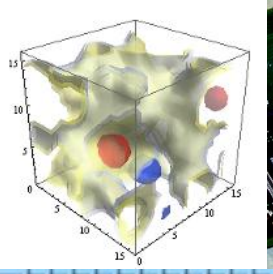
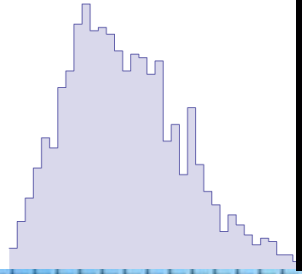
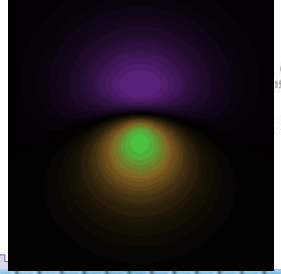
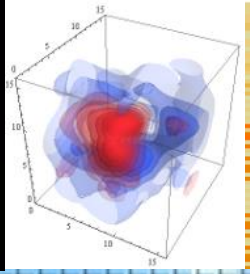
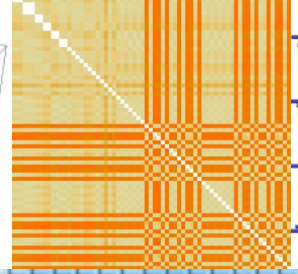
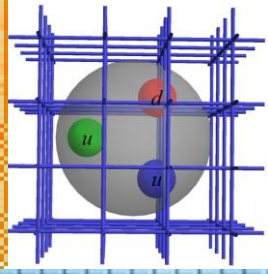


Constraining PDFs for New-Physics Searches

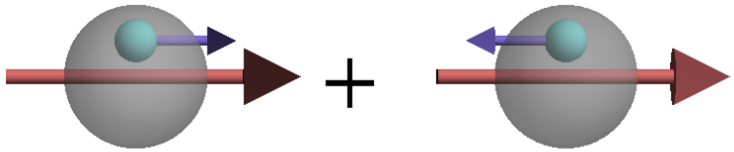
Huey-Wen Lin

Parton Distribution Functions

§ PDFs are universal quark/gluon distributions inside nucleon

§ Quark distribution $q(x)$

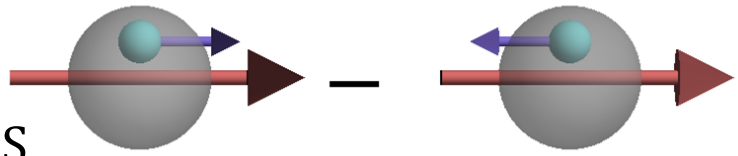
- Processes: DIS (F_2, σ), Drell-Yan, W-asymmetry, Z-rapidity, (γ+) jet, …
- Experiments: BCDMS, NMC, SLAC, JLab, HERA, E866, CDF, DØ,…



spin-averaged/unpolarized

§ Helicity distribution $\Delta q(x)$

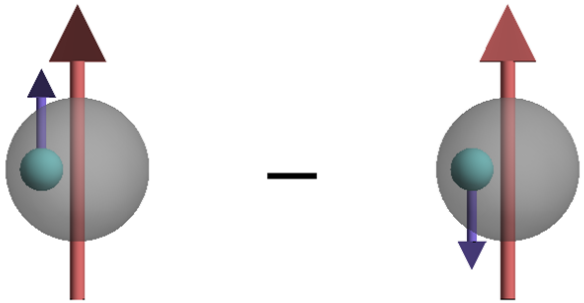
- Processes: polarized DIS, semi-inclusive DIS, photo- and electroproduction of hadrons and charm, pp collisions
- Experiments: EMC, HERMES, Hall A, CLAS, COMPASS, STAR, PHENIX, …



spin-dep./long. polarized

§ Transversity distribution $\delta q(x)$

- Process: single-spin asymmetry in SIDIS, …
- Experiments: HERMES, COMPASS, Belle…



transversely polarized

Parton Distribution Functions

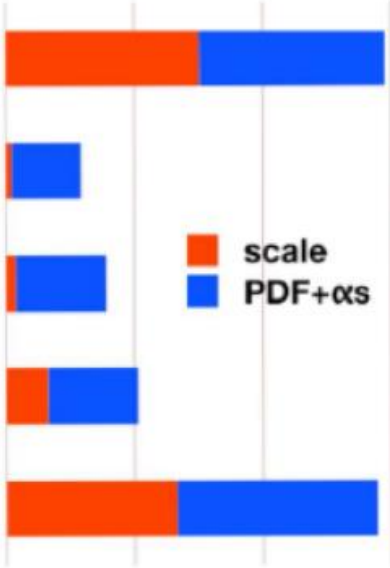
§ PDFs are universal quark/gluon distributions inside nucleon

§ Important inputs to discern new physics at LHC

↝ Currently dominate errors in Higgs production

HIGGS PRODUCTION

		σ (8 TeV)	uncertainty
NNLL QCD +NLO EW	gg→H	19.5 pb	14.7%
	VBF	1.56 pb	2.9%
NNLO QCD +NLO EW	WH	0.70 pb	3.9%
	ZH	0.39 pb	5.1%
NLO QCD	ttH	0.13 pb	14.4%

