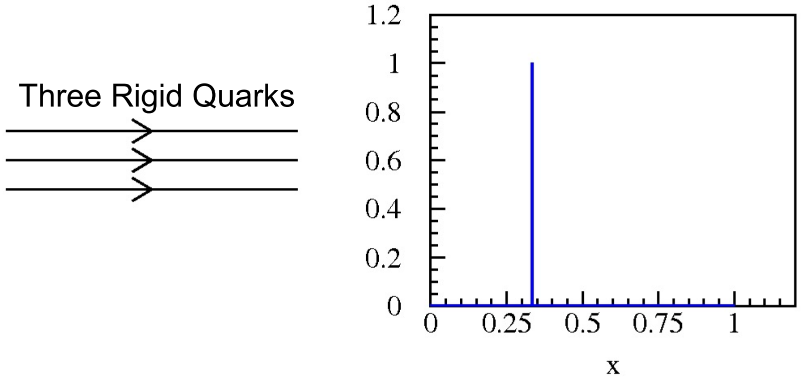
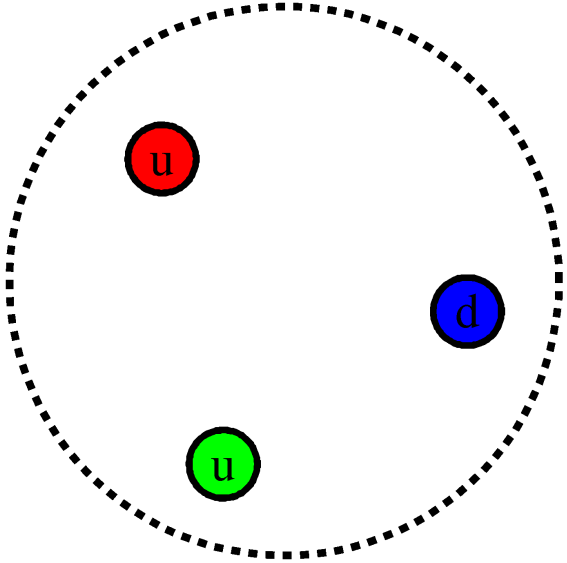
FROM CONSTITUENT QUARKS TO PARTONIC QUARKS

- 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





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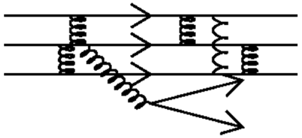
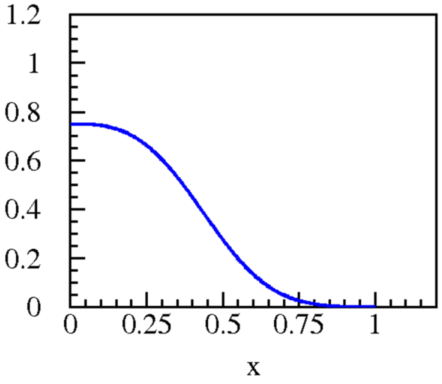
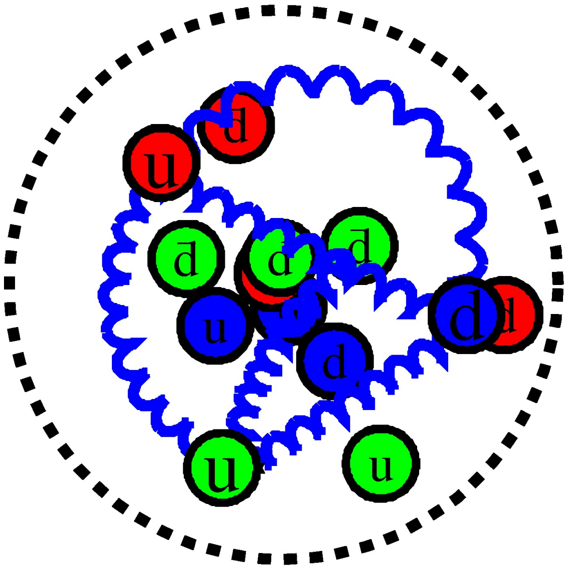






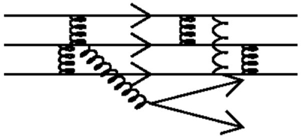
From Constituent Quarks to Partonic Quarks

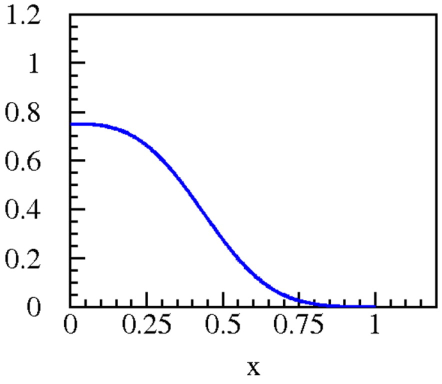
- Constituent Quark/Bag Model motivated valence approach
  - Use valence-like (primordial) quark distributions at some very low scale, Q^2, perhaps a few hundred MeV
  - Radiatively generate sea and glue.
    Gluck, Reya, Vogt, ZPC 53, 127 (1992)

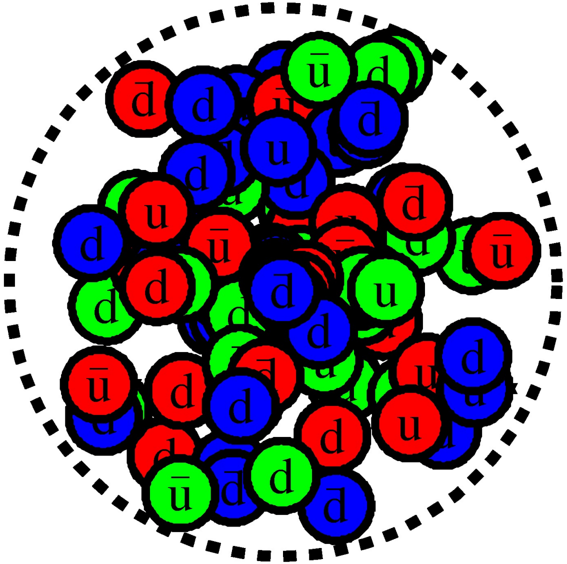
What does valence mean?

$$\int_0^1 [u(x) - \bar{u}(x)]\, dx = 2$$

$$\int_0^1 [d(x) - \bar{d}(x)]\, dx = 1$$







VOLUME 23, NUMBER 24 PHYSICAL REVIEW LETTERS 15 DECEMBER 1969

VERY HIGH-ENERGY COLLISIONS OF HADRONS

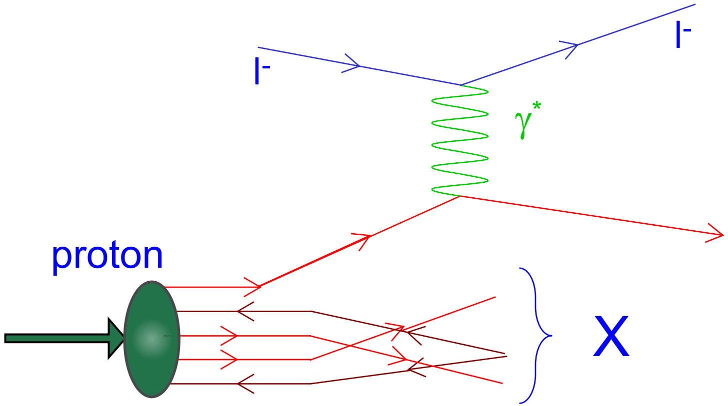
Richard P. Feynman
California Institute of Technology, Pasadena, California
(Received 20 October 1969)

Proposals are made predicting the character of longitudinal-momentum distributions in hadron collisions of extreme energies.

. . . I have difficulty in writing this note because it is not in the nature of a deductive paper, but is the result of induction. I am more sure of the conclusions than of any single argument which suggested them to me for they have an internal consistency which surprises me and exceeds the consistency of my deductive arguments which hinted at there existence.

Only the barest indications of the logical bases of these suggestions will be indicated here. Perhaps in a future publication I can be more detailed.[2]

VOYAGE INTO THE SEA



$$F_2^{\mu p}(x) \propto \sum_{q\in\{u,d,\dots\}} e_q^2 x\left[q(x,Q^2)+\bar{q}(x,Q^2)\right]$$

$$F_2^{\nu p}(x) + F_2^{\nu n} \propto \sum_{q\in\{u,d,\dots\}} x\left[q(x,Q^2)+\bar{q}(x,Q^2)\right]$$

$$xF_3^{\nu N}(x) \propto \sum_{q\in\{u,d,\dots\}} x\left[q(x,Q^2)-\bar{q}(x,Q^2)\right]$$

$$N^{\pi^\pm} \propto \sum_{q\in\{u,d,\dots\}} \left[q(x,Q^2)D^{\pi^\pm}+\bar{q}(x,Q^2)D^{\pi^\pm}\right]$$

How can we measure the sea distributions?

Need a process that can isolate sea contributions:

- SIDIS
  - K/π identification
  - Knowledge of fragmentation functions (D^π)
  - HERMES, COMPASS, JLab 12 GeV

- Collider W production
  - Fermilab Tevatron, CERN LHC, BNL RHIC

- Drell-Yan
  - Rest of talk

$$F_2^{\mu p}(x) \propto \sum_{q\in\{u,d,\dots\}} e_q^2 x\left[q(x,Q^2)+\bar{q}(x,Q^2)\right]$$

$$F_2^{\nu p}(x)+F_2^{\nu n} \propto \sum_{q\in\{u,d,\dots\}} x\left[q(x,Q^2)+\bar{q}(x,Q^2)\right]$$

$$xF_3^{\nu N}(x) \propto \sum_{q\in\{u,d,\dots\}} x\left[q(x,Q^2)-\bar{q}(x,Q^2)\right]$$

$$N^{\pi^\pm} \propto \sum_{q\in\{u,d,\dots\}} \left[q(x,Q^2)D^{\pi^\pm}+\bar{q}(x,Q^2)D^{\pi^\pm}\right]$$

$$A_W(y) \propto \frac{u(x_1)\bar{d}(x_2)-d(x_1)\bar{u}(x_2)}{u(x_1)\bar{d}(x_2)+d(x_1)\bar{u}(x_2)}$$

$$\frac{d\sigma}{dx_1 dx_2} \propto \sum_{q\in\{u,d,\dots\}} e_q^2\left[q(x_1)\bar{q}(x_2)+\bar{q}(x_1)q(x_2)\right]$$

The Sea is a Fundamental Part of the Proton

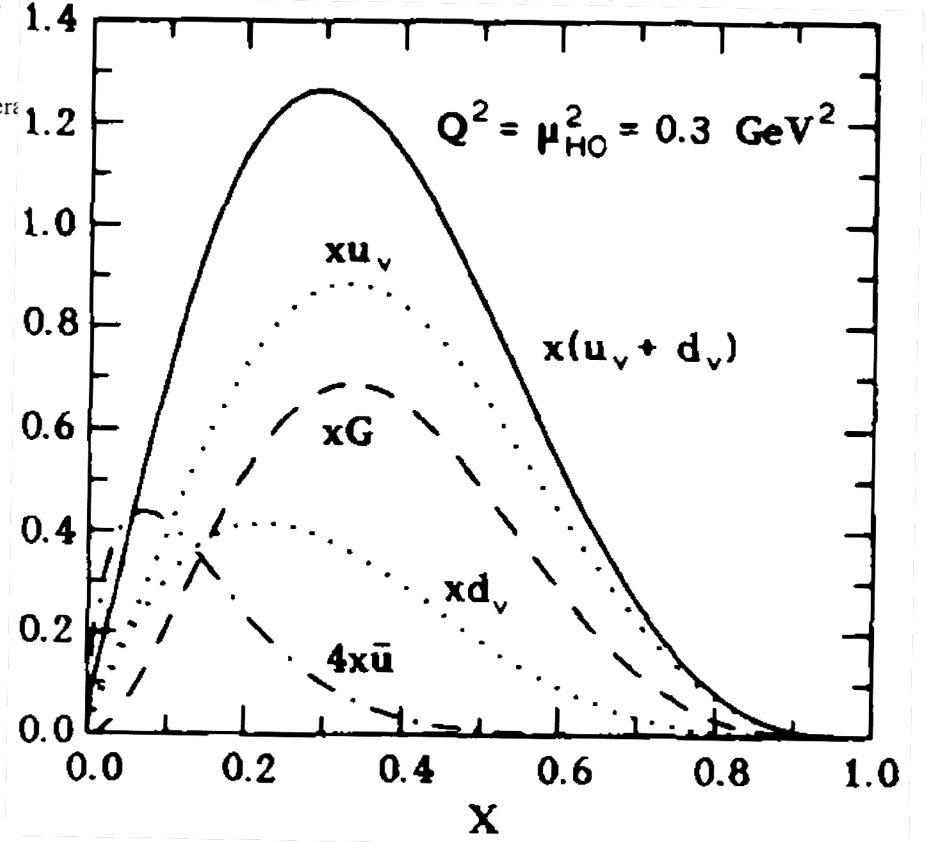
Parton distributions for high energy collisions

M. Glück, E. Reya, A. Vogt
Institut für Physik, Universität Dortmund, Postfach 500500, W-4600 Dortmund 50, Federa

Received 10 June 1991

Recent data from deep inelastic scattering experiments at $x > 10^{-2}$ are used to fix the parton distributions down to $x = 10^{-4}$ and $Q^2 = 0.3\ GeV^2$. The predicted extrapolations are uniquely determined by the requirement of a *valence*-like structure of *all* parton distributions at some low resolution scale . . . .

