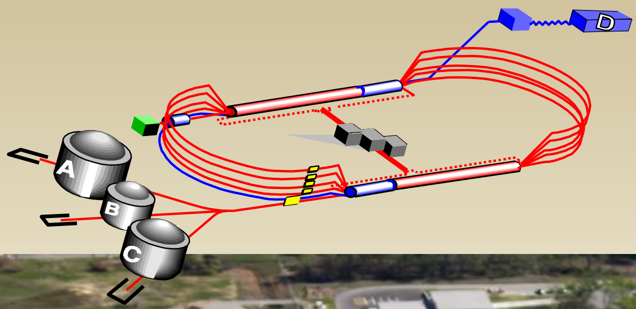


Jefferson Laboratory *Science Overview*

R. D. McKeown

Hadron2012
Beijing, China

Jefferson Lab
Thomas Jefferson National Accelerator Facility

Outline

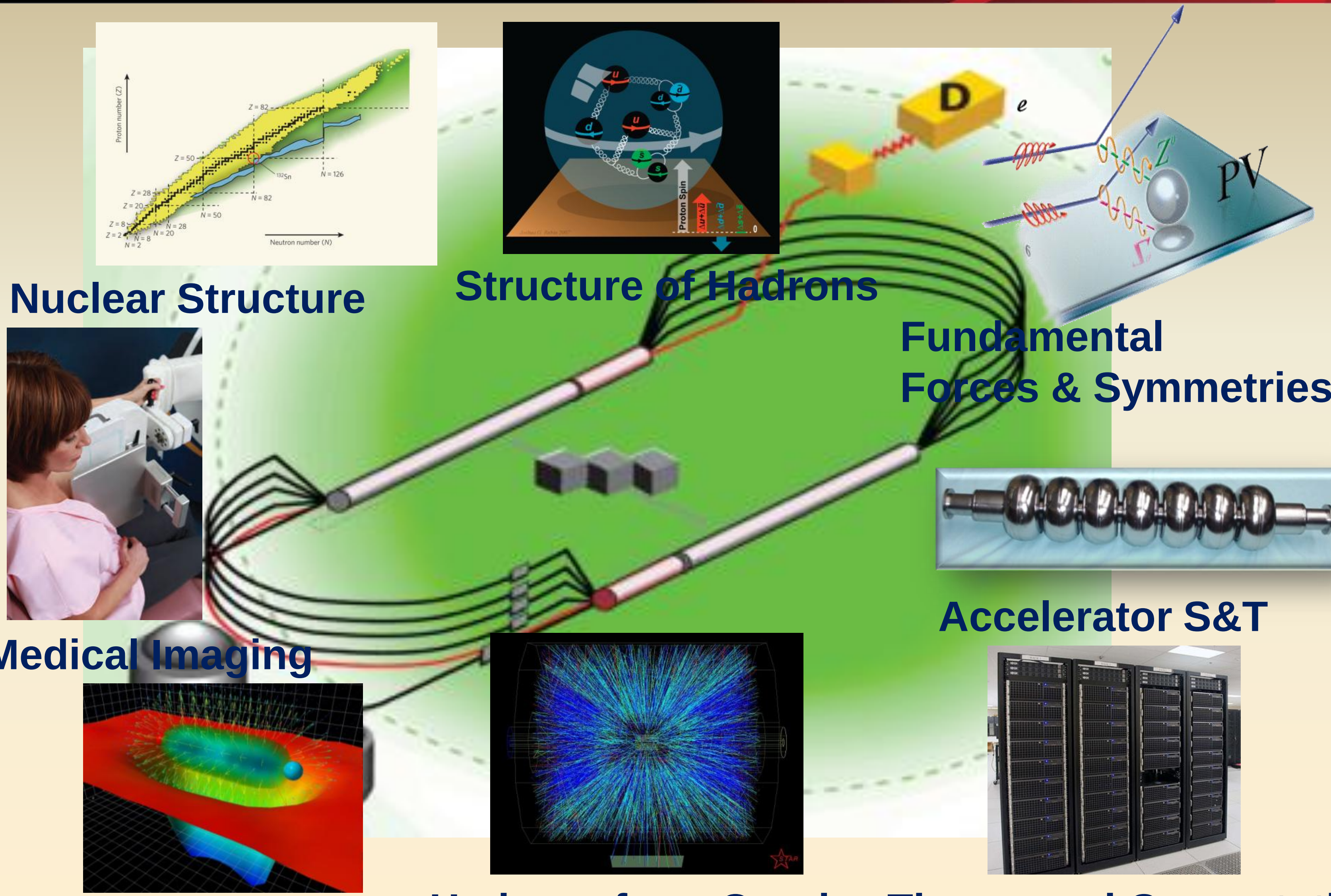
- JLab context in Nuclear Physics
- 12 GeV Physics Program
  - phenomenology
  - techniques (theory+exp)
  - standard model tests

New

→ **Discovery Potential**

- MEIC
- Outlook

A Laboratory for Nuclear Science



Nuclear Structure

Structure of Hadrons

Fundamental Forces & Symmetries

Medical Imaging

Accelerator S&T

Quark Confinement

Hadrons from Quarks

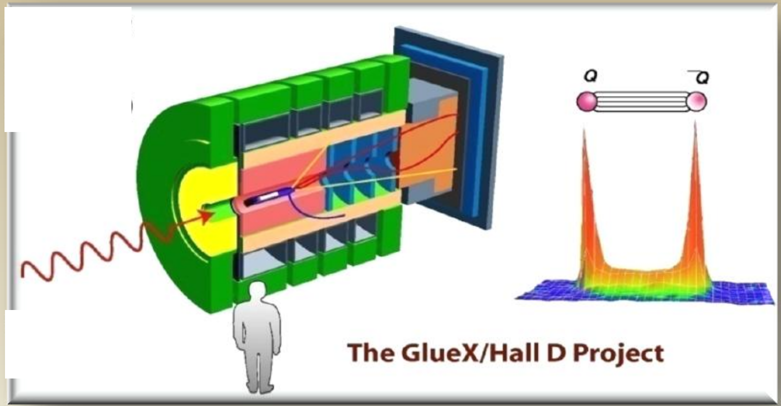
Theory and Computation

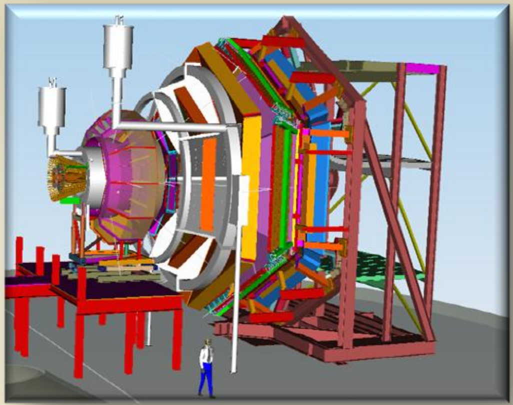
JLab: 21st Century Science Questions

- 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?

12 GeV Scientific Capabilities

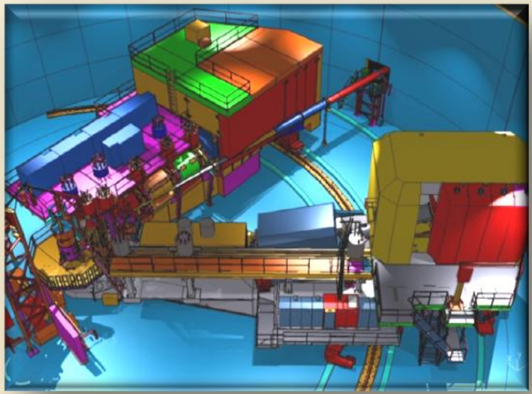
Hall D – exploring origin of confinement by studying exotic mesons

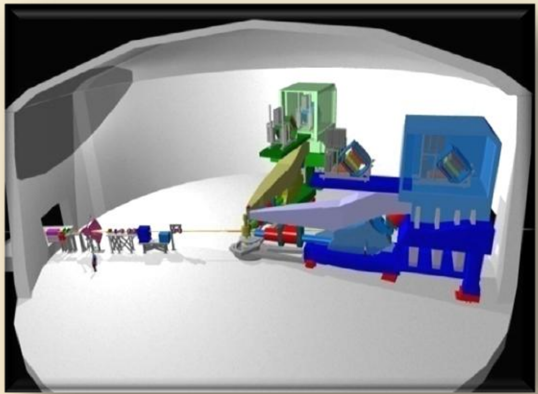




Hall B – understanding nucleon structure via generalized parton distributions

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

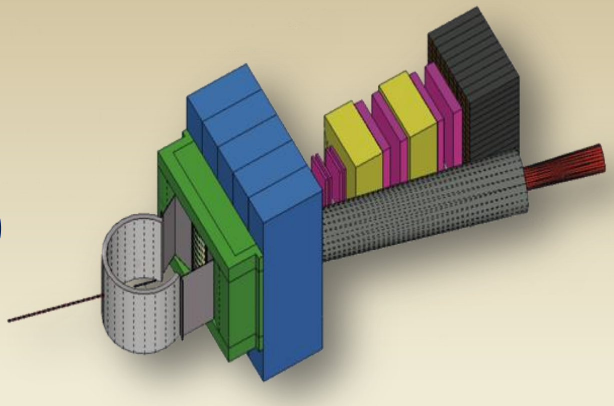




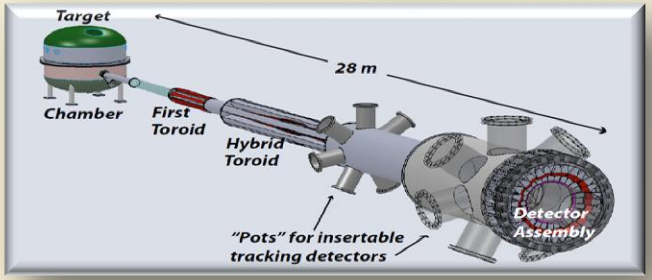
Hall A –form factors, future new experiments (e.g., SoLID and MOLLER)

Beyond 12 GeV Upgrade

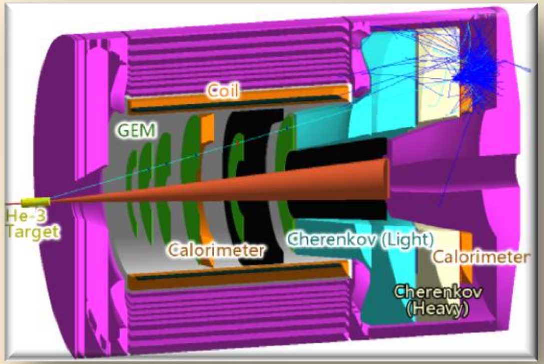
- **Super BigBite Spectrometer**
  (Approved for FY13-15 construction)



- **MOLLER experiment**
  (MIE – FY14-18?)



