Nucleon and Resonance Structure from em Processes

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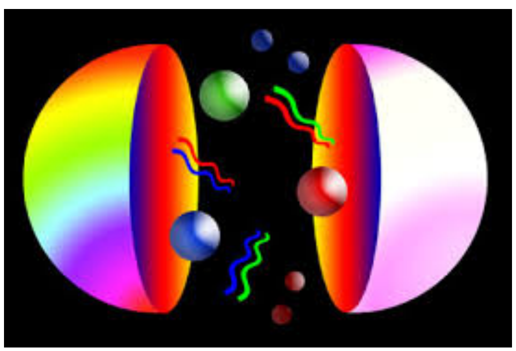
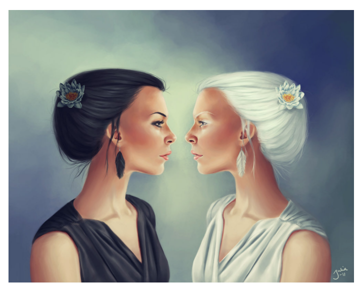
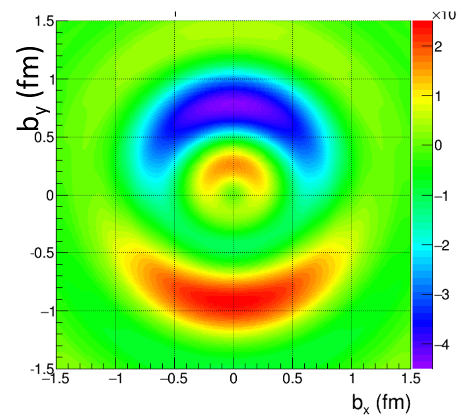
Jefferson Lab

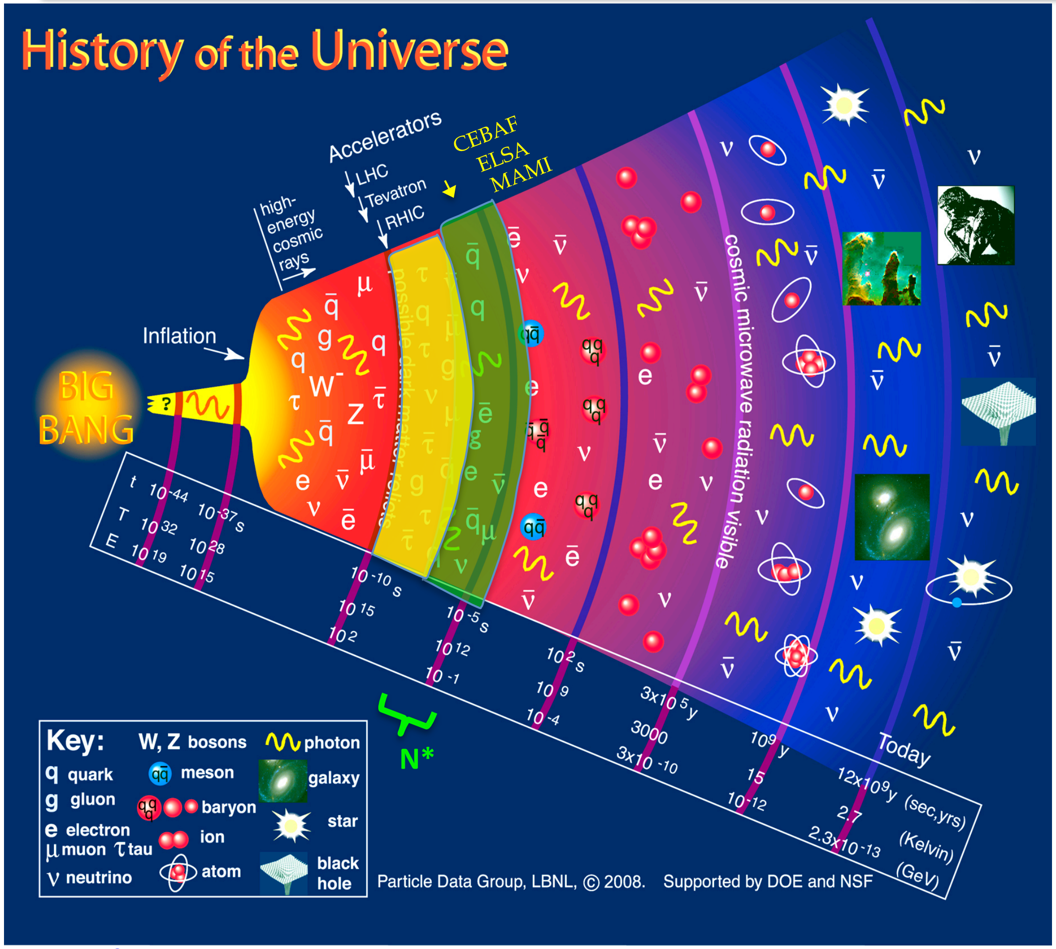
Workshop on Nucleon and Resonance Structure at Hard Processes, Orsay University, May 29-31, 2017



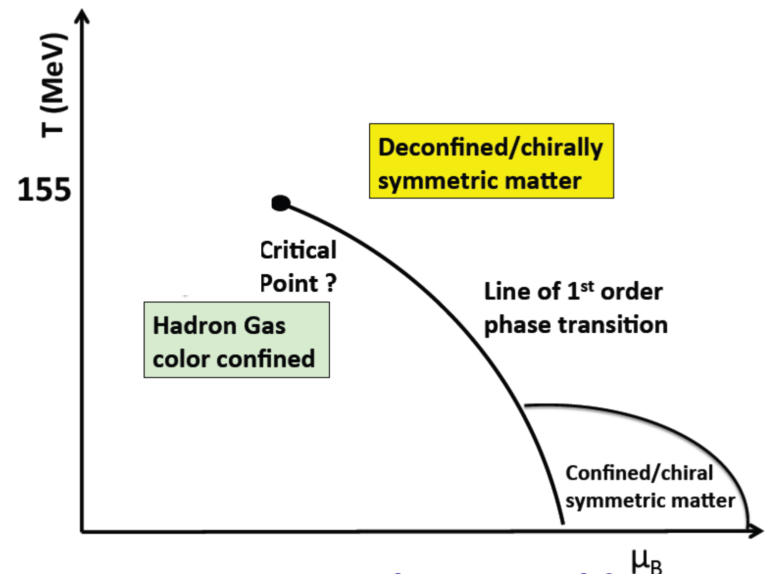




The emergence of Confinement



N*s existed abundantly 13.7 billion years ago
when they were encoded in the proton's "DNA"

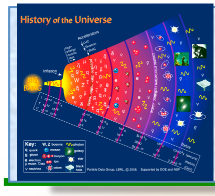


Dramatic events in the μsec old universe

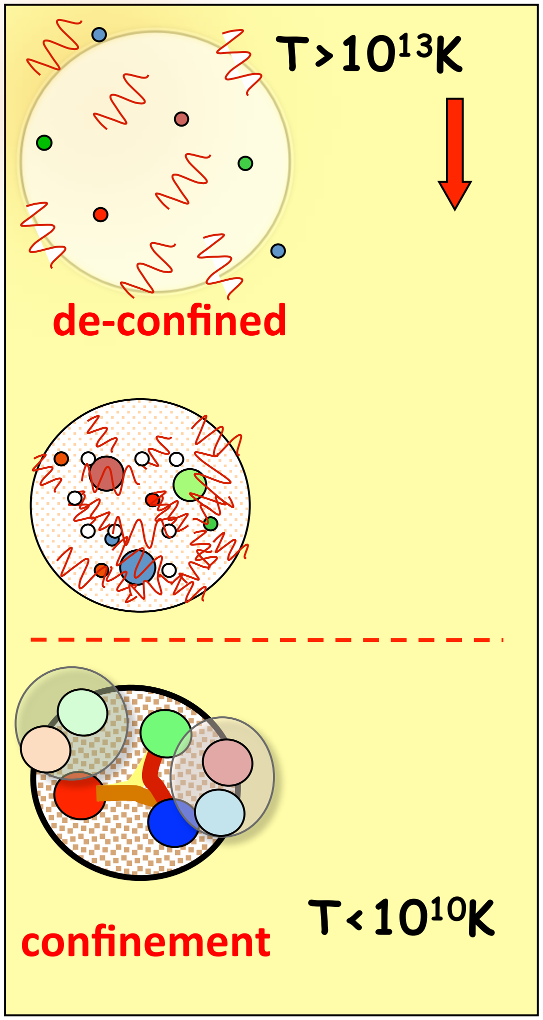
- Chiral symmetry is broken
- Quarks attain masses dynamically
- Quark confinement occurs

QGP -> Hadron gas phase
is governed by excited baryons

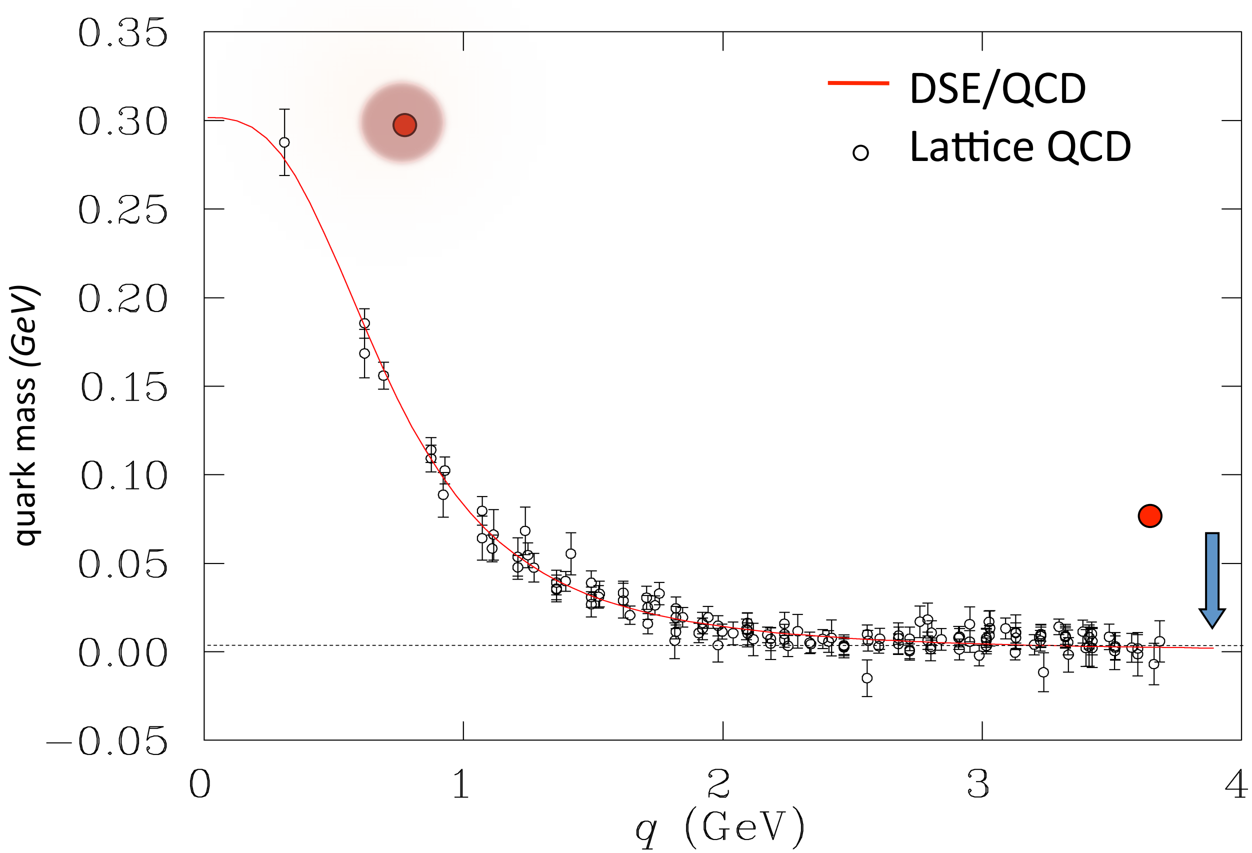
With electron machines we explore these events to unravel the mechanisms of confinement



Light quarks become heavy



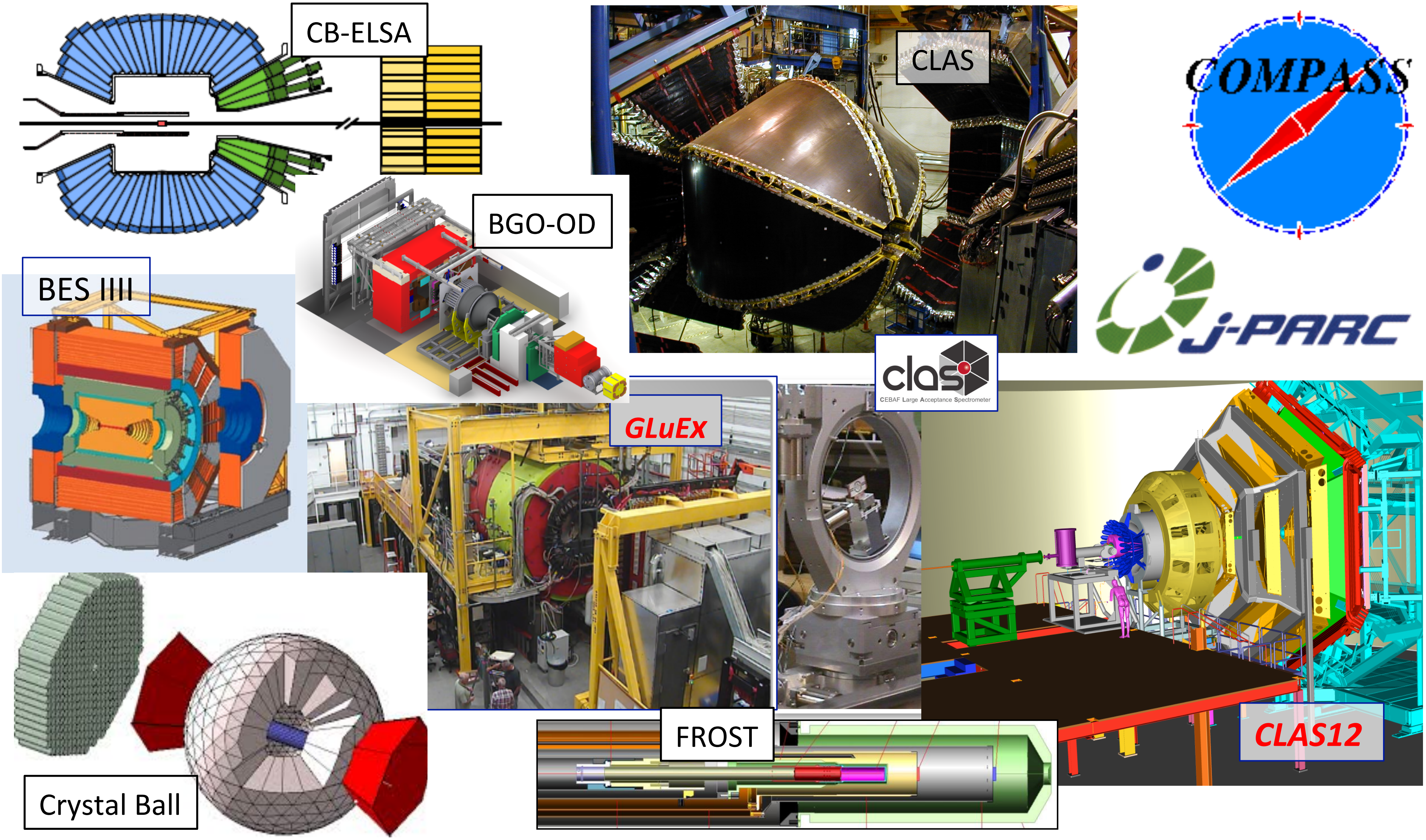
As the Universe cools down, quarks develop their gluon cloud and acquire mass dynamically



