Recent advances in hadron structure at JLab

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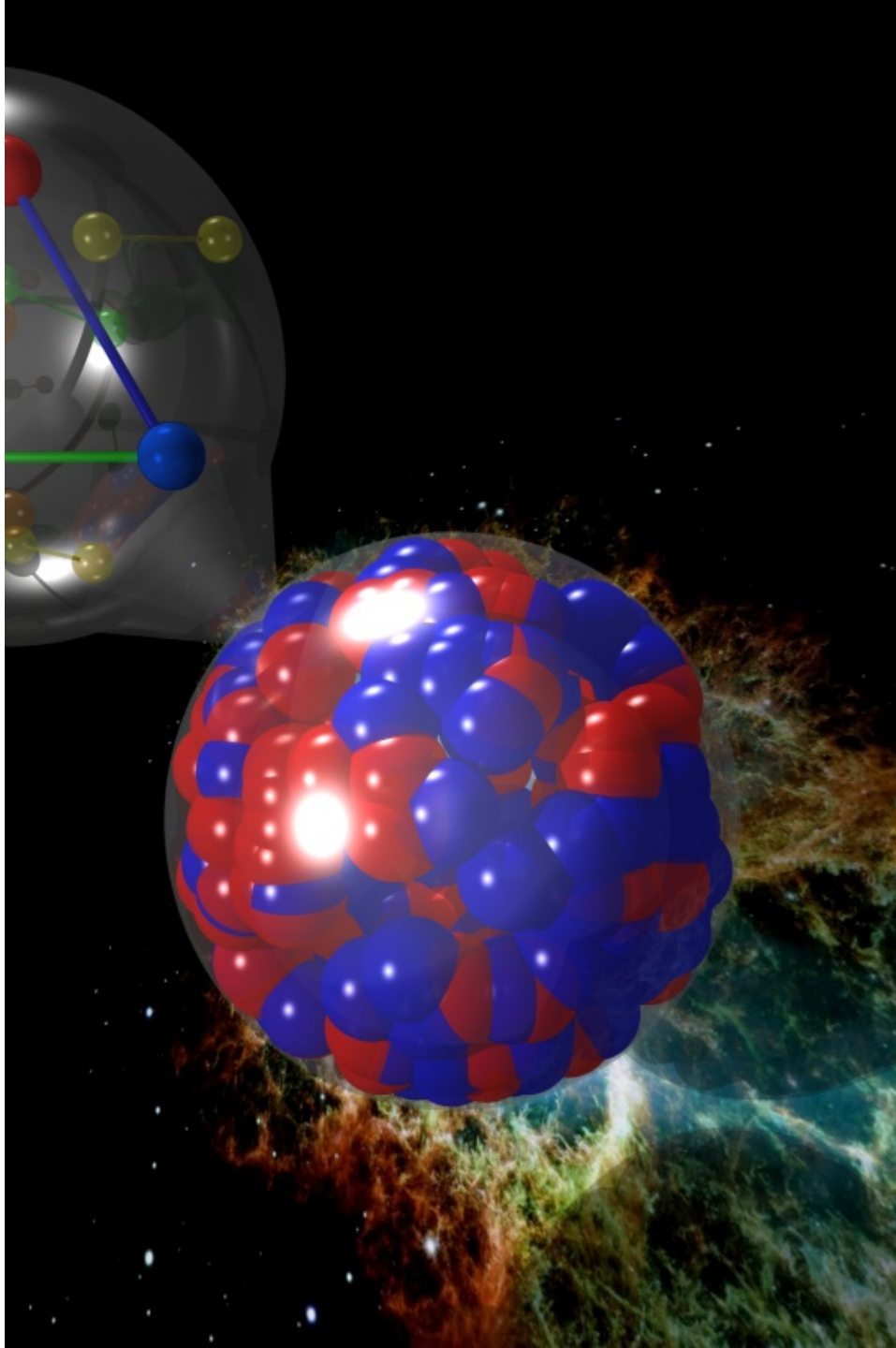
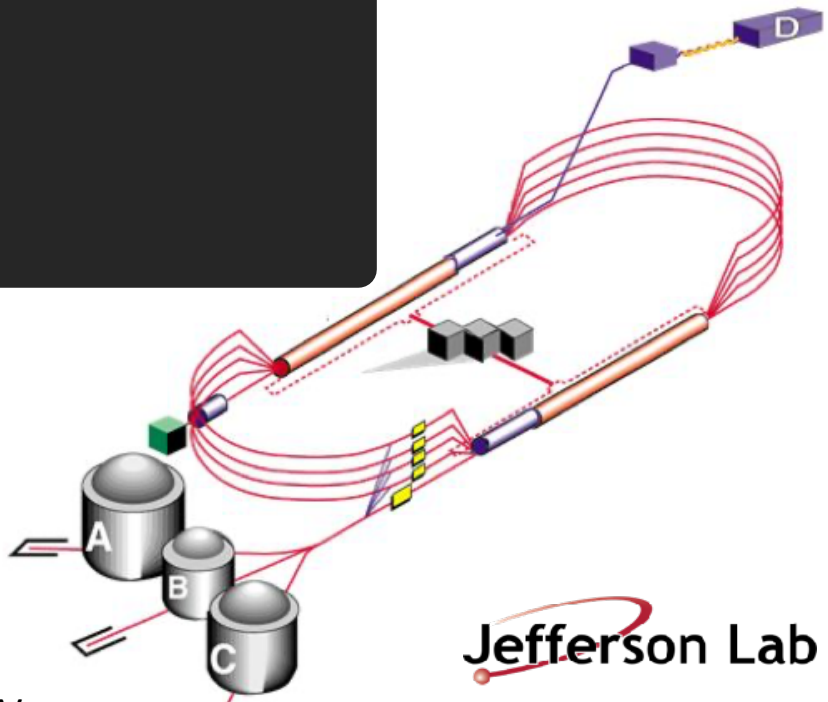
University of Glasgow