- **SoLID**
  Chinese collaboration
  CLEO Solenoid?



12 GeV Science Program

- The physical origins of quark confinement (GlueX, meson and baryon spectroscopy)
- The spin and flavor structure of the proton and neutron (PDF's, GPD's, TMD's…)
- The quark structure of nuclei
- Probe potential new physics through high precision tests of the Standard Model

- Defining the Science Program:
  - Eight Reviews: Program Advisory Committees (PAC) - 2006 through 2011
  - Results: *52 experiments approved; 15 conditionally approved*
  - White paper for NSAC subcommittee (in progress)

Experiments for 4 Halls approved for more than seven years of operation beginning in FY15.

12 GeV Approved Experiments by Physics Topics

Topic	Hall A	Hall B	Hall C	Hall D	Total
The Hadron spectra as probes of QCD (GluEx and heavy baryon and meson spectroscopy)		1		1	2
The transverse structure of the hadrons (Elastic and transition Form Factors)	4	3	2		9
The longitudinal structure of the hadrons (Unpolarized and polarized parton distribution functions)	2	2	5		9
The 3D structure of the hadrons (Generalized Parton Distributions and Transverse Momentum Distributions)	5	10	3		18
Hadrons and cold nuclear matter (Medium modification of the nucleons, quark hadronization, F N-N correlations, hypernuclear spectroscopy, few-body experiments)	3	2	6		11
Low-energy tests of the Standard Model and Fundamental Symmetries	2			1	3
Total	**16**	**18**	**16**	**2**	**52**

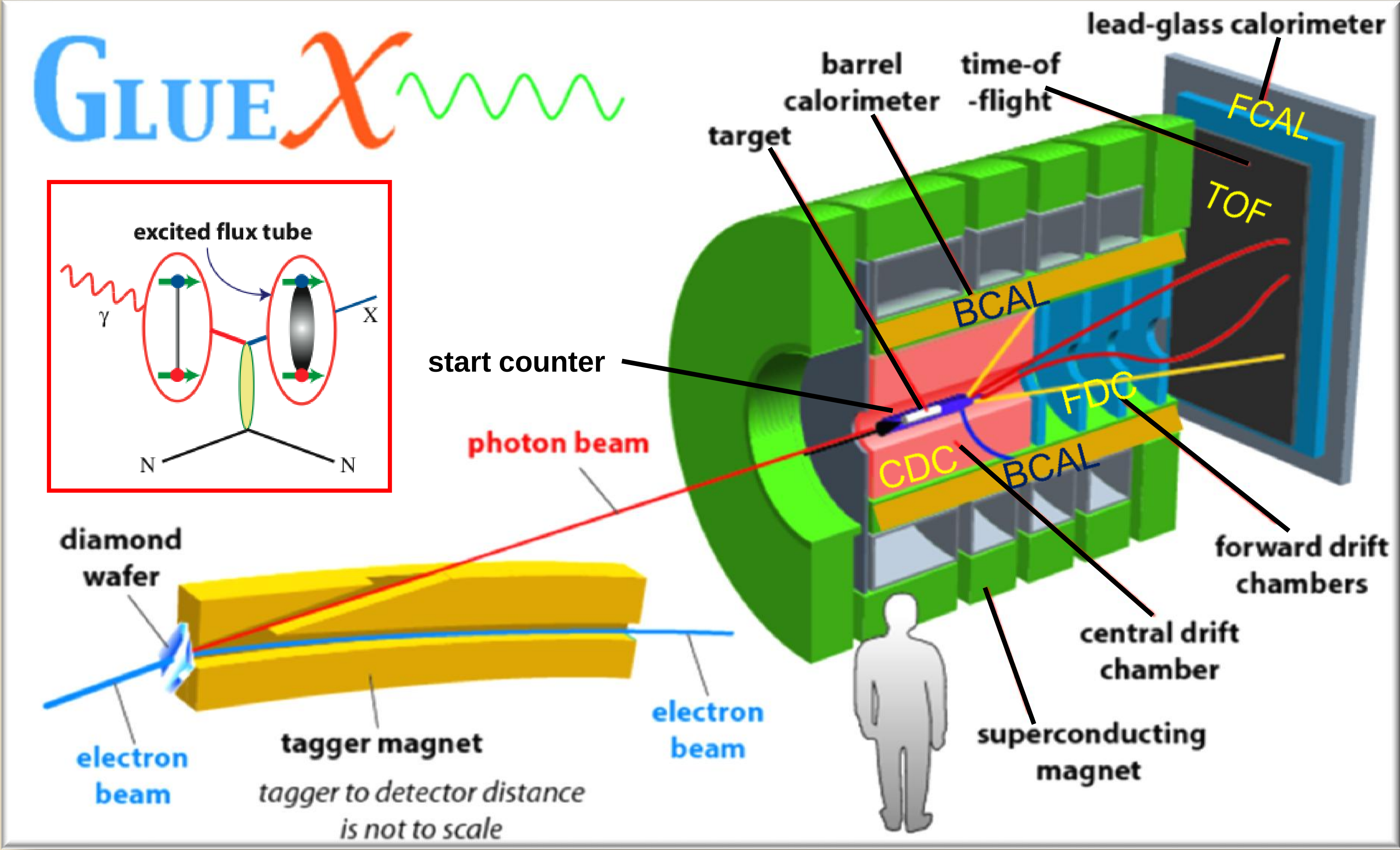
E12-11-105 has not been counted with the experiments since it is considered a test

12 GeV Approved Experiments by PAC Days

Topic	Hall A	Hall B	Hall C	Hall D	Total
The Hadron spectra as probes of QCD (GluEx and heavy baryon and meson spectroscopy)		119		120	239
The transverse structure of the hadrons (Elastic and transition Form Factors)	144	85	102		331
The longitudinal structure of the hadrons (Unpolarized and polarized parton distribution functions)	65	120	140		325
The 3D structure of the hadrons (Generalized Parton Distributions and Transverse Momentum Distributions)	409	982	108		1499
Hadrons and cold nuclear matter (Medium modification of the nucleons, quark hadronization, F N-N correlations, hypernuclear spectroscopy, few-body experiments)	114	120	179		413
Low-energy tests of the Standard Model and Fundamental Symmetries	513			79	592
Total	**1245**	**1426**	**529**	**199**	**3399**

More than 7 years of approved experiments

Hall D



GlueX
excited flux tube
γ
X
N
N
lead-glass calorimeter
barrel calorimeter
time-of -flight
target
FCAL
TOF
BCAL
start counter
FDC
CDC
BCAL
photon beam
diamond wafer
forward drift chambers
central drift chamber
superconducting magnet
electron beam
tagger magnet
electron beam
tagger to detector distance is not to scale

Quantum Numbers of Hybrid Mesons

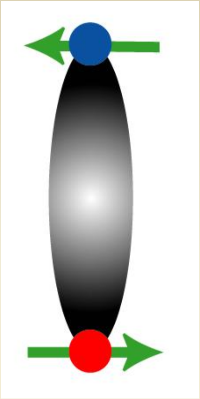
Quarks $\oplus$ **Excited Gluon Field** → **Hybrid Meson**

$S = 0$

$L = 0$

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

like π, K



$$J^{PC} = \begin{cases} 1^{+-} \\ 1^{-+} \end{cases}$$

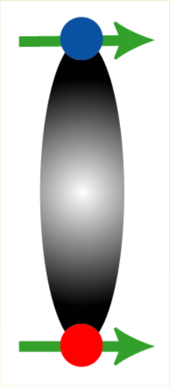
$$J^{PC} = \begin{cases} 1^{--} \\ 1^{++} \end{cases}$$

$S = 1$

$L = 0$

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

like γ, ρ



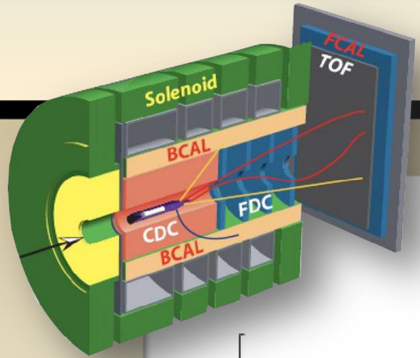
$$J^{PC} = \begin{cases} 1^{+-} \\ 1^{-+} \end{cases}$$

