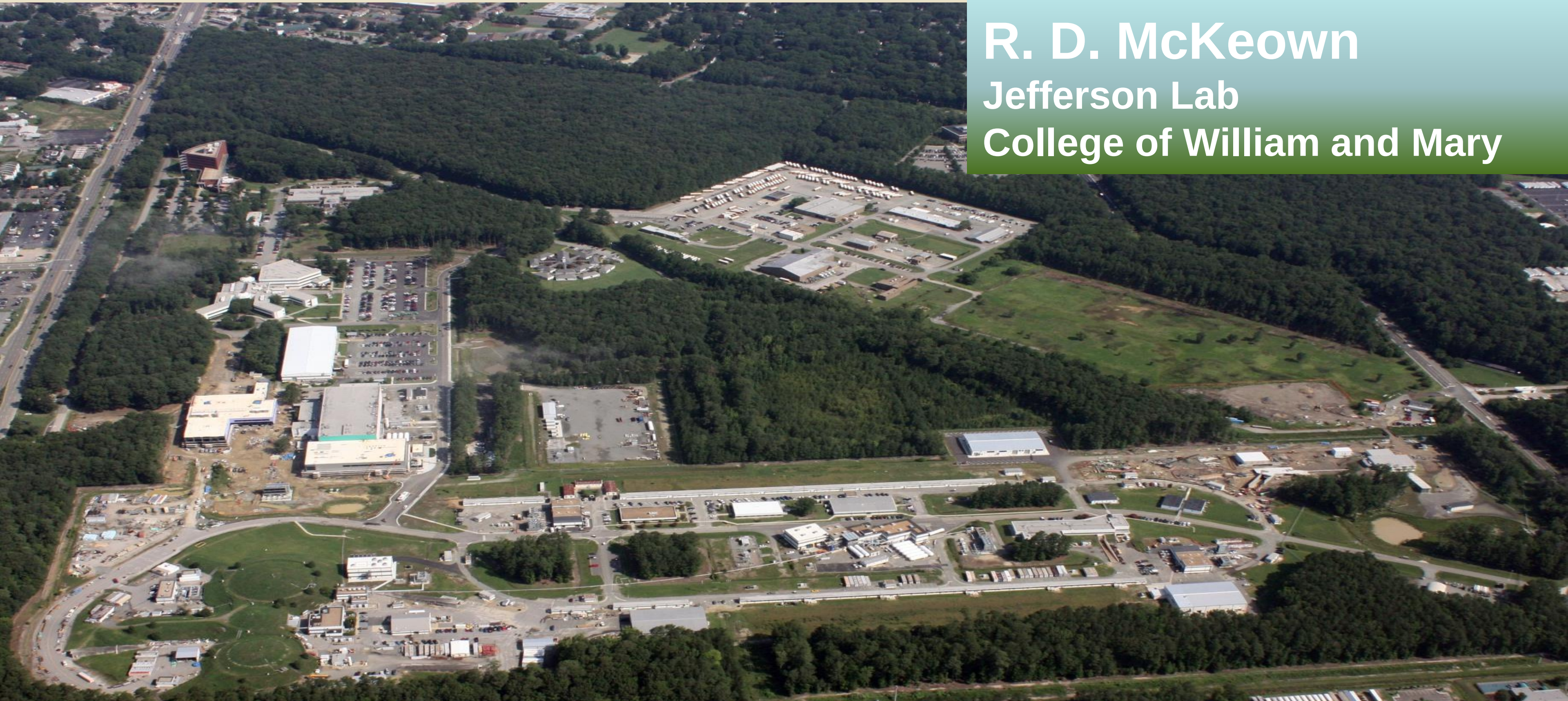
Jefferson Lab Program and MEIC

R. D. McKeown
Jefferson Lab
College of William and Mary

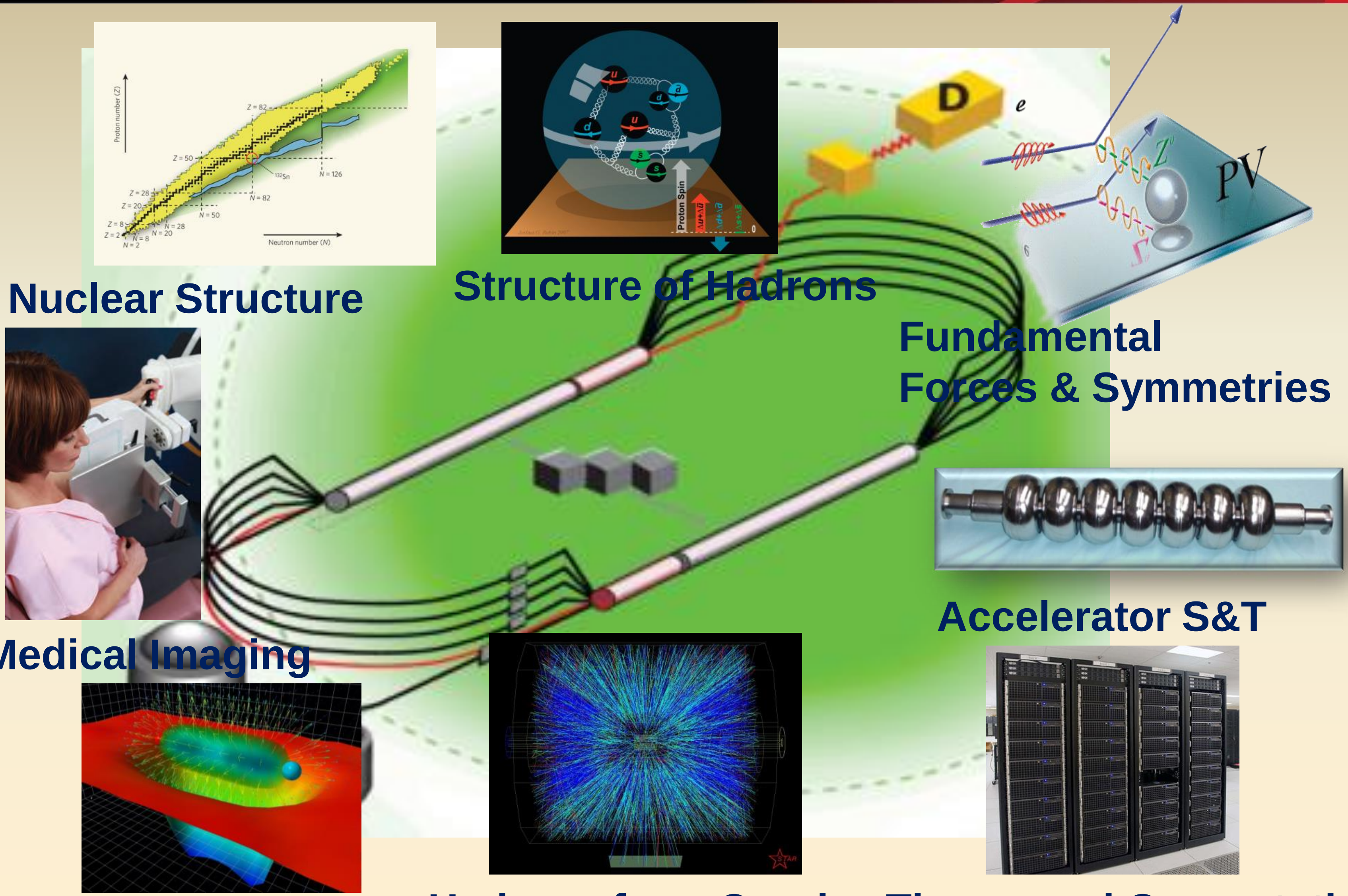


Hadron Workshop, Lanzhou
July 21, 2014

Outline

- Recent Highlights
- 12 GeV Science Overview
- 12 GeV Project Status
- EIC Science
- MEIC project

A Laboratory for Nuclear Science



Nuclear Structure

Structure of Hadrons

Fundamental
Forces & Symmetries

Medical Imaging

Accelerator S&T

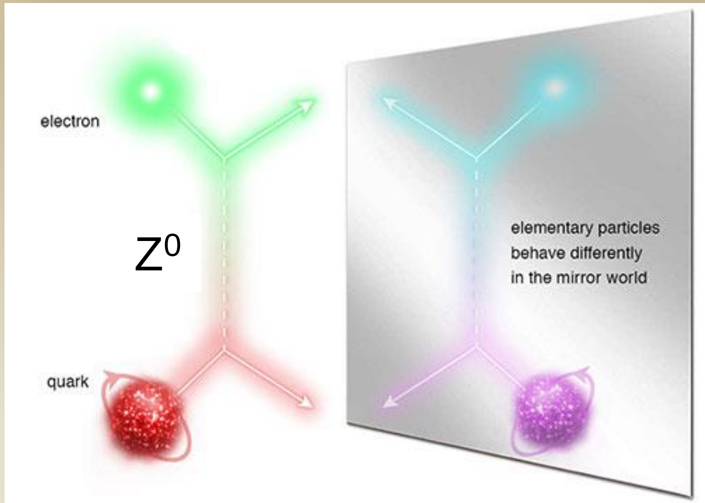
Quark Confinement

Hadrons from Quarks

Theory and Computation

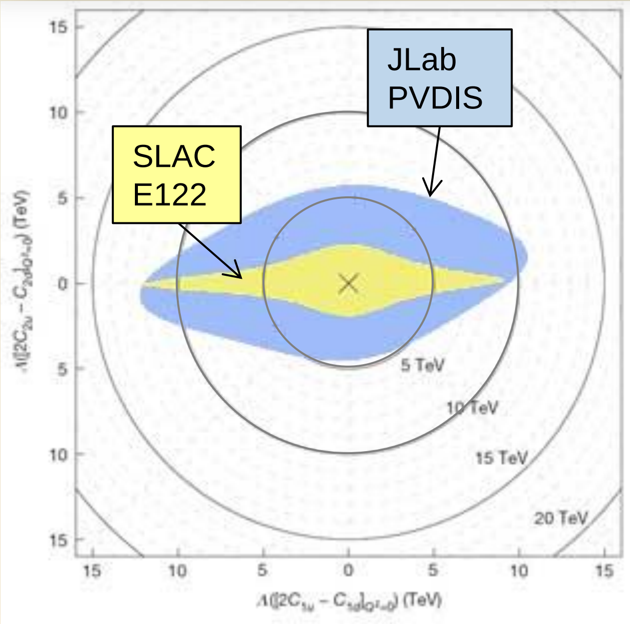
Measurement of the Parity-Violating Asymmetry in eD Deep Inelastic Scattering

Nature 506, 67–70 (06 February 2014)
The Jefferson Lab PVDIS Collaboration
See also News & Views, *Nature* 506, 43–44 (06 February 2014)



Longitudinally Polarized Electron Scattering from Unpolarized Deuterium

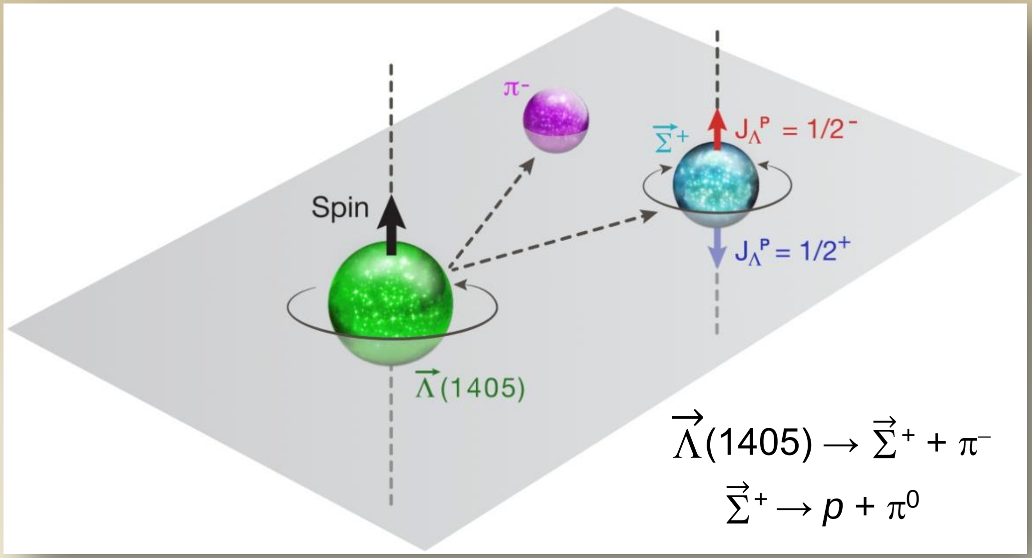
- Precise determination of the effective electron-quark weak coupling combination $2C_{2u} - C_{2d}$, five times more precise than previous measurement.
- Combined with previous experiments like Qweak, first non-zero C_{2q} (at 95% confidence level).
- Provides a mass exclusion limit (Λ) on the electron and quark compositeness and contact interactions of ~5 TeV.