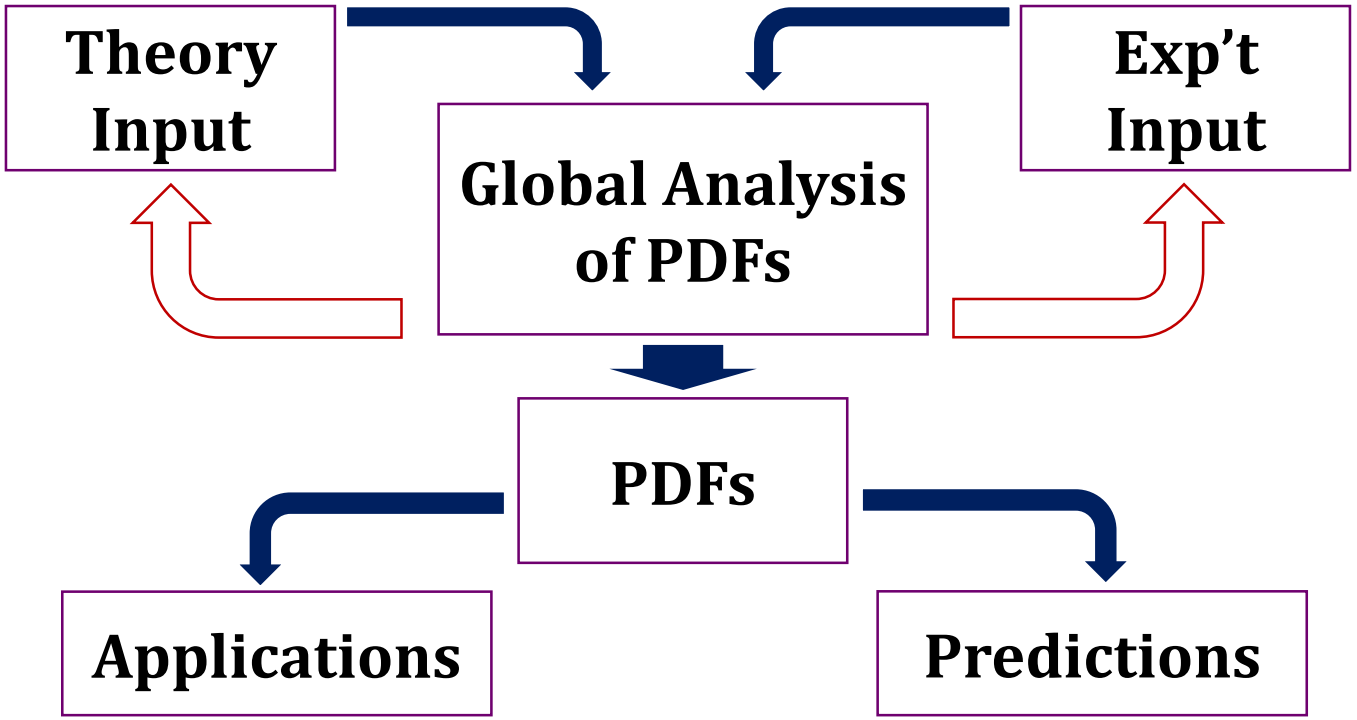


(J. Campbell, HCP2012)

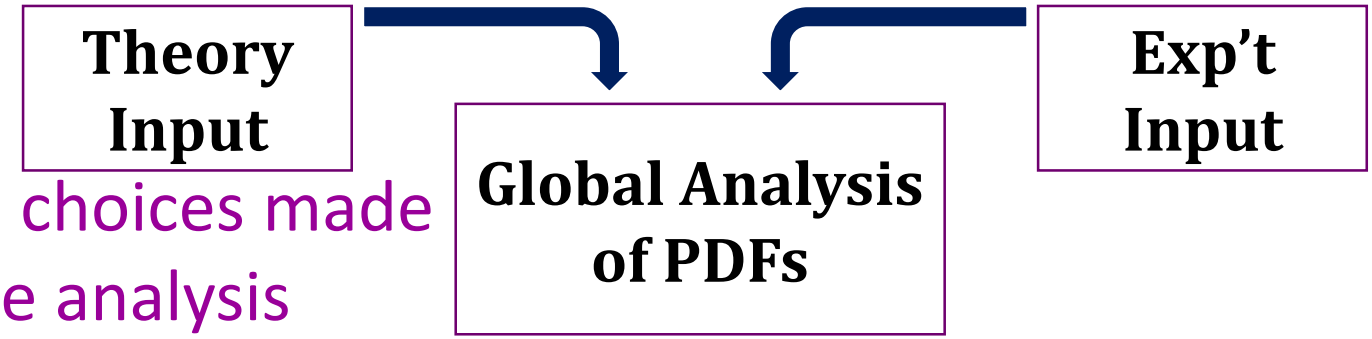
Global Analysis

§ Experiments cover diverse kinematics of parton variables

- Global analysis takes advantage of all data sets



Global Analysis



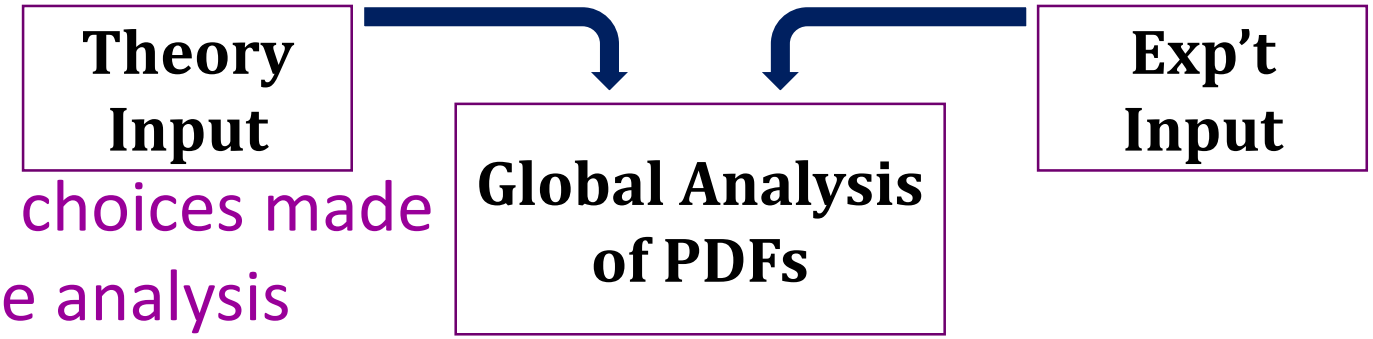
§ Some choices made for the analysis

- Choice of data sets and kinematic cuts
- Strong coupling constant $\alpha_s(M_Z)$
- How to parametrize the distribution

