科研浅谈

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

目的

- 创新实践课的目的是帮助大家了解科研、进入科研以及更好地做好科研工作
- 创新实践课的目的不是帮助大家做科研
  - 科研不是做题，没有明确答案，甚至不一定有答案
  - 科研顺利的同学可以分享经验
  - 科研不顺的同学可以获得帮助
  - 外在的过程把握、节点门控

课程规划

- 集中讲座
  - 科研和科研方法简介
  - 学科和研究方向简介
- 分组实践
  - 联系课题组，参与实际科研过程
  - 定期分组沟通交流进展
  - 科研技能的培养，如学术报告、综述阅读、文章阅读等
- 课程报告

为什么要做科研？

- 科研报国、科教兴国
- 感兴趣：探索感兴趣的方向
- 长见识：理实交融、学以致用，摆脱做题模式
- 学本领：学习课本上学习不到的
- 刷简历：发文章、申请藤校
- 随大流：大家都进实验室
- 其他：蹭网、蹭空调，赚钱，……

科研与上课

不同的学习阶段，需要不同的学习方法

	高中	大学	研究生
知识面	宽	较宽	窄
知识深度	较浅	较深	深
知识系统性	不成体系	体系性较强	体系不唯一
知识获取	以教师为中心: 听课+作业+考试	以学生为中心: 听课+讨论+项目+报告	以研究为中心: 自学+上手做+论文+演讲
学习方法	做题	理解	创造

《礼记 • 学记》:君子之教，喻也。

科研与上课

- 美国Research Experiences for Undergraduates (REU) program，尤其是对于STEM
- 大学生研究计划（大研）
- 本科毕业论文（毕设）
- 2023年，国家自然科学基金委首次将本科生纳入其人才资助体系，科大等8所高校的优秀本科生被推荐参加基金委青年学生基础研究项目选拔面试，资助强度10万元

本科生卷GPA、研究生卷科研 → 低年级卷GPA、高年级卷科研!

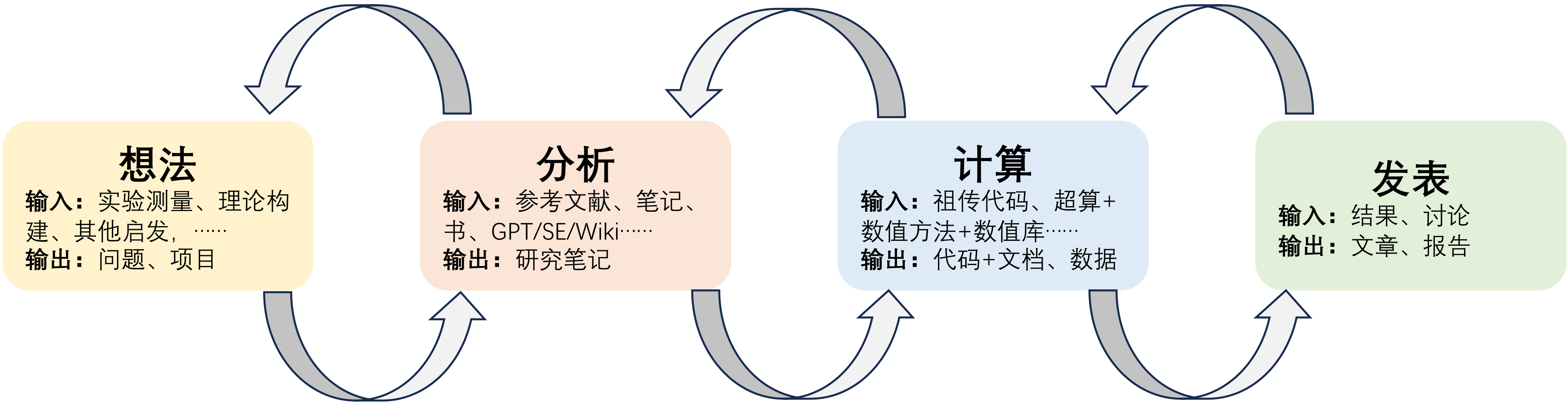
什么是科研 (Research)