IoP APP / HEPP / NP conference
Liverpool, 9th April 2024

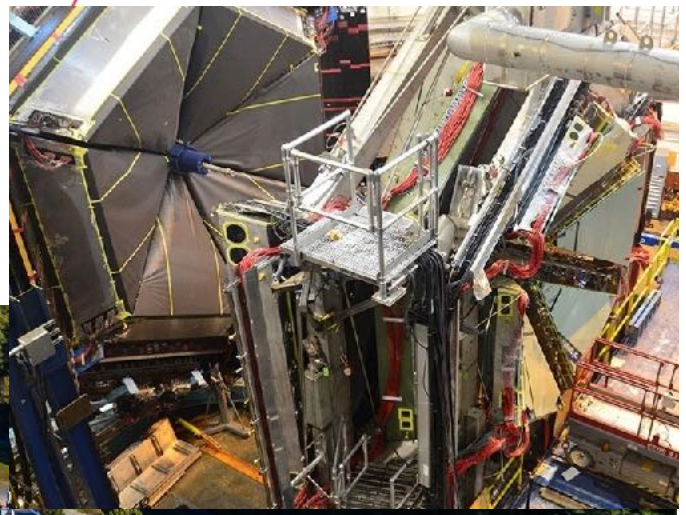


Jefferson Lab

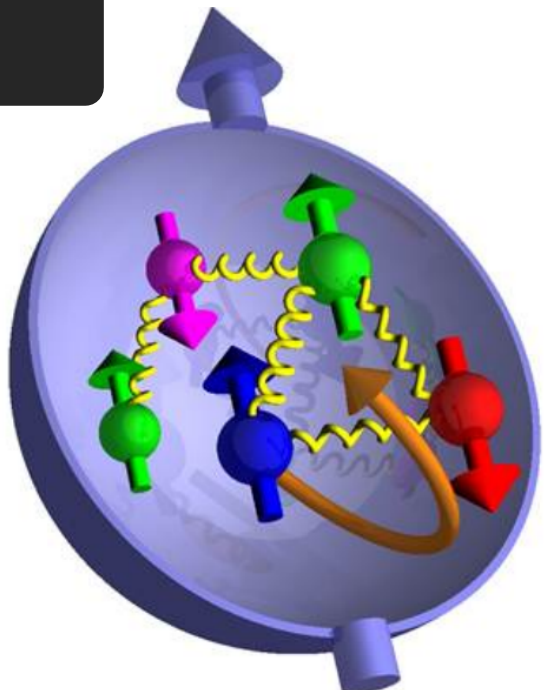


Jefferson Lab

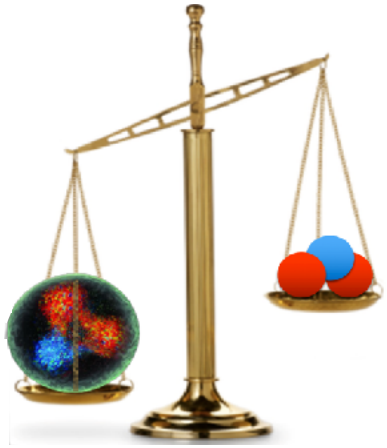
- CEBAF at JLab is a 12 GeV, high power SRF electron accelerator which delivers high polarisation beams to four experimental halls simultaneously.
- Researchers have been doing experiments there since the late 1990s, although the 12 GeV program has only been running since 2012.
- Two STFC-funded UK NP groups involved (Glasgow and York).



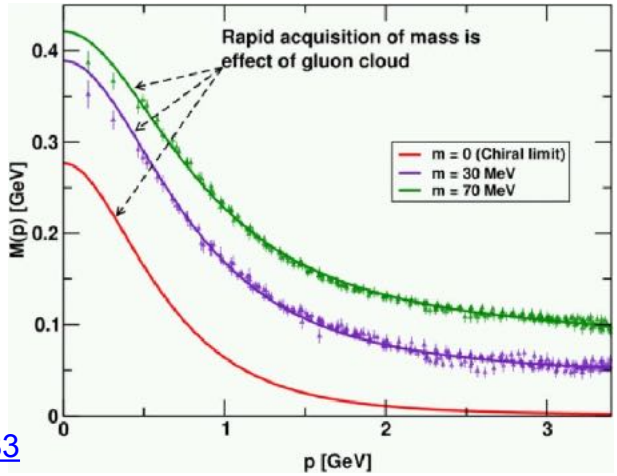
Hadron structure and the strong interaction

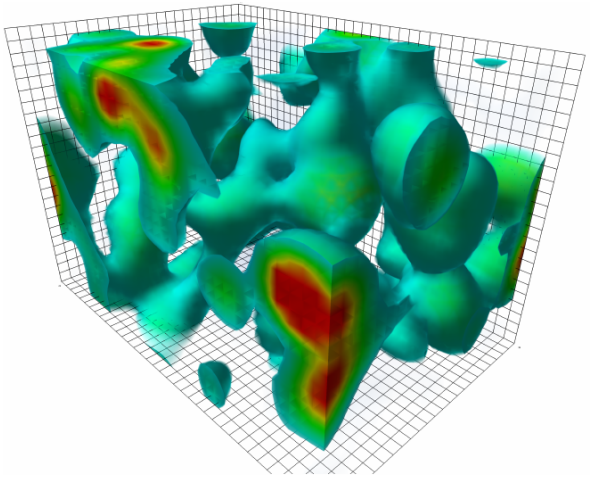


- Studying the dynamic structure of hadrons helps answer key questions about the nature of matter, including:
  - How do the valence quarks, sea quarks and gluons contribute to hadron properties such as mass and spin?
  - What can we learn about the nature of the unique complexity associated with the strong interaction (QCD)?

