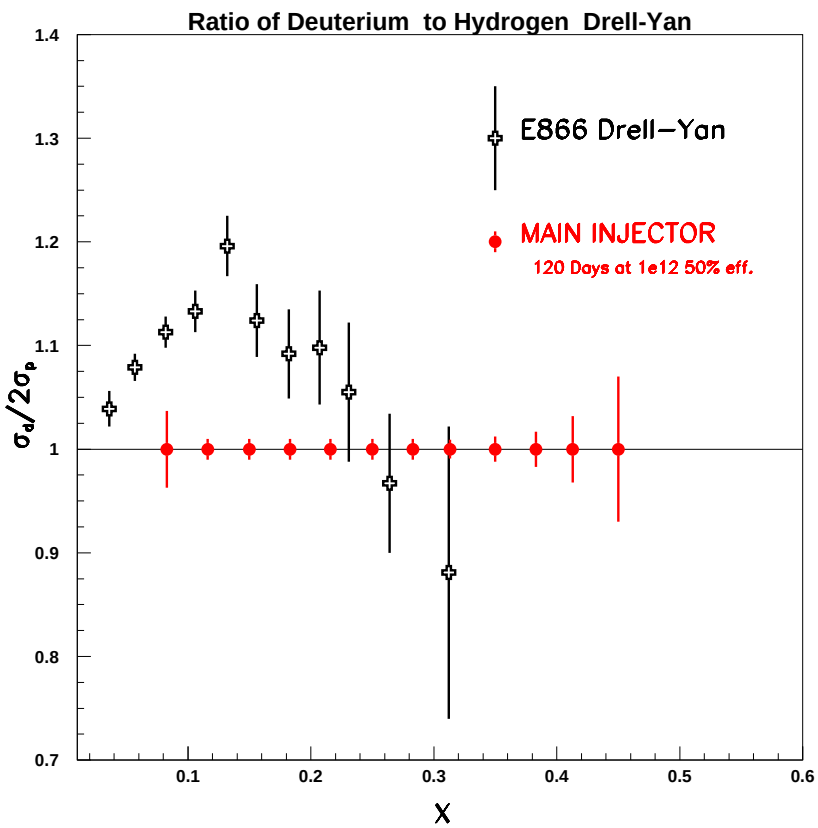
P906 – Proposal for
Drell-Yan Measurements of Nucleon and Nuclear Structure with the FNAL Main Injector.

The E906 Collaboration
(D. F. Geesaman Spokesman)

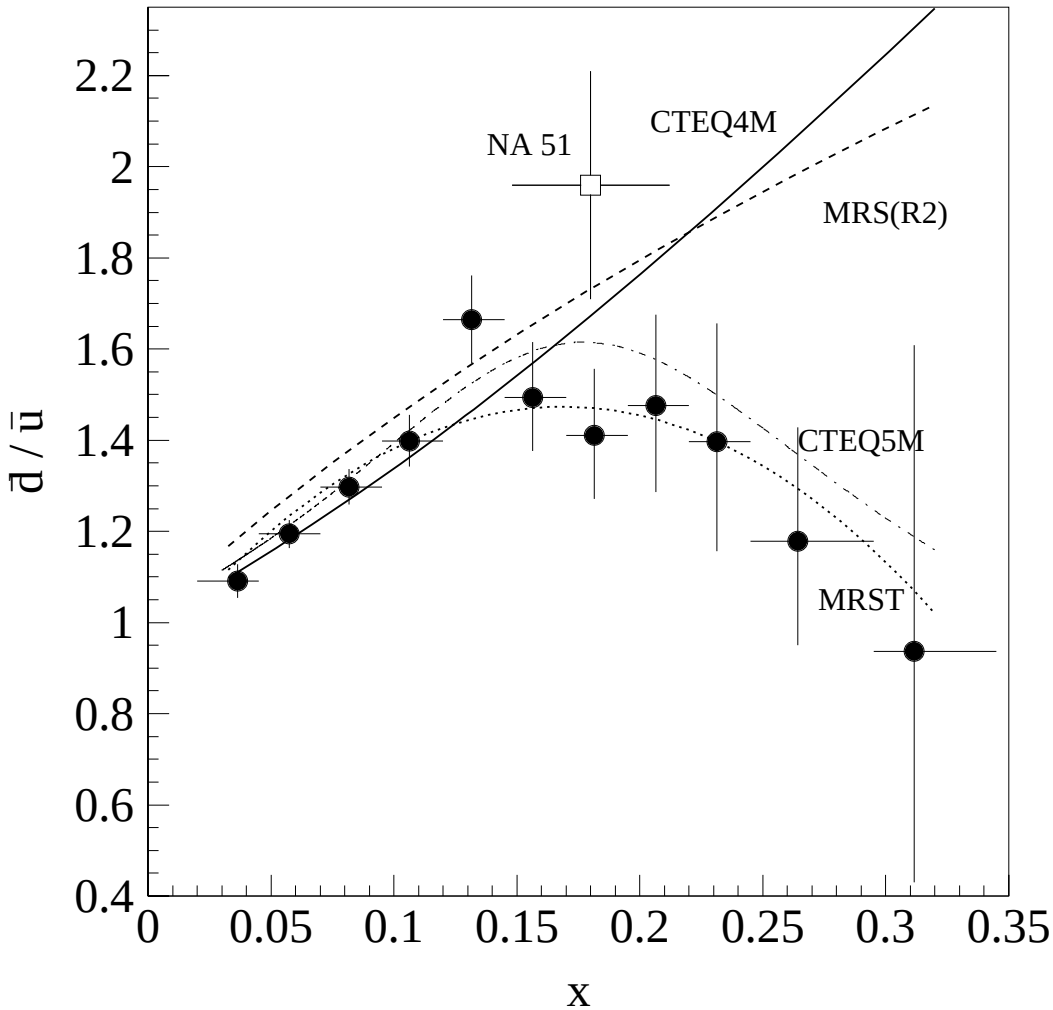
FNAL Physics Advisory Committee

May 14, 1999



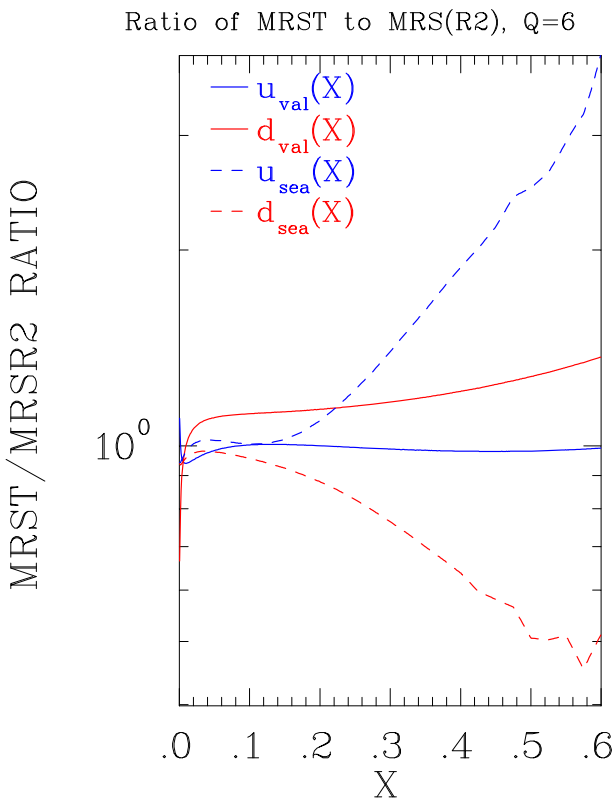
FNAL E866 results[7] for the x dependence of the ratio of $\sigma_d/2\sigma_p$. The statistical uncertainties expected for the measurement proposed here are shown as the error bars on the solid circles (which are arbitrarily plotted at 1.0). The systematic errors are estimated to be less than 1%.