没有确定答案，但一般涉及到下面几个要素：

- 文献阅读和文献调研
- 提出问题
- 解决问题
- 发表文章
- 学术交流

如何做科研

- 如何做科研并没有固定范式



项目式科研 (Project based research)

- 项目式科研是一种有效的科研组织方式，尤其是对于新手来说：
  - 确定研究方向、范围和目标 (What)
  - 确定可能用到的方法和工具 (hoW)
  - 确定团队和分工 (Who)
  - 科研过程的跟进、交流和指导
  - 文章发表项目结束

（前三项）} 确定研究项目 (project)

- 项目式科研一般应当以文章发表为目标
  - 科研本身并不限于文章发表，但是将文章作为一个目标，可以较好划分科研项目的范围，避免研究项目失去焦点，无限拖沓下去
- 项目式科研便于协作和管理
  - 对于学生来说，是一份与导师签订的非正式协议，对于双方来说都是一种约束，也是一种合作共赢

我的科研看板(Kanban)

IDEAS		RESEARCH			PUBLICATION				TALKS		JUNKYARD
Inception	Incubator	Derivation	Numerics	Visualizations	Draft	Revise	Review	Published	Todo	Done	
		Xu: Charmonium form factor									
								Xu: Bottomonium form factor			
					Li & Tuchin: quarkonium in B						
				Wen: pion structures							
	Li & Vary: BLFQ to quark										

项目负责人

研究内容

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)
→ <u>非微扰效应在海夸克味不对称性中起到什么样的作用？</u>

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, arXiv: 2404.07755 [hep-ph]; PRC in print

研究想法 (Idea)