Gluck, Reya, Vogt, ZPC 53, 127 (1992)



Light Antiquark Flavor Asymmetry: Brief History

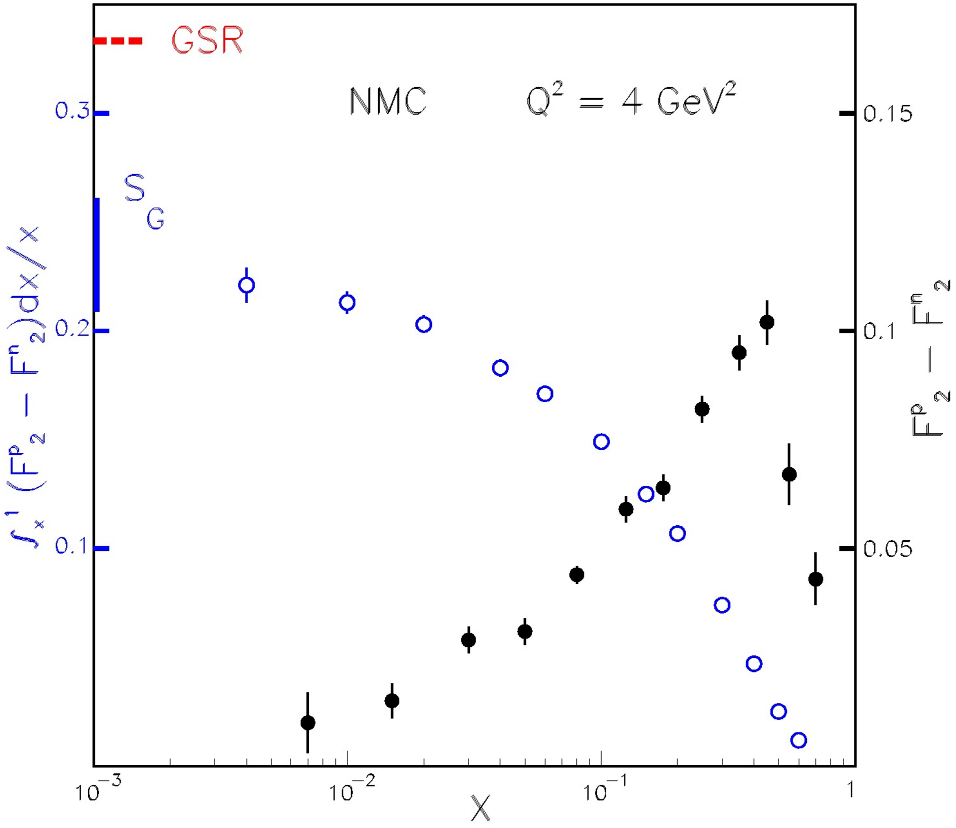
- Naïve Assumption:

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

- NMC (Gottfried Sum Rule)

$$\int_0^1 \left[F_2^p(x) - F_2^n(x)\right]\frac{dx}{x} = \frac{1}{3}$$

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



Light Antiquark Flavor Asymmetry: Brief History

- Naïve Assumption:

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

- NMC (Gottfried Sum Rule)

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

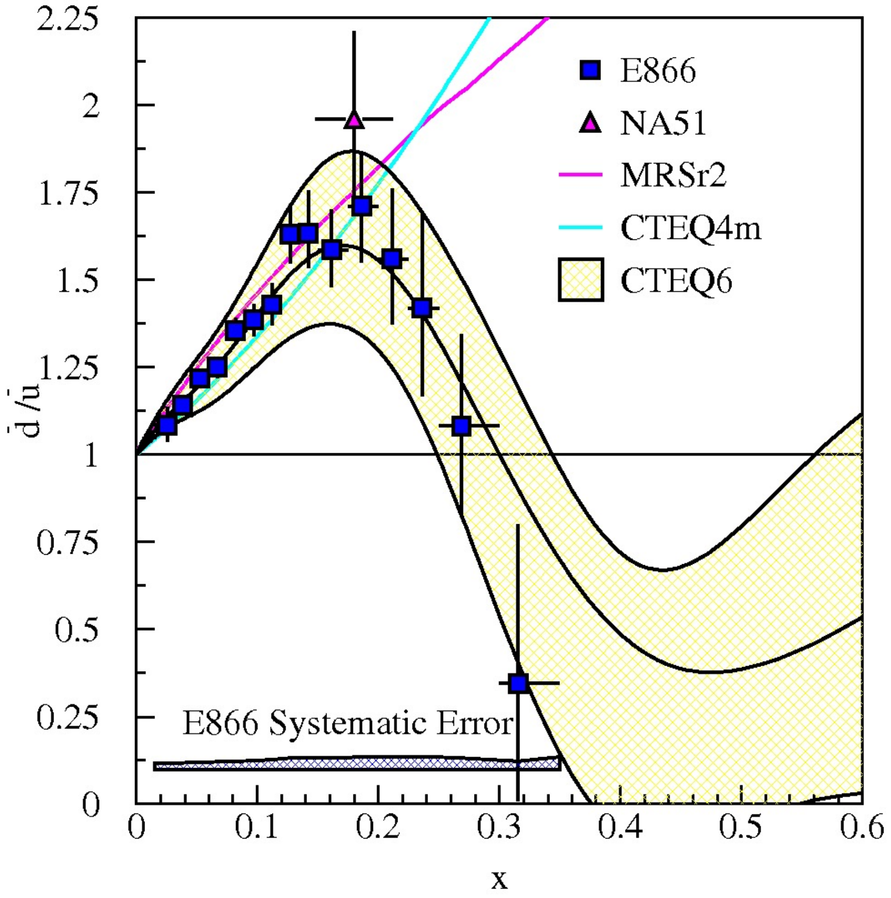
- CERN NA51 (Drell-Yan):

$$\bar{d}(0.18) \approx 2\times\bar{u}(0.18)$$

- Fermilab E866/NuSea:

$\bar{d}(x)/\bar{u}(x)$ for $0.015 \leq x \leq 0.035$

- Knowledge of sea dist. are data driven
- Non-pQCD allow $\bar{d}(x) > \bar{u}(x)$



How is the Sea Created?

- pQCD does create a Sea

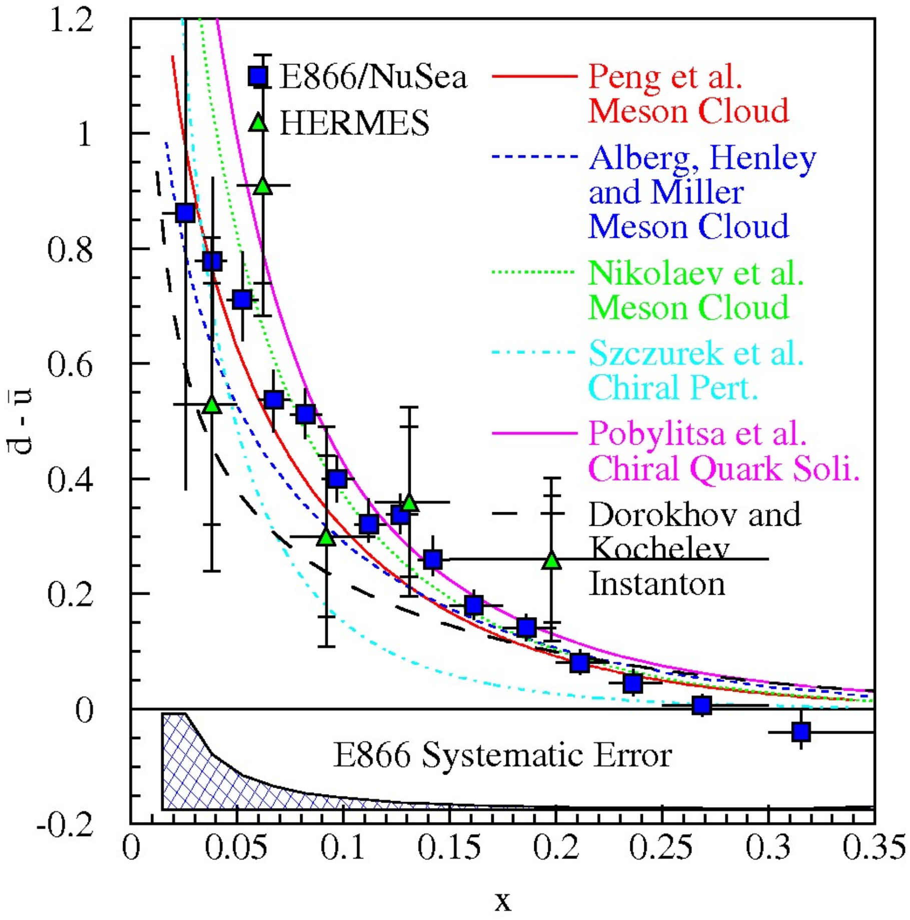
$$\bar{d}(x) = \bar{d}_{\text{pQCD}}(x) + \bar{d}_{\text{non pQCD}}(x)$$
$$\bar{u}(x) = \bar{u}_{\text{pQCD}}(x) + \bar{u}_{\text{non pQCD}}(x)$$

- Gluon splitting component is symmetric

$$\bar{d}_{\text{pQCD}}(x) = \bar{u}_{\text{pQCD}}(x)$$

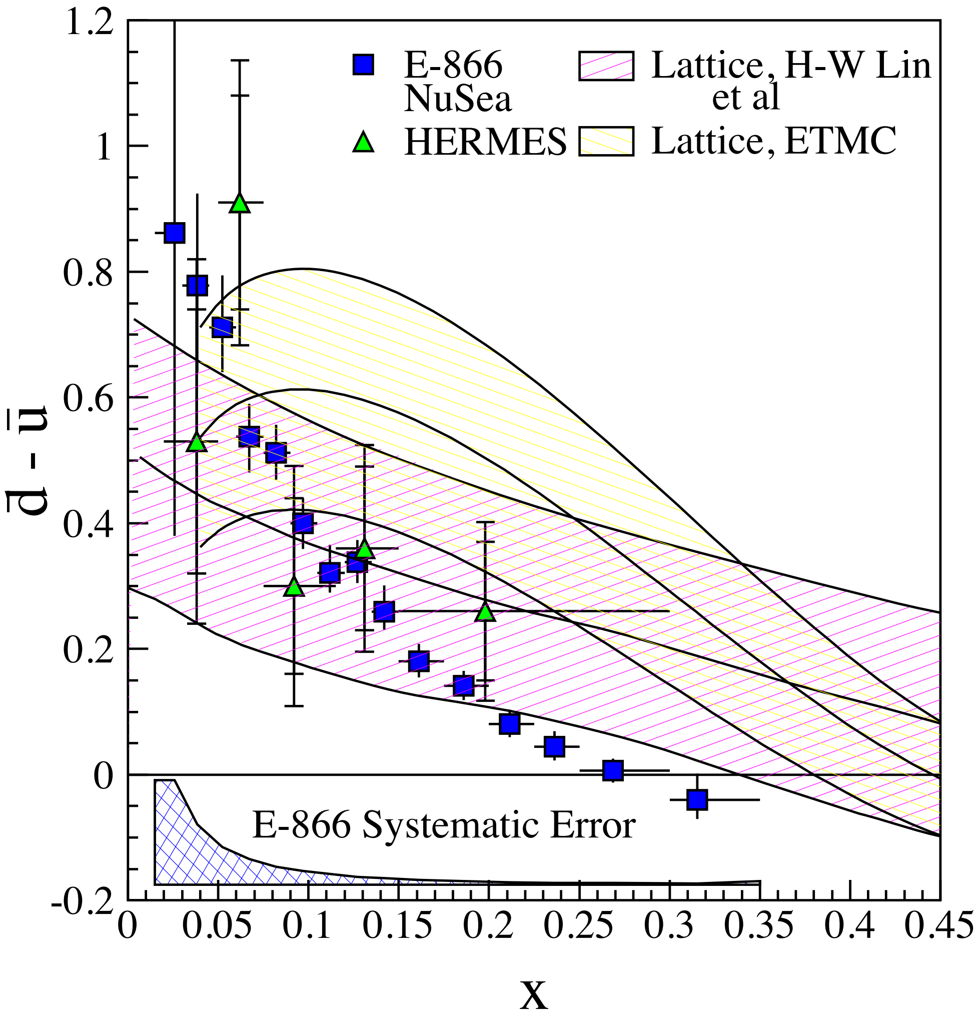
$$\bar{d}(x) - \bar{u}(x) = \bar{d}_{\text{non pQCD}}(x) - \bar{u}_{\text{non pQCD}}(x)$$

- Symmetric sea via subtracts away
- No Gluon contribution at 1st order in α_s
- Non-pQCD models compare to difference

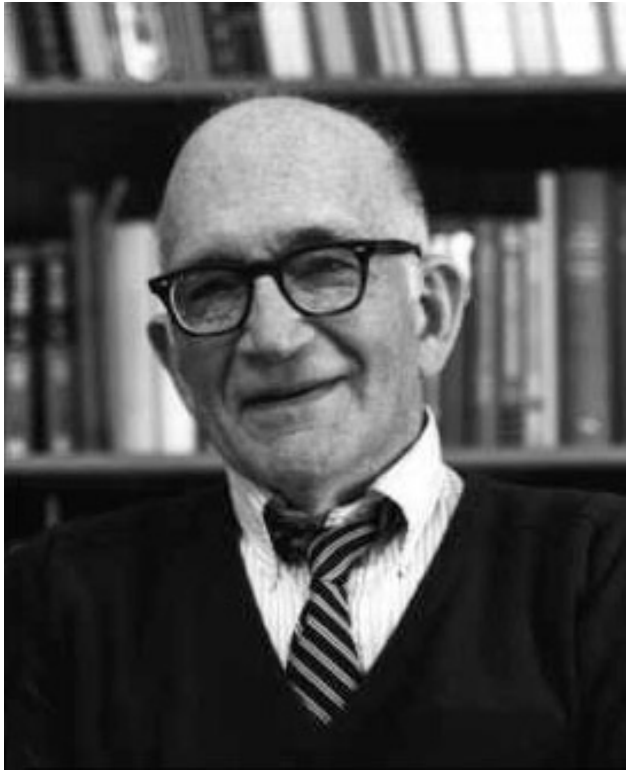


How is the Sea Created?

- Lattice weighs in!!