$\bar{d}/\bar{u}$ of the Proton



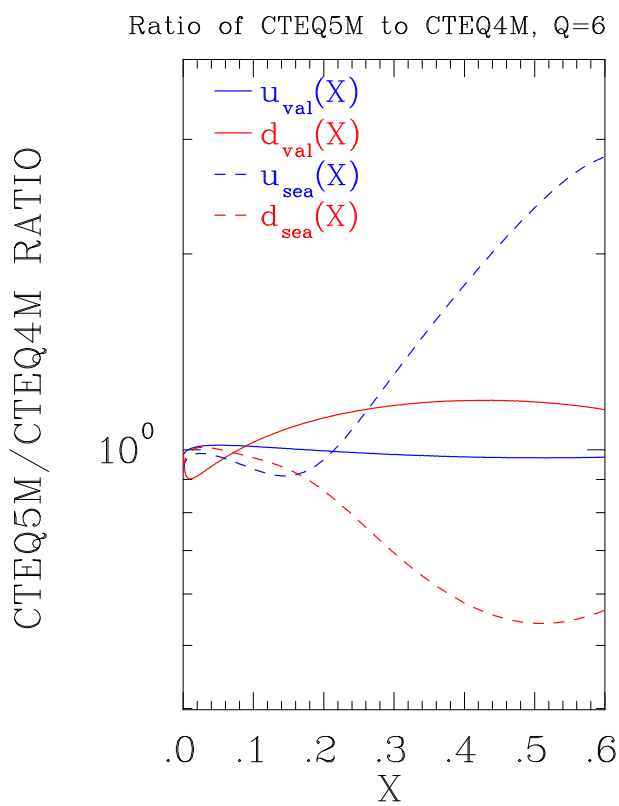
FNAL E866 results[7] for the x dependence of the ratio $\bar{d}/\bar{u}$ of the proton at a mass scale of 7.35 GeV. The square is the NA51 result at a mass scale of 5.2 GeV [6]. The solid (dashed) curve represents the CTEQ4M [1] (MRS(R2) [3]) parameterization prior to the E866 results. The dot-dashed (dotted) curve is the CTEQ5 [2] (MRST [4]) parameterization which included the E866 data in the fitting procedure.

Impact on Parton Distributions

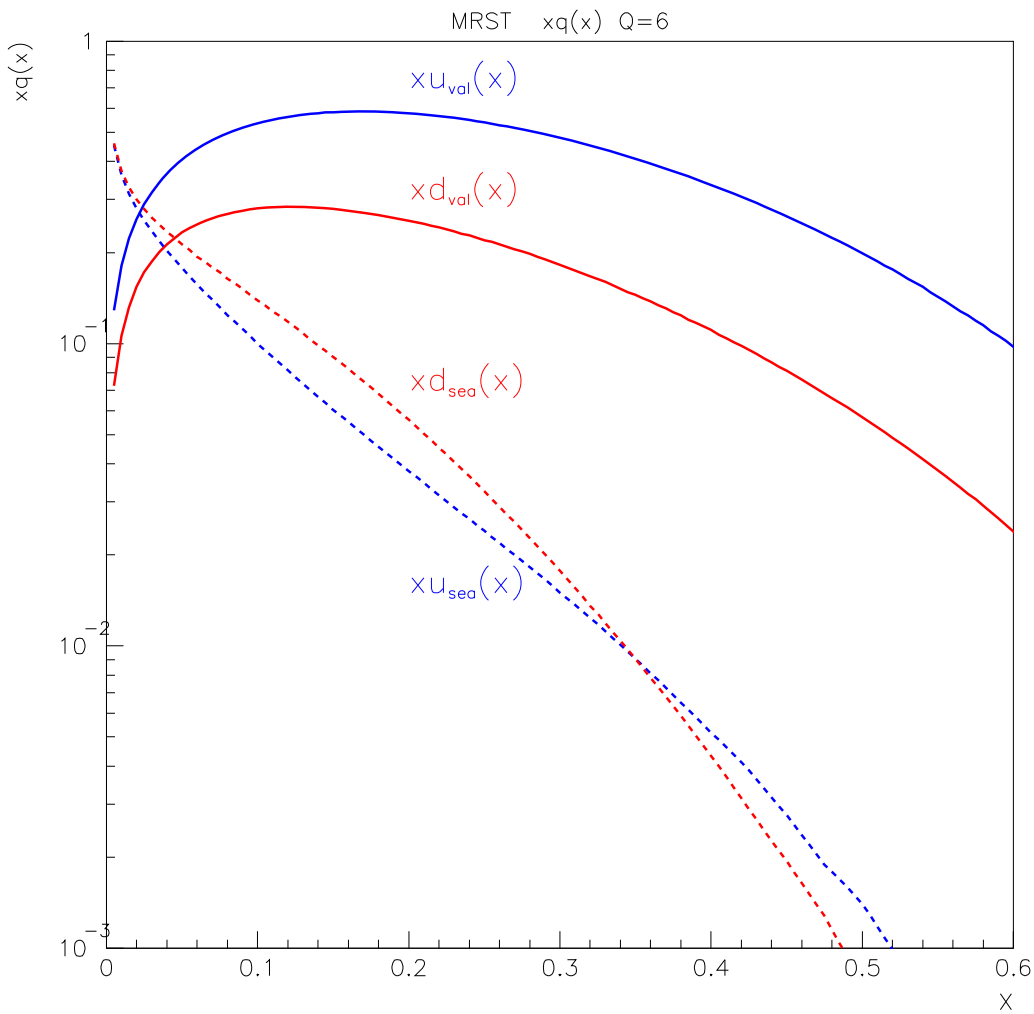


Ratio of MRST to MRS(R2) parton distributions at Q=6 GeV.

Ratio of CTEQ5 to CTEQ4 parton distributions at Q=6 GeV.



