A QCD town meeting on hadron physics

January 12-14, 2007

Rutgers University

Pages:

- Home
- Committees and Contact Information
- Agenda
- Phases of QCD Matter
- QCD and Hadron Physics
- Registration
- Meeting Hotel
- Transportation Information
- Information for Speakers
- Meeting Rooms / Parking
- Rutgers Department of Physics and Astronomy Homepage

APS Division of Nuclear Physics: 2007 Long Range Plan

Joint Town Meetings on Quantum Chromodynamics

Hosted by the Rutgers University Department of Physics and Astronomy in Piscataway, New Jersey

Sponsored by:

BROOKHAVEN NATIONAL LABORATORY

Jefferson Lab

National Science Foundation

WHERE DISCOVERIES BEGIN

Committees and Contact Information

QCD and Hadron Physics Town Meeting:

Simon Capstick (Florida State University)
Lawrence S. Cardman (Jefferson Lab)
Abhay L. Deshpande> (SUNY Stony Brook)
Xiangdong Ji (University of Maryland), *Co-Chair*
Cynthia Keppel (Hampton University)
Curtis Meyer (Carnegie-Mellon University)
Zein-Eddine Meziani (Temple University), *Co-Chair*
John Negele (MIT)
Jen-Chieh Peng (Illinois)

Phases of QCD Matter Town Meeting:

Peter Jacobs (Lawrence Berkeley National Laboratory), *Co-Chair*
Dima Kharzeev (BNL)
Berndt Mueller (Duke University), *Co-Chair*
Jamie Nagle (Colorado)
Krishna Rajagopal (MIT)
Steve Vigdor (Indiana)

Organizers

- Simon Capstick (Florida State University)
  Lawrence S. Cardman (Jefferson Lab)
  Abhay L. Deshpande (SUNY Stony Brook)
  Xiangdong Ji (University of Maryland), *Co-Chair*
  Cynthia Keppel (Hampton University)
  Curtis Meyer (Carnegie-Mellon University)
  Zein-Eddine Meziani (Temple University), *Co-Chair*
  John Negele (MIT)
  Jen-Chieh Peng (Illinois)

- Number of registered participants: 112

Schedule

- Jan. 12,
  - Hadron structure at short distance

    Qiu, Chen, Makins, Vanderhaeghen
  - Hadron structure at long distance

    Arrington, Cates, Phillips, Griesshammer, Weller
  - Nuclear physics at short distance

    Geesaman, Ransome, Brooks, Owens, Reinhold

Schedule continues

- Jan. 13, Joint session with phases of QCD matter
  - JLab 12 GeV upgrade and RHIC II upgrade

    Thomas, Zajc
  - International opportunities

    Wyslouch, Henning, Saito
  - QCD theory

    Kaplan, Negele
  - Electron-Ion Collider

    Kovchegov, Vogelsang, Surrow, Ent, Merminga

Schedule continues

- Jan. 14,
  - Hadron spectroscopy

    Barnes, Dudek, Dzierba, Burkert, Lee, Crede
  - Hadron physics theory

    Steward, Szczpaniak, Orginos
  - Education and outreach

    Cizewski
  - Discussion of priority and recommendations

Key questions in hadron physics

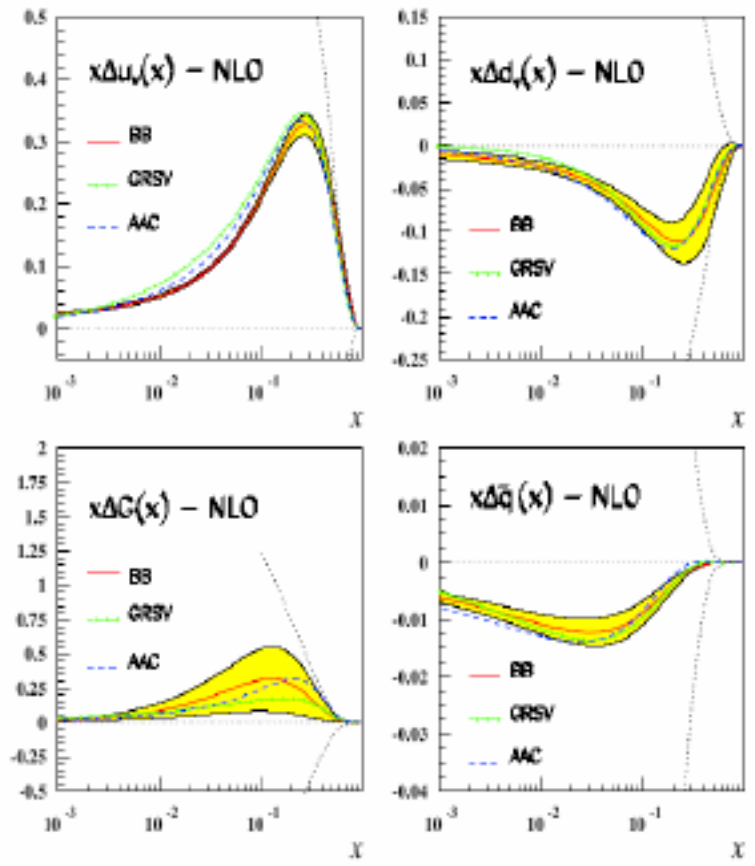
- What is the role of gluons in the nucleon and nuclei?
- What is the internal spin and flavor landscape of hadrons?
- How do hadron final states emerge from QCD quarks and gluons in high-energy scattering?
- What are the effective degrees of freedom describing hadron spectroscopy?
- What happen to the nucleons at short distance in a nucleus?

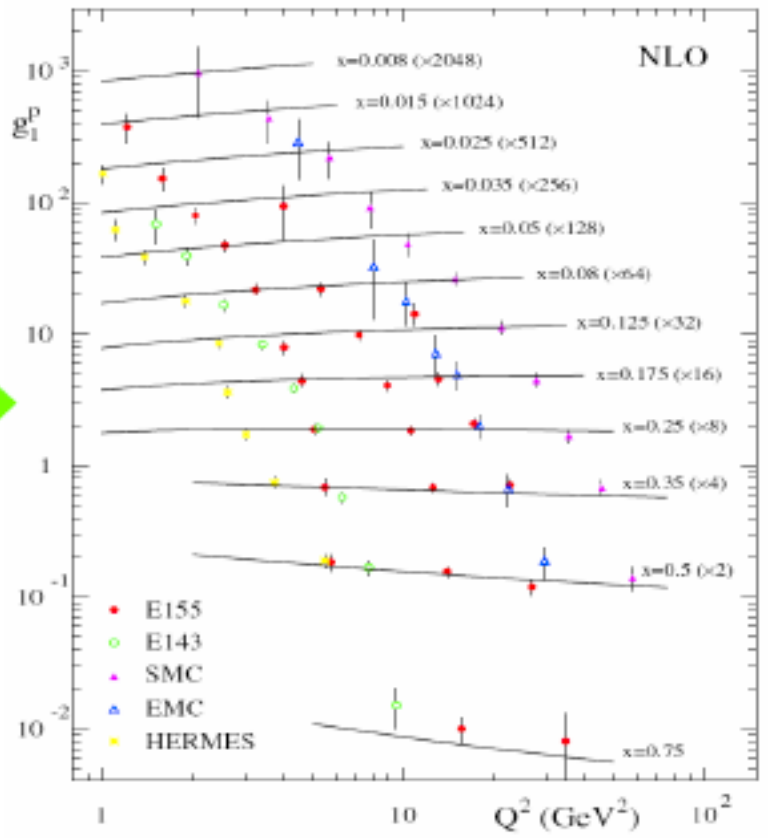
Accomplishment (since last long range plan)

- Hadron structure at short distance
  - Sea quark at large-x
  - Generalized parton distributions
  - Transverse-momentum-dependent distributions
  - Spin physics at RHIC
- Hadron strucure at long distance
  - Strange form factor
  - Electromagnetic form factors
- Spectroscopy
- Nuclear Physics at short distance
- Theory

Spin-dependent PDFs of a proton

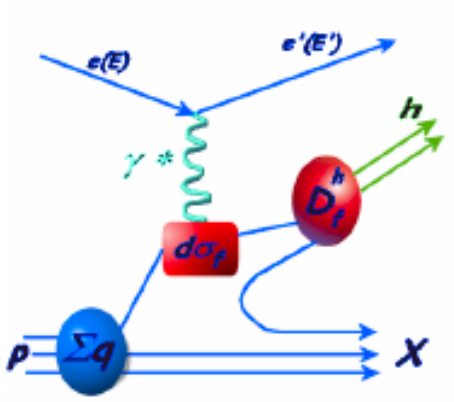
❖ DIS data on g1 + QCD global fits:

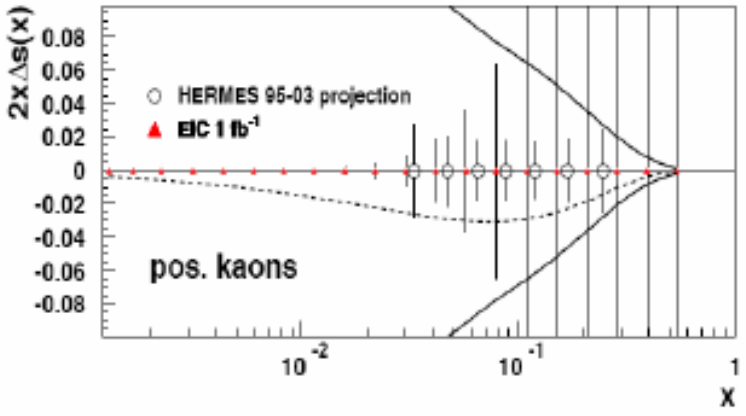


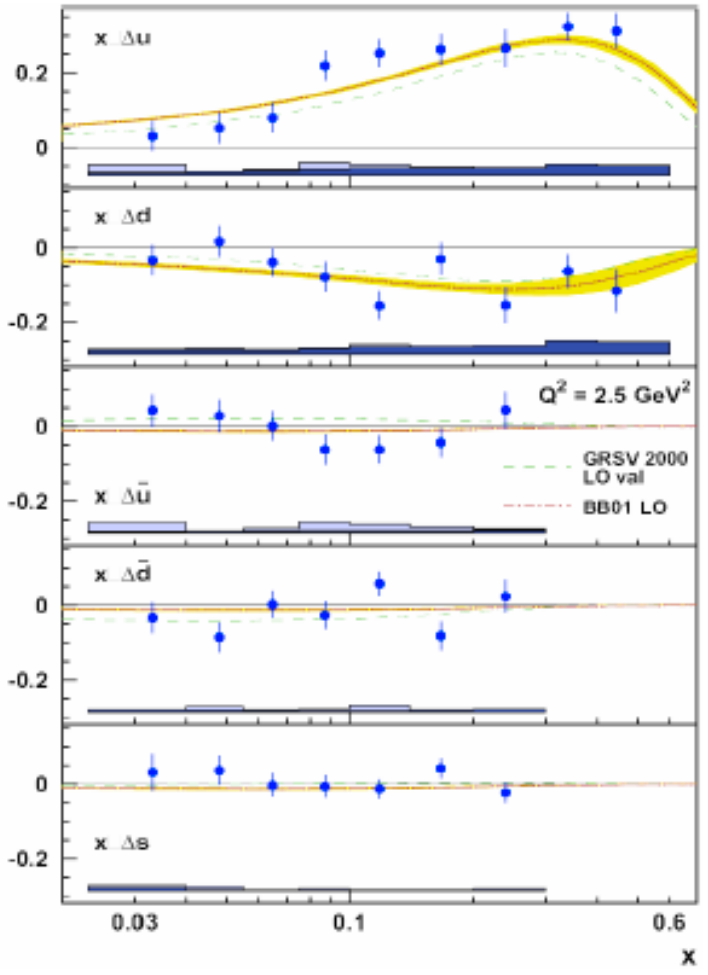


SIDIS at HERMES

❖ Hadron flavor tagging:

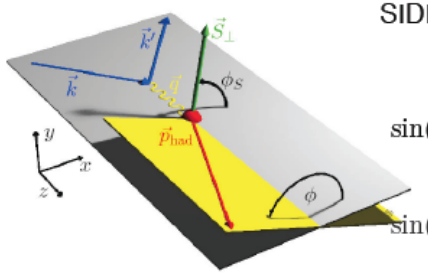






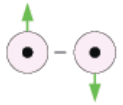
Transverse-momentum dependent parton distributions and fragmentations

Lepto-production: SIDIS with Transverse Target

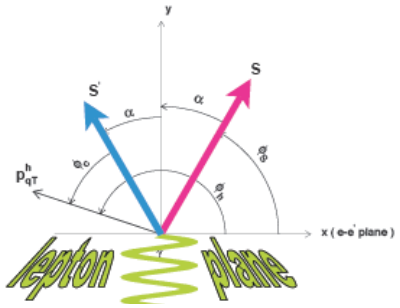


SIDIS xsec with *transverse target* polarization has ***two*** similar terms:

$\sin(\phi_h^l + \phi_S^l) \Rightarrow h_1 =$  $\otimes H_1^\perp =$ 

$\sin(\phi_h^l - \phi_S^l) \Rightarrow f_{1T}^\perp =$  $\otimes D_1 =$ 

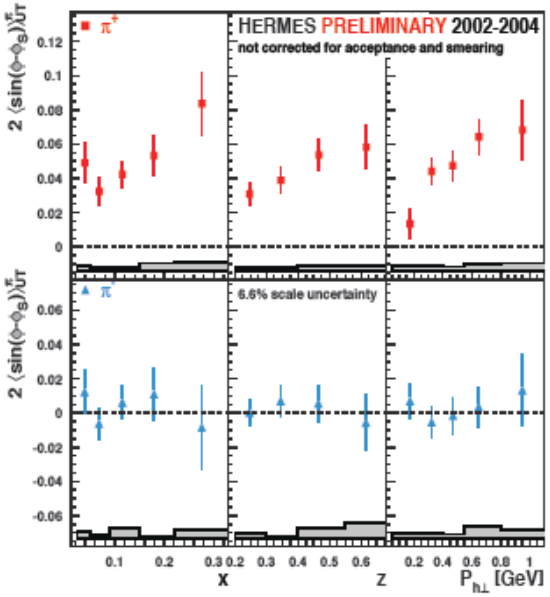
seperate Sivers and Collins mechanisms

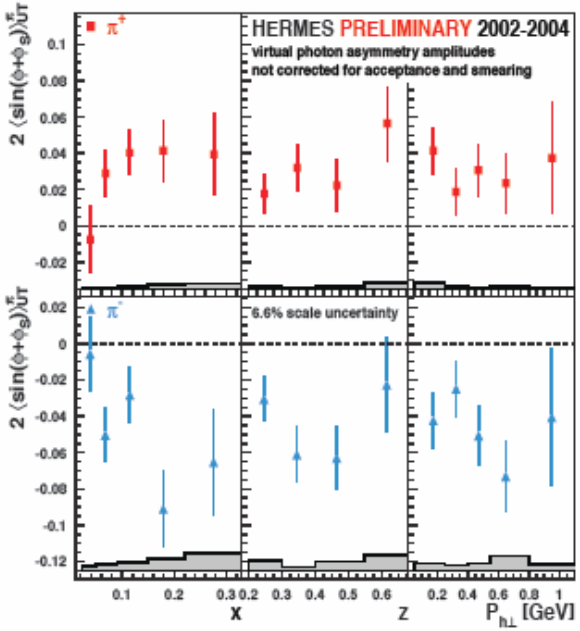


- $(\phi_h^l - \phi_S^l)$ = angle of hadron relative to **initial** quark spin
- $(\phi_h^l + \phi_S^l) = \pi + (\phi_h^l - \phi_S^{l'}) =$ hadron relative to **final** quark spin

