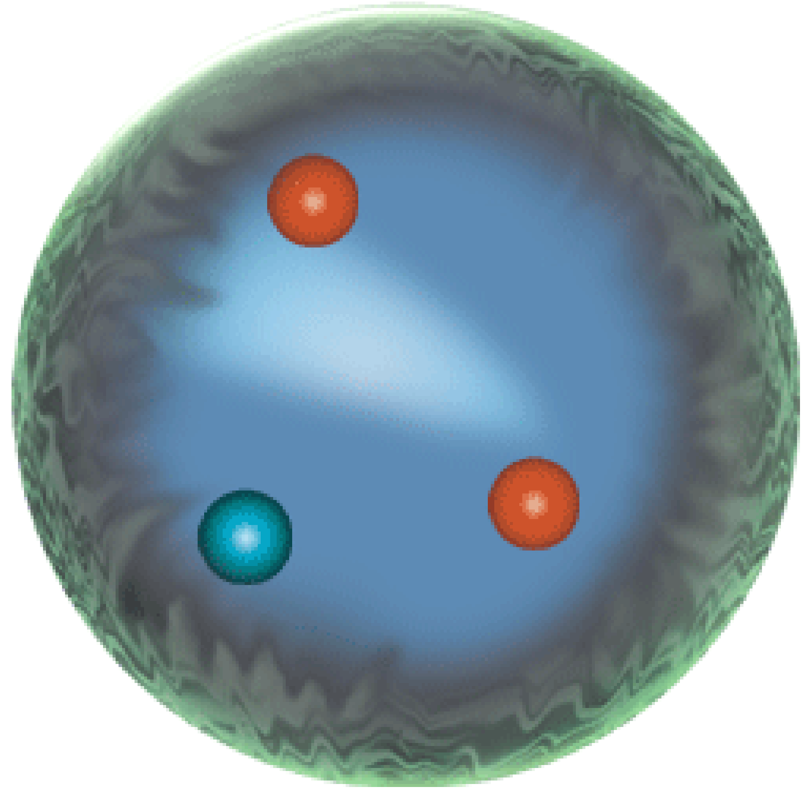
Argonne NATIONAL LABORATORY

... for a brighter future

Probing Antiquarks in Nucleons and Nuclei: Fermilab E906/Drell-Yan

Paul E. Reimer

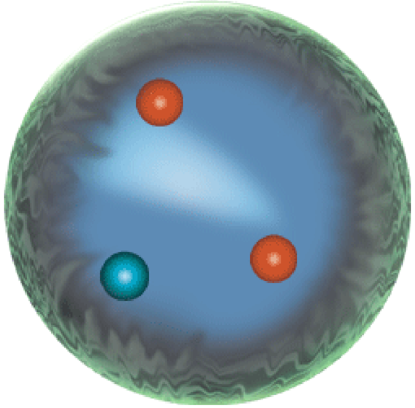
6 March 2008



Graphic Courtesy of JLab

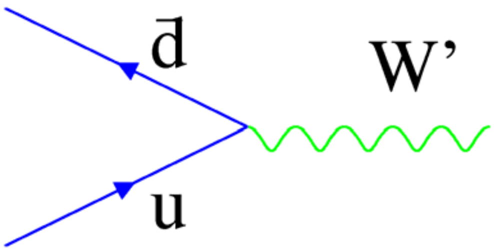
- What are the origins of the sea?
- How can we measure them with Drell-Yan
- Future Drell-Yan experiments at J-PARC

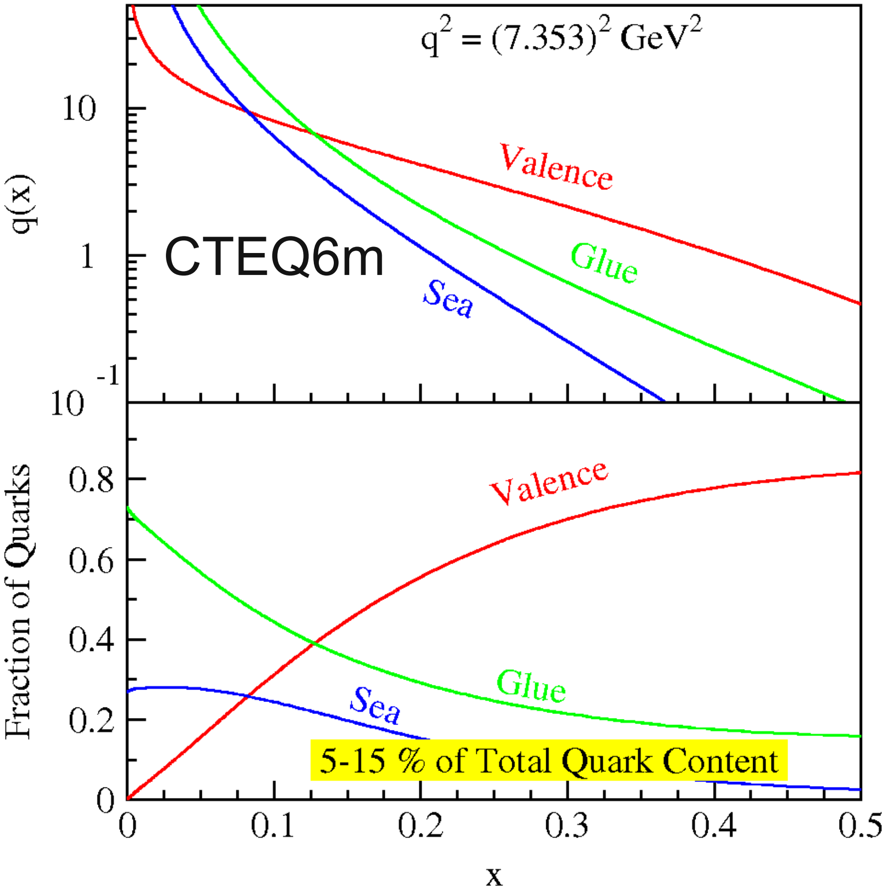
What is the distribution of sea quarks?



In the nucleon:

- Sea and gluons are important:
  - 98% of mass; 60% of momentum at $Q^2 = 2$ GeV^2
- Not just three valence quarks and QCD.
- What are the origins of the sea?
- Significant part of LHC beam.

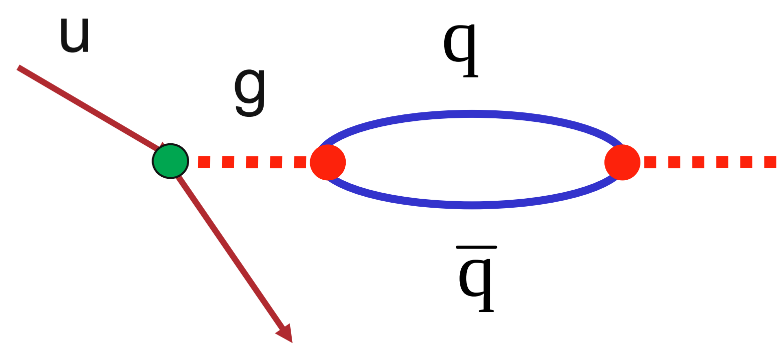




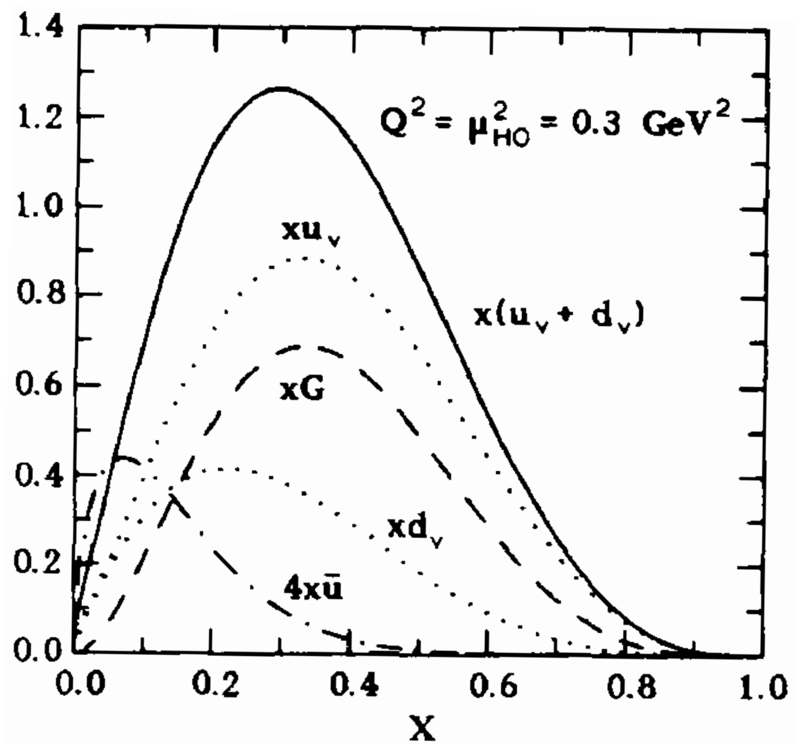
In nuclei:

