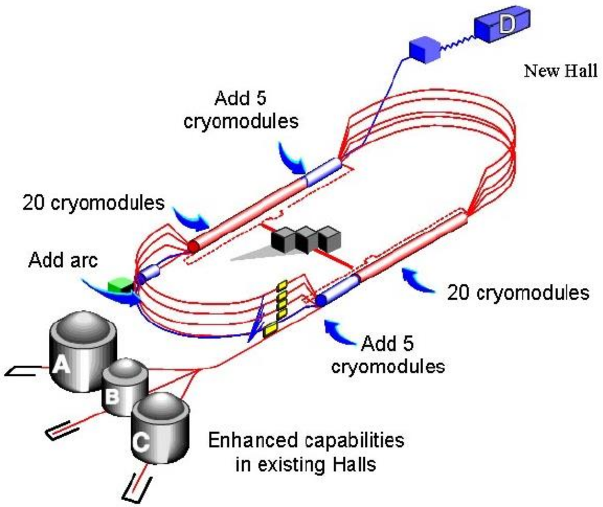
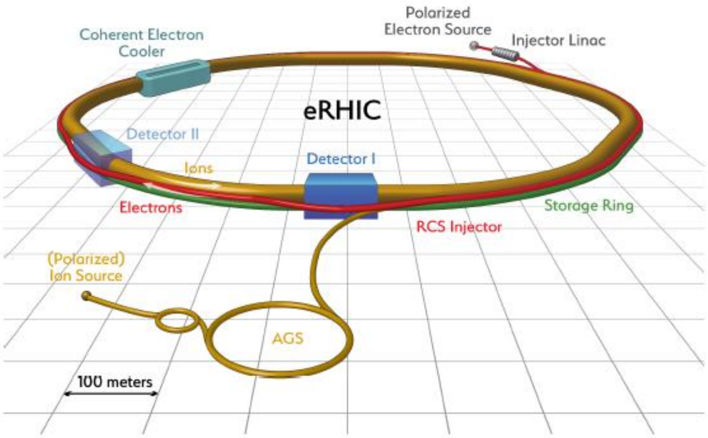
Instrumentation R&D for hadron physics at Jefferson Lab and the future EIC





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(IJCLab, CNRS/IN2P3)

French-Ukrainian Workshop
19-23 octobre 2020

Outline

- Introduction
- Jefferson Lab program on exclusive reaction
  - Some detector R&D projects
  - Future experiments
- Electron-Ion Collider project
  - Timeline
  - Detector R&D opportunities

Quantum Chromodynamics (QCD)

How are hadrons formed from their underlying quark and gluonic degrees of freedom?

- **Confinement:** in contrast to QED, we cannot observe the elementary constituents.
- **Asymptotic freedom:** the effective coupling constant α_s become very small (< 1) at small distances ($< 0.2\,\text{fm}$).
- **Chiral symmetry:** mass of the u and d quarks very small.

Understanding the proton

Building blocks:

- Quarks (u, d, $s \dots$, spin $1/2$, m_q small, 3 colors).
- Gluons (spin-1, massless, $3^2 - 1$ colors).

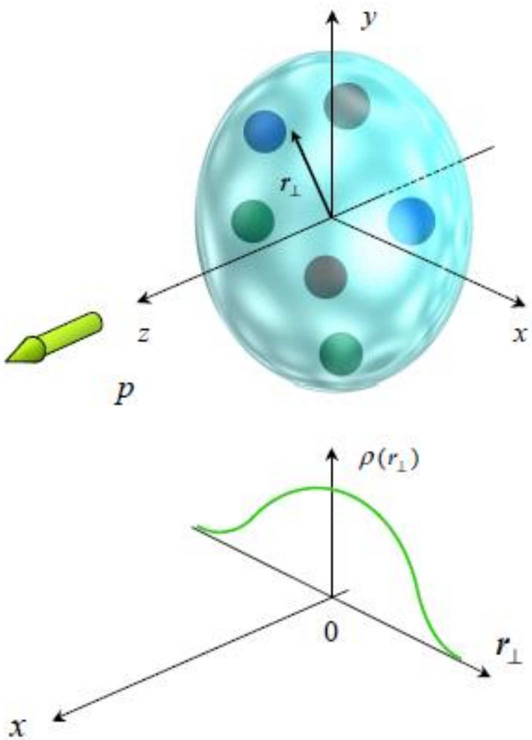
Relativistic, strongly coupled, quantum many-body problem

- Theoretically, i.e. solving QCD:
  - Lattice QCD: numerical calculation.
  - Effective field theories: large N_c, chiral physics...
- Experimentally:

Study of hadron structure
through low and high-energy scattering

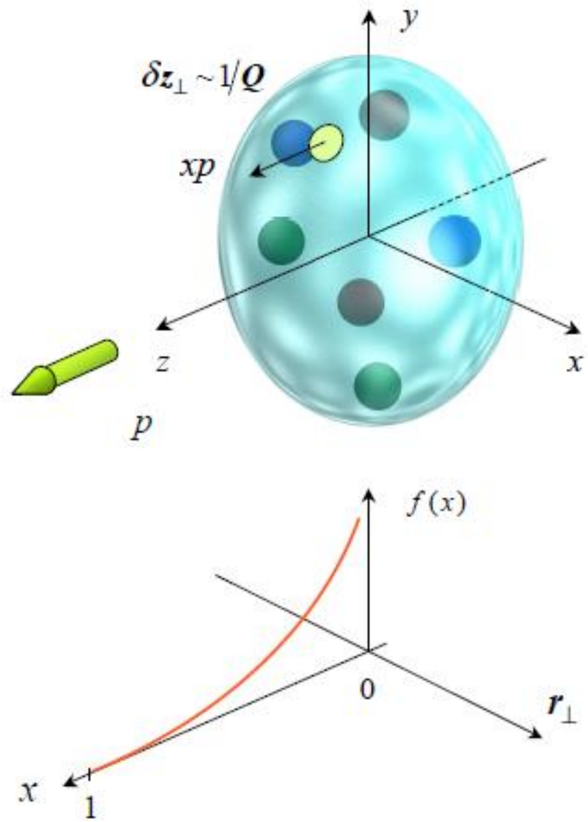
Studying the structure of the nucleon experimentally

Elastic scattering



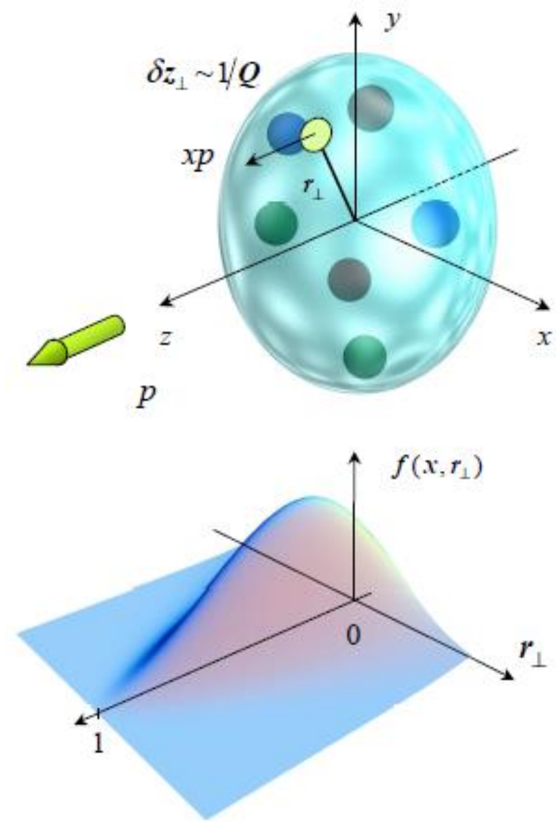
Form factors

Deeply Inelastic Scattering



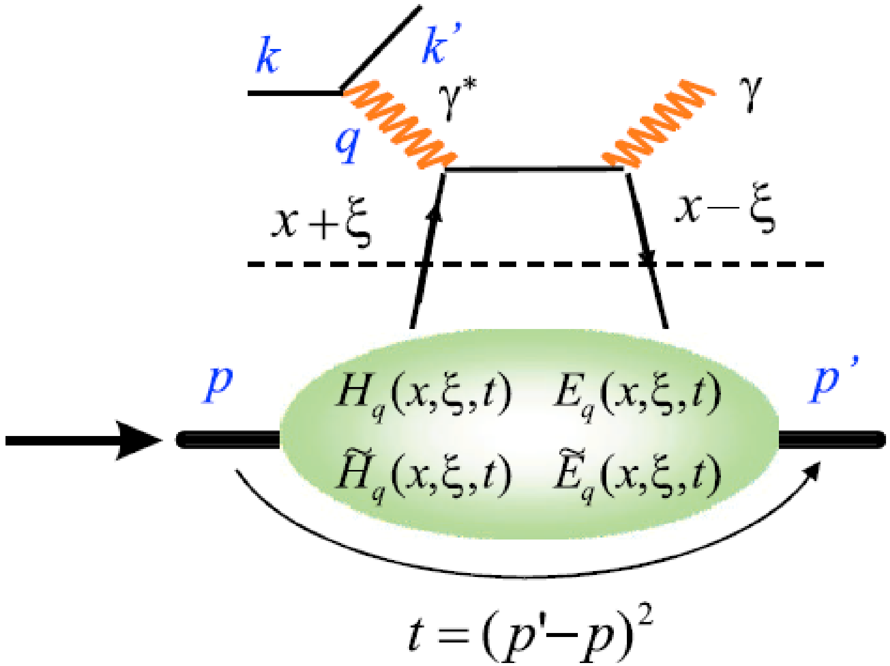
Parton distributions

Hard exclusive processes



Generalized Parton Distributions (GPDs)

Deeply Virtual Compton Scattering (DVCS): $\gamma^* \, p \to \gamma \, p$



Handbag diagram

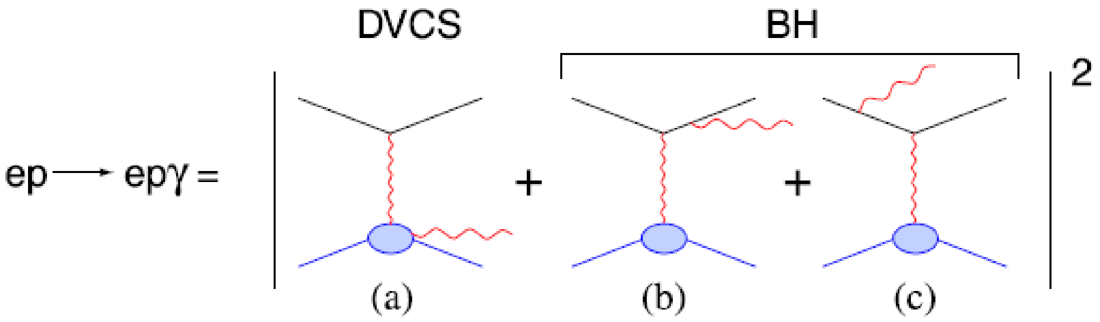
High Q^2
Perturbative QCD

Non-perturbative
GPDs

Bjorken limit :

$$\left.\begin{array}{rl} Q^2 = -q^2 \to & \infty \\ \nu \to & \infty \end{array}\right\} \quad x_B = \frac{Q^2}{2M\nu} \text{ fixed}$$

DVCS experimentally: interference with Bethe-Heitler



At leading order in $1/Q$ (leading twist) :

$$d^5\overrightarrow{\sigma} - d^5\overleftarrow{\sigma} = \Im m\,(T^{BH}\cdot T^{DVCS})$$

$$d^5\overrightarrow{\sigma} + d^5\overleftarrow{\sigma} = |BH|^2 + \Re e\,(T^{BH}\cdot T^{DVCS}) + |DVCS|^2$$

$$\mathcal{T}^{DVCS} = \int_{-1}^{+1} dx \frac{H(x,\xi,t)}{x-\xi+i\epsilon} + \cdots =$$

$$\underbrace{\mathcal{P}\int_{-1}^{+1} dx \frac{H(x,\xi,t)}{x-\xi}} \quad - \quad \underbrace{i\pi\, H(x=\xi,\xi,t)} \quad + \ldots$$

Access in helicity-independent cross section

Access in helicity-dependent cross-section

Accessing different GDPs

Polarized beam, unpolarized target (BSA)

$$d\sigma_{LU} = \sin\phi \cdot \mathcal{I}m\{F_1\mathcal{H} + x_B(F_1+F_2)\tilde{\mathcal{H}} - kF_2\mathcal{E}\}d\phi$$

Unpolarized beam, longitudinal target (lTSA)

$$d\sigma_{UL} = \sin\phi \cdot \mathcal{I}m\{F_1\tilde{\mathcal{H}} + x_B(F_1+F_2)(\tilde{\mathcal{H}} + x_B/2\mathcal{E}) - x_B kF_2\tilde{\mathcal{E}} \ldots\}d\phi$$

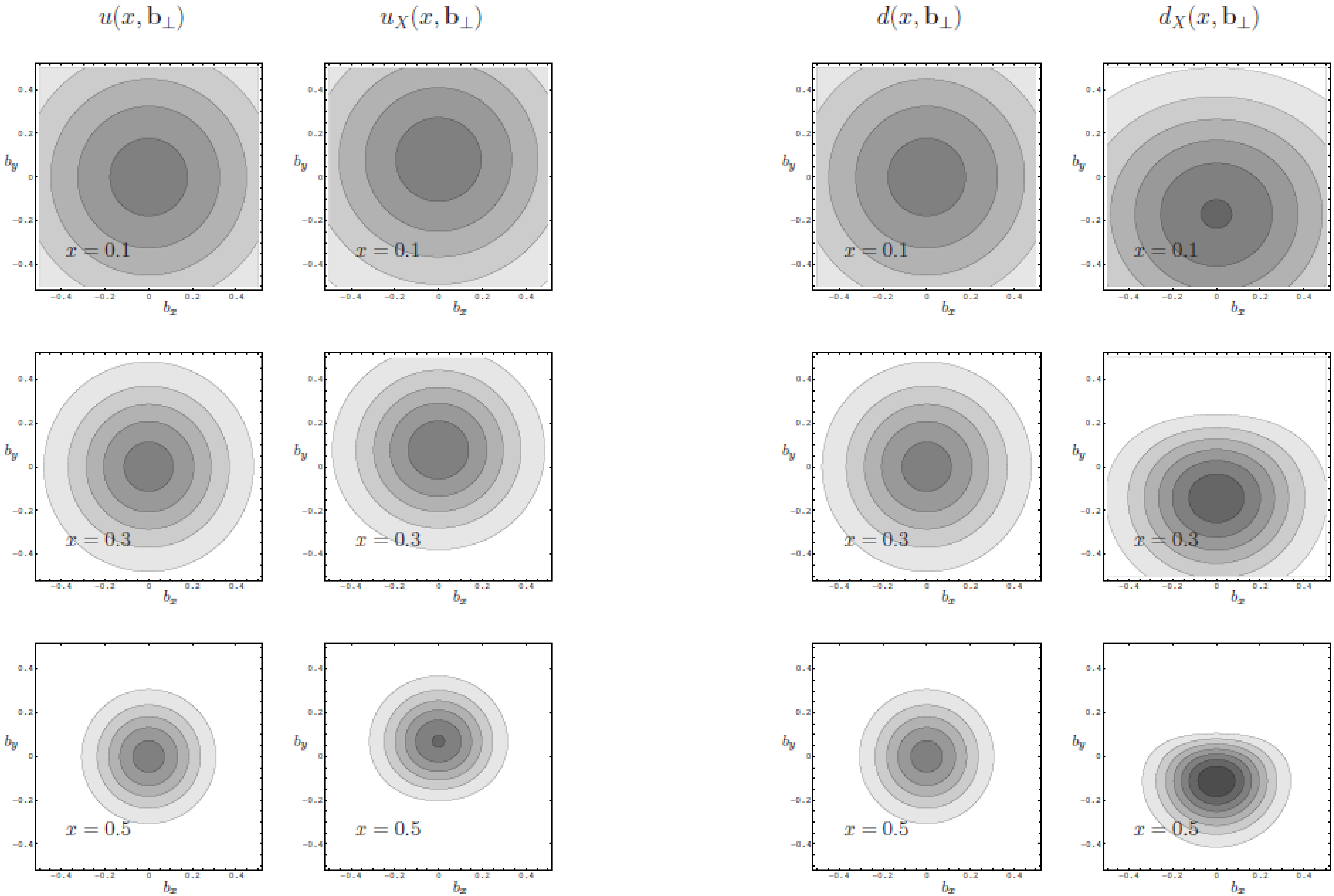
Polarized beam, longitudinal target (BlTSA)

$$d\sigma_{LL} = (A + B\cos\phi) \cdot \mathcal{R}e\{F_1\tilde{\mathcal{H}} + x_B(F_1+F_2)(\tilde{\mathcal{H}} + x_B/2\mathcal{E}) \ldots\}d\phi$$