N.C.R. Makins, QCD and Hadron Physics, Rutgers Univ, Jan 12-14, 2007

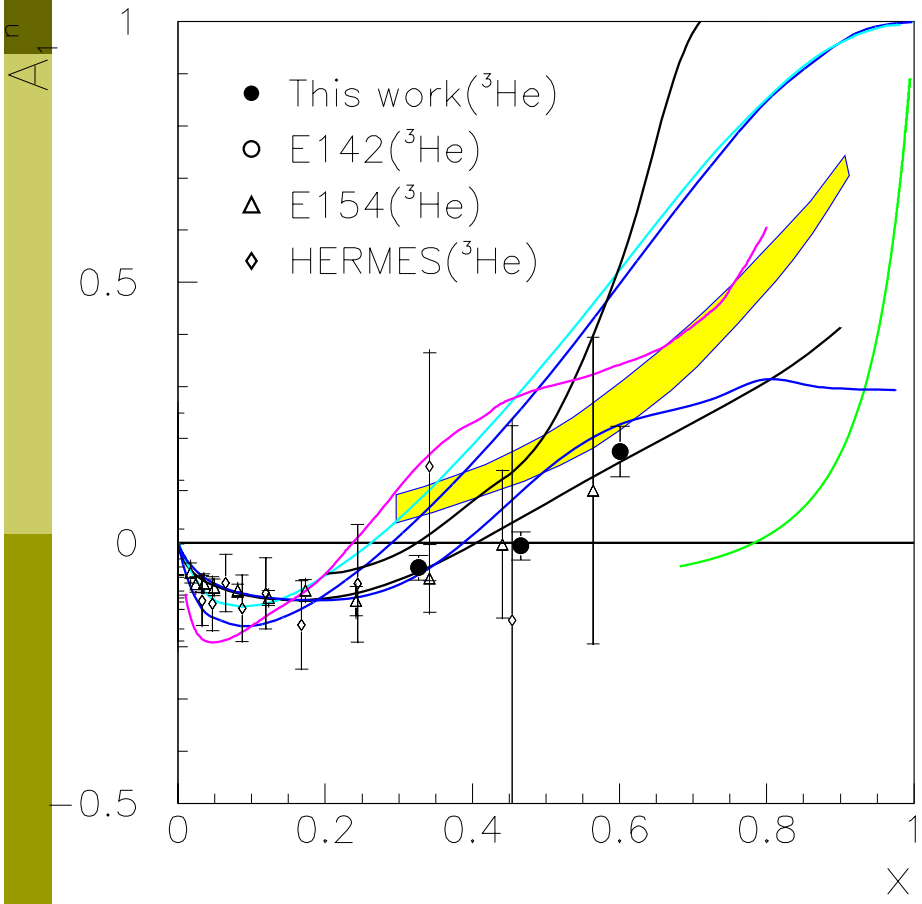
Sivers Asymmetry

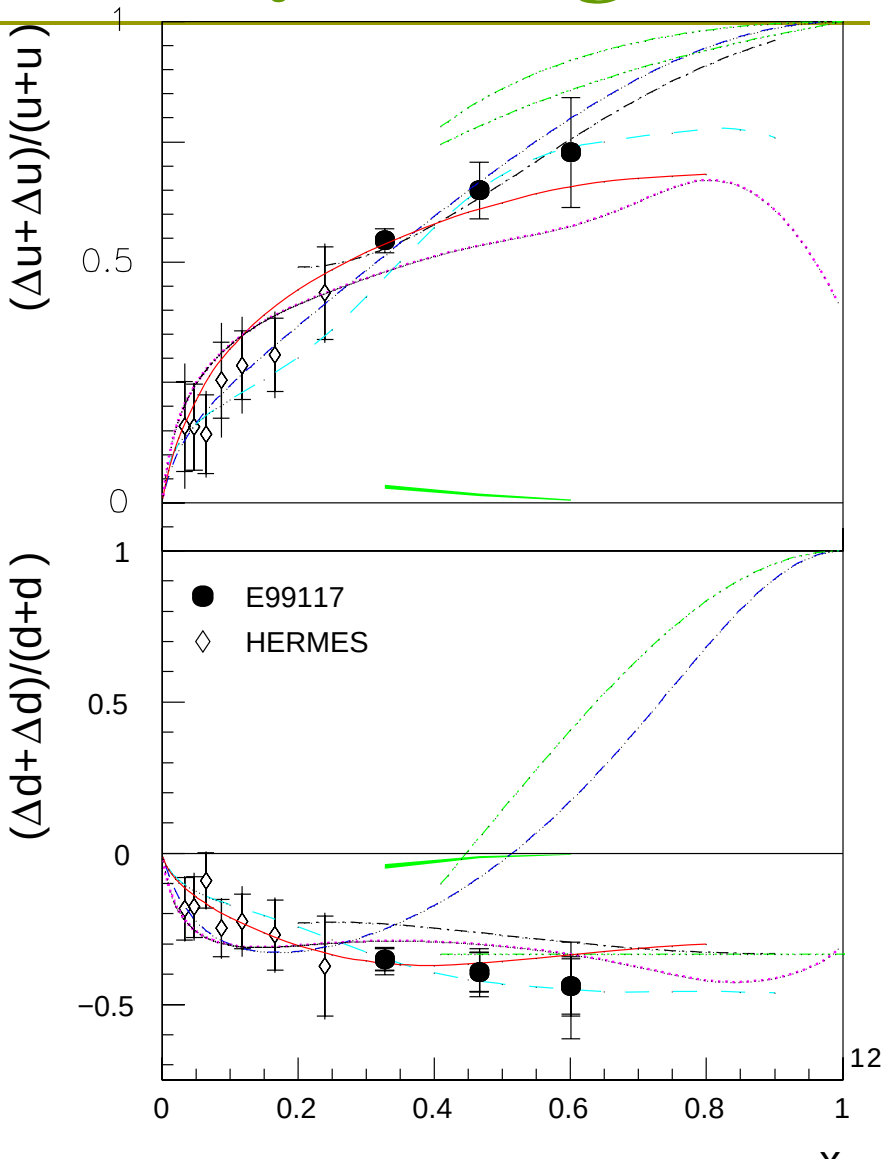




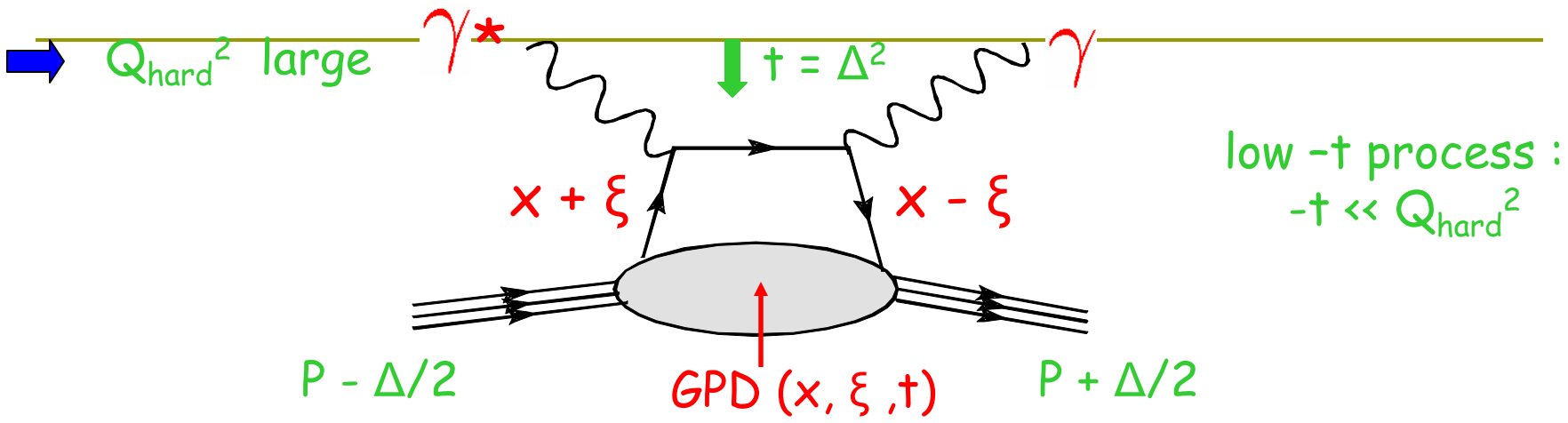
Collins Asymmetry

Neutron spin asymmetry at large x





Generalized Parton Distributions



$(x + \xi)$ and $(x - \xi)$: longitudinal momentum fractions of quarks

➡ at large Q^2 : QCD factorization theorem ➡ hard exclusive process can be described by 4 transitions (GPDs) :

Vector : $H(x, \xi, t)$ **Axial-Vector** : $\tilde{H}(x, \xi, t)$

Tensor : $E(x, \xi, t)$ **Pseudoscalar** : $\tilde{E}(x, \xi, t)$

DVCS on neutron

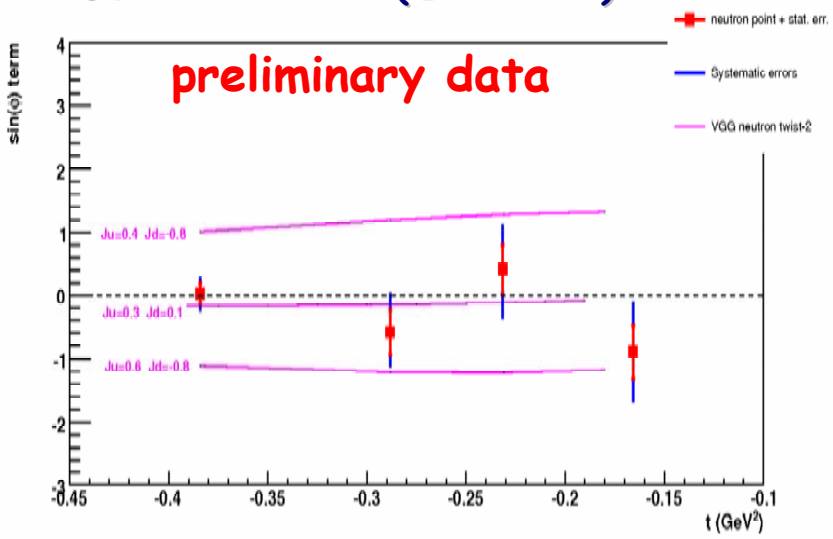
$$C_n^I(\mathcal{F}) = F_1(t)\,\mathcal{H} + \xi\left(F_1(t)+F_2(t)\right)\tilde{\mathcal{H}} - \frac{t}{4M^2}F_2(t)\,\mathcal{E}$$

0 because $F_1(t)$ is small

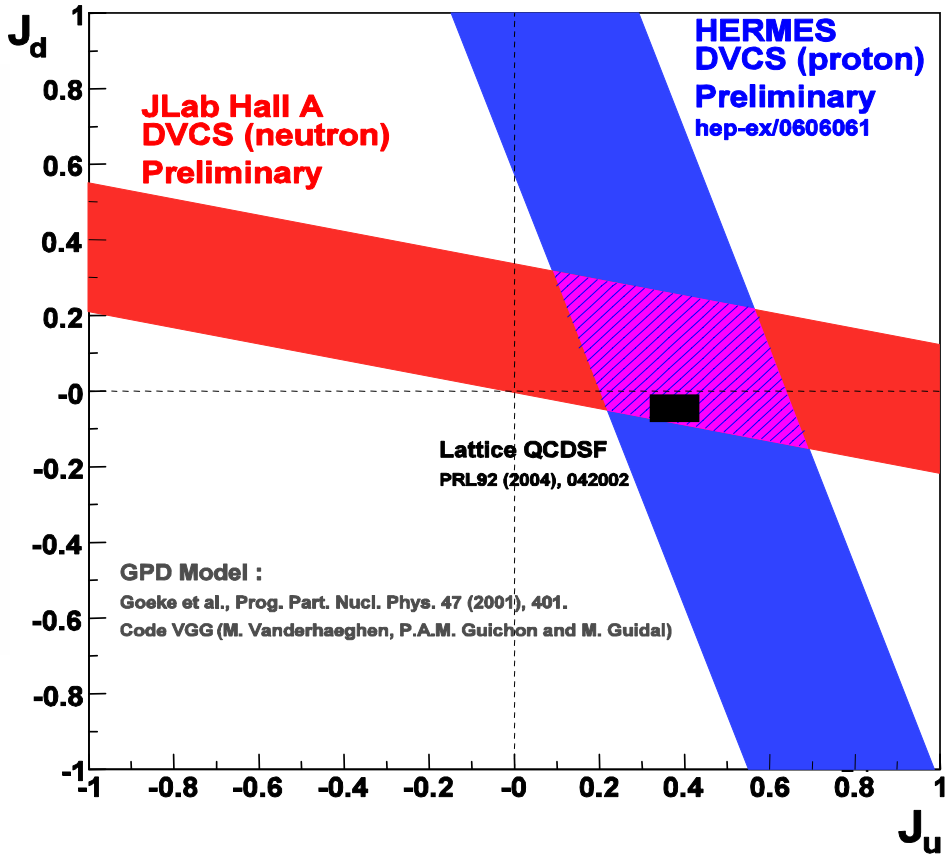
0 because of cancelation of u and d quarks

n-DVCS gives access to the least known and constrained GPD, E

JLab / Hall A (E03-106) :



Voutier, thesis M. Mazouz (Grenoble)



Spin-dependent gluon distribution

❖ Spin-dependent gluon distribution:

$$\Delta g(x) \;=$$  $$-$$

❖ Net gluon helicity:

$$\Delta G(Q^2) \;=\; \int_0^1 dx\, \Delta g(x, Q^2)$$

❖ Proton helicity sum rule:

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

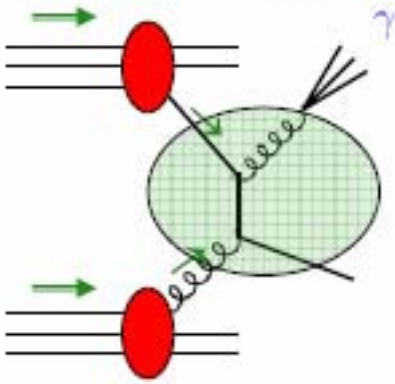
Covered by other talks

Extensive effort at RHIC, HERMES, COMPASS

Quark spin ≈ 0.1

EMC, SMC, E142-155, HERMES

Polarized hadronic collision - RHIC



$\gamma, \mathrm{jet(s)}, \pi^0, c\bar{c}, \ldots$

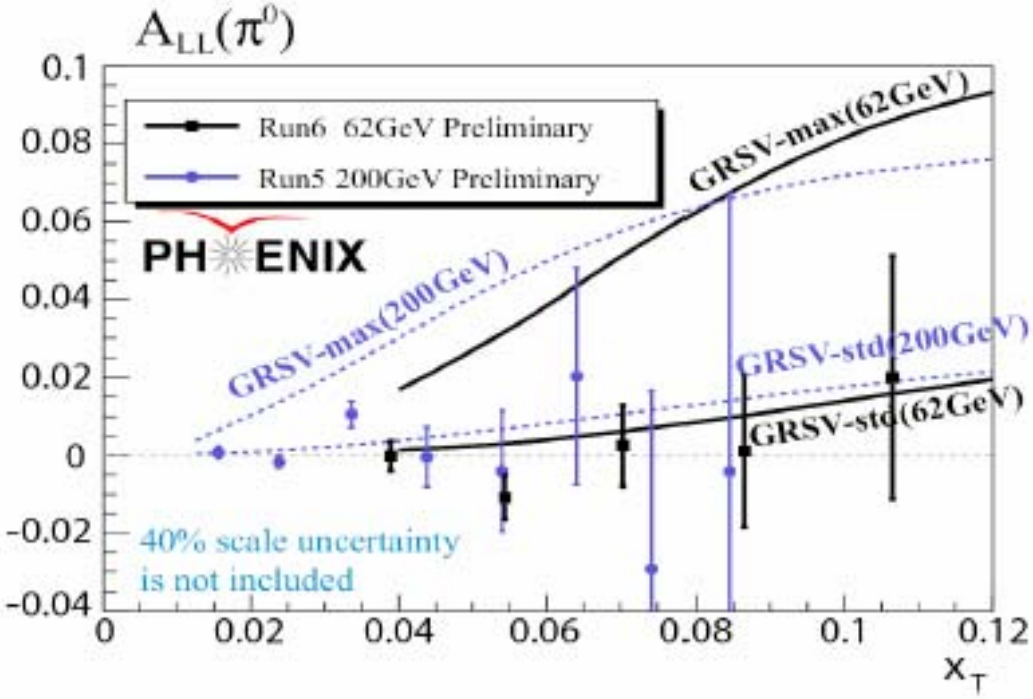
PHENIX, STAR

Very rich final states

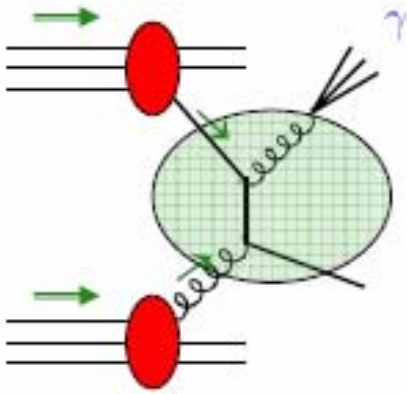
Variable collision energies

PHENIX - π^0

200, 62 GeV



Polarized hadronic collision - RHIC



$\gamma, \mathrm{jet(s)}, \pi^0, c\bar{c}, \ldots$

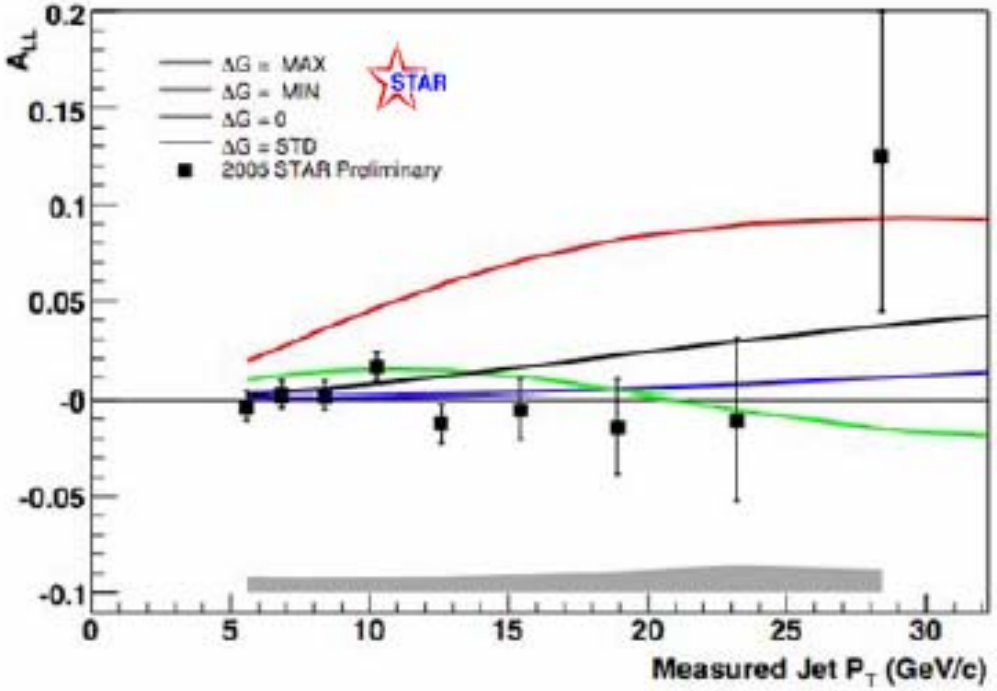
PHENIX, STAR

Very rich final states

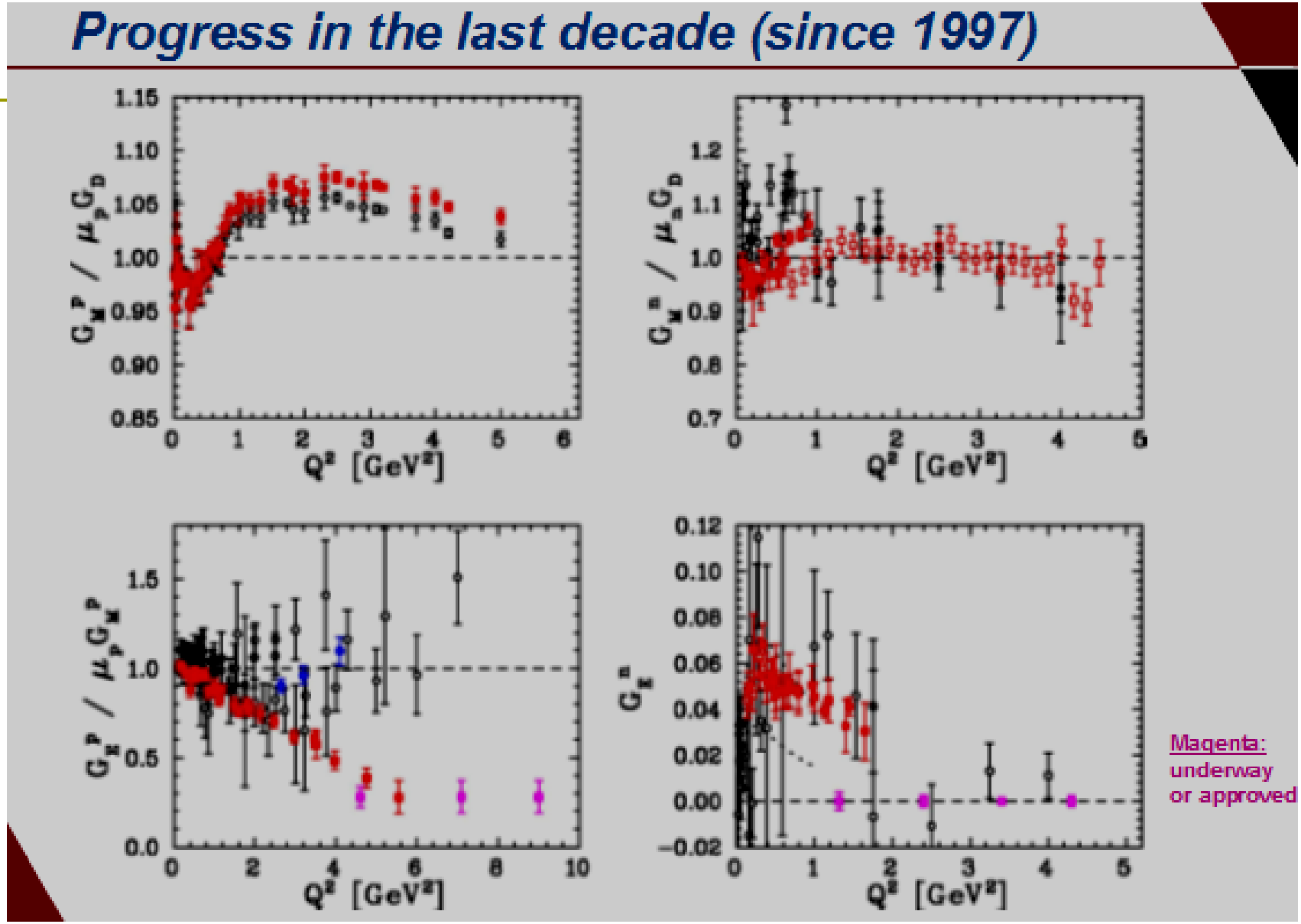
Variable collision energies

STAR – jets

200 GeV

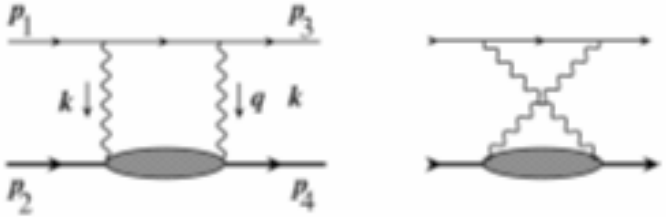


Nucleon form factors

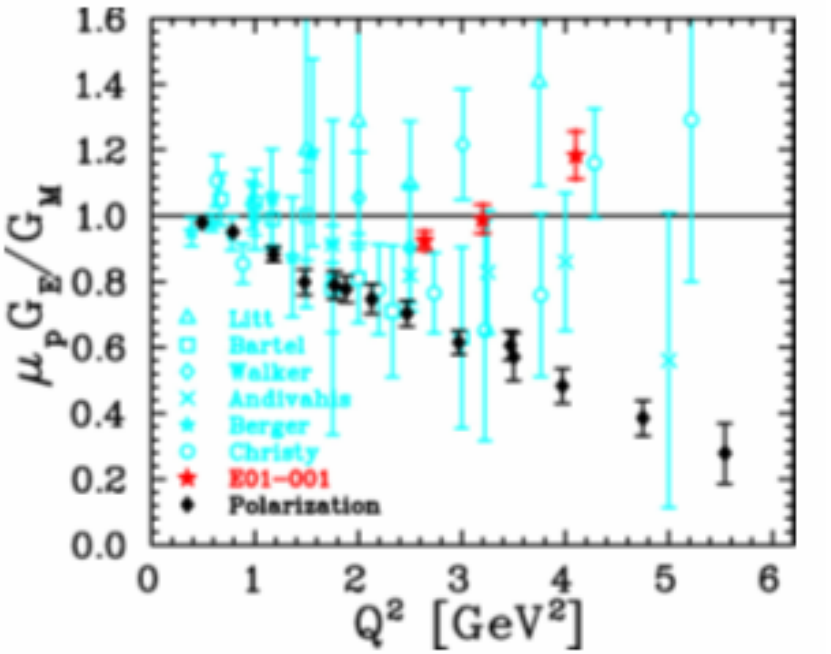


Two-Photon Exchange

- **Proton form factor measurements**
  - Comparison of precise Rosenbluth and Polarization measurements of G_{Ep}/G_{Mp} show clear discrepancy at high Q^2
- **Two-photon exchange corrections believed to explain the discrepancy**



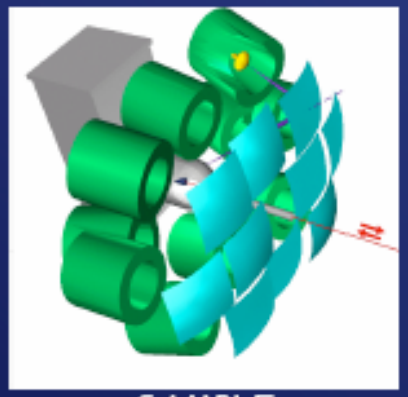
P.A.M.Guichon and M.Vanderhaeghen, PRL 91, 142303 (2003)



- **Compatible with e+/e- ?**
  - Yes: previous data limited to low Q^2 or small scattering angle
- **Still lack direct evidence of effect on cross section**
  - Beam normal spin asymmetry the only observable in elastic e-p where TPE observed

M.K.Jones, et al., PRL **84**, 1398 (2000)
O.Gayou, et al., PRL **88**, 092301 (2003)
I.A.Qattan, et al., PRL **94**, 142301 (2005)

experiments to measure strange form factors



SAMPLE

Open geometry, backward angle, integrating,

G_M^s and G_A at Q^2=0.1 GeV^2

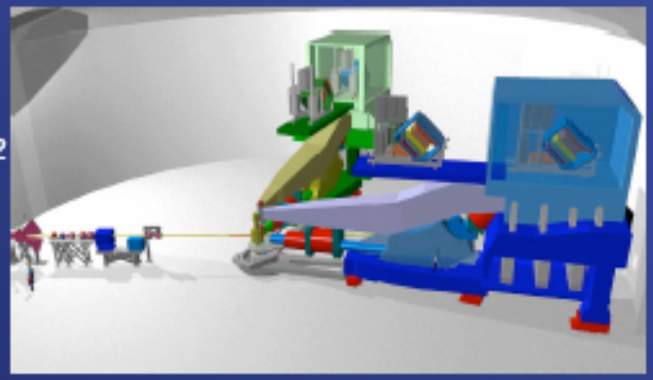
HAPPEX

forward angle, integrating,

$G_E^s + 0.39\ G_M^s$ at Q^2=0.48 GeV^2

$G_E^s + 0.08\ G_M^s$ at Q^2=0.1 GeV^2

G_E^s at Q^2=0.1 GeV^2 (^{4}He)



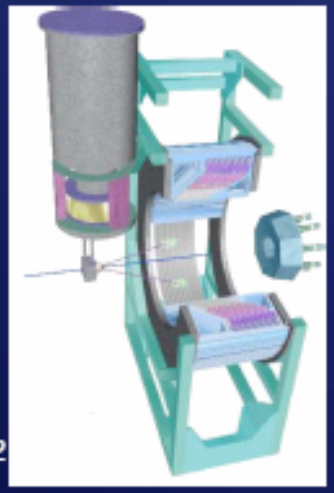
A4 (Mainz)

fast-counting calorimeter for background rejection

$G_E^s + 0.23\ G_M^s$ at Q^2=0.23 GeV^2

$G_E^s + 0.1\ G_M^s$ at Q^2=0.1 GeV^2

G_M^s, G_A at Q^2=0.1, 0.23, 0.5 GeV^2

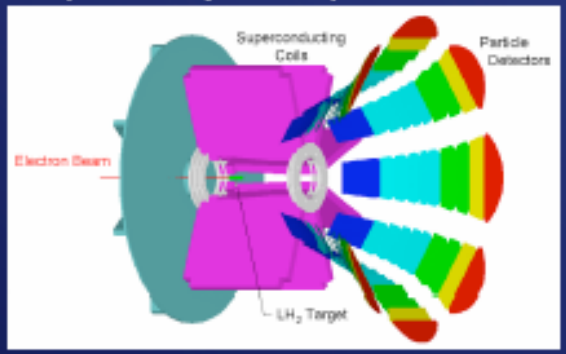


G0

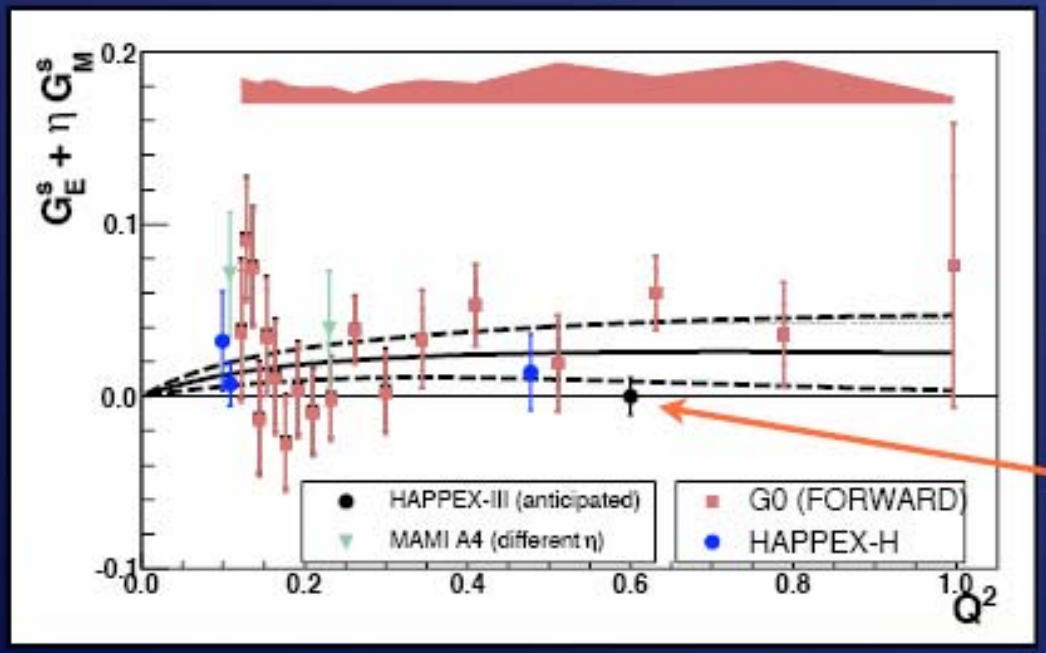
fast counting, open geometry with ToF for background rejection

$G_E^s + \eta\ G_M^s$ over Q^2=[0.12,1.0] GeV^2

G_M^s, G_A at Q^2= 0.23, 0.63 GeV^2



Current and future data on $G_E^s + \eta G_M^s$ at forward angles at all Q^2



Black line shows very simple naive fit.

Data are suggestive of positive values, but would be unlikely to convince a skeptic.

More Happex data are forthcoming at $Q^2 = 0.6$ GeV^2, (centered at zero). Not shown are upcoming back-angle data from both G0 and A4

New data at $Q^2 = 0.6$ GeV^2 should strongly constrain the higher Q^2 region.

CLAS Search for New Baryon States

reactions	beam pol.	target pol.	recoil	status
$\gamma p \to N\pi, p\eta, p\pi\pi, K\Lambda/\Sigma$	-	-	Λ,Σ	complete
$\gamma p \to p(\rho,\varphi,\omega)$	linear	-	-	complete
$\gamma p \to N\pi$, $p\eta$, $p\pi\pi$, $K\Lambda$	lin./circ.	long./trans.	Λ,Σ	2007
$\gamma D \to K\Lambda$, $K\Sigma$	circ./lin.	unpol.	Λ,Σ	2006/2009
$\gamma(HD) \to K\Lambda, K\Sigma, N\pi$	lin./circ.	long./trans.	Λ,Σ	2009/2010

This program will, for the first time, provide complete amplitude information on the $K\Lambda$ final state, and nearly complete information on the $N\pi$ final states.

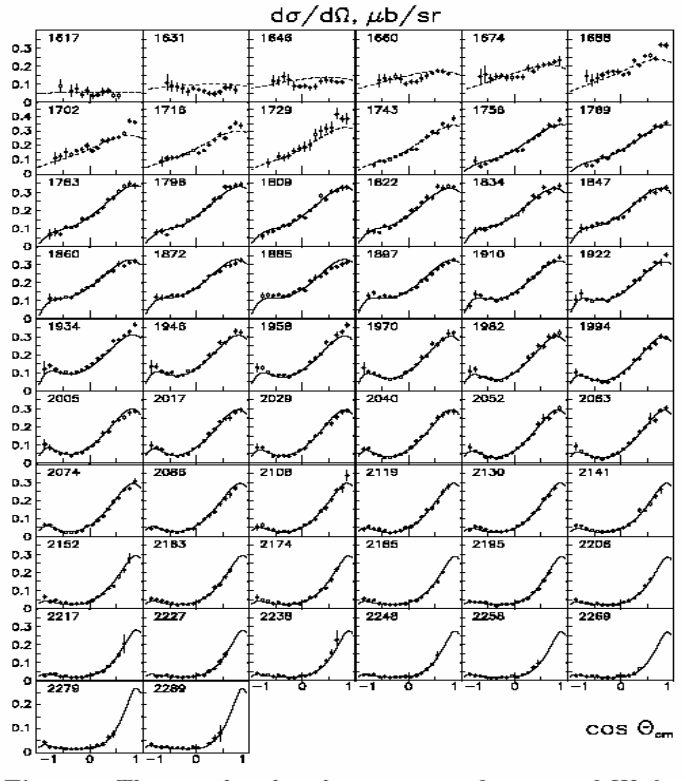
New N* states in $K\Lambda/K\Sigma$ production?

