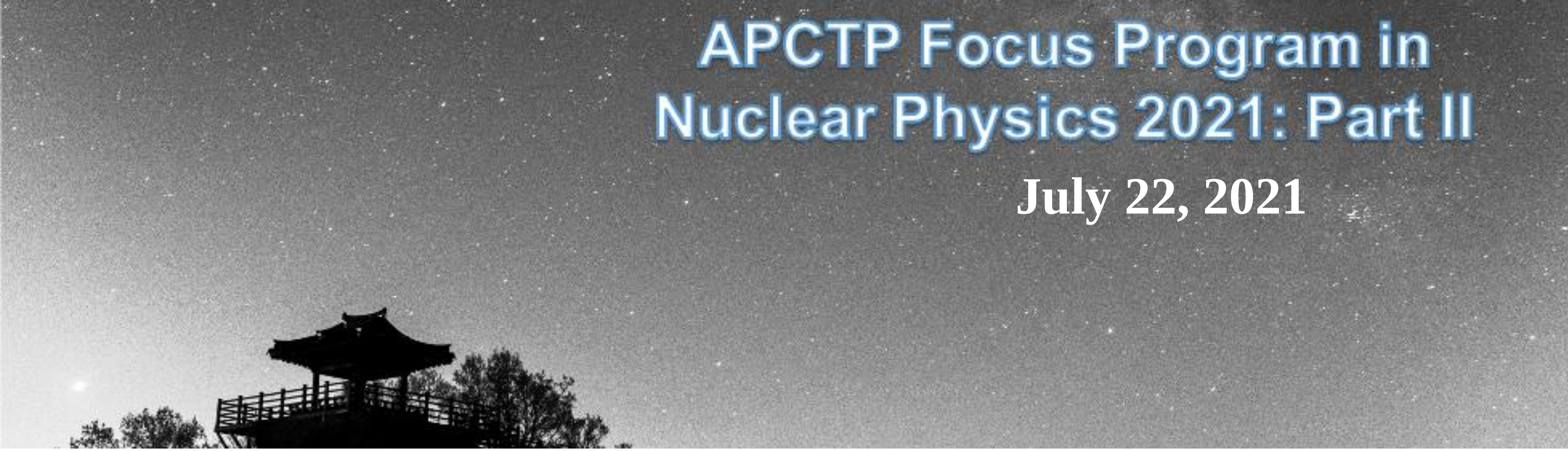
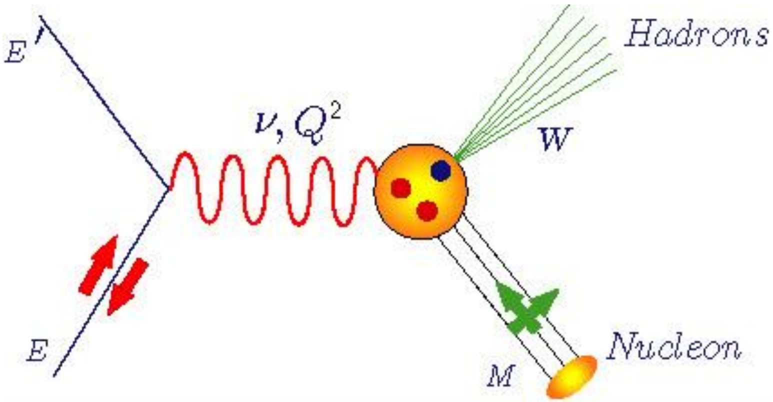
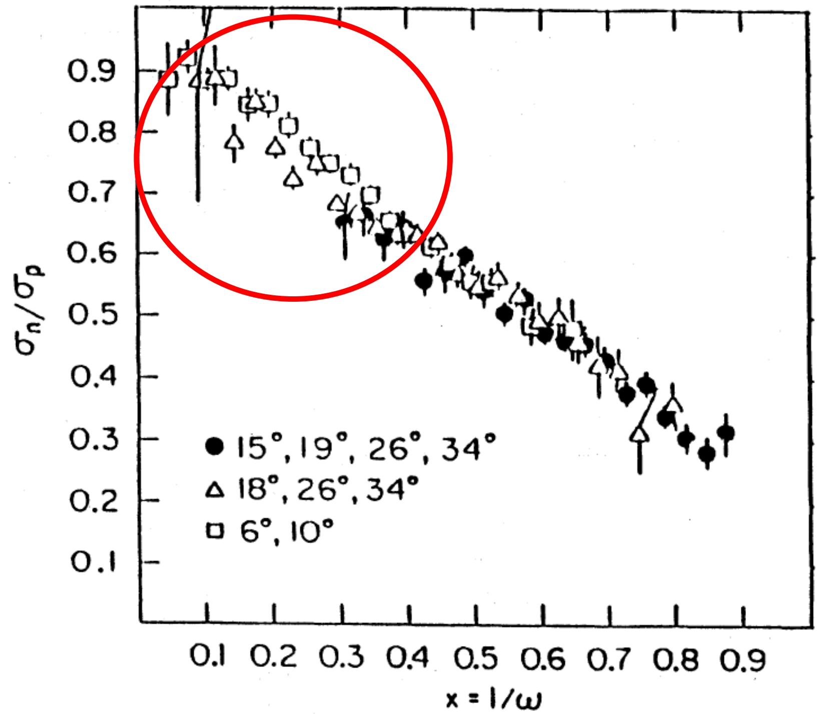


The saga of proton sea asymmetry

Wen-Chen Chang 章文箴
Institute of Physics, Academia Sinica

Deep Inelastic Scattering





Q^2 :Four-momentum transfer
x : Bjorken variable (=$Q^2/2M\nu$)
ν : Energy transfer
M : Nucleon mass
W : Final state hadronic mass

$$\frac{d^2\sigma}{d\Omega dE'} = \sigma_{Mott}[W_2(\nu,Q^2) + 2W_1(\nu,Q^2) * \tan^2(\theta/2)]$$

$$= \sigma_{Mott}[F_2(x,Q^2)/\nu + 2F_1(x,Q^2)/M * \tan^2(\theta/2)]$$

Parton model

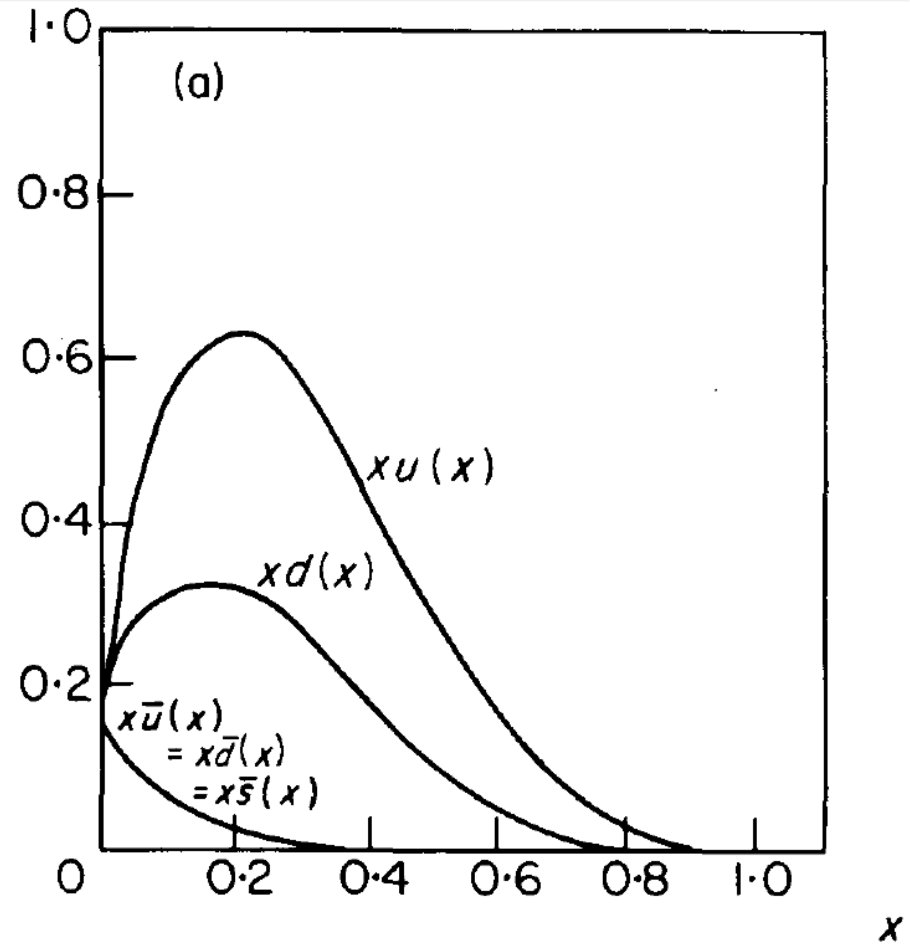
$$F_2^{ep} = x[\tfrac{1}{9}(d_v^p + d_s^p + \bar{d}_s^p) + \tfrac{4}{9}(u_v^p + u_s^p + \bar{u}_s^p) + \tfrac{1}{9}(s_s + \bar{s}_s)]$$

$$F_2^{en} = x[\tfrac{1}{9}(d_v^n + d_s^n + \bar{d}_s^n) + \tfrac{4}{9}(u_v^n + u_s^n + \bar{u}_s^n) + \tfrac{1}{9}(s_s + \bar{s}_s)]$$

- Scaling
- Valence quarks
- $q\bar{q}$ pairs (Sea)

Naïve Expectation of Nucleon Sea: SU(3) Symmetric

$$q(x) = q_V(x) + q_S(x)$$
$$u_V(x) = 2d_V(x)$$
$$s_V(x) = \bar{u}_V(x) = \bar{d}_V(x) = \bar{s}_V(x) = 0$$
$$u_S(x) = \bar{u}_S(x) = d_S(x) = \bar{d}_S(x) = s_S(x) = \bar{s}_S(x)$$



F.E. Close, "An Introduction to Quarks and Partons"

Is $\bar{u}(x) = \bar{d}(x)$ in the Nucleon?

Gottfried Sum Rule (GSR)

$$S_G = \int_0^1 [(F_2^p(x) - F_2^n(x)) / x] dx$$

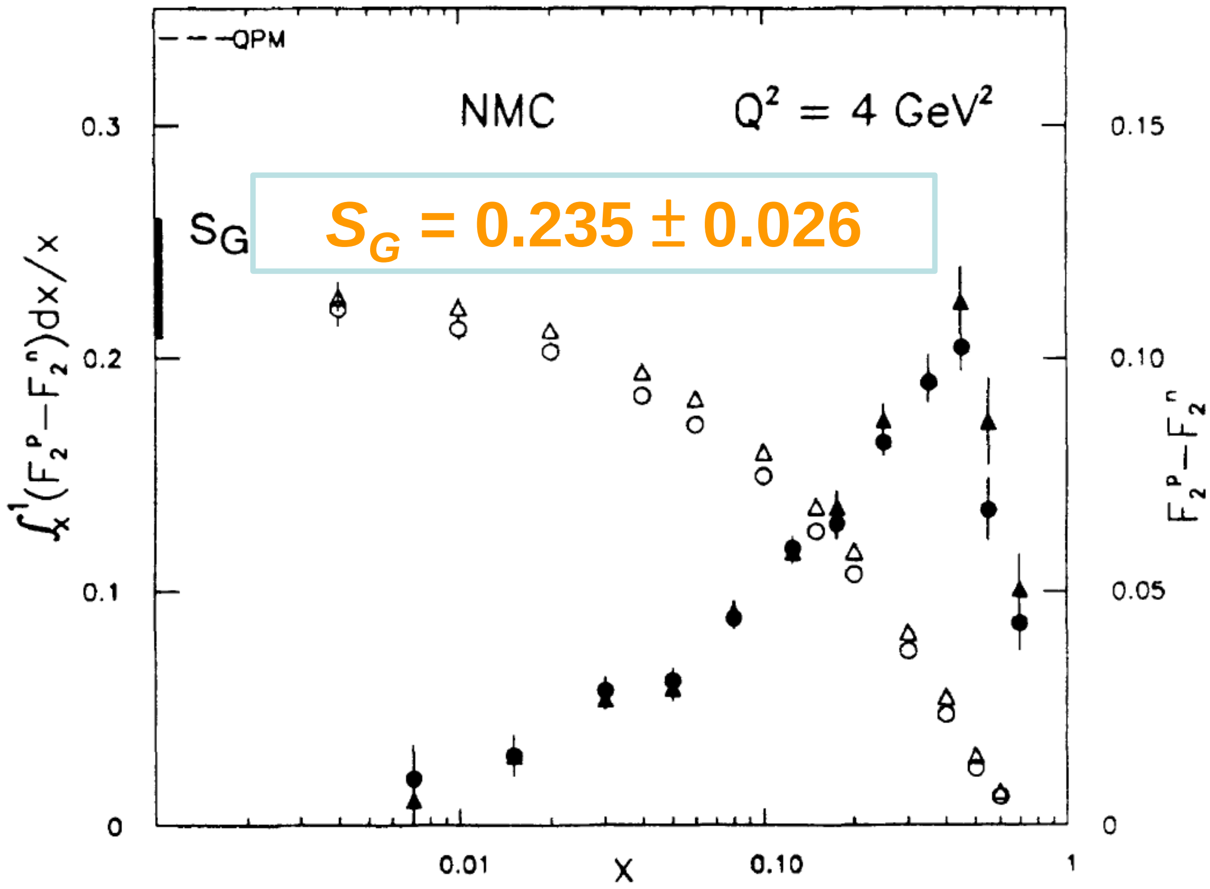
$$= \frac{1}{3}\int_0^1 (u_v(x) - d_v(x))\, dx + \frac{2}{3}\int_0^1 (\bar{u}(x) - \bar{d}(x))\, dx$$

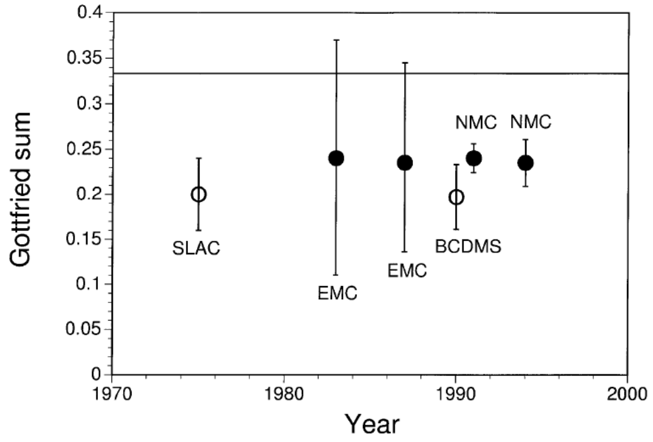
$$= \frac{1}{3} \quad \text{(Leading order, Leading twist, } \bar{u}(x) = \bar{d}(x)\text{)}$$

Assume a symmetric quark-antiquark sea,
GSR is only sensitive to the valence quarks.

Gottfried Sum

New Muon Collaboration (NMC), Phys. Rev. D50 (1994) R1



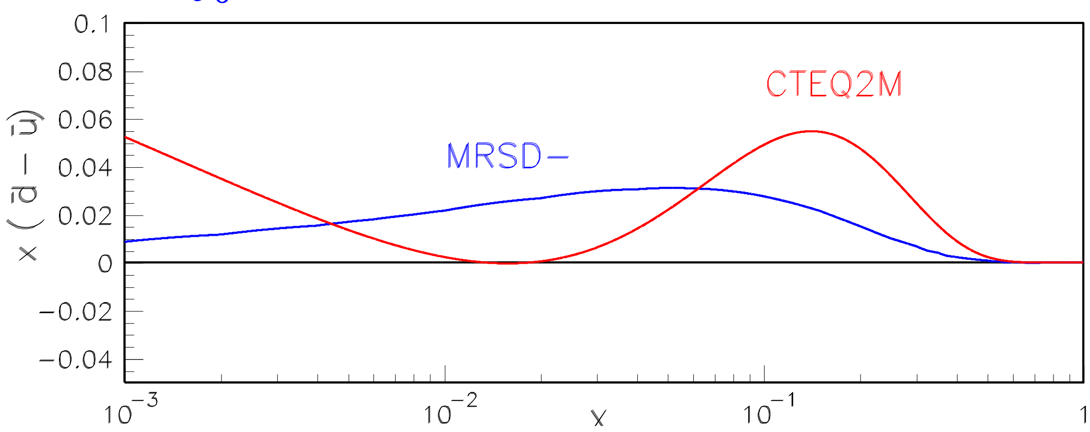


S_G is significantly lower than 1/3 !