Unpolarized beam, transverse target (tTSA)

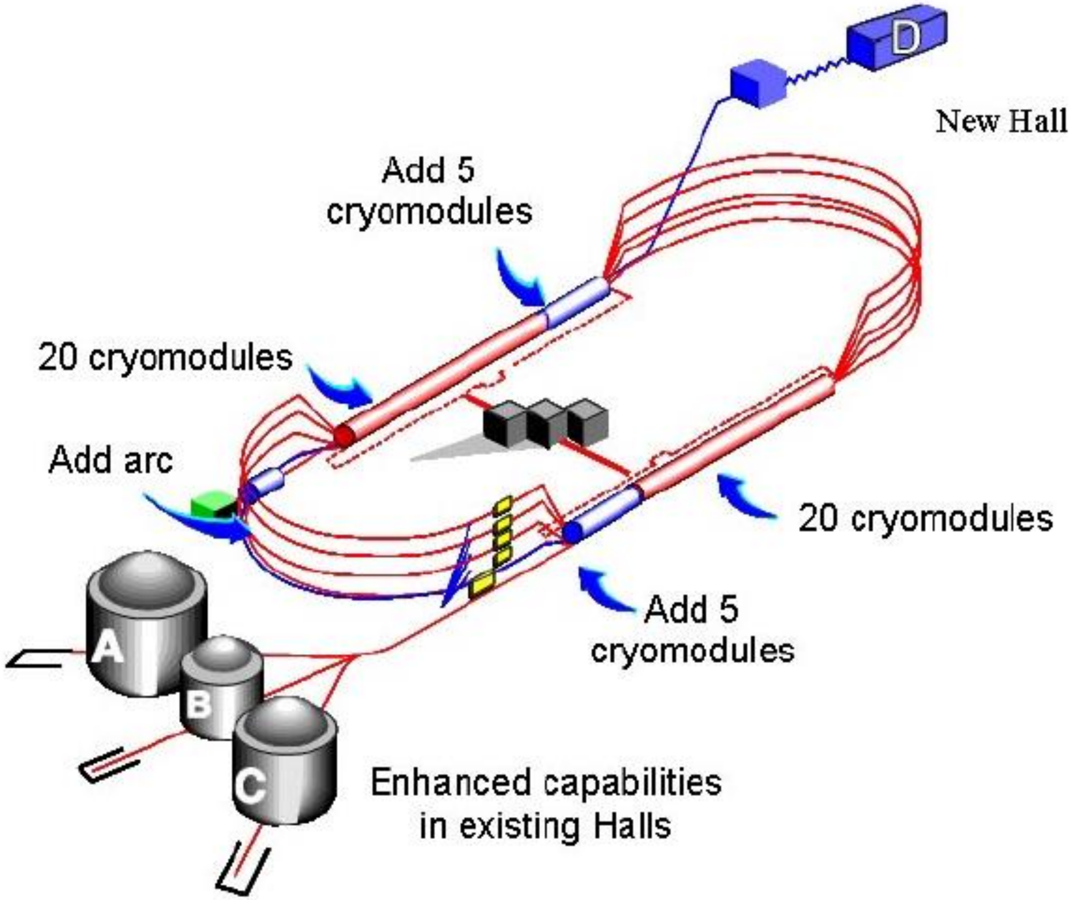
$$d\sigma_{UT} = \cos\phi \cdot \mathcal{I}m\{k(F_2\mathcal{H} - F_1\mathcal{E}) + \ldots\}d\phi$$

Impact-parameter interpretation of GPDs

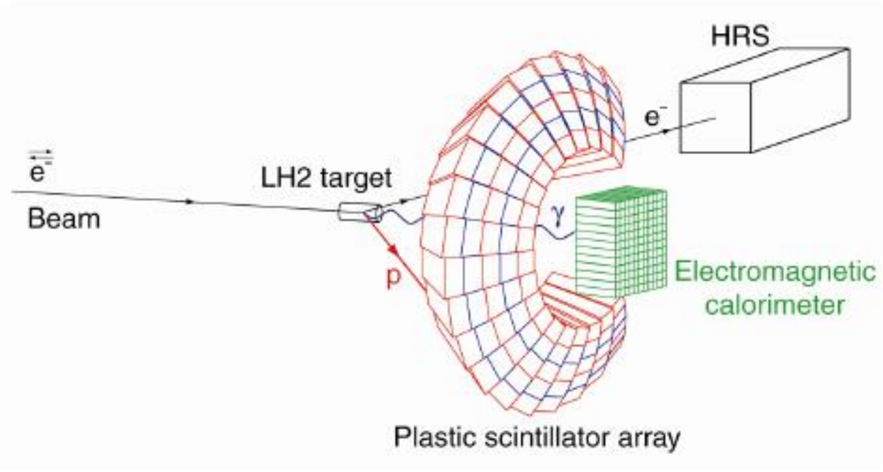


Jefferson Lab: upgraded to 12 GeV

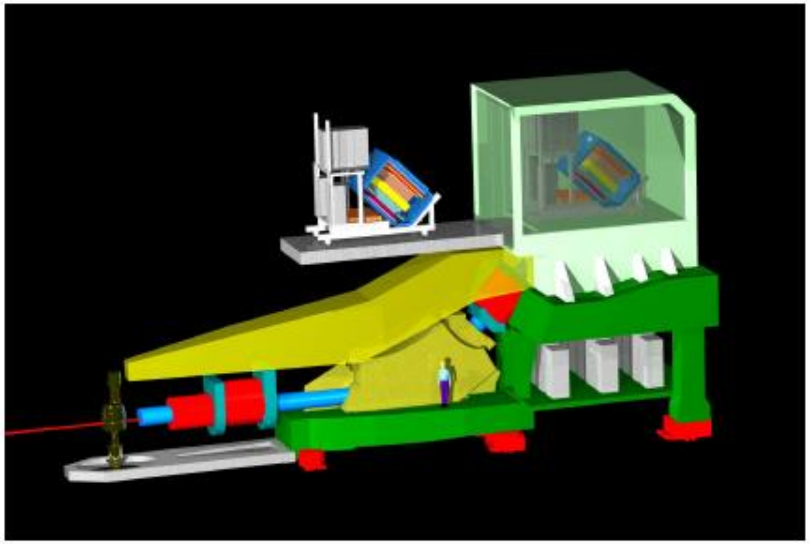
- 6-12 GeV longitudinally polarized (>85%) continuous electron beam
- High intensity (>100 μA): luminosities $> 10^{38}\,s^{-1}\,cm^{-2}$
- 3 experimental Halls (A, B, C) w/ fixed target and dedicated detectors