- The nucleus is not just a sum of protons and neutrons
- What is the difference?
  - Binding via virtual mesons affects antiquarks distributions

Simple view of parton distributions: A historic approach



- Constituent Quark/Bag Model motivated valence approach
  - Use valence-like (primordial) quark distributions at some very low scale, Q^2, perhaps a few hundred MeV
  - Radiatively generate sea and glue. Gluck, Godbole, Reya, ZPC **41** 667 (1989)
- It was quickly realized that some valence-like (primordial) sea was needed. Gluck, Reya, Vogt, ZPC 53, 127 (1992)
  - Driven by need to agree with BCDMS and EMC data
  - Assumption of symmetric sea remained



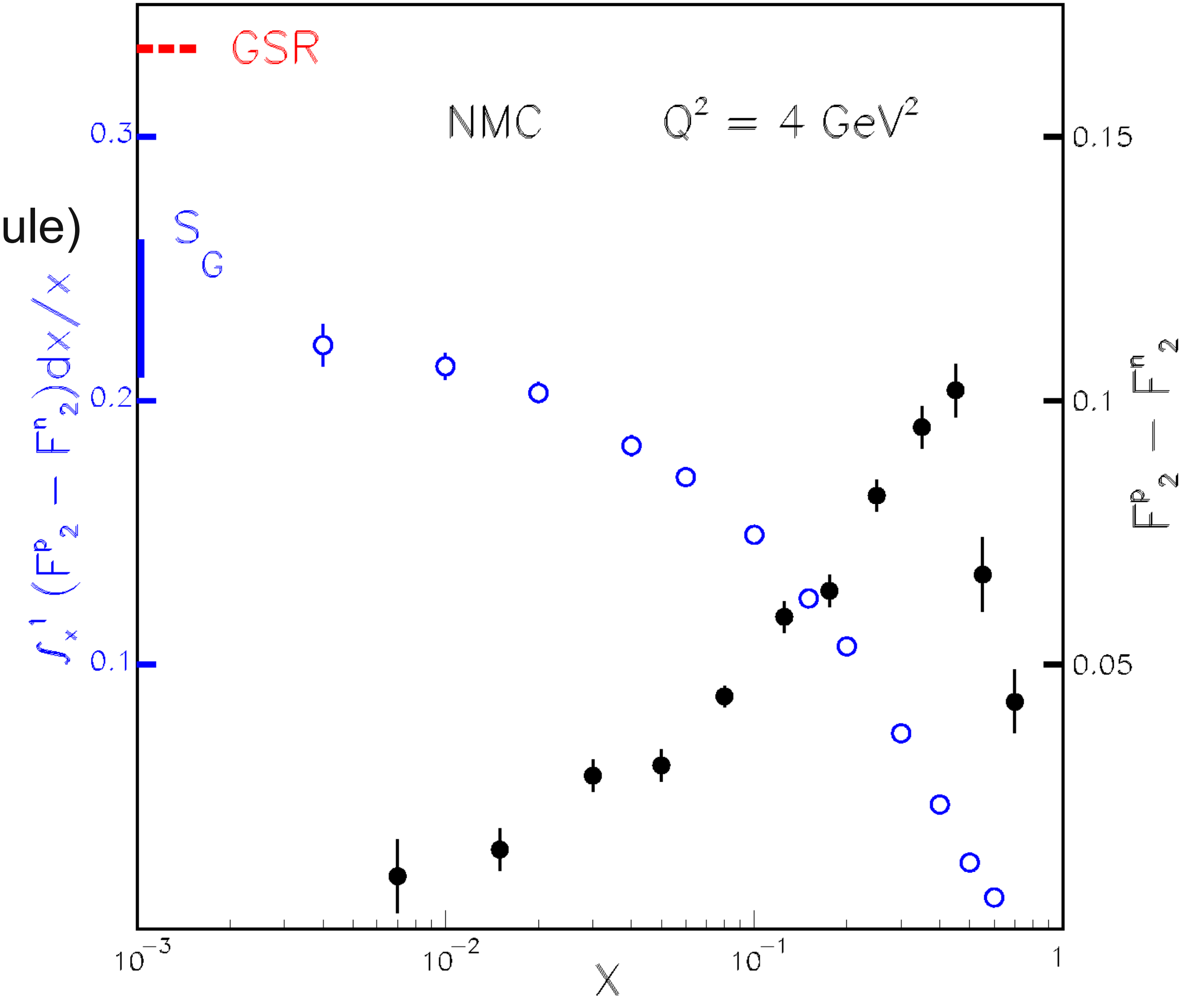
Light Antiquark Flavor Asymmetry: Brief History

- Naïve Assumption:

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

- NMC (Gottfried Sum Rule)

$$\int_0^1 \left[\bar{d}(x) - \bar{u}(x)\right] dx \neq 0$$



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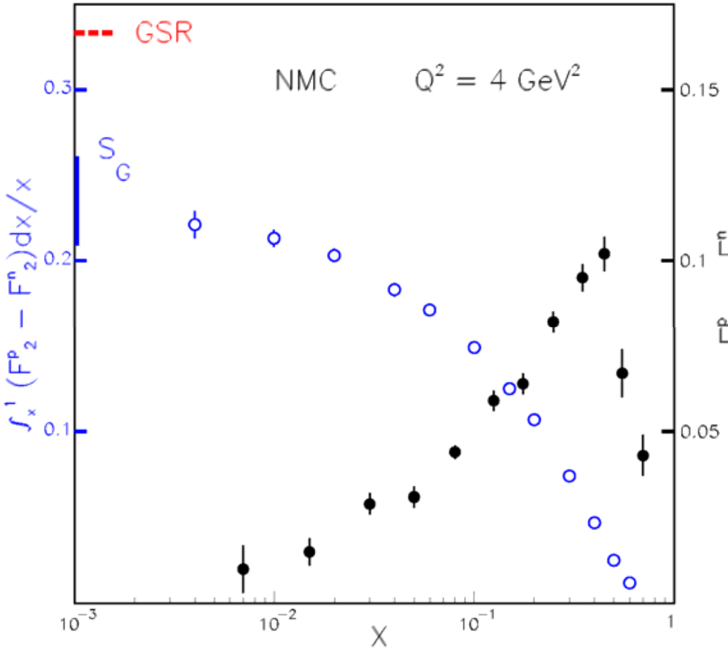