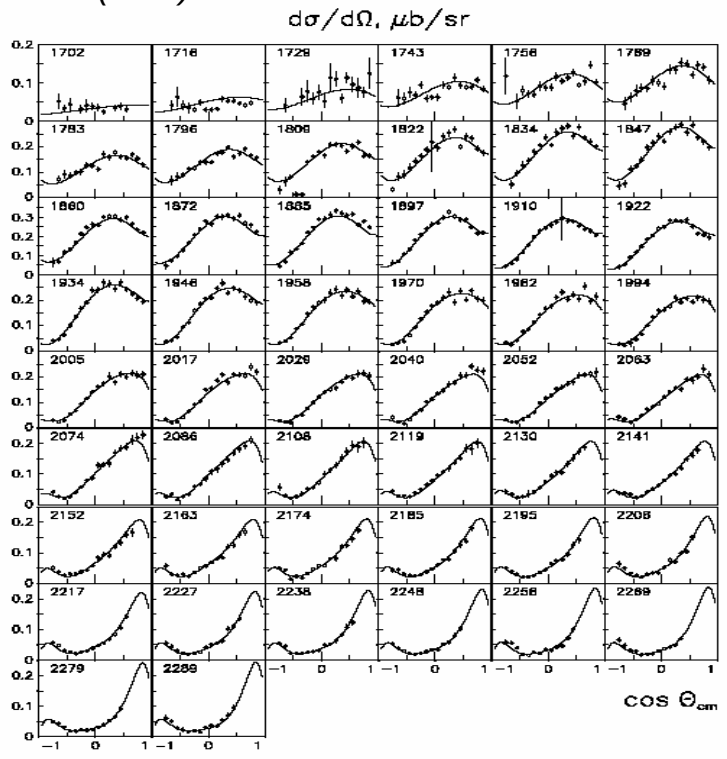
- PWA of data on $\gamma p \rightarrow K^+\Lambda, K^+\Sigma, K^0\Sigma^+$

A. Sarantsev et al.,
C. Bennhold, et al.,

J. McNabb et al, PRC69 (2004)

$K^+\Lambda$





$K^+\Sigma^0$

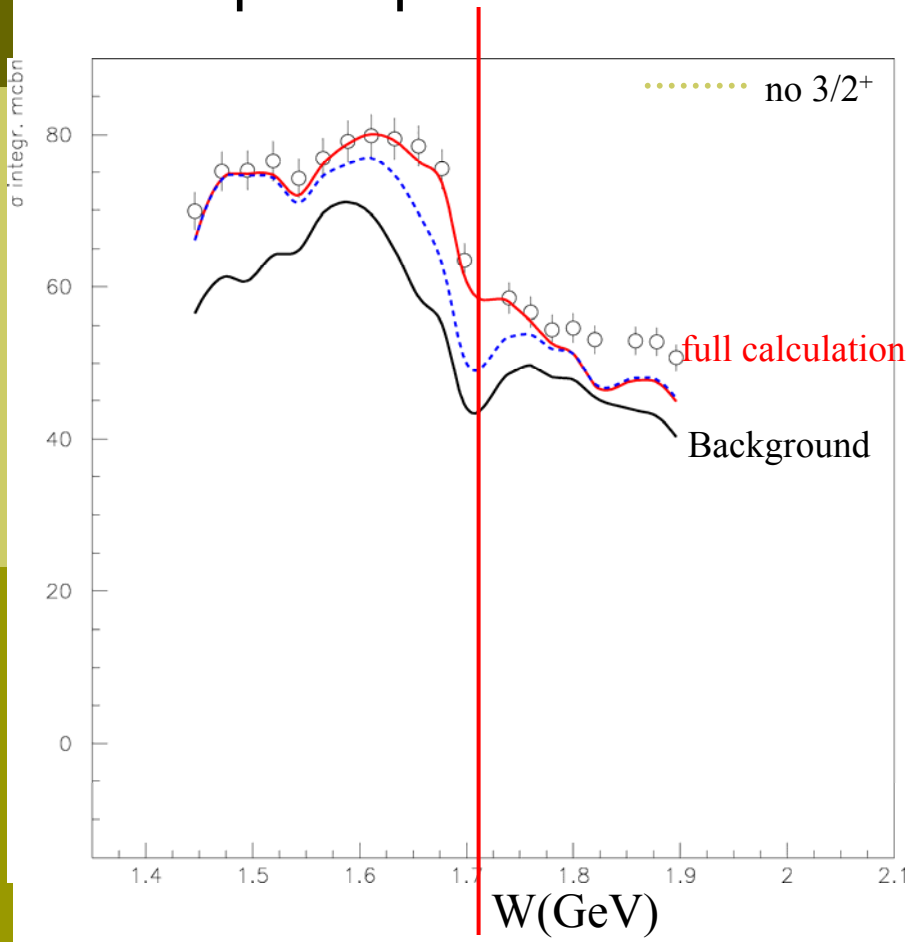
- Analyses find needs for various new candidate states.
- Solutions based on unpolarized cross sections alone have ambiguities; demonstrates the need for polarization measurements.

CLAS N* candidate at 1720 MeV in $p\pi^+\pi^-$?

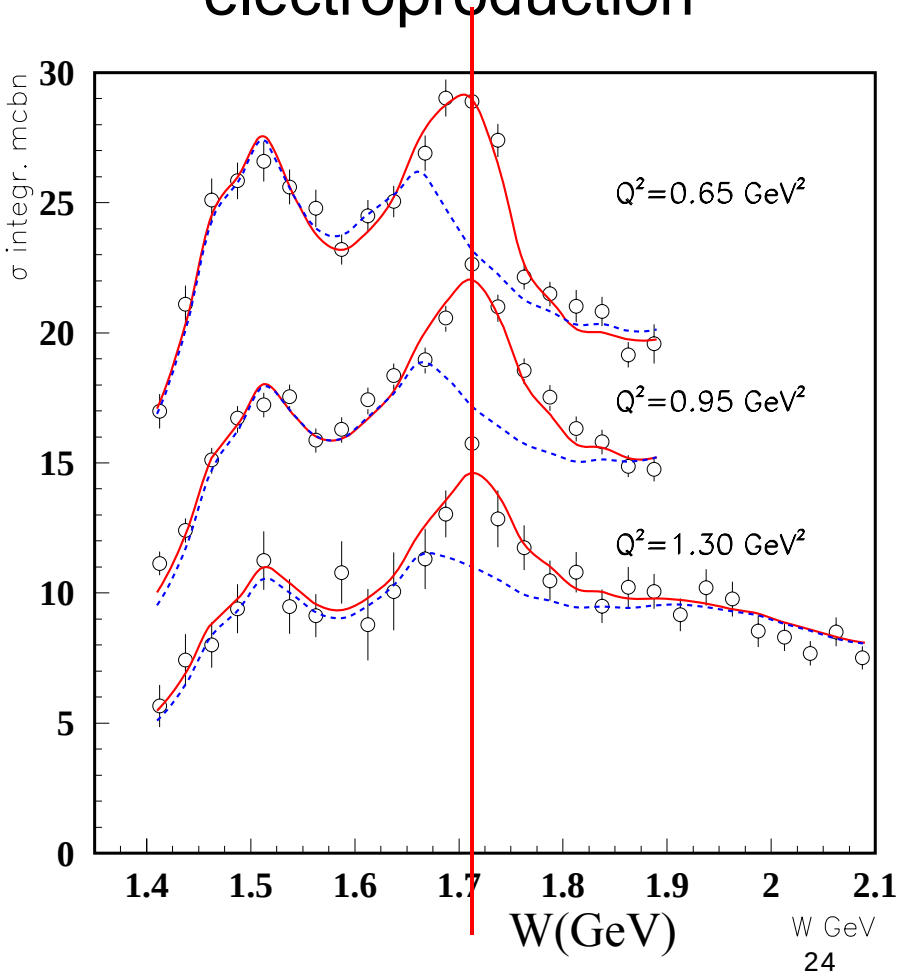
no $3/2^+$ (1720)

full

photoproduction



electroproduction



M. Ripani et al, Phys.Rev.Lett. 91, 2003

Nuclear Short Range Correlations

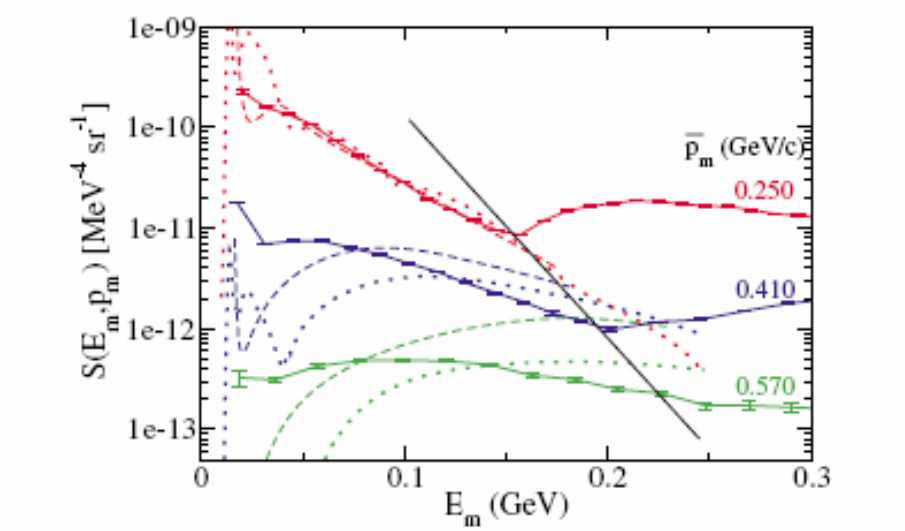


FIG. 3 (color online). Comparison of the experimental spectral function (solid) with the theories of Ref. [33] (dashed) and Ref. [28] (dotted) for three momentum bins. The line indicates the cut made to separate the correlated and resonance region.

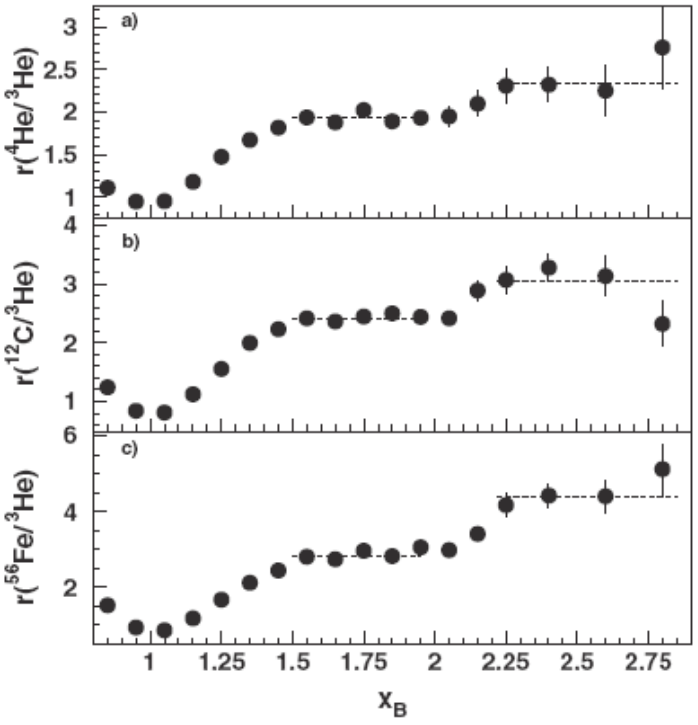


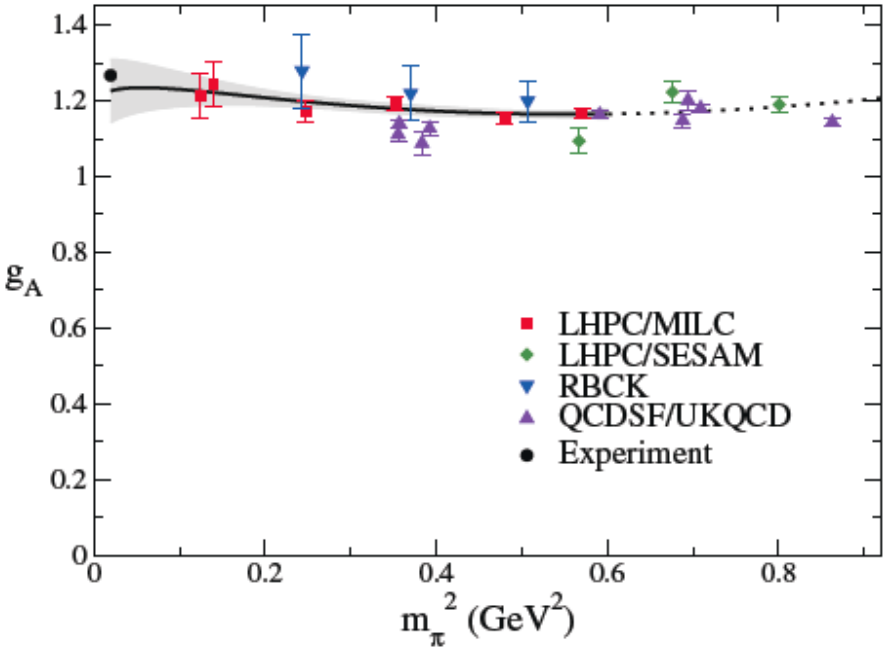
FIG. 1. Weighted cross section ratios [see Eq. (2)] of (a) ^{4}He, (b) ^{12}C, and (c) ^{56}Fe to ^{3}He as a function of x_B for $Q^2 > 1.4$ GeV^2. The horizontal dashed lines indicate the NN ($1.5 < x_B < 2$) and $3N$ ($x_B > 2.25$) scaling regions.

Rohe et al. PRL 93, 182501 (04)

Egiyan et al, PRL, (06)

Lattice QCD

Axial Coupling (present)

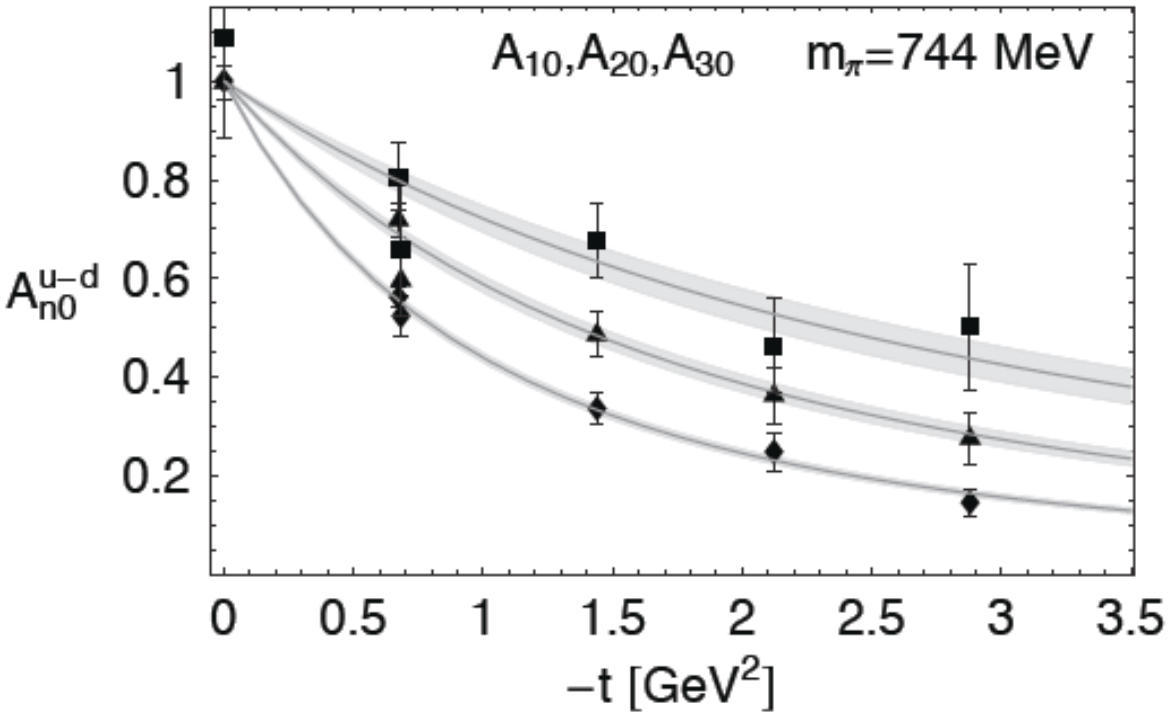


- Large volumes

Cost: ~ 1Tflop-year

- Lighter pion masses
- $g_A(m_\pi=140\text{MeV}) =$ 1.23(8)

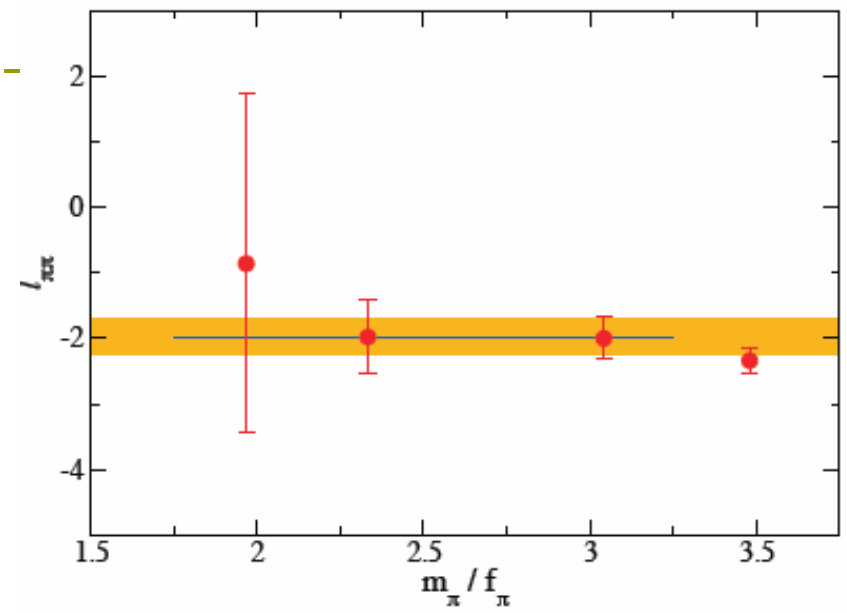
Moments of Generalized Parton Distributions [LHPC 2003]

