科研写作浅谈

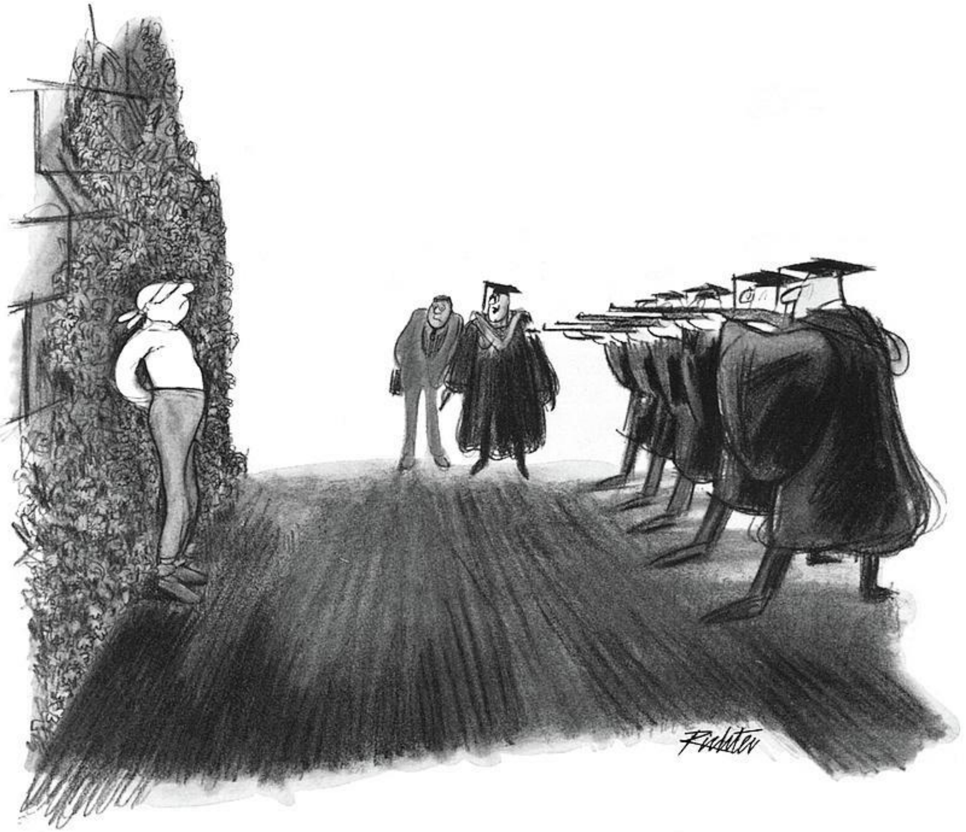
李 阳

中国科学技术大学近代物理系

严济慈英才班科研创新实践课

科研写作： Publish or perish

- 科研论文是传播知识的主要途径： 研究人员通过阅读和引用他人的工作，了解最新的研究进展，并在此基础上开展进一步的研究
- 科研写作对研究人员的职业发展至关重要
- 科研论文既是对研究工作的总结反思，也是对其包装推销，归根结底是一种交流的手段



"It's publish or perish, and he hasn't published."

科研论文：“八股文”

科研论文是一种正式的写作风格，旨在通过逻辑推理和证据支持来传达研究发现和理论，其特点包括：

- **采用结构化的格式：**
  - 标题、作者信息、摘要、引言、方法、结果、讨论、总结、致谢、参考文献、附录等
- **符合一般学术规范：**
  - 理论推导正确、数据处理规范
  - 逻辑推理完整、证据支持充分
  - 结果描述准确、总结讨论深入
  - 参考文献引用充分恰当

科研论文：“八股文”

- **写作风格专业正式**
  - 立场客观
  - 用词准确
  - 行文流畅
  - 语气克制
- **恪守学术诚信**
  - 避免学术剽窃
  - 避免造假
  - 避免其他学术不端行为

如何上手论文写作

模版法：

- 第一次写作可以找一篇类似的文章作为“模版”，学习科技写作技巧，但是注意不可抄袭!

“以结果为中心”写作方法：

- 首先确定文章最重要的结果（图、公式、表）
- 其次将这些结果描述清楚
- 最后围绕这些结果撰写前因后果

PHYSICAL REVIEW C **110**, 065201 (2024)

Flavor asymmetry from the nonperturbative nucleon sea

Yihan Duan,[1] Siqi Xu,[2,3,4] Shan Cheng,[5] Xingbo Zhao,[2,3,6] Yang Li,[1,7,*] and James P. Vary[4]