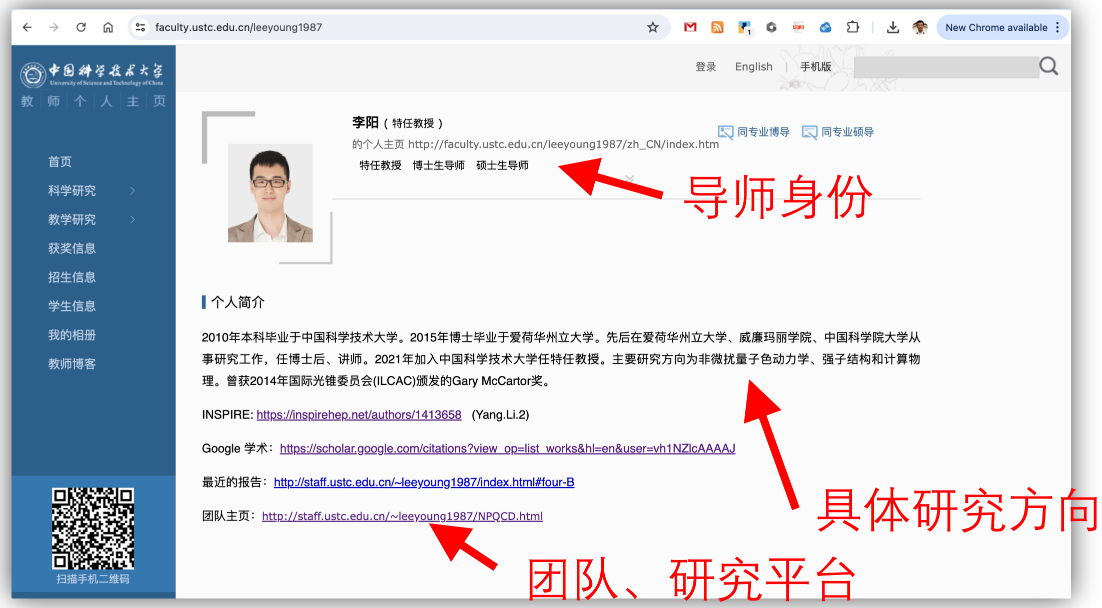
想法是一个科研项目的核心

- 对于我们同学们来说，研究想法一般来自导师、合作者，包括通过与其讨论获得
- 成为一个独立研究者的标志就是能够提出独立且具有创新性的想法
- 创新建立在对领域研究前沿的熟悉和理解，避免重复、错误；很可能还存在与其他组的竞争（谁先想到+谁先做出来）
- 研究想法随着科研的进行，可能会不断修正

找方向、找导师

- 确定自己感兴趣的方向（一个或多个）
- 了解导师信息（主页、媒体、报道、课程）
- 游泳时不想被淹死应该到波涛汹涌的水域去（找新兴的、尚不成熟的领域）

——温伯格



如何联系导师

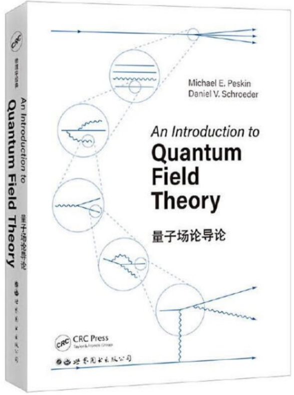
- 了解一下组里基本情况（文章、报告、宣传、学长学姐等）
- 发邮件表达兴趣、到办公室找导师谈一谈表达自己的兴趣
- 导师希望了解的信息：
  - 身份 —— 了解学生的基本情况
  - GPA、专业课成绩或相关课成绩 —— 理解学生基础
  - 兴趣、能力 —— 是否大致匹配
  - 规划 —— 该如何安排学生
- 原则上是一种双向选择
- 到最顶尖的地方去，跟着最顶尖的人，做最顶尖的事情

Don’t be shy!

文献阅读

- **教科书**：了解一个领域的第一个向导，但即使是最好的教科书也都是严重滞后以及过于粗略的
- **综述和经典文献**：进入一个领域的第一步，它提供了一个小领域的全面概览，包括研究背景、研究现状和待解决的问题
- **相关参考文献、相关报告**：介绍了最前沿的问题和最前沿的技术
- **组内的研究笔记、毕业论文**：独门绝技

没人知道所有的事情，你也无需知道每件事情 —— 温伯格



教科书

[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: 1

[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

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

[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:

综述

笔记

主要参考文献


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

Pions in proton structure and everywhere else

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(Received 12 September 2021; accepted 21 June 2022; published 30 June 2022)

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.

DOI: 10.1103/PhysRevD.105.114054

The recent striking experimental finding [1] that antidown quarks are more abundant in the proton than antiup quarks for all observed values of the Bjorken x variable demands an interpretation and assessment of the consequences. This paper is aimed at providing such.

The results of [1] provide definitive experimental measurements of the ratio $\bar{d}/\bar{u}$. Although our early prediction [2] using a pion cloud model is in qualitative agreement with that experiment, it is necessary to update the calculation by providing results for the specific kinematics of the experiment that are known only since the publication [1].

We begin by explaining why it is natural to expect that the pion cloud would play a role in probes of proton structure. Pion exchange between nucleons provides in the one pion exchange potential (OPEP) the longest-ranged component of the strong force. It is an element of all models, from the ancient to the newest, of the nucleon-nucleon interaction. The OPEP is crucially responsible for the binding of nuclei [3,4]. Moreover, the presence of the pion as a significant component of the nuclear wave function is reinforced by the dominance of the pion in meson exchange corrections to a variety of nuclear properties. This was discussed long ago [5,6] and recently [7].

