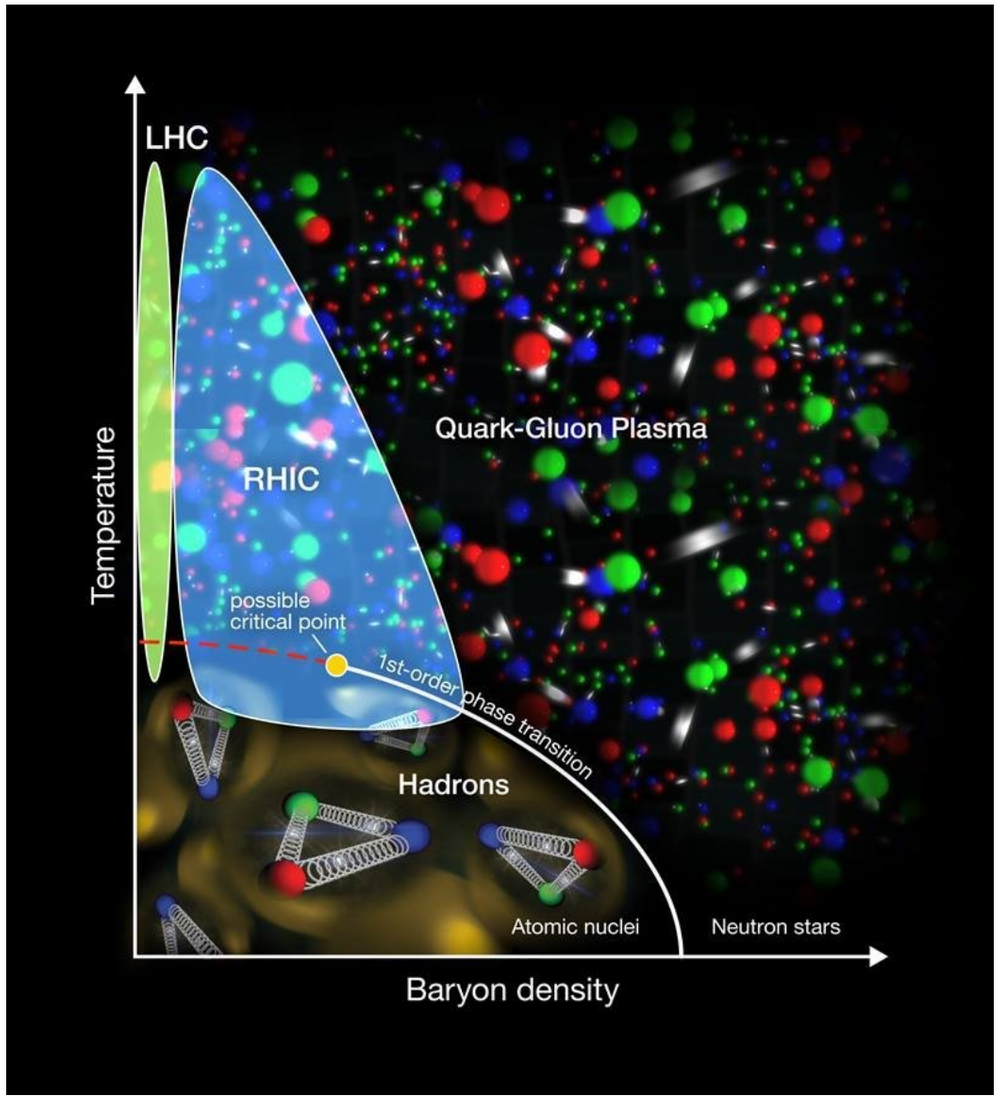
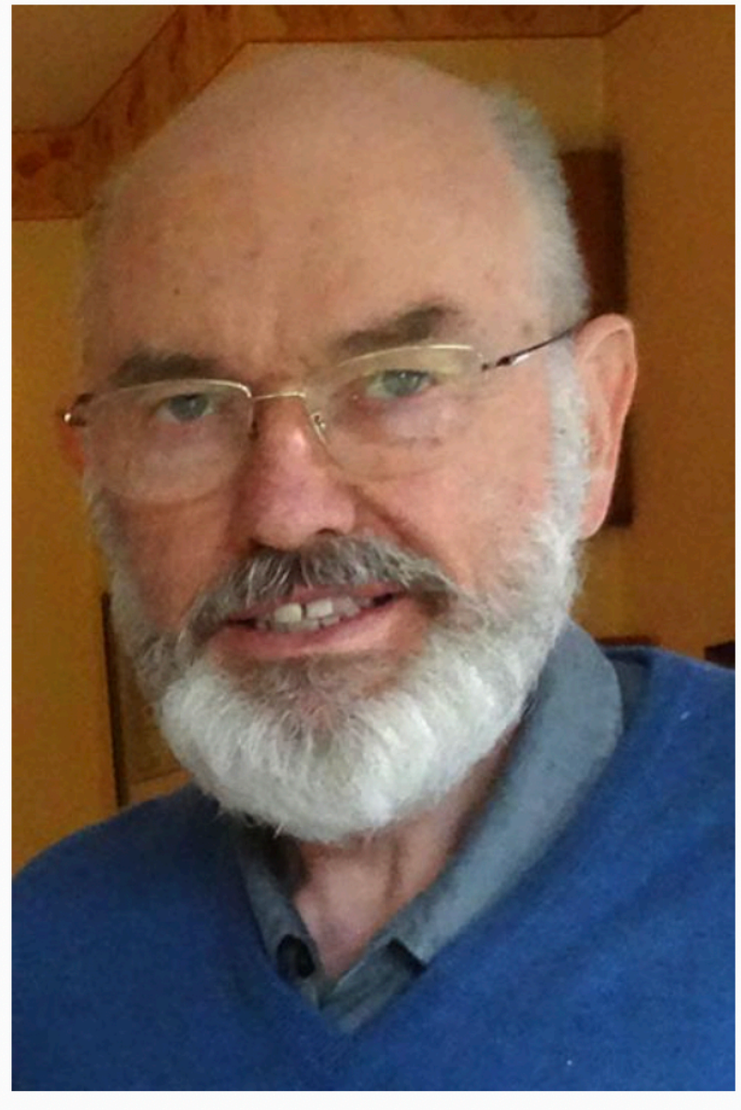
When KSU Became Keane on Physics

Peter C. Tandy

Dept of Physics, Kent State University





Topics

- Declan Keane, and his record, as seen by a KSU colleague
- Some of my recent research…… Distinguishing quark and gluon contributions to structure, angular momentum, and mass distributions

• The Dept's Nuclear Group:

- Prior to 1979, there was Dick Madey (Dept Chair), Bryon Anderson, John Watson. NSF funded for nuclear structure expts at Indiana Cyclotron & nuclear matter expts at Berkley Bevalac. Expansion….