Explanations for the NMC result

- Uncertain extrapolation for 0.0 < x < 0.004
- Charge symmetry violation $(\bar{u}_n \neq \bar{d}_{p,}\ \bar{d}_n \neq \bar{u}_p)$
- $\bar{u}(x) \neq \bar{d}(x)$ in the proton

$$\int_0^1 (\bar{d}(x) - \bar{u}(x))\, dx = 0.148 \pm 0.04$$



Need independent methods to check the $\bar{d} - \bar{u}$ asymmetry, and to measure its ***x-dependence !***

The Drell-Yan Process

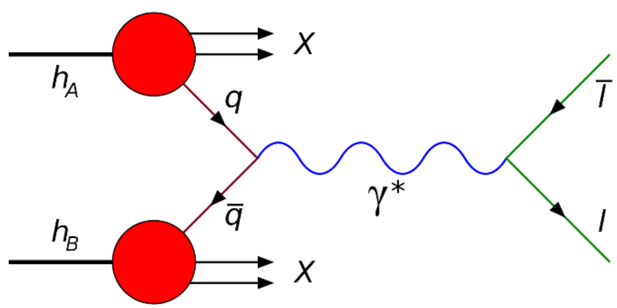
S.D. Drell and T.M. Yan, PRL 25 (1970) 316

MASSIVE LEPTON-PAIR PRODUCTION IN HADRON-HADRON COLLISIONS AT HIGH ENERGIES*

Sidney D. Drell and Tung-Mow Yan
Stanford Linear Accelerator Center, Stanford University, Stanford, California 94305

(Received 25 May 1970)

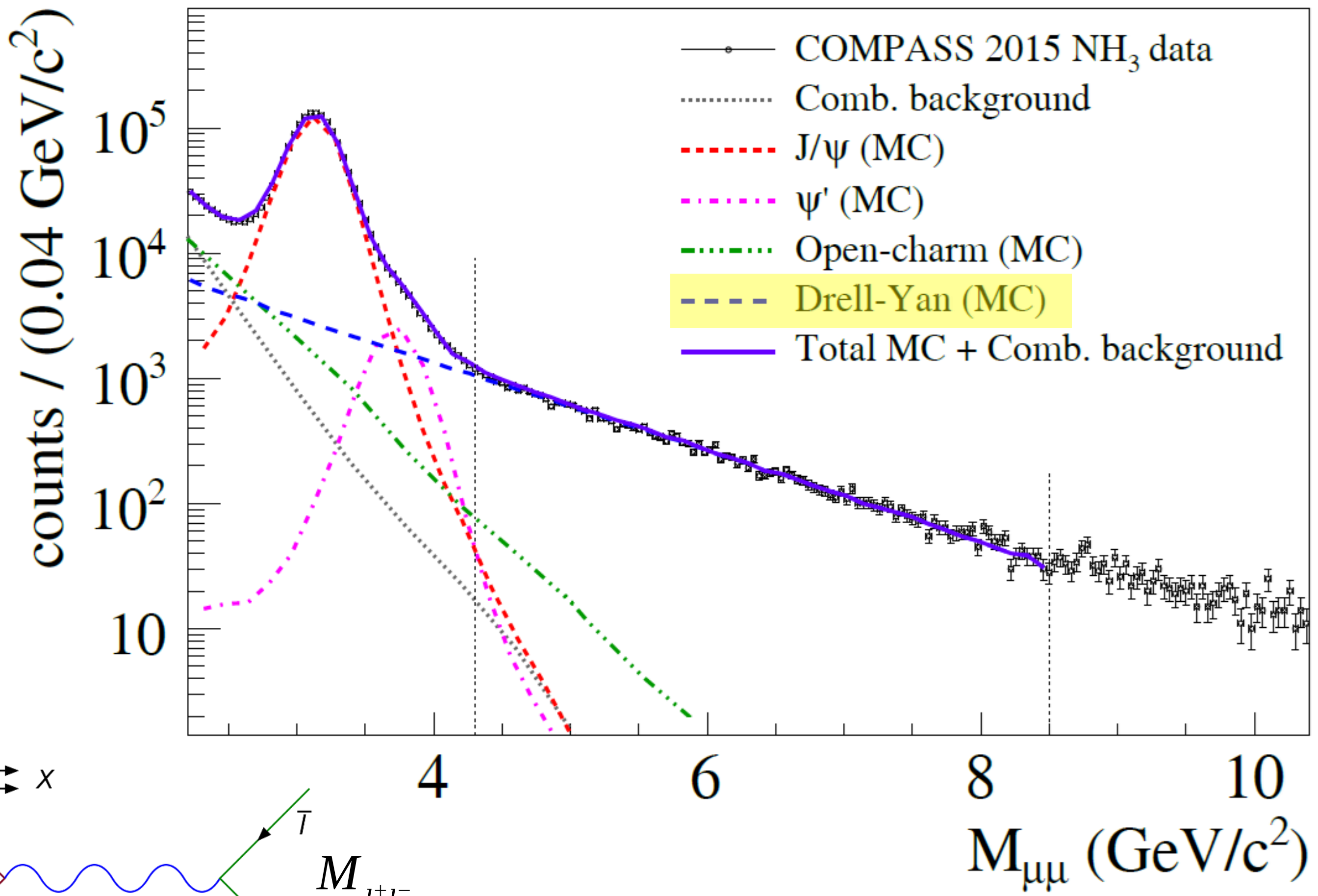
On the basis of a parton model studied earlier we consider the production process of large-mass lepton pairs from hadron-hadron inelastic collisions in the limiting region, $s \to \infty$, Q^2/s finite, Q^2 and s being the squared invariant masses of the lepton pair and the two initial hadrons, respectively. General scaling properties and connections with deep inelastic electron scattering are discussed. In particular, a rapidly decreasing cross section as $Q^2/s \to 1$ is predicted as a consequence of the observed rapid falloff of the inelastic scattering structure function νW_2 near threshold.

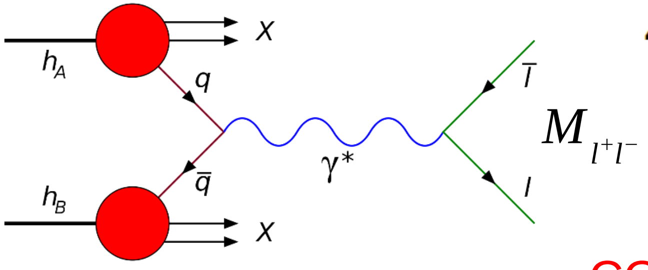


$$\tau = \frac{Q^2}{s} = x_1 x_2$$

$$\frac{d\sigma}{dQ^2} = \left(\frac{4\pi\alpha^2}{3Q^2}\right)\left(\frac{1}{Q^2}\right)\mathfrak{F}(\tau) = \left(\frac{4\pi\alpha^2}{3Q^2}\right)\left(\frac{1}{Q^2}\right)\int_0^1 dx_1 \int_0^1 dx_2\, \delta(x_1x_2-\tau)\sum_a \lambda_a^{-2} F_{2a}(x_1) F_{2\bar{a}}{}'(x_2),$$

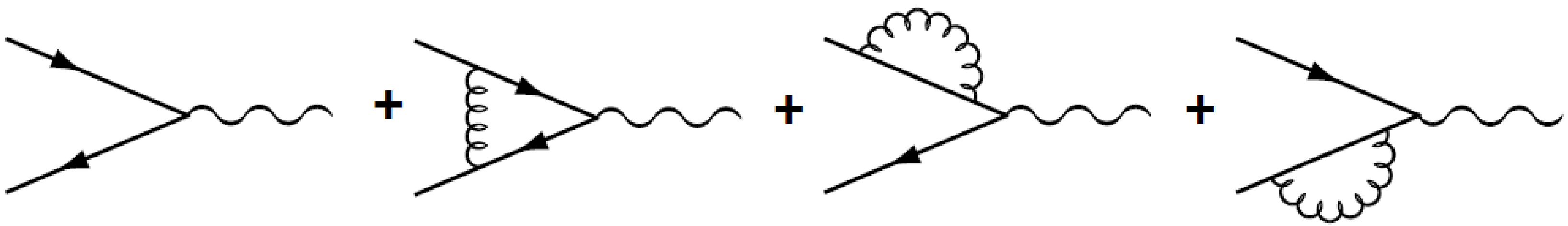
Dimuon Invariant-mass Distributions





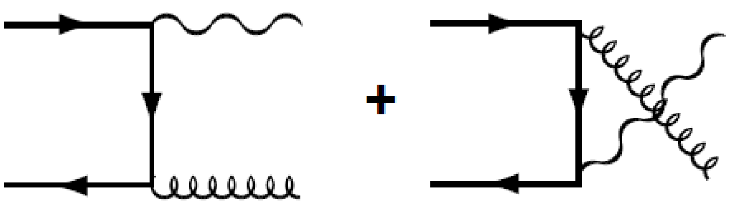
COMPASS, PRL 119 (2017) 112002

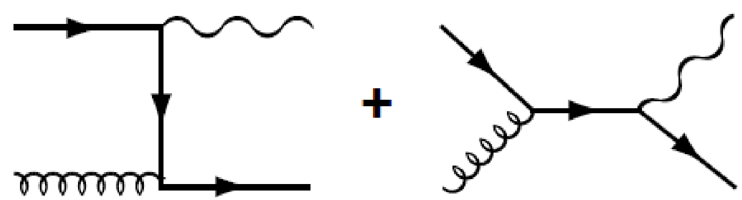
Drell-Yan Process



(a)

Quark-antiquark annihilation





(b)

Quark-antiquark annihilation

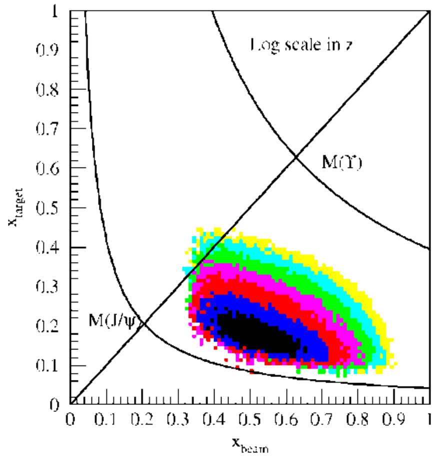
(c)

Quark-gluon Compton scattering

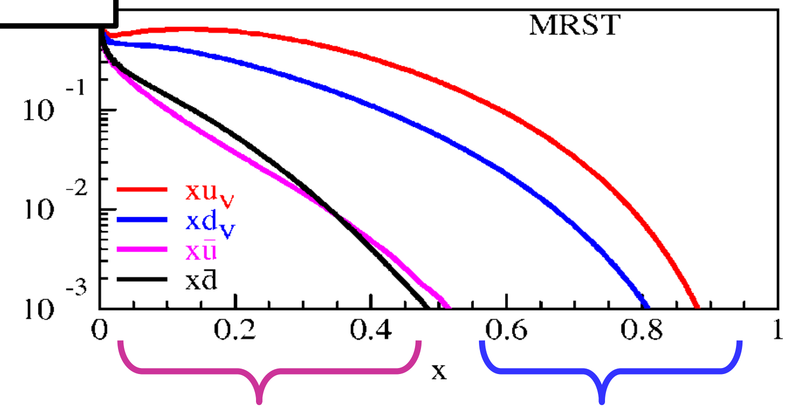
x-dependence of Sea Quarks

Acceptance for fixed-target experiment:
$x_{beam} >> x_{target}$

x_{target}



x_{beam}



x_{target} x_{beam}

$$\frac{d^2\sigma}{dx_{beam}dx_{target}} = \frac{4\pi\alpha^2}{9x_{beam}x_{target}}\frac{1}{s}\sum_i e_i^2[q_i(x_{beam})\bar{q}_i(x_{target}) + \bar{q}_i(x_{beam})q_i(x_{target})]$$

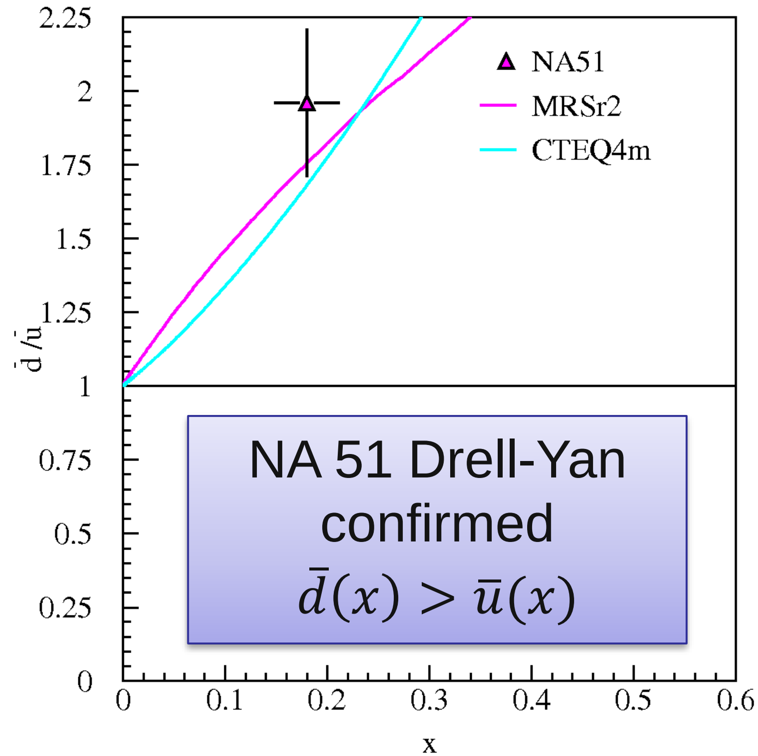
$$\frac{\sigma^{pd}}{2\sigma^{pp}}\Big|_{x_{beam} >> x_{target}} \approx \frac{1}{2}\left[1+\frac{\bar{d}(x_{target})}{\bar{u}(x_{target})}\right]$$

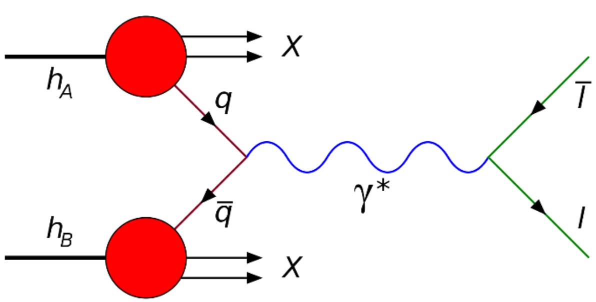
Light Antiquark Flavor Asymmetry: Drell-Yan Experiments

- Naïve Assumption: $\bar{d}(x) = \bar{u}(x)$
- NMC (Gottfried Sum Rule):

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

- NA51 (Drell-Yan, 1994):
  $\bar{d} > \bar{u}$ at $x = 0.18$



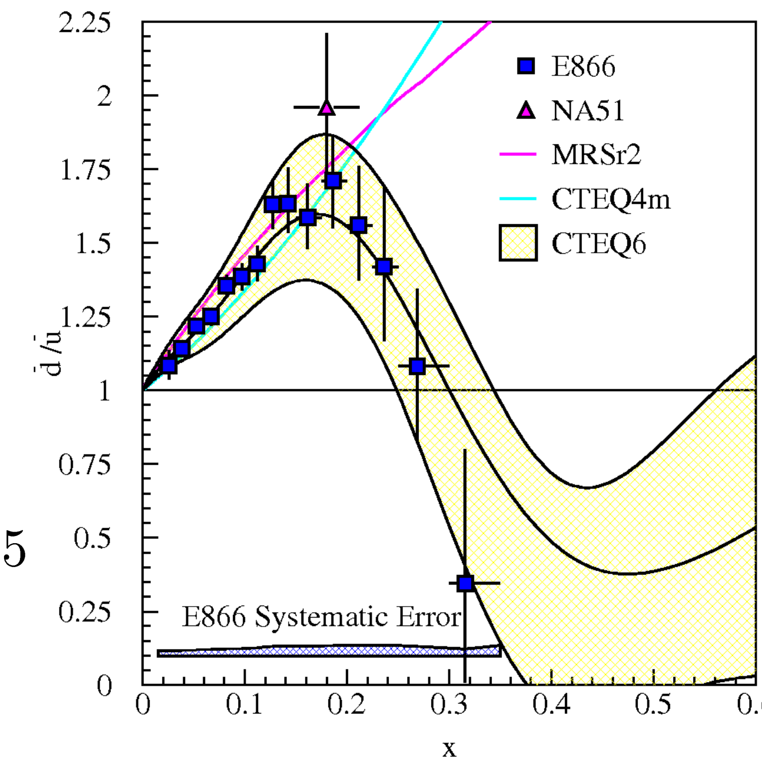


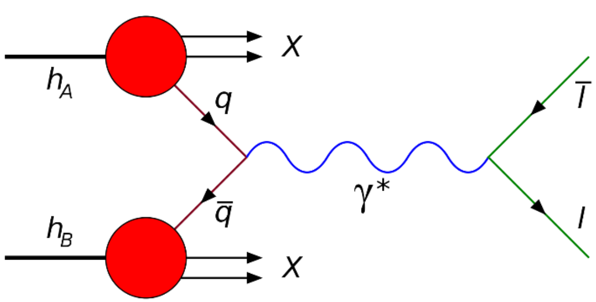
Light Antiquark Flavor Asymmetry: Drell-Yan Experiments

- Naïve Assumption: $\bar{d}(x) = \bar{u}(x)$
- NMC (Gottfried Sum Rule):

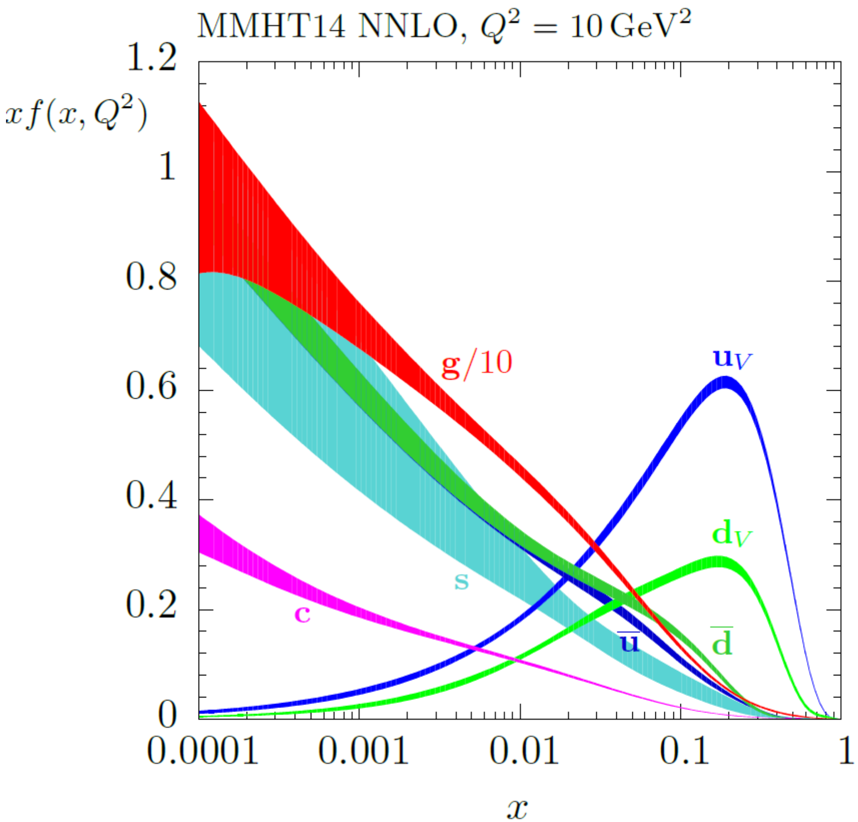
$$\int_0^1 \left[\bar{d}(x) - \bar{u}(x)\right] dx \neq 0$$

- NA51 (Drell-Yan, 1994):
  $\bar{d} > \bar{u}$ at $x = 0.18$
- E866/NuSea (Drell-Yan, 1998): $\bar{d}(x)/\bar{u}(x)$ for $0.015 \leq x \leq 0.35$

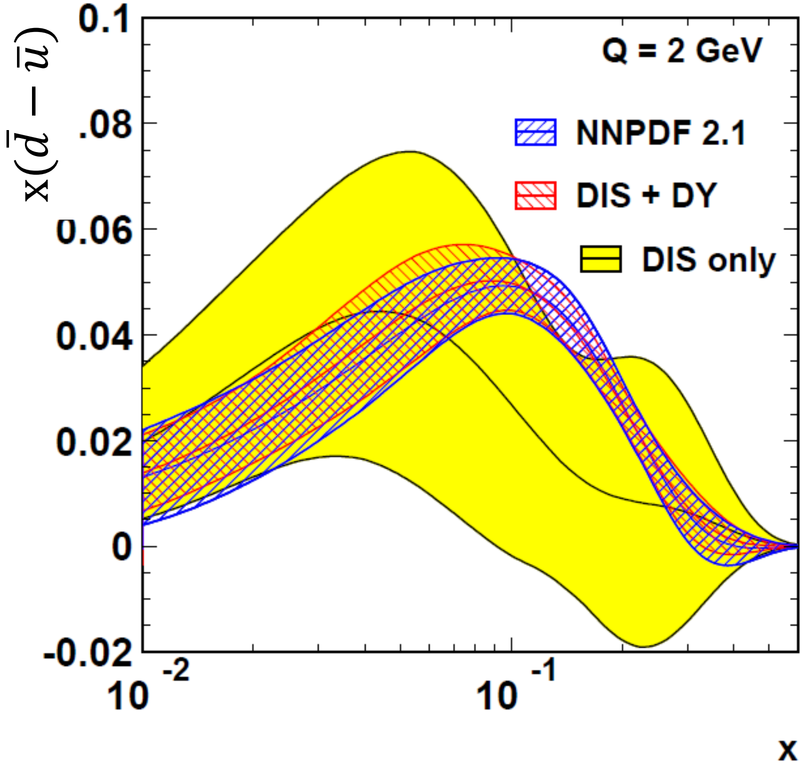




Parton distributions of Protons From Global Analysis

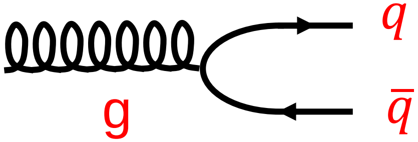


arXiv:1412.3989



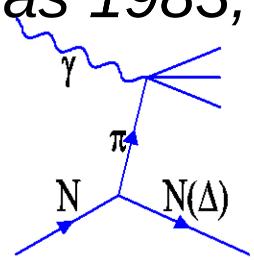
arXiv:1208.1178

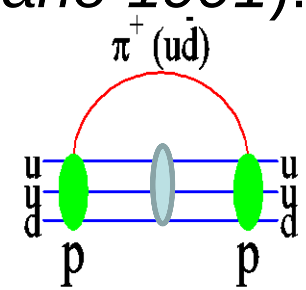
Origin of $\bar{u}(x) \neq \bar{d}(x)$: pQCD or non-pQCD effect?