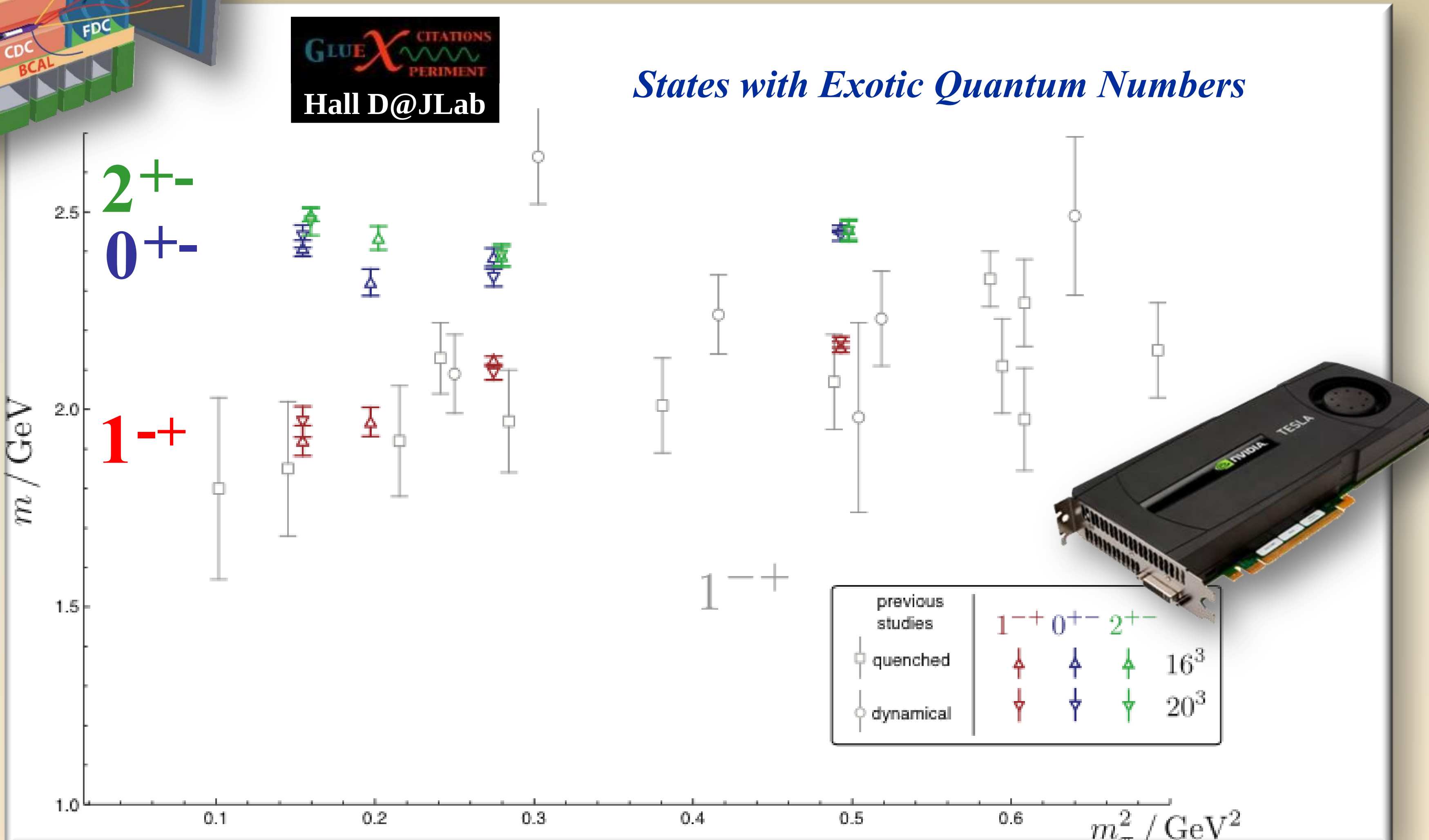
Exotic

$$J^{PC} = \begin{cases} 0^{-+} \quad 1^{-+} \quad 2^{-+} \\ 0^{+-} \quad 1^{+-} \quad 2^{+-} \end{cases}$$

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

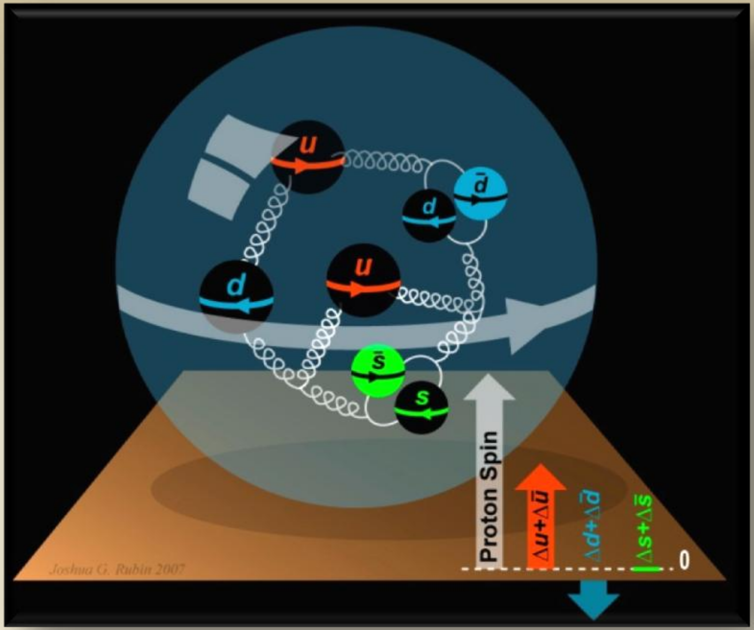
Isovector Meson Spectrum





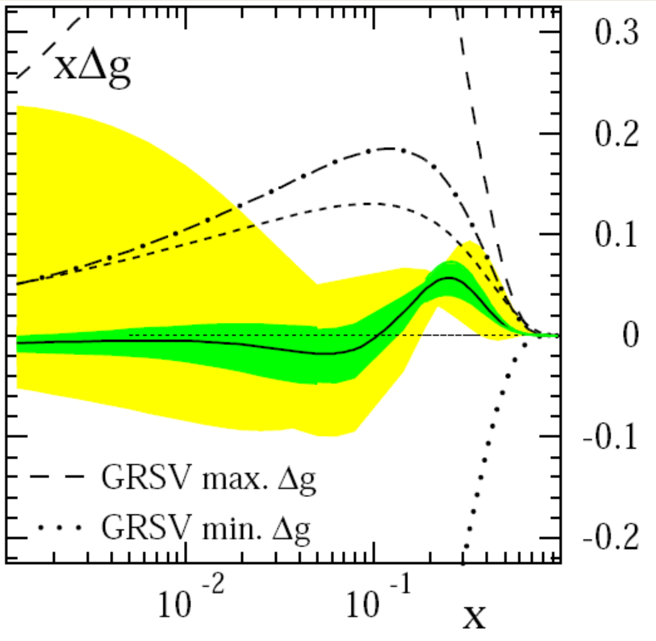
Dudek et al.

The Incomplete Nucleon: Spin Puzzle



$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + L_q + J_g$$

[X. Ji, 1997]



D. de Florian et al., PRL 101 (2008) 072001

- DIS $\rightarrow \Delta\Sigma \cong 0.25$
- RHIC + DIS $\rightarrow \Delta G \ll 1$
- $\rightarrow L_q$

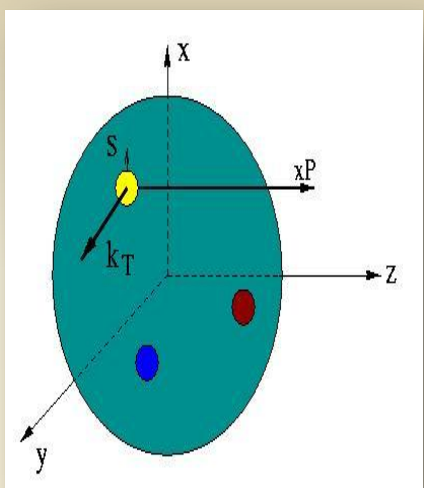
Unified View of Nucleon Structure

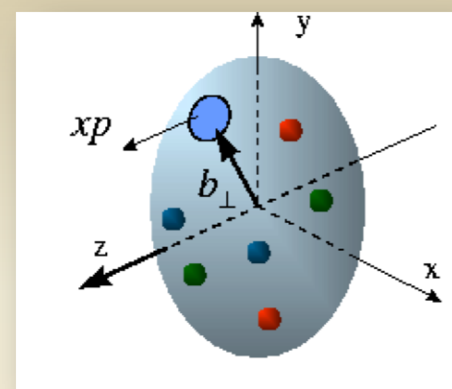
6D Dist.

$W_p^u(x,k_T,\boldsymbol{r})$ Wigner distributions

$d^3\boldsymbol{r}$

$d^2k_T\,dr_z$





TMD PDFs
$f_1^u(x,k_T)$, .. $h_1^u(x,k_T)$

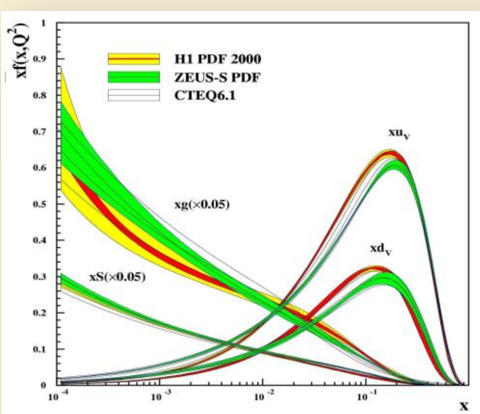
GPDs/IPDs

3D imaging

d^2k_T

d^2r_T

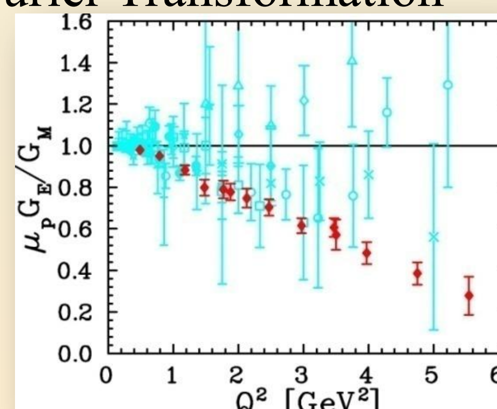
dx &
Fourier Transformation



PDFs
$f_1^u(x)$, .. $h_1^u(x)$

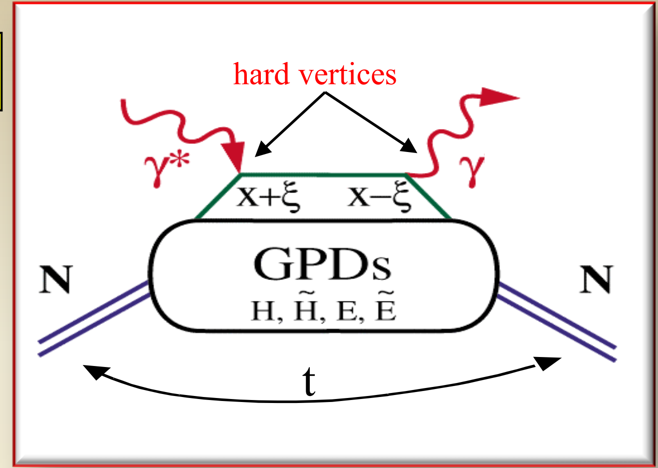
1D

Form Factors
$G_E(Q^2)$,
$G_M(Q^2)$



Extraction of GPD's

Cleanest process: Deeply Virtual Compton Scattering



$$A = \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-} = \frac{\Delta\sigma}{2\sigma}$$

$\xi = x_B/(2-x_B)$

Polarized beam, unpolarized target:

$$\Delta\sigma_{LU} \sim \sin\phi\{F_1 H + \xi(F_1+F_2)\tilde{H} + kF_2 E\}d\phi$$

