Transition Form Factors:
A unique Opportunity to Connect Non-Perturbative Strong Interaction to QCD

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UNIVERSITY OF SOUTH CAROLINA

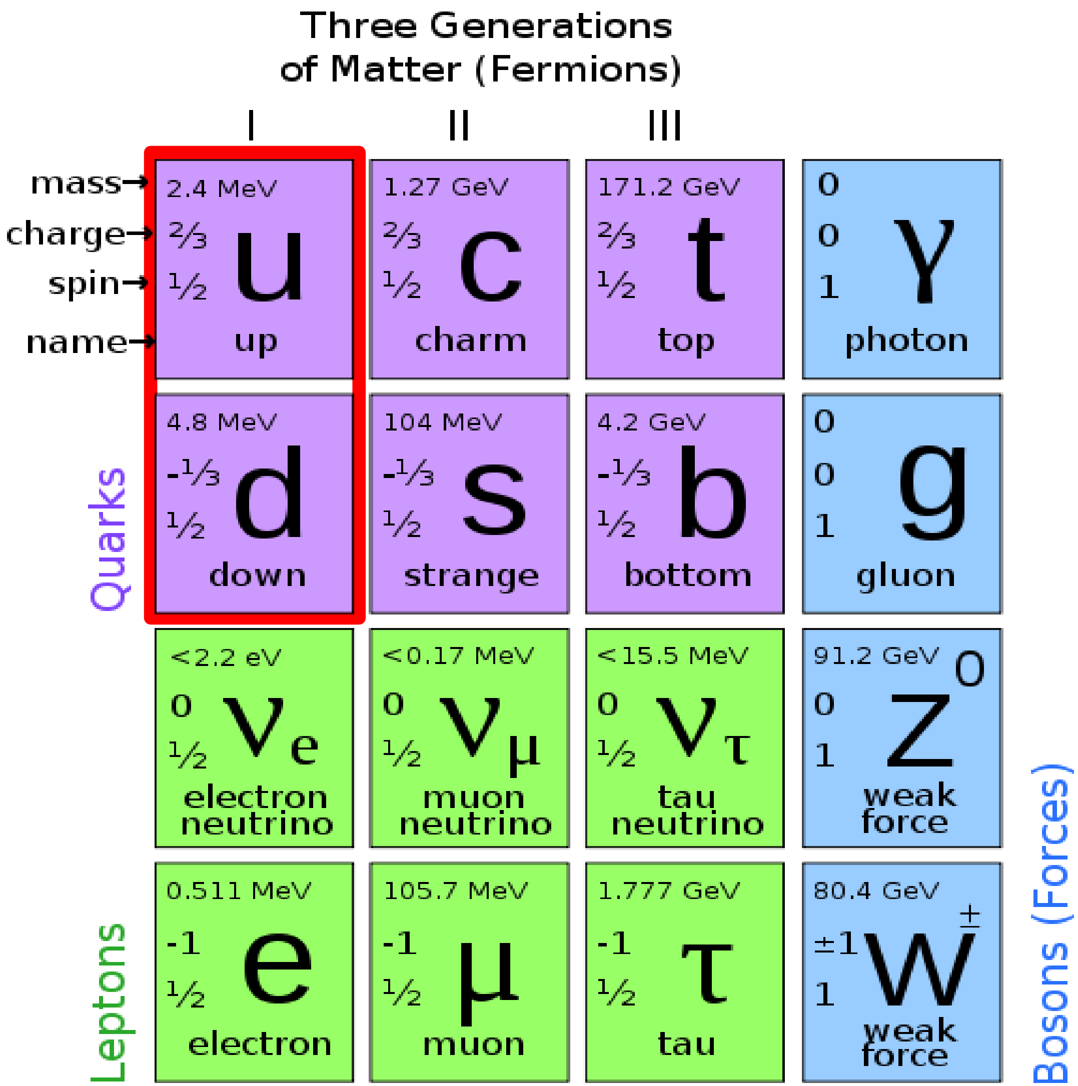
NSTAR 2013

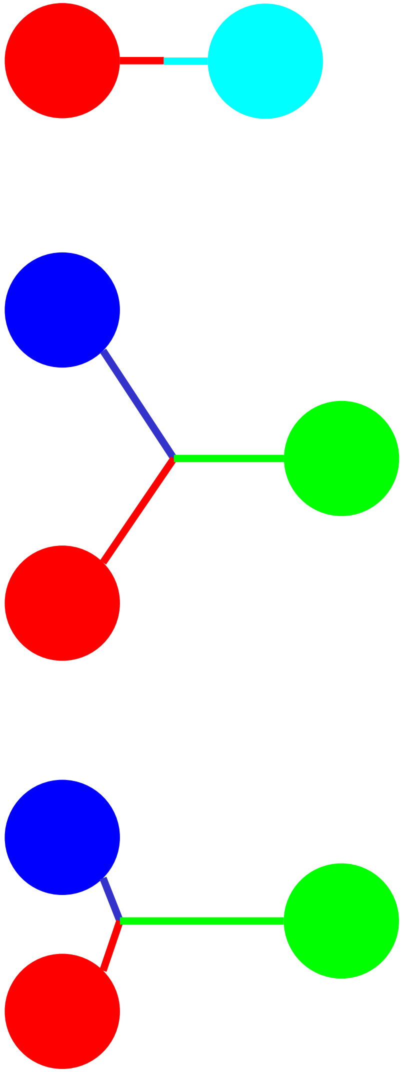
9th International Workshop on the Physics of Excited Nucleons

May 27-30, 2013, Peñiscola, Valencian Community,Spain

- **γ_vNN* Experiments:** The Best Access to the Baryon and Quark Structure?
  - Spectroscopy, Elastic Form Factors, and Transition Form Factors
- **Analysis:** Phenomenological Extraction … who can do better?
  - Consistent extraction of γ_vNN* electrocouplings in various decay channel with various models
- **QCD based Theory:** Solve Non-Perturbative QCD and Confinement?
- **Outlook:** Extended kinematics, new experiments … what can be done next?

