Exploring the Light Anti-Quark Flavor Asymmetry in the Nucleon Sea using Semi Inclusive Charged Pion Production in Hall C

A Letter of Intent for PAC50

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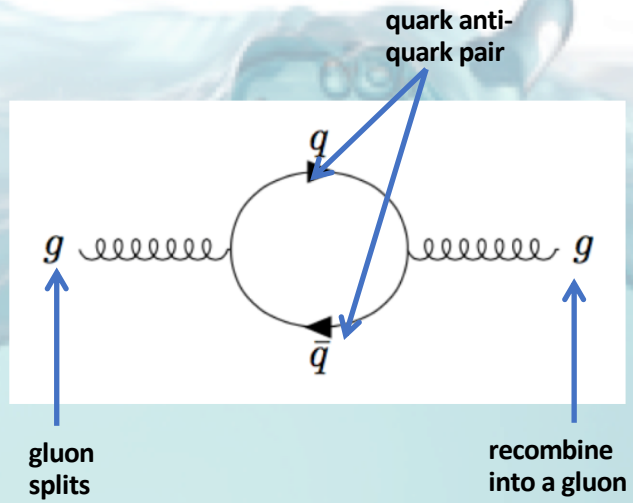
Jefferson Lab

Old proposal: PR 12-06-111
LOI: 12-22-01

Nucleon sea (Flavor symmetric?)

- Nucleon sea naively assumed to be flavor symmetric
- Gluons don't couple to flavor
- Masses of u and d quarks are small and similar, compared to QCD scale



Perturbative contributions calculated to be small!

D. A. Ross and C. T. Sachrajda, Nucl. Phys. B149, 497 (1979)

NMC (1991)

- Gottfried Sum Rule gives insight into the relative light quark flavor content of the nucleon

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

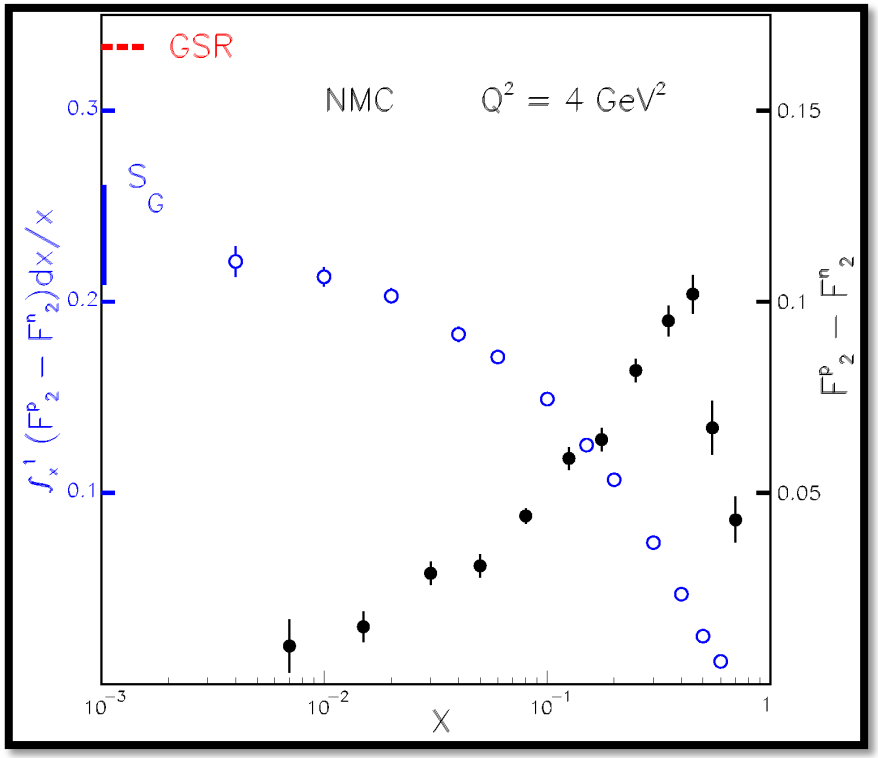
- Symmetric sea implies S_G = 1/3
- NMC experiment (LD2, LH2, 90 GeV and 280 GeV muon beam)