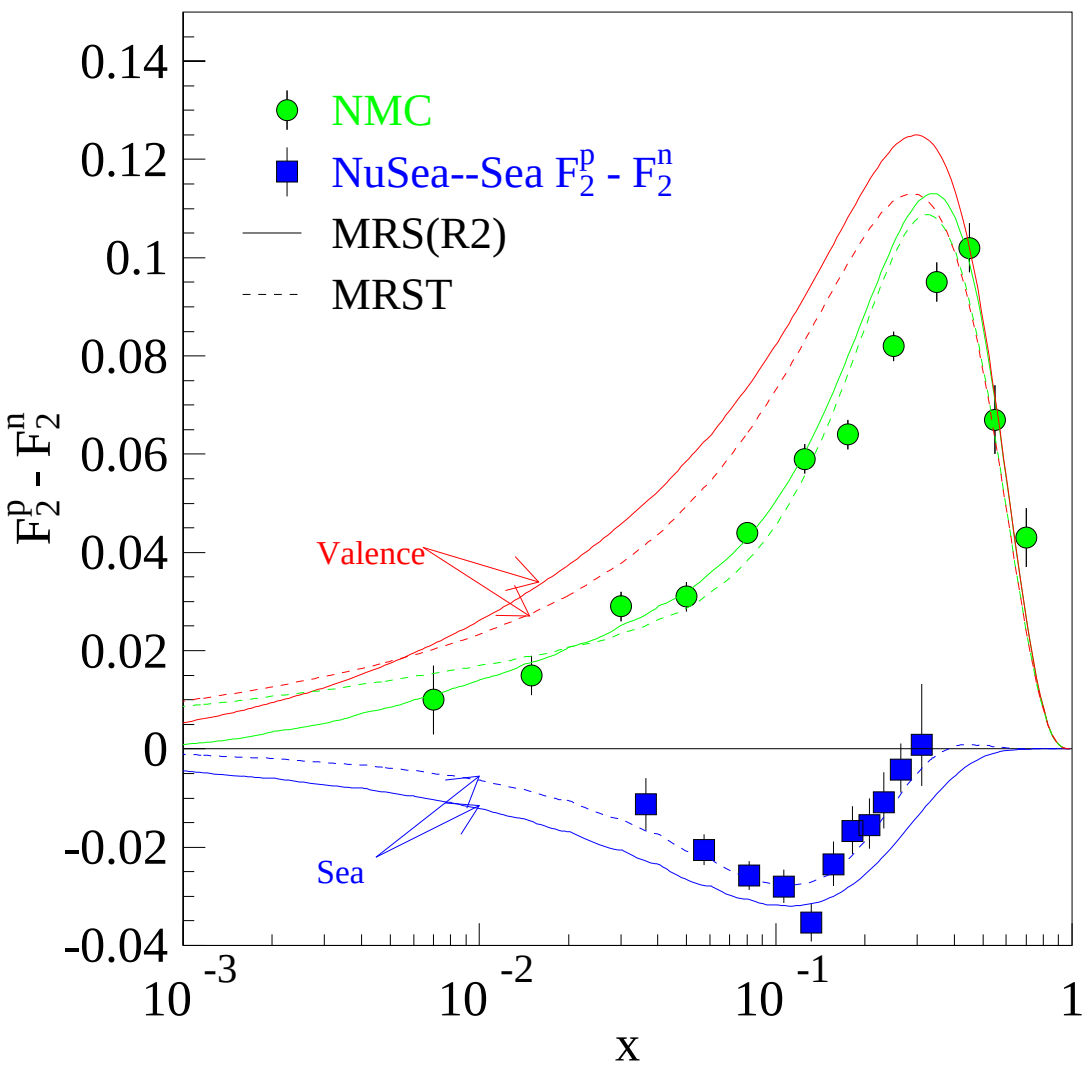
xq(x) for the MRST Parton Distribution Functions.



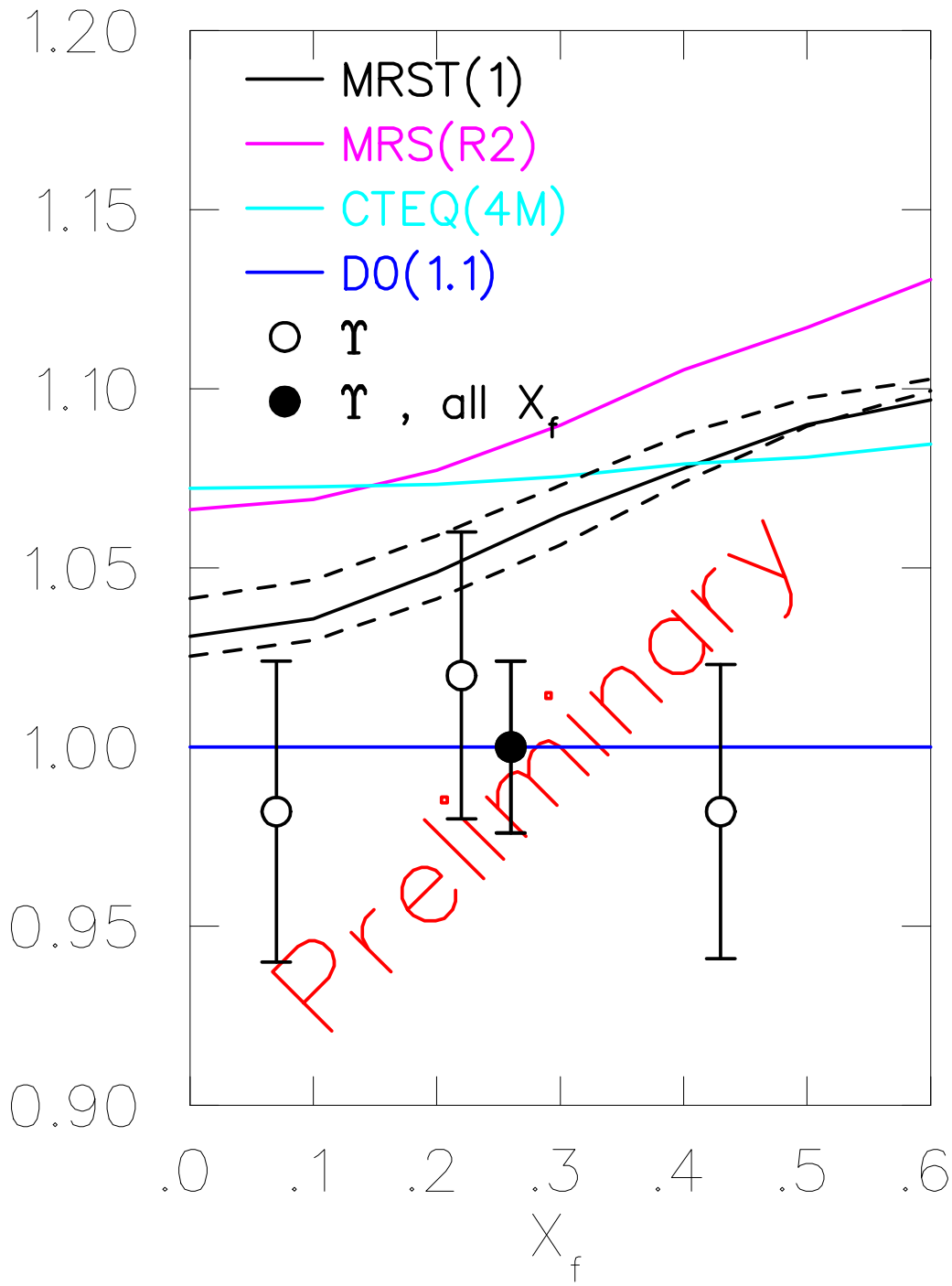
Comparison with NMC $F_2^{\mu p} - F_2^{\mu n}$

- Divide $F_2^{\mu p} - F_2^{\mu n}$ into its valence and sea parts

$$F_2^{\mu p} - F_2^{\mu n} = \frac{x}{3}\left[(u_v - d_v) + 2\left(\bar{u}_s - \bar{d}_s\right)\right]$$



Ratio of Υ Production on Hydrogen and Deuterium.