- Added 2 theorists: an Australian (me, 1979), a Hungarian (George Fai, 1984). Then for expts they added a Louisianian (Mark Manley, 1986).

- Sometimes, good things happen when you are not looking…..

- While I was taking a sabbatical leave at Univ. of Maryland (1987-88), they went full Irish (Declan Keane, 1988)

- That was a good move!

~1987 @ Grand Canyon
From Univ Calif Riverside
to KSU?

Created with Photomyne

Brief record at KSU

NAME	POSITION TITLE
Declan Keane	Professor of Physics

EDUCATION

INSTITUTION AND LOCATION	DEGREE	YEAR(s)	FIELD OF STUDY
University College, Dublin, Ireland	B.Sc.	1971-1975	Physics
University College, Dublin, Ireland	Ph.D.	1976-1981	Particle Physics

APPOINTMENTS

Position	Institution	Dates
Full-time Lecturer	National Univ. of Ireland, Galway	1980-1981
Postgrad Research Physicist	University of California, Riverside	1981-1982
Staff Research Associate	University of California, Riverside	1983-1987
Assistant Professor	Kent State University	1988-1992
Special Staff Scientist II	Lawrence Berkeley National Lab., California	1991-1992
Associate Professor	Kent State University	1992-1998
Assistant Chair	Physics Department, Kent State	2000-2001
Director	Center for Nuclear Research, KSU	2006-2007
Graduate Prog Coordinator	Physics Department, Kent State	2007-2011
Professor	Kent State University	1998-

Brief record at KSU

"STAR" = **S**olenoidal **T**racker **a**t **R**HIC

RECENT DISTINCTIONS

2017: PhD advisee received "Outstanding Thesis Award" from Brookhaven National Lab Director.
2016: KSU President's Faculty Excellence Award.
2014: Elected Fellow of American Physical Society.
2014: Media coverage of paper on phase transition, based on PhD work of advisee.
2013: Named one of the *Top 25 STEM Professors in Ohio* by Ohio Online Schools.
2012: Co-mentored Dr. Jinhui Chen, recipient of George Valley Prize from American Physical Soc.
2011: Distinguished Scholar Award, Kent State University.
2010-11: Group had lead role in two antimatter discoveries; *Discover* Magazine's #3 physics/math story for 2011.
More particulars at `http://www.kent.edu/physics/profile/declan-keane`

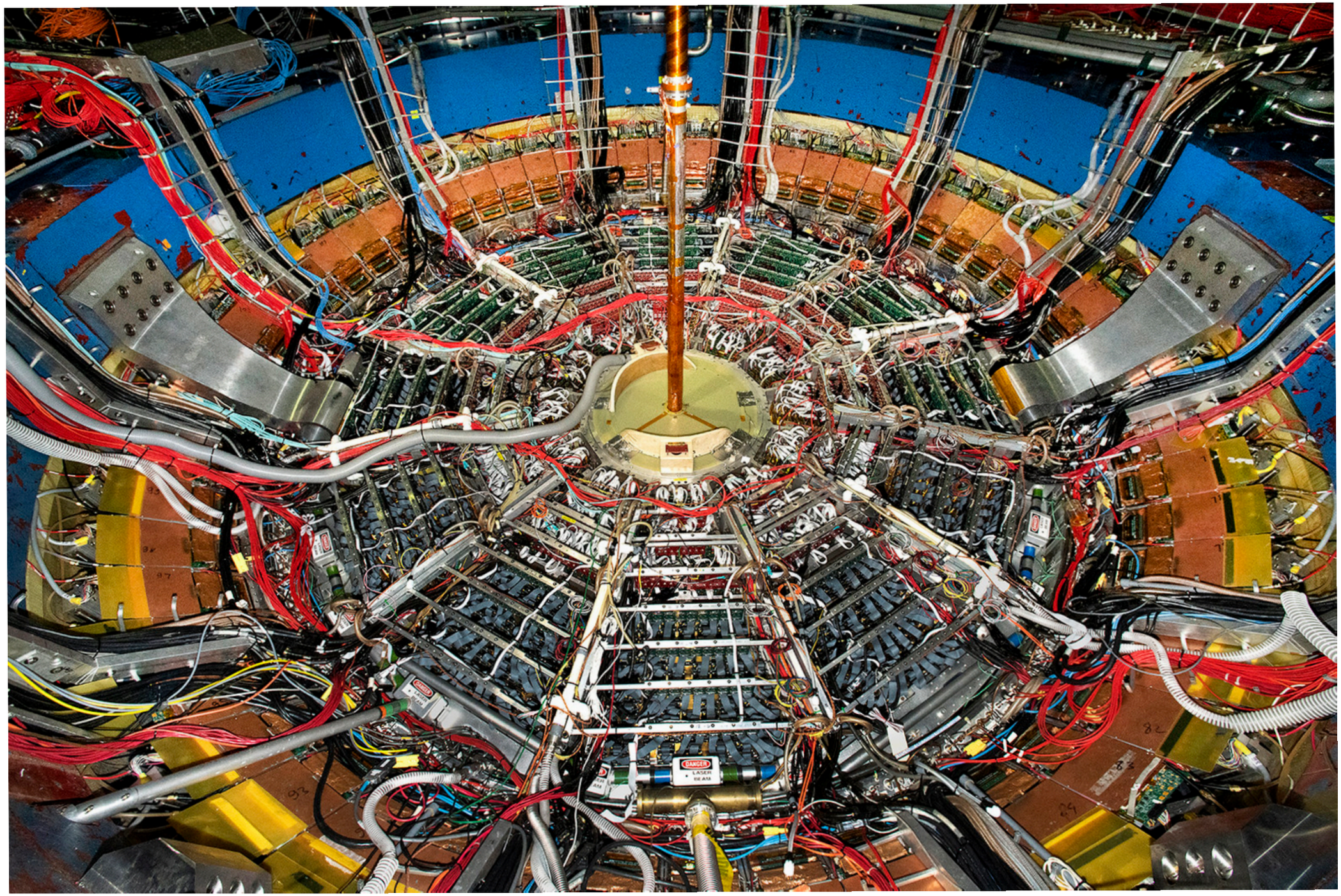
EXTRAMURAL FUNDING

Primary PI, continuous funding from Dept. of Energy, 1989 - present ($467K/yr. for 2 PIs);
PI, subcontract from Brookhaven, May 2017 - present ($54K/yr.);
Primary PI, grant from DOE (Advanced Sci. Computing), 2002 - 2005;
PI, grants from National Science Foundation, 1990 - 1996;
Various completed subcontracts from National Laboratories & co-PI on grants from State of Ohio.