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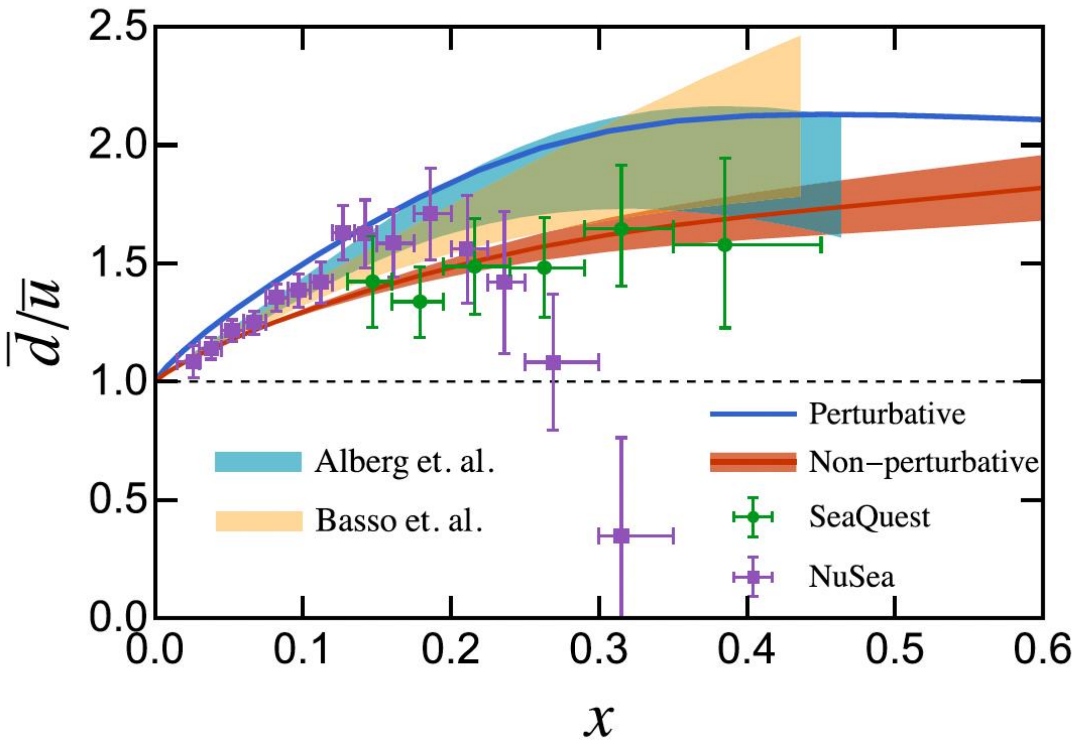

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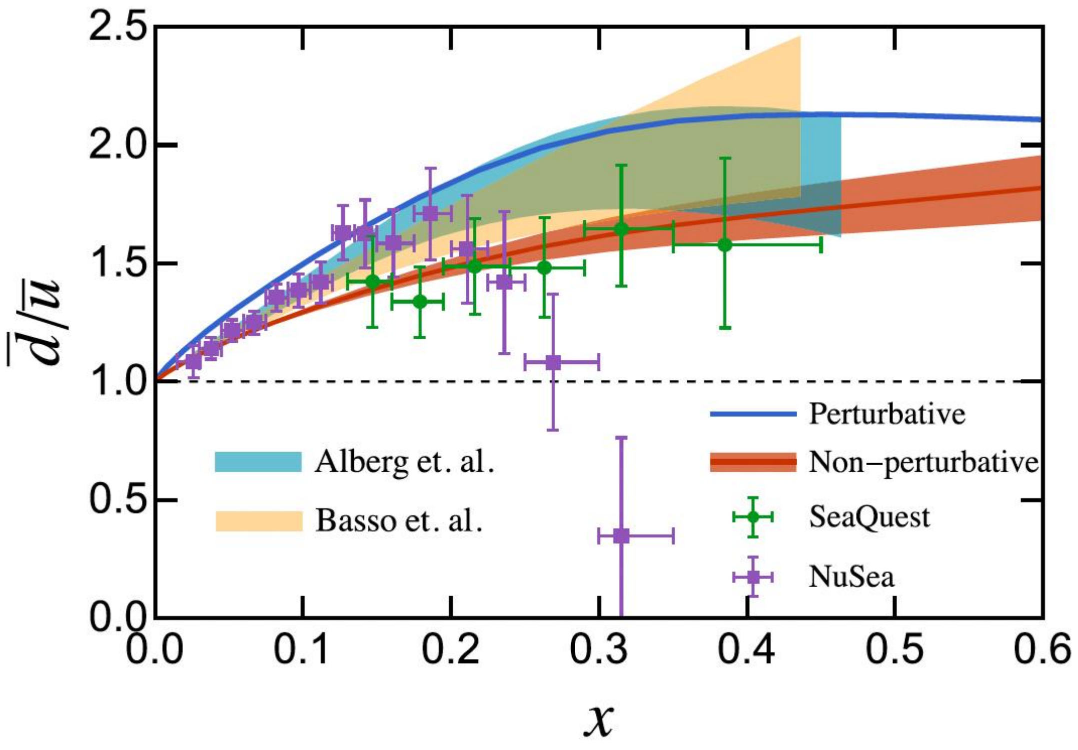
- **其次将这些结果描述清楚**
  - 说明文字(caption)：简约(concise)但自立(self-contained)
  - 正文(main texts)：足够支持文章论点
- 最后围绕这些结果撰写前因后果



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the nonperturbative nucleon sea

Xingbo Zhao,[2,3,6] Yang Li,[1,7,*] and James P. Vary[4]

