How should we view the sea: threatening or calm?

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1 June 2018
Palm Springs, CA

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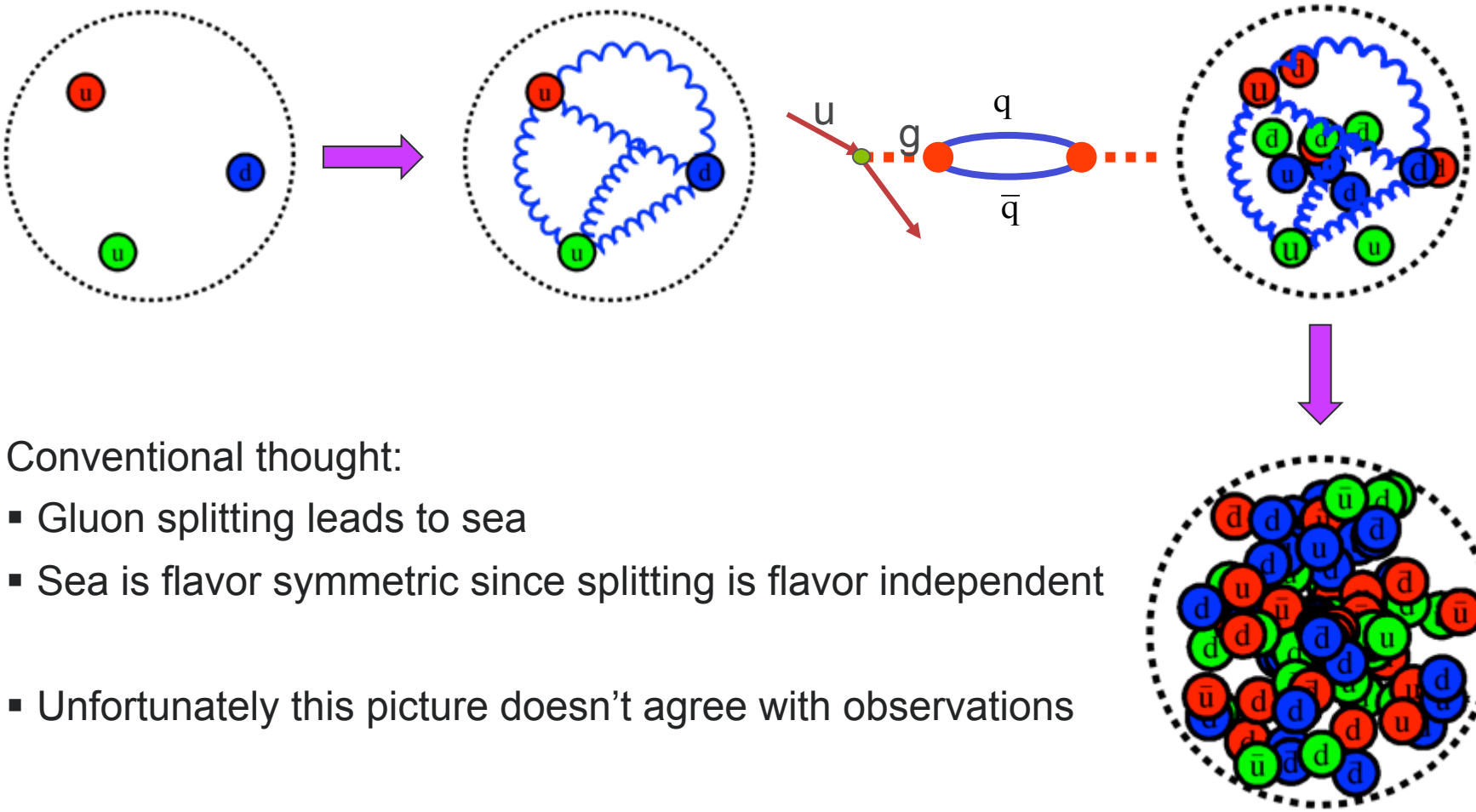
What are the origins of the Sea?



Conventional thought:

- Gluon splitting leads to sea
- Sea is flavor symmetric since splitting is flavor independent

- Unfortunately this picture doesn't agree with observations

Evidence for a turbulent sea (I).

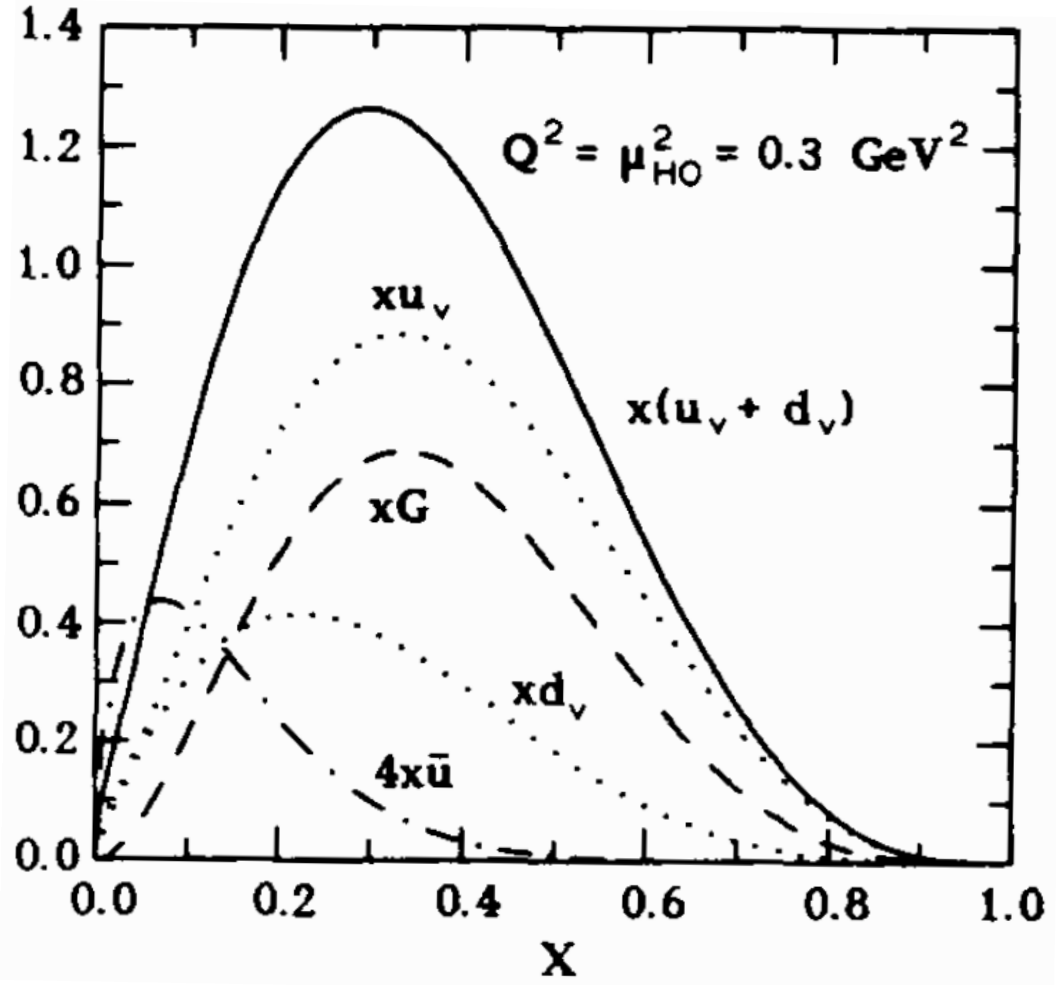
Parton distributions for high energy collisions

M. Glück, E. Reya, A. Vogt
Institut für Physik, Universität Dortmund, Postfach 500500, W-4600 Dortmund 50, Federal Republic of Germany

Received 10 June 1991

Abstract. 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)



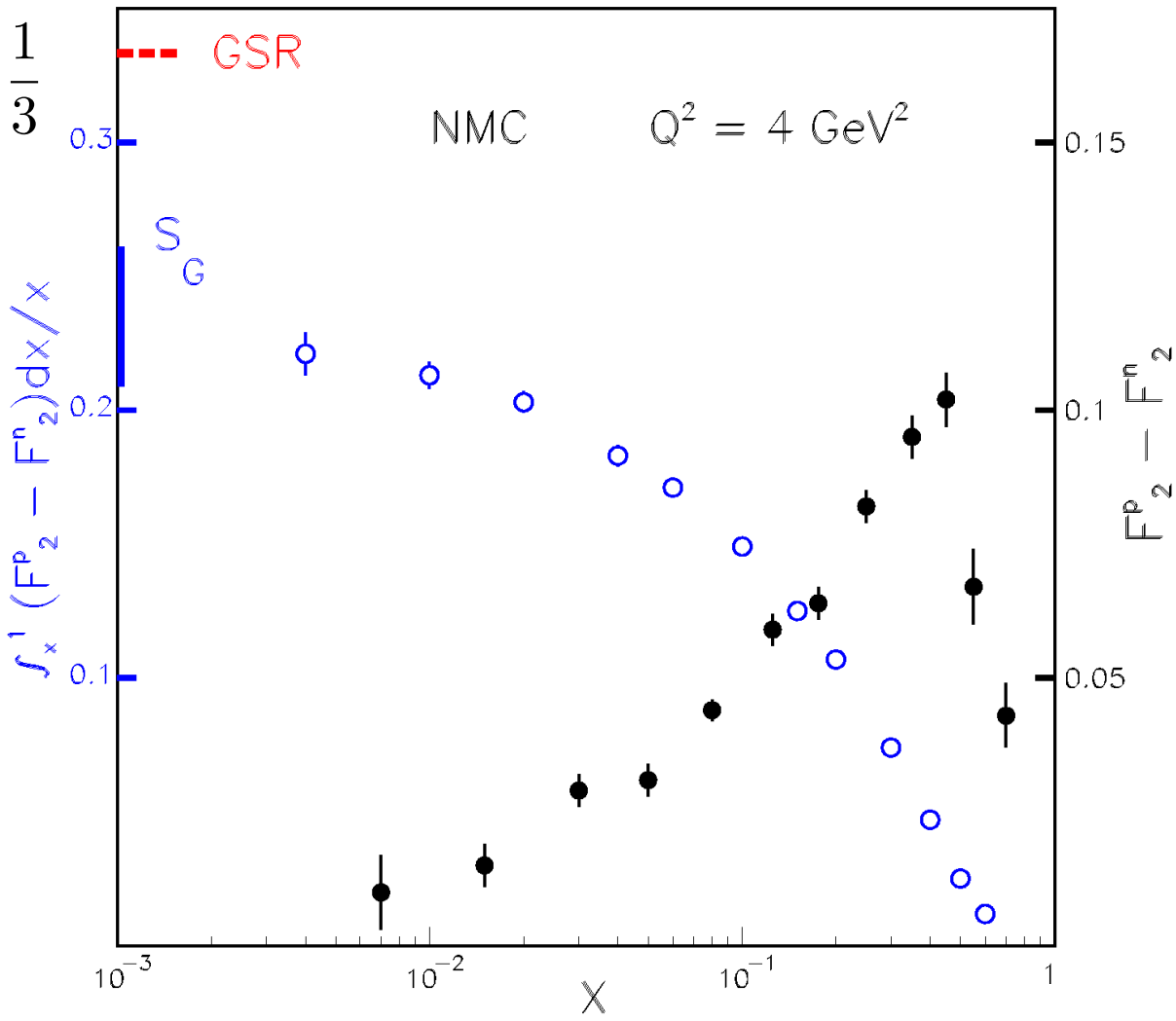
Evidence for a turbulent sea (II)

- Gottfried Sum Rule (NMC)