If a nucleon emits a virtual pion that is absorbed on another nucleon, as in the OPEP, it can emit a pion that is absorbed by itself. This is because nucleons are identical particles and a pion can be absorbed on any nucleon. Thus, the nucleon must consist, at least part of the time, of a nucleon and a virtual pion. The very significant contributions of pions to nucleon and baryon properties have been well documented for a long time [8–12]. Particular examples in which the pion-cloud effects are prominent are the neutron charge distribution [9] and baryon magnetic moments [11].

Given that the proton wave function has $n\pi^+(u\bar{d})$ and $p\pi^0$ components, with a two to one ratio of probabilities, there should be more antidown quarks than antiup quarks in the nucleon. This means that the textbook description that nucleons are composed of u and d valence constituent quarks, cannot be the whole story. Furthermore, the gluons inherent in QCD generate quark-antiquark pairs via perturbative interactions. Thus, one is led to the question; Do the pairs arise only from perturbative evolution at high momentum scales, or do they have a nonperturbative origin as in the pion cloud? A definitive answer would provide great help in understanding the nature of confinement and also the fundamental aspects of the nucleon-nucleon force. Perturbative QCD predicts a sea that is almost symmetric in light flavor. However, the discovery of the violation of the Gottfried sum rule told us that $\bar{d}$ quarks are favored over $\bar{u}$ quarks [13]. This highlighted the importance of the pion cloud of the nucleon [14,15]. Reviews are presented in [16–19]. More recent calculations of the difference $\bar{d}-\bar{u}$, the isovector component of the proton sea, have been published in [20–23]. We focus on the ratio $\bar{d}/\bar{u}$, determined by the SeaQuest experiment. The ratio has been a greater challenge for theory, since it depends on both the isoscalar and isovector components of the sea.

The concept of a component of a nucleon wave function makes sense only within a light front description of the nucleon. Our previous formalism [2] provided a light cone perturbation theory approach capable of making predictions with known uncertainties. Previous calculations had noted ambiguities related to the dependence of the pion-baryon vertex function on momentum transfer and on the possible dependence upon the square of the four-momentum of intermediate baryons, and much discussion ensued [16,24–34]. Another more fundamental issue involving the loss of relativistic invariance occurs when

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2470-0010/2022/105(11)/114054(8) 114054-1 © 2022 American Physical Society

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

其他参考文献(它引了谁、谁引了它)

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
- 贵在坚持、在精不在多

泛读：

Pions in Proton Structure and Everywhere Else

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(Dated: July 12, 2022)

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.

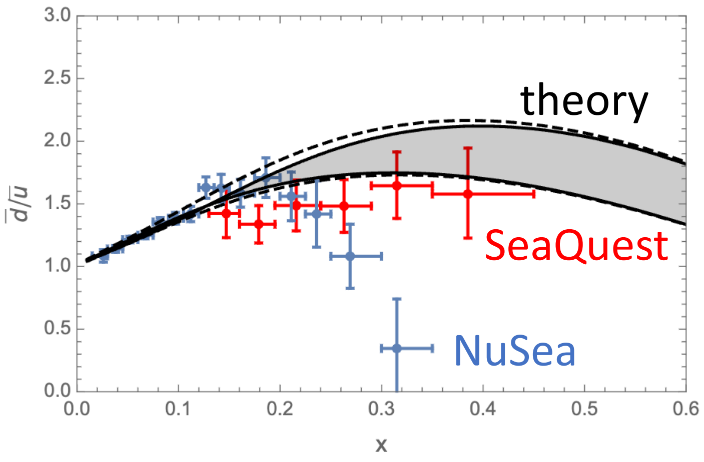


FIG. 5. $\bar{d}(x)/\bar{u}(x)$ Blue symbols from E866 [73]. Red symbols are from SeaQuest [1]. The solid band is computed using minimum and maximum values of the splitting functions shown in Fig. 3 in convolution with ASV or xFitter pion pdfs, plus the bare sea of [53]. All pdfs were evolved to the 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

our prediction band lower, improving its agreement with

Our 2019 paper said "The pion-baryon form factors

values of x greater than about 0.15, the pion cloud effects dominate. The rise and then fall of the ratio $\bar{d}/\bar{u}$ 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