⟹ $H(\xi,t)$

Unpolarized beam, longitudinal target:

$$\Delta\sigma_{UL} \sim \sin\phi\{F_1\tilde{H} + \xi(F_1+F_2)(H + \xi/(1+\xi)E)\}d\phi$$

⟹ $\tilde{H}(\xi,t)$

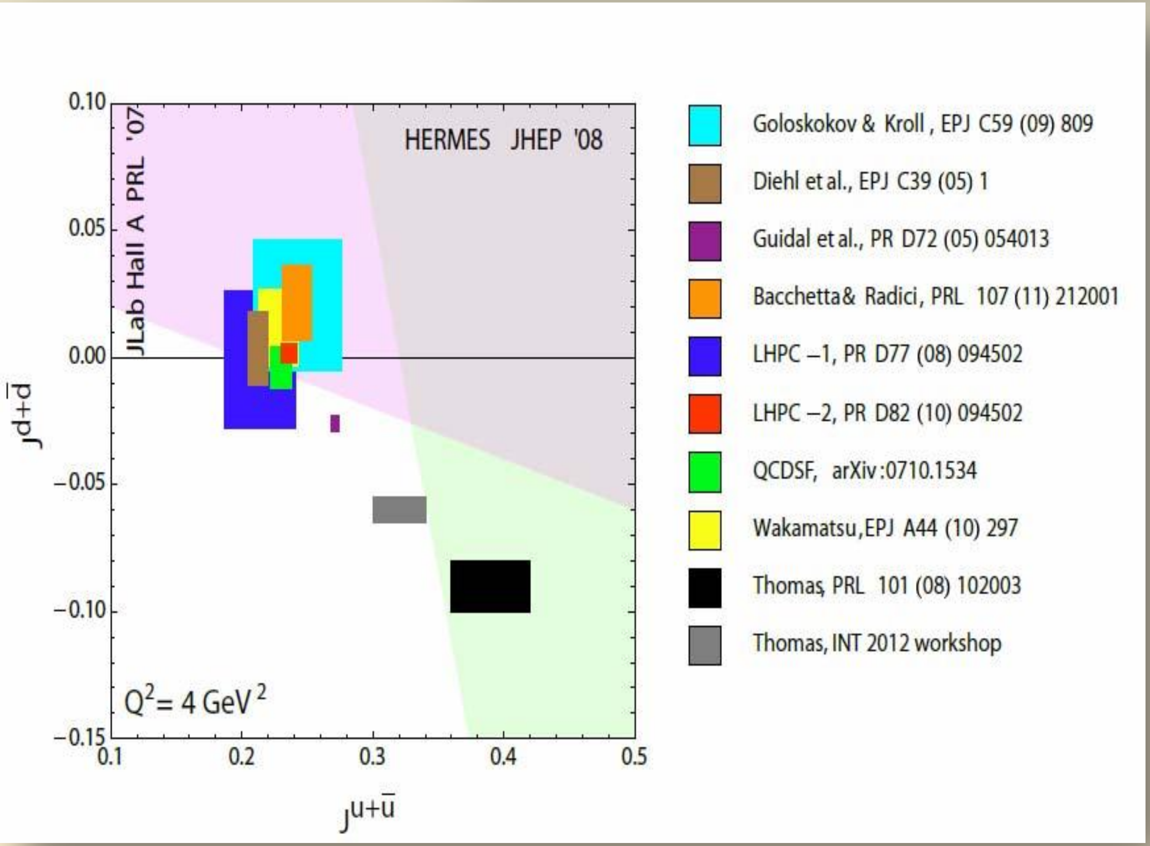
Unpolarized beam, transverse target:

$$\Delta\sigma_{UT} \sim \sin\phi\{k(F_2 H - F_1 E)\}d\phi$$

⟹ $E(\xi,t)$

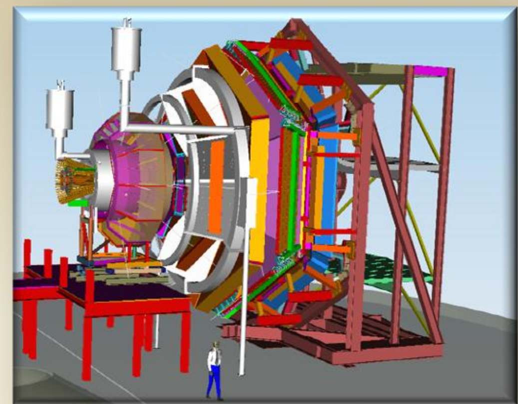
Quark Angular Momentum

$$J^q(t) = \int_{-1}^{+1} dx x[H^q(x,\xi,t) + E^q(x,\xi,t)]$$



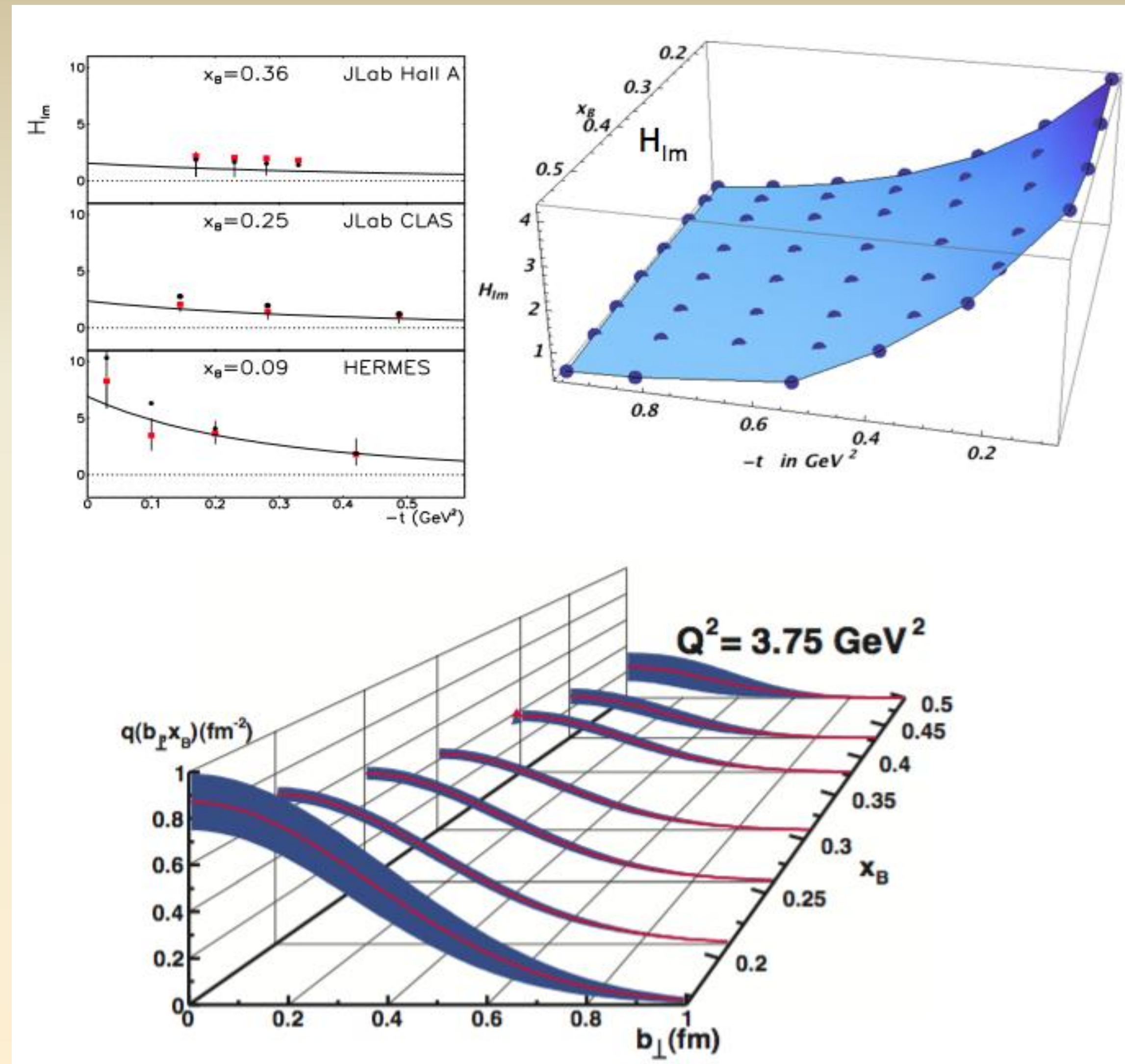
→ **Access to quark orbital angular momentum**

DVCS beam asymmetry at 12 GeV *CLAS12*



$\vec{e}p \longrightarrow ep\gamma$

High luminosity and large acceptance allows wide coverage in $Q^2 < 8$ GeV^2, $x_B < 0.65$, and $t < 1.5$GeV^2



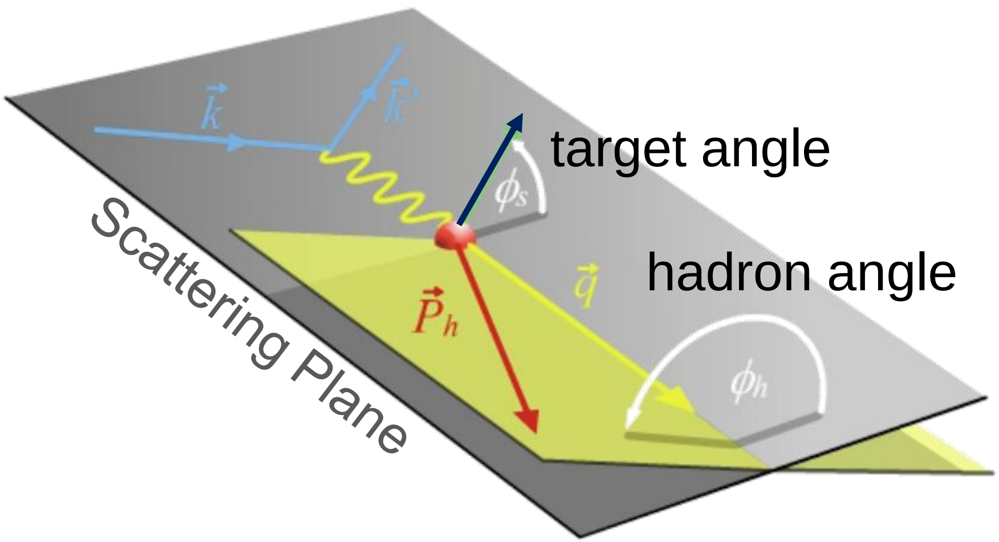
Leading Twist

→ Nucleon Spin
→ Quark Spin

Nucleon Polarization		Quark polarization: Un-Polarized	Quark polarization: Longitudinally Polarized	Quark polarization: Transversely Polarized
	U	f_1 =		$h_1^{\perp}$ = − **Boer-Mulder**
	L		g_1 = − **Helicity**	$h_{1L}^{\perp}$ = −
	T	$f_{1T}^{\perp}$ = − **Sivers**	$g_{1T}^{\perp}$ = −	h_{1T} = − **Transversity** $h_{1T}^{\perp}$ = − **Pretzelosity**