EM interactions to probe baryons

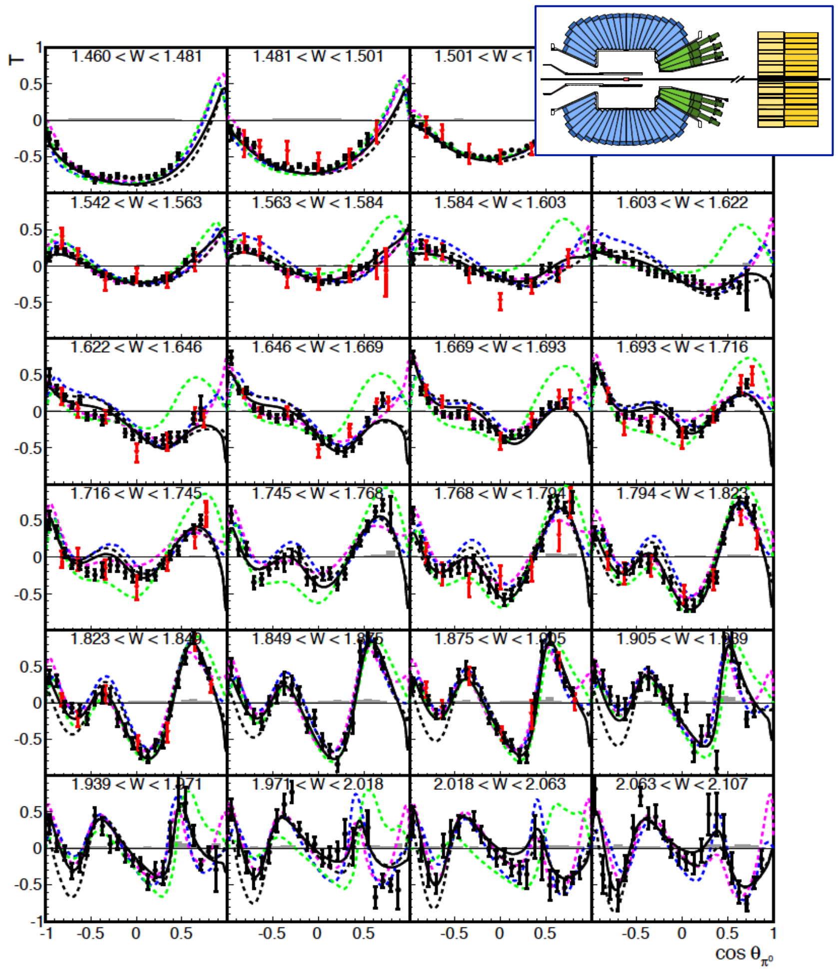
- **Spectrum** search for new baryon states ➪ Symmetries underlying hadronic matter
- **Form factors** ➪ measure charge and current (transition) densities and map the transition from soft to hard processes
- **Structure functions** ➪ parton and spin densities
- **Deeply exclusive processes** ➪ probe the nucleon GPDs, 3D imaging of the quark content, orbital angular momentum
- **Moments of GPDs** ➪ Pressure on quarks and mapping confinement forces

Equipment to explore the excited baryons

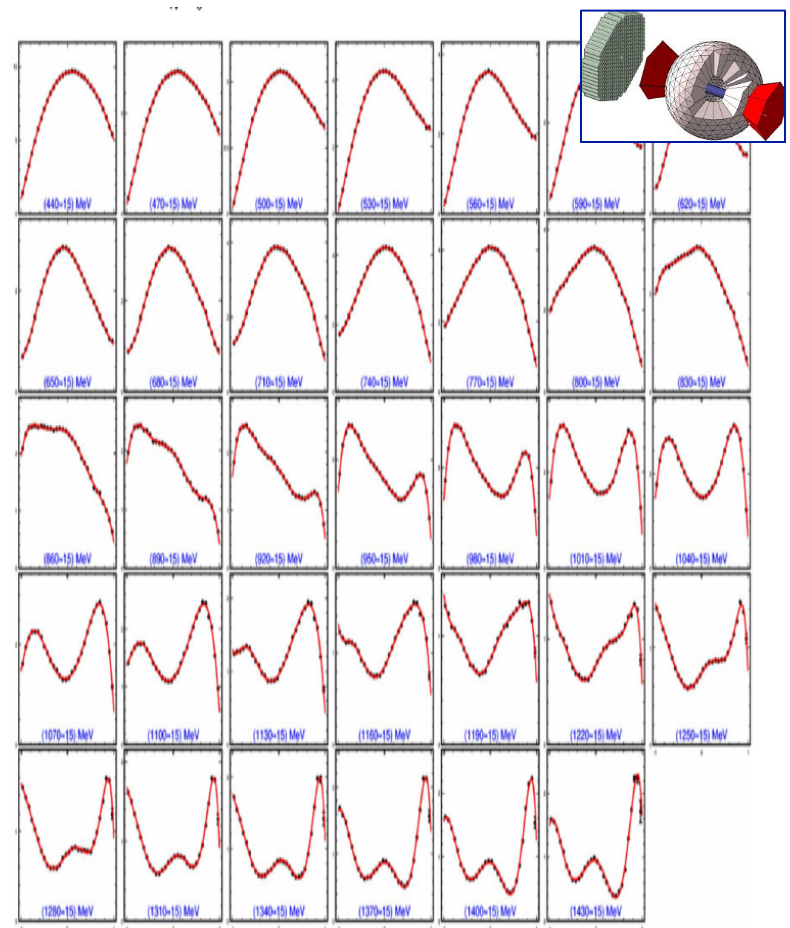


Example of CB-ELSA and MAMI-CB Data

Target Asymmetry in π^0 production off protons fitted with several.



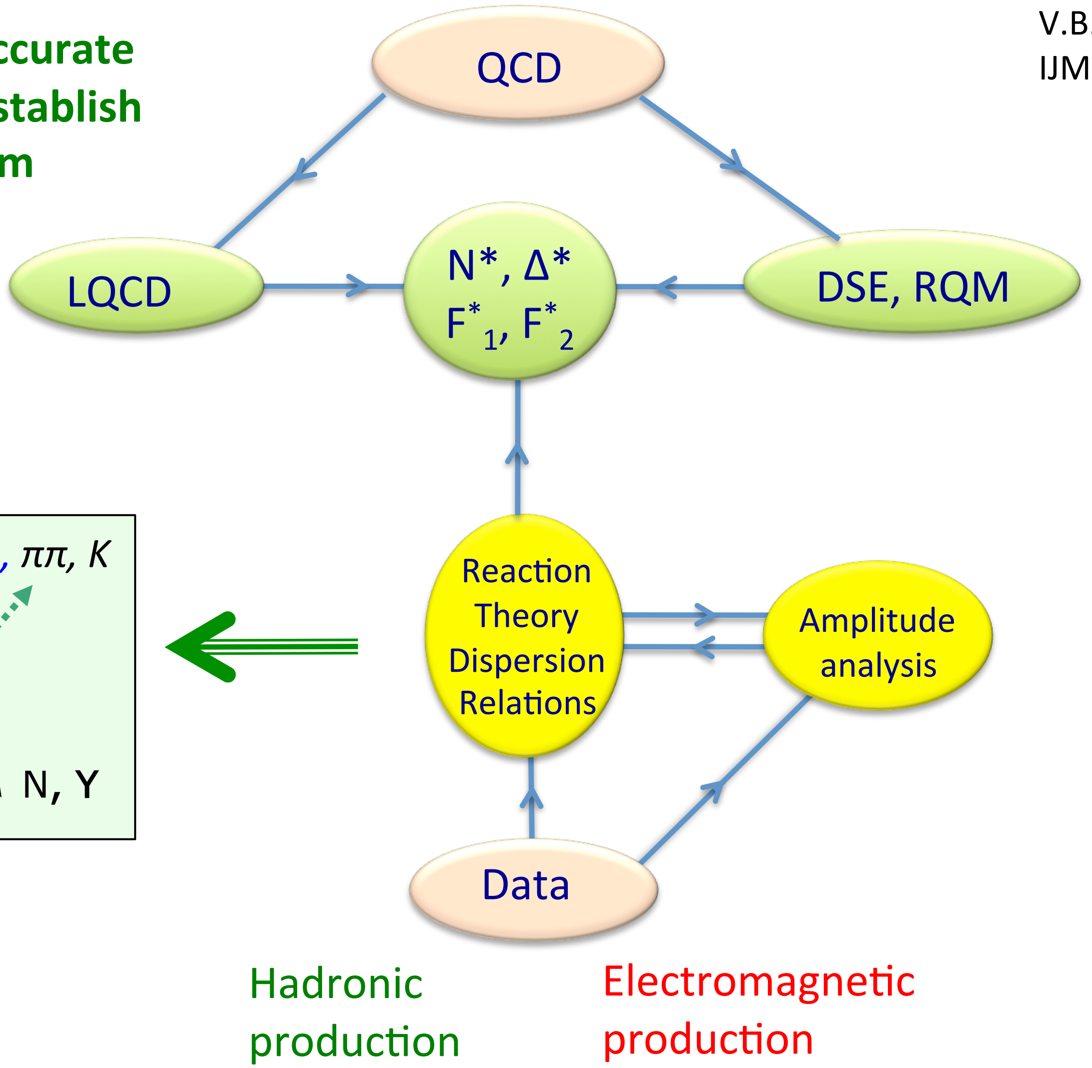
Differential $p\pi^0$ cross section at MAMI-CB fitted with L=4 Legendre expansion.

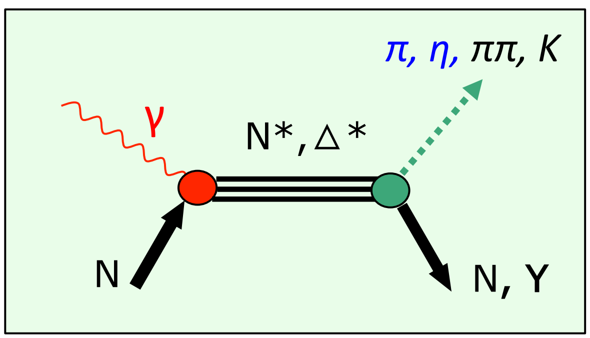


Establishing the N* and Δ* Spectrum

Precision data require accurate analysis procedures to establish the baryon spectrum

V.B., T.S.-H. Lee
IJMP E13 (2004)