Competition between $Q - \bar{Q}$ and **g-g** production

Proton Structure

A model of the proton as 3 valence quarks plus glue cannot be right at any scale!

$\bar{d} - \bar{u} \Longrightarrow$ No gluon contribution at first order in α_s.
PQCD first contributes at 2nd order and is quantitatively small.

Non-Perturbative Structure

- **Hadronic Models** $|p\rangle + |N\pi\rangle + |\Delta\pi\rangle$

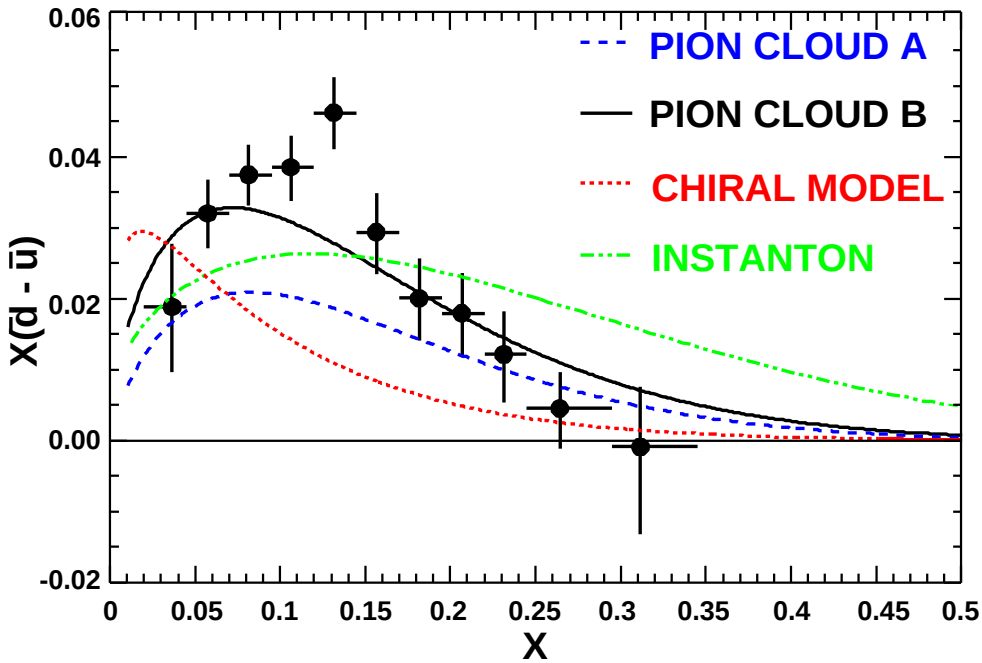
- **Chiral Quark Models** Effective Lagrangians

$$|q\rangle + |q\pi\rangle$$

- **Instantons**

$$\mathcal{L} \sim \bar{u}_R u_L \bar{d}_R d_L + \bar{u}_L u_R \bar{d}_L d_R$$

Model Comparisons for $x(\bar{d} - \bar{u})$



FNAL E866 results[8] for the x dependence of $x(\bar{d} - \bar{u})$ of the proton at a mass scale of 7.35 GeV. The curves represent four model calculations of $x(\bar{d} - \bar{u})$. The solid and dashed curves are the meson-cloud model calculations including nucleons, deltas and pions [8] with differing vertex cut-offs. The dotted curve is a chiral quark model of Szczurek et al. [15] and the dot-dot-dashed curve is the instanton inspired parameterization of Dorokhov and Kochelev [17].

- Hadronic model describes data for $x < 0.25$

  Calculation sensitive to hadron vertex functions.

- Chiral Models too soft

- Instanton - No prediction of x dependence

  Expected P_T dependence not observed.

Each of These Non-Perturbative Models Predicts Relations between $\bar{d} - \bar{u}$ and Spin Carried by Quarks.

- Hadron Models
  For
  $\langle P|P\rangle = (1-a-b)\langle P_0|P_0\rangle + a\langle N_0\pi|N_0\pi\rangle + b\langle\Delta_0\pi|\Delta_0\pi >$

$$\int_0^1 [\bar{d} - \bar{u}]dx = \frac{2a-b}{3} = .10 \rightarrow a = .2 = 2b$$

$$G_A = \int_0^1 [\Delta u - \Delta d]dx = \frac{5}{3} - \frac{20}{27}(2a+b) + \frac{32}{27}\sqrt{2ab} \rightarrow 1.5$$

- Chiral Models
  For $\langle q|q\rangle = (1-3a/2)\langle q|q\rangle + 3a/2\langle q\pi|q\pi\rangle$ in SU(2) toy model

$$\int_0^1 [\bar{d} - \bar{u}]dx = \frac{2a}{3} = .10 \rightarrow a = 0.14$$

$$G_A = \int_0^1 [\Delta u - \Delta d]dx = \frac{5}{3} - 3a \rightarrow 1.43$$

- Instantons

$$\bar{d}_I(x) - \bar{u}_I(x) \quad = \quad \frac{3}{5}(\Delta u_I(x) - \Delta d_I(x))$$

Using Drell-Yan to Measure $\bar{d}/\bar{u}$

$$p + p \to \gamma_v + X \to \mu^+\mu^- + X$$

$$x_F = p_{\|}^{\gamma}/p_{\|}^{\gamma,max} = x_1 - x_2$$
$$x_1 x_2 s = M_{\gamma}^2$$

$$\frac{d\sigma}{dx_1 dx_2} = \frac{4\pi\alpha^2}{9sx_1x_2}\sum_i e_i^2(q_i^b(x_1,Q^2)\bar{q}_i^t(x_2,Q^2)+\bar{q}_i^b(x_1,Q^2)q_i^t(x_2,Q^2))$$

