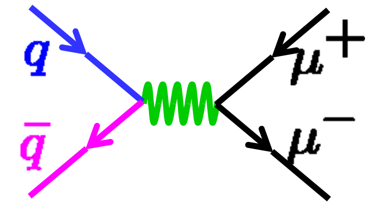
Future Drell-Yan fixed target experiments at Fermilab

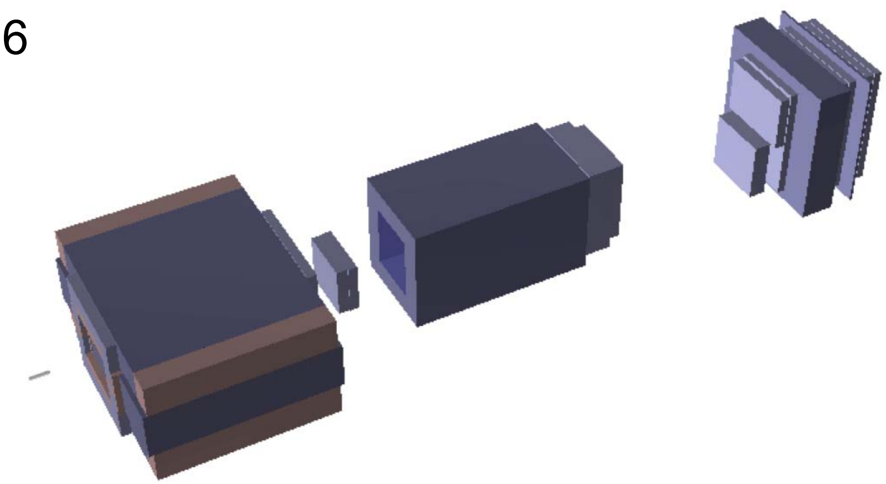


Wolfgang Lorenzon

University of Michigan

on behalf of the SeaQuest Collaboration

- Introduction
- SeaQuest: Fermilab Experiment E906
  - ➡ What will we learn?
  - ➡ What will we measure?
  - ➡ How will we measure it?
  - ➡ When we will do it?
- Beyond SeaQuest



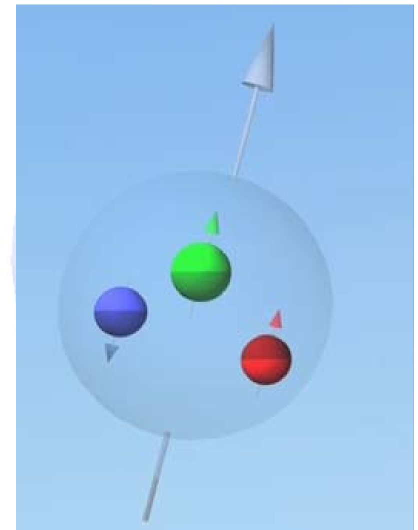
This work is supported by

NSAC Long Range Plan 2007 (2002)

- QCD
  - ➡ What are the phases of strongly interacting matter, and what roles do they play in the cosmos?
  - ➡ What is the internal landscape of the proton?
  - ➡ What does QCD predict for the properties of strongly interacting matter?
  - ➡ What governs the transition of quarks and gluons into pions and nucleons?
  - ➡ What is the role of gluons and gluon self-interactions in nucleons and nuclei?
  - ➡ What determines the key features of QCD, and what is their relation to the nature of gravity and spacetime?
- Nuclei and Nuclear Astrophysics
- Fundamental Symmetries and Neutrinos

Internal Landscape of the Proton

http://www.sciencecartoonsplus.com/index.htm



- Just three valence quarks?

Internal Landscape of the Proton

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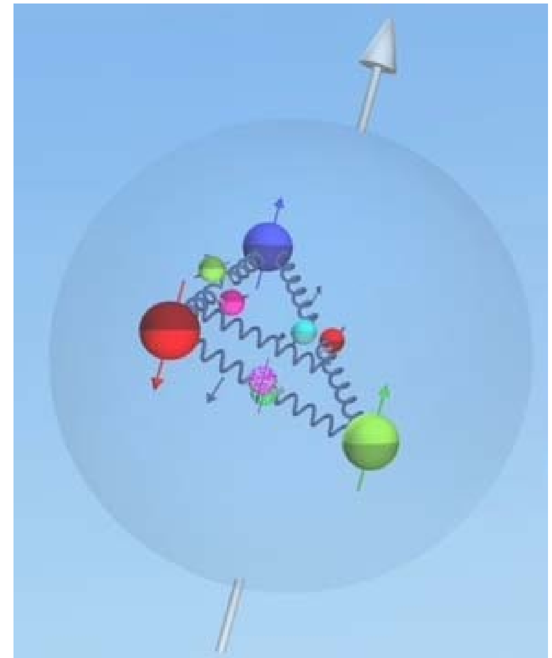
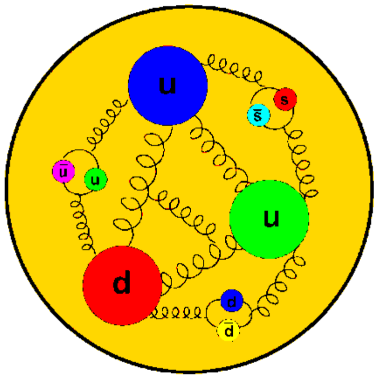
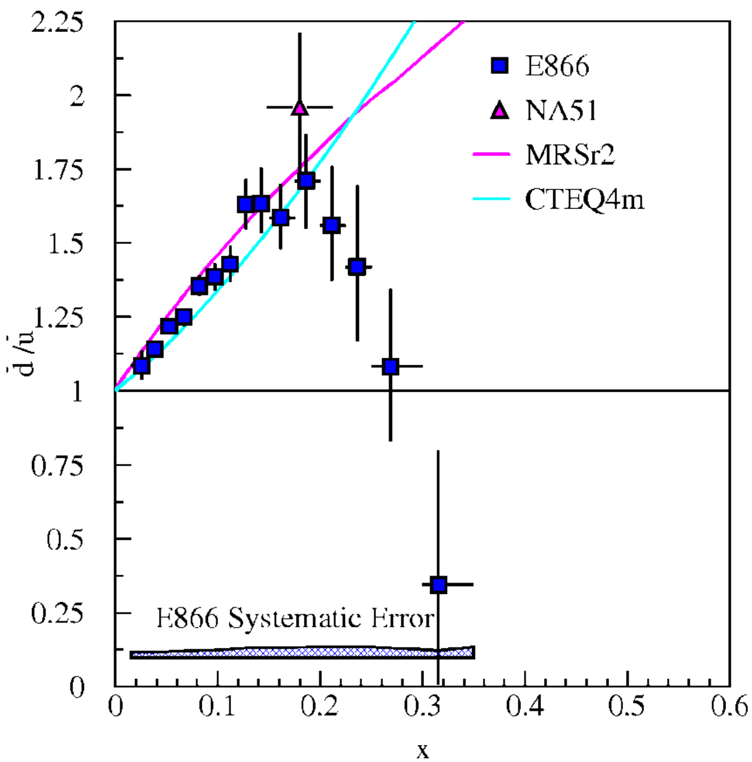


- Just three valence quarks?
- No!!
- And, quark distributions change in the nucleus

Flavor Structure of the Proton



E866: $\bar{d} > \bar{u}$



➡ Constituent Quark Model

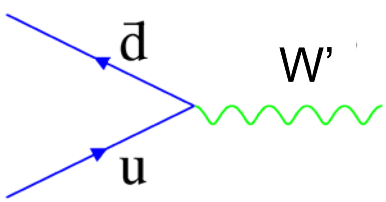
Pure valence description: proton = 2u + d

➡ Perturbative Sea

sea quark pairs from g → q$\bar{q}$
should be flavor symmetric: $\bar{d} = \bar{u}$

➡ What is the origin of the sea?