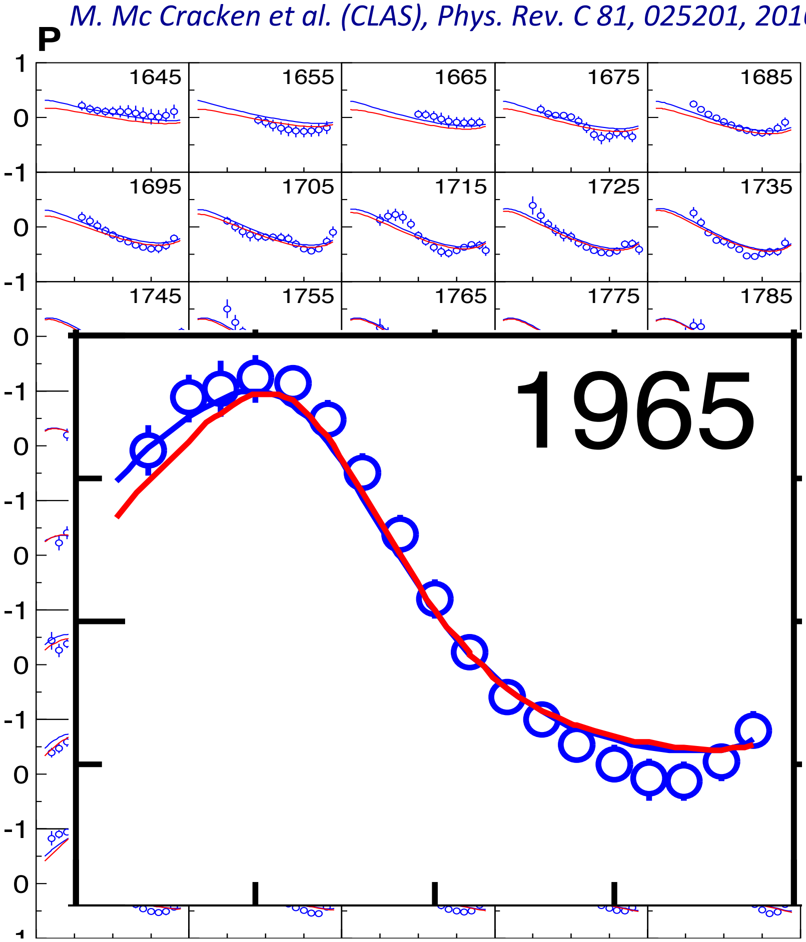




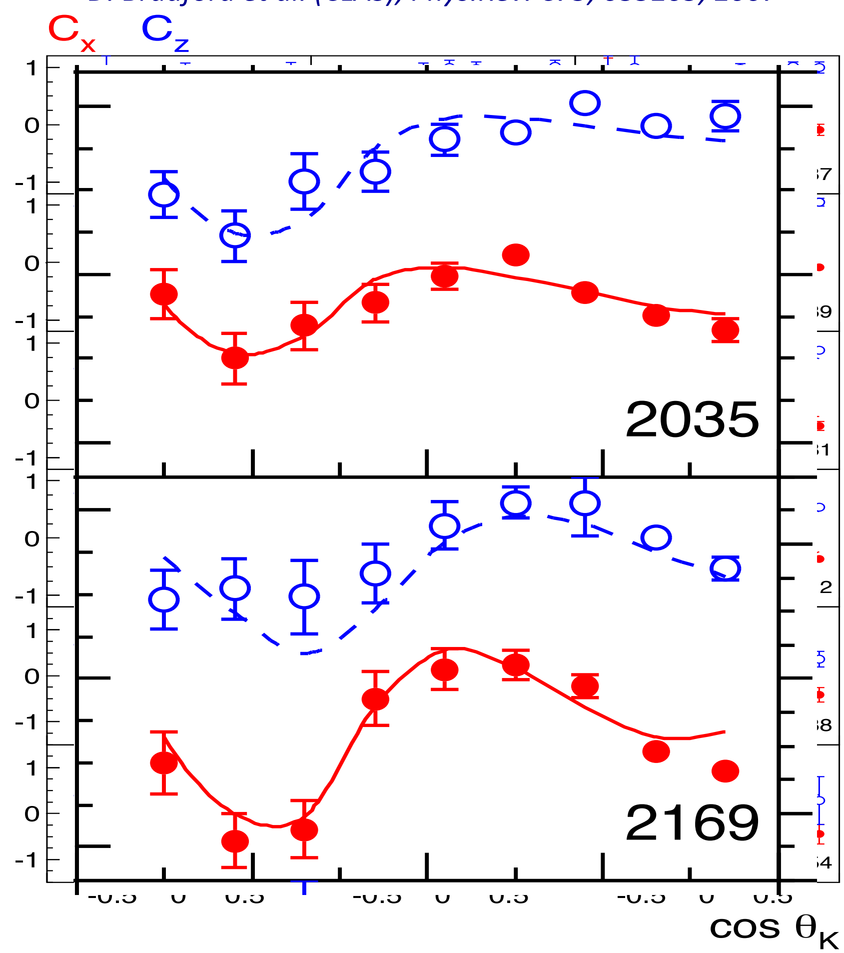
Precision data to establish the N* spectrum

Hyperon photoproduction $\vec{\gamma} p \rightarrow K^+ \vec{\Lambda} \rightarrow K^+ p \pi^-$

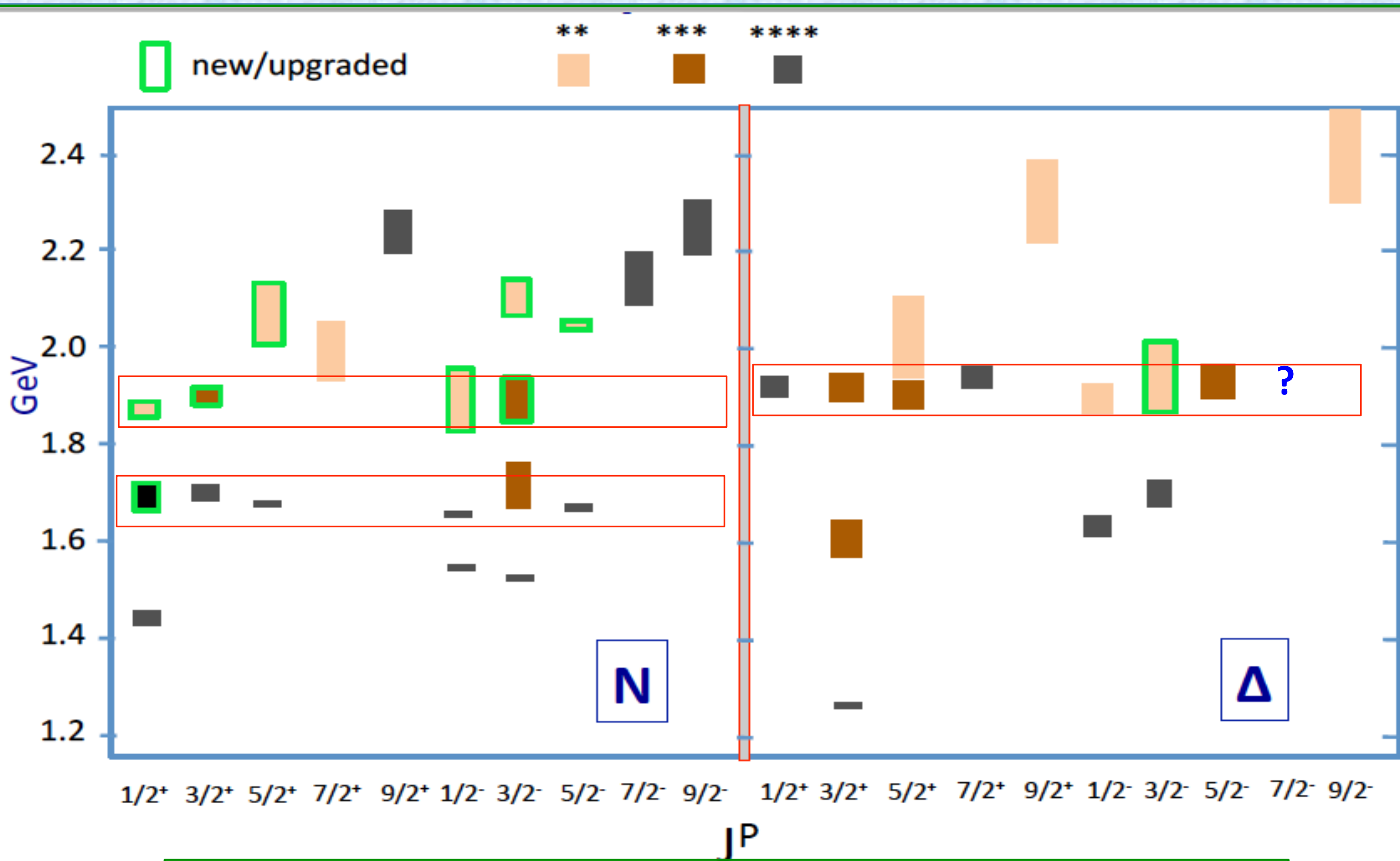
M. Mc Cracken et al. (CLAS), Phys. Rev. C 81, 025201, 2010



D. Bradford et al. (CLAS), Phys.Rev. C75, 035205, 2007

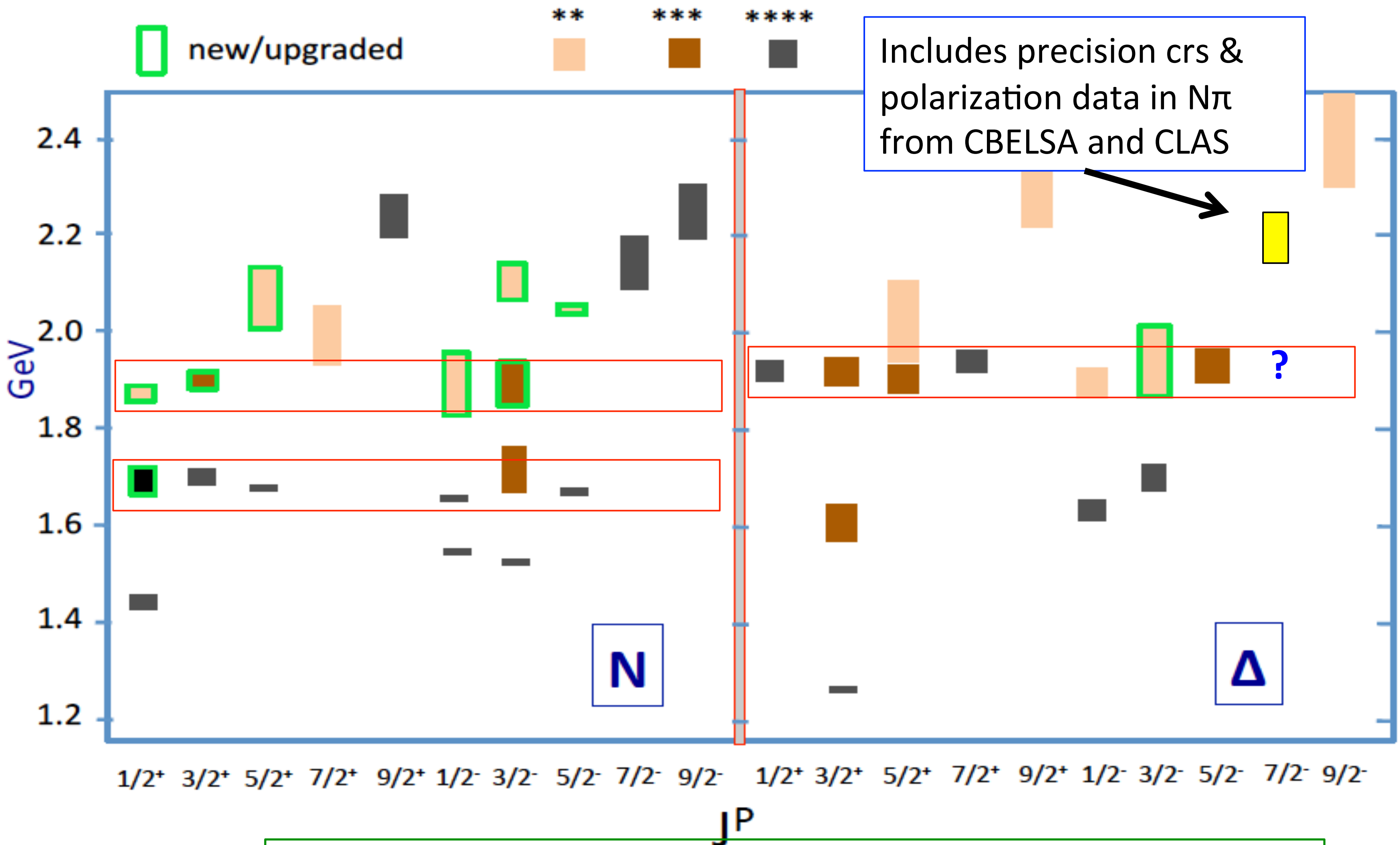


Lower mass N/Δ Spectrum 2016



Do we observe mass-degenerate spin multiplets or parity doublets?

Lower mass N/Δ Spectrum 2017

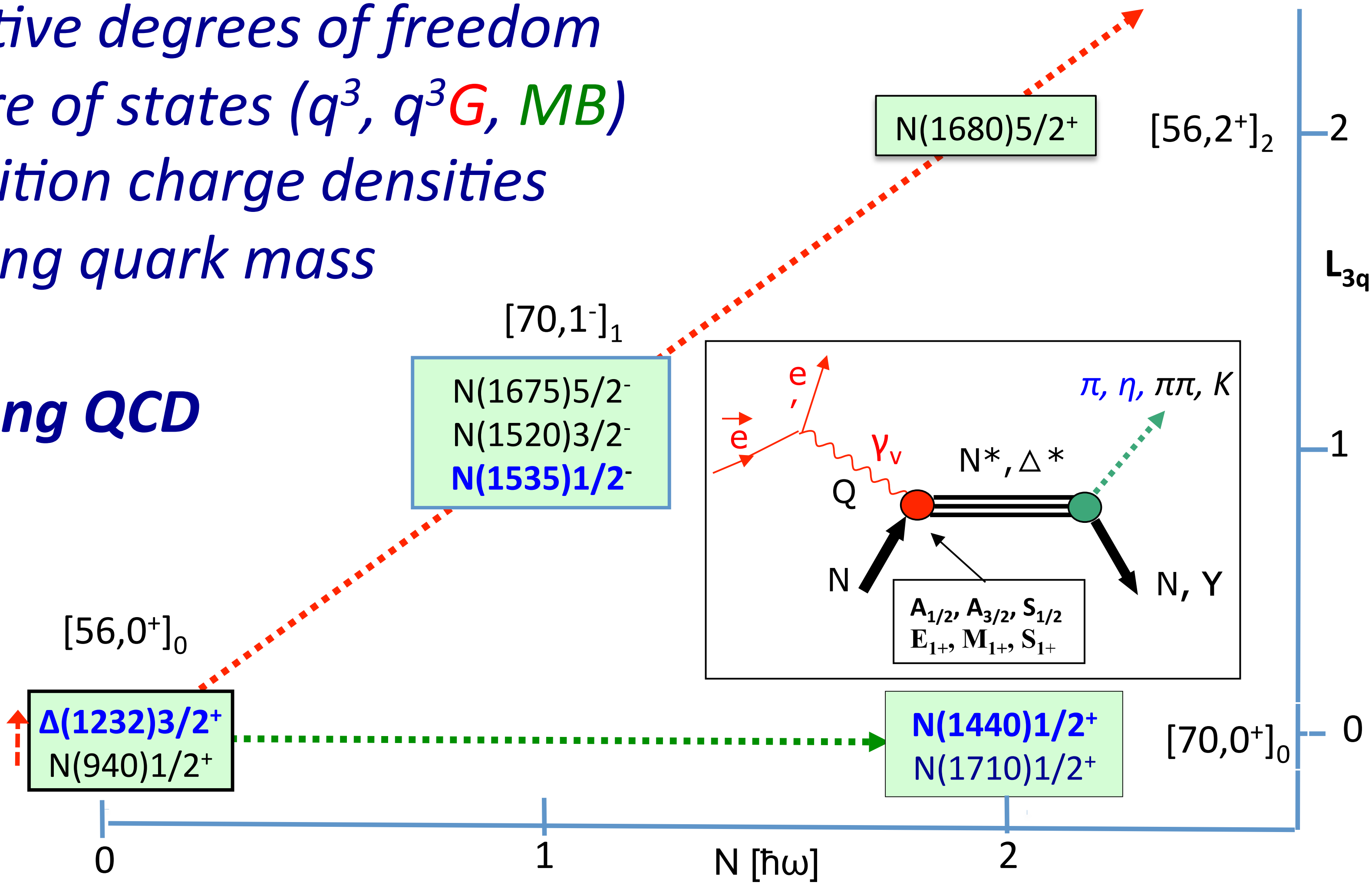


Δ(1950)7/2$^+$ and Δ(1950)7/2$^-$ are not members of parity doublet.