Assumptions and Technique

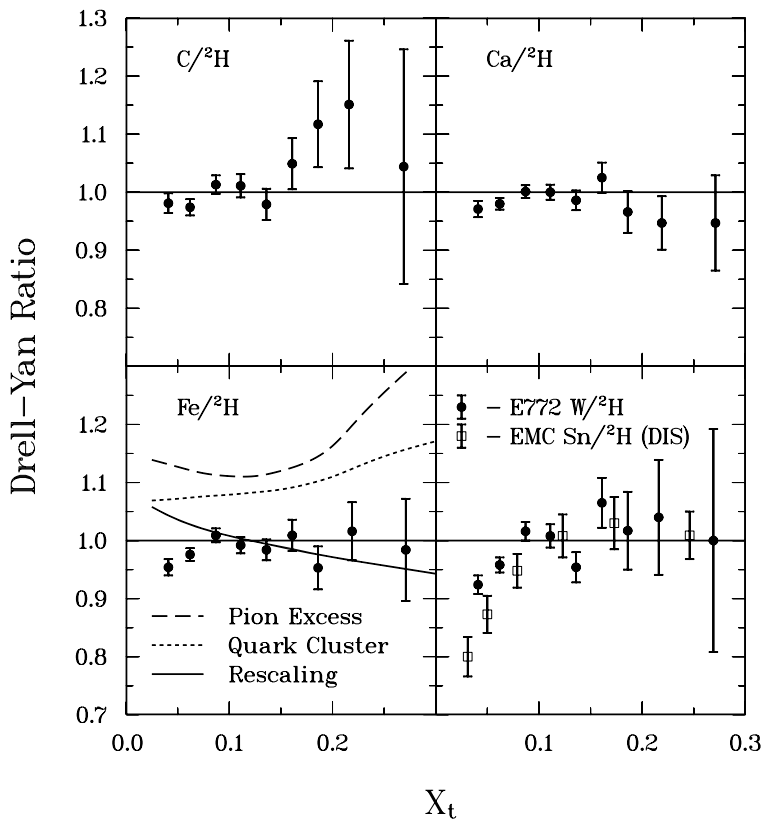
- No nuclear effects in deuterium.
- Charge symmetry $\bar{u}_p = \bar{d}_n$, $u_p = d_n$ etc.
- Choose kinematics with x_1 in valence dominated region of proton.
- To extract $\bar{d}/\bar{u}$ take u_{val}, d_{val}, $\bar{u}_p + \bar{d}_p$, s, c, from global fits: CTEQ, MRS.

$$\frac{\sigma^{pd}}{2\sigma^{pp}}\bigg|_{x_1>>x_2} \approx \frac{1}{2}\frac{(1+\frac{d(x_1)}{4u(x_1)})}{(1+\frac{d(x_1)\bar{d}(x_2)}{4u(x_1)\bar{u}(x_2)})}\left(1+\frac{\bar{d}(x_2)}{\bar{u}(x_2)}\right)$$

$$\frac{\frac{1}{A_X}\frac{d\sigma^X}{dx_1dx_2}}{\frac{1}{A_Y}\frac{d\sigma^Y}{dx_1dx_2}} \approx \frac{\bar{u}^X(x_2)}{\bar{u}^Y(x_2)}.$$

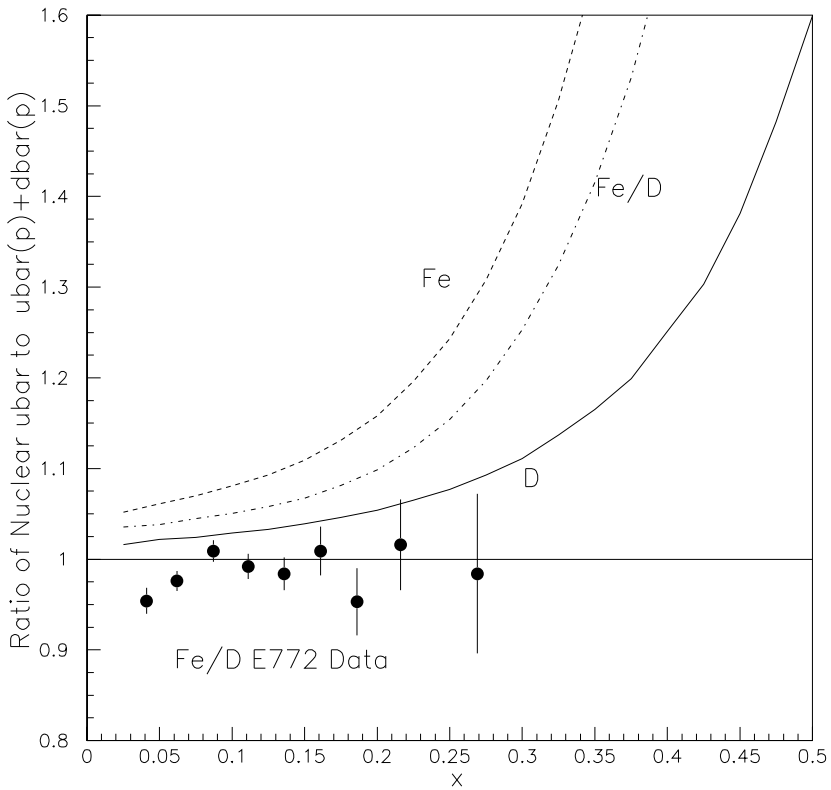
Nuclear Effects

- Experimental test that nuclear effects are under control in deuterium.
- Compare $\bar{u} + \bar{d}$ with CCFR iron measurements
- Intrinsic interest in models of nuclear dependence of parton distributions and parton energy loss.



E772 measurements of the ratio of Drell-Yan cross sections on nuclear targets to deuterium [18].

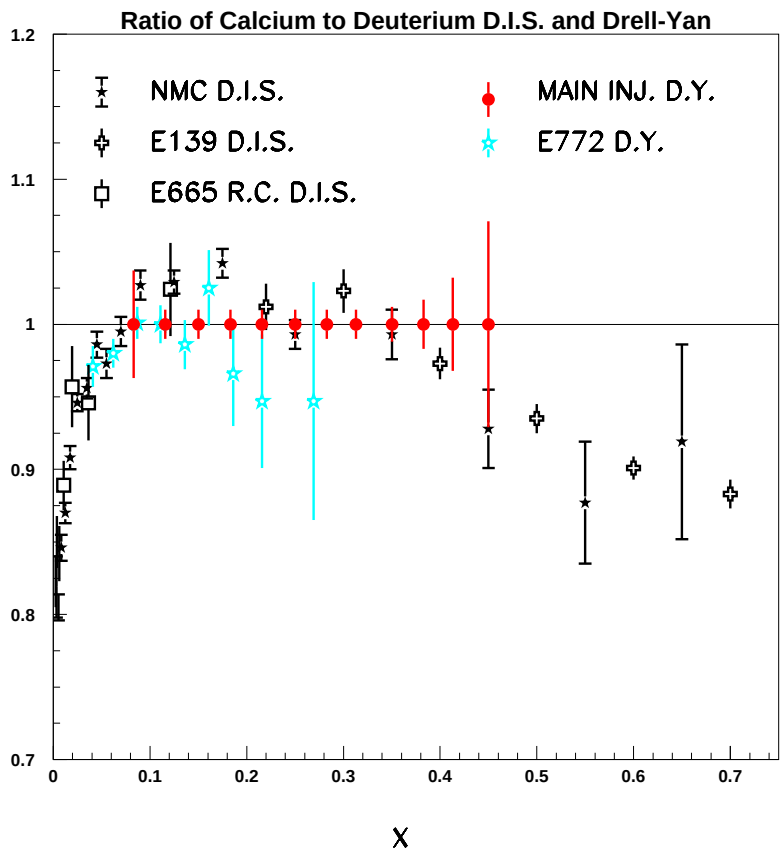
Nuclear Pion Calculations Predict Larger Nuclear Effects.