$$S_G = \int_{0.004}^{0.8} (F_2^p - F_2^n)\,dx/x$$

$$= 0.221 \pm 0.008 \pm 0.019$$

- After extrapolation to 0 and 1

$$= 0.235 \pm 0.026$$



Amaudruz *et. al.* Phys. Rev. D 66, 21
Arneodo *et. al.* Phys. Rev. D 50, 1

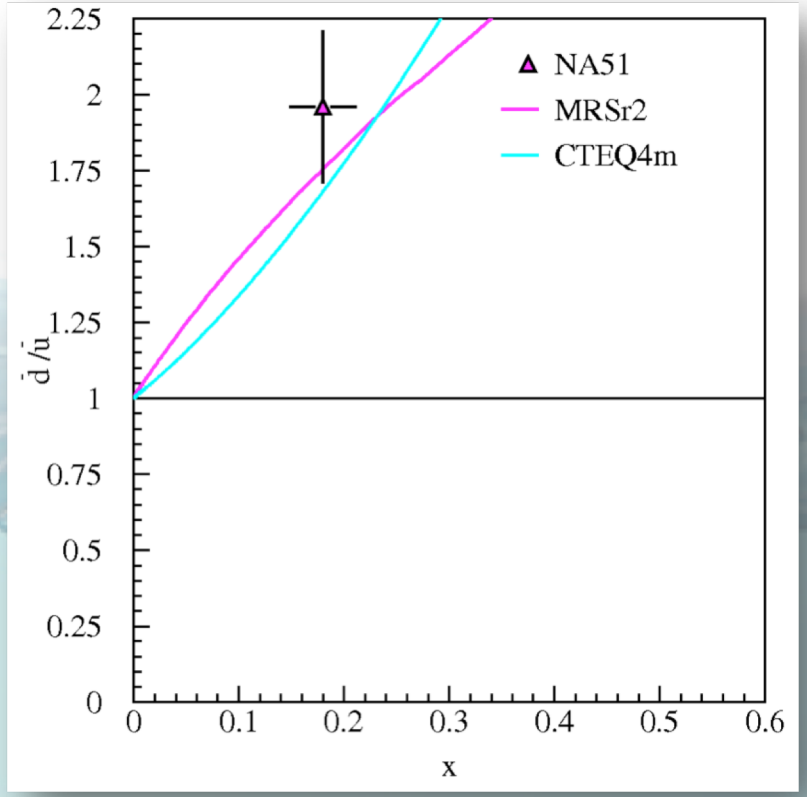
NA51 (1994)

- 450 GeV proton beam, LD2, LH2 targets

$$A_{DY} = \frac{\sigma_{pp} - \sigma_{pn}}{\sigma_{pp} + \sigma_{pn}} = 2\frac{\sigma_{pp}}{\sigma_{pd}} - 1$$

$$\sigma_{pd} \approx \sigma_{pp} + \sigma_{pn}$$

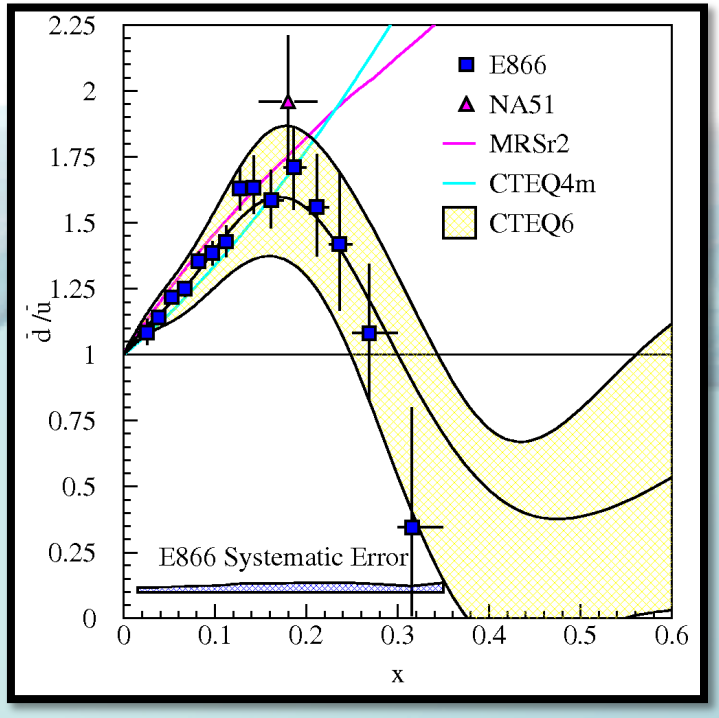
$$\left.\frac{\bar{d}}{\bar{u}}\right|_{\langle x \rangle = 0.18} = 1.96 \pm 0.15 \pm 0.05$$



Baldit *et. al.* Phys. Lett. B 332, 244-250

E866 (1998)

- Mapped out the *x* dependence
- Overturn at 0.2
- Drop in the ratio below 1 at x_B = 0.25 (limited statistical uncertainty and bin on edge of acceptance)
- This asymmetry has to come from a non-perturbative origin!