- **Pauli blocking**
  - $g \rightarrow u\bar{u}$ is more suppressed than $g \rightarrow d\bar{d}$ in the proton since $|p\rangle = |uud\rangle$ (*Field and Feynman, PRD 2590 (1977)*)
  - pQCD calculation: S_G=0.335 (*Ross, Sachrajda 1979*)
- **Meson cloud**

(*Thomas 1983, Kumano 1991*): Sullivan process in DIS.

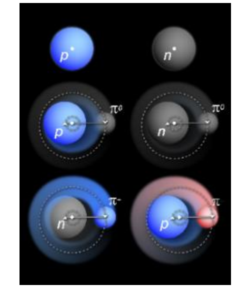




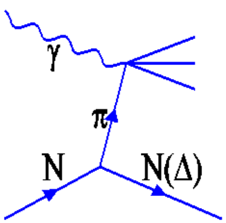
$$|p\rangle = a|p_0\rangle + b|p_0\pi^0\rangle + c|n_0\pi^+\rangle$$

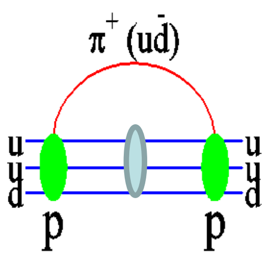
$$p \rightarrow N\pi;\ \pi^+(u\bar{d}) : \pi^0(u\bar{u} + d\bar{d}) : \pi^-(\bar{u}d) = 2:1:0$$

Origin of $\bar{u}(x) \neq \bar{d}(x)$: Non-perturbative QCD effect



- Meson cloud in the nucleons (Thomas 1983, Kumano 1991): Sullivan process in DIS.



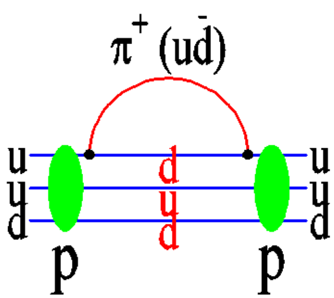


$$|p\rangle = \sqrt{Z}\,|p_0\rangle + a_{N\pi/p}\left[-\sqrt{\frac{1}{3}}|p_0\pi^0\rangle + \sqrt{\frac{2}{3}}|n_0\pi^+\rangle\right] + a_{\Delta\pi/p}\left[\sqrt{\frac{1}{2}}|\Delta_0^{++}\pi^-\rangle - \sqrt{\frac{1}{3}}|\Delta_0^{+}\pi^0\rangle + \sqrt{\frac{1}{6}}|\Delta_0^{0}\pi^+\rangle\right]$$

$$+ a_{\Lambda K/p}\,|\Lambda_0 K^+\rangle + a_{\Sigma K/p}\left[-\sqrt{\frac{1}{2}}|\Sigma_0^+ K^0\rangle + \sqrt{\frac{1}{2}}|\Sigma_0^0 K^+\rangle\right] + \cdots$$

n

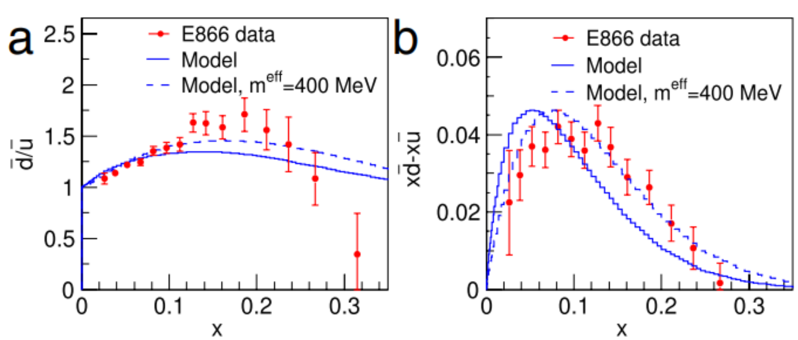
- Chiral quark model (Eichten et al. 1992; Wakamatsu 1992): Goldstone bosons couple to valence quarks.



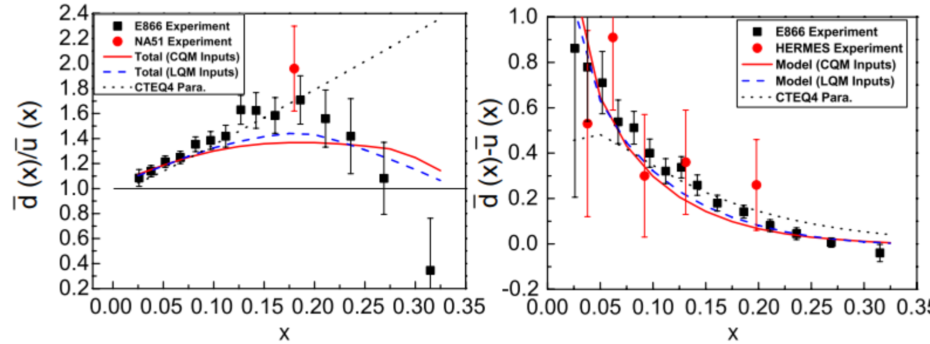
$$|U\rangle = \sqrt{Z}|u\rangle + \sqrt{\frac{1}{3}}a_{\pi/U}|u\pi^0\rangle + \sqrt{\frac{2}{3}}a_{\pi/U}|d\pi^+\rangle + a_{K/U}|sK^+\rangle + \cdots$$

$$|D\rangle = \sqrt{Z}|d\rangle + \sqrt{\frac{1}{3}}a_{\pi/D}|d\pi^0\rangle + \sqrt{\frac{2}{3}}a_{\pi/D}|u\pi^-\rangle + a_{K/D}|sK^0\rangle + \cdots,$$

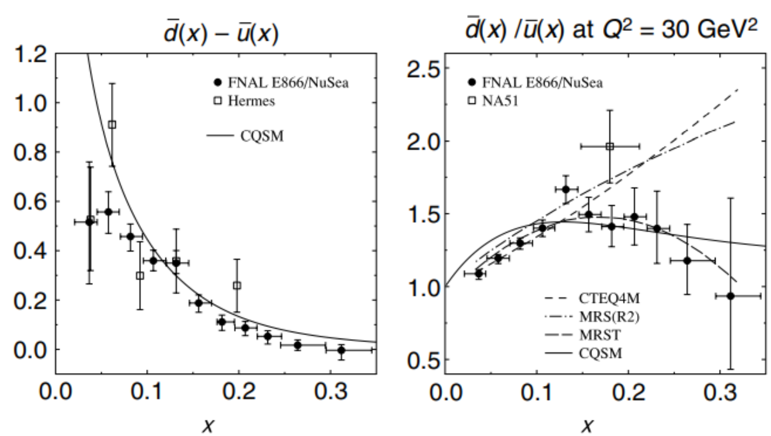
Pion cloud is a source of antiquarks in the protons and it lead to $\bar{d} > \bar{u}$.



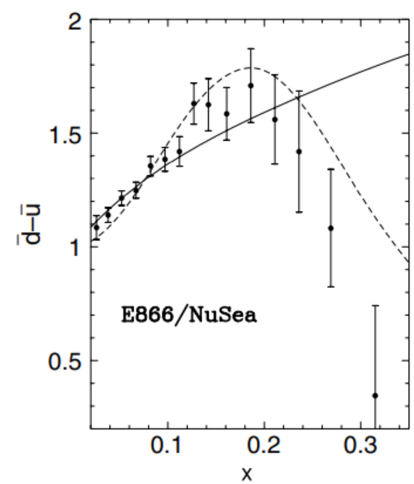
(a) Meson cloud model. Figure from [34].



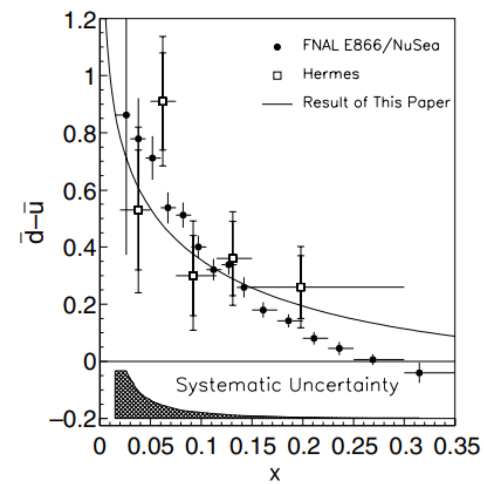
(b) Chiral quark model. Figure from [37].



(c) Chiral quark model. Figure from [37].



(d) Chiral quark model. Figure from [37].

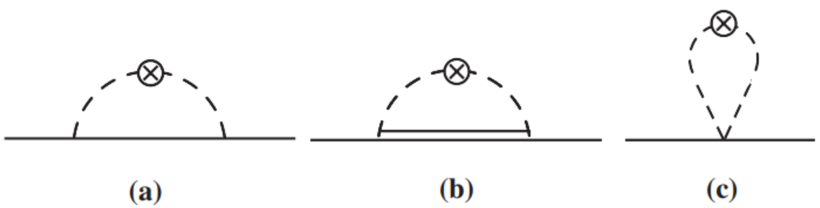


(e) Balance model. Figure from [47].

"*Flavor structure of the nucleon sea*", Wen-Chen Chang and Jen-Chieh Peng
Progress in Particle and Nuclear Physics 79 (2014) 95; arXiv:1406.1260

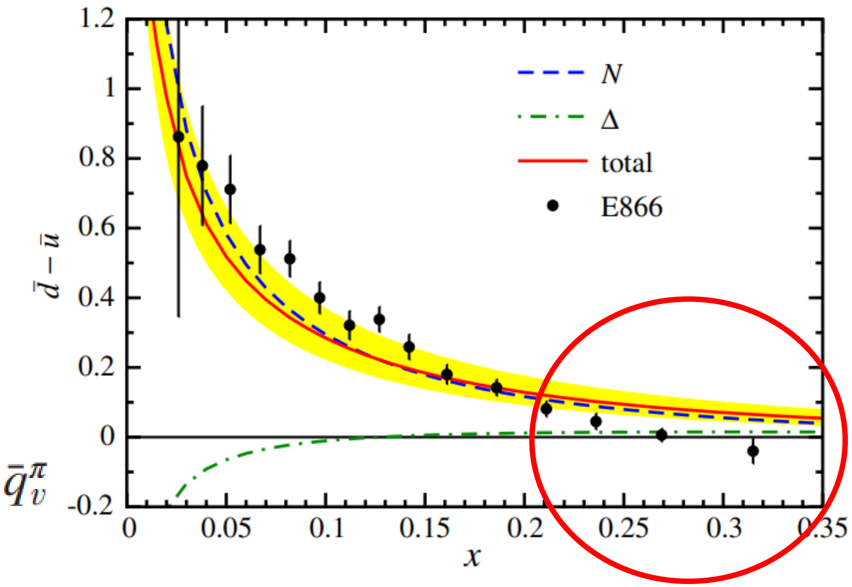
Chiral Effective Theory

Salamu, Ji, Melnitchouk and Wang, PRL 114, 122001 (2015)



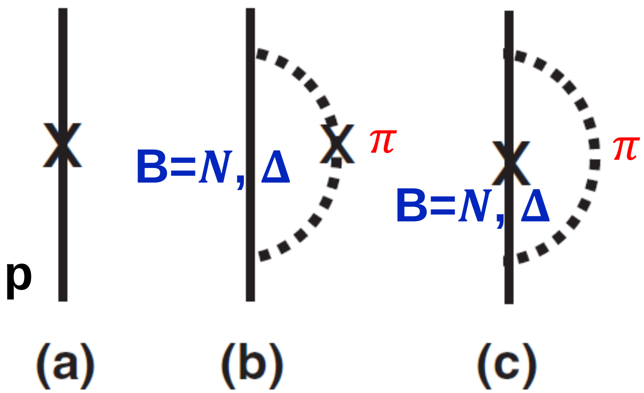
πN $\pi\Delta$ π bubble

$$\bar{d} - \bar{u} = \left(f_{\pi^+ n} + f_{\pi^+ \Delta^0} - f_{\pi^- \Delta^{++}} + f_{\pi(\mathrm{bub})}\right) \otimes \bar{q}_v^{\pi}$$



Chiral Pion Cloud Model:

Alberg and Miller, PRC 100, 035205 (2019)

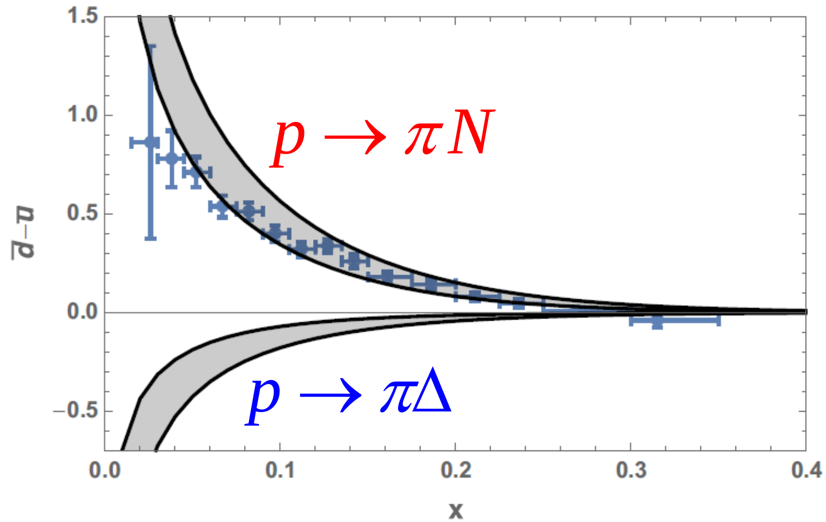


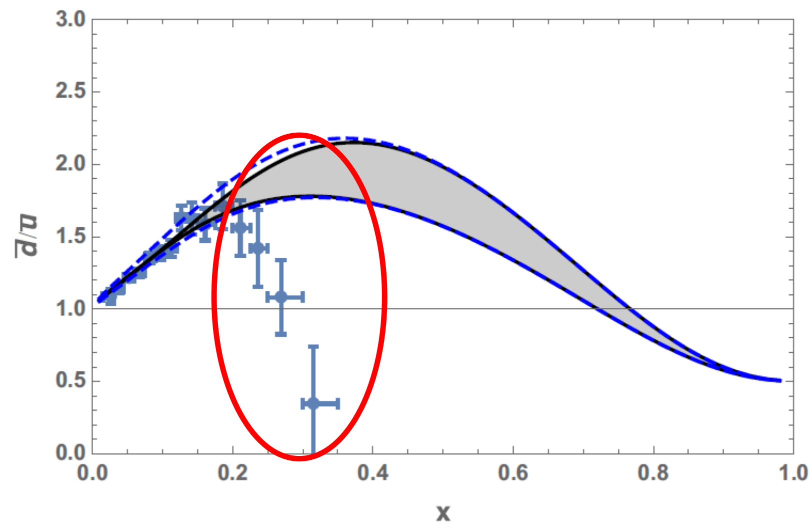
$$q_N^f(x) = Zq_{N0}^f(x) + \sum_{B=N,\Delta} f_{\pi B} \otimes q_\pi^f + \sum_B f_{B\pi} \otimes q_B^f$$

$$\bar{d}(x) = \left(\frac{5}{6} f_{\pi N} + \frac{1}{3} f_{\pi \Delta}\right) \otimes q_\pi^v + \bar{q}_{\rm sym}(x),$$

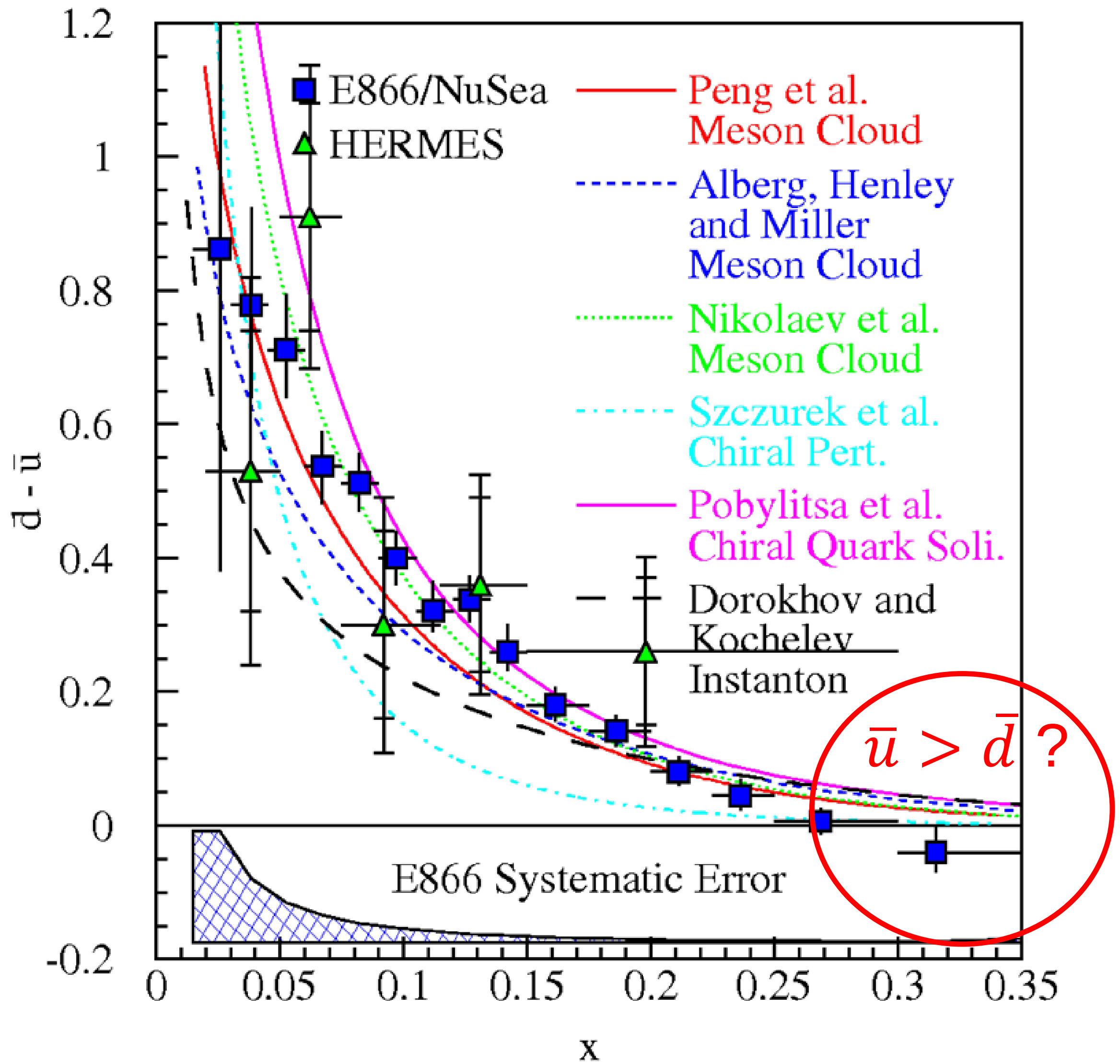
$$\bar{u}(x) = \left(\frac{1}{6} f_{\pi N} + \frac{2}{3} f_{\pi \Delta}\right) \otimes q_\pi^v + \bar{q}_{\rm sym}(x),$$

$$f_{\pi B} \otimes q_\pi^f \equiv \int_x^1 \frac{dy}{y} f_{\pi B}(y) q_\pi^f\left(\frac{x}{y}\right)$$