$$f(x,\mu_0) = a_0 x^{a_1}(1-x)^{a_2} P(x)$$

$$P(x) = \begin{cases} 1 + a_3 x + a_4 x^2 \\ e^{a_3 x}(1 + e^{a_4} x)^{a_5} \end{cases}$$

Global Analysis



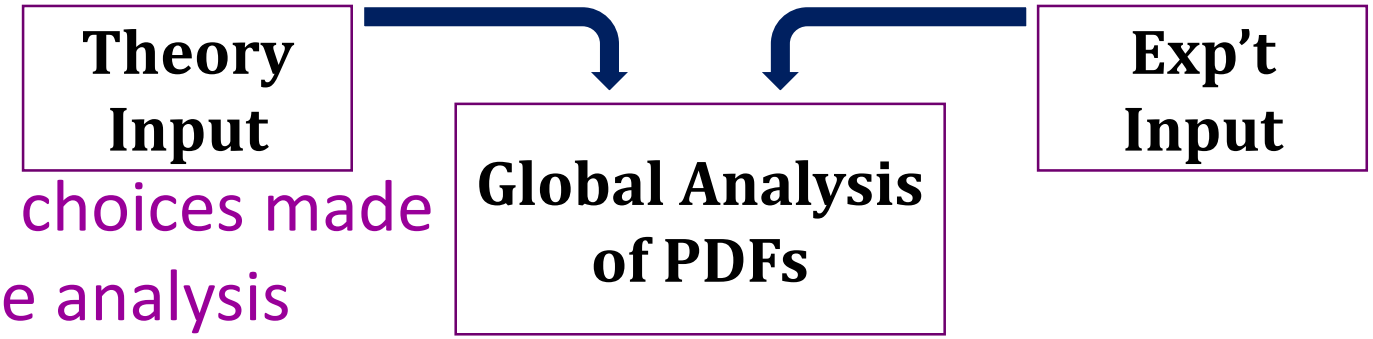
§ Some choices made for the analysis

- Choice of data sets and kinematic cuts
- Strong coupling constant $\alpha_s(M_Z)$
- How to parametrize the distribution
- Assumptions imposed

  SU(3) flavor symmetry, charge symmetry, strange and sea distributions

For example, $s = \bar{s} = \kappa(\bar{u} + \bar{d})$
or symmetric sea in helicity

Global Analysis



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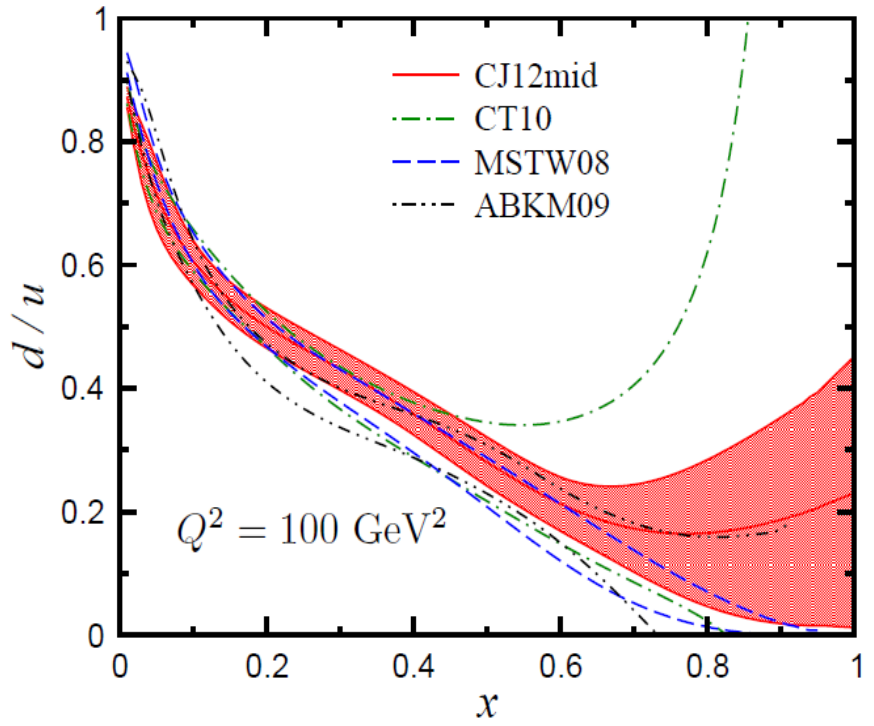
  SU(3) flavor symmetry, charge symmetry, strange and sea distributions

