



轻夸克比例与SU(2) flavor asymmetry

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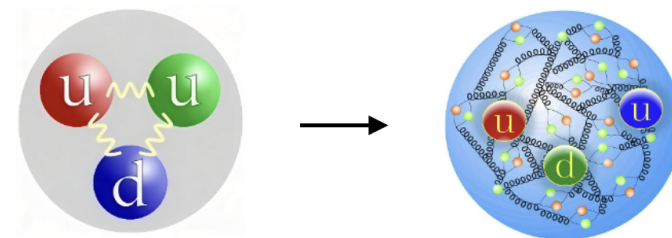
2026. 05. 24 @ 广州

质子结构与SU(2) flavor asymmetry

质子中的价夸克与海夸克

➤ 高能(GeV)反应: 价夸克+海夸克

$$\sigma(p) = \sum_q f_q(x, Q^2) \otimes \text{HardScattering}(q; x, Q^2)$$



Constituent quark model:
 $p = uud$

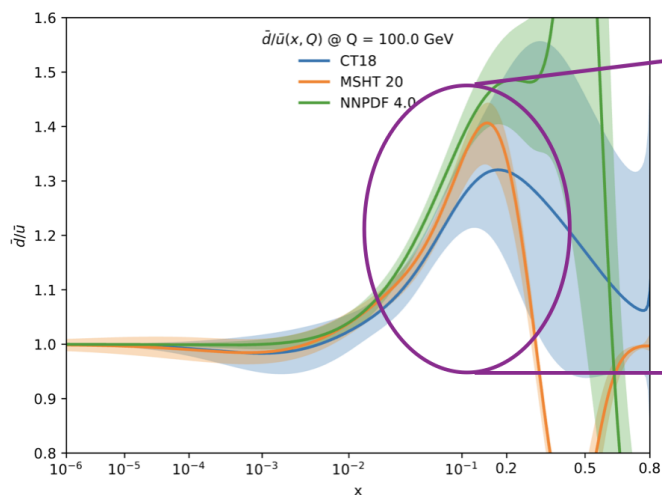
QCD improved parton model:
 $p = u_v d_v + g u \bar{u} d \bar{d} s \bar{s} \dots$

质子内的海夸克是如何产生的?

反轻夸克比例 \bar{d}/\bar{u} 与海夸克产生机制

➤ 微扰QCD机制: 胶子劈裂主导, \bar{d} 与 \bar{u} 分布相似, $\bar{d}/\bar{u} \sim 1$

➤ 非微扰QCD机制: SU(2) flavor asymmetry $\bar{d}(x) \neq \bar{u}(x)$

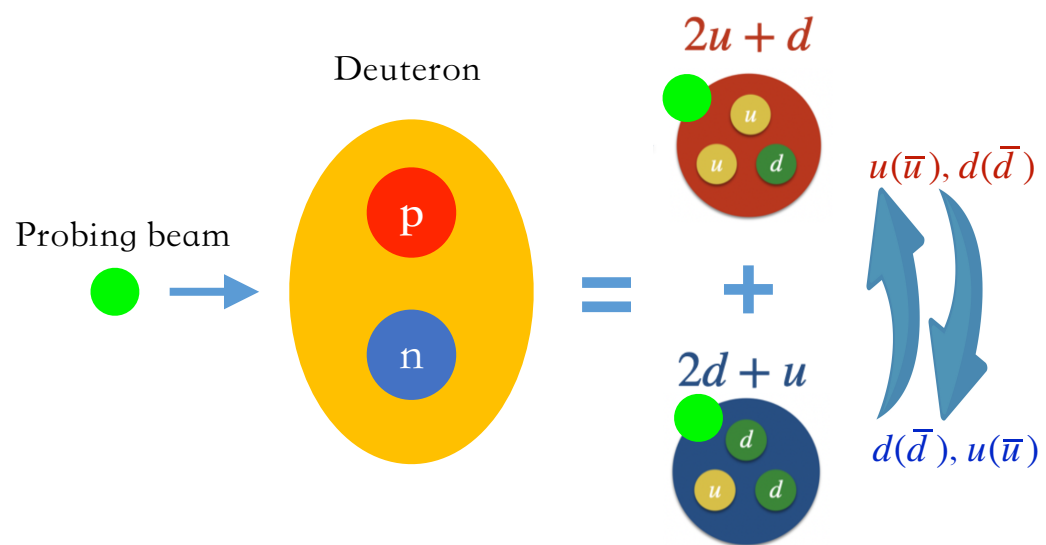


过去数十年, \bar{d}/\bar{u} 比例被认为在 $x \sim 0.1$ 处急剧上升, 产生了40%左右的SU(2) flavor asymmetry, 是质子内海夸克产生具有非微扰特性的核心证据

\bar{d}/\bar{u} 的实验测量

唯一直接实验输入信息：高能氘核实验

- 质子实验：难以实现，无法区分 \bar{d} 、 \bar{u} 贡献
- 高能氘核实验：目前唯一实验观测



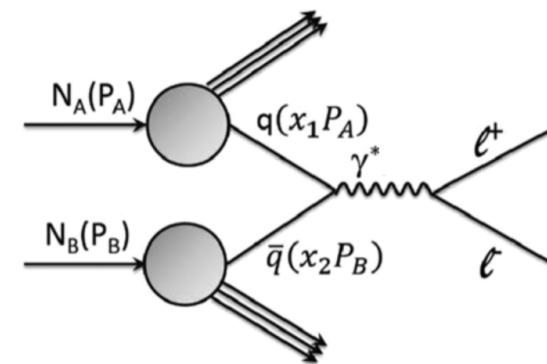
\bar{d}/\bar{u} 通过对比高能氘核反应和高能质子反应确定。此方案依赖两个重要假设：

i. 经典氘核模型： $\sigma(D) = \sigma(p) + \sigma(n)$

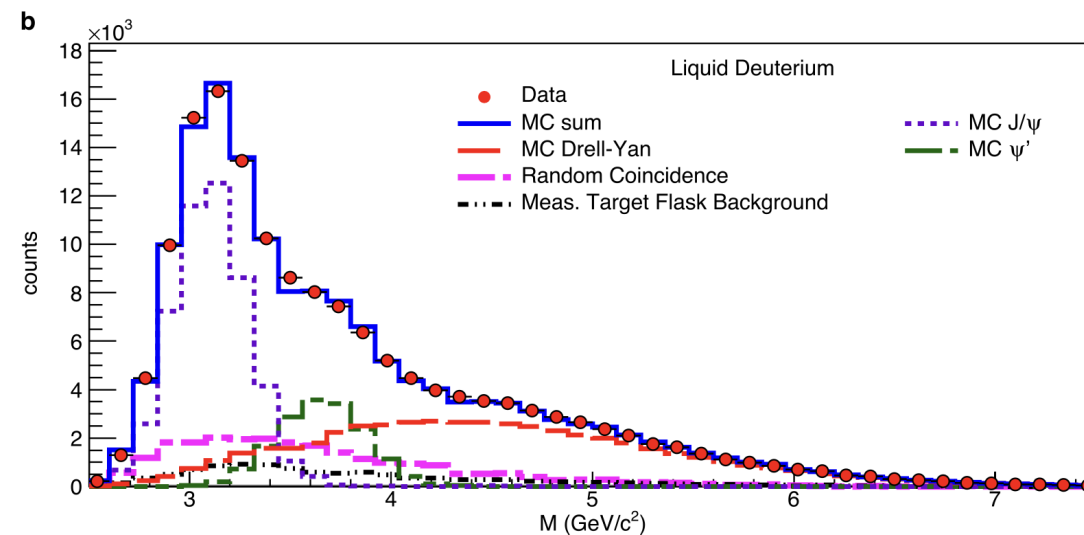
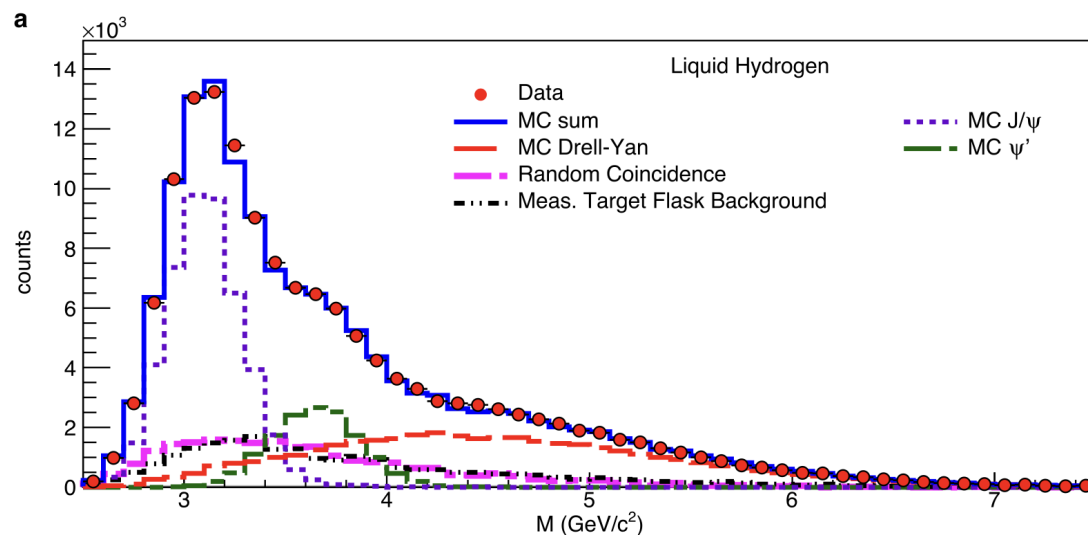
ii. Isospin-symmetry: $u_n(\bar{u}_n) = d_p(\bar{d}_p), d_n(\bar{d}_n) = u_p(\bar{u}_p)$

高能质子-氘核/质子-质子打靶实验

- 高能质子束流(800 GeV/120 GeV)轰击氘靶 vs. 氢靶
- 物理反应: 质心系 ~ 10 GeV Drell-Yan过程
- 直接实验观测量: $\sigma_{pD}/(2\sigma_{pp})$



$$\frac{\sigma_{pD}}{2\sigma_{pp}} \sim \frac{1}{2} \left(1 + \frac{\bar{d}}{\bar{u}} \right)$$