SIDIS Electroproduction of Pions

- Separate Sivers and Collins effects



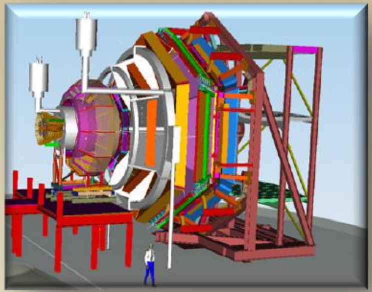
- Previous data from HERMES,COMPASS
- New landscape of TMD distributions
- Access to orbital angular momentum

- **Sivers** angle, effect in distribution function: $(\phi_h - \phi_s)$
- **Collins** angle, effect in fragmentation function: $(\phi_h + \phi_s)$

SIDIS Studies with 12 GeV at JLab

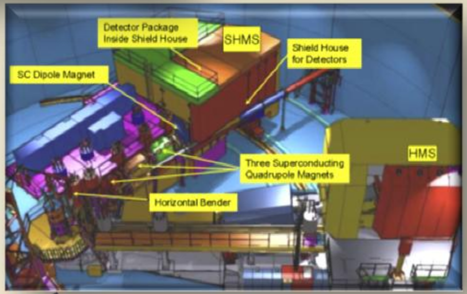
- **CLAS12 in Hall B**

  General survey, medium lumi



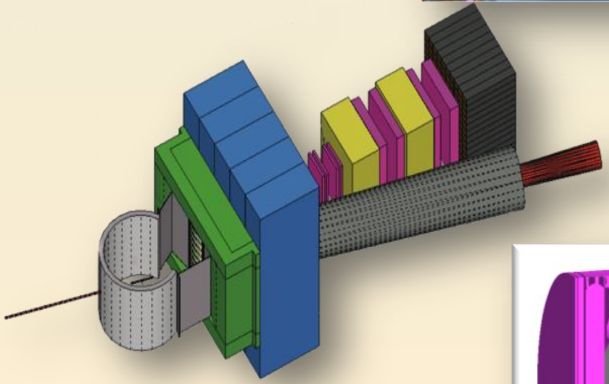
- **SHMS- HMS in Hall C**

  L-T studies, precise π^+/π^- ratios



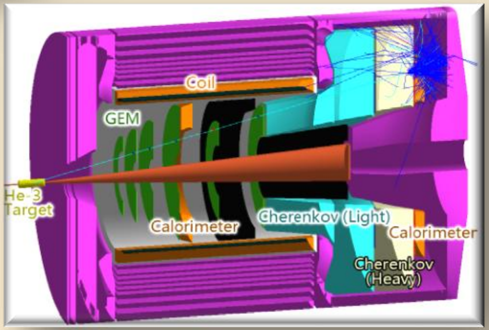
- **SBS in Hall A**

  High x, High Q^2, 2-3D



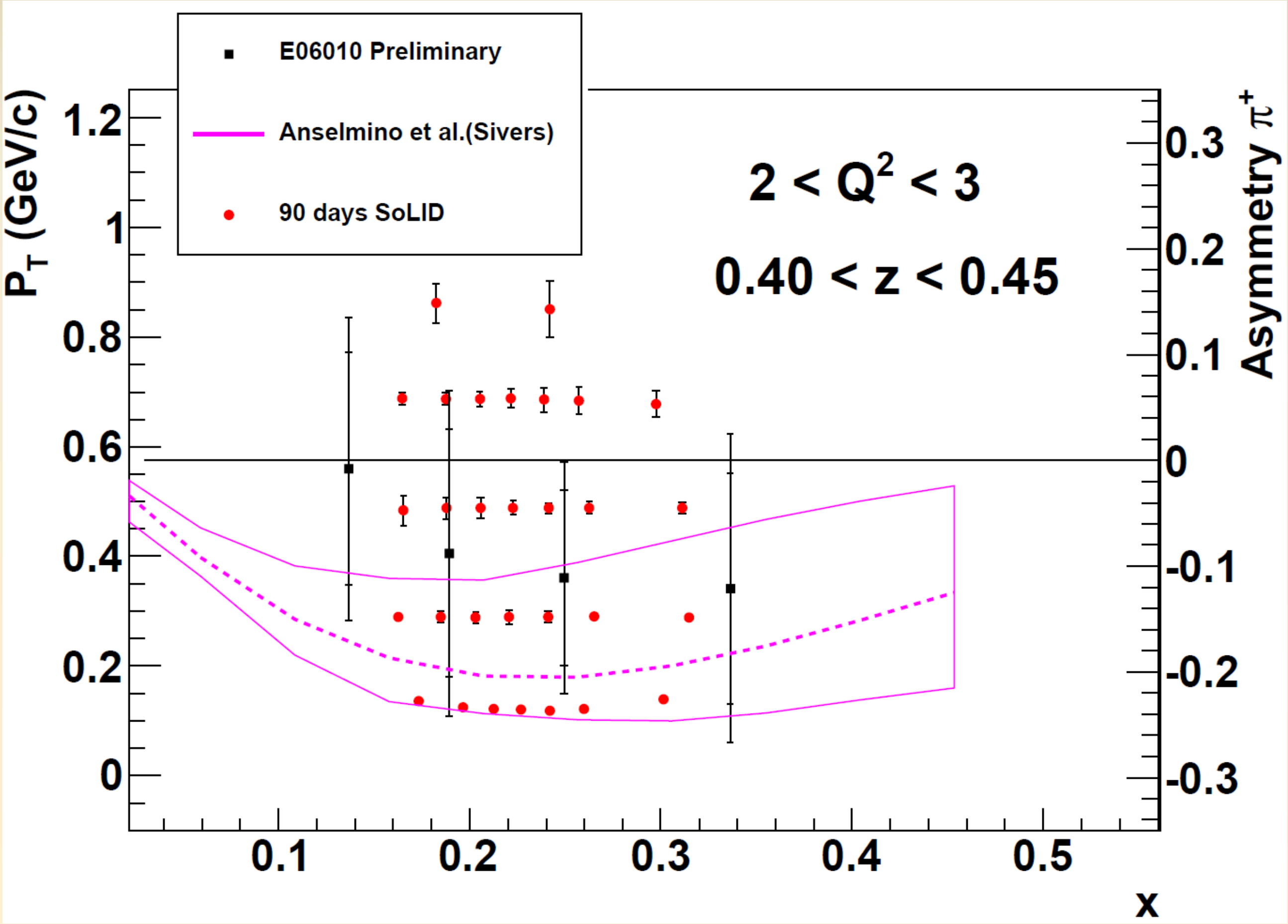
- **SOLID in Hall A**

  High Lumi and acceptance – 4D



SoLID Transversity Projected Data

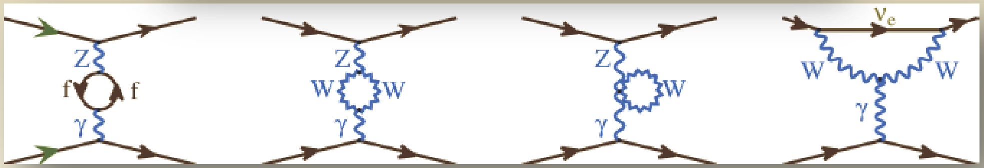
- Total 1400 bins in x, Q^2, P_T and z for 11/8.8 GeV beam.
- z ranges from 0.3 ~ 0.7, only one z and Q^2 bin of 11/8.8 GeV is shown here. π^+ projections are shown, similar to the π^- .