R.S. Towell *et. al.* Phys. Rev. D 64, 244-250

Origin of the Nucleon sea

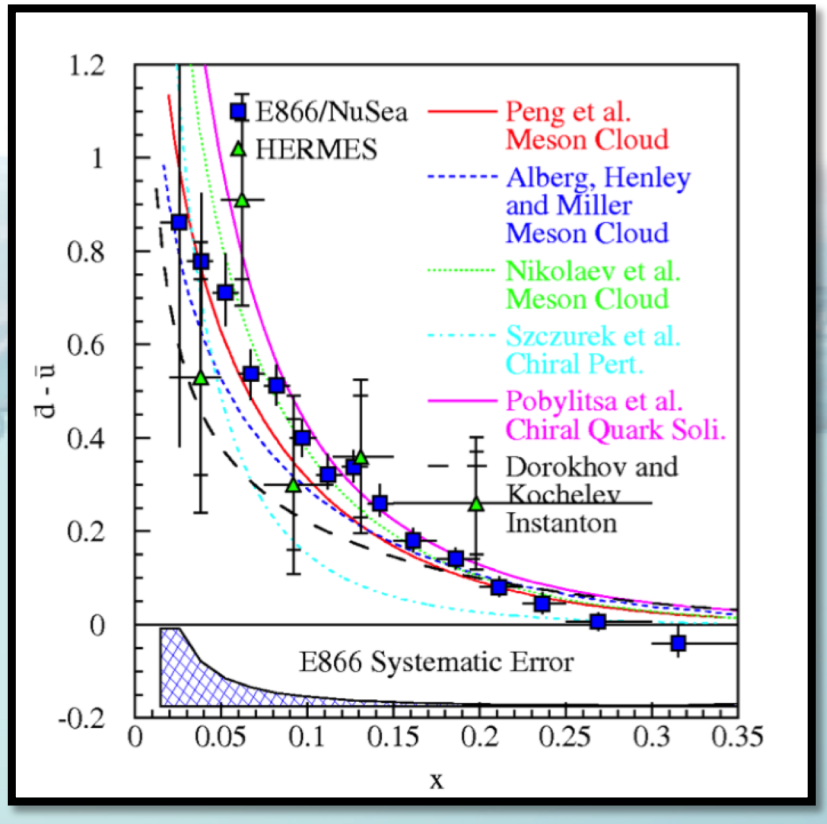
- Symmetric (perturbative and non-perturbative) component cancels away in the difference
- HERMES explored this region with modest precision
- Non-perturbative models are motivated to explain the observed difference

x_{min}	x_{max}	$\int_{x_{min}}^{x_{max}}(\bar{d}-\bar{u})dx$	Q^2 (GeV^2)	Source	Ref.
0.0	1.0	0.147 ± .026	4	NMC	[8]
0.015	0.35	0.080 ± 0.011	54	NUSEA	[12]
0.0	1.0	0.118 ± 0.012	54	NUSEA	[12]
0.001	1.0	0.165	54	CT66nlo	[31]
0.001	1.0	0.114	54	CT10nlo	[16]
0.001	1.0	0.116	2	CT10nlo	[16]
0.01	1.0	0.090	54	CT14nlo	[17]
0.001	1.0	0.086	1	Stat. Mod.	[32]
0.	1.0	0.13	?	Det. Bal.	[33]
0.02	0.345	0.108	54	Chiral Soliton	[34]
0.0	1.0	0.13 ± 0.07	?	Lattice	[35]

Table I. Integrals of $(\bar{d}-\bar{u})$ from x_{min} to x_{max} from experiment (NMC and NUSEA) and from several global fits (CTEQ6.6, CTEQ10, CTEQ14), calculations (Lattice), and models (Statistical and Detailed Balance). The weak variation of the integral to the choice of scale is illustrated with the CTEQ10 comparison at 2 and 54 GeV^2. The scales of the detailed balance and lattice calculations are not explicitly reported in those references.