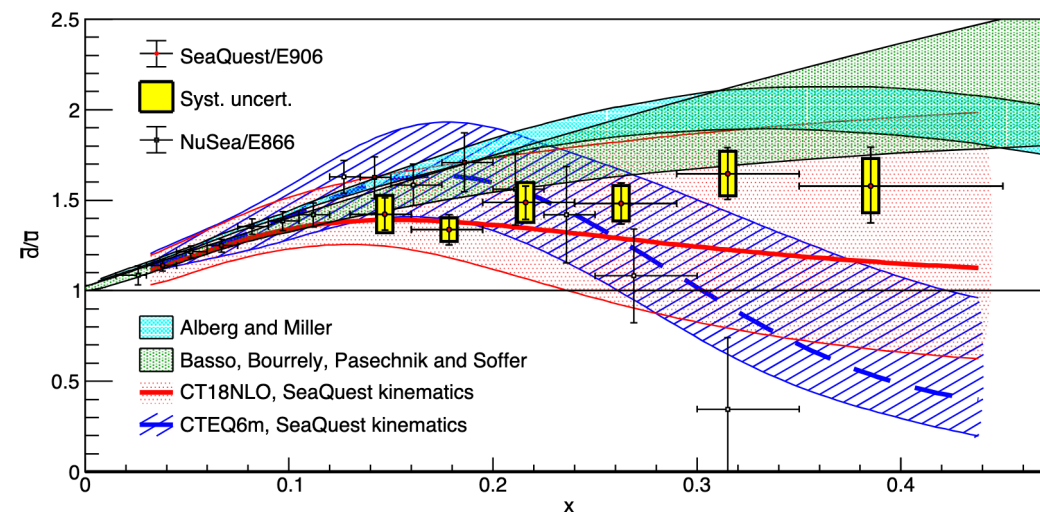
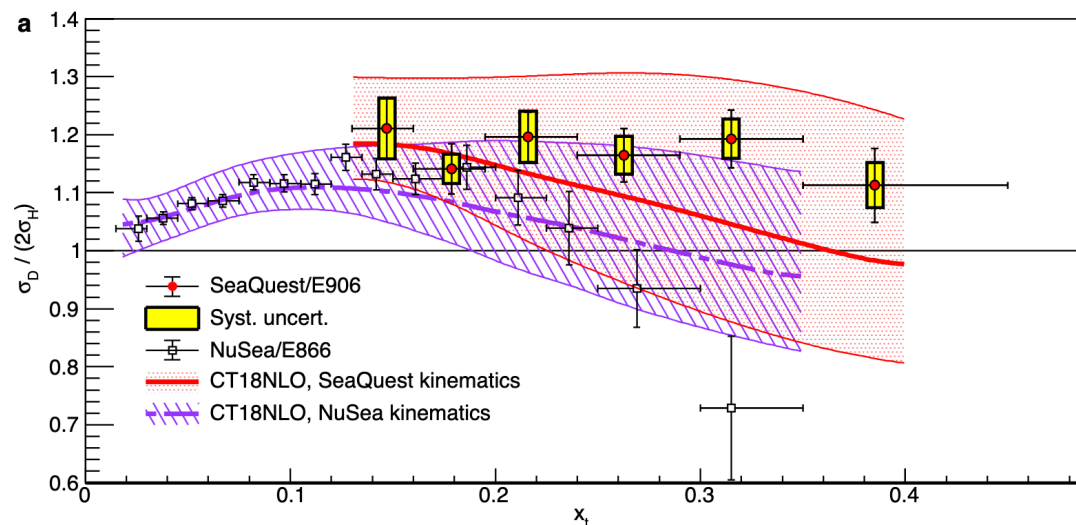
[Nature Vol 590, 561-565, 2021](#)

NuSea/SeaQuest experimental results

氘核反应反常偏大

- 实验观测到氘核反应偏大，程度远高于高阶微扰QCD效应，直接导致 $\bar{d}/\bar{u} > 1$ 结论
- 核结构假设: $\sigma(D) \approx \sigma(p) + \sigma(n)$

$$\frac{\sigma_{pD}}{2\sigma_{pp}} \sim \frac{1}{2} \left(1 + \frac{\bar{d}}{\bar{u}} \right) > 1 \rightarrow \frac{\bar{d}}{\bar{u}} > 1$$

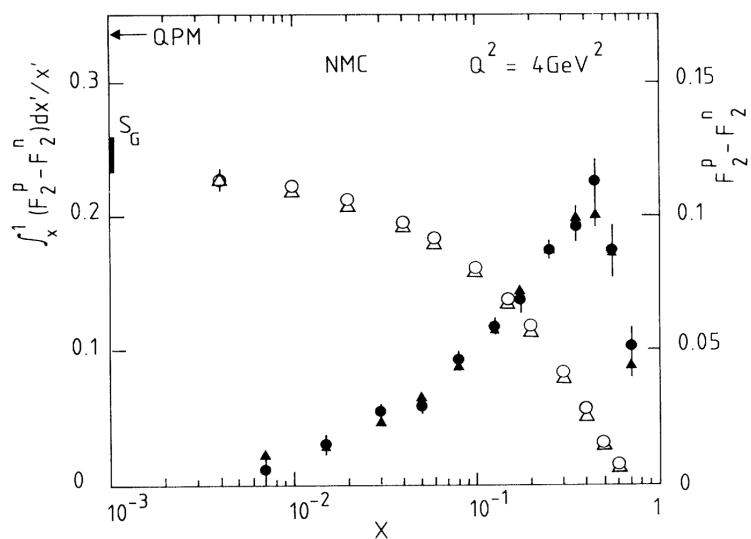


Nature Vol 590, 561-565, 2021

其他实验结果

一系列氘核实验，结论一致

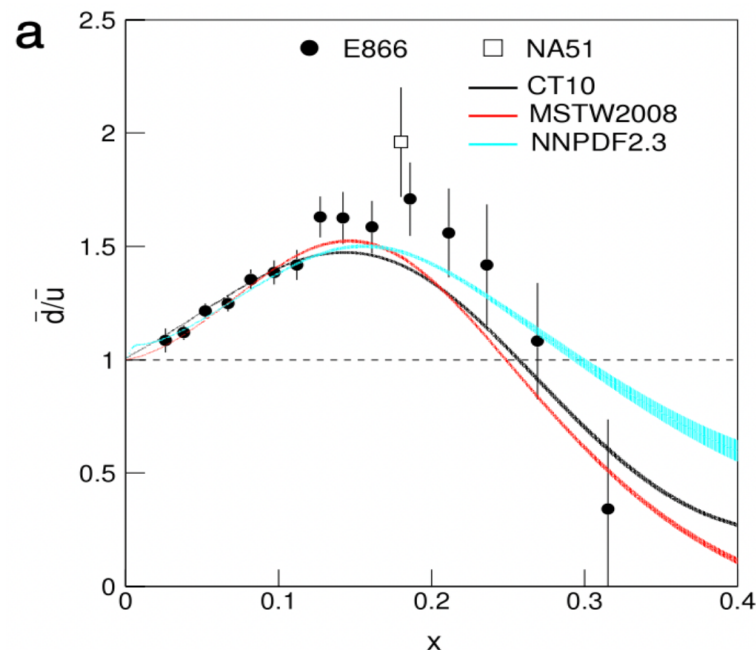
➤ NMC inclusive DIS



$\int_0^1 dx [\bar{d}(x) - \bar{u}(x)] = 0.147 \pm 0.039,$
 Muon 90-280GeV on H₂/D₂ targets
 @ CERN SPS

Phys. Rev. Lett. 66 (1991) 2712

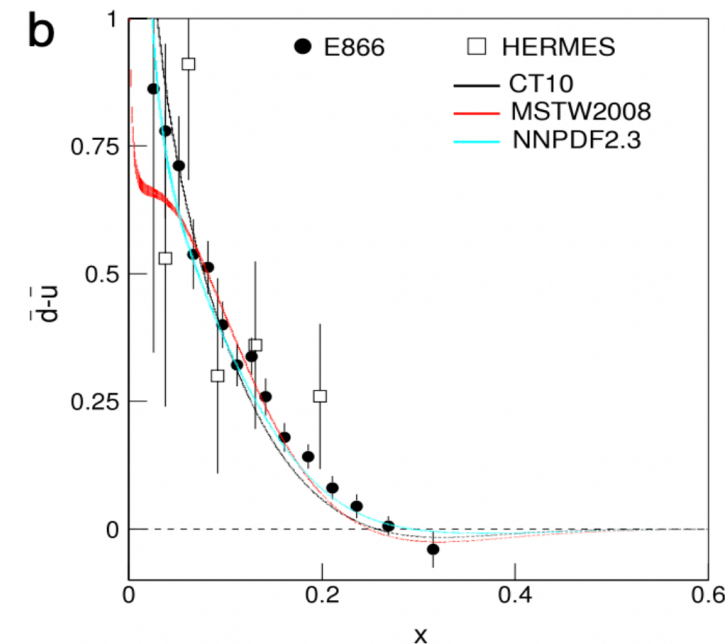
➤ NA51 Drell-Yan process



Proton 450GeV on H₂/D₂ targets
 @ CERN SPS

Phys. Lett. B 332 (1994) 244

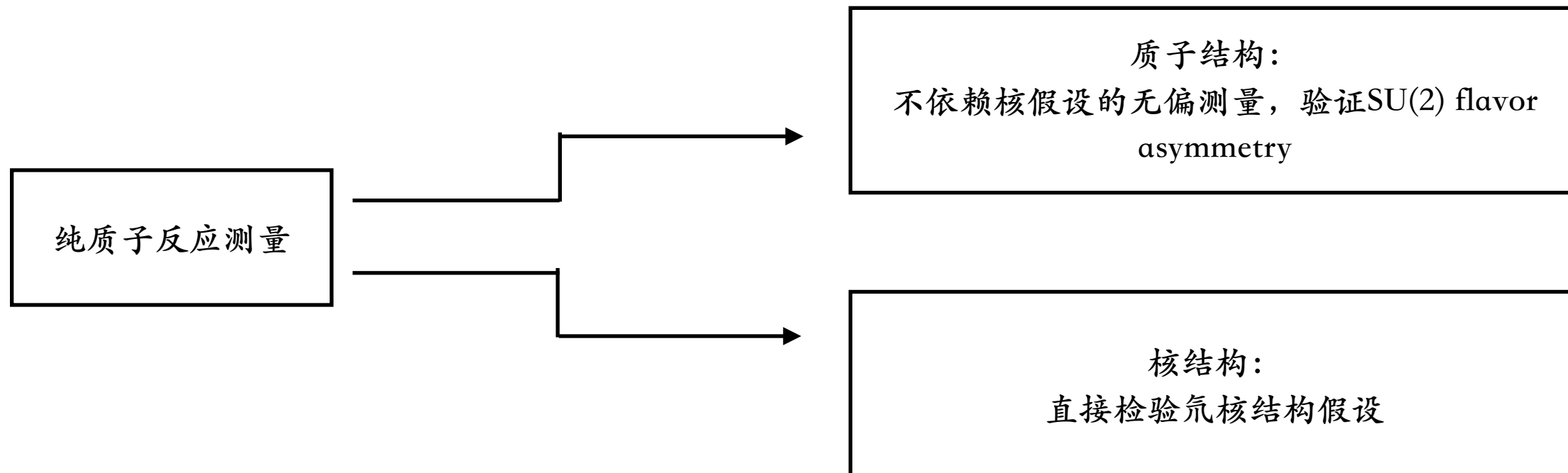
➤ HERMES semi-inclusive DIS



Positron 27.5GeV on H₂/D₂ targets
 @ DESY HERA

Phys. Lett. B 81 (1998) 5519

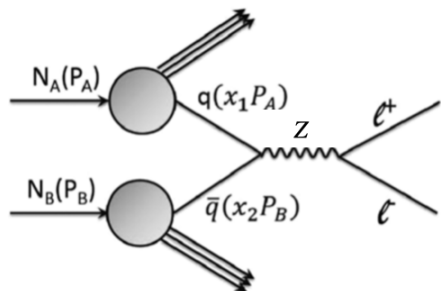
纯质子反应测量轻夸克比例



弱作用与空间不对称性

弱中性流Drell-Yan过程

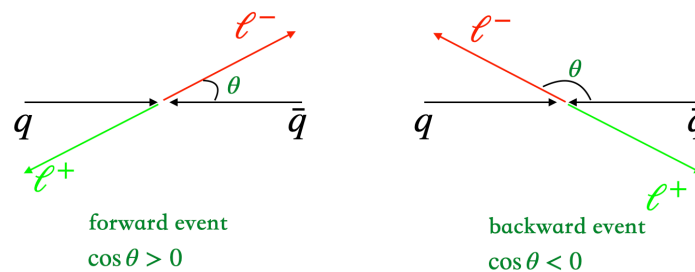
- 天然与flavor相关, $u(\bar{u})$ 、 $d(\bar{d})$ 贡献可区分
- 实验观测: 空间不对称性 A_{FB}