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

if and only if

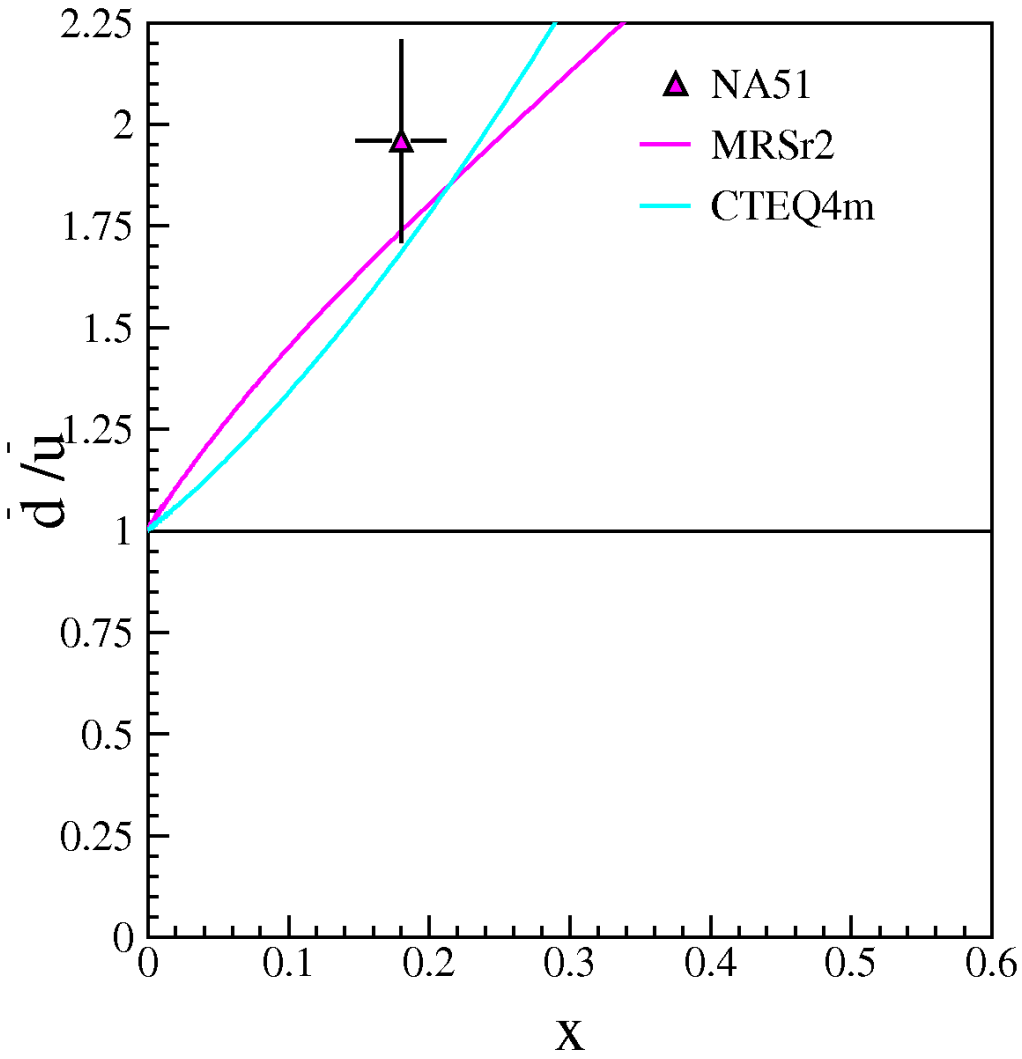
$$\int_0^1 [\bar{d}(x) - \bar{u}(x)]\, dx \neq 0$$



Evidence for a turbulent sea (III)

- Drell-Yan
  NA51 at CERN

$$\bar{d} > \bar{u} \text{ at } x = 0.18$$



Evidence for a turbulent sea (IIIb)

- Drell-Yan

  NA51 at CERN

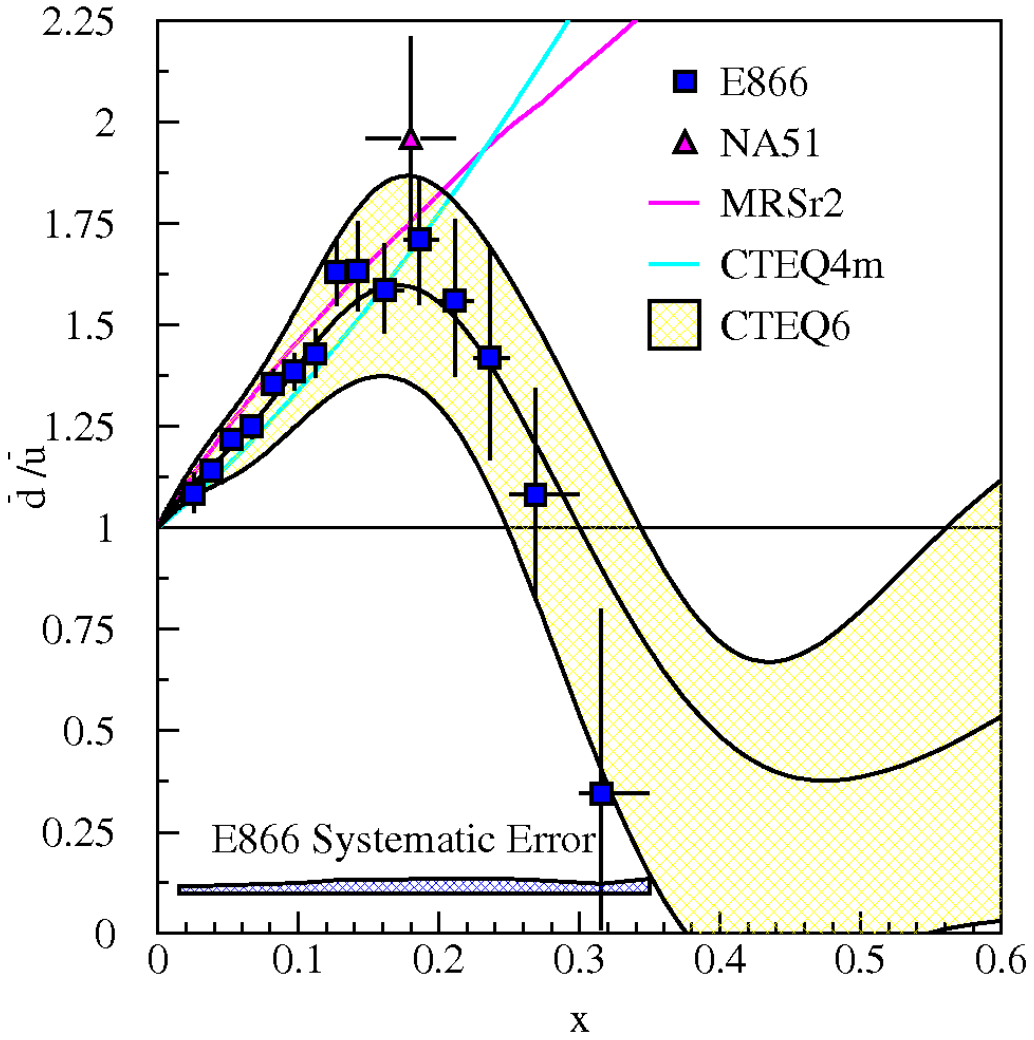
  $\bar{d} > \bar{u}$ at $x = 0.18$

  E866/NuSea (Fermilab)

  $\bar{d}(x)/\bar{u}(x)$ for $0.015 \leq x \leq 0.35$

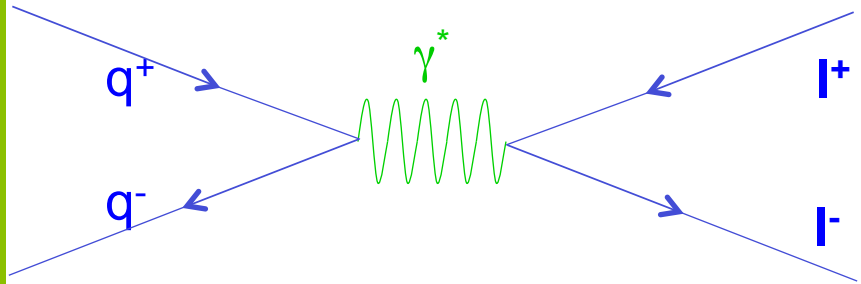
  - Knowledge of sea dist. are data driven

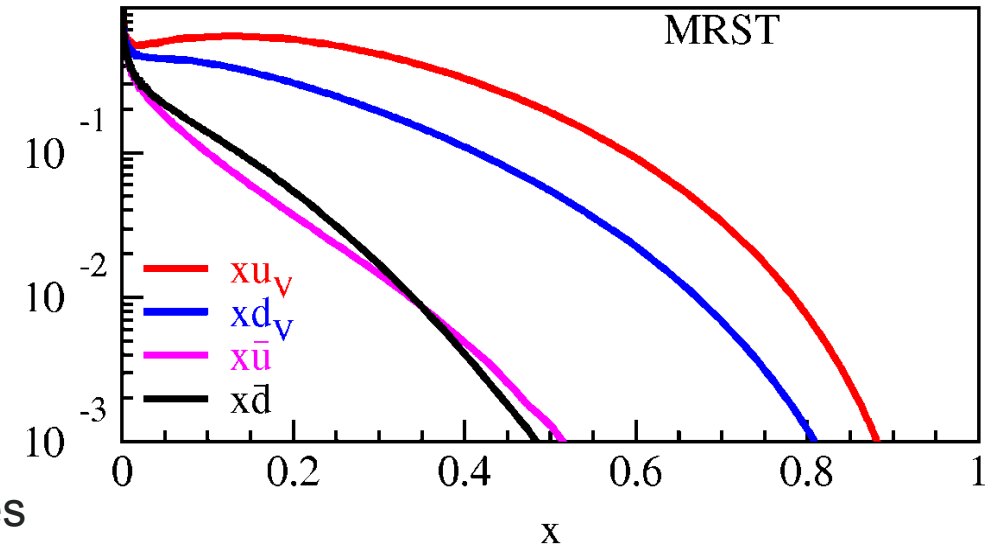
- Sea quark distributions are difficult for Lattice QCD*



