Alexei Prokudin

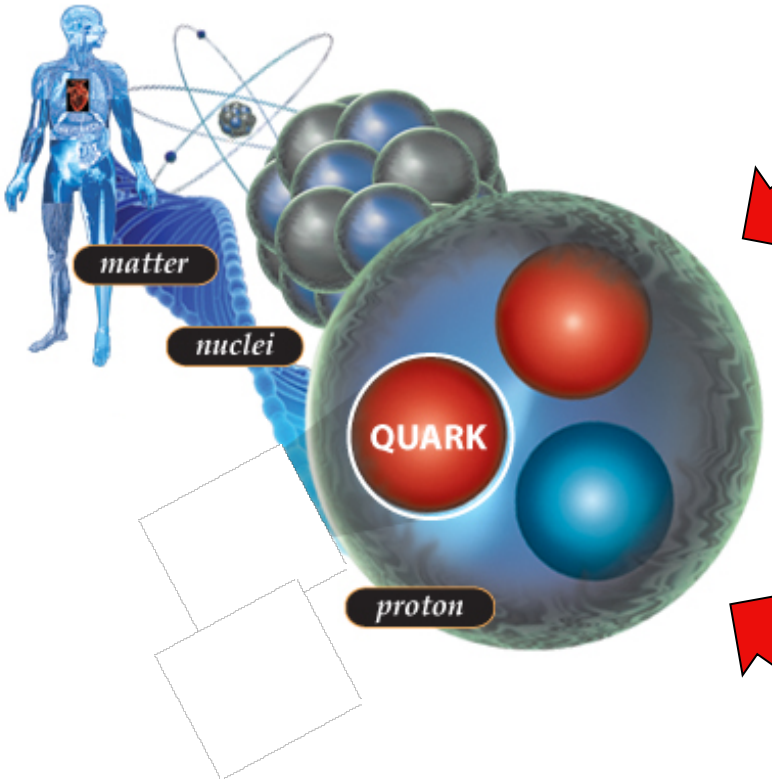
XXIX International Workshop on High Energy Physics,
June 26 – 28, IHEP, Protvino, Russia

Inward horizons of Spinning Nucleons

June 27, 2013

Jefferson Lab
Thomas Jefferson National Accelerator Facility

Exploring the nucleon: a fundamental quest

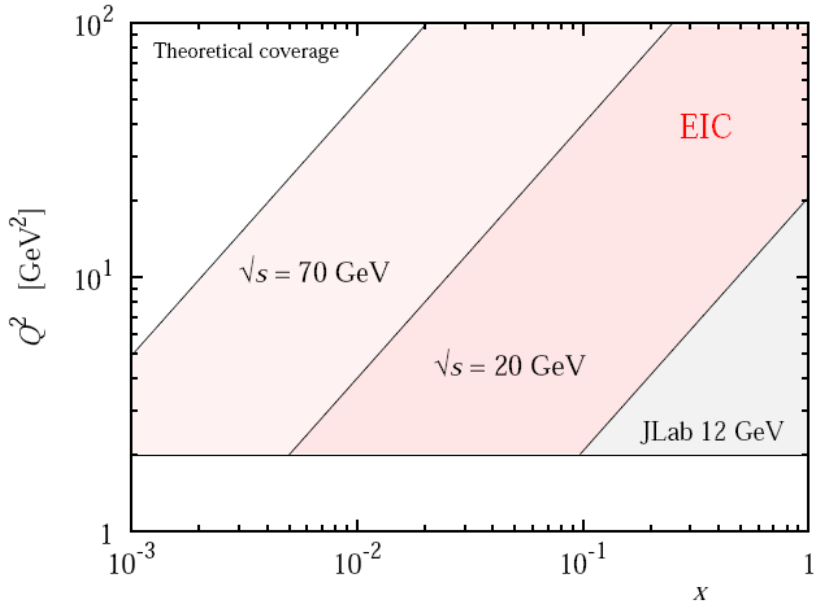


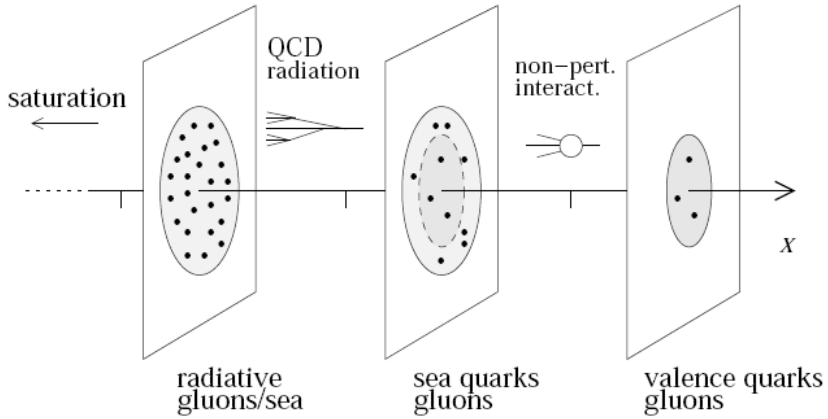
Know what we are made of !

Understand the strong force: "QCD"

Use protons as tool for discovery (e.g. LHC)

Nucleon landscape





Nucleon is a many body dynamical system of quarks and gluons

Changing x we probe different aspects of nucleon wave function

How partons move and how they are distributed in space is one of the future directions of development of nuclear physics

Technically such information is encoded into Generalised Parton Distributions and Transverse Momentum Dependent distributions

These distributions are also referred to as 3D (three-dimensional) distributions

Spin and QCD

"Experiments with spin have killed more theories than any other single physical parameter"

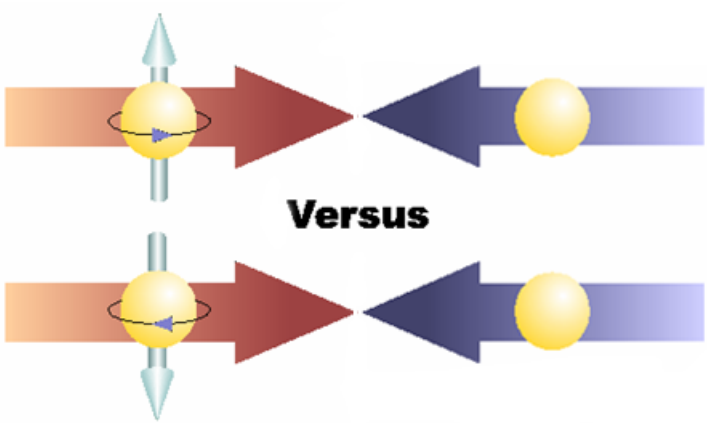
Elliot Leader, Spin in Particle Physics, Cambridge U. Press (2001)

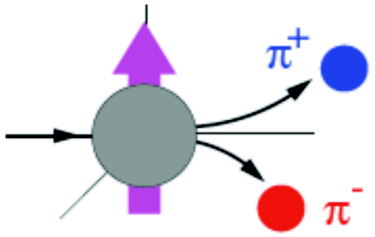
"Polarisation data has often been the graveyard of fashionable theories. If theorists had their way they might well ban such measurements altogether out of self-protection."

J. D. Bjorken, Proc. Adv. Research Workshop on QCD Hadronic Processes, St. Croix, Virgin Islands (1987).

Spin and QCD

Consider A_N in hadron hadron collision:



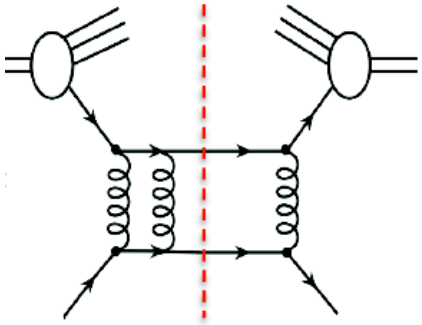


$$A_N = \frac{\sigma^{\uparrow} - \sigma^{\downarrow}}{\sigma^{\uparrow} + \sigma^{\downarrow}}$$

Spin and QCD

QCD had a very simple prediction:

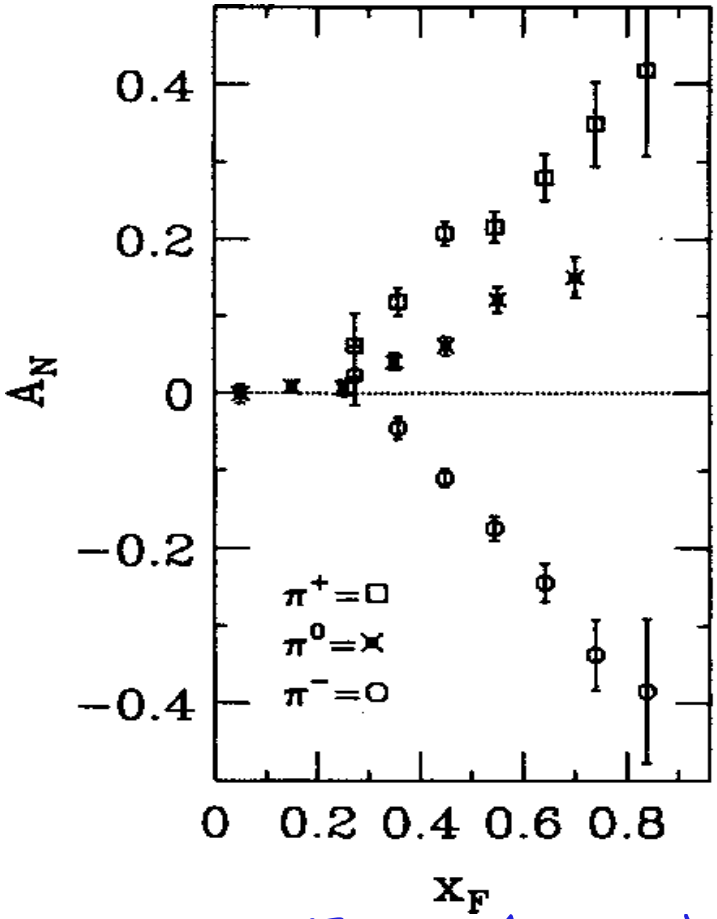
Helicity flip is proportional to the small mass of the quark, thus



$$\propto \alpha_s \frac{m_q}{p_T} \qquad A_N \simeq 0.001$$

Kane, Pumplin and Repko (1978)

Experiment proved this prediction wrong



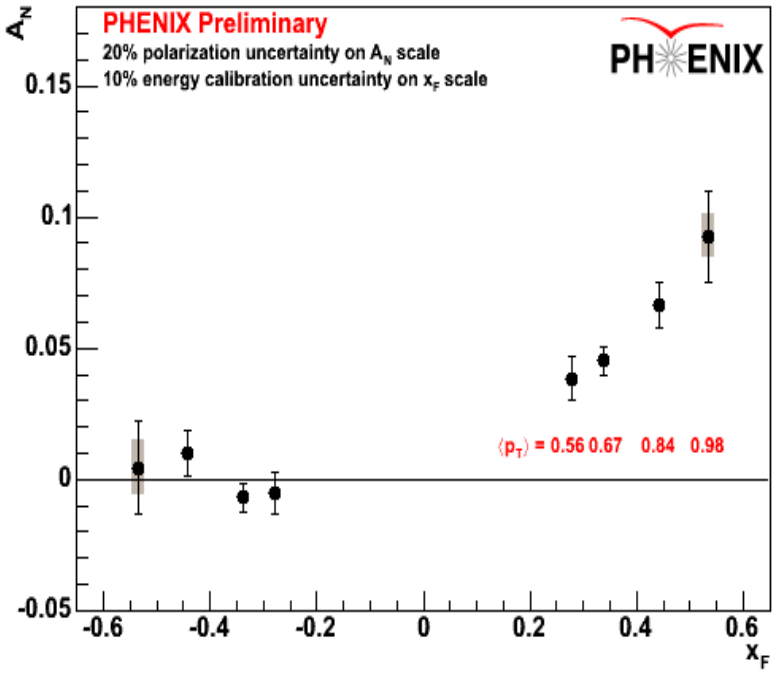
E704 (1991)