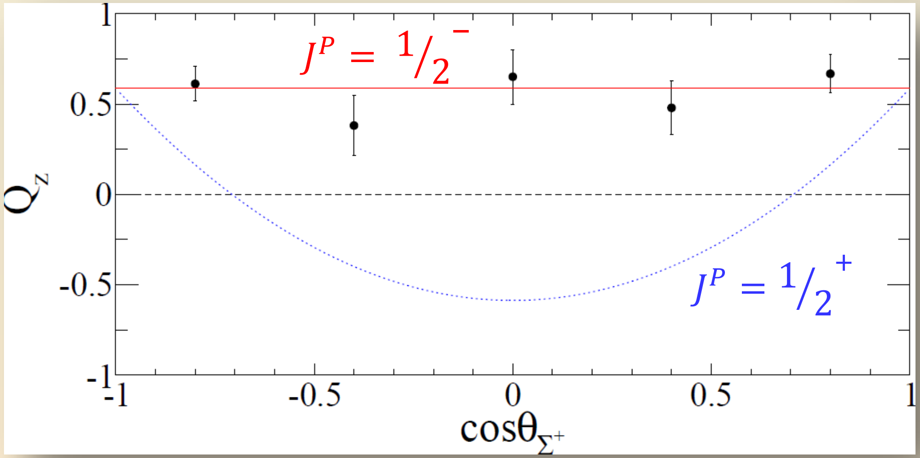


Spin and Parity of the Λ(1405) Baryon

- Λ(1405) is a well‑known hyperon (PDG Status: ★★★★)
- Spin-Parity, J^P, has never been definitively measured
- Λ(1405) created polarized via photoproduction in liquid hydrogen & detected in CLAS

$$\gamma + p \rightarrow K^+ + \vec{\Lambda}(1405),$$
$$\vec{\Lambda}(1405) \rightarrow \vec{\Sigma}^+ + \pi^-$$





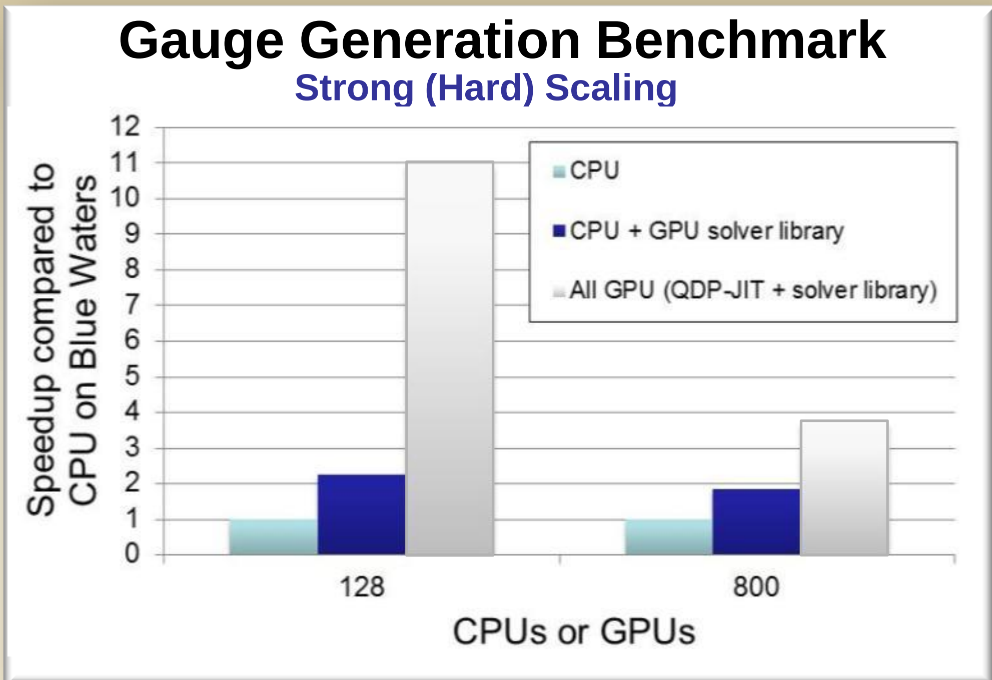
- Isotropic decay of Λ(1405) is consistent with spin $J = {}^1/_2$
- Polarization transfer to Σ^+ direction reveals $J^P = {}^1/_2{}^-$ vs. $J^P = {}^1/_2{}^+$
- Quark model expectation confirmed
- Higher spins are disfavored by the data and by theoretical expectations

- K. Moriya, R. A. Schumacher *et al.* (CLAS Collaboration), Phys. Rev. Lett. **112** 082004 (2014).

- Selected as an "Editors' Suggestion" by PRL

Jefferson Lab

Accelerating Science with GPUs



Data from: F. Winter (JLab), M. A. Clark (NVIDIA), B. Joo (JLab), R. Edwards (JLab) - Accepted for IPDPS'14 conference

Applicable to leadership GPU systems such as DOE Titan (ORNL) and NSF Blue Waters (NCSA - University of Illinois)

Large ASCR Computing Challenge Award in May 2014: 250M core hours

Revolutionary developments:

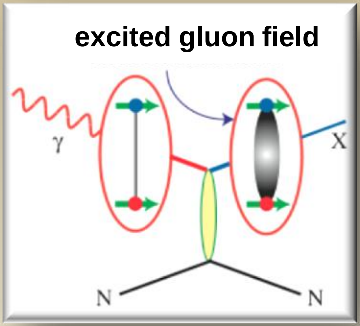
- Juit-in-time (JIT) and GPUs allow analysis of gauge generations to be dramatically accelerated
- ***2x-5x speedup*** over GPU solver library alone, ***3.7x-11x speedup*** over CPU alone

TOP 500 (#364) Supercomputer

(for only $750K!)

Jefferson Lab 12 GeV Science Questions

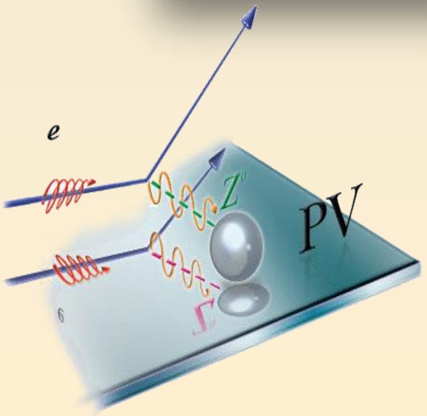
- What is the role of gluonic excitations in the spectroscopy of light mesons?



- Where is the missing spin in the nucleon? Role of orbital angular momentum?

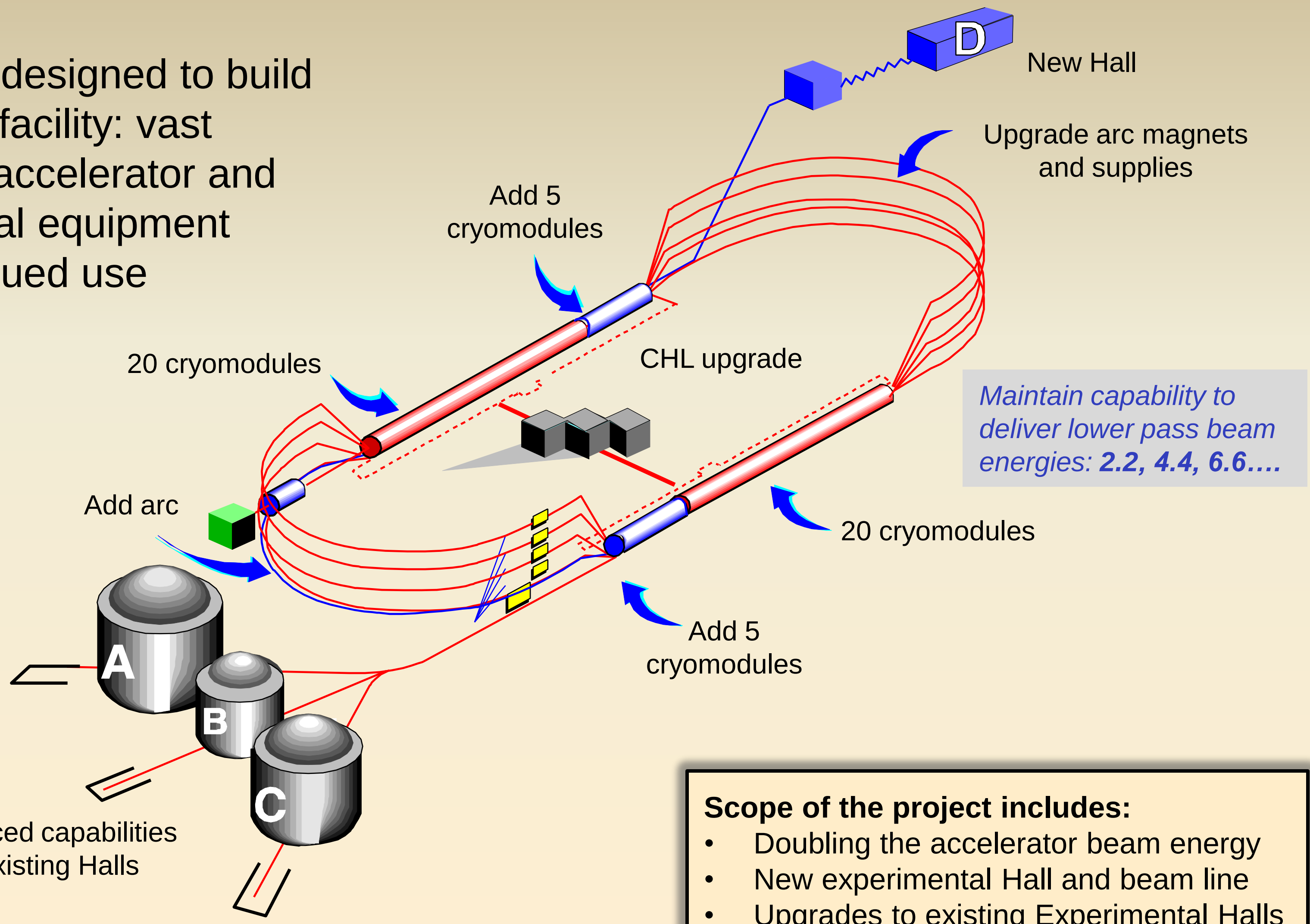
- Can we reveal a novel landscape of nucleon substructure through measurements of new multidimensional distribution functions?

- Can we discover evidence for physics beyond the standard model of particle physics?