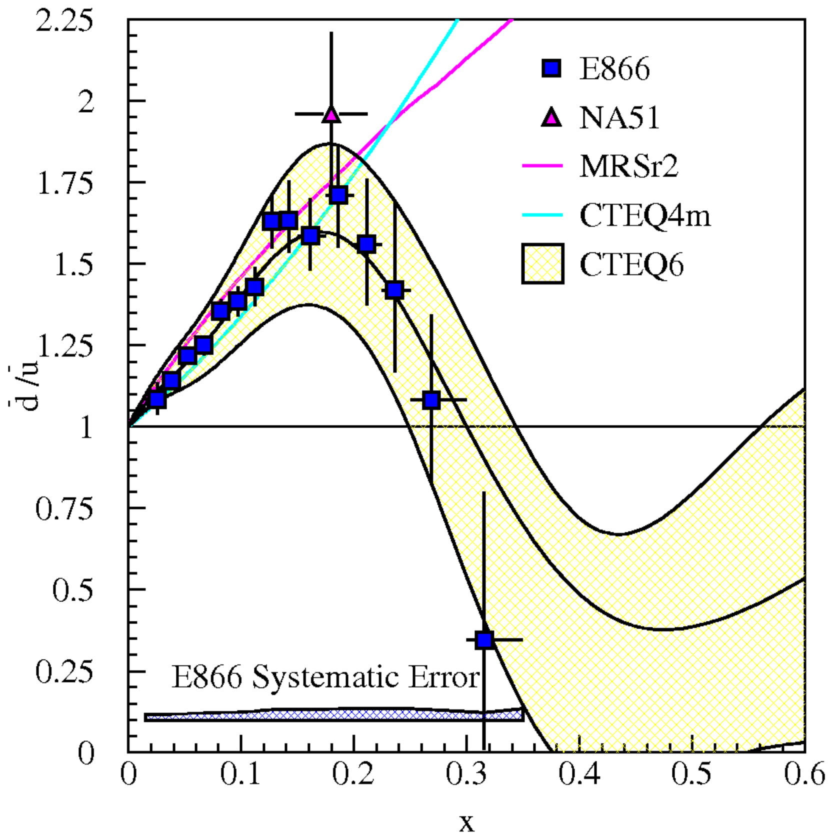




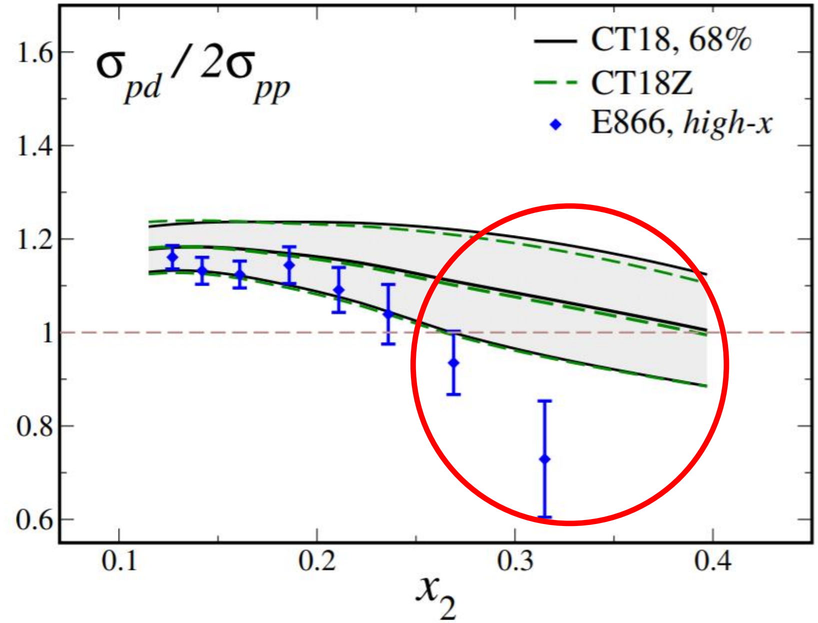
$\bar{d}(x) - \bar{u}(x)$ vs. Theoretical Models



$\bar{d}(x)/\bar{u}(x)$ vs. PDFs

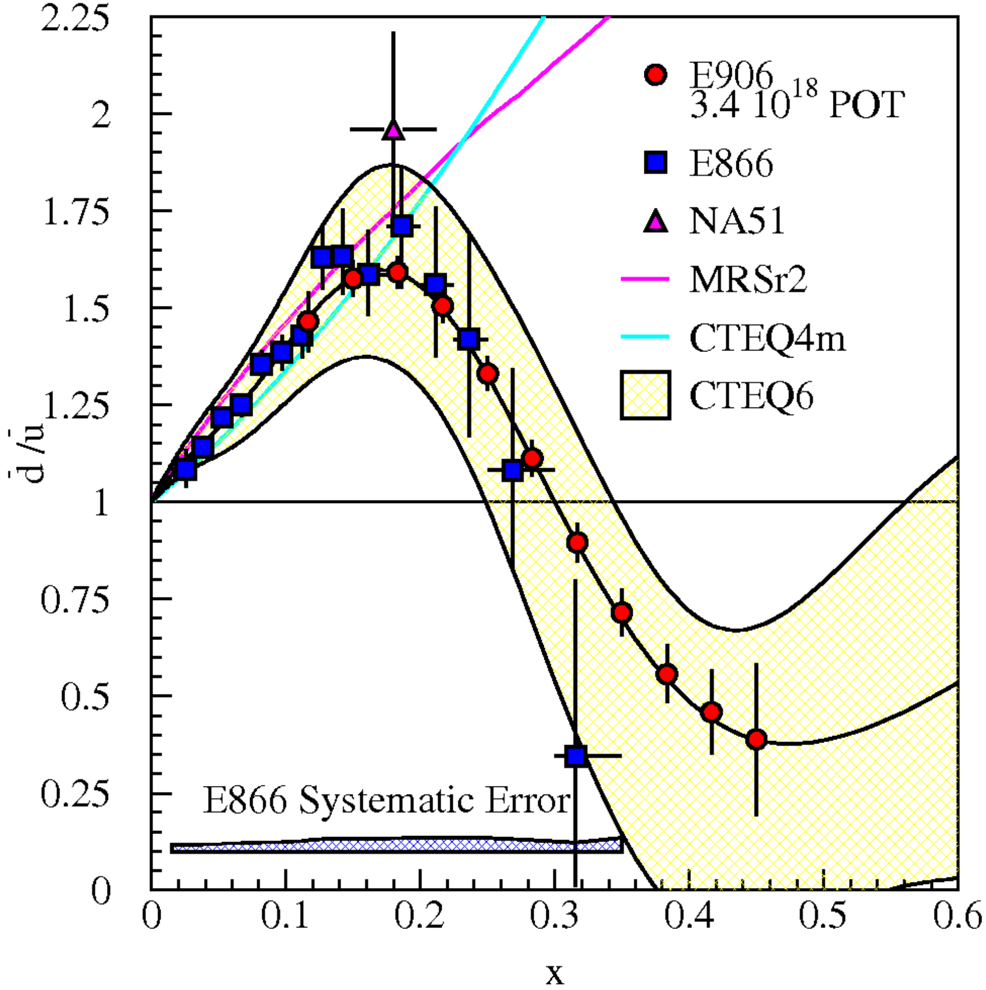


CT18NLO: PRD 103 (2021) 014013



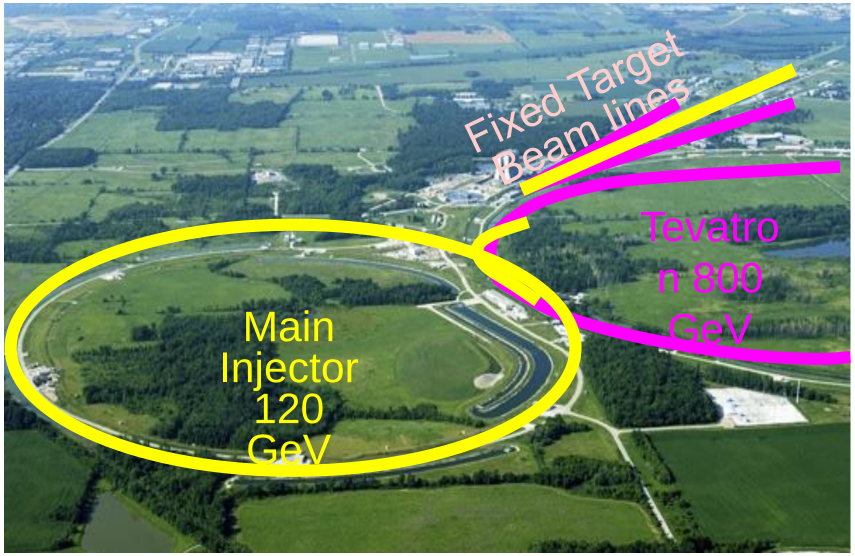
Tension shows up with the collider data!

$\bar{d}(x)/\bar{u}(x)$ Measured by FNAL E906/SeaQuest Experiment



Fermilab E906

- $x_B x_T = \frac{M}{s}$; smaller s, larger x_T
- Unpolarized Drell-Yan using 120 GeV proton beam from Main Injector
- ^{1}H, ^{2}H, and nuclear targets



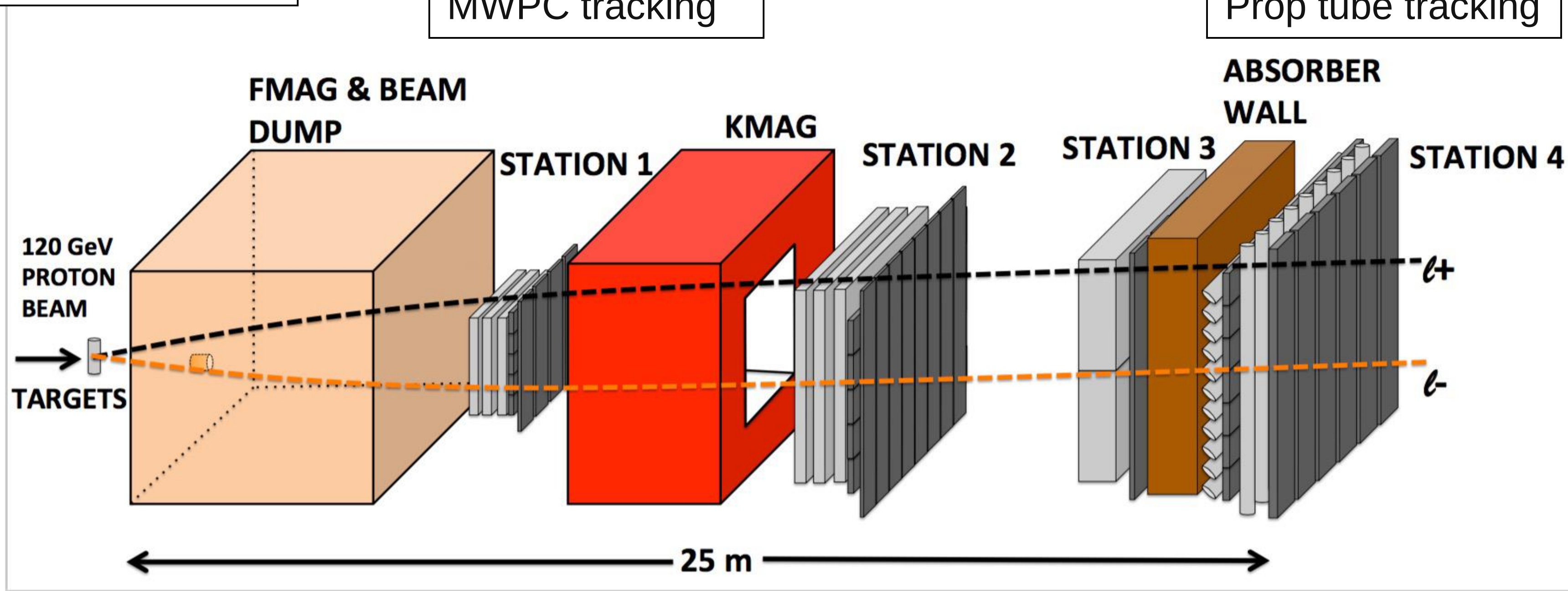
$(\bar{d}(x)/\bar{u}(x))$ up to $x_T \sim 0.45$

E906 Spectrometer

Liquid H_2, D_2, and solid targets

Station 1:
Hodoscope array
MWPC tracking

Station 4:
Hodoscope array
Prop tube tracking



Solid Iron Focusing Magnet, Hadron absorber and beam dump

Station 2 and 3:
Hodoscope array
Drift Chamber tracking

E906/SeaQuest Timeline

- Schedules:
  - **2002: E906 Approved by Fermilab PAC**
  - 2006: E906 funded by DOE Nuclear Physics
  - 2008: With participation of Japan and Taiwan groups, Stage-II approval by Fermilab Director. MOU between Fermilab and E906 Collaboration finalized.
  - 2009-2010: Construction and installation of spectrometer and readout electronics.

E-906/SeaQuest Collaboration

Abilene Christian University
- Brandon Bowen
- Brianna Edlund
- Tyler Hague
- Donald Isenhower
- Ben Miller
- Tim Sipos
- Rusty Towell
- Shon Watson

Academia Sinica
- Wen-Chen Chang
- Yen-Chu Chen
- Hsi-Hung Yao
- Shiuan-Hal Shiu
- Da-Shung Su

Argonne National Laboratory
- John Arrington
- Kevin Bailey
- Don Geesaman*
- Kawtar Hafidi
- Roy Holt
- Harold Jackson
- Tom O'Connor
- David Potterveld
- Paul E. Reimer*
- Josh Rubin

University of Colorado
- Ed Kinney
- Po-Ju Lin

Fermi National Accelerator Laboratory
- Chuck Brown
- David Christian

University of Illinois
- Bryan Dannowitz
- Bryan Kerns
- Naomi C.R Makins
- R. Evan McClellan
- Jen-Chieh Peng

KEK
- Shin'ya Sawada

Kyoto University
- KenIchi Imai
- Tomo Nagae

Los Alamos National Laboratory
- Christine Aidala
- Gerry Garvey
- Mike Leitch
- Han Liu
- Ming Xiong Liu
- Pat McGaughey
- Andrew Puckett

University of Maryland
- Betsy Beise
- Kaz Nakahara

University of Michigan
- Chiranjib Dutta
- Wolfgang Lorenzon
- Richard Raymond
- Michael Steward

National Kaohsiung Normal University
- Rurngsheng Guo
- Su-Yin Wang

University of New Mexico
- Imran Younus

RIKEN
- Yoshinori Fukao
- Yuji Goto
- Atsushi Taketani

Rutgers University
- Lamiaa El Fassi
- Ron Gilman
- Ron Ransome
- Yawei Zhang

Texas A & M University
- Carl Gagliardi
- Robert Tribble

Thomas Jefferson National Accelerator Facility
- Dave Gaskell
- Patricia Solvignon

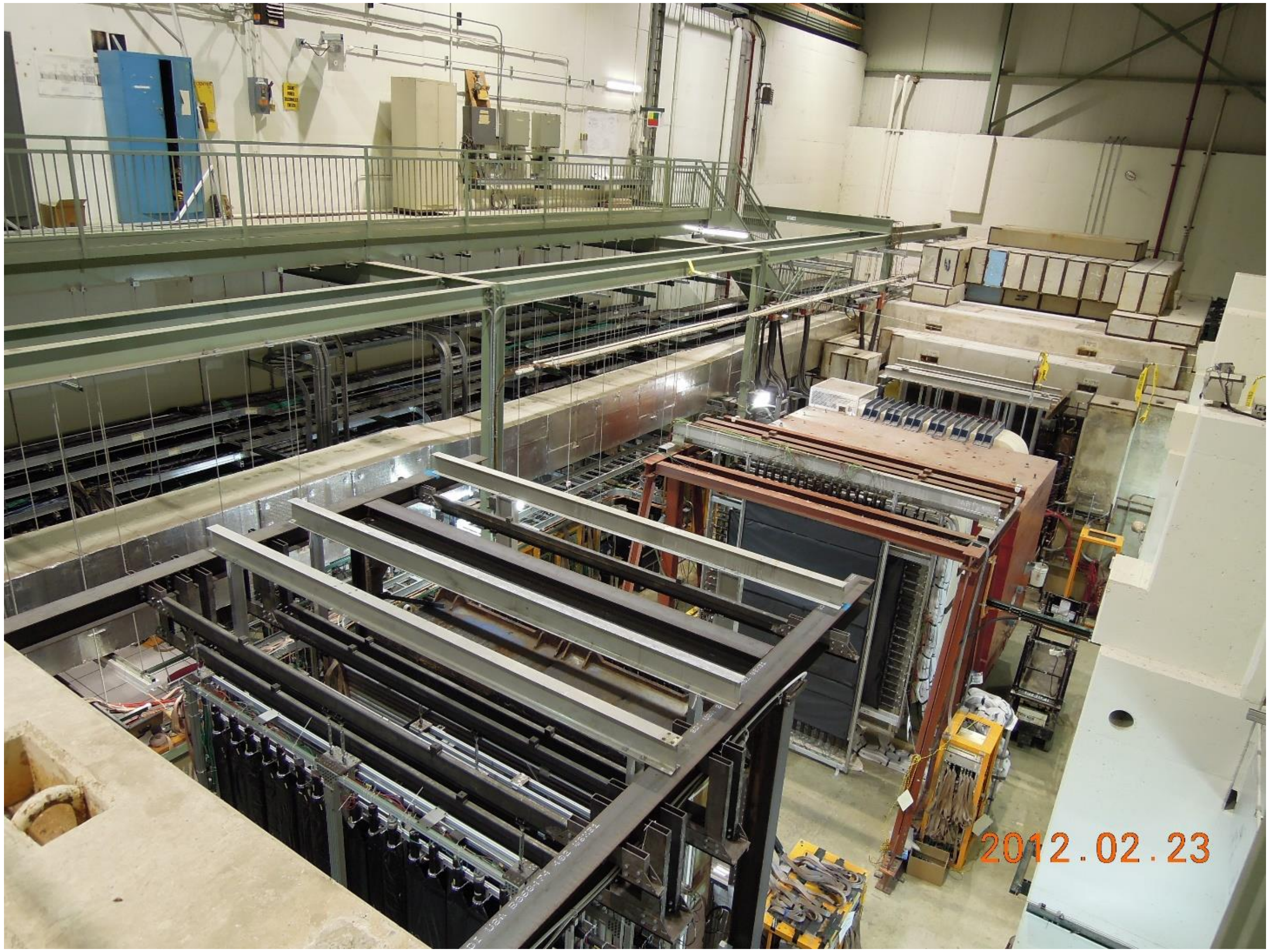
Tokyo Institute of Technology
- Shou Miyaska
- Ken-ichi Nakano
- Florian Sanftl
- Toshi-Aki Shibata
- Shintaro Takeuchi