D.F. Geesaman, P.E. Reimer Rept.Prog.Phys. 82 (2019) 4, 046301

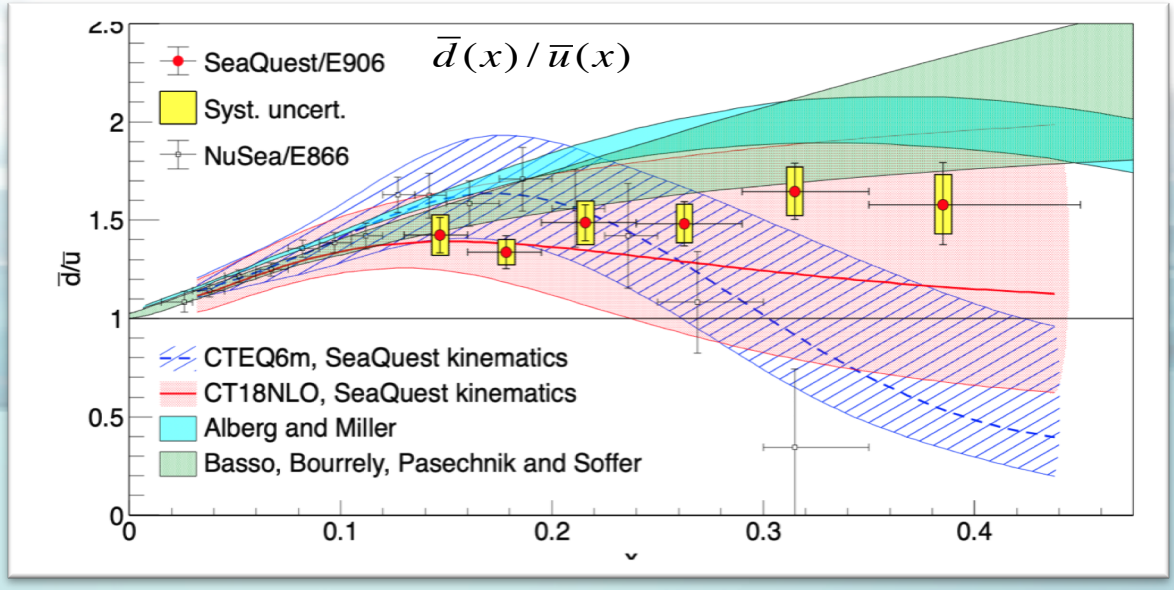
Peng *et al.* Phys. Rev. D 58 092004



SeaQuest results

- SeaQuest results show that nature prefers dbar over ubar in the proton sea
- Non-perturbative mechanism other than gluon splitting must be the source
- Good agreement with meson baryon model and statistical parton distribution functions

Dove et. al. Nature 590, 561 – 565 (2021)



See Jefferson Lab Virtual Physics Division Seminar, Apr 2, 2021*

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

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LOI submitted to PAC50

Old proposal: PR 12-06-111
LOI: 12-22-01
Reader: Alessandro Bachetta

Goals of the LOI

- To explore the region 0.1 < x < 0.25 using SIDIS to establish consistency with previous Drell-Yan measurements confirming process independence

- To explore the high-x (0.25 < x < 0.4) region where there is apparent tension between NuSea and SeaQuest results using sensitivity to charged pion yield ratios