The Drell-Yan Process



Early Muon Pair Data

Volume 25, Number 21 PHYSICAL REVIEW LETTERS 23 November 1970

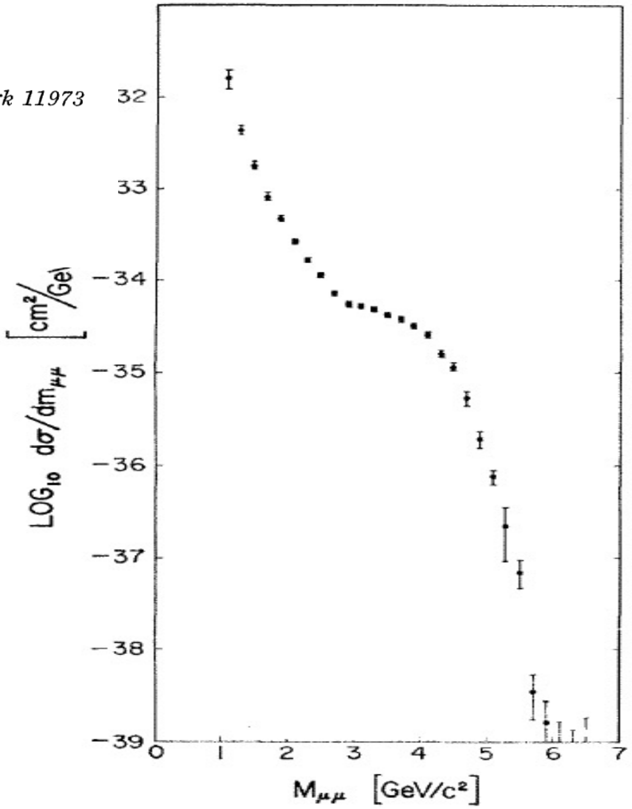
Observation of Massive Muon Pairs in Hadron Collisions*

J. H. Christenson, G. S. Hicks, L. M. Lederman, P. J. Limon, and B. G. Pope
Columbia University, New York, New York 10027, and Brookhaven National Laboratory, Upton, New York 11973

and

E. Zavattini
CERN Laboratory, Geneva, Switzerland
(Received 8 September 1970)

Muon Pairs in the mass range $1 < m_{\mu\mu} < 6.7$ GeV/c^2 have been observed in collisions of high-energy protons with uranium nuclei. At an incident energy of 29 GeV, **the cross section varies smoothly as $d\sigma/dm_{\mu\mu} \approx 10^{-32} / m_{\mu\mu}^5$ cm^2 (GeV/c)$^{-2}$ and exhibits no resonant structure.** The total cross section increases by a factor of 5 as the proton energy rises from 22 to 29.5 GeV.

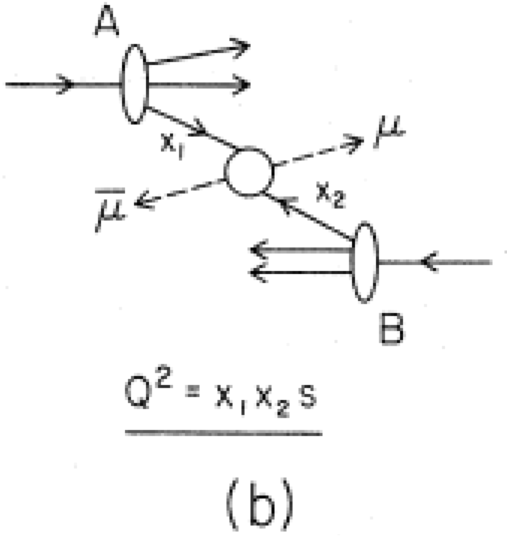


DRELL AND YAN'S EXPLANATION

VOLUME 25, NUMBER 5 PHYSICAL REVIEW LETTERS 3 AUGUST 1970

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)



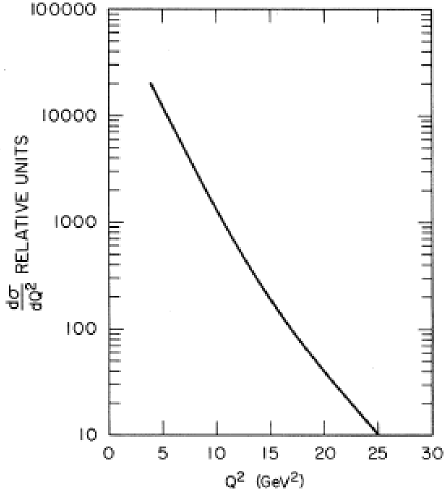
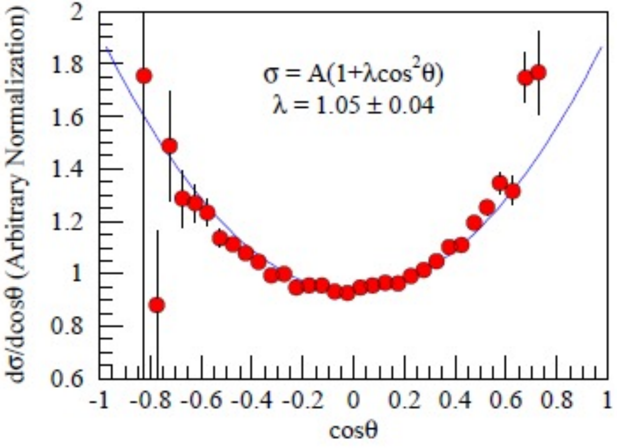
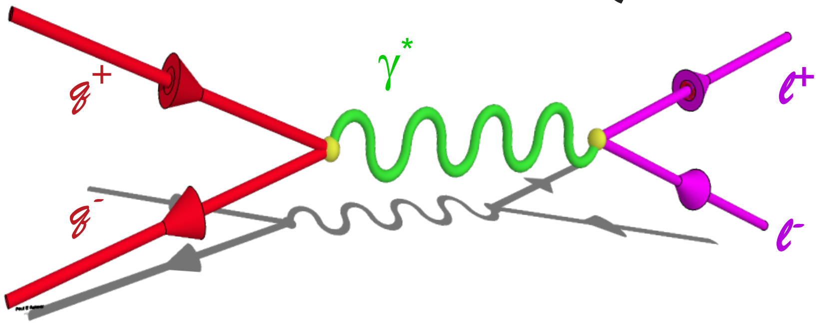


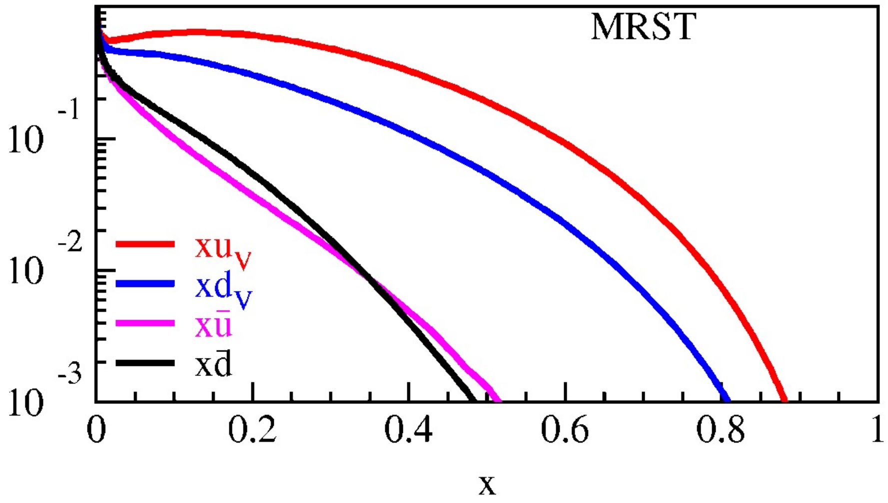
FIG. 2. $d\sigma/dQ^2$ computed from Eq. (10) assuming identical parton and antiparton momentum distributic and with relative normalization.

Also predicted $\lambda(1+\cos^2\theta)$ angular distributions



Drell-Yan Cross Section—Sensitivity to Sea Quarks



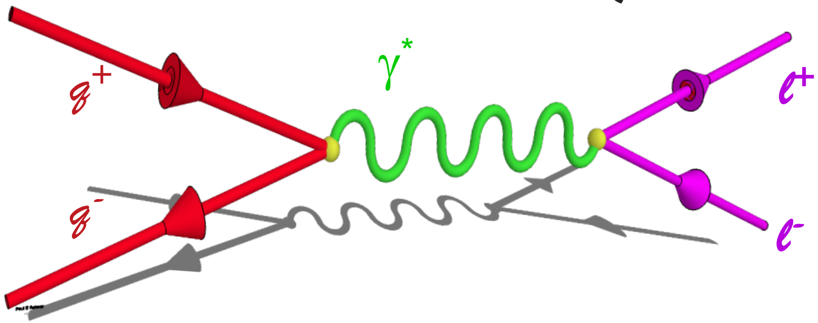


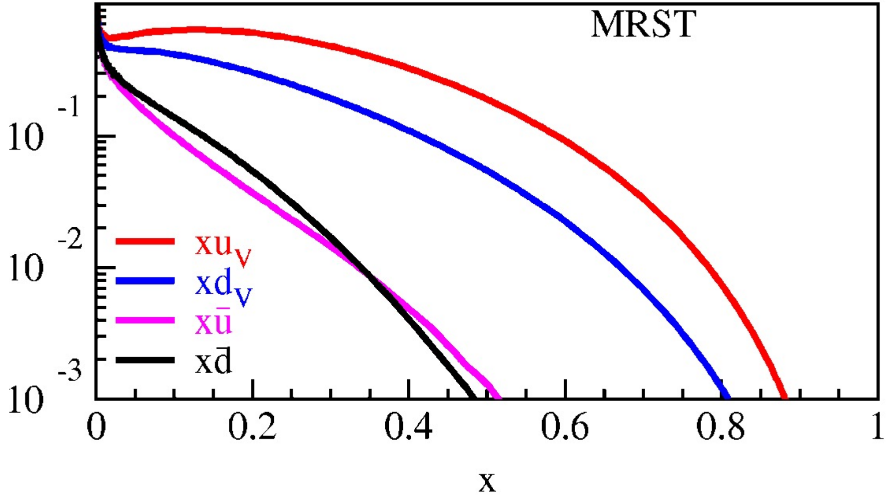
Cross Section

- Point-like scattering of spin-1/2 particles
- Convoluted of beam and target parton distributions

$$\frac{d^2\sigma}{dx_{\mathrm{b}}dx_{\mathrm{t}}} = \frac{4\pi\alpha^2}{x_{\mathrm{b}}x_{\mathrm{t}}s} \sum_{q\in\{u,d,s,\dots\}} e_q^2 \left[\bar{q}_{\mathrm{t}}(x_{\mathrm{t}})q_{\mathrm{b}}(x_{\mathrm{b}}) + \bar{q}_{\mathrm{b}}(x_{\mathrm{b}})q_{\mathrm{t}}(x_{\mathrm{t}})\right]$$

Drell-Yan Cross Section—Sensitivity to Sea Quarks





Cross Section

- Point-like scattering of spin-1/2 particles
- Convoluted of beam and target parton distributions

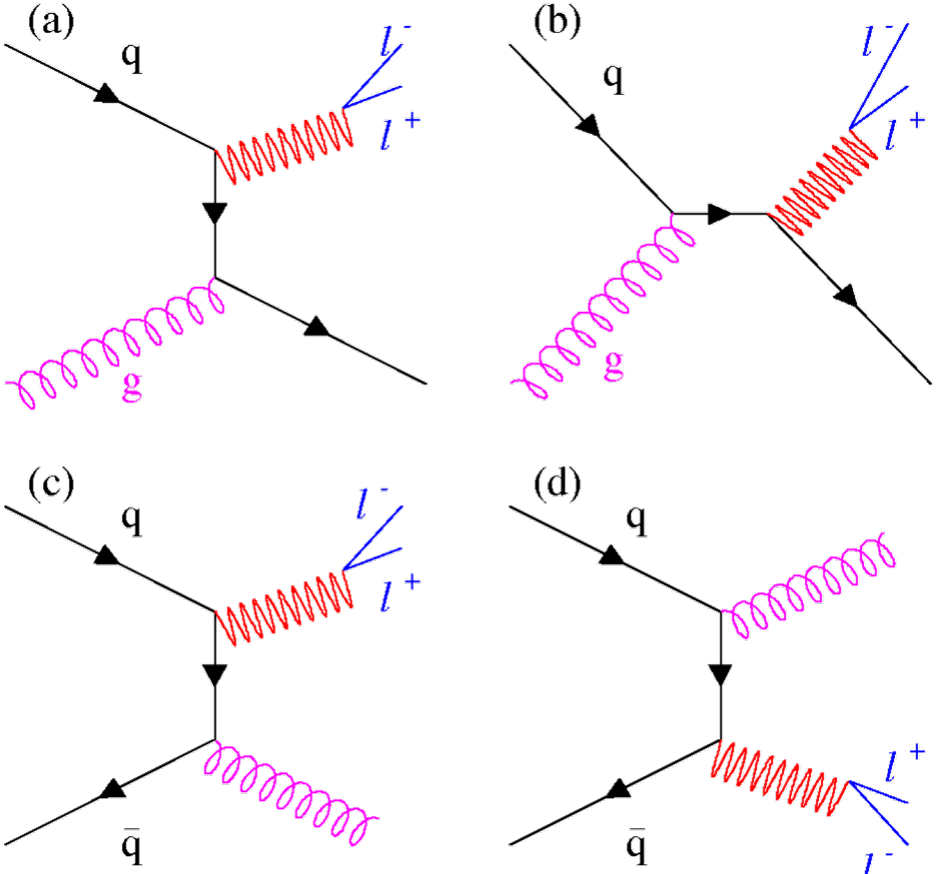
$$\frac{\sigma^{pd}}{2\sigma^{pp}} = \frac{1}{2}\left[1 + \frac{\bar{d}(x)}{\bar{u}(x)}\right]$$

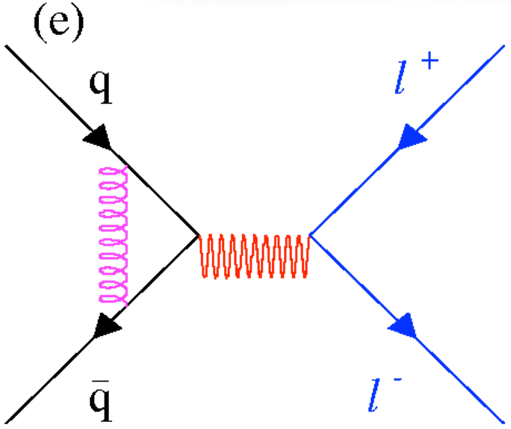
$$\frac{d^2\sigma}{dx_b dx_t} = \frac{4\pi\alpha^2}{x_b x_t s} \sum_{q\in\{u,d,s,\ldots\}} e_q^2 [\bar{q}_t(x_t) q_b(x_b) + \bar{q}_b(x_b) q_t(x_t)]$$

