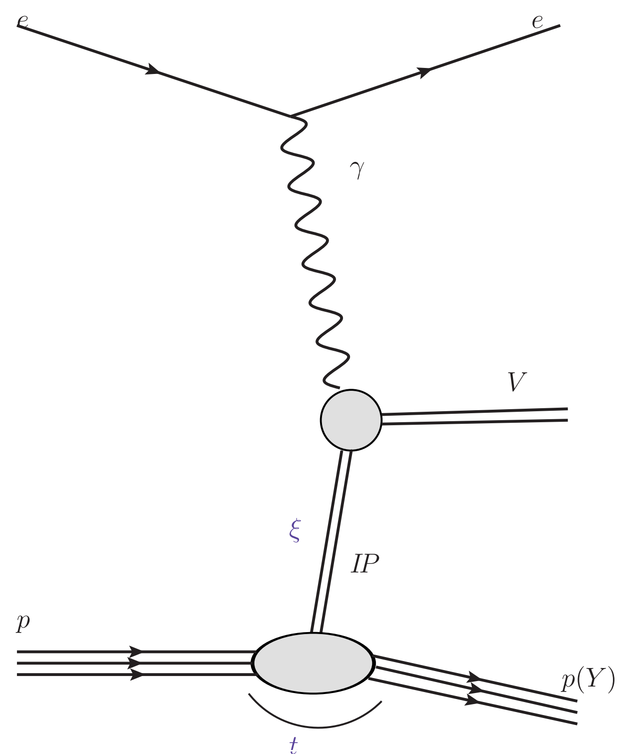
Source: Office of Biological and Environmental Research of the U.S. Department of Energy Office of Science

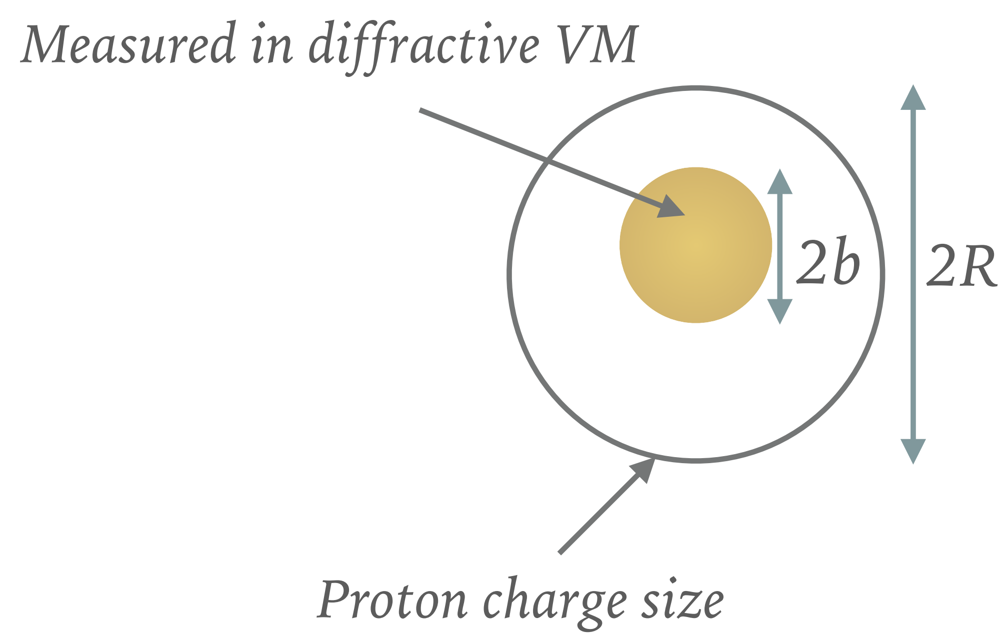
Diffraction can provide very detailed information about the structure of an object.

The object cannot be destroyed in this process.

Diffractive elastic VM production

Diffractive elastic vector meson production as a way to study nucleon structure





Radius measured in diffractive scattering of vector mesons

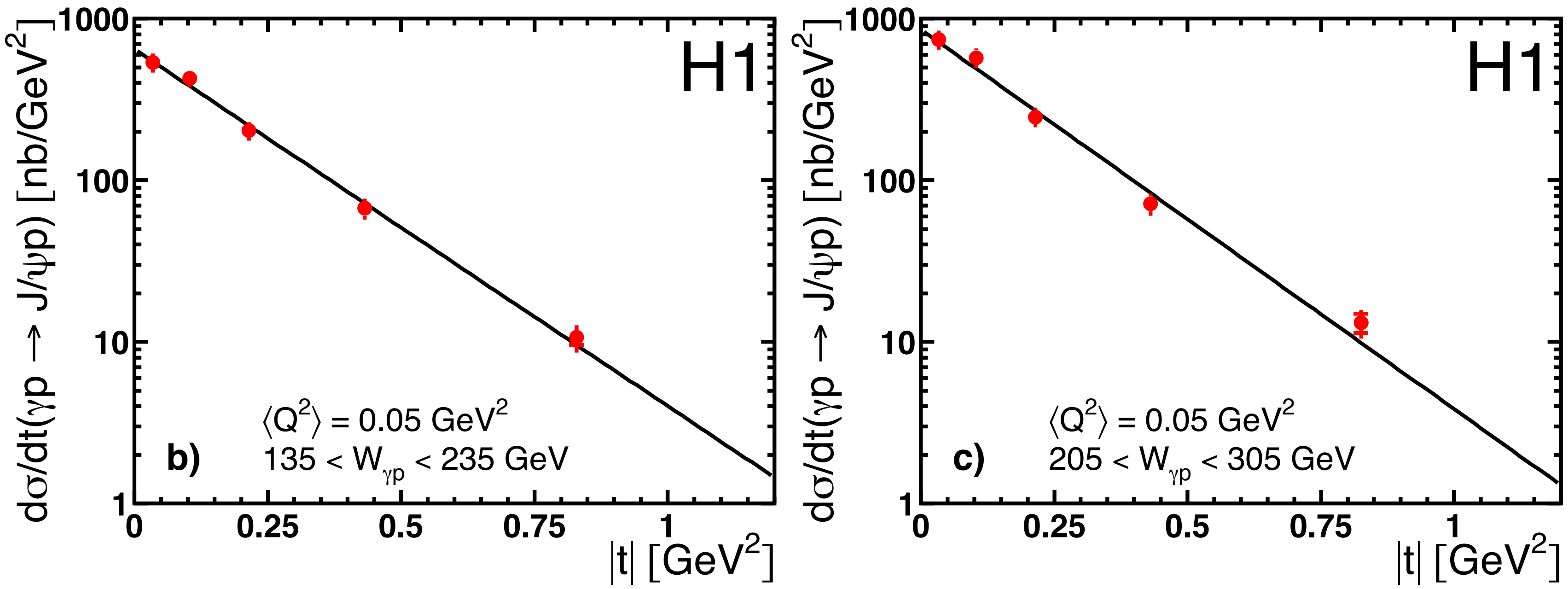
$$b \approx 0.5 \div 0.6 \text{ fm}$$

Proton charge radius

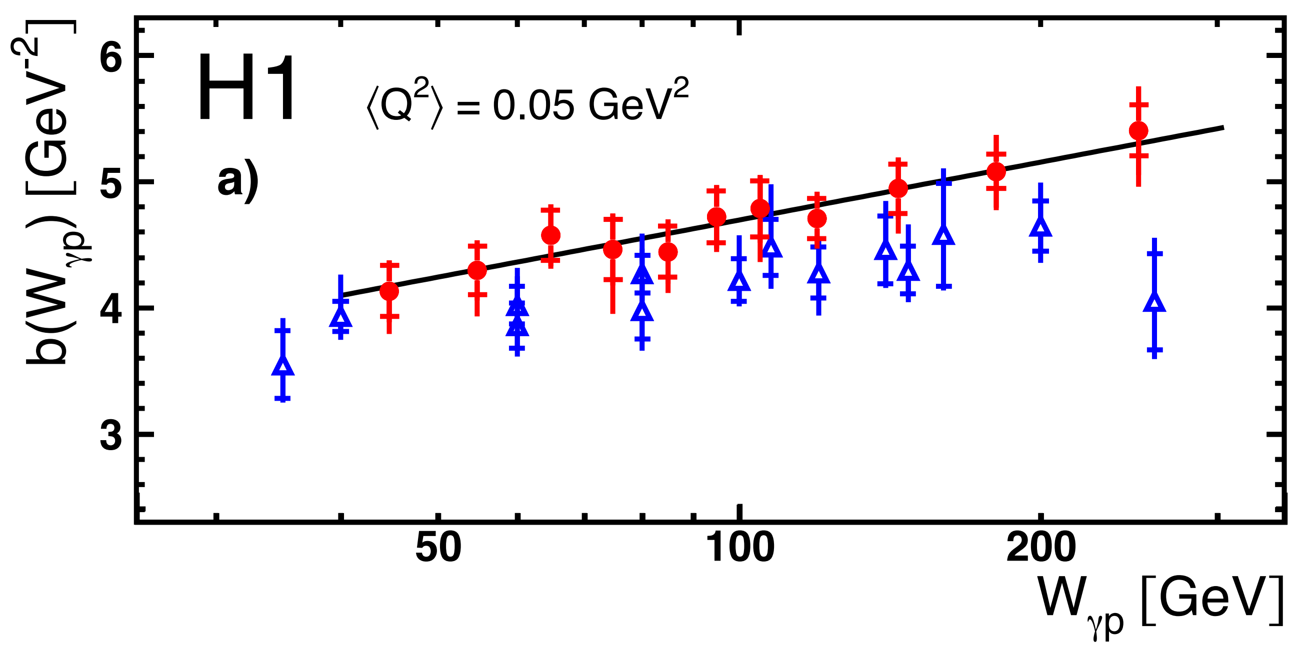
$$R \approx 0.84 \div 0.87 \text{ fm}$$

Experiments on elastic VM production suggest gluons are concentrated in smaller regions than quarks