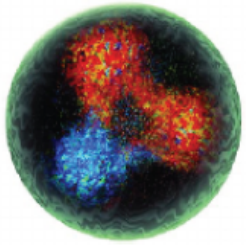


C.D. Roberts et al.
DOI: 10.1016/j.ppnp.2021.103883





Hadron imaging via lepton scattering

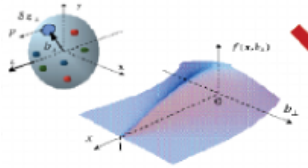


Wigner function: full phase space parton distribution of the nucleon

$\int d^2k_T$

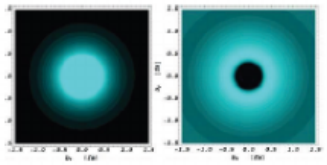
$\int d^2b_T$

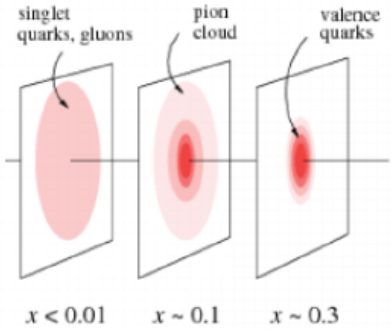
Generalised Parton Distributions (GPDs)



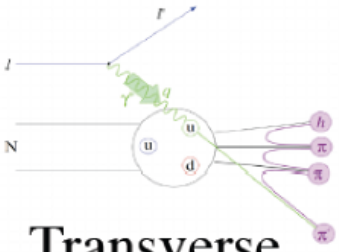
$\int dx$

Form Factors *eg*: G_E, G_M



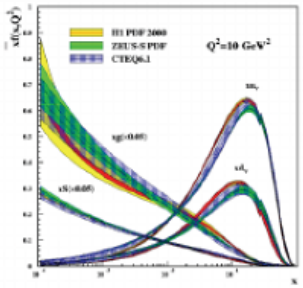


Transverse Momentum Distributions (TMDs)



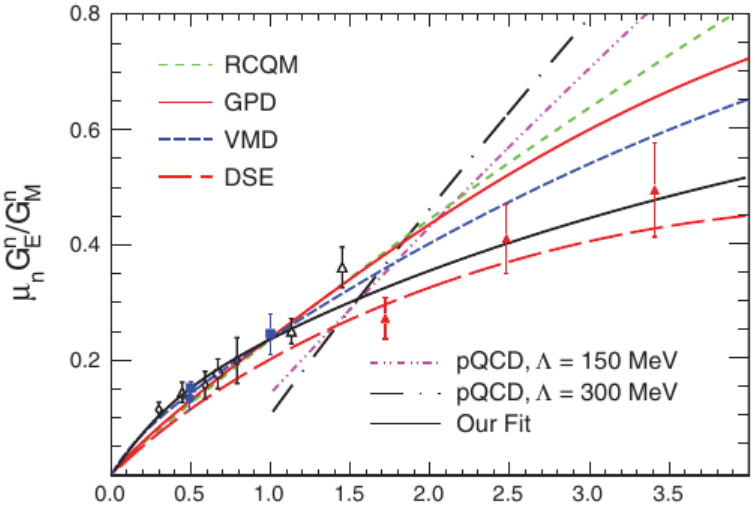
$\int d^2k_T$

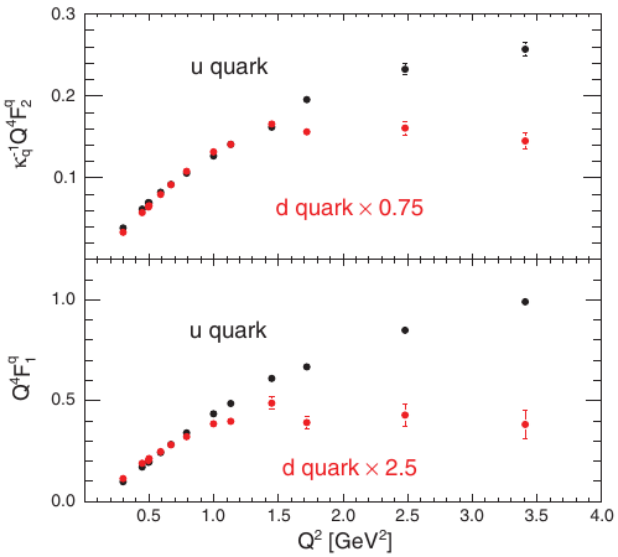
Parton Distribution Functions (PDFs)



Electromagnetic form factors: exclusive structure of the nucleon

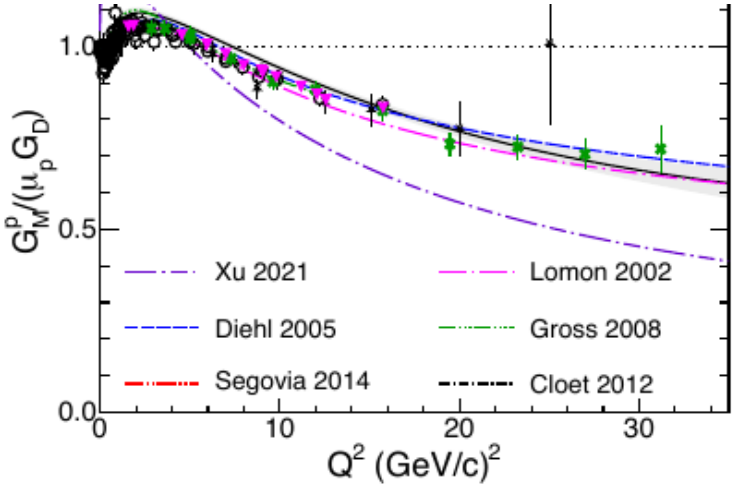
- The electromagnetic form factors of the nucleon are one of the most fundamental parameterisations of the nucleon's transverse structure, relating to the distribution of electric charge and magnetic moment.
- Measurements at high momentum are extremely challenging but offer the possibility of key insights into the strong interaction.
- The most recent results of the neutron electric form factor from JLab (over 10 years ago) allowed for the first ever quark flavour decomposition, and revealed differences in scaling between u and d quarks.