➡ Significant part of the LHC beam

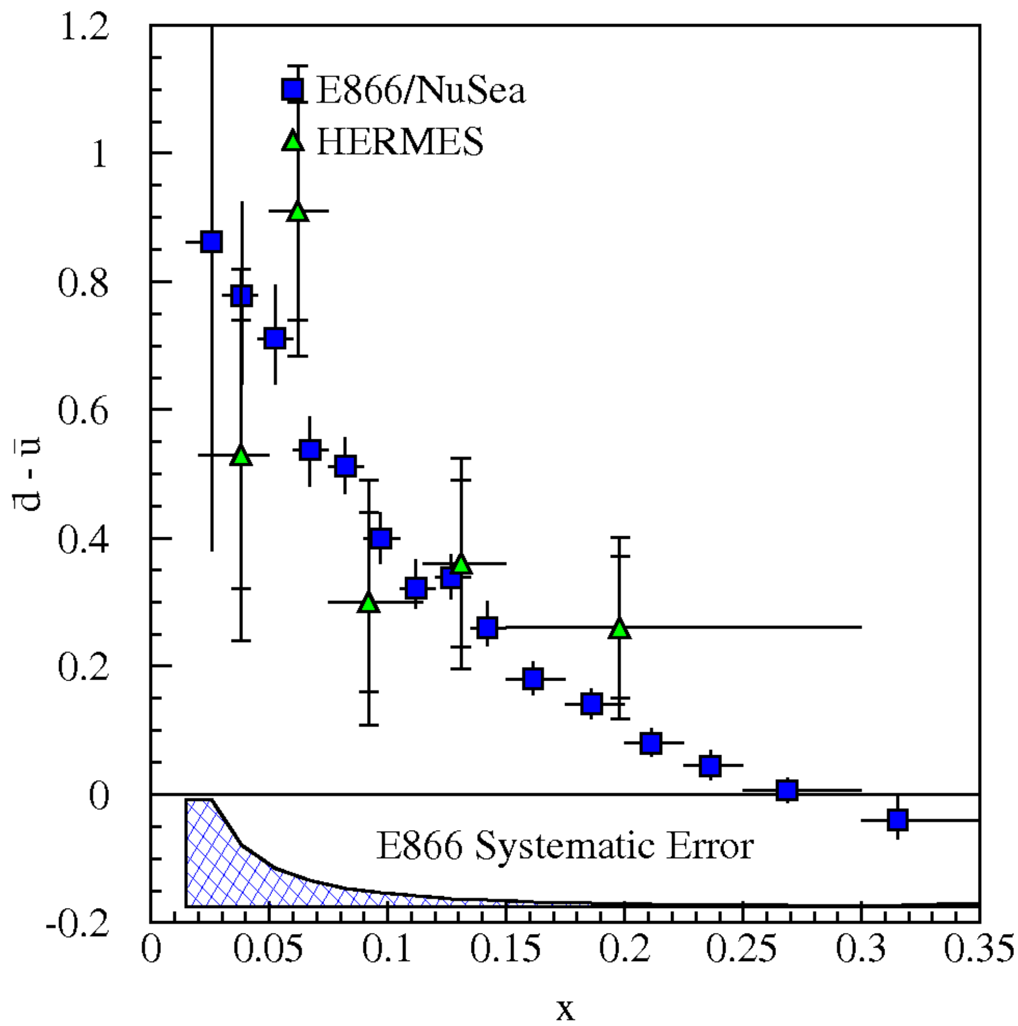


Flavor Structure of the Proton - II

- There is a gluon splitting component which is symmetric

$$\bar{d}(x) = \bar{u}(x) = \bar{q}(x)$$

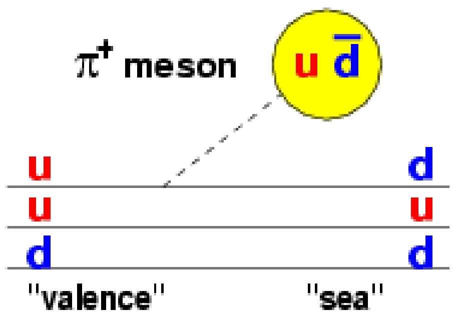
- $\bar{d} - \bar{u}$
  - ➡ Symmetric sea via pair production from gluons subtracts off
  - ➡ No gluon contribution at 1st order in α_s
  - ➡ Non-perturbative models are motivated by the observed difference
- A proton with 3 valence quarks plus glue cannot be right at any scale!!



Flavor Structure of the Proton - III

Non-perturbative models: alternate d.o.f.

Meson Cloud Models



Quark sea from cloud of 0^- mesons:

$\rightarrow$ $\bar{d} > \bar{u}$

Chiral-Quark Soliton Model

- quark d.o.f. in a pion mean-field: u $\rightarrow$ d + π^+
- nucleon = chiral soliton
- one parameter: dynamically generated quark mass
- expand in $1/N_c$:

$\rightarrow$ $\bar{d} > \bar{u}$

Statistical Model

- nucleon = gas of massless partons
- few parameters: generate parton distribution functions
- input: QCD: chiral structure DIS: u(x) and d(x)

$\rightarrow$ $\bar{d} > \bar{u}$

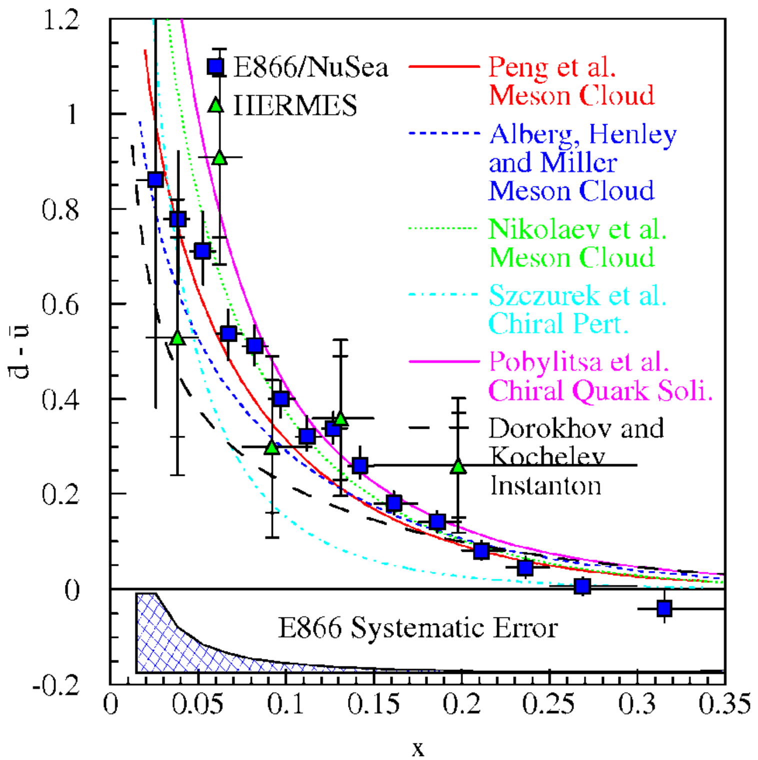
$\Rightarrow$ important constraints on flavor asymmetry for polarization of light sea