RESEARCH & EXTRAMURAL SERVICE

Shift Coordinator, STAR experiment (2015 – present);
Co-convener, Beam Energy Scan Focus Group for STAR experiment (2007 – present);
Co-convener, STAR Event-by-Event Physics Working Group (2002 – 2006);
Spokesman for AGS/BNL experiment E895 [12 institutions] (1999 –);
Spokesman for various experimental collaborations at Bevalac (1985 – 1993);
Elected member, STAR Advisory Board (2006 - 2009); Chair, various ad hoc committees for STAR Collaboration (2000 –); Member, Council for STAR experiment (1991 - present); Chair, STAR Talks Committee (2002 - 2004); Elected member, Bevalac Users' Executive Committee (1991 - 1993).

Time Projection Chamber in the STAR Detector



From the Past

Nuclei & Nuclear Matter in Collision

KSU Distinguished Scholar Award 2011

KSU Distinguished Scholar Award 2011

KSU President's Faculty Excellence Award ~ 2016

Nuclear Matter in Collisions

- 2010: The discovery of the first antimatter nucleus containing a strange quark, published in Science with postdoc advisee Jinhui Chen (now a professor at Fudan University)
- 2011: The significant finding of anti-alpha, the heaviest stable anti-nucleus known so far, published in Nature with former PhD student Aihong Tang (now a scientist at BNL).
- 2014: With PhD advisee Yadav Pandit, published in PRL possible indications of a phase transition never previously observed in Nuclear Physics—-first order, like ice-water-vapor.
- 2023: The notable observation of Global Spin alignment of phi and K* vector mesons in nuclear collisions, published in Nature with Aihong Tang and postdoc advisee Subhash sing (now a staff scientist at IMP), and Jinhui Chen.

Some STAR Collab papers with Declan among the significant authors

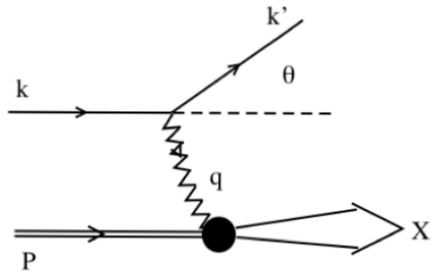
- ***“Azimuthal anisotropic in AuAu collisions at 200 GeV" PRC 72 014904. 1029 citations***
- ***"Elliptic flow from two- and four-particle correlations in Au+Au collisions at 130 GeV" PRC 66 034904 (2002). 733 citations***
- ***"Bulk properties of the medium produced in relativistic heavyion collisions from the beam energy scan program" PRC 96 044904 (2017). 583 citations***

Now for the Painful Stuff: Recent Hadron Physics & QCD activities

- "Parton decomposition of nucleon spin and momentum: gluons from dressed quarks", P. C. Tandy, Phys. Lett. **B842** 137972 (2023)
- "Gluon PDF from quark dressing in the nucleon and pion", A. Freese, I. C. Cloet, P. C. Tandy, Phys. Lett. **B823** 136719 (2021)

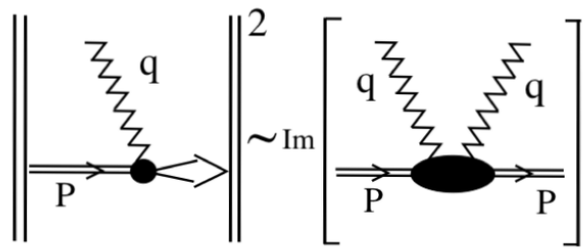
Parton Content of Nucleon J = Jq + Jg

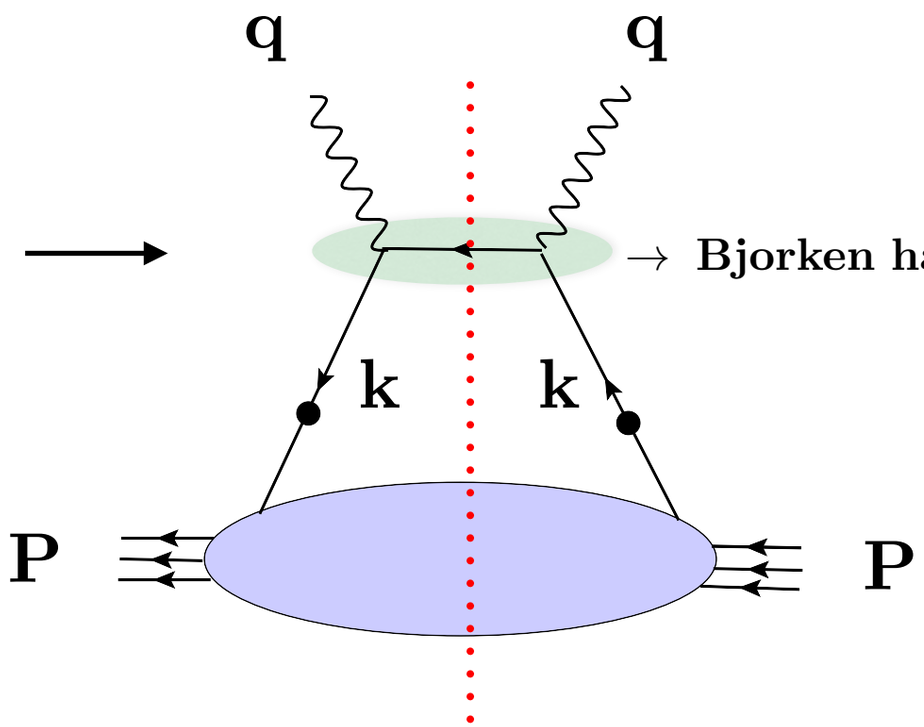
- **Does dressed quark J_q already include J_g from gluons that dress it and carry part of its spin?**
- **Since u, d quark dressing is very strong does it dominate $J_{g,tot}$?**
- **Do the "binding" gluons that propagate between different quarks of hadron state contribute to $J_{g,tot}$?**
- **If so, how big is $J_{g,Bind}$?**



$$\mathbf{x} = \frac{\mathbf{Q^2}}{\mathbf{2P.q}}$$

PDFs





$\rightarrow$ **Bjorken hard limit** $\Rightarrow \gamma^+ \, \delta(\mathbf{x} - \frac{\mathbf{k}^+}{\mathbf{P}^+})$