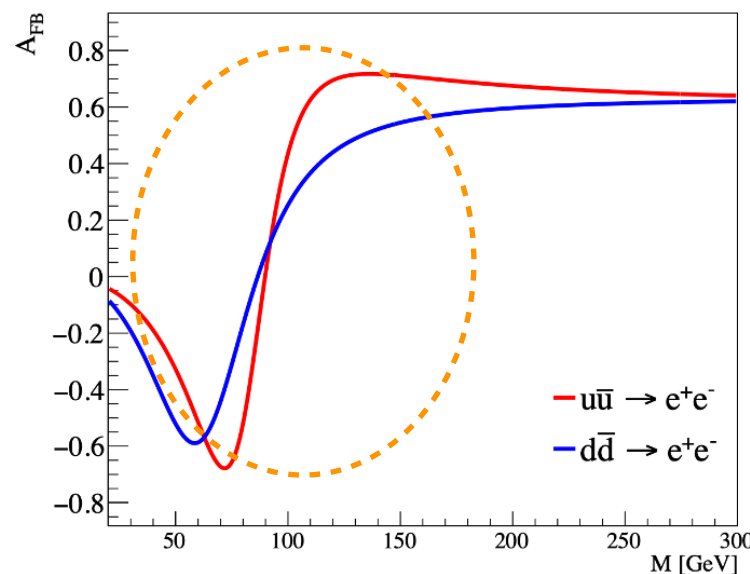
$$-\frac{g}{2 \cos \theta_W} \sum_i \bar{\psi}_i \gamma^\mu (g_V^i - g_A^i \gamma^5) \psi_i Z_\mu$$

$$g_V^i \equiv t_{3L}(i) - 2q_i \sin^2 \theta_W,$$

$$g_A^i \equiv t_{3L}(i),$$



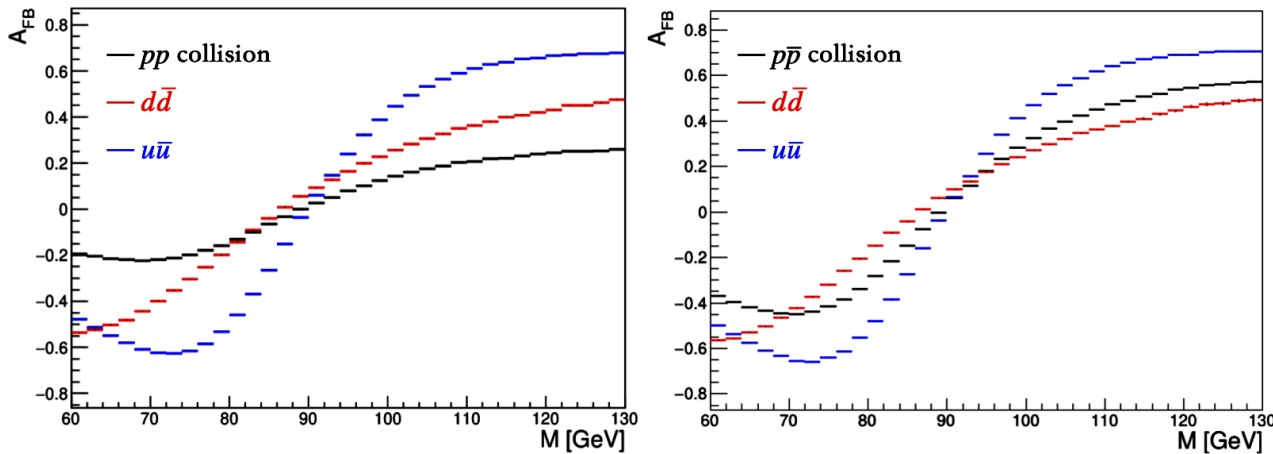
$$A_{FB} = \frac{N_F - N_B}{N_F + N_B}$$



硬散射过程: A_{FB}^u 和 A_{FB}^d 在Z pole区域明显不同

A_{FB} 的严格参数化与Drell-Yan asymmetry结构参数

A_{FB} 中定义Drell-Yan过程结构参数



- 观测 $A_{FB} = A_{FB}^u$ 和 A_{FB}^d 的混合平均
- 结构参数 C_u 、 C_d : 混合权重
- QCD任意阶严格成立

$$A_{FB}^h = C_u[u(x); \bar{u}(x)] \times A_{FB}^u[\sin^2 \theta_W] + C_d[d(x); \bar{d}(x)] \times A_{FB}^d[\sin^2 \theta_W]$$



$$R = \frac{C_d}{C_u} \propto \frac{d - \bar{d}}{u - \bar{u}}$$

$$C_u(x_1, x_2) = \frac{[u(x_1)\bar{u}(x_2) - \bar{u}(x_1)u(x_2)] \mathcal{N}_u}{\sum_{q=u,d,s,c,b} [q(x_1)\bar{q}(x_2) + \bar{q}(x_1)q(x_2)] \mathcal{N}_q}$$

$$C_d(x_1, x_2) = \frac{[d(x_1)\bar{d}(x_2) - \bar{d}(x_1)d(x_2)] \mathcal{N}_d}{\sum_{q=u,d,s,c,b} [q(x_1)\bar{q}(x_2) + \bar{q}(x_1)q(x_2)] \mathcal{N}_q}$$

For LHC's pp collisions

$$C_u(x_1, x_2) = \frac{[u(x_1)u(x_2) - \bar{u}(x_1)\bar{u}(x_2)] \mathcal{N}_u}{\sum_{q=u,d,s,c,b} [q(x_1)q(x_2) + \bar{q}(x_1)\bar{q}(x_2)] \mathcal{N}_q}$$

$$C_d(x_1, x_2) = \frac{[d(x_1)d(x_2) - \bar{d}(x_1)\bar{d}(x_2)] \mathcal{N}_d}{\sum_{q=u,d,s,c,b} [q(x_1)q(x_2) + \bar{q}(x_1)\bar{q}(x_2)] \mathcal{N}_q}$$

For Tevatron's $p\bar{p}$ collisions

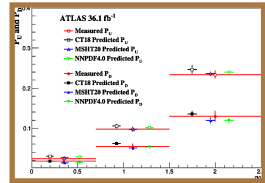
[Phys. Rev. D106 \(2022\) 033001](#)

[Eur. Phys. J. C82 \(2022\) 368](#)

[Chinese Phys. C 45 \(2021\) 053001](#)

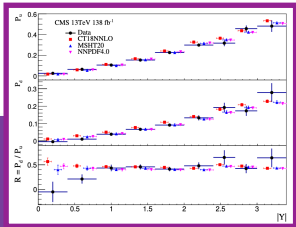
实验测量

一系列强子对撞测量，结论一致

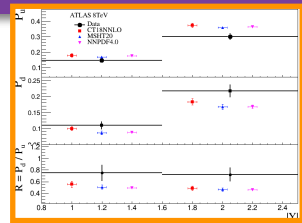


ATLAS pp @ 13 TeV
Consistent at small x region (preliminary)

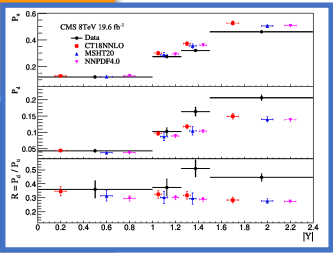
CMS pp @ 13 TeV
Discrepancy observed at high ZY region



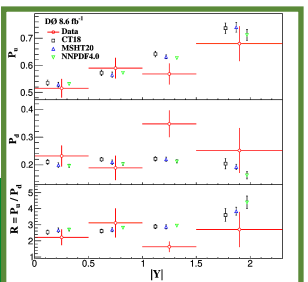
ATLAS pp @ 8 TeV (preliminary)
Discrepancy observed ($> 2\sigma$)



CMS pp @ 8 TeV
Discrepancy observed ($> 4\sigma$)



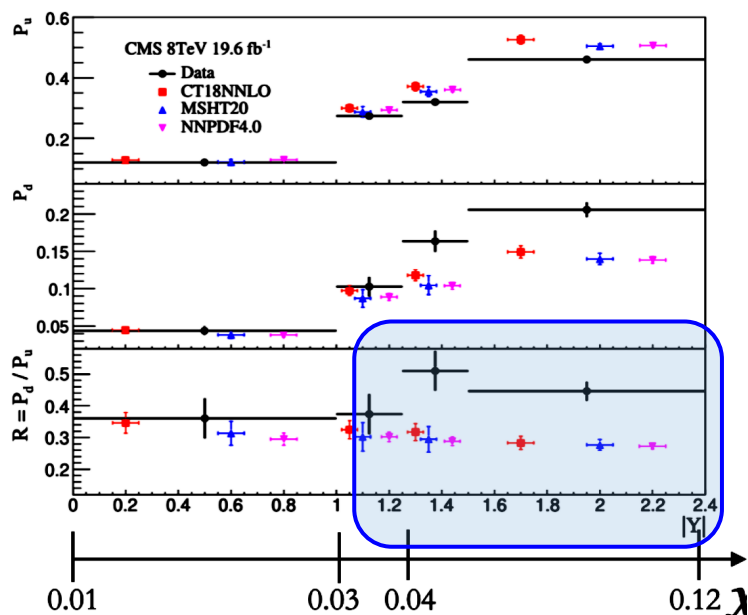
D0 $p\bar{p}$ @ 1.96 TeV
Discrepancy observed ($> 3.5\sigma$)



LHCb pp @ 13 TeV
Discrepancy observed ($> 2\sigma$, preliminary)



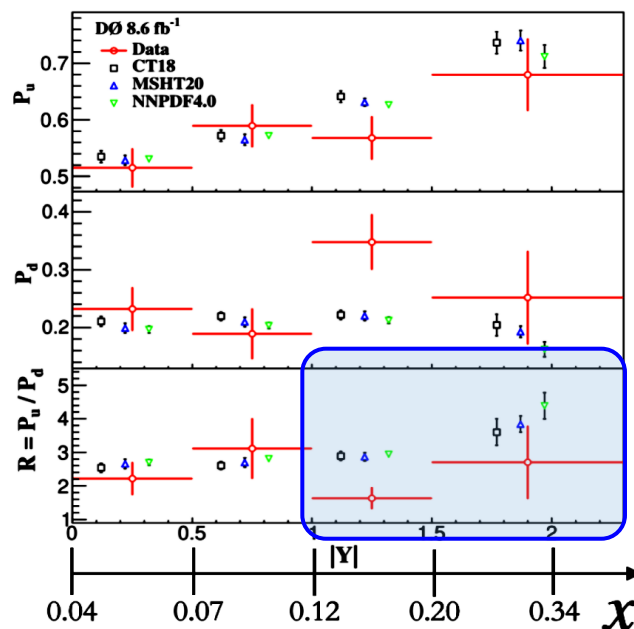
代表性实验测量



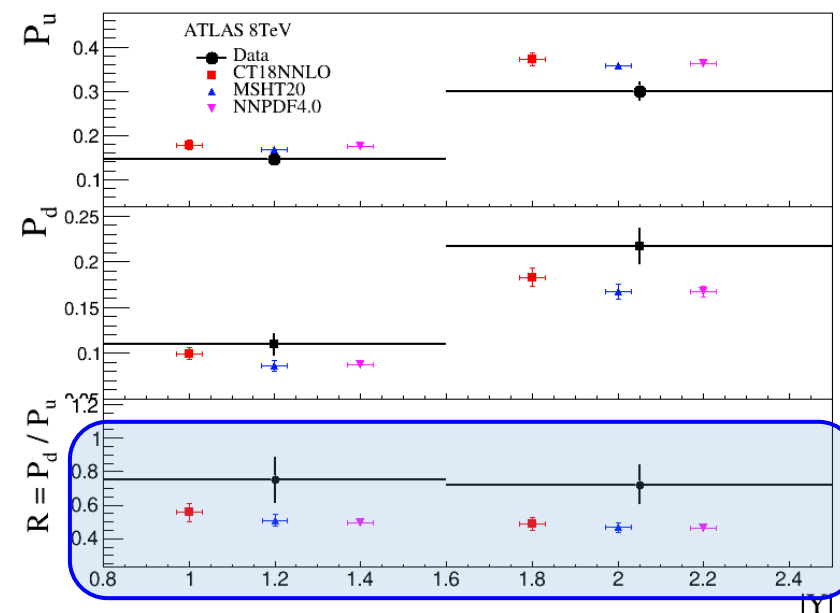
R parameter fitted from A_{FB} spectrum measurement in CMS 8 TeV pp collision data

$$R = \frac{C_d}{C_u} \propto \frac{d - \bar{d}}{u - \bar{u}}$$

实验数据一致表明, \bar{d}/\bar{u} 偏低、 d/u 偏高



R parameter measured in D0 1.96 TeV $p\bar{p}$ collision data (注意此测量中 R 定义为 $(u - \bar{u})/(d - \bar{d})$)