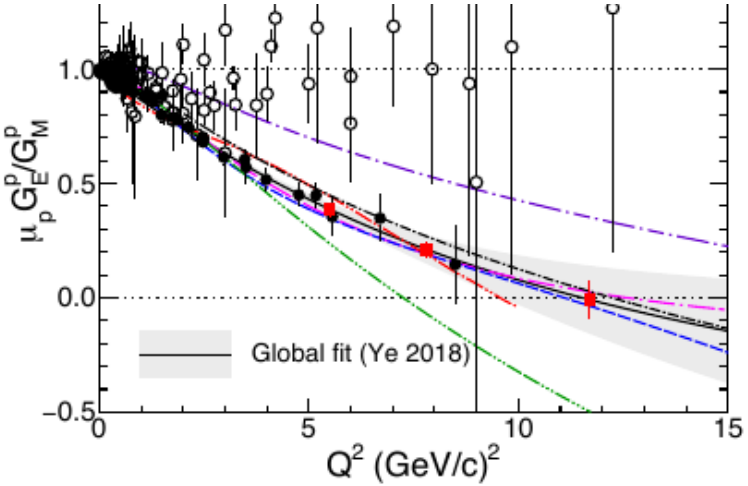


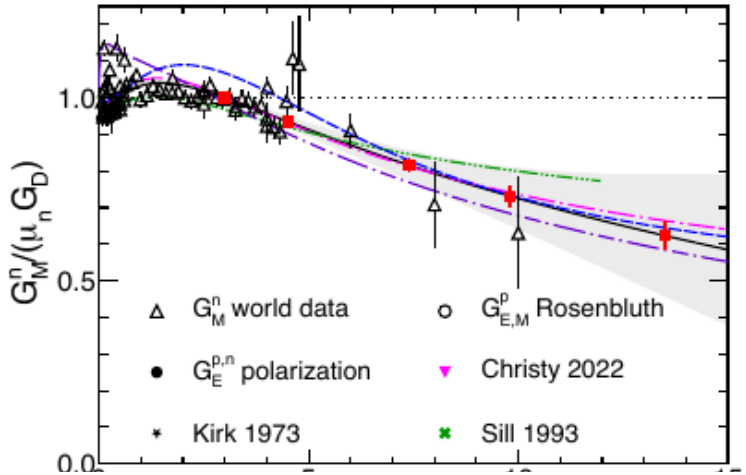


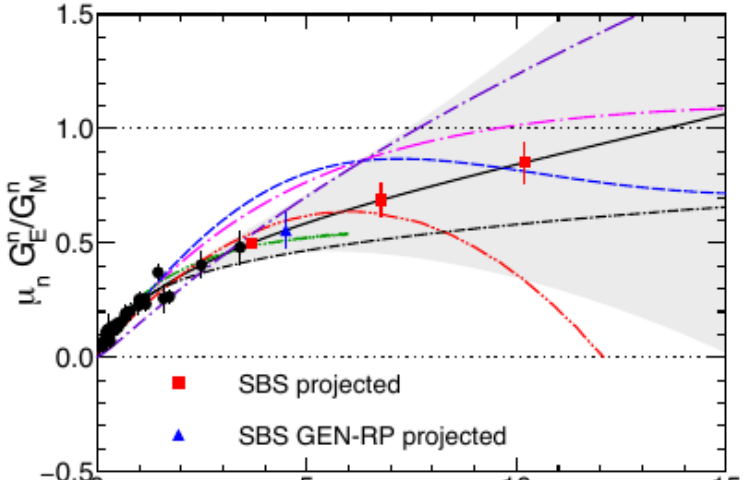
Cates et al
DOI: 10.1103/PhysRevLett.106.252003