$$\mathbf{q(x)} = \int \frac{\mathbf{d}\lambda}{\mathbf{4}\,\pi}\, \mathbf{e}^{-\mathbf{i x\, P\cdot n}\,\lambda}\, \langle \mathbf{P}|\, \bar{\mathbf{q}}(\lambda \mathbf{n})\, \not{n}\, \mathbf{W}(\lambda, \mathbf{A})\, \mathbf{q(0)}\, |\mathbf{P}\rangle_{\mathbf{c}}$$

$$\not{n} = \gamma \cdot \mathbf{n} = \gamma^+$$

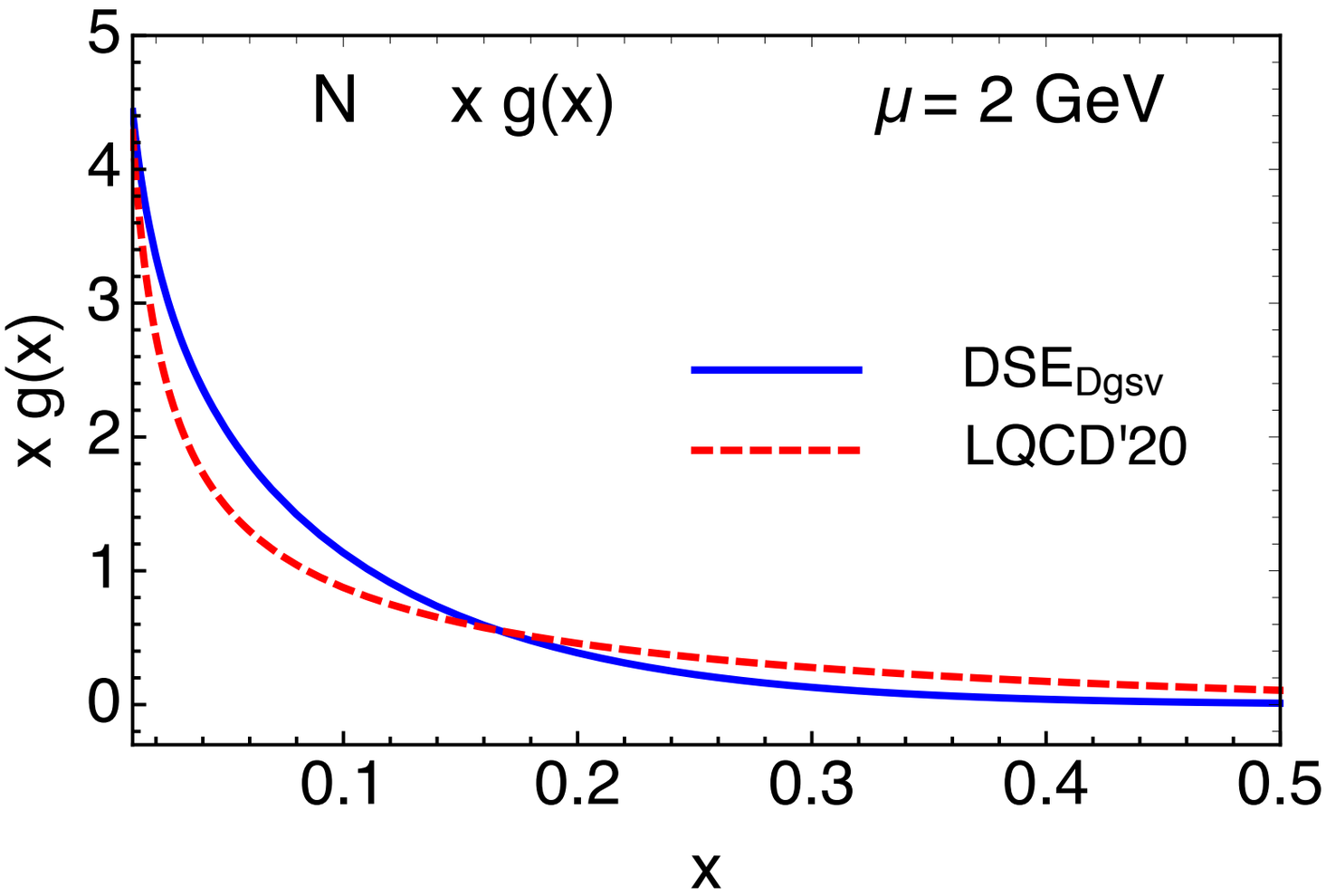
$$\mathbf{g(x)} = \int \frac{\mathbf{d}\lambda}{\mathbf{2}\,\pi} \frac{\mathbf{e}^{-\mathbf{i x\, P\cdot n}\,\lambda}}{\mathbf{xP^+}}\, \langle \mathbf{P}|\, \mathbf{G}^{+\,\mu}(\lambda \mathbf{n})\, \mathbf{W}\, \mathbf{G}_{\mu\,+}(\mathbf{0})\, |\mathbf{P}\rangle_{\mathbf{c}}$$

$$\mathbf{k \cdot n = k^+ = k^0 + k^3}$$

sim for $\mathbf{\Delta q(x)}$ & $\mathbf{\Delta g(x)}$

$$\mathbf{W}(\lambda, \mathbf{A}) = \mathbf{P}\, \mathbf{e}^{-\mathbf{i\, g} \int_0^\lambda \mathbf{d}\xi\, \mathbf{n\cdot A(n}\xi\mathbf{)}}$$

Comparison with recent LCD results



Z. Fan, R. Zhang, H.-W. Lin, arXiv:2007.16113 (2020)

$\langle x \rangle_g^N$ **at 2 GeV :**

Here	Deka (2013)	Yang (2018)	Alexandrou (2017)	Yang (2018)	Fan (2020)	ave
0.42	0.33	0.42	0.27	0.47	0.41	0.38

$$\frac{\langle x \rangle_{g,Bind}}{\langle x \rangle_{g,Tot}} = 10\%$$

$\langle x \rangle_g^\pi = 0.343$ **at 2 GeV**

Parton Content of Nucleon P, J, M & Distributions

$$\mathcal{J}^{\mathbf{q}}_{\mathbf{s}',\mathbf{s}} = \int \frac{\mathbf{d}\lambda}{\mathbf{4}\,\pi}\, \mathbf{e}^{-\mathbf{ixK}\cdot\mathbf{n}\lambda}\, \langle \mathbf{P}', \mathbf{s}' | \bar{\mathbf{q}}(\lambda \mathbf{n})\, \not{n}\, \mathbf{W}(\lambda, \mathbf{A})\, \mathbf{q}(\mathbf{0}) | \mathbf{P}, \mathbf{s} \rangle_{\mathbf{c}} \ ,$$