R parameter fitted from A_{FB} spectrum in ATLAS 8 TeV pp collision data (preliminary)

[Phys. Rev. D 107 \(2023\) 054008](#)

[Phys. Rev. D 110 \(2024\) L091101](#)

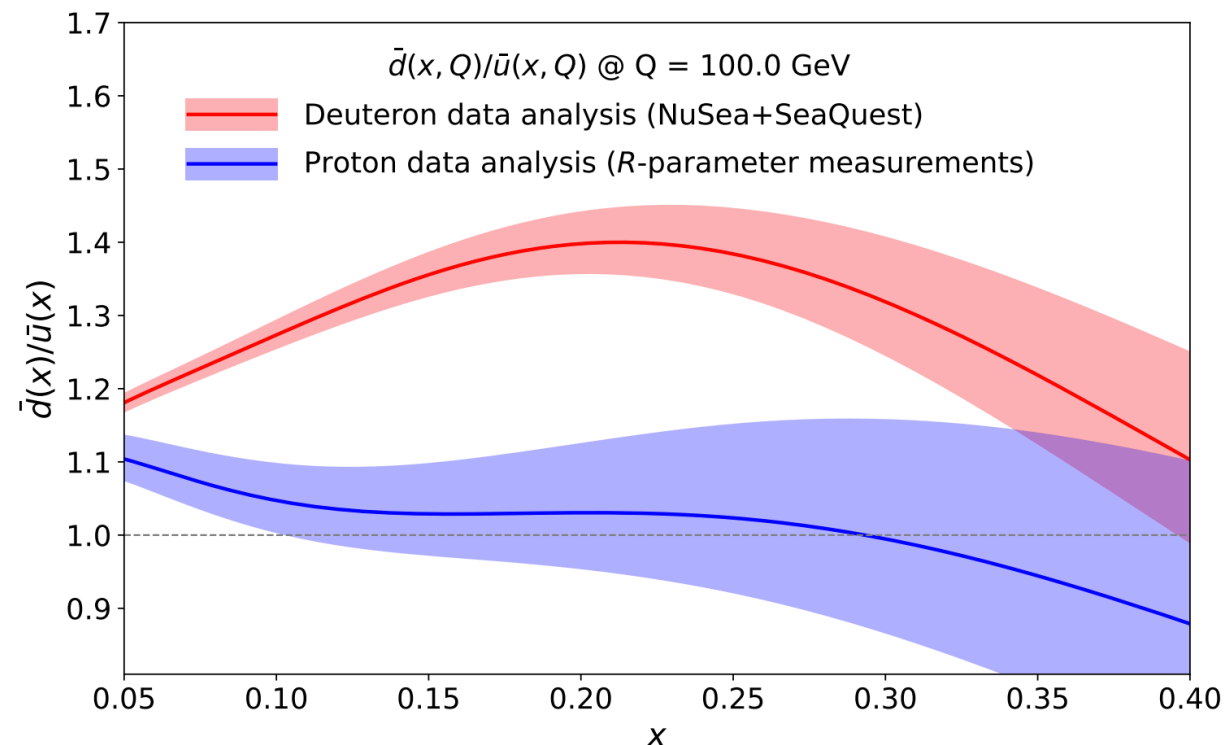
[Phys. Rev. D 113 \(2026\) L011504](#)

纯质子实验与氘核实验的对比

纯质子实验测量观测到 \bar{d}/\bar{u} 接近 1，不支持大的SU(2) flavor asymmetry

[arXiv: 2510.08941](https://arxiv.org/abs/2510.08941)

- 对质子结构：海夸克产生由微扰QCD机制主导
- 对核结构：高能反应中氘核经典结构假设不成立



氘核核效应(反常核结构)的粗估

经典模型下氘核内核子有效动量分布

$$\mathcal{F}_q^D(x, Q^2) = \frac{1}{2} \sum_N \int_x^1 \frac{dz}{z} \text{LMDF}(z) \mathcal{F}_q^N\left(\frac{x}{z}, Q^2\right)$$

- 尖峰：核子间相互作用小 (B.E. ~ 2 MeV)
- 峰位0.5：质子-中子对称，平分氘核能量

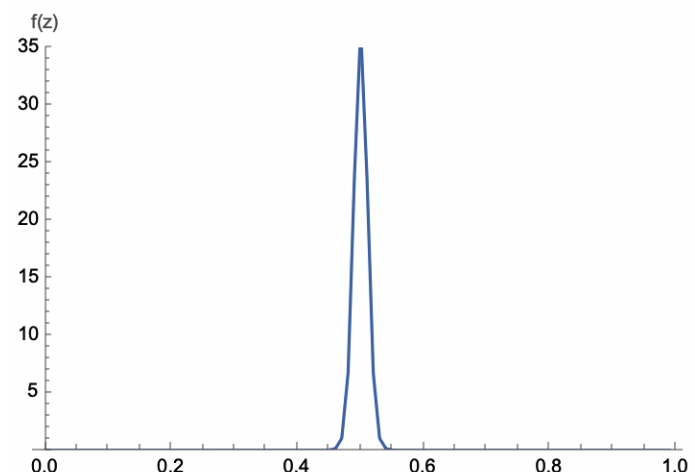
$$\mathcal{F}_q^D(x, Q^2) = \frac{1}{2} \sum_N \int_x^1 \frac{dz}{z} \text{LMDF}(z) \mathcal{F}_q^N\left(\frac{x}{z}, Q^2\right)$$

Overall distribution of quarks

PDF of quarks in nucleons (proton)

Distribution of nucleons in
the deuteron

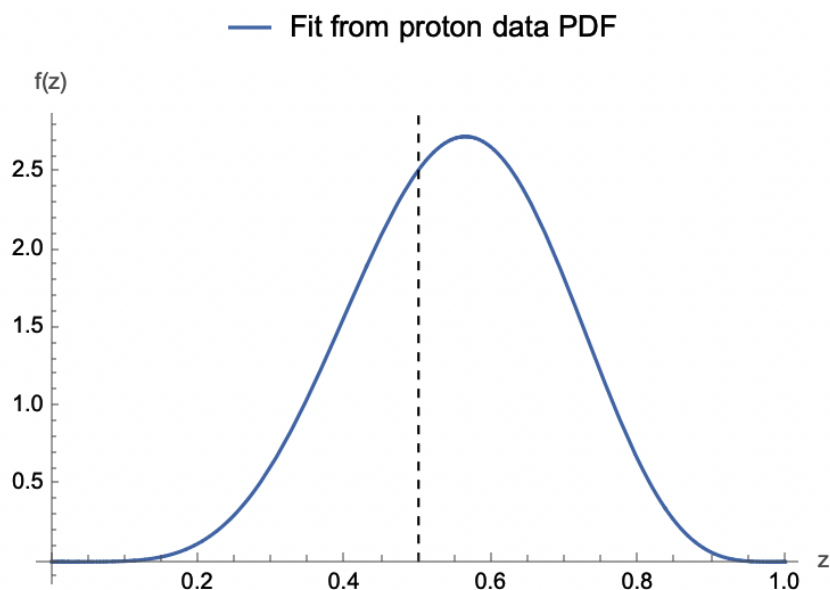
LMDF in classic picture



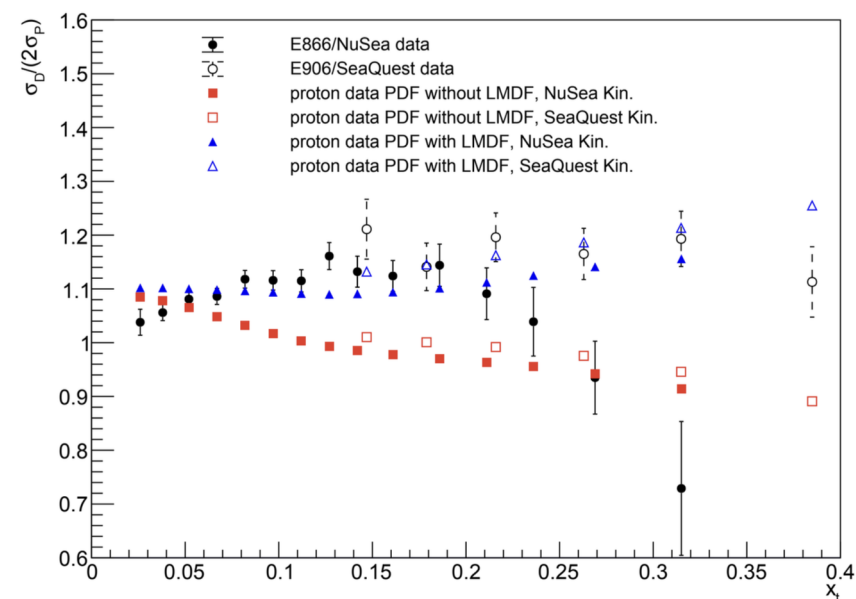
氙核核效应(反常核结构)的粗估

利用纯质子PDF ($\bar{d}/\bar{u} \sim 1$) 拟合氙核LMDF

- 宽分布：氙核内相互作用极强
- 非对称峰位：氙核并非简单质子+中子



$$\mathcal{F}_q^D(x, Q^2) = \frac{1}{2} \sum_N \int_x^1 \frac{dz}{z} \text{LMDF}(z) \mathcal{F}_q^N\left(\frac{x}{z}, Q^2\right)$$



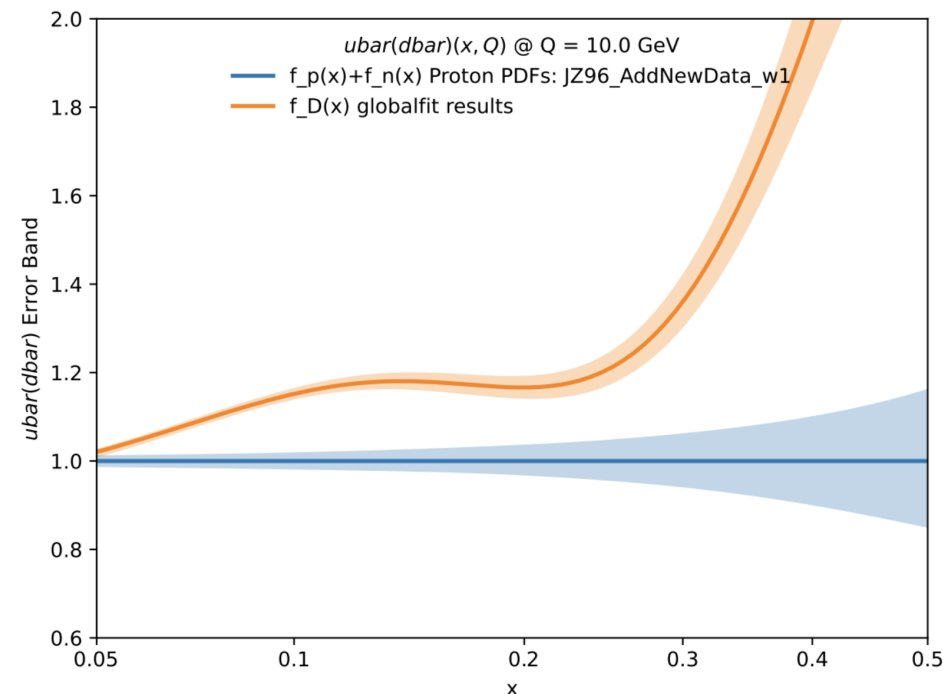
氦核内海夸克分布测量

氦核-夸克分布 vs 质子-夸克分布 PDF global fit (JZ-96p/JZ-96D, preliminary)

$$\sigma(p) = \sum_q f_q(x, Q^2) \otimes \text{HardScattering}(q; x, Q^2)$$

$$\sigma(D) = \sum_q f_q^D(x, Q^2) \otimes \text{HardScattering}(q; x, Q^2)$$

	氦核global fitting 实验数据	质子global fitting 实验数据
DIS 实验测量	BCDMS NMC	HERA
Drell-Yan过程测量	NuSea E866 SeaQuest E906	Tevatron LHC