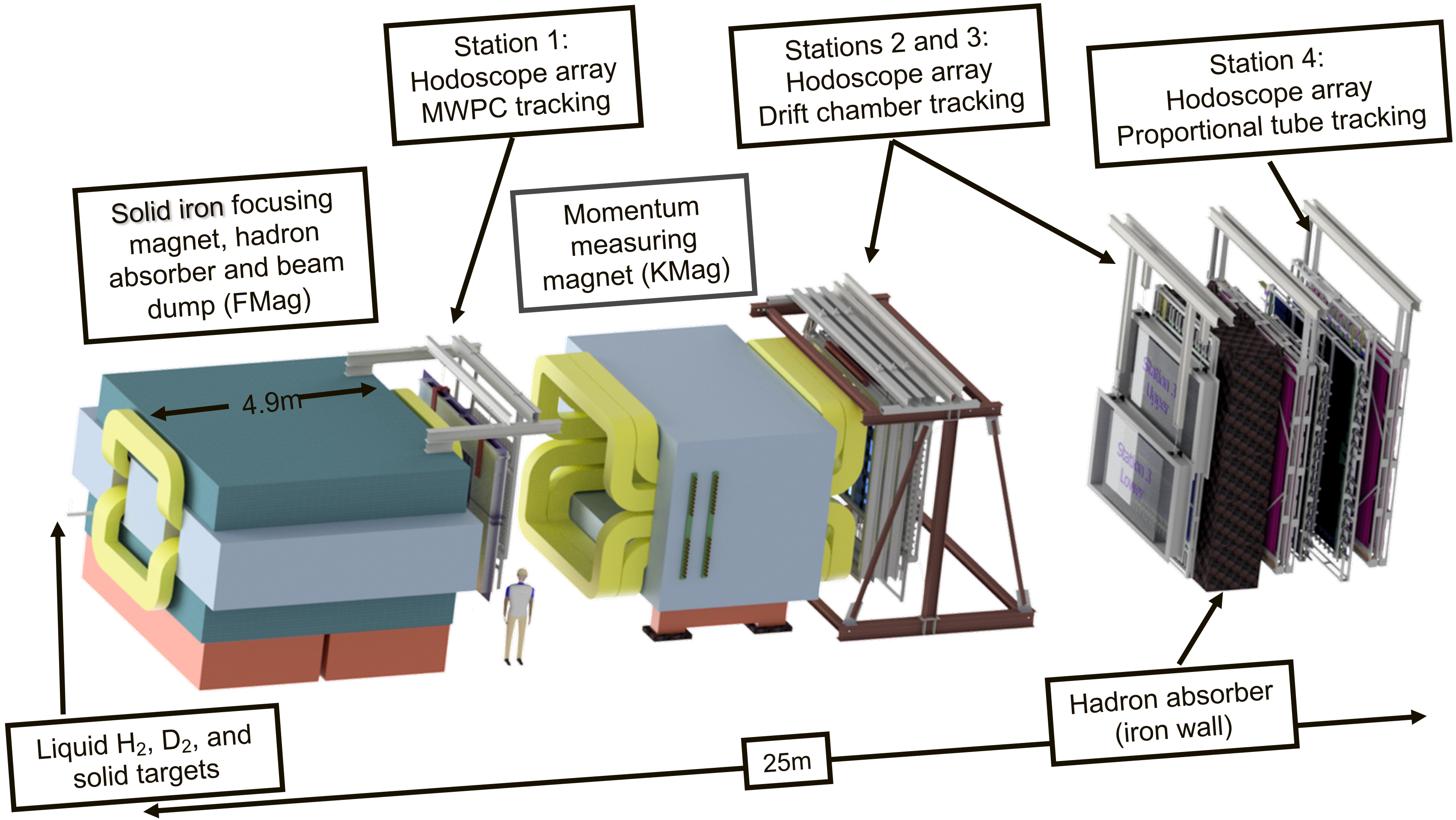
u-quark dominance
$(2/3)^2$ vs. $(1/3)^2$

Acceptance limited
(Fixed Target, Hadron Beam)

Next-to-Leading Order in α_s






Station 1:
Hodoscope array
MWPC tracking
Stations 2 and 3:
Hodoscope array
Drift chamber tracking
Station 4:
Hodoscope array
Proportional tube tracking
Solid iron focusing magnet, hadron absorber and beam dump (FMag)
Momentum measuring magnet (KMag)
4.9m
Liquid H_2, D_2, and solid targets
25m
Hadron absorber (iron wall)

Experimental Plan

I. Build detector
II. Launch protons at targets
III. Record data

IV. Analyze data

V. Publish

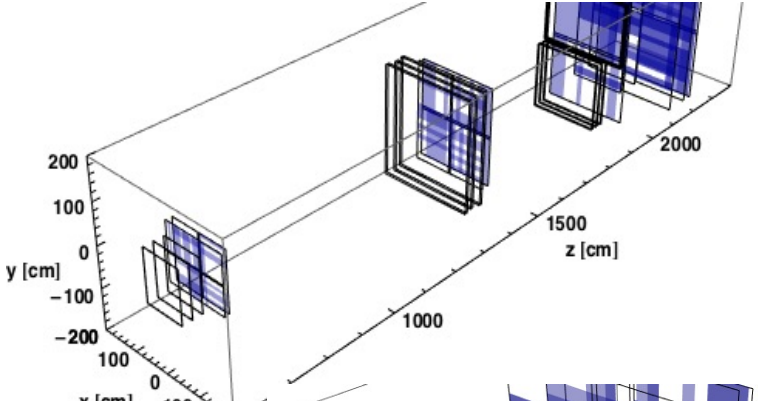
EXPERIMENTAL PLAN

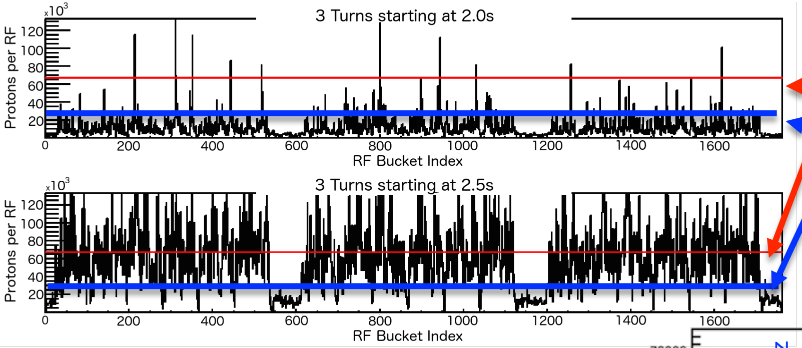
I. Build detector

II. Launch protons at targets

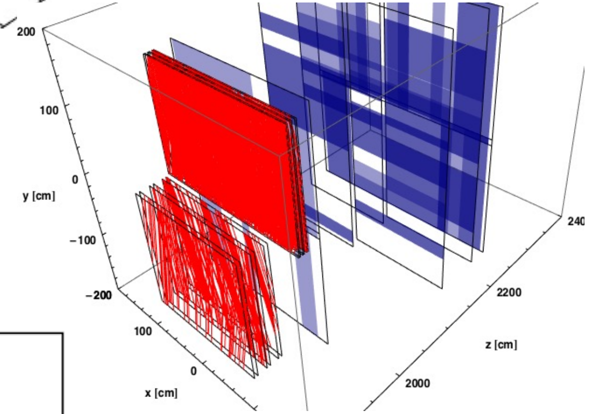
III. Record data

  a. Beam instabilities/Rate effects

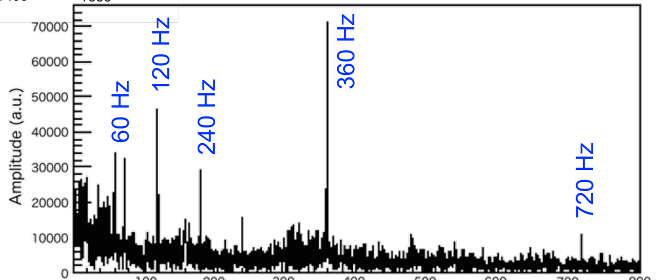




- **Each bin is 19 ns**
- Veto Level
- Even beam distribution

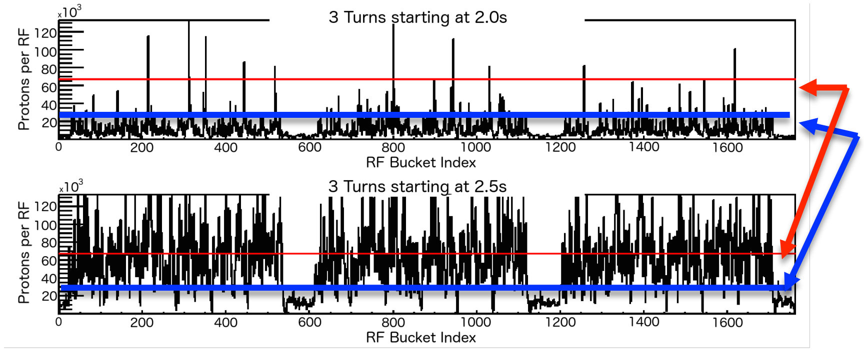


- **Fourier transform**

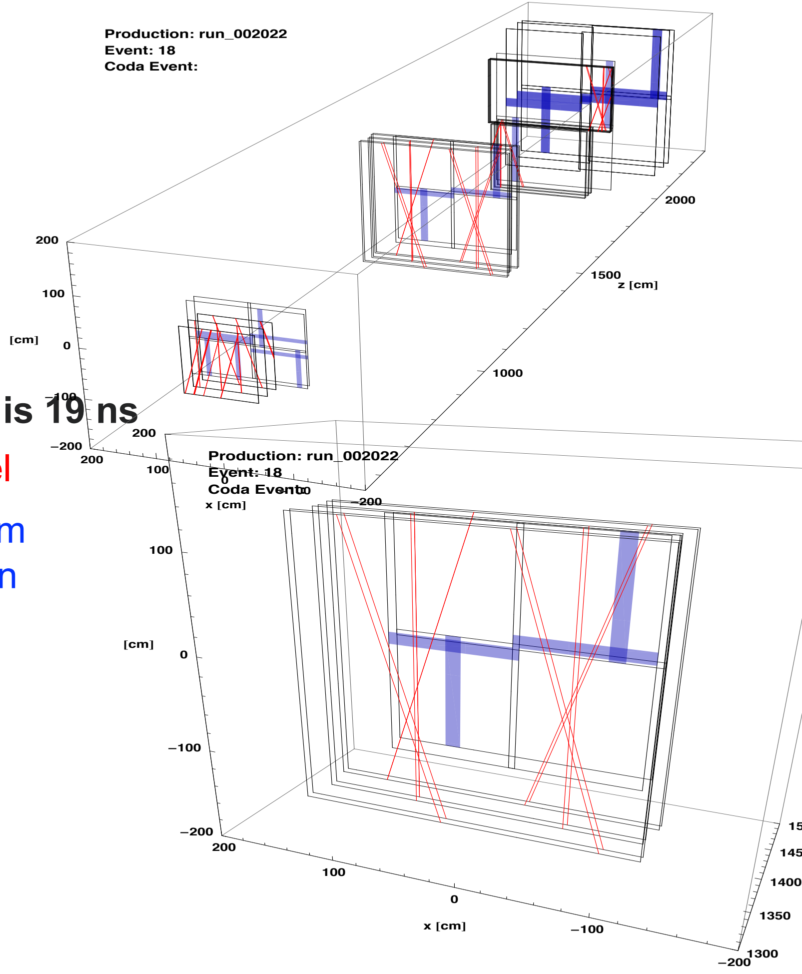


Experimental Plan

I. Build detector
II. Launch protons at targets
III. Record data
   a. Beam instabilities/Rate effects



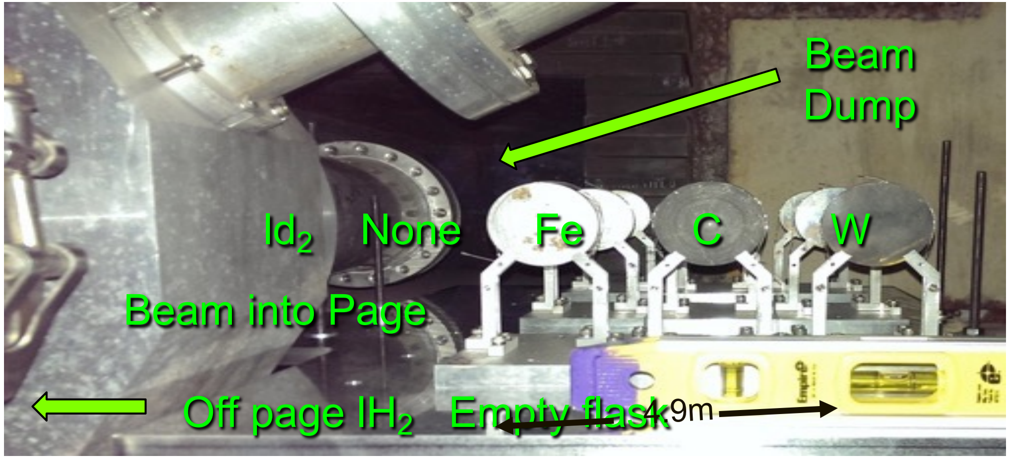
- **Each bin is 19 ns**
- Veto Level
- Even beam distribution