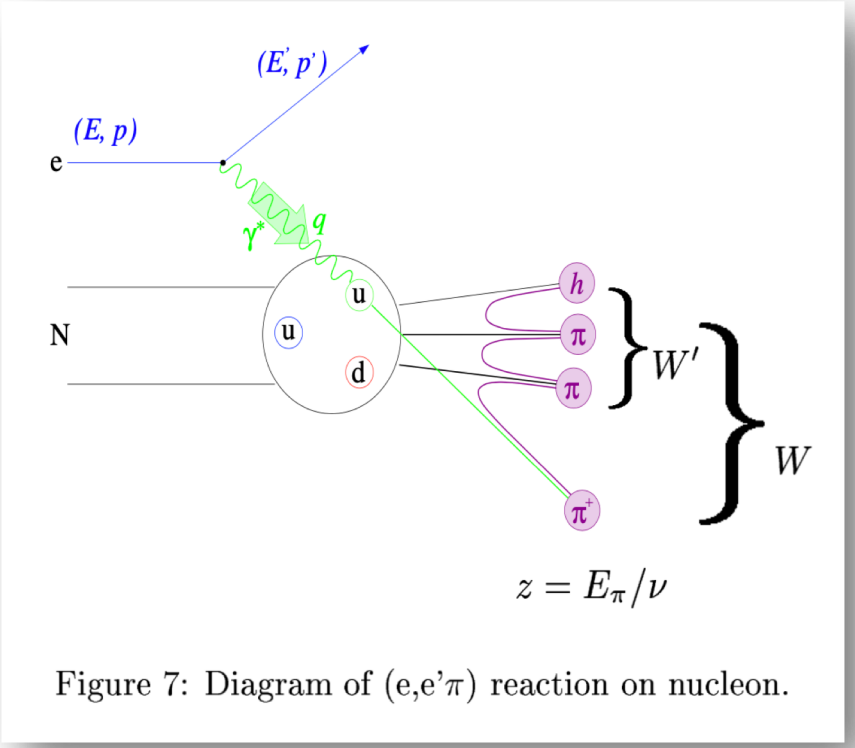
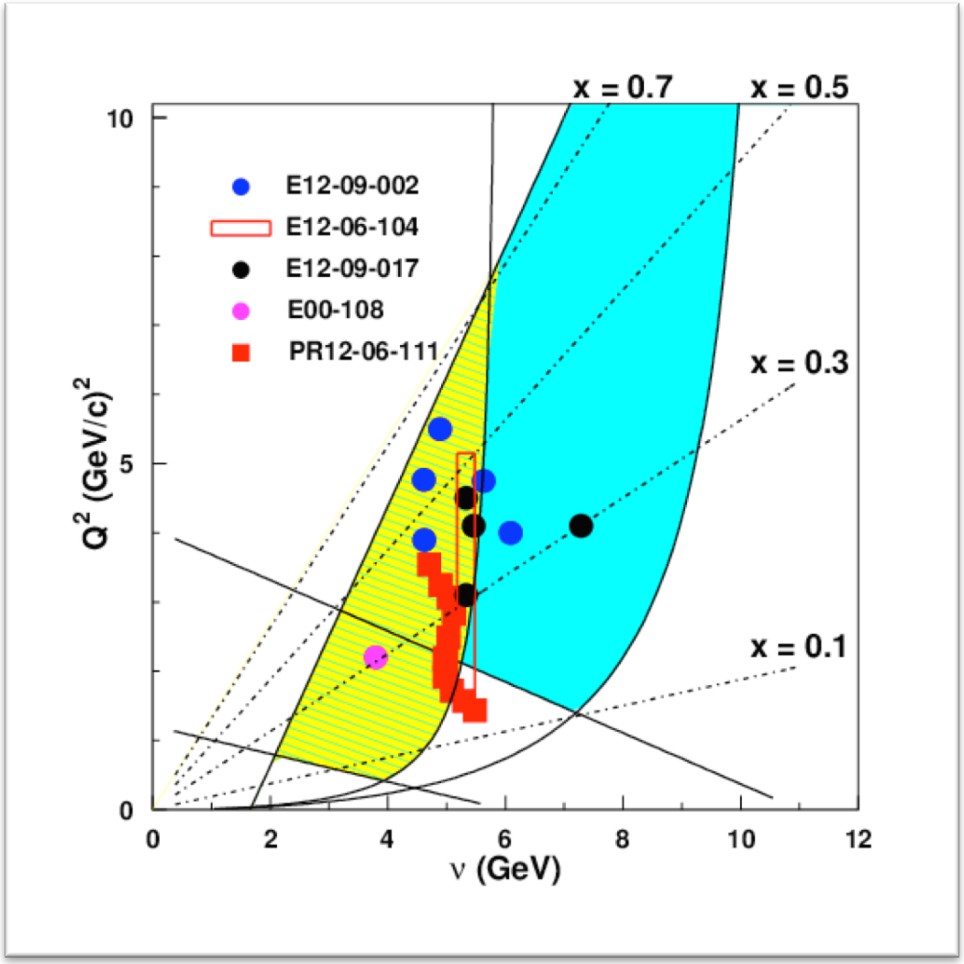


Figure 7: Diagram of (e,e'π) reaction on nucleon.

SIDIS landscape of JLab experiments

- Some opportunistic R_SIDIS
  - kinematics overlap
    - 11 GeV $e-$ beam
    - $0.1 < x < 0.48$
    - $1.2 < Q^2 < 4.3$ (GeV/c)^2
    - $0.3 < z < 0.7$
  - Same targets (LH2 and LD2)
  - Standard detector package (HMS and SHMS)
- Will avoid considerable overhead due to the above mentioned factors