Electromagnetic form factors: SBS experiments



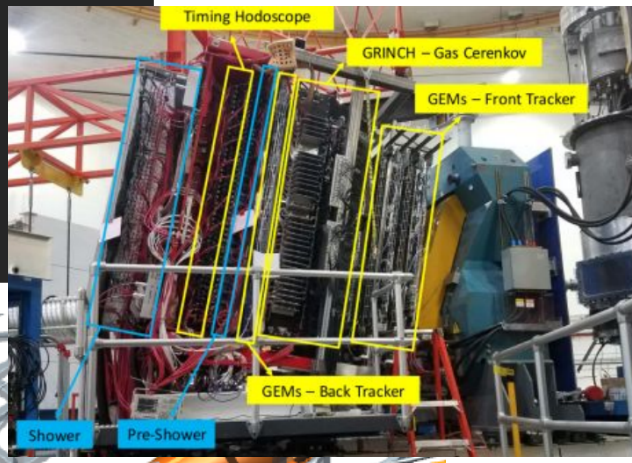


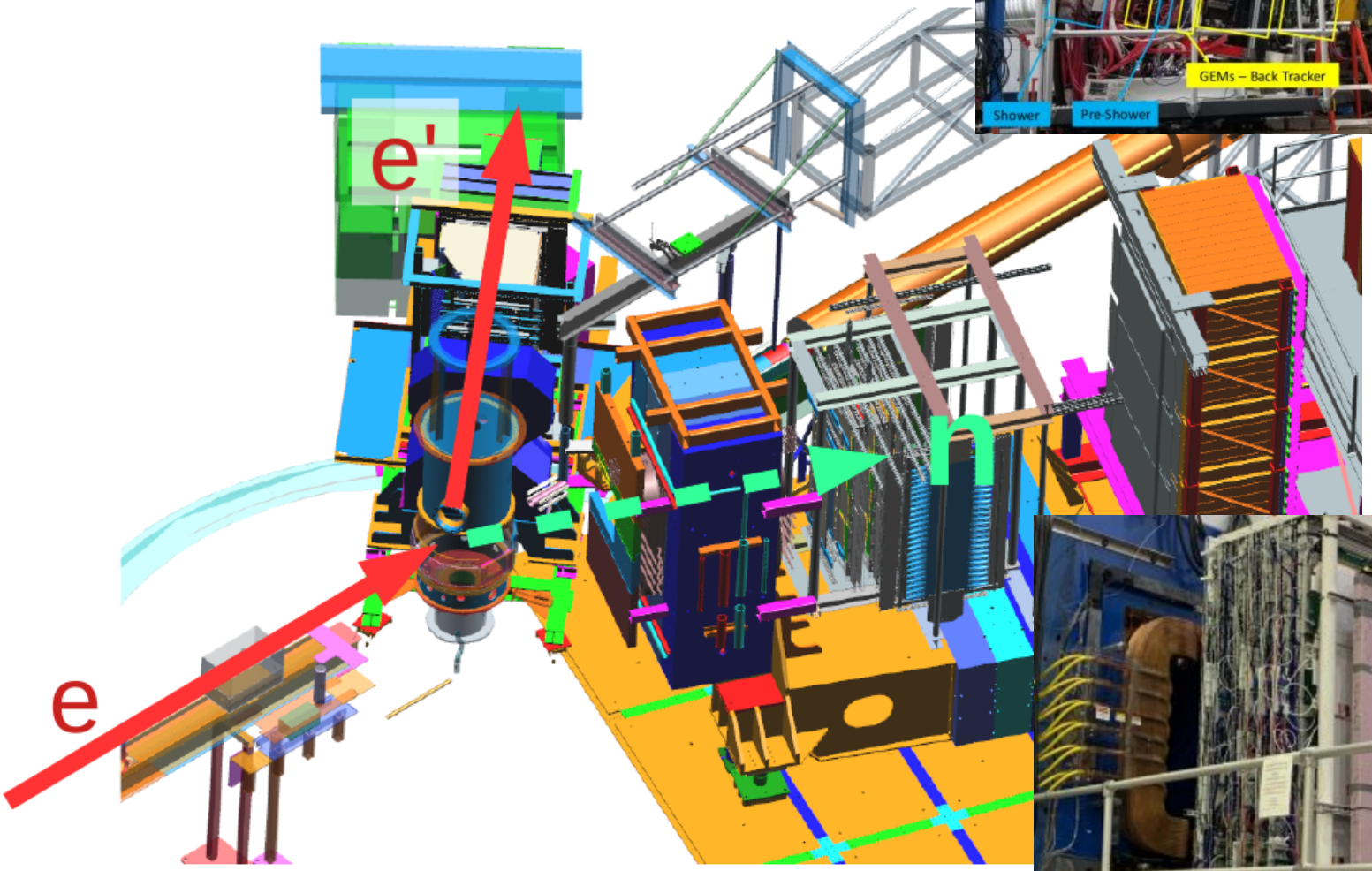




A.J.R. Puckett
hep-ph:2212:11107

Electromagnetic form factors: SBS experiments

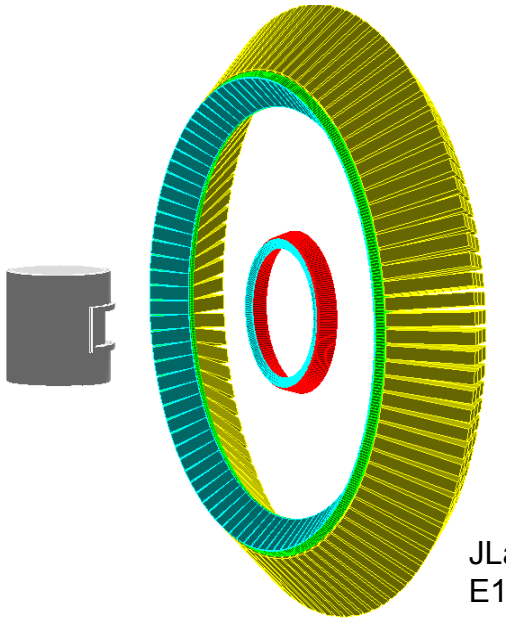




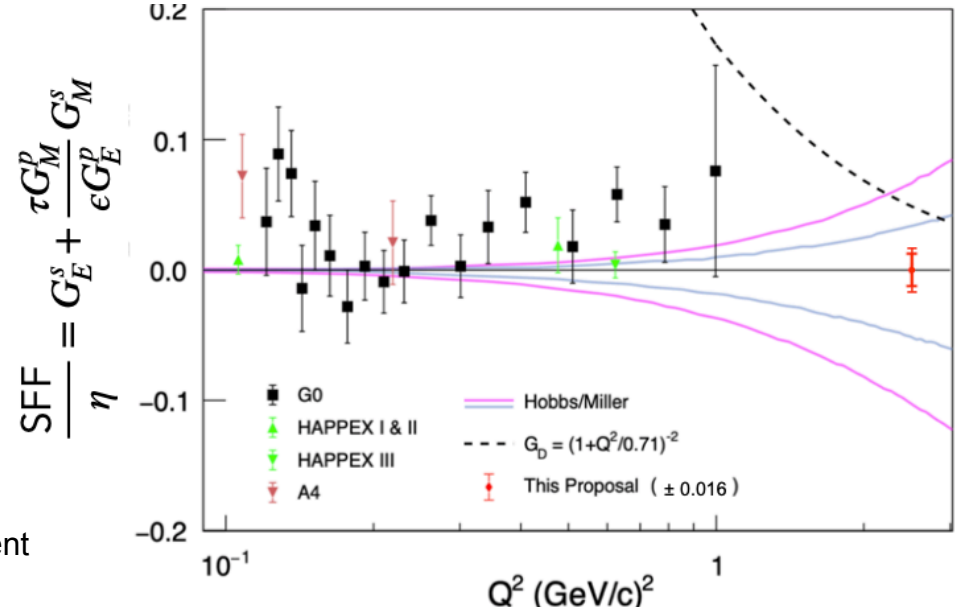
JLab experiment
E12-17-008

Electromagnetic form factors: strange quark contribution

- Measurement of the parity-violating asymmetry in polarised elastic electron-nucleon scattering allows access to the strange quark contribution to the form factors.
- All previous parity-violating electron scattering measurements (at SLAC, Mainz and JLab) have run in integrating mode at low four-momentum transfer;
  - A new JLab experiment will be the first to make a coincidence measurement at moderately high momentum transfer.