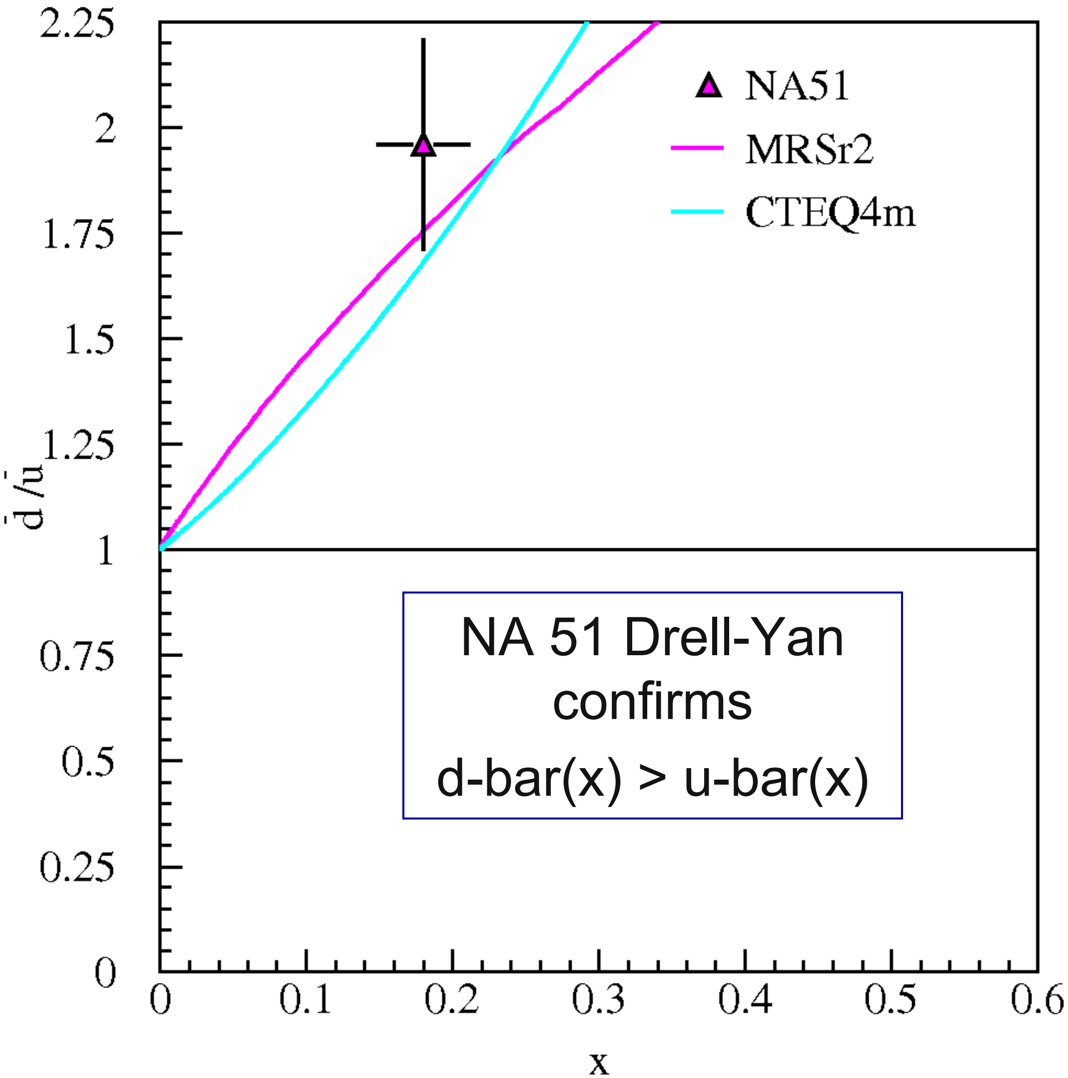

NA 51 Drell-Yan confirms d-bar(x) > u-bar(x)

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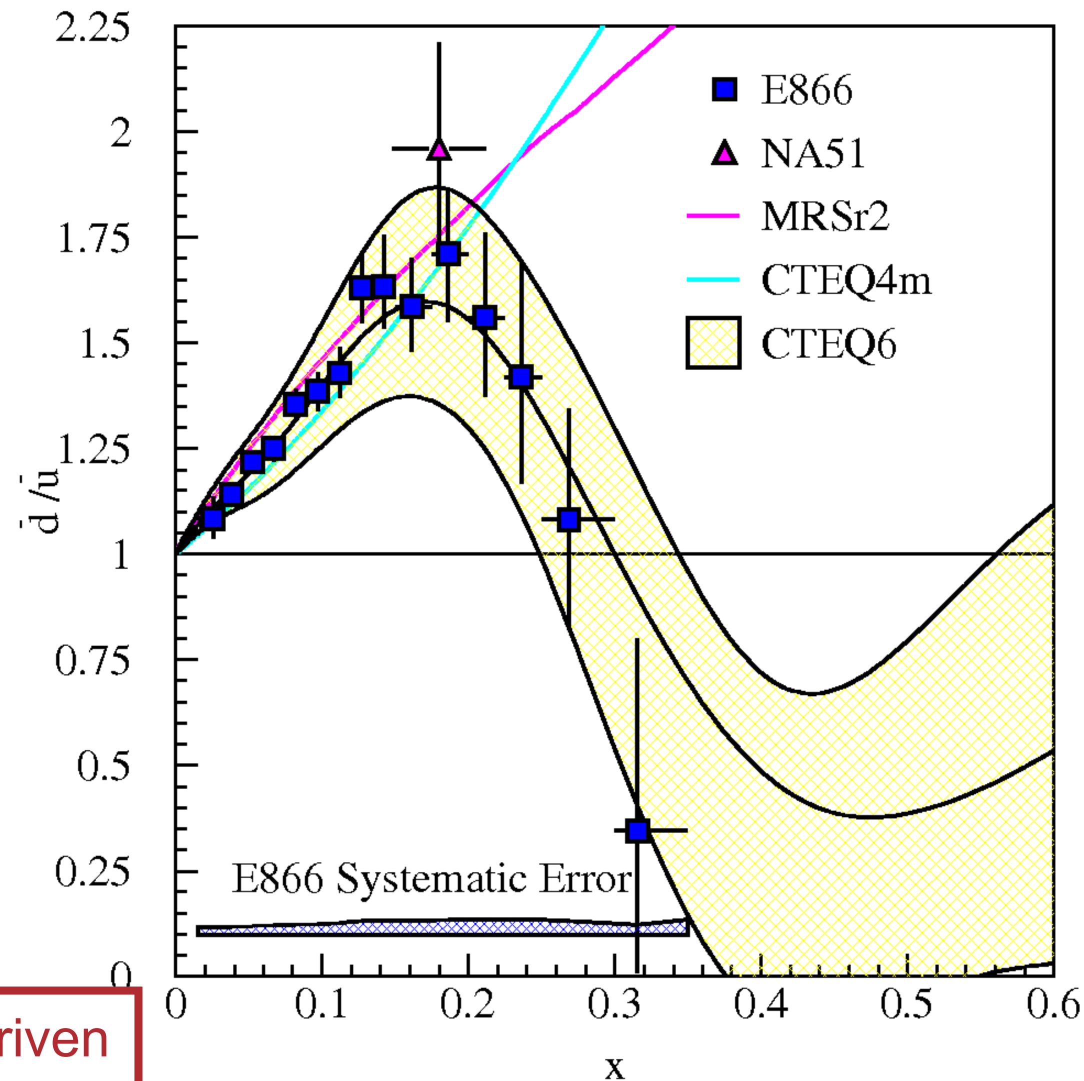
Drell-Yan

5 ˘q [v / Q5 [v _b H H I f/Q f l q»_d / ¢»_d }

- NA51 (Drell-Yan)
  $\bar{d} > \bar{u}$ at $x = 0.18$
- E866/NuSea (Drell-Yan)
  $\bar{d}(x)/\bar{u}(x)$ for $0.015 \leq x \leq 0.35$