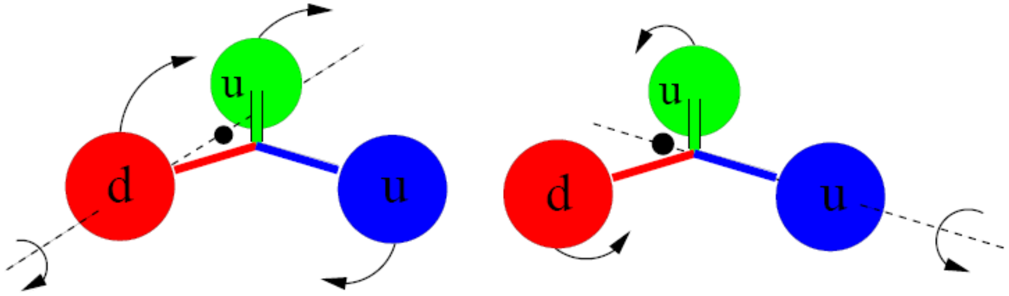
Build your Mesons or Excite Baryons …



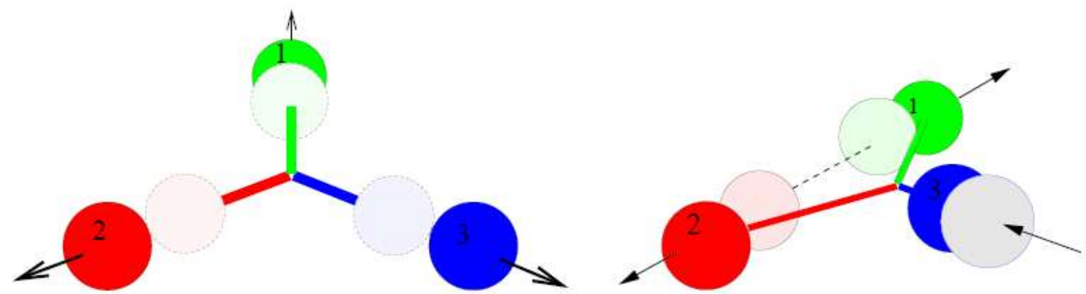


N and Δ Excited Baryon States …

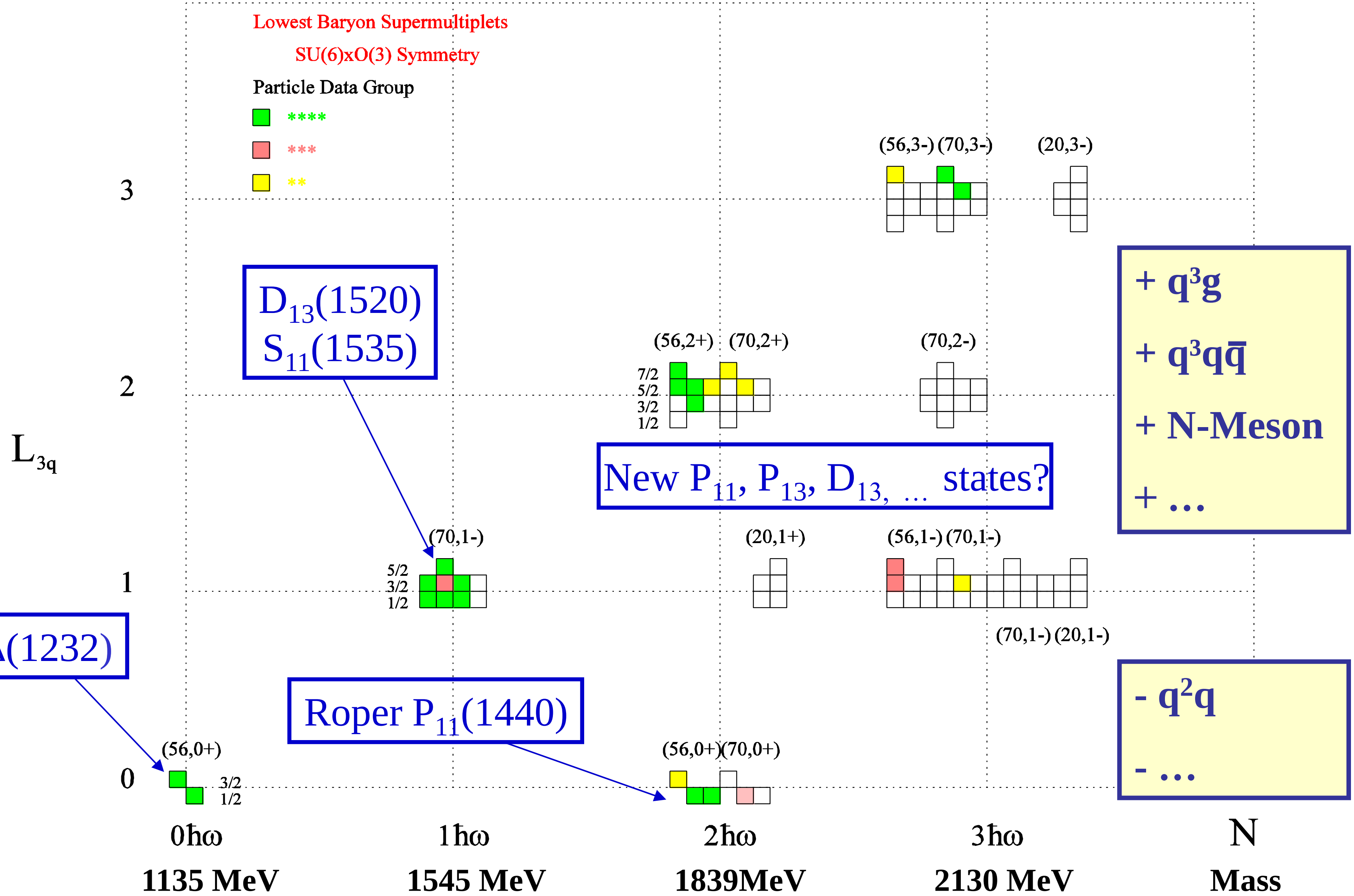
➢ Orbital excitations (two distinct kinds in contrast to mesons)



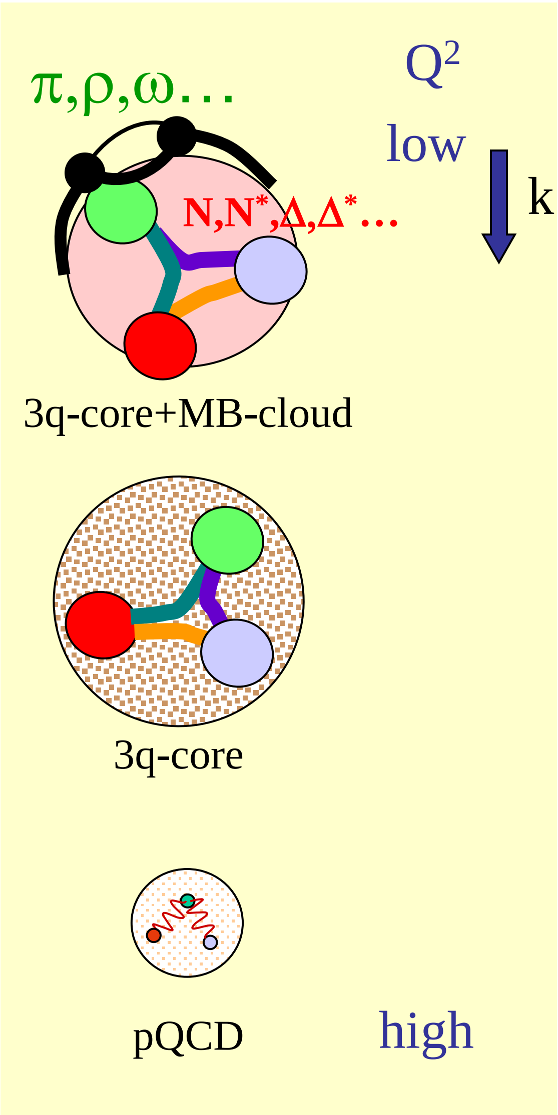
➢ Radial excitations (also two kinds in contrast to mesons)