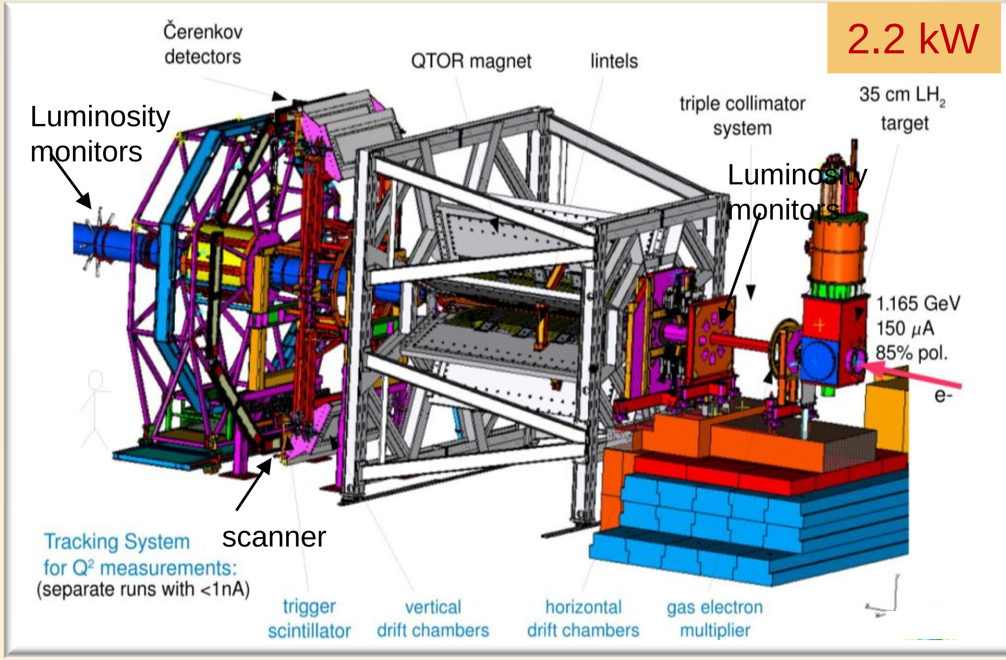


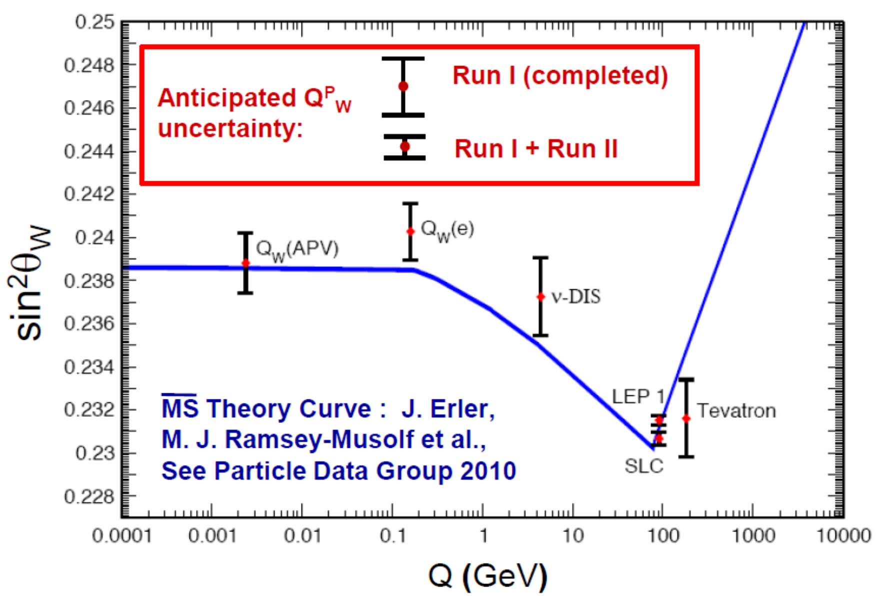
Qweak

Precise determination of the weak charge of the proton

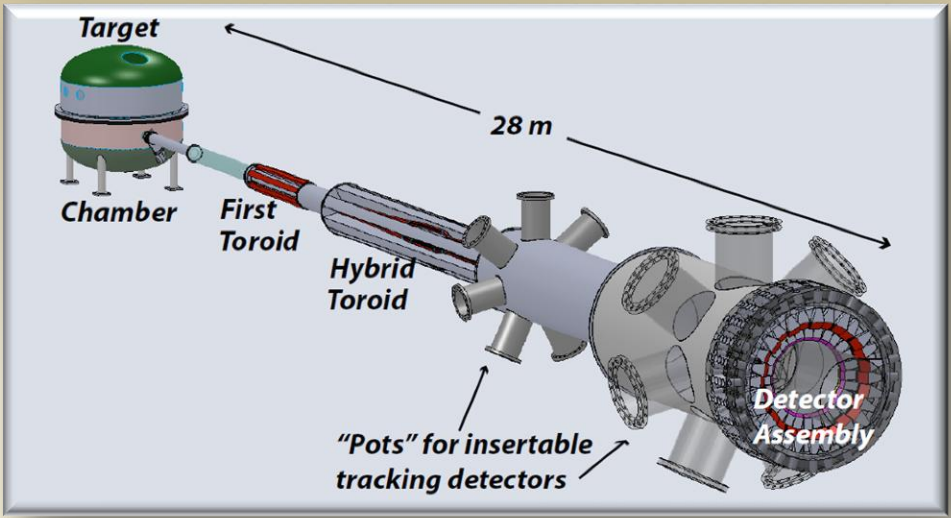
$$Q_W = -2(2C_{1u}+C_{1d})$$
$$=(1 - 4\sin^2\theta_W)$$







Future PV Program at JLab

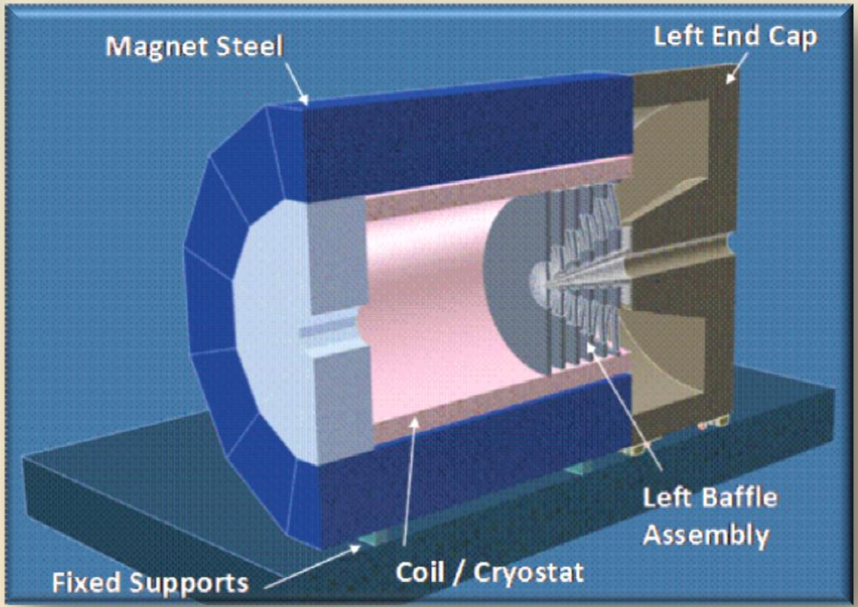


PV Moller Scattering:

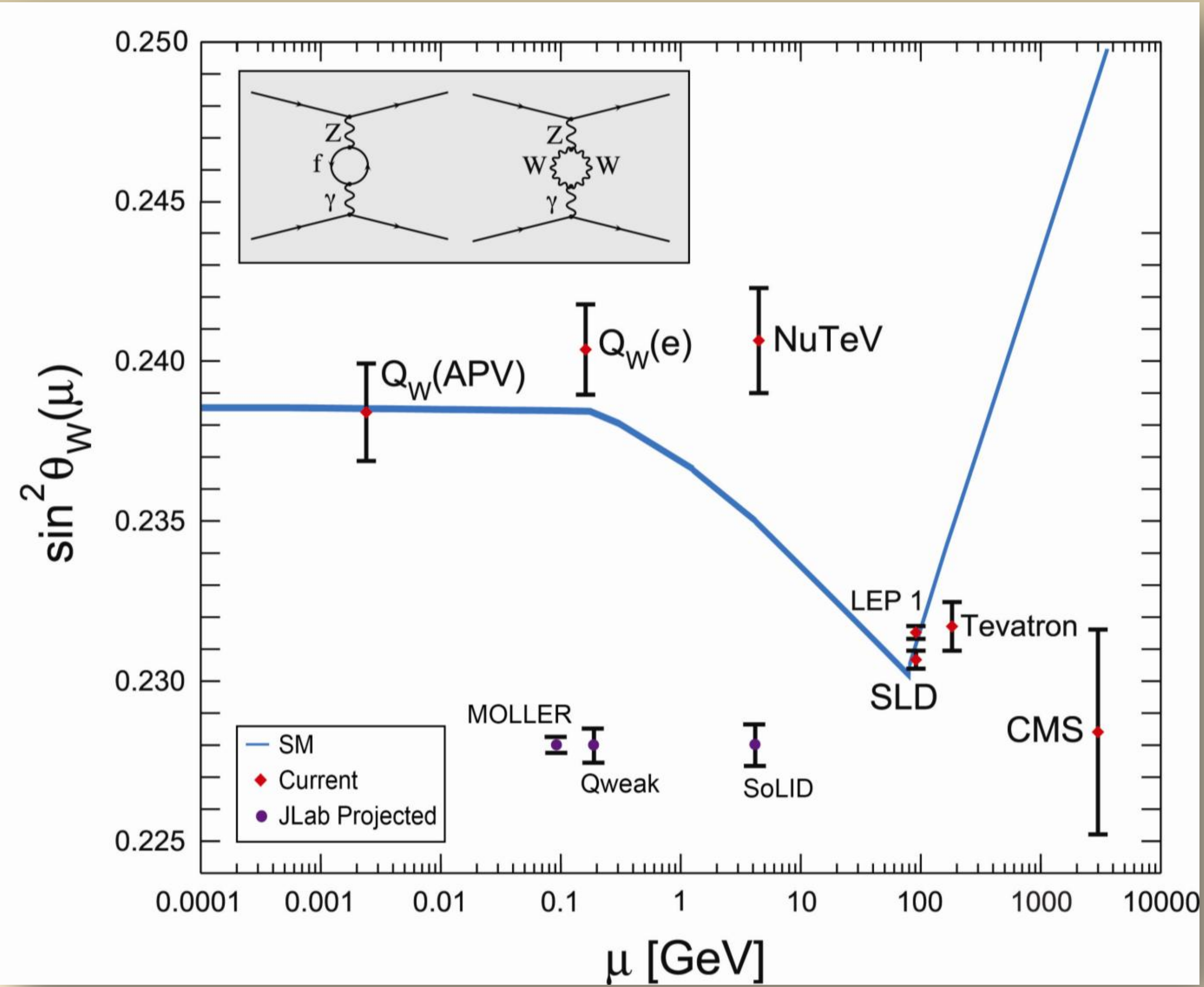
- Custom Toroidal Spectrometer
- 5kW LH Target

SOLID (PVDIS):

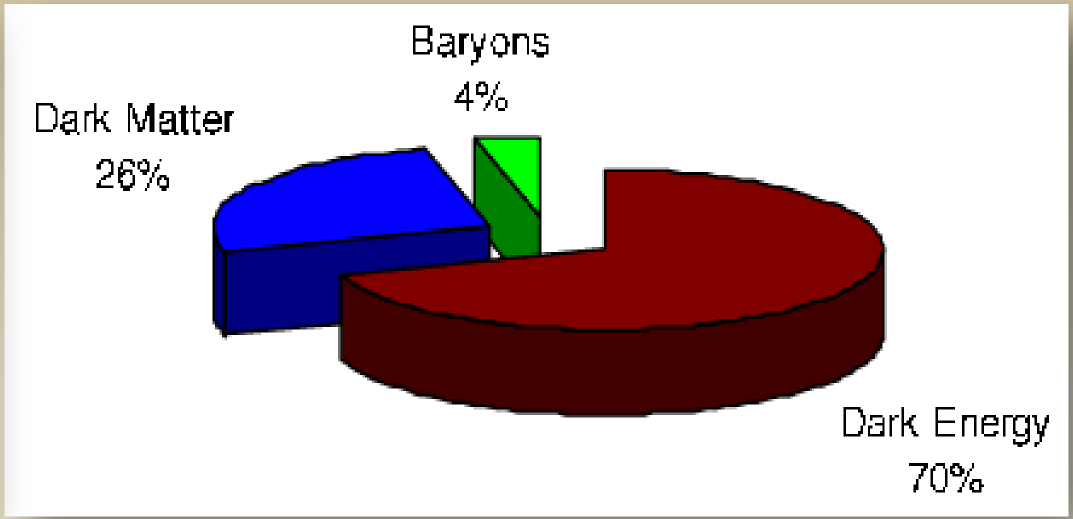
- High Luminosity on LD2 and LH2
- Better than 1% errors for small bins
- Large Q^2 coverage
- x-range 0.25-0.75
- $W^2 > 4$ GeV^2