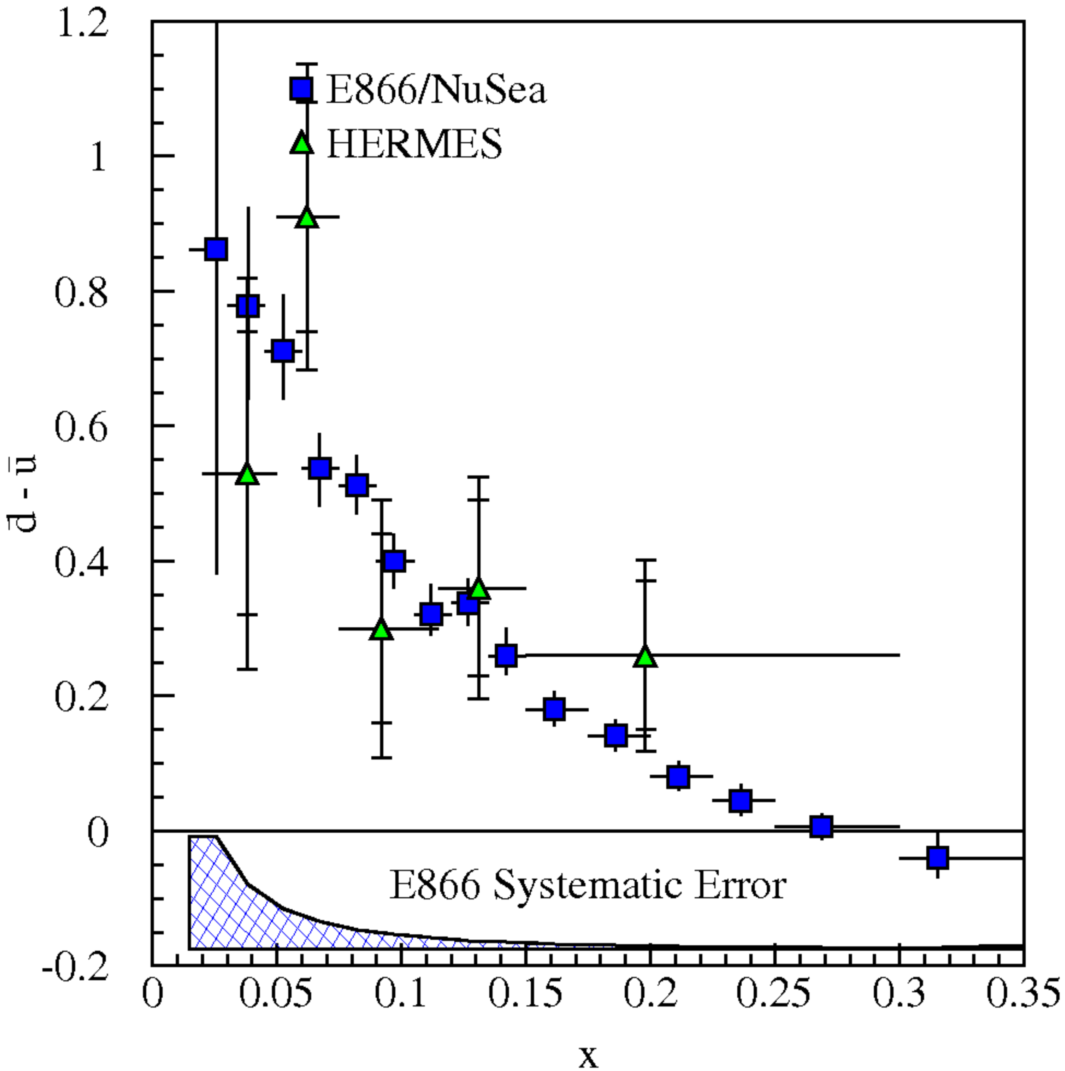
- Knowledge of partons is data driven
  – Sea quark difficult for Lattice QCD

Proton Structure: By What Process Is the Sea Created?

- 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
  - Nonperturbative models are motivated by the observed difference



Models Relate Antiquark Flavor Asymmetry and Spin

- Meson Cloud in the nucleon—Sullivan process in DIS

#" O" x I »ƒ 1 ‰ 1 kd#" H O" H x l ‰#} H DO} H D x l ˘#& H DO& H DxSSS

X ƒ j ˚ q»_d1 ¢»_d † I Q‰ 1 k / – I HSƒH , ‰ I HSQ I Qk   O| I X ƒ ^& ¢ 1 & qhq_ I … / – 1 QH D / Q– Q‰k , ƒS..
H   H

- Chiral Quark models—effective Lagrangians

#rOrx I ƒ 1 –‰ / Q #rOrx l –‰ / Q #rDOrDx

X ƒ j ˚ q»_d1 ¢»_d † I Q‰ / – I HSƒH , ‰ I HSƒ [O| I X ƒ ^& ¢ 1 & qhq_ I … / – –‰ , ƒS[–
H   H

- Instantons

r / ¢ ‡ ¢ u q ‡ q u l ¢ u ¢ ‡ q u q ‡   q`»_d1 ¢`»_d I – / … ^& ¢`»_d1 & q`»_dh

- Statistical Parton Distributions

& ¢»_d1 & q»_d7 q»_d1 ¢»_d

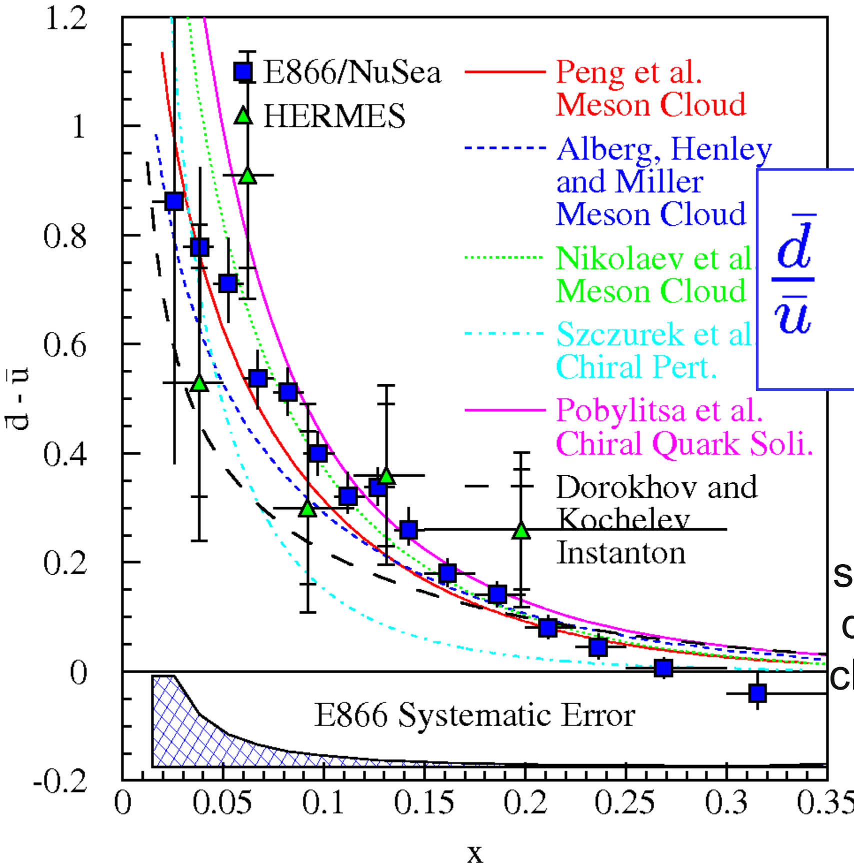
Proton Structure: By What Process Is the Sea Created?