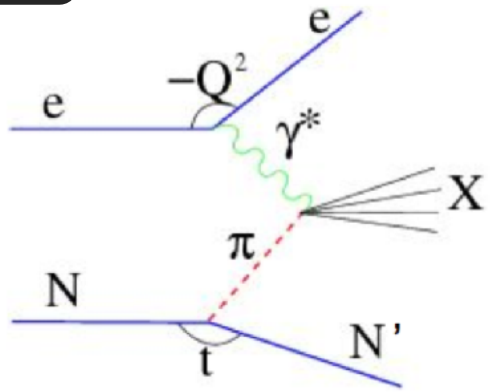


JLab experiment
E12-23-004

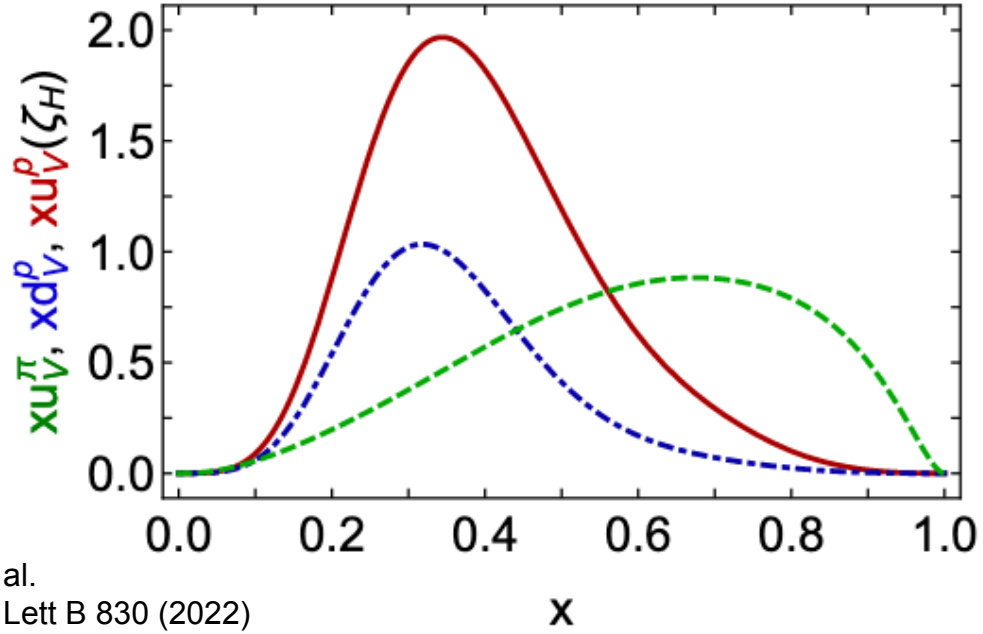


Inclusive meson structure functions: tagged DIS

- Tagged deep inelastic scattering allows access to meson structure via the Sullivan process, which is a natural complement to the more traditional Drell-Yan process.
- Extraction of PDFs can help answer questions on the mass budget of light hadrons and in particular on the difference in gluon content between the pion, kaon and proton.



Hadron	Observed Mass (MeV)	Higgs Generated Mass (MeV)
Proton (uud)	~940	~10
Pion ($u\bar{d}$)	~140	~7
Kaon ($u\bar{s}$)	~490	~100

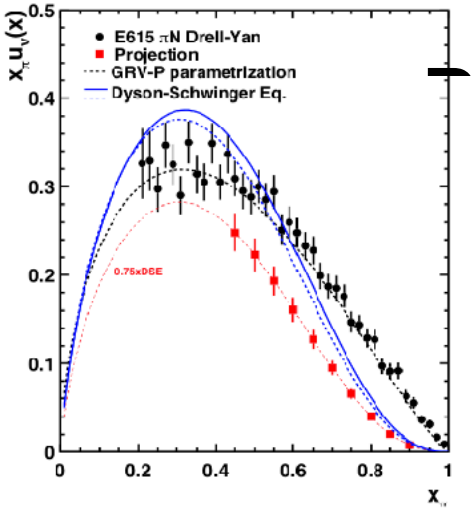


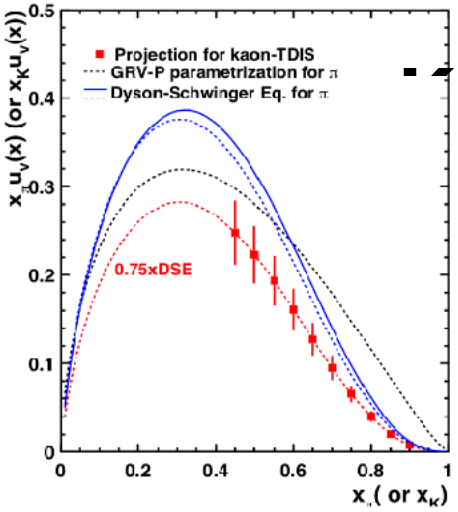
Lu et al.
Phys Lett B 830 (2022)

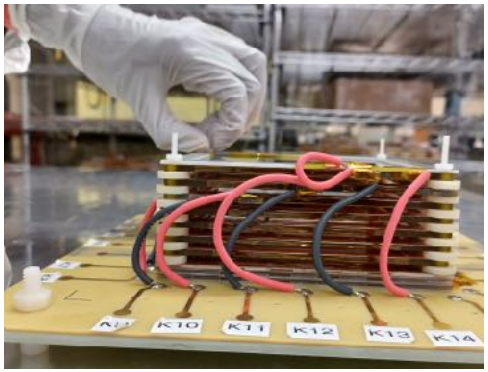
Inclusive meson structure functions: tagged DIS

- Detecting recoil (and spectator) nucleon provides an effective tag of the pionic content of the nucleon, while tagging the final state from hyperon decay will allow for the first ever measurement of DIS from a kaon.

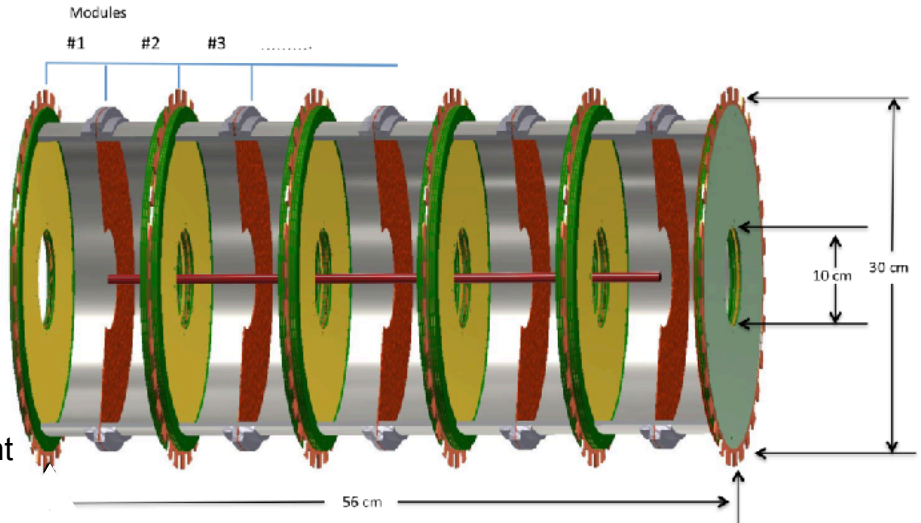
- Requires detection of low energy hadrons in a high luminosity, fixed target arrangement using a new mTPC device.