Growth of the target size with energy



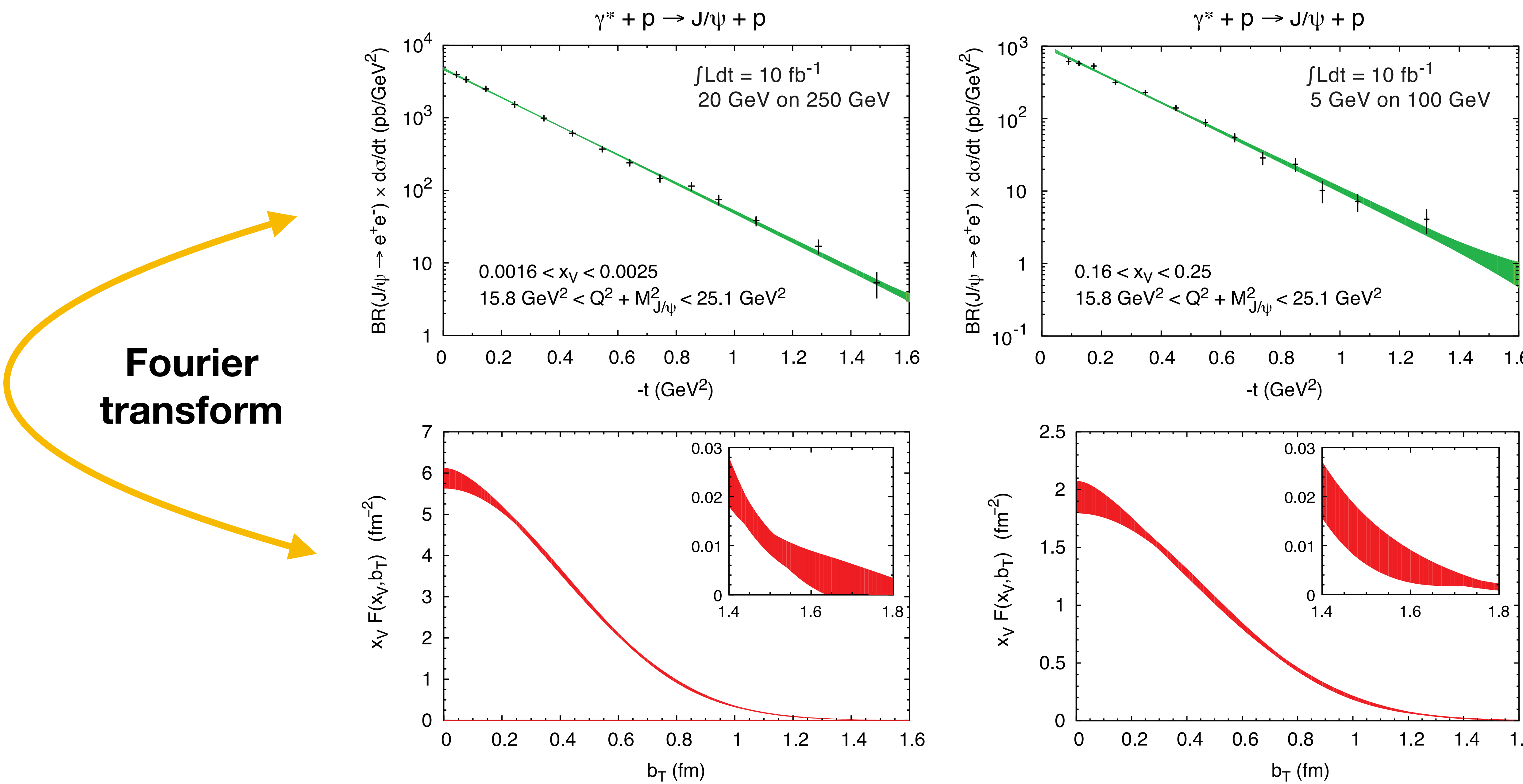
$$\frac{d\sigma}{dt} \sim e^{bt}$$



The slope growths with energy:

$$b(W) = b_0 + 4\alpha' \ln(W_{\gamma p}/W_0)$$

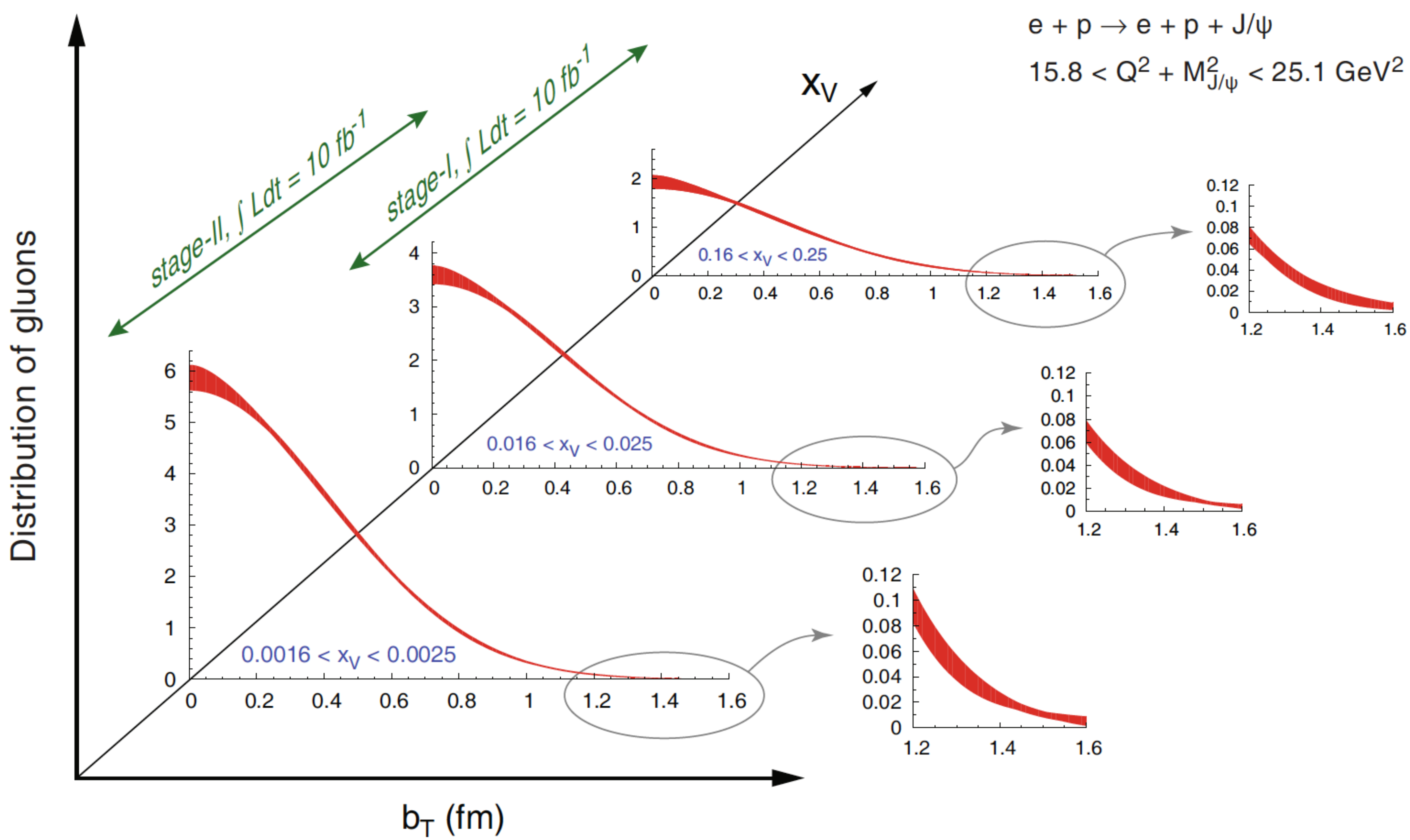
Elastic vector meson production at EIC



EIC, White paper

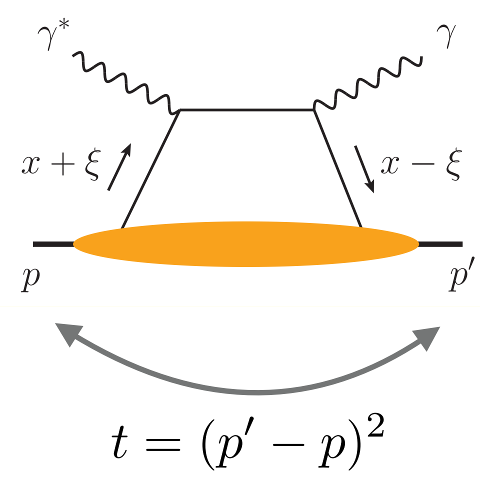
EIC: lower energy than HERA, different kinematics.
Very high statistics, high precision

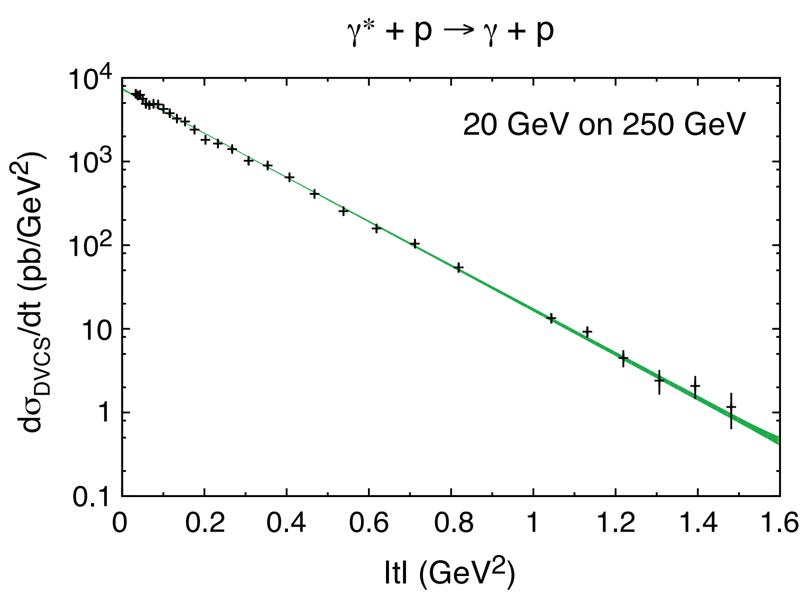
Profile function from elastic vector meson production