- Meson Cloud in the nucleon

  Sullivan process in DIS
  $|p\rangle = |p_0\rangle + \alpha\,|N\pi\rangle + \beta|\Delta\pi\rangle + \ldots$

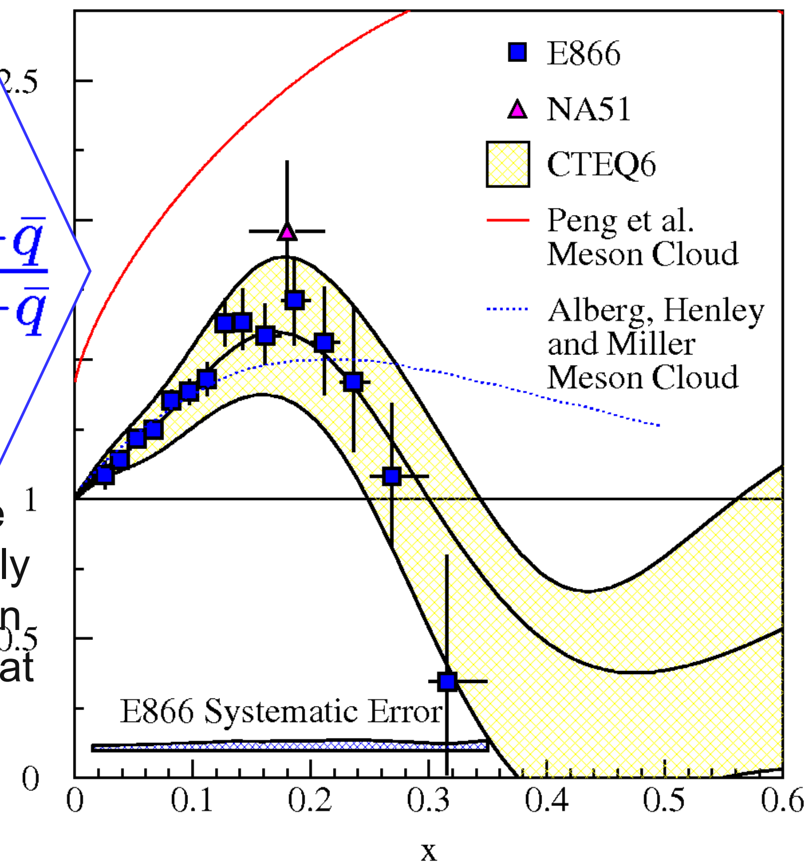
- Chiral Models

  Interaction between Goldstone Bosons and valence quarks
  $|u\rangle,\ |d\pi^+\rangle$ and $|d\rangle,\ |u\pi^-\rangle$

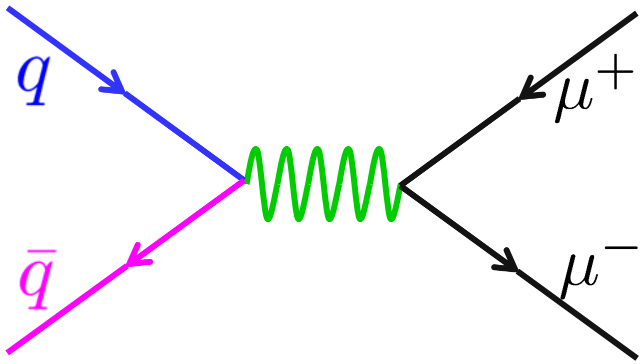


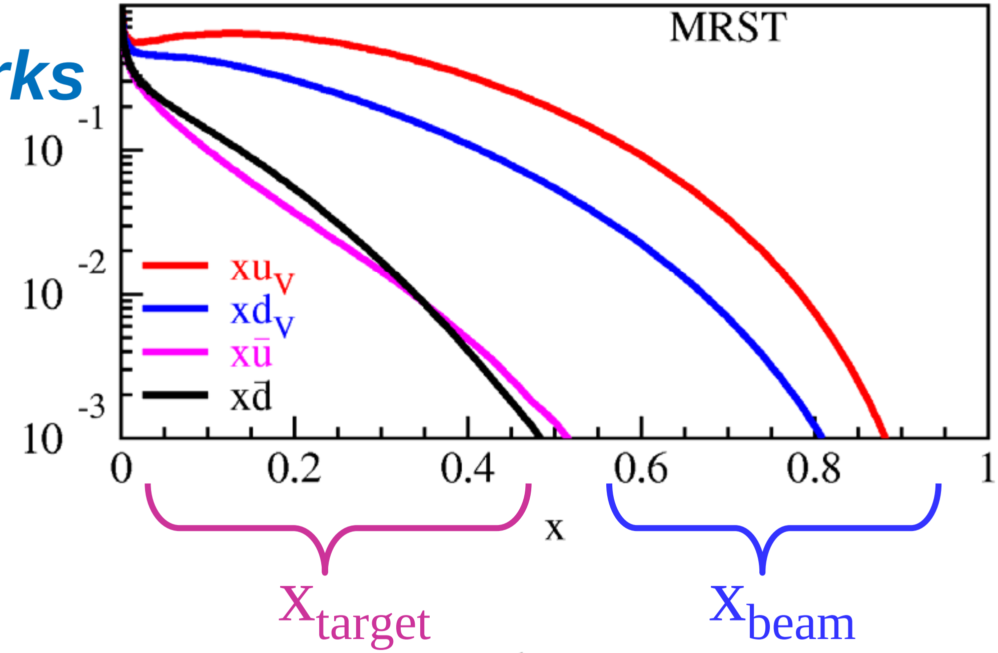
$$\frac{\bar{d}}{\bar{u}} = \frac{\bar{d}^{\pi} + \bar{q}}{\bar{u}^{\pi} + \bar{q}}$$

Perturbative sea apparently dilutes meson cloud effects at large-x



Drell-Yan scattering:
A laboratory for sea quarks

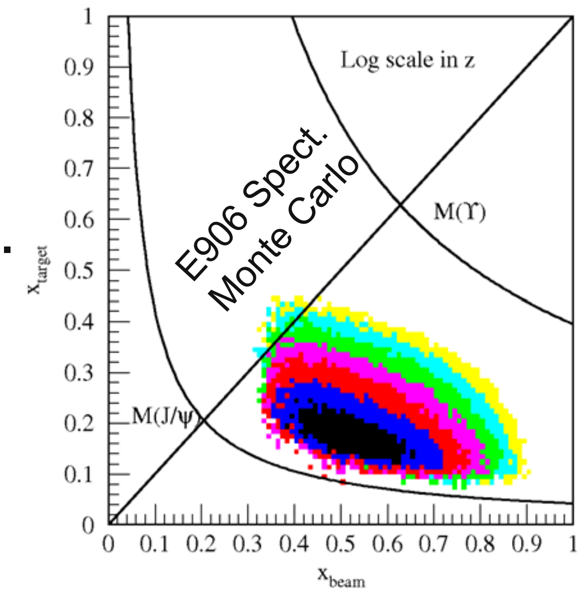




$$\frac{d^2\sigma}{dx_1 dx_2} = \frac{4\pi\alpha^2}{9x_1x_2}\frac{1}{s}\sum e^2\left[\bar{q}_t(x_t)q_b(x_b) + q_t(x_t)\bar{q}_b(x_b)\right]$$