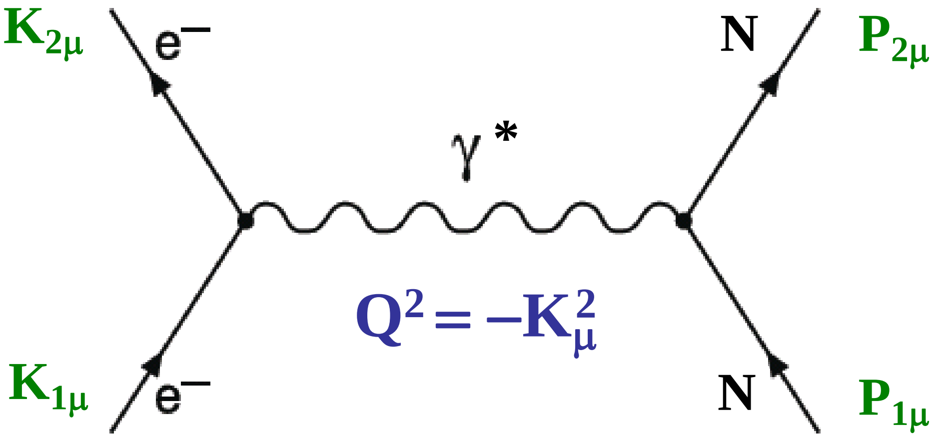
Quark Model Classification of N*



Hadron Structure with Electromagnetic Probes

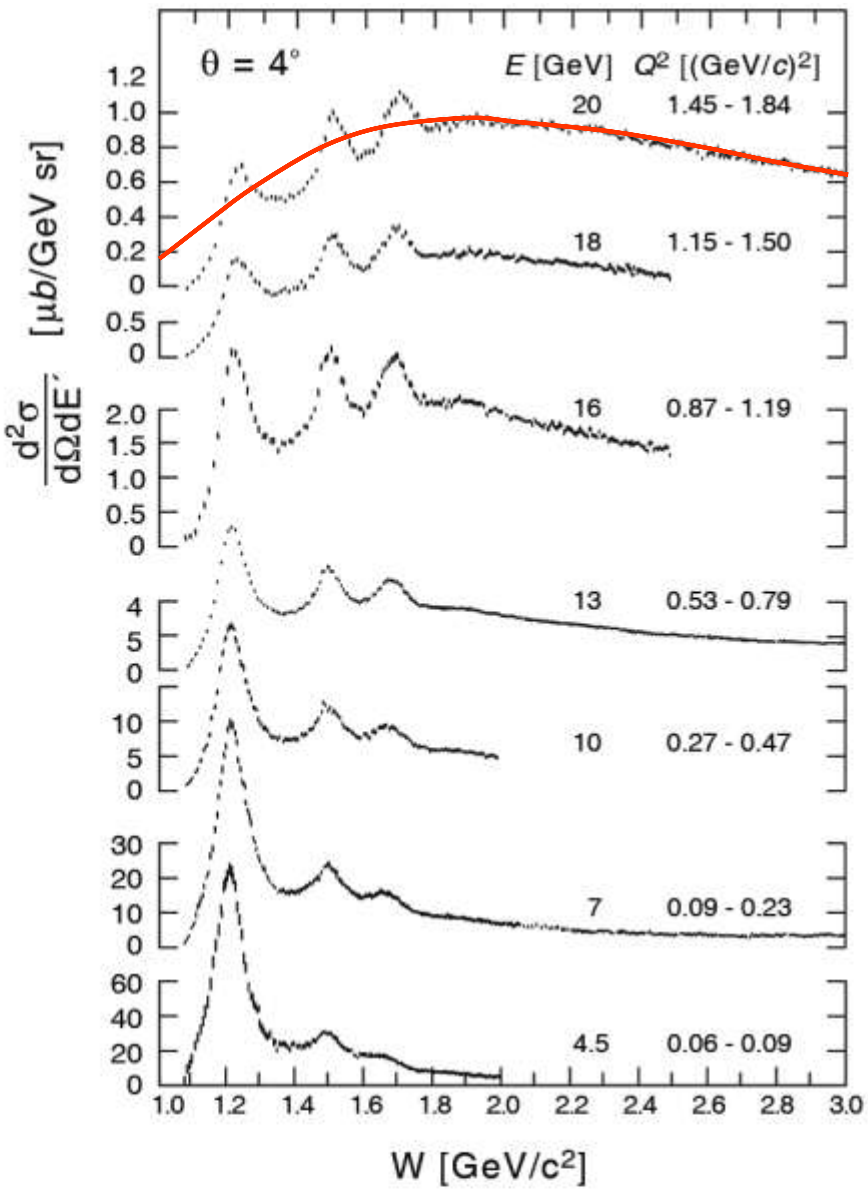


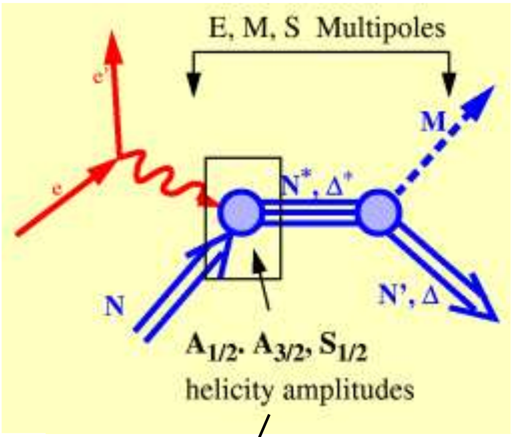
- Study the structure of the nucleon spectrum in the domain where dressed quarks are the major active degree of freedom.
- Explore the formation of excited nucleon states in interactions of dressed quarks and their emergence from QCD.