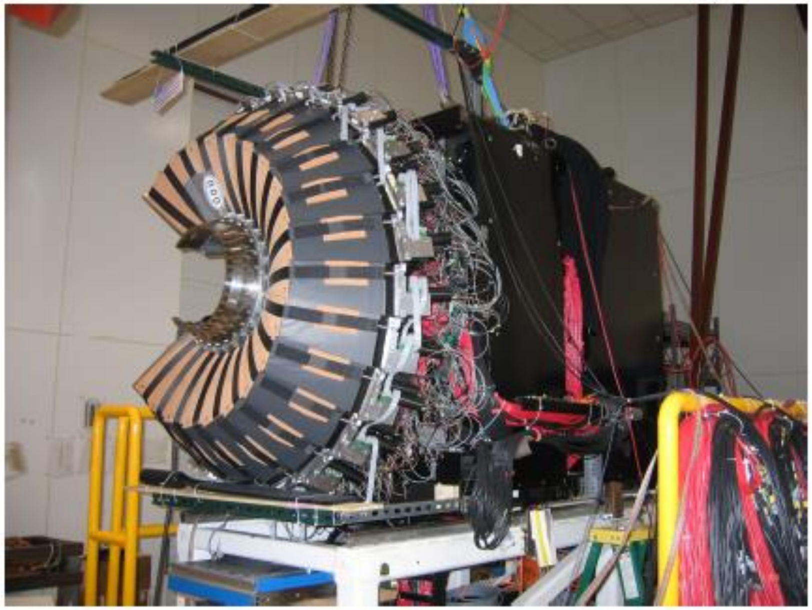
Experimental setup



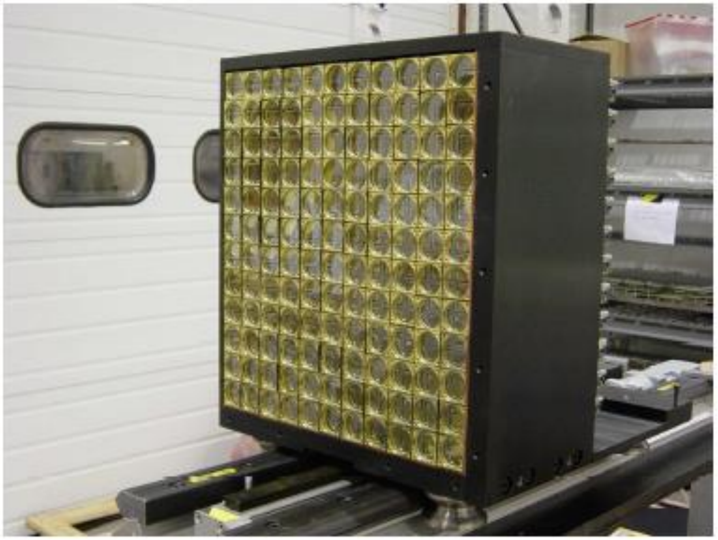
High Resolution Spectrometer



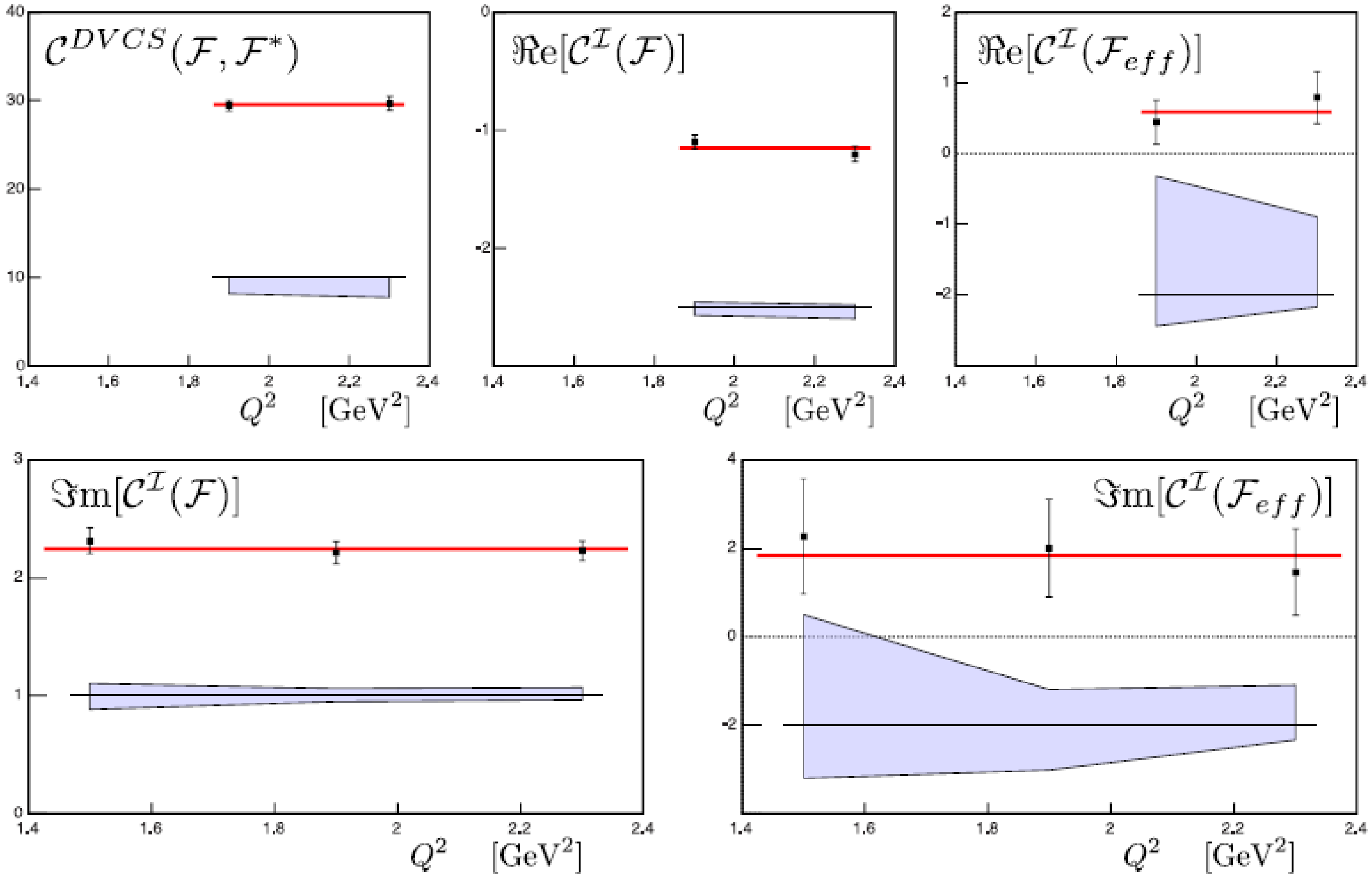
100-channel scintillator array



132-block PbF_2 electromagnetic calorimeter



DVCS cross sections: Q^2–dependance

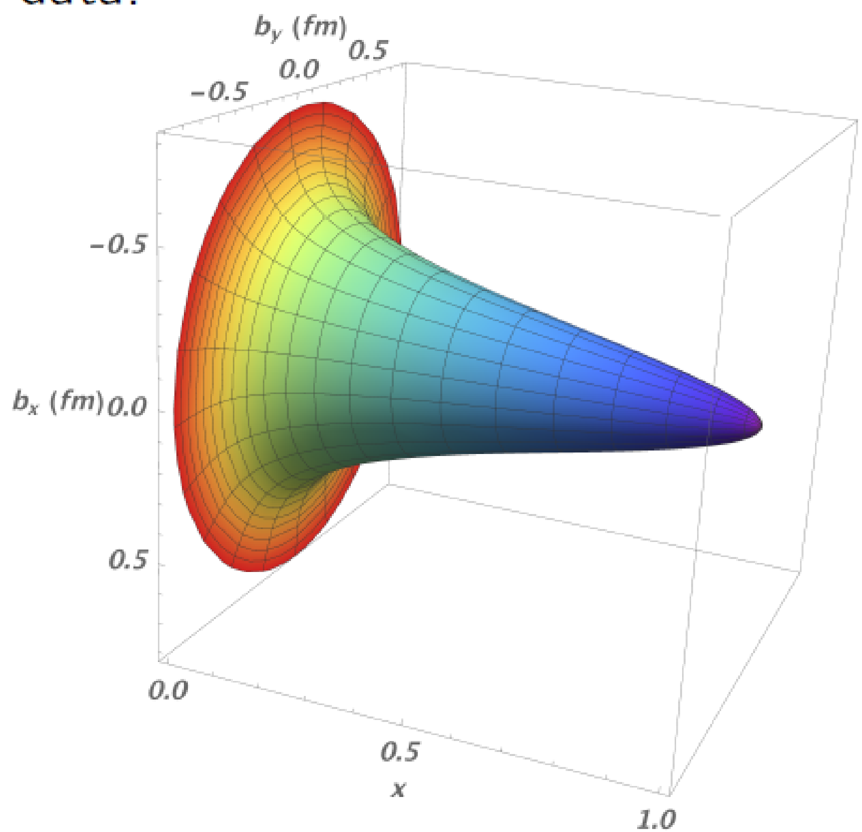


No Q^2-dependance within limited range $\Rightarrow$ leading twist dominance

First 3D-imaging of the proton from DVCS

From a simultaneous fit of JLab DVCS data:

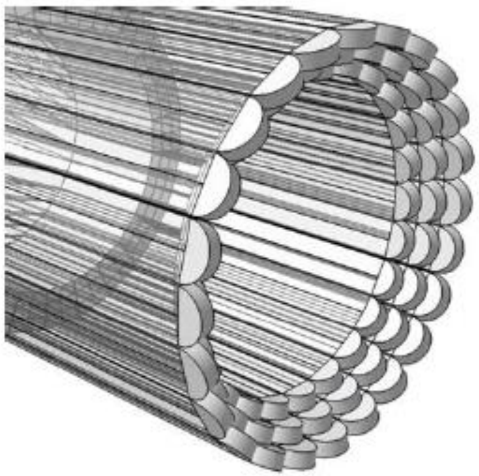
- Fast-moving partons localized in the center of the proton
- Low energy and sea quarks mostly in the outer region

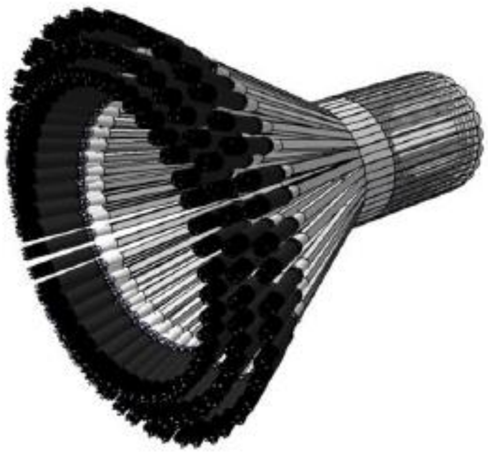


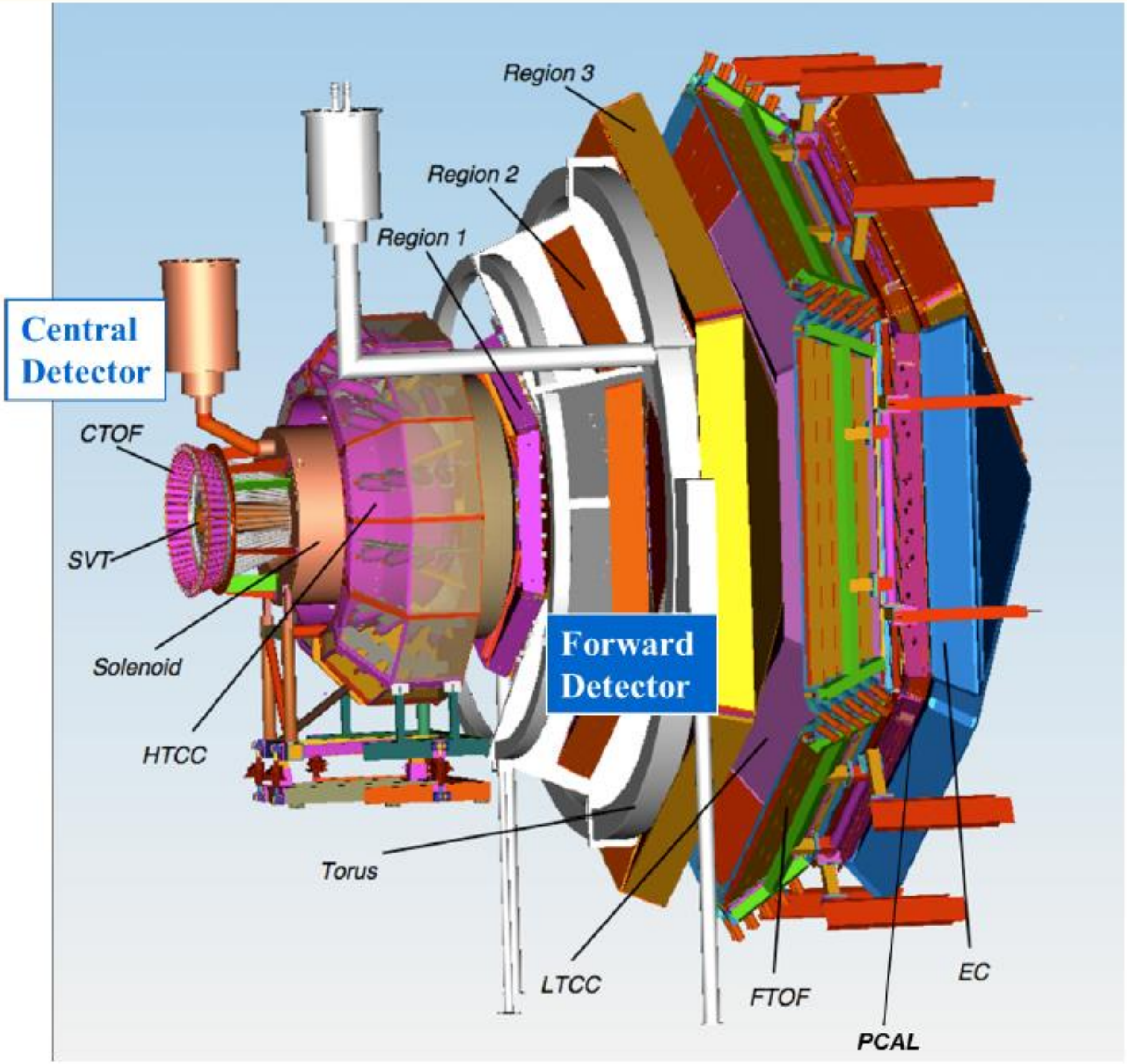
Much more results to come with JLab12 data: neutron, polarized protons. . .

Phys. Rev. D95, 011501 (2017)

E12-11-003: DVCS on the neutron with CLAS12

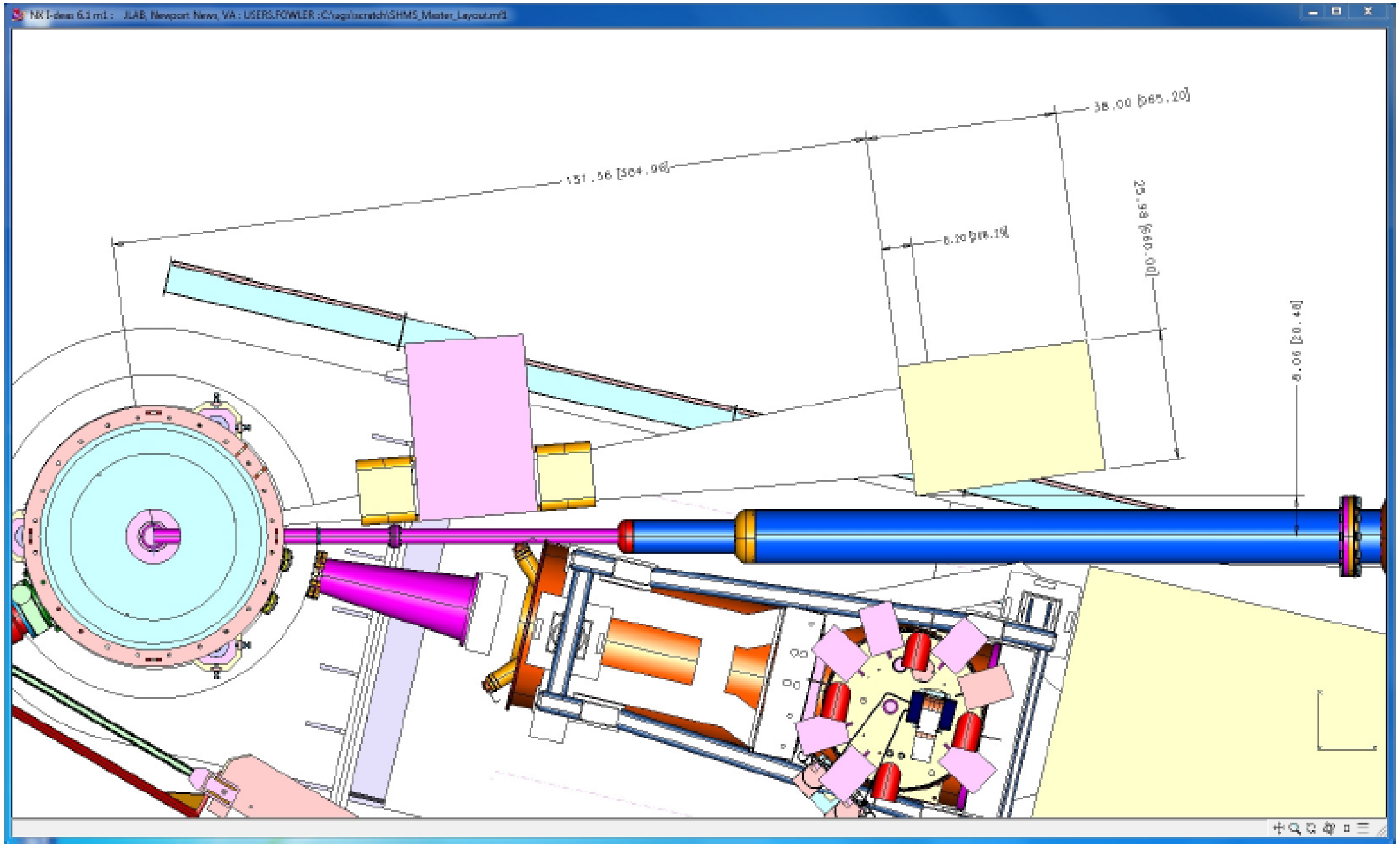




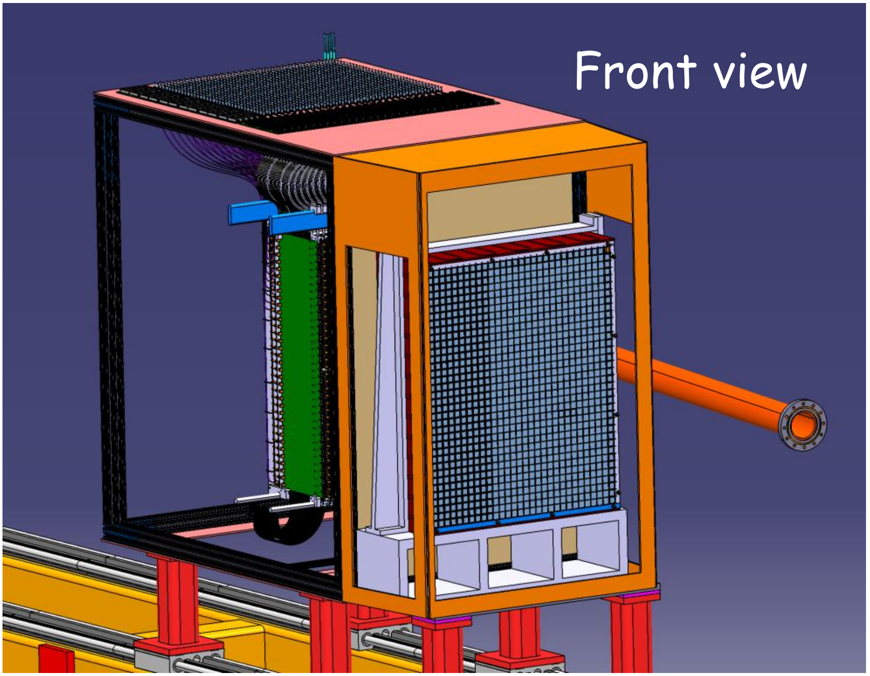


E12-13-010: DVCS in Hall C

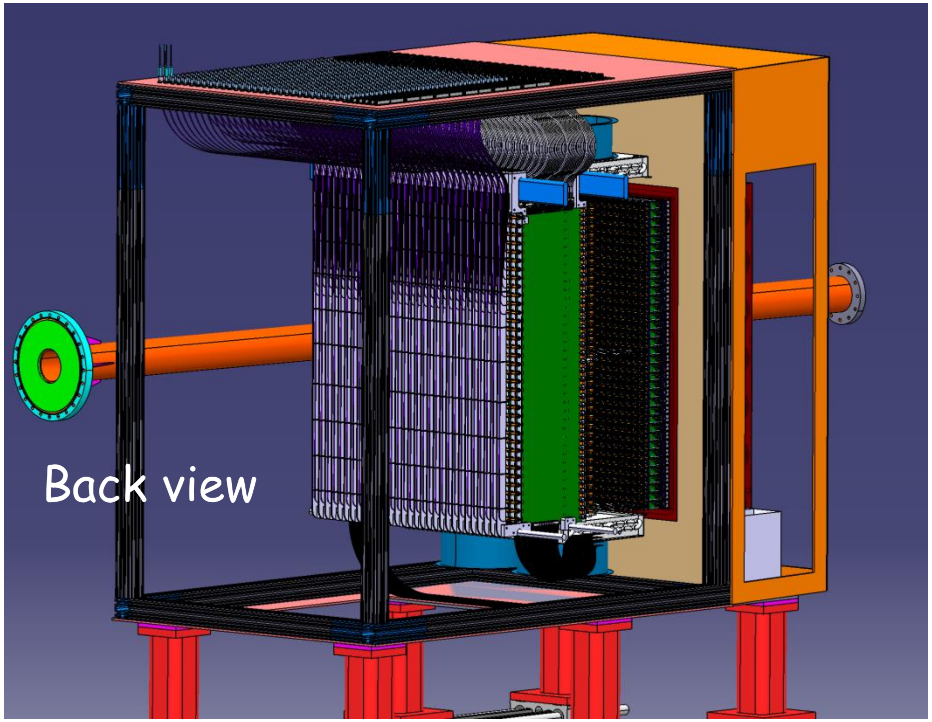
- HMS ($p < 7.3GeV$): scattered electron
- $PbWO_4$ calorimeter: γ/π^0 detection
- Sweeping magnet