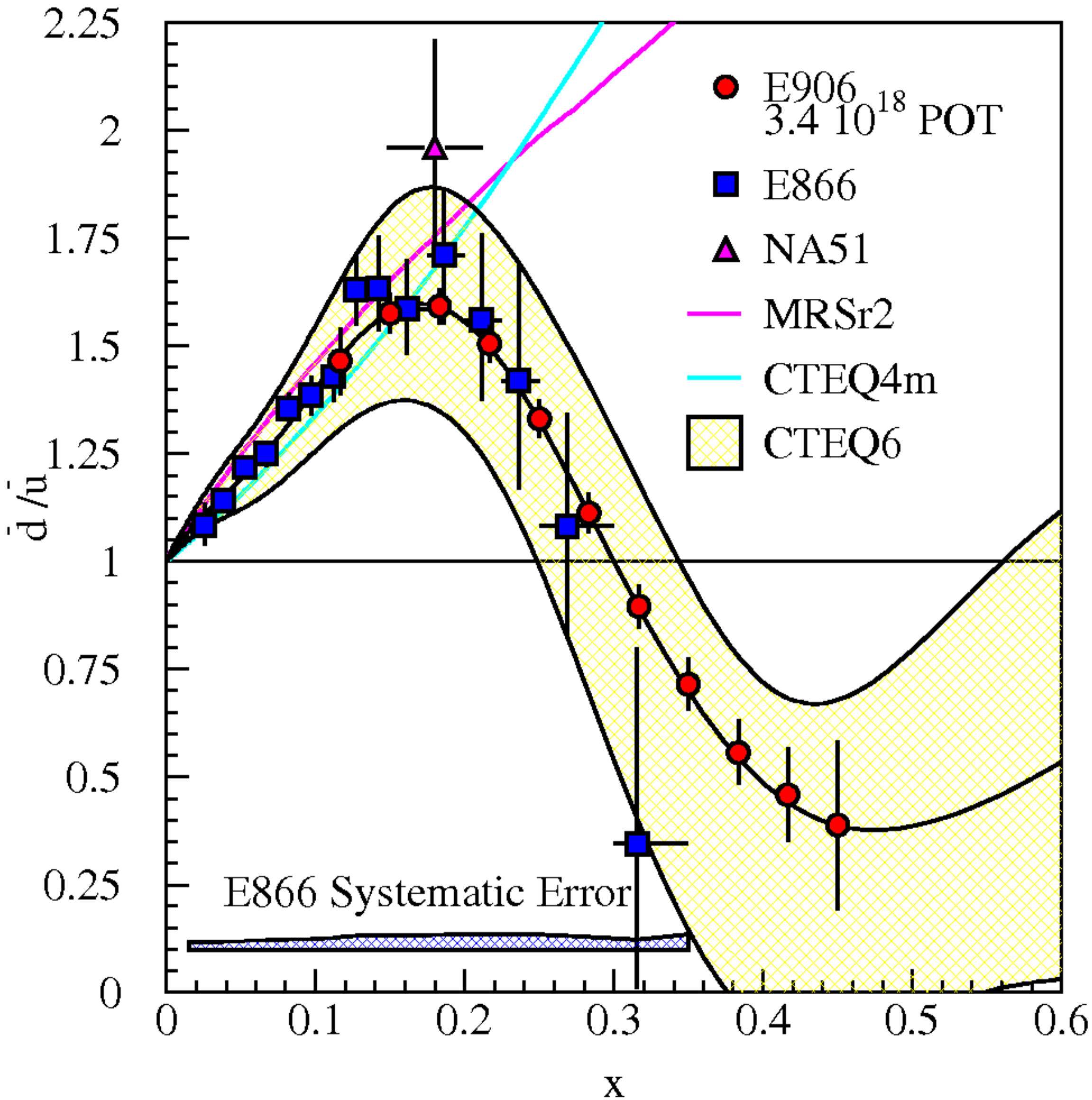
Detector acceptance chooses x_{target} and x_{beam}.

- Fixed target ‡ high $x_F = x_{beam} - x_{target}$
- Valence Beam quarks at high-x.
- Sea Target quarks at low/intermediate-x.



Extracting d-bar/-ubar From Drell-Yan Scattering

- E906/Drell-Yan will extend these measurements and reduce statistical uncertainty.
- E906 expects systematic uncertainty to remain at approx. 1% in cross section ratio.



Advantages of 120 GeV Main Injector

The (very successful) past:

Fermilab E866/NuSea

- Data in 1996-1997
- ^1H, ^2H, and nuclear targets
- 800 GeV proton beam

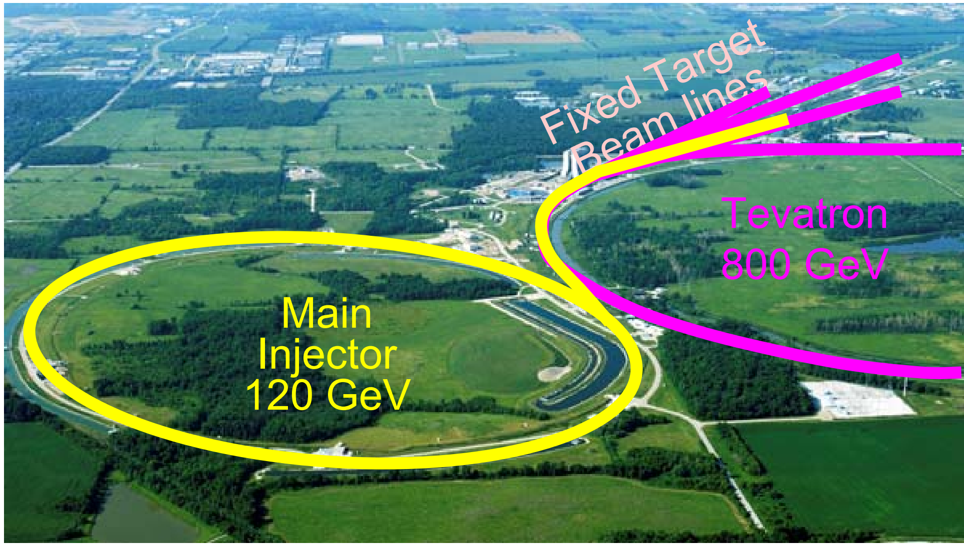
The future:

Fermilab E906

- Data in 2009
- ^1H, ^2H, and nuclear targets
- 120 GeV proton Beam

$$\frac{d^2\sigma}{dx_1 dx_2} = \frac{4\pi\alpha^2}{9x_1x_2}\frac{1}{s} \times \sum_i e_i^2 \left[q_{ti}(x_t)\bar{q}_{bi}(x_b) + \bar{q}_{ti}(x_t)q_{bi}(x_b)\right]$$

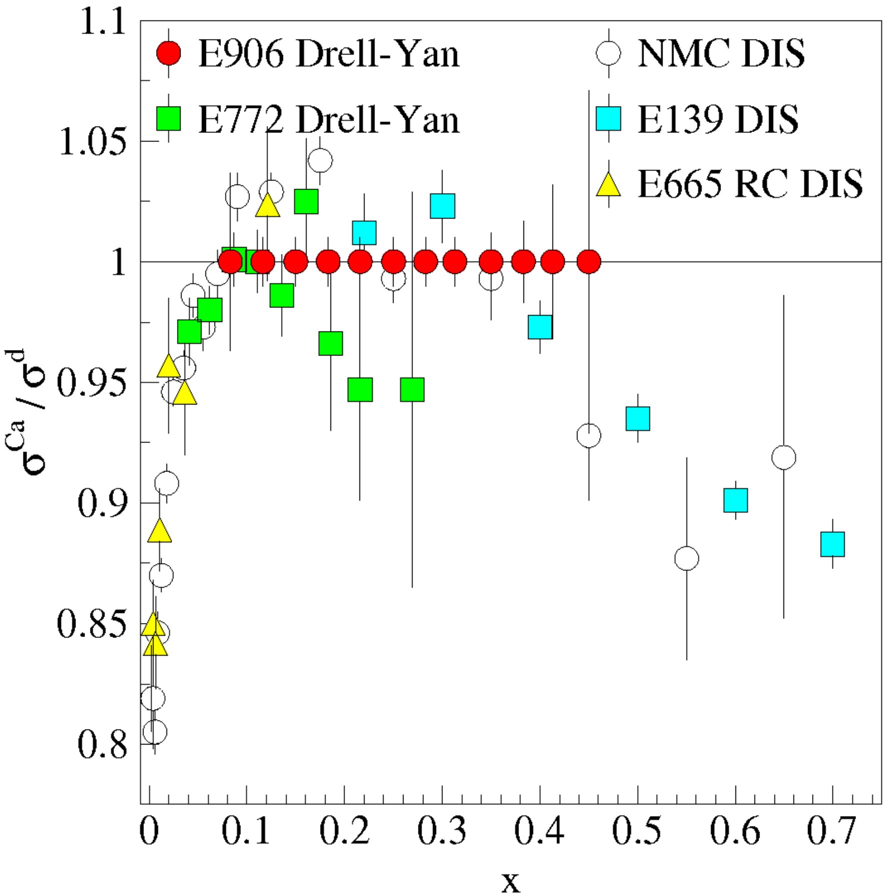
- Cross section scales as *1/s*
  - 7 × that of 800 GeV beam
- Backgrounds, primarily J/ψ decays scale as *s*
  - 7 × Luminosity for same det. rate