Yamagata University
- Yoshiyuki Miyachi

*Co-Spokespersons

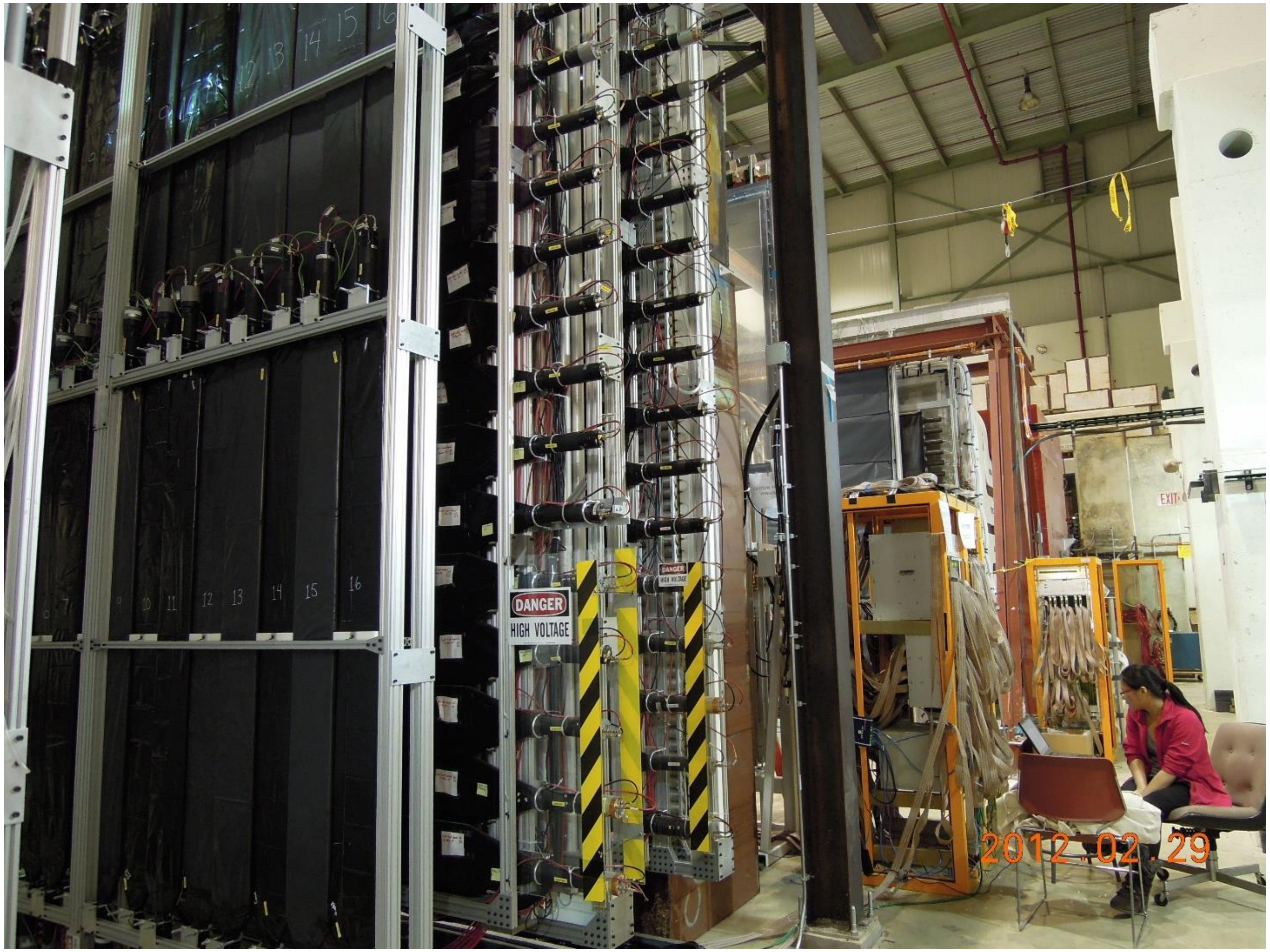
Fermilab NM4/KTeV Hall (before installation)

Fermilab NM4/KTeV Hall (after installation)

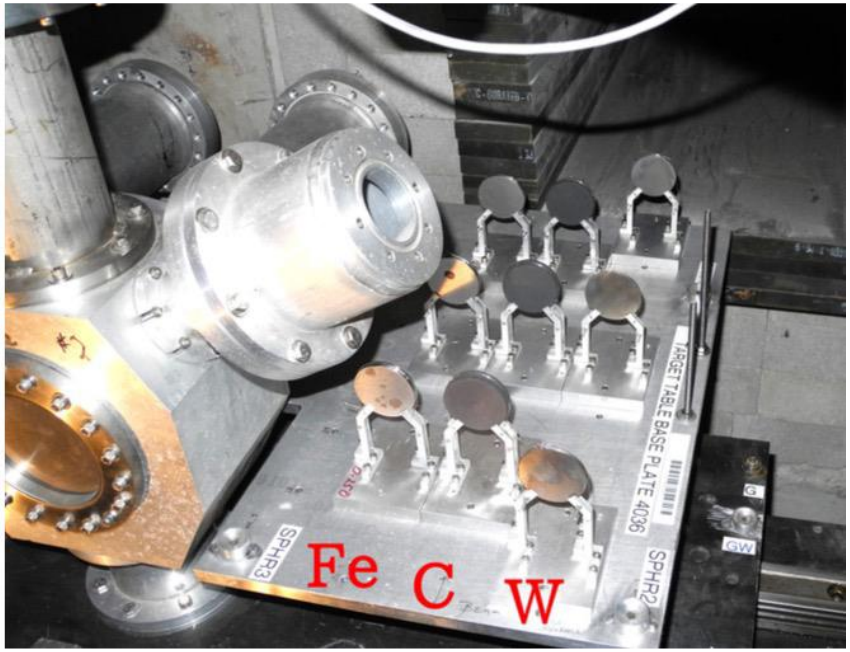


Fermilab NM4/KTeV Hall (after installation)

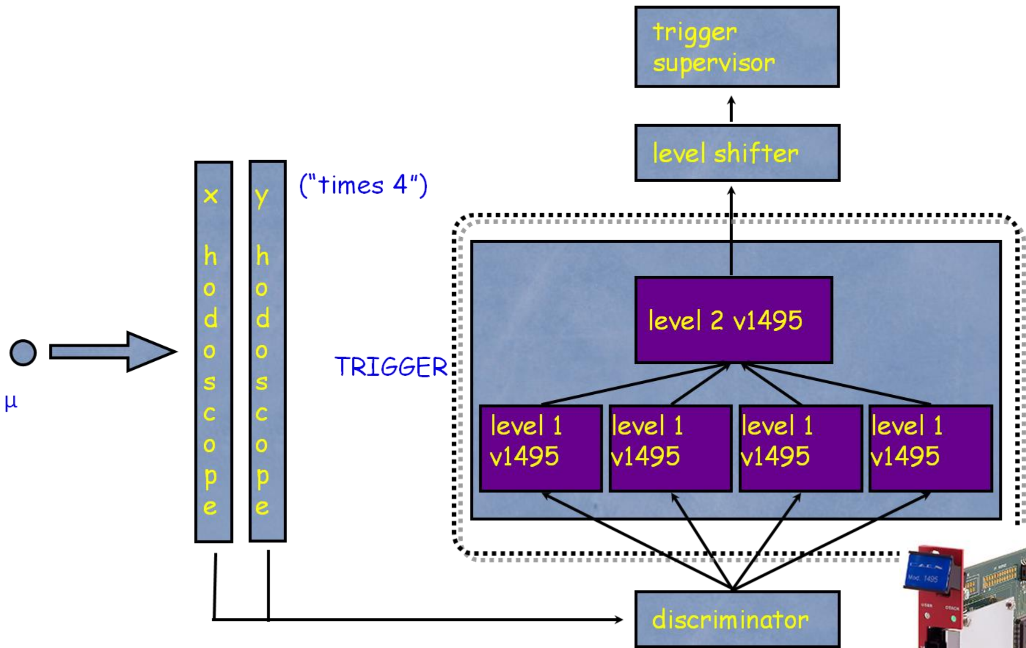
Fermilab NM4/KTeV Hall (after installation)

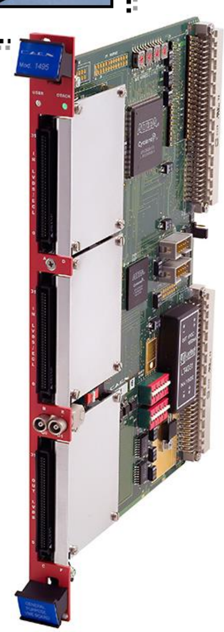


Liquid H_2, D_2, Empty Cell and Nuclear Targets



Dimuon Online Trigger





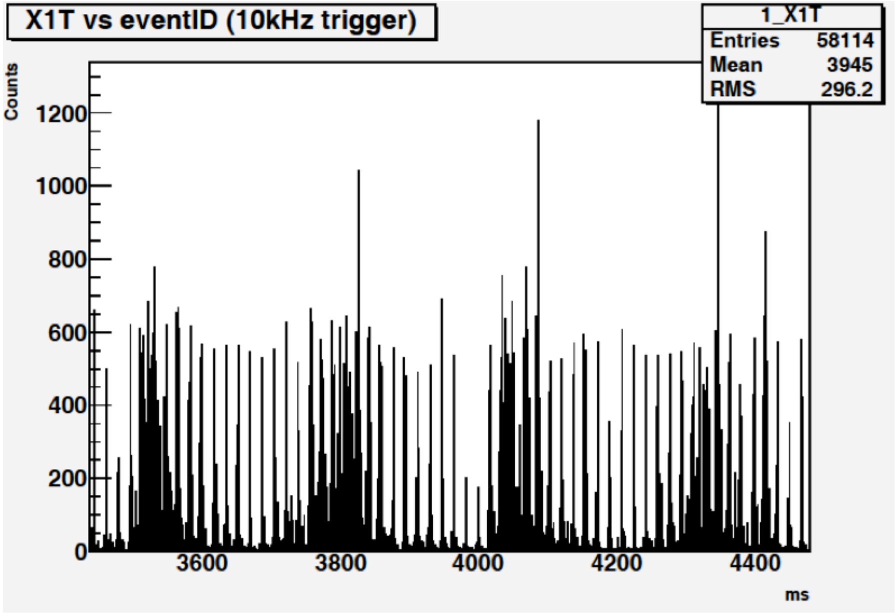
- Online trigger system is composed of 5 CAEN V1495 FPGA modules.
- Without deadtime, the decision of a di-muon trigger or a single-muon trigger can be made within 200 ns, based on the input of 400 channels of the four hodoscopes.

E906/SeaQuest Timeline

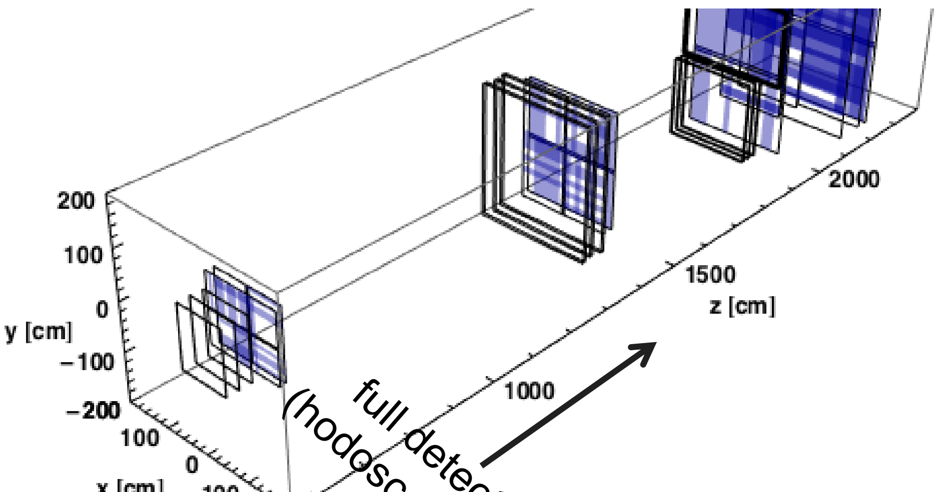
- Schedules:
  - **2002: E906 Approved by Fermilab PAC**
  - 2006: E906 funded by DOE Nuclear Physics
  - 2008: With participation of Japan and Taiwan groups, Stage-II approval by Fermilab Director. MOU between Fermilab and E906 Collaboration finalized.
  - 2009-2010: Construction and installation of spectrometer and readout electronics.
  - The commission of experiment was originally scheduled to start in September 2010. Unfortunately a leakage of the upstream beam pipe was found, and FNAL spent a lot of efforts in fixing it up.
  - Run 1 (Mar. 2012 – Apr., 2012): commissioning run
  - Run 2 (Nov. 2013 – Sep., 2014): 1st physics run
  - Run 3 (Nov. 2014 – Jul., 2015): 2nd physics run
  - Run 4 (Oct. 2015 – Aug., 2016): 3rd physics run
  - Run 5 (Nov. 2016 – Jul., 2017): 4th physics run

Primary Challenge in the Data Analysis: Large Fluctuations of Beam Intensity

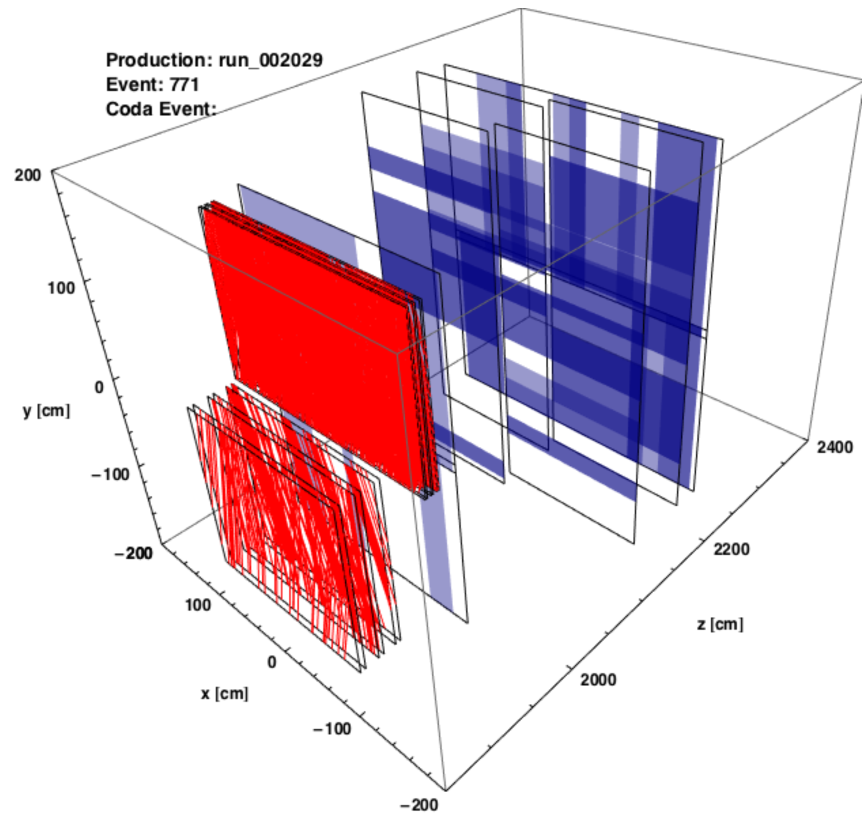
- Proton beam: 4s every 60s, extracted from Fermilab Main Injector; 1-ns-long micro-bunches of approximately 0 to 80,000 protons at 53 MHz repetition rate. *About $6x10^{12}$ proton on target every 4s*.
- The average duty factor, $\langle I \rangle^2/\langle I^2 \rangle$, ranged between 20% and 40%.