X. Ji (1997)

$$\mathcal{J}^{\mathbf{g}}_{\mathbf{s}',\mathbf{s}} = \int \frac{\mathbf{d}\lambda}{\mathbf{2}\,\pi}\, \frac{\mathbf{e}^{-\mathbf{ixK}\cdot\mathbf{n}\lambda}}{\mathbf{xK}^{+}}\, \left\langle \mathbf{P}', \mathbf{s}' \right| \mathbf{G}^{+\,\alpha}(\lambda \mathbf{n})\, \mathbf{W}\, \mathbf{G}_{\alpha\,+}(\mathbf{0}) \left| \mathbf{P}, \mathbf{s} \right\rangle_{\mathbf{c}}$$

$$\xi = -\frac{\mathbf{Q}\cdot\mathbf{n}}{\mathbf{2K}\cdot\mathbf{n}}$$

$$\mathcal{J}^{\mathbf{q/g}}_{\mathbf{s}',\mathbf{s}}(\mathbf{x}, \xi, \mathbf{Q^2}) = \bar{\mathbf{u}}_{\mathbf{s}'}(\mathbf{P}') \left[\not{n}\, \mathbf{H_{q/g}} + \frac{\mathbf{i}\sigma^{\mathbf{n}\alpha}\mathbf{Q}_{\alpha}}{\mathbf{2M}}\, \mathbf{E_{q/g}} \right] \mathbf{u}_{\mathbf{s}}(\mathbf{P})$$

$\mathbf{GPDs}(\mathbf{x}, \xi, \mathbf{Q^2})$

$$\langle \mathbf{x} \rangle_{\mathbf{q/g}} = \int \mathbf{dx}\, \mathbf{x}\, \mathbf{H_{q/g}}(\mathbf{x}, \mathbf{0}, \mathbf{0})$$

$$\mathbf{J_{q/g}} = \frac{\mathbf{1}}{\mathbf{2}} \int \mathbf{dx}\, \mathbf{x}\, \{ \mathbf{H_{q/g}}(\mathbf{x}, \mathbf{0}, \mathbf{0}) + \mathbf{E_{q/g}}(\mathbf{x}, \mathbf{0}, \mathbf{0}) \}$$

J Content of "Physical" q in 1-loop QCD

$\langle x\rangle_g$	$\langle x\rangle_q^{\rm LC}$	$\langle x\rangle_q^{\rm LG}$	$\langle x\rangle_q^{\rm W}$	J_g	$J_q^{\rm LC}$	$J_q^{\rm LG}$	$J_q^{\rm W}$
0.233	0.767	0.821	−6.5%	0.120	0.380	0.411	−7.5%

- Gluons contribute $\sim 25\%$ in both cases.

$\mathbf{J_{q/g}}$, $\mathbf{L_{q/g}}$, $\mathbf{S_{q/g}}$ of Proton @ μ_0

	J_{u_v}	J_{d_v}	J_g	J_{tot}	$J_{\bar u}$	$J_{\bar d}$
v only	0.478	-0.119	0.119	0.478	0	0
	100%	-25%	25%	100%	0	0
	$J_{u+\bar u}$	$J_{d+\bar d}$	J_g	J_{tot}	$J_{\bar u}$	$J_{\bar d}$
v + πN	0.439	-0.051	0.119	0.507	0.0104	0.0520
	86.6%	-10.1%	23.5%	100%	2.1%	10.3%

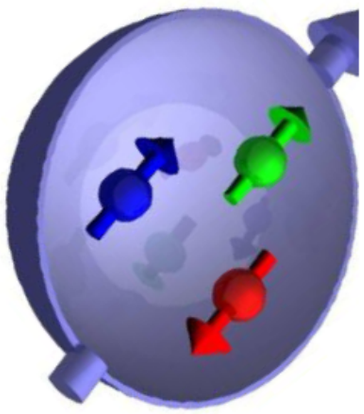
Table III. Parton sharing of the proton J at the model scale $\mu_0 = 0.64$ GeV. The first section at the top is from the previously established DSE-RL model containing only valence quarks and the dynamically involved dressing glue. The next section shows the quark J values from pion cloud dressing of the proton involving πN Fock terms.

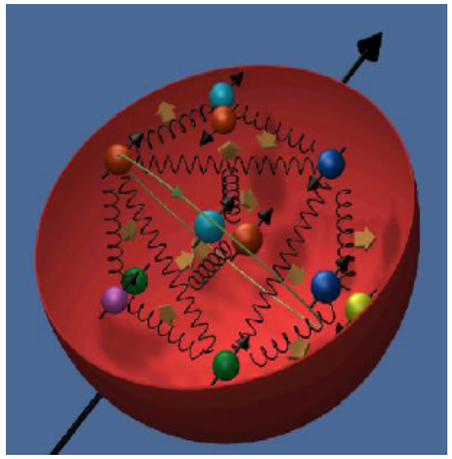
	L_{u_v}	L_{d_v}	L_g	ΔG	$\Sigma_q/2$	J_{tot}	$L_{\bar u}$	$L_{\bar d}$
v only	0.133	-0.033	0.041	0.078	0.259	0.478	0	0
	27.7%	-6.9%	8.6%	16.3%	54%	100%	0	0
	$L_{u+\bar u}$	$L_{d+\bar d}$	L_g	ΔG	$\Sigma_q/2$	J_{tot}	$L_{\bar u}$	$L_{\bar d}$
v + πN	0.167	0.031	0.041	0.078	0.190	0.507	0.0104	0.0520
	33%	6.2%	8.1%	15%	37%	100%	2.1%	10%

Table IV. Parton sharing of the proton L at the model scale $\mu_0 = 0.64$ GeV. Top section is from the previously established DSE-RL model containing valence quarks and the dynamically involved dressing glue. The bottom section comes after supplementing that valence Fock term with pion cloud dressing of the proton involving $\pi^+ n$ and $\pi^0 p$ contributions.

H_{QCD}: 1.3% 26% S. Xu, J. Vary et al PRD **108** (2023)

$J_{q/g},\ L_{q/g},\ S_{q/g}$ of Proton in LQCD @ 2 GeV





	J	J_{LQCD}	L	L_{LQCD}	S	S_{LQCD}
$u+\bar{u}$	0.333 (66%)	0.308 (57%)	0.061	-0.107	0.272	0.415
$d+\bar{d}$	-0.030 (-6%)	0.054 (10%)	0.052	0.247	-0.083	-0.193
$s+\bar{s}$	0.008 (2%)	0.046 (9%)	0.008	0.067	0	-0.021
g	0.194 (38%)	0.133 (25%)	-0.163	-	0.357	-
Tot	0.504	0.541	-0.042	-	0.546	-

[40] C. Alexandrou, M. Constantinou, K. Hadjiyiannakou, K. Jansen, C. Kallidonis, G. Koutsou, A. Vaquero Aviles-Casco, and C. Wiese, Phys. Rev. Lett. **119**, 142002 (2017), arXiv:1706.02973 [hep-lat].