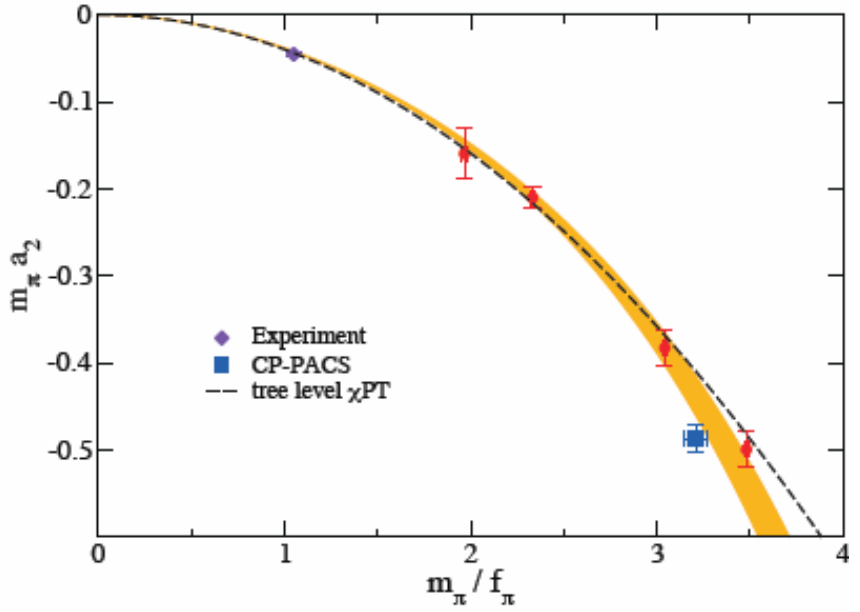


- Heavy dynamical quarks
- Slope at small t decreases as we go to higher moments
- Higher moments dominated by higher x

I=2 Pion Scattering

NPLQCD





$$m_\pi a_2 = -\frac{m_\pi^2}{8\pi f_\pi^2}\left[1 + \frac{3m_\pi^2}{16\pi^2 f_\pi^2}\left(\log\frac{m_\pi^2}{\mu^2} + l_{\pi\pi}(\mu)\right)\right]$$

[Gasser-Leutwyler '84]
[Colangelo et al. '01]

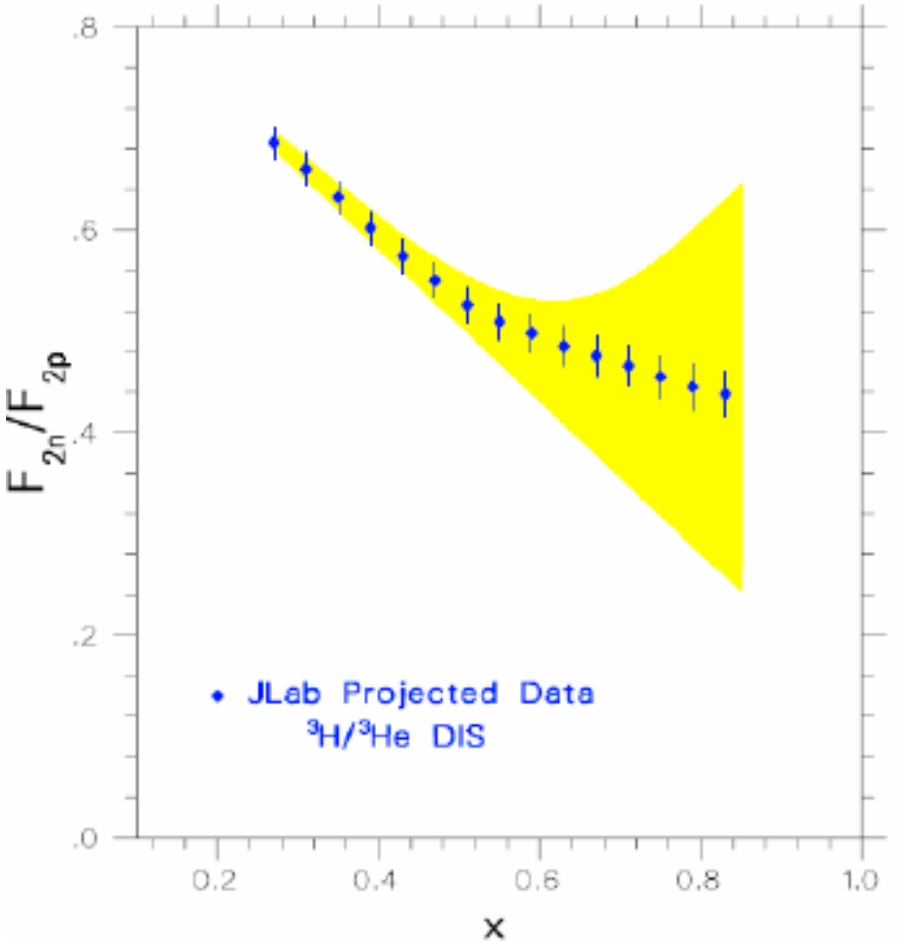
- $m_\pi a_2 = -0.0422(3)(18)$
- Experiment: $m_\pi a_2 = -0.0454(31)$
- SχPT has insignificant effect to the result [Chen et al. '05]

Opportunities

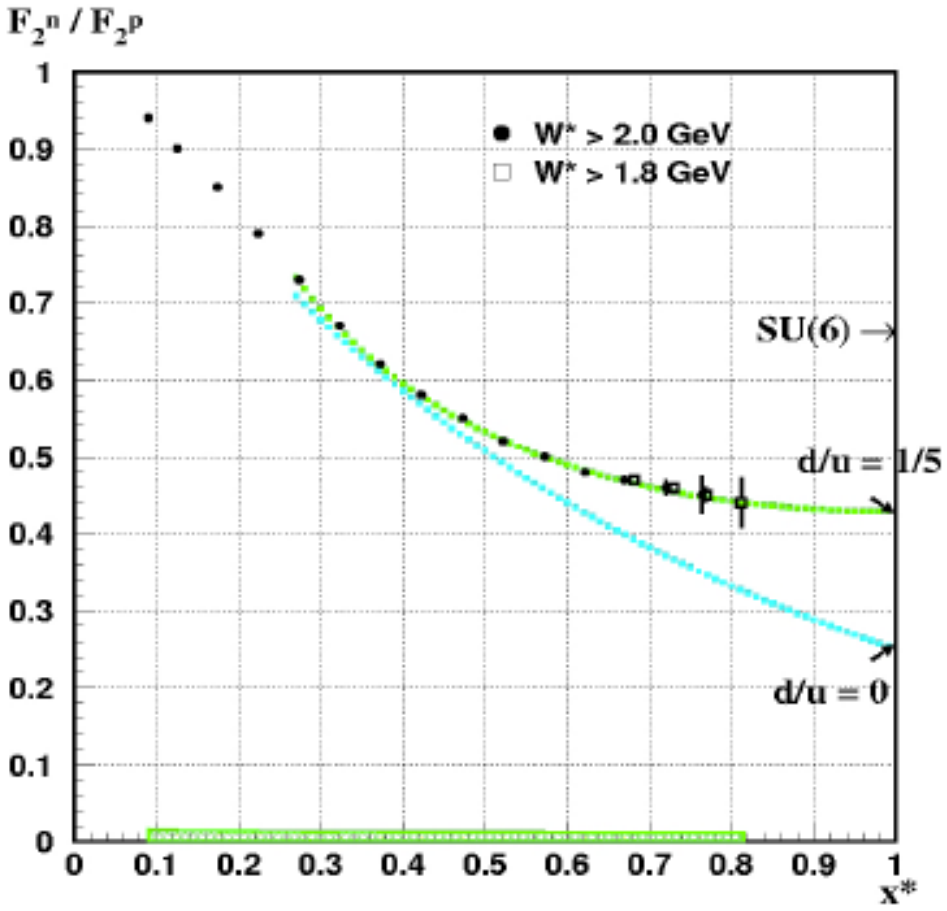
- 12 GeV upgrade
- EIC
- International Collaboration
- Theory

12 GeV : Unambiguous Flavor Structure x→ 1

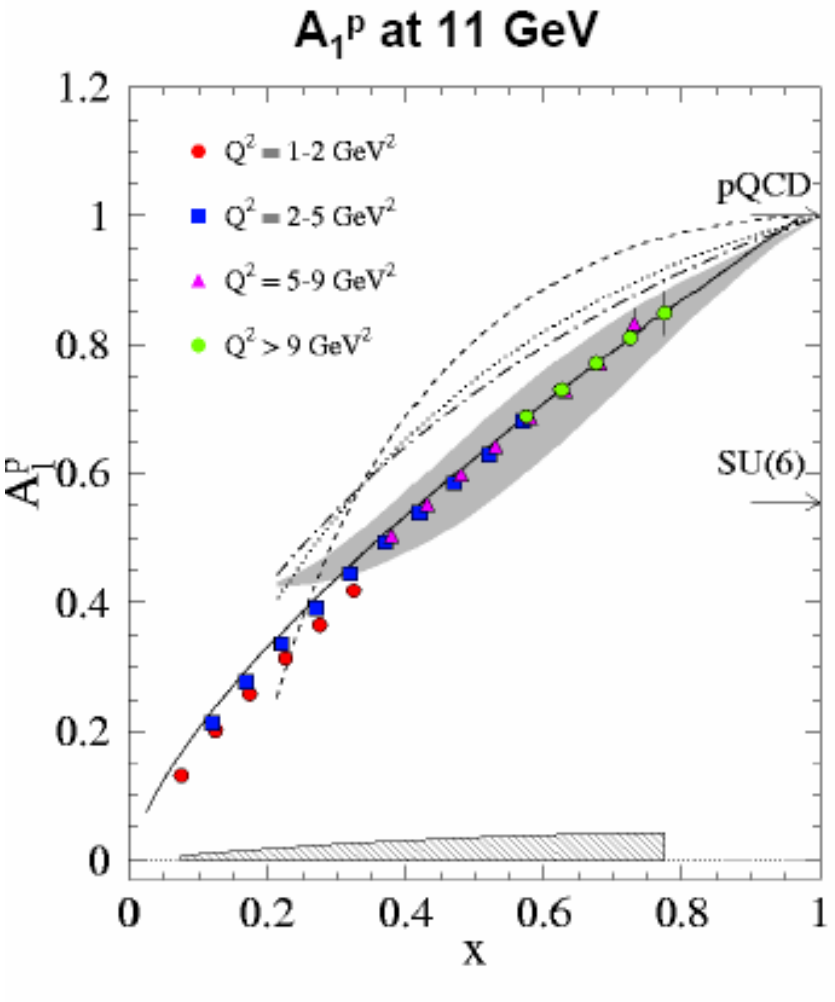
Hall A 11 GeV with HMS

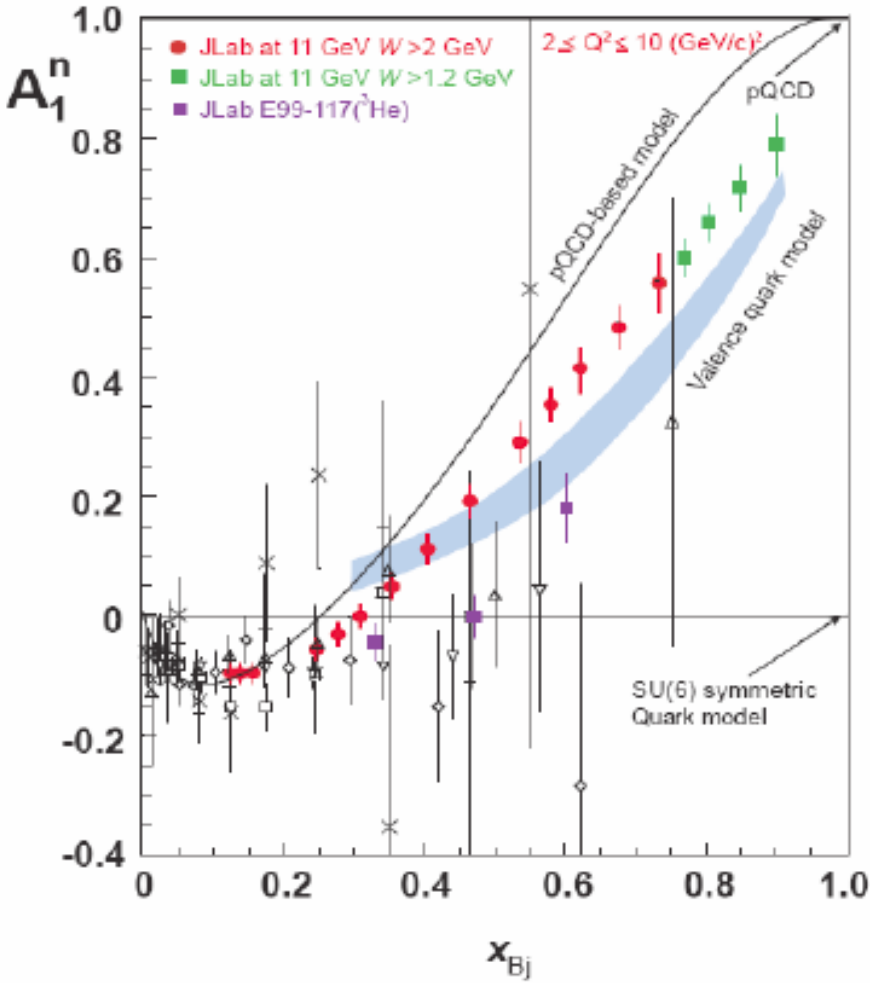


Hall B 11 GeV with CLAS12



12 GeV : Unambiguous Resolution of Valence Spin





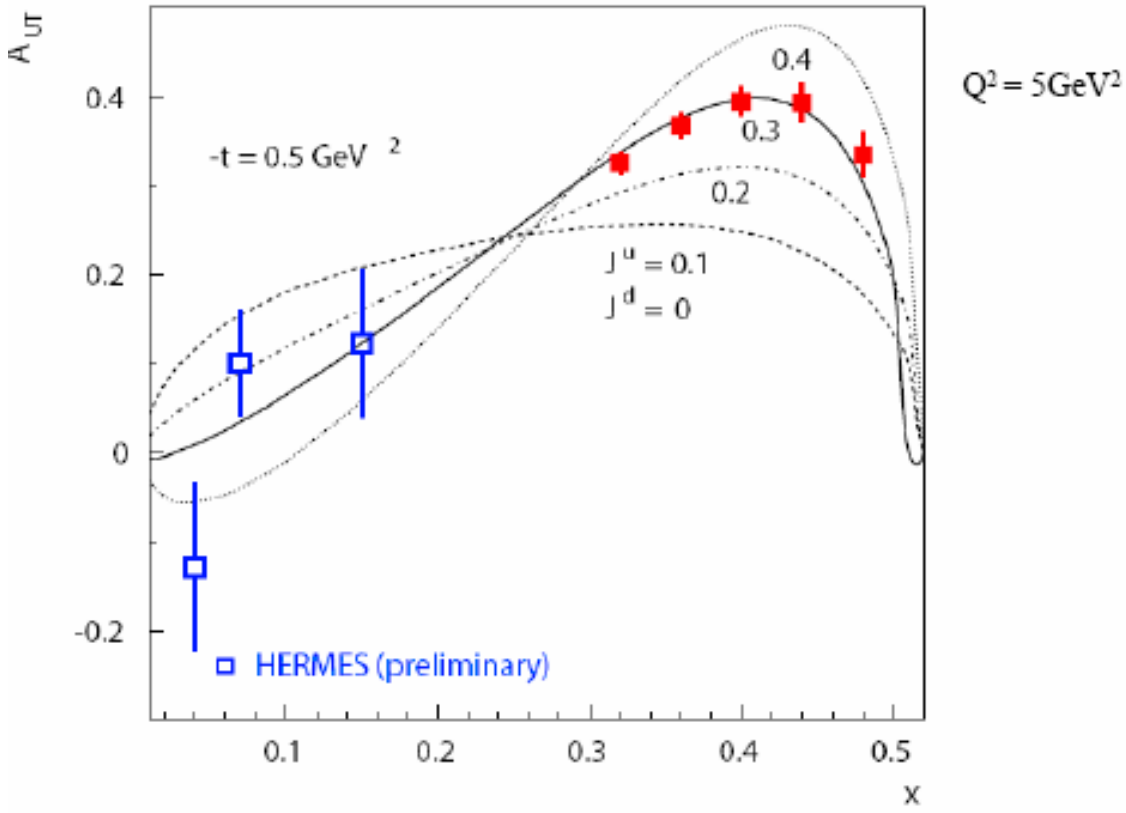
At 12 GeV: Exclusive ρ^0 with transverse target

$$A_{UT} = - \frac{2\Delta\,(\mathrm{Im}(AB^*))/\pi}{|A|^2(1-\xi^2) - |B|^2(\xi^2+t/4m^2) - \mathrm{Re}(AB^*)2\xi^2}$$

ρ^0

$A \sim (2H^u + H^d)$

$B \sim (2E^u + E^d)$

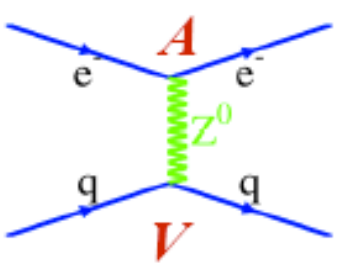


$Q^2 = 5\mathrm{GeV}^2$

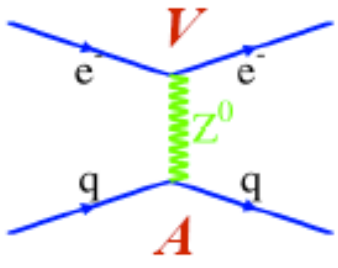
Asymmetry depends linearly on the GPD E, which enters Ji's sum rule.