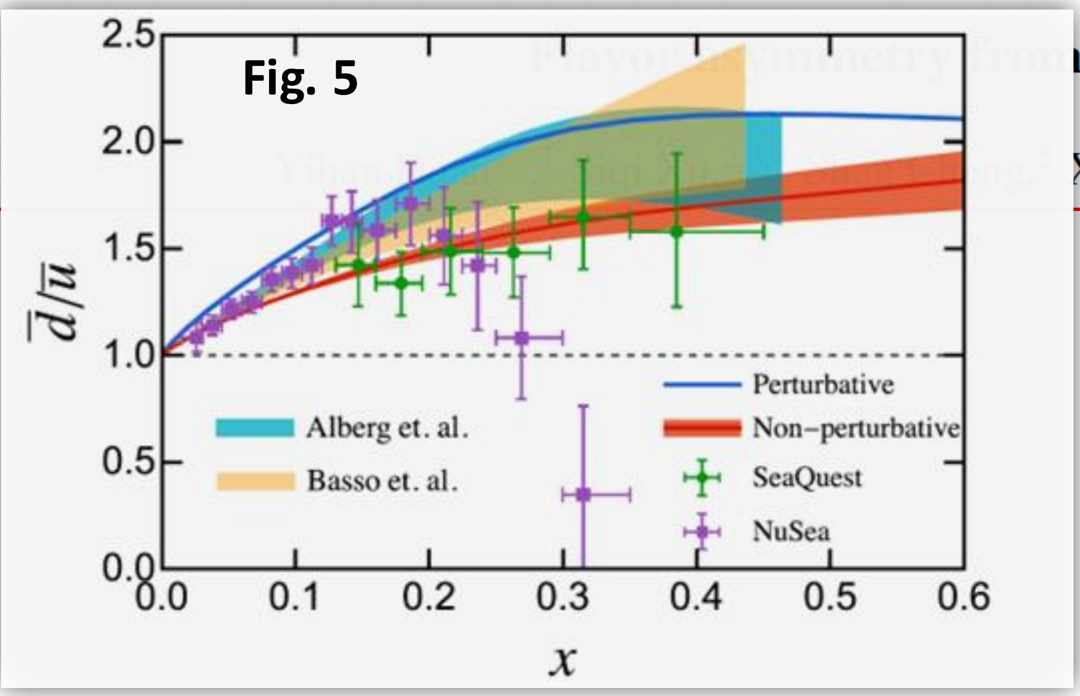

FIG. 5. Flavor asymmetry of the nucleon sea: (top) $\bar{d} - \bar{u}$; (bottom) $\bar{d}/\bar{u}$ from the perturbative, and nonperturbative solutions of a pion cloud model with scalar type interactions in comparison with available experimental data from NuSea/E866 [13–15] and SeaQuest/E906 [7,9] at the scale $Q^2 = 25.5\ \mathrm{GeV}^2$. The nonperturbative result is obtained with a Fock-space truncation up to four-body (one baryon plus up to three pions). The difference between the results with three-body and four-body truncations are shown as bands to indicate the convergence of the Fock-space expansion. Results from the pion cloud model with light-cone perturbation theory by Alberg *et al.* [47] and from the statistical model by Basso *et al.* [39] are also shown for comparison.

图表的说明文字(caption)：

- 对图中的重要元素做客观描述
- 对图表的重要信息，如数据来源、参数选择等，作恰当的补充

Flavor asymmetry from the nonperturbative nucleon sea

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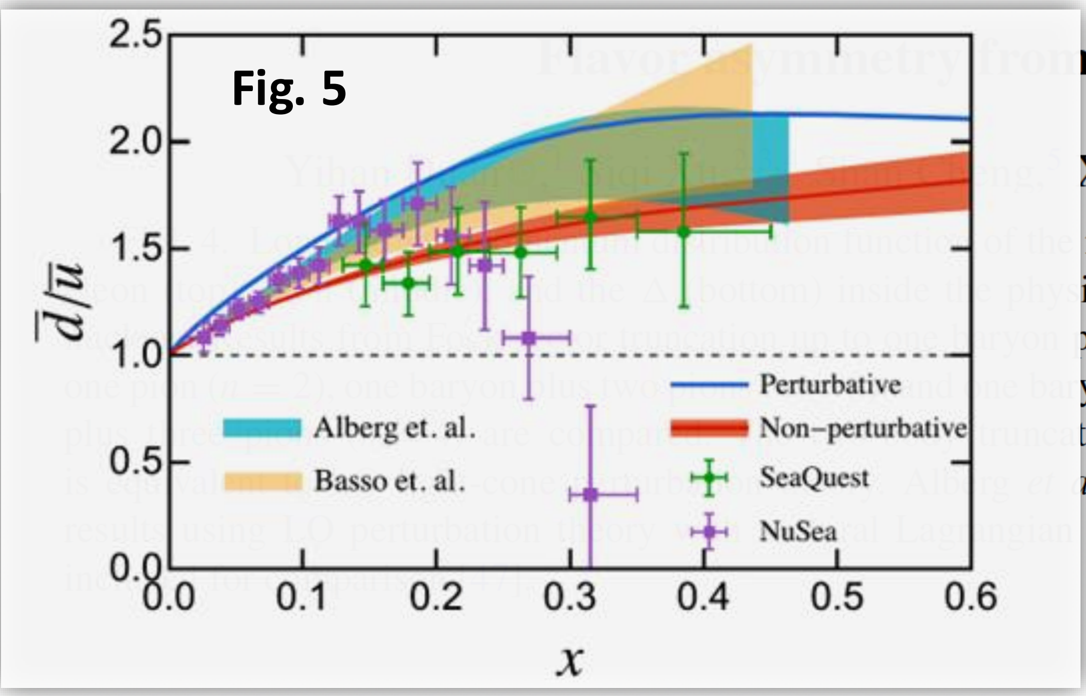

图表的正文描述：

- 客观地描述、分析、总结
- 结果要能够支持文章结论

Figure 5 shows the flavor asymmetry of the "scalar nucleon" sea from this theory along with available experimental data at the scale $Q^2 = 25.5\ \mathrm{GeV}^2$. Results from the pion cloud model by Alberg *et al.* [47] and from the statistical model by Basso *et al.* [39] are also shown for comparison. While perturbative and nonperturbative results for $\bar{d} - \bar{u}$ are close to each other, their difference in $\bar{d}/\bar{u}$ is moderately large, which signifies the high Fock sector contributions in the nonperturbative regime especially at large x. Within the same theory, our three- (one baryon plus up to two pions) and four-body (one baryon plus up to three pions) truncation results show a good convergence pattern as seen in Fig. 4. However, these results are different from the two-body truncation results. The flavor asymmetry results exhibit significant sensitivity to the two-body versus four-body truncation, as shown in Fig. 5, which signals important nonperturbative effects originating from the multipion sea contributions.