The Beam was Delivered, But…

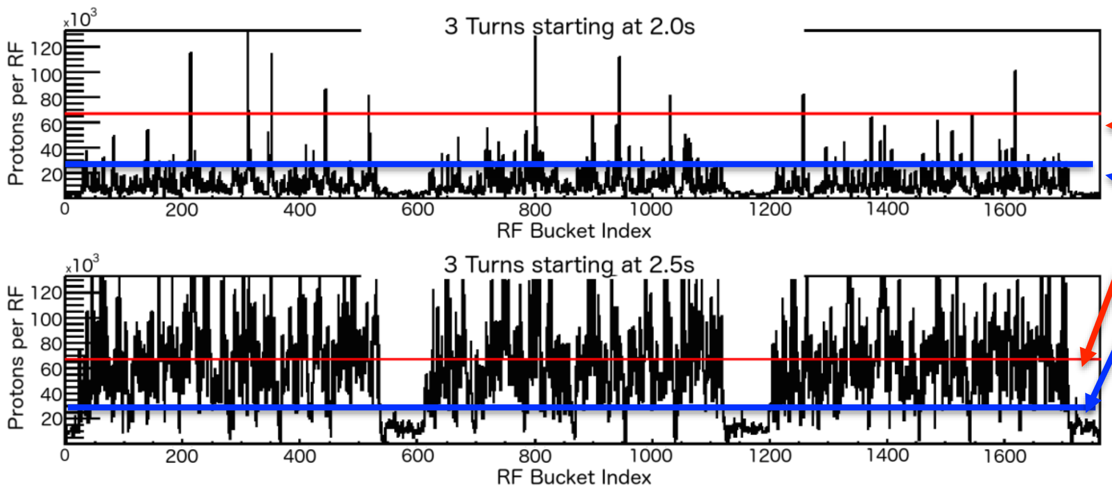


full detector
(hodoscope hits)



Stations 3+4
(all hits)

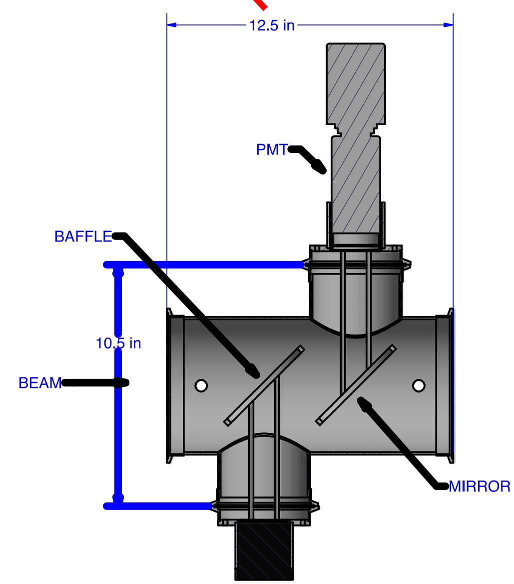
Beam Intensity Profile



- **Each bin is 19 ns**
- Veto Level
- Even beam distribution

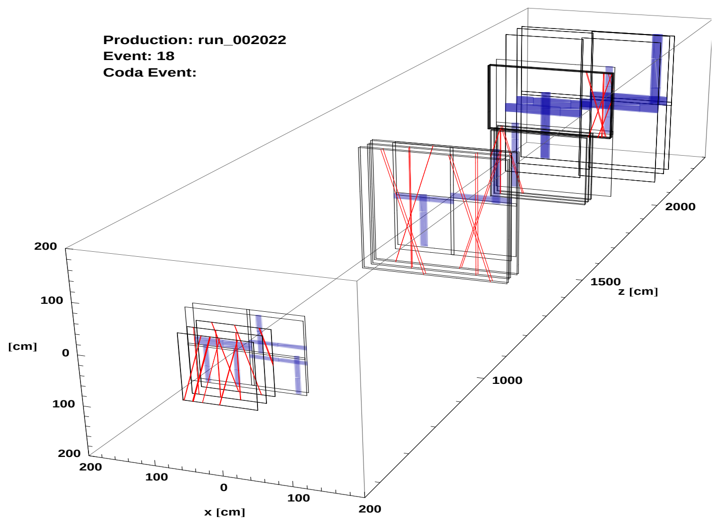
Beam Cherenkov

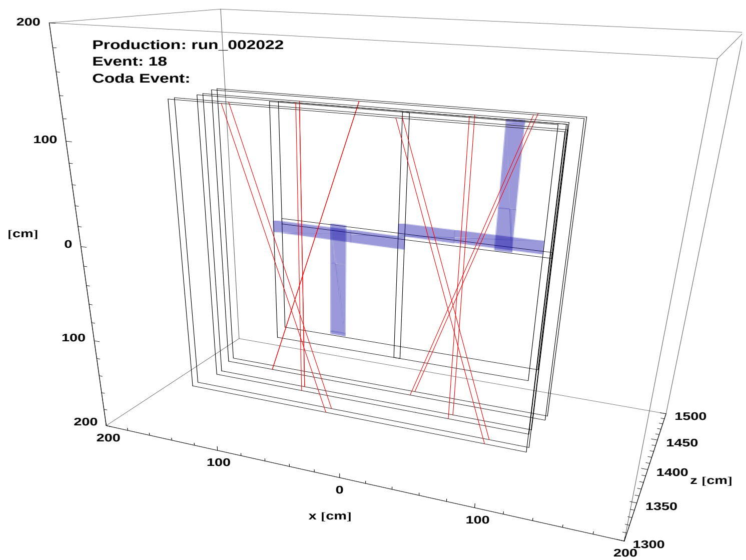
- <16 ns time resolution
- Approx. 30 to 3×10^{16} protons/RF cycle
- Calibrated every minute against beam line SEM (secondaryelectron emission)



Trigger Veto

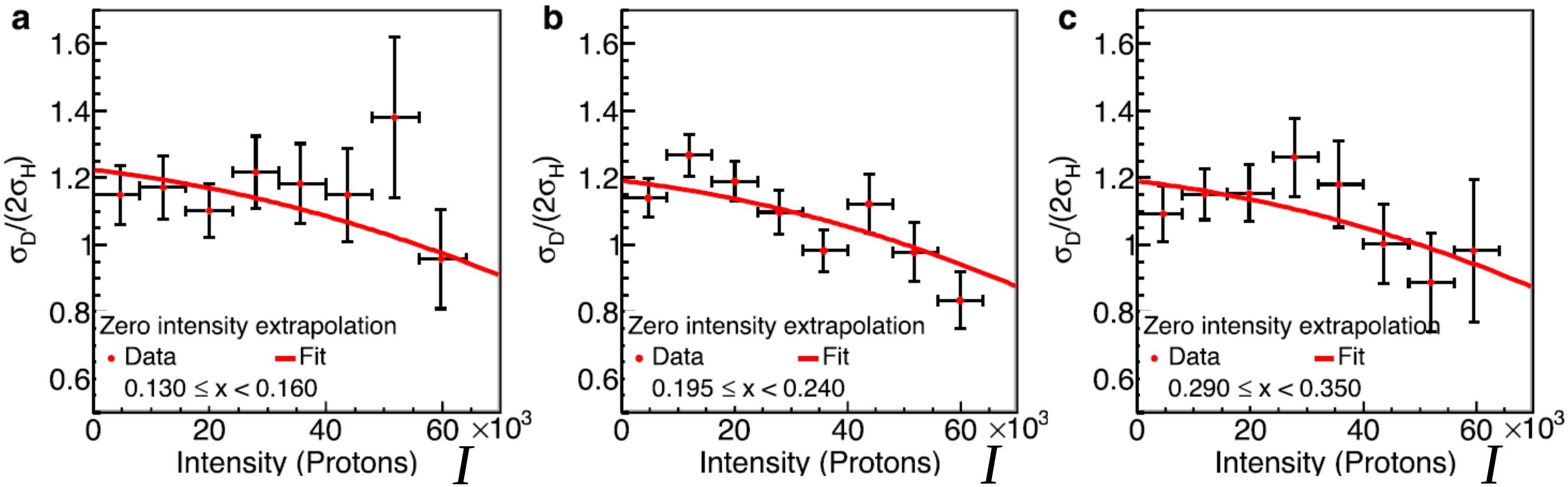
- Electronic running average of the multiplicity over a 160 ns window (8 RF buckets).
- If average multiplicity above threshold, raises a trigger veto
- Luminosity greatly reduced, but trigger suppresses windows of time with large beam intensities.





Extrapolation to zero intensity

$0.13 \leq x < 0.16$ $0.195 \leq x < 0.24$ $0.29 \leq x < 0.35$



- Large intensity variations had two primary consequences:
  - a variation in the track reconstruction efficiency
  - a change in the rate of accidental coincidences

$$\frac{Y_D(x,I)}{2Y_H(x,I)} = R(x) + aI + bI^2$$

Nature 590, 561–565 (2021)

Article

The asymmetry of antimatter in the proton

https://doi.org/10.1038/s41586-021-03282-z

Received: 2 June 2020

Accepted: 15 December 2020

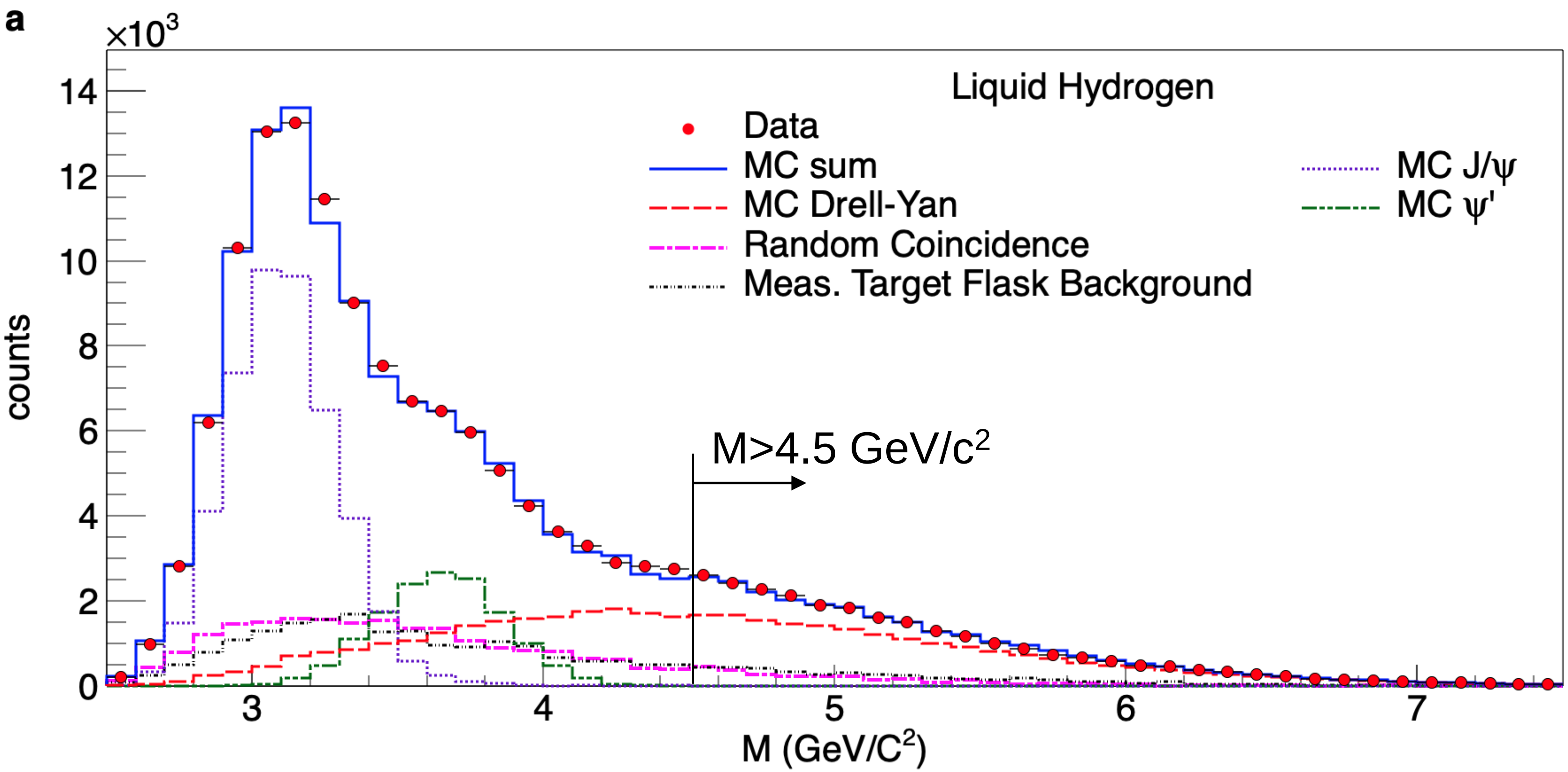
Published online: 24 February 2021

Check for updates

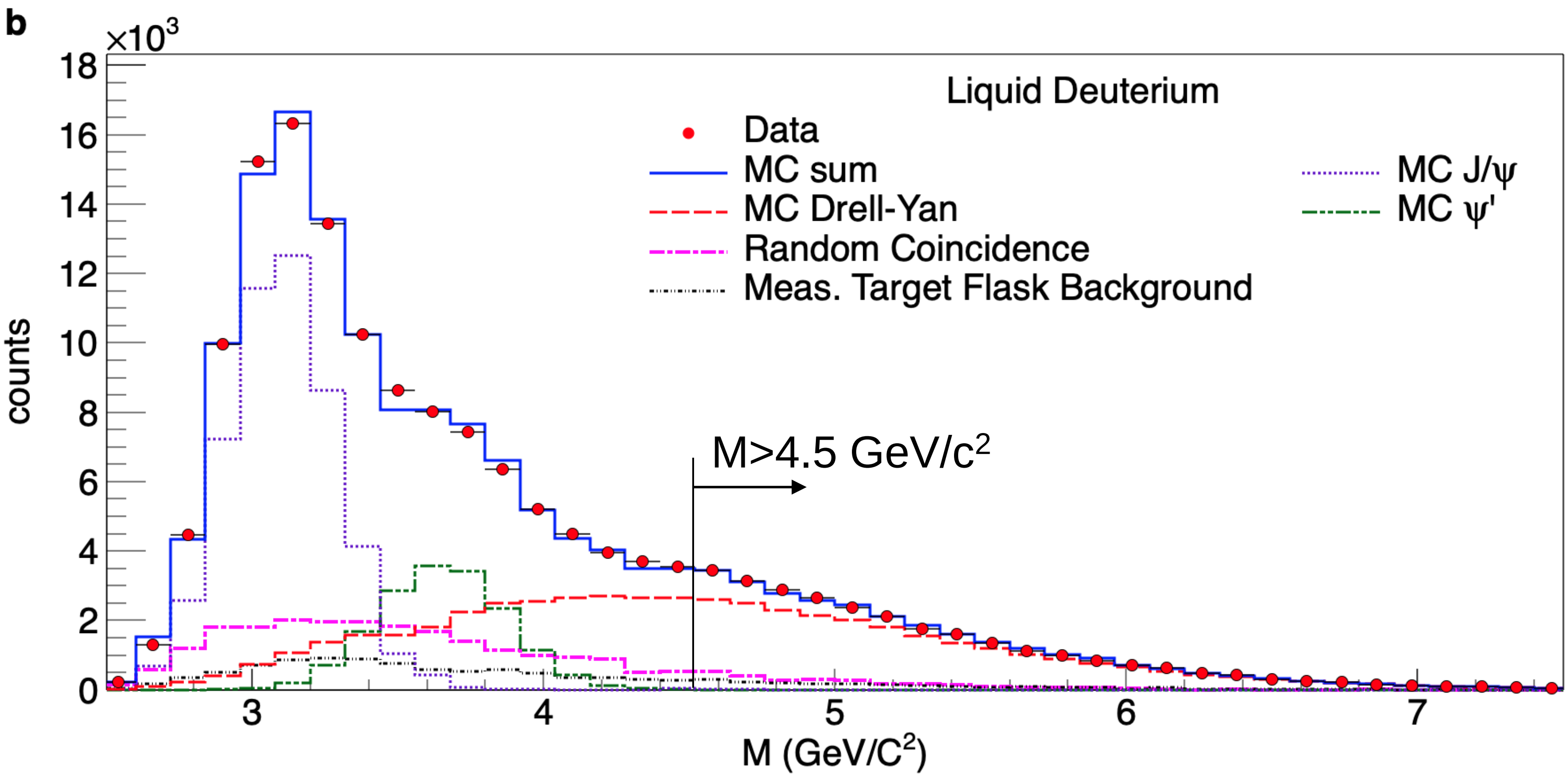
J. Dove[1], B. Kerns[1], R. E. McClellan[1,18], S. Miyasaka[2], D. H. Morton[3], K. Nagai[2,4], S. Prasad[1], F. Sanftl[2], M. B. C. Scott[3], A. S. Tadepalli[5,18], C. A. Aidala[3,6], J. Arrington[7,19], C. Ayuso[3,20], C. L. Barker[8], C. N. Brown[9], W. C. Chang[4], A. Chen[1,3,4], D. C. Christian[10], B. P. Dannowitz[1], M. Daugherity[8], M. Diefenthaler[1,18], L. El Fassi[5,11], D. F. Geesaman[7,21], R. Gilman[5], Y. Goto[12], L. Guo[6,22], R. Guo[13], T. J. Hague[8], R. J. Holt[7,23], D. Isenhower[8], E. R. Kinney[14], N. Kitts[8], A. Klein[6], D. W. Kleinjan[6], Y. Kudo[15], C. Leung[1], P.-J. Lin[14], K. Liu[6], M. X. Liu[6], W. Lorenzon[3], N. C. R. Makins[1], M. Mesquita de Medeiros[7], P. L. McGaughey[6], Y. Miyachi[15], I. Mooney[3,24], K. Nakahara[16,25], K. Nakano[2,12], S. Nara[15], J.-C. Peng[1], A. J. Puckett[6,26], B. J. Ramson[3,27], P. E. Reimer[7]✉, J. G. Rubin[3,7], S. Sawada[17], T. Sawada[3,28], T.-A. Shibata[2,29], D. Su[4], M. Teo[1,30], B. G. Tice[7], R. S. Towell[8], S. Uemura[6,31], S. Watson[8], S. G. Wang[4,13,32], A. B. Wickes[6], J. Wu[10], Z. Xi[8] & Z. Ye[7]

The fundamental building blocks of the proton—quarks and gluons—have been known for decades. However, we still have an incomplete theoretical and

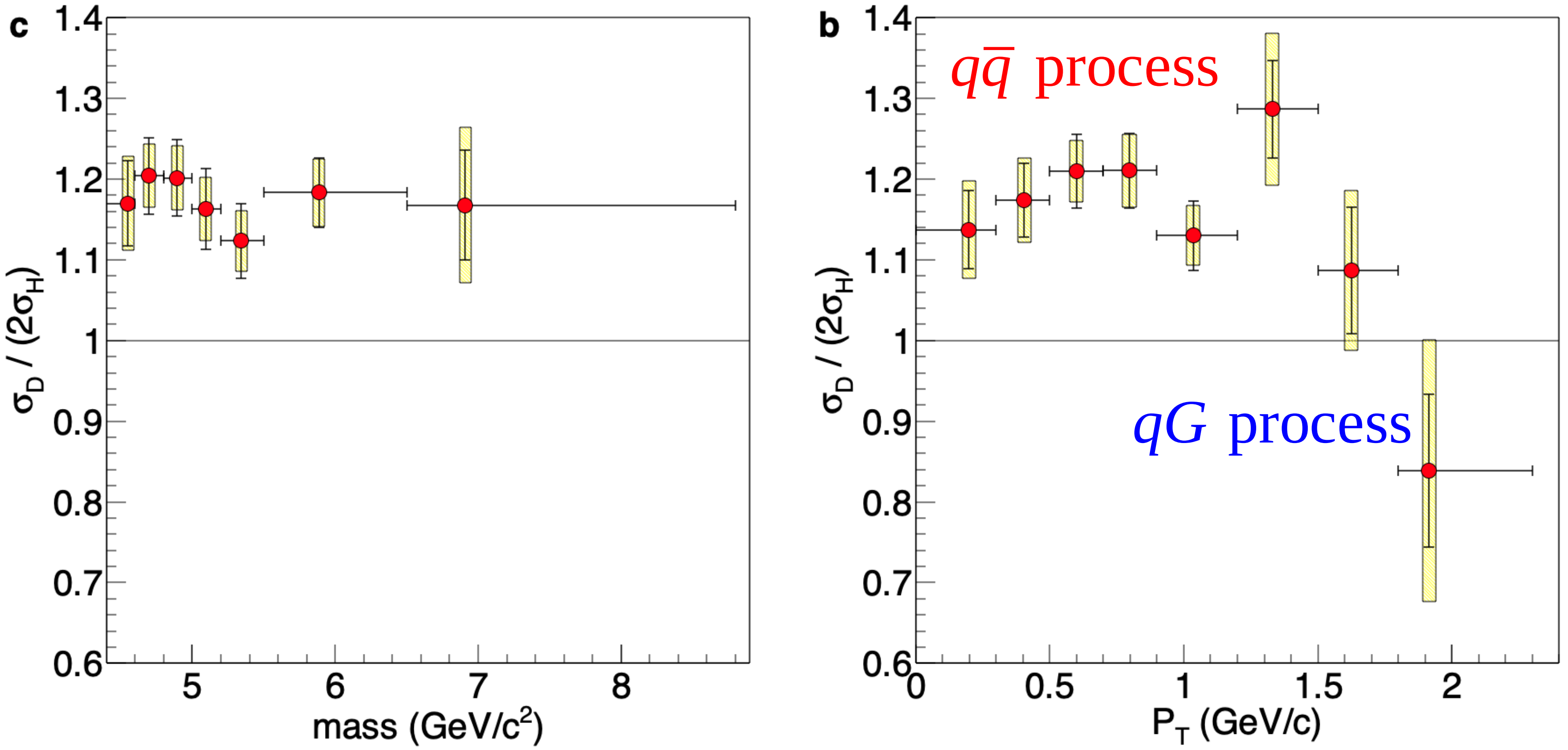
Dimuon Mass Spectrum – Hydrogen Target (H)