*but significant progress is being made by the lattice community

Drell-Yan Cross Section—Sensitivity to Sea Quarks



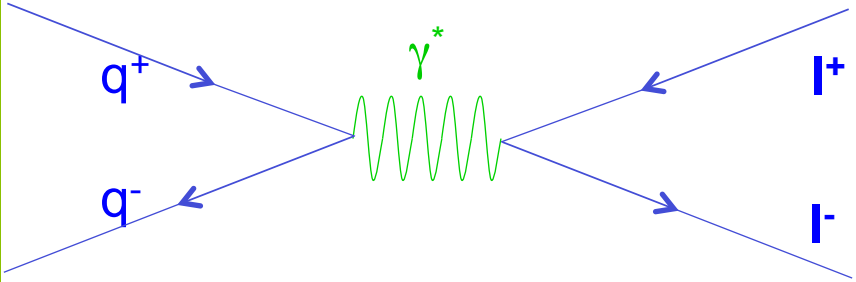


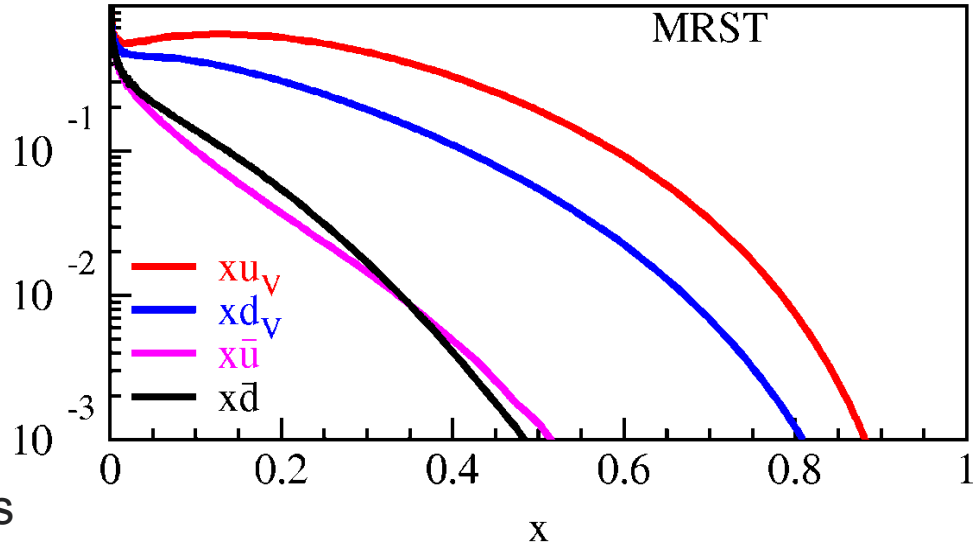
Cross Section

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

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

Drell-Yan Cross Section—Sensitivity to Sea Quarks





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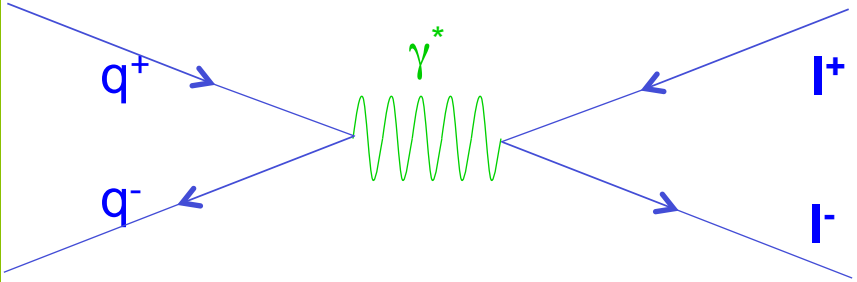
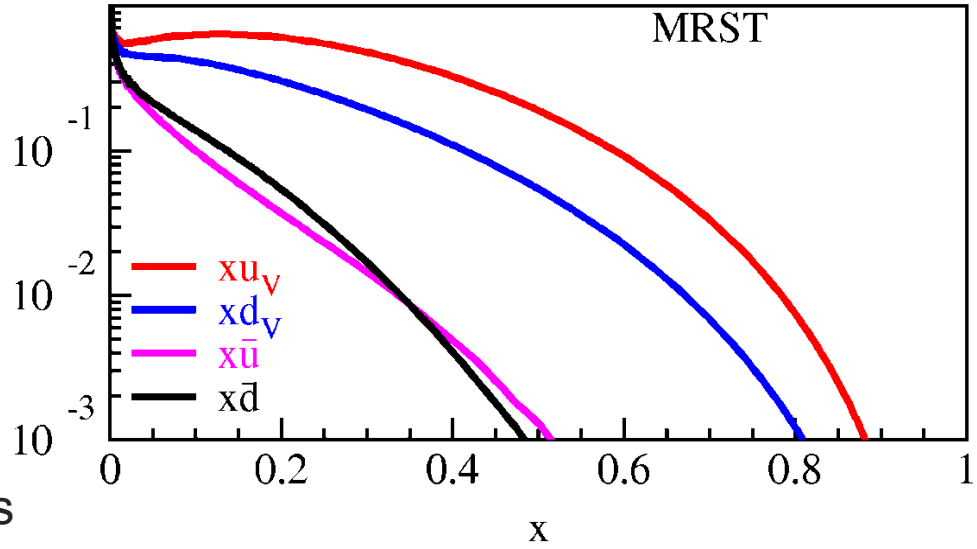
u-quark dominance
$(2/3)^2$ vs. $(1/3)^2$

Acceptance limited
(Fixed Target, Hadron Beam)

Beam	Sensitivity	Experiment
Hadron	Beam quarks target antiquarks	Fermilab, J-PARC RHIC (forward acpt.)
Anti-Hadron	Beam antiquarks Target quarks	J-PARC, GSI-FAIR Fermilab Collider
Meson	Beam antiquarks Target quarks	**COMPASS**, J-PARC

Drell-Yan Cross Section—Sensitivity to Sea Quarks





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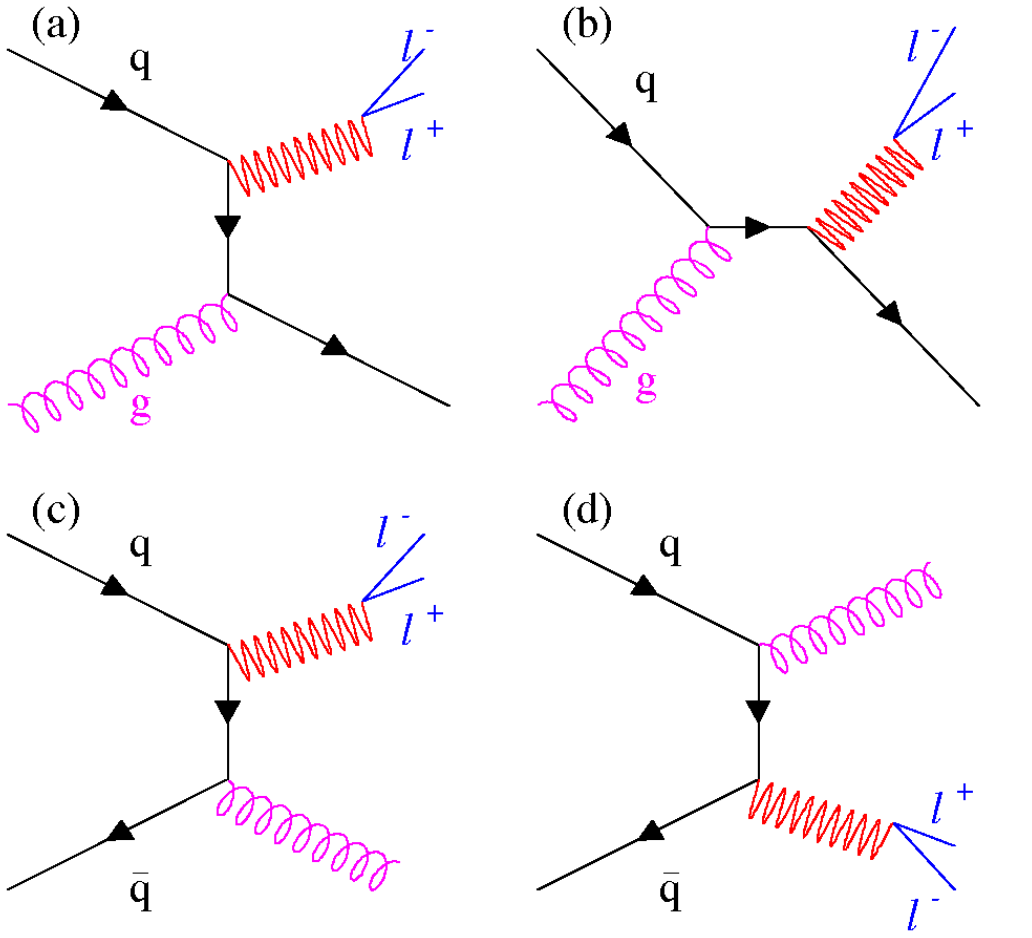
u-quark dominance
$(2/3)^2$ vs. $(1/3)^2$

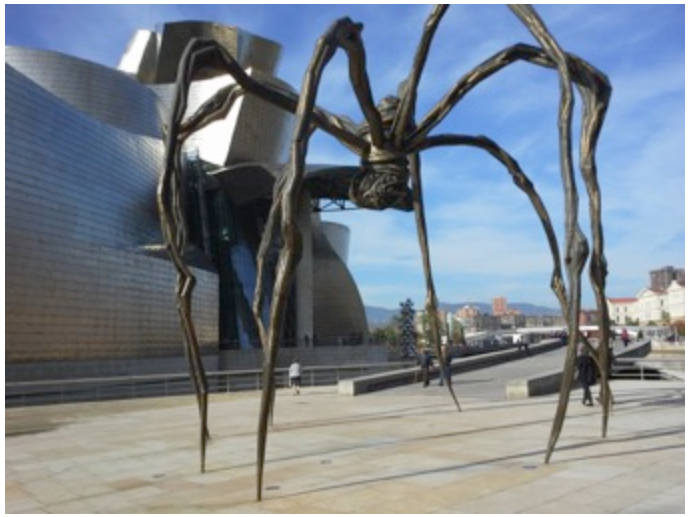
Acceptance limited
(Fixed Target,
Hadron Beam)

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

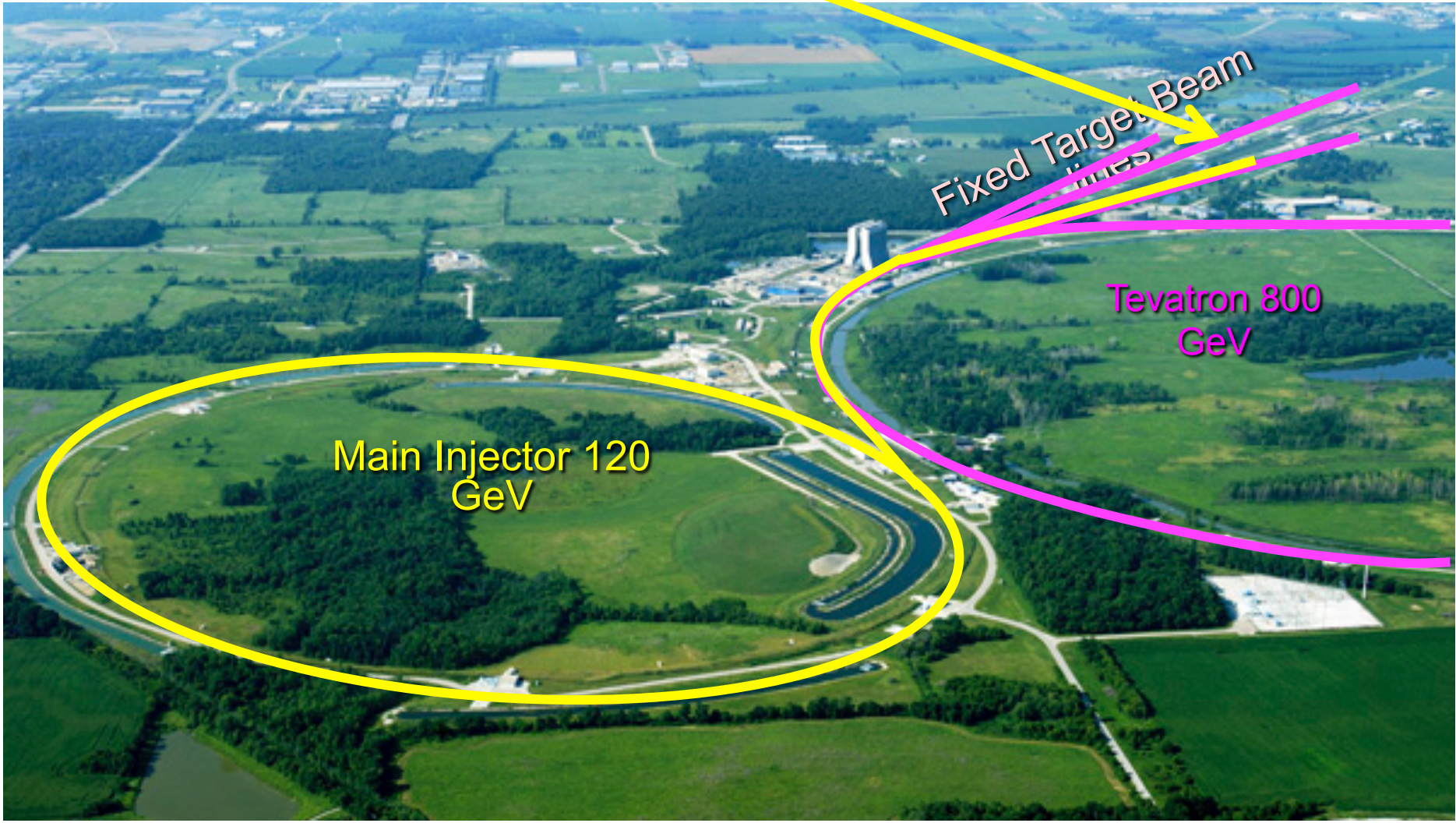
Drell-Yan Cross Section—Next-to-leading order α_s