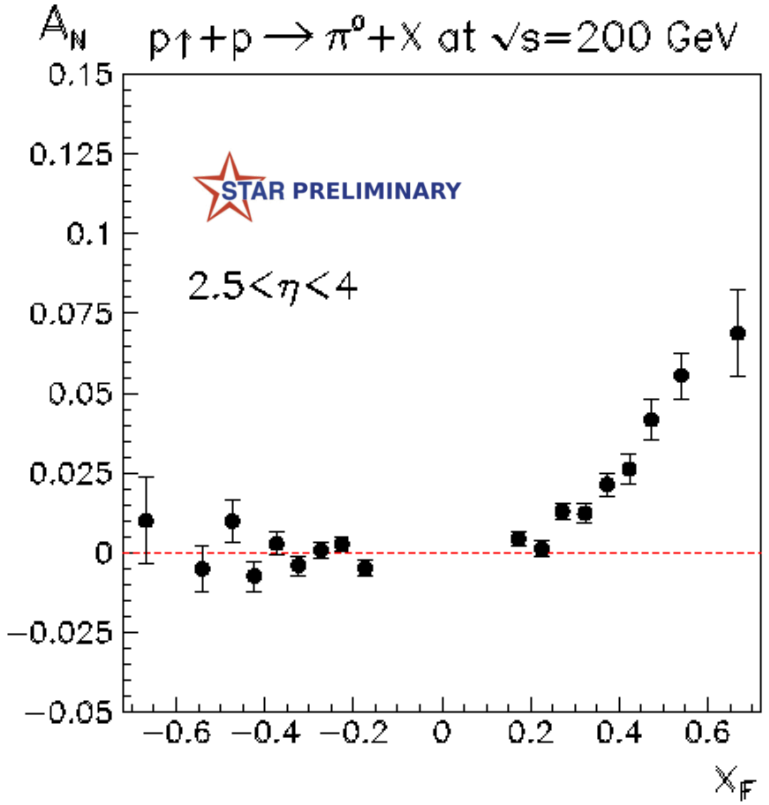
$$A_N \simeq 40\%$$

Spin and QCD

Asymmetry survives with energy

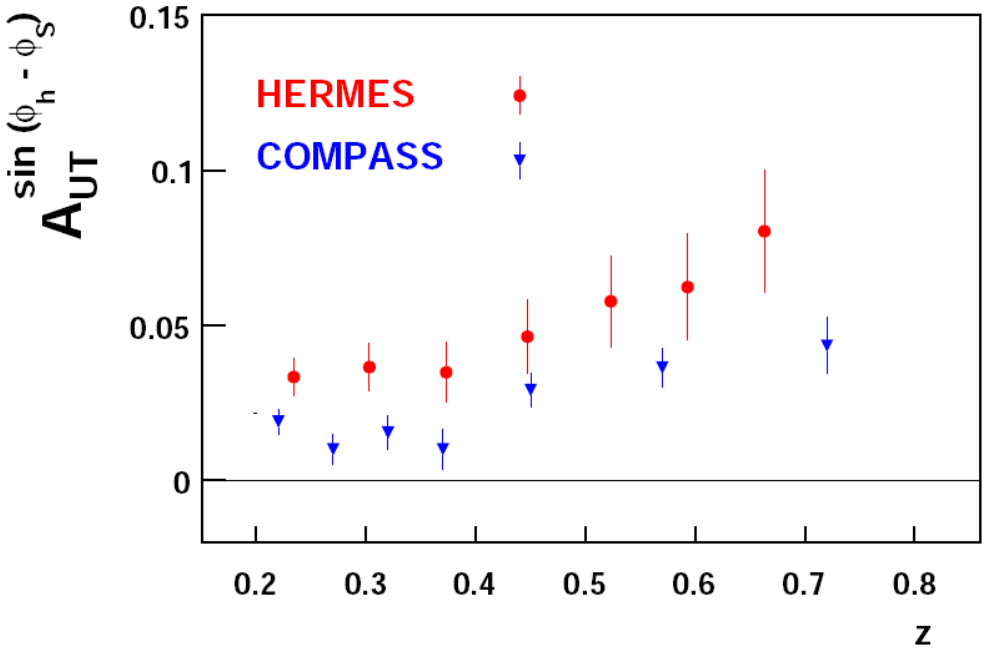
$\sqrt{s} = 62$ GeV





RHIC: STAR, BRAHMS and PHENIX

Asymmetry survives with energy



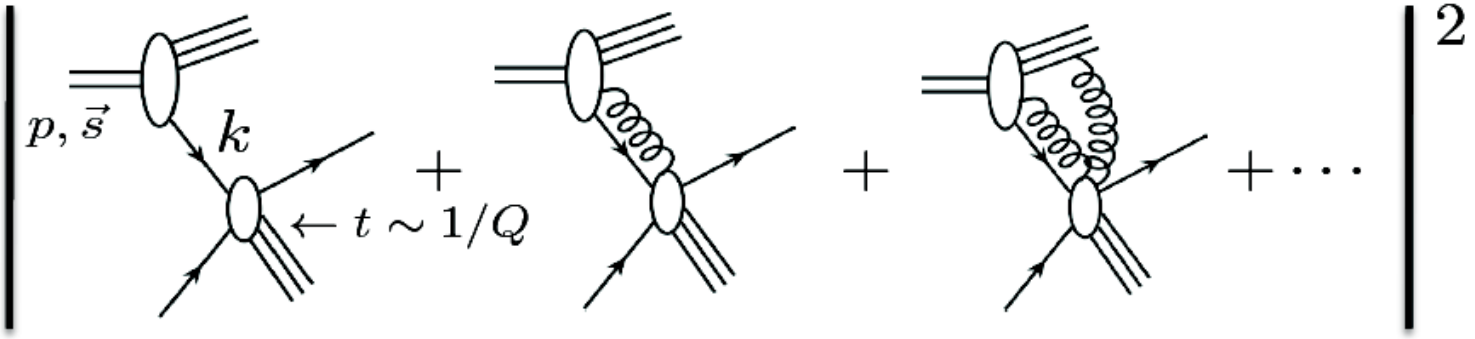
HERMES, JLAB and COMPASS

Failure of QCD?

Not at all: better understanding of QCD

Better understanding of QCD

$$\sigma(Q,\vec{s}) \propto$$



Multy parton correlations contribute to the cross section.

These correlations are called
Efremov-Teryaev-Qiu-Sterman matrix elements,
They appear at twist-3 level in cross section.

$$\sigma = \sigma^{LT} + \frac{Q_s}{Q}\sigma^{HT} + \ldots$$

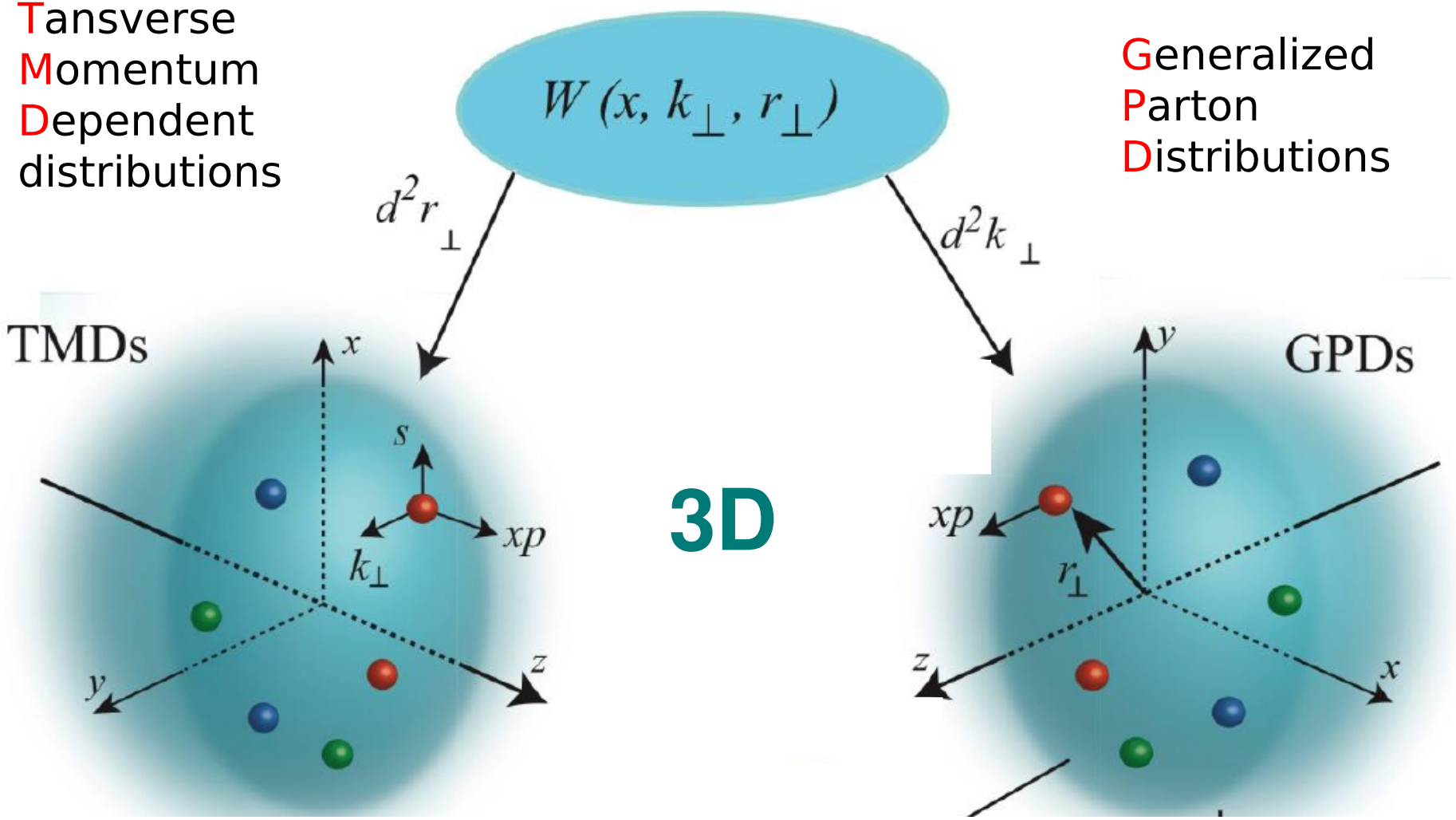
$$= H^{LT} \otimes f_2 \otimes f_2 + \frac{Q_s}{Q} H^{HT} \otimes f_3 \otimes f_2 + \ldots$$

Unified View of Nucleon Structure

Wigner function **5D**

Tansverse
Momentum
Dependent
distributions

Generalized
Parton
Distributions



3D

Unified View of Nucleon Structure

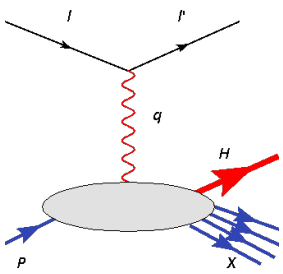
TMD

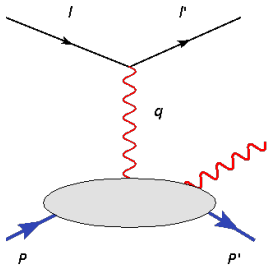
Wigner function

$W(x, \mathbf{k}_\perp, \mathbf{b}_\perp)$

5D

GPD

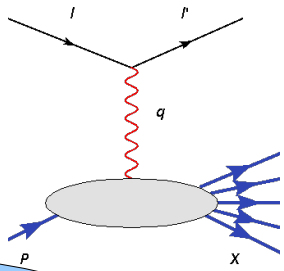


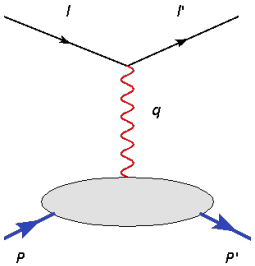


$f(x, \mathbf{k}_\perp)$

3D

$H(x, \xi, t)$





PDF

FF

$f(x)$

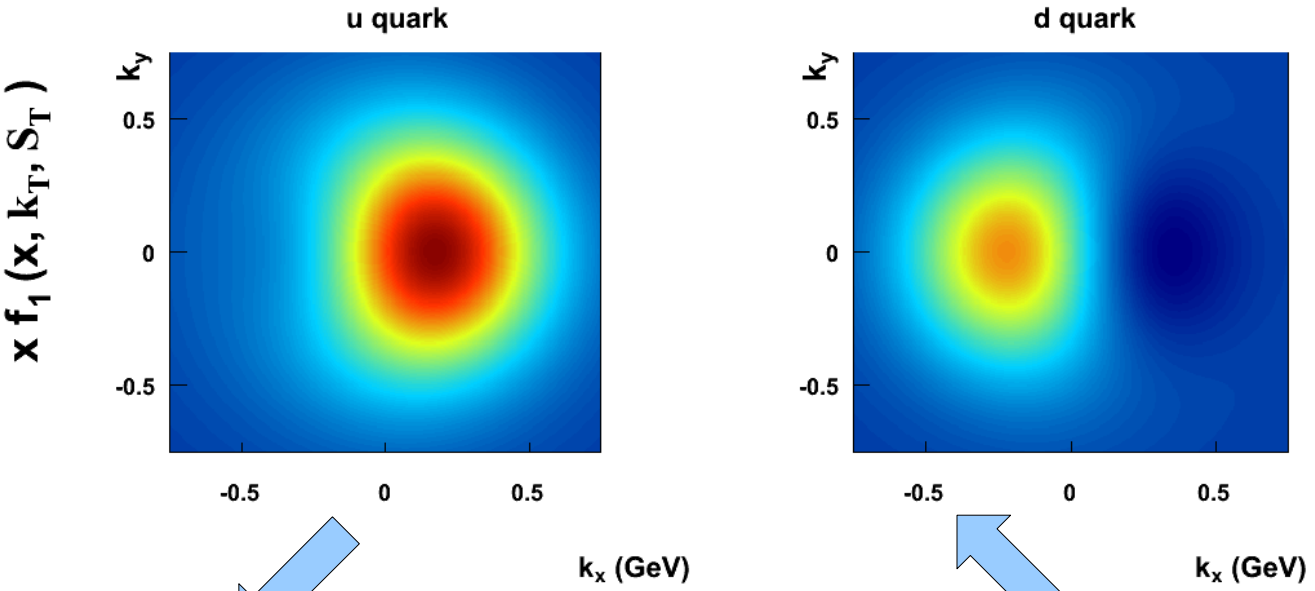
1D

$F(Q^2)$

Particular processes to study. Polarization is required!