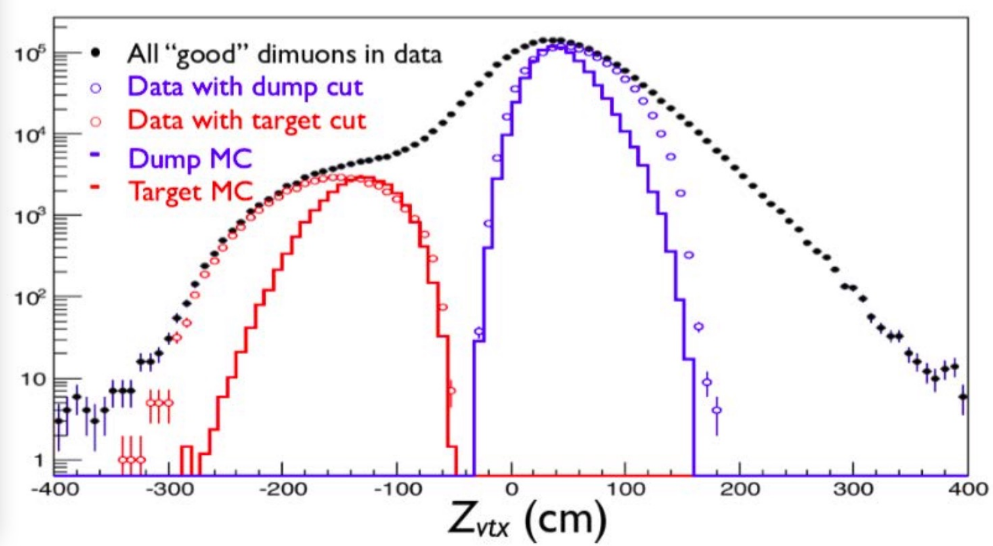


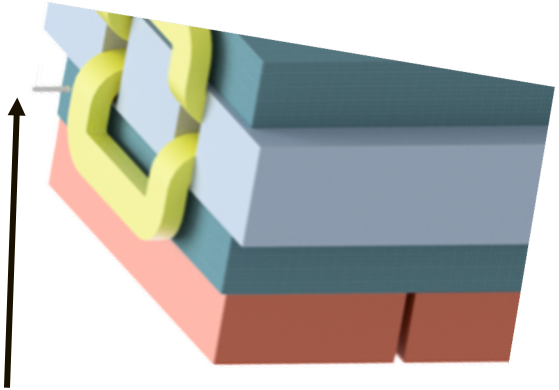
- Beam line Cherenkov counter veto on intense 19 ns/53 MHz "buckets"
- Removed 50% of luminosity
- Allowed experiment to run

EXPERIMENTAL PLAN

I. Build detector
II. Launch protons at targets
III. Record data
   a. Beam instabilities/Rate effects
IV. Analyze data
   a. Target—Beam dump separation

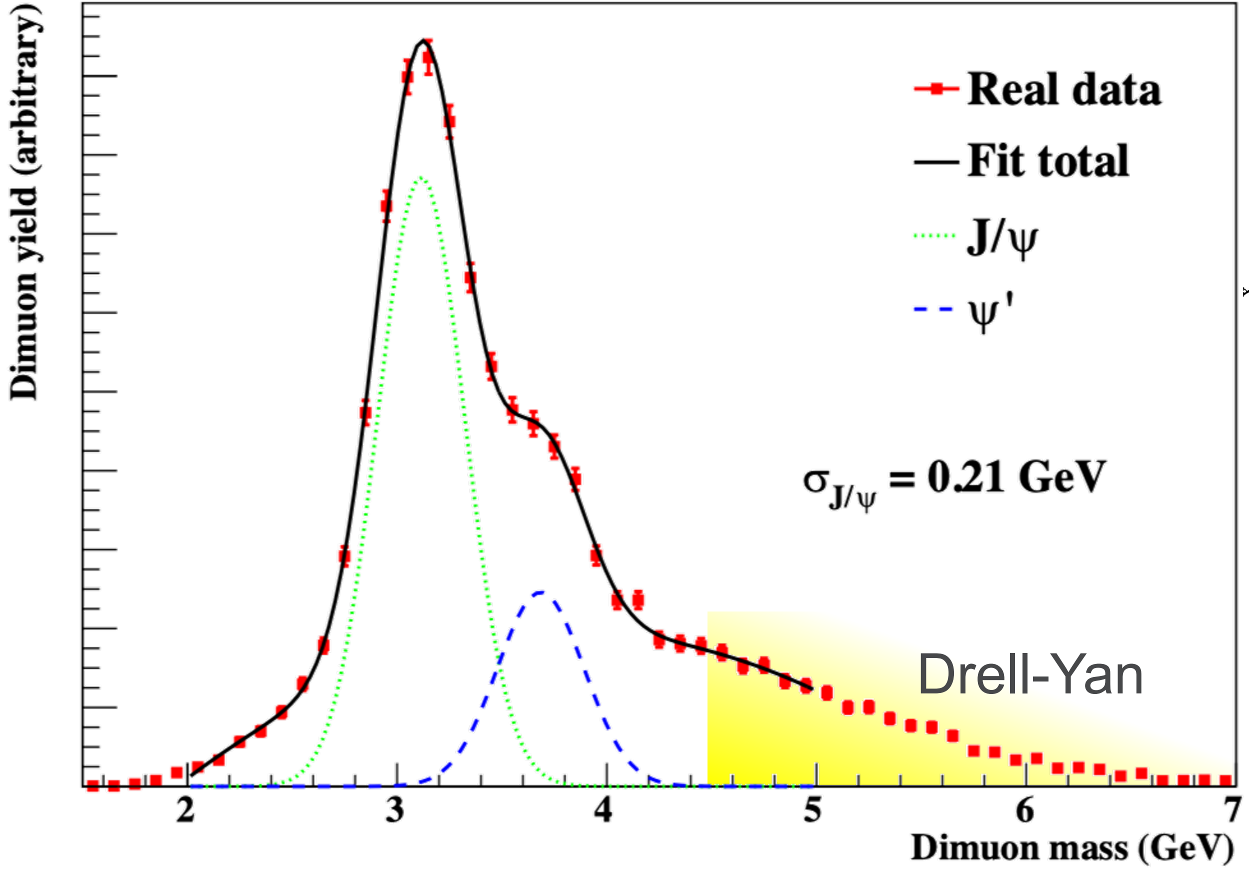


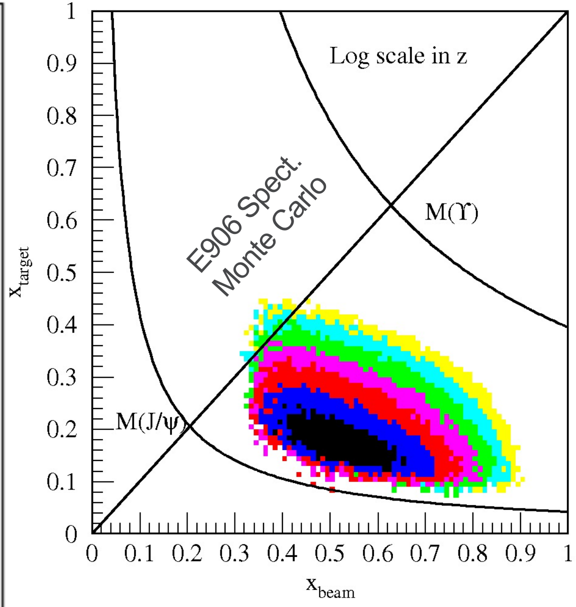




Liquid H_2, D_2, and solid targets

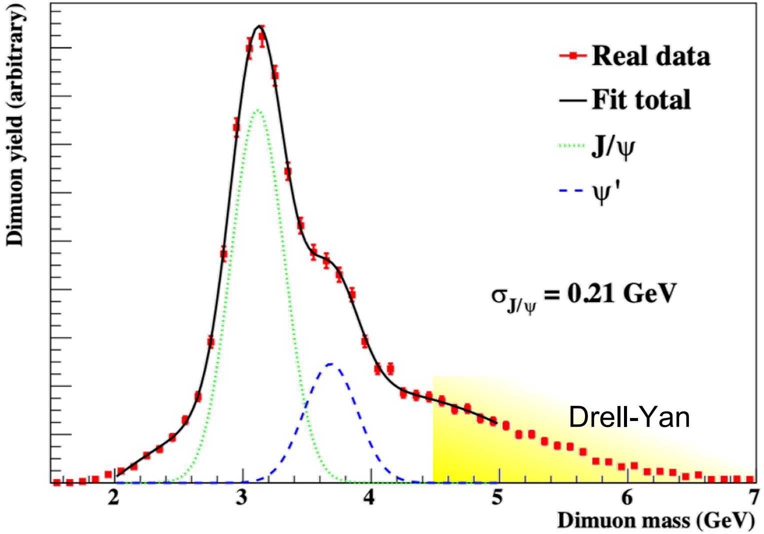
E906 Mass Spectrum

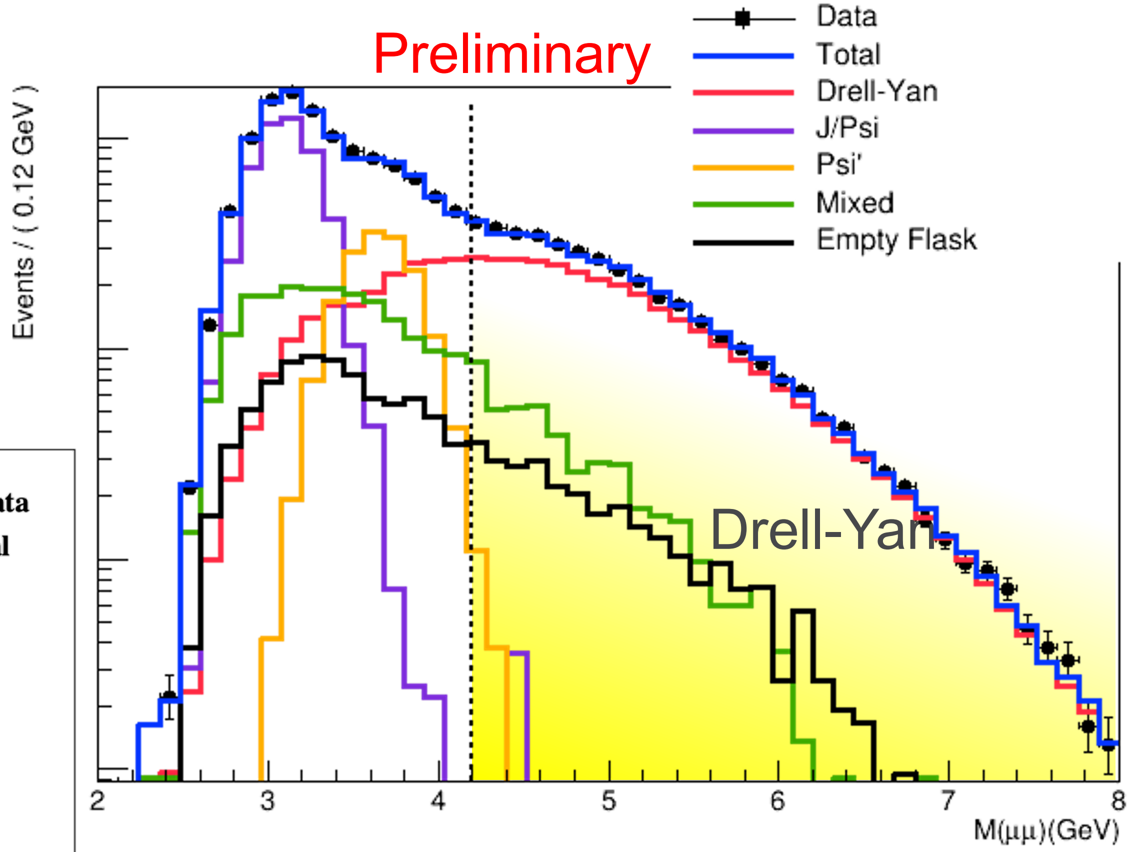




Cross Check of Rate Dependence

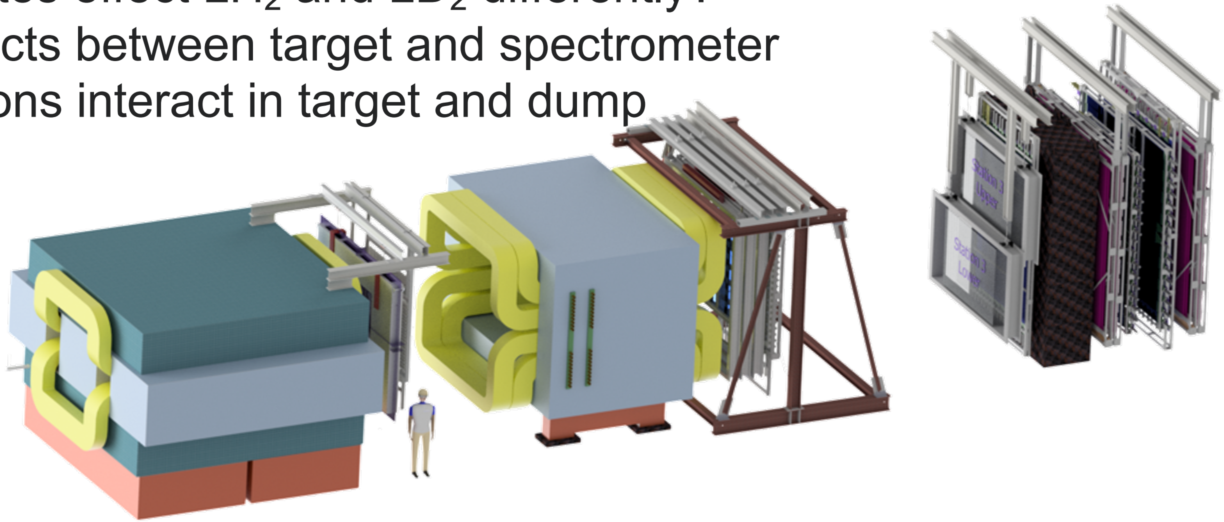
- Multi-component mass fit
- Combinatorial background "mixed" and reconstruction efficiency





Rate Dependent Effects

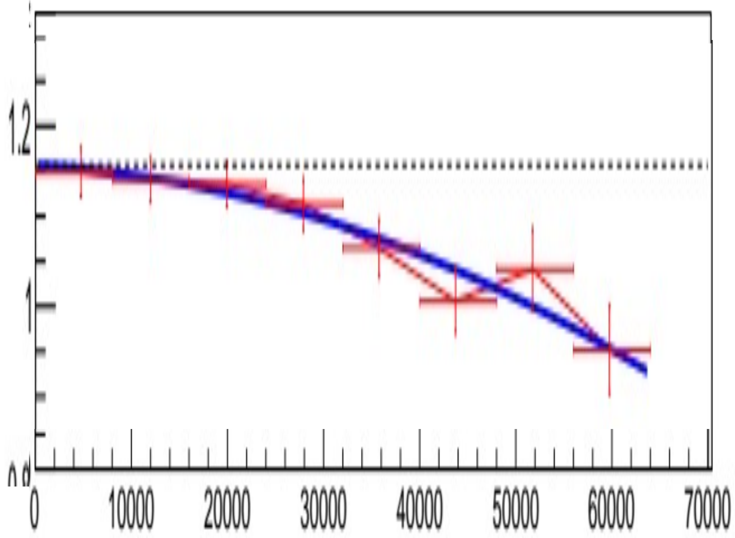
- We were expecting these effects and had handled them in E866/NuSea
- Overall question: Do the rates effect LH_2 and LD_2 differently?
  - 1st order, all beam interacts between target and spectrometer
  - 2nd order, different fractions interact in target and dump



- Primary problem:
  - Background from two uncorrelated muons
  - Different target thicknesses imply distribution of events from target and dump

Is There Still an Intensity Dependence?