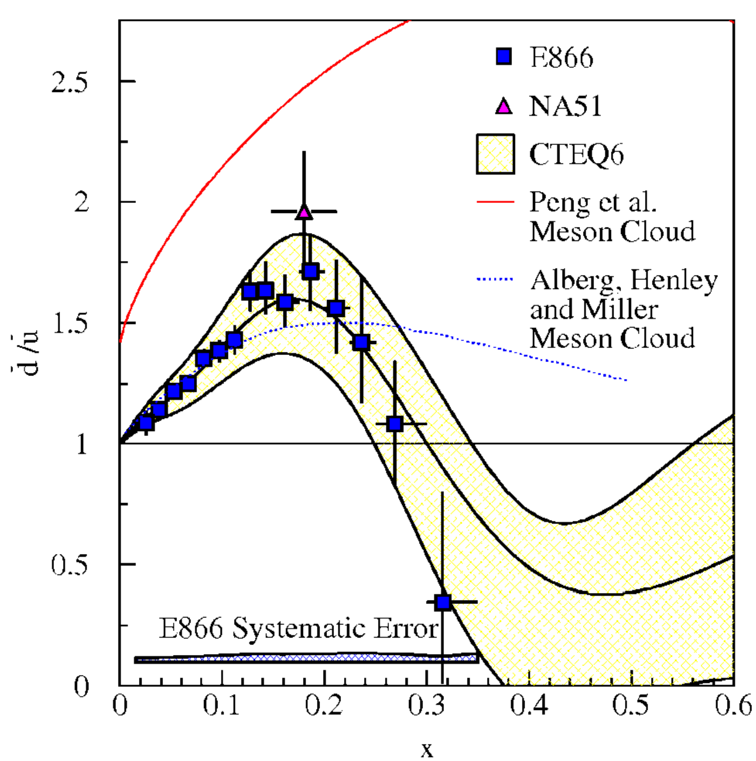
$\Delta\bar{q} = 0$

$\Delta\bar{u} \cong -\Delta\bar{d} > 0$

$\Delta\bar{d} < 0, \ \Delta\bar{u} < 0$

Flavor Structure of the Proton - IV





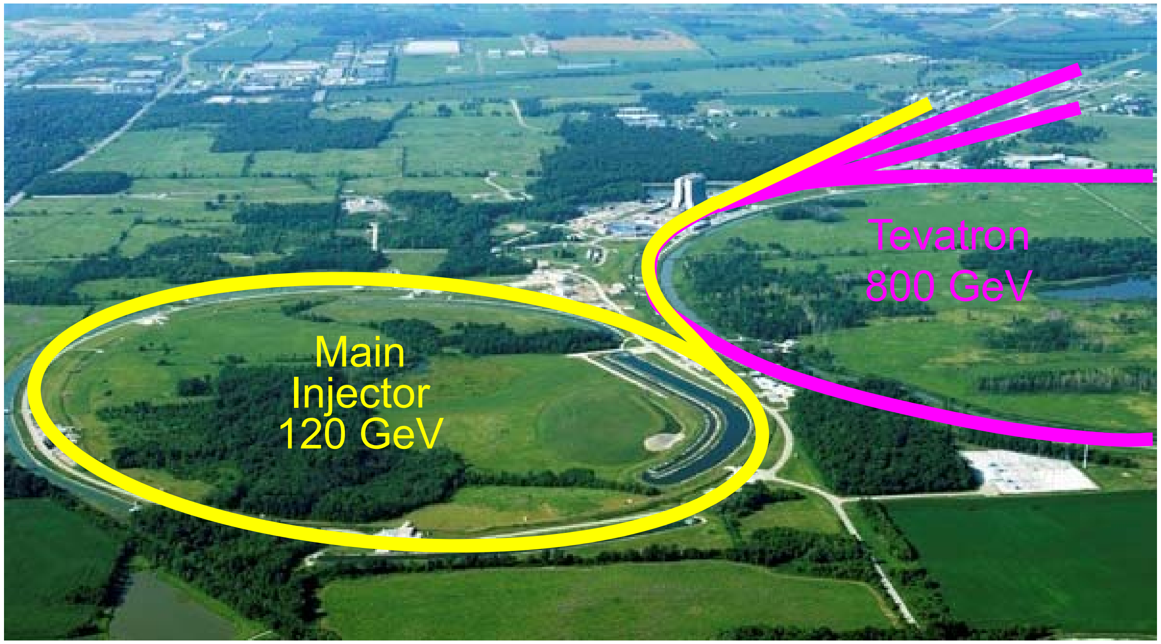
Comparison with models

- High x behavior is not explained
- Perturbative sea seems to dilute meson cloud effects at large x (but this requires large-x gluons)

- Measuring the ratio is powerful
- Are there more gluons and thus symmetric anti-quarks at higher x?
- Unknown other mechanisms with unexpected x-dependence?

Fermilab Experiment E906

- E906 will extend Drell-Yan measurements of E866 (with 800 GeV protons) using upgraded spectrometer and 120 GeV proton beam from main injector
- Lower beam energy gives factor 50 improvement “per proton” !
  - ➡ Drell-Yan cross section for given x increases as $1/s$
  - ➡ Backgrounds from J/Ψ and similar resonances decreases as s
- Use many components from E866 to save money/time, in NM4 Hall
- Hydrogen, Deuterium and Nuclear Targets



Fermilab E906/Drell-Yan Collaboration

Abilene Christian University
Donald Isenhower, Mike Sadler, Rusty Towell, S. Watson

Institute of Physics, Academia Sinica
Wen-Chen Chang, Yen-Chu Chen, Da-Shung Su

Argonne National Laboratory
John Arrington, Don Geesaman*, Kawtar Hafidi, Roy Holt, Harold Jackson, David Potterveld, Paul E. Reimer*, Patricia Solvignon

KEK
Shinya Sawada

Kyoto University
KenIchi Imai, Tomofumi Nagae

RIKEN
Yuji Goto, Atsushi Taketani, Yoshinori Fukao, Manabu Togawa

Tokyo Tech

Ling-Tung University
Ting-Hua Chang

Los Alamos National Laboratory
Gerry Garvey, Mike Leitch, Ming Liu Xiaodong Jiang, Pat McGaughey, Joel Moss

Maryland
Betsy Beise

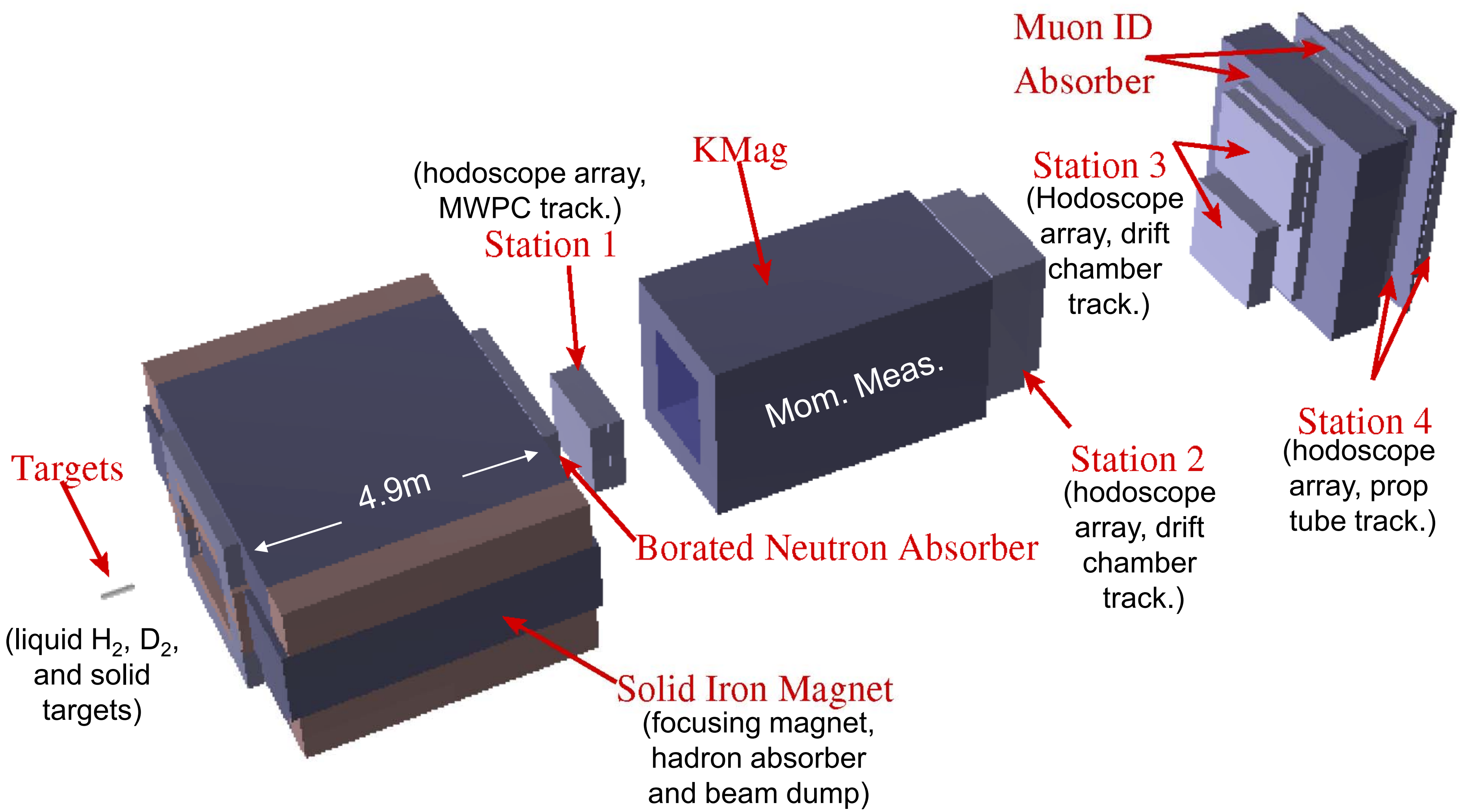
Rutgers University
Ron Gilman, L. El Fassi