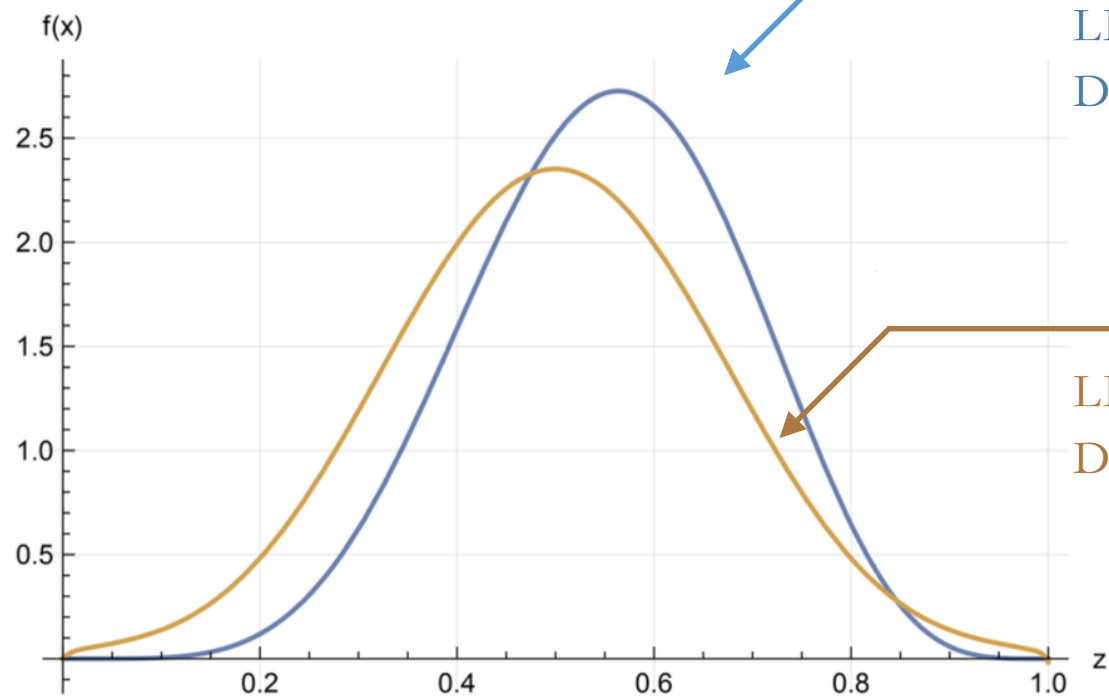


- 橙色：直接从氦核实验数据中拟合氦核内 $\bar{u}_D = \bar{d}_D$ 分布(相对于经典模型)
- 蓝色：纯质子实验数据拟合得到 $\bar{u}_p + \bar{d}_p$

其他情况

利用氘核电磁形状因子观测LMDF

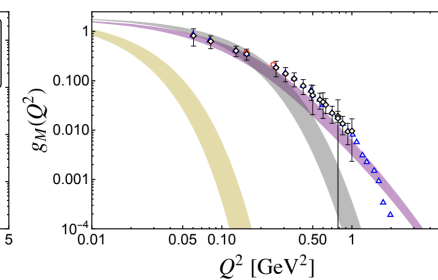
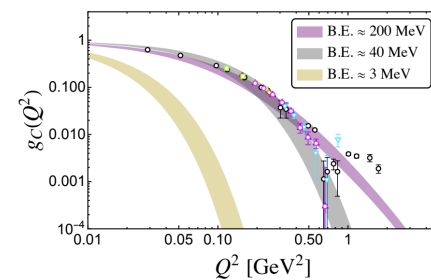
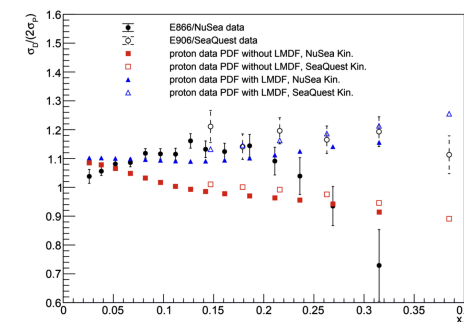
➤ 结论基本一致



LMDF fitted from NuSea/SeaQuest data:
Deuteron breaks into quarks

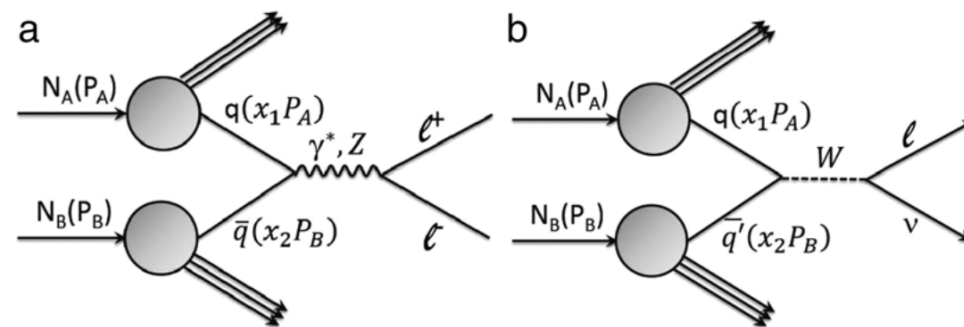
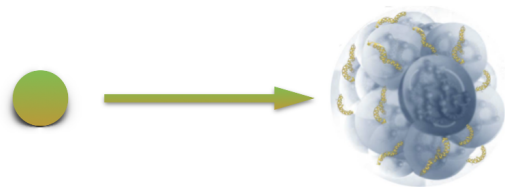
LMDF fitted from electromagnetic form factors:
Deuteron overall shape

[Phys. Rev. D 113, 054008 \(2026\)](#)



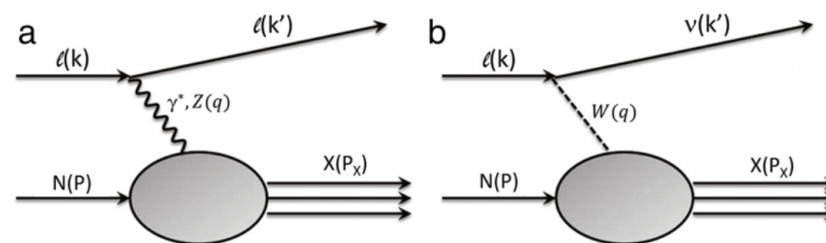
进一步的实验测量

利用Drell-Yan过程测量高能原子核反应



Drell-Yan过程：可选择价、海夸克进行研究

Drell-Yan过程是 $q\bar{q}$ 反应，可以通过调节束流能量、选择末态相空间来实现对 q 、 \bar{q} 的选择



DIS过程：价夸克主导

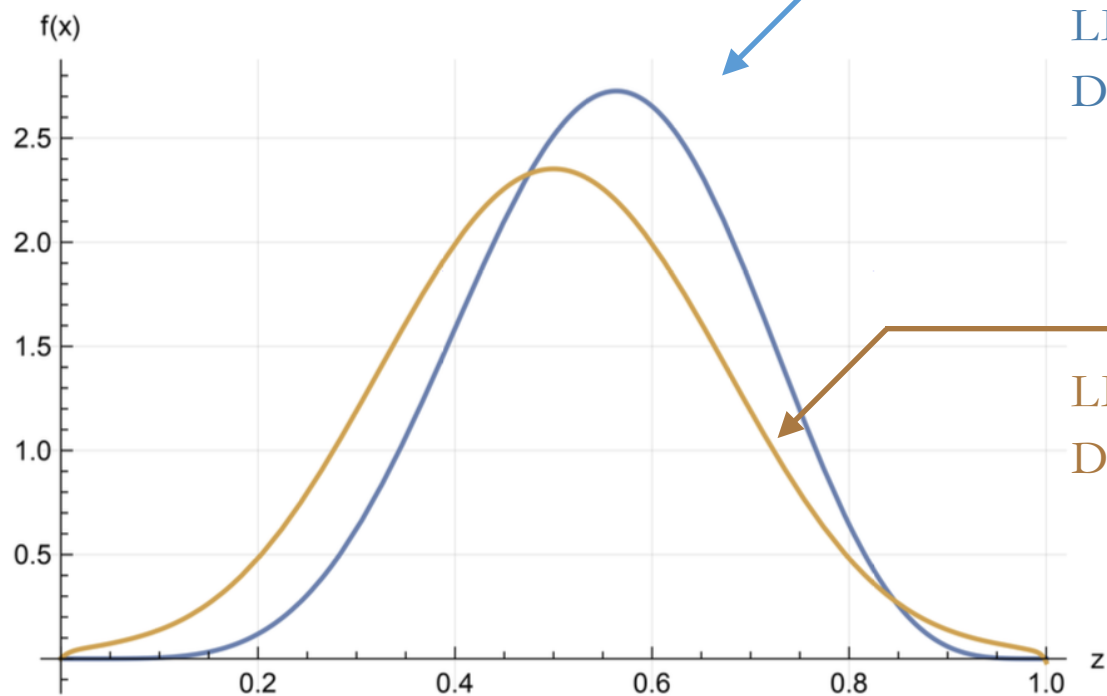
Thanks



- Light quark ratio measurement achieved in pure proton data
- Discrepancy compared to deuteron experiments:
No SU(2) flavor asymmetry? Non-classic nuclear structure?
- A new frontier:
Proton structure from proton interactions
New experiments on deuteron
Phenomenology studies
First principle calculation/Lattice QCD/Confinement

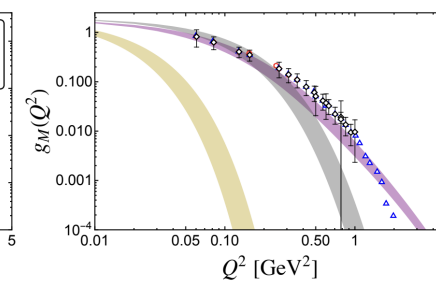
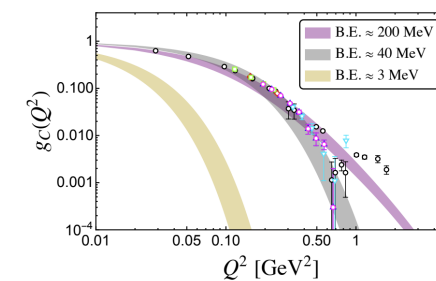
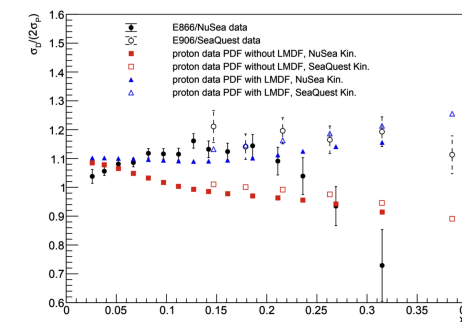
Other indirect experimental hints