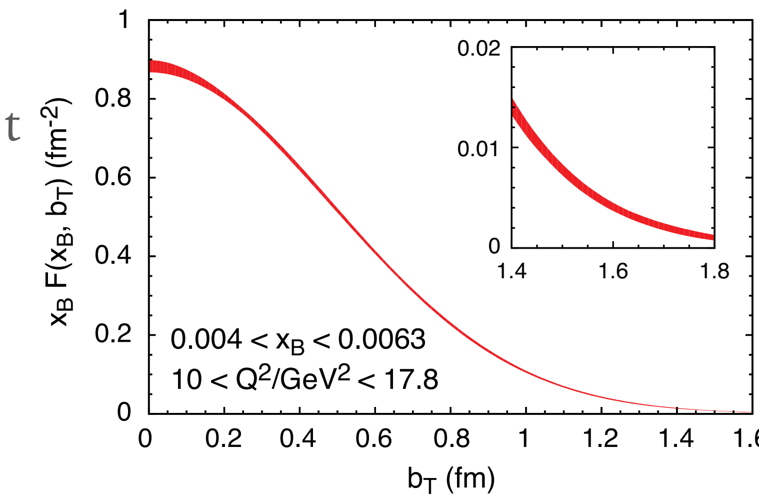
Imaging of nucleon: quarks

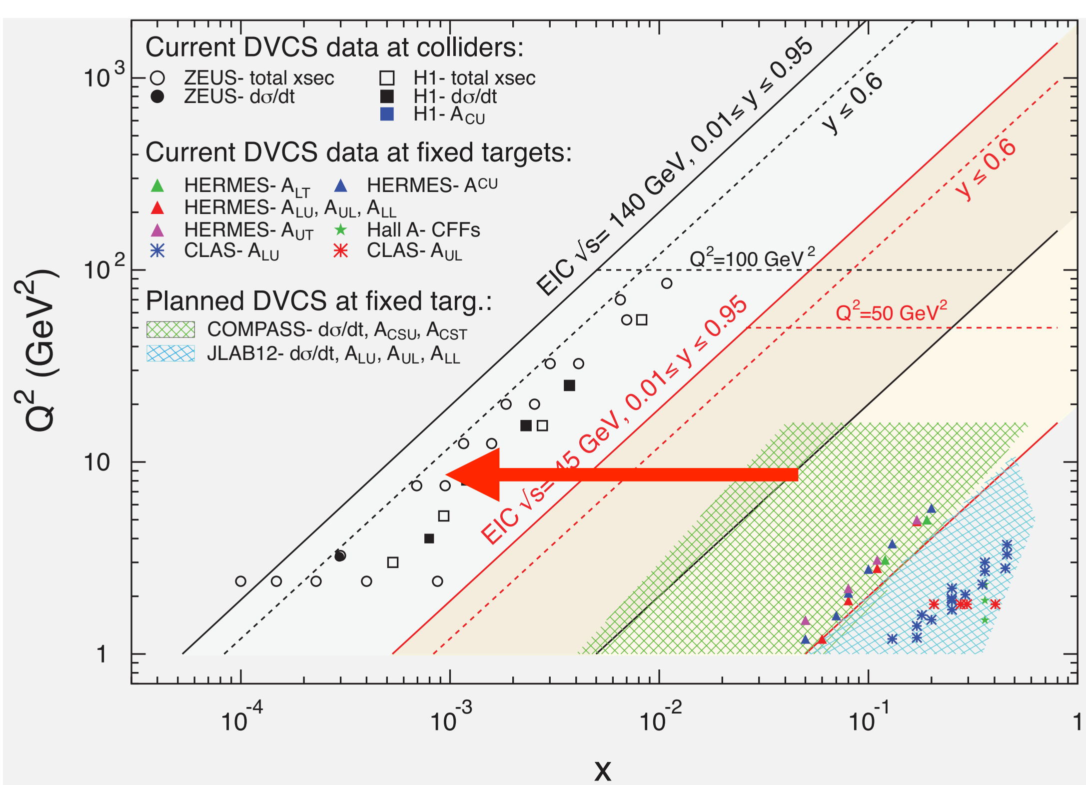
DVCS
Quark information

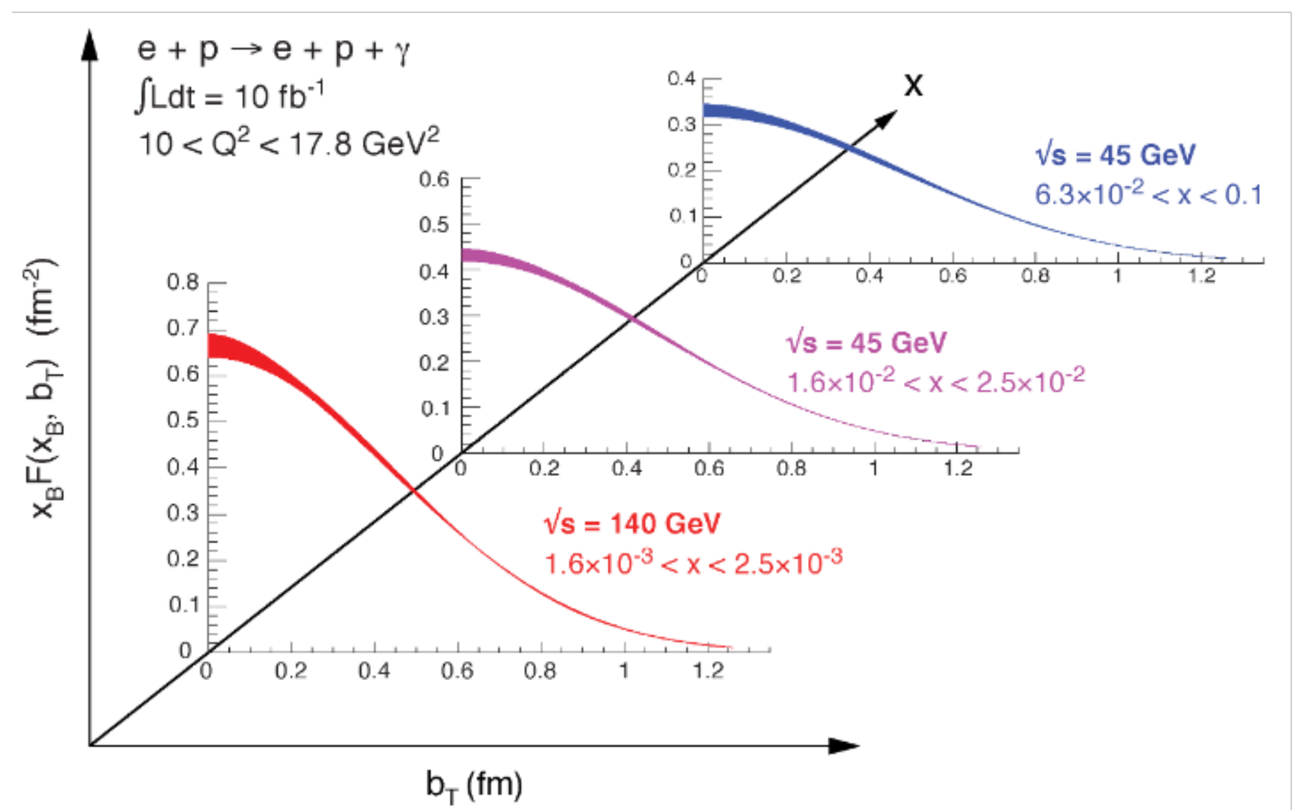




Fourier transform in t provides spatial distribution of quarks







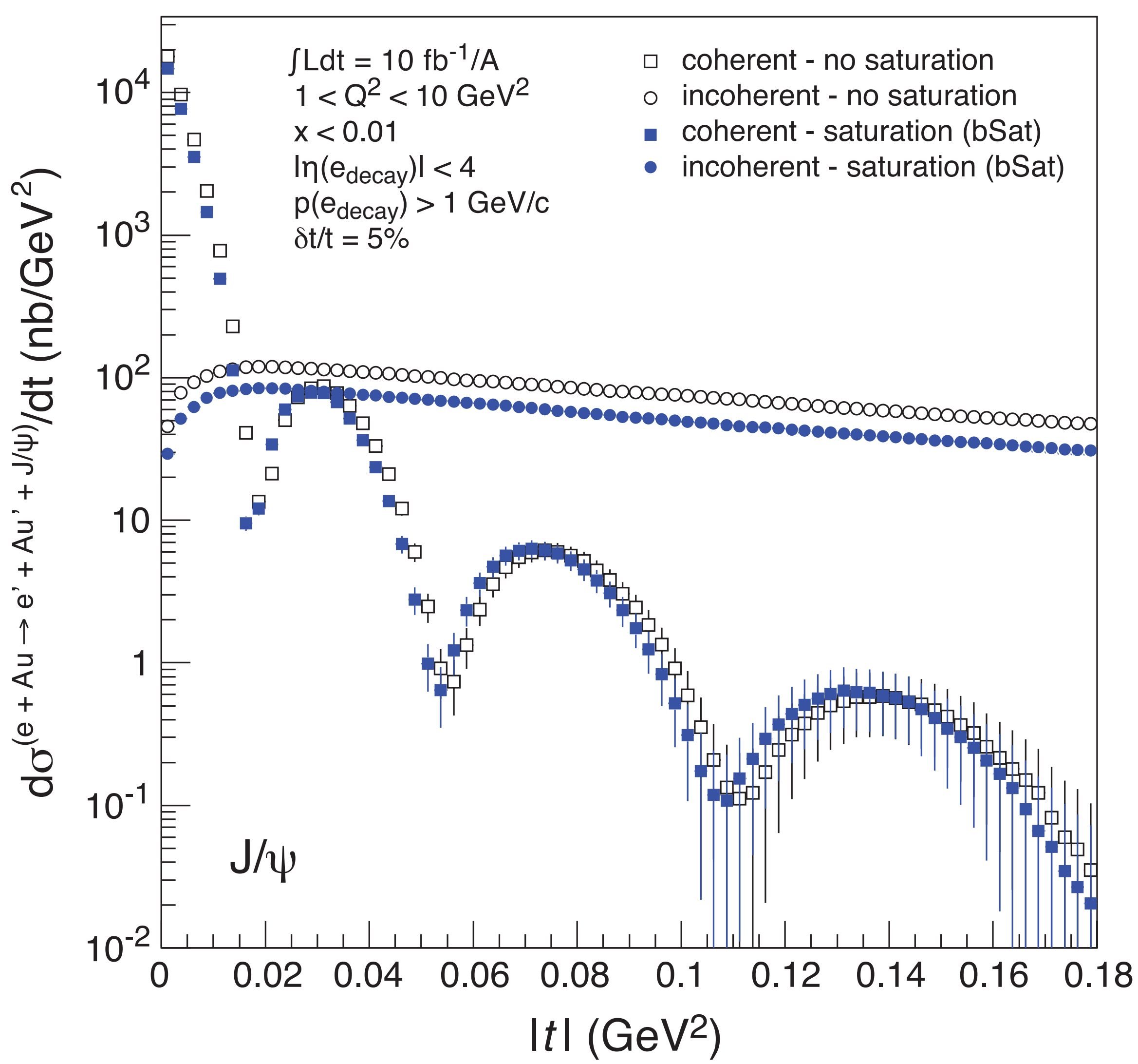
Elastic vector meson production at EIC : eA