- Responsible for up to 50% of the cross section



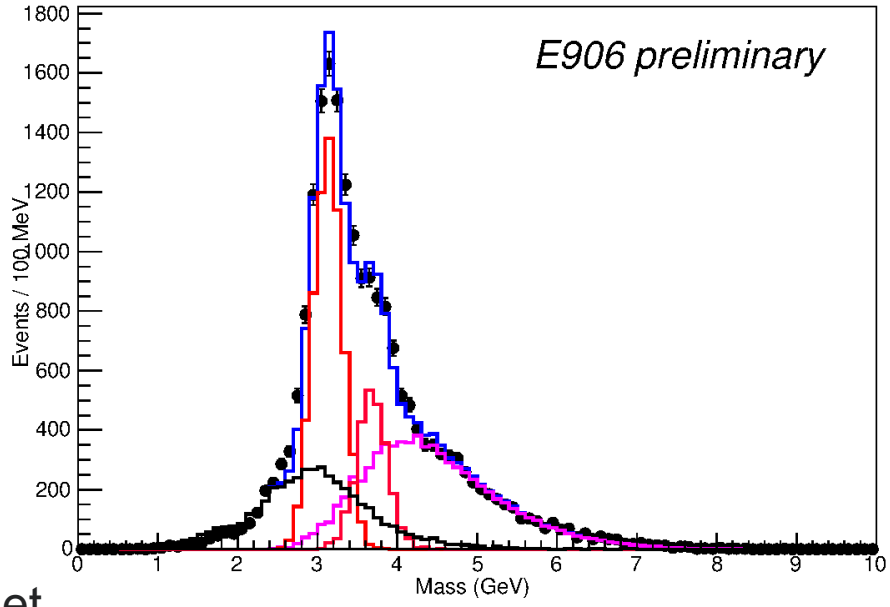


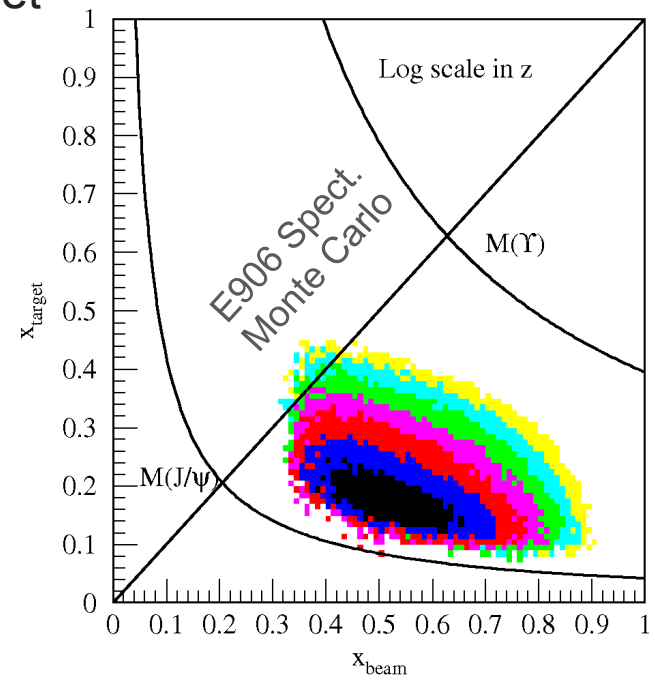
SeaQuest Experiment

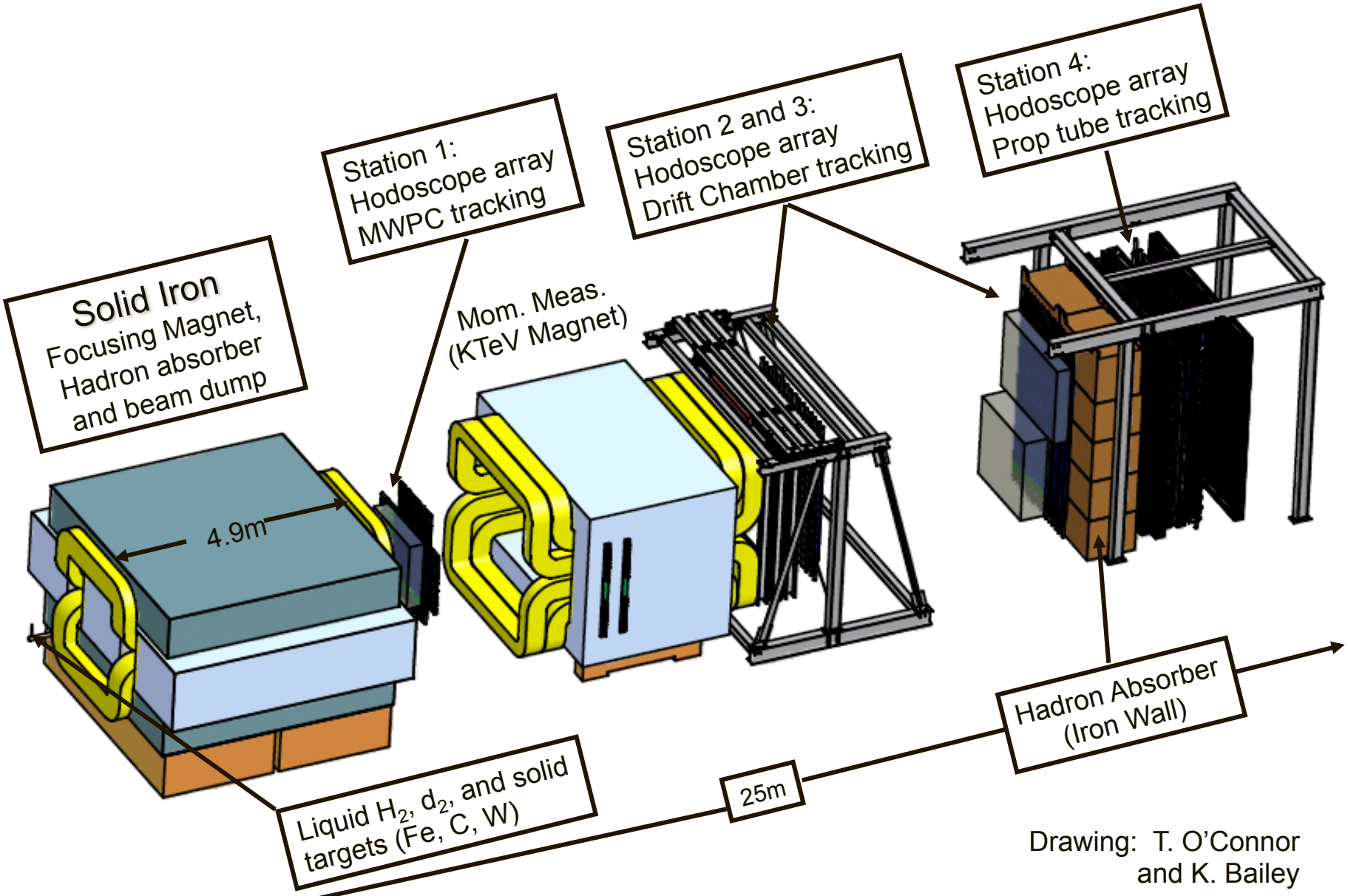


E906/SeaQuest Status

- Data with ^{1}H, ^{2}H, C, Fe and W targets
- Acceptance from below J/ψ to ≈8 GeV
- Completed data recording summer 2017
- Recorded 1.8 × 10^{18} "live" protons on target
  - 1/3 of requested integrated luminosity



