

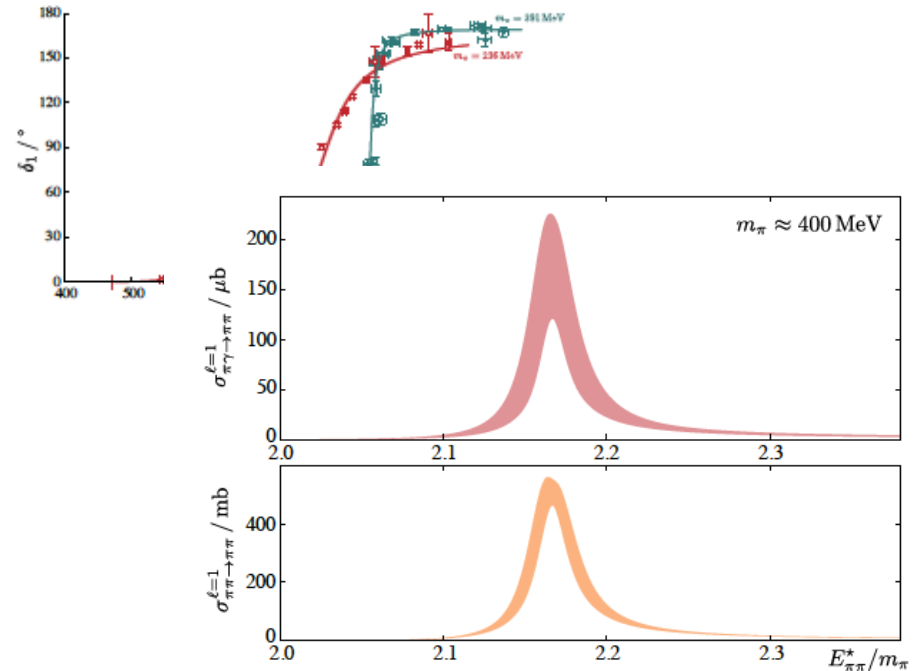
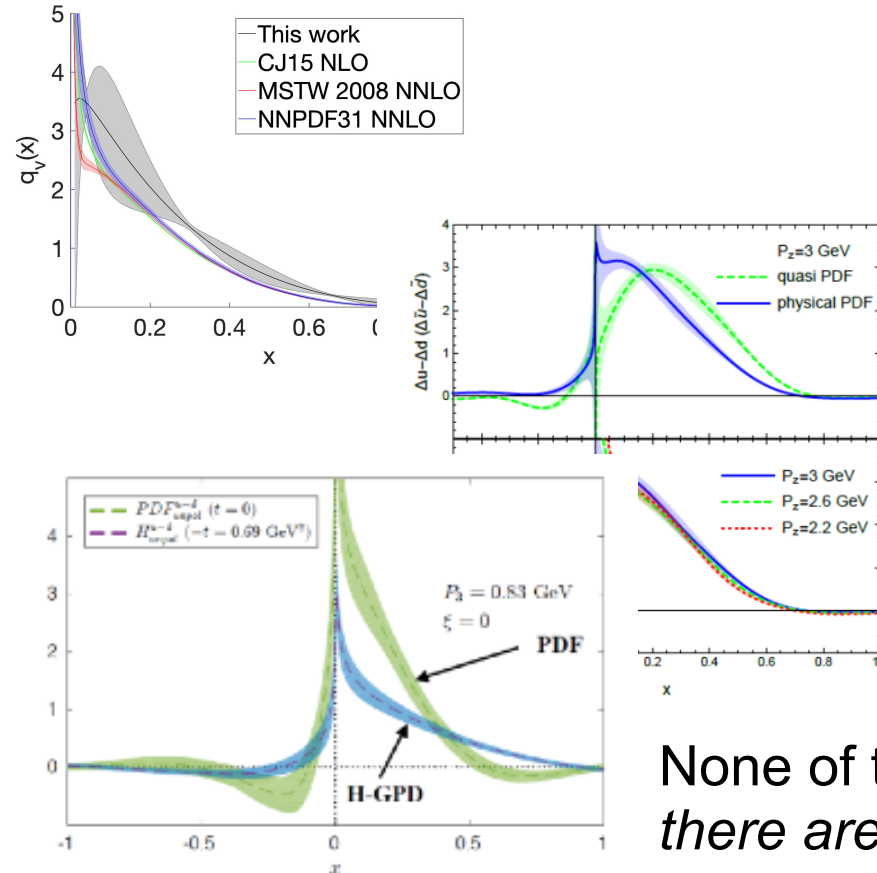
What are the prospects for the evaluation of the meson and baryon spectra, elastic and transition electromagnetic form factors, and the parton structure functions from the first principles of QCD in the approach to the exascale era, and what are the computational and theoretical challenges?