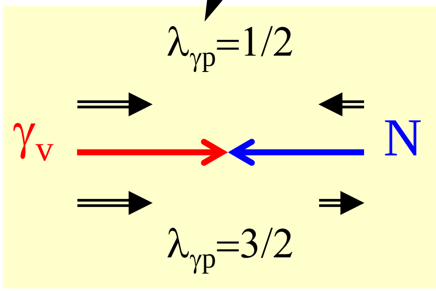


Hard Scattering off Bound and Confined Quarks

Baryon Excitations and Quasi-Elastic Scattering

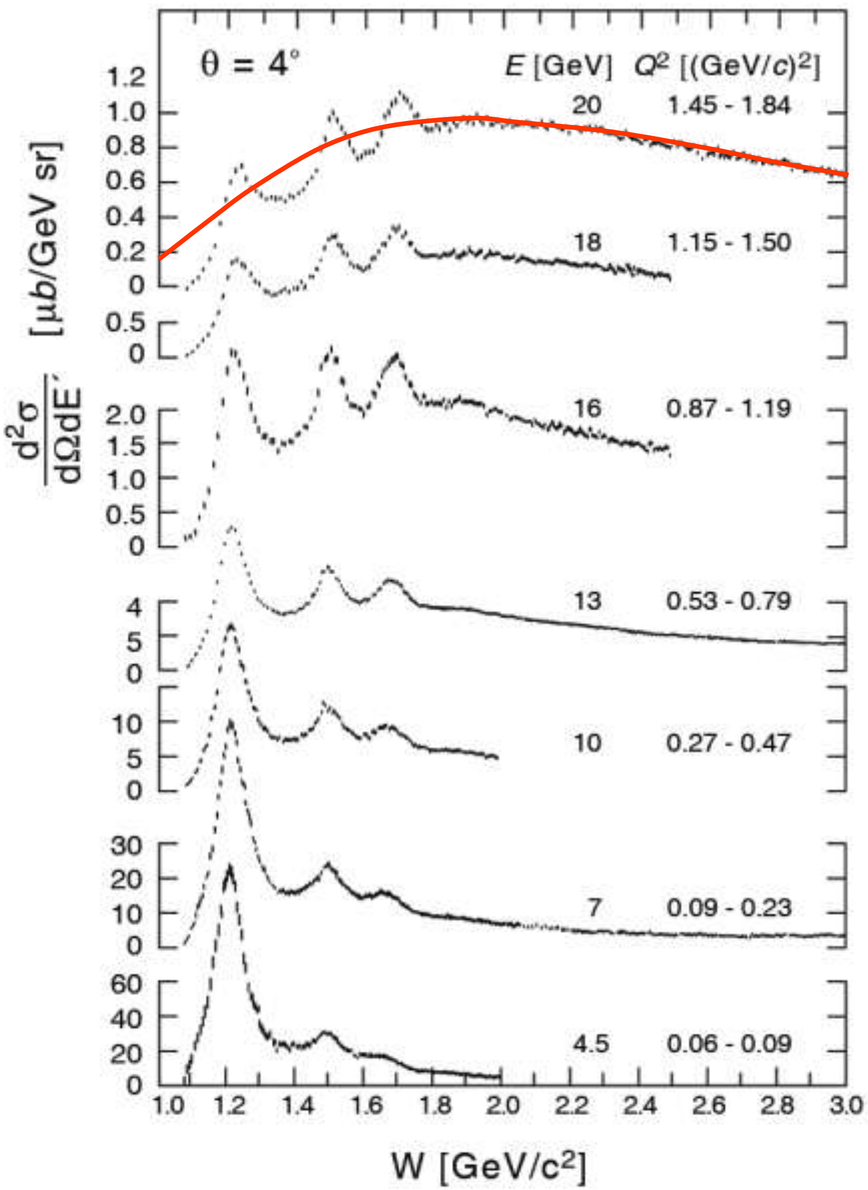




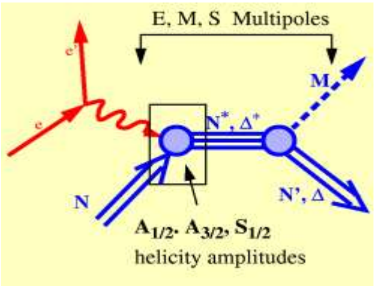


Deep Inelastic Scattering
S. Stein et al., PR **D22** (1975) 1884

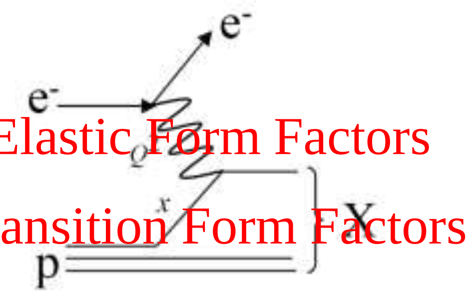
Baryon Excitations and Quasi-Elastic Scattering