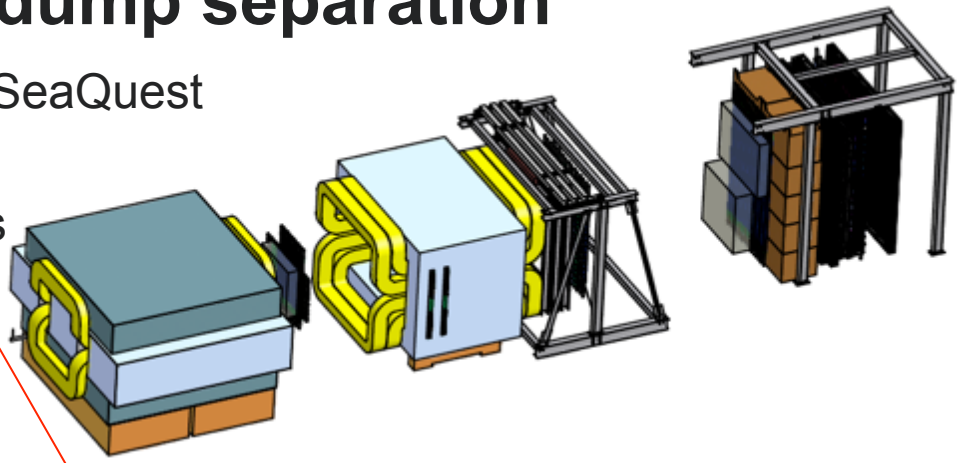


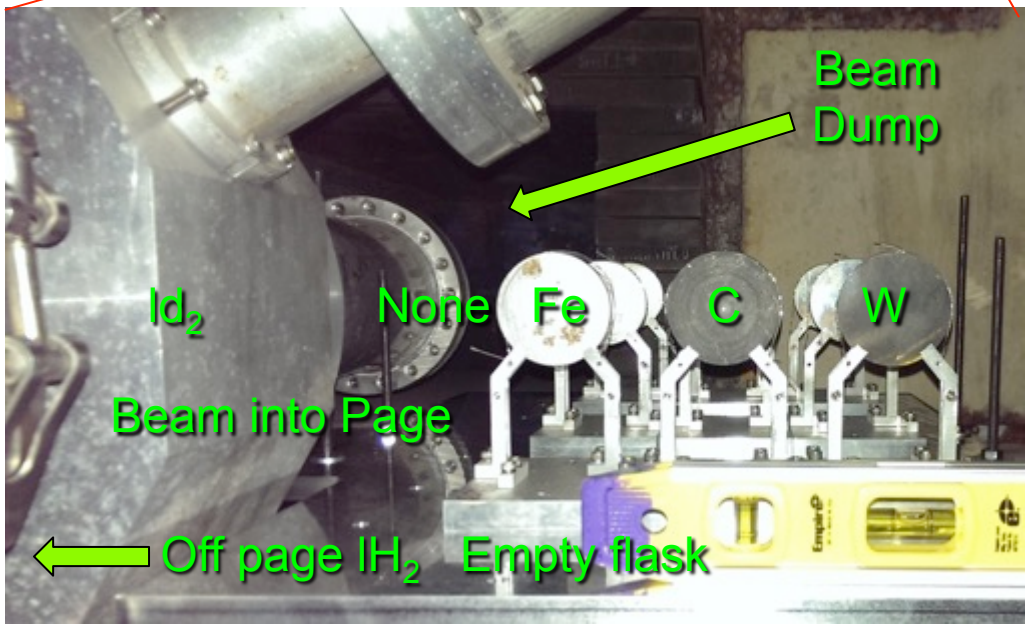


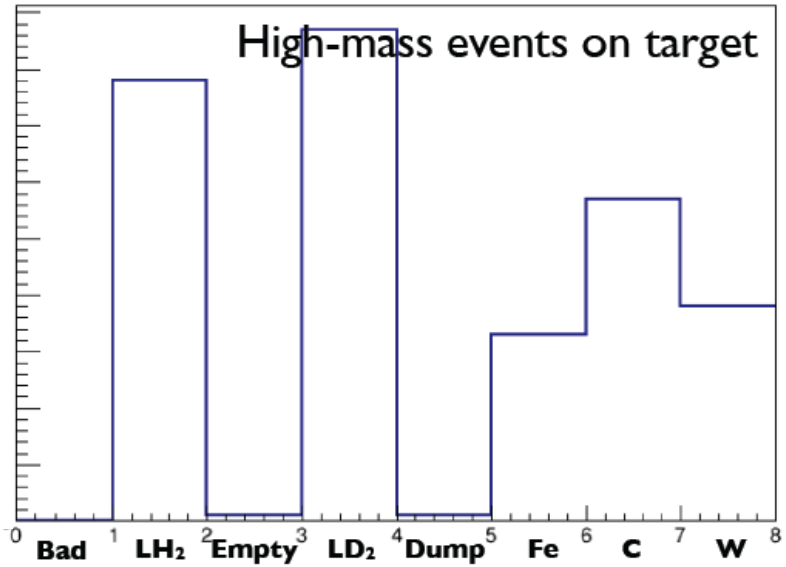
Drawing: T. O'Connor
and K. Bailey

Data From FY2014—target-dump separation

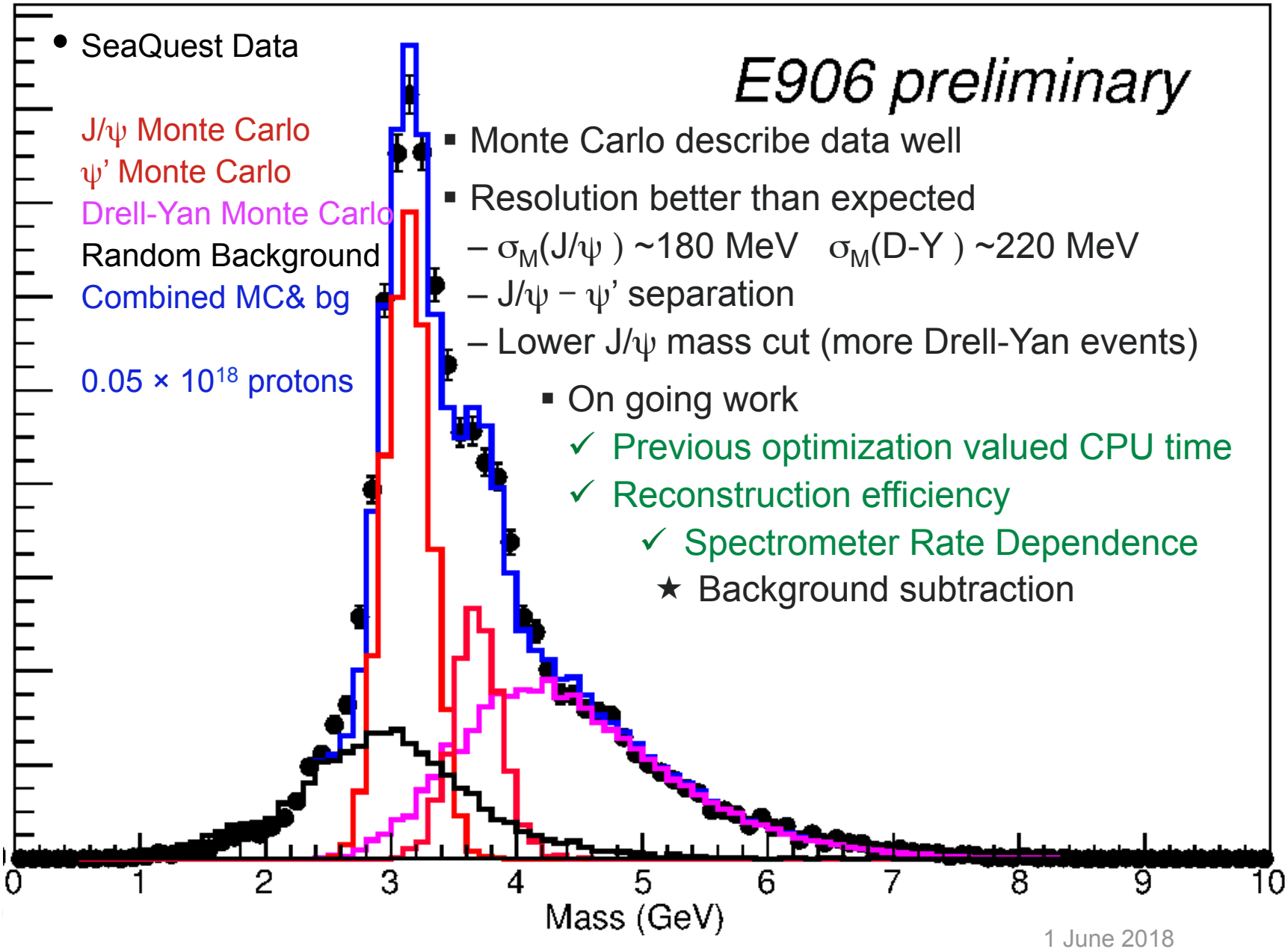
- Entire beam interacts upstream of first SeaQuest Spectrometer tracking chamber
- Spatial resolution poor along beam axis
- Resolve target vs beam dump