描述

比较、分析

总结

Finally, as a consistency check, Fig. 6 shows the quark-antiquark asymmetry $d(x)$ vs $\bar{d}(x)$ obtained from this model using the nonperturbative solutions. The CT18 NNLO results are shown for comparison [92].

PHYSICAL REVIEW C 110, 065201 (2024)

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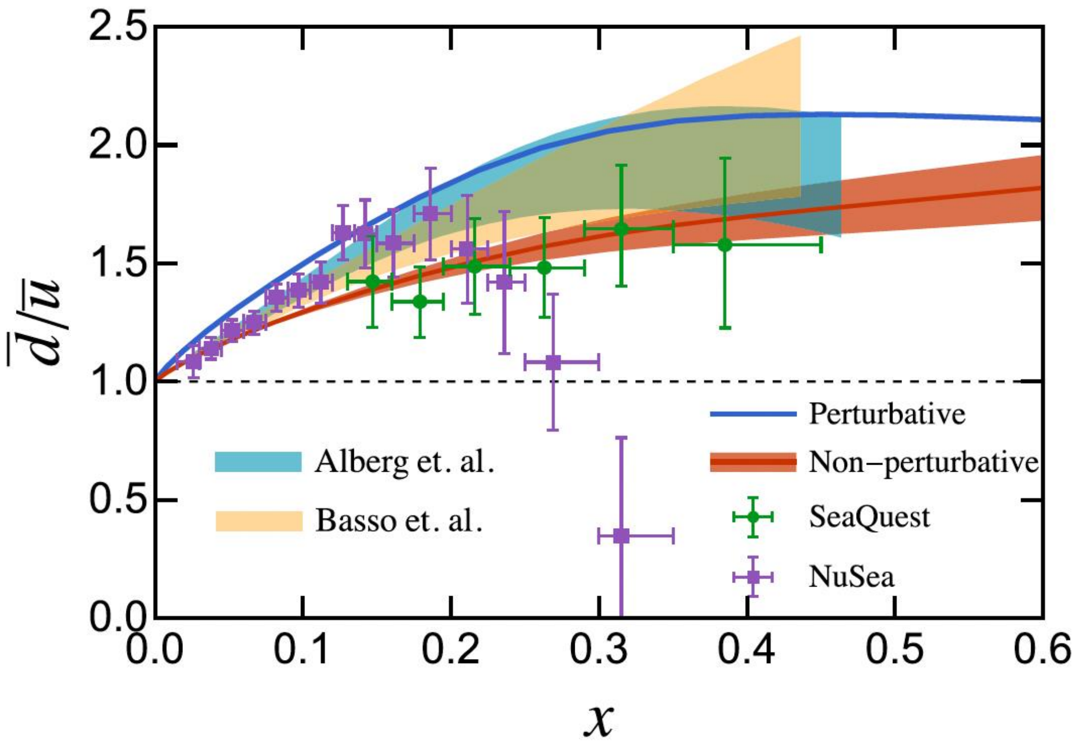
  - 每一个结果是如何得到的；
  - 引用或对比的结果有哪些特征；
  - 不同结果之间该如何比较（符合程度、趋势、极限值、形状等）
  - 不同图表之间按照逻辑层次安排



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The PDF describes the probability of finding a collinear parton with fractional momentum x inside the proton. In analogy to the QCD definition, we introduce an LMDF as [86]

$$f_{B\pi}(x) = \frac{k^+}{2}\int \mathrm{d}z^- e^{\frac{i}{2}xp^+z^-} \times \langle p|\bar{B}\left(-\frac{z}{2}\right)B\left(\frac{z}{2}\right)|p\rangle\Big|_{z^+=z_\perp=0}, \tag{3}$$

where $x = k^+/p^+$ is the longitudinal momentum fraction of the baryon B inside the physical nucleon, $B = N, \Delta$. This expression is diagrammatically shown in Fig. 2. In the light-front wave-function representation [87],

$$f(x) = f_1(x) + f_2(x) + \cdots, \tag{4}$$

where the n-body contribution is (the nth particle is taken as the baryon)

$$f_n(x) = \frac{1}{(n-1)!}\prod_{i=1}^{n}\int \frac{\mathrm{d}x_i \mathrm{d}^2k_{i\perp}}{(2\pi)^3 2x_i} 2(2\pi)^3\delta(x - x_n) \times \delta(x_1 + \cdots + x_n - 1)\delta^2(\vec{k}_{1\perp} + \cdots + \vec{k}_{n\perp}) \times |\psi_n(x_1, \vec{k}_{1\perp}, x_2, \vec{k}_{2\perp}, \ldots, x_n, \vec{k}_{n\perp})|^2. \tag{5}$$

Since the scalar theory is super-renormalizable, the "factorization scale" of the LMDFs can be taken to infinity [88]. The PDFs of the physical nucleon are obtained from convoluting the LMDF with the PDFs of its constituent hadrons, as shown in Eq. (1). We adopt the same pion and bare proton PDFs as Alberg *et al.* at a scale $\mu^2 = 25.5$ GeV^2 [47,89–91].