Ratio of $\bar{u}$ in deuterium to $(\bar{u}_p + \bar{d}_p)/2$ (solid) as calculated by Coester [19] including both nuclear motion and pion contributions. The dashed curve is the same quantity for Fe, and the dot-dashed curve is the ratio of iron to deuterium which should be directly comparable to the E772 data [18].

• Predicted effects in deuterium are small in region of E866 data but become more important at $x > 0.3$.

Expected Precision in P906 D.Y. Nuclear Cross Section Ratios



Compilation of deep inelastic and Drell-Yan results on the ratio of cross sections on calcium to deuterium. The statistical uncertainties expected for the measurement proposed are shown as the error bars on the solid circles (which are arbitrarily plotted at 1.0).

- Have the sensitivity to see reduction expected in Q^2 rescaling model of EMC effect.

120 GeV Drell-Yan with the Main Injector

Advantages

- For fixed x_1 and x_2 the cross section is $\propto 1/E_{beam}$. Factor of ~7 advantage at Main Injector compared to Tevatron.

- In E866 at 800 GeV, single muons from J/Ψ events from the beam dump were a significant contribution to the muon singles rates. At 120 GeV the total $\sigma(J/\Psi)$ are an order of magnitude lower.

Disadvantages

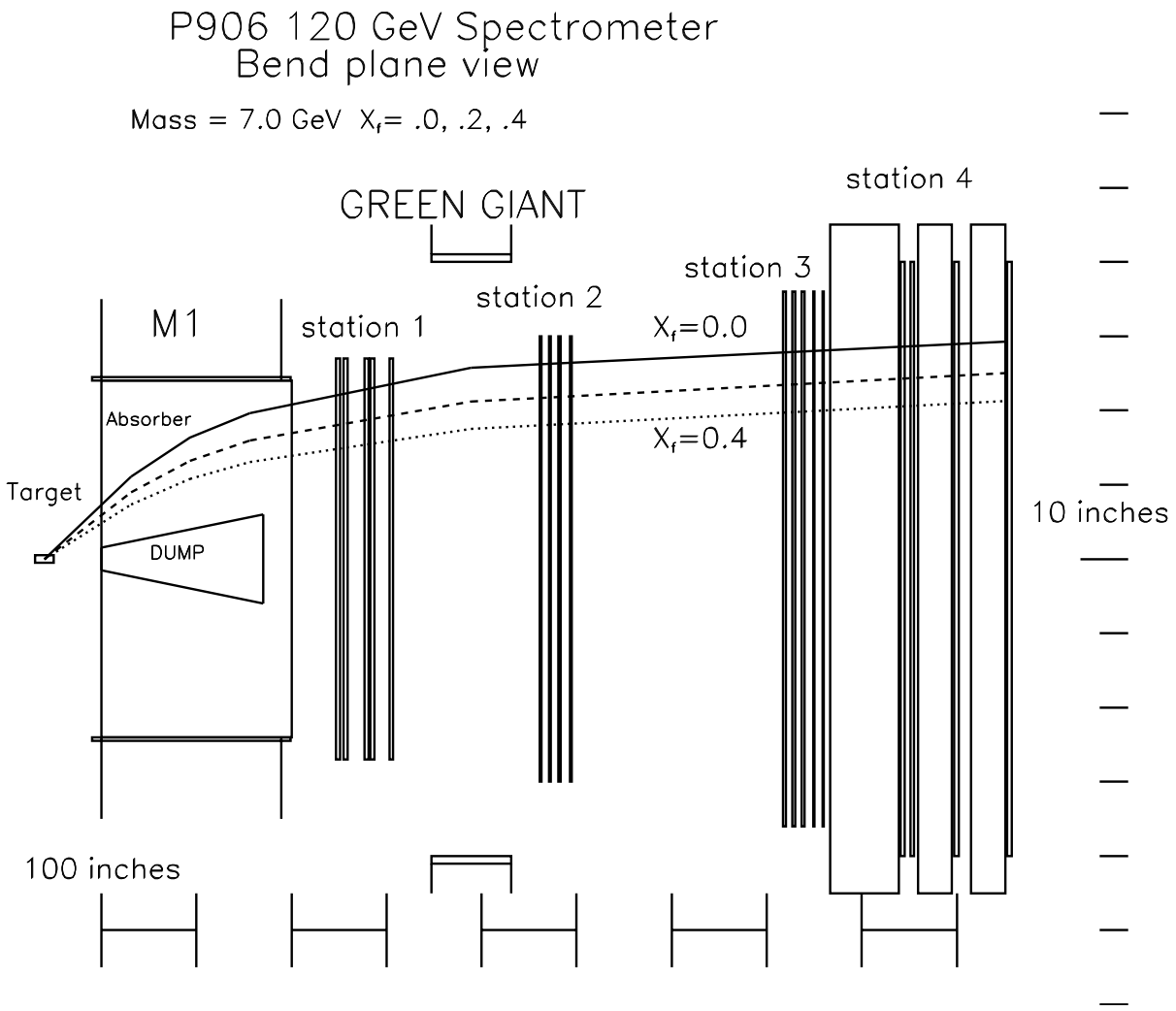
- The lower particle energies lead to increased probabilities for hadron decay to muons. Reduce target-to-hadron-absorber distance to $\sim 1.0 - 1.5$ m.

- The lower energy muons multiple scatter more easily in the hadron absorber.