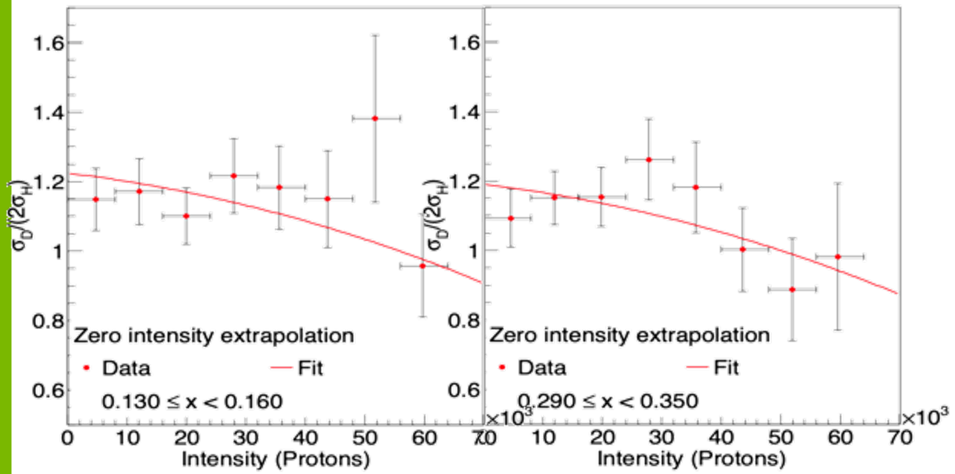
Plot ${}^{\sigma_D}/_{2\sigma_H}$ as a function of the # of protons in the triggered bucket



Possible sources:

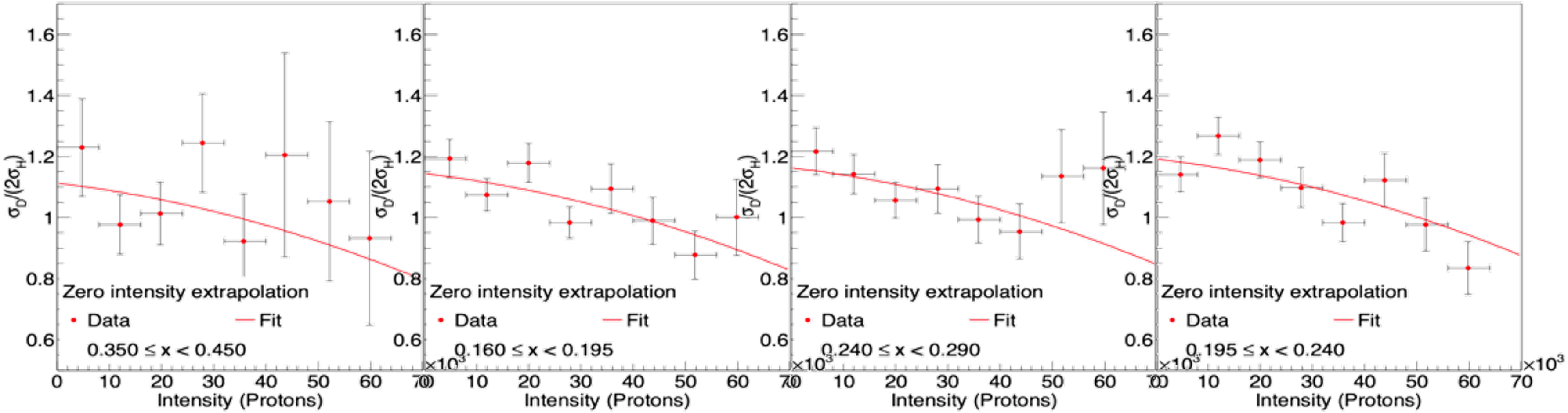
- Trigger inefficiency at high rates
- Increased triggering on noise events
- Reconstruction inefficiency at high occupancy
- . . . . .
- Cut on beam intensity
  - Lose statistical power of the data
- Model-based corrections
  - Fit data w/model of source
  - Monte Carlo to verify
  - Used by E866/NuSea
  - Becomes difficult with multiple effects

Intensity Extrapolation

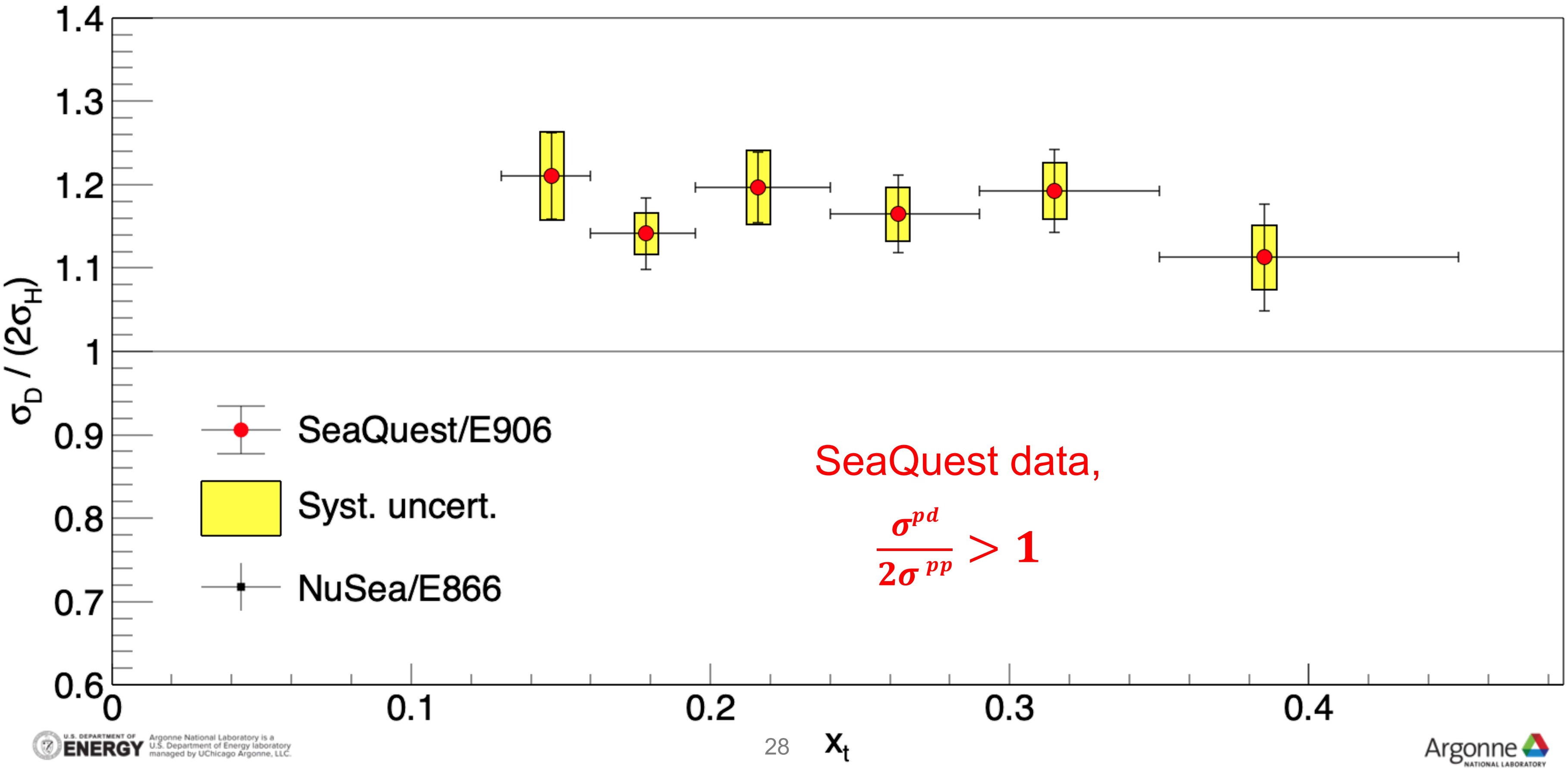


Intensity = 0 intercept from simultaneous fits gives ${}^{\sigma_d}/_{2\sigma_p}$ for different x_T bins