High luminosity calorimeter NPS



- 30x36 (1080) $PbWO_4$ crystals (2x2x20 cm^3)
- Hamamatsu R4125 PMTs
- Custom-made active bases

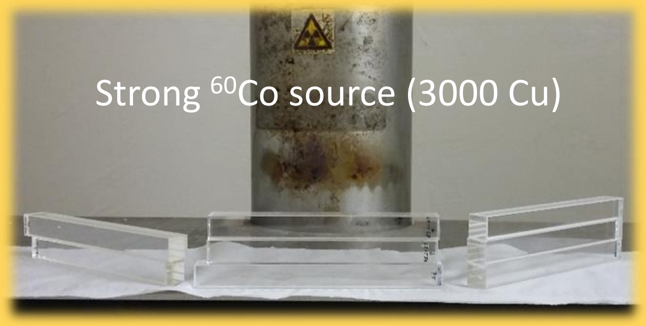


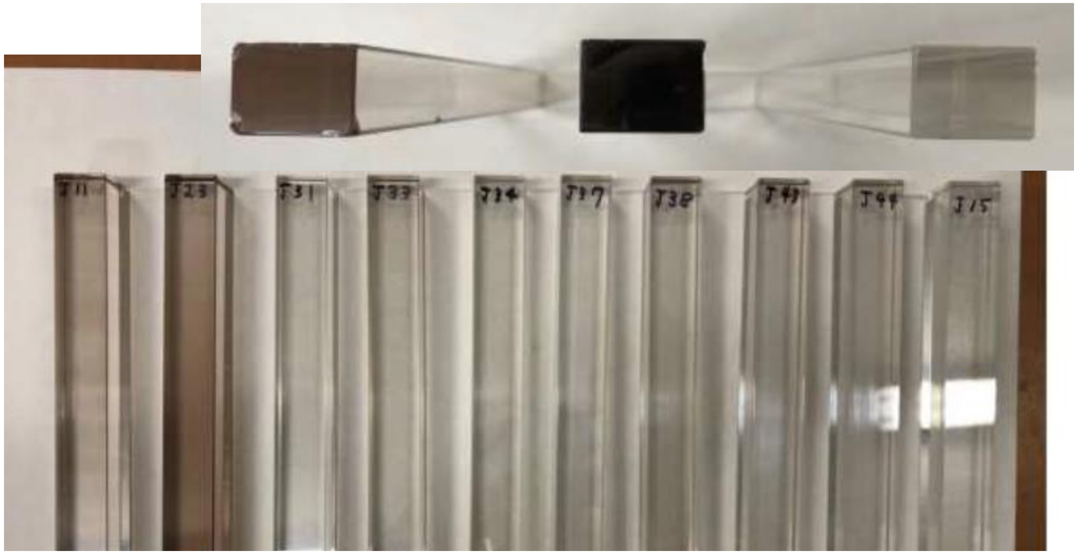
Calorimeter frame:

- Crystals placed in a 0.5 mm-thick carbon frame to ensure good positioning
- PMTs accessible from the back side to allow maintenance
- Calibration and radiation curing with blue LED light though quartz optical fiber

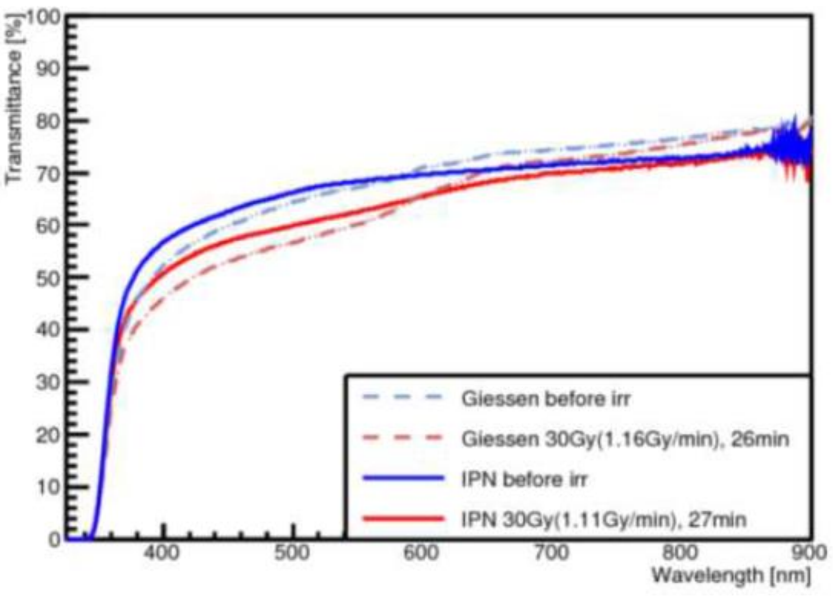
Irradiation and curing tests

Radiation hardness measurements

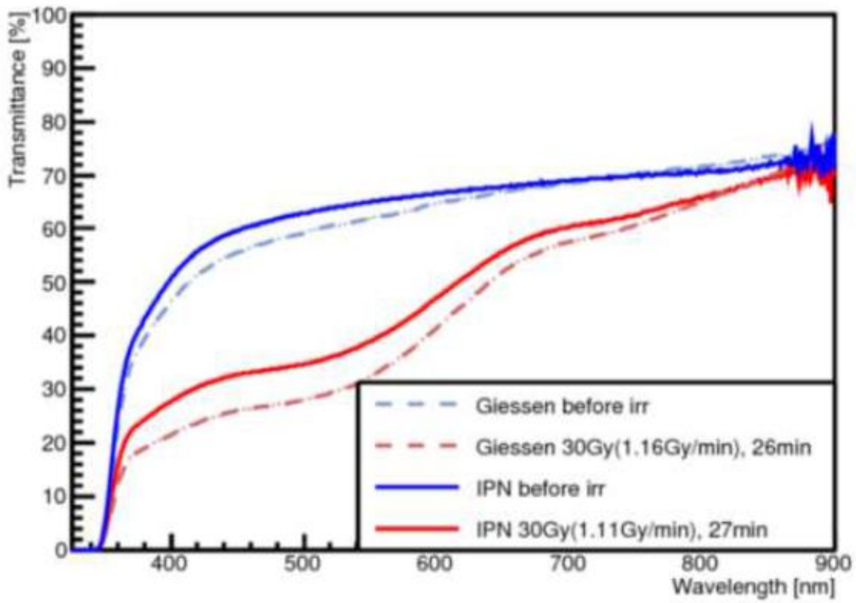




J43



J23



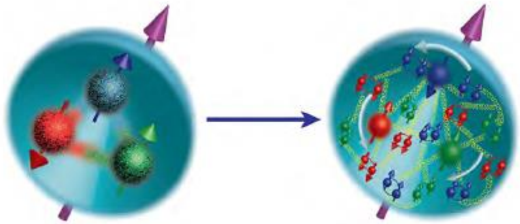
Summary of Jlab program

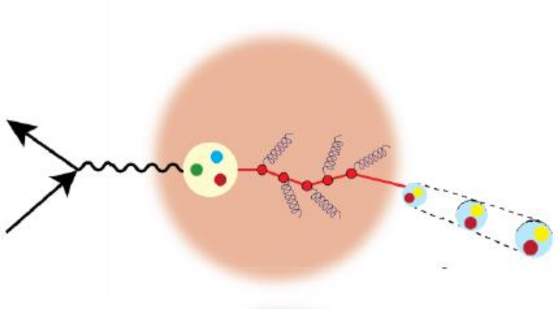
- DVCS golden channel to access GPDs experimentally, but also accessible in:
  - Deep meson production
  - Time-like Compton Scattering, Double DVCS. . .
- Large and accurate set of data (cross-sections and asymmetries) is now available in the valence region
  - Dominance of leading twist, but. . .
  - Necessity of higher twist corrections to explain high precision data
- Compeling GPD program in the future at Jefferson Lab 12 GeV in all 3 electron Hall A, B & C.

Motivation – the EIC science program

How are the sea quarks and gluons, and their spins, distributed in space and momentum inside the nucleon?

How do the nucleon properties emerge from them and their interactions?





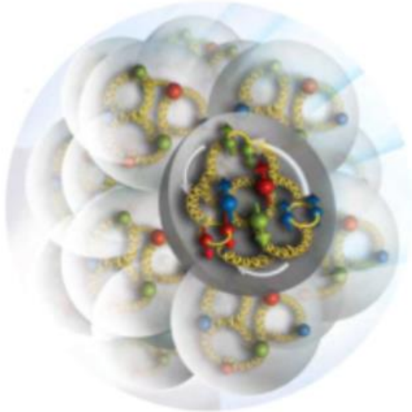
How do color-charged quarks and gluons, and colorless jets, interact with a nuclear medium?

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 quarks and gluons, their correlations, and their interactions?

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?

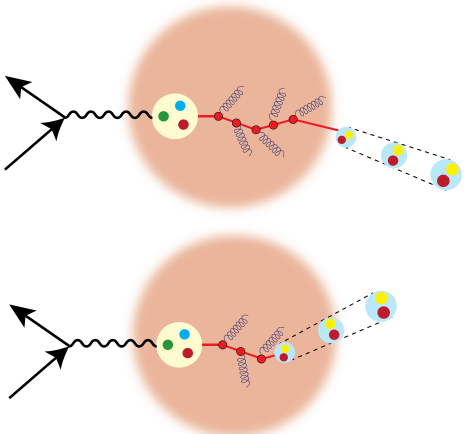


Emergence of hadrons from partons

Nucleus as a Femtometer sized analyzer

Unprecedented ν, the virtual photon energy range @ EIC : *precision & control*

$$\nu = \frac{Q^2}{2mx}$$

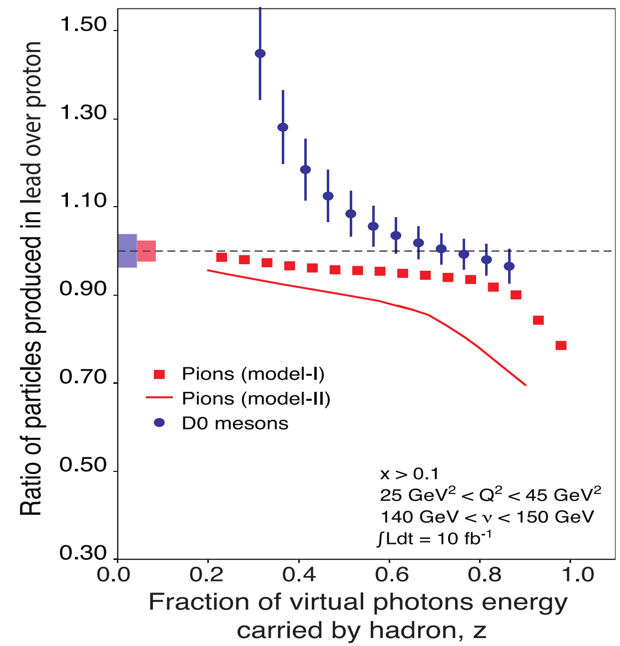


Control of ν by selecting kinematics;

Also under control the nuclear size.

Colored quark emerges as color neutral hadron ➔ What is the impact of colored media on confinement?

Energy loss by light vs. heavy quarks:

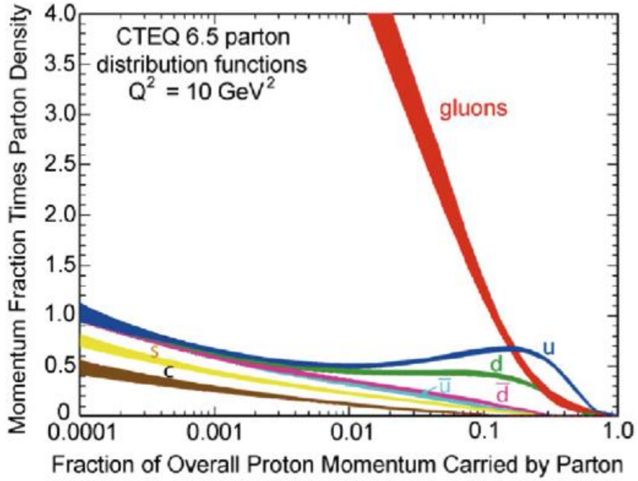


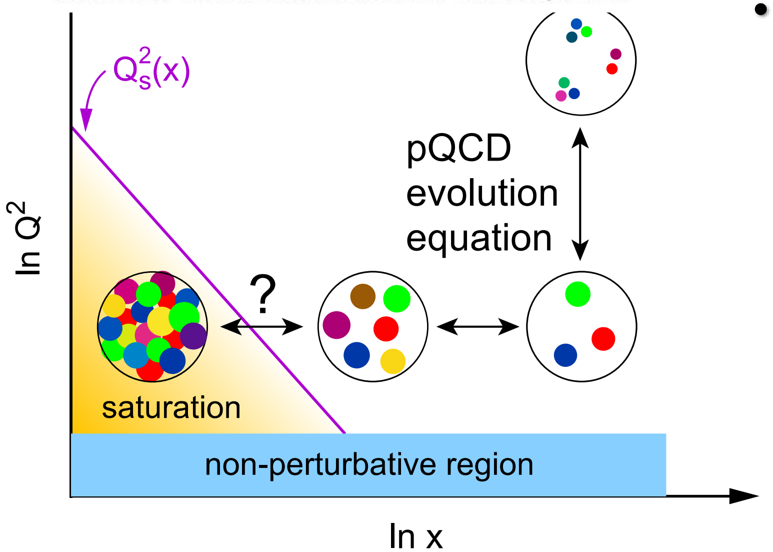
Identify light vs. charm hadrons in e-A: Understand energy loss of light vs. heavy quarks in cold nuclear matter.