粗读：

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

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

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 $m_\pi = 0$),

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

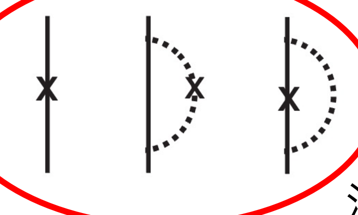
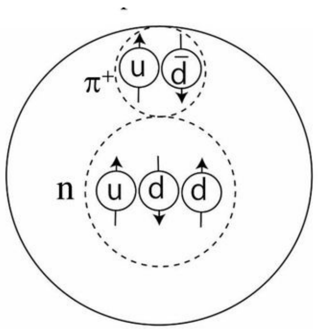


FIG. 2. (a) External interaction, X, with bare nucleon (solid line), (b) External interaction, X, with the pion, (c) External interaction, X, with the intermediate baryon. Here X represents the deep inelastic scattering operator.

派介子云模型

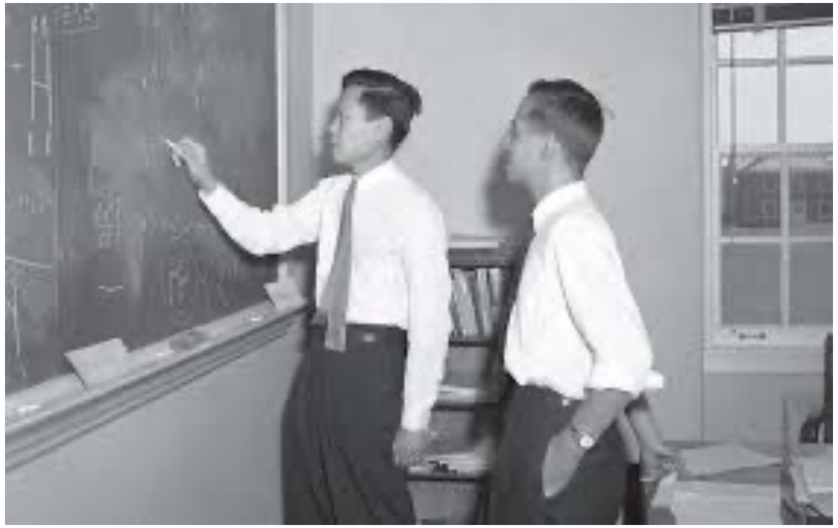


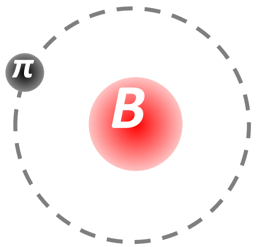
Alberg & Miller 基于手征有效理论，利用派介子云模型，结合微扰光锥方法计算了质子海夸克的味道不对称性