Tomographic scan of the nucleon

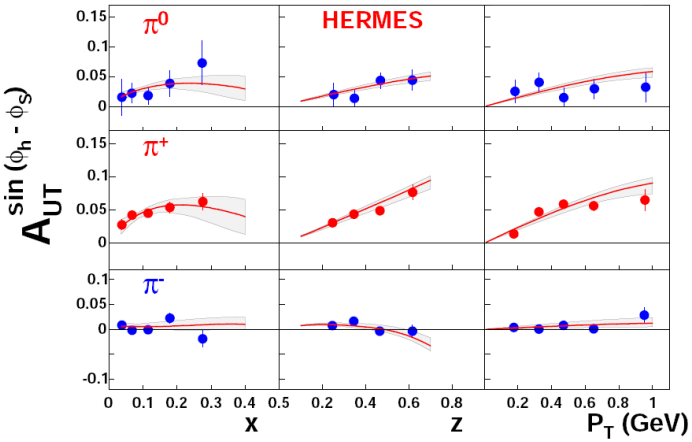
Theory



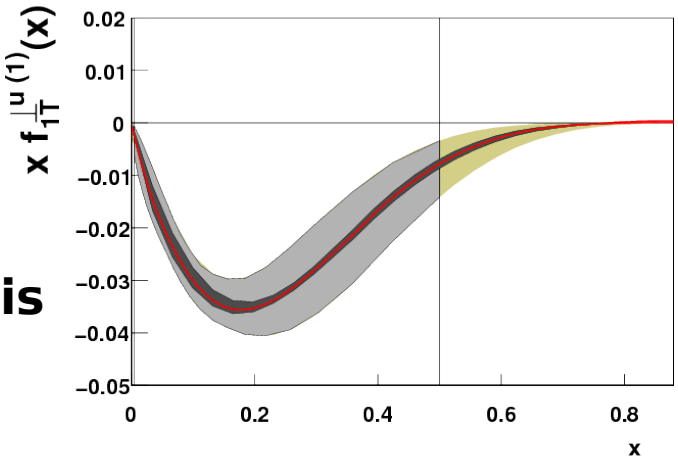
AP 2012

Measurement

Results

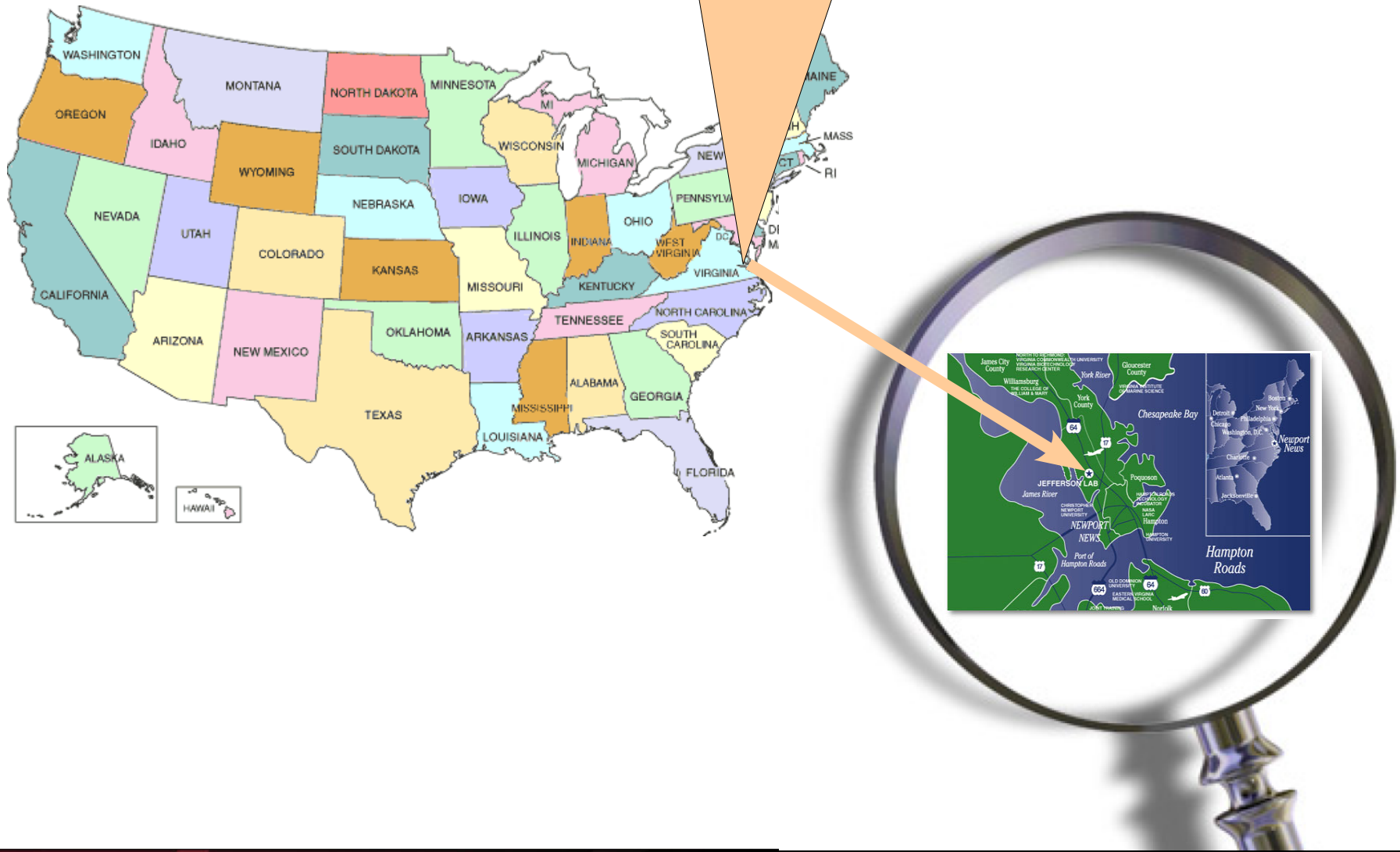


Global analysis of the data



How and where do we measure all this?

Jefferson Lab



Jefferson Lab: CEBAF

Continuous
Electron
Beam
Accelerator
Facility

Jefferson Lab: CEBAF

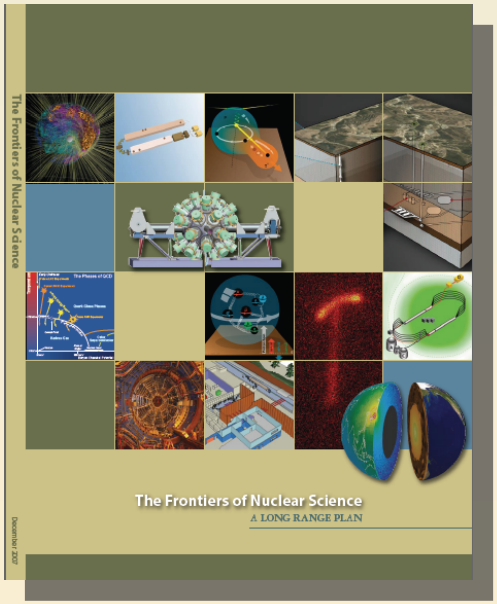
HALL D

HALL A

HALL B

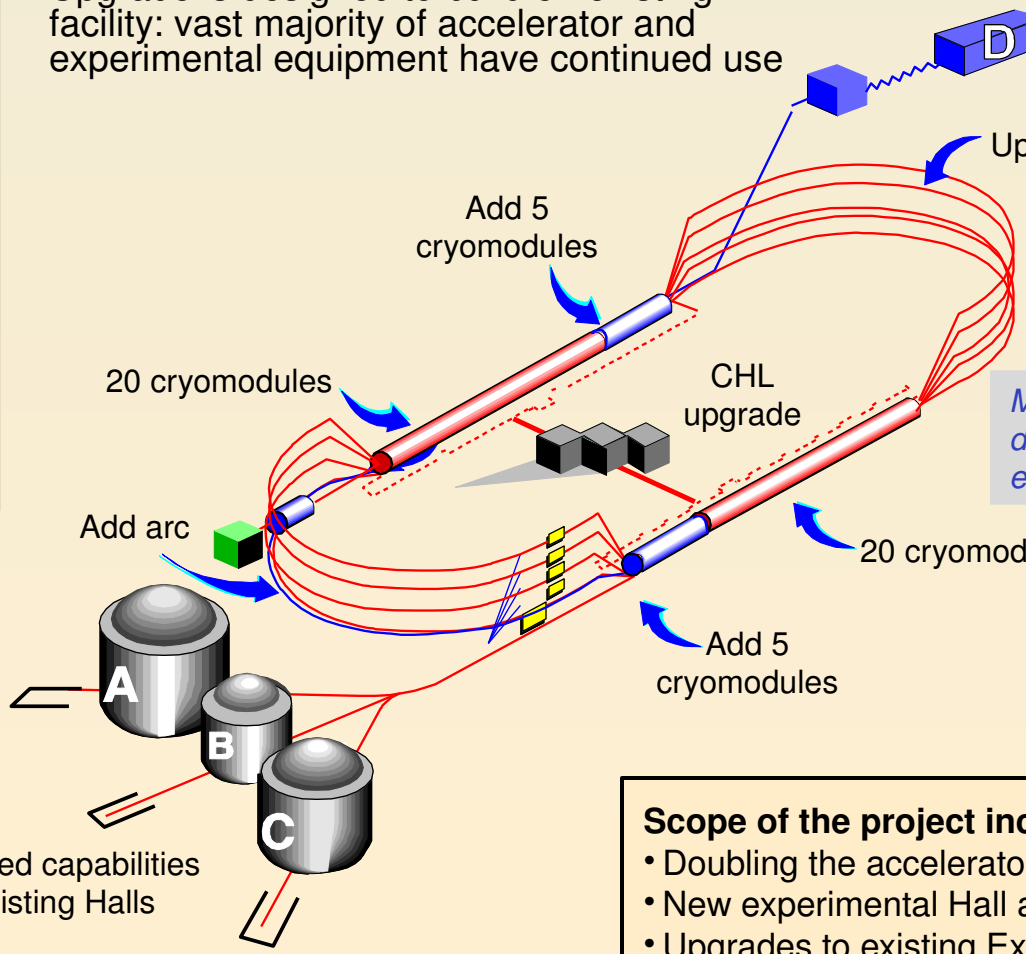
HALL C

12 GeV Upgrade Project



The completion of the 12 GeV Upgrade of CEBAF was ranked the highest priority in the 2007 NSAC Long Range Plan.