*Co-Spokespersons

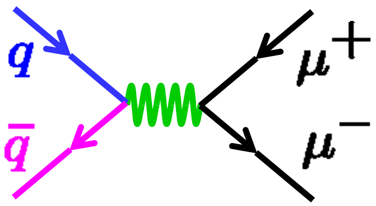
Jan, 2009

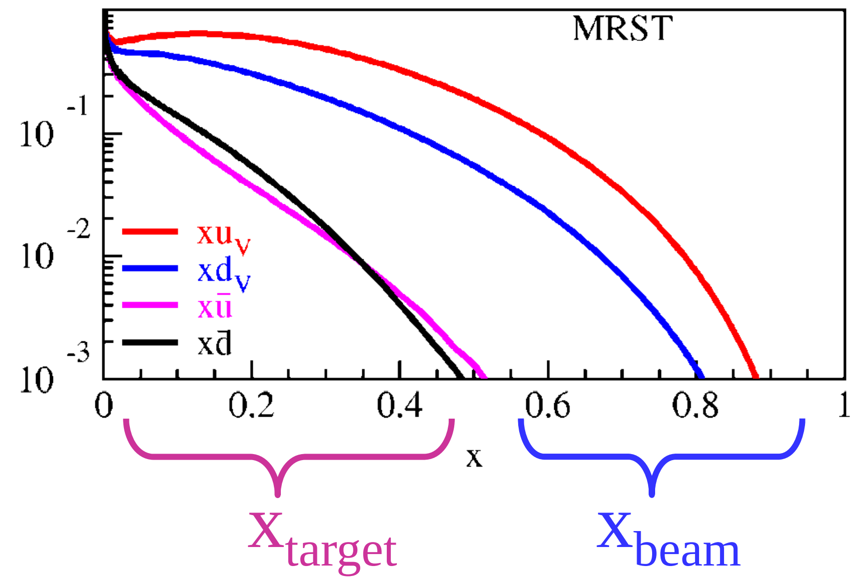
Collaboration contains many of the E-866/NuSea groups and several new groups (total 17 groups)

Drell-Yan Spectrometer for E-906
(25m long)



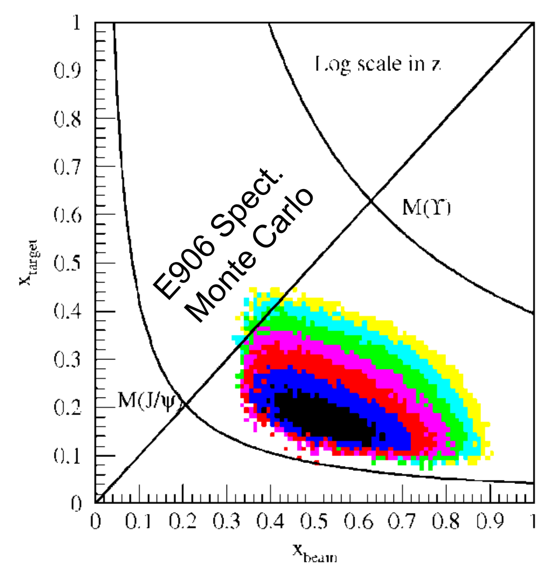
Fixed Target Drell-Yan: What we really measure





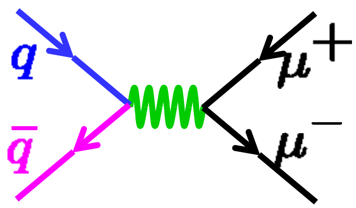
- Measure yields of $\mu^+\mu^-$ pairs from different targets
- Reconstruct p_γ , $M^2_\gamma = x_b x_t s$
- Determine x_b, x_t
- Measure differential cross section

$$\frac{d^2\sigma}{dx_1 dx_2} = \frac{4\pi\alpha^2}{9x_1x_2}\frac{1}{s}\sum e^2\left[\bar{q}_t(x_t)q_b(x_b) + q_t(x_t)\bar{q}_b(x_b)\right]$$



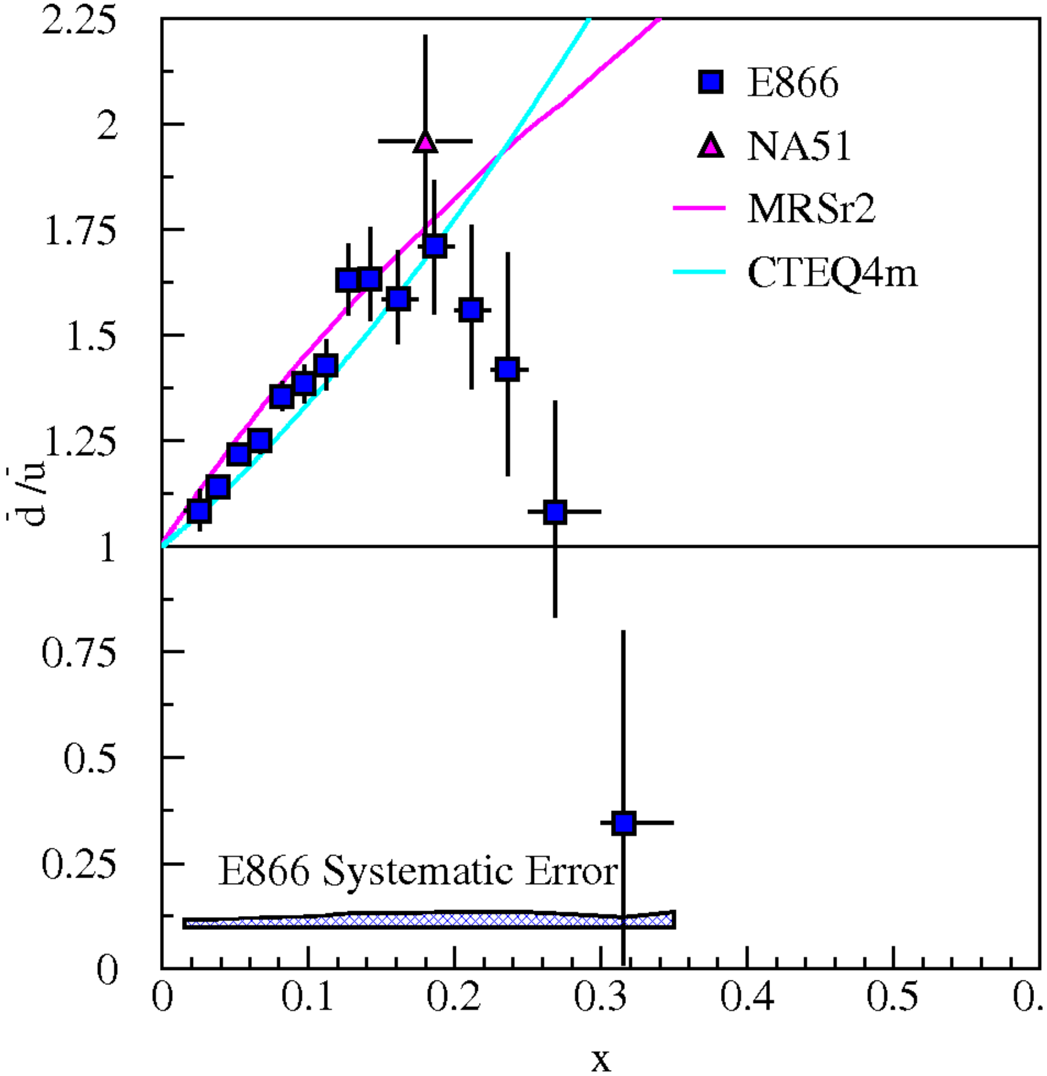
- Fixed target kinematics and detector acceptance give $x_b > x_t$
  - ➡ $x_F = 2p_{||}^{\gamma}/s^{1/2} \approx x_b - x_t$
  - ➡ Beam valence quarks probed at high x
  - ➡ Target sea quarks probed at low/intermediate x