hard and confined



quasi-elastic

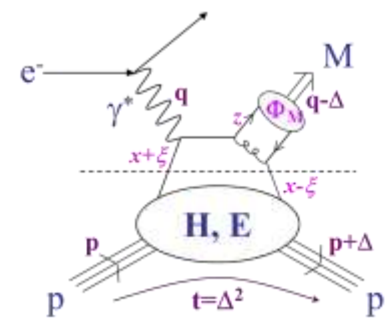


Elastic Form Factors

Transition Form Factors

hard

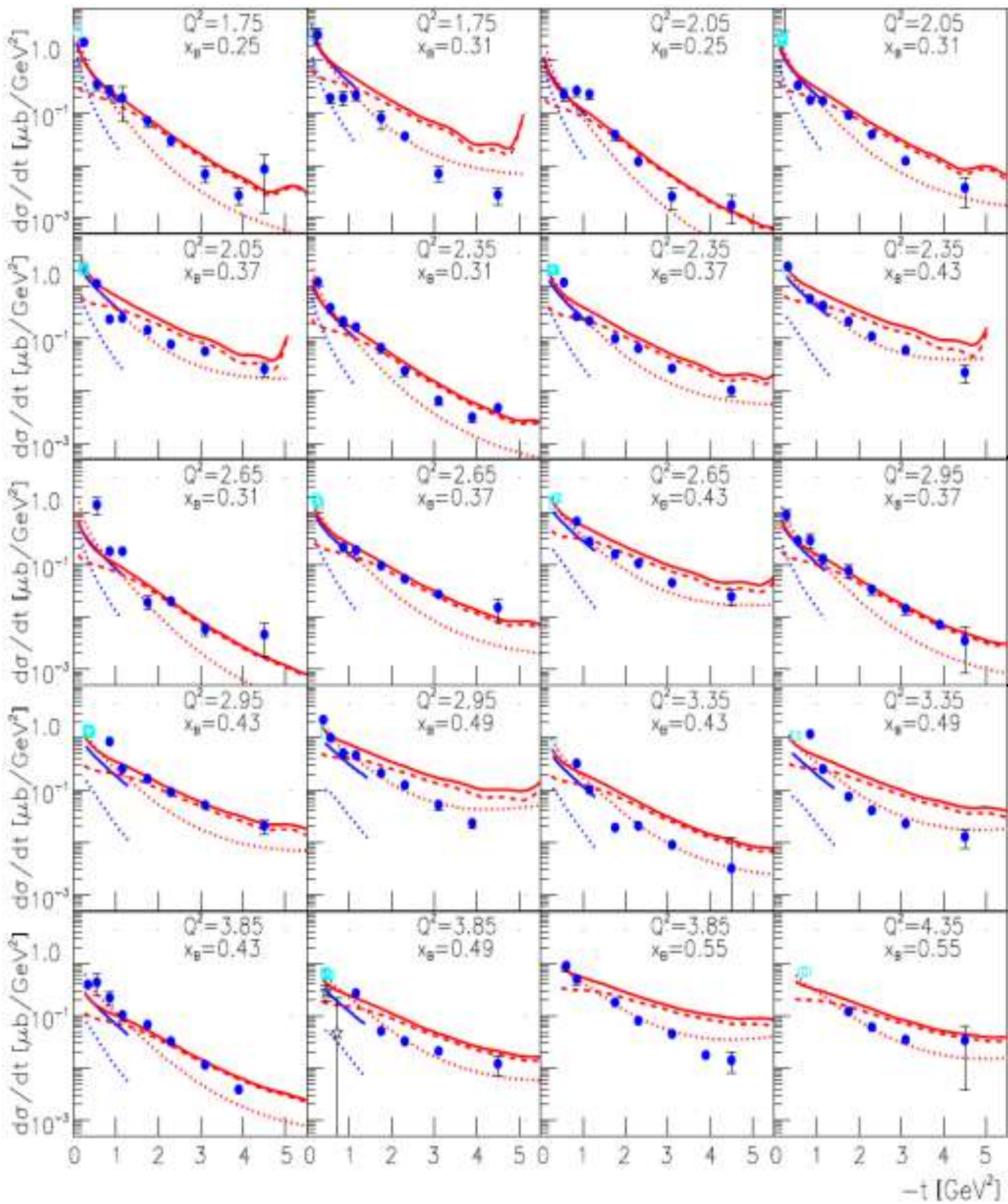
soft

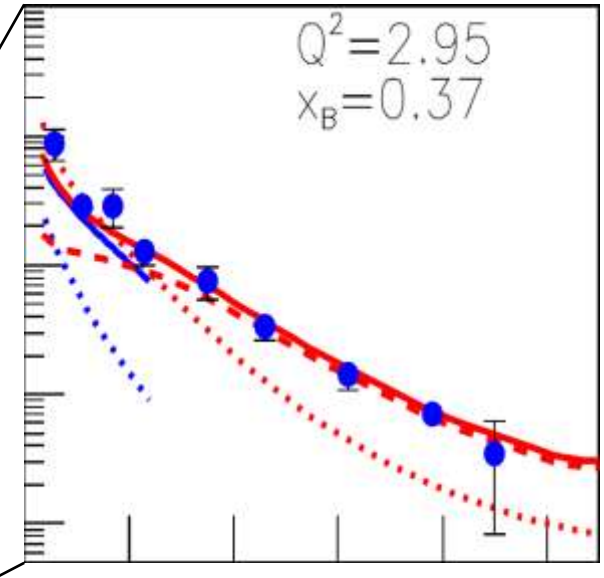


Deep Inelastic Scattering

S. Stein et al., PR **D22** (1975) 1884

Deep Exclusive π^+ Electroproduction off the Proton





K. Park et al., Eur. Phys. J. A 49 (2013) 16

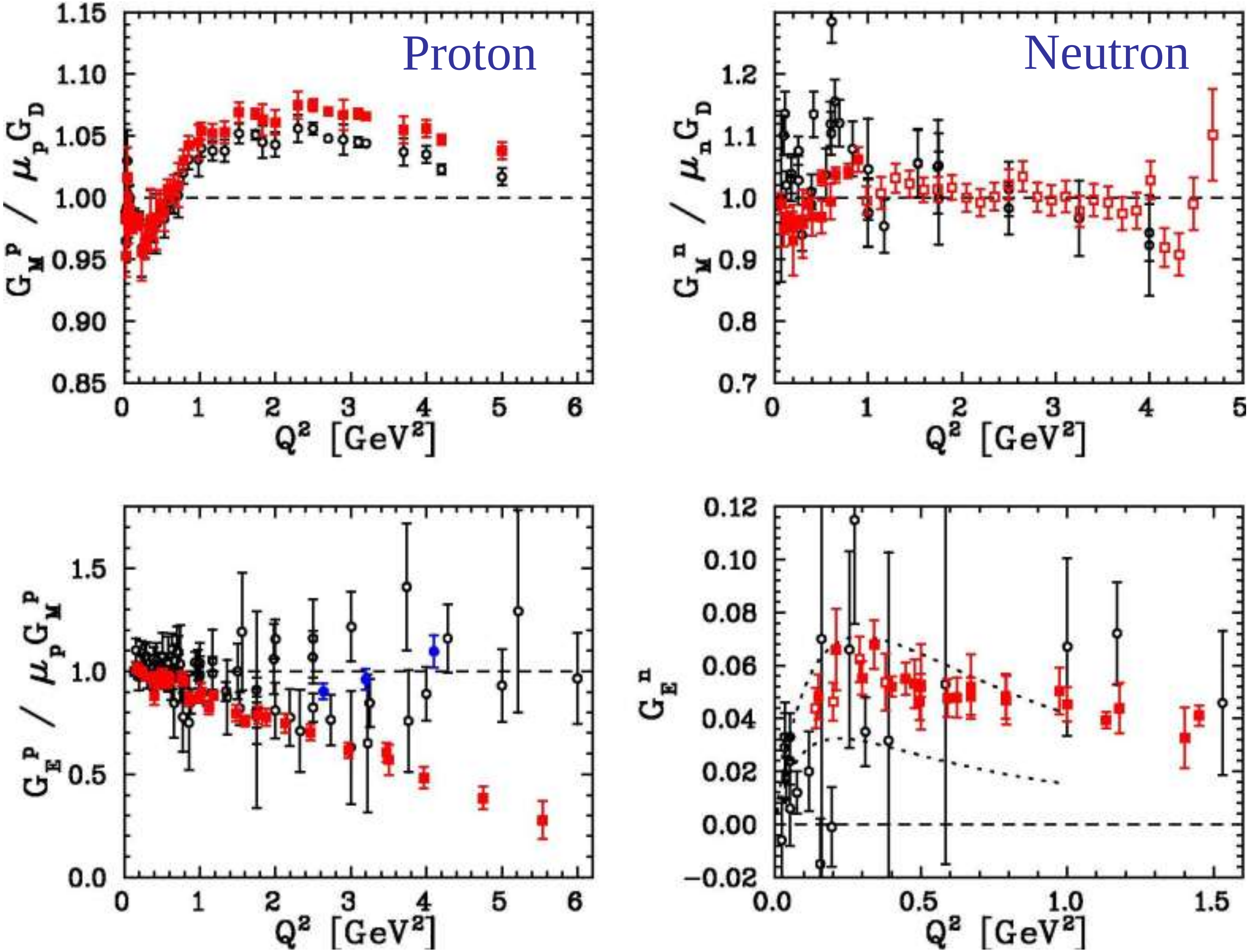
The red solid ($d\sigma/dt$), dotted ($d\sigma_L/dt$), and dashed ($d\sigma_T/dt$) curves are the calculations from a hadronic model (Regge phenomenology) with (Q^2, t)-dependent form factors at the photon-meson vertices. The blue solid and dotted curves are the calculations of $d\sigma/dt$ and $d\sigma_L/dt$, respectively, of a partonic model (handbag diagrams).