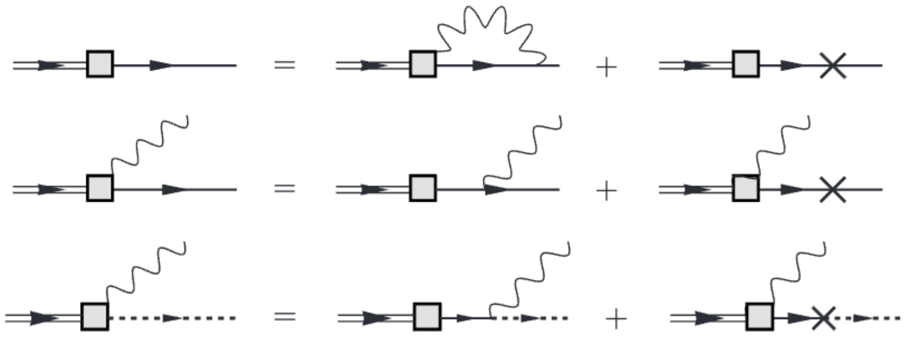
研究过程

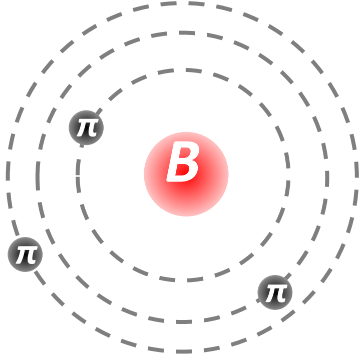
研究过程没有定式，不同人有不同的风格

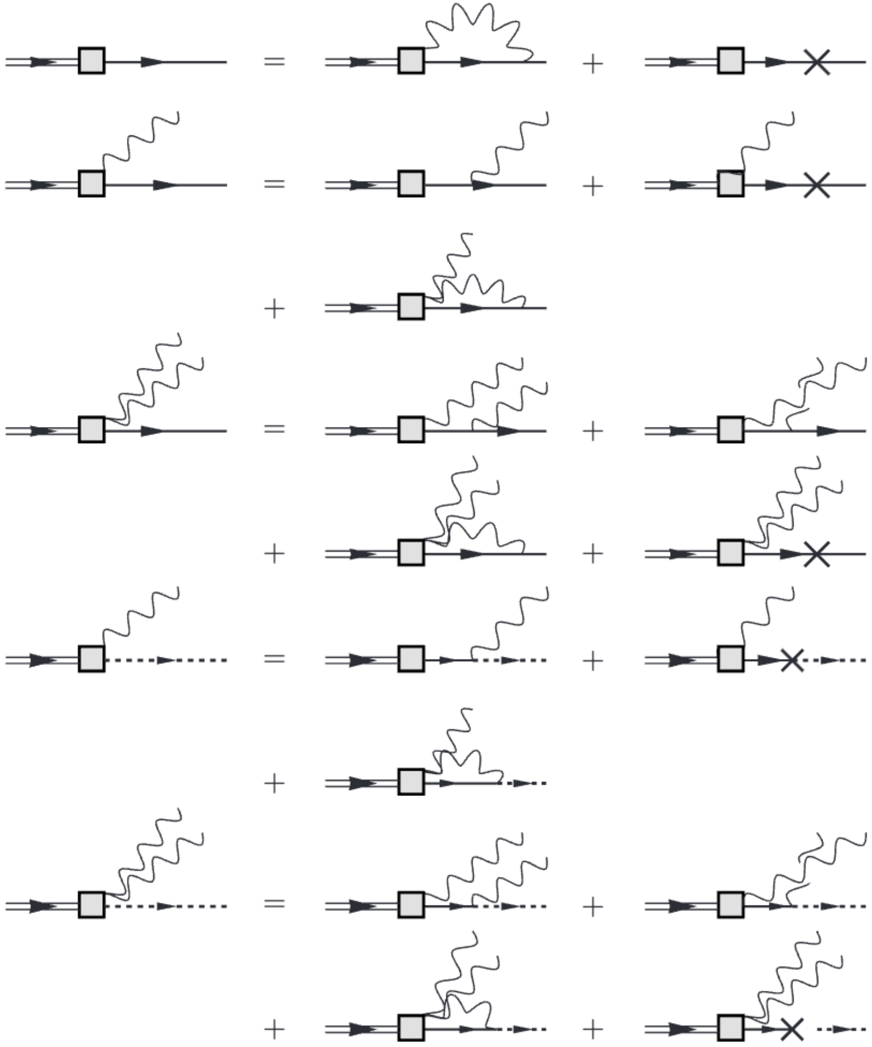
- 一个常用的策略是“问题-解答”模式，即对于需要回答的大问题，首先分解为一系列小问题，分别解答之
- 一般需要学习组内前沿的方法以及代码
- 讨论、争论、辩论
- 大多数同学缺乏做相关问题所需要的领域知识(domain knowledge),
  - 应该边做边学!
  - 最低门槛问题：导师把关，科大的基础教育是足够的
  - 以解决问题为中心，不要沉溺于文山书海