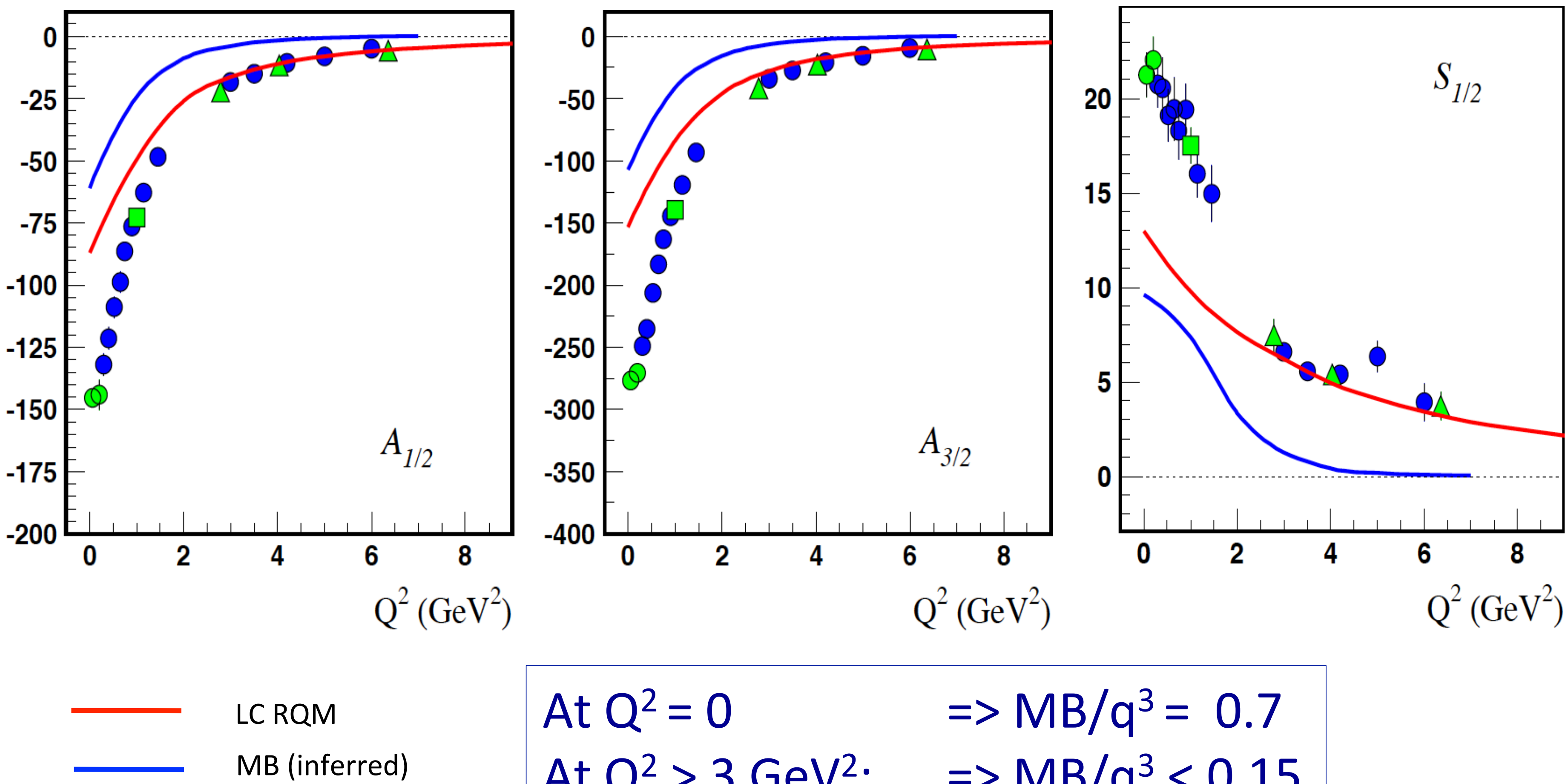
Structure of Excited Baryons

- *effective degrees of freedom*
- *nature of states (q^3, q^3G, MB)*
- *transition charge densities*
- *running quark mass*

=> strong QCD



q^3 and MB contributions in NΔ(1232)



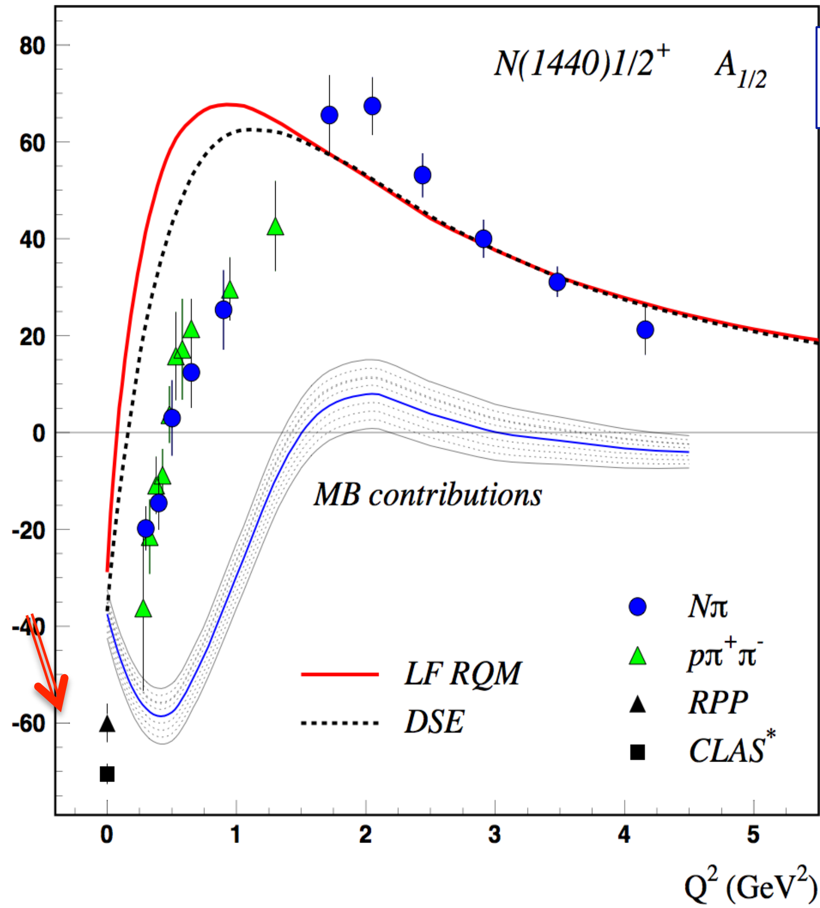
At $Q^2 = 0$ => $MB/q^3 = 0.7$

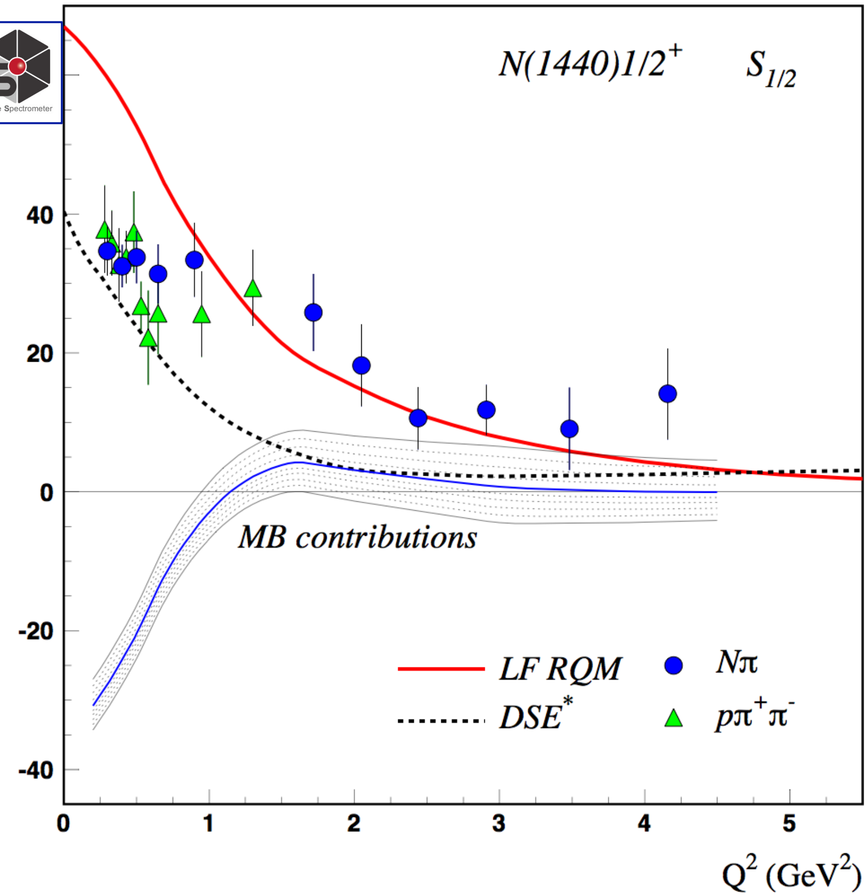
At $Q^2 > 3$ GeV^2: => $MB/q^3 < 0.15$

Solving the Roper N(1440)1/2+ Puzzle

DSE: J. Segovia et al., PRL 115 (2015); 1504.04386

LF RQM: I. Aznauryan, V.B., 1603.06692





- Importance of MB at $Q^2 < 1.5 GeV^2$. Quark core contributions dominate at $Q^2 > 2\ GeV^2$

The 1st radial excitation of the 3-quark core seen when the probe penetrates the MB cloud.

MB contributions to $N(1675)5/2^-$

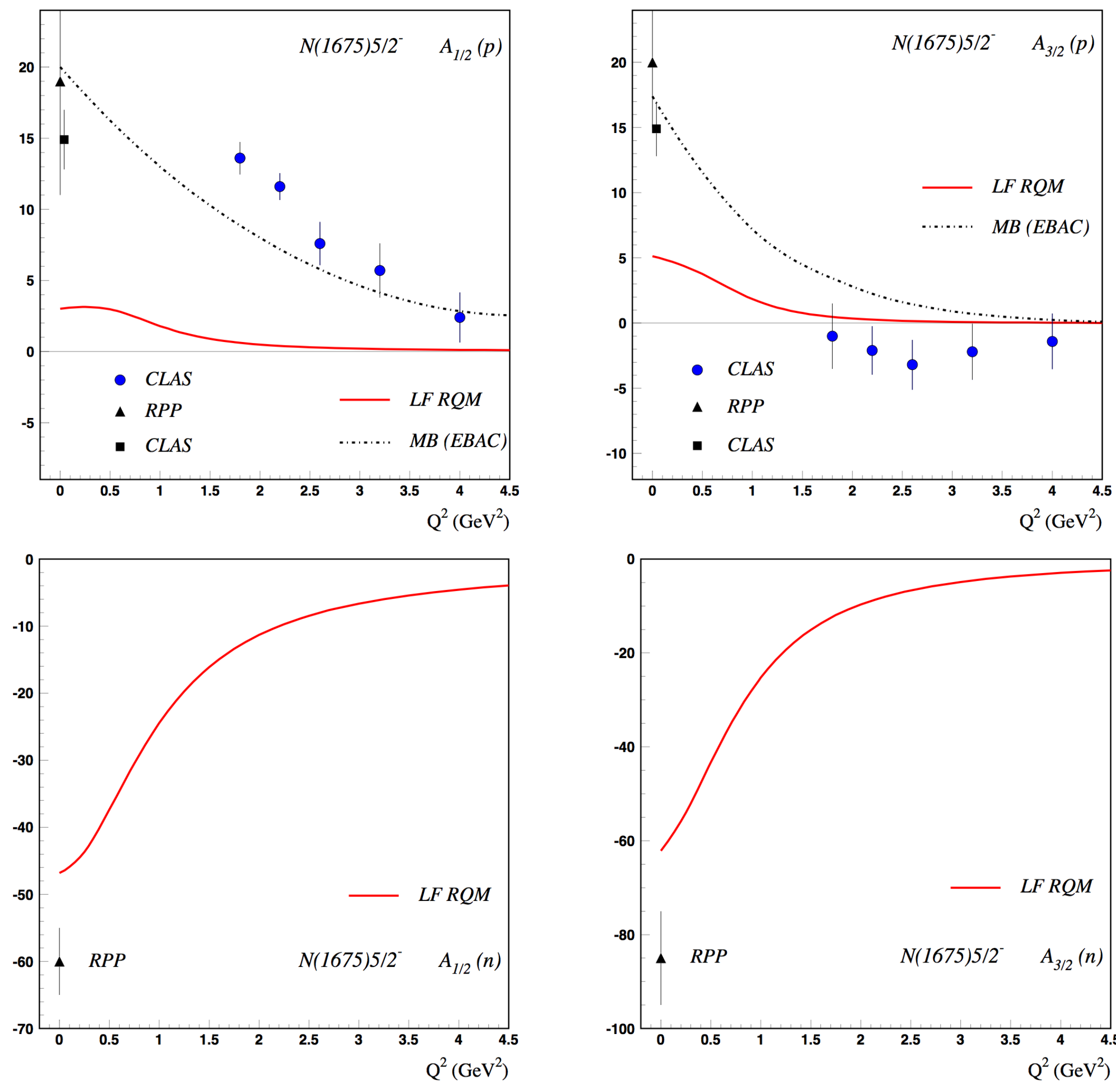
In the SQTM the $N(1675)5/2^-$ resonance is not excited in photoproduction on protons (Moorhouse selection rule).

LF RQM predict very small q^3 amplitudes at all Q^2.

$\Rightarrow$ We measure the strength of non-quark components directly. Consistent with dynamical coupled channel models.

This is NOT a dynamically generated resonance!

Excitation on neutron is not suppressed. LF RQM predict large amplitudes.