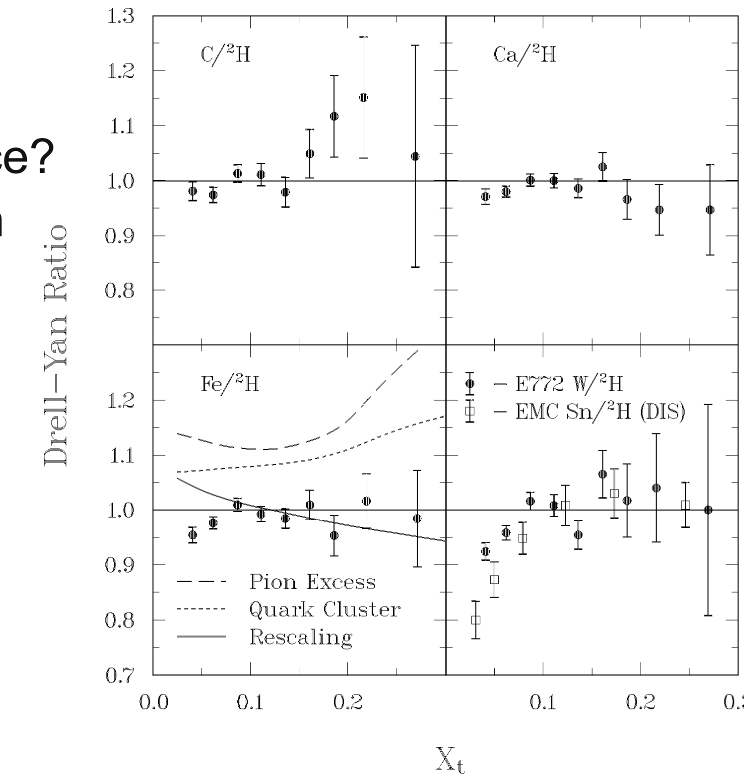


50 × Statistics

How do sea quark distributions differ in a nucleus?

- Sea PDF's set by ν-DIS on iron.
  - Nuclear effects the same for sea and valence?
  - Are nuclear effects with the weak interaction the same as electromagnetic?



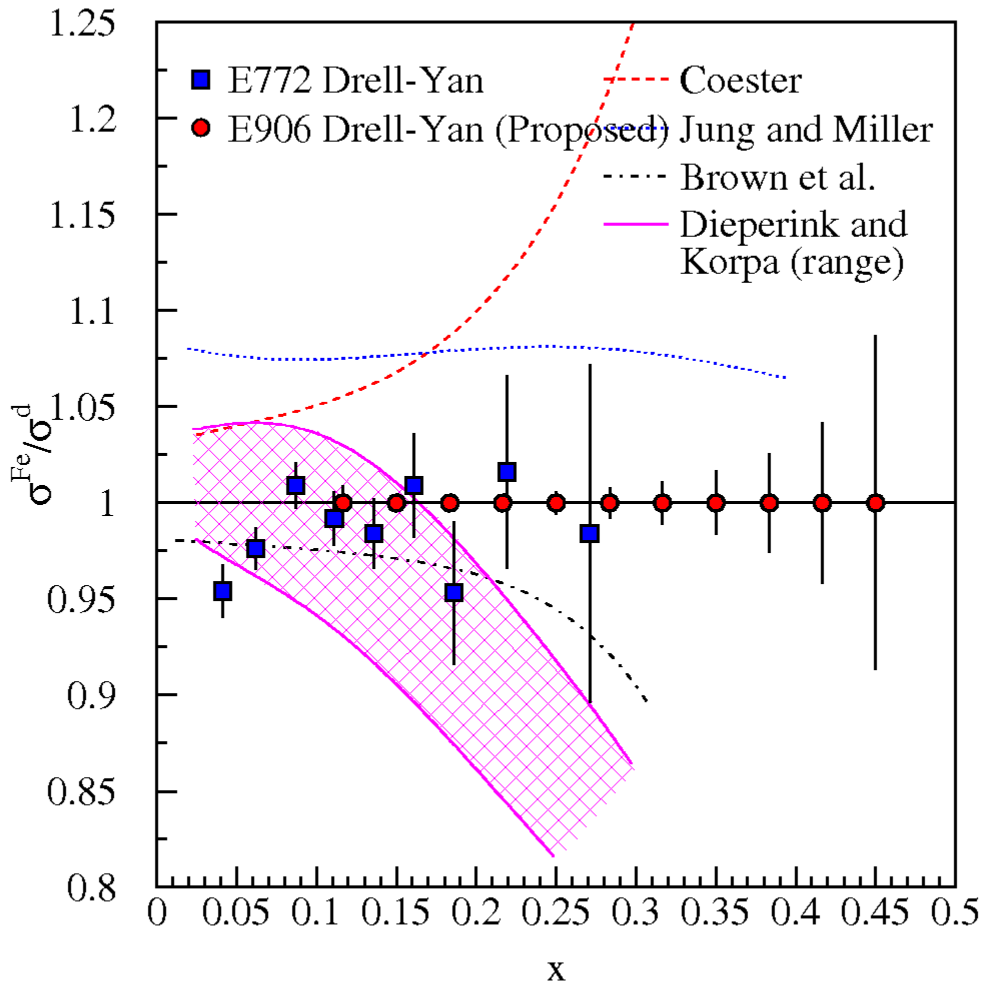


Alde *et al* (Fermilab E772) Phys. Rev. Lett. **64** 2479 (1990)

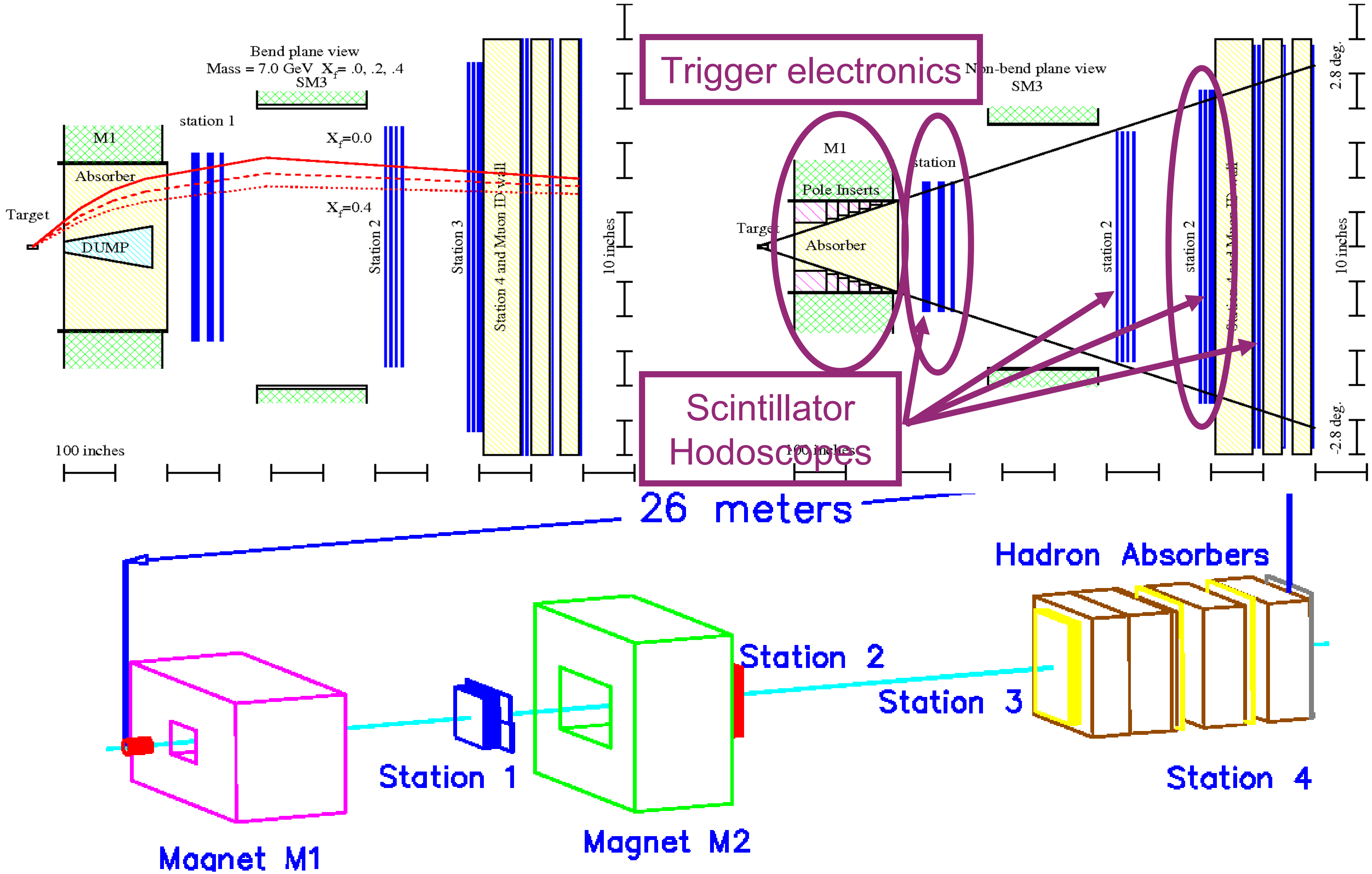
- EMC: Parton distributions of bound and free nucleons are different.
- Antishadowing not seen in Drell-Yan—Valence only effect
- What can the sea parton distributions tell us about the effects of nuclear binding?