Discrepancies appear when data is scarce

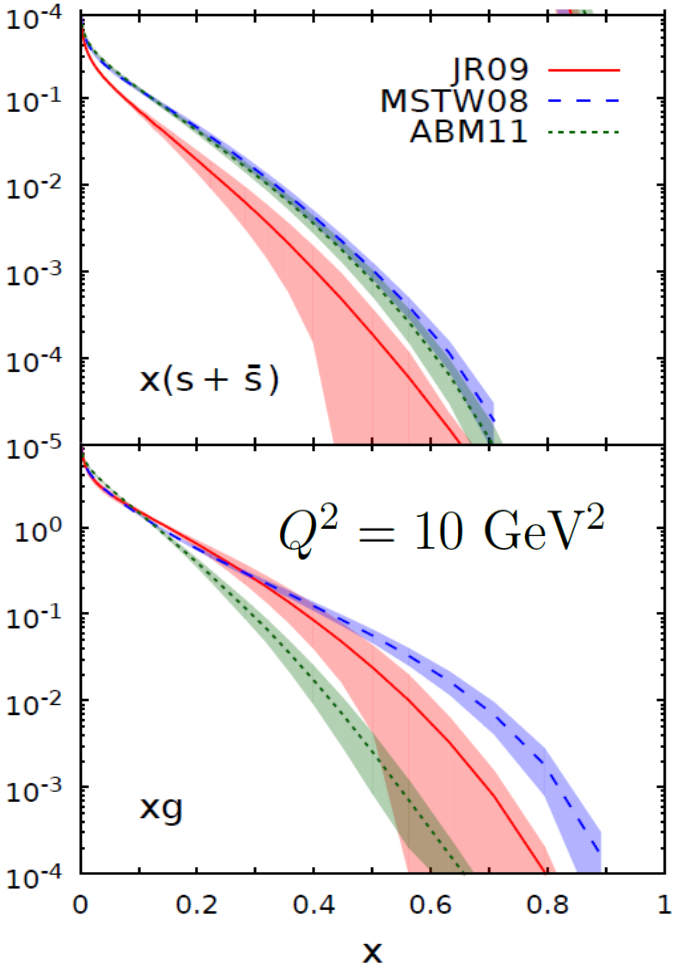
Global Analysis

§ Many groups have tackled the analysis

- CTEQ, MSTW, ABM, JR, NNPDF, etc.



Jimenez-Delgado, Melnitchouk, Owens, J.Phys. G40 (2013) 09310



PDFs on the Lattice

Long existing obstacles!

§ Lattice calculations rely on operator product expansion,
only pr

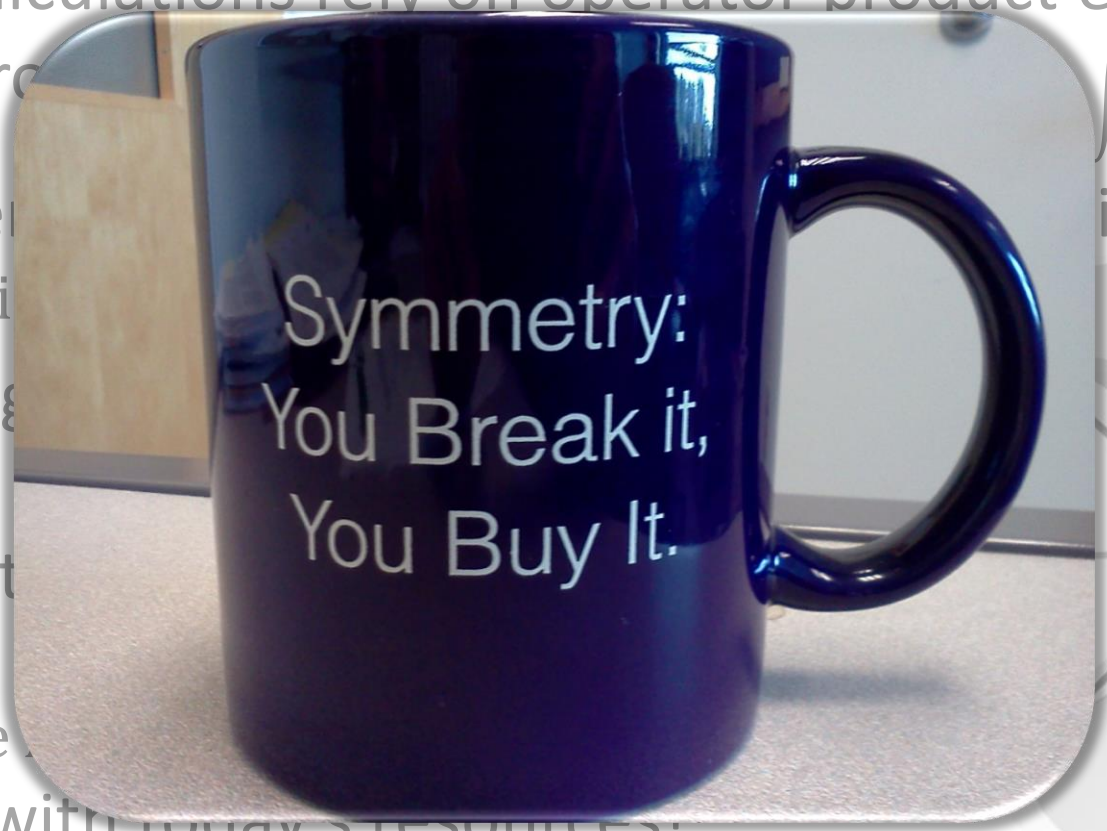
$$\int_{-1}^{1} dx\, x^{n-1} q(x)$$

§ For highe imension ops
↝ No practi

New Strateg

§ Calculate
quark dist
↝ In $P_z \to \infty$
↝ For finite

§ Feasible with today's resources?