Fixed Target Drell-Yan: What we really measure - II



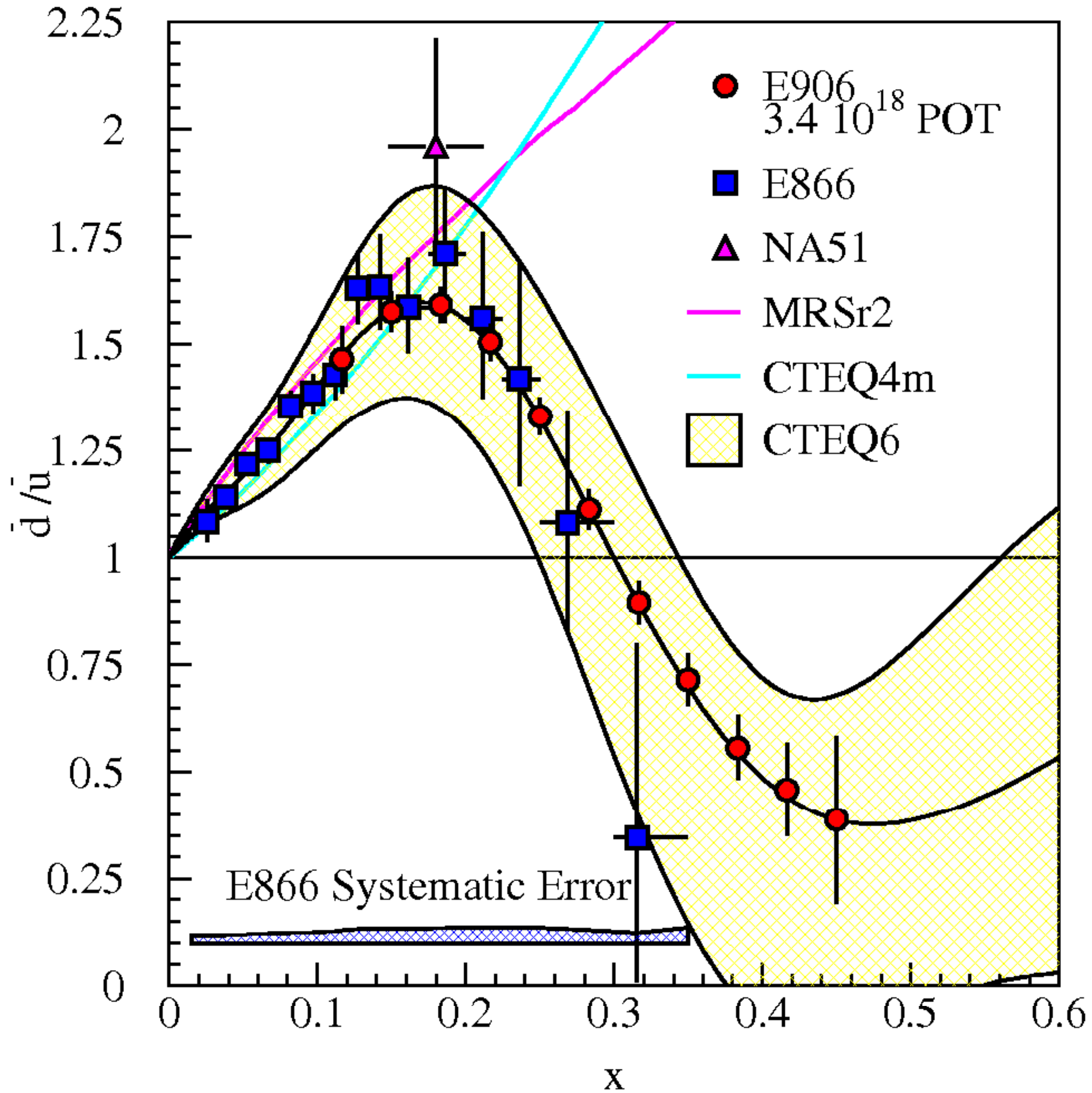
- Measure cross section ratios on Hydrogen, Deuterium (and Nuclear) Targets

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



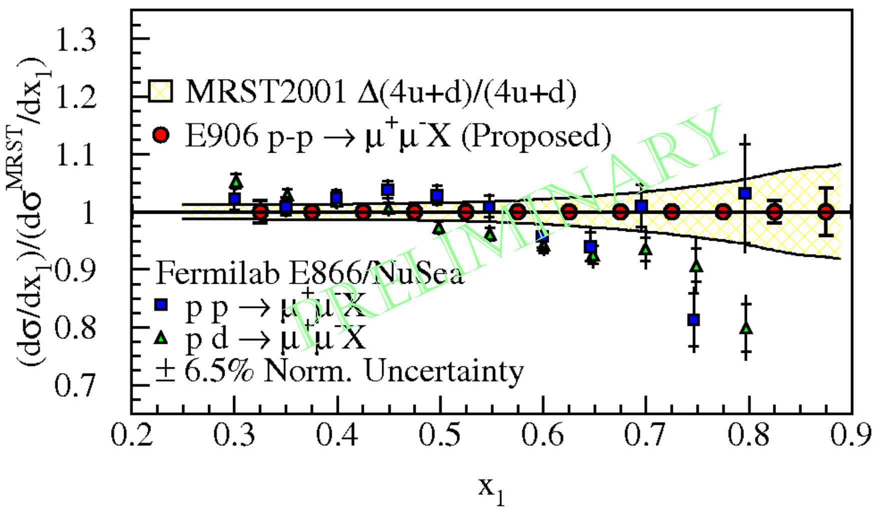
SeaQuest Projections for d-bar/u-bar Ratio