线性代数问题

论文写作

论文即是对研究工作的包装，也是对研究工作的反思，归根结底是一种交流的手段

- 第一次写作，一个有用的办法是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！
- 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
- 一个有用的策略是“以结果为中心”：首先确定文章最重要的结果（图、公式、表），力图将这些结果描述清楚；然后围绕这些结果撰写前因后果
- 写作是一个过程，好的论文需要与导师一起打磨

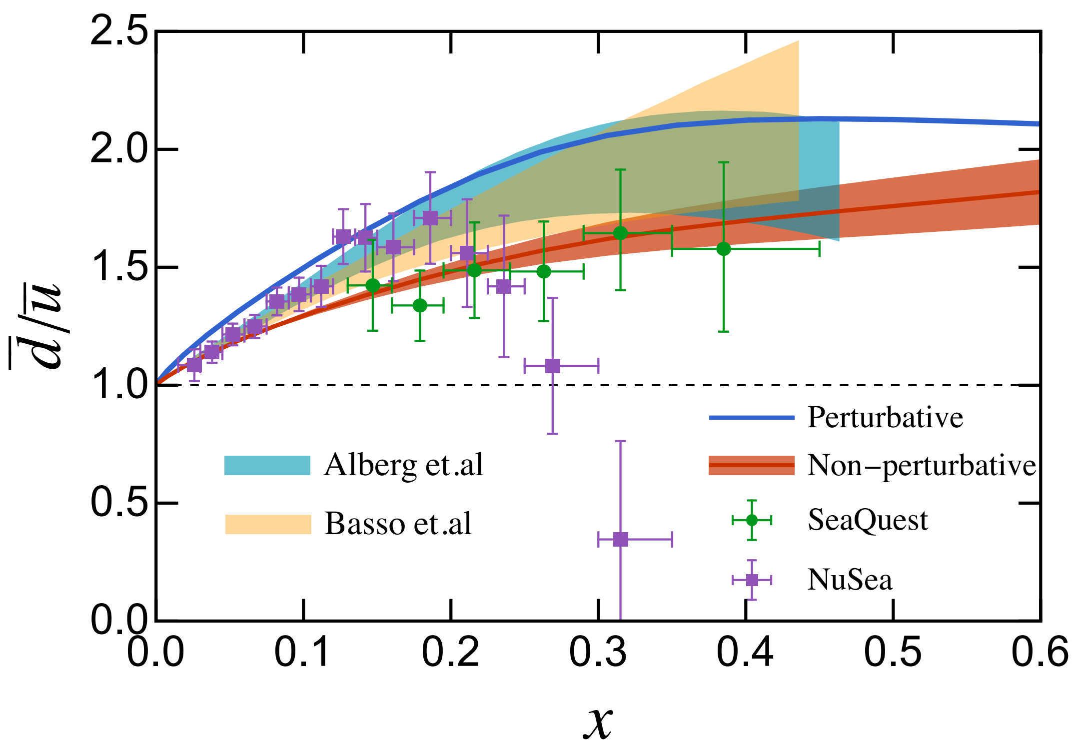


FIG. 5. Flavor asymmetry of the nucleon sea: (*Top*) $\bar{d} - \bar{u}$; (*Bottom*) $\bar{d}/\bar{u}$ from the perturbative and non-perturbative solutions of a pion cloud model with scalar type interactions in comparison with available experimental data from NuSea/E866 [13–15] and SeaQuest/E906 [7, 9]. The non-perturbative 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. [45] and from the statistical model by Basso et. al. [37] are also shown for comparison.