Xiangdong Ji, Phys. Rev. Lett. 111, 039103 (2013)

PDFs on the Lattice

Long existing obstacles!

§ Lattice calculations rely on operator product expansion, only provide moments $\langle x^n \rangle$

$$\langle x^{n-1} \rangle_q = \int_{-1}^{1} dx\, x^{n-1} q(x)$$

§ For higher moments, all ops mix with lower-dimension ops

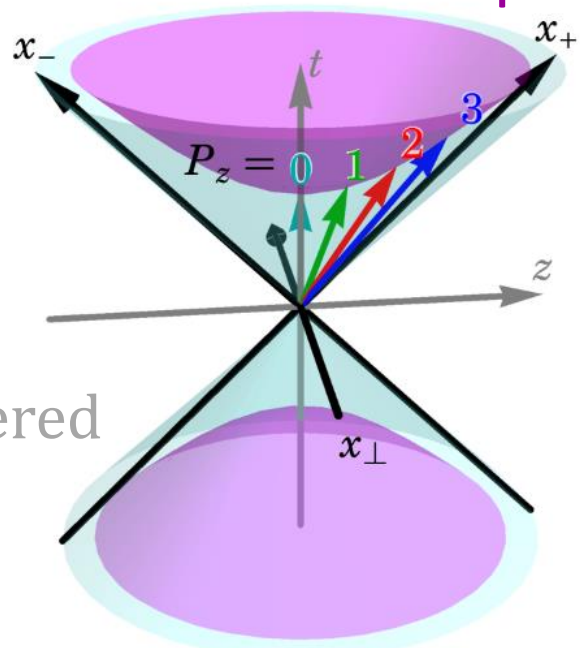
- No practical proposal to overcome this

New Strategy (LaMET):

§ Calculate finite-momentum boosted quark distribution

- In $P_z \to \infty$ limit, parton distribution is recovered
- For finite P_z, corrections are needed

§ Feasible with today's resources!



Xiangdong Ji, Phys. Rev. Lett. 111, 039103 (2013)

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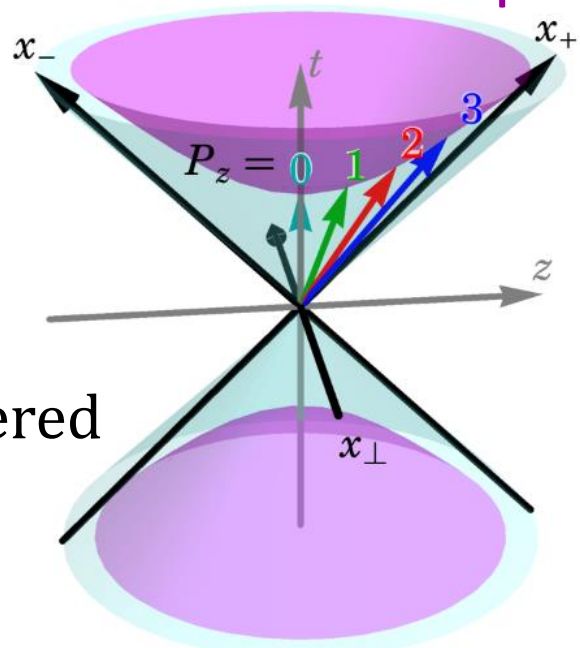
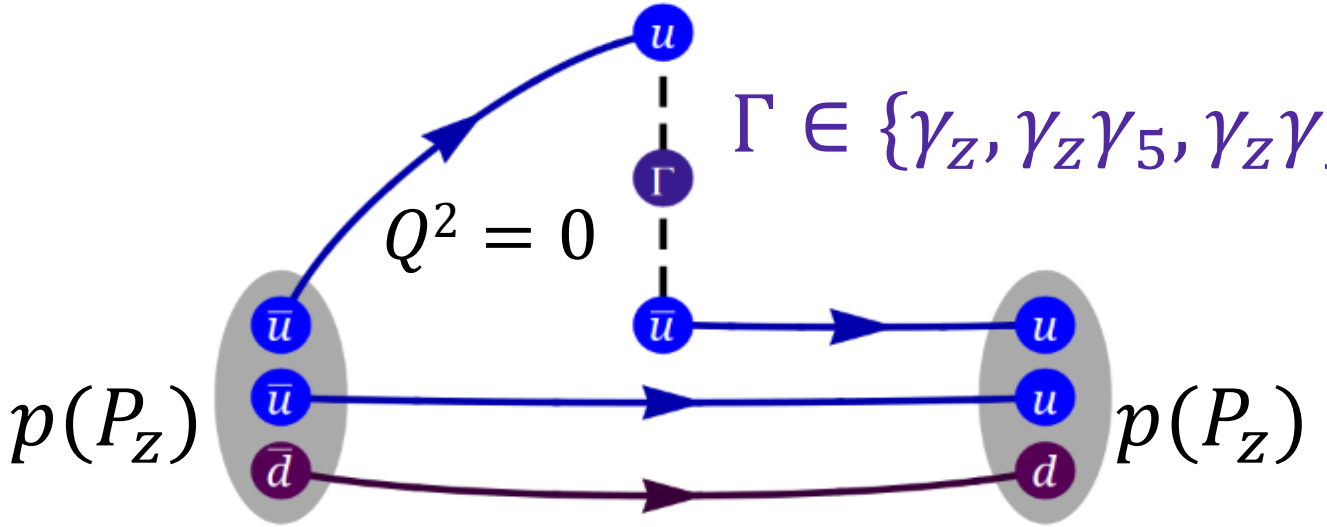


Xiangdong Ji, Phys. Rev. Lett. 111, 039103 (2013)