Proton: $\langle x \rangle_{q/g}$, $J_{q/g}$ @ $\mu = 2$ GeV

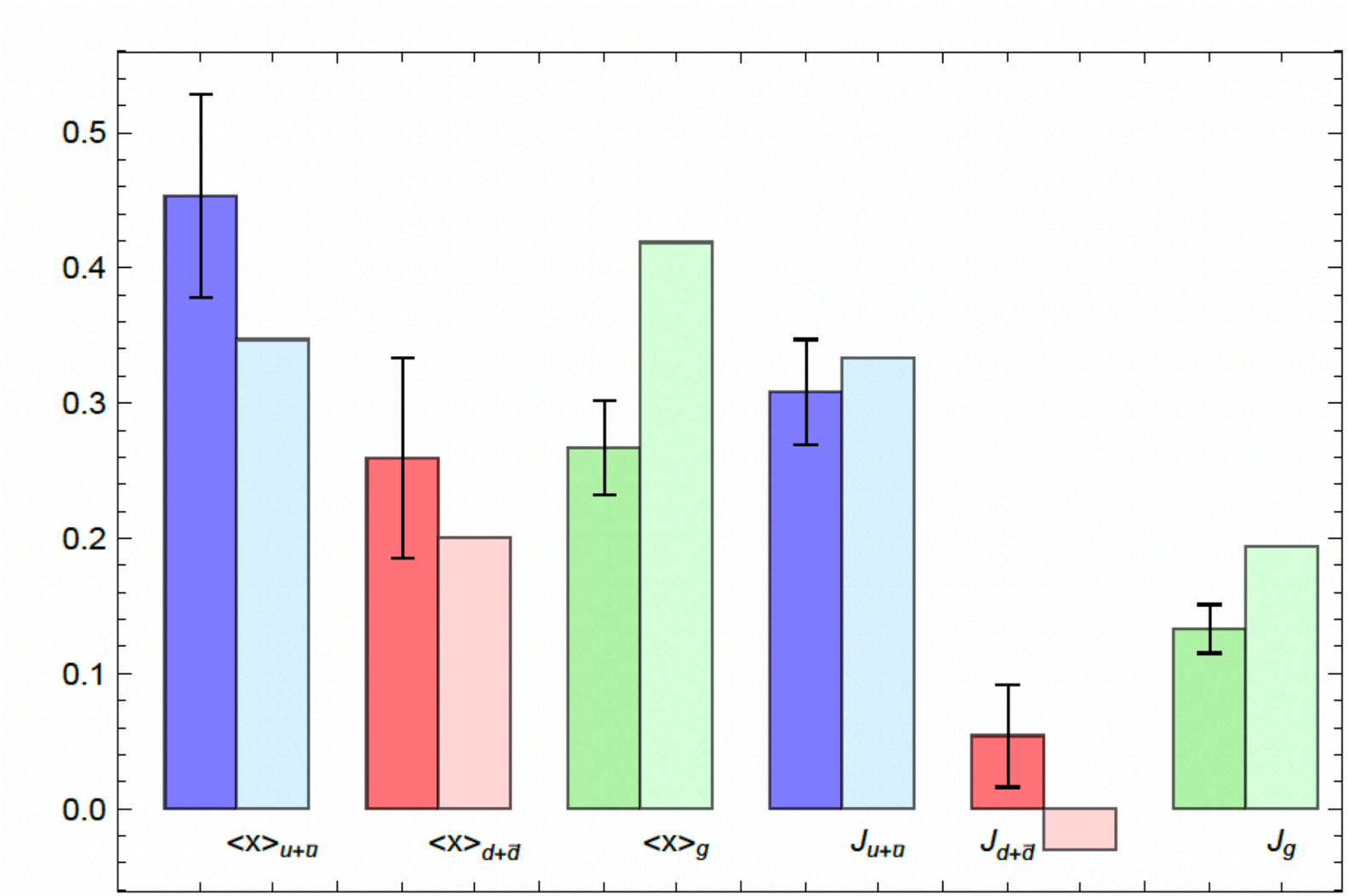


Figure 3. Values for parton momentum fractions and angular momenta at $\mu = 2$ GeV compared to lattice QCD results reported by

[40] C. Alexandrou, M. Constantinou, K. Hadjiyiannakou, K. Jansen, C. Kallidonis, G. Koutsou, A. Vaquero Aviles-Casco, and C. Wiese, Phys. Rev. Lett. **119**, 142002 (2017), arXiv:1706.02973 [hep-lat].

Parton Content of Hadron P, J, M & Distributions

E – M Tensor $\langle \mathbf{P'}|\tilde{\mathbf{T}}_{\mu\nu}(\mathbf{q/g})|\mathbf{P}\rangle = \bar{\mathbf{u}}(\mathbf{P'})\{\mathbf{A_{q/g}(Q^2)}\,\mathbf{2K_\mu K_\nu} + \cdots\}\mathbf{u(P)}$ $\quad \mathbf{K} = \frac{\mathbf{P'+P}}{\mathbf{2}}$