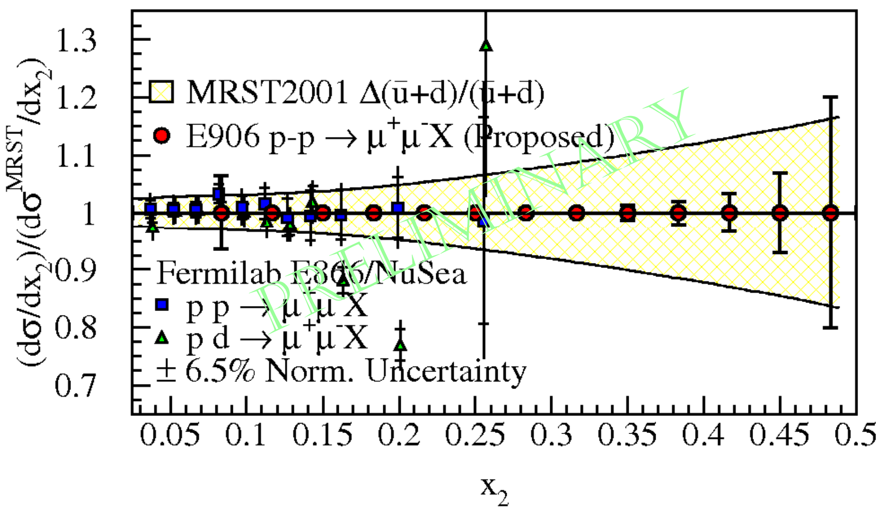
- SeaQuest will extend these measurements and reduce statistical uncertainty
- SeaQuest expects systematic uncertainty to remain at ≈1% in cross section ratio
- 5 s slow extraction spill each minute
- Intensity:
  - 2×10^{12} protons/s
  - 1×10^{13} protons/spill



SeaQuest Projections for absolute cross sections

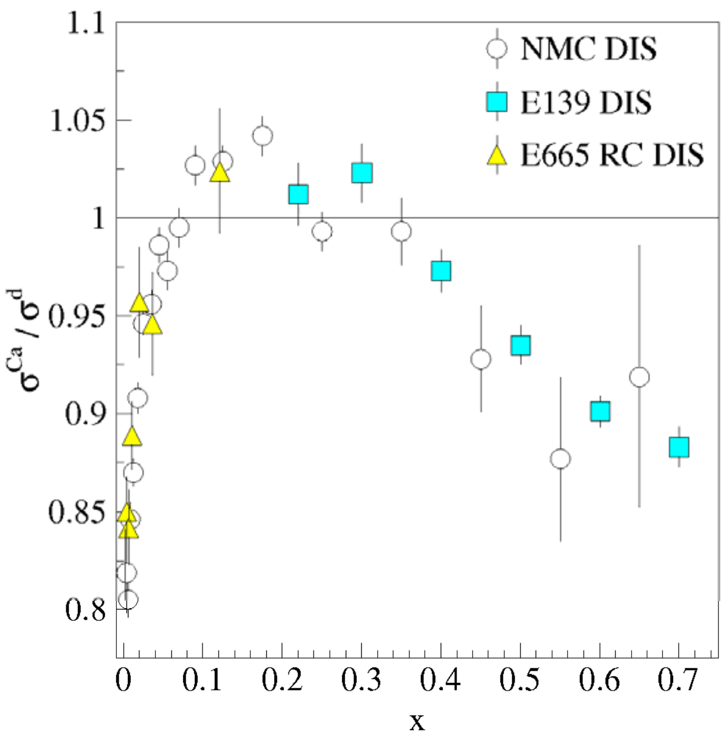
- Reach high x through beam proton
  - large x_F gives large x_{beam}
- High x distributions poorly understood
  - nuclear corrections are large, even for deuterium
  - lack of proton data
- In *pp* cross section, no nuclear corrections
  - direct measure of 4*u*+*d*
- Measure convolution of beam and target PDF
  - absolute magnitude of high x valence distributions
  - absolute magnitude of the sea in target ($\bar{d} + \bar{u}$)
    (currently determined by *ν-Fe* DIS)