- LMDF fitting: large smearing
consistent results from quark-level interactions and electromagnetic form factors



LMDF fitted from NuSea/SeaQuest data:
Deuteron breaks into quarks

LMDF fitted from electromagnetic form factors:
Deuteron overall shape



Lack of constraints due to quark mixture

	mixed quarks	x range
γ DIS	$u(x) + \bar{u}(x) + \frac{1}{4}d(x) + \frac{1}{4}\bar{d}(x) + \mathcal{O}(s, c, b, \dots)$	$x \sim \mathcal{O}(0.001)$ to $\mathcal{O}(0.1)$
Z DIS (lower precision)	$u(x) + \bar{u}(x) + 1.2d(x) + 1.2\bar{d}(x) + \mathcal{O}(s, c, b, \dots)$	$x \sim \mathcal{O}(0.1)$
W^+ DIS (lower precision)	$u(x) + \bar{d}(x) + \mathcal{O}(s, c, b, \dots)$	$x \sim \mathcal{O}(0.01)$ to $\mathcal{O}(0.1)$
W^- DIS (lower precision)	$u(x) + \bar{d}(x) + \mathcal{O}(s, c, b, \dots)$	$x \sim \mathcal{O}(0.01)$ to $\mathcal{O}(0.1)$
γ Drell-Yan Target	$u(x_1)\bar{u}(x_2) + \bar{u}(x_1)u(x_2) + 1.2d(x_1)\bar{d}(x_2) + 1.2\bar{d}(x_1)d(x_2) + \mathcal{O}(s, c, b, \dots)$	$x_{1,2} \sim \mathcal{O}(0.1)$
Z Drell-Yan LHC	$u(x_1)\bar{u}(x_2) + \bar{u}(x_1)u(x_2) + 1.2d(x_1)\bar{d}(x_2) + 1.2\bar{d}(x_1)d(x_2) + c\bar{c}(x_1, x_2) + 1.2s\bar{s}(x_1, x_2) + 1.2b\bar{b}(x_1, x_2) + \mathcal{O}(qg, \dots)$	$x_1 \sim \mathcal{O}(0.01)$ to $\mathcal{O}(0.1)$ $x_2 \sim \mathcal{O}(0.0001)$ to $\mathcal{O}(0.01)$
Z Drell-Yan Tevatron (lower precision)	$u(x_1)u(x_2) + \bar{u}(x_1)\bar{u}(x_2) + 1.2d(x_1)d(x_2) + 1.2\bar{d}(x_1)\bar{d}(x_2) + c\bar{c}(x_1, x_2) + 1.2s\bar{s}(x_1, x_2) + 1.2b\bar{b}(x_1, x_2) + \mathcal{O}(qg, \dots)$	$x_1 \sim \mathcal{O}(0.1)$ $x_2 \sim \mathcal{O}(0.01)$
W^+ Drell-Yan LHC	$u(x_1)\bar{d}(x_2) + \bar{d}(x_1)u(x_2) + c(x_1)\bar{s}(x_2) + s(x_1)\bar{c}(x_2) + \mathcal{O}(q_i\bar{q}_j, qg, \dots)$	$x_1 \sim \mathcal{O}(0.01)$ to $\mathcal{O}(0.1)$ $x_2 \sim \mathcal{O}(0.0001)$ to $\mathcal{O}(0.01)$
W^- Drell-Yan LHC	$d(x_1)\bar{u}(x_2) + \bar{u}(x_1)d(x_2) + s(x_1)\bar{c}(x_2) + c(x_1)\bar{s}(x_2) + \mathcal{O}(q_i\bar{q}_j, qg, \dots)$	$x_1 \sim \mathcal{O}(0.01)$ to $\mathcal{O}(0.1)$ $x_2 \sim \mathcal{O}(0.0001)$ to $\mathcal{O}(0.01)$
W^+ Drell-Yan Tevatron	$u(x_1)d(x_2) + \bar{d}(x_1)\bar{u}(x_2) + c(x_1)s(x_2) + \bar{s}(x_1)\bar{c}(x_2) + \mathcal{O}(q_i\bar{q}_j, qg, \dots)$	$x_1 \sim \mathcal{O}(0.1)$ $x_2 \sim \mathcal{O}(0.01)$
W^- Drell-Yan Tevatron	$d(x_1)u(x_2) + \bar{u}(x_1)\bar{d}(x_2) + s(x_1)c(x_2) + \bar{c}(x_1)\bar{s}(x_2) + \mathcal{O}(q_i\bar{q}_j, qg, \dots)$	$x_1 \sim \mathcal{O}(0.1)$ $x_2 \sim \mathcal{O}(0.01)$

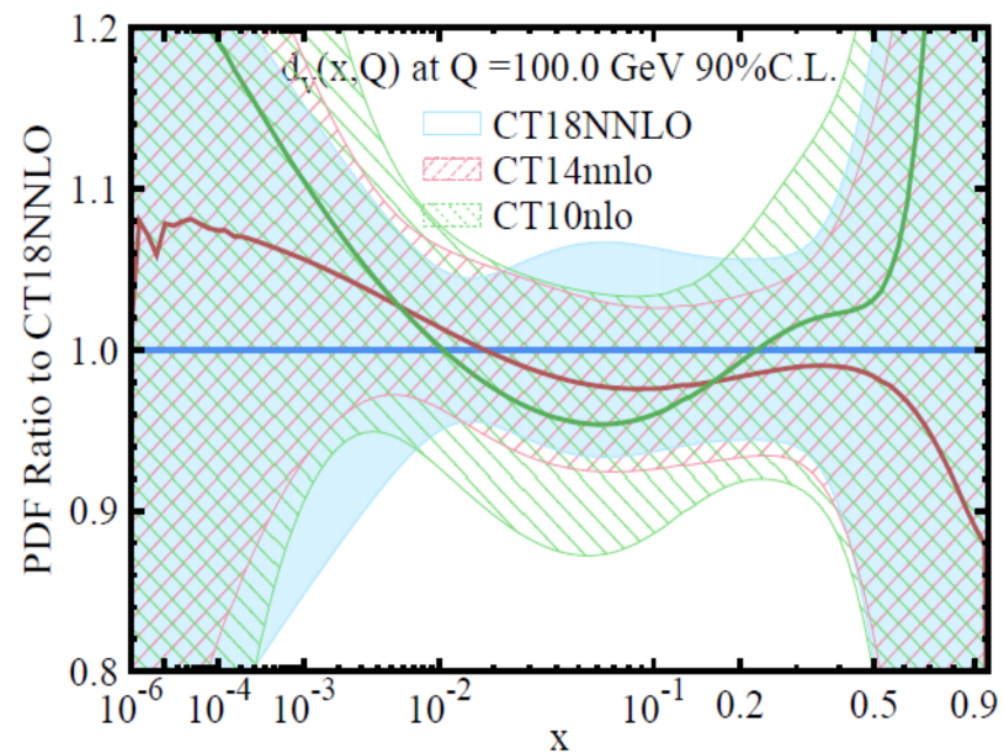
These are quark sums. Where is quark ratio ?

The experimental inputs are not enough to constrain a “complete” PDF global analysis, making the current PDF highly depends on various assumptions

More about PDF

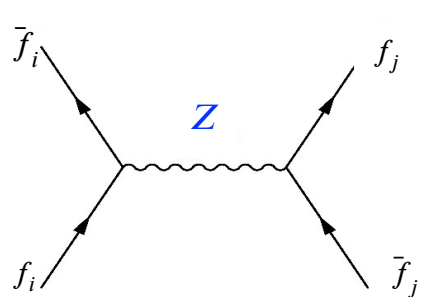
More observable, not higher precision

$$\sigma_{DY}^{pp} \sim \mathcal{N}_{u\bar{u}} u(x_1)\bar{u}(x_2) + \mathcal{N}_{d\bar{d}} d(x_1)\bar{d}(x_2) + \dots$$



More about PDF

How did we come to this



$$- \frac{g}{2 \cos \theta_W} \sum_i \bar{\psi}_i \gamma^\mu (g_V^i - g_A^i \gamma^5) \psi_i Z_\mu$$

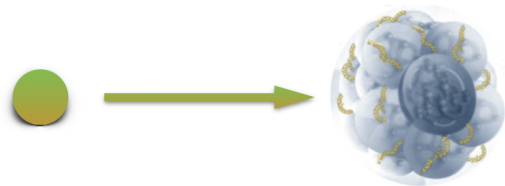
$$g_V^i \equiv t_{3L}(i) - 2q_i \sin^2 \theta_W,$$

$$g_A^i \equiv t_{3L}(i),$$

Experiments	Total unc. on $\sin^2 \theta_W$	PDF-induced uncertainty
LEP/SLC	0.00029/0.00026	-
Tevatron	0.00033	0.00018
LHC	expected. ~ 0.00010 for stat. and syst.	0.00034 (CT14)
		0.00038 (CT18)

What do we learn ?

Measurements on deuteron in Drell-Yan process



Why Drell-Yan?

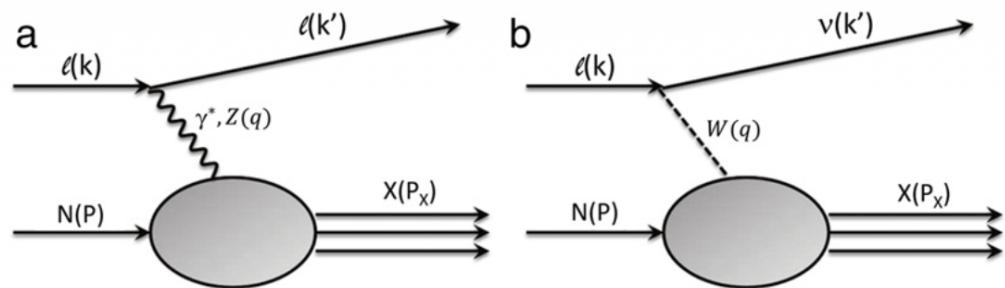
With high energy hadron beam (or boosted forward kinematics), it is easy to individually probe anti-quarks and quarks inside deuteron

Probing anti-quarks in deuteron	Hadron beam \rightarrow deuteron target
	Hadron \rightarrow deuteron collision boosted toward deuteron direction
Probing quarks in deuteron	Deuteron beam \rightarrow hadron target
	Hadron \rightarrow deuteron collision boosted toward hadron direction

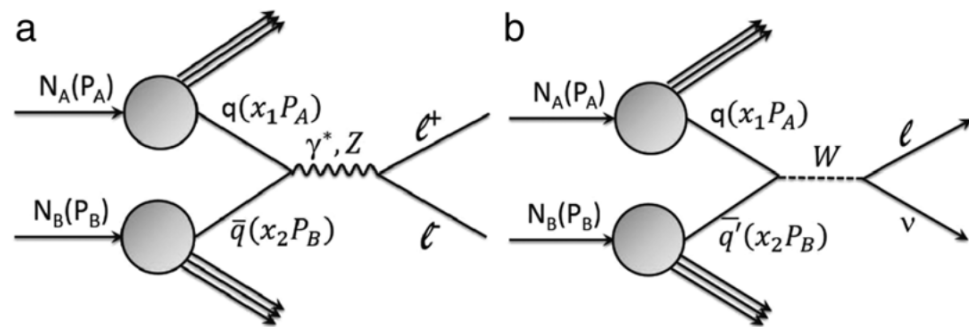
\bar{d}/\bar{u} 的实验测量

HERA? Tevatron? LHC? No!