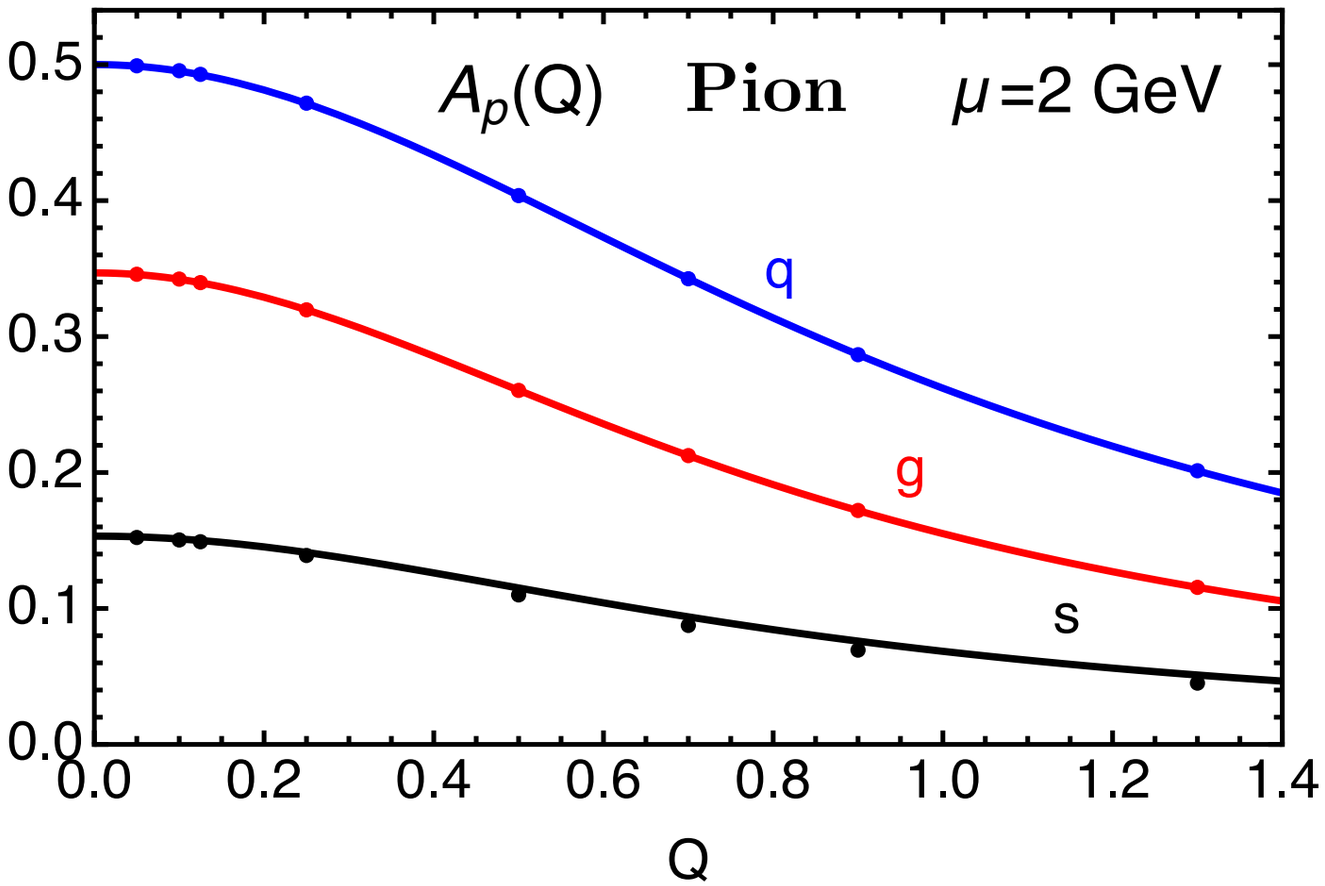
$$\mathbf{A_q(0) + A_g(0) = 1 = \langle x\rangle_q + \langle x\rangle_g}$$

$$\mathbf{= \int dx\, x\, \{H_q(x,0,0) + H_g(x,0,0)\}}$$

$$\mathbf{A_{q/g}(Q^2) = \int dx\, x\, H_{q/g}(x,0,Q^2)}$$

GPD

Distribution of Mass^2



$$\mathbf{R^\pi_{mass} \approx 80\%\, R^\pi_{em}}$$

[cf Hackett-Shanahan, LQCD (2023) 63%]

$$\mathbf{R^\pi_{mass(g)} \approx 1.19\, R^\pi_{mass(q)}}$$

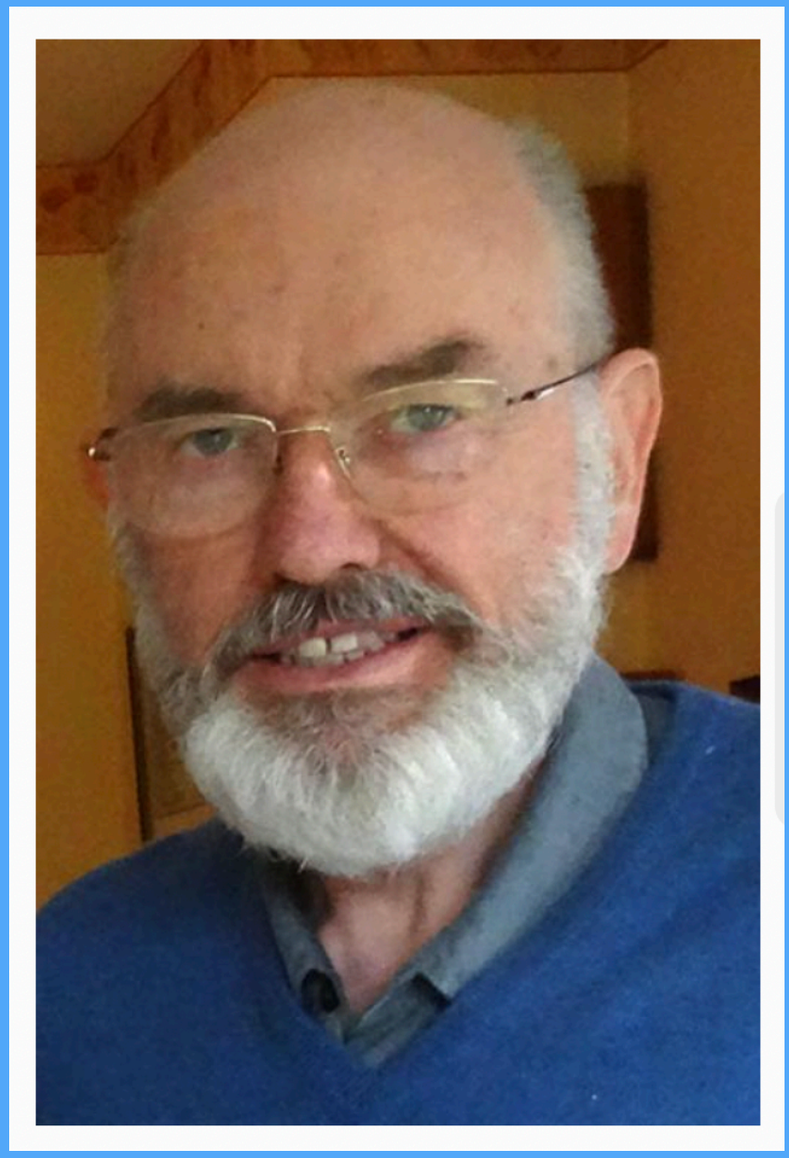
[cf Hackett-Shanahan, LQCD (2023) 1%]

Understandable? YES

Physics Summary

- **Modeling QCD for PDFs $q(x),\ g(x)$ of pion & nucleon: Appropriate QCD mechanisms included? Yes**
- **Insights from : $\langle x\rangle_q,\ \langle x\rangle_g,\ J_q,\ J_g$ for a "physical" quark target in 1-loop QCD**
- **DSE-RL approach centers around quark dressing (DCSB). Does that generate a realistic $g(x)$? Yes, $\langle x\rangle_g(\mu_0) \sim 0.24$**
- **Estimated Wilson line correction to Landau gauge $\langle x\rangle_q,\ J_q$ is -7%**
- **There is a small "binding" gluon contribution $\langle x\rangle_{g,B} \sim 0.02$**
- **Presented some earlier DSE-RL PDF results (prior to these recent insights)**

Congratulations
And
Well Done Declan!