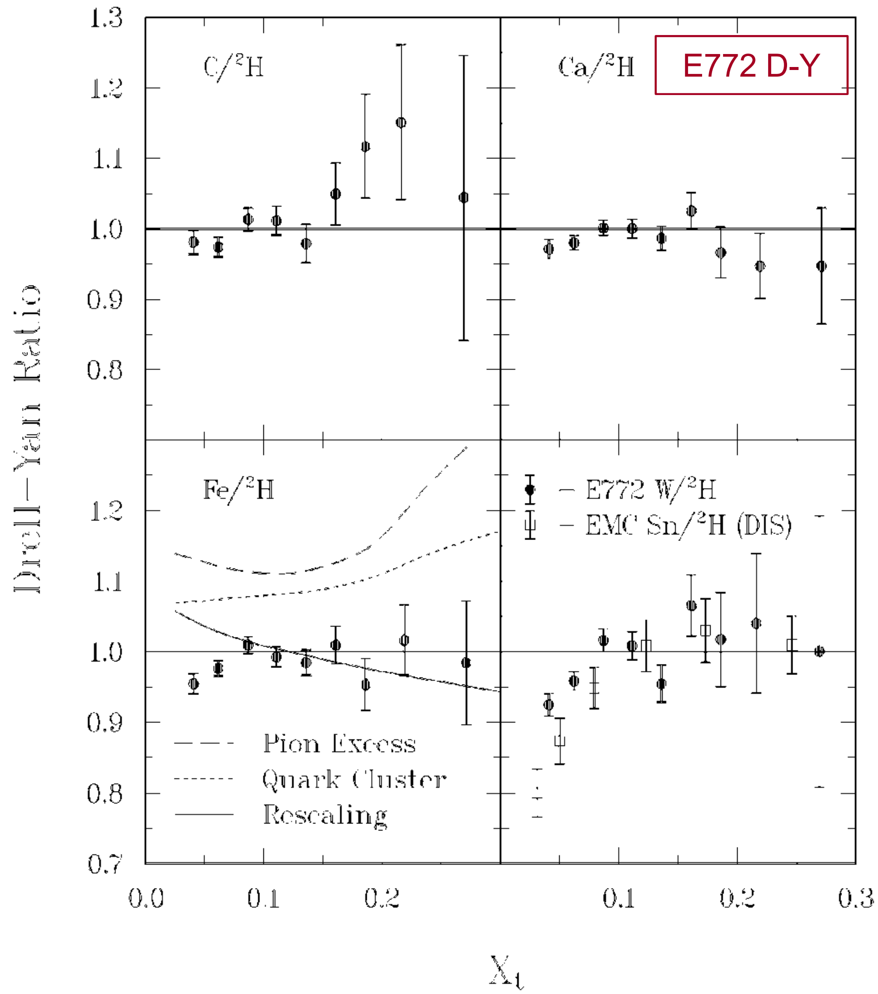




Sea quark distributions in Nuclei

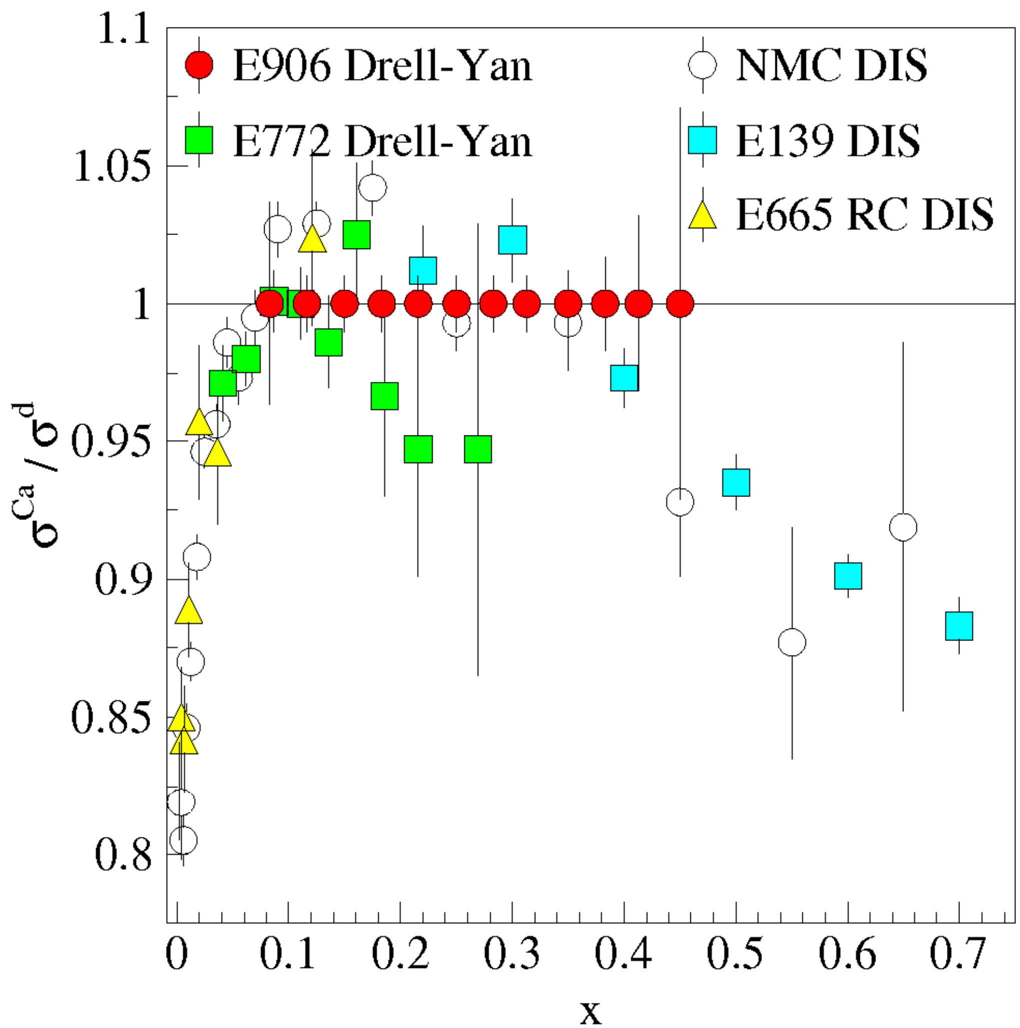
- EMC effect from DIS is well established
- But Drell-Yan apparently sees no Anti-shadowing effect (valence only effect)





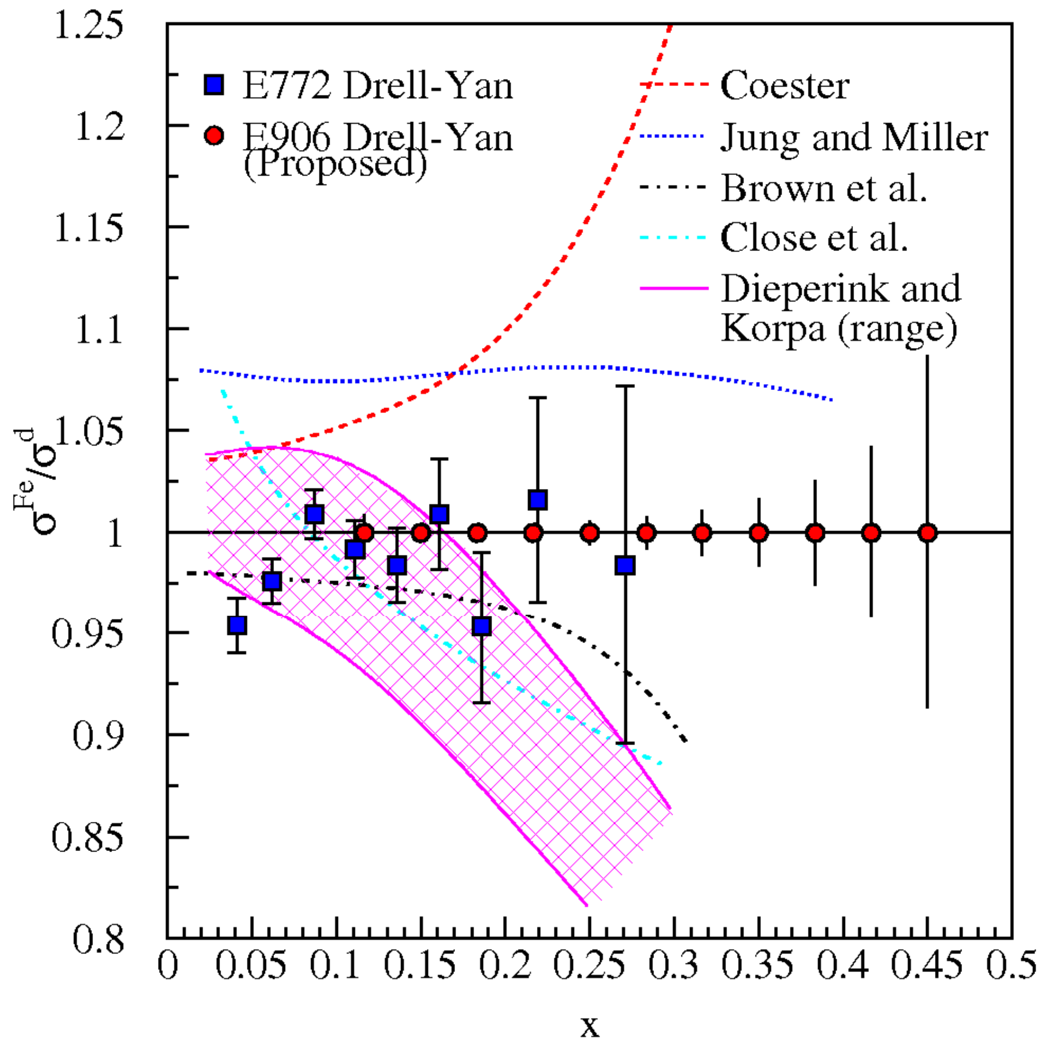
Sea quark distributions in Nuclei - II

- SeaQuest can extend statistics and x-range
- Are nuclear effects the same for sea and valence distributions?
- What can the sea parton distributions tell us about the effects of nuclear binding?

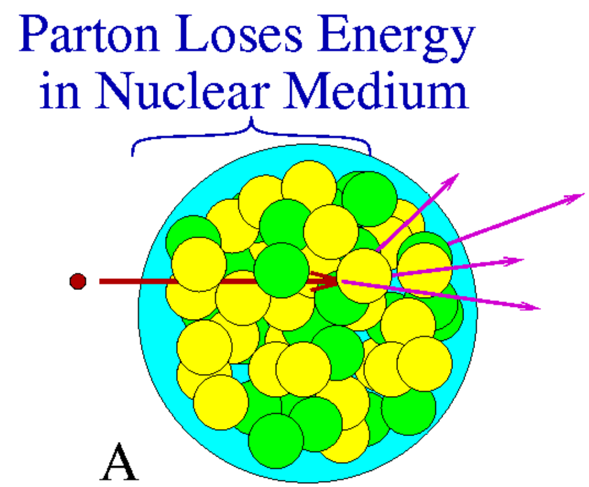


Where are the exchanged pions in the nucleus?