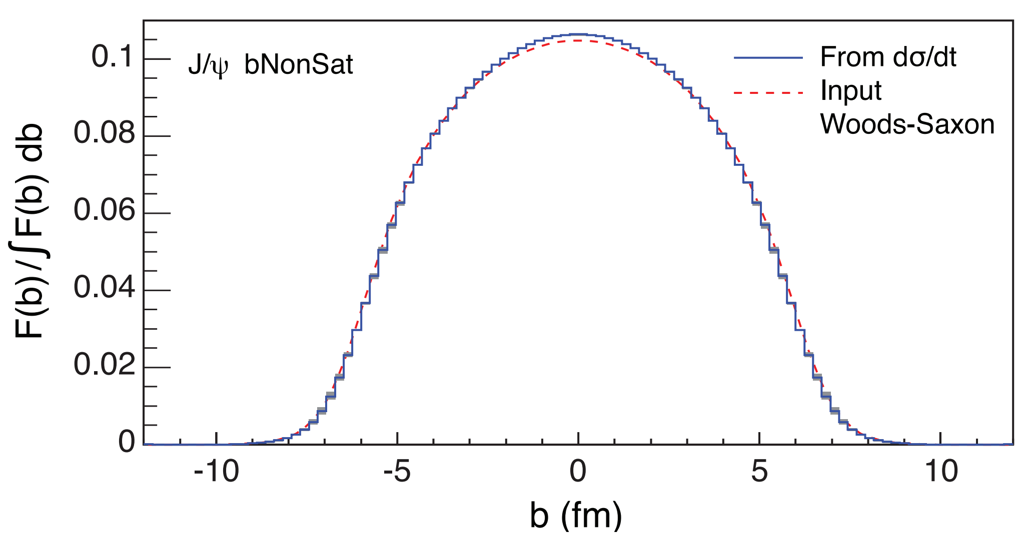
EIC, White paper

Nuclear target: Au

$$e + Au \rightarrow e + Au + J/\psi$$

Characteristic 'dips' in t-distribution

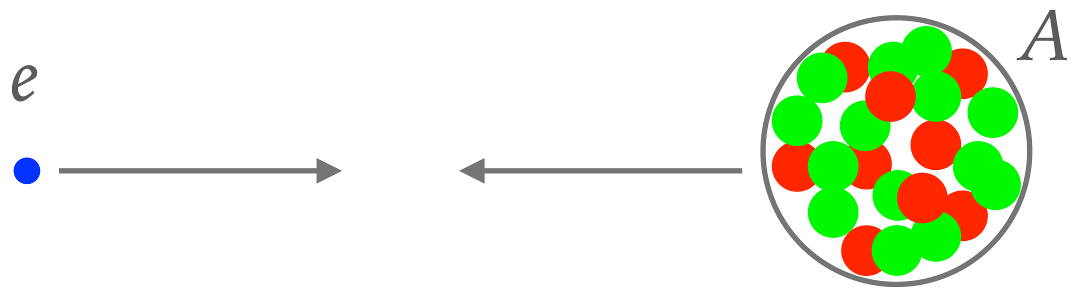




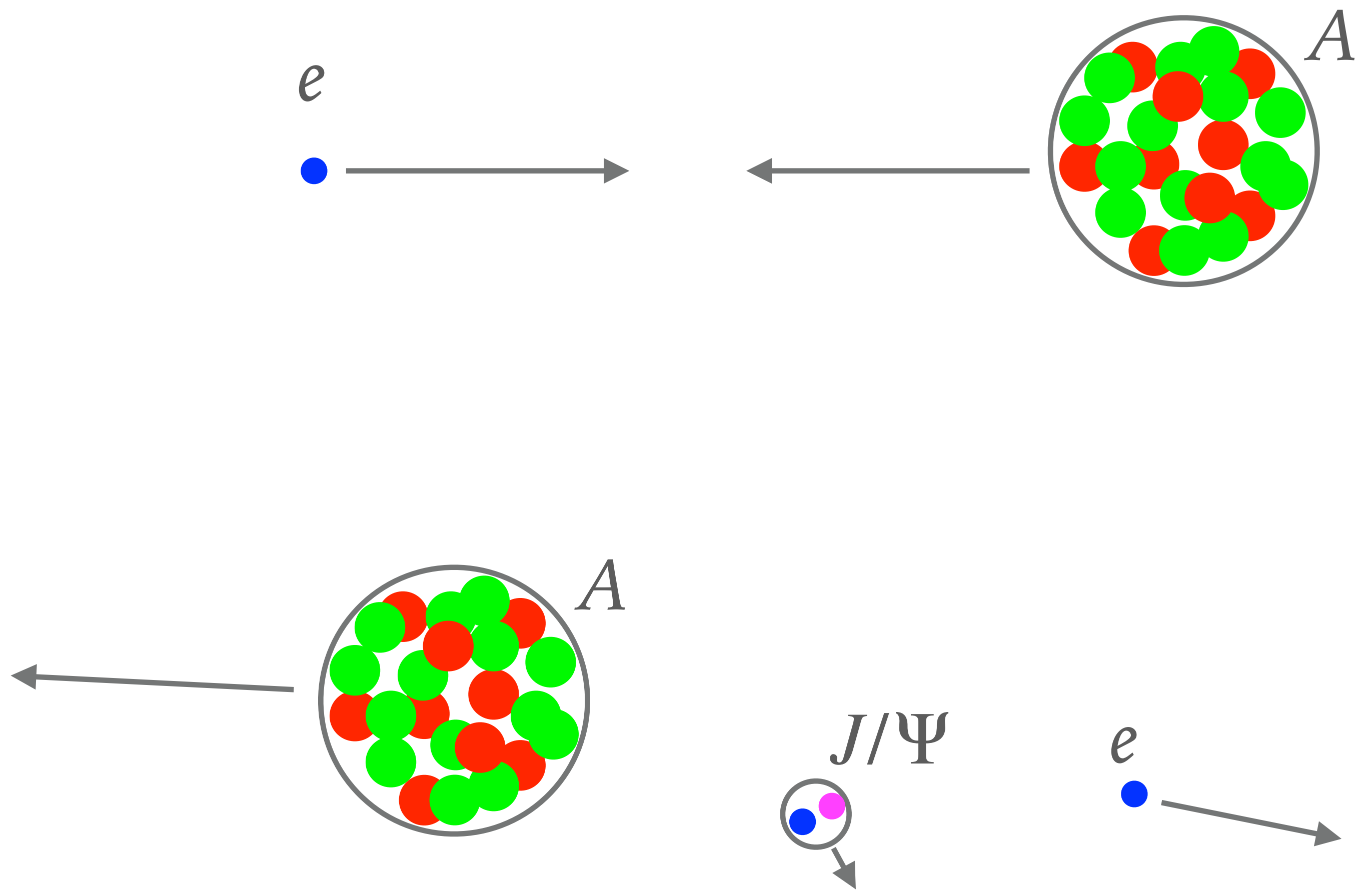
$$F(b) = \int_0^\infty \frac{q\,dq}{2\pi} J_0(qb) \sqrt{\frac{d\sigma_{\text{coherent}}}{dt}}$$

$$t = -q^2$$

Coherent vs incoherent

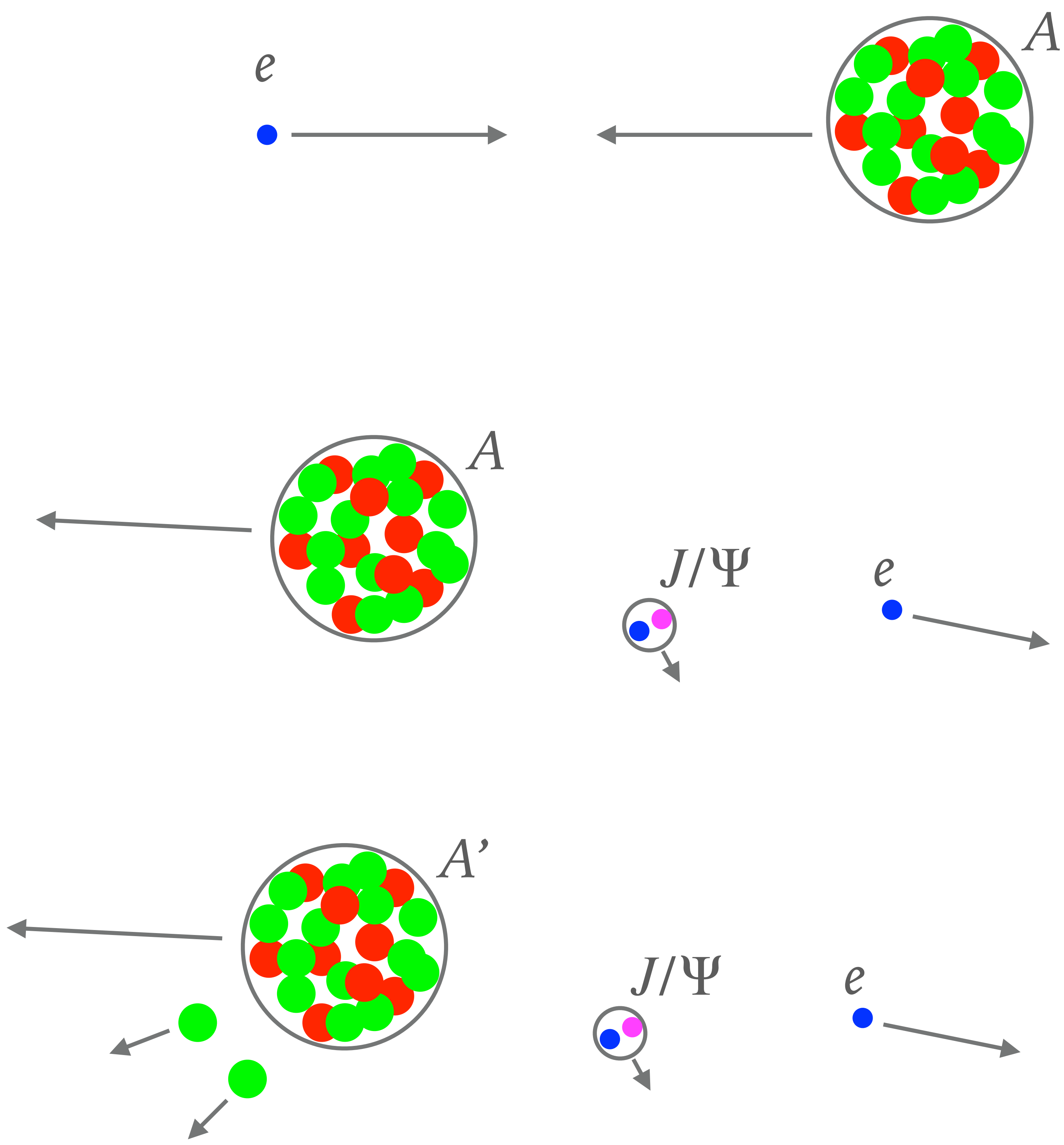


Coherent vs incoherent



Coherent
Nucleus stays intact

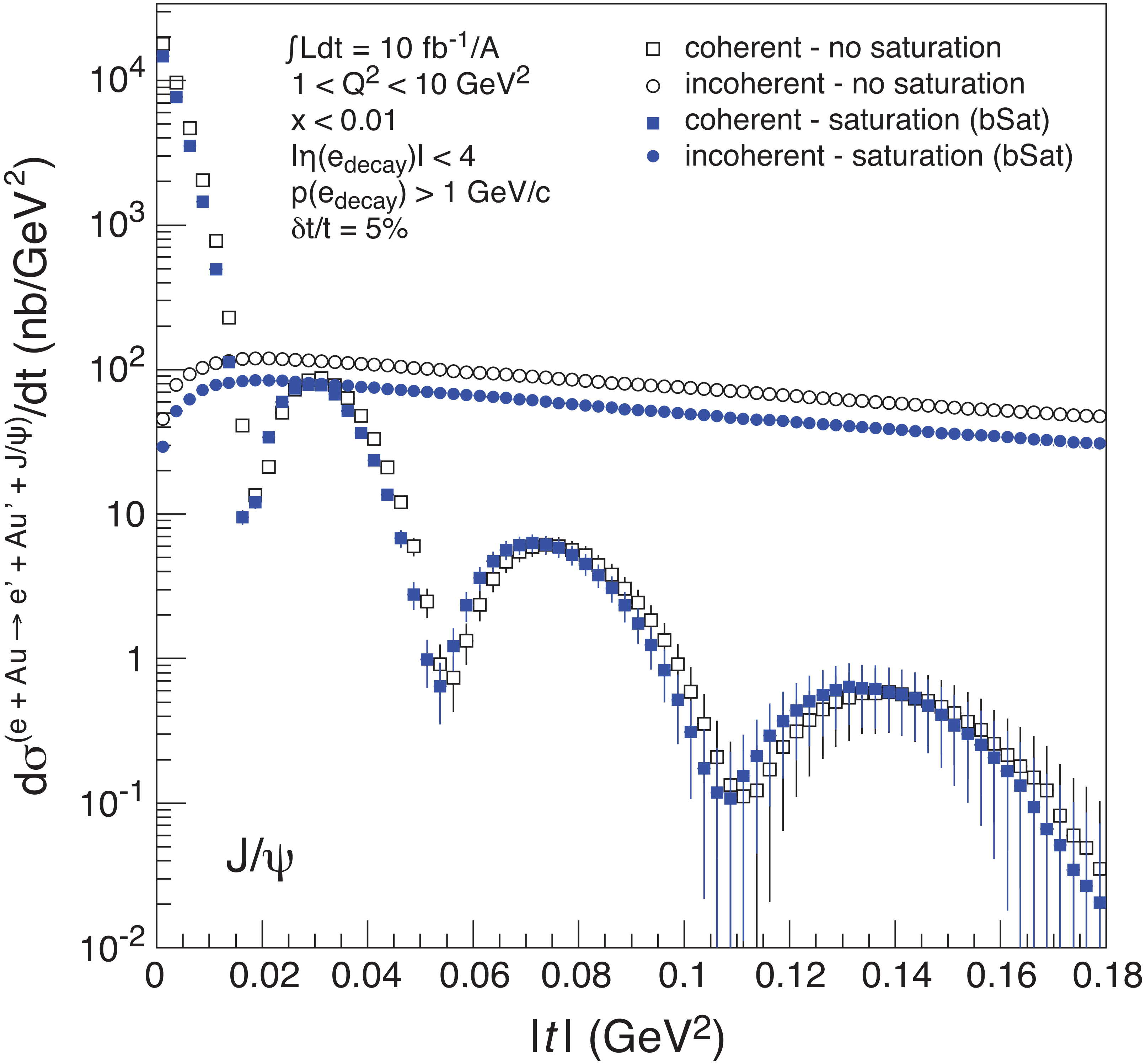
Coherent vs incoherent



Coherent
Nucleus stays intact

Incoherent
Nucleus breaks up

Coherent vs incoherent



Coherent:

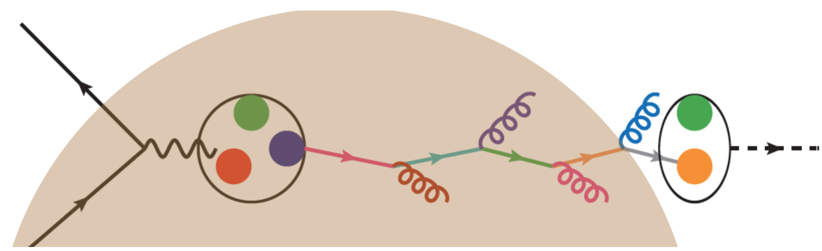
Depends on the shape of the source, average distribution

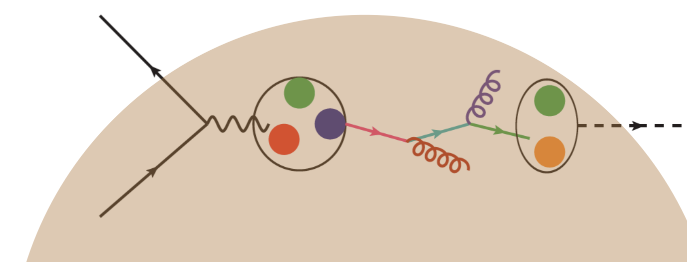
Incoherent:

Provides information about the fluctuations or lumpiness of the source

Passage of color charges through cold nuclear matter

- Modern theories of QCD in matter (such as $SCET_G$ and $NRQCD_G$) have enabled novel understanding of parton showers on matter. Capabilities to calculate higher order and resumed calculations in reactions with nuclei
- EIC will provide important input on **hadronization** mechanism in eA
- Different scenarios: **parton evolution in medium** or **hadron absorption**





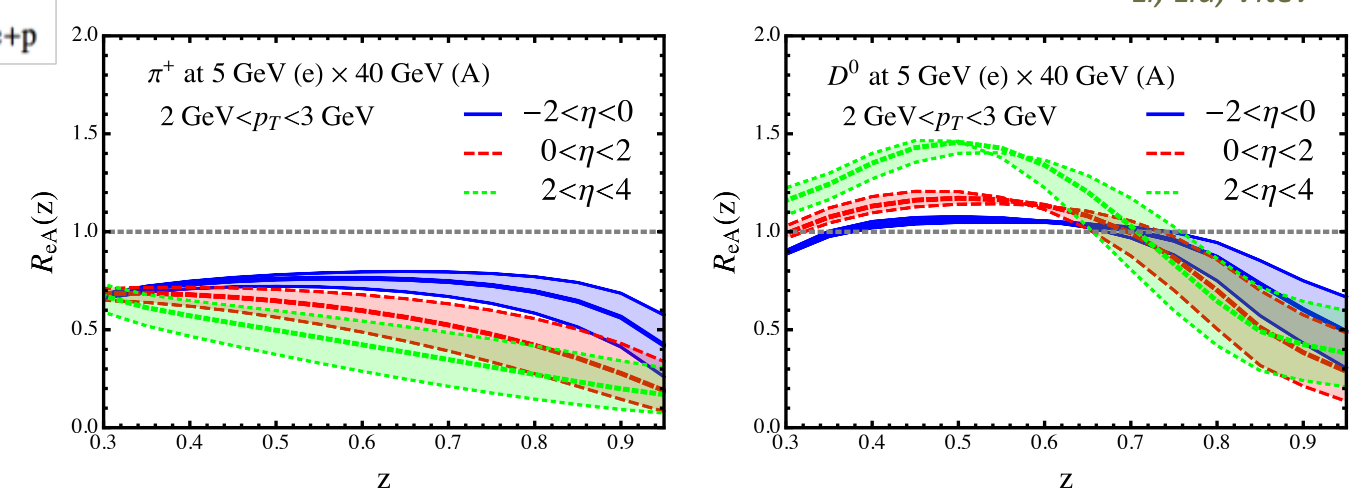
Parton energy loss and in-medium fragmentation function modification

$$\frac{d}{d\ln\mu^2}\tilde{D}^{h/i}(x,\mu) = \sum_j \int_x^1 \frac{dz}{z}\tilde{D}^{h/j}\left(\frac{x}{z},\mu\right)\left(P_{ji}(z,\alpha_s(\mu)) + P_{ji}^{\mathrm{med}}(z,\mu)\right)$$

$$R_{eA}^h(p_T,\eta,z) = \frac{\left.\frac{N^h(p_T,\eta,z)}{N^{\mathrm{inc}}(p_T,\eta)}\right|_{\mathrm{e+Au}}}{\left.\frac{N^h(p_T,\eta,z)}{N^{\mathrm{inc}}(p_T,\eta)}\right|_{\mathrm{e+p}}}$$

Modification (e+A vs e+p) of light vs heavy mesons vs the fragmentation fraction z

Li, Liu, Vitev



Constrain the space-time picture of hadronization.

Differentiate **energy loss** and **hadron absorption** models (based on ability to measure heavy flavors)

Lower energy beams better for this process

Jets as probes of cold nuclear matter

Jets emerged as a premier diagnostic tool for **hot** nuclear matter at RHIC and LHC

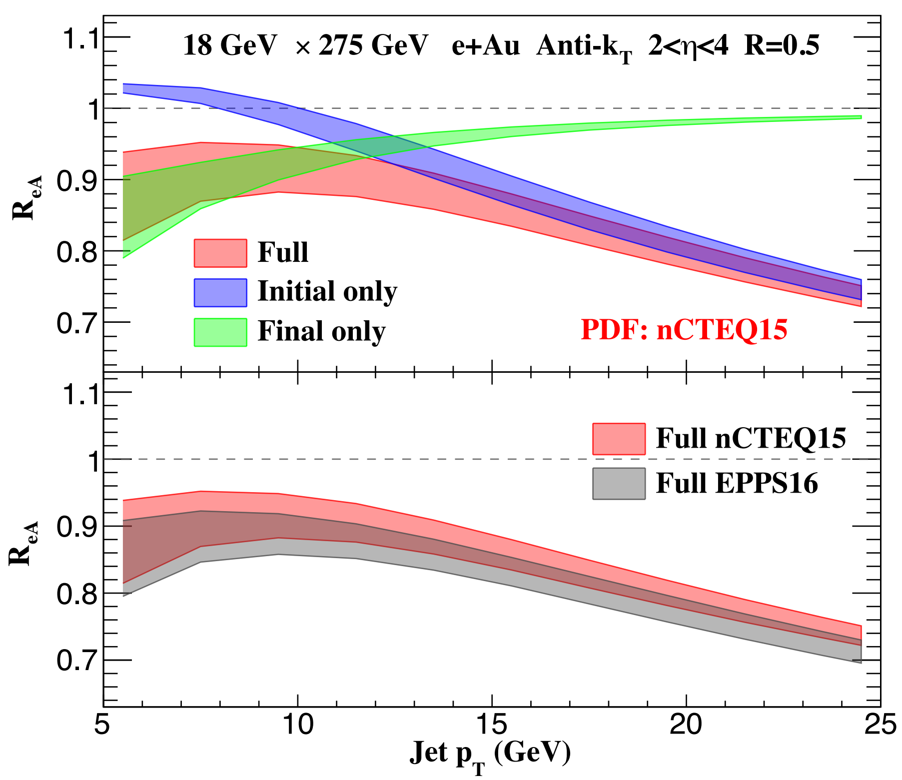
Also excellent probes for **cold** nuclear matter. Using jets, elucidate the properties of in-medium parton showers.

PDF — partonic cross section — jet function

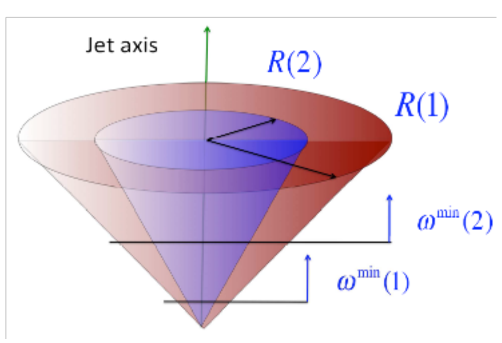
$$d\sigma \sim f_a(z,\mu) \otimes H_{ab}(x,z;p_T,\eta) \otimes J_b(z,\mu,R)$$

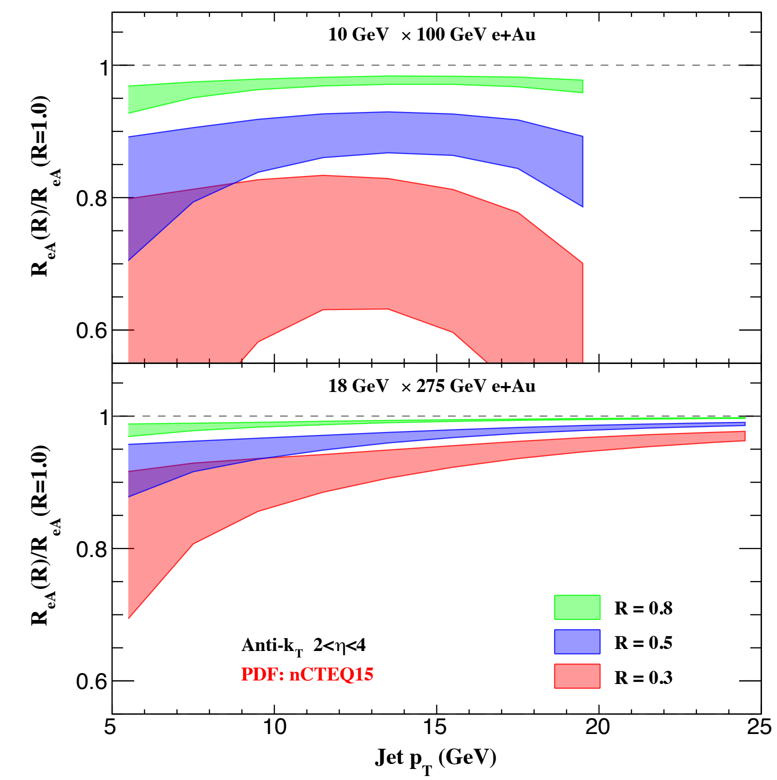
initial — final

Yellow Report



- IS (large and small p_T) vs FS (small p_T) contributions to nuclear ratio
- Small nPDF effects
- Ratios with different jet cone allow to separate parton shower effects