12 GeV Upgrade Project

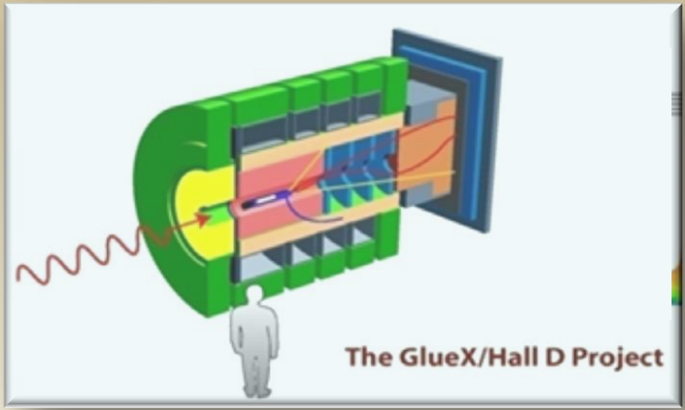
Upgrade is designed to build on existing facility: vast majority of accelerator and experimental equipment have continued use



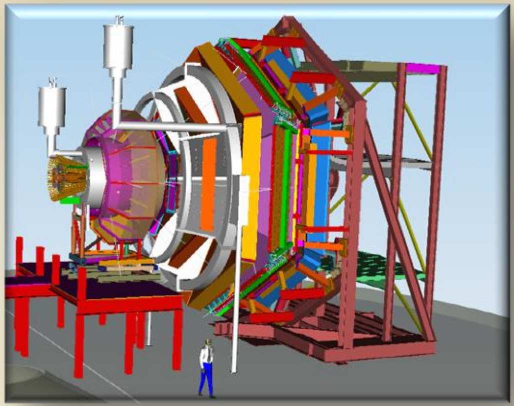
Scope of the project includes:

- Doubling the accelerator beam energy
- New experimental Hall and beam line
- Upgrades to existing Experimental Halls

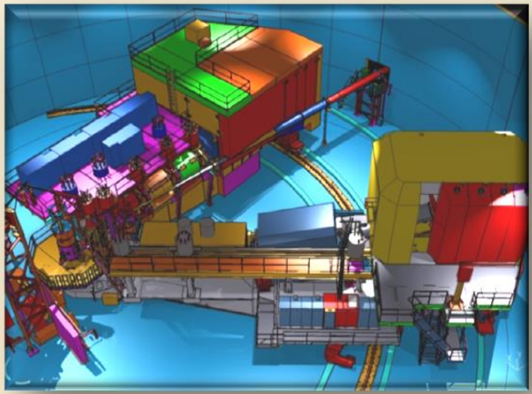
12 GeV Scientific Capabilities



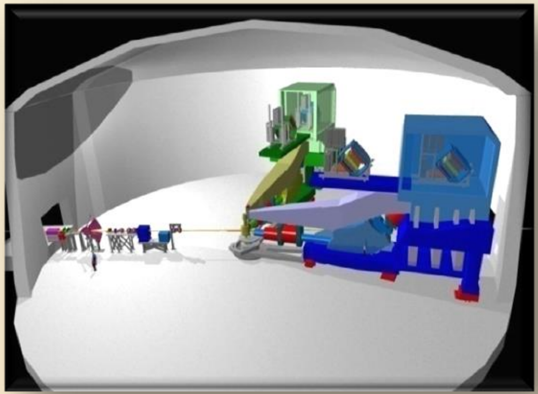
Hall D – exploring origin of confinement by studying exotic mesons



Hall B – understanding nucleon structure via generalized parton distributions



Hall C – precision determination of valence quark properties in nucleons and nuclei



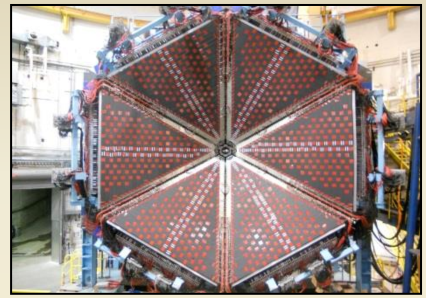
Hall A –form factors, future new experiments (e.g., SoLID and MOLLER)

12 GeV Upgrade Project Highlights

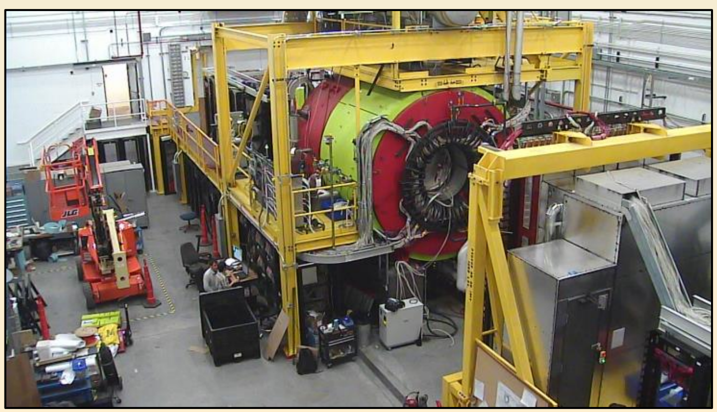
12 GeV Upgrade progress on many fronts

Accelerator 99% complete:
cryomods, cryogenics, beam transport done

Hall B 71% complete:
PCAL/FTOF installed ; Torus coil winding



Hall D 95% complete:
on track for beam commissioning Fall 2014

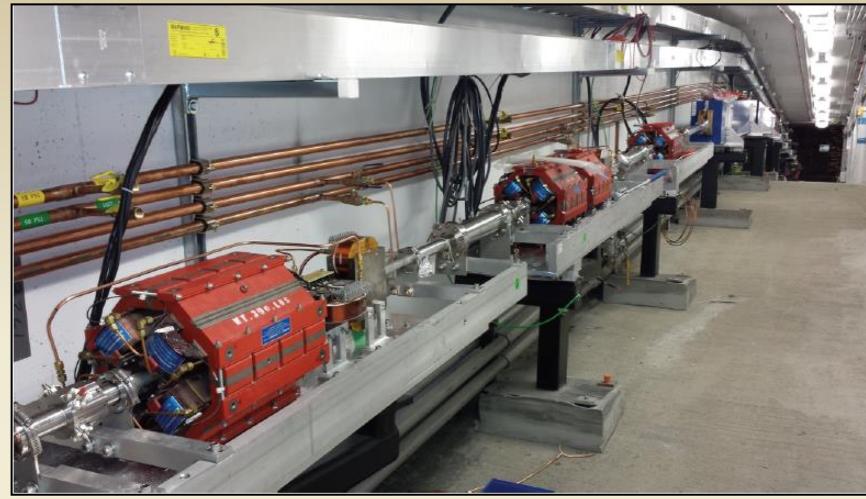


Hall C 69% complete:
shield house installed ; Dipole coil winding

5.5 Pass: 10.5 GeV to Tagger Dump

Hall D Tagger Magnet and Dump

Hall D Beamline



23:42
May 7, 2014

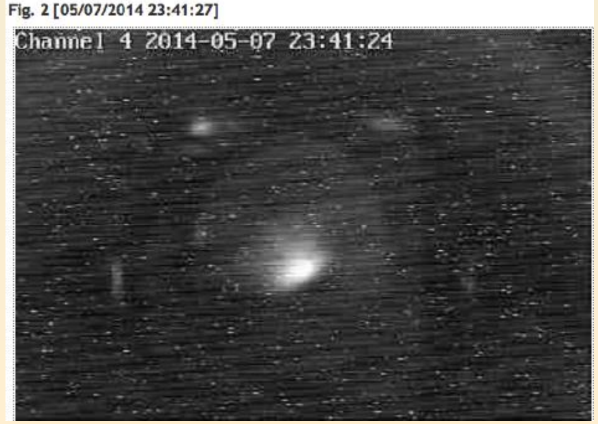
10.5 GeV to 5C

QuickPic - BEAM ON HALL D TAGGER DUMP!

Lognumber 3285622. Submitted by eforman on Wed, 05/07/2014 - 23:41.
Last updated on Wed, 05/07/2014 - 23:42

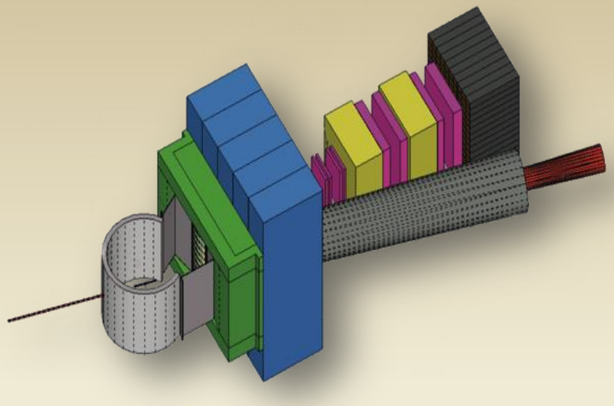
Logbooks:	ELOG
Tags:	Readme
Entry Makers:	eforman

Fig. 2 [05/07/2014 23:41:27]

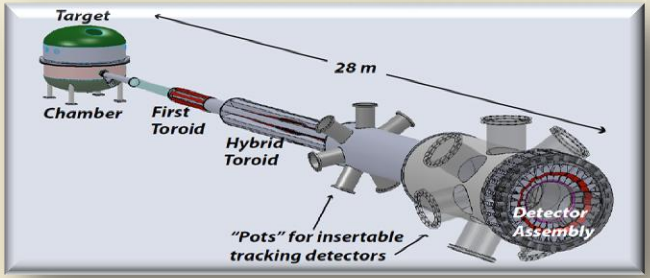


Beyond 12 GeV Upgrade

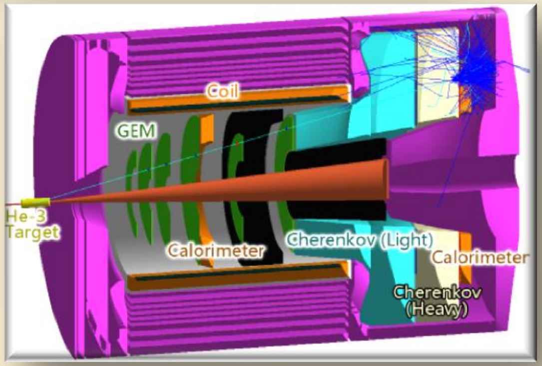
- **Super BigBite Spectrometer**
  (FY13-16 construction)
  - **high Q^2 form factors**
  - **SIDIS**



- **MOLLER experiment**
  (MIE – FY15-18?)
  - **Standard Model Test**

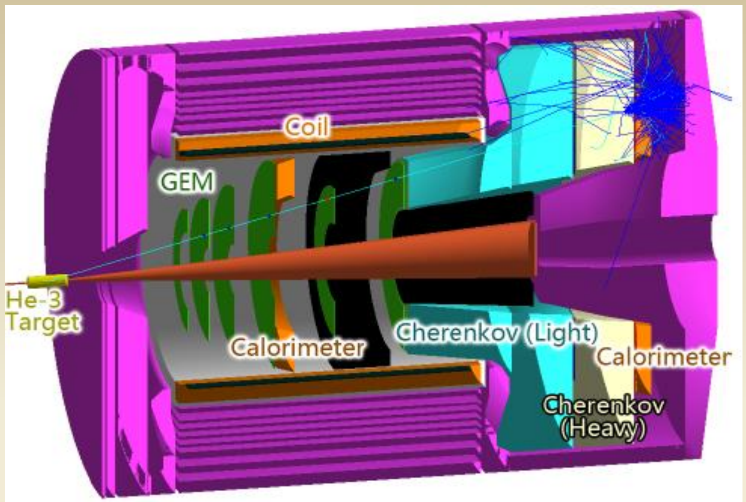


- **SoLID**
  Chinese collaboration
  CLEO Solenoid ✓



- **Enhancements of equipment in B, C, D**
  (Leverage external investments)

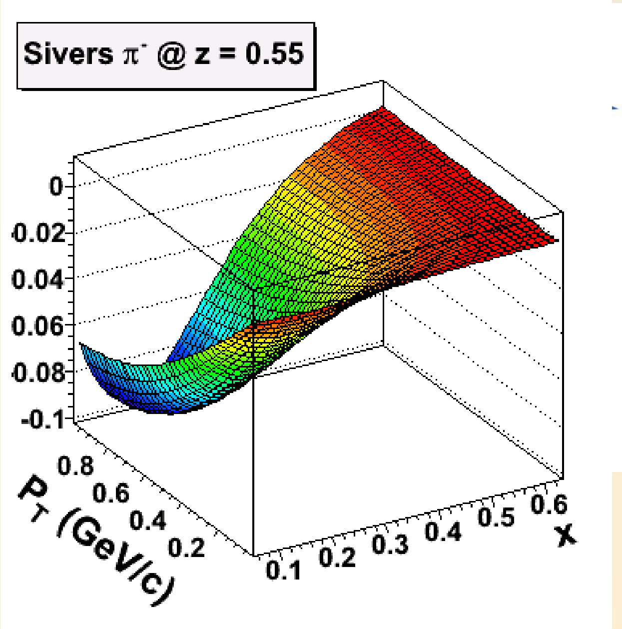
SoLID at Jefferson Lab

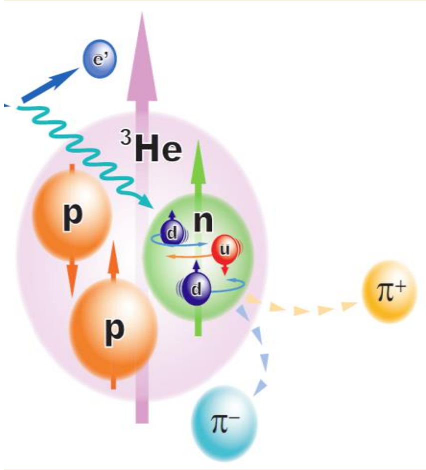


Semi-inclusive Deep Inelastic Scattering program:
Large Acceptance + High Luminosity
+ Polarized targets
→ **4-D** mapping of asymmetries
→ Tensor charge, TMDs …
→Lattice QCD, QCD Dynamics, Models.