Provides insight into energy loss in the Quark-Gluon Plasma

DIS at collider energies enables control of parton/event kinematics

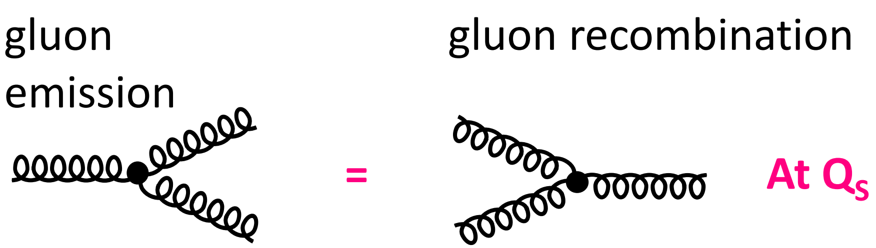
Gluon saturation at low-x





What tames the low-x rise?

- New evolution equations at low x & moderate Q^2
- **Saturation Scale $Q_S(x)$** where gluon emission and recombination become comparable



First observation of gluon recombination effects in nuclei:

➔ leading to a collective gluonic system

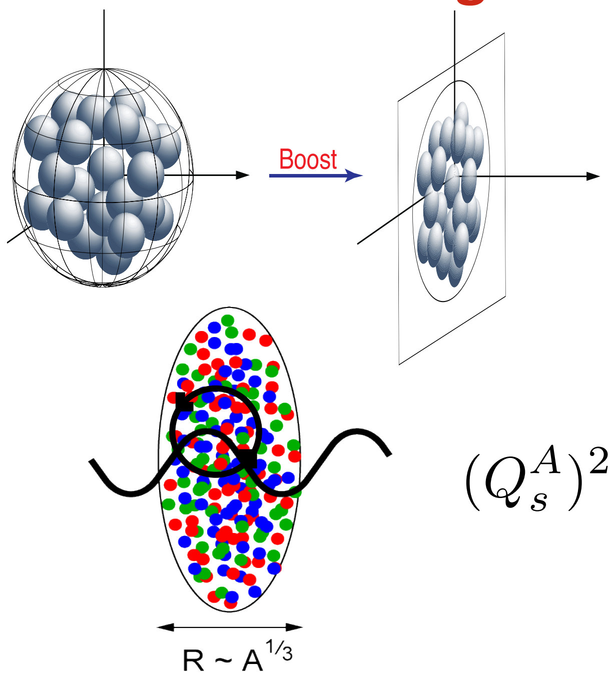
First observation of gluon recombination in different nuclei

→ Is this a universal property?

What is the new effective theory in this regime?

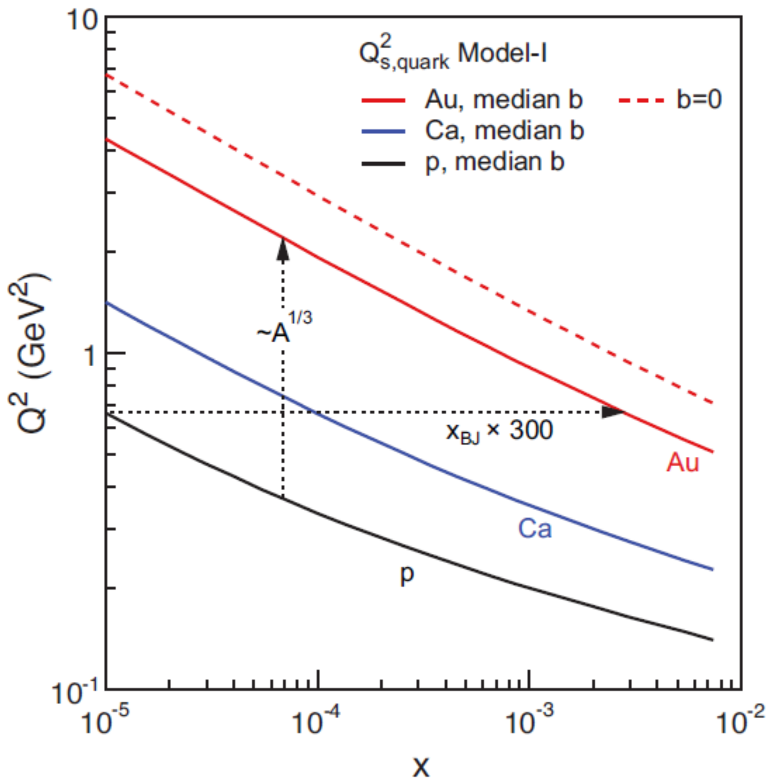
How to explore/study this new phase of matter?

Advantage of nucleus →



$L \sim (2m_N x)^{-1} > 2\, R_A \sim A^{1/3}$

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



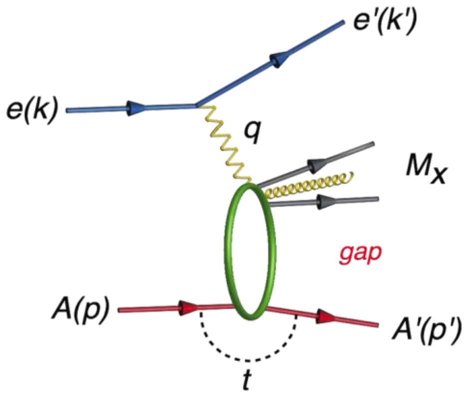
Enhancement of Q_S with A:
Saturation regime reached at significantly lower energy
(read: "cost") in nuclei

Diffraction events & gluon densities

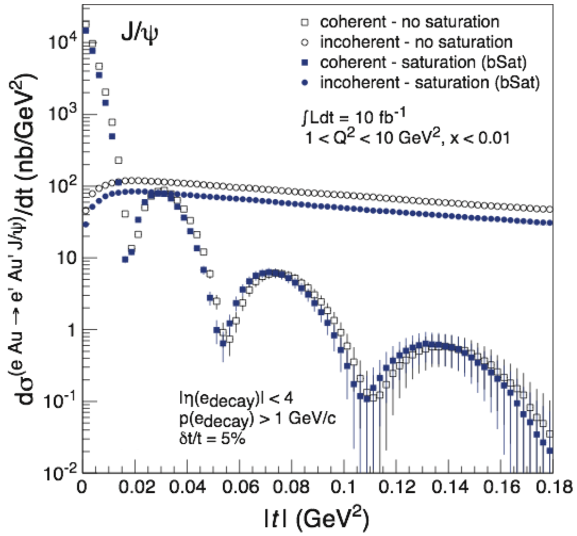
Diffraction cross-sections have strong discovery potential:

High sensitivity to gluon density in linear regime: $\sigma \sim [g(x,Q^2)]^2$

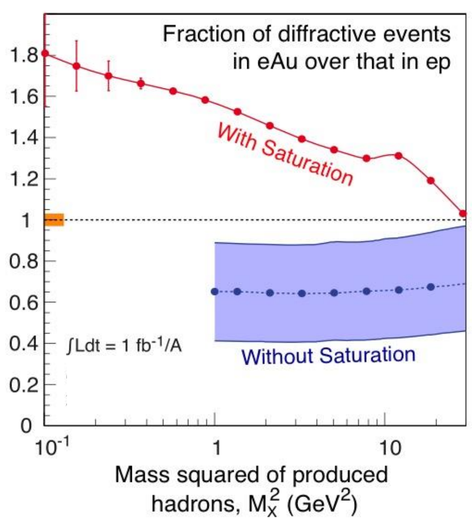
Dramatic changes in cross-sections with onset of non-linear strong color fields



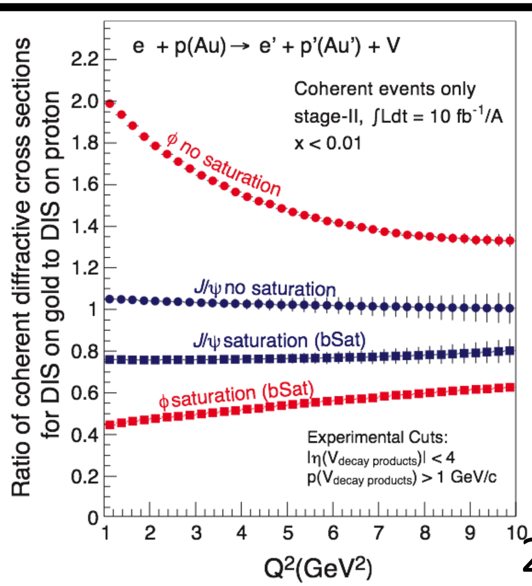
Extracting the gluon distribution $\rho(b_T)$ of nuclei via Fourier transformation of $d\sigma/dt$ in diffractive J/ψ production



Probing gluon saturation through measuring $\sigma_{diff}/\sigma_{tot}$



Probing Q^2 dependence of gluon saturation in diffractive vector meson production

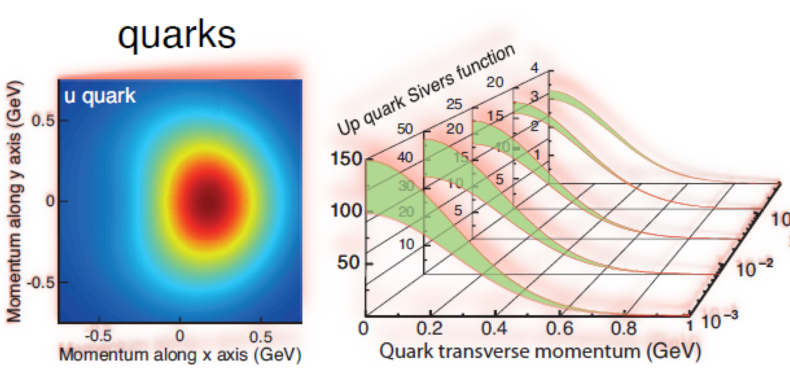


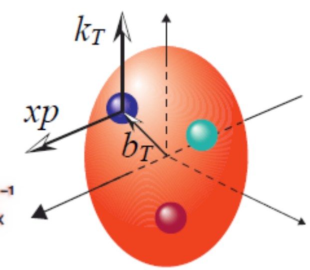
Three-dimensional imaging of the nucleon

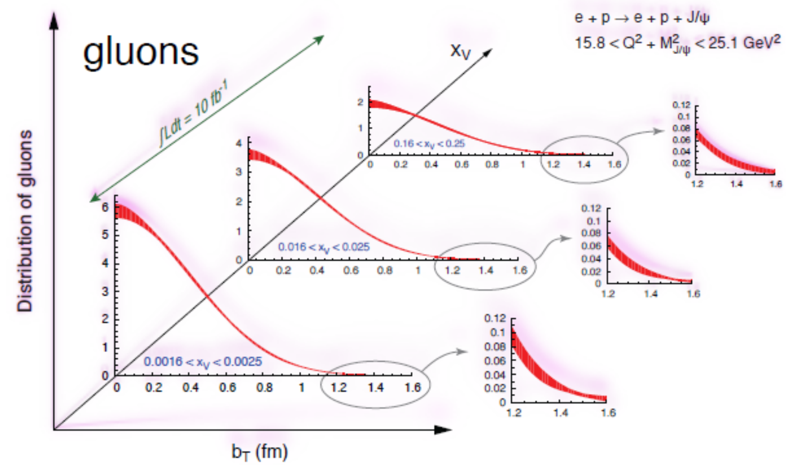
- Transverse Momentum Distribution and Spatial Imaging   arXiv:1212.1701

$f(x, k_T)$ 1+2D $\int d^2 b_T$ $W(x, b_T, k_T)$ $\int d^2 k_T$ $f(x, b_T)$ 1+2D

Transverse Momentum Distribution (TMD)   Wigner Distribution   Impact Parameter Distribution







Fourier transf.
$b_T \longleftrightarrow \Delta$: $t = -\Delta^2$

$H(x, 0, t)$

$\xi = 0$

$H(x, \xi, t)$

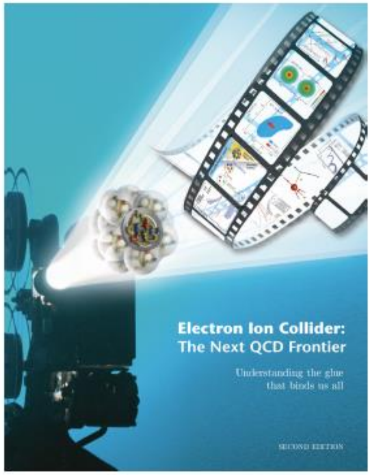
Generalized Parton Distribution (GPD)

- Spin-dependent 1+2D momentum space (transverse) images from semi-inclusive scattering
- Spin-dependent 1+2D impact parameter (transverse) images from exclusive scattering