Hadron Structure

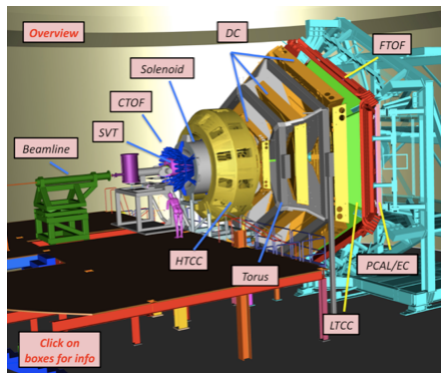
Jianwei Qiu, Huey-Wen Li
Xiangdong Ji, Anatoly Radyushkin

Properties of excited states

Raul Briceno - *tomorrow*



None of this thought possible a decade ago -
there are no "no-go" theorems.



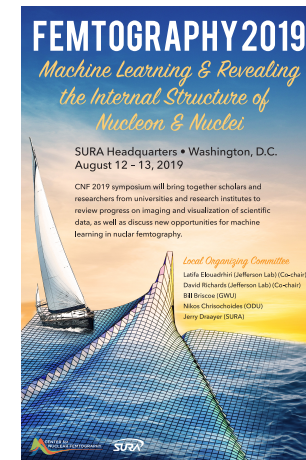
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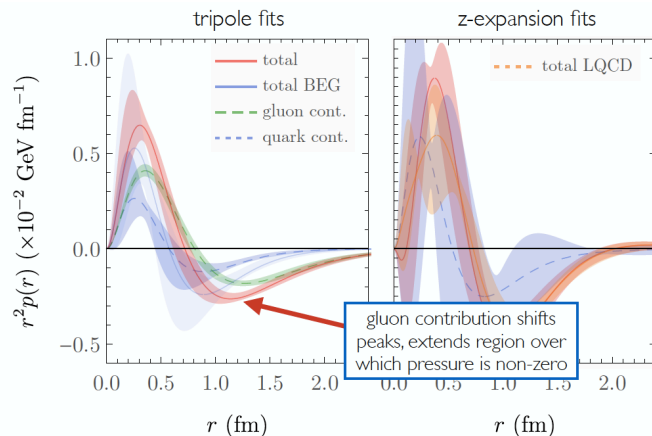


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LQCD: not *testing* but *understanding* QCD

P. Shanahan, EINN2019



Gluon GFFs: Shanahan, Detmold, PRD99, 014511 & PRL122, 072003 (2019)
 Quark GFFs: P. Hägler et al. (LHPC), PRD77, 094502 (2008)
 Expt quark GFFs (BEG): Burkert et al, Nature 557, 396 (2018)

LQCD can predict and complement: **gluon structure**
 Tremendous theoretical progress, and computational advances to exploit it.

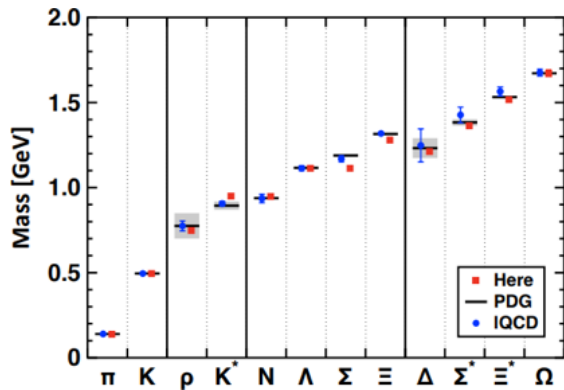
→ *Robert Edwards*

What is the needed interplay between experiment, phenomenology, and theory in order to shed light on the connection between hadron mass generation and dynamical chiral symmetry breaking? How can the data on the $\gamma p N^$ electrocouplings of chiral-partner resonances be used for the exploration of this connection?*

QCD is a complicated many-body system - but much of it can be described in terms of simple degrees of freedom, and the emergence of "symmetries".