- HERA/Tevatron/LHC do produce light quark interactions, but not \bar{d}/\bar{u}
- The observed cross sections of DIS/Drell-Yan processes are mixture of all light quarks, experimentally indistinguishable



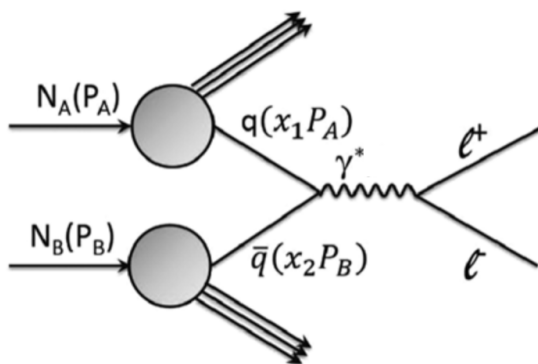
DIS, typically at HERA



Drell-Yan, typically at Tevatron/LHC

高能质子-氘核/质子-质子打靶实验

➤ 高能质子束流(800 GeV/120 GeV)轰击氘靶 vs. 氢靶



$$\frac{d^2\sigma}{dx_b dx_t} = \frac{4\pi\alpha^2}{9s x_b x_t} \sum_q e_q^2 [q(x_b)\bar{q}(x_t) + \bar{q}(x_b)q(x_t)]$$

$$\begin{aligned} \frac{\sigma_{pD}}{\sigma_{pp}} &= \frac{\sigma_{pp} + \sigma_{pn}}{\sigma_{pp}} = 1 + \frac{\sigma_{pn}}{\sigma_{pp}} \\ &\approx 1 + \frac{4u_p\bar{u}_n + d_p\bar{d}_n}{4u_p\bar{u}_p + d_p\bar{d}_p} = 1 + \frac{4u_p\bar{d}_p + d_p\bar{u}_p}{4u_p\bar{u}_p + d_p\bar{d}_p} \\ &= 1 + \frac{\frac{\bar{d}_p}{u_p} + \frac{d_p}{4u_p}}{1 + \frac{d_p}{4u_p}} \approx 1 + \frac{\bar{d}_p}{u_p} \end{aligned}$$

High energy proton beam and stationary target



Anti-quarks come from target

Kinematics designed at the peak of valence quarks $x_t \sim \mathcal{O}(0.1)$



s, c, b, g contributions suppressed

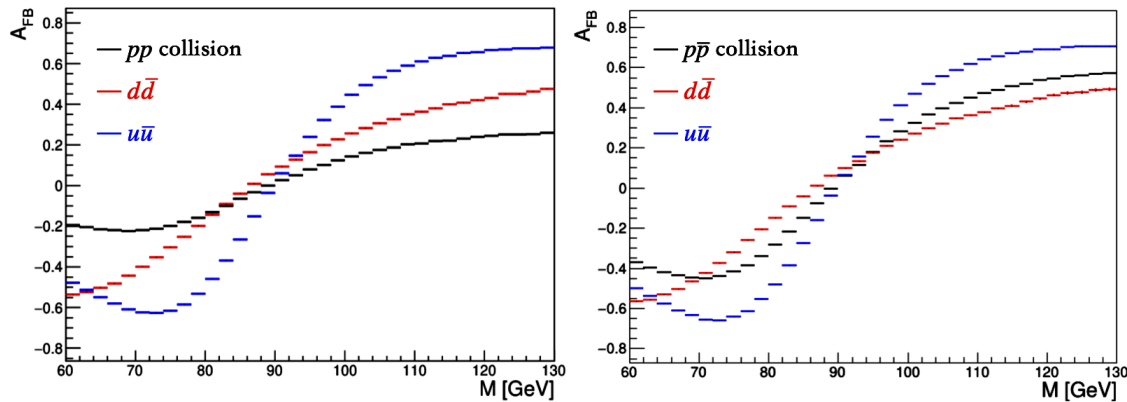
~ 10 GeV high energy interactions, γ -exchanged



u/d contribution suppressed

Factorization on A_{FB}

Proton structure parameters defined in the observed A_{FB} spectrum



$$A_{FB}^h = C_u[u(x); \bar{u}(x)] \times A_{FB}^u[\sin^2 \theta_W] + C_d[d(x); \bar{d}(x)] \times A_{FB}^d[\sin^2 \theta_W]$$

- Observed $A_{FB} =$ combination of A_{FB}^u and A_{FB}^d
- Weighted by the structure parameter C_u and C_d
- Strictly holds at all orders of QCD

$$C_u(x_1, x_2) = \frac{[u(x_1)\bar{u}(x_2) - \bar{u}(x_1)u(x_2)] \mathcal{N}_u}{\sum_{q=u,d,s,c,b} [q(x_1)\bar{q}(x_2) + \bar{q}(x_1)q(x_2)] \mathcal{N}_q}$$

$$C_d(x_1, x_2) = \frac{[d(x_1)\bar{d}(x_2) - \bar{d}(x_1)d(x_2)] \mathcal{N}_d}{\sum_{q=u,d,s,c,b} [q(x_1)\bar{q}(x_2) + \bar{q}(x_1)q(x_2)] \mathcal{N}_q}$$

For LHC's pp collisions

$$C_u(x_1, x_2) = \frac{[u(x_1)u(x_2) - \bar{u}(x_1)\bar{u}(x_2)] \mathcal{N}_u}{\sum_{q=u,d,s,c,b} [q(x_1)q(x_2) + \bar{q}(x_1)\bar{q}(x_2)] \mathcal{N}_q}$$

$$C_d(x_1, x_2) = \frac{[d(x_1)d(x_2) - \bar{d}(x_1)\bar{d}(x_2)] \mathcal{N}_d}{\sum_{q=u,d,s,c,b} [q(x_1)q(x_2) + \bar{q}(x_1)\bar{q}(x_2)] \mathcal{N}_q}$$

For Tevatron's $p\bar{p}$ collisions

[Chinese Phys. C 45 \(2021\) 053001](#)

[Eur. Phys. J. C82 \(2022\) 368](#)

[Phys. Rev. D106 \(2022\) 033001](#)

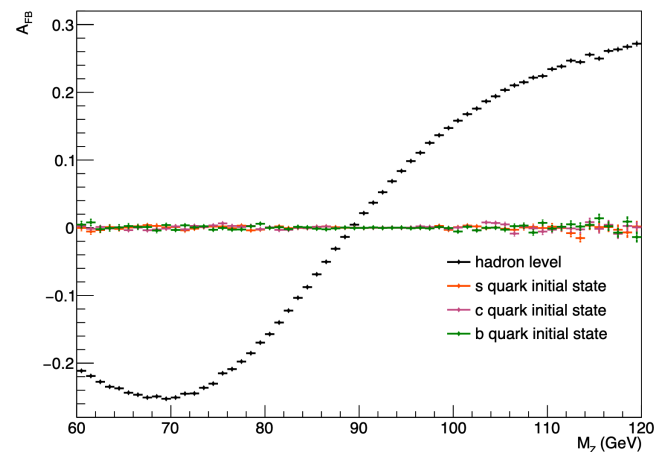
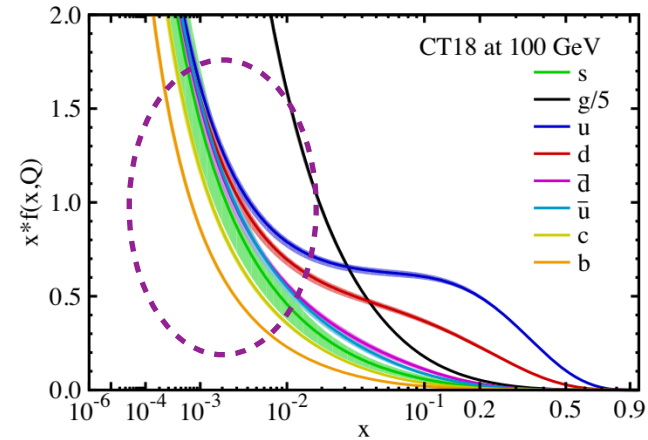
Factorization on A_{FB}

$$R = \frac{C_d}{C_u} \propto \frac{d(x_1)\bar{d}(x_2) - d(x_2)\bar{d}(x_1)}{u(x_1)\bar{u}(x_2) - u(x_2)\bar{u}(x_1)} \approx \frac{d(x_1) - \bar{d}(x_1)}{u(x_1) - \bar{u}(x_1)} \sim \frac{\bar{d}}{\bar{u}}$$

$$x_{1,2} = \frac{\sqrt{M^2 + Q_T^2}}{\sqrt{s}} \times e^{\pm Y}$$

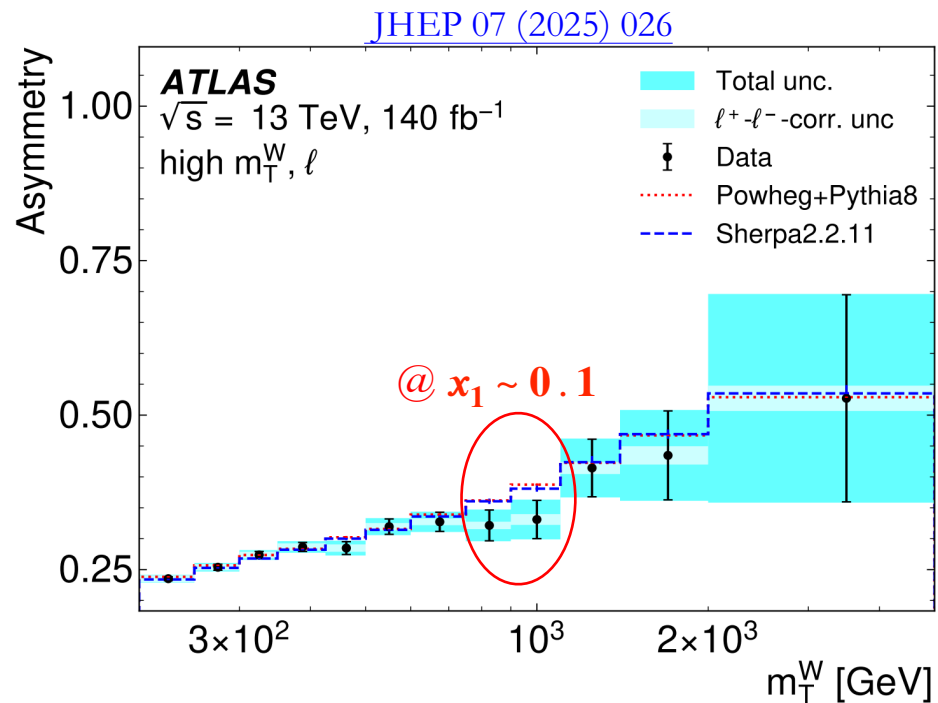
- Light quark distributions are consistent at $x_2 < 0.01$ so that x_2 terms cancelled in the ratio. The R parameter is dominated by the $x_1 \sim 0.1$ information
- Contributions of s , c , and b quarks are significantly suppressed as they have consistent anti-quark and quark distributions

In conclusion: R is an experimental observable in pure proton interactions which is very sensitive to \bar{d}/\bar{u}