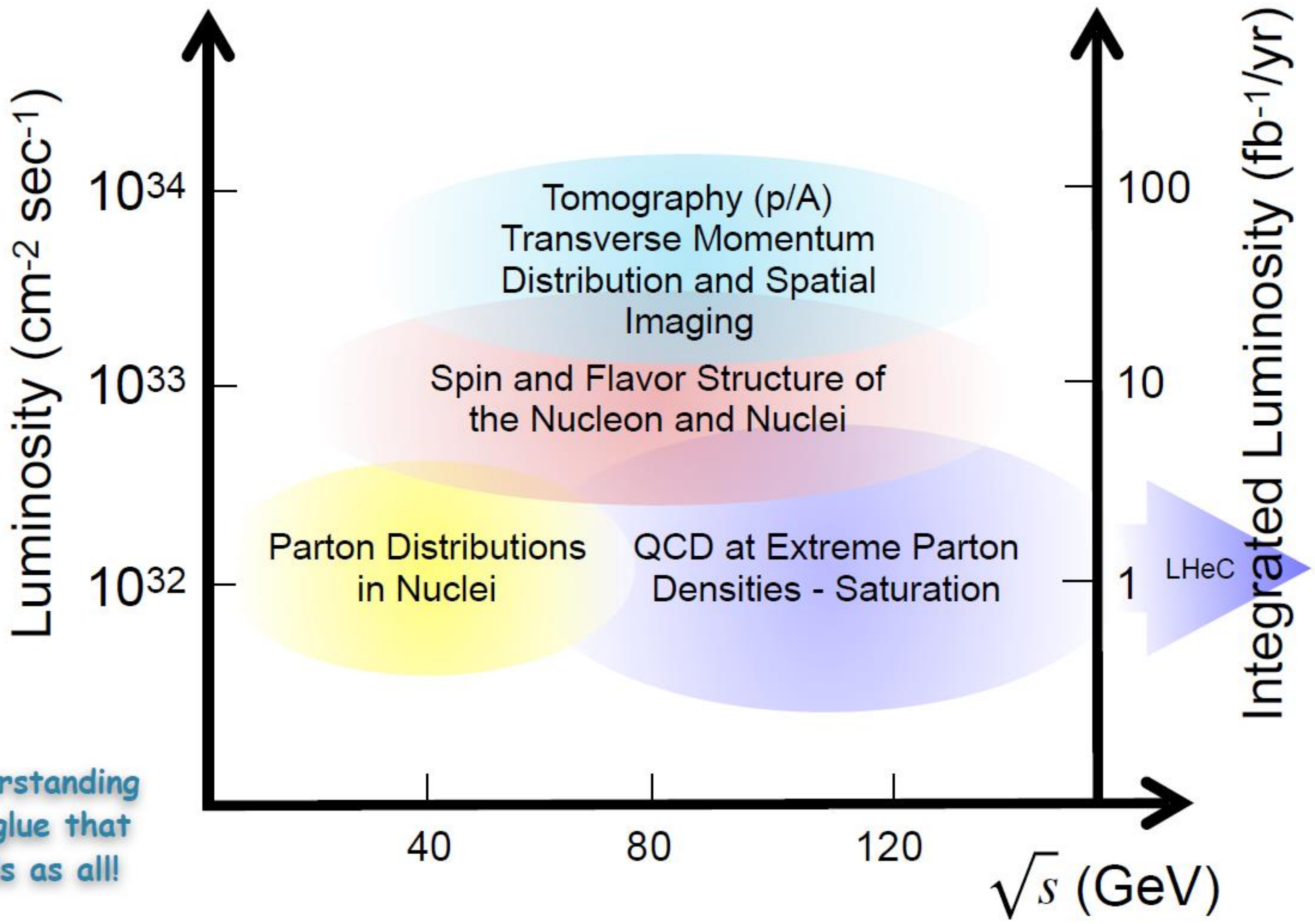
EIC Pillars

- EIC: Study structure and dynamics of matter at high luminosity, high energy with polarized beams and wide range of nuclei
- Whitepaper:

arXiv:1212.1701

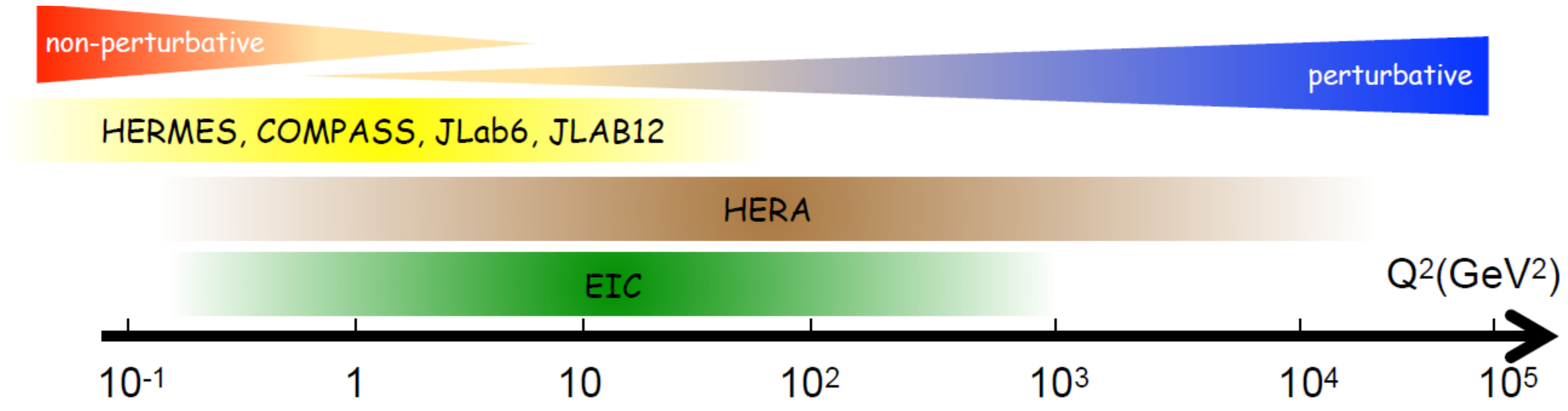


Understanding the glue that binds as all!

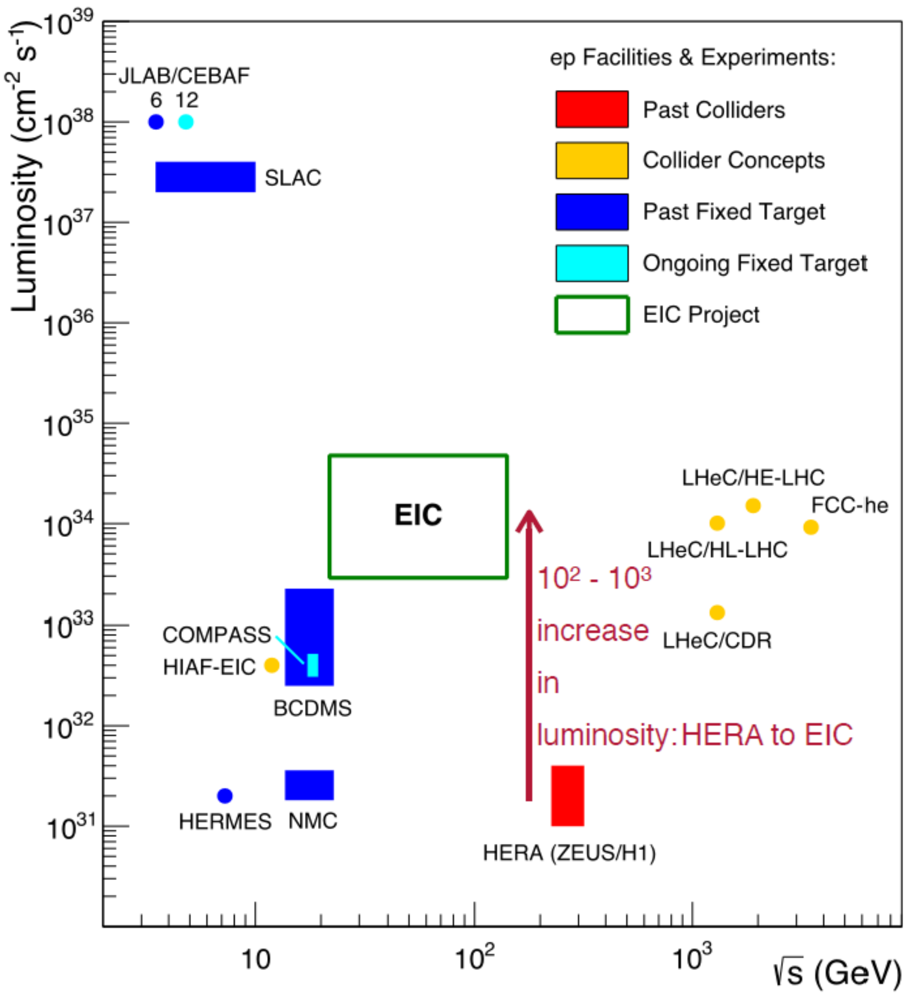


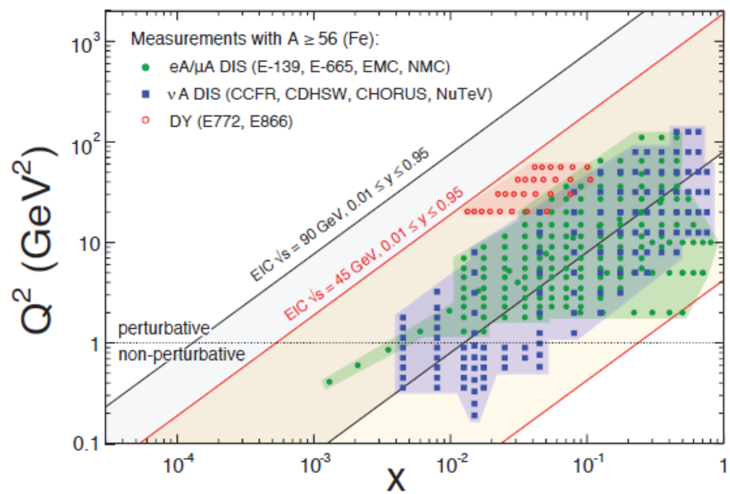
EIC machine requirements

- High luminosity: $10^{33} cm^{-2}s^{-1}$ - $10^{34} cm^{-2}s^{-1}$
- Flexible center-of-mass energy $\sqrt{s} = \sqrt{4\, E_e\, E_p}$: Wide kinematic range $Q^2 = s\, x\, y$
- Highly polarized electron (0.8) and proton / light ion (0.7) beams: Spin structure studies
- Wide range of nuclear beams (d to Pb/U): High gluon density

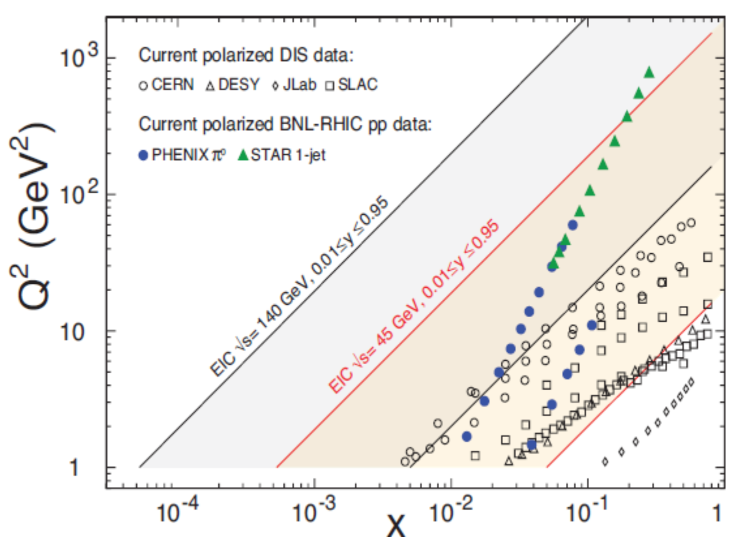


Luminosity and kinematic coverage





eA



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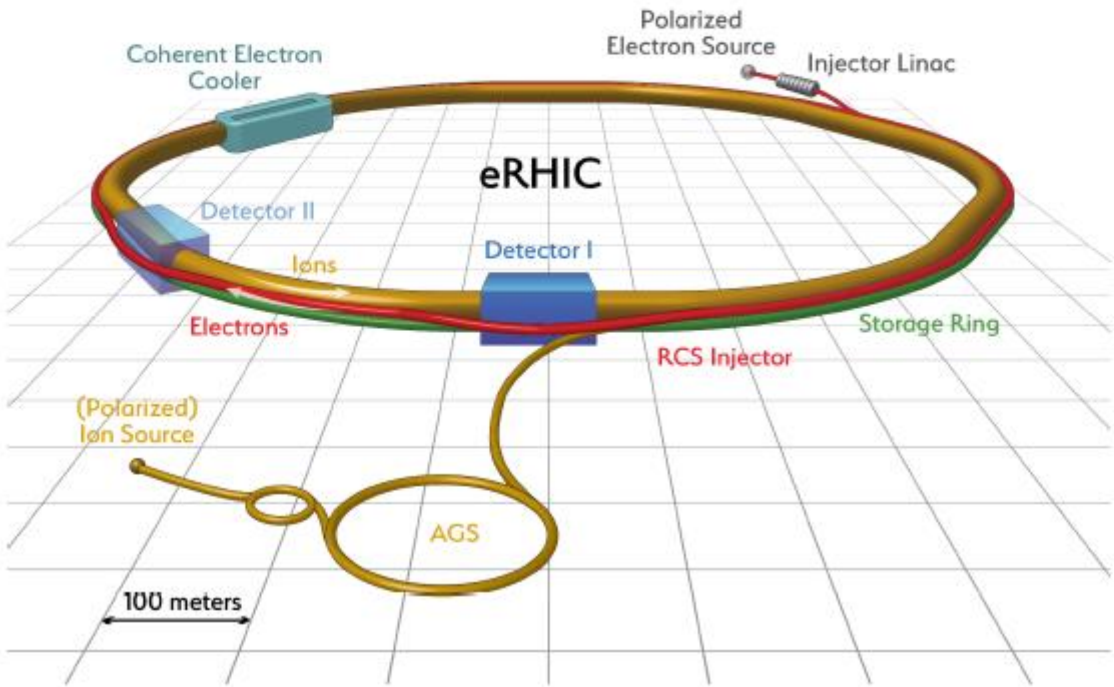
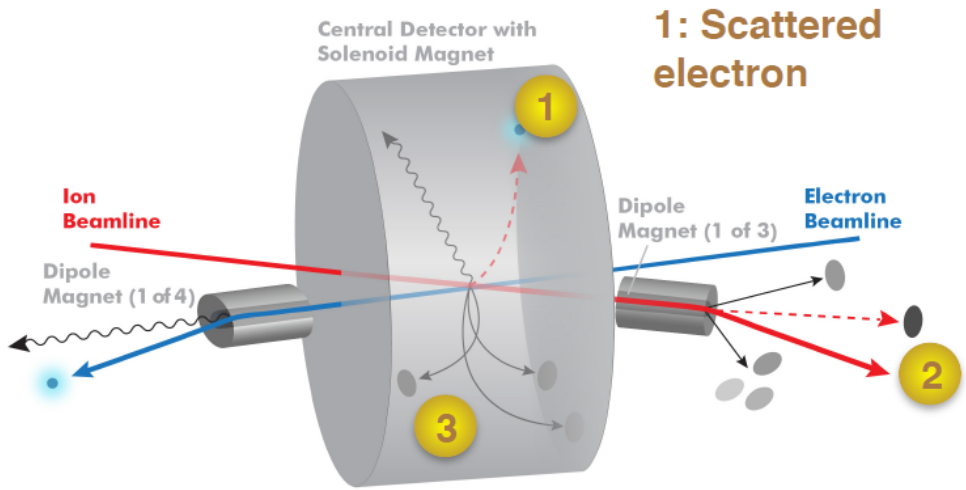
EIC Facility

- Highly polarized electron / Highly polarized proton and lights ions /Unpolarized heavy ions
- CME: ~ 20-100GeV
- Luminosity: ~ $10^{33-34}cm^{-2}s^{-1}$



- Polarized electron source and 400 MeV injector linac
- Polarized proton beams and ion beams based on existing RHIC facility
- 2 detector interaction points capability in the design