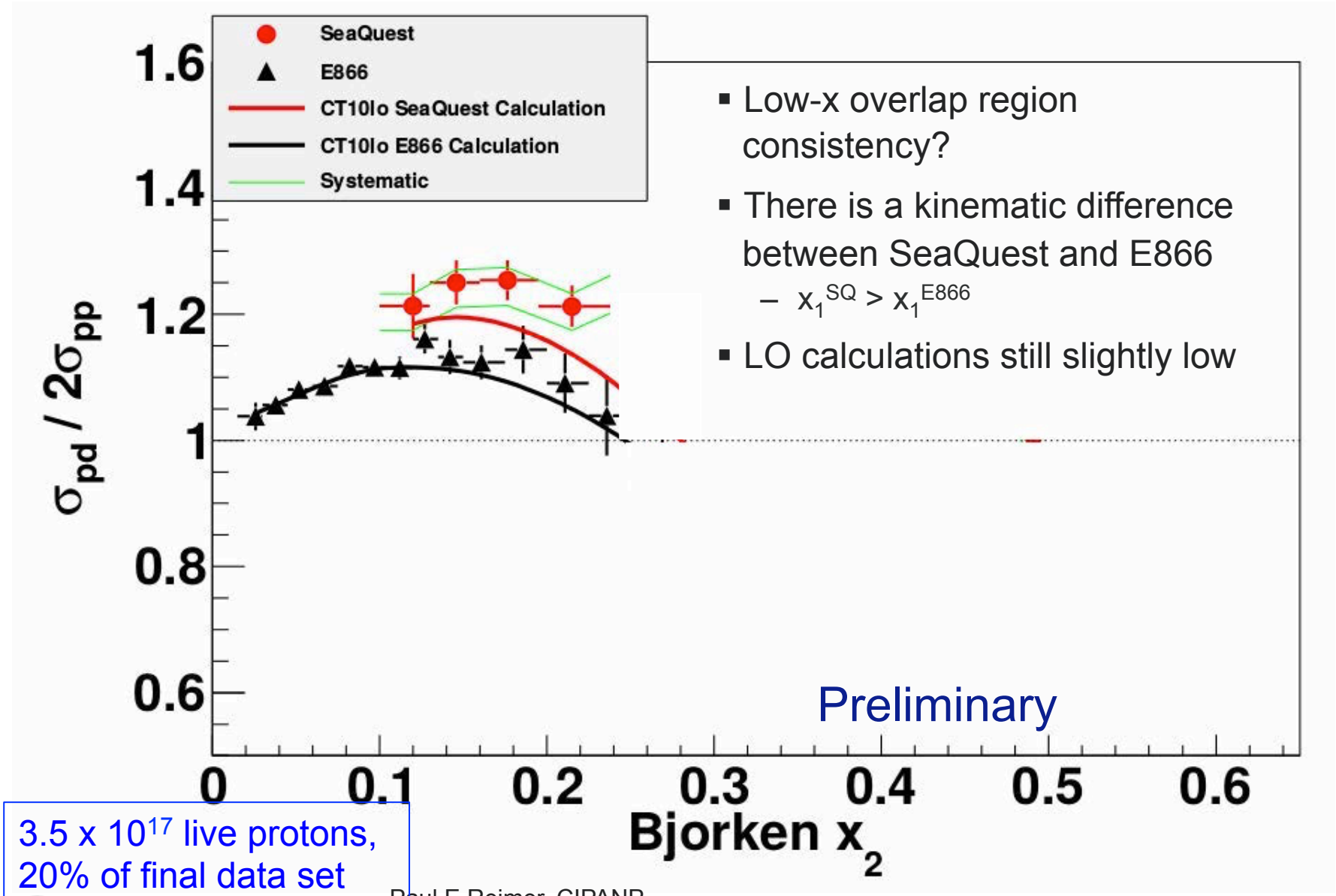




Data From FY2014



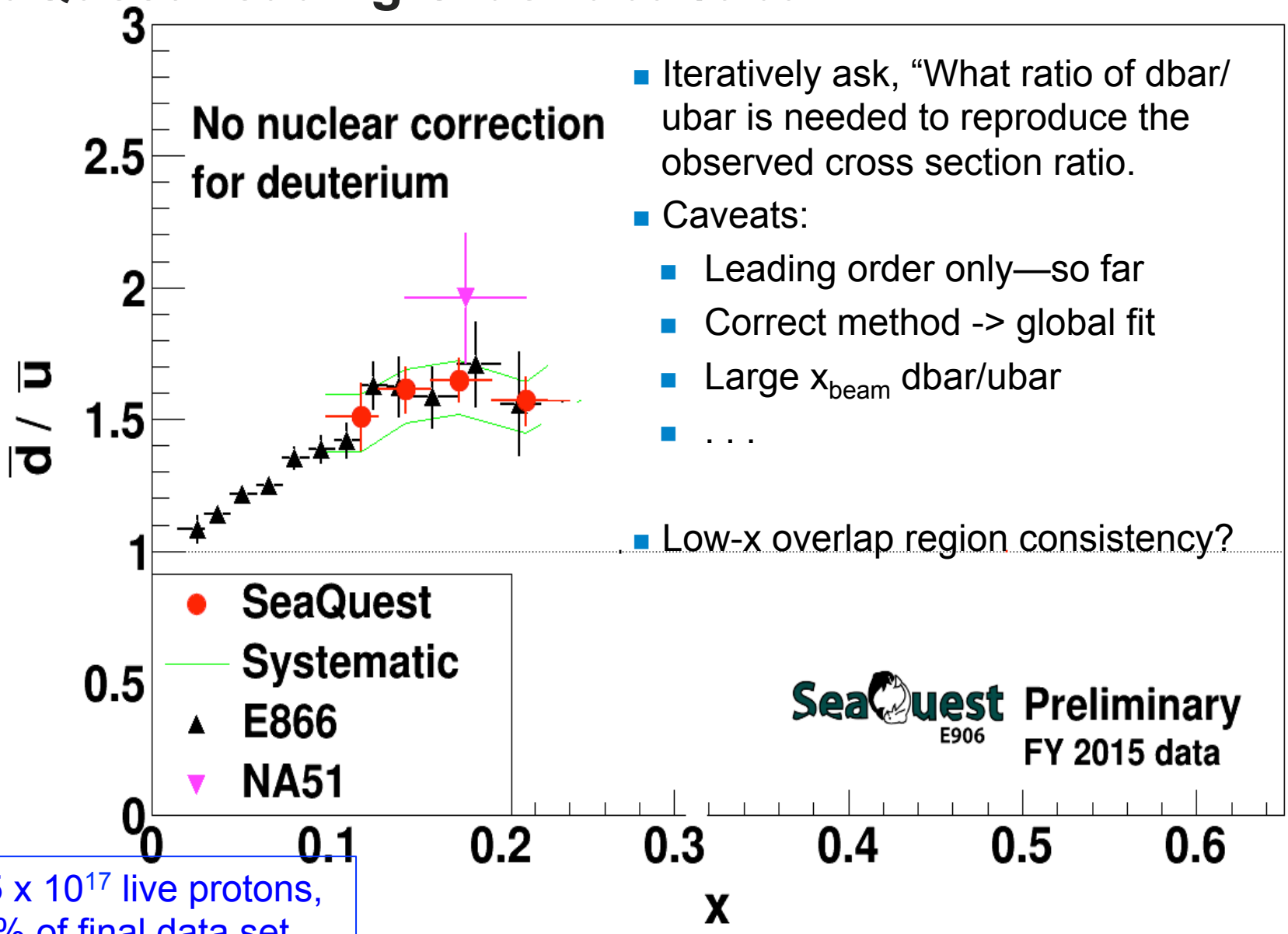
SeaQuest Cross Section Ratio



- Low-x overlap region consistency?
- There is a kinematic difference between SeaQuest and E866
  - $x_1^{SQ} > x_1^{E866}$
- LO calculations still slightly low

3.5 x 10^{17} live protons, 20% of final data set

SeaQuest Leading Order dbar/ubar



- Iteratively ask, "What ratio of dbar/ubar is needed to reproduce the observed cross section ratio.
- Caveats:
  - Leading order only—so far
  - Correct method -> global fit
  - Large x_{beam} dbar/ubar
  - . . .
- Low-x overlap region consistency?

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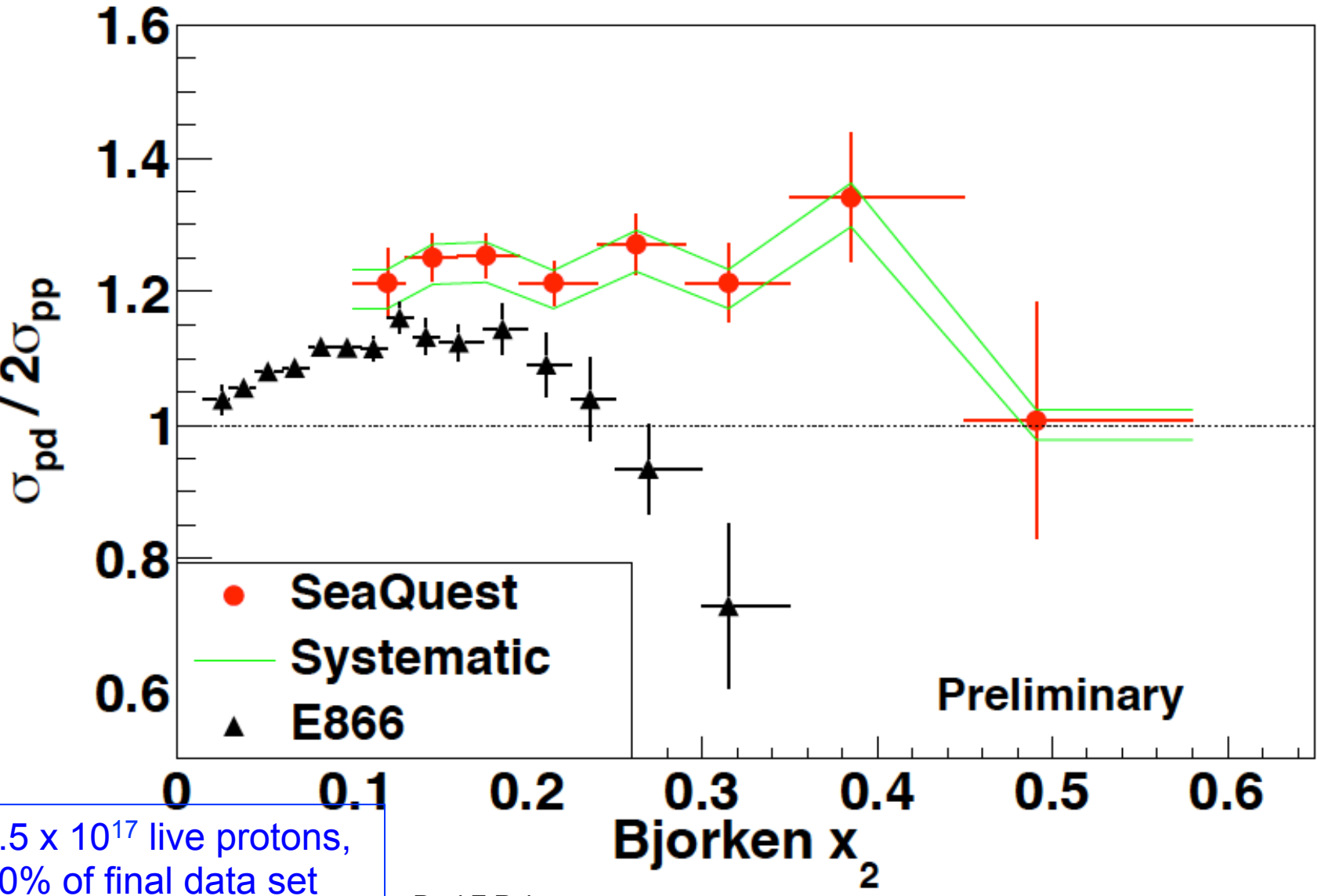
SeaQuest Cross Section Ratio



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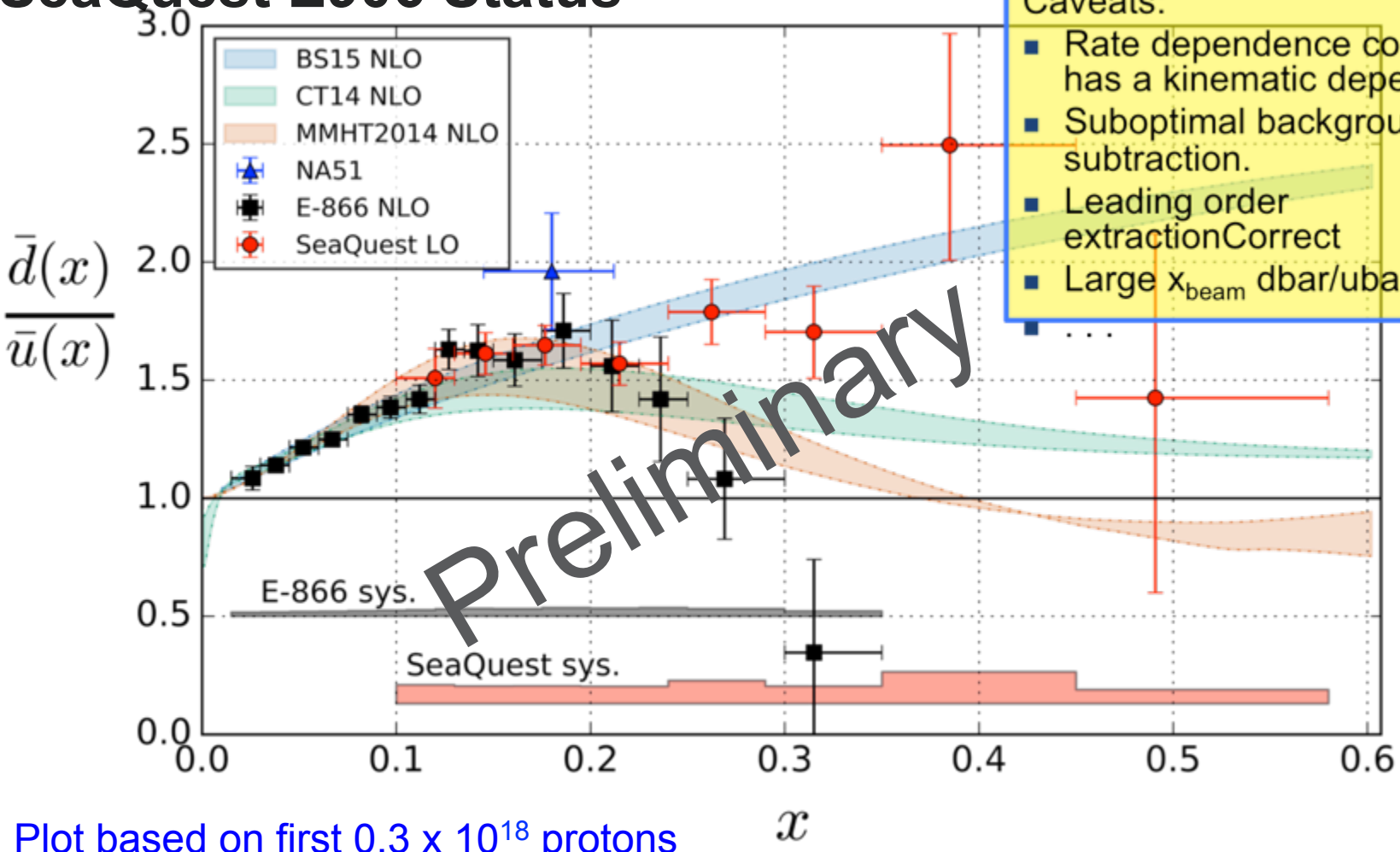
SeaQuest E906 Status



Caveats:

- Rate dependence correction has a kinematic dependence
- Suboptimal background subtraction.
- Leading order extractionCorrect
- Large x_{beam} dbar/ubar

. . .