PHYSICAL REVIEW C **110**, 06520

Flavor asymmetry from the nonperturbat

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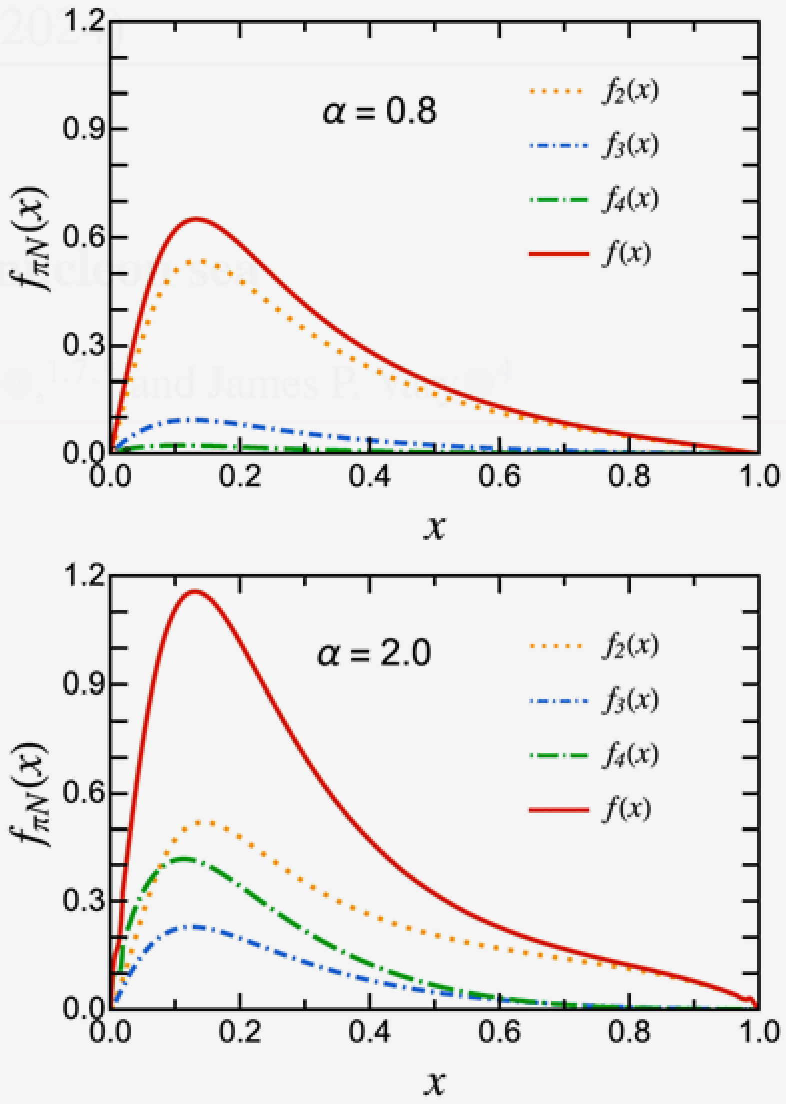

FIG. 3. Longitudinal momentum distribution function of the pion inside the physical scalar nucleon for coupling (top) $\alpha = 0.8$ and (bottom) $\alpha = 2.0$. The coupling to Δ is turned off in both cases, i.e., $g_\Delta = 0$. The contributions from the multipion Fock sectors are also shown in each panel. For $\alpha = 2.0$ there are significant three- and four-body contributions at the large longitudinal momentum fraction x.

科研论文的结构：逻辑顺序

1. 标题（Title）、作者信息（Authors）、摘要（Abstract）、引言（Introduction）、文献综述（Literature Review）
2. 研究方法（Methodology）、结果（Results）、讨论（Discussion）、结论（Conclusion）
3. 致谢（Acknowledgements）、参考文献（References）、附录（Appendices）

科研论文的结构：写作顺序

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研究方法、结果、讨论与结论

- **研究方法（Methodology）**：详细描述研究设计、数据收集和分析方法。确保研究的可重复性和可靠性。
- **结果（Results）**：呈现研究的主要发现，通常以图表和文字描述的形式展示数据。
- **讨论（Discussion）**：解释结果的意义，讨论其与已有研究的关系，分析研究的局限性和未来研究的方向。有时候会和结果或结论放在一起。
- **结论（Conclusion）**：总结研究的主要发现和贡献，强调研究的重要性和实际应用价值，展望研究前景和下一步工作。

研究方法、结果、讨论与结论

前因

后果

- **研究方法（Methodology）**：详细描述研究设计、数据收集和分析方法。确保研究的可重复性和可靠性。
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标题、摘要、引言、文献综述、结论

- **标题（Title）**：简明扼要地概括论文的核心内容，吸引读者的注意。
- **摘要（Abstract）**：提供论文的简要概述，包括研究目的、方法、主要结果和结论。帮助读者快速了解论文的主要内容。
- **引言（Introduction）**：介绍研究背景、问题陈述、研究目的和意义。引导读者进入研究主题，并说明研究的必要性。
- **文献综述（Literature Review）**：回顾相关领域的已有研究，指出研究空白和争议点。为自己的研究提供理论基础和支持。文献综述常常包含在引言里。

标题：简明扼要地概括论文的核心内容

- 如实、准确地概括核心内容，突出论文创新点与特色
- 既要避免使用过于笼统的词汇，又要避免不必要的技术细节。**克制使用主观、夸张和泛滥的词汇**，例如first、great、best、revolutionary、novel，用词与风格可参考领域内其他文章
- 可以适当“活泼”一些
  - Sea quark flavor asymmetry from the nonperturbative calculation of pion cloud model → Flavor asymmetry from the nonperturbative nucleon sea
  - Light-front Hamiltonian approach to electric dipole transitions of charmonia → Shedding light on charmonia