Parton Distribution Functions

Large-Momentum Effective Theory for PDFs

$$\int \frac{dz}{4\pi} e^{-izk_z} \left\langle P \left| \bar{\psi}(z)\, \Gamma \exp\left(-ig \int_0^z dz'\, A_z(z')\right) \psi(0) \right| P \right\rangle$$



$P_z \to \infty$ limit

$$q(x,\mu) = \tilde{q}(x,\mu,P_z) + \mathcal{O}(\alpha_s) + \mathcal{O}(M_N^2/P_z^2) + \mathcal{O}\left(\Lambda_{\rm QCD}^2/P_z^2\right)$$

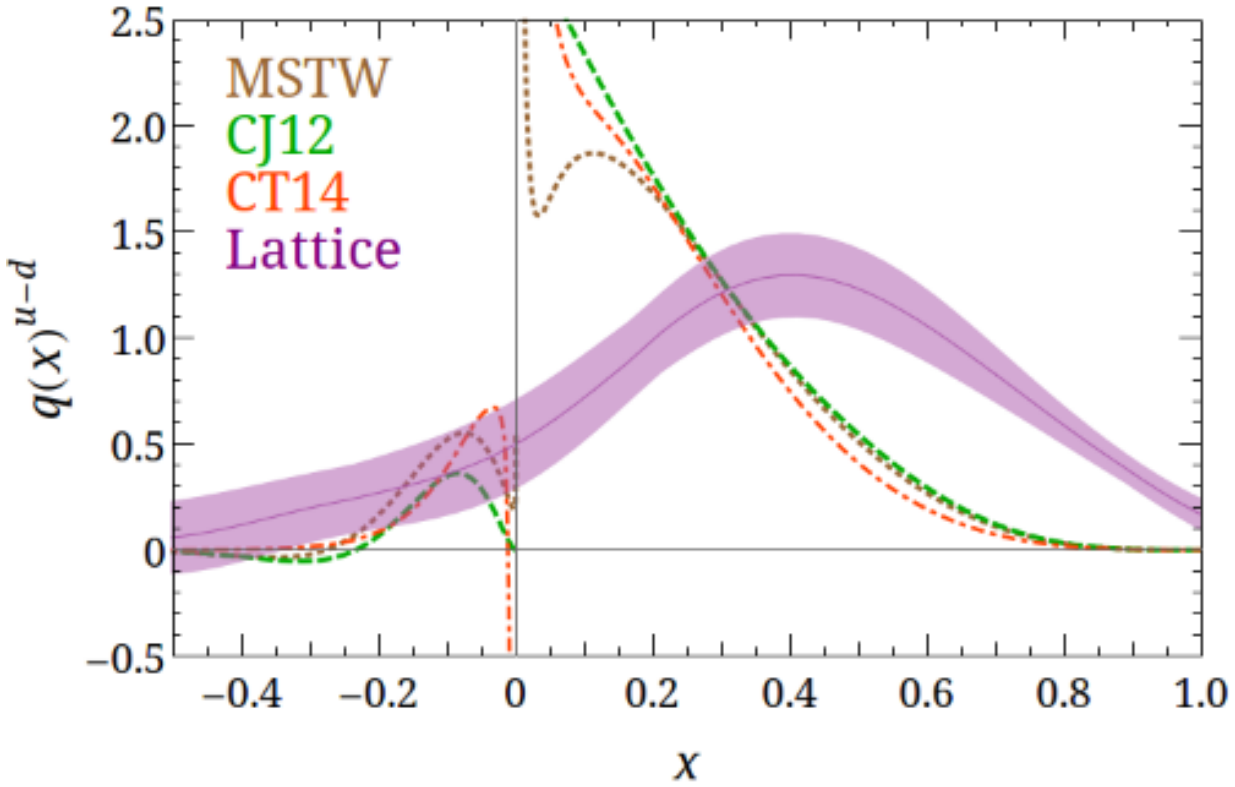
X. Xiong et al., 1310.7471; J.-W. Chen et al, 1603.06664

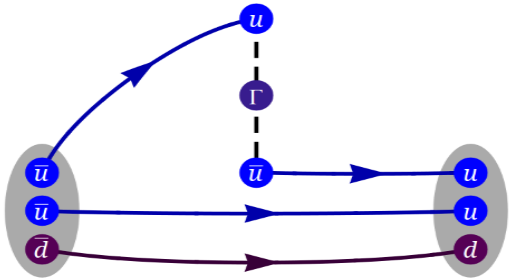
Quark Distribution

§ A first exploratory study

HWL et al. 1402.1462

- N_f= 2+1+1 clover/HISQ lattices (MILC)
  $M_\pi \approx$ **310 MeV**, $a \approx 0.12$ fm ($M_\pi L \approx 4.5$), O(10^3) measurements





A.D. Martin et al. Eur.Phys.J. C63, 189 (2009)

J.F. Owens et al. PRD 87, 094012 (2012)