$$\frac{Y_D(x_t, I)}{2Y_H(x_t, I)} = R_{x_t} + a\,I + b\,I^2$$



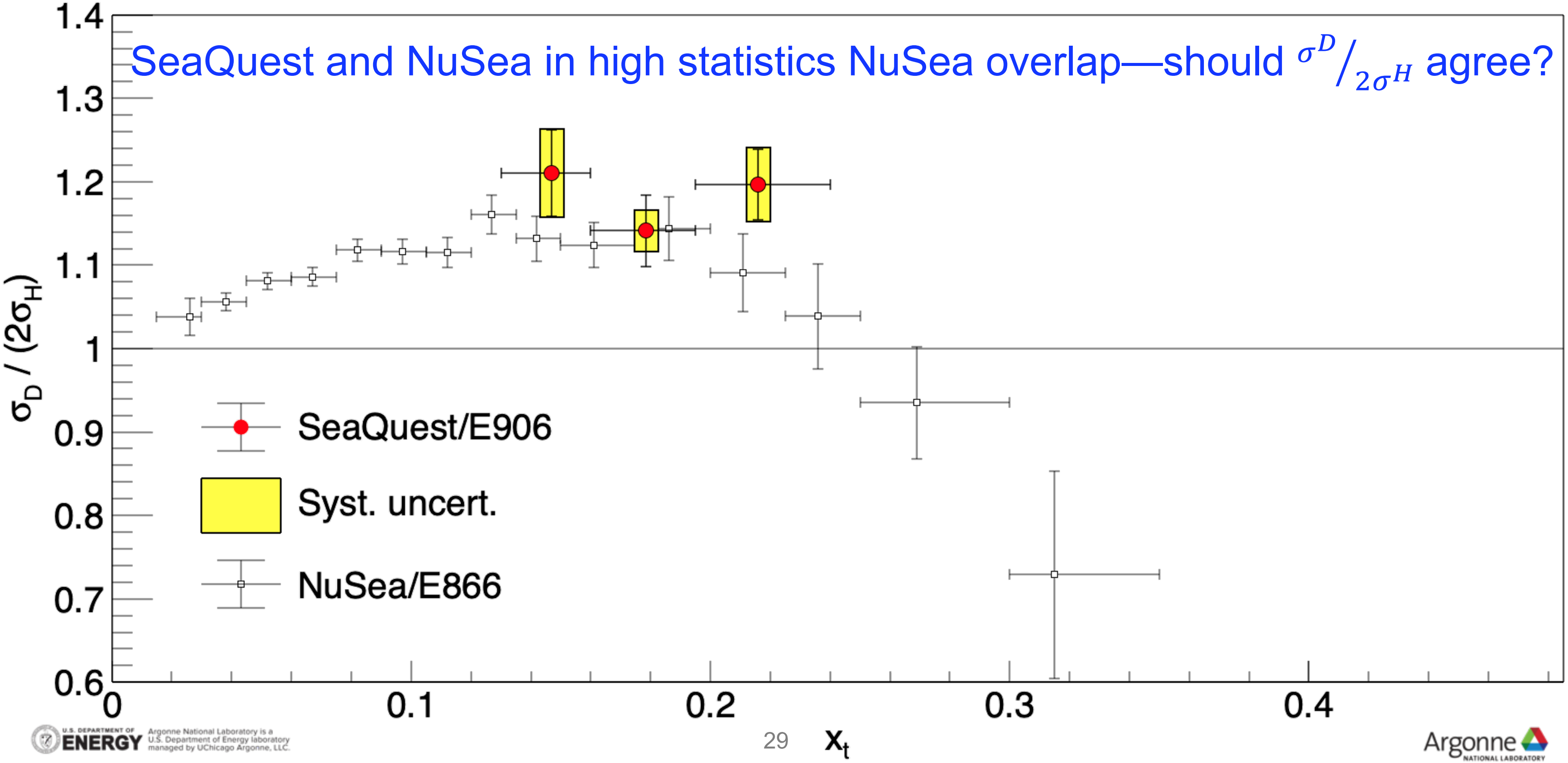
SeaQuest



SeaQuest data,

$$\frac{\sigma^{pd}}{2\sigma^{pp}} > 1$$

SEAQUEST AND E866



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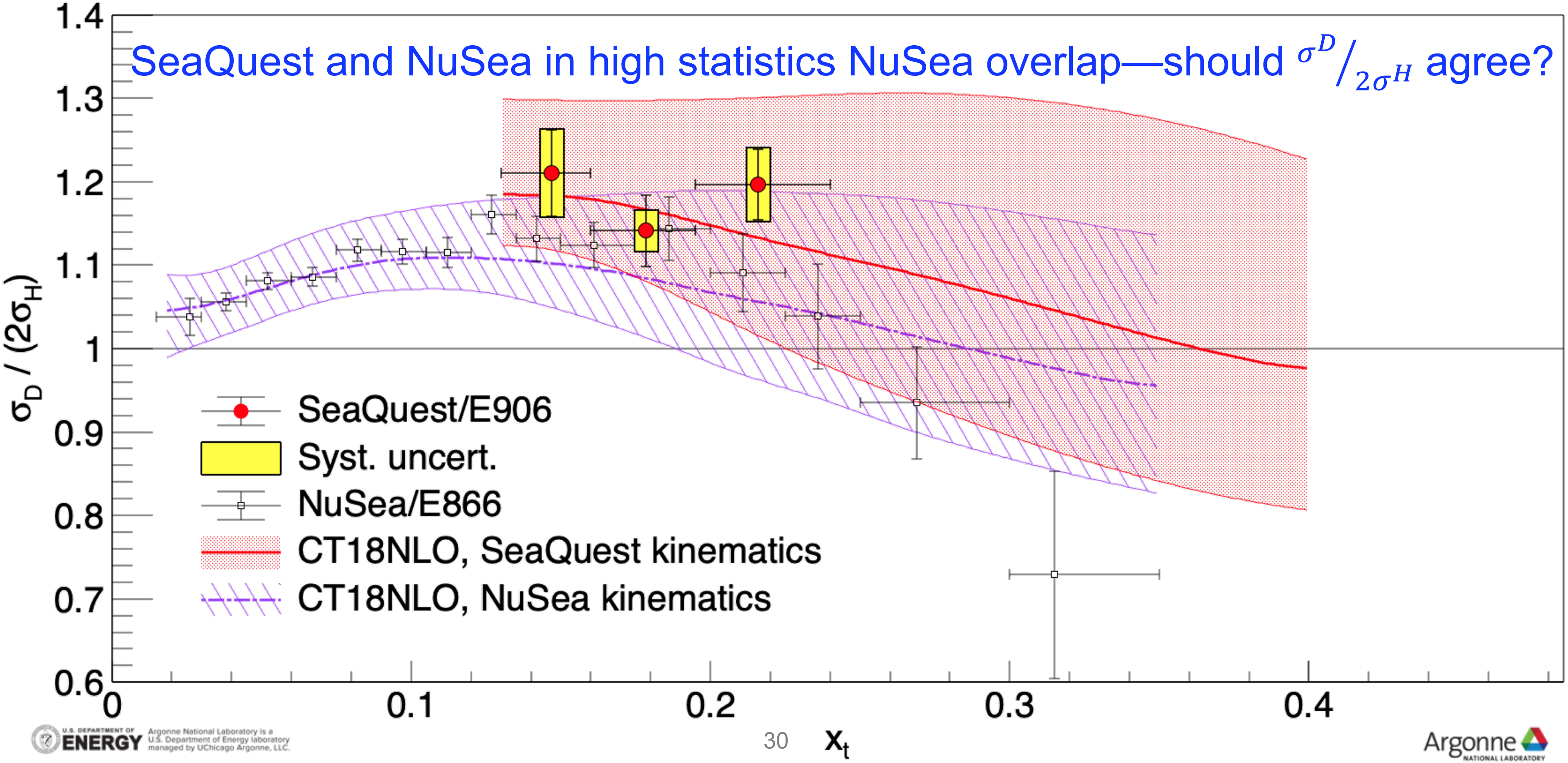

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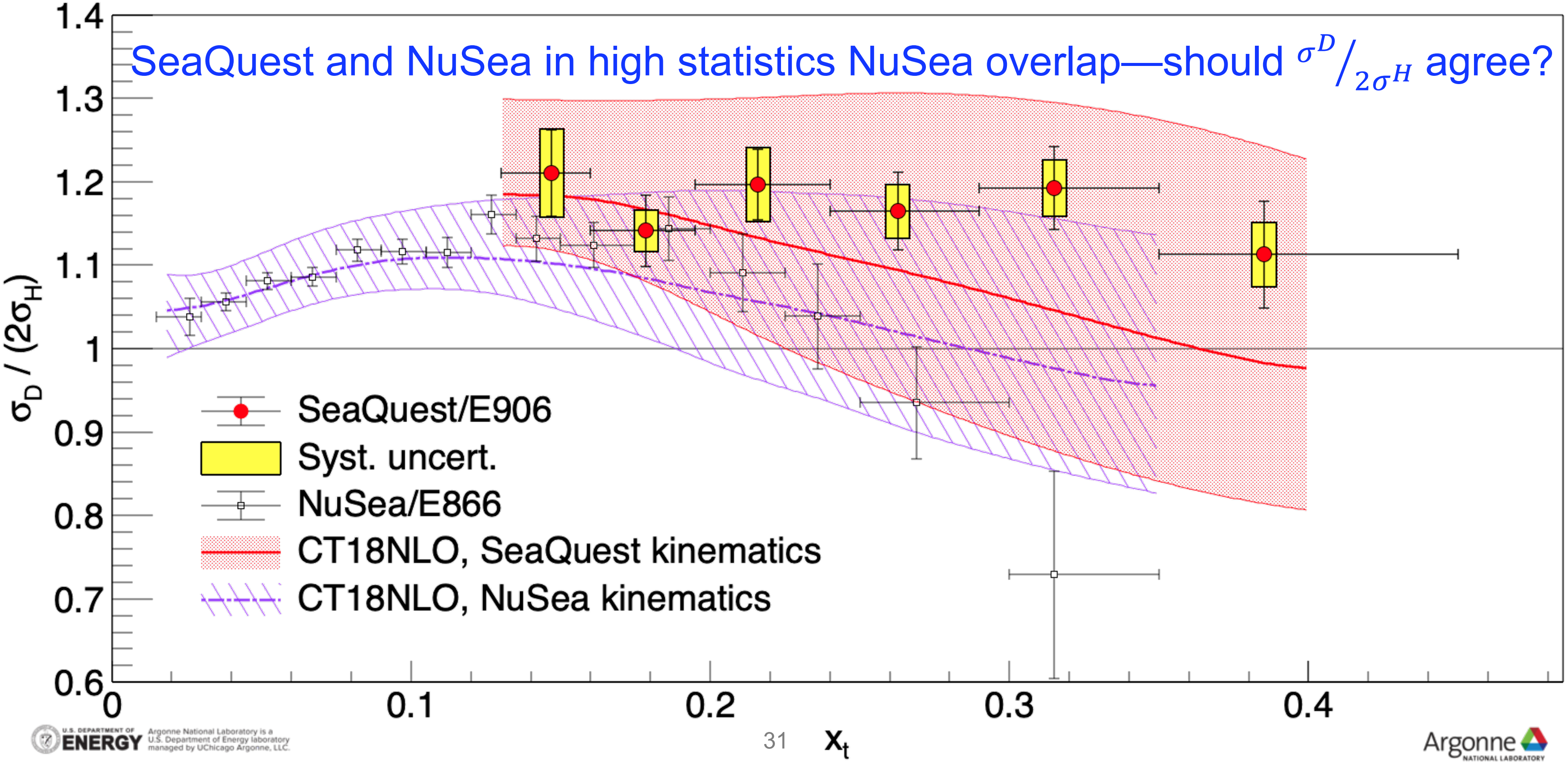


SeaQuest's $\bar{d}/\bar{u}$ Extraction

$$\frac{\sigma^D}{2\,\sigma^H} = \frac{1}{2}\left[1 + \frac{\bar{d}}{\bar{u}}\right]$$

Correct way to extract quark distributions is within the context of a global fit.

What we did instead:

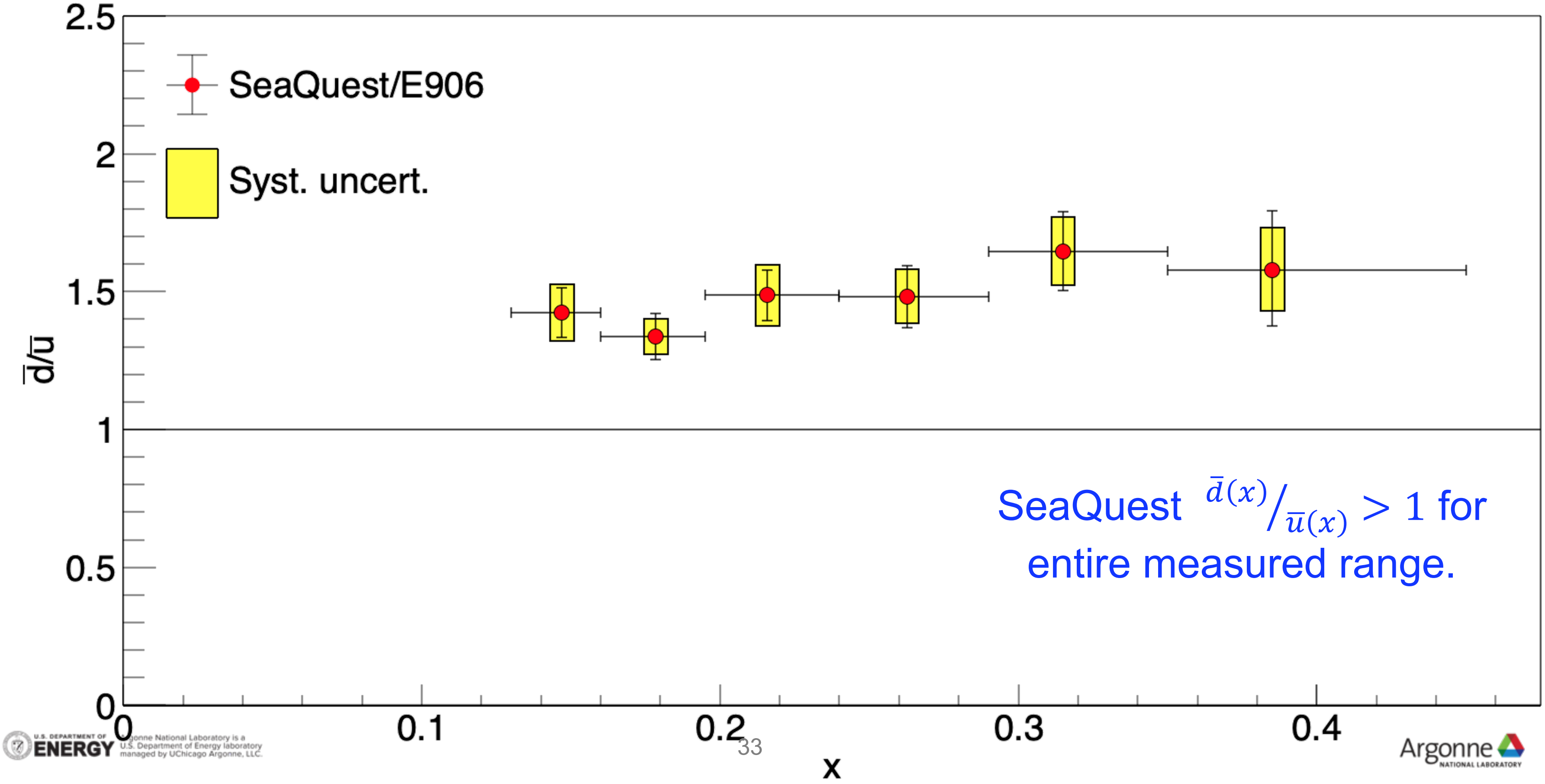
- Assume the current global fits are omnipotent except for $\bar{d}/\bar{u}$
- Compute

$$\frac{\sigma^D}{2\sigma^H} = \frac{\iint \frac{d\sigma^D_{NLO}}{dx_1 dx_2} dx_1\, dx_2}{2 \iint \frac{d\sigma^H_{NLO}}{dx_1 dx_2} dx_1\, dx_2} \text{ with } \bar{d}/\bar{u}\,\big]_i$$

  and the integrals are over the experimental acceptance

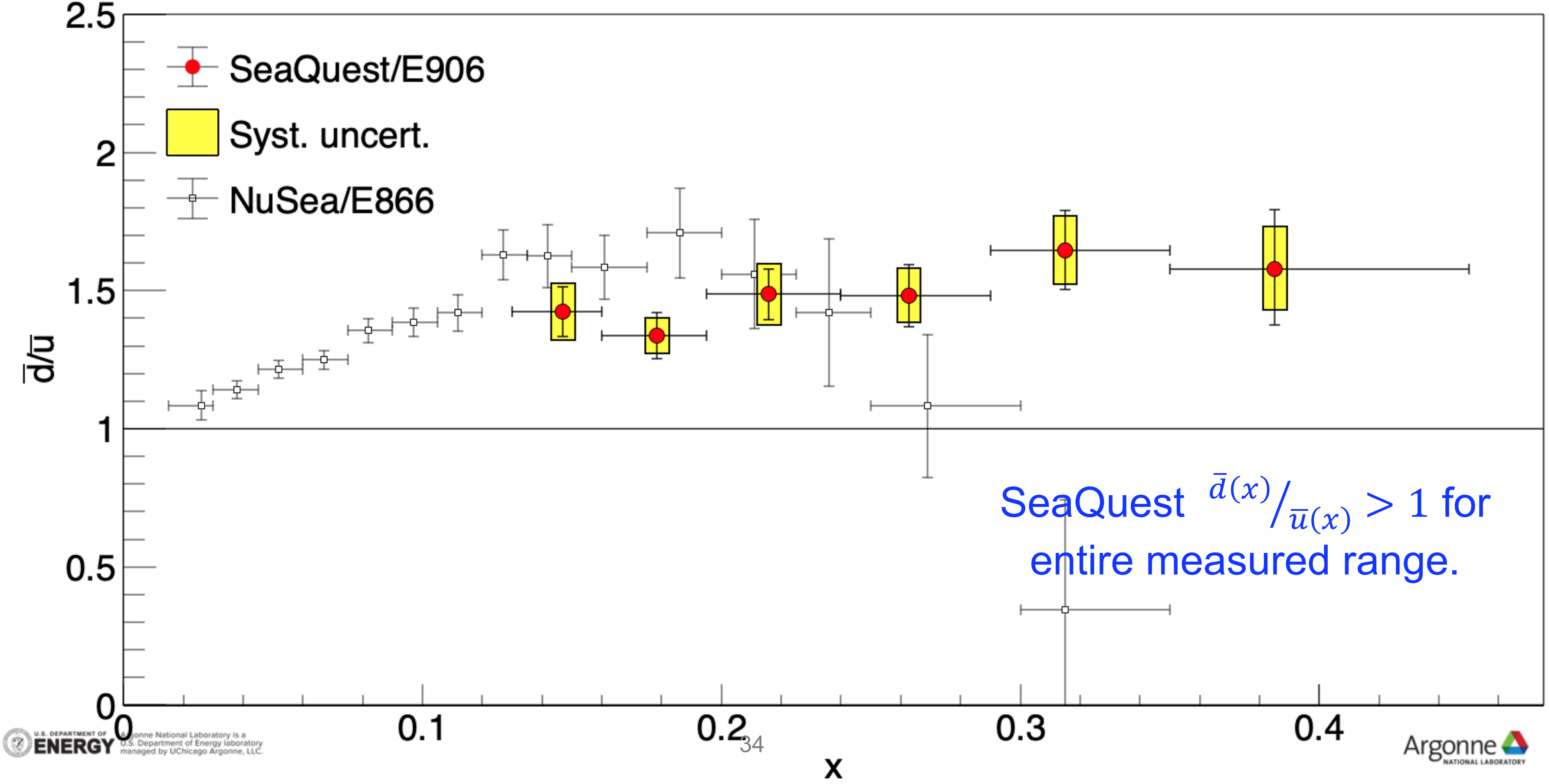
- Compare with measured $\frac{\sigma^D}{2\sigma^H}$, and iterate on $\bar{d}/\bar{u}\,\big]_{i+1}$

SeaQuest and E866



SeaQuest $\bar{d}(x)/\bar{u}(x) > 1$ for entire measured range.