C.Roberts

V.Burkert

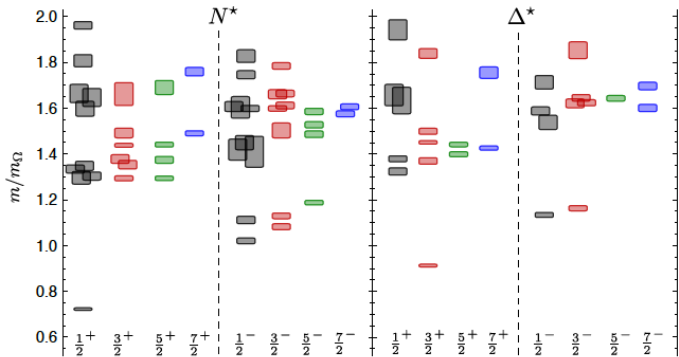


not included

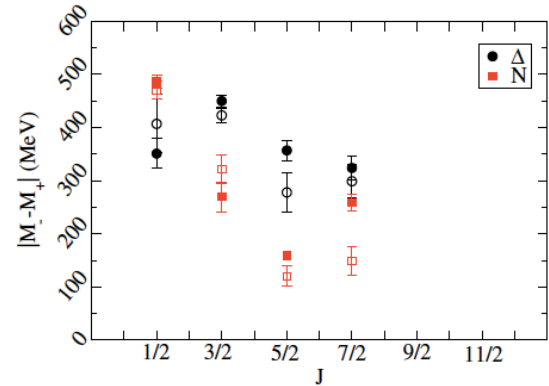
PDG 2016 with *, **	
$N(1860)$	$N(1880)$
$N(1895)$	
$N(2000)$	$N(2040)$
$N(2060)$	$N(2100)$
$N(2120)$	$N(2300)$
$N(2570)$	$N(2700)$
$\Delta(1750)$	$\Delta(1900)$
$\Delta(1940)$	$\Delta(2000)$
$\Delta(2150)$	$\Delta(2200)$
$\Delta(2300)$	$\Delta(2350)$
$\Delta(2390)$	$\Delta(2400)$
$\Delta(2750)$	$\Delta(2950)$
$N(1875)$	

PDG 2018 with ***, ****

Restoration of chiral symmetry in excited spectrum? Cohen, Glozman, ...



→ R.Briceno



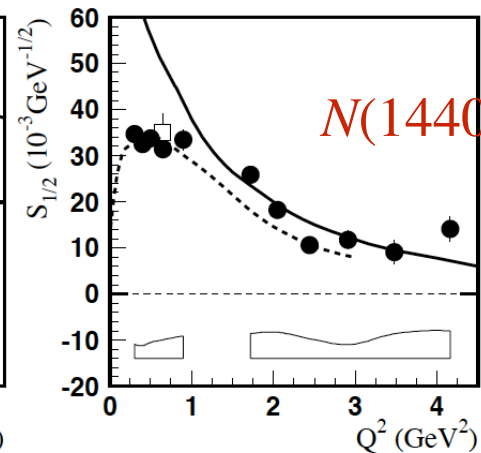
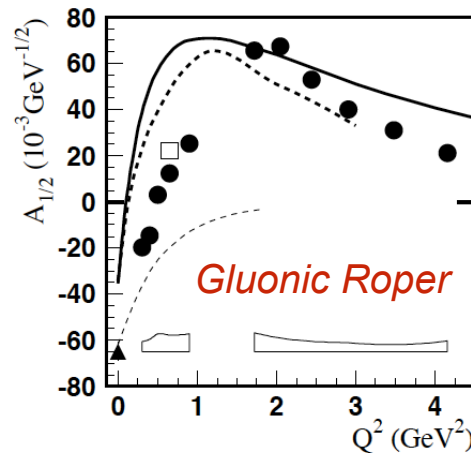
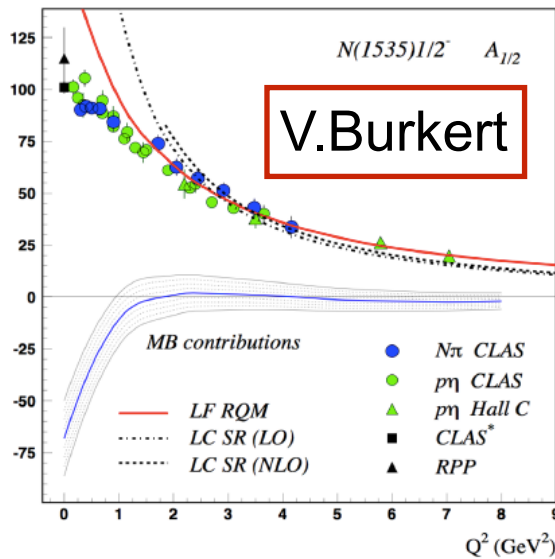
PHYSICAL REVIEW D 94, 054006 (2016)
Mapping chiral symmetry breaking in the excited baryon spectrum