EIC Detector requirements



- Acceptance: Close to 4π coverage with a η-coverage ($\eta = -\ln(\tan(\theta/2))$) of approximately $\eta < |3.5|$ combined calorimetry (EM CAL and hadron CAL at least in forward direction) and tracking coverage
- Low dead material budget in particular in rear direction (~5% X/X_0)
- Good momentum resolution $\Delta p/p$ ~ few %
- Electron ID for e/h separation varies with θ / η at the level of 1:10^4 / ~2-3%/√E for η<-2 and ~7%/√E for -2<η<1
- Particle ID for π/K/p separation over wide momentum range (Forward η up to ~50GeV/c / Barrel η up to ~4GeV/c / Rear η up to ~6 GeV/c)
- High spatial vertex resolution ~ 10-20μm for vertex reconstruction
- Low-angel taggers:
  - Recoil proton
  - Low Q^2 electron
  - Neutrons on hadron direction
- Luminosity (Absolute and relative) and local polarization direction measurement

Generic Detector R&D for EIC

In January 2011 BNL, in association with JLab and the DOE Office of NP, announced a generic detector R&D program to address the scientific requirements for measurements at a future EIC

Goals of Effort

- Enable successful design and timely implementation of an EIC experimental program
  - Quantify the key physics measurements that drive instrumentation requirements
  - Develop instrumentation solutions that meet realistic cost expectations
- Stimulate the formation of user collaborations to design and build experiments

- Peer-reviewed program funded by DOE and managed by BNL with $1M/year to $1.5M/year

- Wide range of R&D programs: Calorimetry / Tracking (GEM, MicroMegas, TPC) incl. silicon / Particle ID (TRD, Dual-RICH, Aerogel RICH, DIRC, TOF) / Polarimetry / Background / Simulation Tools /

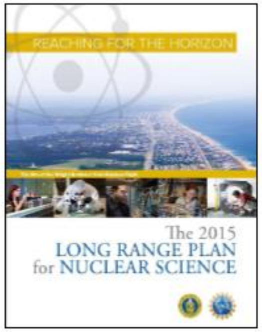
EIC Development

- Critical steps over the last couple of years - 1
  - INT Workshop series / Documentation of Physics Case - Whitepaper: "Understanding the glue that binds us all!"
    - INT Workshop: 2010
    - WP: 2012, updated in 2014 for LRP
  - 2015 Long-range plan (LRP): T. Hallman

The 2015 Long Range Plan for Nuclear Science

Recommendations:

1. Capitalize on investments made to maintain U.S. leadership in nuclear science.
2. Develop and deploy a U.S.-led ton-scale neutrino-less double beta decay experiment.
3. Construct a high-energy high-luminosity polarized electron-ion collider (EIC) as the highest priority for new construction following the completion of FRIB.
4. Increase investment in small-scale and mid-scale projects and initiatives that enable forefront research at universities and laboratories.

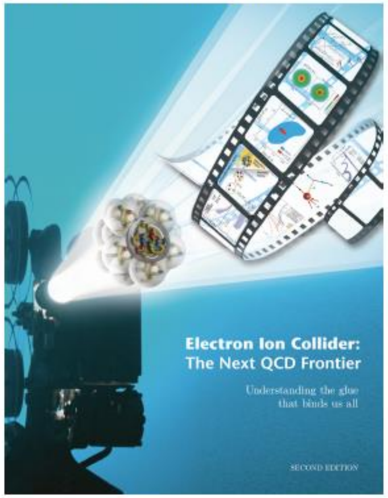


The FY 2018 Request supports progress in important aspects of the 2015 LRP Vision

U.S. DEPARTMENT OF ENERGY | Office of Science   NSAC Meeting   June 2, 2017   16

  - Request to review EIC Science Case by National Academy of Sciences, Engineering, and Medicine (NAS)

arXiv:1212.1701



Understanding the glue that binds as all!

T. Hallman

Next Formal Step on the EIC Science Case is Continuing

THE NATIONAL ACADEMIES OF SCIENCES, ENGINEERING, AND MEDICINE
Division on Engineering and Physical Science
Board on Physics and Astronomy
U.S.-Based Electron Ion Collider Science Assessment

Summary
The National Academies of Sciences, Engineering, and Medicine ("National Academies") will form a committee to carry out a thorough, independent assessment of the scientific justification for a U.S. domestic electron ion collider facility. In preparing its report, the committee will address the role that such a facility would play in the future of nuclear science, considering the field broadly, but placing emphasis on its potential scientific impact on quantum chromodynamics. The need for such an accelerator will be addressed in the context of international efforts in this area. Support for the 18-month project in the amount of $540,000 is requested from the Department of Energy.

"U.S.-Based Electron Ion Collider Science Assessment" is now getting underway. The Chair will be Gordon Baym. The rest of the committee, including a co-chair, will be appointed in the next couple of weeks. The first meeting is being planned for January, 2017

U.S. DEPARTMENT OF ENERGY | Office of Science   NSAC Meeting   June 2, 2017   19

The EIC science assessment by the US NAS

- NAS Webinar and NAS report release: 07/24/2018

http://www8.nationalacademies.org/onpinews/newsitem.aspx?RecordID=25171&_ga=2.209086742.50427317.1532451645-1385917444.1532451645

- Webinar on Tuesday, July 24, 2018 - Public presentation and report release
- Gordon Baym (Co-chair): Webinar presentation

“The committee finds that the science that can be addressed by an EIC is compelling, fundamental and timely.”

- “Glowing” report on a US-based EIC facility!

Click to download report!

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July 24, 2018

FOR IMMEDIATE RELEASE

A Domestic Electron Ion Collider Would Unlock Scientific Mysteries of Atomic Nuclei, Maintain U.S. Leadership in Accelerator Science, New Report Says

WASHINGTON – The science questions that could be answered by an electron ion collider (EIC) – a very large-scale particle accelerator – are significant to advancing our understanding of the atomic nuclei that make up all visible matter in the universe, says a new report by the National Academies of Sciences, Engineering, and Medicine. Beyond its impact on nuclear science, the advances made possible by an EIC could have far-reaching benefits to the nation's science- and technology-driven economy as well as to maintaining U.S. leadership in nuclear physics and in collider and accelerator technologies.

The National Academies were asked by the U.S. Department of Energy (DOE) to examine the scientific importance of an EIC, as well as the international implications of building domestic EIC facility. The committee that conducted the study and wrote the report concluded that the science that could be addressed by an EIC is compelling and would provide long-elusive answers on the nature of matter. An EIC would allow scientists to investigate where quarks and gluons, the tiny particles that make up neutrons and protons, are located inside protons and neutrons, how they move, and how they interact together. While the famous Higgs mechanism explains the masses of the quarks, the most significant portion of the mass of a proton or neutron comes from its gluons and their interactions. Crucial questions that an EIC would answer include the origin of the mass of atomic nuclei, the origin of spin of neutrons and protons – a fundamental property that makes magnetic resonance imaging (MRI) possible, how gluons hold nuclei together, and whether emergent forms of matter made of dense gluons exist.

The report says a new EIC accelerator facility would have capabilities beyond all previous electron scattering machines in the U.S., Europe, and Asia. High energies and luminosities – the measure of the rate at which particle collisions occur – are required to achieve the fine resolution needed, and to reach such intensities and energy levels requires a collider where beams of electrons smash into beams of protons or heavier ions. Comparing all existing and proposed accelerator facilities around the world, the committee concluded that an EIC with high energy and luminosity, and highly polarized electron and ion beams, would be unique and in a position to greatly further our understanding of visible matter.

"An EIC would be the most sophisticated and challenging accelerator currently proposed for construction in the U.S. and would significantly advance accelerator science, and more specifically collider science and technologies, here and around the world," said committee co-chair Gordon Baym, Center for Advanced Study Professor Emeritus, George and Ann Fisher Distinguished Professor of Engineering Emeritus, and Research Professor at the University of Illinois at Urbana-Champaign. "The realization of an EIC is absolutely crucial to maintaining the health of the field of nuclear physics in the U.S. and would open up new areas of scientific investigation."

Currently, the Brookhaven National Laboratory (BNL) in Long Island, New York, has a heavy ion collider, and the Thomas Jefferson National Accelerator Laboratory (JLab) in Newport News, Virginia, has very energetic electron beams. Both labs have proposed design concepts for an EIC that would use their already available infrastructure, expertise, and experience. The report, without favoring one over the other, says that taking advantage of the existing facilities would make development of an EIC cost-effective and reduce associated risks that come with building a large accelerator facility. While both labs have well-developed designs for an EIC, both would require considerable R&D to fully deliver on the compelling science questions. The report states DOE R&D investment has been and would continue to be crucial to minimizing design risks in a timely fashion and to addressing outstanding accelerator challenges.

The committee added that along with advancing nuclear science, an EIC would also benefit other areas such as astrophysics, particle physics, accelerator physics, and theoretical and computational modeling. It would also play a valuable role in sustaining the U.S. nuclear physics workforce in the coming decades. Moreover, it would have a significant role in advancing more broadly the technologies that would result from the research and development undertaken in the implementation and construction of an EIC in the U.S. The report emphasizes that an EIC is the only high-energy collider being planned for construction in the U.S. currently, and building such a facility would maintain U.S. leadership in accelerator collider science while benefiting the physical sciences.

"The science that an EIC would achieve is simply unique and would ensure U.S. leadership in nuclear science as well as the accelerator science and technology of colliders around the world," said committee co-chair Ani Aprahamian, Freimann Professor of Experimental Nuclear Physics at the University of Notre Dame.

The study was sponsored by DOE. The National Academies of Sciences, Engineering, and Medicine are private, nonprofit institutions that provide independent, objective analysis and advice to the nation to solve complex problems and inform public policy decisions related to science, technology, and medicine. The National Academies operate under an 1863 congressional charter to the National Academy of Sciences, signed by President Lincoln. For more information, visit http://national-academies.org.

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EIC CD0 and site selection

- Announcement by the Department of Energy on January 9, 2020

https://www.energy.gov/articles/us-department-energy-selects-brookhaven-national-laboratory-host-major-new-nuclear-physics

Department of Energy

U.S. Department of Energy Selects Brookhaven National Laboratory to Host Major New Nuclear Physics Facility

JANUARY 9, 2020

WASHINGTON, D.C. – Today, the U.S. Department of Energy (DOE) announced the selection of Brookhaven National Laboratory in Upton, NY, as the site for a planned major new nuclear physics research facility. The Electron Ion Collider (EIC), to be designed and constructed over ten years at an estimated cost between $1.6 and $2.6 billion, will smash electrons into protons and heavier atomic nuclei in an effort to penetrate the mysteries of the "strong force" that binds the atomic nucleus together.

The EIC's high luminosity and highly polarized beams will push the frontiers of particle accelerator science and technology and provide unprecedented insights into the building blocks and forces that hold atomic nuclei together. Design and construction of an EIC was recommended by the National Research Council of the National Academies of Science, noting that such a facility "would maintain U.S. leadership in nuclear physics" and "help to maintain scientific leadership more broadly." Plans for an EIC were also endorsed by the federal Nuclear Science Advisory Committee.

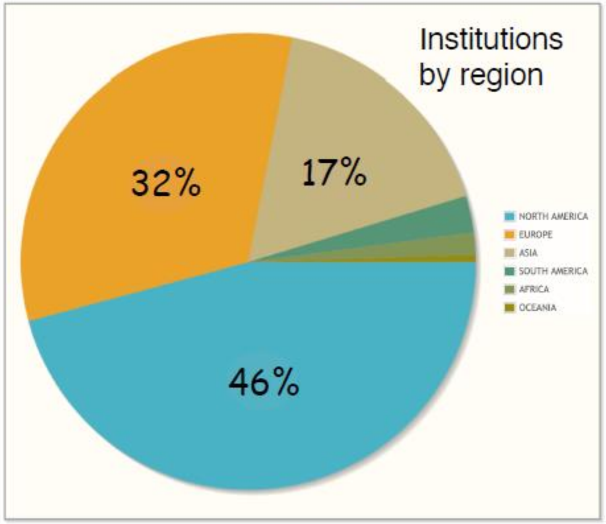
Secretary Brouillette approved Critical Decision-0, "Approve Mission Need," for the EIC on December 19, 2019. "The Department is excited to be moving forward with an Electron Ion Collider at Brookhaven National Laboratory," stated **Office of Science Director Dr. Chris Fall**. "However, participation from many parts of the DOE laboratory complex will be essential if the EIC is to be a success."
Thomas Jefferson National Accelerator Facility in Newport News, VA will be a major partner in realizing the EIC, and several other DOE laboratories are expected to contribute to EIC construction and to the groundbreaking nuclear physics research program that will be accomplished there.