International collaboration (8 countries, 50+ institutes and 190+ collaborators)
• Rapid Growth in US - China Collaboratio
(2 grants from NSFC + MOU)
• Chinese Hadron collaboration
(USTC, CIAE, PKU, Tsinghua U,
- large GEM trackers
- MRPC-TOF

Five experiments approved for SoLID with two having Chinese collaborators as co-spokesperson (Li from CIAE and Yan from USTC)





12 GeV Approved Experiments by PAC Days

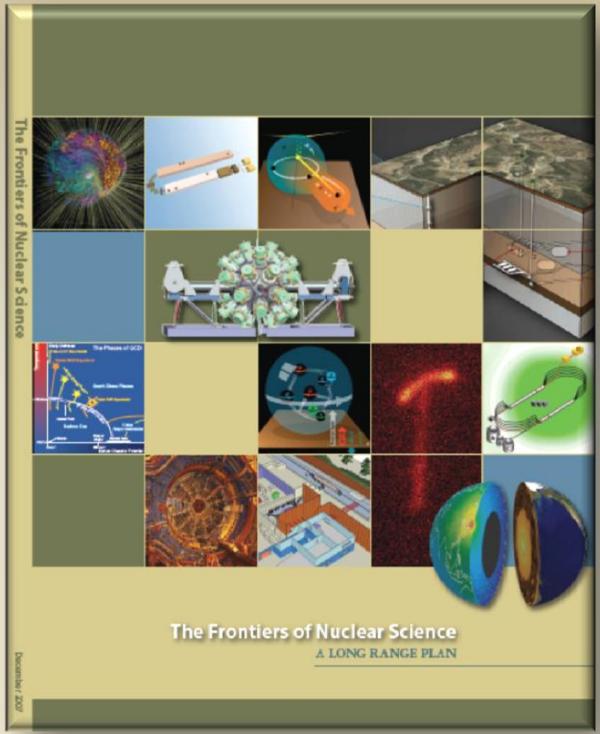
Topic	Hall A	Hall B	Hall C	Hall D	Other	Total
The Hadron spectra as probes of QCD (GluEx and heavy baryon and meson spectroscopy)		119		320		**439**
The transverse structure of the hadrons (Elastic and transition Form Factors)	144	85	102	25		**356**
The longitudinal structure of the hadrons (Unpolarized and polarized parton distribution functions)	65	230	165			**460**
The 3D structure of the hadrons (Generalized Parton Distributions and Transverse Momentum Distributions)	409	872	161			**1442**
Hadrons and cold nuclear matter (Medium modification of the nucleons, quark hadronization, N-N correlations, hypernuclear spectroscopy, few-body experiments)	159	120	179		14	**472**
Low-energy tests of the Standard Model and Fundamental Symmetries	547	205		79	60	**891**
TOTAL	**1324**	**1631**	607	424	**74**	**4060**

More than 10 years of approved experiments

Electron Ion Collider

NSAC 2007 Long-Range Plan:

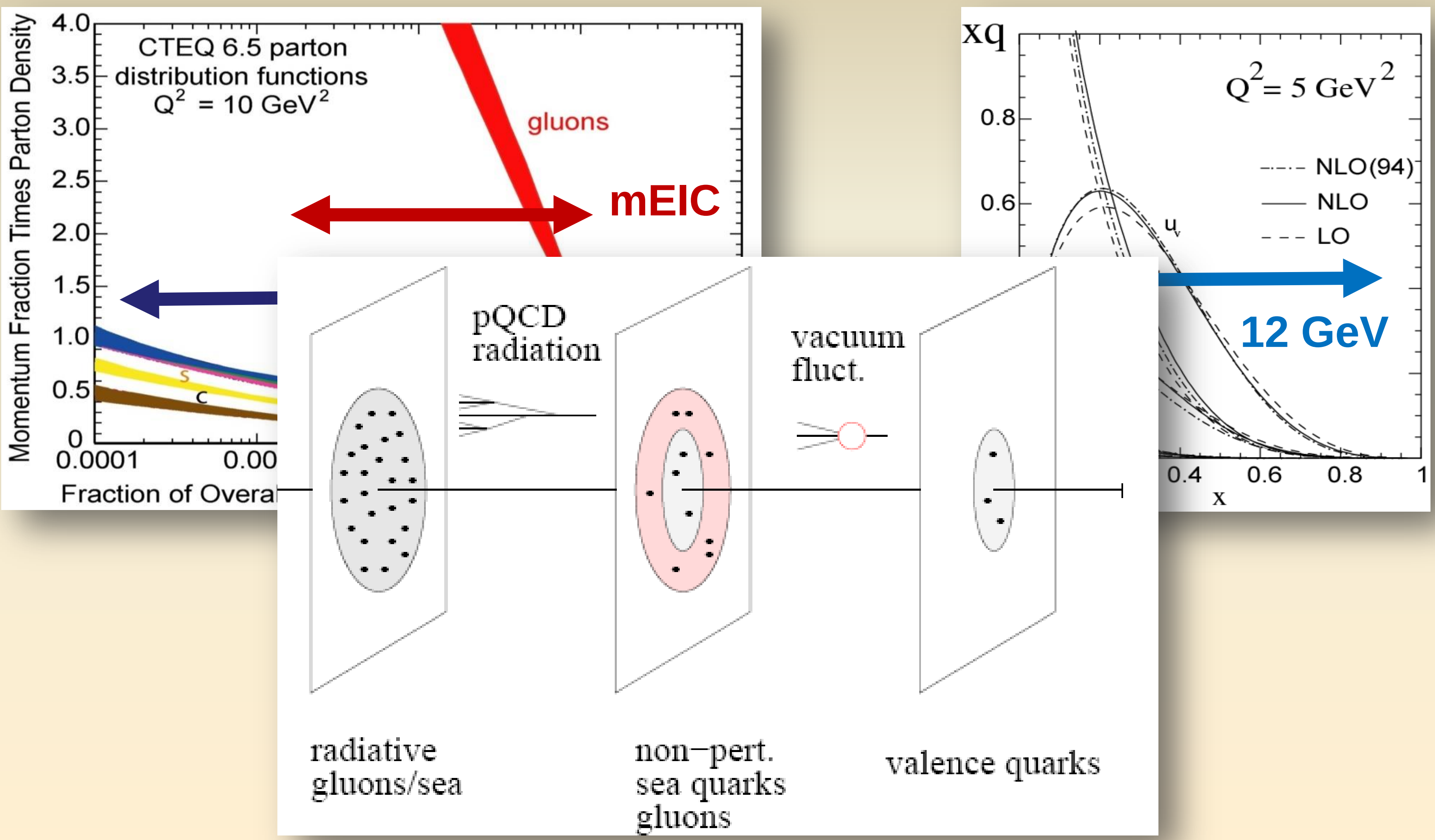
"An **Electron-Ion Collider (EIC)** with **polarized** beams has been **embraced by the U.S. nuclear science community** as embodying the vision for **reaching the next QCD frontier**. EIC would provide unique capabilities for the study of QCD well beyond those available at existing facilities worldwide and complementary to those planned for the next generation of accelerators in Europe and Asia."



- **Jefferson Lab and BNL developing facility designs**
- **Joint community efforts to develop science case → white paper (2013)**
- **2015 Long Range Plan in progress**
  – opportunity for EIC recommendation

The Landscape of EIC

- An EIC aims to study gluon dominated matter.
- With 12 GeV we study mostly the valence quark component

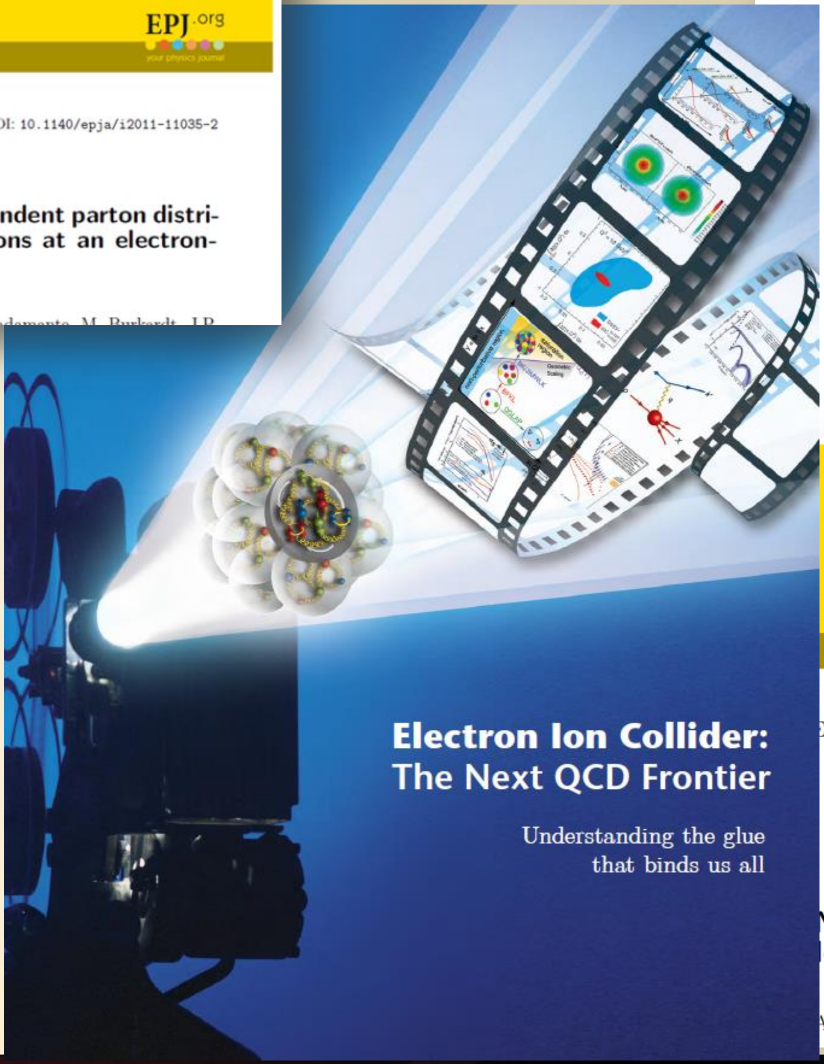


Recent Documents

EPJ A
Hadrons and Nuclei

Eur. Phys. J. A (2011) **47**: 35 DOI: 10.1140/epja/i2011-11035-2

Transverse-momentum–dependent parton distribution/fragmentation functions at an electron-ion collider



The EIC Science case: a report on the joint BNL/INT/JLab program

Gluons and the quark sea at high energies: distributions, polarization, tomography

Institute for Nuclear Theory, University of Washington, USA
September 13 to November 19, 2010

Editors:

D. Boer, Universiteit Groningen, The Netherlands
M. Diehl, Deutsches Elektronen-Synchroton DESY, Germany
R. Milner, Massachusetts Institute of Technology, USA
R. Venugopalan, Brookhaven National Laboratory, USA
W. Vogelsang, Universität Tübingen, Germany

EPJ A
Hadrons and Nuclei

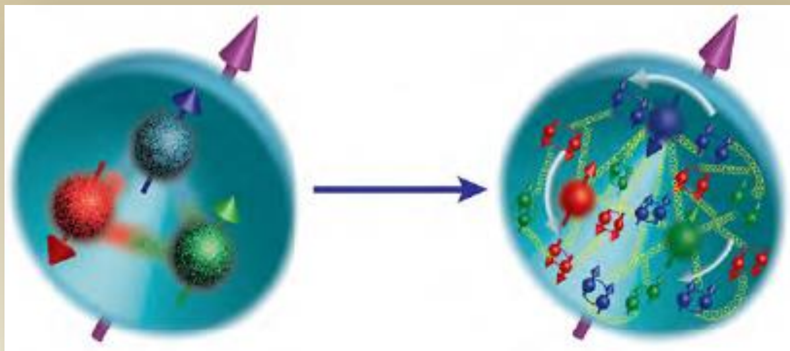
Eur. Phys. J. A (2012) **48**: 92 DOI 10.1140/epja/i2012-12092-7

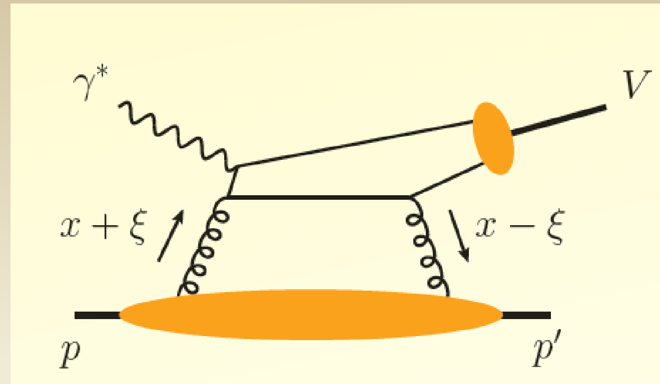
Nuclear physics with a medium-energy Electron-Ion Collider

A. Accardi, V. Guzey, A. Prokudin and C. Weiss

Jefferson Lab

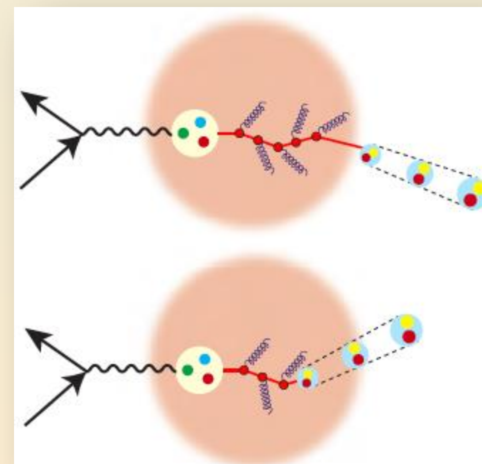
Electron Ion Collider: A QCD Laboratory





Understanding the "99%", the glue that binds us

- Gluons and sea quarks
  - tomography
  - spin
  - orbital angular momentum
  - nuclear effects
- QCD at high gluon density
- Quark hadronization in depth

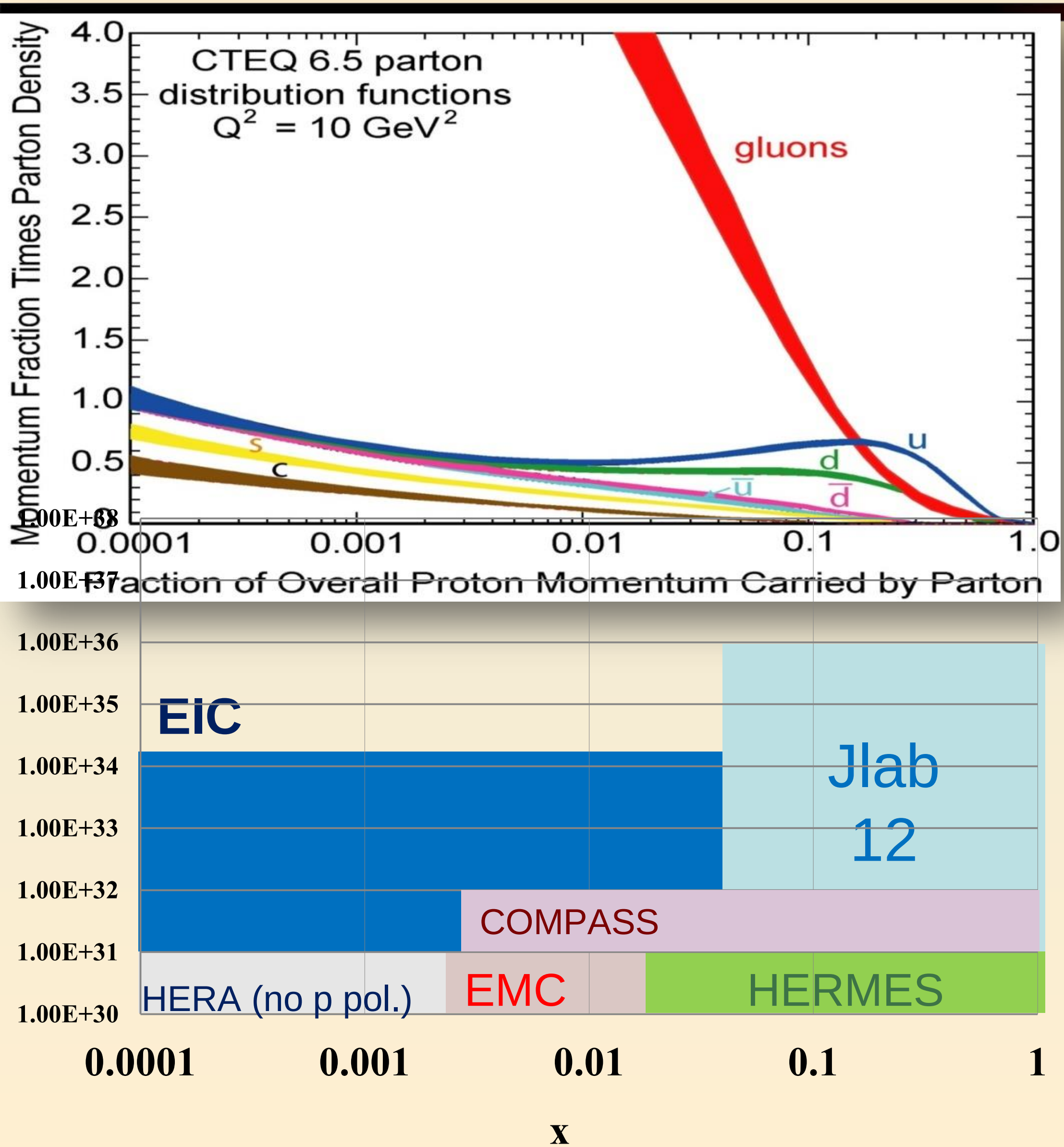


EIC Requirements

From the 2013 EIC White Paper:

- Highly polarized ($\sim$ 70%) electron and nucleon beams
- Ion beams from deuteron to the heaviest nuclei (uranium or lead)
- Variable center of mass energies from $\sim$ 20 – $\sim$100 GeV, upgradable to $\sim$150 GeV
- High collision luminosity $\sim 10^{33-34}$ $cm^{-2}s^{-1}$
- Possibilities of having more than one interaction region

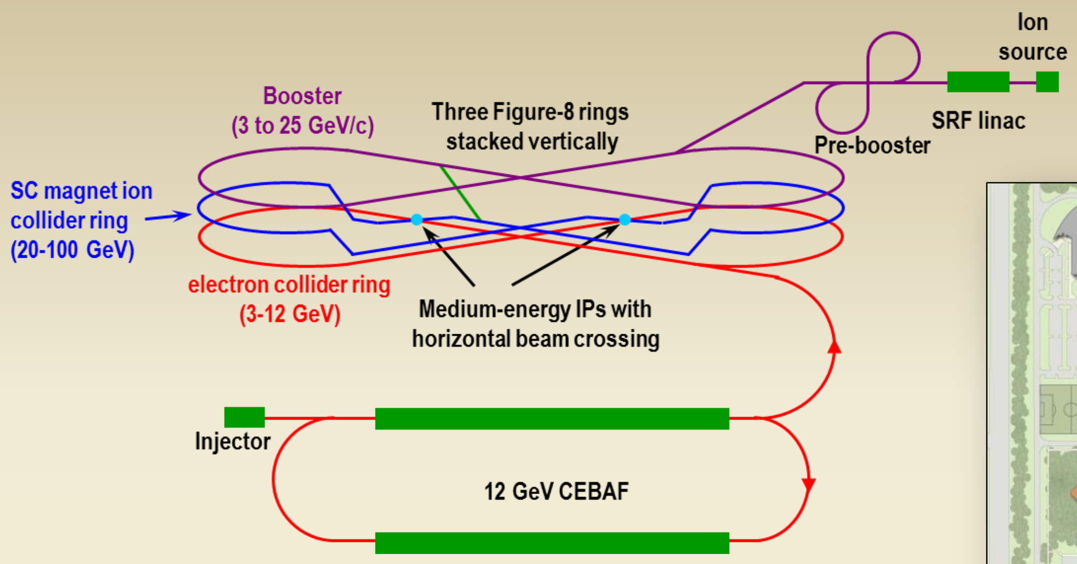
The Reach of EIC



- **High Luminosity** → $10^{34}cm^{-2}s^{-1}$
- **Low x regime** x → 0.0001
- **High Polarization** → 70%

Discovery Potential!

Medium Energy EIC@JLab



JLab Concept

- Initial configuration (MEIC):
  - 3-12 GeV on 20-100 GeV ep/eA collider
  - Fully-polarized, longitudinal and transverse
  - Luminosity:

    up to few x 10^{34} e-nucleons cm^{-2} s^{-1}
- Upgradable to higher energies

  250 GeV protons + 20 GeV electrons

MEIC Design Goals

Energy

Full coverage of √**s** from **15** to **70** GeV

Electrons **3-12** GeV, protons **20-100** GeV, ions **12-40** GeV/u

Ion species

Polarized light ions: **p**, **d**, **^{3}He**, and possibly **Li**

Un-polarized light to heavy ions up to A above 200 (Au, Pb)

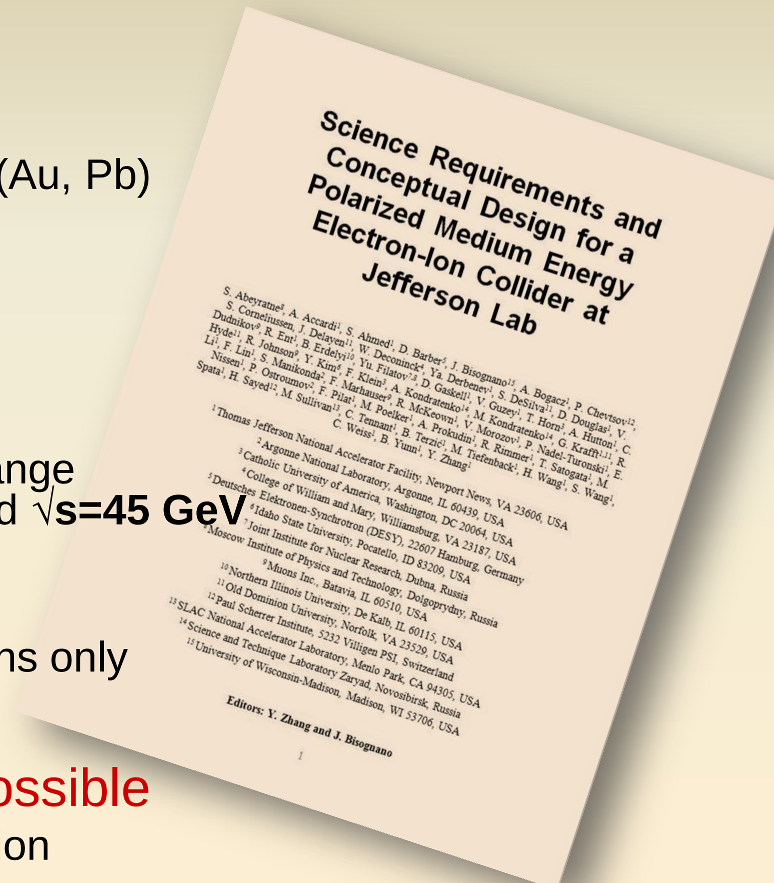
At least 2 detectors

Full acceptance is critical for the primary detector

Luminosity

Above 10^{33} $cm^{-2}s^{-1}$ per IP in a *broad* CM energy range

Maximum luminosity >10^{34} optimized to be around **√s=45 GeV**



Science Requirements and Conceptual Design for a Polarized Medium Energy Electron-Ion Collider at Jefferson Lab