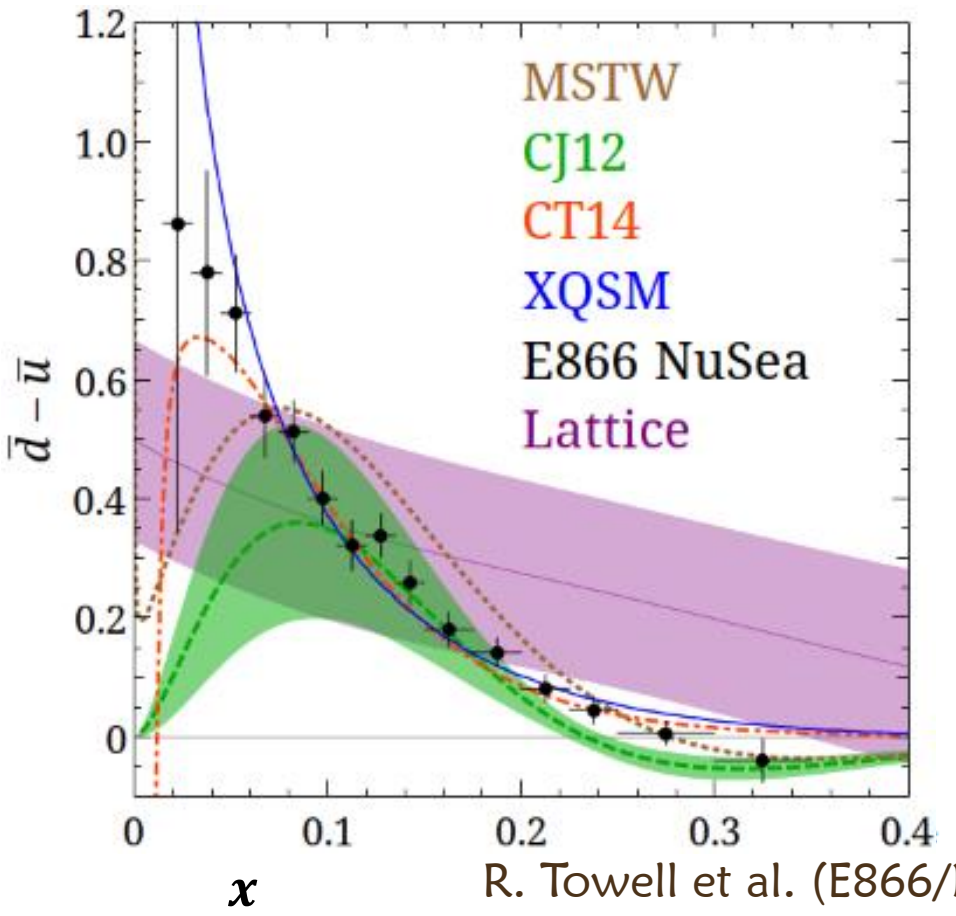
S. Dulat et al. arXiv:1506.07443

Sea Flavor Asymmetry

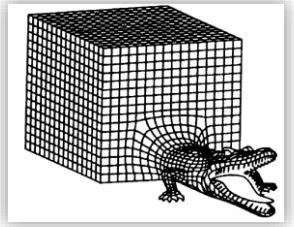
§ First time in LQCD history to study antiquark distribution!

$M_\pi \approx 310$ MeV

HWL et al. 1402.1462



$$\bar{q}(x) = -q(-x)$$



Lost resolution in small-*x* region

Future improvement: larger lattice volume

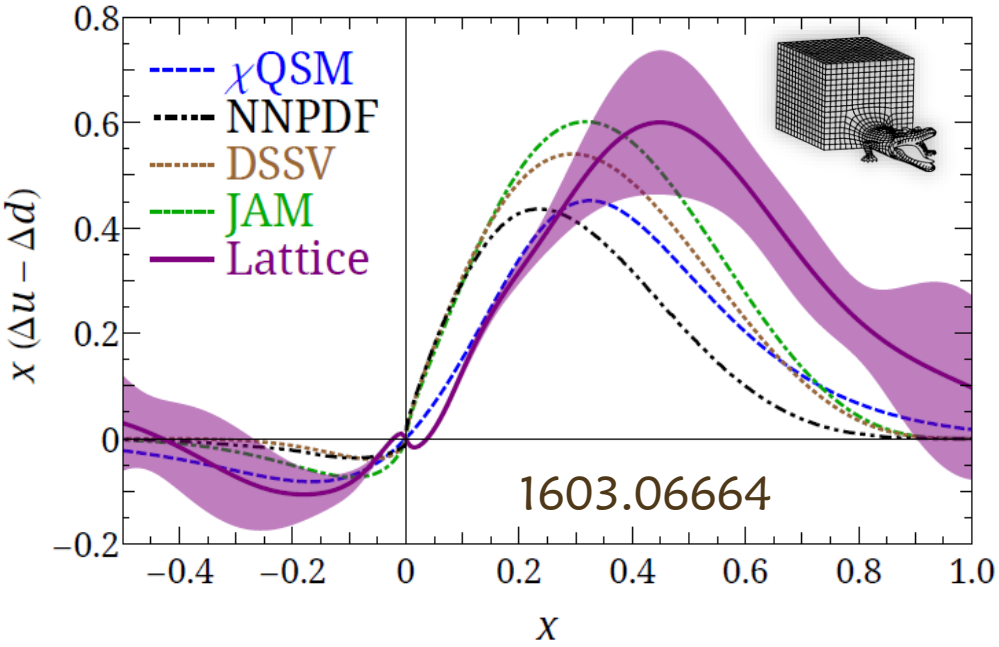
$$\int dx \left(\bar{u}(x) - \bar{d}(x)\right) \approx -0.16(7)$$

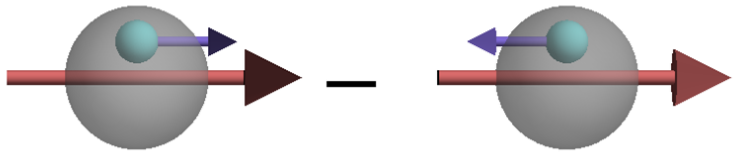
Experiment	x range	$\int_0^1[\bar{d}(x)-\bar{u}(x)]dx$
E866	$0.015<x<0.35$	0.118 ± 0.012
NMC	$0.004<x<0.80$	0.148 ± 0.039
HERMES	$0.020<x<0.30$	0.16 ± 0.03