Dimuon Mass Spectrum – Deuterium Target (D)

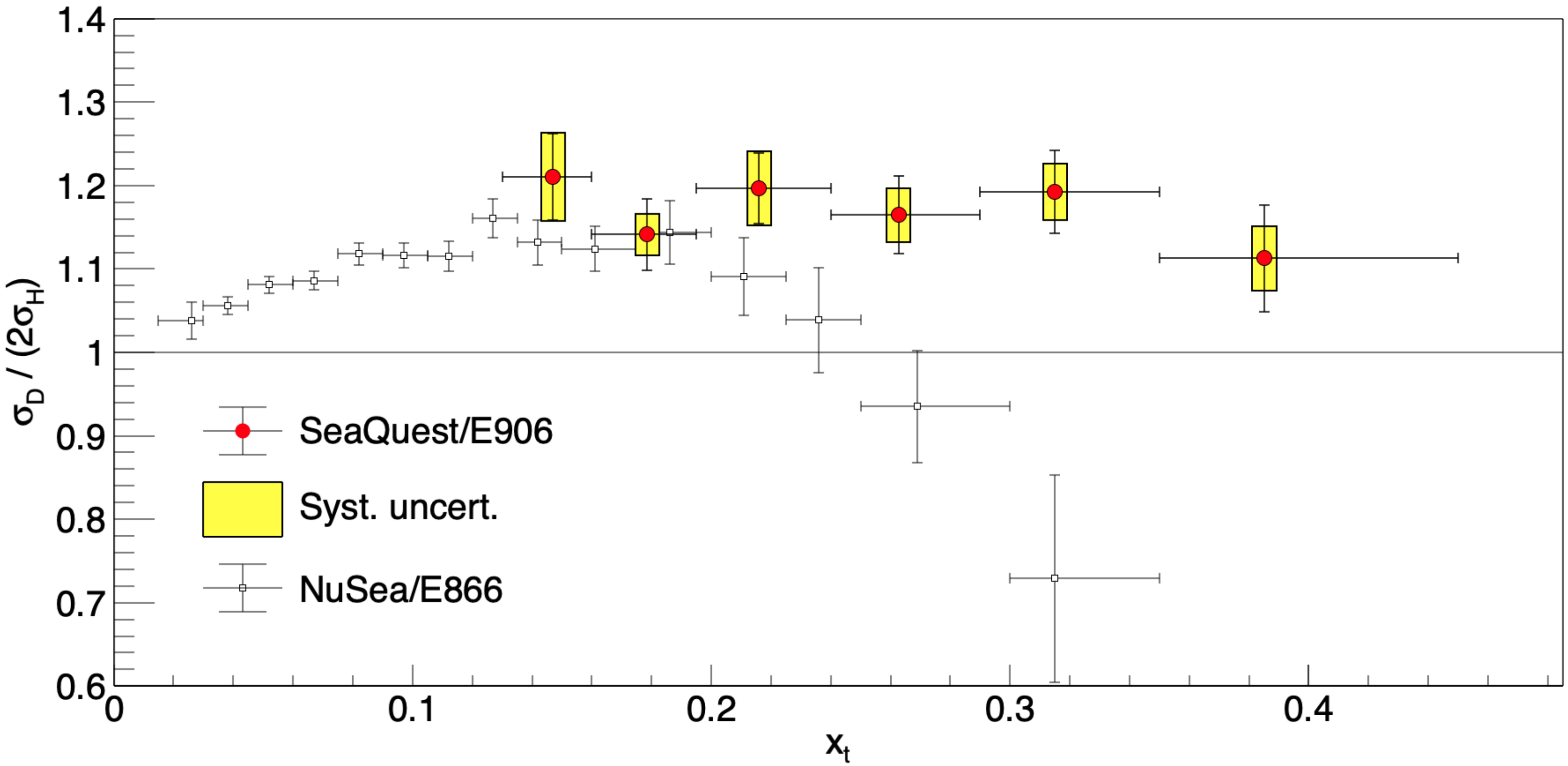


Cross Section Ratios



Cross Section Ratios

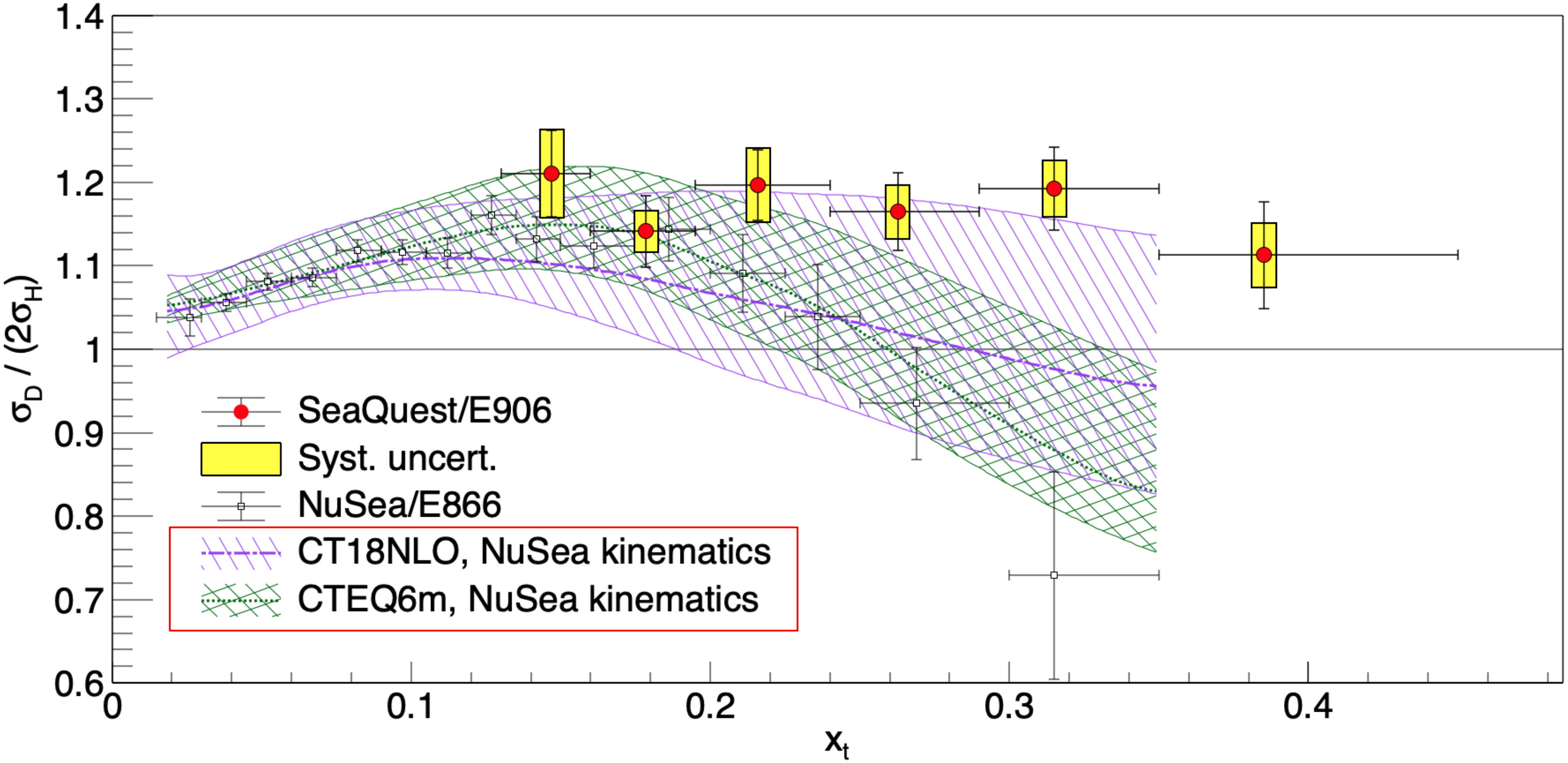
$$\left\langle M^2_{NuSea} \right\rangle = 54\ \text{GeV}^2, \left\langle M^2_{SeaQuest} \right\rangle = 22 - 40\ \text{GeV}^2$$



$$\frac{\sigma^{pd}}{2\sigma^{pp}}\Big|_{x_{\text{beam}} \gg x_{\text{target}}} \approx \frac{1}{2}\left[1 + \frac{\bar{d}(x_{\text{target}})}{\bar{u}(x_{\text{target}})}\right]$$

Cross Section Ratios

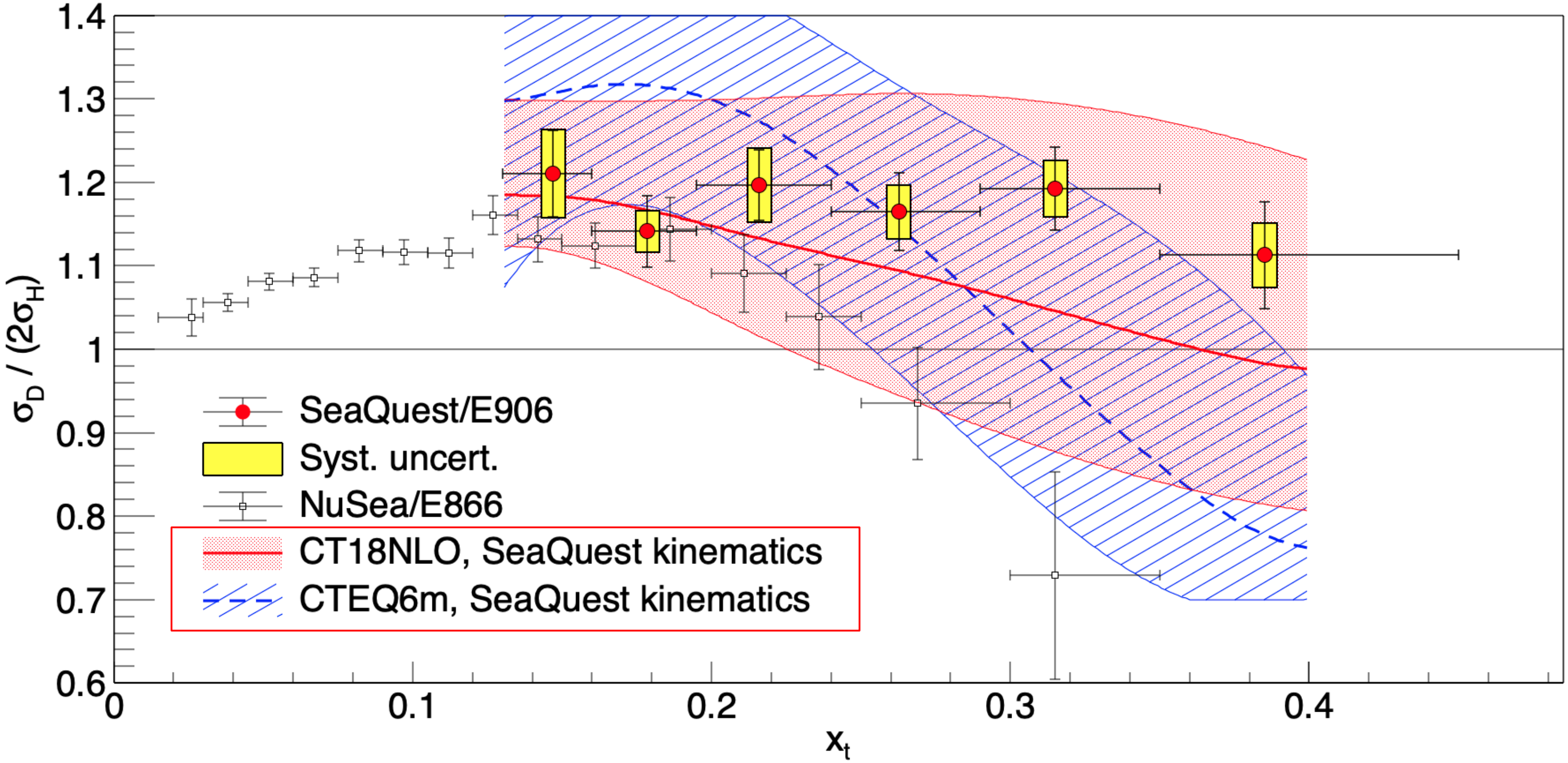
$$\left\langle M^2_{NuSea} \right\rangle = 54\ \mathrm{GeV}^2, \left\langle M^2_{SeaQuest} \right\rangle = 22 - 40\ \mathrm{GeV}^2$$



CTEQ6m: JHEP 0207:012,2002; hep-ph/0201195
CT18NLO: PRD 103 (2021) 014013; 1912.10053

Cross Section Ratios

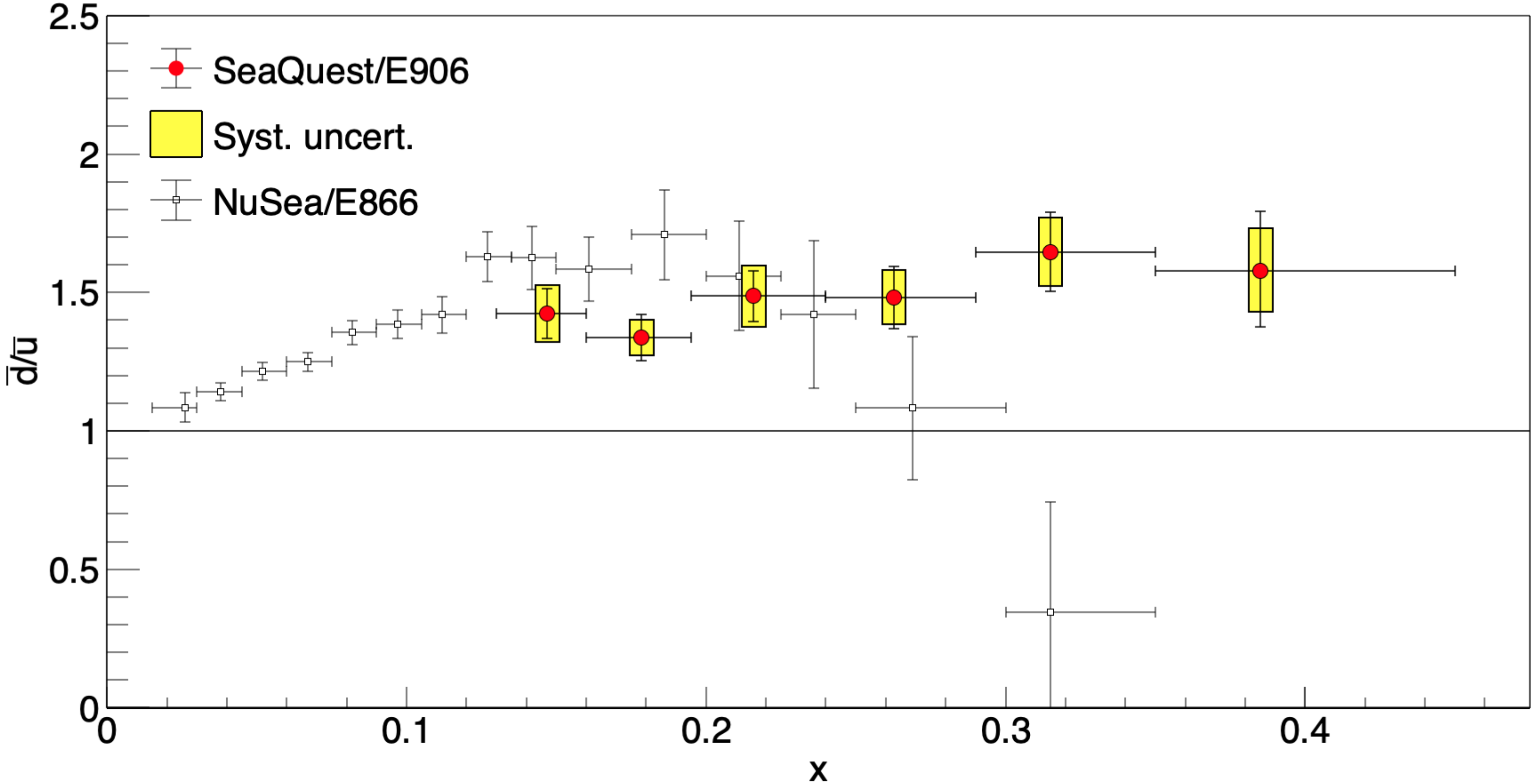
$$\langle M^2_{NuSea} \rangle = 54\ \mathrm{GeV}^2, \langle M^2_{SeaQuest} \rangle = 22 - 40\ \mathrm{GeV}^2$$



SeaQuest results are consistent with the NLO calculation with CT18NLO.