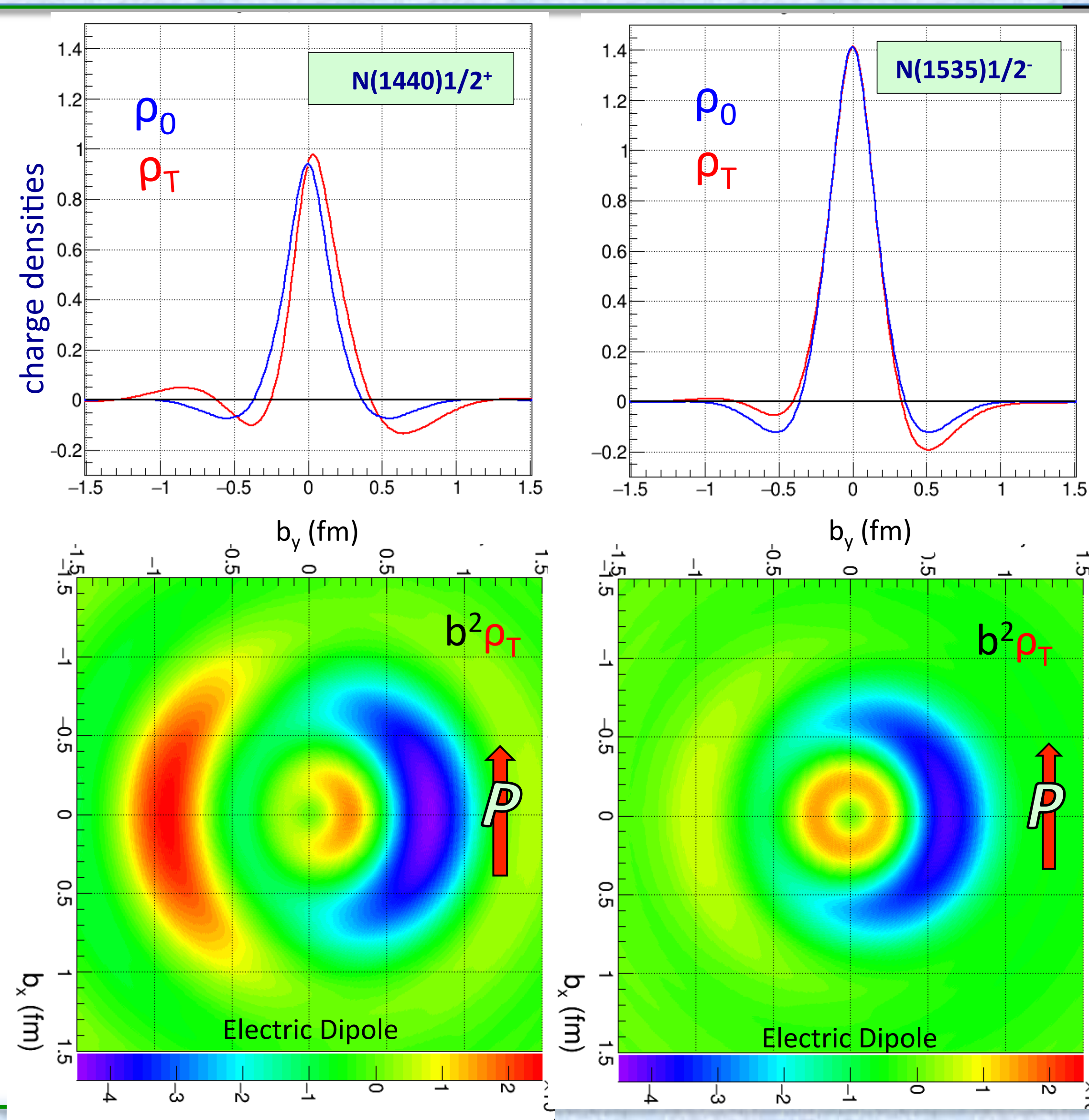
Light Front γpN* transition charge densities

Fourier transform in Q^2 of transition form factors result in the IMF in **transition charge densities** **from the proton to the two states.**

The N(1440) exhibits a softer core and wider clouds than N(1535)

FT involves integral in $Q^2 \rightarrow \infty$
=> need data at higher Q^2 to reduce systematics.

courtesy
F.X. Girod



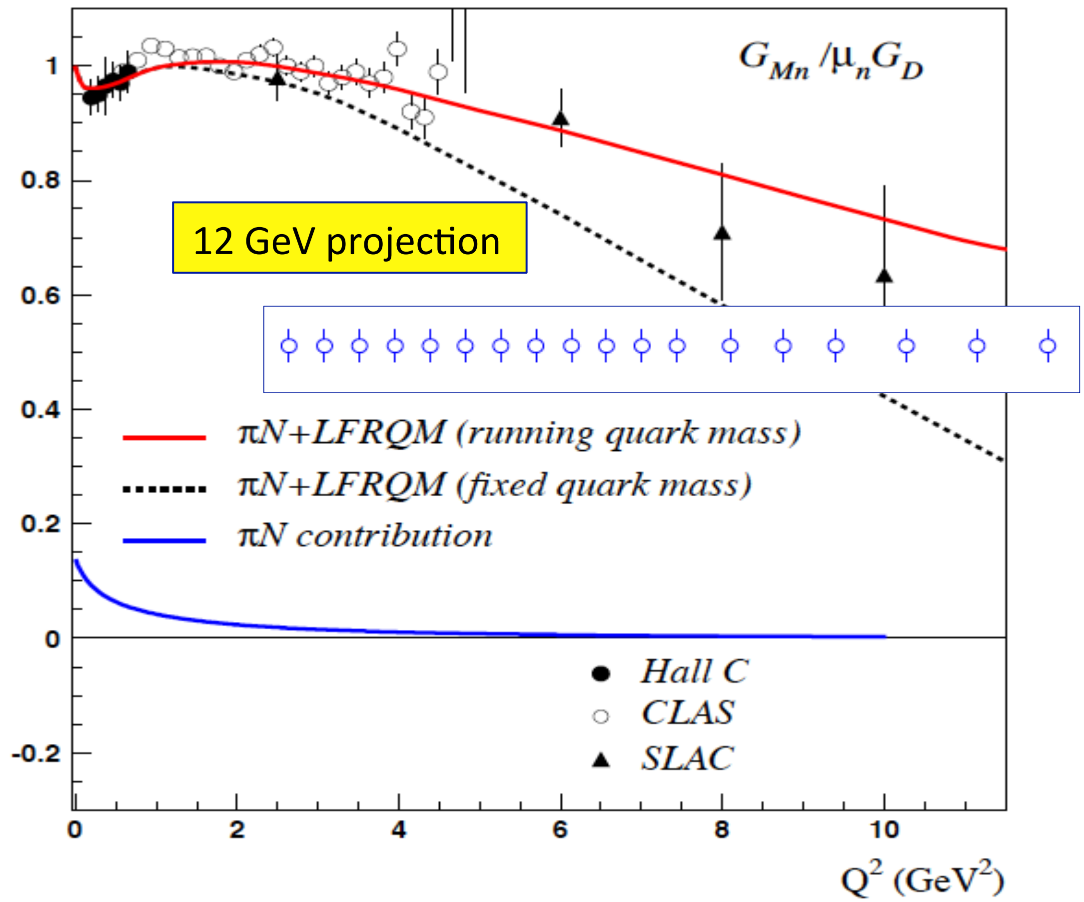
NSAC 2015 Long Range Plan

Recommendation I

1) With the imminent completion of the CEBAF 12-GeV Upgrade, its forefront program of using electrons to unfold the quark and gluon structure of hadrons and nuclei and to probe the Standard Model ***must be realized****.*

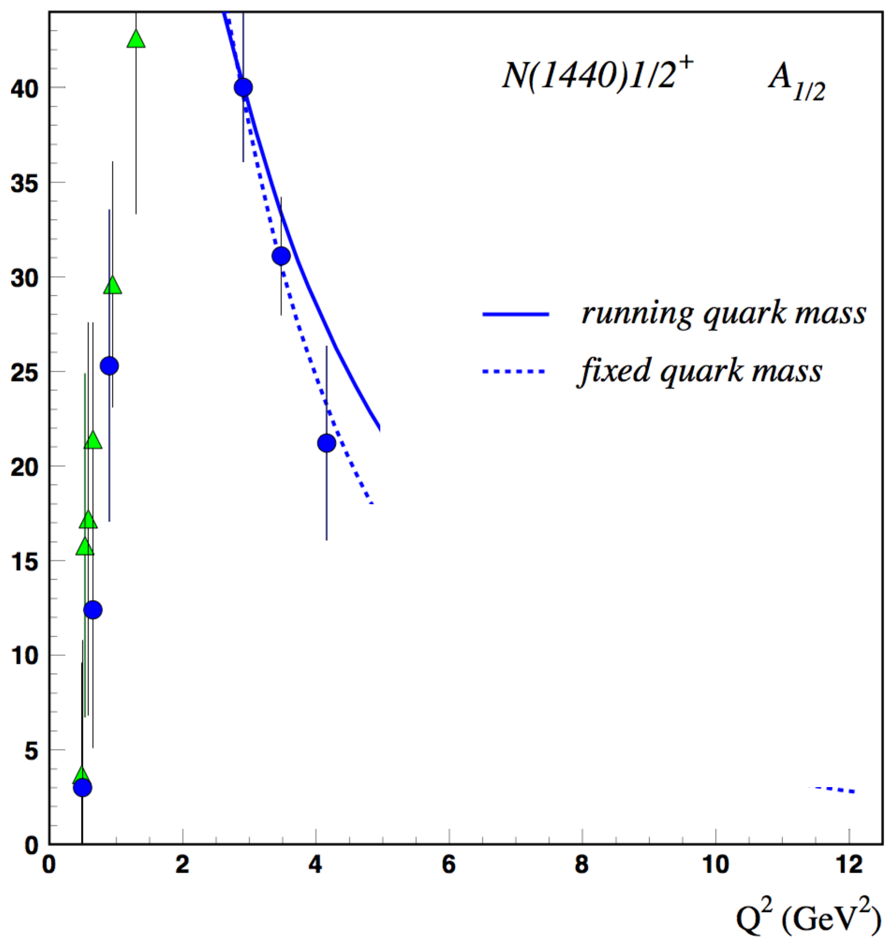
Probing the running quark mass at JLab12

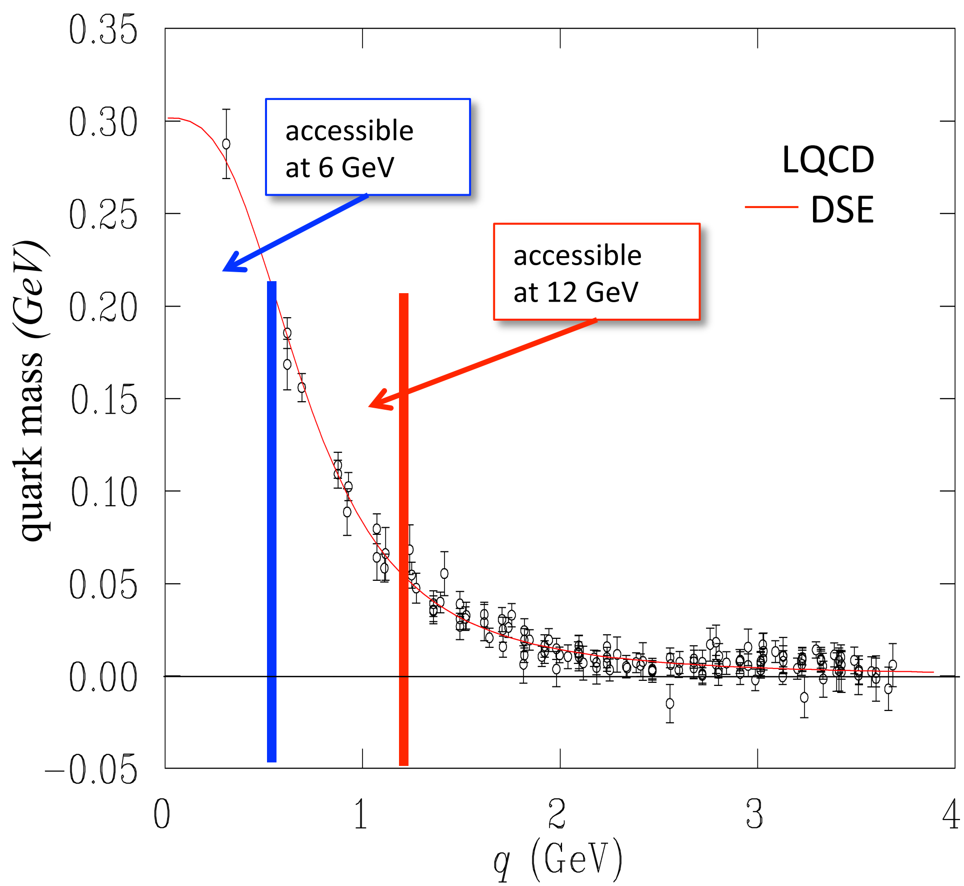
Nucleon elastic and resonance transition FF at high Q^2 probe the running quark mass function.



Quark mass function probed with Roper

Can resonance transitions be described with the same mass function?