K. Goeke, M.V. Polyakov, M. Vanderhaeghen, 2001

Electron-Quark Phenomenology



$C_{1i} \equiv 2 g_A^e g_V^i$



$C_{2i} \equiv 2 g_V^e g_A^i$

$$C_{1u} = -\tfrac{1}{2} + \tfrac{4}{3}\sin^2(\theta_W) \approx -0.19$$
$$C_{1d} = \tfrac{1}{2} - \tfrac{2}{3}\sin^2(\theta_W) \approx 0.35$$
$$C_{2u} = -\tfrac{1}{2} + 2\sin^2(\theta_W) \approx -0.04$$
$$C_{2d} = \tfrac{1}{2} - 2\sin^2(\theta_W) \approx 0.04.$$

C_{1u} and C_{1d} will be determined to high precision by APV and Qweak

C_{2u} and C_{2d} are small and poorly known: can be accessed in PV DIS

New physics such as compositeness, new gauge bosons:

Deviations in C_{2u} and C_{2d} might be fractionally large

Proposed JLab upgrade experiment will permit increase in precision of measurement of $2C_{2u}$-C_{2d} by more than a factor of 20

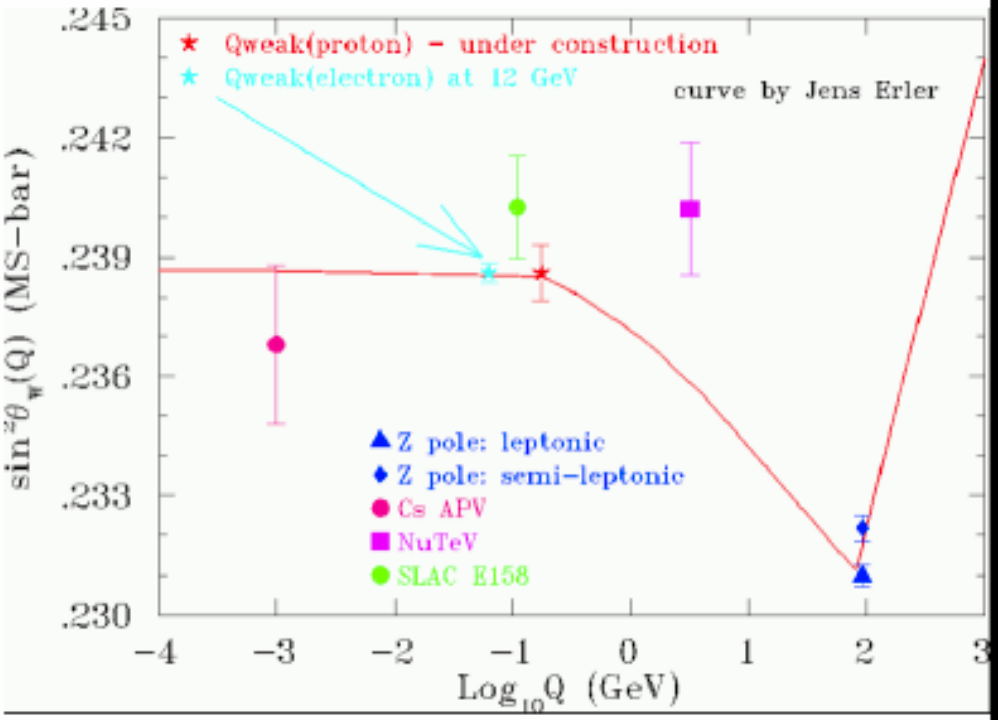
Future Möller Experiment at 12 GeV

Appears feasible to measure $\sin^2 \theta_W$ to $\pm$ 0.0002

Consensus Statement from December 2006 Workshop:

"There was overwhelming enthusiasm to aggressively proceed with the design of such an experiment"

"unique sensitivity to properties of new physics phenomena such as R-parity violating SUSY"

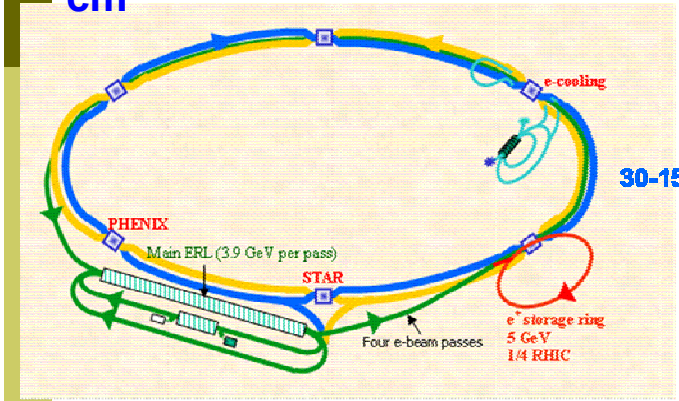


Proposed EIC Designs

eRHIC

$L = 2.6 \times 10^{33}\ cm^{-2}s^{-1}$

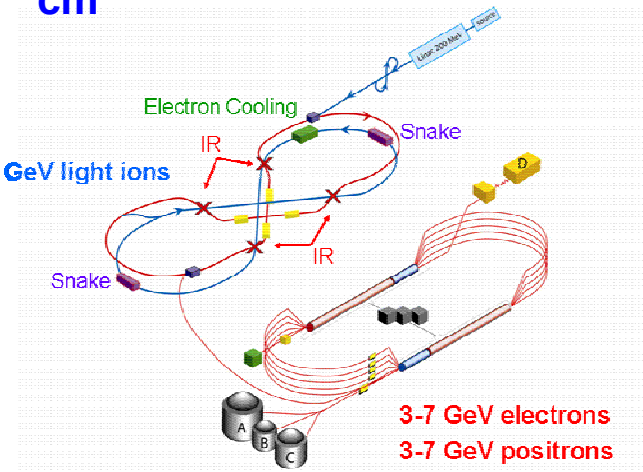
$E_{cm} = 140$ GeV



ELIC

$L = 7.7 \times 10^{34}\ cm^{-2}s^{-1}$

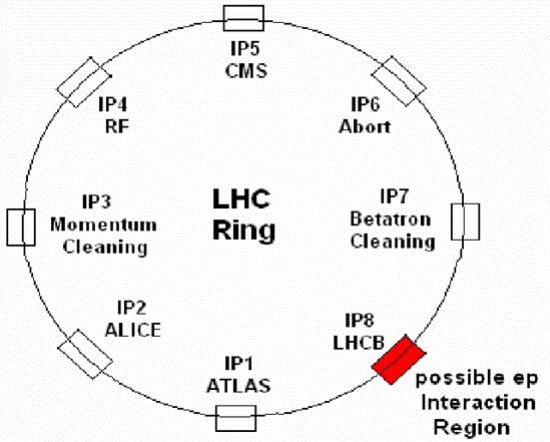
$E_{cm} = 65$ GeV



LHeC

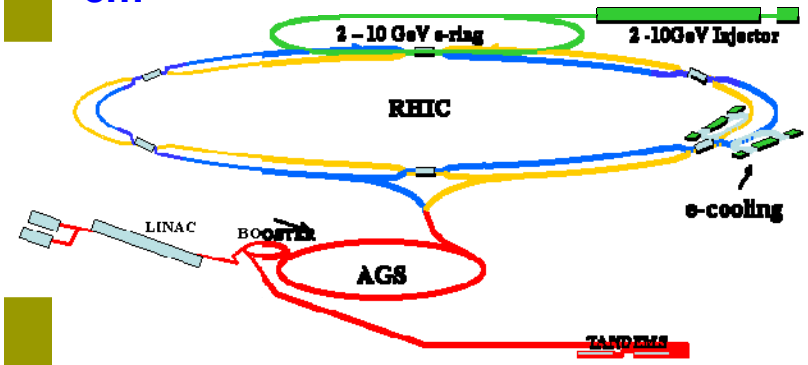
$L = 1.1 \times 10^{33}\ cm^{-2}s^{-1}$

$E_{cm} = 1.4$ TeV



$L = 0.47 \times 10^{33}\ cm^{-2}s^{-1}$

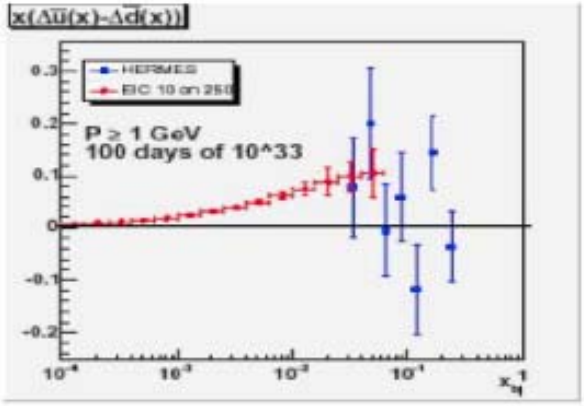
$E_{cm} = 100$ GeV

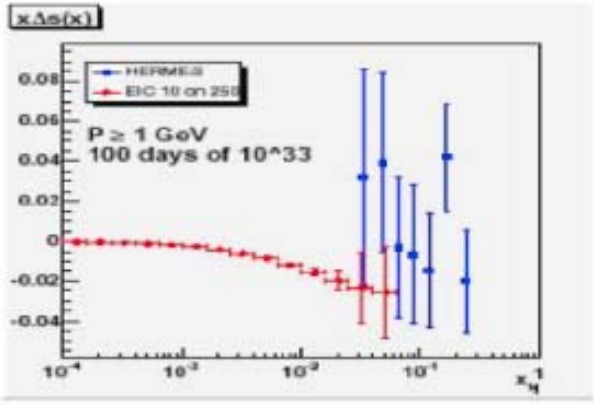


Luminosities are for e-p collisions

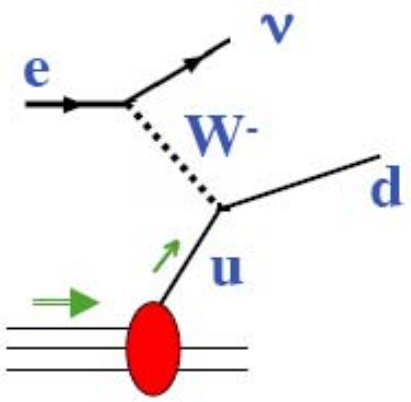
EIC:

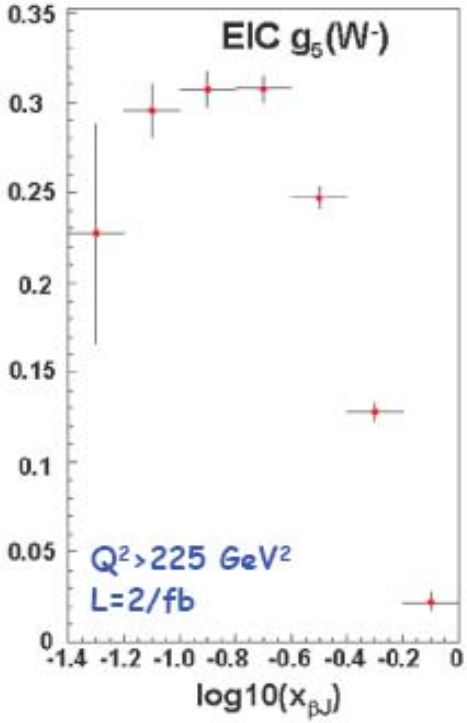
J. Seele





- also, at EIC:



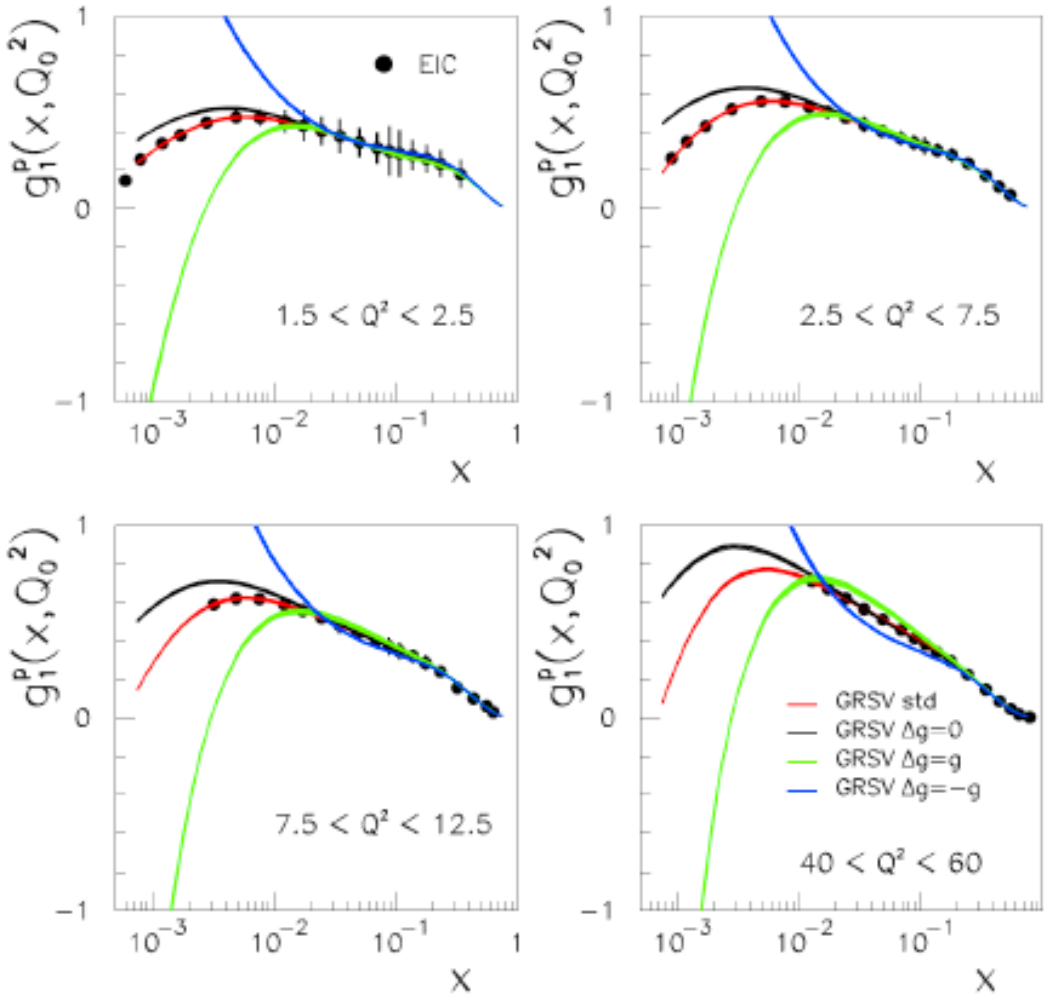


$$g_5 \propto \Delta u - \Delta \bar{d} - \Delta \bar{s}$$

- get $\sin^2(\Theta_W)$?