The End

DK 70th Dec2023

Parton Content of Nucleon J

X. Ji (1997)

QCD GPDs : H, E from

$$\mathcal{J}^{\mathbf{q}}_{\mathbf{s}',\mathbf{s}} = \int \frac{\mathbf{d}\lambda}{\mathbf{4}\,\pi}\, \mathbf{e}^{-\mathbf{ixK\cdot n}\lambda}\, \langle \mathbf{P}', \mathbf{s}' | \bar{\mathbf{q}}(\lambda \mathbf{n})\, \not{n}\, \mathbf{W}(\lambda, \mathbf{A})\, \mathbf{q}(\mathbf{0}) | \mathbf{P}, \mathbf{s} \rangle_{\mathbf{c}} \ ,$$

$$\mathcal{J}^{\mathbf{g}}_{\mathbf{s}',\mathbf{s}} = \int \frac{\mathbf{d}\lambda}{\mathbf{2}\,\pi}\, \frac{\mathbf{e}^{-\mathbf{ixK\cdot n}\lambda}}{\mathbf{xK}^{+}}\, \left\langle \mathbf{P}', \mathbf{s}' \right| \mathbf{G}^{+\,\alpha}(\lambda \mathbf{n})\, \mathbf{W}\, \mathbf{G}_{\alpha\,+}(\mathbf{0}) \left| \mathbf{P}, \mathbf{s} \right\rangle_{\mathbf{c}}$$

GPDs

general form : $\mathcal{J}^{\mathbf{q/g}}_{\mathbf{s}',\mathbf{s}}(\mathbf{x}, \xi, \mathbf{Q^2}) = \bar{\mathbf{u}}_{\mathbf{s}'}(\mathbf{P}') \left[\not{n}\, \mathbf{H^{q/g}} + \frac{\mathbf{i}\sigma^{\mathbf{n}\alpha}\mathbf{Q}_{\alpha}}{\mathbf{2M}}\, \mathbf{E^{q/g}} \right] \mathbf{u_s}(\mathbf{P})$

$$\mathbf{P}', \mathbf{P} = \mathbf{K} \pm \mathbf{Q}_{\perp}/\mathbf{2}, \quad \xi = -\frac{\mathbf{Q}\cdot\mathbf{n}}{\mathbf{2K}\cdot\mathbf{n}} \to \mathbf{0} \quad \Rightarrow \quad \mathbf{J_{q/g}} = \lim_{\mathbf{Q}\to\mathbf{0}} \frac{-\mathbf{iM}}{\mathbf{Q}_{\perp}} \int \mathbf{dx\, x}\, \mathcal{J}^{\mathbf{q/g}}_{\uparrow\downarrow}(\mathbf{x}, \mathbf{0}, \mathbf{Q^2}) \,,$$

$$\Rightarrow \quad \mathbf{J_{q/g}} = \frac{\mathbf{1}}{\mathbf{2}} \int \mathbf{dx\, x} \left(\mathbf{H^{q/g}}(\mathbf{x}, \xi, \mathbf{Q^2 = 0}) + \mathbf{E^{q/g}}(\mathbf{x}, \xi, \mathbf{Q^2 = 0}) \right)$$

$$\langle \mathbf{x} \rangle_{\mathbf{q/g}}$$

Summary

- **X. Ji's space-like correlator approach to PDFs—a model investigation. Spurious anti-quark contributions seem unavoidable if Pz < 2 GeV. For x > 0.8, need Pz > 4 GeV for confidence in the qualitative shape. Further work in progress.**

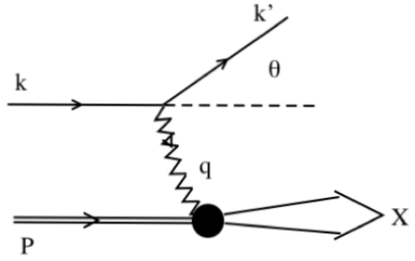
- **Parton Distribution Amplitudes (pion, kaon). DSE approach shows good contact with available lattice-QCD moments. Flavor symmetry breaking in kaon DA made quantitative.**

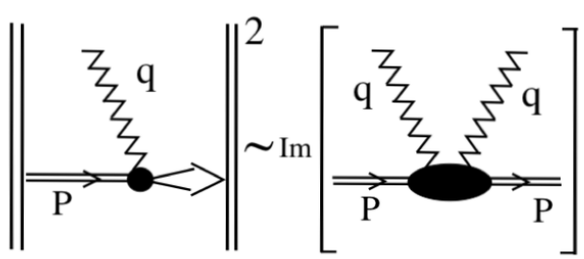
- **Pion Transition & Elastic Form Factors DSE TFF calculation for all Q^2—- agrees with Belle not BaBar. DSE eIFF——Connection with asymptotic QCD reconciled. Identify that the ultraviolet partonic behavior is within reach of proposed JLab pion FF experiments.**

- **Parton Distribution Functions (pion). Qualitative behavior of empirical data fits reproduced by DSE q-qbar + pion loop analysis.**

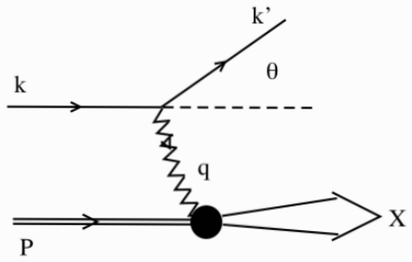
- **Time to declare we understand the pion and kaon in QCD ?**

Aristotle





Deep Inelastic Lepton Scattering



Bjorken limit:

$$\nu = q \cdot P/M \to \infty \;\; ; \;\; -q^2 = Q^2 \to \infty$$

$$0 < x = \frac{Q^2}{2P \cdot q} < 1$$

$$W^{\alpha\beta} = \left\| \; \right\|^2 \sim \mathrm{Im} \left[\; \right] = \frac{1}{2\pi} \, \mathrm{Disc} \, T^{\alpha\beta}(\nu)$$

$$W^{\alpha\beta} = -(g^{\alpha\beta} - \frac{q^\alpha q^\beta}{q^2}) \, F_1 + \frac{P_T^\alpha(q) \, P_T^\beta(q)}{P \cdot q} \, F_2$$

$$F_1(x) = \Sigma_q \, \frac{e_q^2}{2} f_q(x) + \cdots$$