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



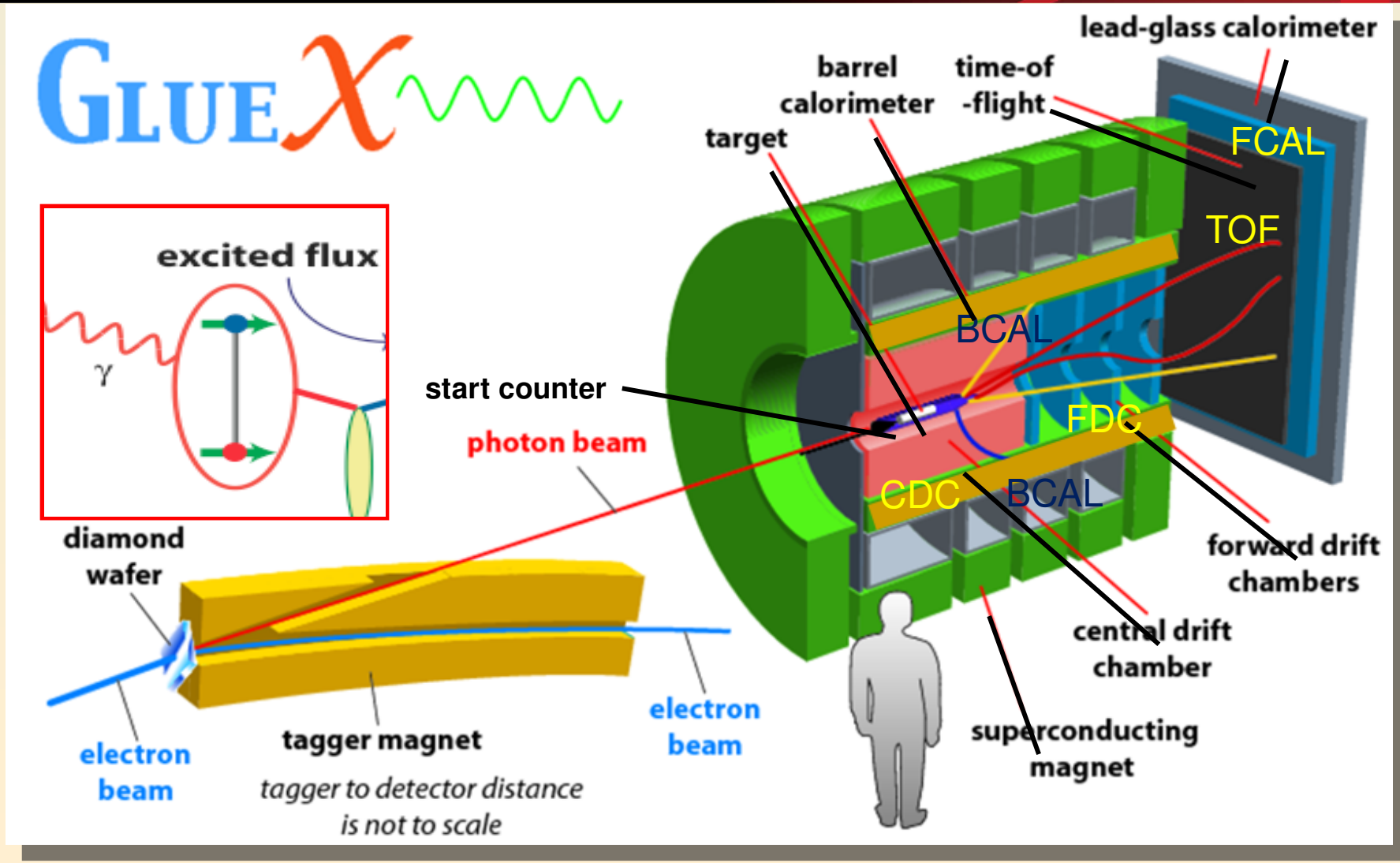
*Maintain capability to deliver lower pass beam energies: **2.2, 4.4, 6.6….***

Scope of the project includes:
- Doubling the accelerator beam energy
- New experimental Hall and beamline
- Upgrades to existing Experimental Halls

JLab: 21st Century Science Questions

- What is the role of gluonic excitations in the spectroscopy of light mesons? Can these excitations elucidate the origin of quark confinement?
- Where is the missing spin in the nucleon? Is there a significant contribution from valence quark orbital angular momentum?
- Can we reveal a novel landscape of nucleon substructure through measurements of new multidimensional distribution functions?
- What is the relation between short-range N-N correlations and the partonic structure of nuclei?
- Can we discover evidence for physics beyond the standard model of particle physics?

Hall D



9 GeV photons at a rate of 10^7 photons per second

Quantum Numbers of Hybrid Mesons

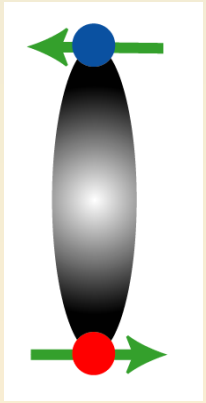
Quarks ⊕ **Excited Gluon Field** → **Hybrid Meson**

$S = 0$

$L = 0$

$J^{PC} = 0^{-+}$

like π, K



$J^{PC} = \{ 1^{+-}, 1^{-+} \}$

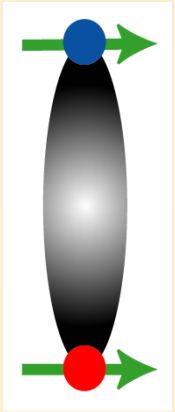
$J^{PC} = \{ 1^{--}, 1^{++} \}$

$S = 1$

$L = 0$

$J^{PC} = 1^{--}$

like γ, ρ



$J^{PC} = \{ 1^{+-}, 1^{-+} \}$

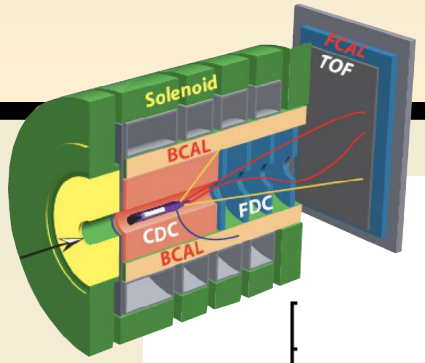
Exotic

$J^{PC} = \{ 0^{-+}, 1^{-+}, 2^{-+}, 0^{+-}, 1^{+-}, 2^{+-} \}$

Gluonic excitation (and parallel quark spins) lead to exotic J^{PC}

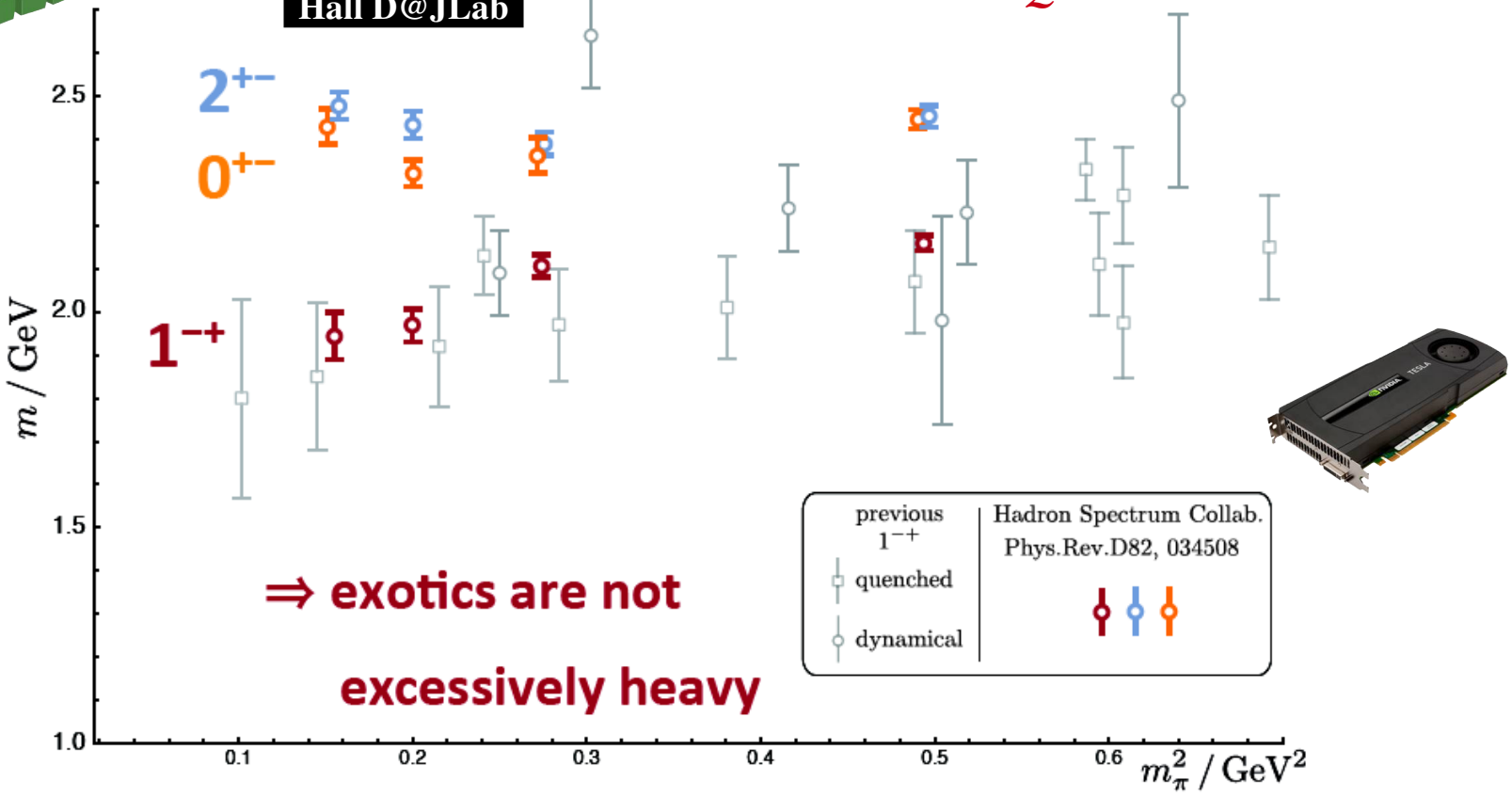
GlueX is optimised for exotics, polarised photon beam