Previously proposed kinematics

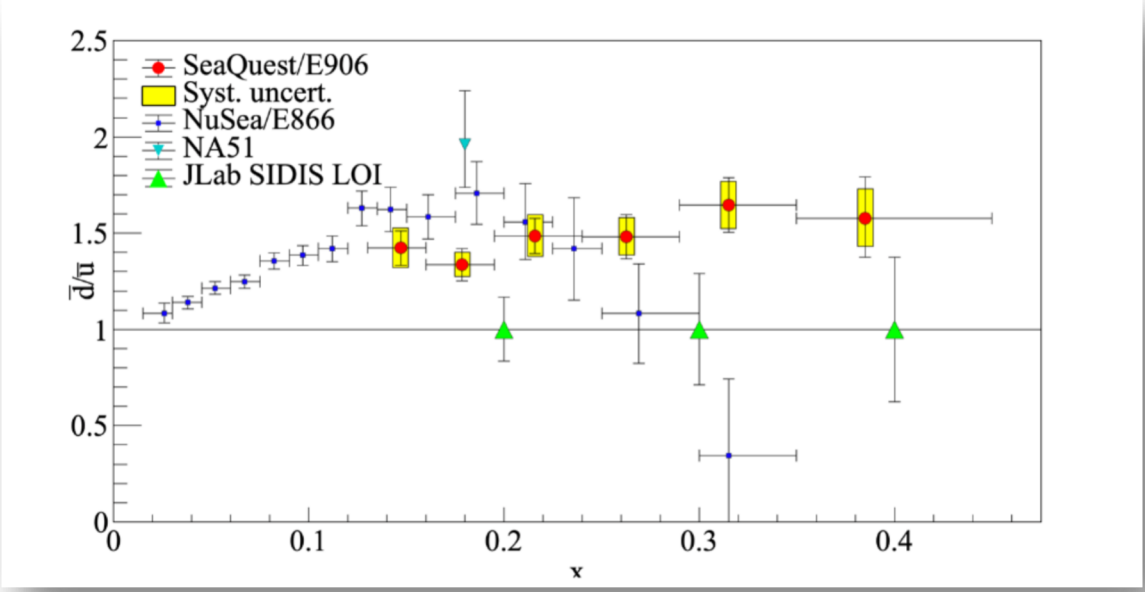
- Region of kinematics where factorization is believed to work well
- Emphasis of impactful kinematic x regions will be worked out for the full proposal

x	Q^2 (GeV^2/c^2)	z	W (GeV)	W' (GeV)
0.139	1.43	0.415	3.12	2.43
0.158	1.57	0.431	3.04	2.34
0.180	1.72	0.448	2.96	2.26
0.206	1.92	0.452	2.88	2.19
0.235	2.19	0.458	2.82	2.14
0.264	2.49	0.456	2.79	2.12
0.294	2.83	0.451	2.76	2.10
0.324	3.06	0.459	2.69	2.04
0.353	3.24	0.462	2.61	1.98
0.401	3.54	0.473	2.48	1.87

Grain of salt

Preliminary projections exercise

- As an exercise we considered 17 PAC days total at x = 0.2, 0.3 and 0.4
- We would need more statistical precision in the high-x region in order to resolve the tension between NuSea and SeaQuest
- Emphasis on impactful kinematic regions will be worked out for the full proposal