摘要与总结：最后写/修改

- 摘要：提供论文的简要概述，包括研究目的、方法、主要结果和结论。帮助读者快速了解论文的主要内容。
- 总结：论文做了什么，即用什么方法、研究什么问题、得到什么结论，有什么意义。
- 整个文章要按照一个故事来写，摘要和总结要呼应这个故事，其中摘要是这个故事的高度概括，总结是其强化和发掘

想法

输入： 实验测量、理论构建、其他启发，……
输出： 问题、项目

分析

输入： 参考文献、笔记、书、GPT/SE/Wiki……
输出： 研究笔记

计算

输入： 祖传代码、超算+数值方法+数值库……
输出： 代码+文档、数据

发表

输入： 结果、讨论
输出： 文章、报告

SeaQuest, *Nature* (2021) 测量了海夸克味不对称性; 大会报告
→ Miller et al. 派介子云模型 (微扰)
→ **非微扰效应在海夸克味不对称性中起到什么样的作用?**

根据Alberg & Miller 2019, 以及Li et al. 2015, 推导新的表达式

利用之前发展的数值方法求解方程，计算结果

Duan et al., Flavor asymmetry from the non-perturbative nucleon sea, PRC 110, 065201 (2024); [arXiv: 2404.07755]

科学问题：非微扰效应在海夸克味不对称性中起到什么样的作用?

ABSTRACT

We demonstrate, in the context of a scalar version of the chiral effective-field theory, that the multisea quark contribution to the nucleon is significant and highly nontrivial, in sharp contrast with the prediction of perturbation theory. The nonperturbative calculation is performed in the Fock sector dependent renormalization scheme on the light front, in which the nonperturbative renormalization is incorporated. The calculation suggests that a fully nonperturbative calculation of the chiral EFT is needed to obtain a robust result to be compared with the recent experimental measurement of flavor asymmetry in the proton.

IV. SUMMARY AND OUTLOOK

We investigated the nonperturbative effects of the nucleon sea within a scalar version of the pion cloud model. The nonperturbative dynamics is generated by the light-front Schrödinger equation with a systematic Fock sector expansion. Within this simple model, the convergence is observed already with three-body contributions (one baryon plus two pions) though we proceed to include four-body contributions as well. We show that the obtained longitudinal momentum distributions from the nonperturbative solutions are considerably different from those obtained from a leading order light-front perturbation theory. The difference can be attributed to the multipion dynamics, which are the sea contributions within the pion cloud model. We also applied the solutions to describe the nucleon flavor asymmetry using the pion cloud model. While both the perturbative and nonperturbative sea can describe the $\bar{d} - \bar{u}$ data well, the nonperturbative nucleon sea can describe the $\bar{d}/\bar{u}$ data better for $x \gtrsim 0.1$. These comparisons between the perturbative and nonperturbative pion clouds indicates that the nonperturbative effects are important and may help improve the model. Indeed, part of the multipion sea can be taken into account by evolving the sea, which may help to explain the improved agreement in their updated prediction [47]. Nevertheless, a full investigation of the nonperturbative sea requires a nonperturbative calculation of chiral effective-field theory [85], which is a natural next step.

引言：讲故事

- **引言（Introduction）**：介绍研究背景、问题陈述、研究目的和意义。引导读者进入研究主题，并说明研究的必要性。文献综述（Literature Review）是其中重要的组成部分。
- 通过引言讲好一个开头，引言的开始是一个诱人的目标或问题（破题），引言的结尾要导向论文研究结论（承题）。

I. INTRODUCTION

Understanding the sea-quark contribution of hadrons is of fundamental importance [1–4]. It not only provides a sharper view of the fundamental structure of matter [5] but also serves as a tool for detecting physics beyond the standard model [6]. Recently, the SeaQuest/E906 experiment published their first measurement of the flavor asymmetry $\bar{d}/\bar{u}$ of the proton sea from the muon pair production within the Drell-Yan process of high-energy proton-ion collisions [7–9], challenging the previous measurement by the NuSea/E866 experiment at large momentum fraction $x \gtrsim 0.3$ [10–15]. In particular, the NuSea/E866 experiment predicted that $\bar{d}/\bar{u}$ dips below unity at $x \approx 0.3$, which is contrary to the SeaQuest/E906 measurement. The tension between these experimental measurements calls for a better understanding from theories, including global analysis [6,16–21]. It was generally believed that the flavor asymmetry of the proton encodes the nonperturbative physics of quantum chromodynamics (QCD), making it a particular challenge for calculations from first principles [22,23]. The flavor asymmetry is also related to other sea quark asymmetries, such as the nucleon strangeness as well as the intrinsic charm [24].