Isovector Meson Spectrum



GlueX Collaboration
Hall D@JLab

States with Exotic Quantum Numbers



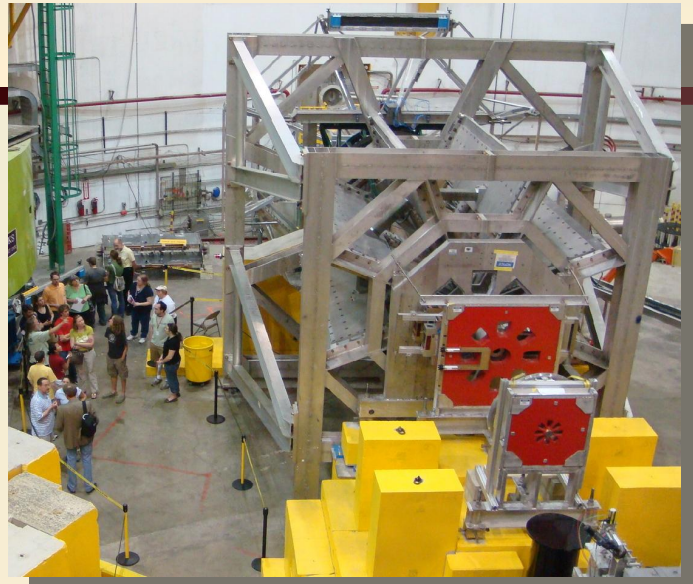
⇒ exotics are not excessively heavy

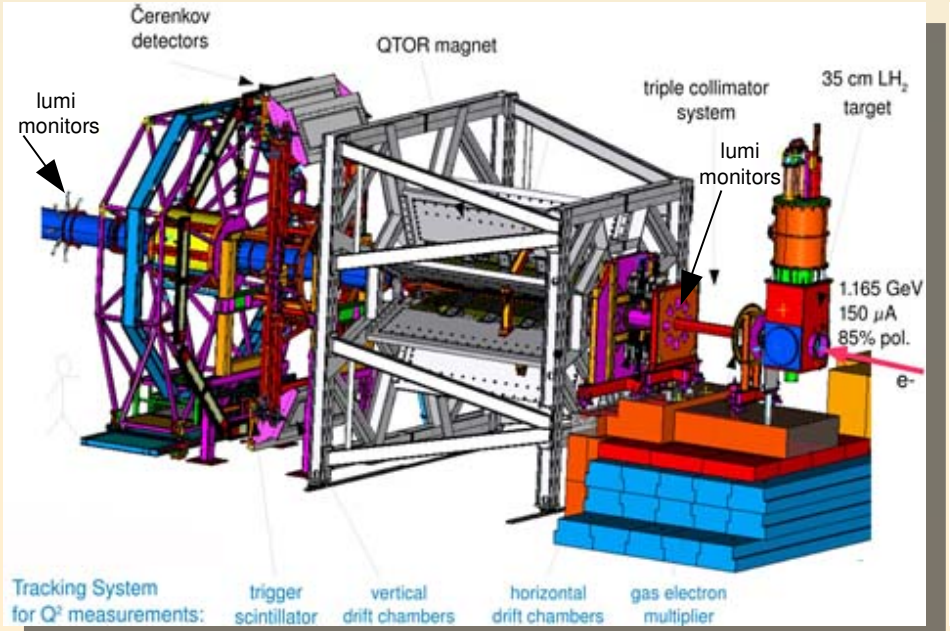
Dudek et al

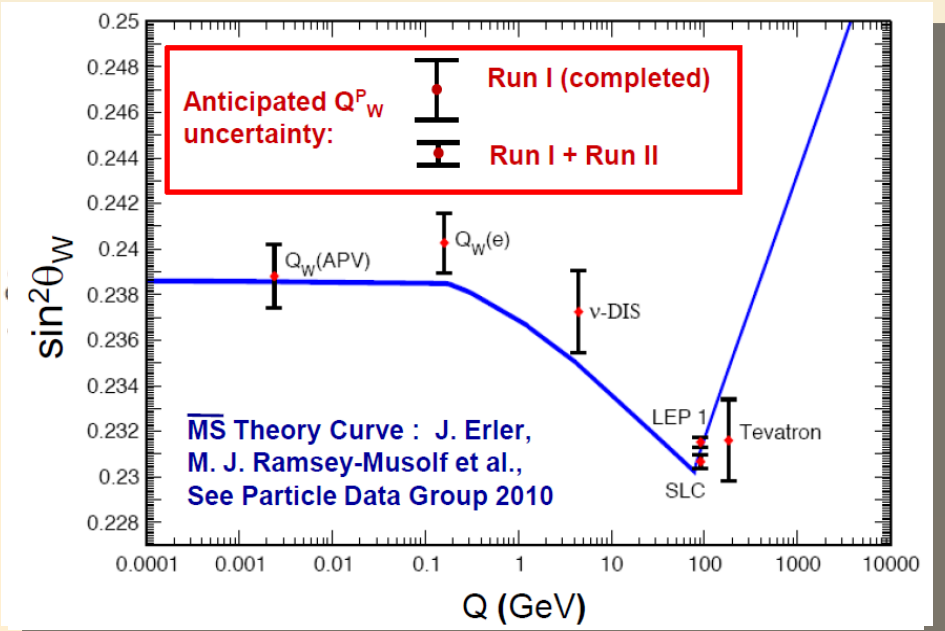
Qweak, HALL C

Precise determination of the weak charge of the proton

$$Q^p_w = (1 - 4 \sin^2 \theta_W)$$

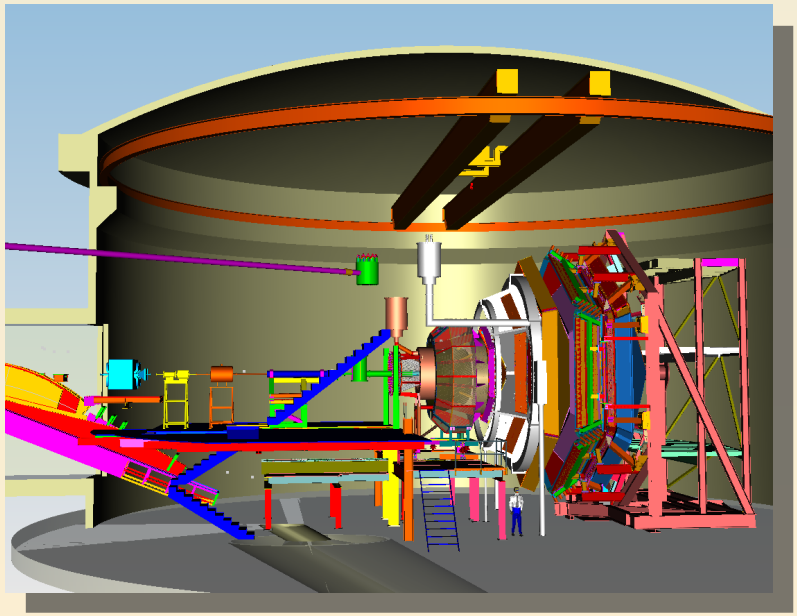






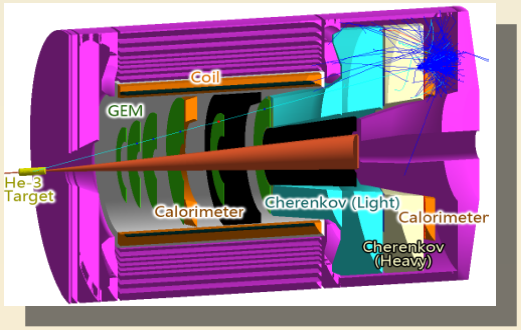
Halls B and A

Hall B
CLAS12 = CEBAF Large Acceptance Spectrometer

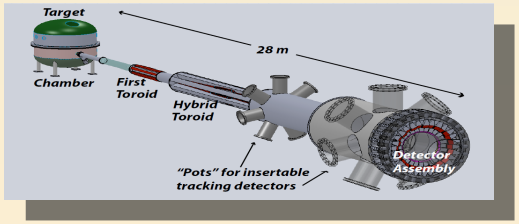


Structure functions, TMD, GPD studies

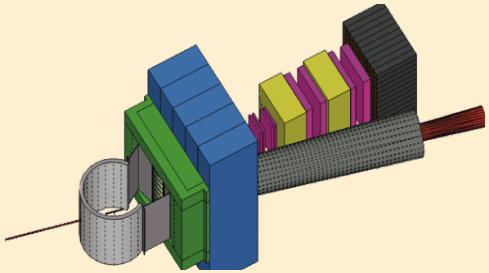
Hall A
SoLID – PV studies and TMD studies



Moeller PV e-e scattering

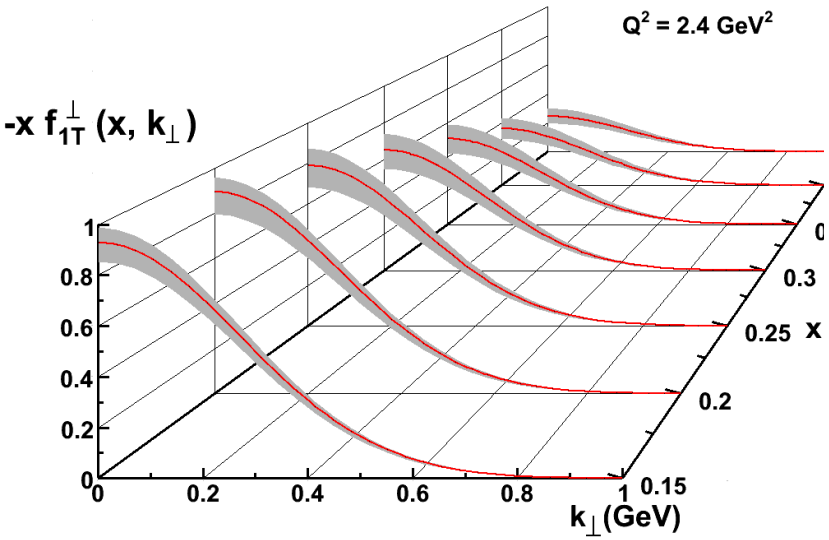


Super BigBite – Form Factors studies



What will be achieved? Example:

Expected result for tensor cha extraction:



Expected accuracy of TMD profile

A. Prokudin (2012) contribution To JLab12 white paper

1 - JLab 12
2 - Anselmino et al., Nucl.Phys.Proc.Suppl. (2009)
3 - Cloet, Bentz and Thomas, Phys.Lett.B (2008)
4 - Wakamatsu, Phys.Lett.B (2007)
5 - Gockeler et al., Phys.Lett.B (2005)
6 - He and Ji, Phys. Rev. D (1995)
7 - Pasquini et al, Phys. Rev. D (2007)
8 - Gamberg and Goldstein, Phys. Rev. Lett. (2001)
9 - Hecht, Roberts and Schmidt Phys. Rev. C (2001)

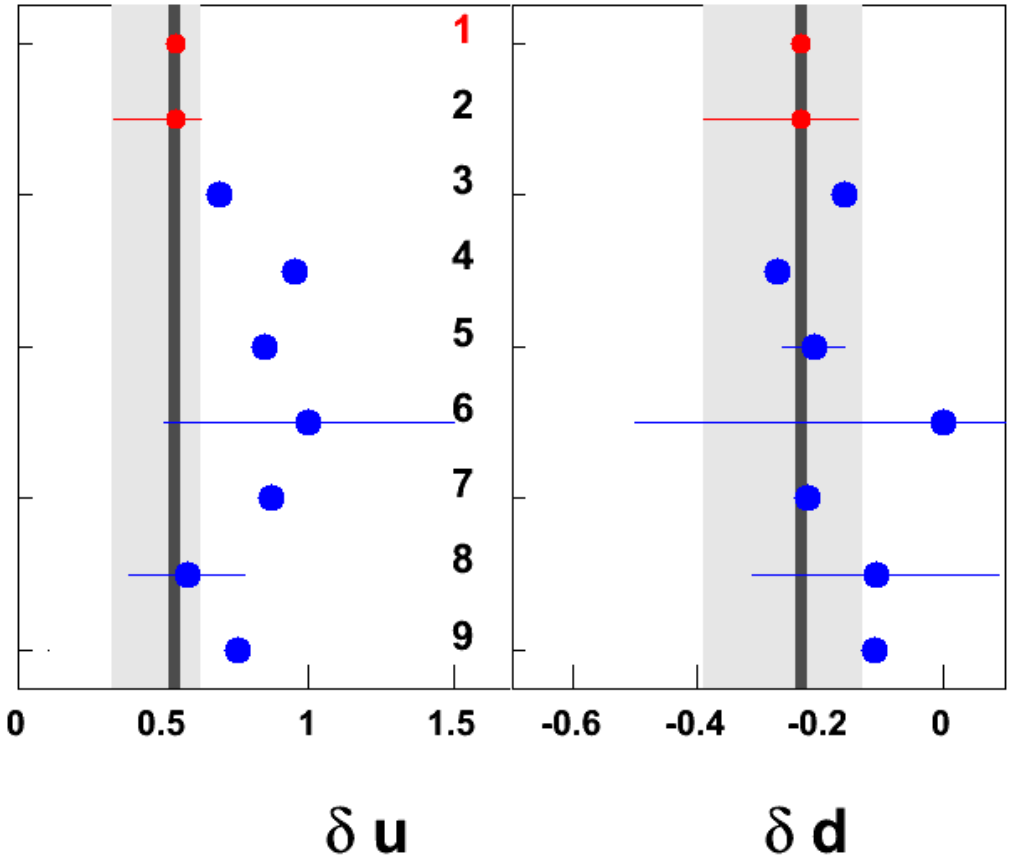
$\delta q = \int dx\, (h^q(x) - h_1^{\overline{q}}(x))$

$\delta u = 0.54^{+0.09}_{-0.22}$, $\delta d = -0.23^{+0.09}_{-0.16}$

JLab 12 Proton and He^3 targets

$\delta u = 0.54^{+0.02}_{-0.02}$, $\delta d = -0.23^{+0.01}_{-0.01}$

Statistical errors only



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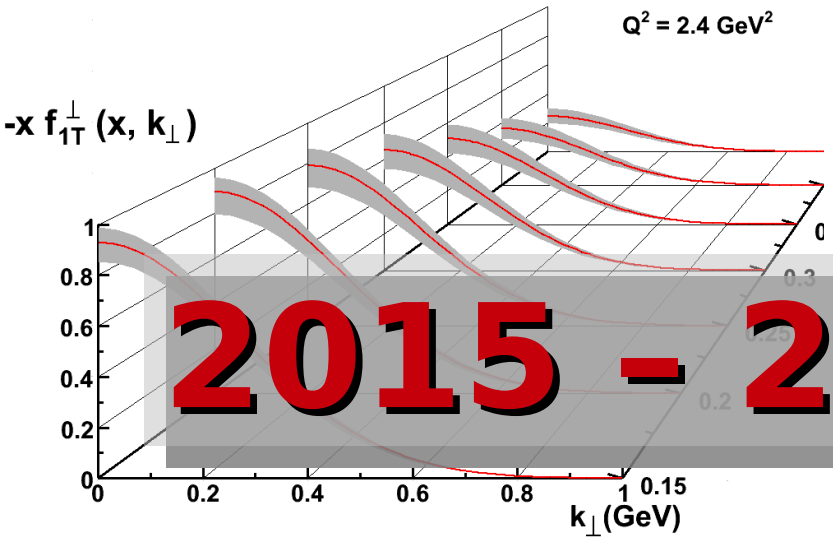