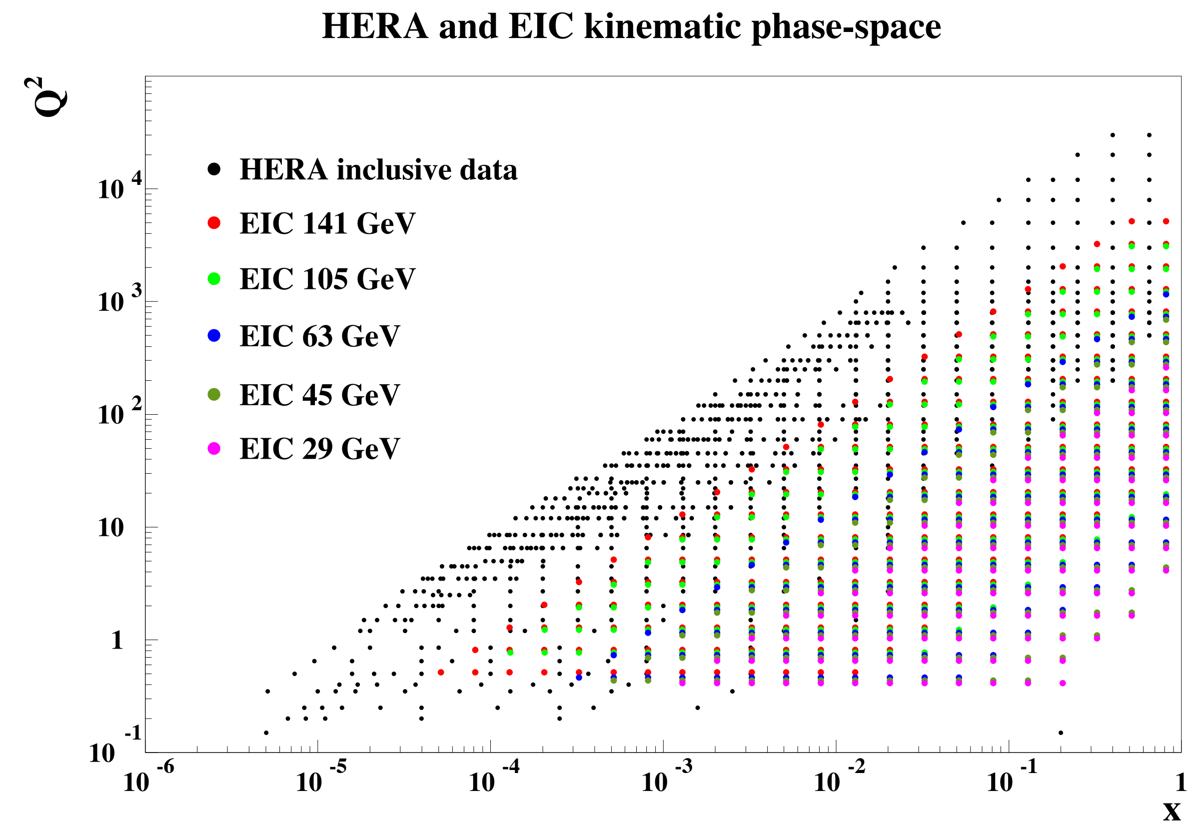


Li, Vitev

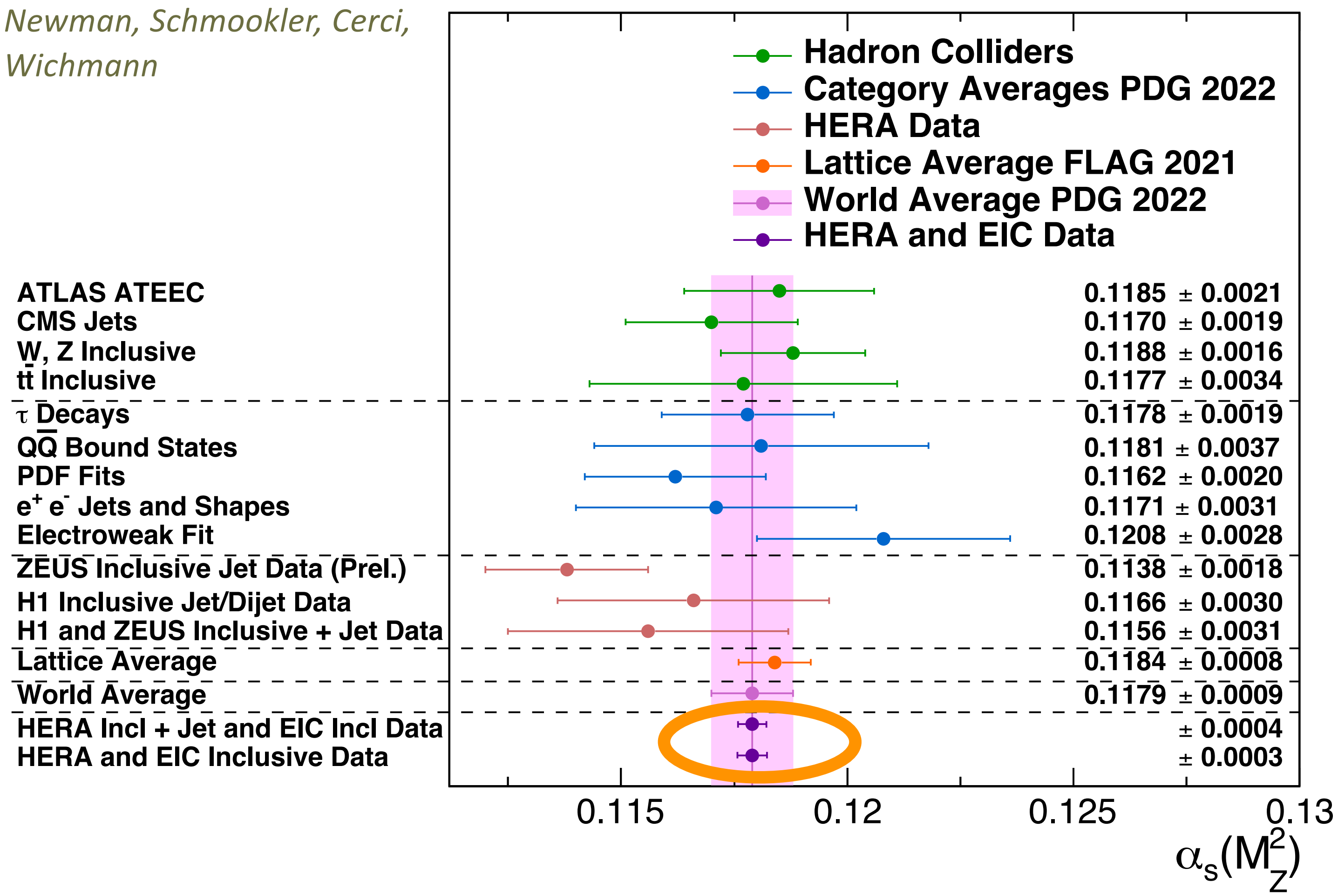
- Pioneer jet **substructure** studies with heavy quark initiated jets performed in a EIC regime very different from the one probed in heavy ion collisions *Li, Liu, Vitev*
- Pave the way to a qualitatively new level of understanding of the role of **heavy quark mass**

Extraction of α_s from HERA and EIC

- Inclusive DIS cross section sensitive to α_s
- Need to know with **high precision**, α_s essential for **SM** calculations, and for constraints on **BSM**
- EIC complementary to HERA



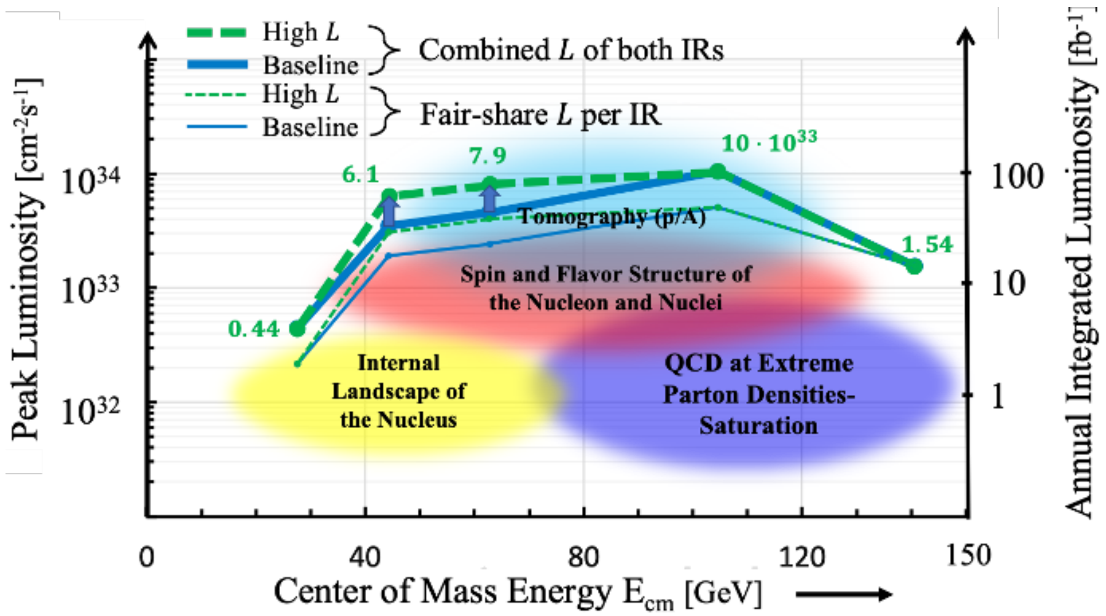
Cerci, Demiroglu, Deshpande, Newman, Schmookler, Cerci, Wichmann

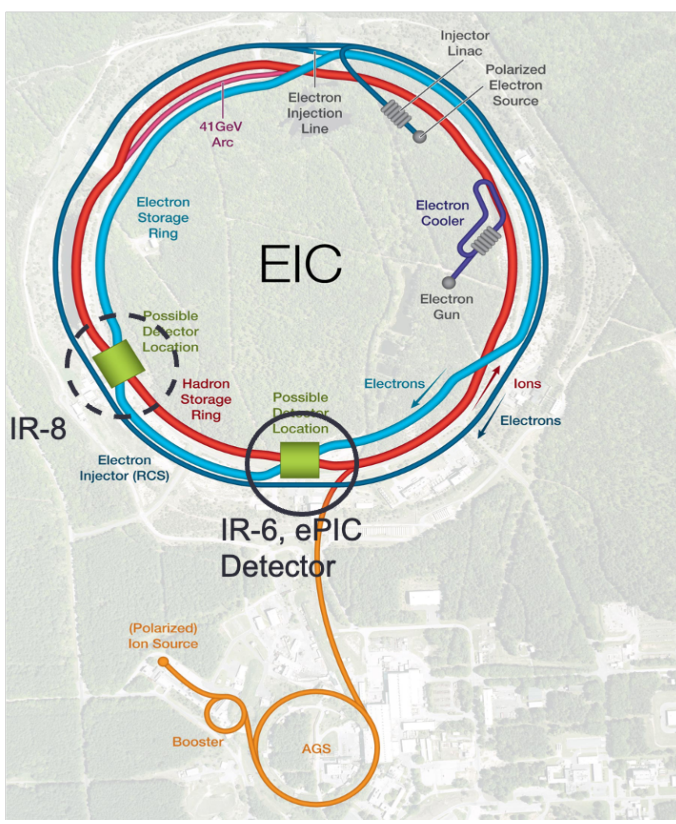


HERA inclusive (or inclusive + jets) + EIC inclusive data allows for **determination of α_s** with **unprecedented precision :** $\leq 0.3\,\%$

$$\alpha_s(M_Z^2) = 0.1161 \pm 0.0003\ (\mathrm{exp}) \pm 0.0001(\mathrm{model} + \mathrm{param})\ {}^{+0.0002}_{-0.0001}\ (\mathrm{scale})$$