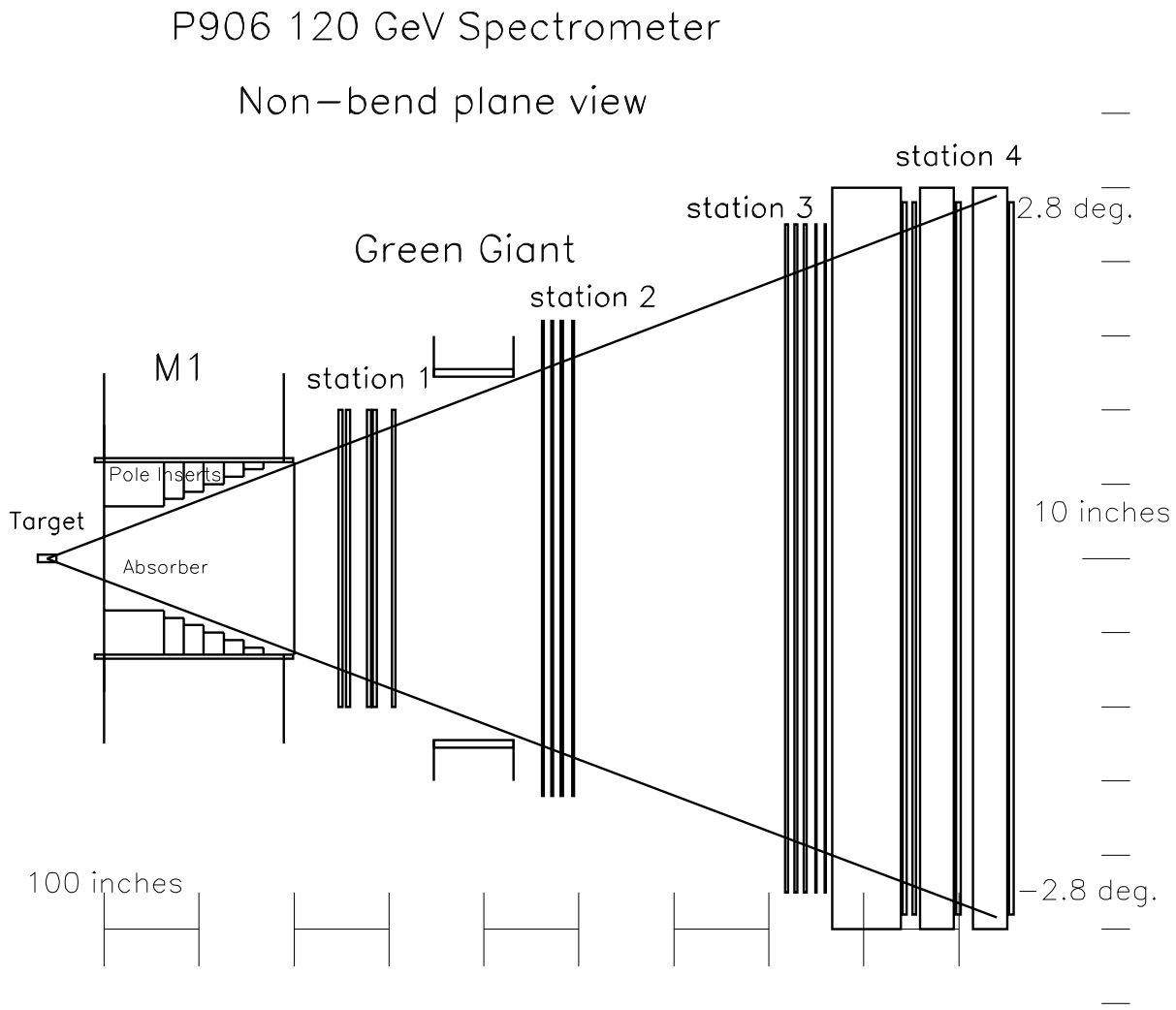
Interpretability

G. T. Bodwin, S. J. Brodsky and G. P. Lepage, Phys. Rev. D **39**, 3287 (1989).

$$\begin{aligned} P_{min} &\approx \frac{p_\perp A^{2/3}}{x_1} \\ &\approx 30 \text{ GeV for Ca, } x_1 \sim 0.3 \ll 120 \text{ GeV} \end{aligned}$$



Bend plane view of the trajectories of one of the two muons resulting from the muon decay of a 7 GeV virtual photon (which has x_F of 0.0, 0.2 or 0.4) in an 8 T-m spectrometer.



Non-bend plane view in an 8 T-m spectrometer. Only muons which pass around the beam dump in the bend plane contribute to the acceptance and so the beam dump is not shown.

Same Detector Strategy as E605-E772-E866

- Relatively short ($<$15% interaction length, L_I) targets to minimize secondary reactions in the target.
- Two independent magnetic field volumes, one to focus the high transverse momentum muons and defocus low transverse momentum muons and one to measure the muon momenta.
- A 10 L_I hadron absorber and a 25 L_I beam dump at the entrance of the first magnet.
- Zinc and concrete walls for muon identification at the rear of the apparatus.

Much of the E866 apparatus could be reused

- Detectors and absorber Wall
- SM12 iron
- Target system

Major New Items

- Replace SM12 with shorter version, (new coils with SM12 Iron)
- Replace SM3. (Jolly Green Giant?)
- Replace first set of chambers with existing wire chambers.
- Replace scintillators

Detector Optimization

Simulations

- GEANT simulation to study absorber and background rates.
  - Dump and absorber sufficient to eliminate hadrons and minimize muons.
    170" copper dump
    Graded absorber- 80" C – 40"Cu – 40" C– 60" borated CH_2
  - Muon rates up to 50 MHz, half from dump.
    Multiply by 2 for soft stuff. $\rightarrow$ Plan for 100 MHz.
    Led to choice of MWPC for Station 1.
- Physics simulation with Fast Monte Carlo but realistic multiple scattering and energy loss. Drell-Yan, J/ψ production, hadronic decays.
  - Optimize acceptance and resolution
  - Need 8 T-m (2.4 GeV) of field to contain muons from 6-8 GeV virtual photons and reduce rate of muons from hadron decays.
  - Preliminary magnet design by Jack Jagger and Ken Thompson using SM12 iron return yoke. $1M for new coil including EDIA and contingency.
  - Study trigger
    Flexible scintillator roads with 3/4 X and 4/4 Y.

Triggers	Rate
Physics	0.3 Hz
Real Pairs	70 Hz
Randoms	270 Hz
Calibration	80 Hz
Total	420 Hz
Design	1000 Hz

  - Study random rates

Magnets

M1 Magnet Characteristics

Length	189 in
Width	95 in
Height	198 in
Vertical Aperture	48 in
Horizontal Aperture without inserts	26 in
Field Integral	8.14 T-m
Ampere-Turns	670230
Current	2394 Amp
Power	0.58 Mwatt
Inlet Water Temperature	38 deg C
Temperature Rise	25 deg C
Water Flow	88 gal/min
Weight of Pole Inserts	9.5 t
Weight of Coils	19 t
Weight of Return Yoke	420 t
Total Weight	450 t

Jolly Green Characteristics

Length	84 in
Width	135 in
Height	190 in
Vertical Aperture	96 in
Horizontal Aperture	49.14 in
Field Integral	1.65 Tm
Ampere-Turns	1010000
Current	980 Amp
Power	0.89 Mwatt
Inlet Water Temperature	35 deg C
Temperature Rise	22 deg C
Water Flow	152 gal/min
Total Weight	220 t

Wire Chambers

	Type	X size (cm)	Y size (cm)	wire spacing (mm)	wire orientations	Number of Channels	Singles Rates (MHz)
1	MWPC	101.6	137.2	2.0	Y,U,V,Y,Y',U',V'	7000	40
2	DC	137.7	149.9	10.2	Y,Y',U,U',V,V'	1000	10
3	DC	203.0	162.4	20.3	Y,Y',U,U',V,V'	700	2
4	Prop. Tube	254.0	211.0	10.0	Y, Y', X, X'	900	2

Station 1 Planes of E605 MWPC plus 4 planes of E871 MWPC

Readout from E871

Use fast gas

Station 2 Existing E866 station 2 drift chambers.

Add Multihit TDC readout

Station 3 Existing E866 station 3 drift chambers.

Add Multihit TDC readout

Station 4 New limited streamer tubes operated in proportional mode.