研究背景
（破题）

→ 切入点，一般从大的研究领域入手

→ 提出具体研究话题，提出科学问题

→ 对科学问题的分析和话题的引导

文献综述

- 回顾相关领域的已有研究，指出研究空白和争议点。为自己的研究提供理论基础和支持。
- 文献综述要全面，可以从重要参考文献以及相关综述入手，进行正向和反向检索
- 综述（Reviews）是快速了解问题研究现状的绝佳手段
- 对于相关文献要进行总结、分析，以支持自己的研究故事。

PHYSICAL REVIEW D **105**, 114054 (2022)

Pions in proton structure and everywhere else

Mary Alberg,[1,2,*] Lucas Ehinger,[1,†] and Gerald A. Miller[2,‡]

Pions in proton structure and everywhere else

#1

Mary Alberg (Seattle U. and Washington U., Seattle), Lucas Ehinger (Seattle U.), Gerald A. Miller (Washington U., Seattle) (Aug 27, 2021)

Published in: *Phys.Rev.D* 105 (2022) 11, 114054 • e-Print: 2108.12439 [nucl-th]

pdf DOI cite claim reference search 6 citations

[1] Flavor asymmetry of anti-quark distributions in the nucleon
S. Kumano (Saga U., Japan and Washington U., Seattle)
Phys.Rept. 303 (1998) 183-257 • e-Print: hep-ph/9702367 • DOI: 10.1016/S0370-1573(98)00016-7

[2] Flavor asymmetry of light quarks in the nucleon sea
Gerald T. Garvey (Los Alamos), Jen-Chieh Peng (Los Alamos)
Prog.Part.Nucl.Phys. 47 (2001) 203-243 • e-Print: nucl-ex/0109010 • DOI: 10.1016/S0146-6410(01)00155-

[3] Flavor Structure of the Nucleon Sea
Wen-Chen Chang (Taiwan, Inst. Phys.), Jen-Chieh Peng (Illinois U., Urbana)
Prog.Part.Nucl.Phys. 79 (2014) 95-135 • e-Print: 1406.1260 • DOI: 10.1016/j.ppnp.2014.08.002

[4] The sea of quarks and antiquarks in the nucleon
D.F. Geesaman (Argonne), P.E. Reimer (Argonne)
Rept.Prog.Phys. 82 (2019) 4, 046301 • e-Print: 1812.10372 • DOI: 10.1088/1361-6633/ab05a7

#1 Probing nonperturbative transverse momentum dependent PDFs with chiral perturbation theory: the $\bar{d} - \bar{u}$ asymmetry
Marston Copeland (Duke U.), Thomas Mehen (Duke U.) (Dec 10, 2024)
e-Print: 2412.07717 [hep-ph]
pdf cite claim reference search 0 citations

#2 Flavor asymmetry from the nonperturbative nucleon sea
Yihan Duan (Hefei, CUST), Siqi Xu (Lanzhou, Inst. Modern Phys. and Beijing, GUCAS and Iowa State U.), Shan Cheng (Hunan U.), Xingbo Zhao (Lanzhou, Inst. Modern Phys. and Beijing, GUCAS), Yang Li (Hefei, CUST and USTC, Hefei and PCFT, Hefei) et al. (Apr 11, 2024)
Published in: *Phys.Rev.C* 110 (2024) 6, 065201 • e-Print: 2404.07755 [hep-ph]
pdf DOI cite claim reference search 1 citation

#3 Probing parton distributions in proton using Drell-Yan and charmonium production in p + p and p + d interactions with 120 GeV proton beam at Fermilab
Ching Him Leung (Illinois U., Urbana (main)) (Mar 15, 2024)

文献阅读

- 泛读：题目+摘要+图（结果），了解文章大致做了什么事情
- 粗读：阅读文章的全文，重点了解文章的想法，也就是说，谁用什么方法解决了什么问题（WWW）
- 精读：仔细阅读文章，搞清楚文章思路，与同学、老师讨论，对于重要的文章应该自己去重复结果

Pions in Proton Structure and Everywhere Else

泛读：

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The pion cloud is important in nuclear physics and in a variety of low-energy hadronic phenomena. We argue that it is natural to expect it to also be important in lepton-proton deep inelastic scattering and Drell-Yan studies of proton structure. We compute the necessary consequences of the pion cloud in connection with the recent SeaQuest data. The effects are detailed by using the exact kinematics of the experiment. Good agreement with the measurements is obtained. Thus the universality of pionic effects is understood.

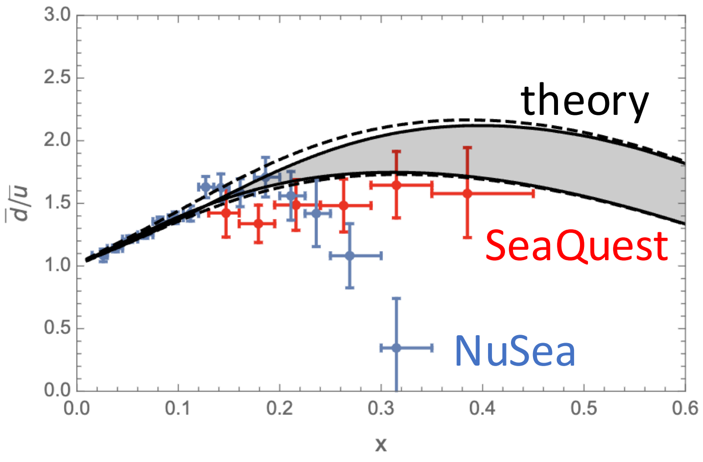

FIG. 5. $\bar{d}(x)/\bar{u}(x)$ Blue symbols from E866 [73]. Red symbols are from SeaQuest [1]. The solid band is computed using minimum and maximum values of the splitting functions shown in Fig. 3 in convolution with ASV or xFitter pion pdfs, plus the bare sea of [53]. All pdfs were evolved to the SeaQuest scale of $Q^2 = 25.5$ GeV^2. The dashed lines include the effects of varying the bare sea by a factor of 0.75 or 1.25.