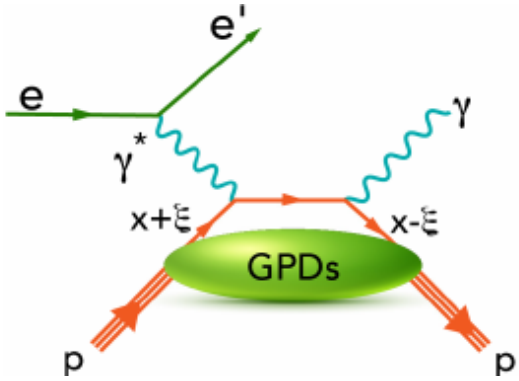
JLab experiment E12-14-010

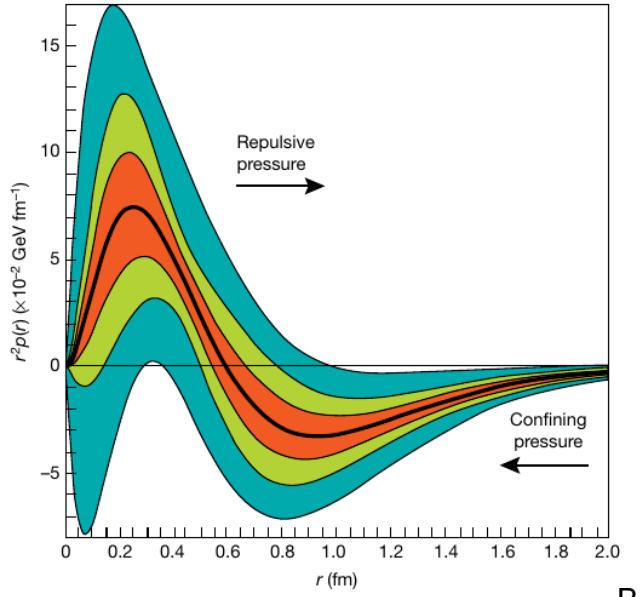


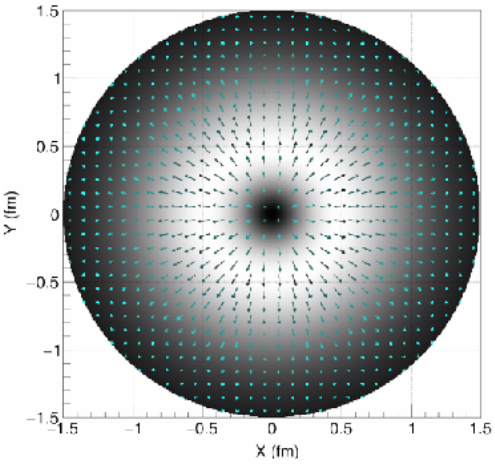
Gravitational structure of the nucleon: quark pressure and shear distributions

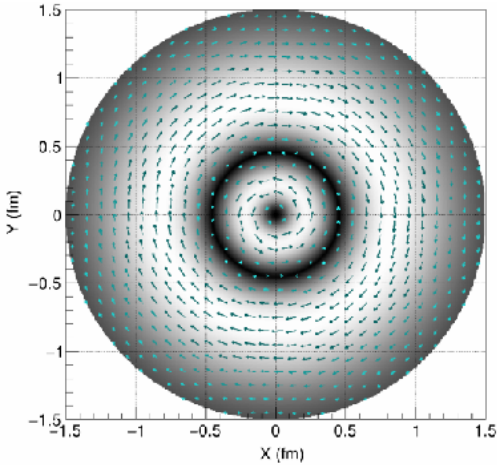
- Recent advances in the understanding of deeply virtual Compton scattering (DVCS) at JLab have allowed for the first time a determination of the nucleon's energy-momentum tensor via its gravitational form factor.

- From this, the radial pressure and shear forces on quarks can be extracted.