Readout from E871

P906 Apparatus Responsibilities

Component	Subcomponent	Source	Cost (k$)	Responsible Institution
Beam line	Instrumentation			FNAL BD
Target		E866		FNAL PPD
M1	Coils	New	900	ANL
	Inserts	New	100	ANL
	Return Yoke	E866		FNAL PPD
	Assembly	New	220	FNAL PPD
	Power Supplies	E866		FNAL PPD
Jolly Green	Repair Coil			FNAL PPD
Giant	Assemble in Meson			FNAL PPD
	Power Supplies	E866		FNAL PPD
Station 1 MWPC	Chambers	E871 and E866		?, ACU, FNAL
	Electronics	E871 and E866		?, ACU, FNAL
	Readout	E871		?, ACU, FNAL
Station 1 Hodoscopes		New	20	ACU
Station 2 DC	Chambers	E866		Rutgers
	Electronics	E866		Rutgers
	Readout	New		FNAL PREP
Station 2 Hodoscopes		New	30	ACU
Station 3 DC	Chambers	E866		Rutgers
	Electronics	E866		Rutgers
	Readout	New		FNAL PREP
Station 3 Hodoscopes		New	30	ACU
Station 4 Prop. Tubes	Chambers	New	30	?, LANL
	Electronics	E866		LANL
	Readout	E871		LANL
Muon ID Wall	Assembly	E866		FNAL PPD
Gas System	Mixing	New		LANL
	Distribution	New		FNAL PPD
Station 4 Hodoscopes		New	80	ACU
Trigger		E866 and New	15	TAMU
	LRS2367	New	56	FNAL PREP
DAQ	Hardware	E871		?
	Software	E871 and New		?,VALPO,TAMU
Analysis	Software	E866		Lead - LANL

FNAL BD – Beams Division
FNAL PPD – Particle Physics Division
FNAL PREP – Physics Research Equipment Pool

Requests for FNAL

- Repair coil of Jolly Green Giant magnet
- Install Jolly Green Giant magnet in Meson as a vertical bending magnet.
- Assemble M1 magnet in Meson with the coil provided by ANL and return yoke from SM12.
- Provide beam dump with closed loop water recirculating cooling system.
- Provide magnet power supplies.
- Provide utilities (power and cooling Water) for magnets and power supplies.
- Move and install muon ID absorber walls.
- Provide beam line instrumentation
- Provide liquid hydrogen and deuterium targets and drive mechanism to interchange liquid and solid targets remotely.
- PREP electronics. Essentially E866 PREP electronics plus 1700 channels of multi-hit TDC (LRS3377) , 16 LRS2367 units and 32 channels of mean-timers.
- Provide chamber gas distribution system plumbing.
- Provide flammable gas safety system.
- Provide rigging for Installation
- Provide use of Lab 6 facilities for scintillator and light guide fabrication.
- Provide counting House and electronics areas with appropriate utilities installed.
- Two analysis workstations for counting House

P906 Collaboration

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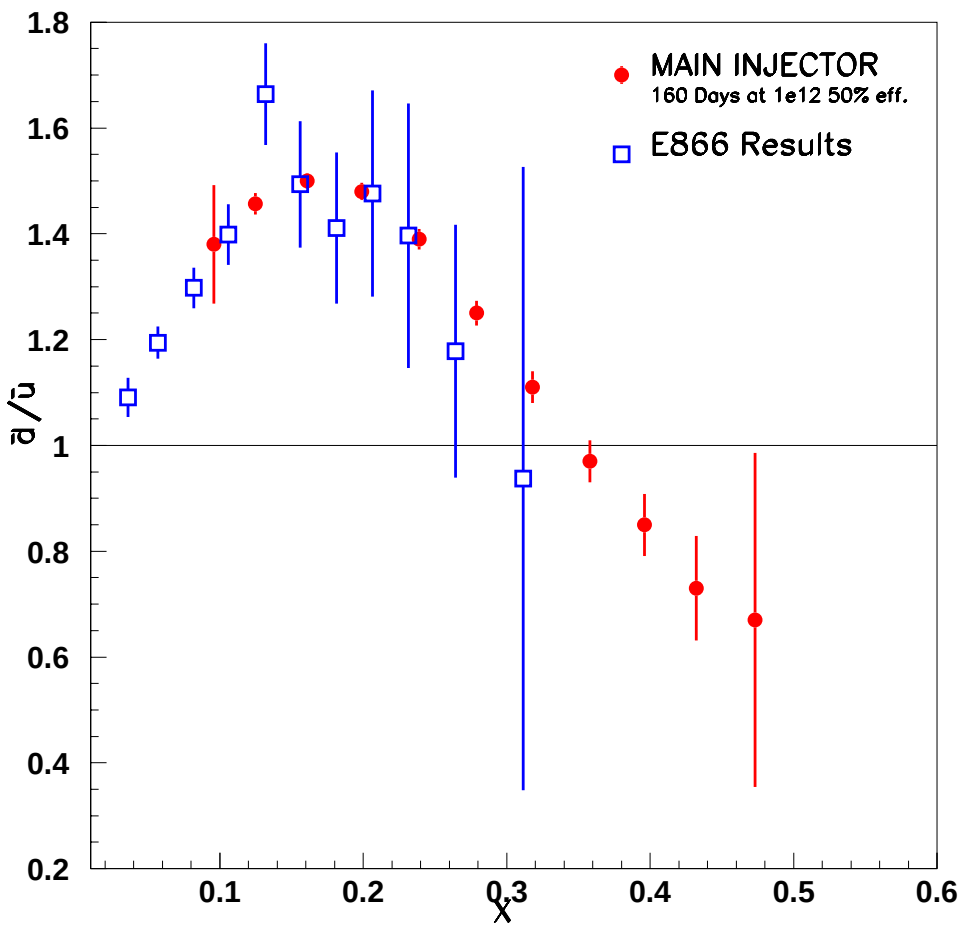
P906 Expected Precision in $\bar{d}/\bar{u}$ of the Proton



E866 results and projected P906 results for the extraction of $\bar{d}/\bar{u}$ from a 160 day 50% efficiency run with 10^{12} protons per pulse on a 20" long liquid hydrogen and deuterium targets with the P906 apparatus based on the MRST [4] distribution of $\bar{d}/\bar{u}$.

Summary

- We propose to make accurate measurements of $\bar{d}_p/\bar{u}_p$ from x of 0.2 to 0.5. (3.8×10^{18} incident protons.)
- These measurements are important to determine parton distribution functions and to understand the non-perturbative structure of the proton.
- We propose also to make measurements on three nuclear targets ($\sim$ 35 % of the beam time). This will test the nuclear corrections to extracting $\bar{d}_p/\bar{u}_p$ and expand our understanding of the nuclear dependence of parton distributions. (1.8×10^{18} incident protons)
- The Main Injector is ideally suited for these measurements:
  1. Right energy
  2. High Intensity
- Resources required are modest.
- Beam time required
  - 9 months at 1e12 ppp and 66% accelerator efficiency
  - 5.2×10^{18} incident protons
- The collaboration has shown it knows how to do these experiments.