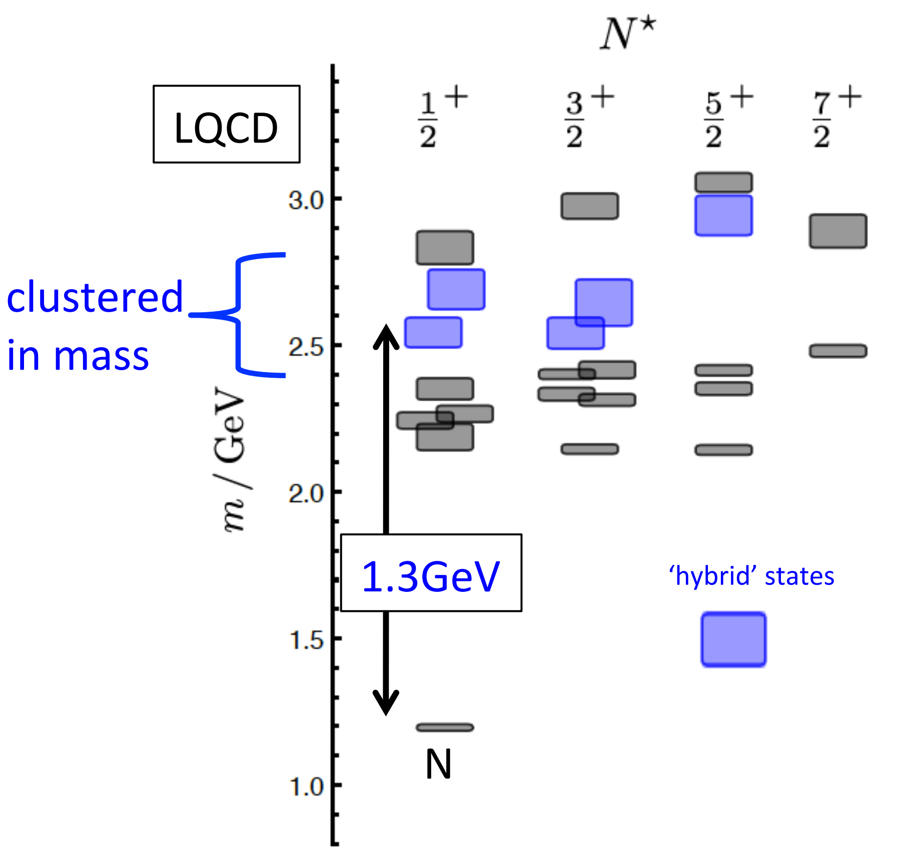


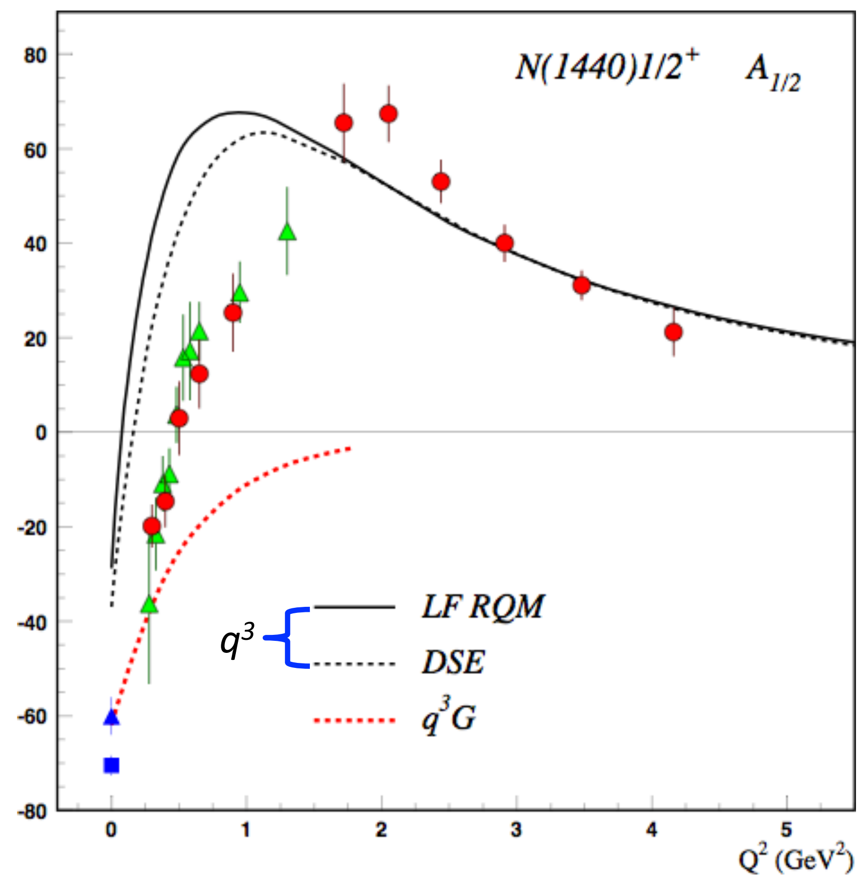
Similar measurements are planned for other baryon resonances.

Search for Hybrid Baryons q^3G

J.J. Dudek and R.G. Edwards, PRD 85 (2012) 054016

q^3G: Z.P. Li, V.B., Zh. Li, PRD 46 (1992) 70





q^3G baryons have same J^P values as q^3 states

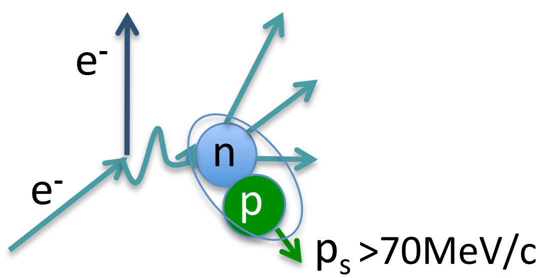
--> Q^2 dependence to separate them.

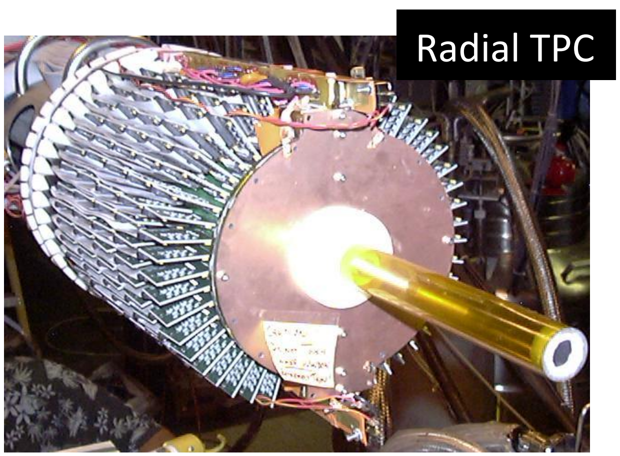
Neutron structure and quark distributions

Measure F_2^n/F_2^p to determine d(x)/u(x)

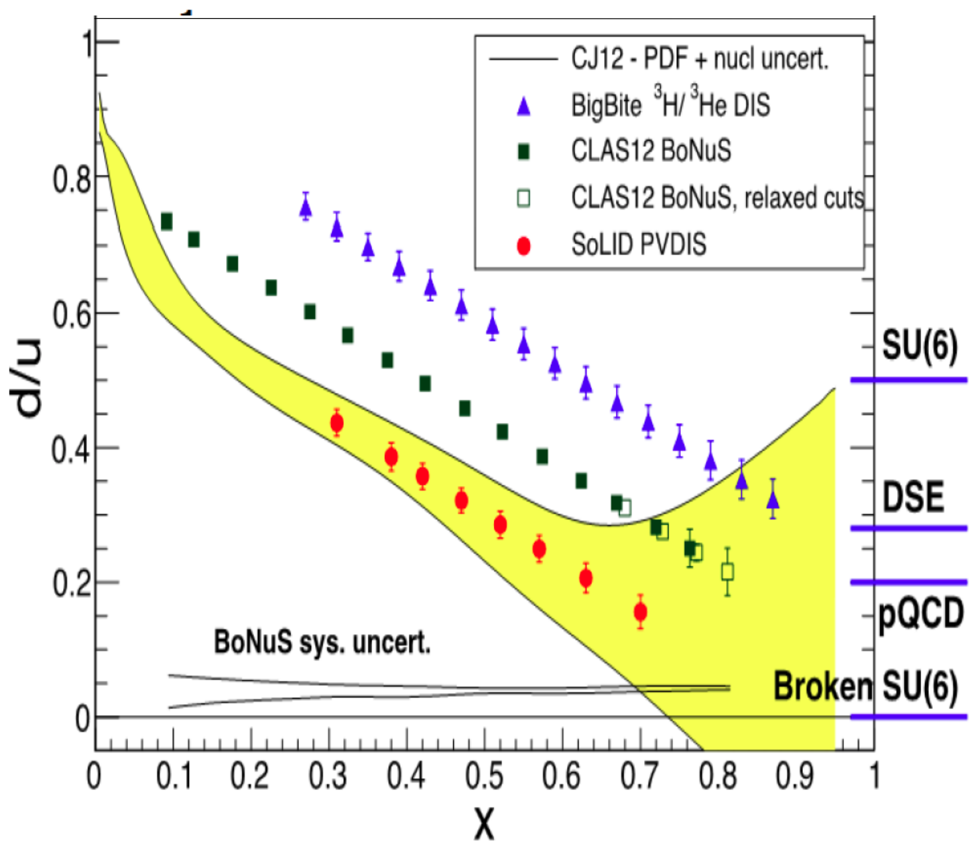
1) Detect low momentum protons to tag nearly unbound neutrons in deuterium
2) Measure cross section ratio $^3H/^3He$ of mirror nuclei.

$e^- D \rightarrow e^- p_s X$





track low energy protons in 5 Tesla mag. field



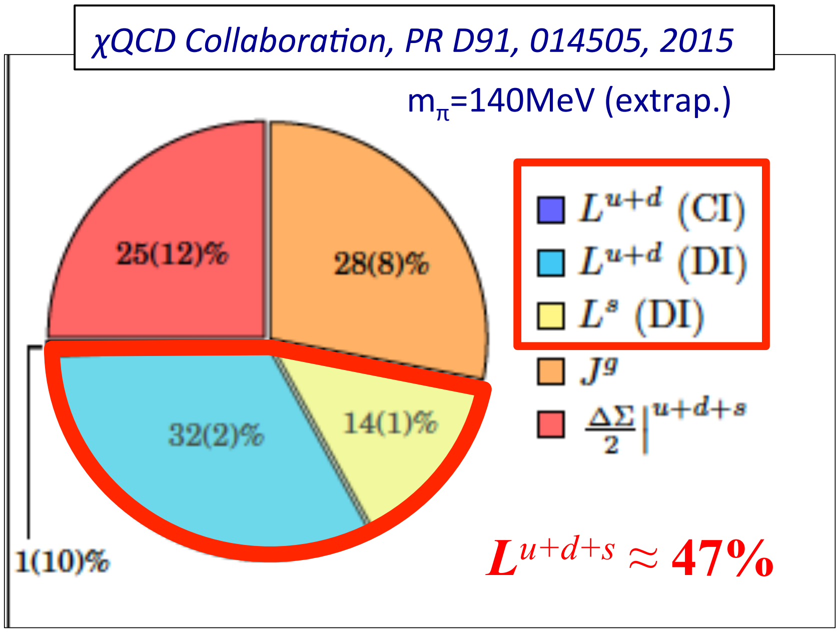
First model-independent measurement of F_2^n/F_2^p

New twist on the Proton Spin Puzzle

In LQCD, gauge invariant decomposition (X. Ji):

$$J_p = \tfrac{1}{2} = (\tfrac{1}{2}\,\Delta\Sigma^q + L^q) + J^g$$

LQCD Predictions before 2015 showed negligible values for L^q (no DI).



Probe the OAM in accessing GPDs E^q and H^q in DVCS measurements.

X. Ji relation for quarks:

$$\int dx\, x\, [H^q(x,\xi,t) + E^q(x,\xi,t)] = 2J^q(t)$$

~ 50% of the proton spin is unknown

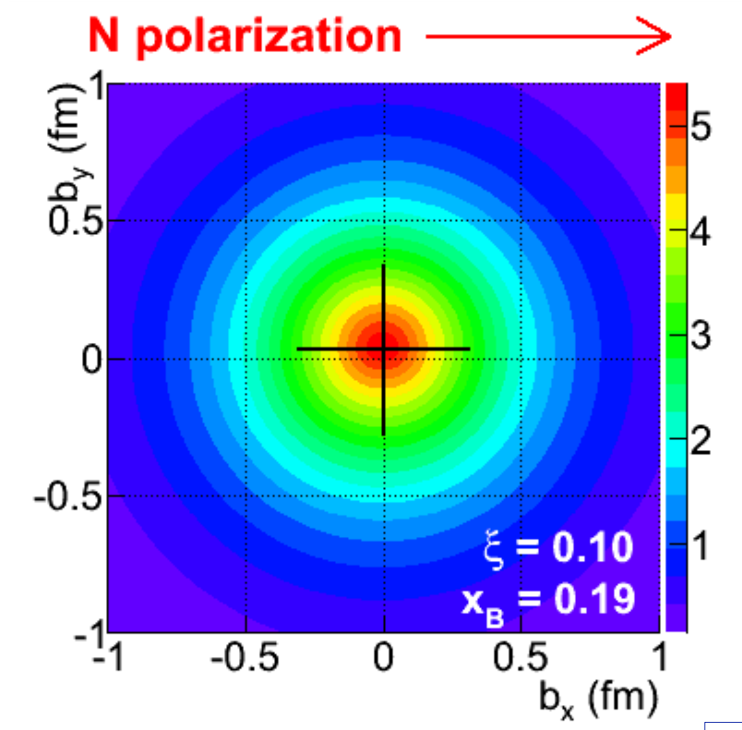
Solving the OAM puzzle must be a priority

Generalized PDFs and 3D imaging

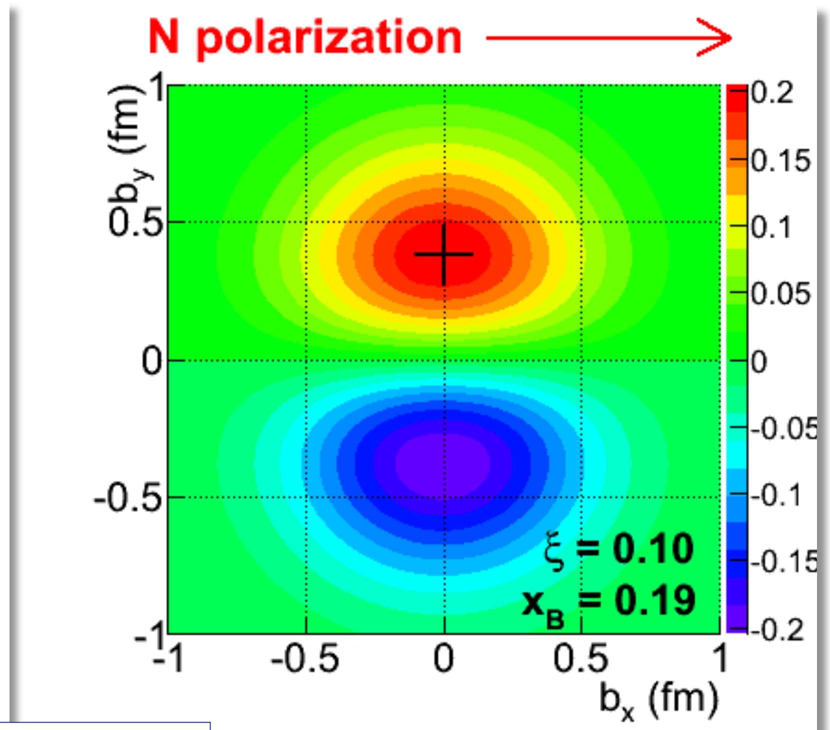
The GPD (CFF) can be accessed in DVCS processes with ***pol. beam and pol. target***.
Fourier transform in Mandelstam variable ***t*** ➔ charge densities in b space.

$$\rho_X(x,\vec{b}_\perp) = \int \frac{d^2\vec{\Delta}_\perp}{(2\pi)^2}\left[H(x,0,t) - \frac{E(x,0,t)}{2M}\frac{\partial}{\partial b_y}\right] e^{-i\vec{\Delta}_\perp\cdot\vec{b}_\perp}$$

VGG Model for H, E as input, projected results from DVCS measurements at 12GeV.