S. Abeyratne[8], A. Accardi[1], S. Ahmed[1], D. Barber[5], J. Bisognano[15], A. Bogacz[1], P. Chevtsov[12], S. Corneliussen, J. Delayen[11], W. Deconinck[4], Ya. Derbenev[1], S. DeSilva[11], D. Douglas[1], V. Dudnikov[9], R. Ent[1], B. Erdelyi[10], Yu. Filatov[7,8], D. Gaskell[1], V. Guzey[1], T. Horn[3], A. Hutton[1], C. Hyde[11], R. Johnson[9], Y. Kim[6], F. Klein[3], A. Kondratenko[14], M. Kondratenko[14], G. Krafft[1,11], R. Li[1], F. Lin[1], S. Manikonda[2], F. Marhauser[9], R. McKeown[1], V. Morozov[1], P. Nadel-Turonski[1], E. Nissen[1], P. Ostroumov[2], F. Pilat[1], M. Poelker[1], A. Prokudin[1], R. Rimmer[1], T. Satogata[1], M. Spata[1], H. Sayed[12], M. Sullivan[13], C. Tennant[1], B. Terzić[1], M. Tiefenback[1], H. Wang[1], S. Wang[1], C. Weiss[1], B. Yunn[1], Y. Zhang[1]

[1] Thomas Jefferson National Accelerator Facility, Newport News, VA 23606, USA
[2] Argonne National Laboratory, Argonne, IL 60439, USA
[3] Catholic University of America, Washington, DC 20064, USA
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[7] Joint Institute for Nuclear Research, Dubna, Russia
[8] Moscow Institute of Physics and Technology, Dolgoprydny, Russia
[9] Muons Inc., Batavia, IL 60510, USA
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[12] Paul Scherrer Institute, 5232 Villigen PSI, Switzerland
[13] SLAC National Accelerator Laboratory, Menlo Park, CA 94305, USA
[14] Science and Technique Laboratory Zaryad, Novosibirsk, Russia
[15] University of Wisconsin-Madison, Madison, WI 53706, USA

Editors: Y. Zhang and J. Bisognano

1

Polarization

At IP: longitudinal for both beams, transverse for ions only

All polarizations >70%

Upgrade to higher energies and luminosity possible

20 GeV electron, **250 GeV** proton, and **100 GeV/u** ion

Design goals consistent with the White Paper requirements

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Design Features: High Polarization

All ion rings (two boosters, collider) have a figure-8 shape

- Spin precession in the left & right parts of the ring are exactly cancelled
- Net spin precession (spin tune) is zero, thus energy independent

- Ensures spin preservation and ease of spin manipulation
- Avoids energy-dependent spin sensitivity for ion all species
- ***The only practical way to accommodate polarized deuterons***

which allows for "clean" neutron measurements

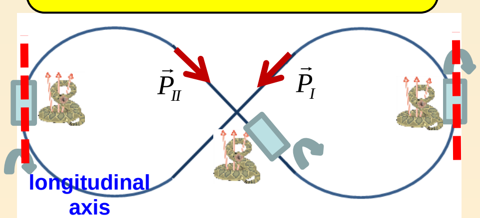
This design feature permits a **high polarization** for all light ion beams

(The electron ring has a similar shape since it shares a tunnel with the ion ring)

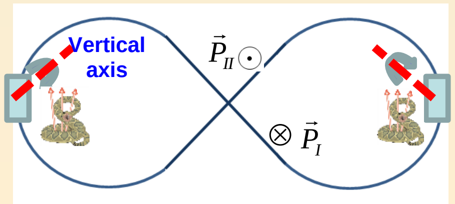
Use Siberian Snakes/solenoids to arrange polarization at IPs

Proton or Helium-3 beams

Longitudinal polarization at both IPs

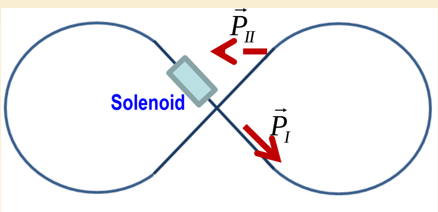


Transverse polarization at both IPs

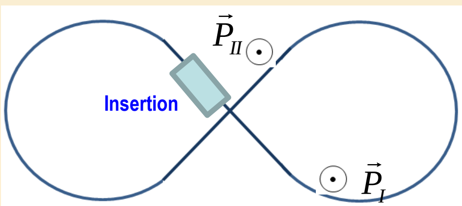


Deuteron beam

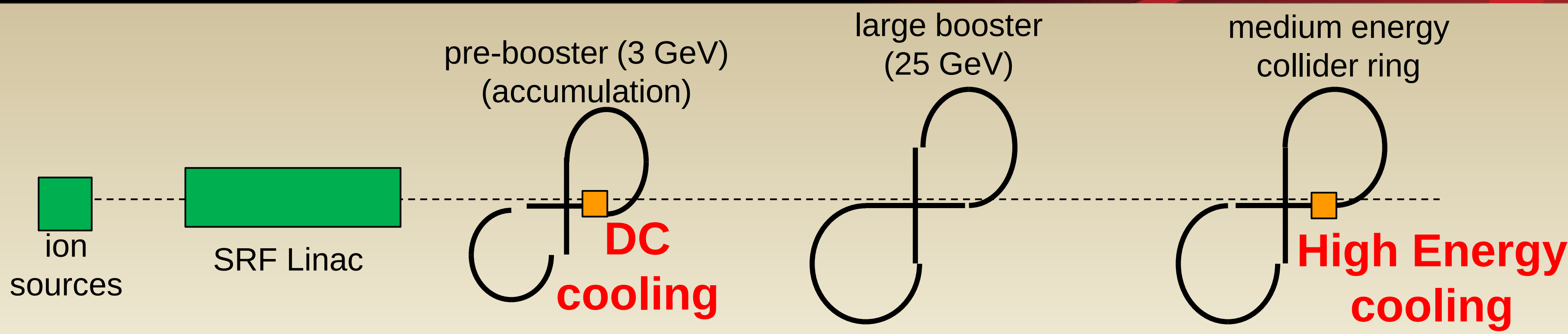
Longitudinal polarization at one IP



Transverse polarization at one IP



Multi-Staged e-Cooling Scheme



	Stage	Ion (GeV/u)	Electron (MeV)	Cooling beam /Cooler
Pre-booster	Assisting accumulation of positive ions	0.1 (injection) long bunches	0.59	Existing technology DC
	Initial cooling to reduce emittance	3 (extraction) long bunches	2.1	DC
Collider ring	Initial cooling for emittance reduction	25 (injection) long bunches	13	Bunched /ERL
	Final cooling for emittance reduction	Up to 100 bunched beam	55	Bunched /ERL
	During collision (suppress IBS)	Up to 100 bunched beam, 1 cm	55	Bunched /ERL

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Proposed Cooling Experiments at IMP

Two storage rings for Heavy ion coasting beam

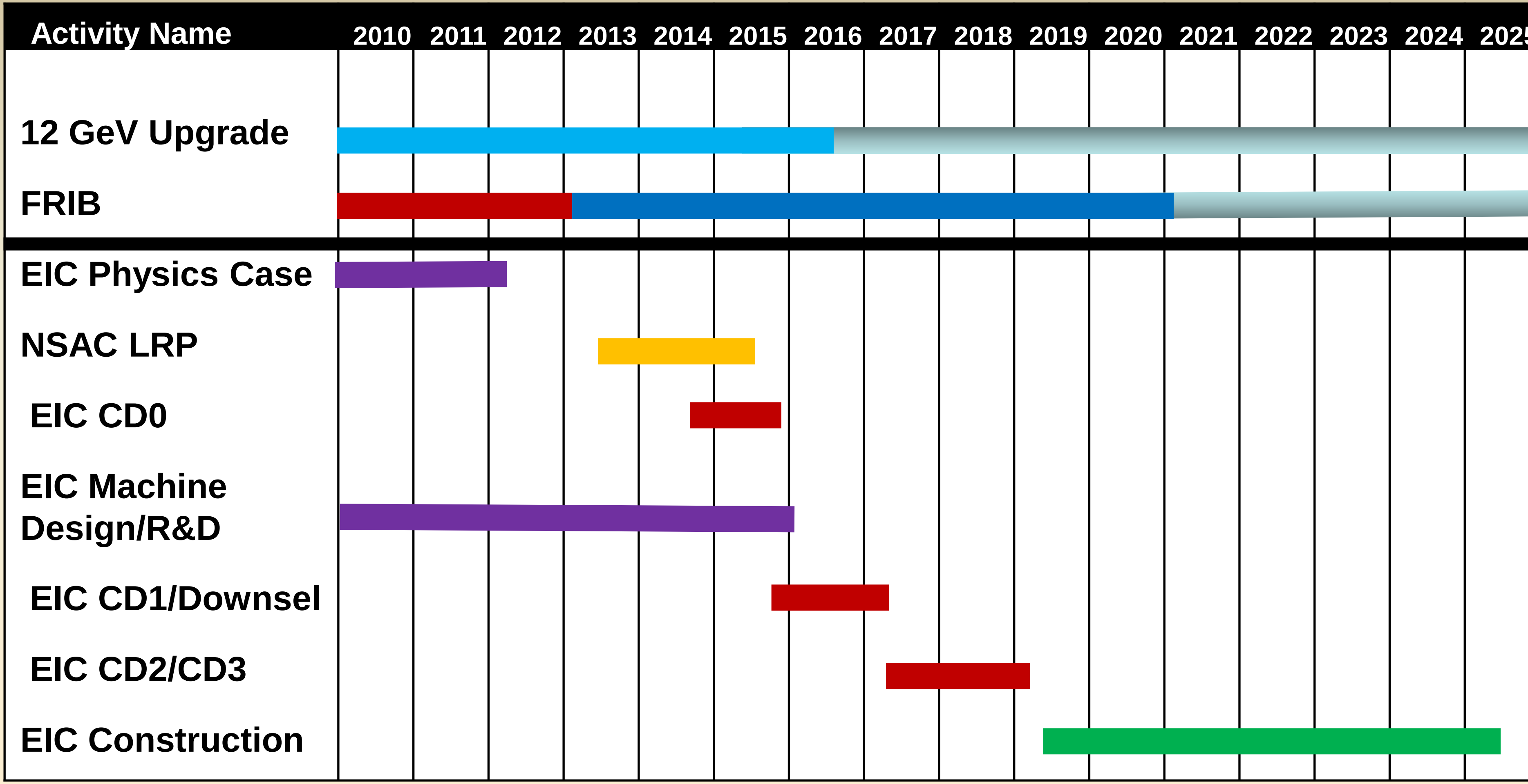
DC cooler

- ***Idea***: pulse the beam from the existing thermionic gun using the grid (Hongwei Zhao)
- Non-invasive experiment to a user facility

Proposed experiments

- Demonstrate cooling of a DC ion beam by a bunched electron cooling (Hutton)
- Demonstrate a new phenomena: longitudinal bunching of a bunched electron cooling (Hutton)
- (***Next phase***) Demonstrate cooling of bunched ion beams by a bunched electron beam (need an RF cavity for bunching the ion beams)