- 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

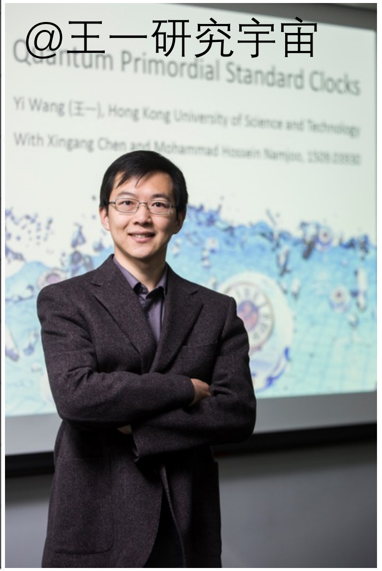
学术报告

学术报告的目的是向同行宣传介绍自己的工作，聆听反馈，接受同行的批评指教

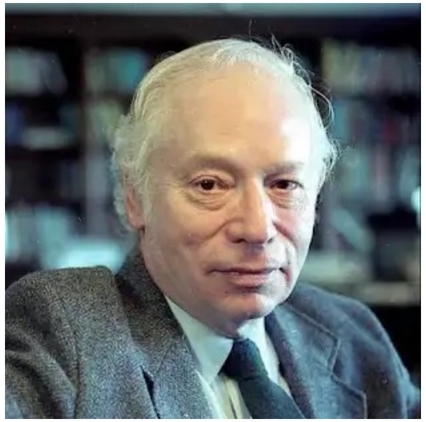
- 写ppt的过程可以帮助我们凝练科学问题、升华物理结果
- 报告要结构合理，重点突出
- 好的报告需要与导师一起反复打磨
- 好的演讲需要练习

科研训练

	参考		读研阶段	¼		½		¾		
课程学习			■	■						
前沿学习		综述，经典文献	■	■	■					
		arXiv 预印本为主			■	■	■	■	■	■
		暑期学校			■	■	■	■	■	■
想法	【1】	找导师要	■	■	■	■	■	■		
		独立想、与外界合作					■	■	■	■
调研		按引文快速掌握小方向	■	■	■	■	■	■	■	■
科研		小方向技术不断深化	■	■	■	■	■	■	■	■
		通过合作多学技术					■	■	■	■
写文章	【2】	学术写作基本规范	■	■						
		精益求精			■	■	■	■	■	■
学术交流	【3】	组会，journal club	■	■	■	■	■	■	■	■
		会议 parallel section				■	■	■	■	■
		访问（短、长期）					■	■	■	■
找工作		Build up your CV, connection	■	■	■	■	■	■	■	■
		申请博后							■	



温伯格 Four golden lessons



- 没人知道所有的事情，你也无需知道每件事情
  - 边做边学
- 应该到波涛汹涌的水域去游泳
  - 去混乱的、尚不确定的领域去做研究
- 原谅自己浪费时间
  - 没有人知道自己的工作在五十年以后是否仍然有价值
- 了解科学史，让你认识到自己工作的价值
  - 每个人都知道爱因斯坦，谁记得1905年大不列颠首相？

https://www.nature.com/articles/426389a

我的建议

- 与导师（或实际指导老师 mentor）的沟通对于科研项目的进展至关重要
  - 与导师的主动沟通是最高效的学习方式
  - 大多数导师都欣赏积极主动的学生
  - 有进展时要找导师沟通，卡住时更要及时找导师交流，此外还要保持与导师的定期沟通（如组会）
- 边做边学效率最高，不要等搞清楚了所有事情再回头来做研究
  - 从综述性文献入手，迅速了解领域的近况
  - 不理解的时候，可以先搞清楚计算规则，先上手算起
  - 搞不清楚的地方，可以先记下来，过段时间回过头来再看也许会有新的认识
- 卷科研固然可行，但寻找个人兴趣、学习前沿知识从长期来看是更重要的

谢 谢!