Contribution of *H+E*



Contribution of *E*

F.X. Girod

Unraveling Confinement Forces on Quarks

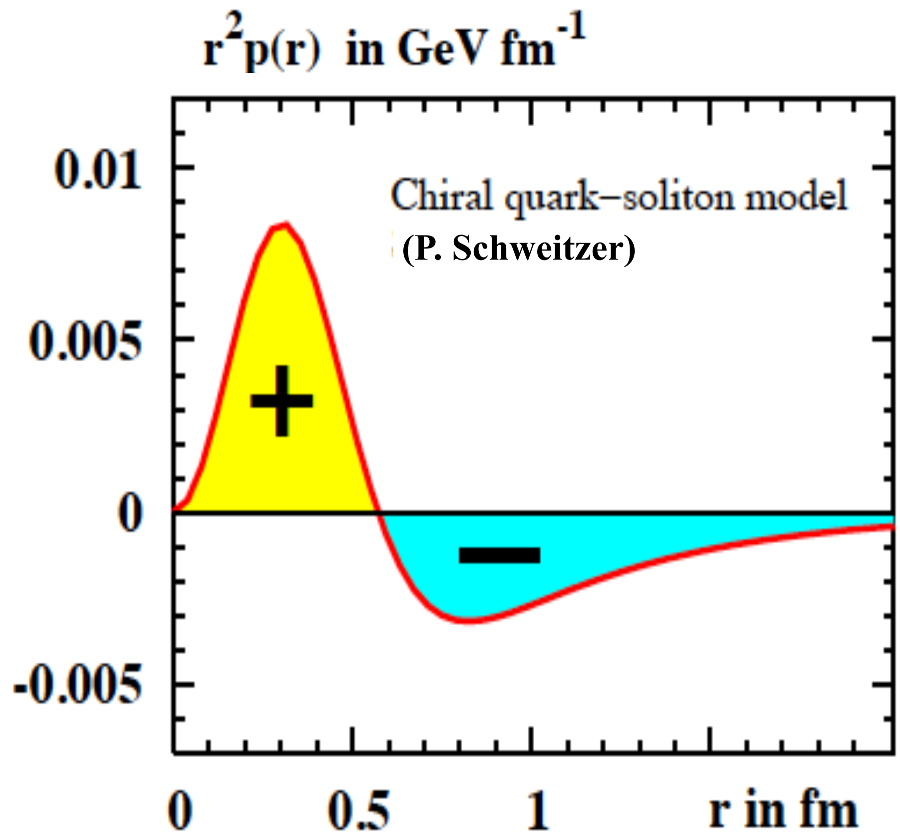
Nucleon matrix element of EMT contains:

$M_2(t)$: Mass distribution inside the nucleon
$J\ (t)$: Angular momentum distribution
$d_1(t)$: **Shear forces and pressure distribution**

Measure directly in graviton-proton scattering

$$\int \mathrm{d}x\, x H(x,\xi,t) \;=\; M_2(t) + \frac{4}{5}\xi^2 d_1(t)$$

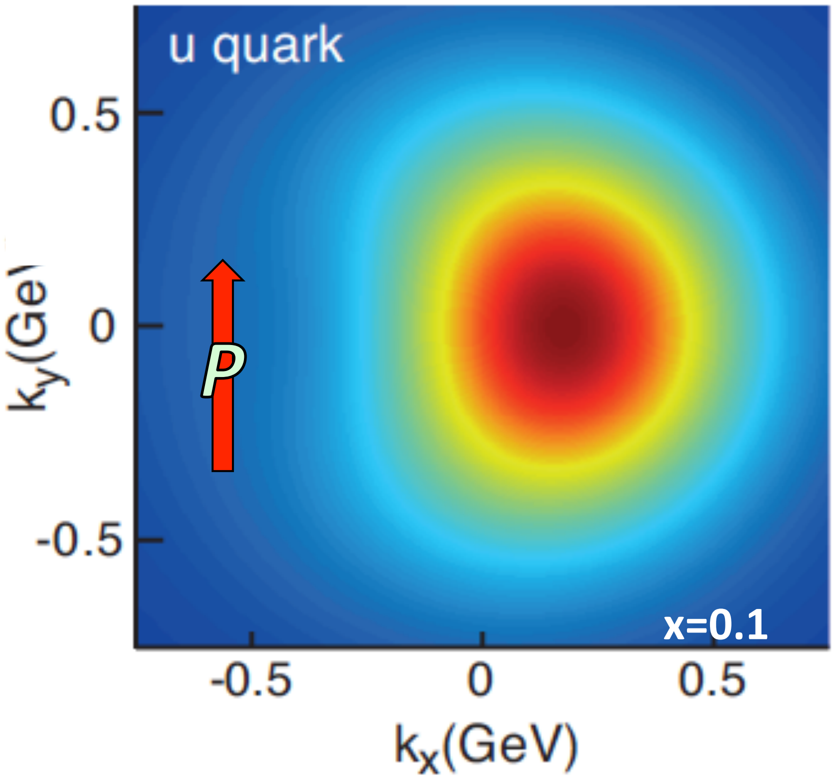
$$\mathrm{Re}\mathcal{H}(\xi,t) \stackrel{\mathrm{LO}}{=} D(\xi,t) + \mathcal{P}\int_{-1}^{1} dx \left(\frac{1}{\xi - x} - \frac{1}{\xi + x}\right) \mathrm{Im}\mathcal{H}(\xi,t)$$



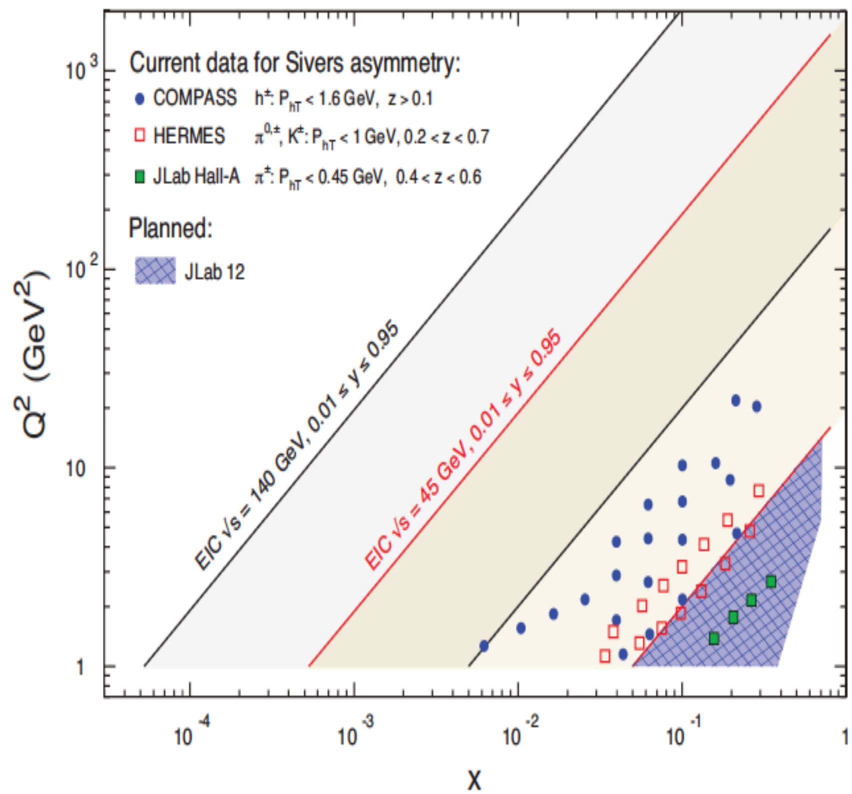
If we measure these form factors, we will learn a lot about confinement forces in the proton.

Nucleon 3D imaging in momentum space

Meson production in SIDIS enables access TMDs to create 3-D images in momentum space



Density in the transv.-momentum plane for unpolarized quarks in a proton polarized along the y direction. The anisotropy due to the proton polarization is described by the Sivers function.

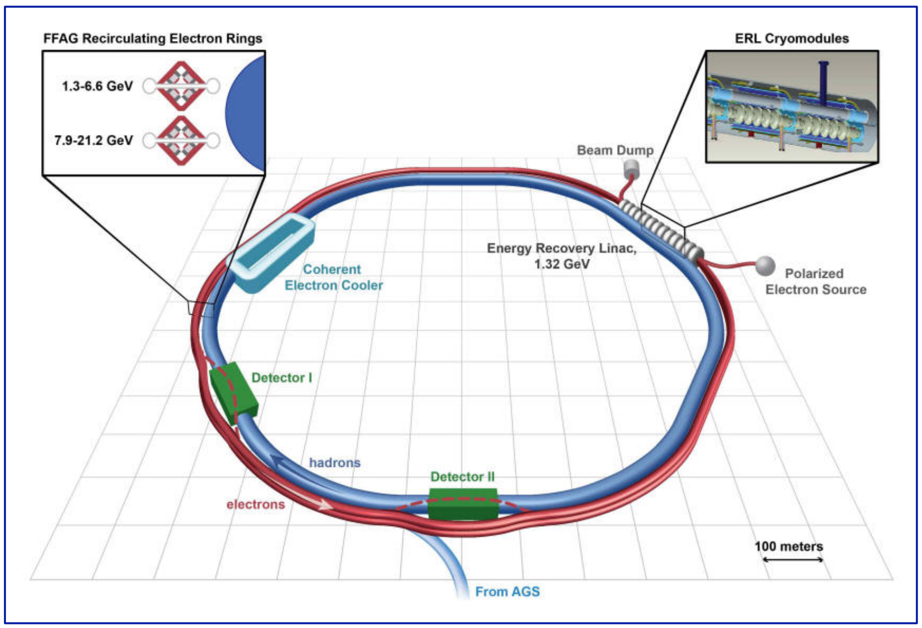


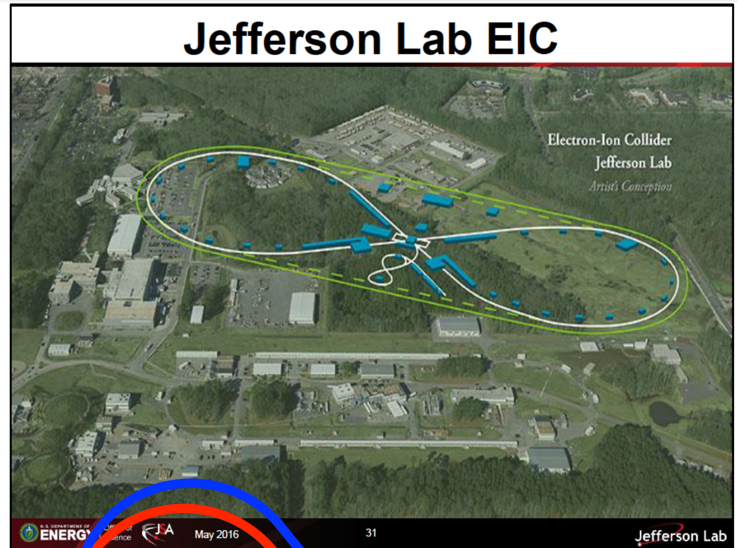
=> **A major program at JLab@12 and EIC.**

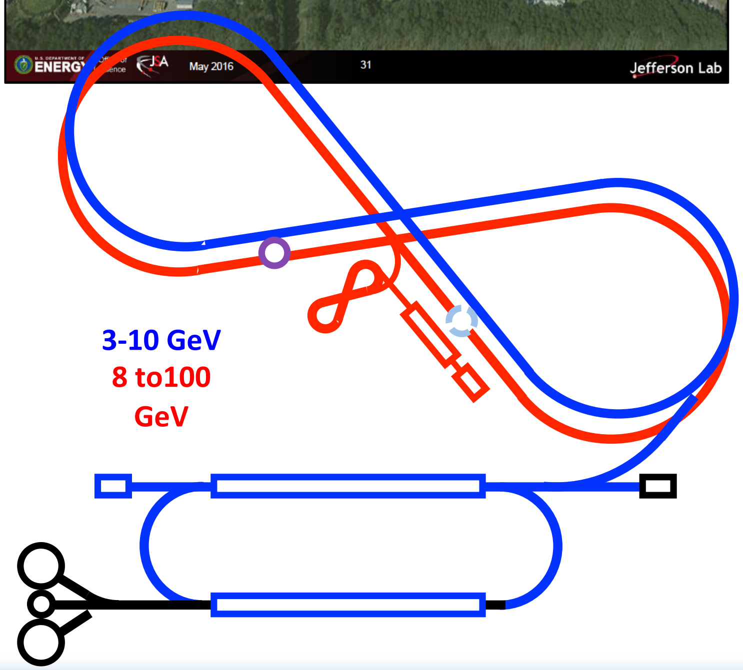
Two versions of the EIC

NSAC LRP Recommendation III:
We recommend a high-energy high-luminosity polarized EIC as the highest priority for new facility construction following the completion of FRIB.

eRHIC: High Energy Electron-Ion Collider



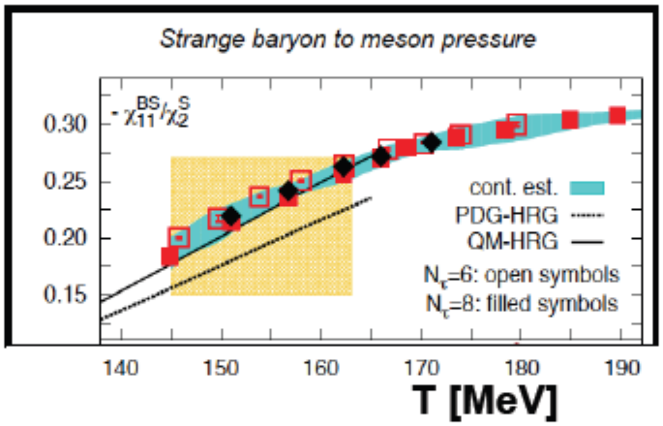




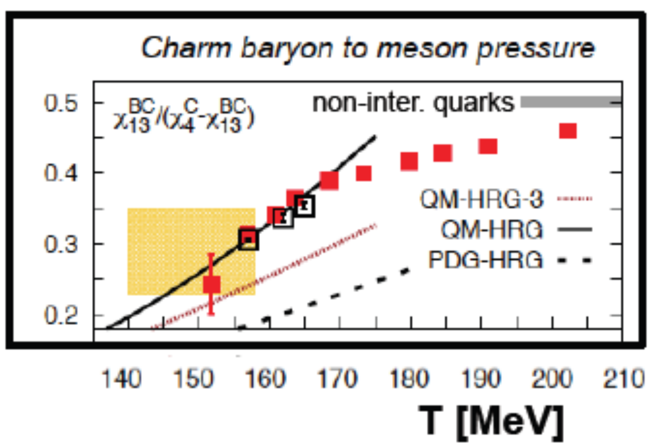
Thank You!