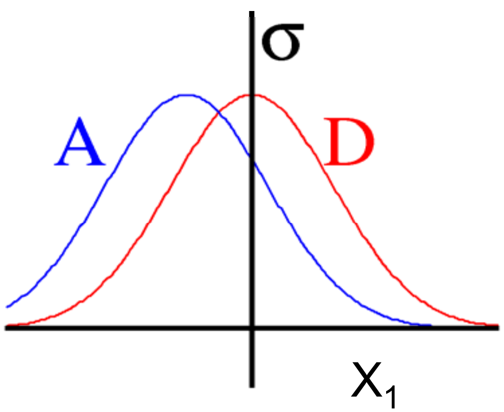
- The binding of nucleons in a nucleus is expected to be governed by the exchange of virtual “Nuclear” mesons.
- No antiquark enhancement seen in Drell-Yan (Fermilab E772) data.
- Contemporary models predict large effects to antiquark distributions as x increases
- Models must explain both DIS-EMC effect and Drell-Yan
- SeaQuest can extend statistics and x-range

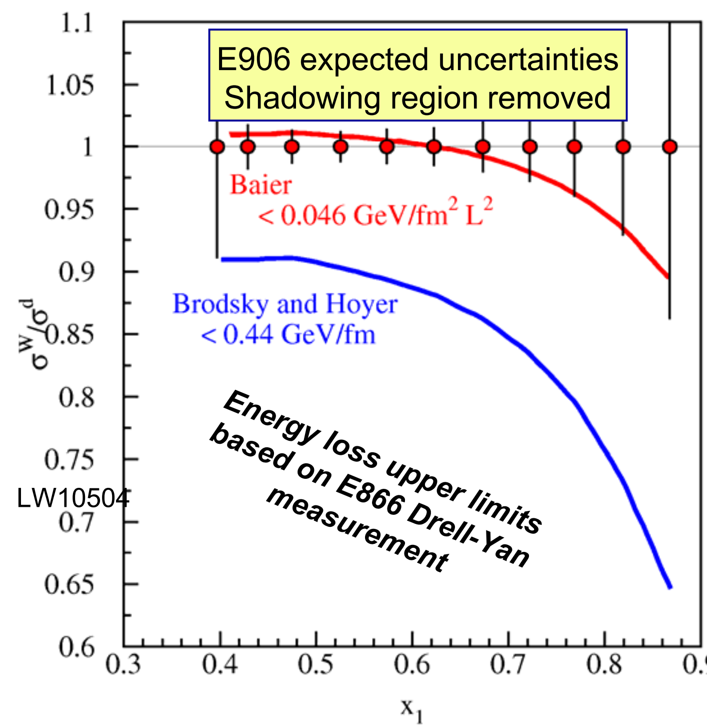


Partonic Energy Loss in Cold Nuclear Matter



- An understanding of partonic energy loss in both cold and hot nuclear matter is paramount to elucidating RHIC data.
- Pre-interaction parton moves through cold nuclear matter and looses energy.
- Apparent (reconstructed) kinematic value (x_1 or x_F) is shifted
- Fit shift in x_1 relative to deuterium
  - ➡ shift in $\Delta x_1 \propto 1/s$ (larger at 120 GeV)

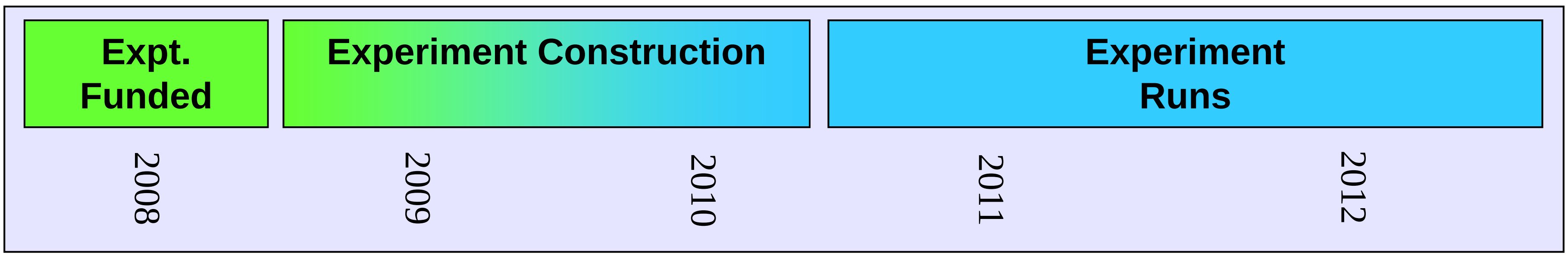




- E906 will have sufficient statistical precision to allow events within the shadowing region, $x_2 < 0.1$, to be removed from the data sample

Fermilab Seaquest Timelines

- Fermilab PAC approved the experiment in 2001, but experiment was not scheduled due to concerns about "proton economics"
- Stage II approval in December 2008
- Scheduled to run in 2010 for 2 years of data collection



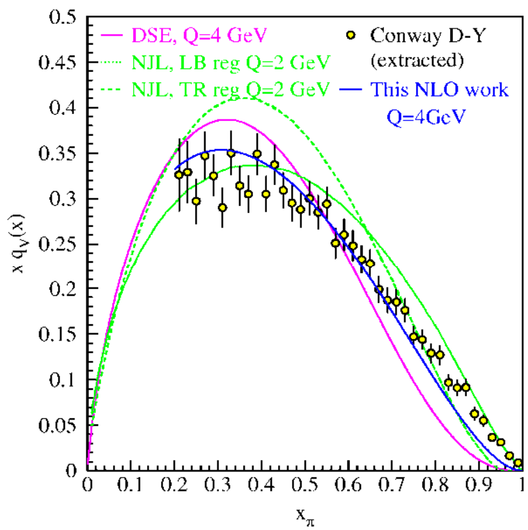
Apparatus available for future programs at, *e.g.* Fermilab, J-PARC or RHIC

➡ significant interest from collaboration for continued program

Future Possibilities

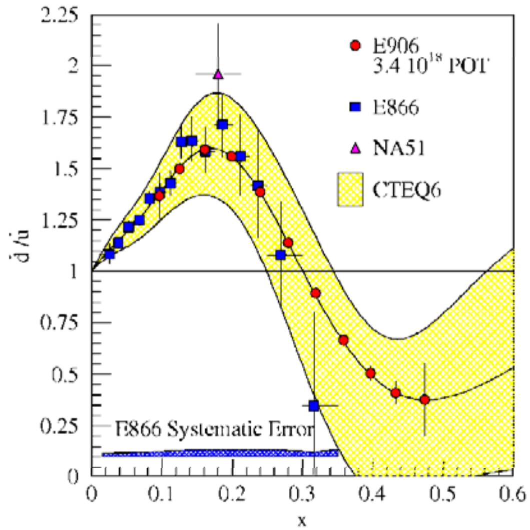
- **Transversely Polarized Target**
  - ➡ Single spin asymmetries $\rightarrow$ Sivers distribution
  - ➡ Check: $$f_{1T}^{\perp q}(x,k_T)\Big|_{DIS} = - f_{1T}^{\perp q}(x,k_T)\Big|_{D-Y}$$
  - ➡ Transversely polarized beam at JPARC???

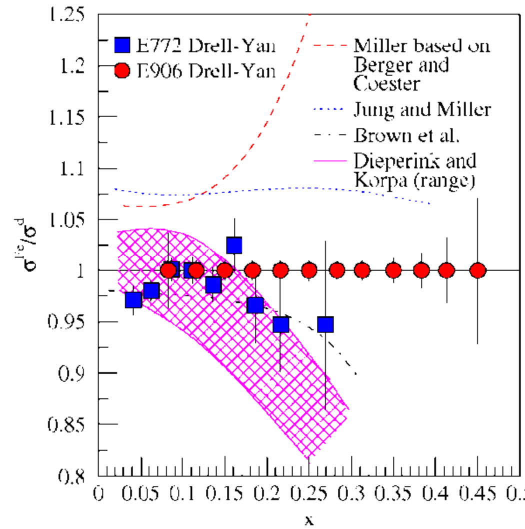
- **Pionic Drell-Yan**
  - ➡ Measure high-x pionic parton distributions
  - ➡ Test charge symmetry violation
    - ✓ $\pi^+\pi^-$ comparison on deuterium target
    - ✓ Difficulty producing pure π^+ beam



Drell-Yan fixed target experiments at Fermilab

- **What is the structure of the nucleon?**
  - ➡ What is $\bar{d} / \bar{u}$?
  - ➡ What is the origin of the sea quarks?
  - ➡ What is the high x structure of the proton?





- **What is the structure of nucleonic matter?**
  - ➡ Where are the nuclear pions?
  - ➡ Is anti-shadowing a valence effect?
- ***Do colored partons lose energy in cold nuclear matter?***
- **SeaQuest: 2010 - 2012**
  - ➡ significant increase in physics reach
- **Beyond SeaQuest**
  - ➡ Polarized Drell-Yan
  - ➡ Pionic Drell-Yan