EIC Realization Imagined



Assumes endorsement for an EIC at the next NSAC Long Range Plan
Assumes relevant accelerator R&D for down-select process done around 2016

Jefferson Lab: Today and Tomorrow

- The Jefferson Lab electron accelerator is a unique world-leading facility for nuclear physics research

- 12 GeV upgrade ensures at least a decade of excellent opportunities for discovery
  - New vistas in QCD
  - Growing program Beyond the Standard Model
  - Additional equipment: SBS, MOLLER, SoLID

- EIC moving forward:
  - Strong science case, much builds on JLab 12 GeV program
  - MEIC design well developed – time scale following 12 GeV program is “natural”
  - JLab and RHIC communities are working together to realize a recommendation for construction from the NSAC Long Range Plan

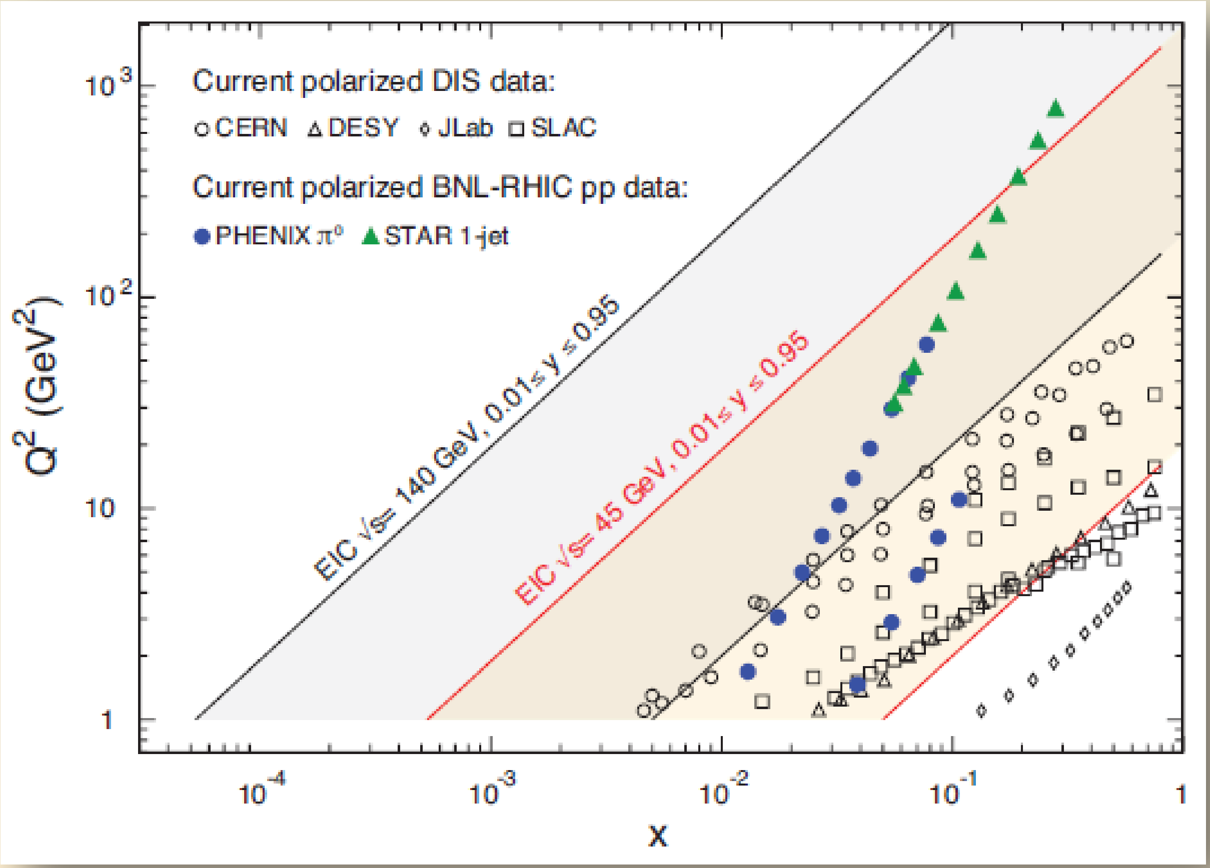
Polarized Luminosity

$x = Q^2/ys$

(x,Q^2) phase space directly correlated with s ($=4E_eE_p$) :

@ $Q^2 = 1$ lowest x scales like s^{-1}

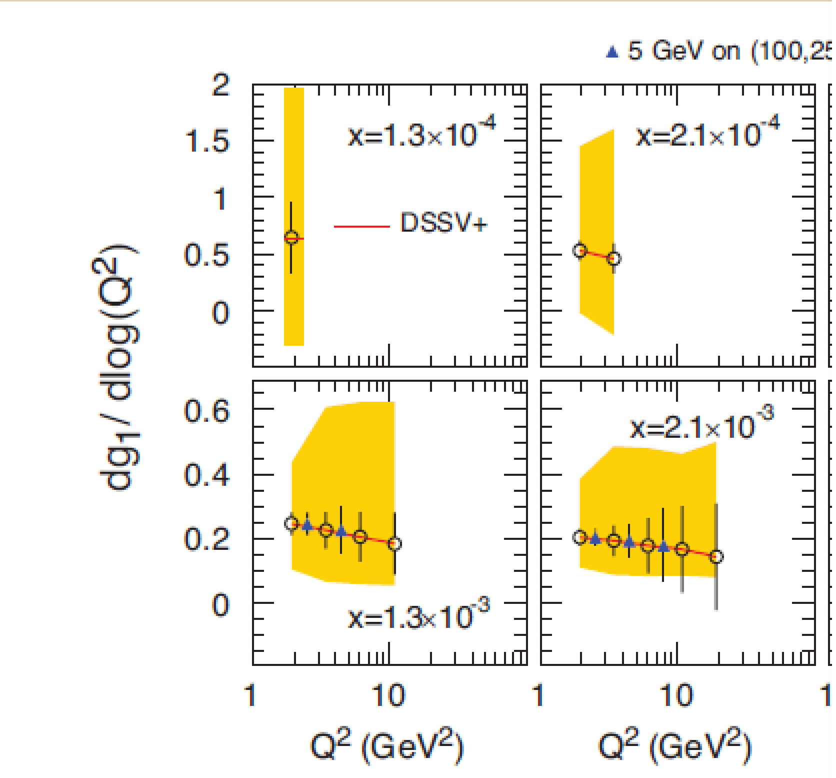
@ $Q^2 = 10$ lowest x scales as $10s^{-1}$

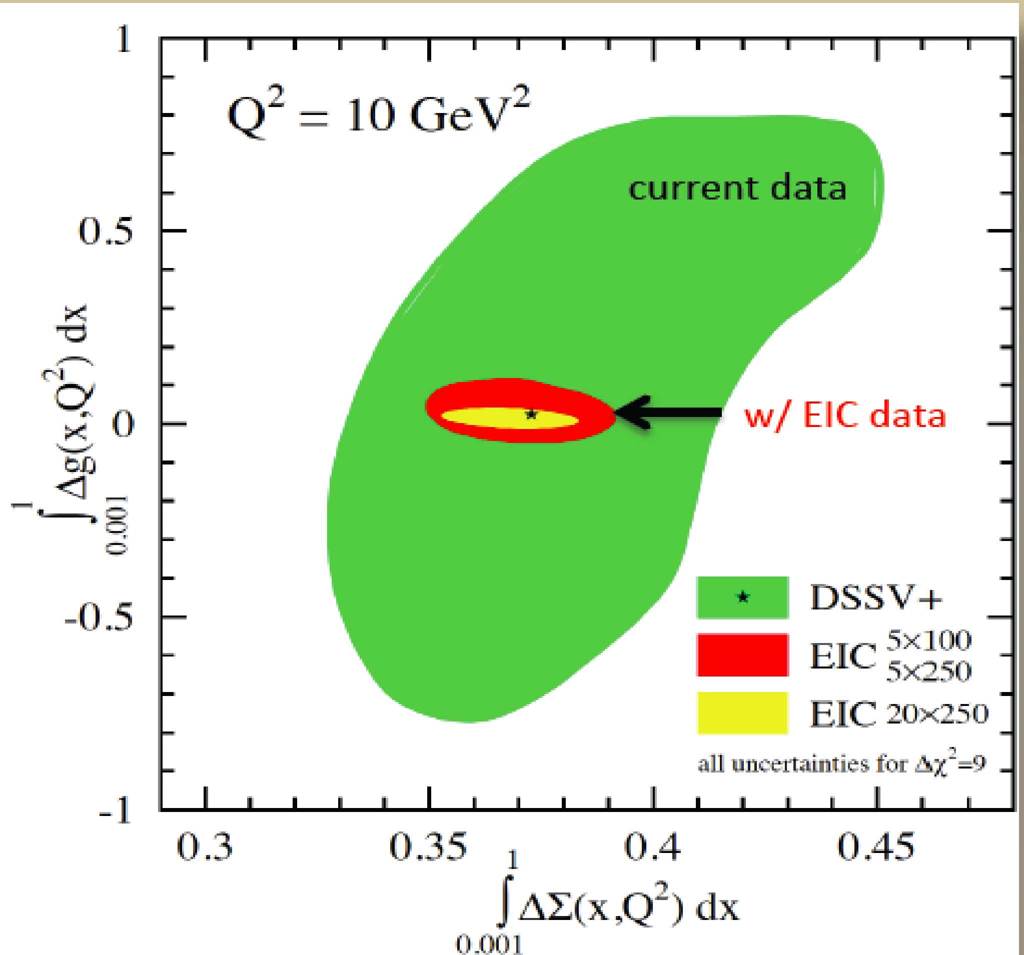


Jefferson Lab

Gluon Contribution to Proton Spin

Study DGLAP evolution of $g_1(x)$

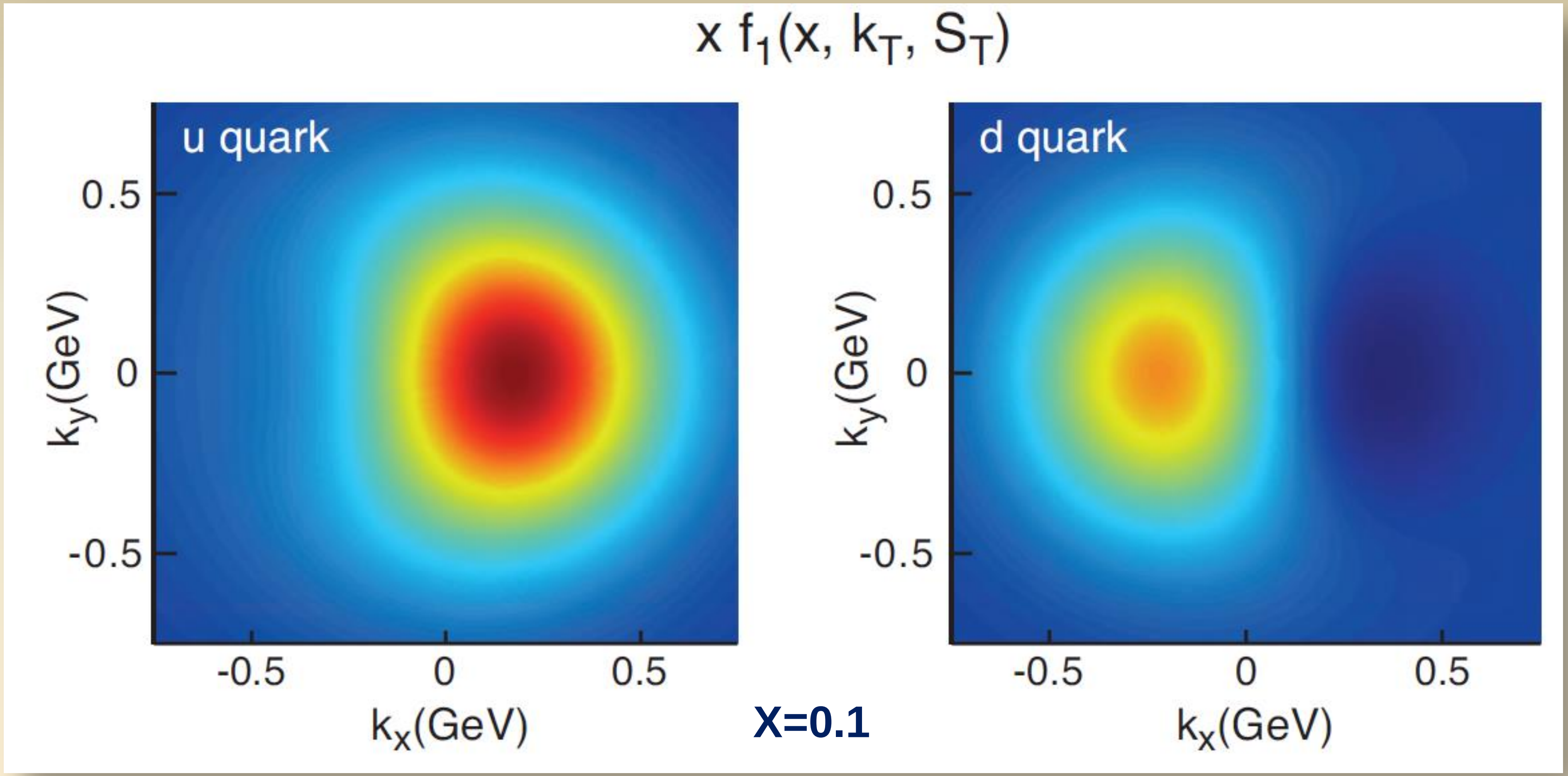




- We need to measure all possible contributions to the nucleon spin
- Reach of EIC is required to pin down the gluon contribution