Additional slides

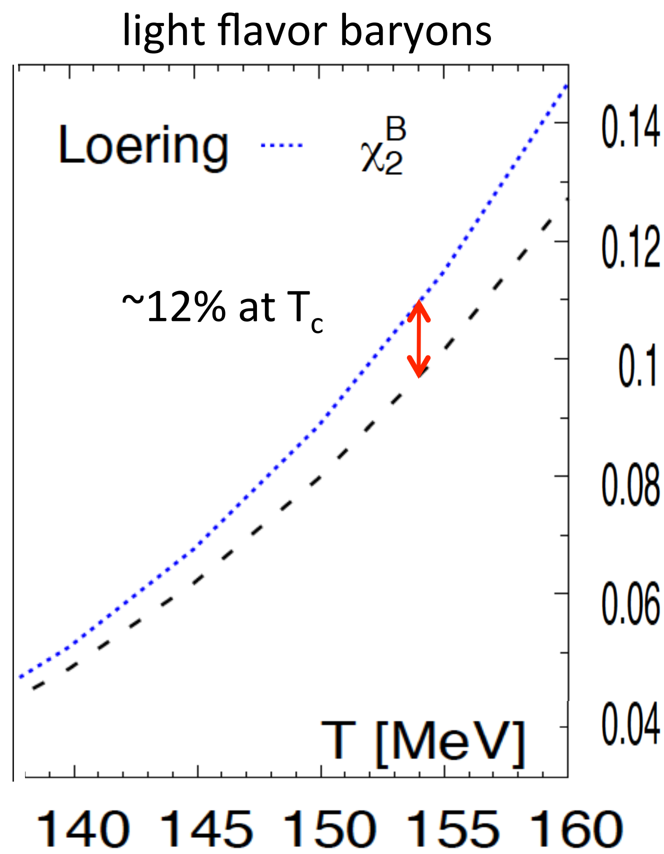
Missing Baryons from Hot LQCD



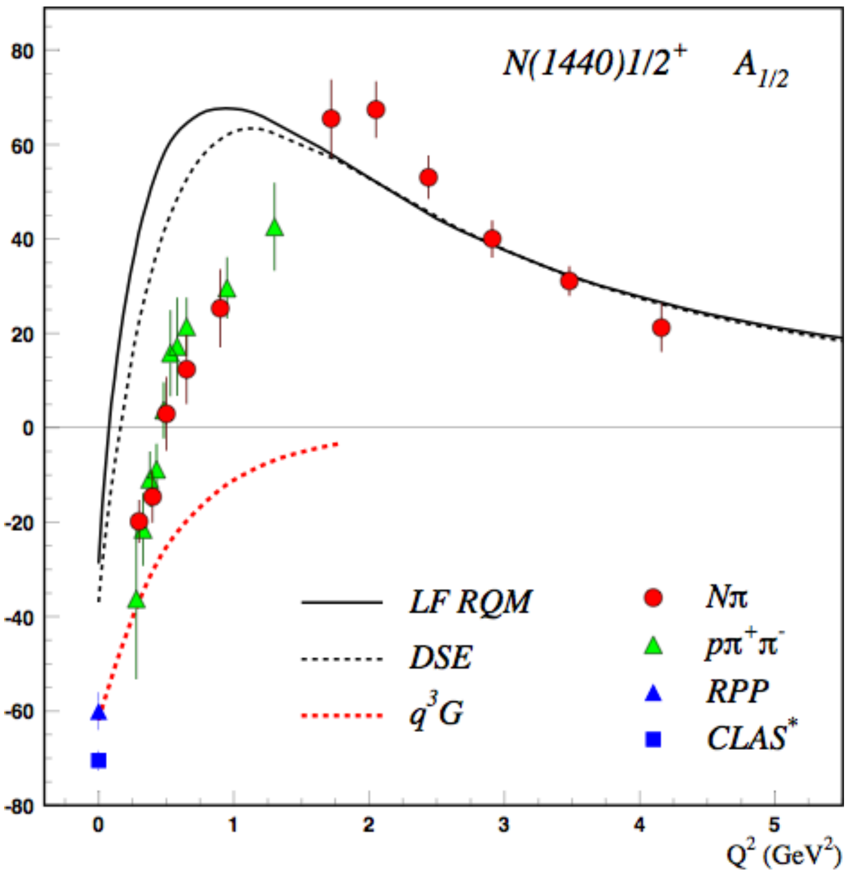
A. Bazavov et al., Phys.Rev.Lett. 113 (2014) 7, 072001

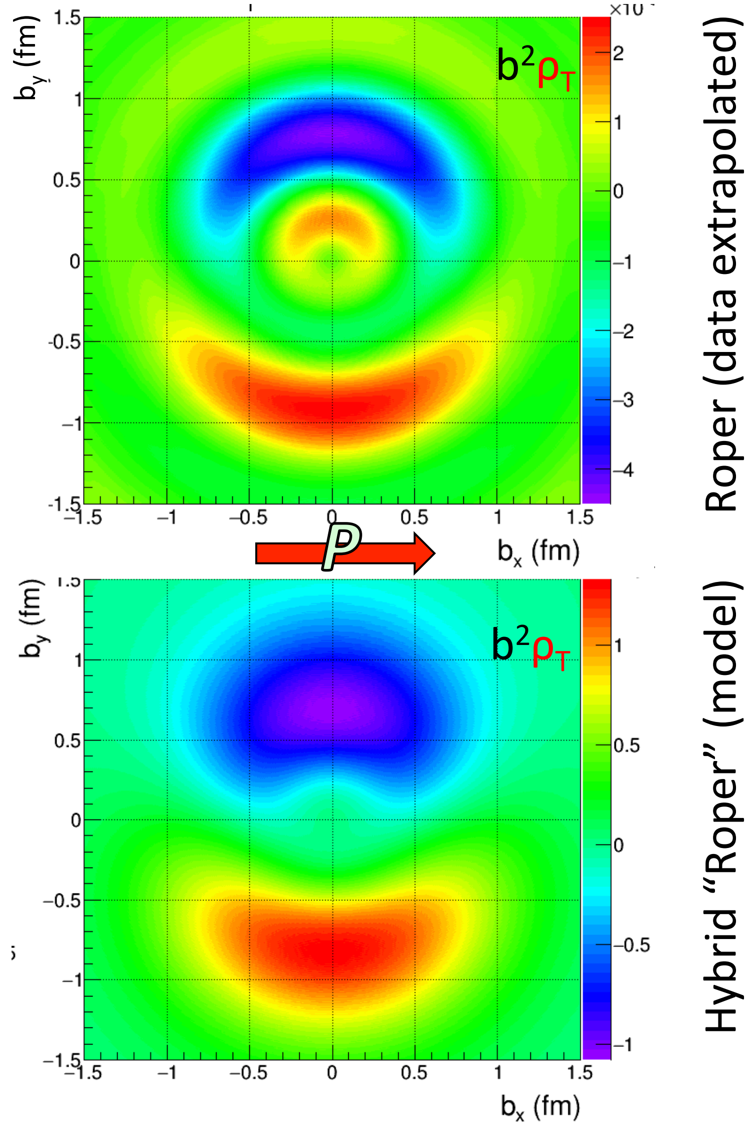


A. Bazavov et al., Phys.Lett. B737 (2014) 210-215



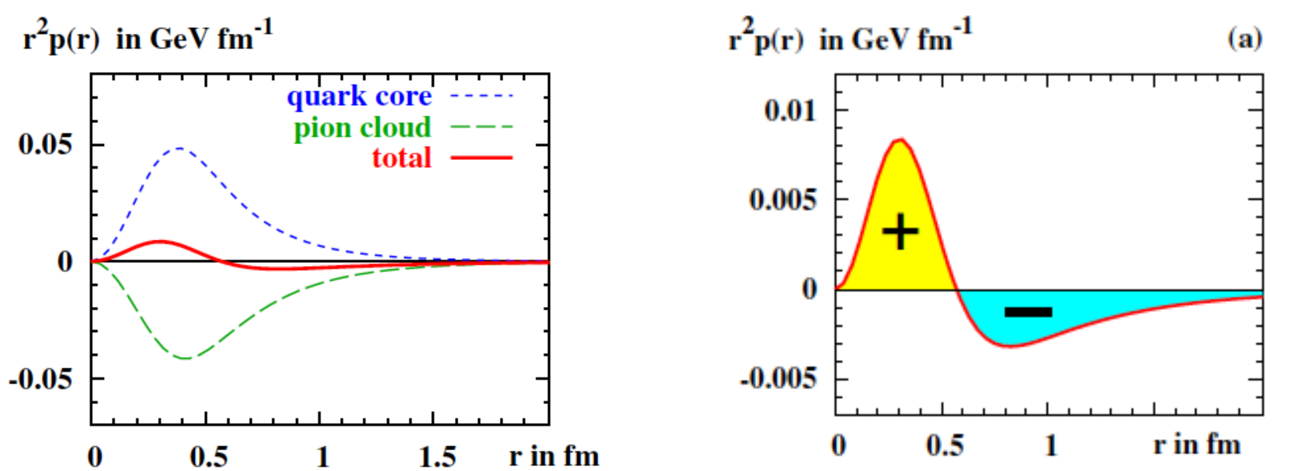
Roper transition charge densities



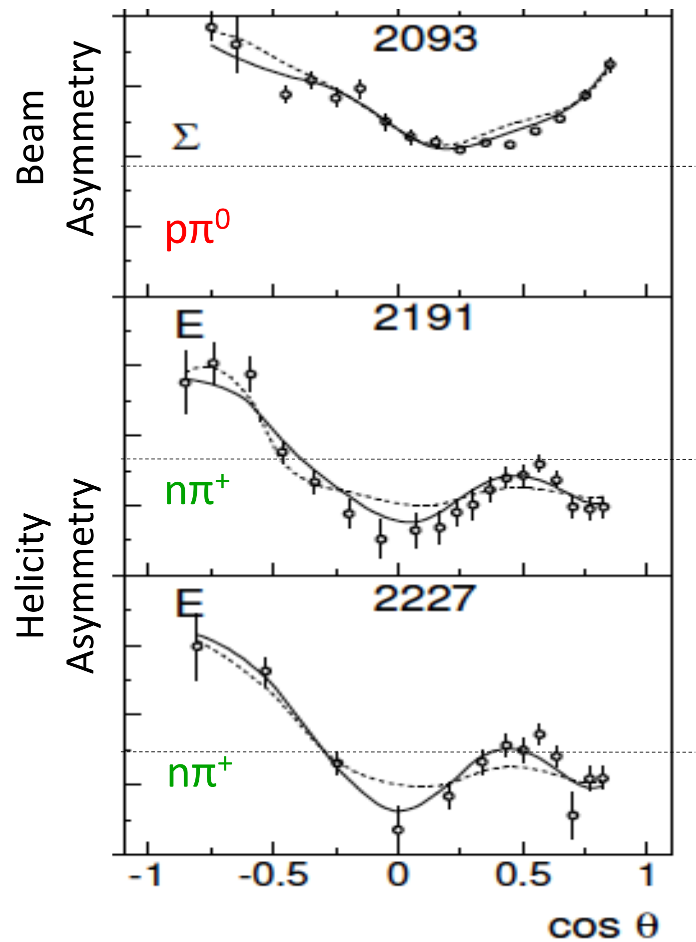


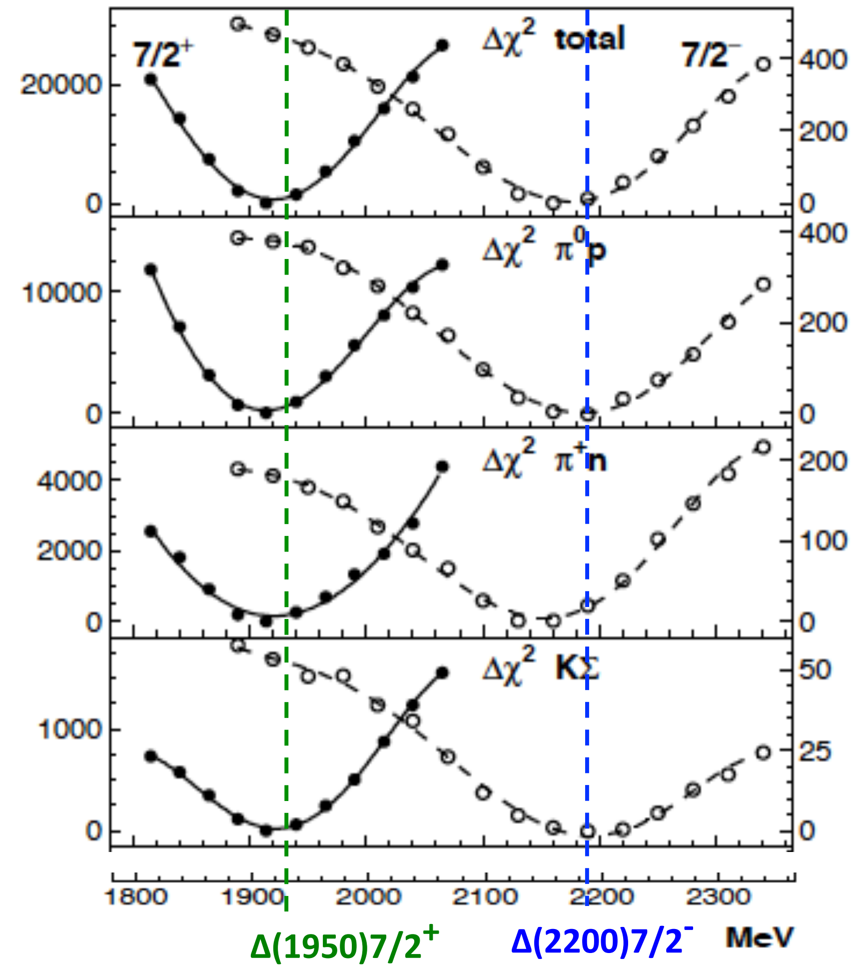
Nucleon Matrix Element of the Energy-Momentum-Tensor

$$\langle p'|\hat{T}^{Q,G}_{\mu\nu}(0)|p\rangle = \bar{u}(p')\Big[M_2^{Q,G}(t)\frac{P_\mu P_\nu}{M_N} + J^{Q,G}(t)\frac{i(P_\mu\sigma_{\nu\rho}+P_\nu\sigma_{\mu\rho})\Delta^\rho}{2M_N} + d_1^{Q,G}(t)\frac{\Delta_\mu\Delta_\nu - g_{\mu\nu}\Delta^2}{5M_N} \pm \bar{c}(t)g_{\mu\nu}\Big]u(p)$$



Polarization is essential $\vec{p}(\vec{\gamma},\pi N)$





$\Delta(1910)1/2^+$ $\Delta(1920)3/2^+$ $\Delta(1905)5/2^+$ $\mathbf{\Delta(1950)7/2^+}$
$\Delta(1900)1/2^-$ $\Delta(1940)3/2^-$ $\Delta(1930)5/2^-$

Phys.Lett. B766 (2017) 357-361