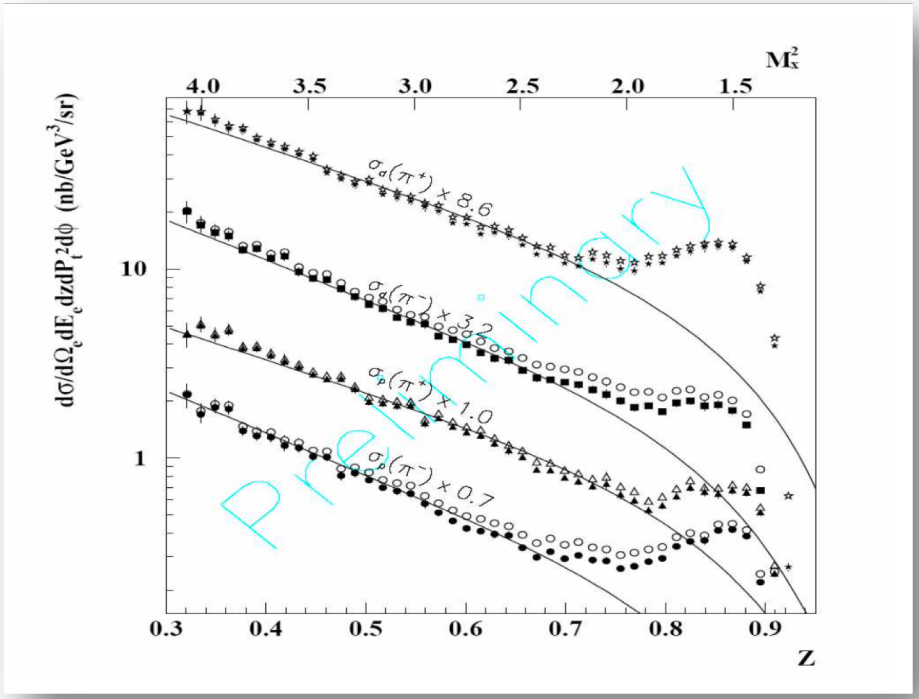
PRELIMINARY EXERCISE PROJECTIONS

Summary

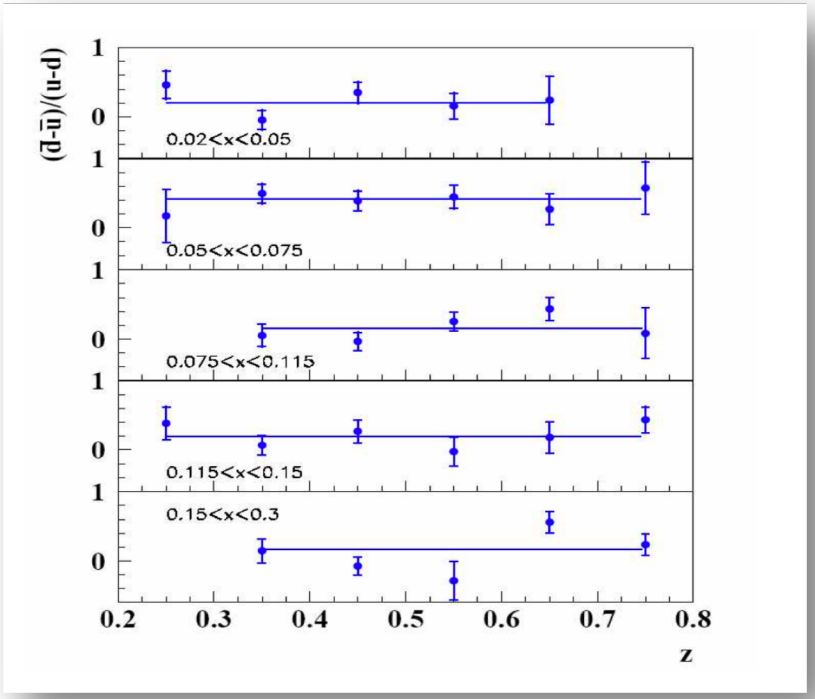
- This LOI aims at realizing deferred PR12-06-111
- Charged pion yield ratios have sensitivity to the light quark flavor asymmetry in the nucleon sea
- After results from various experiments (HERMES, NuSea and SeaQuest), a high statistics data sample with good control over systematic uncertainties using SIDIS reactions will provide an independent study of the region of overlap with previous Drell-Yan measurements establishing process independence
- TAC reports (theory and experiment) received this *morning* have given a positive review and extended support for this measurement