Machine design and parameters



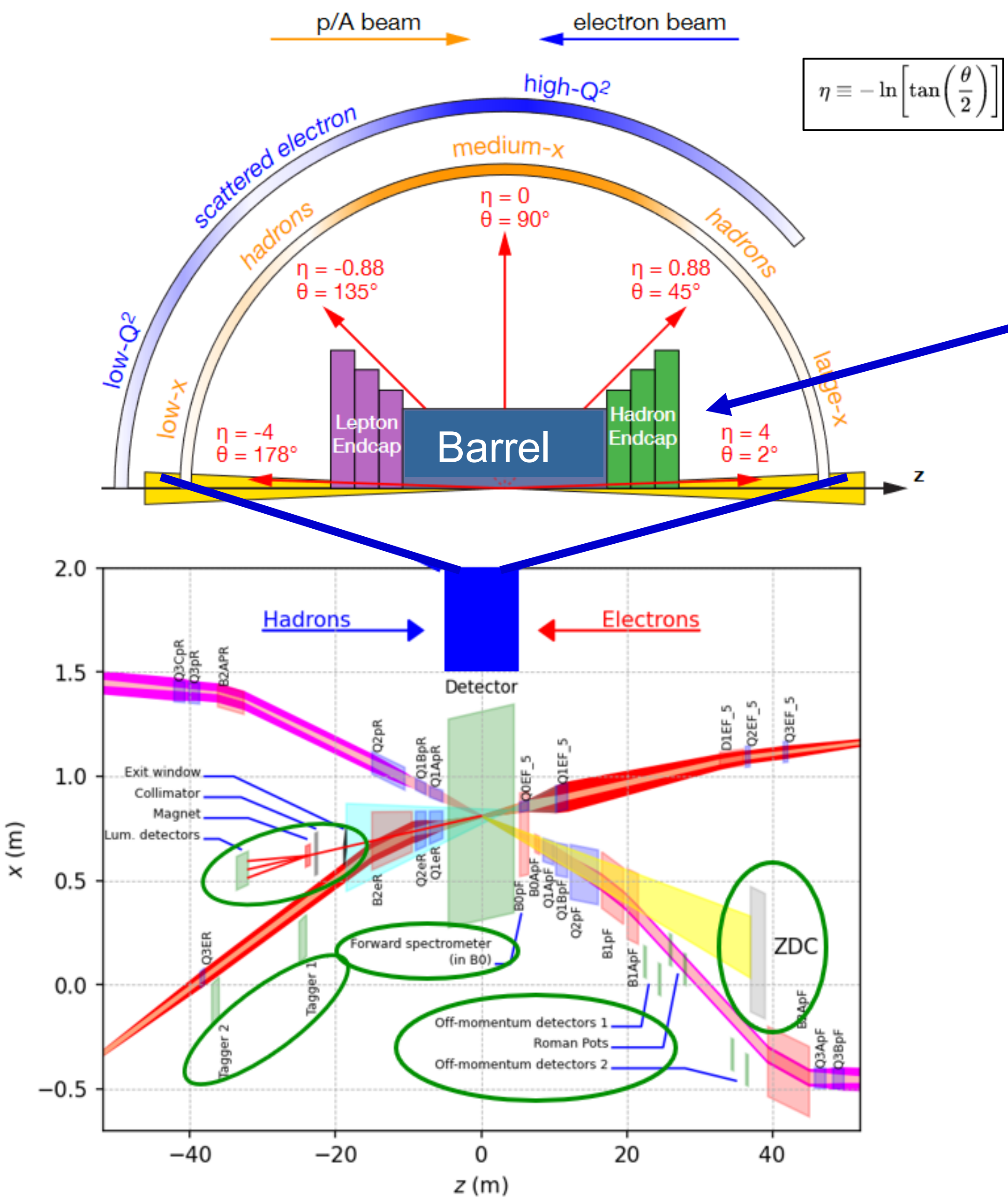


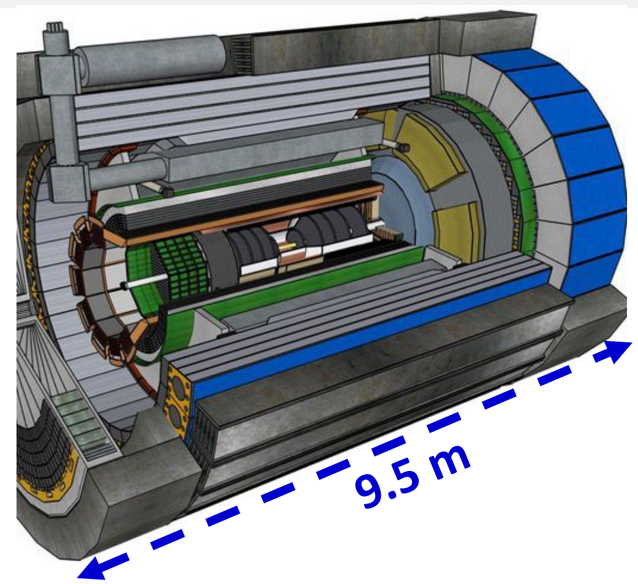
- **Hadron storage ring (HSR): 41-275 GeV** (based on RHIC)
  - up to 1160 bunches, 1A beam current (3x RHIC)
  - bright vertical beam emittance (1.5 nm)
  - strong cooling (coherent electron cooling, ERL)
- **Electron storage ring (ESR): 2.5–18 GeV** (new)
  - up to 1160 polarized bunches
  - high polarization by continual reinjection from RCS
  - large beam current (2.5 A) ➔ 9 MW SR power
  - superconducting RF cavities
- **Rapid cycling synchrotron (RCS): 0.4-18 GeV** (new)
  - 2 bunches at 1 Hz; spin transparent due to high periodicity
- **High luminosity interaction region(s)** (new)
  - $L = 10^{34}$ $cm^{-2}s^{-1}$
  - superconducting magnets
  - 25 mrad crossing angle with crab cavities
  - spin rotators (produce longitudinal spin at IP)

Detector: ePIC

Slide from S. Dalla Torre talk at EICUG

ePIC, an extended detector





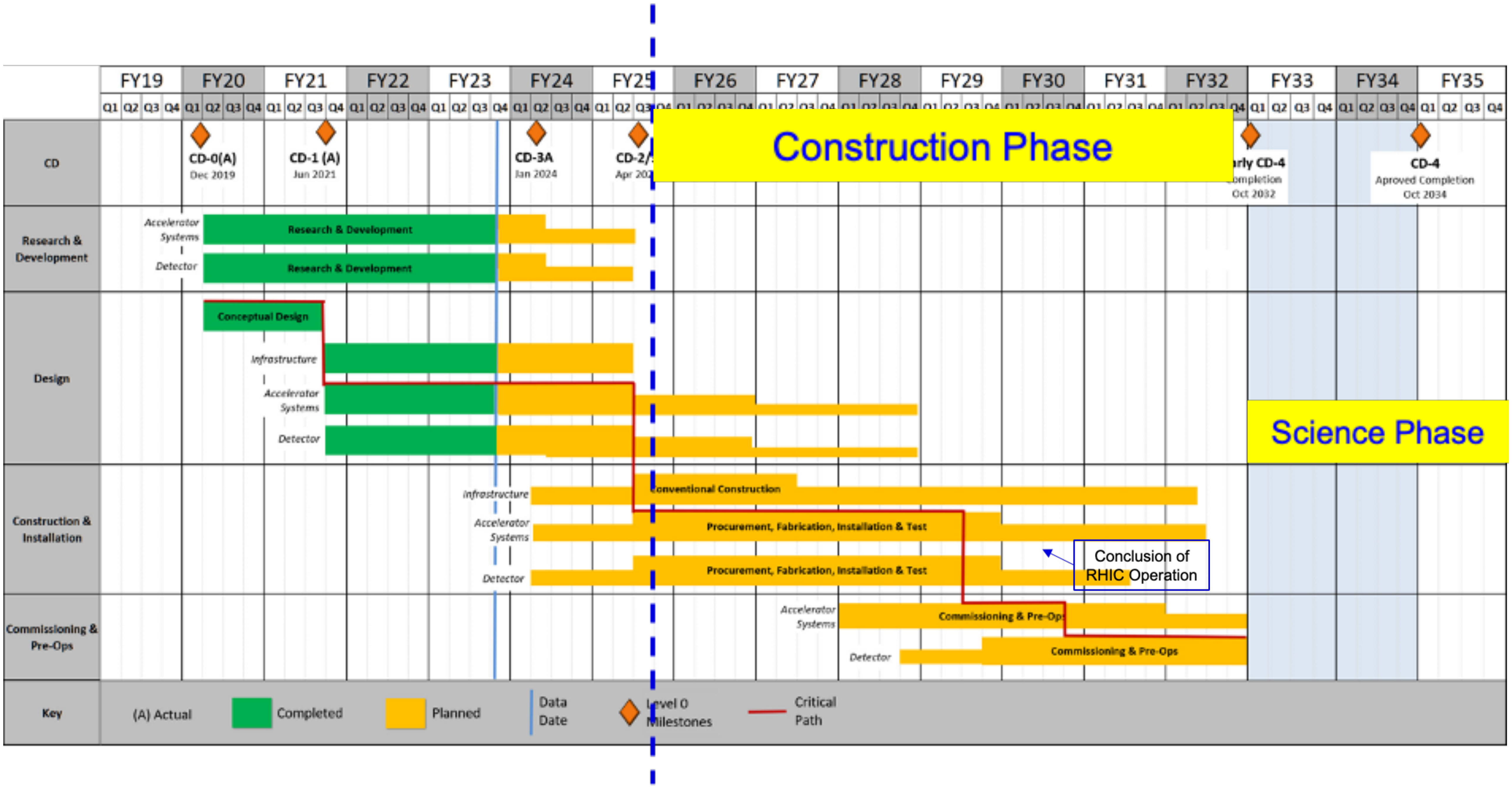
Central Detector (CD)

Total size detector: ~75m
Central detector: ~10m
Far Backward electron detection: ~35m
Far Forward hadron spectrometer: ~40m

Auxiliary detectors needed to tag particles with very small scattering angles both in the outgoing lepton and hadron beam direction (B0-Taggers, Off-momentum taggers, Roman Pots, Zero-degree Calorimeter and low Q2-tagger).

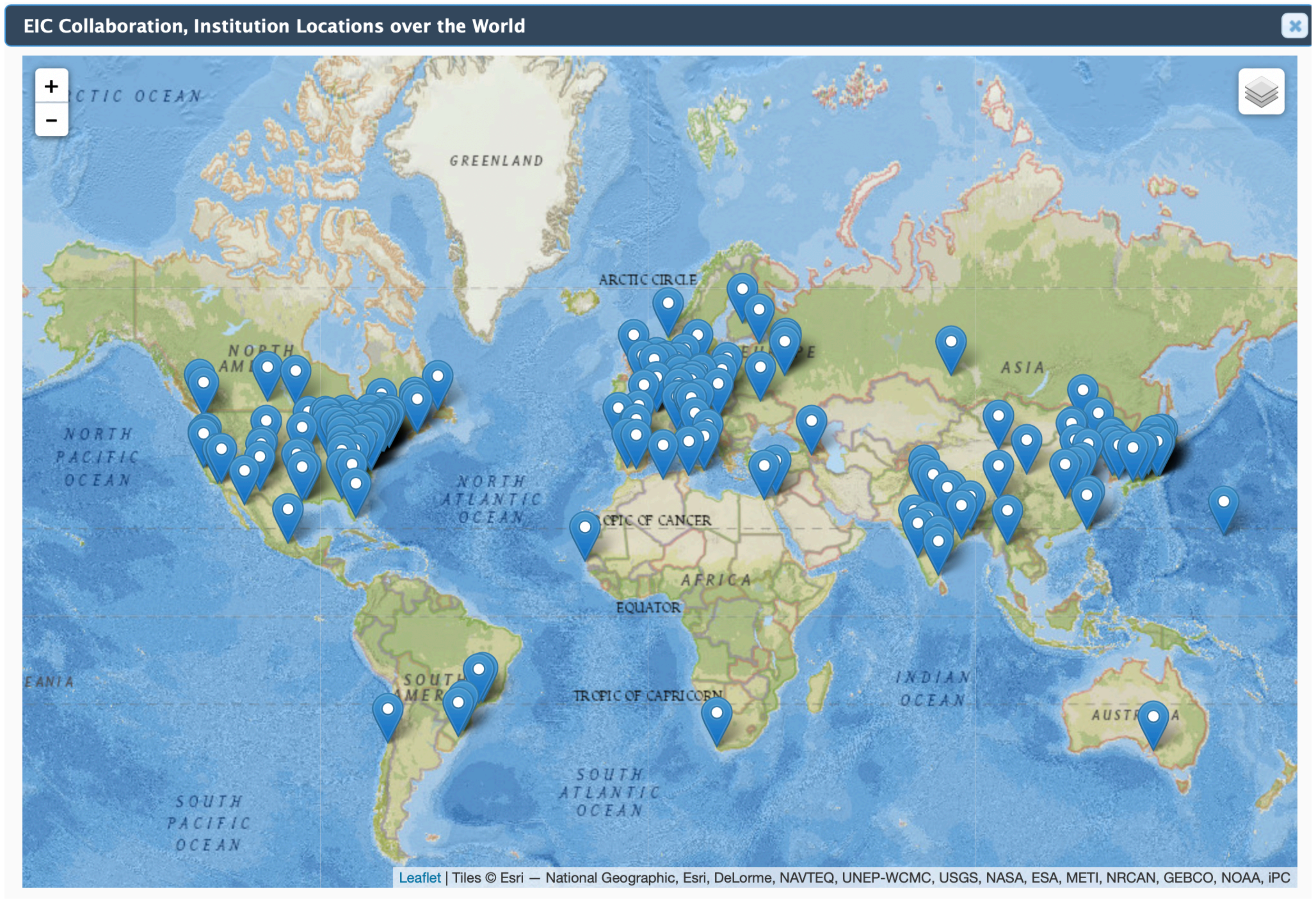
EICUG annual meeting, July 25-26, 2023 ePIC Collaboration (J. Lajoie, S. Dalla Torre) 19