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Felipe J. Llanes-Estrada and Tim Van Cauteren
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(Received 17 May 2016; published 7 September 2016)

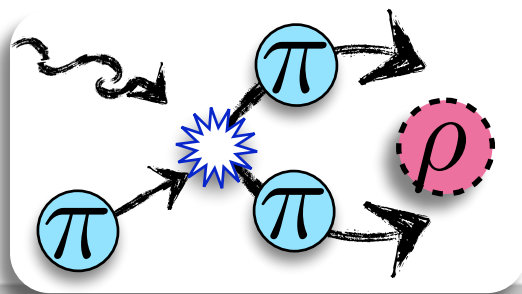
If spectrum enables us to “catalogue” degrees of freedom,
 structure enables us to probe their nature.

Hadron resonance gas → counting degrees of freedom

Hybrid baryons in CLAS12



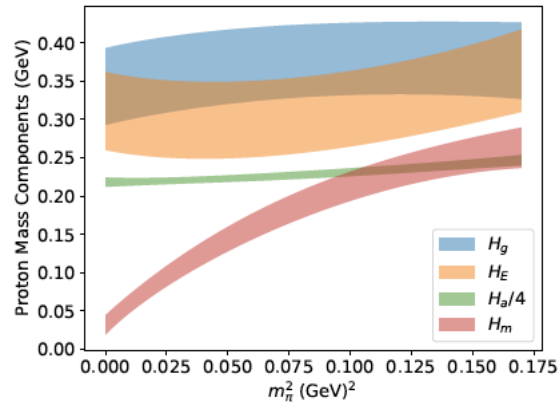
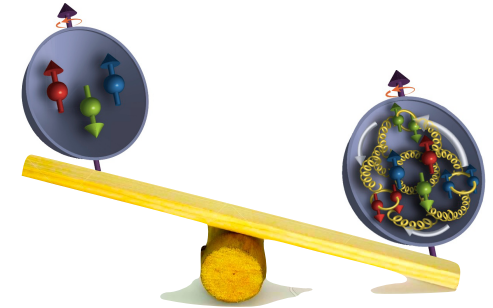
Briceno, Hansen and Walker-Loud, PRD 91, 034501 (2015)



Energy-Momentum Tensor

$$T_{\mu\nu} = \frac{1}{4}\bar{\psi}\gamma_{(\mu}D_{\nu)}\psi + G_{\mu\alpha}G_{\nu\alpha} - \frac{1}{4}\delta_{\mu\nu}G^2; \langle P | T_{\mu\nu} | P \rangle = P_{\mu}P_{\nu}/M$$

$$\text{Trace Anomaly: } T_{\mu\mu} = -(1 + \gamma_m)\bar{\psi}\psi + \frac{\beta(g)}{2g}G^2$$



Yang et al., Phys. Rev. Lett. 121, 212001 (2018)

Excited states?

C.Roberts

Z. Mezziani

T.Horn

Pion is emblematic of relation between mass and chiral symmetry. Studied in DSE, AdS/QCD, Lattice,...

→Raza Sufian