Structure of nucleonic matter: Where are the nuclear pions?

- 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



E906 Detector



Fermilab E906/Drell-Yan Collaboration

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University of Colorado
Ed Kinney

Fermi National Accelerator Laboratory
Chuck Brown

University of Illinois
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Institutions under negotiation

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KenIchi Imai, Tomofumi Nagae

RIKEN

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Tokyo Tech

Toshi-Aki Shibata, Yoshiyuki Miyachi

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Carl Gagliardi, Robert Tribble

Thomas Jefferson National Accelerator Facility
Dave Gaskell

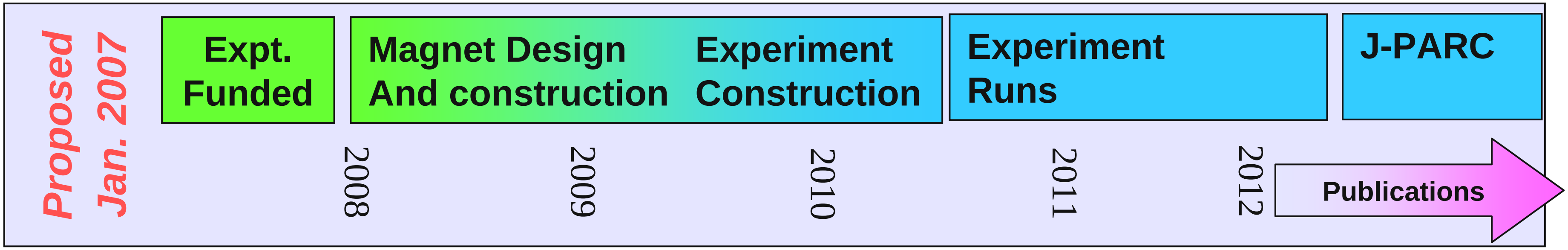
Valparaiso University
Don Koetke, Jason Webb

People with underline are included also in P04 and/or P24 at J-PARC.

E906/Drell-Yan timeline

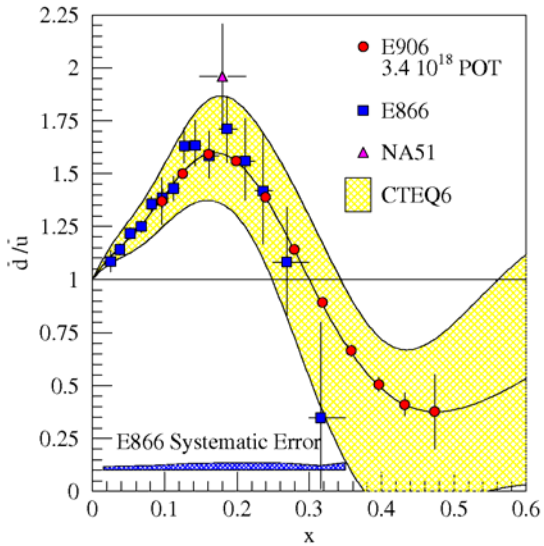
- Fermilab PAC approved the experiment in 2001, but experiment was not scheduled due to concerns about “proton economics”
- Spectrometer upgrade funded by DOE/Office of Nuclear Physics (already received $538k in FY07)
- Fermilab PAC reaffirms earlier decision in Fall 2006
- Scheduled to run in 2010 for 2 years of data collection

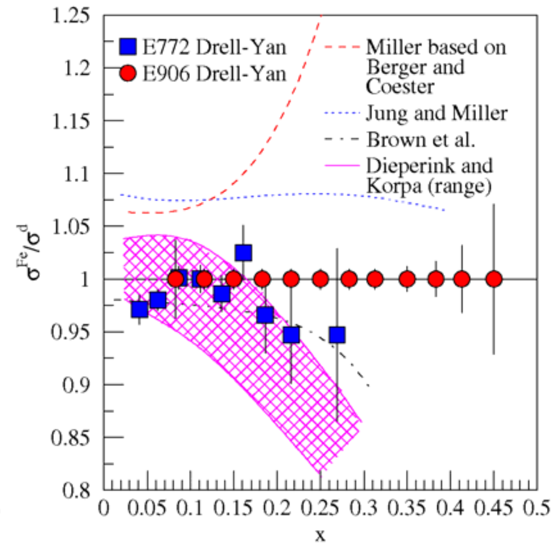
- Apparatus available for future program at J-PARC
  – Significant interest from collaboration for continued program here

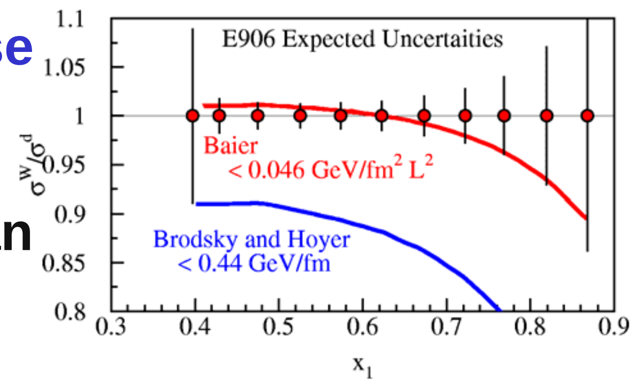


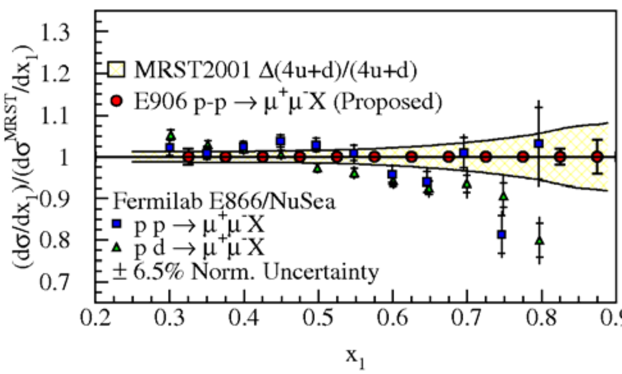
Drell-Yan at Fermilab

- **Study antiquark distributions**
- **Proton: d-bar/ubar**
  - The origins of the sea quarks
- **Nucleon: Antiquark excess**
  - Nuclear binding
- **Absolute cross sections—high-x valence distributions**
- **Do colored partons lose energy in cold nuclear matter?**
- **Fermilab E906/Drell-Yan**
  - Spectrometer funded
  - Expect data in 2010









- **Drell-Yan at J-PARC**
  - Additional interesting physics, particularly with polarized beam/target
  - Collaboration interested in moving spectrometer to J-PARC