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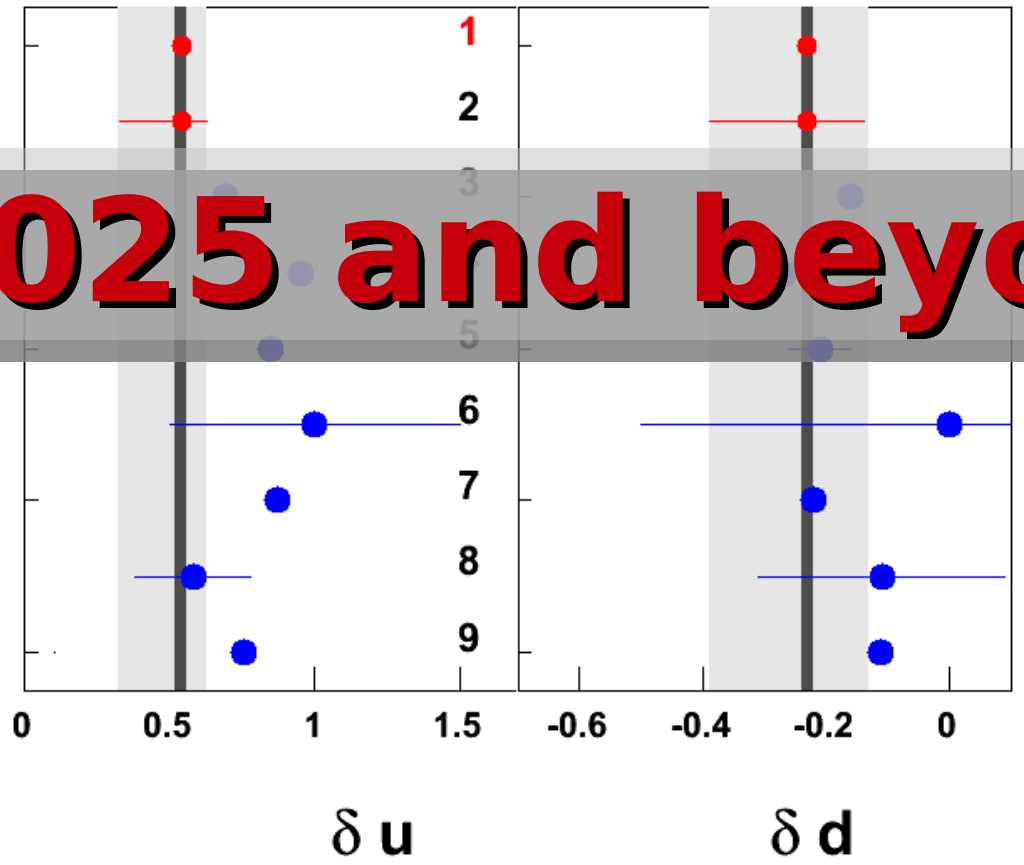
2015 – 2025 and beyo

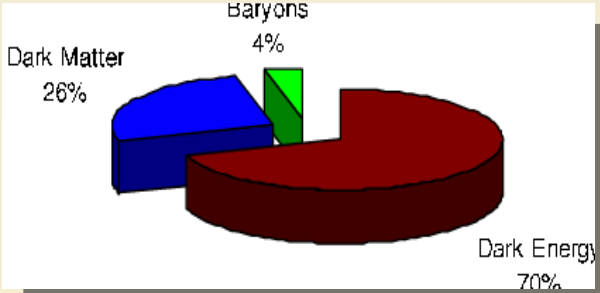


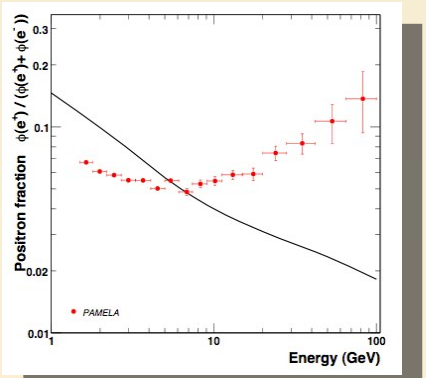
Expected accuracy of TMD profile

A. Prokudin (2012) contribution To JLab12 white paper

Cosmology and Dark Matter

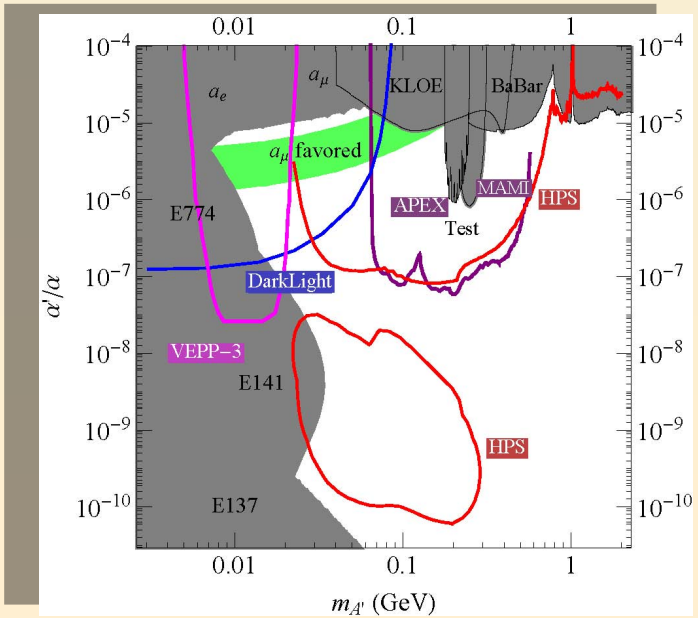
Dark sector is new physics beyond the standard model.
Many direct searches for dark matter interacting with sensitive detectors
(hints, no established signal yet…)





Signal of astrophysical positron excess.

Possible solution: a massive neutral vector boson A' with low mass ($M_{A'} < 1$ GeV)



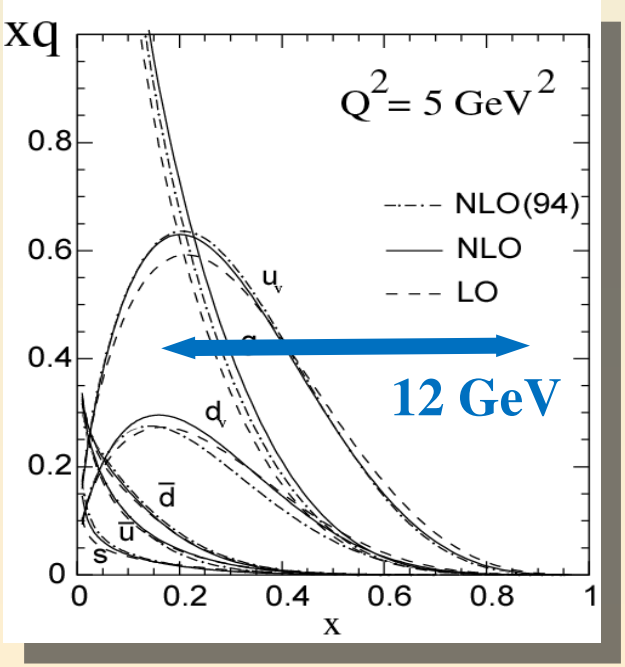
3 Jefferson Lab proposals

- APEX (Hall A) – test run published
- HPS (Hall B) – tested with photon beam
- DarkLight (FEL) – test run complete

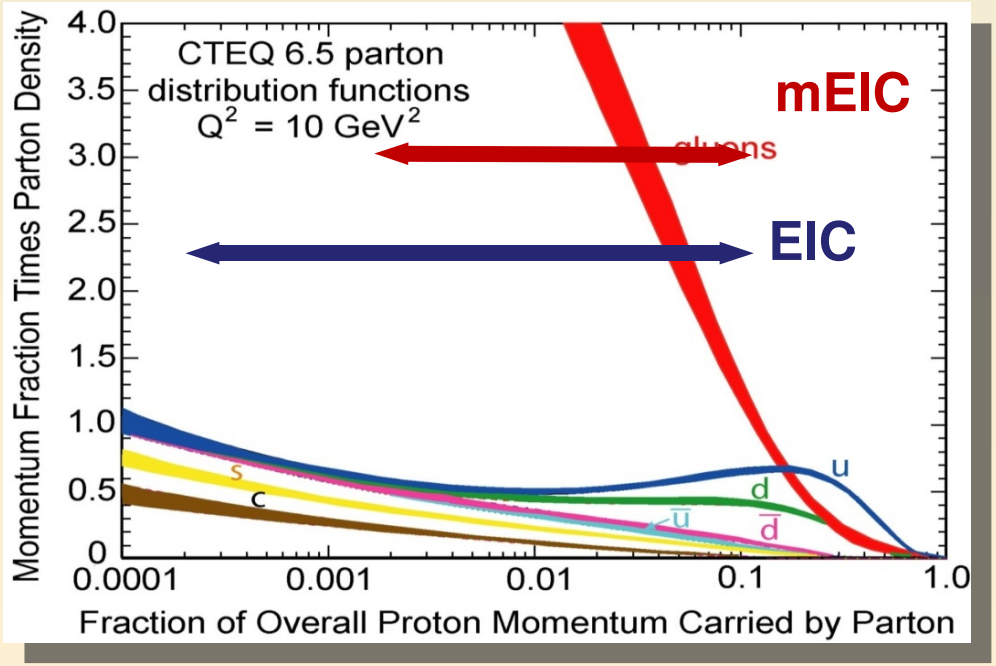
What will happen after Jefferson Lab 12?

Into the "sea": Electron Ion Collider

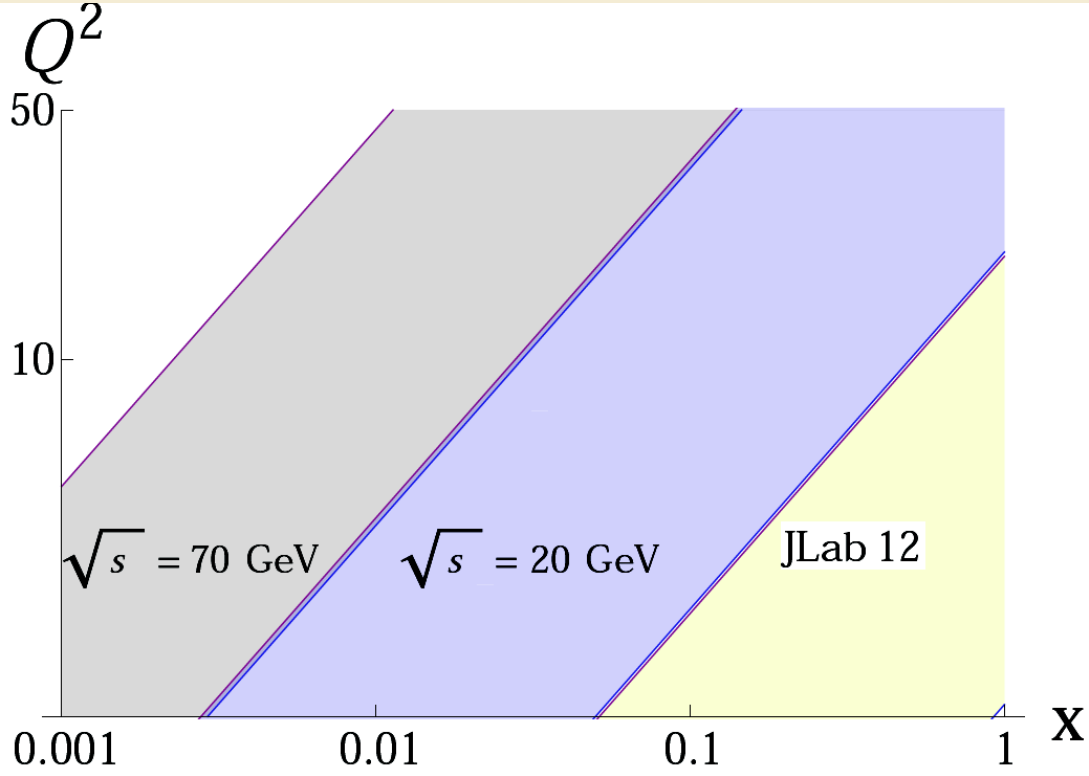
- With 12 GeV we study mostly the valence quark component



An EIC aims to study the sea quarks, gluons, and scale dependence.