BACK UP

Factorization tests

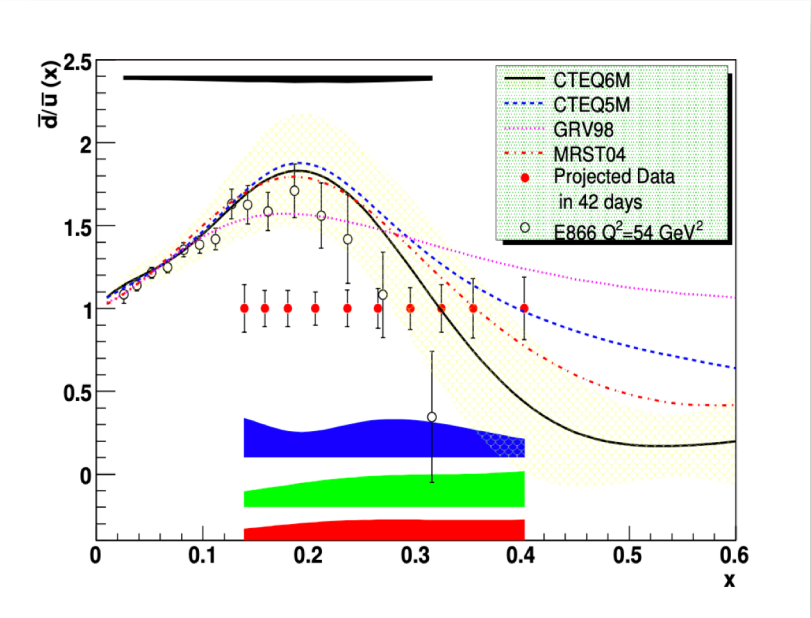


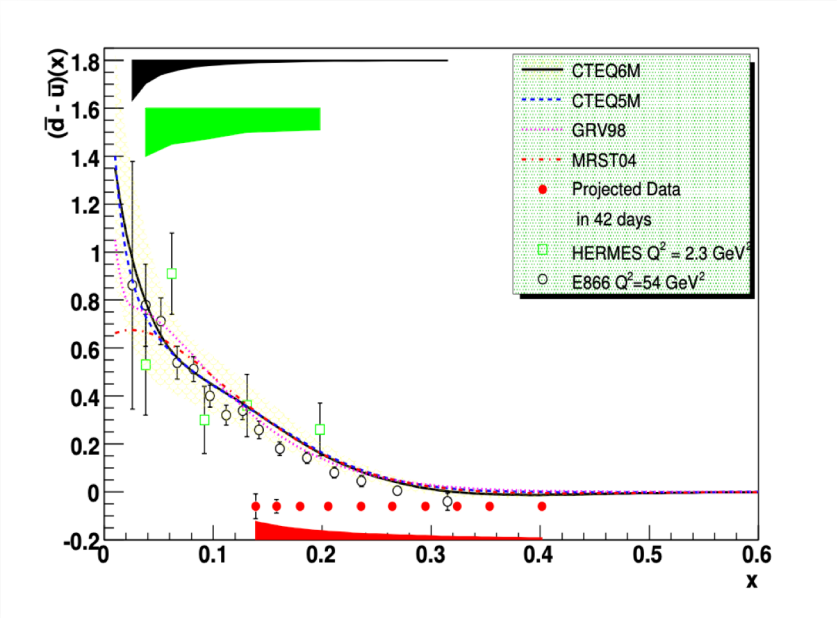
Jlab 6 GeV kinematics



HERMES experiment

Projections of deferred PR12-06-111





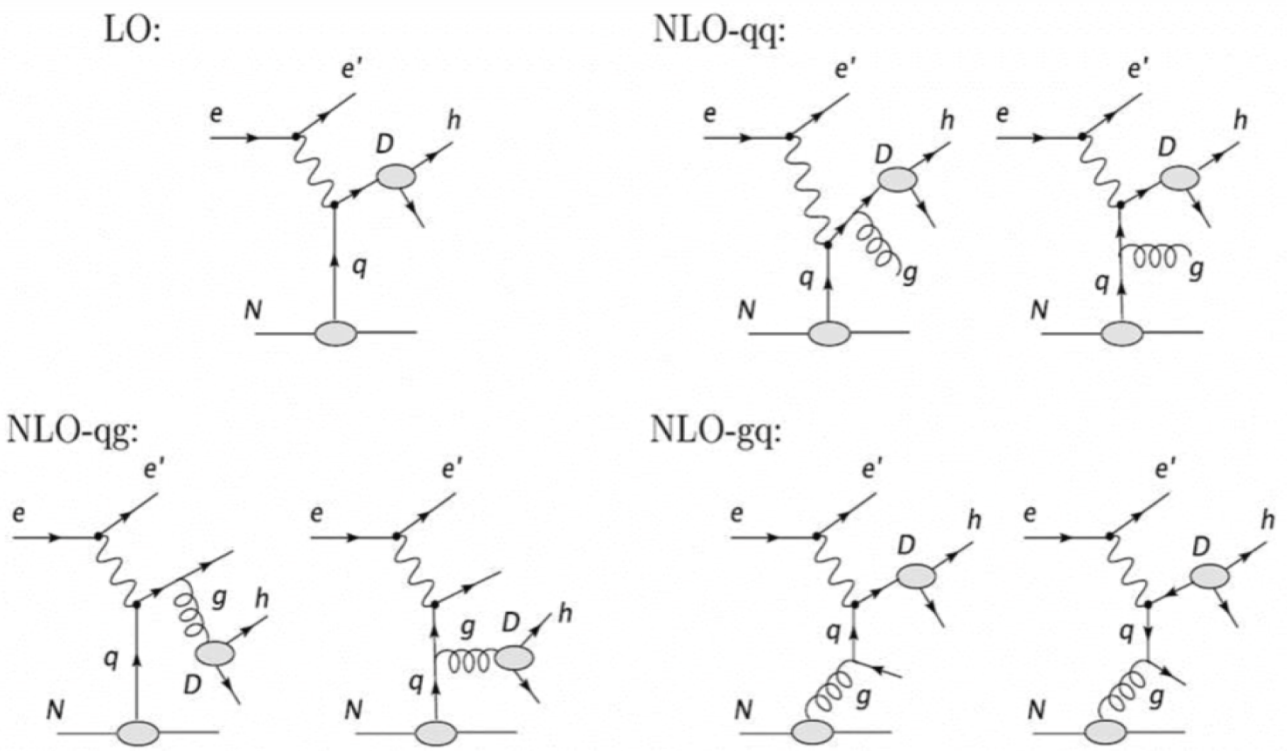


Figure 3: Semi-inclusive deep inelastic scattering diagrams at leading order (LO) and the next-to-leading order (NLO).