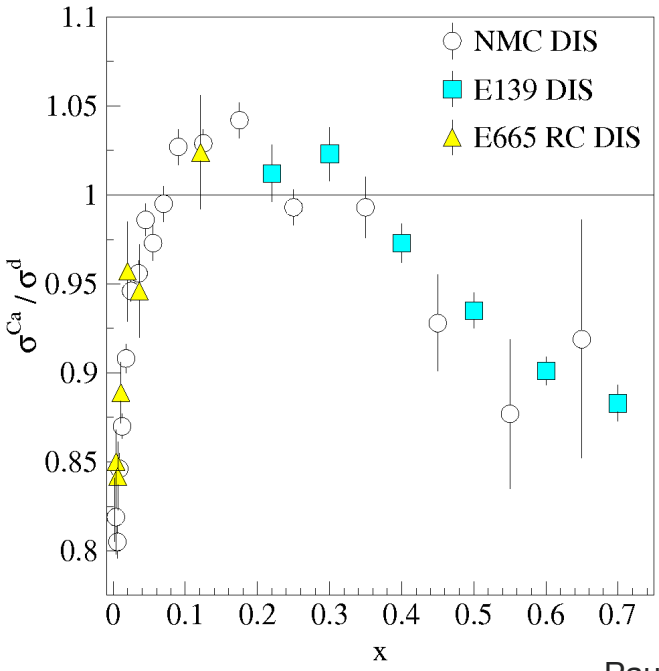
Plot based on first 0.3 x 10^{18} protons

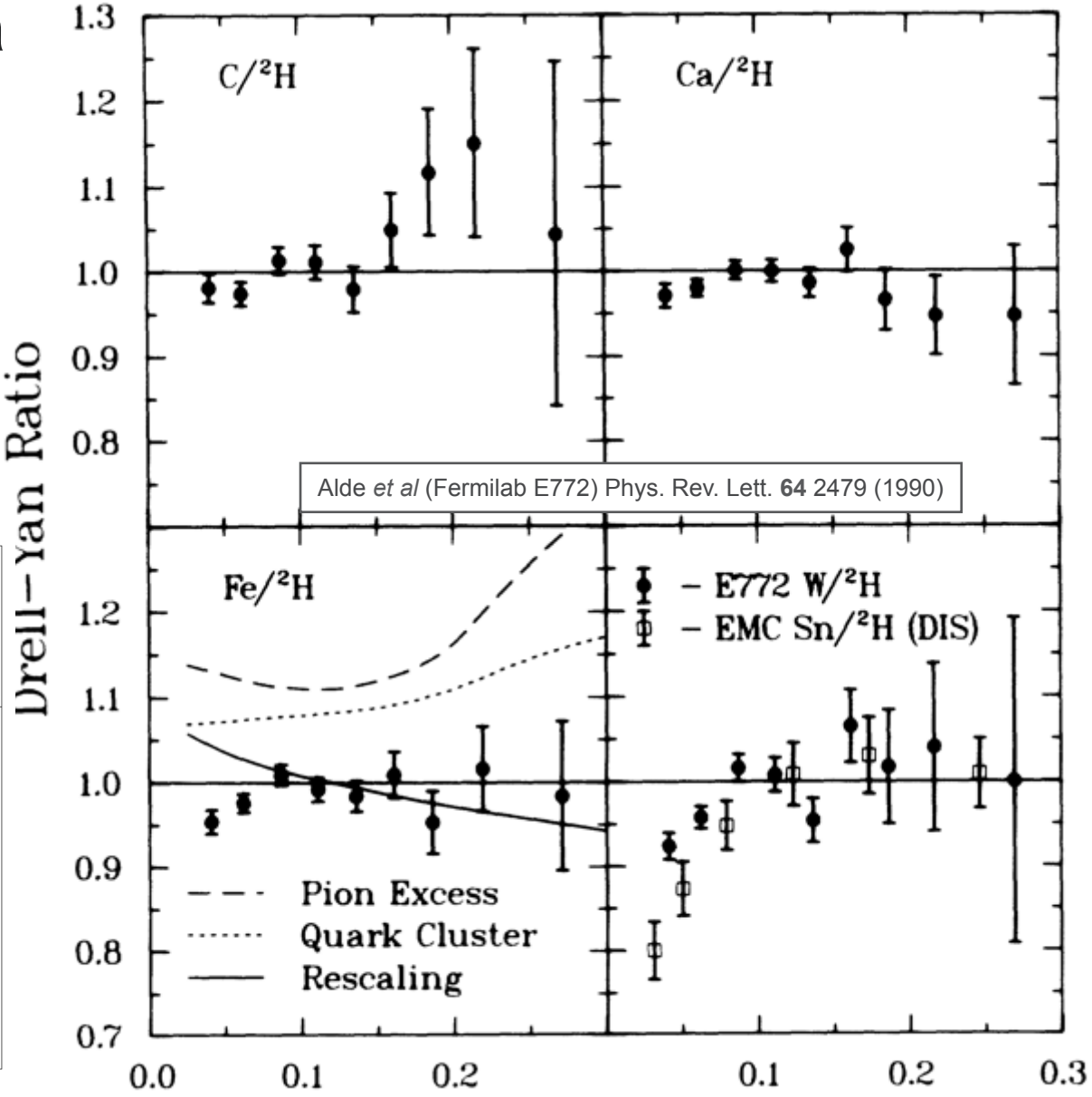
SeaQuest has recorded 1.8 x 10^{18} protons

Acceptance improvements so later protons are “worth” more

Fermilab E772 Data

- No clear EMC effect
- **No evidence for nuclear pion enhancement**



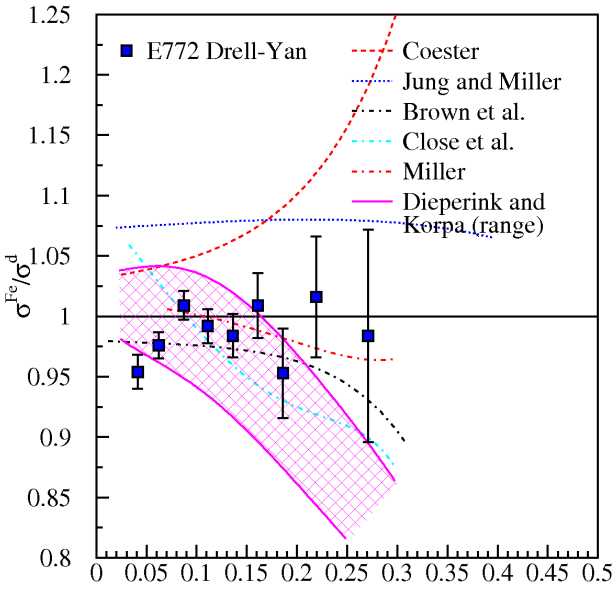


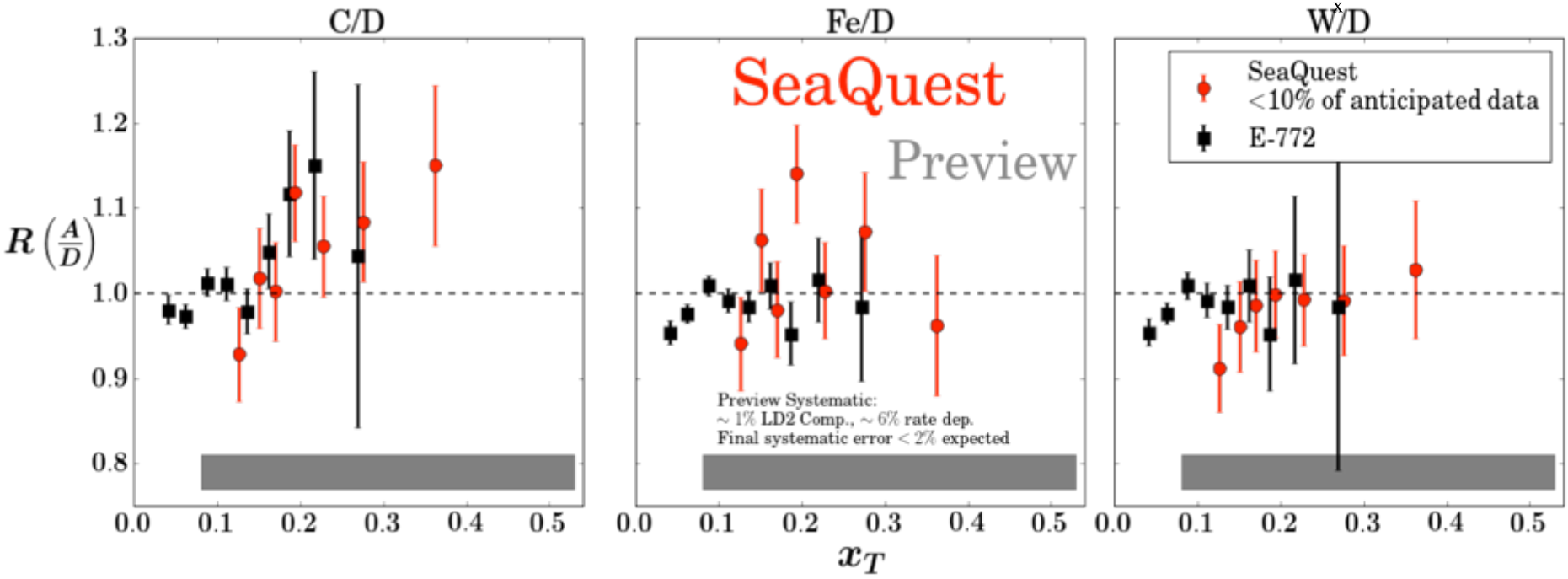
Alde *et al* (Fermilab E772) Phys. Rev. Lett. **64** 2479 (1990)

SeaQuest Seaquark EMC Effect

Parton distributions in nuclei are different than in nucleons!!

- No antiquark enhancement apparent.
- 10% of anticipated statistical precision
- Increased detector acceptance at large-x to come.





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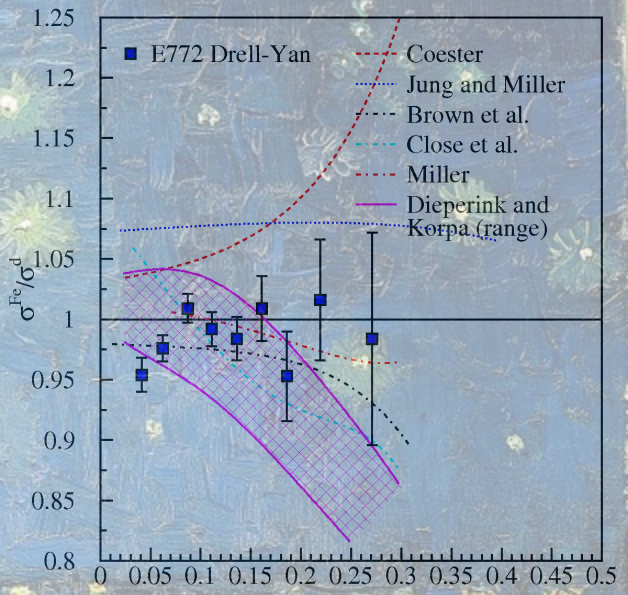
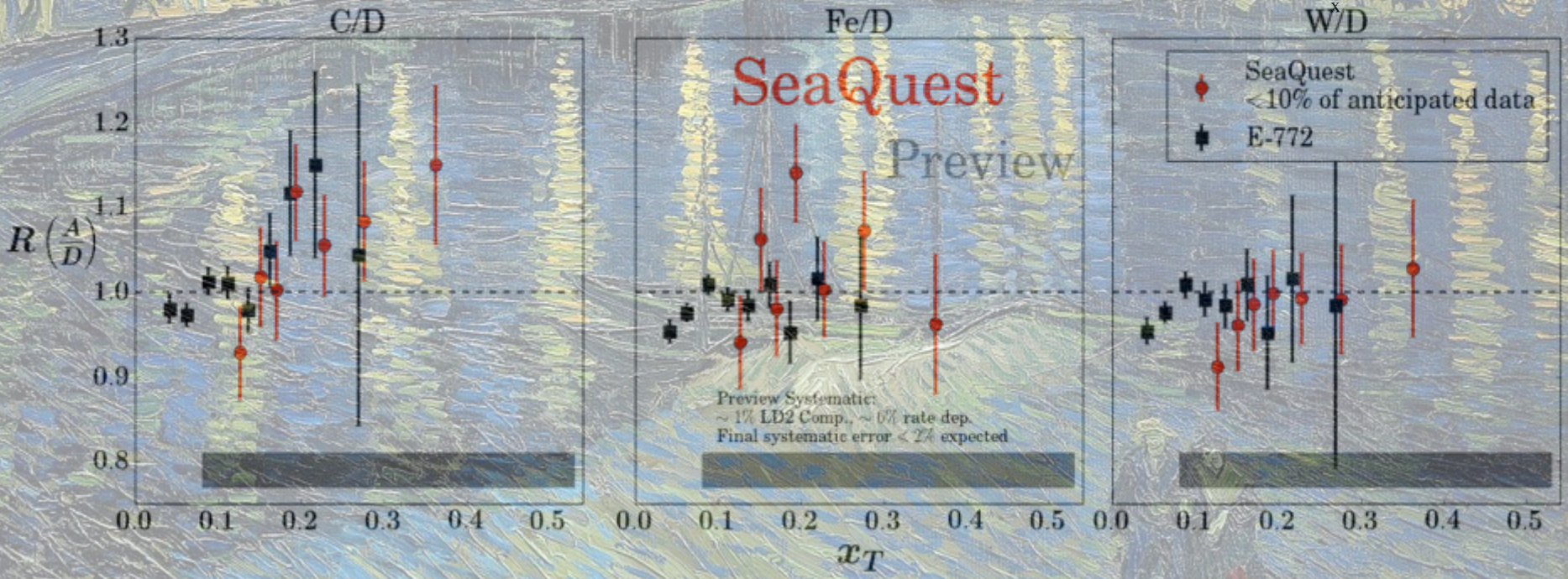
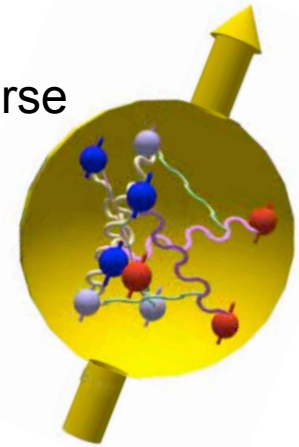