Elastic

Form Factors

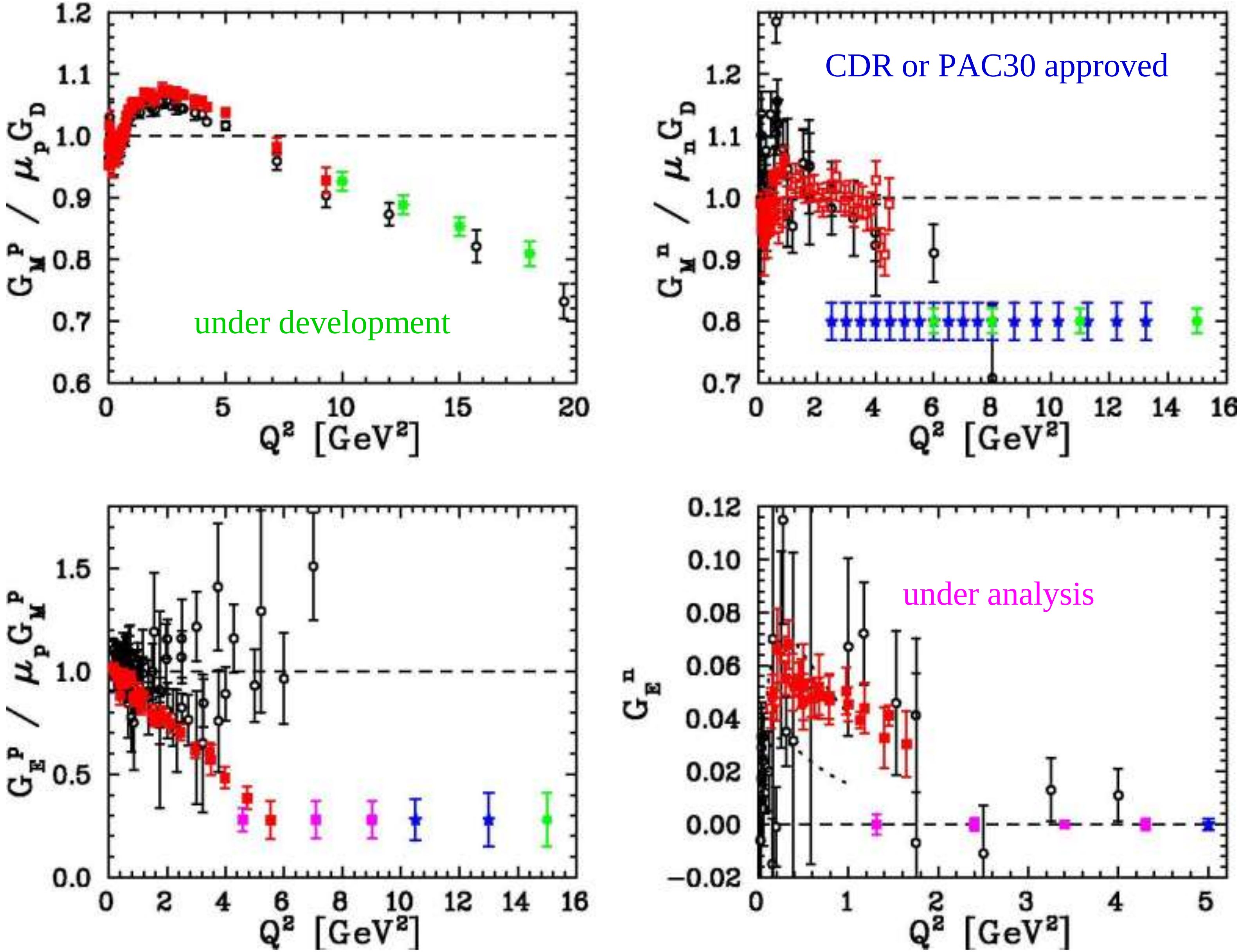
Nucleon Form Factors: Last Ten Years

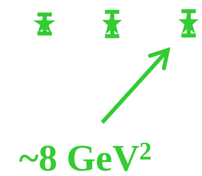
J. Arrington



Extensions with JLab 12 GeV Upgrade

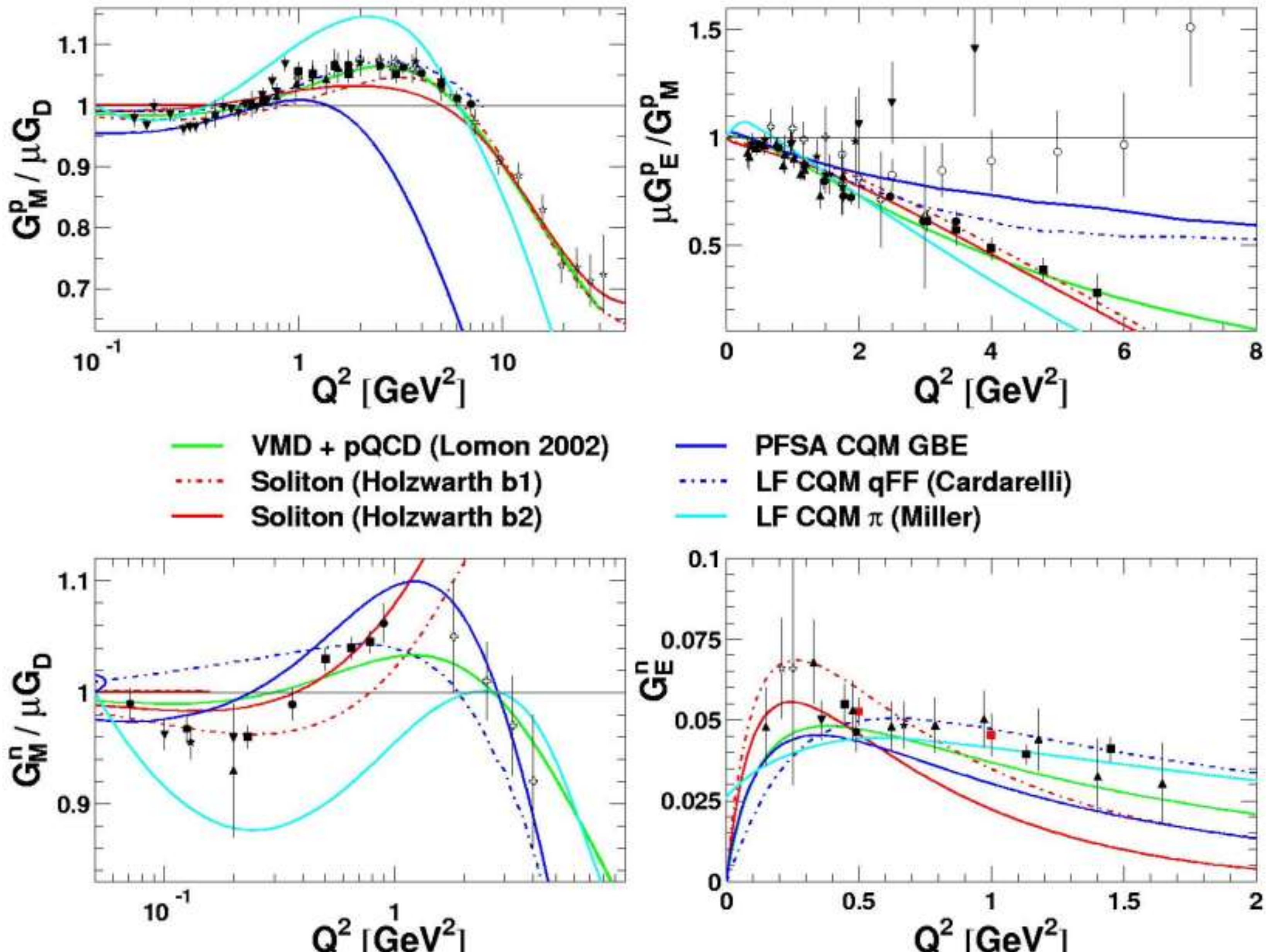