$$\frac{d\,g_1}{d\log(Q^2)} \propto -\Delta g(x,Q^2)$$ **at small x**

E_e=7, E_p=150 at L=10^{33}



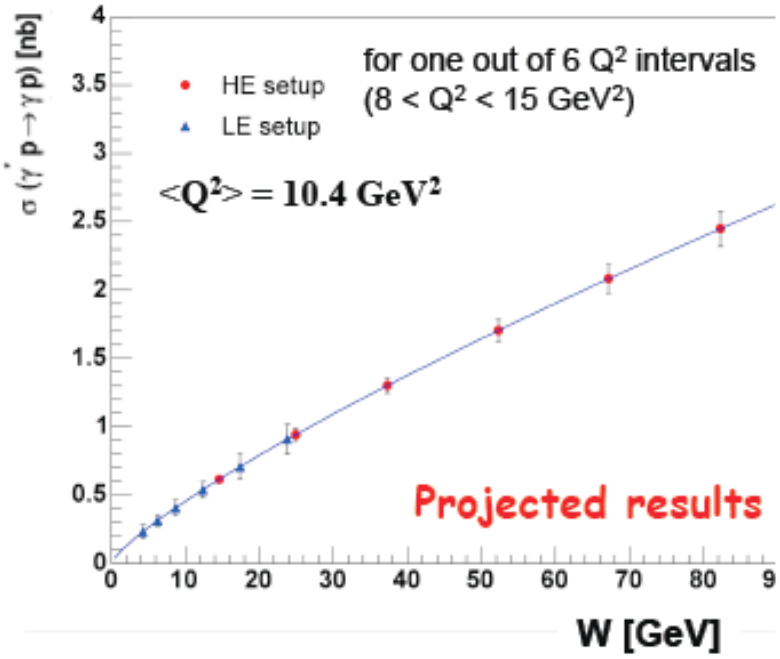
A. Bruell, R. Ent

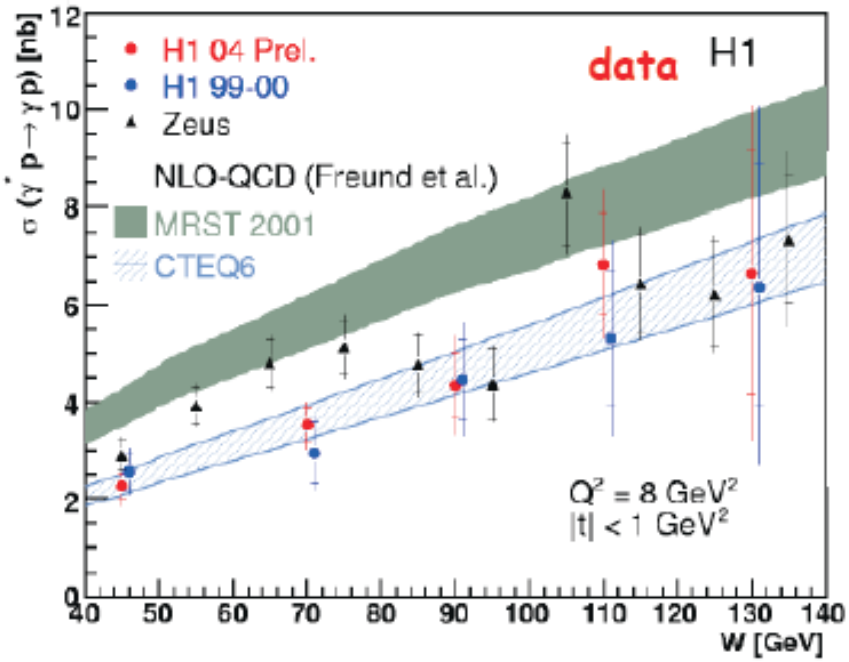
HE setup: $e^{+/-}$ (10 GeV) + p (250 GeV) L = $4.4 \cdot 10^{32}$ $cm^{-2}s^{-1}$ 38 pb^{-1}/day

LE setup: $e^{+/-}$ (5 GeV) + p (50 GeV) L = $1.5 \cdot 10^{32}$ $cm^{-2}s^{-1}$ 13 pb^{-1}/day

Sandacz

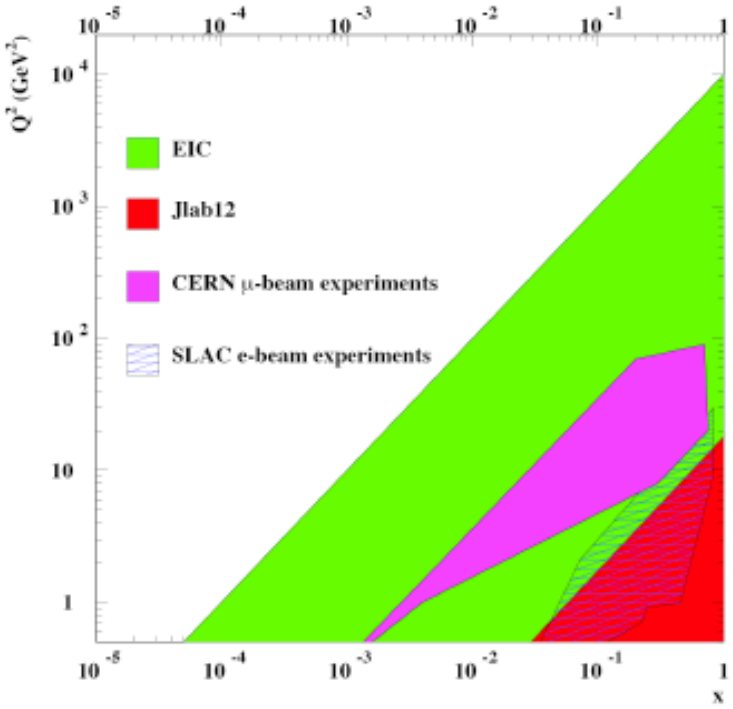
Precision of DVCS unpolarized cross sections

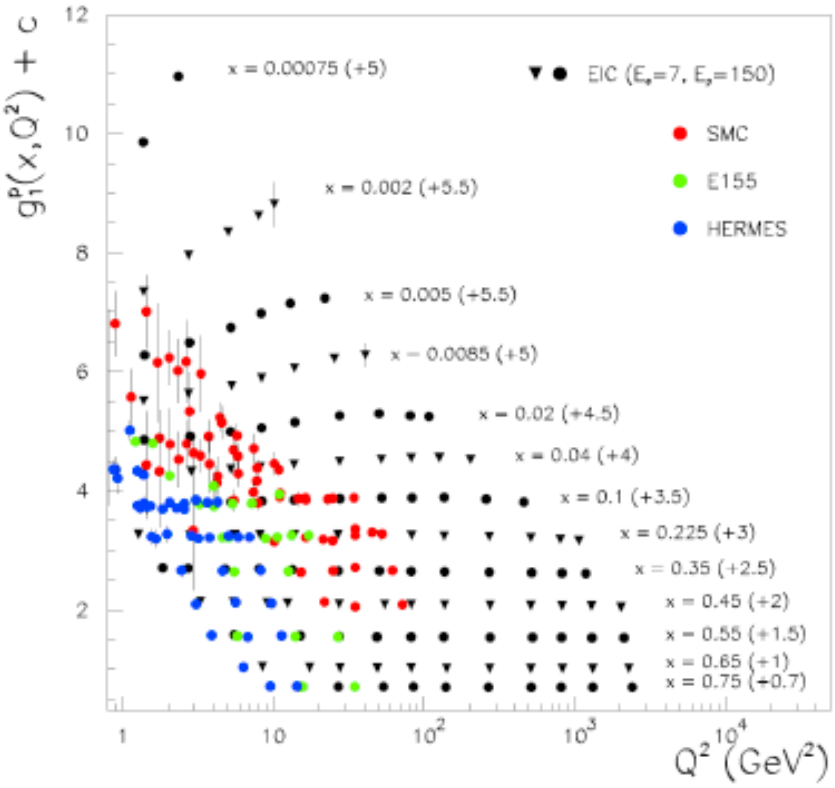




- also: gluon imaging with exclusive J/Ψ

Frankfurt, Strikman, Weiss

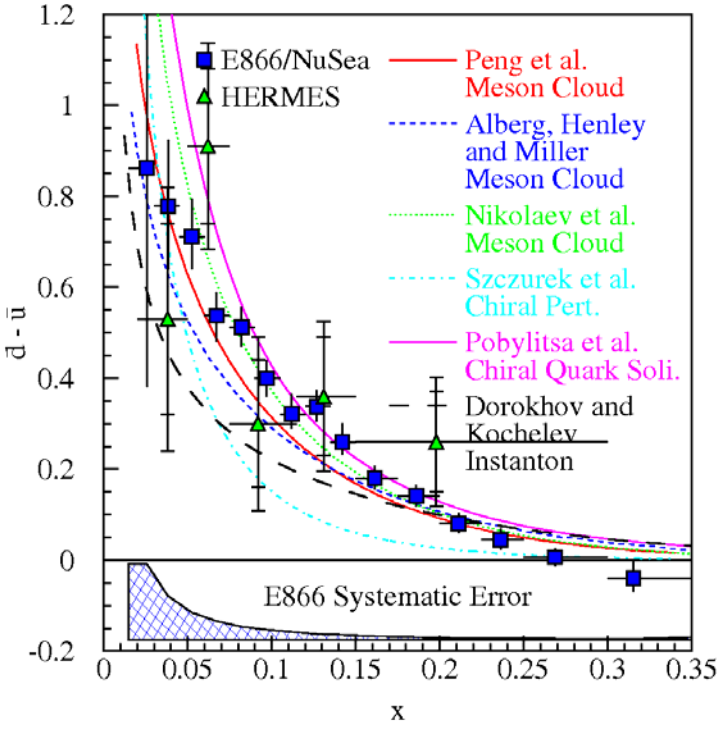


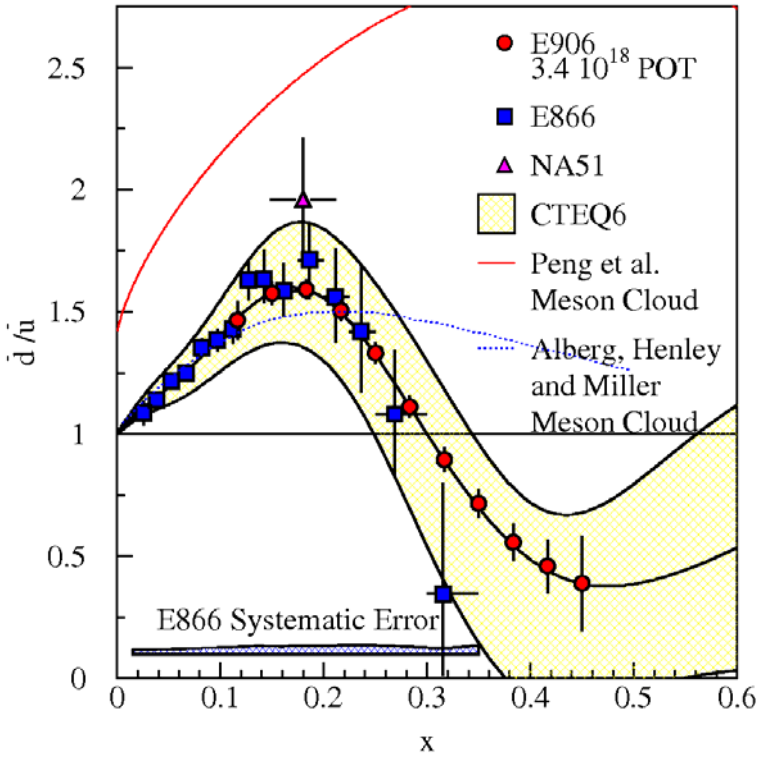


A. Bruell, R. Ent

Extracting d-bar/-ubar From Drell-Yan Scattering (E866/E906)

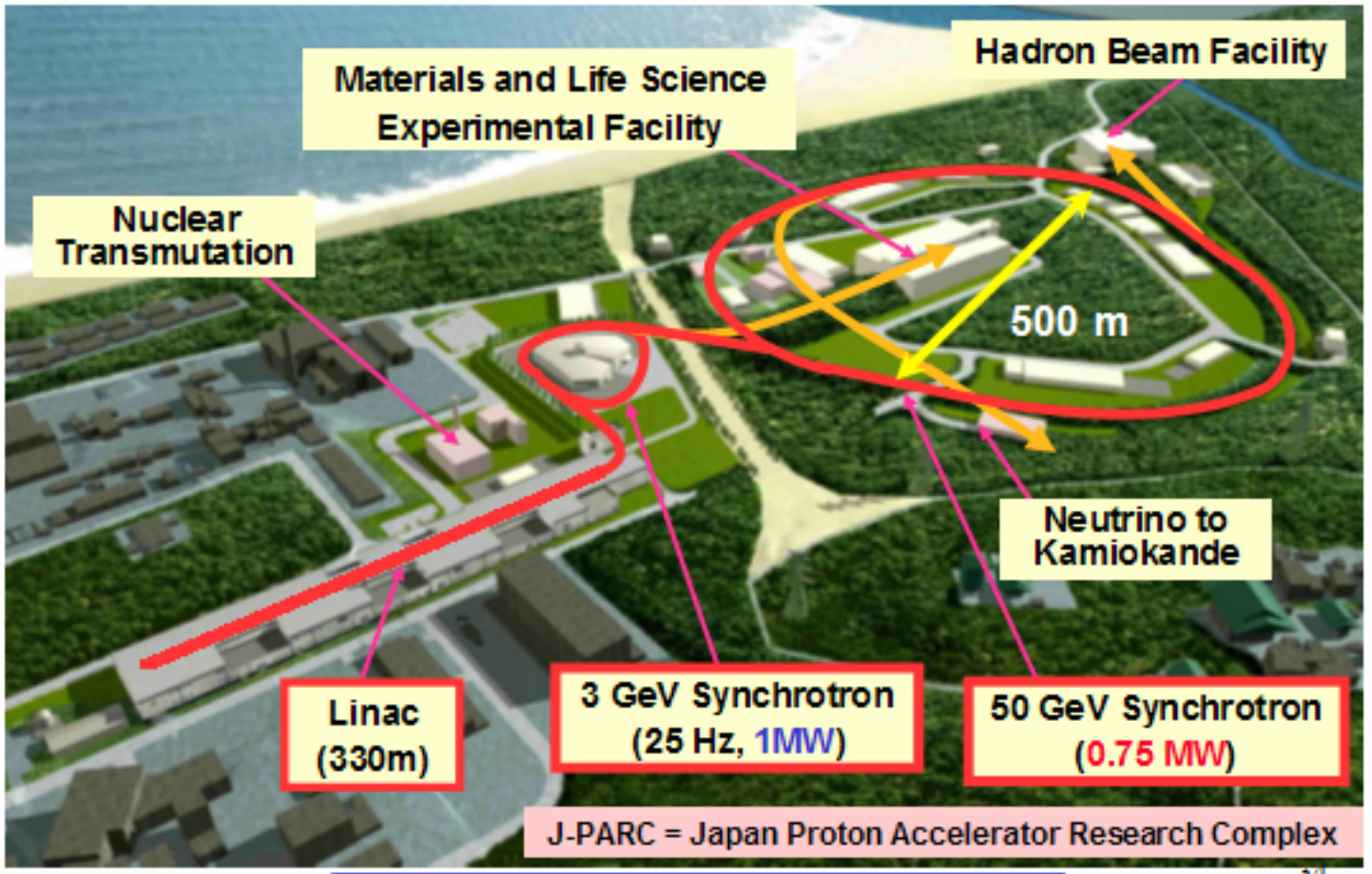
$$\left.\frac{\sigma^{pd}}{2\sigma^{pp}}\right|_{x_b \gg x_t} \approx \frac{1}{2}\left[1 + \frac{\bar{d}(x_t)}{\bar{u}(x_t)}\right]$$