R. Towell et al. (E866/NuSea), Phys.Rev. D64, 052002 (2001)

Helicity Distribution

§ Exploratory study $M_\pi \approx 310$ MeV





Removing
$O(M_N^n/P_z^n)$ errors + $O(\alpha_s)$
+ $O(\Lambda_{QCD}^2/P_z^2)$

- We see polarized sea asymmetry $\int dx \left(\Delta\bar{u}(x) - \Delta\bar{d}(x)\right) \approx 0.14(9)$
- Both STAR and PHENIX at RHIC see $\Delta\bar{u} > \Delta\bar{d}$

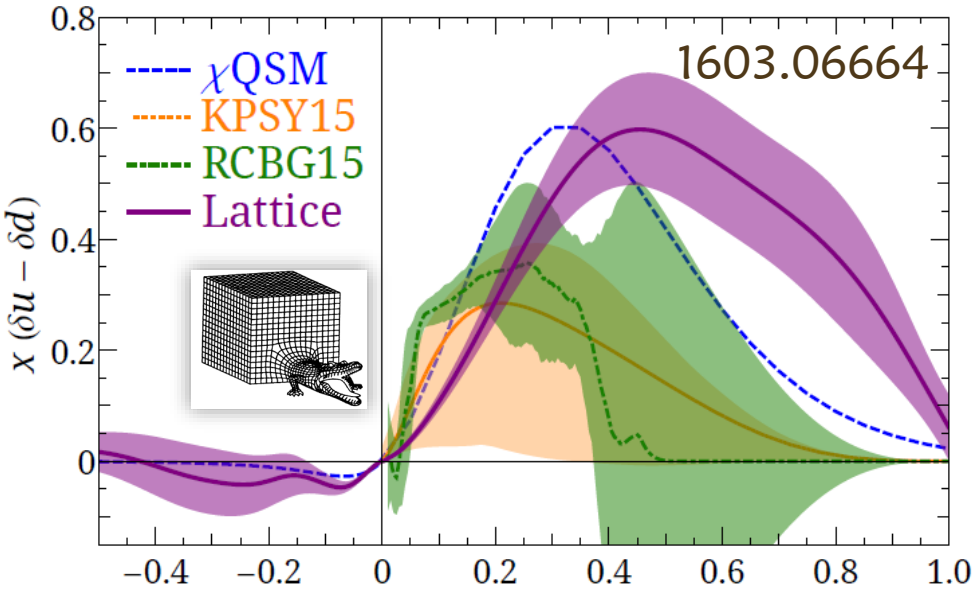
1404.6880 and 1504.07451

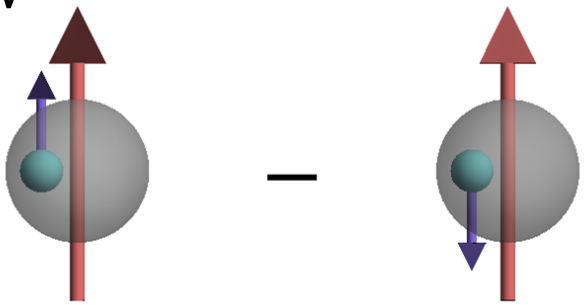
- Other experiments, Fermilab DY exp'ts (E1027/E1039), future EIC

Transversity Distribution

§ Exploratory study

$M_\pi \approx 310$ MeV





Removing
$O(M_N^n/P_z^n)$ errors + $O(\alpha_s)$
+ $O(\Lambda^2_{\rm QCD}/P_z^2)$

$\delta\bar{q}(x) = -\delta q(-x)$

1505.05589; 1503.03495

We found sea asymmetry of $\int dx\,(\delta\bar{u}(x) - \delta\bar{d}(x)) \approx -0.10(8)$

Chiral quark-soliton model $\int dx\,(\delta\bar{u}(x) - \delta\bar{d}(x)) \approx -0.082$

P. Schweitzer et al., PRD 64, 034013 (2001)

SoLID at JLab, Drell-Yan exp't at FNAL (E1027+E1039), EIC, …

This Proposal

§ Extend the isovector PDFs case to control $(pa)^n$ errors

- HISQ 2+1+1f (Thanks to MILC for sharing!)
  $M_\pi \approx 310$ MeV $a = 0.045$ fm lattices
- This is not a channel used in global fit;
  helps with the parametrization assumption

§ First step toward flavor-dependent PDFs

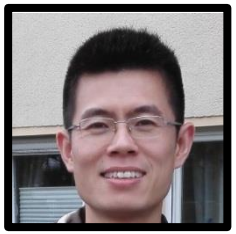
- Develop strange and charm PDFs in LaMET approach
- Comments on LHC?

§ Collaborators

Jiunn-Wei Chen
(NTU)

Xiangdong Ji
(UMD/SJTU/INPAC)

C.-P. Yuan
(MSU)



Jian-Hui Zhang
(Regensburg)

SPC Questions

- Are you in a position to use resources efficiently if they are a) CPU, b) GPU, c) KNL?
- Have you considered running on GPUs?
- Have you considered doing HISQ on HISQ?
- What is the division of labor?
- Have you considered working with the NME proposal?
  - What are the unique features for the quasi-PDF part of that proposal and this current proposal?
- How strong is the impact of the uncertainties in the PDFs you consider (mainly isovector) on new physics searches at LHC?

Backup Slides