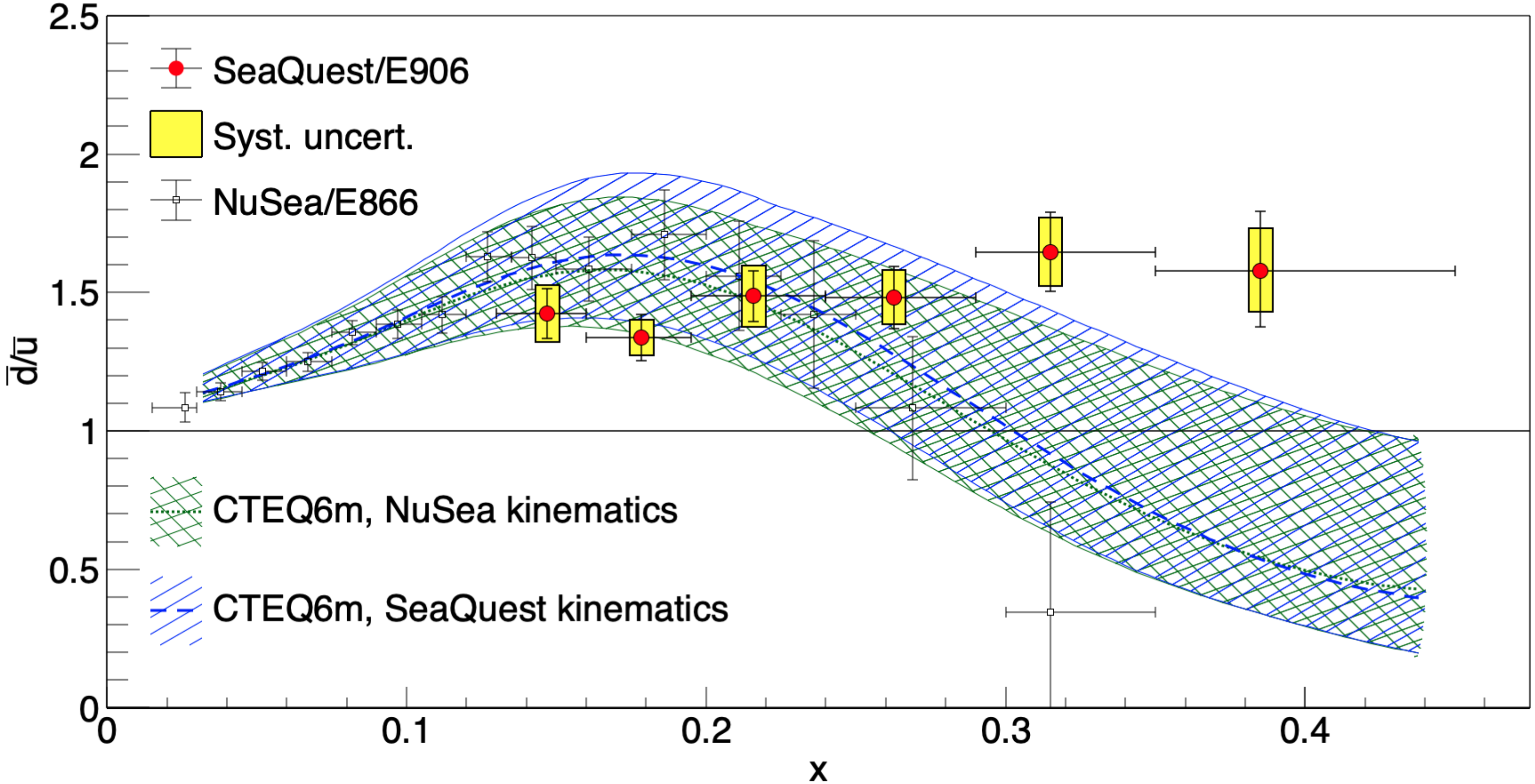
$\bar{d}/\bar{u}(x)$

Extracting $\bar{d}/\bar{u}(x)$ by NLO calculations of $\sigma_D(x)/2\sigma_H(x)$

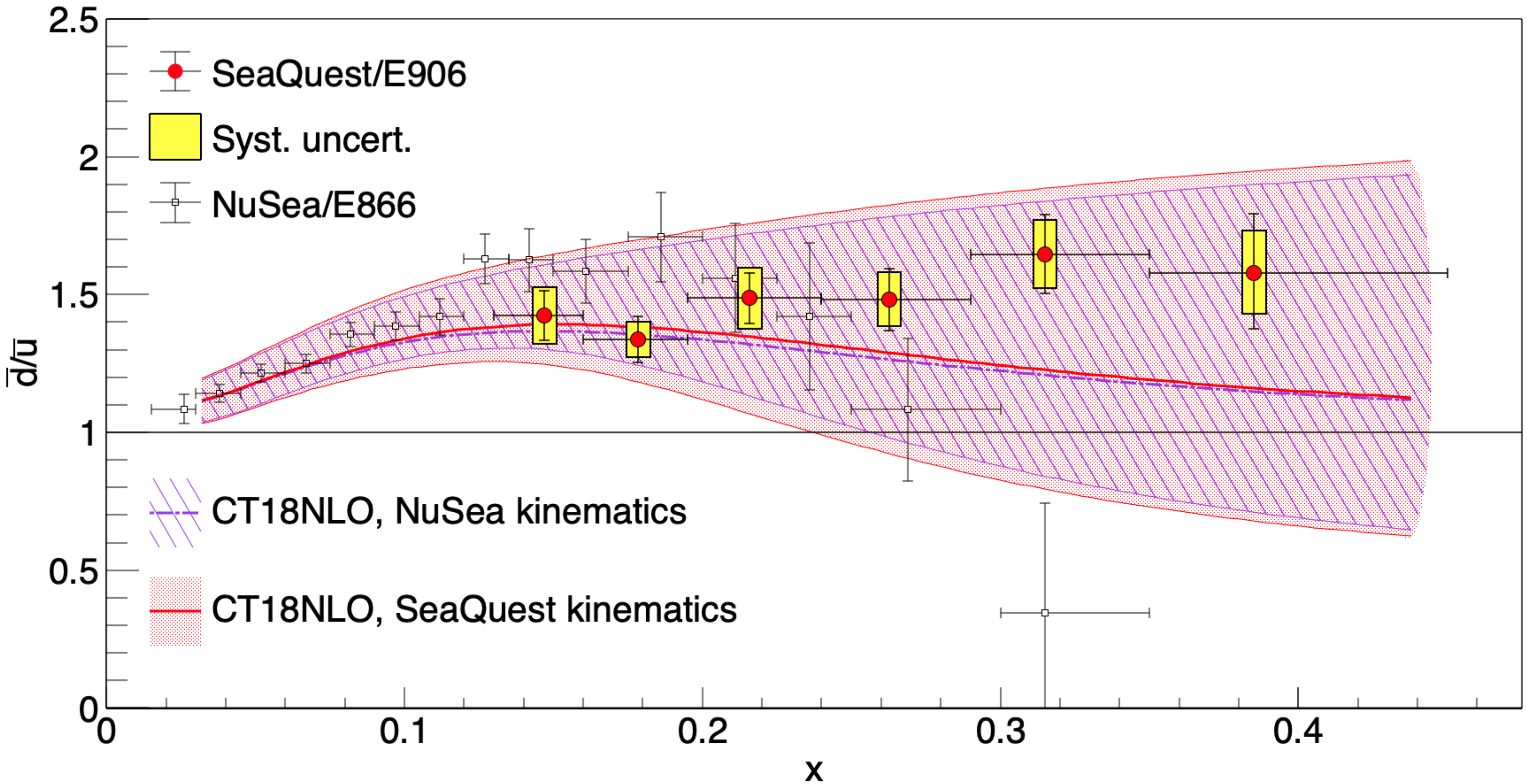


The trends between SeaQuest and NuSea at large x are quite different. No explanation is found for these differences.

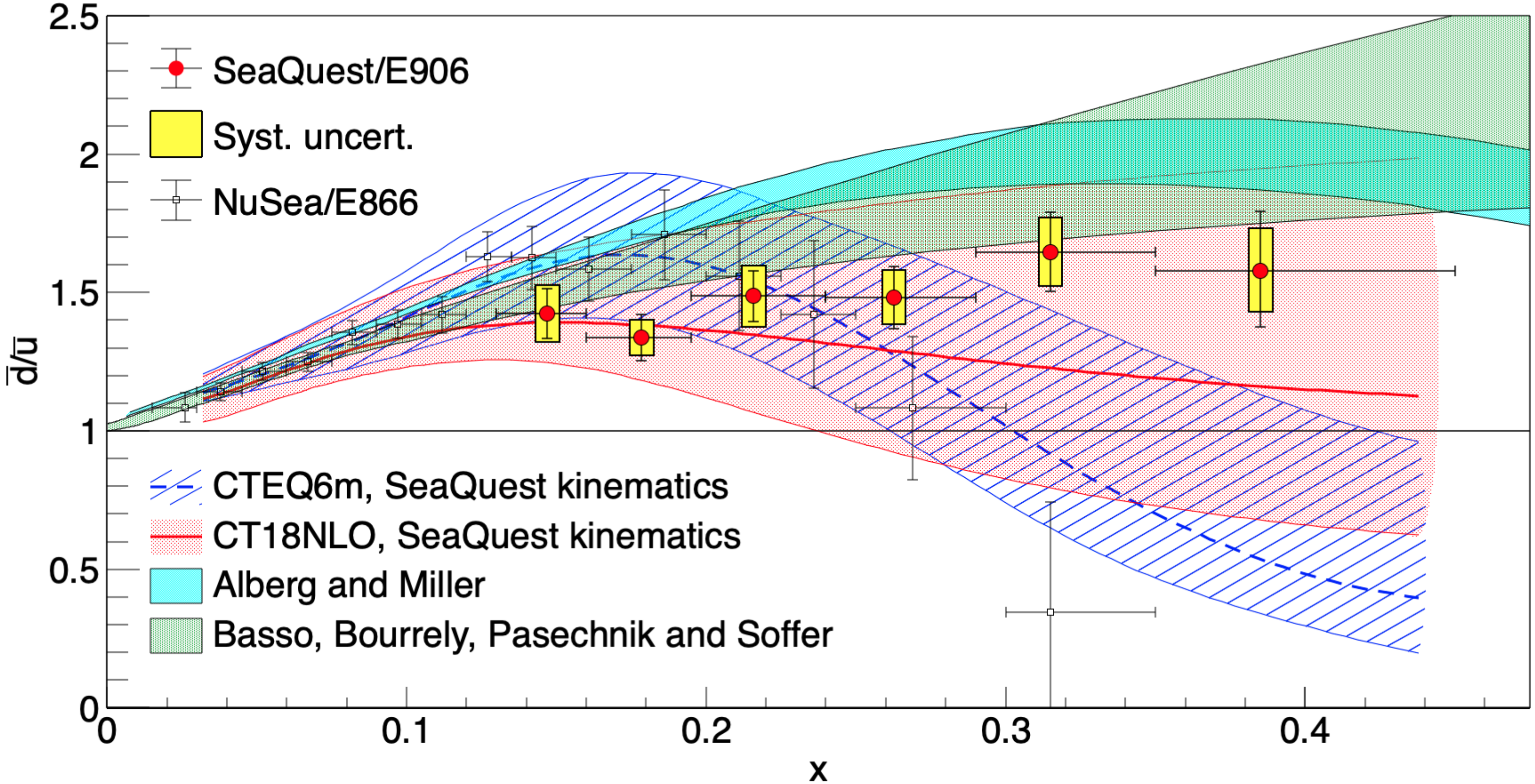
$\bar{d}/\bar{u}(x)$ vs. CTEQ6m



$\bar{d}/\bar{u}(x)$ vs. CT18NLO



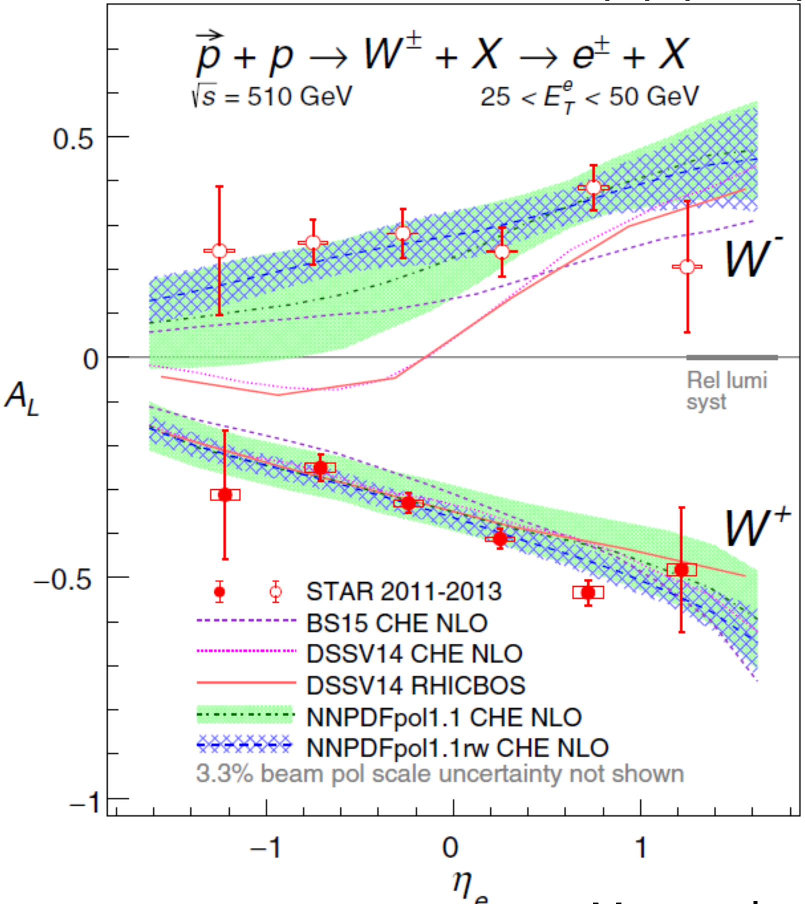
$\bar{d}/\bar{u}(x)$



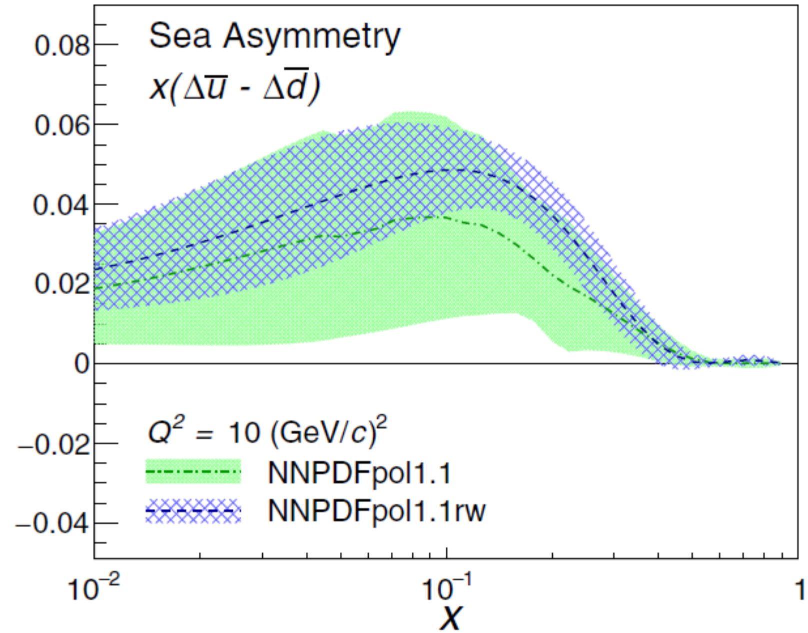
SeaQuest/E906
Syst. uncert.
NuSea/E866
CTEQ6m, SeaQuest kinematics
CT18NLO, SeaQuest kinematics
Alberg and Miller
Basso, Bourrely, Pasechnik and Soffer
2.5
2
1.5
1
0.5
0
0.1
0.2
0.3
0.4
x
d̄/ū

Asymmetry of $\Delta\bar{d}(x)$ and $\Delta\bar{u}(x)$

STAR, PRD 99, 051102(R) (2019)

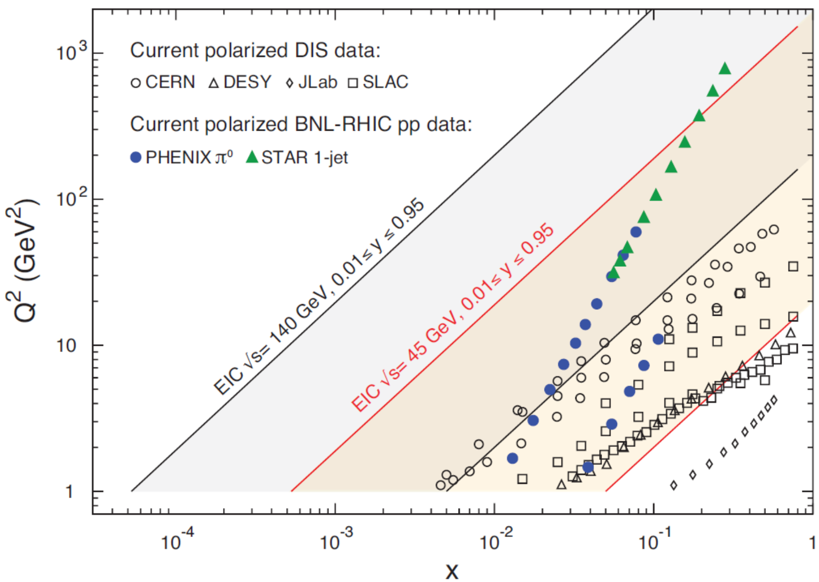


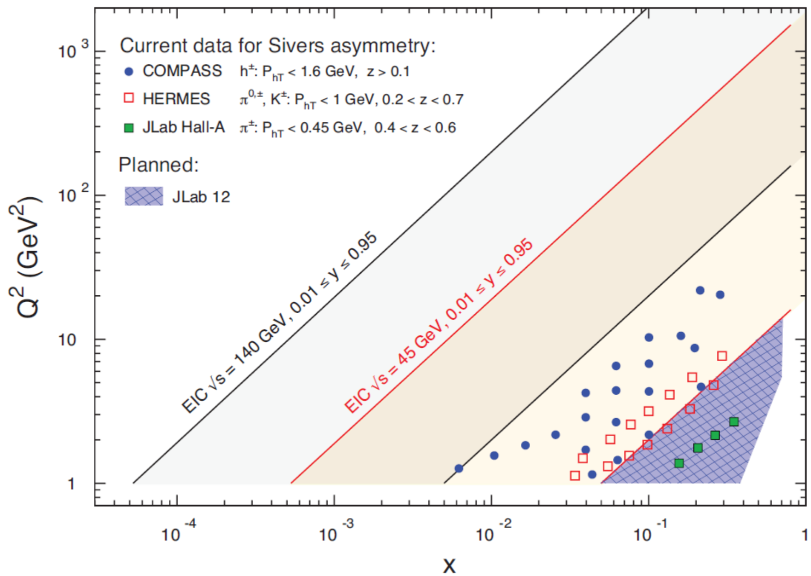
$\Delta\bar{d}(x) < \Delta\bar{u}(x)$



- Meson cloud model: little spin carried by sea quark.
- Statistic model: $\Delta\bar{d}(x) - \Delta\bar{u}(x) = -(\bar{d}(x) - \bar{u}(x))$
- Chiral soliton model: $\Delta\bar{d}(x) - \Delta\bar{u}(x) = -\frac{5}{3}(\bar{d}(x) - \bar{u}(x))$

EIC: Flavor Structures of Spin and TMDs for Nucleon Sea





arXiv:1212.1701

Summary

- From DIS and Drell-Yan, a striking asymmetry of $\bar{d}(x) > \bar{u}(x)$ was observed at the intermediate-x regions.
- FNAL SeaQuest/E906 experiment extends the measurement of $\bar{d}(x)/\bar{u}(x)$ up to 0.45 and no flipping of this ratio at large x is found.
- EIC will explore the flavor structure of spin and TMDs for nucleon sea in the future.

Thanks to Prof. Tung-Mow Yan

Tung-Mow Yan

Professor of Physics

顏東茂

314 Newman Laboratory
Cornell University
Ithaca NY 14853

(607) 255-7125

ty18@cornell.edu

BS, 1960, National Taiwan University. Ph.D., 1968, Harvard University. Research Associate, Stanford Linear Accelerator Center, 1968-70. Assistant Professor, Physics, Cornell University, 1970-76. Associate Professor, Physics, Cornell University, 1976-81. Professor, Physics, Cornell University, 1981-present. Visiting appointments at: Stanford Linear Accelerator Center, 1973-74. Theory Division, CERN, 1977-78. Physics Department, National Taiwan University, 1986. Institue of Physics, Academia Sinica, Taipei, Taiwan, 1991-92. National Center of Theoretical Sciences, Hsinchu, Taiwan, 1997. Alfred Sloan Fellow, 1974-78. Fellow, American Physics Society.