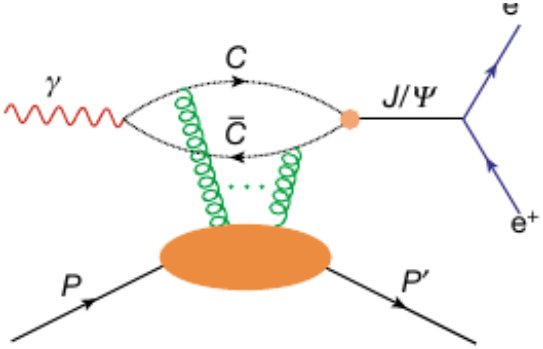


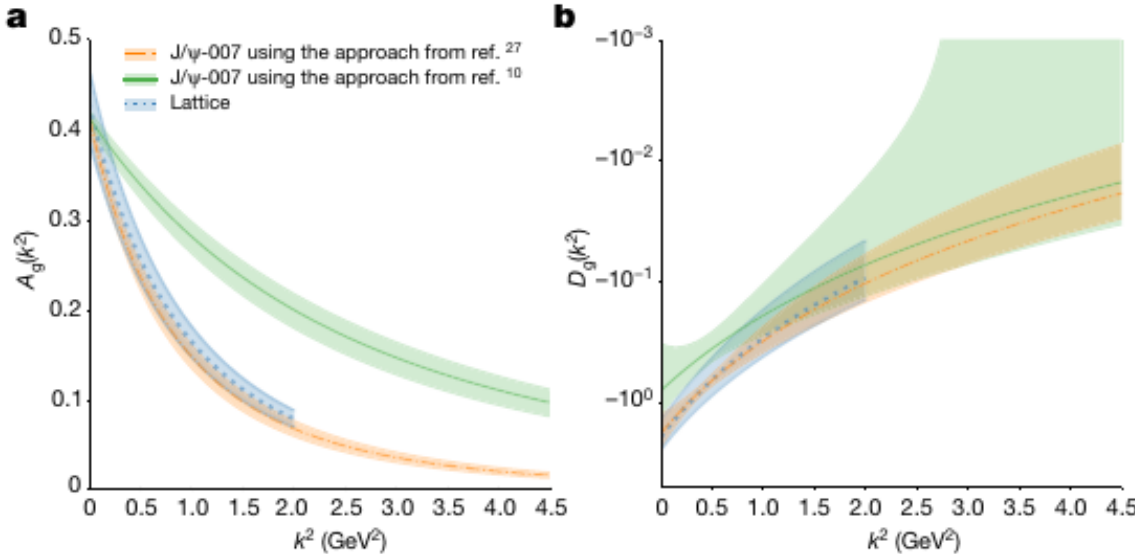


Burkert et al.
Nature 557 (2018)

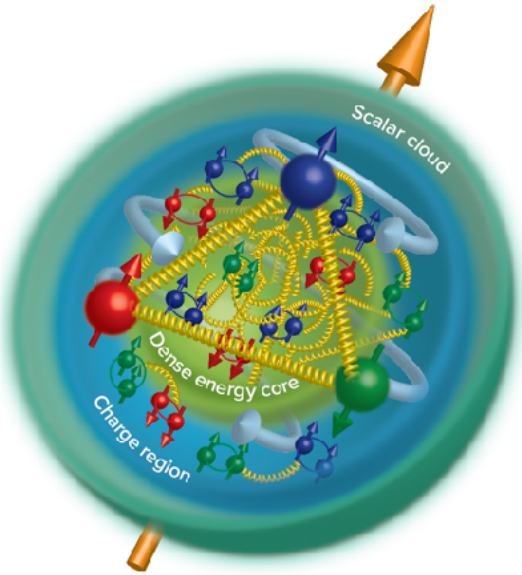
Gravitational structure of the nucleon: gluon mass distributions

- Similarly, access to the gluon gravitational form factors is possible via J/Psi photoproduction.
- Early, tentative results from JLab suggest the nucleon's mass radius may be significantly smaller than its charge radius.



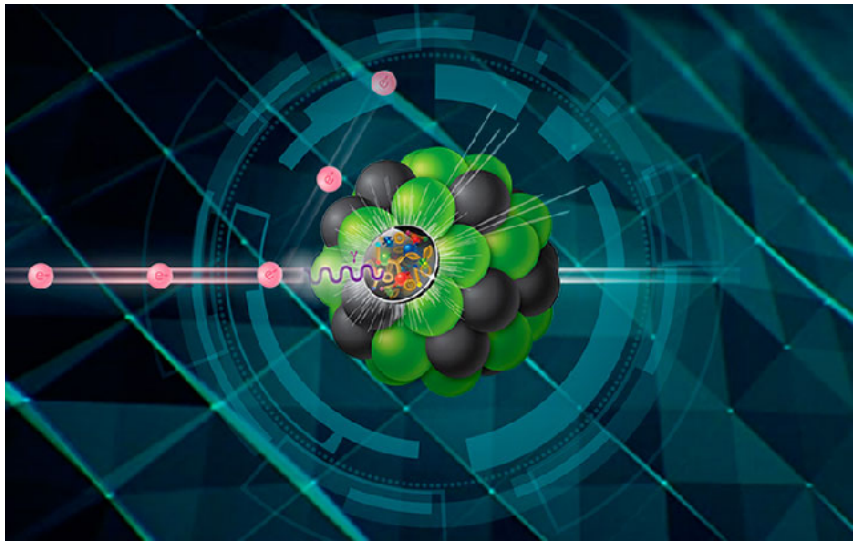


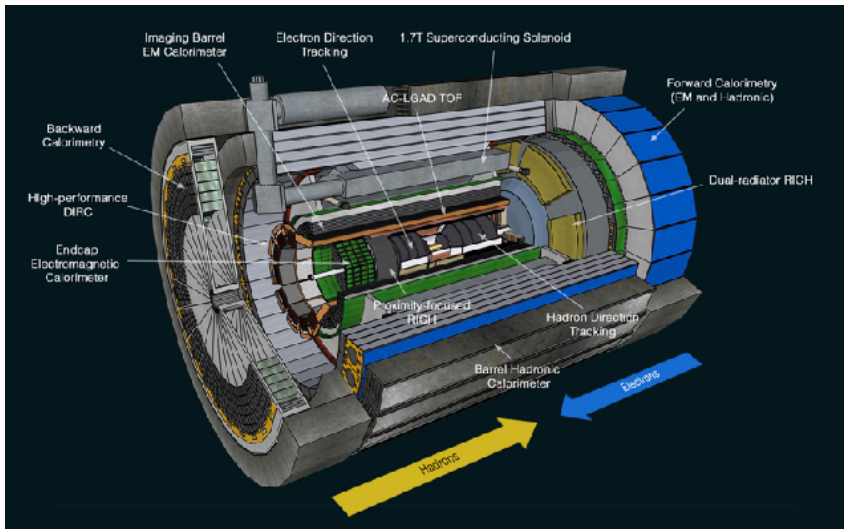
Duran et al.
Nature 615 (202



Summary and Outlook

- Results from recent hadron structure experiments at JLab are offering new insights into the nature of matter and the strong interaction.
- Complementary measurements are expected in the near future with the AMBER experiment at CERN.
- Looking further ahead, the Electron-ion collider at Brookhaven will begin data taking in the 2030s where the focus will be on the gluonic structure of hadrons.





bnl.gov

Acknowledgements

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- Thanks to STFC for funding this research in the UK.

- Thanks to my Glasgow and York colleagues, especially Rachel Montgomery and Bjoern Seitz.