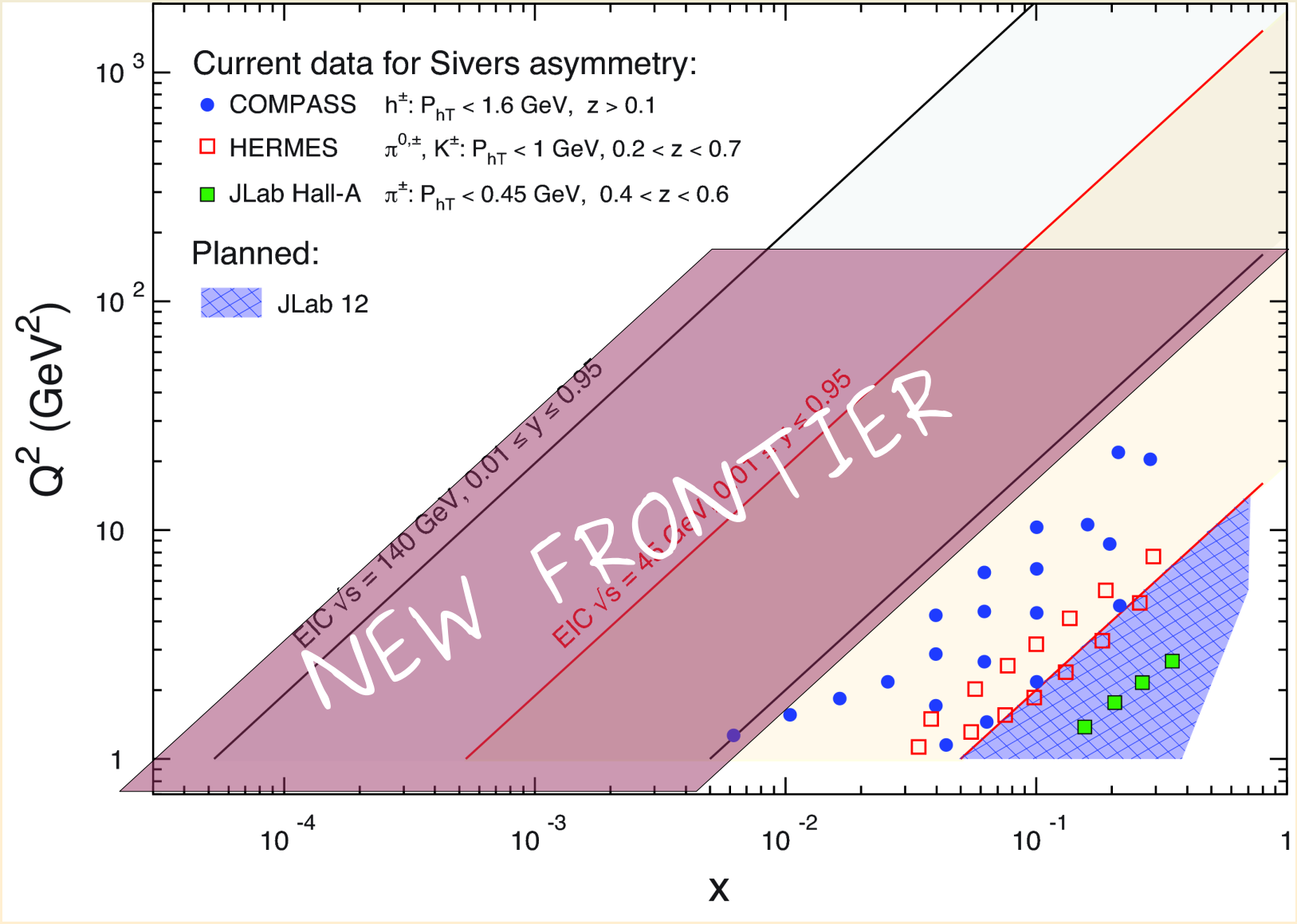


Into the “sea”: Electron Ion Collider



JLab 12 and future Electron Ion Collider are complimentary

Into the “sea”: Electron Ion Collider



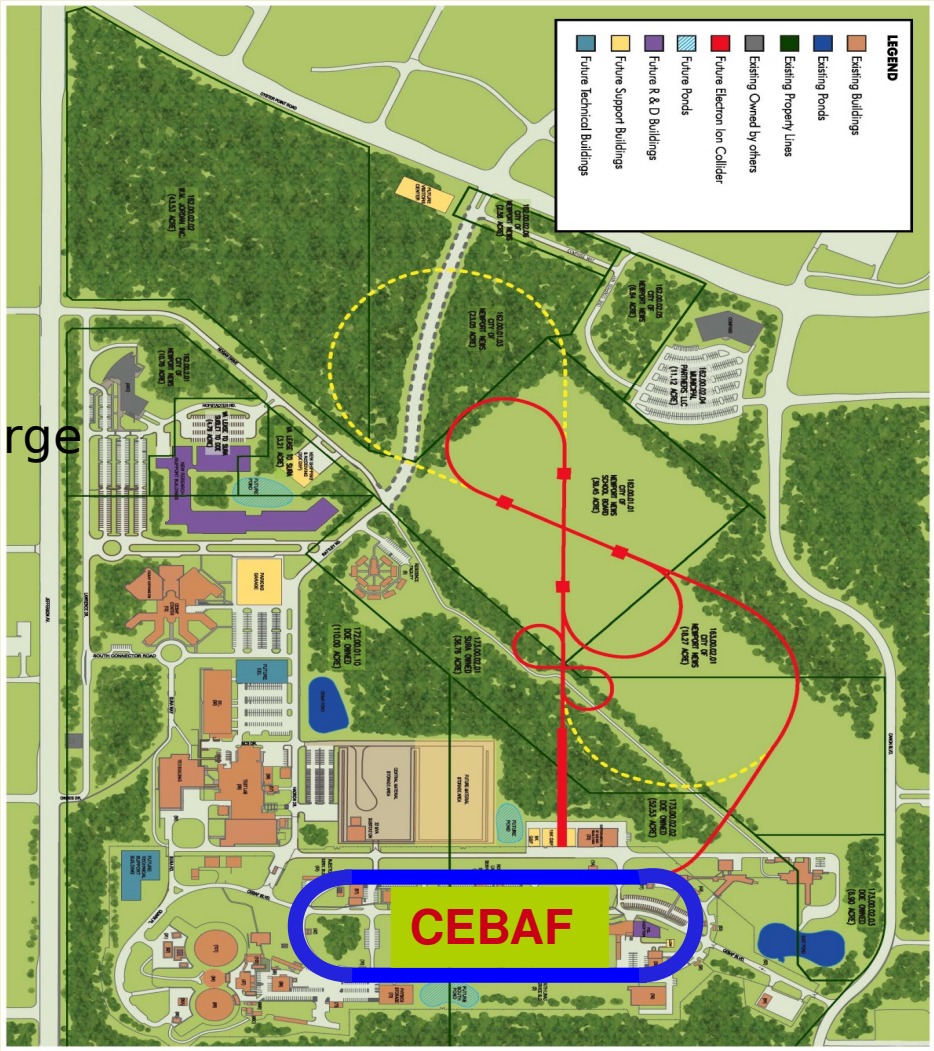
Medium Energy EIC@JLab

Physics driven design

Spin and 3D quark/gluon structute of the hadron

Dynamics of color fields in nuclei

Emergence of hadrons from color charge

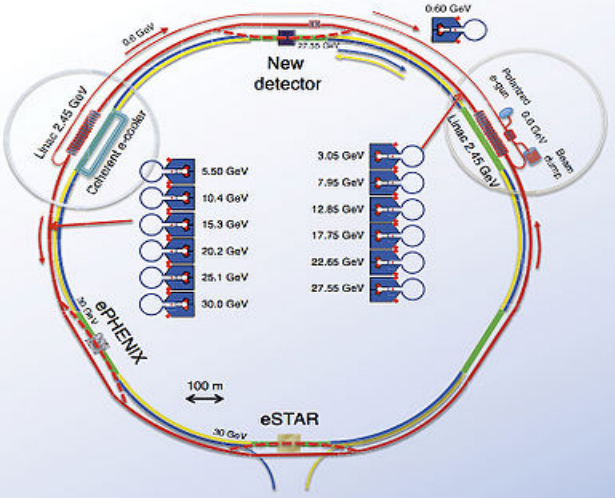


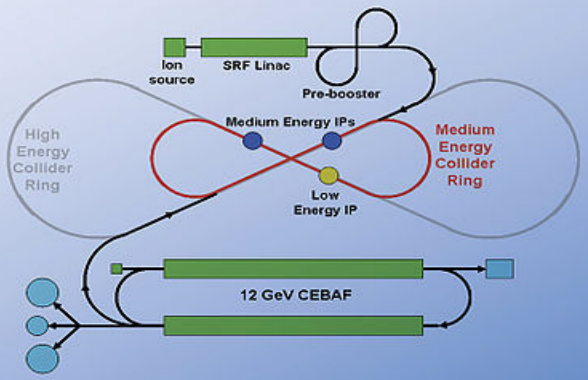
JLab Concept

Initial configuration (MEIC):
3-12 GeV on 20-100 GeV ep/eA collider
fully-polarized, longitudinal and transverse
luminosity: few x 10^{34} e-nucleons cm^{-2} s^{-1}

Upgradable to higher energies (250 GeV)

Electron Ion Collider





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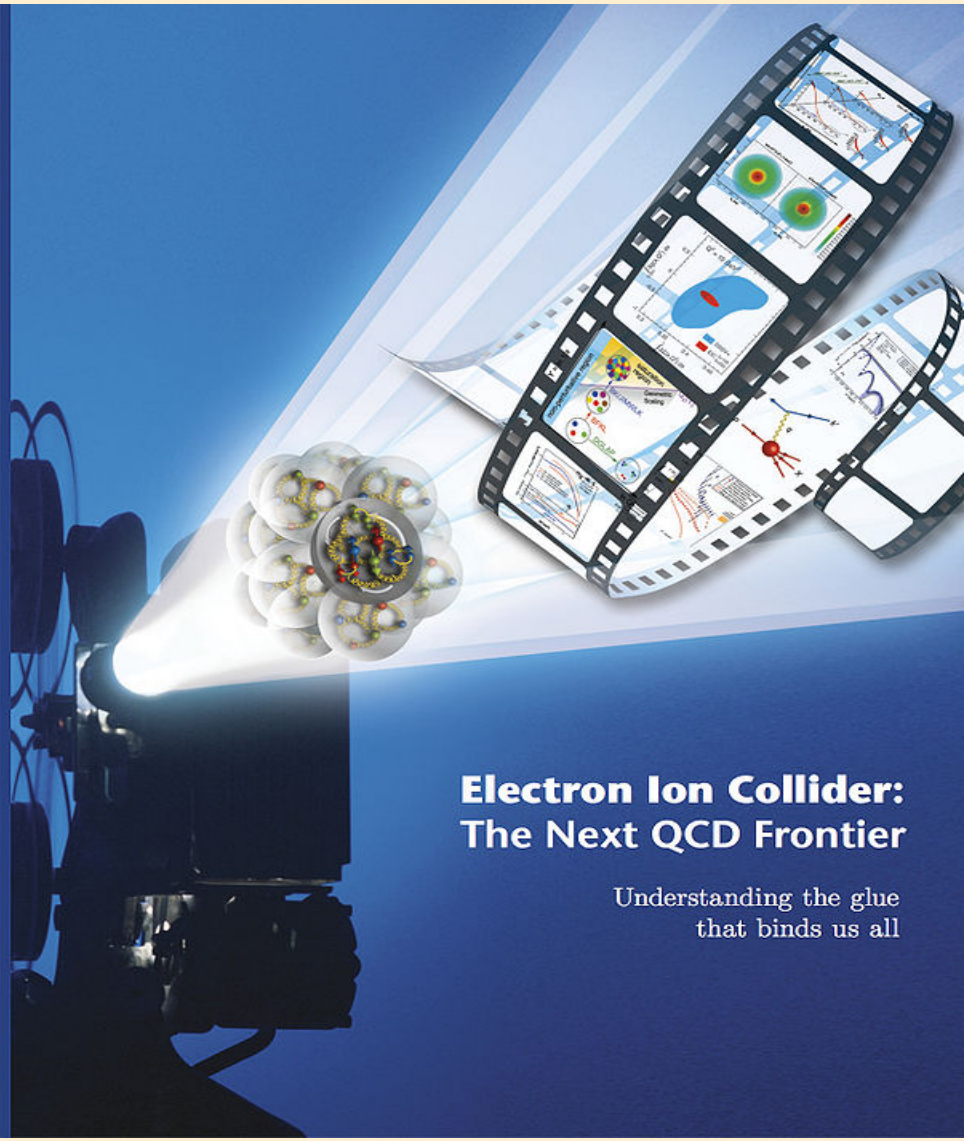
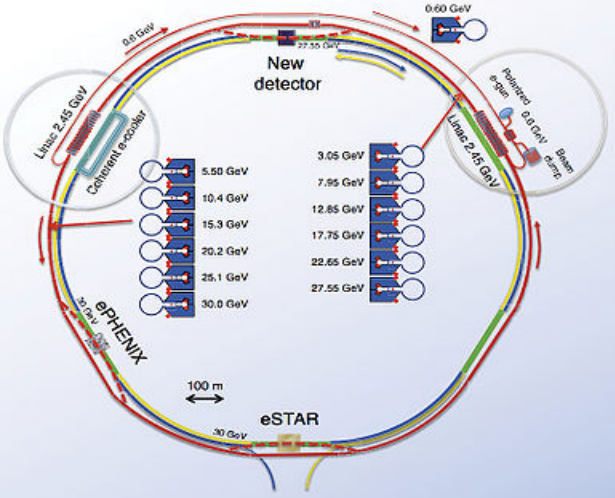
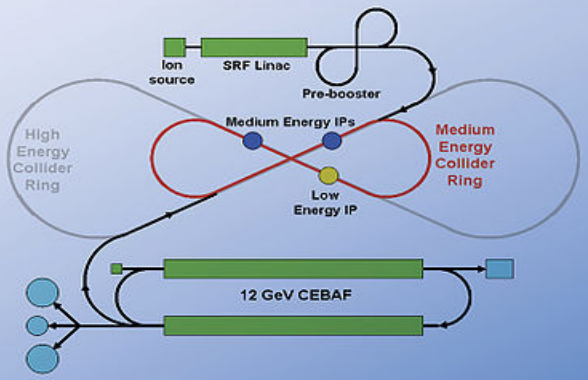