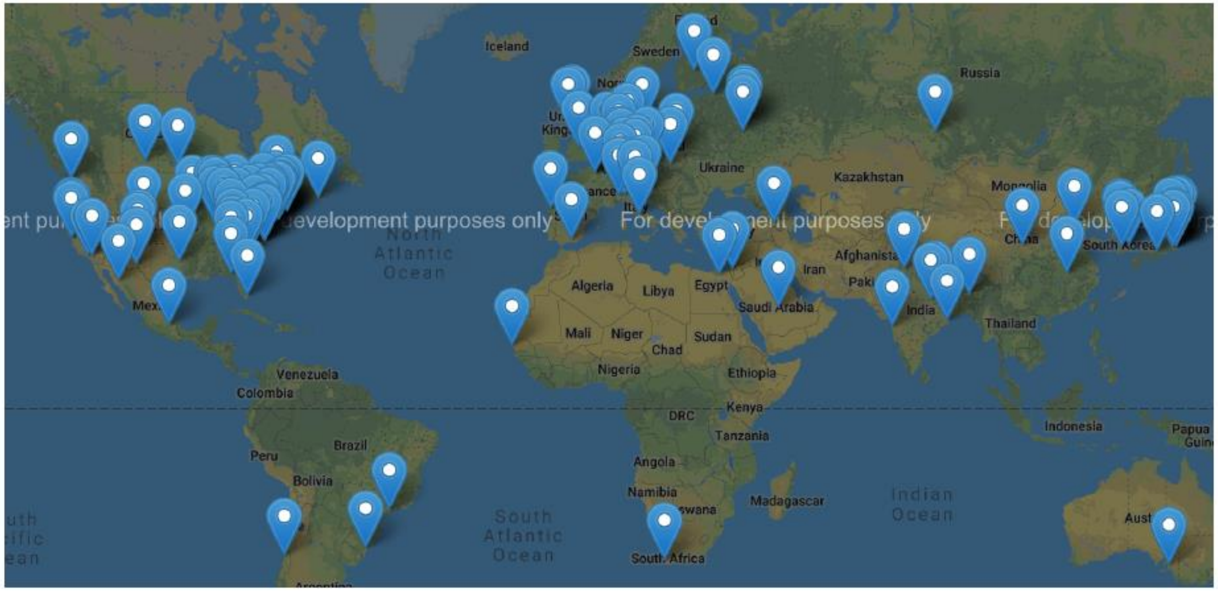
The EIC Users Group

- EIC User Group and R&D activities

WWW-page: www.eicug.org

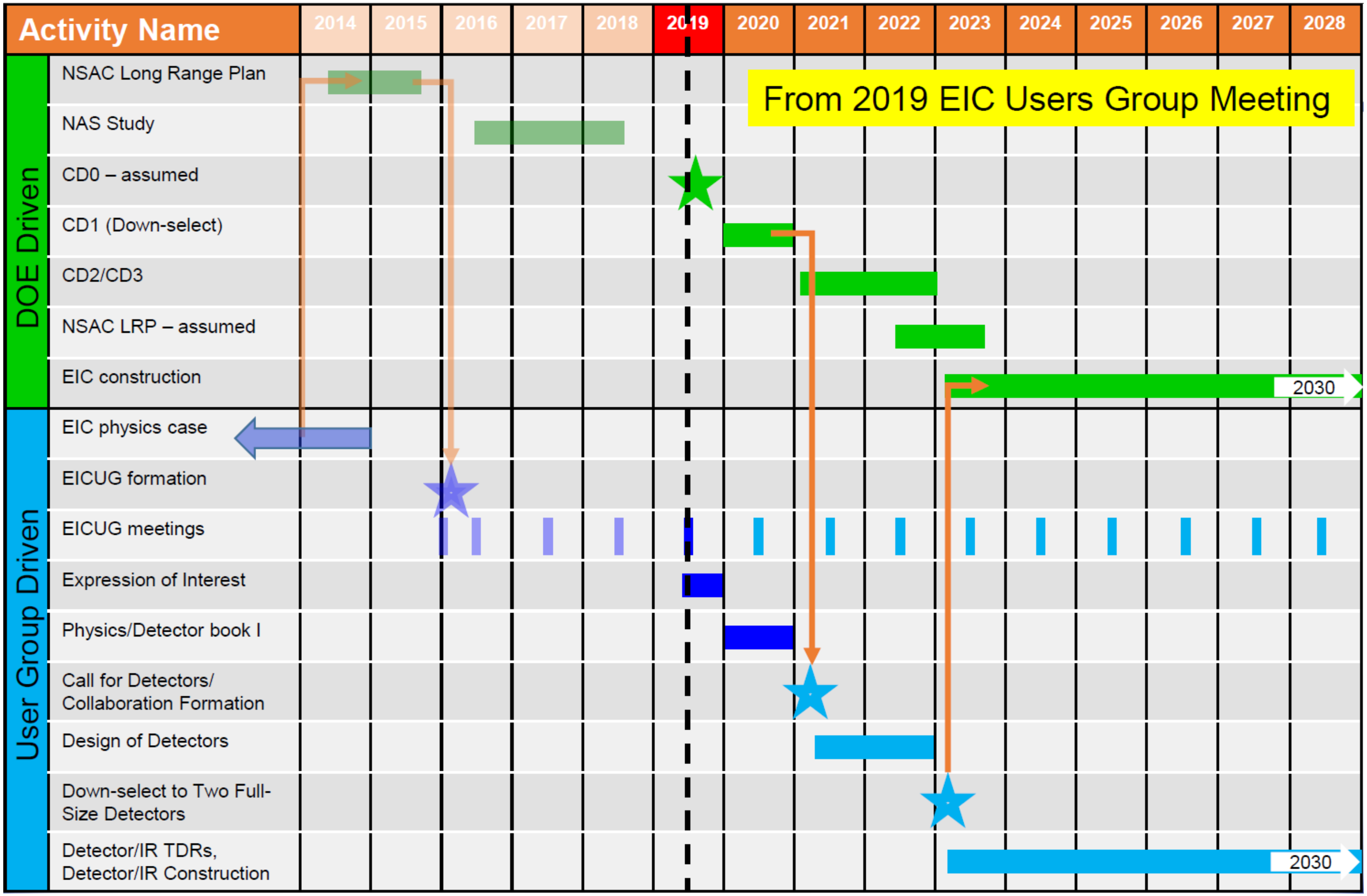
  - EIC User Group:
    - EICUG organization established in summer 2016
    - In numbers….: 945 members (Experimental scientists: 544 / Theory scientists: 221 / Accelerator scientists: 142 / Support: 3 / Other: 39), 192 institutions, 30 countries, 6 world regions
    - World map:





  - R&D activities:
    - EIC Detector R&D program operated by BNL with ~$1M / year
    - EIC Accelerator R&D with ~$7M / year

EIC timeline



CD0 = DOE "Mission Need" statement; **CD1** = design choice and site selection
CD2/CD3 = establish project baseline cost and schedule

EIC Yellow Report initiative

The purpose of the Yellow Report Initiative is to advance the state and detail of the documented physics studies (White Paper, INT program proceedings) and detector concepts in preparation for the realization of the EIC.

The effort aims to provide the basis for further development of concepts for experimental equipment best suited for science needs, including complementarity of two detectors towards future Technical Design Reports (TDRs).

- Work started in January 2020
- Report expected in November 2020
- Significant participation from IJCLab

National & international contributions: Call for Expression of Interest (EoI)

(non-binding) Expressions of Interest (EoI) to get *guidance on detector scope*

Introduce concept and timeline for Call for Expressions of Interest (EoI)

March 2020

(introduce notion for Expressions of Interest for contribution to EIC detectors in plenary talks at 1st Yellow Report (remote) meeting at Temple)

Discussion Call for EoI for ~~contributions~~ potential cooperation to EIC Detectors

~~August 3-7 2020~~ April/May 2020

(assume discussion session at Remote EICUGM, as needed final discussion session at 2nd Yellow Report (remote) meeting at Pavia)

Call for EoI for potential cooperation to EIC Detectors ~~August 2020~~ May 2020

(issue call after folding in feedback of EICUG~~M~~)

Deadline EoI for potential cooperation to EIC Detectors November 2020

(Status report at 4th (final) Yellow Report meeting)

Evaluate EoI and inform Call for Detector Proposal(s) February 2021

(complete after assumed January 2021 Yellow Report completion, EoI can give guidance on detector scope)

Expression of Interest Preamble

Call for Expressions of Interest
for Potential Cooperation to the EIC Experimental Program

Brookhaven National Laboratory (BNL) in association with Jefferson Lab (JLab) calls for an Expression of Interest (EOI) for potential cooperation to the experimental equipment as required for a successful science program at the Electron-Ion Collider (EIC). This call emphasizes all detector components to facilitate the full EIC science program including those integrated in the interaction regions.

The Electron-Ion Collider will be a powerful new facility in the United States that is constructed with the aim of studying the particles, gluons, which bind all the observable matter in the world around us. The EIC facility will collide intense beams of spin-polarized electrons with intense beams of either spin-polarized protons, deuterons, and helium-3 or unpolarized nuclei up to uranium. Detector concepts are now being developed to detect the high-energy scattered particles as well as the low-energy debris as a means to definitively understand how the matter we are all made of is bound together.

The Electron-Ion Collider User Group, which currently has more than 1000 members from over 200 laboratories and universities around the world, initiated a Yellow Report Initiative with its purpose to advance the state and detail of the documented physics studies and detector concepts to prepare for the realization of the EIC (see http://www.eicug.org/web/content/yellow-report-initiative). The effort aims to provide the basis for further development of concepts for experimental equipment best suited for science needs, including the possible complementarity of two detectors towards future Technical Design Reports (TDRs).

This "Call for Expressions of Interest" for cooperation to the EIC experimental program is in phase with the assumed timeline for the Yellow Report completion. The EOI will give the EIC Project guidance on current interest in participation in the EIC experimental program, including an initial understanding of the scope of the experimental equipment that might be available for the expedient start of science operations at the time of EIC project completion.

We encourage interested groups to work together within their country, their geographical region, or as a general consortium, to submit their interest for potential EIC equipment cooperation. Please differentiate if the EOI is for in-kind detector components or those integrated in the interaction regions, and detail if contributions are for full material purchases or cost reductions, are for contributed labor, or for any combination of these. Please also indicate what if any assumptions are made to receive support for the discussed cooperation from the EIC Project or the labs.

To facilitate this process, we have added a listing of "Frequently Asked Questions" below, and also provide a template for a questionnaire that may guide you to what information is useful.

An EOI is <u>non-binding</u>, and will mainly be used to guide expectations and to better understand the potential EIC experimental equipment scope.

Who issues the call:
The EIC Project (BNL together with JLab)

What is the goal:
Gauging the interest of national and international groups/consortia in cooperation to the EIC exp. equipment

Why now:
Information is needed to inform the project on the scope of the experimental equipment for the EIC program and the call for Proposals

What we need to know:
who wants to contribute
what do you want to contribute
what are your assumptions

Timeline beyond EoI

Assumption: CD-1 aligned with accelerator timeline
Goal: CD-2 & CD-3 also aligned!

Form EIC Collaboration(s)

Issue Call for Detector Proposals	March 2021
(consistent with EICUGM assumptions of early 2021)	
Deadline for Proposals	September 2021
(roughly in phase with projected CD-1 date)	
Detector Advisory Committee Meeting	November 2021
(to guide work in TEC phase)	
Selection of Detector(s)	December 2021
(one or two, pending Expression of Interest response)	
CD-2	September 2022
CD-3	September 2023
(CD-2 and CD-3 dates assumed for planning purposes)	

National perspective

- Strong experimental interest from IJCLab and Irfu/CEA
- Large theory interest from many groups: IN2P3+INP (CNRS) & IPhT (CEA)
- Featured in several funded projects:
    - STRONG 2020 (EU)
    - Gluodynamics (P2IO)
- Discussed within the 'Exercise de prospective nationale' (GT03)
    - EIC contribution submitted:
        - 26 permanent staff (9 theory, 13 experiment, 4 IT & Accelerator)
        - 8 different labs (3 theory, 5 experiment)
    - EIC will appear among the recommendations of the report (end of the year)

Exciting opportunities for involvement in detector and accelerator R&D (and construction) in the next few years

Ongoing activities for EIC at IJCLab

Simulations

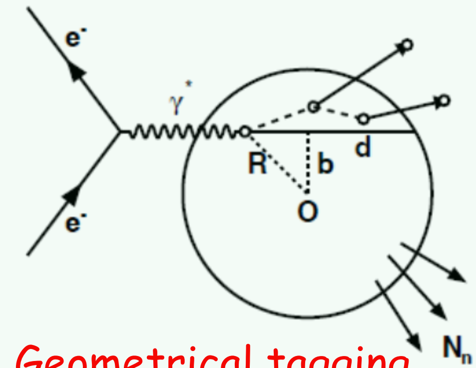
- First measurements of charmonia hadronization
- Indirect access to saturation (interaction with nuclear matter is dominated by low energy gluons)

• Challenges:

- High energy reduces the signal
- High luminosity is key for quarkonia measurements

• Results published in 2 White Papers:

(ArXiv:1108.1713 and Eur.Phys.J. A52 (2016) no.9, 268)



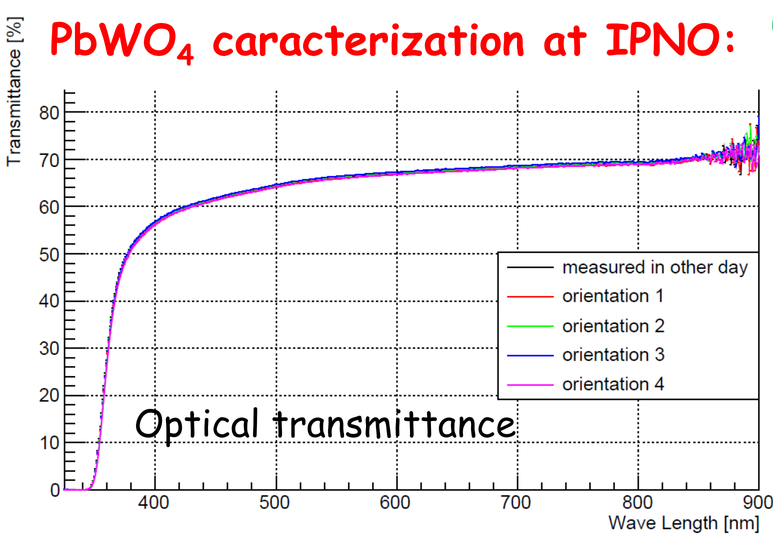
Geometrical tagging

(JLab LDRD working group)

- Impact parameter measurement
- Motivations beyond hadronization (centrality dependence of nuclear effects, shadowing…)

In synergy with developments for JLab CLAS12

$PbWO_4$ caracterization at IPNO:

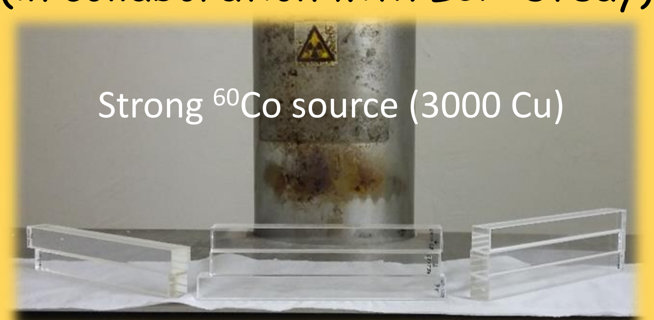


Also: light yield measurements and uniformity using a ^{137}Cs source

Ongoing R&D on crystal calorimetry

International consortium created in 2012 (IPNO joined in 2014)

Radiation hardness measurements (in collaboration with LCP-Orsay)



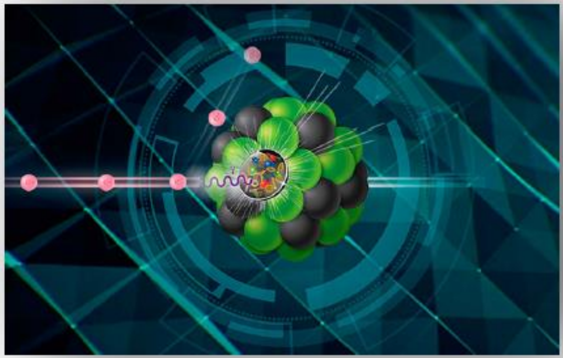
In synergy with developments for JLab NPS

IPNO expertise in calorimetry: CLAS EC, HPS, PANDA…

Activity funded by US DOE: $104k (2015-present)

Summary

- **EIC Physics Pillars**: EIC facility will address fundamental questions on the structure and dynamics of nucleons and nuclei in terms of quarks and gluons using precision measurements including:
  - Parton Distributions in Nuclei / QCD at Extreme Parton Densities - Saturation
  - Spin and Flavor Structure of the Nucleon and Nuclei
  - Tomography (p/A) Transverse Momentum Distribution and Spatial Imaging



- **EIC Facility at BNL under BNL/JLab leadership: Added electron storage ring to existing RHIC facility**
  - Luminosity: $\sim 10^{33-34} cm^{-2} s^{-1}$
  - Polarized e/p and unpolarized heavy ion beams / CME ~20-100GeV
- **EIC Status and Plans:**
  - Awarded CD0 mission statement / Site selection
  - EIC facility construction after FRIB completion realistically in FY22/FY23 timeframe
  - EIC facility completion in roughly a decade from now!

An exciting time is ahead of us to realize a future EIC facility!