Timeline


FY19 FY20 FY21 FY22 FY23 FY24 FY25 FY26 FY27 FY28 FY29 FY30 FY31 FY32 FY33 FY34 FY35
CD
CD-0(A)
Dec 2019
CD-1 (A)
Jun 2021
CD-3A
Jan 2024
Construction Phase
CD-4
Aproved Completion
Oct 2034
Research & Development
Accelerator Systems
Detector
Research & Development
Design
Conceptual Design
Infrastructure
Accelerator Systems
Detector
Science Phase
Construction & Installation
Infrastructure
Conventional Construction
Accelerator Systems
Procurement, Fabrication, Installation & Test
Detector
Procurement, Fabrication, Installation & Test
Conclusion of RHIC Operation
Commissioning & Pre-Ops
Accelerator Systems
Detector
Commissioning & Pre-Ops
Key
(A) Actual
Completed
Planned
Data Date
Critical Path

EIC Users Group

The **Electron-Ion Collider User Group (EICUG)** is an international affiliation of scientists dedicated to developing and promoting the scientific, technological, and educational goals and motivations for a new high energy **Electron-Ion Collider**.



1435 members

- 905 experimentalists
- 363 theorists
- 151 accelerator scientists
- 10 computer scientists
- 3 support
- 3 other

295 institutions

40 countries

https://www.eicug.org/index.html

Status as of December 4, 2023

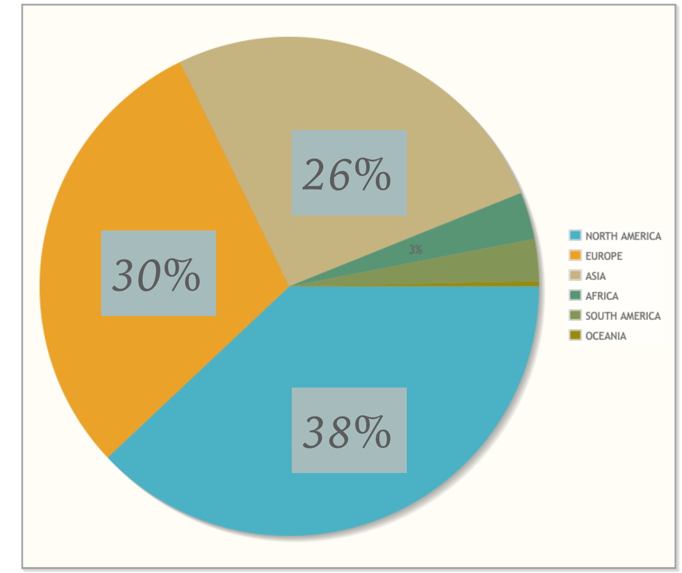
EIC Users Group

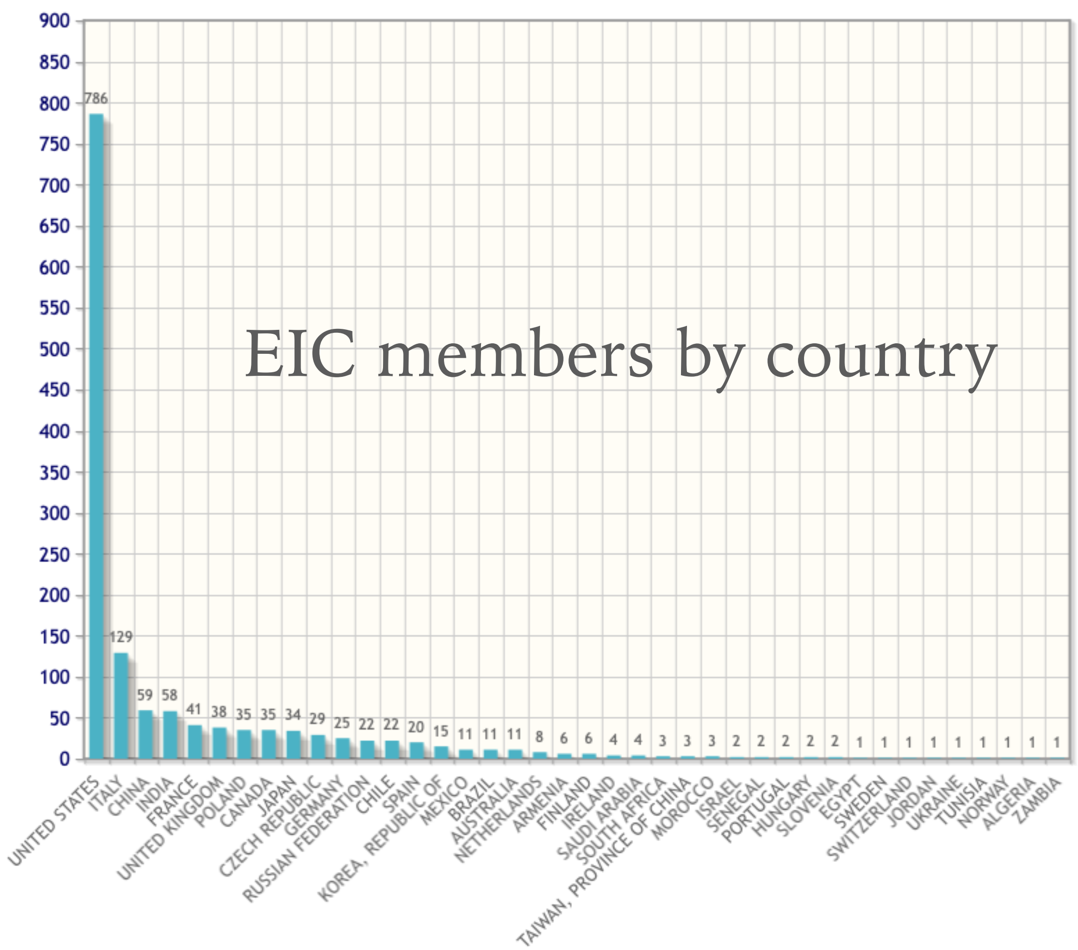
EIC is international at its core

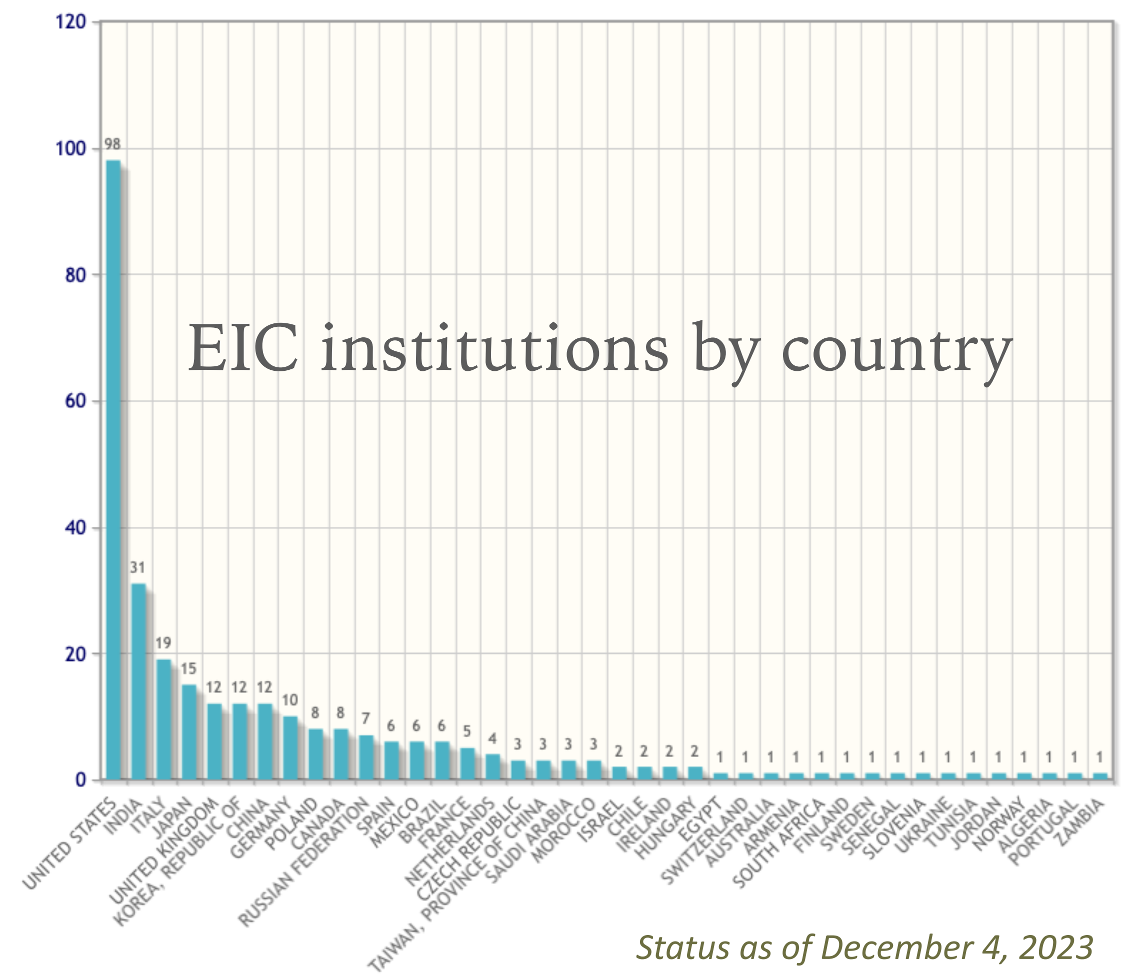
Over 60% institutions are outside US

Last annual meeting: July 25-31, 2023, Warsaw, Poland

Strong community and still growing !







Status as of December 4, 2023

Summary

Electron Ion Collider : high energy, high luminosity, polarized, electron-proton and electron-ion collider, funded by DoE, will be built in this decade and start operating in 2030's

- **Precision tool** which will address most profound unanswered questions in QCD
- One of the most **challenging** and **versatile** accelerator complexes ever built
- EIC is a project with strong **international** engagement
- **ePIC** collaboration: 1st detector collaboration formed
- **2nd** detector: under consideration, needs additional funding

Please join and contribute! *Everybody is welcome: engineers, designers, technicians, administrators, theorists, experimentalists, accelerator physicists…*

Especially early career scientists: *postdocs, undergraduate and graduate students…*