JSA

Jefferson Lab

Electron Ion Collider





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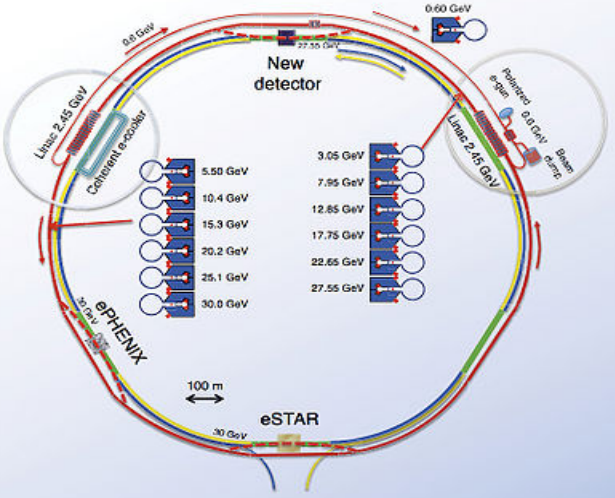
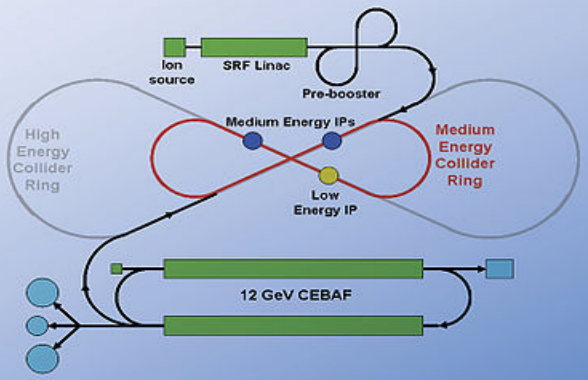
Electron Ion Collider





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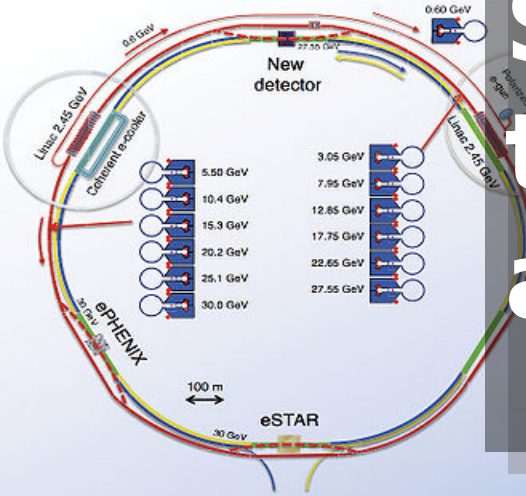
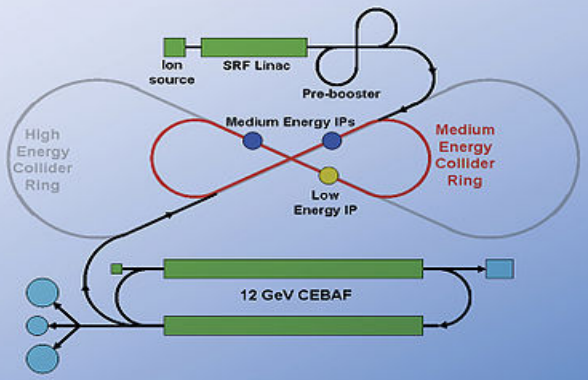
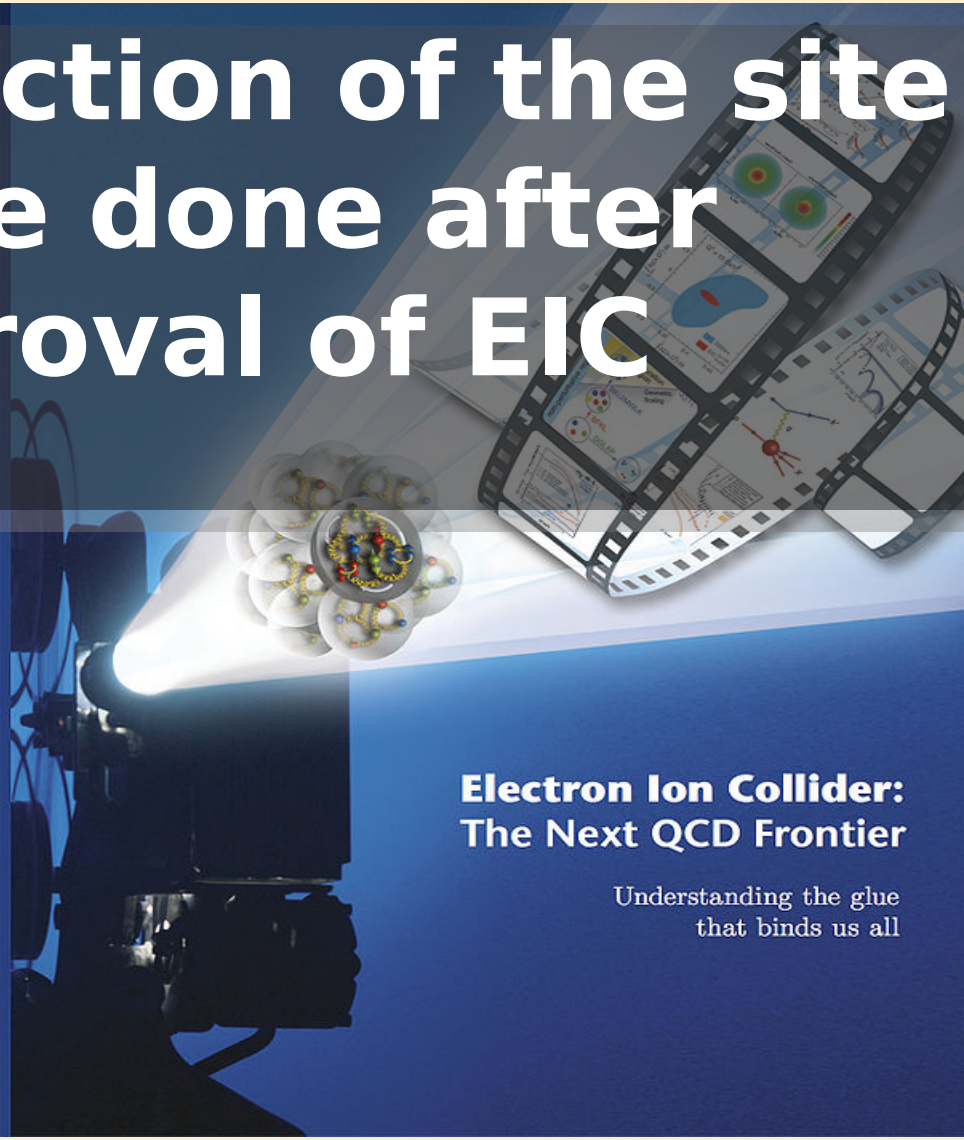
Electron Ion Collider

Selection of the site to be done after approval of EIC







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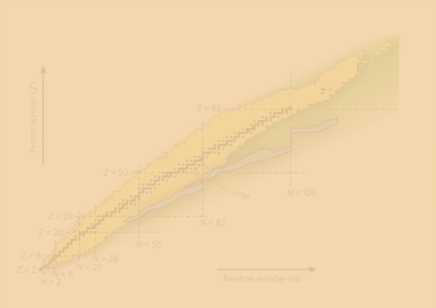
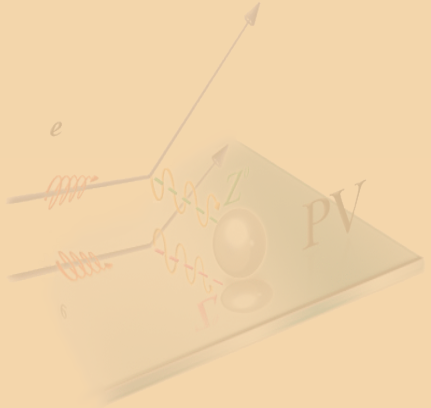
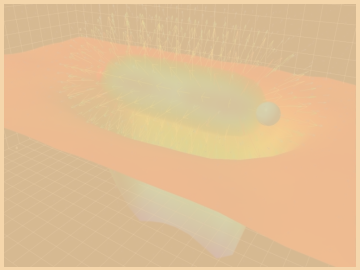
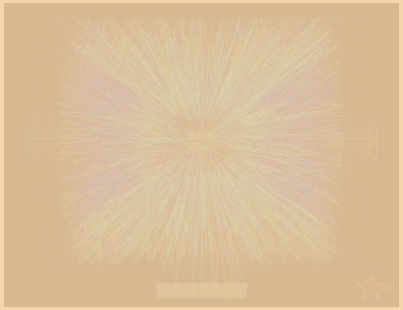
Conclusions

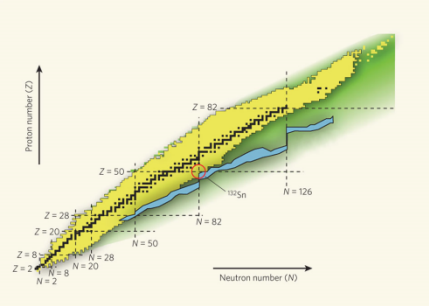




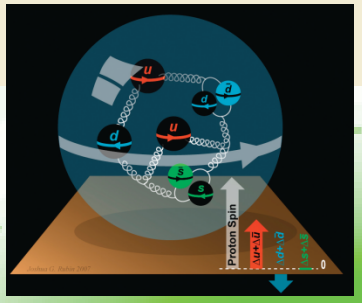




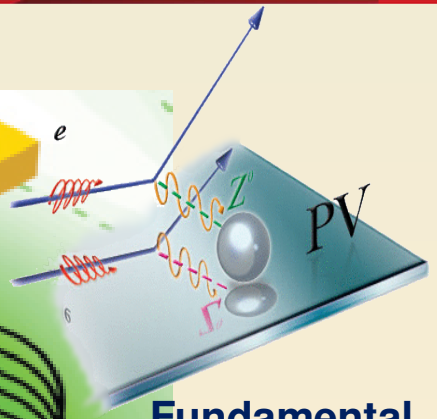
A Laboratory for Nuclear Science



Nuclear Structure



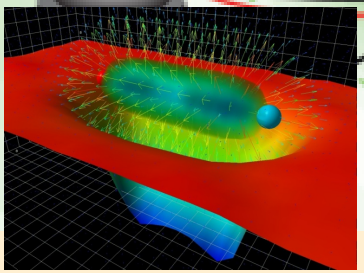
Structure of Hadrons



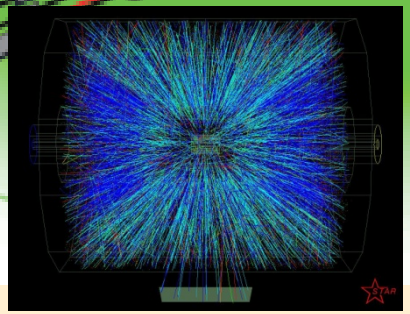
Fundamental Forces & Symmetries

Medical Imaging

Accelerator S&T



Quark Confinement



Hadrons from Quarks

Theory and Computation