J. Arrington





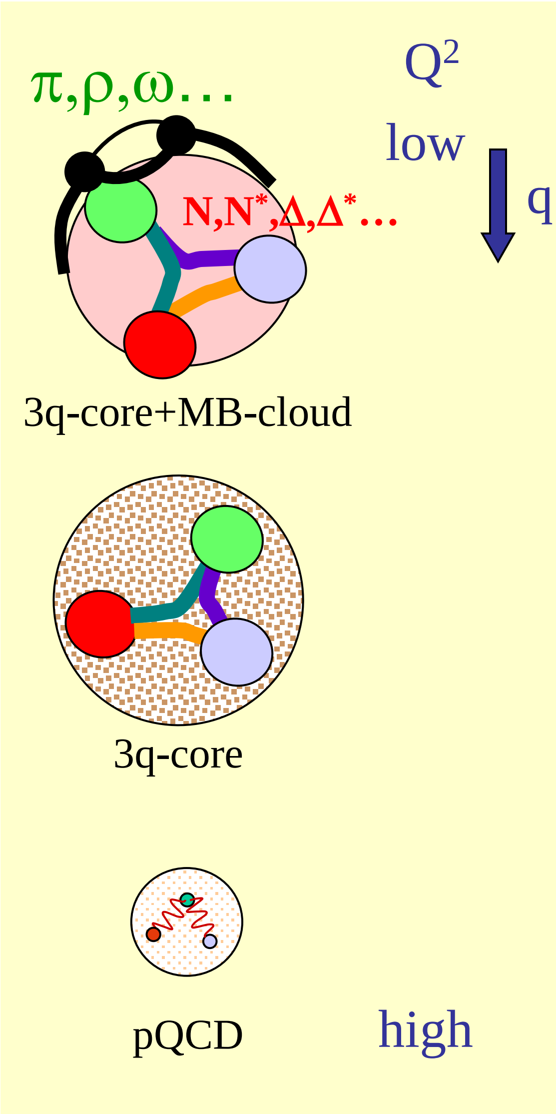
Small Sample of Recent Calculations

J. Arrington



Transition Form Factors

Hadron Structure with Electromagnetic Probes



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