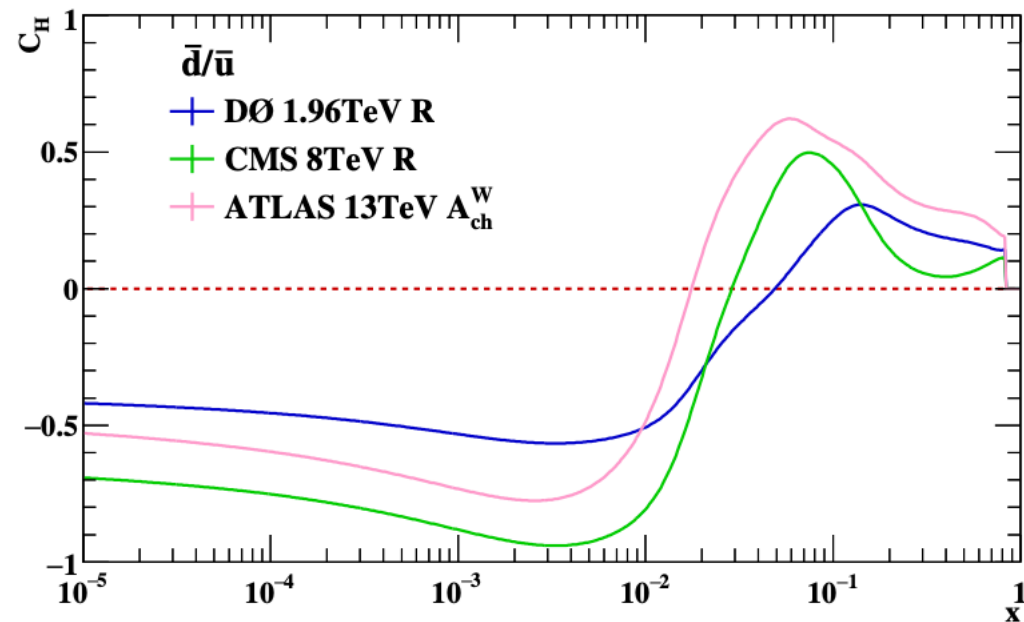
Other indirect experimental hints

- ATLAS W^\pm -asymmetry measurement.
Reaching large x at TeV high m_T



$$A_{ch}^W \equiv \frac{\sigma_{W^+} - \sigma_{W^-}}{\sigma_{W^+} + \sigma_{W^-}}$$

- Correlation study of W/Z -asymmetry at hadron colliders:

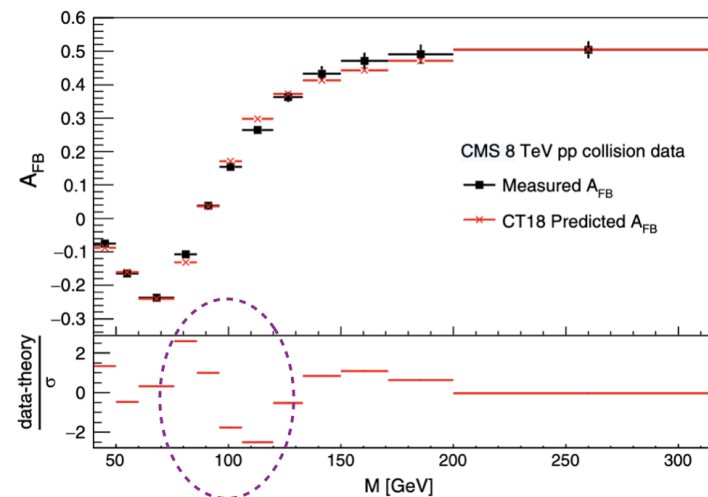
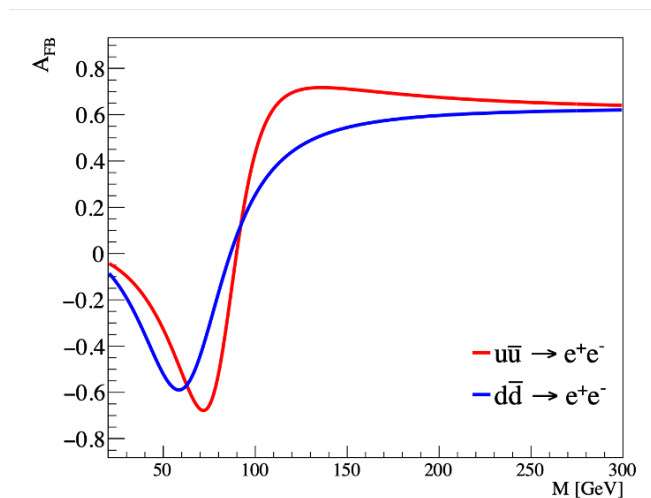


[Chin. Phys. C 50 \(2026\) 023107](#)

$$A_{ch}^W \propto \frac{u\bar{d}}{d\bar{u}} \sim \frac{\bar{d}}{\bar{u}}$$

实验测量 A_{FB}

实验观测到的 A_{FB} 与PDF有偏差



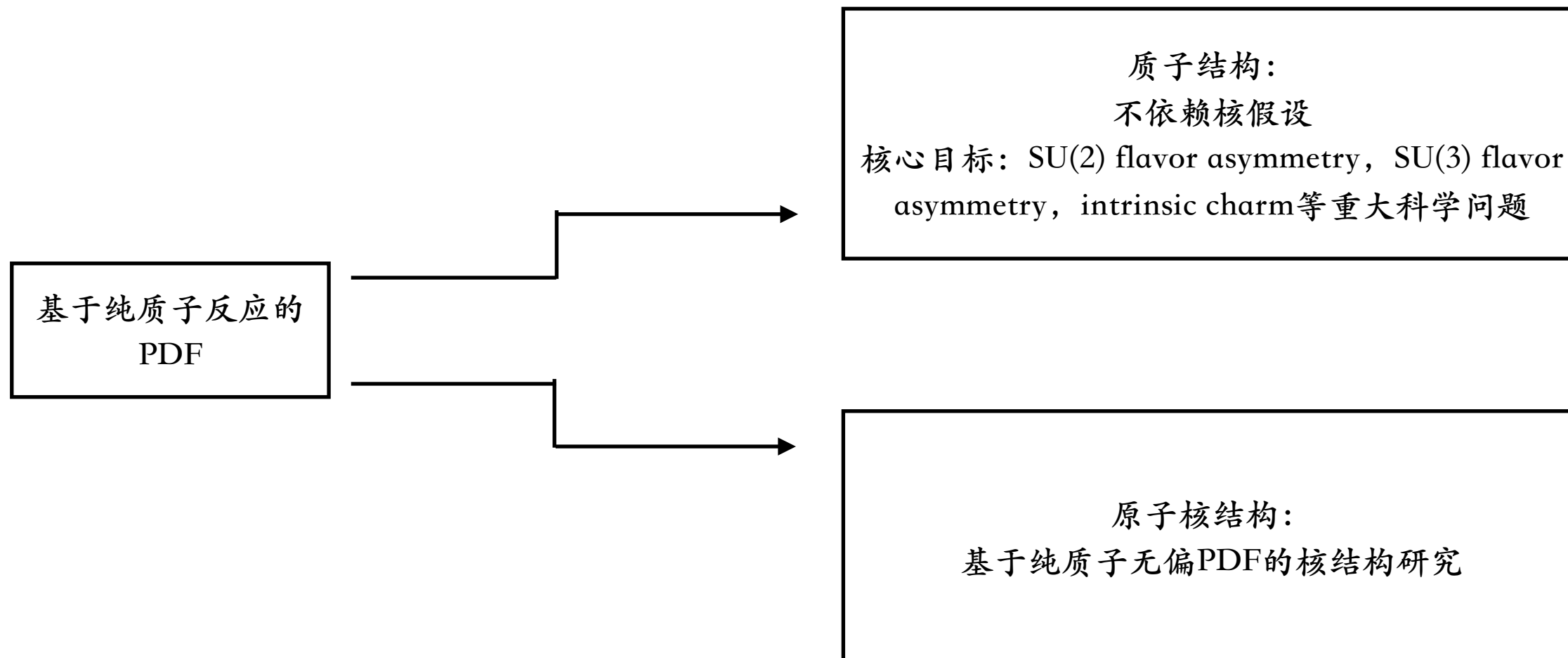
➤ A_{FB} 实验观测结果比PDF压低

➤ A_{FB}^d 弱于 A_{FB}^u , 因此较低的 A_{FB} 观测值必然导致 \bar{d}/\bar{u} 变低且 d/u 变高

$$R = \frac{C_d}{C_u} \propto \frac{d - \bar{d}}{u - \bar{u}}$$

新方向：基于纯质子反应的PDF研究

目标：以新实验观测全面替代高能原子核实验数据



新方向：基于纯质子反应的PDF研究

研究路径：引入新的质子反应测量

传统截面测量

不对称性新测量

<p>中性流DIS过程</p> $\sigma(\text{DIS } Z/\gamma^*) \sim u(x) + d(x) + \bar{u}(x) + \bar{d}(x) + \dots$	<p>W^+W^-过程boost asymmetry:</p> $A_{boost}^{WW} \sim q(x_1)\bar{q}(x_2) - q(x_2)\bar{q}(x_1)$
<p>带电流DIS过程 (e^+p散射)</p> $\sigma(\text{DIS } W^+) \sim u(x) + \bar{d}(x) + \dots$	<p>$W^+\gamma(W^+Z)$过程boost asymmetry:</p> $A_{boost}^{W^+\gamma, W^+Z} \sim u(x_1)\bar{d}(x_2) - u(x_2)\bar{d}(x_1)$
<p>带电流DIS过程 (e^+p散射)</p> $\sigma(\text{DIS } W^-) \sim d(x) + \bar{u}(x) + \dots$	<p>$W^-\gamma(W^-Z)$过程boost asymmetry:</p> $A_{boost}^{W^-\gamma, W^-Z} \sim d(x_1)\bar{u}(x_2) - d(x_2)\bar{u}(x_1)$
<p>中性流Drell-Yan过程 ($p\bar{p}$对撞)</p> $\sigma_{pp}(\text{DY } Z/\gamma^*) \sim u(x_1)\bar{u}(x_2) + u(x_2)\bar{u}(x_1) + d(x_1)\bar{d}(x_2) + d(x_2)\bar{d}(x_1) + \dots$	<p>中性流空间不对称性结构参数 ($p\bar{p}$对撞):</p> $D_{pp}(A_{FB}) \sim u(x_1)u(x_2) - d(x_1)d(x_2)$ $S_{pp}(A_{FB}) \sim q(x_1)q(x_2) _{q=u,d} - q(x_1)q(x_2) _{q=s,c,b}$
<p>带电流Drell-Yan过程 ($p\bar{p}$对撞):</p> $\sigma_{pp}(\text{DY } W^+) \sim u(x_1)d(x_2) + \dots$ $\sigma_{pp}(\text{DY } W^-) \sim u(x_2)d(x_1) + \dots$	<p>中性流空间不对称性结构参数 (pp对撞):</p> $C_{pp}^u(A_{FB}) \sim u(x_1)\bar{u}(x_2) - u(x_2)\bar{u}(x_1)$ $C_{pp}^d(A_{FB}) \sim d(x_1)\bar{d}(x_2) - d(x_2)\bar{d}(x_1)$
<p>带电流Drell-Yan过程 (pp对撞):</p> $\sigma_{pp}(\text{DY } W^+) \sim u(x_1)\bar{d}(x_2) + u(x_2)\bar{d}(x_1) + \dots$ $\sigma_{pp}(\text{DY } W^-) \sim d(x_1)\bar{u}(x_2) + d(x_2)\bar{u}(x_1) + \dots$	

[Phys. Rev. D 113, L011504 \(2026\)](#)

[arXiv: 2603.22478](#)

[Chin. Phys. C 50, 023107 \(2026\)](#)

[Phys. Rev. D 112 074028 \(2025\)](#)

[arXiv: 2510.08941](#)

[JHEP 08, 142 \(2025\)](#)

[Phys. Rev. D 111, 036018 \(2025\)](#)

[Phys. Rev. D 110, L091101 \(2024\)](#)

[Phys. Rev. D 107, 054008 \(2023\)](#)

[Phys. Rev. D 106, L051301 \(2022\)](#)

[Phys. Rev. D 106, 033001 \(2022\)](#)

[Eur. Phys. J. C 82, 368 \(2022\)](#)

[Chin. Phys. C 45, 053001 \(2021\)](#)