(from EIC White Paper)

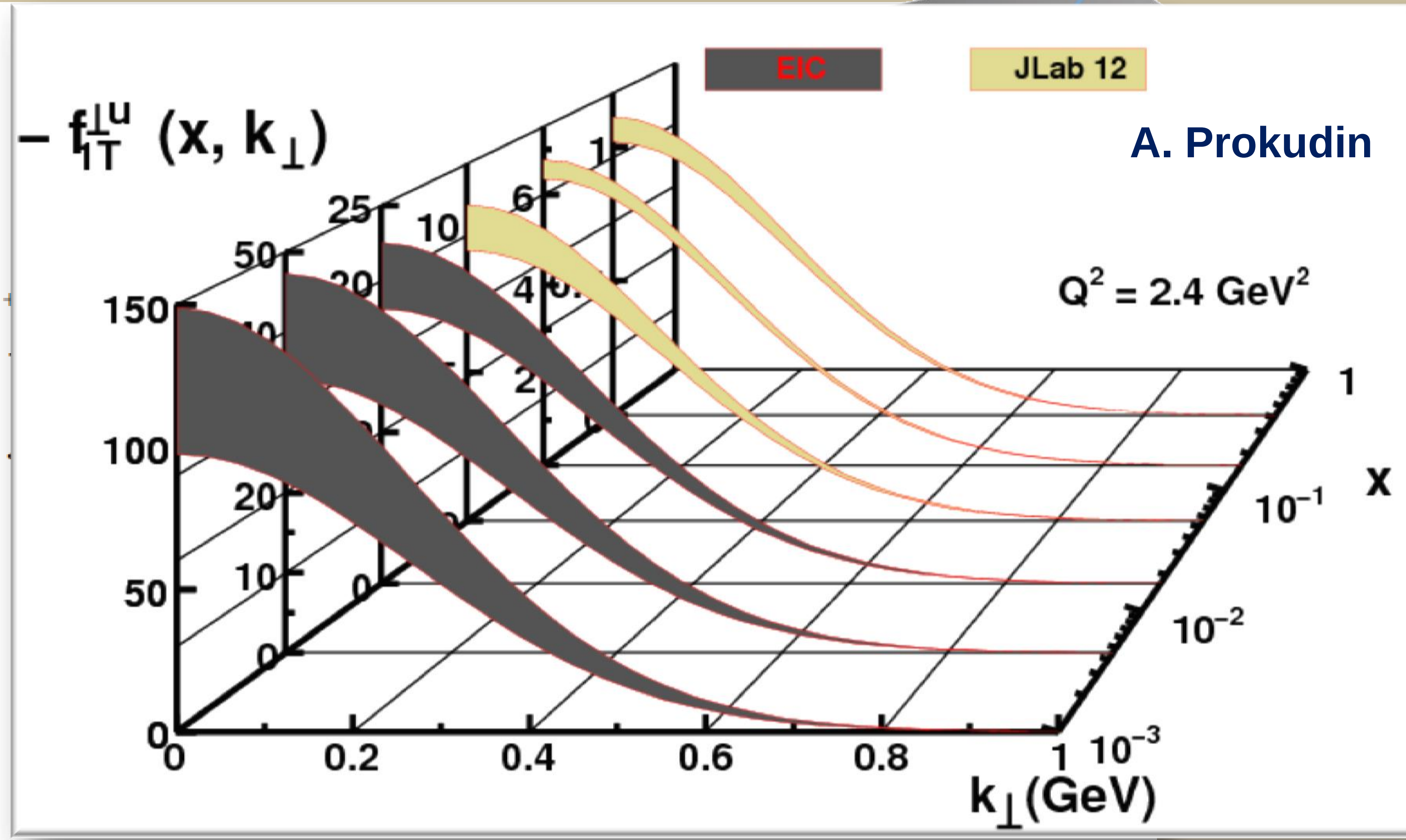
TMD studies at EIC



Nucleon polarized in y direction

(from EIC White Paper)

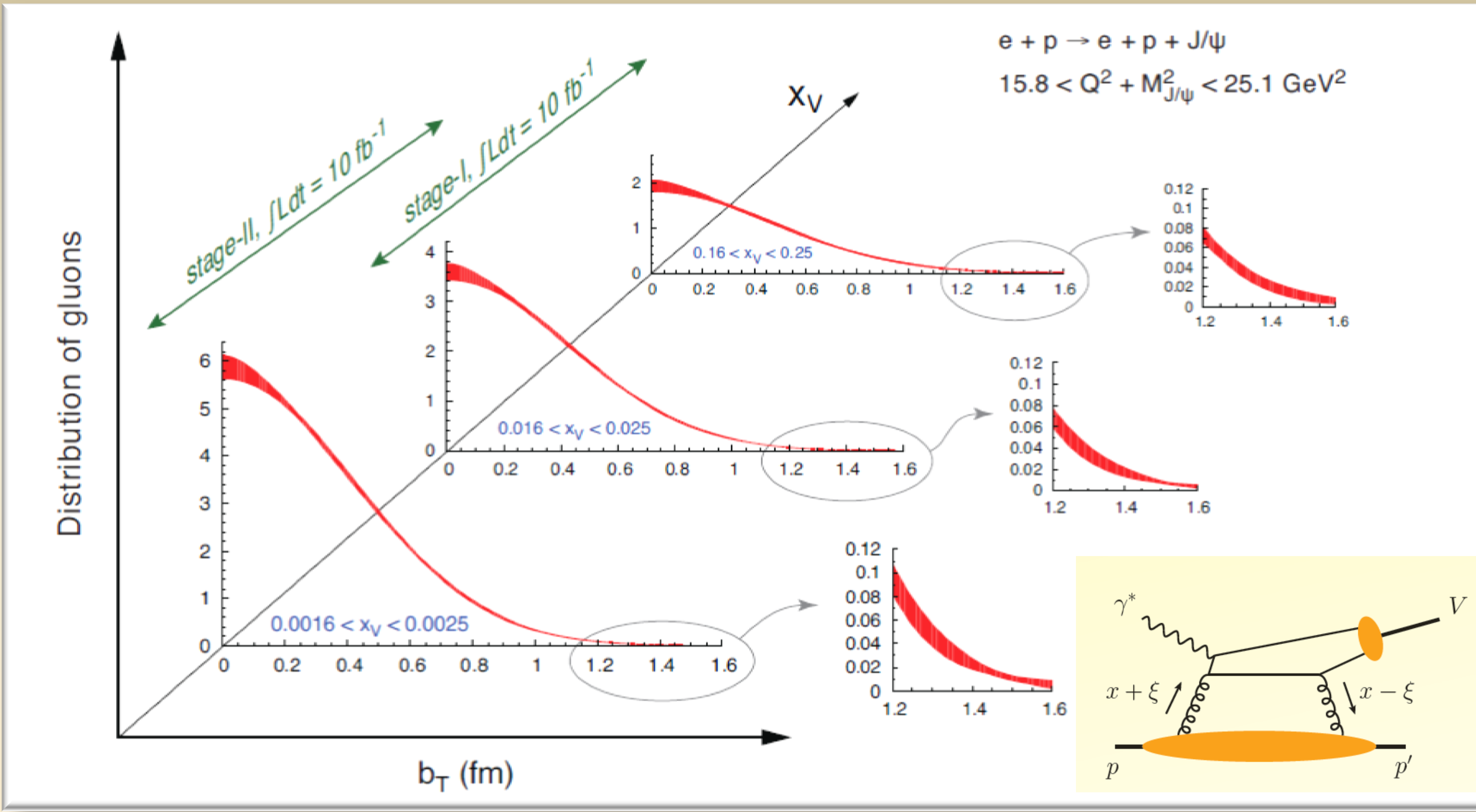
Sivers Tomography



MEIC Point Design Parameters

Detector type		Full acceptance		high luminosity & Large Acceptance	
		Proton	Electron	Proton	Electron
Beam energy	GeV	60	5	60	5
Collision frequency	MHz	750	750	750	750
Particles per bunch	10^{10}	0.416	2.5	0.416	2.5
Beam Current	A	0.5	3	0.5	3
Polarization	%	> 70	~ 80	> 70	~ 80
Energy spread	10^{-4}	~ 3	7.1	~ 3	7.1
RMS bunch length	mm	10	7.5	10	7.5
Horizontal emittance, normalized	µm rad	0.35	54	0.35	54
Vertical emittance, normalized	µm rad	0.07	11	0.07	11
Horizontal and vertical β*	cm	10 and 2	10 and 2	4 and 0.8	4 and 0.8
Vertical beam-beam tune shift		0.014	0.03	0.014	0.03
Laslett tune shift		0.06	Very small	0.06	Very small
Distance from IP to 1st FF quad	m	7	3.5	4.5	3.5
Luminosity per IP, 10^{33}	$cm^{-2}s^{-1}$	5.6		14.2	

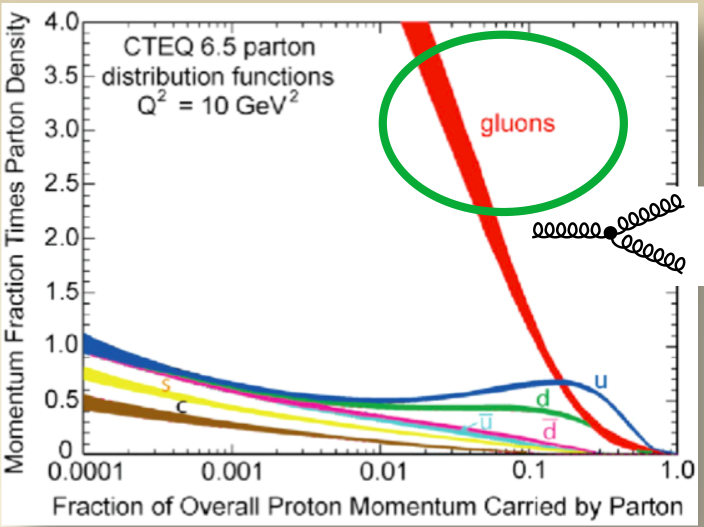
Gluon Tomography



DV J/Ψ Production (from EIC White Paper)

Gluon Saturation

- **HERA's discovery: proliferation of soft gluons:**



How does the unitarity bound of the hadronic cross section survive if soft gluons in a proton or nucleus continue to grow in numbers?

QCD: Dynamical balance between radiation and recombination

- **Gluon saturation**