Projected Results



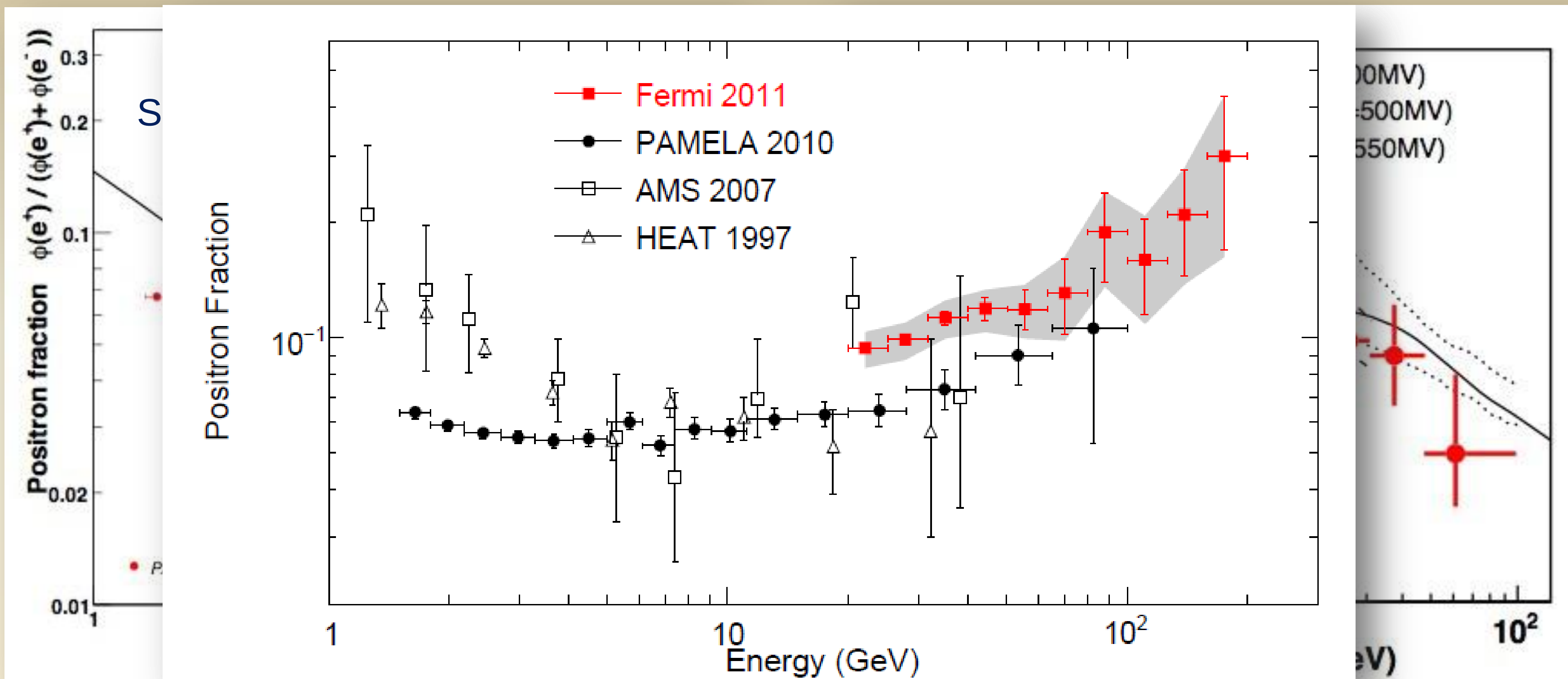
Cosmology and Dark Matter



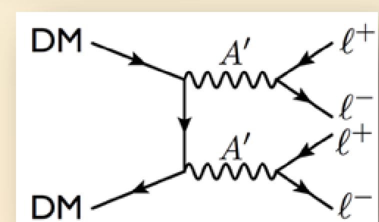
- *Dark sector is new physics, beyond the standard model*
- *Many direct searches for dark matter interacting with sensitive detectors (hints, no established signal yet…)*
- *Controversial evidence for excess astrophysical positrons…*

Jefferson Lab

PAMELA Data on Cosmic Radiation

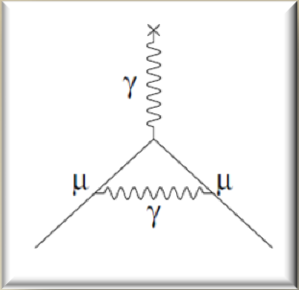


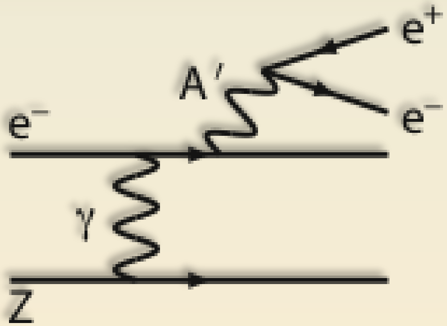
- Could indicate low mass A’ ($M_{A'} < 1$ GeV)
  - Or local astrophysical origin??



New Opportunity: Search for A' at Jefferson Lab

- BNL "g-2" expt: Δa_{μ}(expt-thy) = (295±88) x 10^{-11} (3.4 σ)
- No evidence for SUSY at LHC (yet)
- Another solution: A', a massive neutral vector boson

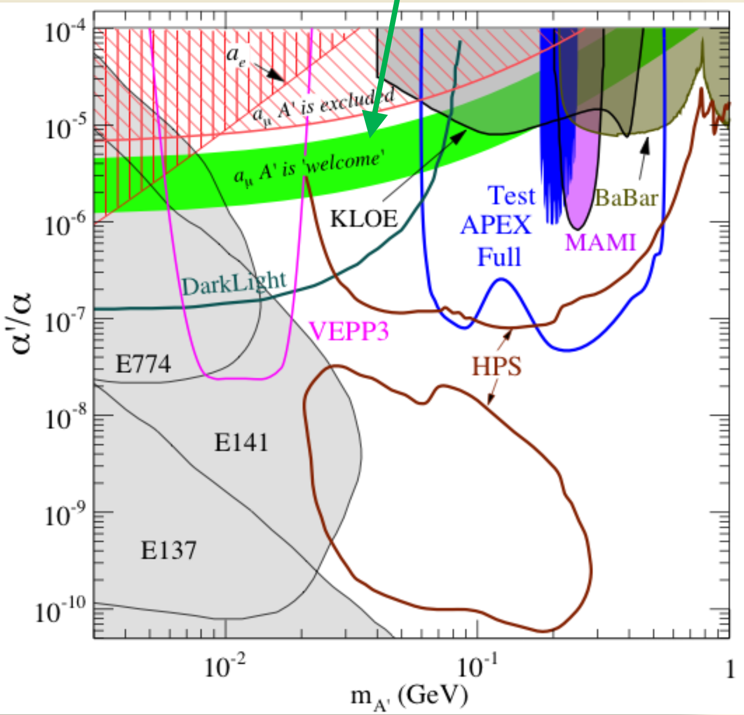




- also useful for dark matter models

- 3 Jefferson Lab proposals:
  - APEX test run (Hall A) – published
  - HPS test run (Hall B) – complete
  - DarkLight test run (FEL) – July 2012

g – 2 preferred!



JSA

Jefferson Lab

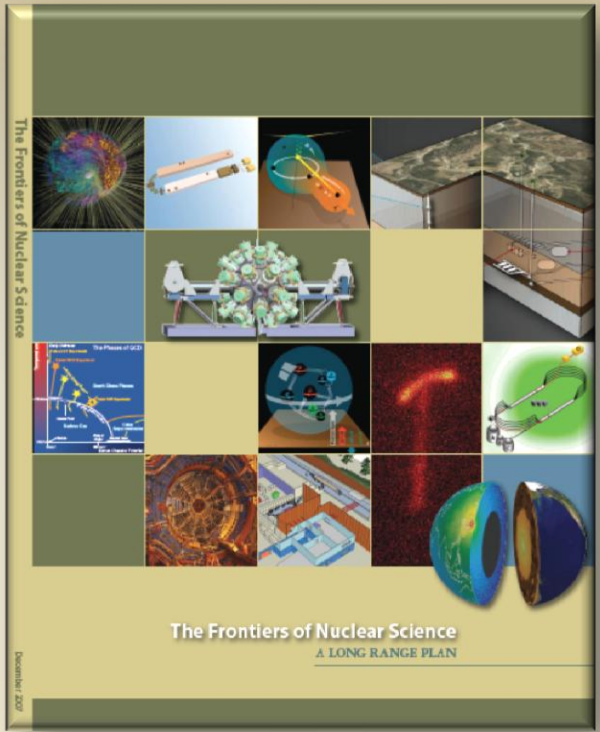
12 GeV JLab – The Potential

- Opportunity to discover and study new exotic mesons to elucidate the mechanism of confinement.
- Open a new landscape of nucleon tomography, with potential to identify the missing angular momentum.
- Establish the quantitative foundation for the short-distance behavior in nuclei, underpinning the development of precision nuclear structure studies.
- Provide stringent new tests of the standard model and extensions, complementing the information obtained at LHC.
- Establish a firm basis for higher energy studies with a future **Electron Ion Collider**

Electron Ion Collider

NSAC 2007 Long-Range Plan:

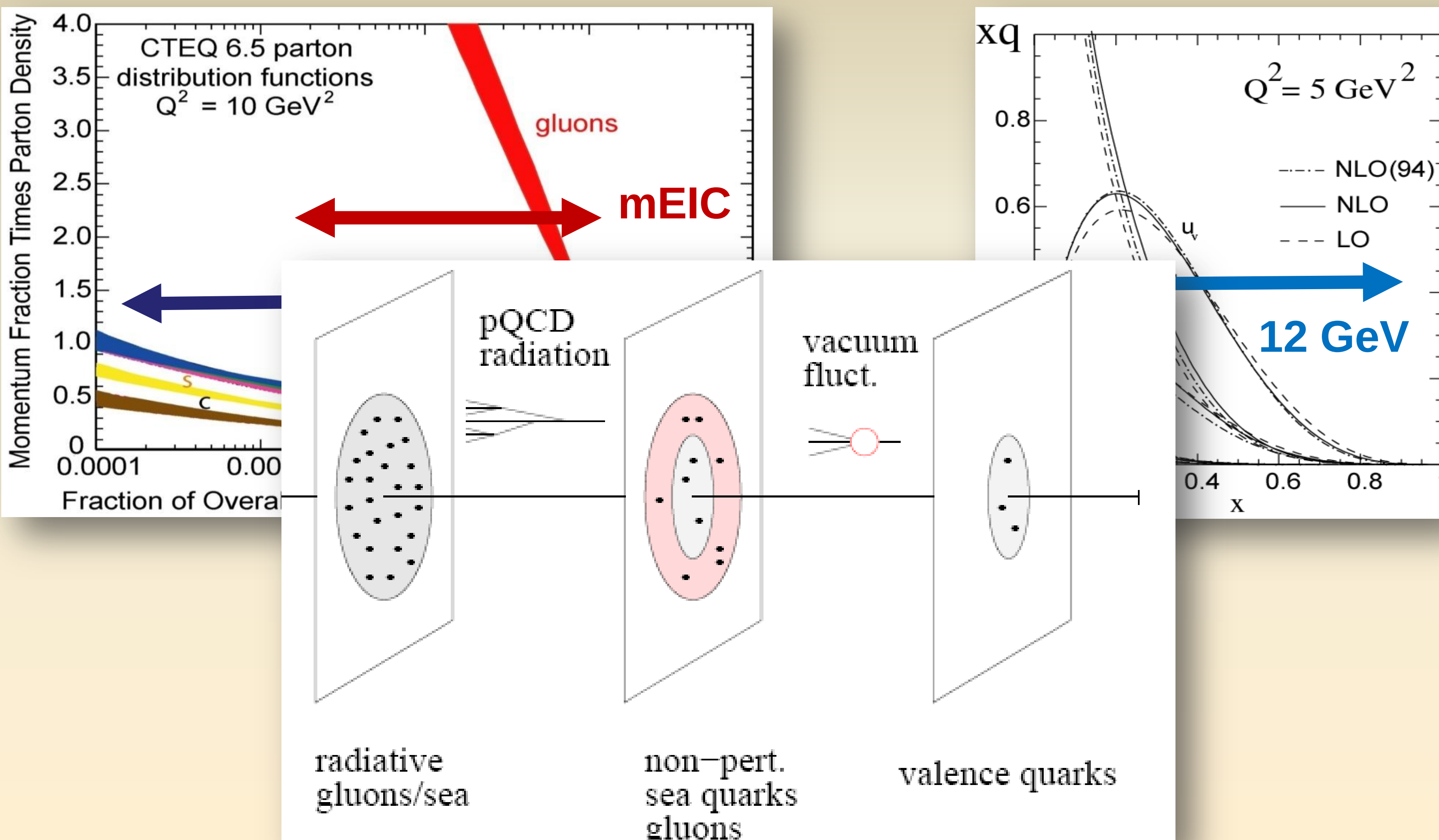
"An **Electron-Ion Collider (EIC)** with **polarized** beams has been **embraced by the U.S. nuclear science community** as embodying the vision for **reaching the next QCD frontier**. EIC would provide unique capabilities for the study of QCD well beyond those available at existing facilities worldwide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



- **EIC "collaboration" – Milner & Deshpande contact persons, involves BNL and JLab communities**
- **JLab and BNL are both developing "staged" designs**
- **EICAC advisory comm. → Montgomery & Aronson (BNL)**
- **Next NSAC Long Range Plan?**

Into the “sea”: EIC

- An EIC aims to study the <u>sea quarks, gluons, and scale (Q^2) dependence</u>.
- With 12 GeV we study mostly the <u>valence quark component</u>

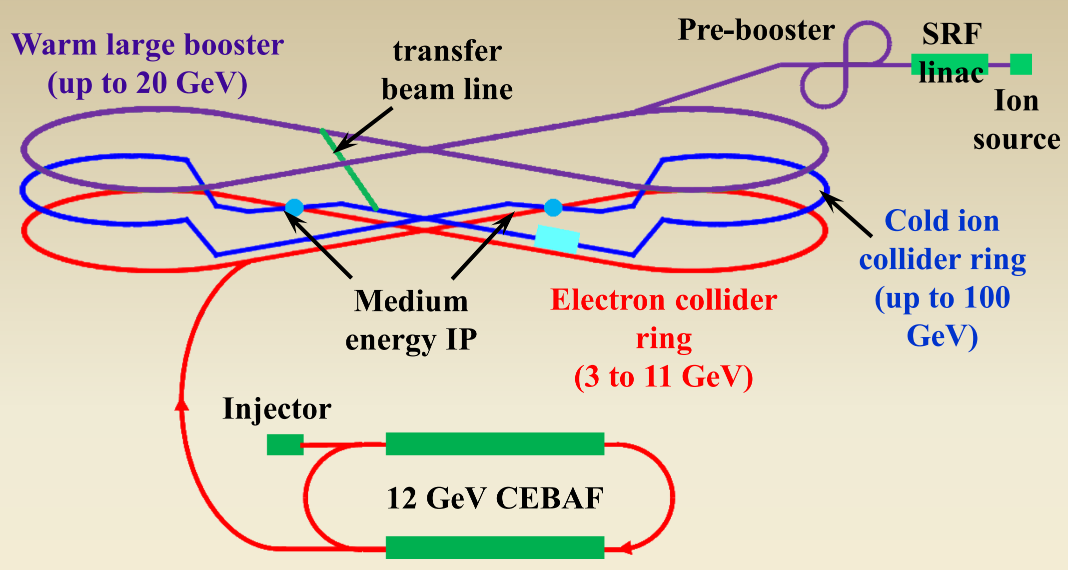


EIC Science Frontier

Explore the nuclear landscape at low x to:

- **Discover the collective effects of gluons in nuclei**
- **Complete the map of the spin and spatial structure of sea quarks and gluons in nucleons**
- **Understand the emergence of hadronic matter from quarks and gluons**

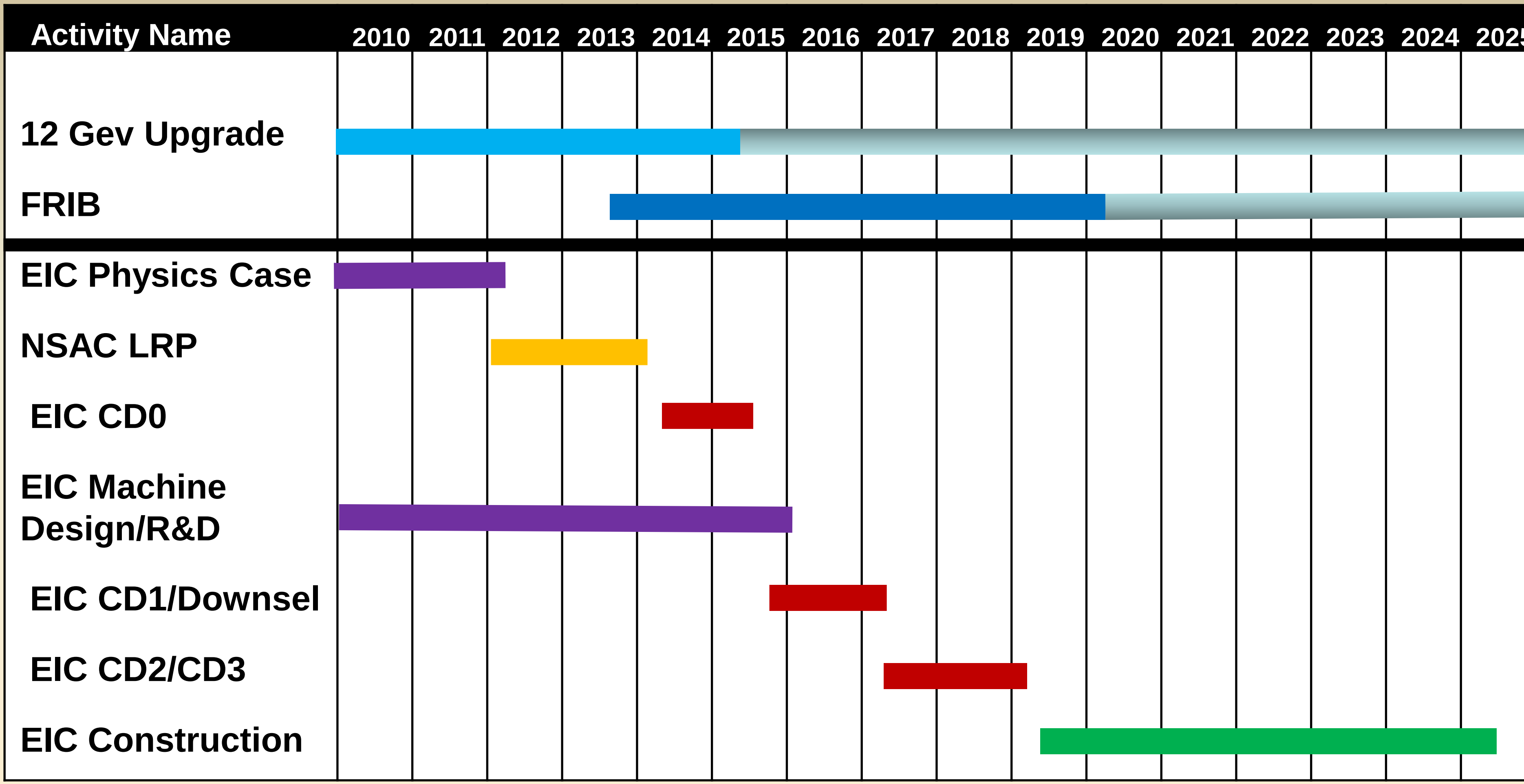
Medium Energy EIC@JLab



JLAB Concept

- Initial configuration (MEIC):
  - 3-11 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)

EIC Realization Imagined



A Laboratory for Nuclear Science

- 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
- 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”