- 模型与新的实验测量 (SeaQuest)符合的更好；
- 模型与实验结果相比偏高

are unalterable consequences of our approach. Significantly changing any of the input parameters would cause severe disagreements with other areas of nuclear physics, and would be tantamount to changing the model. If the high$-x$ E866 results were to be confirmed by the SeaQuest experiment, the model would be ruled out."

It turned out that our predictions were in agreement with the SeaQuest data, even though we did not know the exact values of the kinematics. The present paper updates the earlier calculation by including evolution of the bare nucleon sea and using the now known SeaQuest kinematics. The present calculations show that

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the vertex function is treated as depending on only three of the four necessary momentum variables. Our formalism resolved both of these problems by using a four-dimensional formalism and by using experimental constraints on the pion-baryon vertex function.

In a light-front formalism the proton wave function can be expressed as a sum of Fock-state components [35–38]. Our hypothesis is that the nonperturbative light-flavor sea originates from the bare nucleon, pion-nucleon (πN) and pion-Delta ($\pi\Delta$) components. The interactions are described by using the relativistic leading-order chiral Lagrangian [39,40]. Displaying the interaction terms to the relevant order in powers of the pion field, we use

手征有效理论

$$\mathcal{L}_{\rm int} = -\frac{g_A}{2f_\pi}\bar{\psi}\gamma_\mu\gamma_5\tau^a\psi\partial_\mu\pi^a - \frac{1}{f_\pi^2}\bar{\psi}\gamma_\mu\tau^a\psi\epsilon^{abc}\pi^b\partial_\mu\pi^c - \frac{g_{\pi N\Delta}}{2M}(\bar{\Delta}^i_\mu g^{\mu\nu}\psi\partial_\nu\pi^i + {\rm H.c.}), \quad (1)$$

手征有效理论是描述强子-强子之间有效相互作用的系统方法

$$|p\rangle = \sqrt{Z}|p\rangle_0 + \sum_{B=N,\Delta}\int d\Omega_{\pi B}|\pi B\rangle\langle\pi B|p\rangle_0, \quad (3)$$

where $\int d\Omega_{\pi B}$ is a phase-space integral [37,38]. In this formalism the pion momentum distributions $f_{\pi B}(y)$, which represent the probability that a nucleon will fluctuate into a pion of light front momentum fraction y and a baryon of light front momentum fraction $1-y$, are squares of wave functions, $|\langle\pi B|\Psi\rangle|^2$ integrated over $k_\perp$.

The Lagrangian of Eq. (1) is incomplete because it is not renormalizable. We tame divergences using a physically motivated set of regulators, depending on four-momenta, that are constrained by data. If chiral symmetry is maintained, one finds that the πN vertex function $g_{\pi N}(t)$ and the nucleon-axial form factor are related by the generalized Goldberger-Treiman relation [43] (obtained with $m_\pi = 0$),

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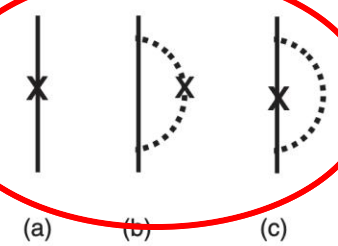
Using $F(k,p,y)$ allows us to obtain a pion-baryon light front wave function. The pion-nucleon component is given by

$$\Psi_{a,{\rm LF}}(k,p,s) = \frac{Mg_A}{2f_\pi(2\pi)^{3/2}}\sqrt{\frac{y}{1-y}}\frac{\bar{u}(p-k)i\gamma^5\tau_a u(p)}{t+\mu^2}F_A(t),$$

$$F_A(t) \equiv \frac{2\Lambda^4}{(\Lambda^2+t+\mu^2)(2\Lambda^2+t+\mu^2)}, \quad (7)$$

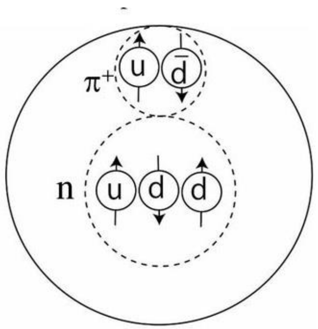
with s and a the spin and isospin labels for the proton. Expanding $F_A(t)$ to first order in t, then comparing the

微扰得到的光锥波函数



派介子云模型

FIG. 2. (a) External interaction, X, with bare nucleon (solid line), (b) External interaction, X, with the pion, (c) External interaction, X, with the intermediate baryon. Here X represents the deep inelastic scattering operator.



Alberg & Miller 基于手征有效理论，利用派介子云模型，结合微扰光锥方法计算了质子海夸克的味道不对称性

致谢、参考文献与附录：最后写

- **致谢（Acknowledgements）**：表达感谢、承认贡献、标注资金来源、技术支持等。那些对研究有重要贡献但未达到作者标准的人应该予以致谢。
- **参考文献（References）**：列出论文中引用的所有文献，确保学术诚信，方便读者查阅相关资料。要注意引用格式以及引用的恰当性与充分性。
- **附录（Appendices）**：可选，提供补充材料，如数据表、问卷、计算过程等，不适合放在正文中的内容。

几点提示

- 第一次写作可以找一篇类似的文章作为“模版”，学习写作风格和写作技巧，但是注意不可抄袭！
- 在研究过程中要随时积累，撰写研究笔记，这些可以作为论文素材。
- 多读文献，了解领域研究现状——读书破万卷，下笔如有神。
- 写作是一个过程，好的论文需要与导师一起打磨。
- 多讲报告，做学术报告可以帮助我们凝练科学问题、升华物理结果，也可以帮助宣传自己的工作以及聆听专家反馈，接受同行的批评指教。

谢 谢!