International opportunities

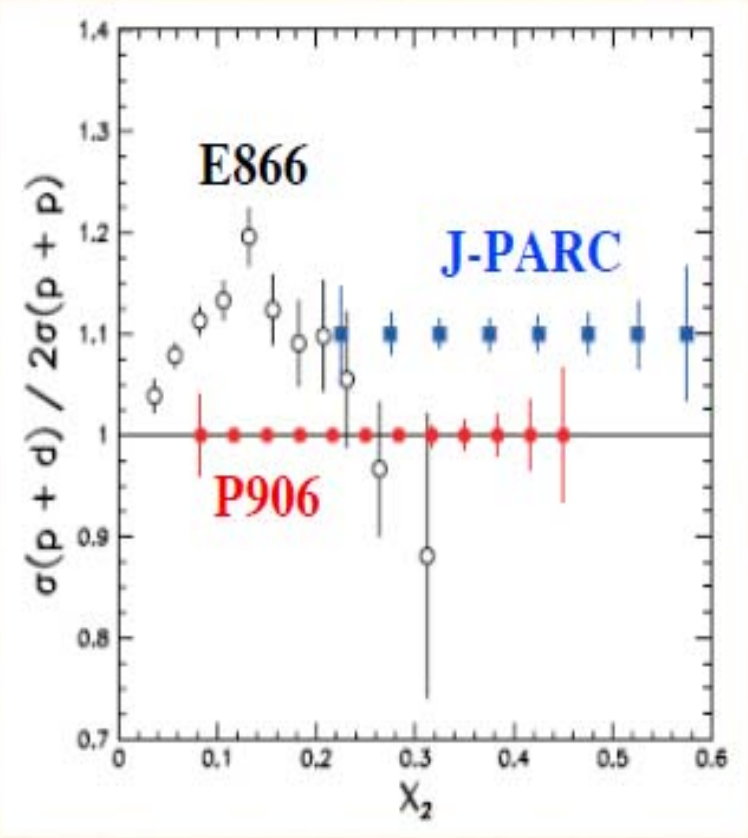
J-PARC Facility



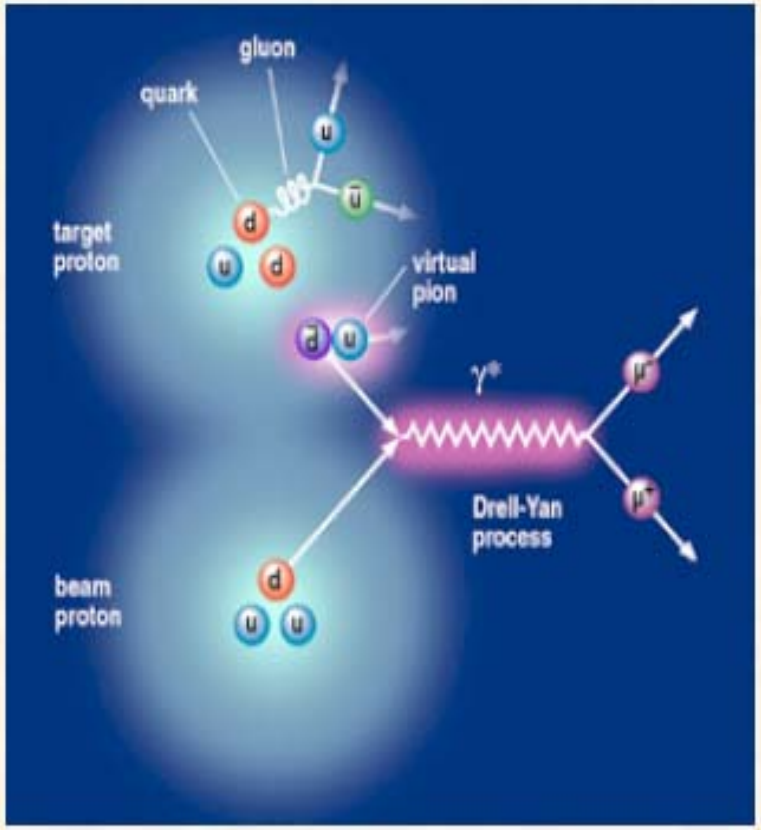
Joint Project between KEK and JAEA

Flavor asymmetric antiquark distributions: $\bar{u}$ / $\bar{d}$

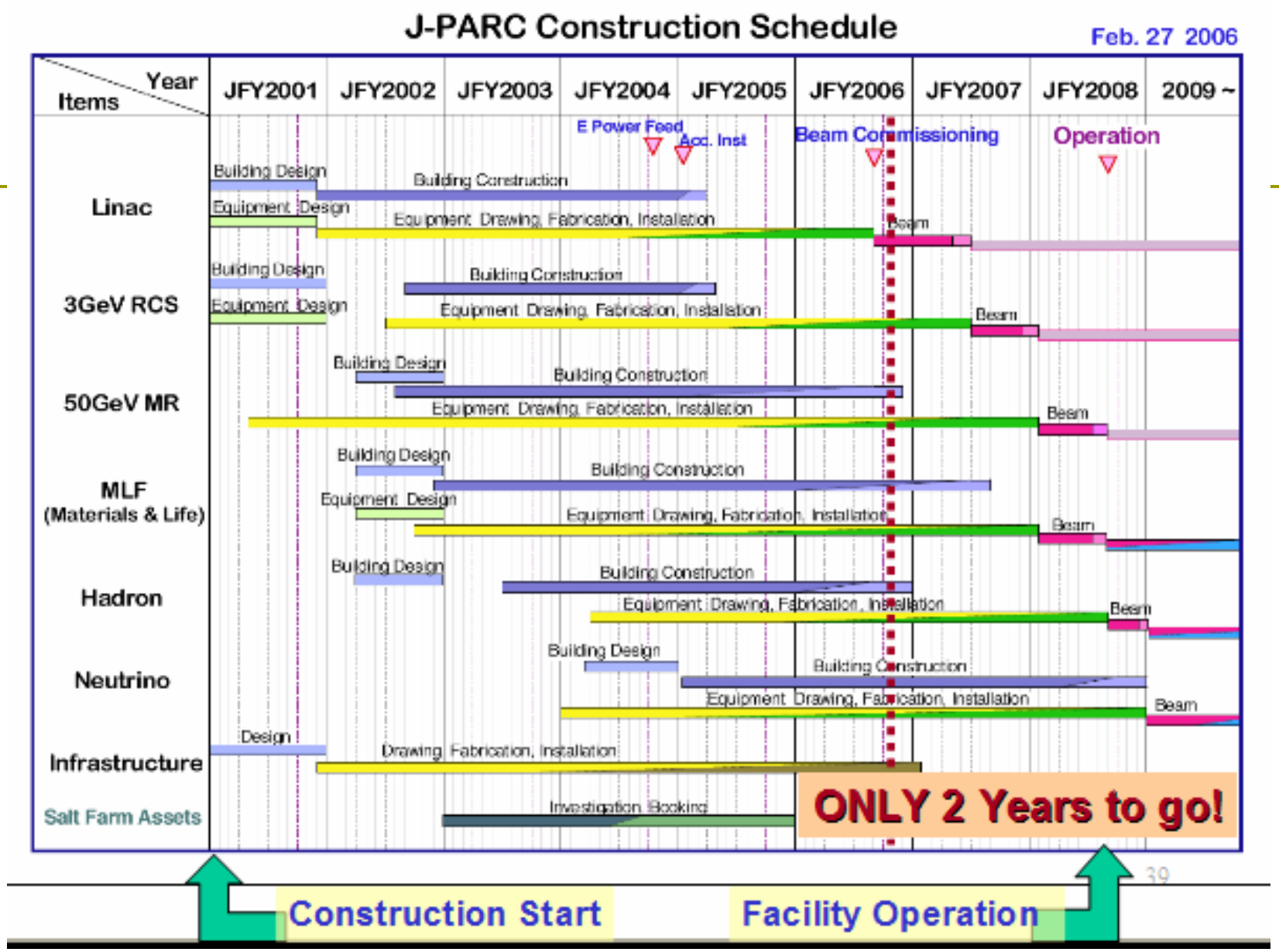
Sawada@J-PARC-HS05

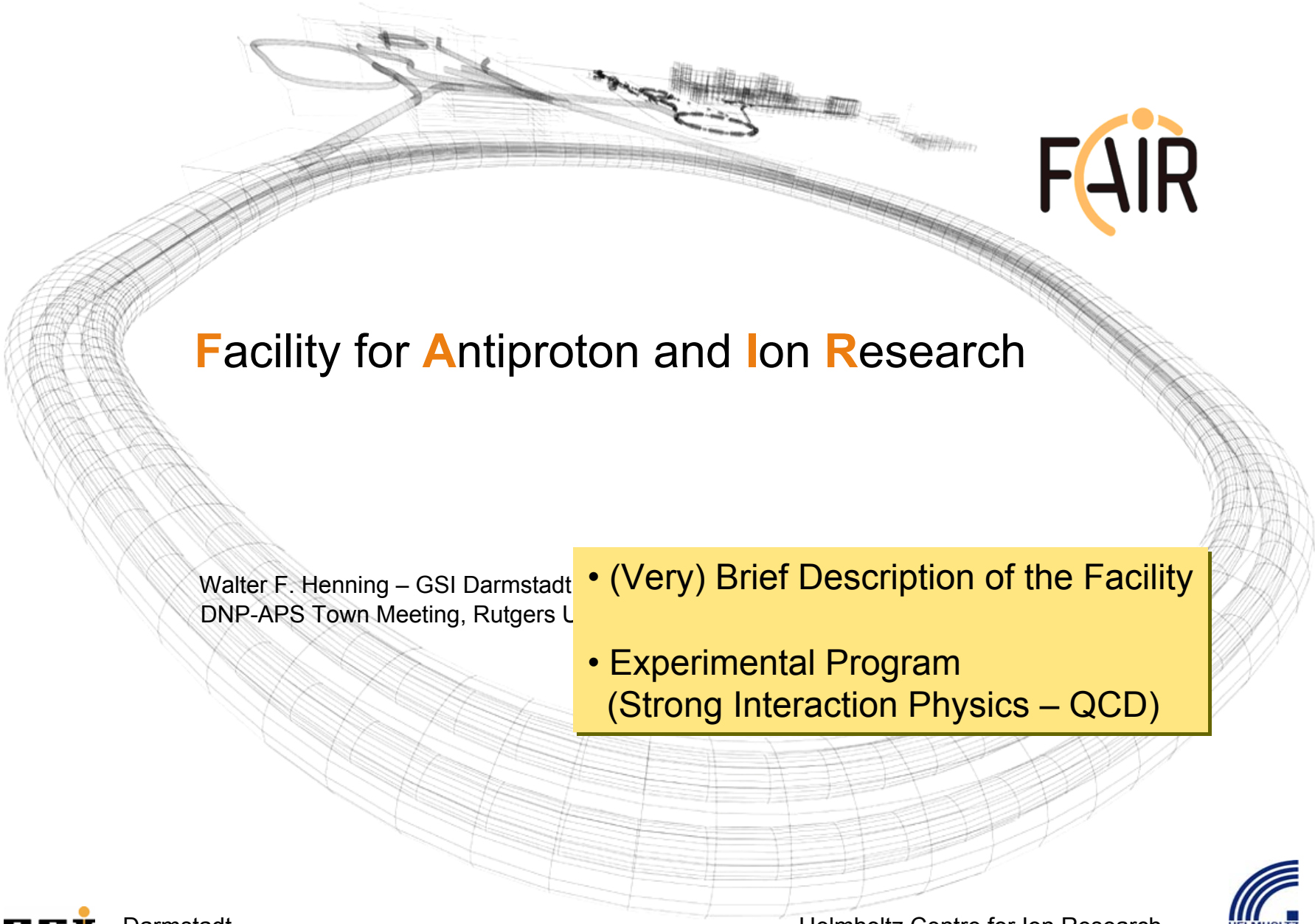


J-PARC proposal, J. Chiba et al. (2006)



http://www.acuonline.edu/academics/cas/physics/research/e906.html


J-PARC Construction Schedule
Feb. 27 2006
Year
Items
JFY2001
JFY2002
JFY2003
JFY2004
JFY2005
JFY2006
JFY2007
JFY2008
2009 ~
E Power Feed
Acc. Inst
Beam Commissioning
Operation
Linac
Building Design
Building Construction
Equipment Design
Equipment Drawing, Fabrication, Installation
Beam
3GeV RCS
Building Design
Building Construction
Equipment Design
Equipment Drawing, Fabrication, Installation
Beam
50GeV MR
Building Design
Building Construction
Equipment Drawing, Fabrication, Installation
Beam
MLF
(Materials & Life)
Building Design
Building Construction
Equipment Design
Equipment Drawing, Fabrication, Installation
Beam
Hadron
Building Design
Building Construction
Equipment Drawing, Fabrication, Installation
Beam
Neutrino
Building Design
Building Construction
Equipment Drawing, Fabrication, Installation
Beam
Infrastructure
Design
Drawing, Fabrication, Installation
Salt Farm Assets
Investigation, Booking
ONLY 2 Years to go!
Construction Start
Facility Operation

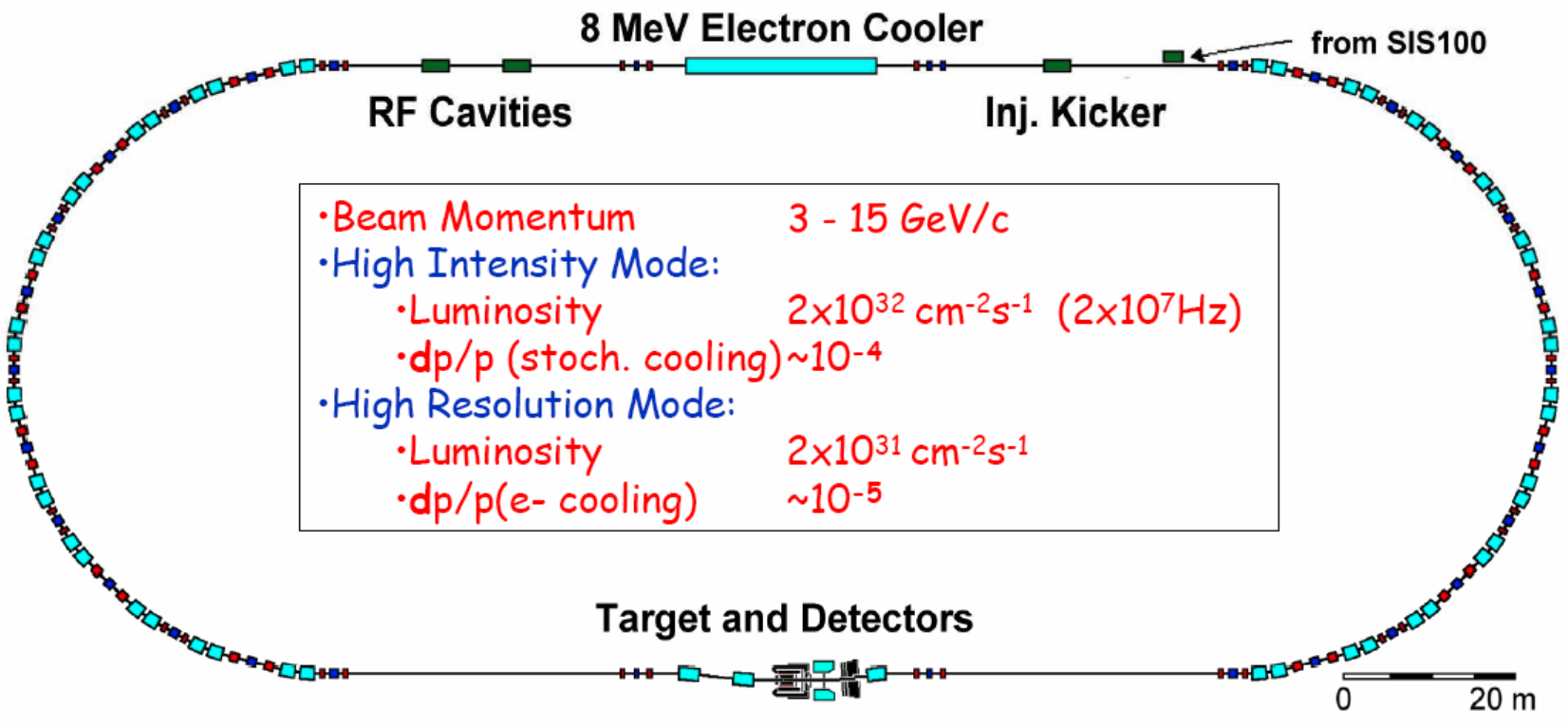


Facility for Antiproton and Ion Research

Walter F. Henning – GSI Darmstadt
DNP-APS Town Meeting, Rutgers U

- (Very) Brief Description of the Facility
- Experimental Program
  (Strong Interaction Physics – QCD)

High Energy Storage Ring, HESR

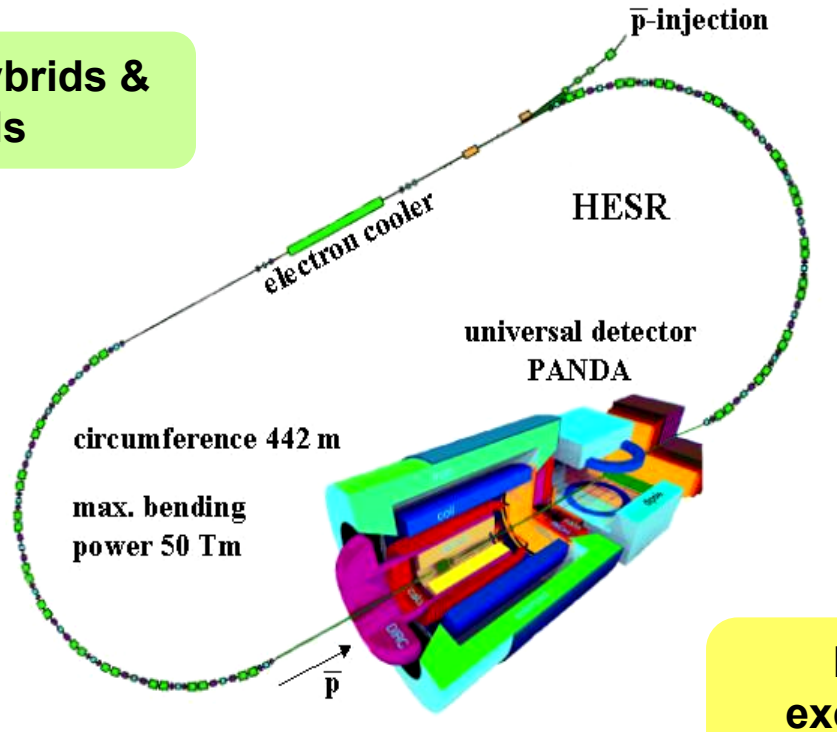


panda

PANDA Physics Program

Charmonium spectroscopy

Exotics: charmed hybrids & heavy glueballs



Time-like form factors

Medium modifications of charmed mesons

Drell-Yan processes

CP-violation (D & Λ - sector)

Hard exclusive processes

Hypernuclei

Recommendations

1. Our highest priority is the timely completion of the 12 GeV Upgrade of CEBAF and the start of its exciting research program.
2. It is imperative that funding be provided to make effective use of our major research facilities, which include operations of CEBAF, RHIC-SPIN, and TUNL-HIGS. We recommend increased federal investment in both people and equipment at our universities to support science and education activities associated with these facilities.

Recommendations (continue)

3. Substantially increased support for nuclear theory is critical to achieving the short and long term scientific goals of the US nuclear physics program. In implementing the recommendations of the 2003 NSAC Report on Nuclear Theory, it is particularly important to focus on recruiting, nurturing and supporting young theorists.

Recommendations (continue)

4. A high luminosity Electron-Ion Collider (EIC) facility is the highest priority of the QCD community for new construction after the JLab 12 GeV and RHIC II luminosity upgrades.
5. We strongly support the recommendations of the workshop on Education and Public Outreach in nuclear sciences.

Outline of the whitepaper

- Executive Summary
  - Background
  - Recommendations
  - Physics cases for recommendations
- Progress since large long-range plan
  - Hadron physics at short distance
  - Hadron physics at long distance
  - Nuclear Physics at short distance
  - Hadron spectroscopy
  - Nuclear theory

Outline of the whitepaper

- Physics Program for Immediate Future
  - Jlab 6 GeV Program
  - RHIC spin physics
  - Other facilities
- Outstanding Opportunities in Future
  - Jlab 12 GeV upgrade
  - Electron-ion collider
  - International opportunities
  - Hadron physics theory
  - Education and outreach