SEAQUEST AND E866



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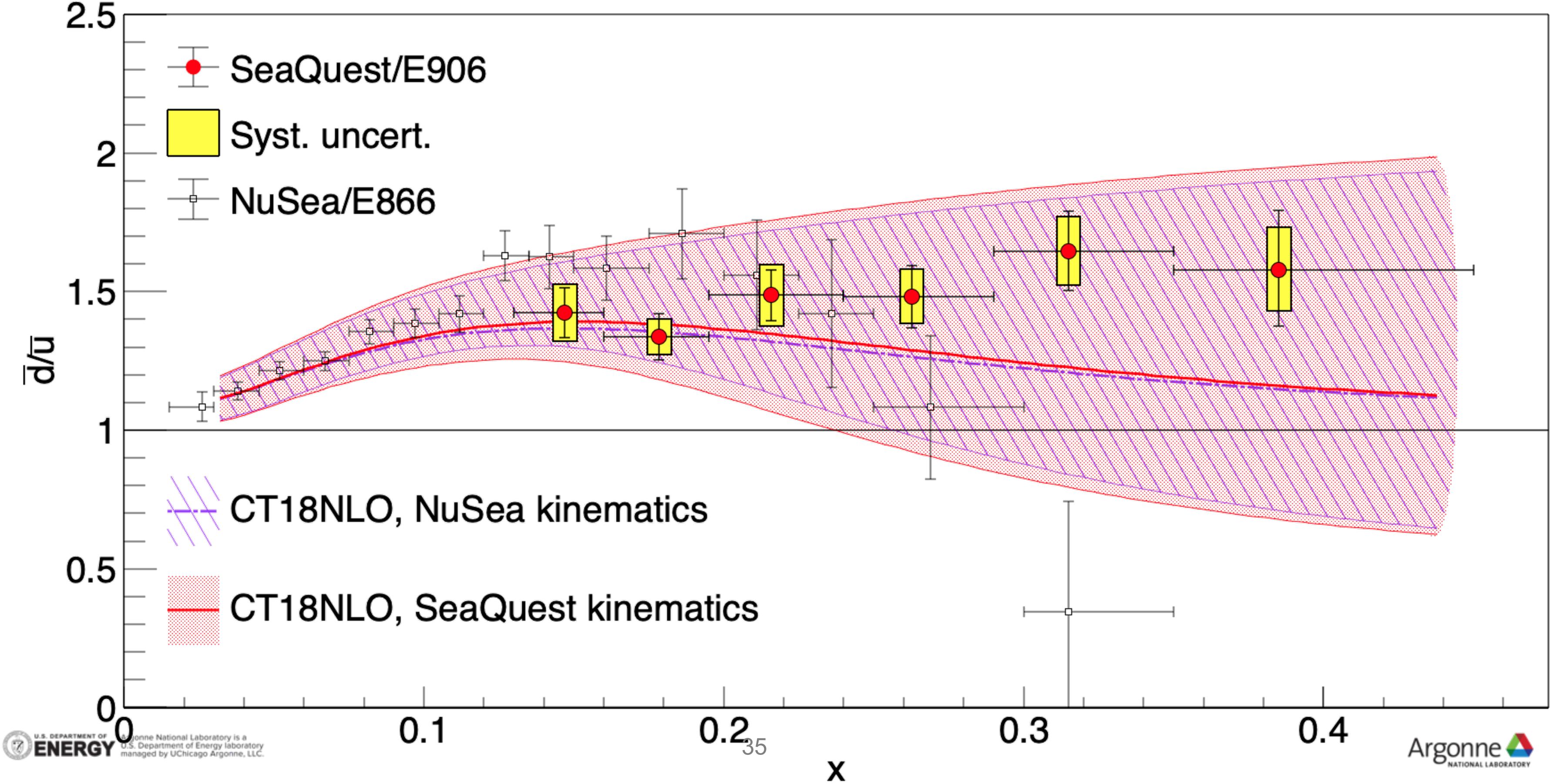
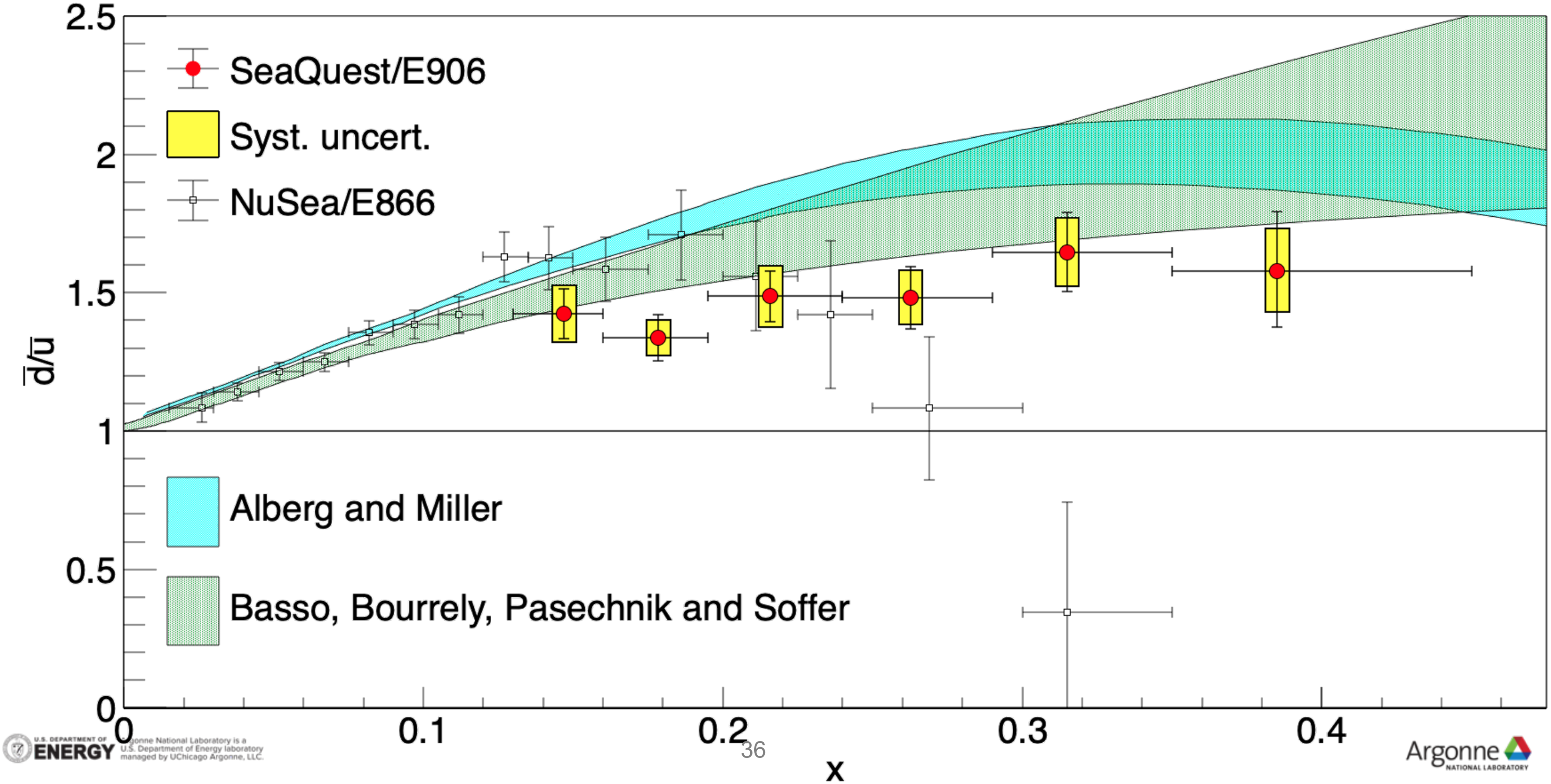
SeaQuest compared with Global Fits



SEAQUEST COMPARED WITH MODELS



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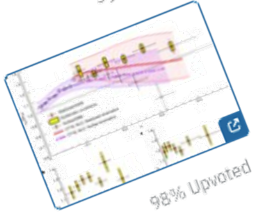

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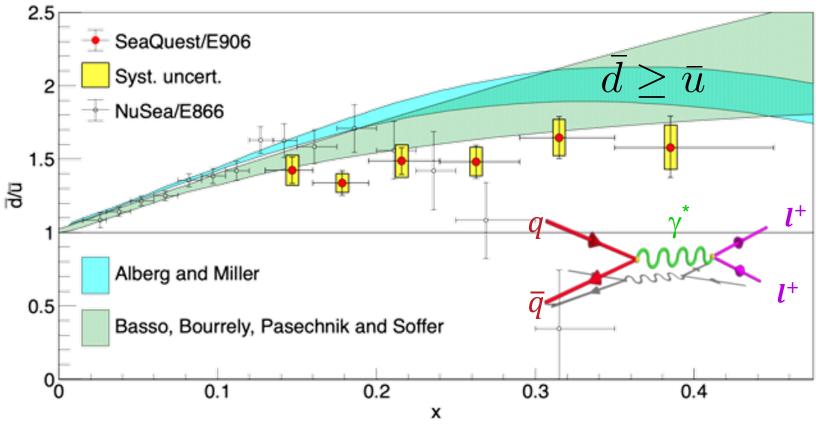
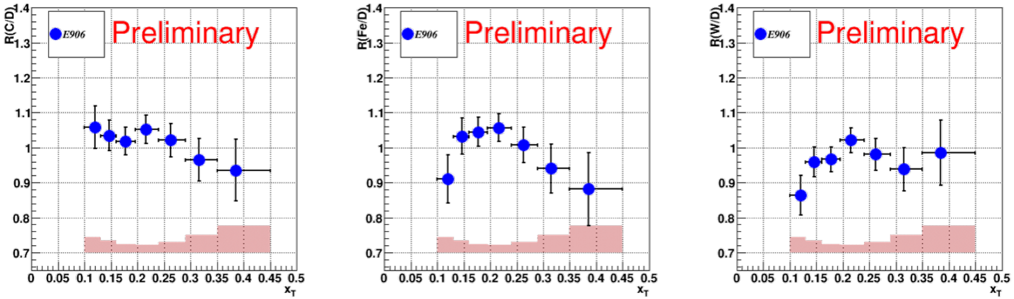
EPILOGUE

- Feynman made it all look easy.
- Drell-Yan provides access to antiquark dist.
- For $x_{Bj} < 0.45$, $\sigma^{pd} / \sigma^{pp} \geq 1$
- SeaQuest has measured the nuclear dependence of the Drell-Yan reaction





Epilogue

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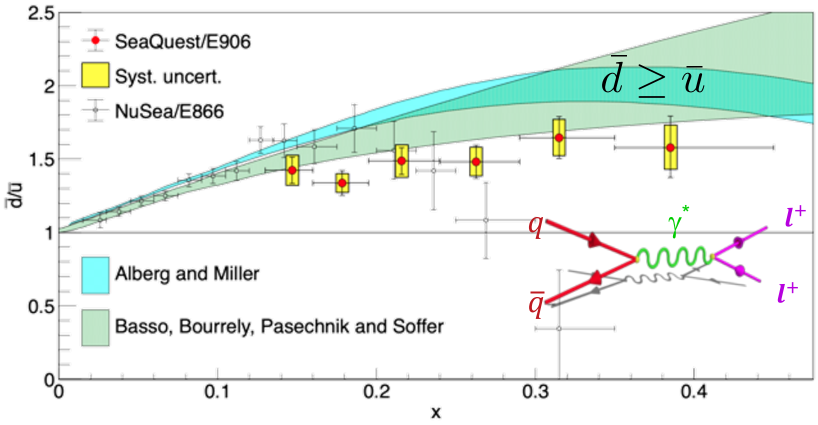
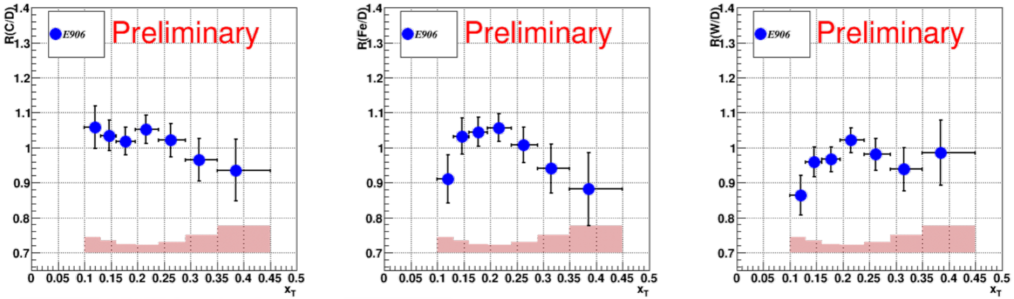
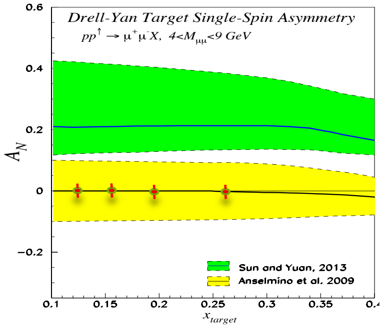




- SpinQuest will measure the Drell-Yan Sivers Function and probe sea quark orbital angular momentum with a polarized target.



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