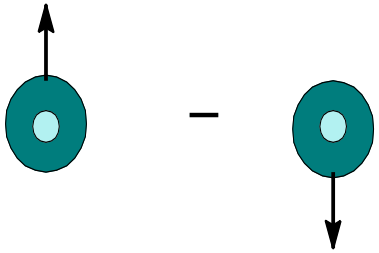


Drell-Yan Future: Polarized Target, Beam



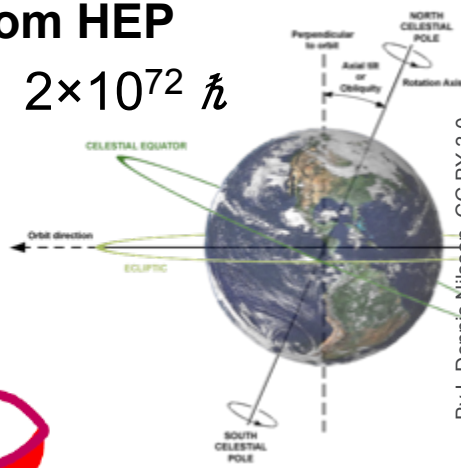
- E-1039: Correlation between unpolarized quarks and nucleon transverse polarization
- **Do sea quarks have orbital angular momentum?**
  - Non-zero Sivers distribution ⇨ non-zero quark orbital momentum:

$$f_{1T}^{\perp} =$$

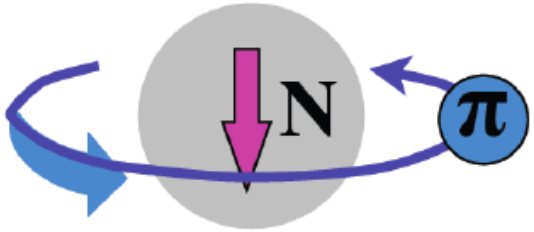


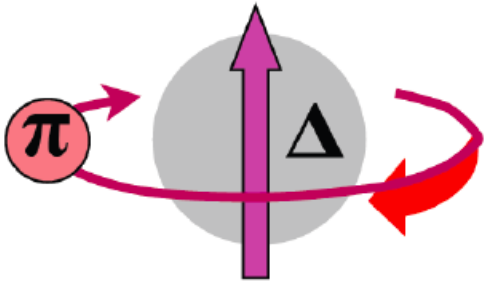
- Requires Transversely polarized target
- Status
  - **Funding from DOE/Nuclear Physics with support from HEP**
  - **Installation beginning!!**
  - Commissioning fall 2018
  - Production data FY19-20.

$2\times10^{72}\ \hbar$

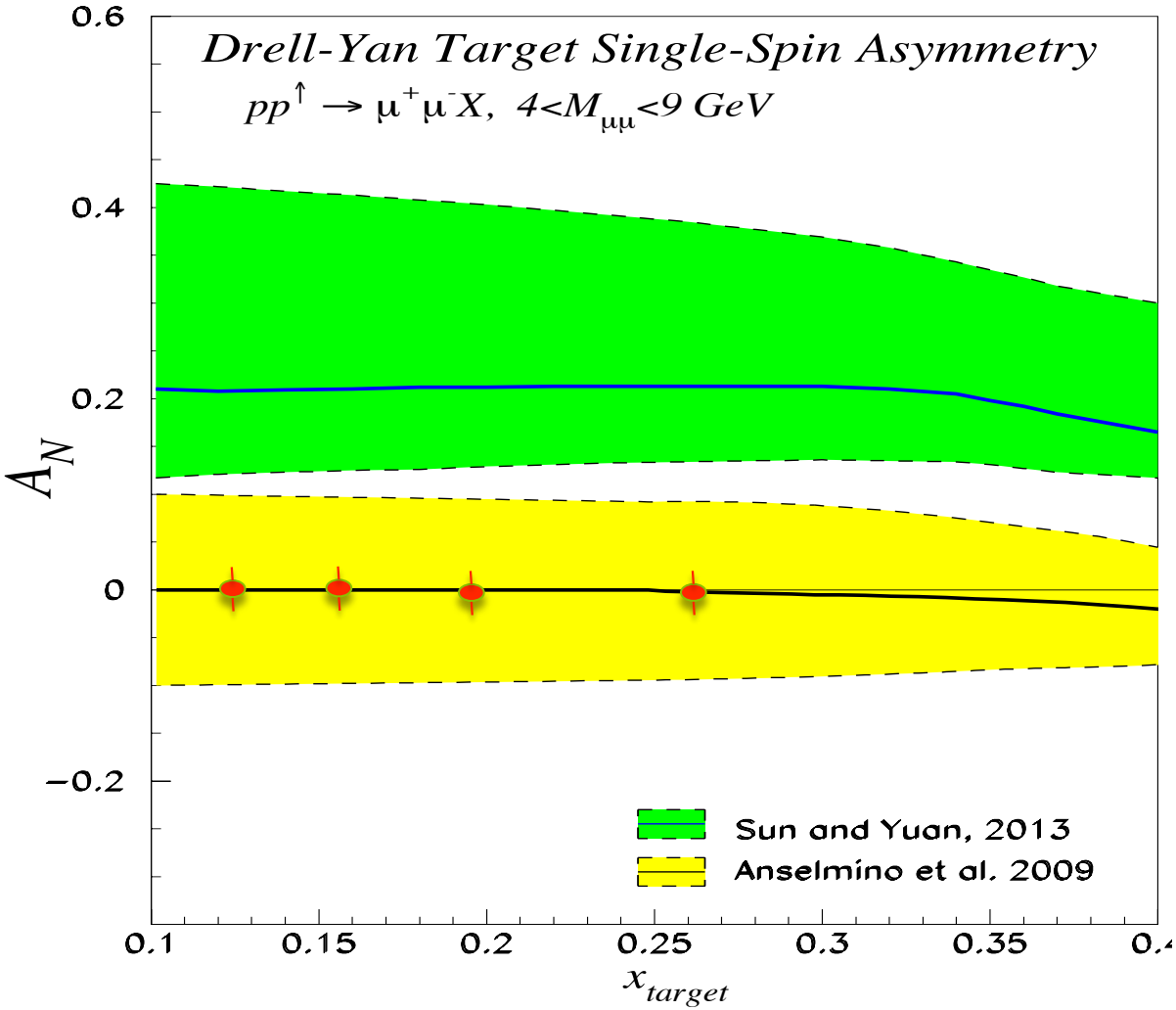


By I, Dennis Nilsson, CC BY 3.0, https://commons.wikimedia.org/w/index.php?curid=3262268





Projected Statistical Precision with a Polarized Target



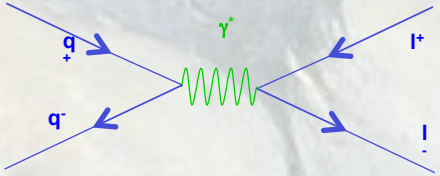
Statistics precision shown for two calendar years of running :

Protons on target = 2.7×10^{18}

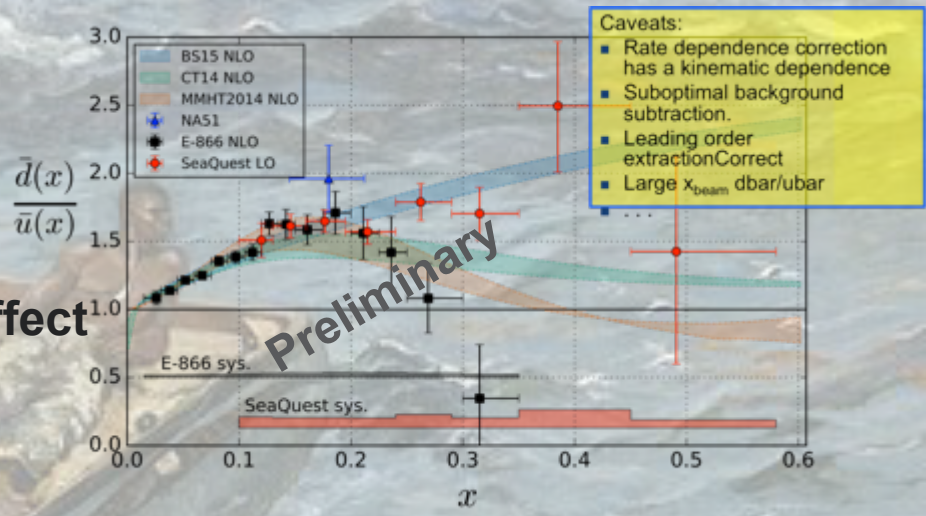
$\mathcal{L} = 7.2 \times 10^{42}\ /cm^2$

TAKE AWAY THOUGHTS

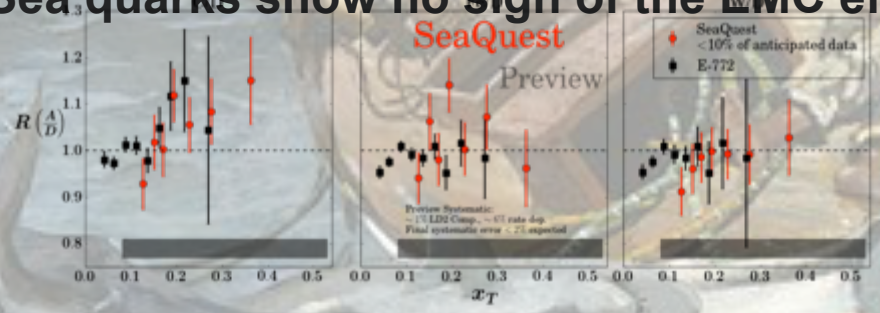
THE PROTON'S SEA IS TURBULENT



- Drell-Yan can select sea quark distribsutions
- SeaQuest extends the reach of previous sea quark measurements to larger x_{Bj}
  - Preliminary results indicate $\bar{d} \geq \bar{u}$
  - 5x more data recorded



- Sea quarks show no sign of the EMC effect



- Drell-Yan Sivers Function and sea quark orbital angular momentum will be probed with polarized target