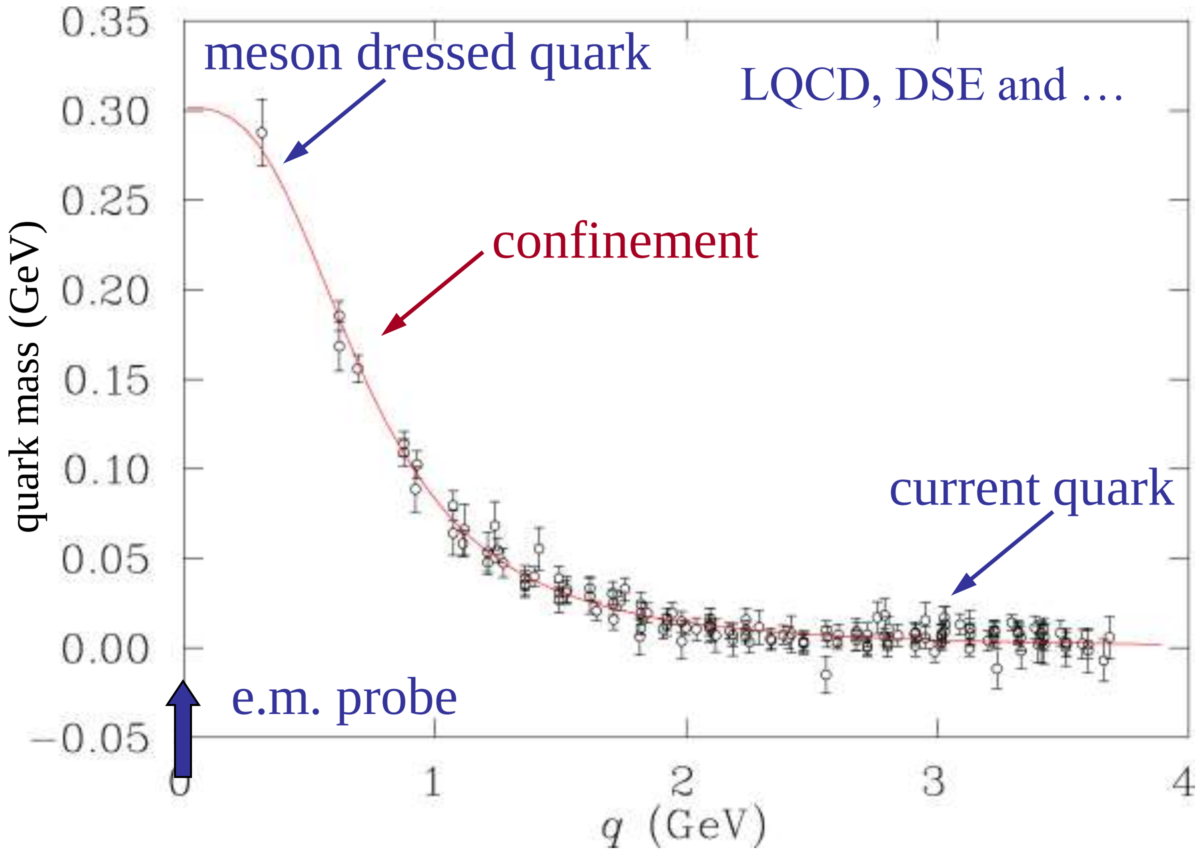
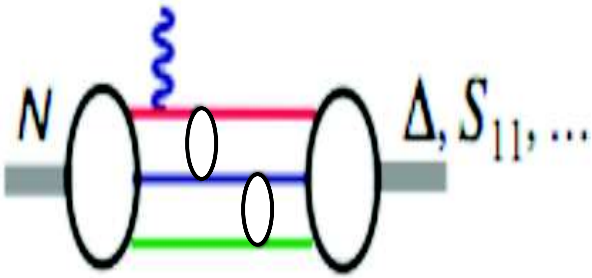
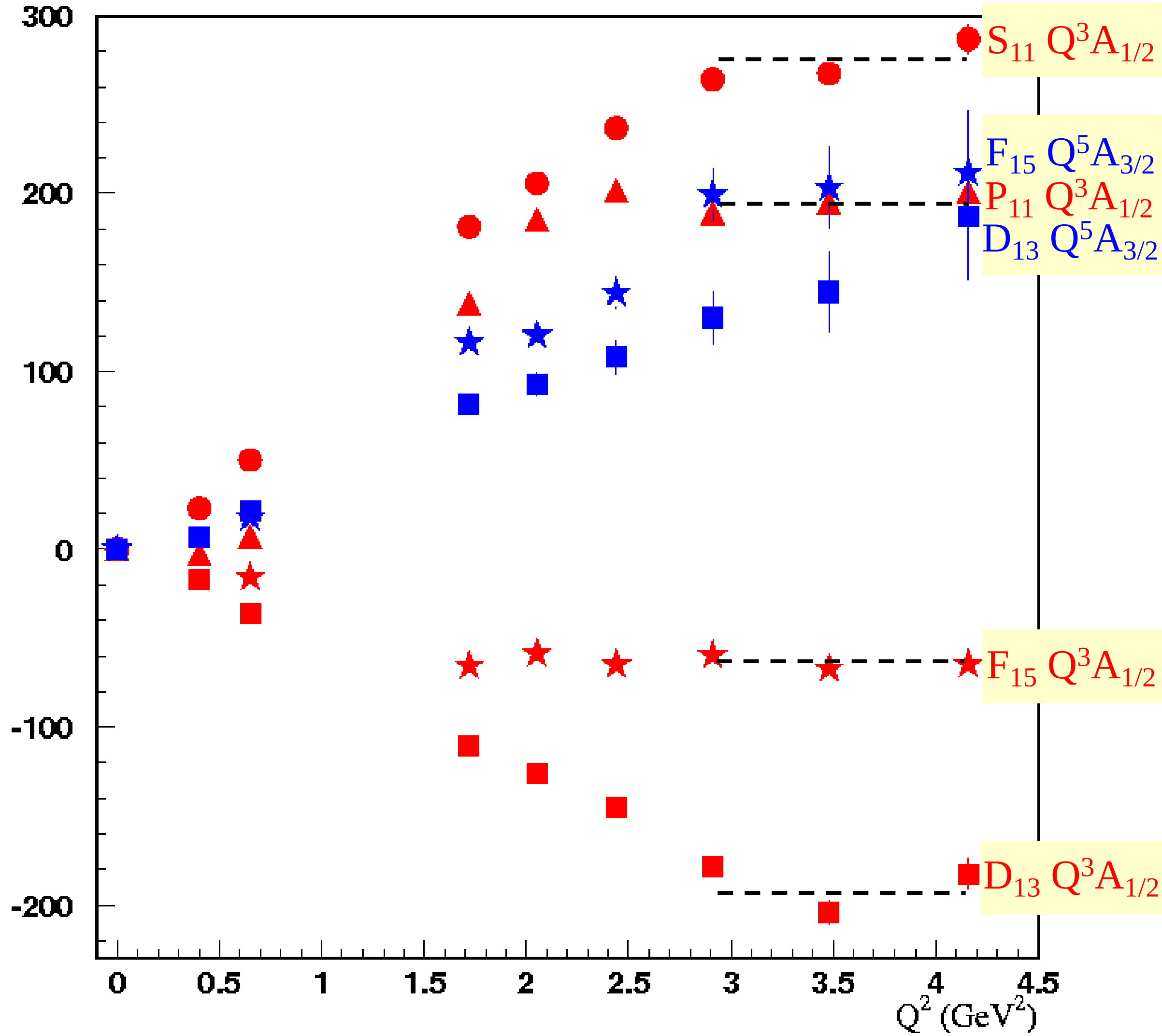


Evidence for the Onset of Scaling?

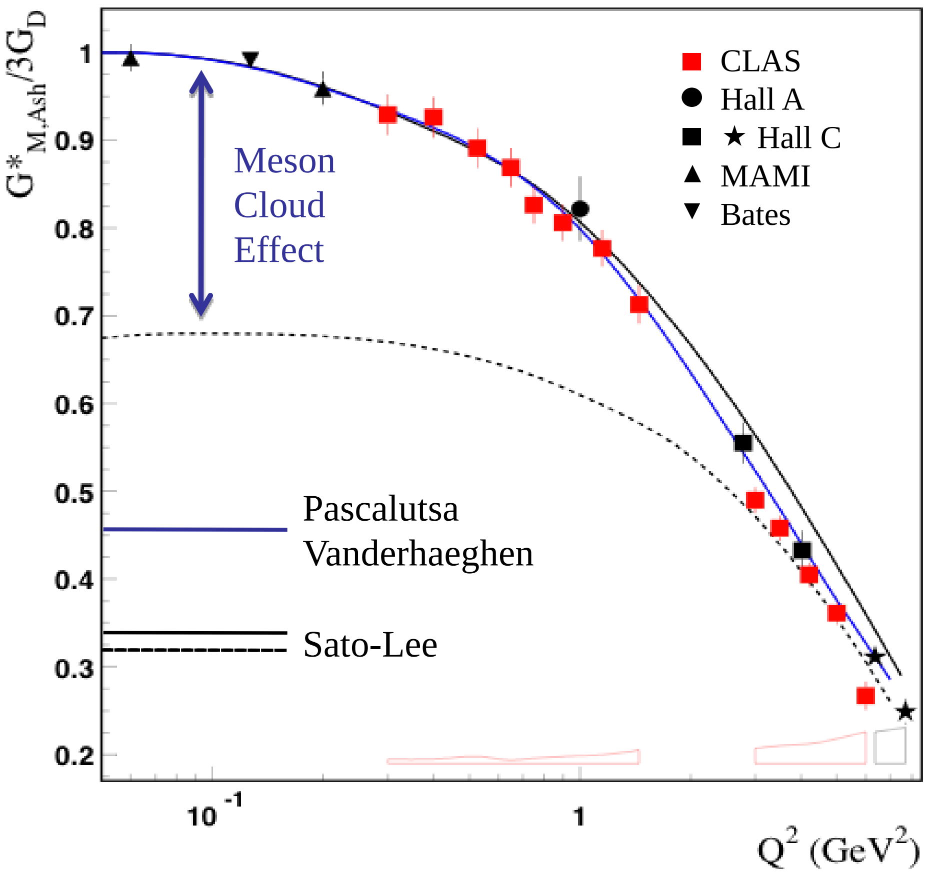


Phys. Rev. C80, 055203 (2009)

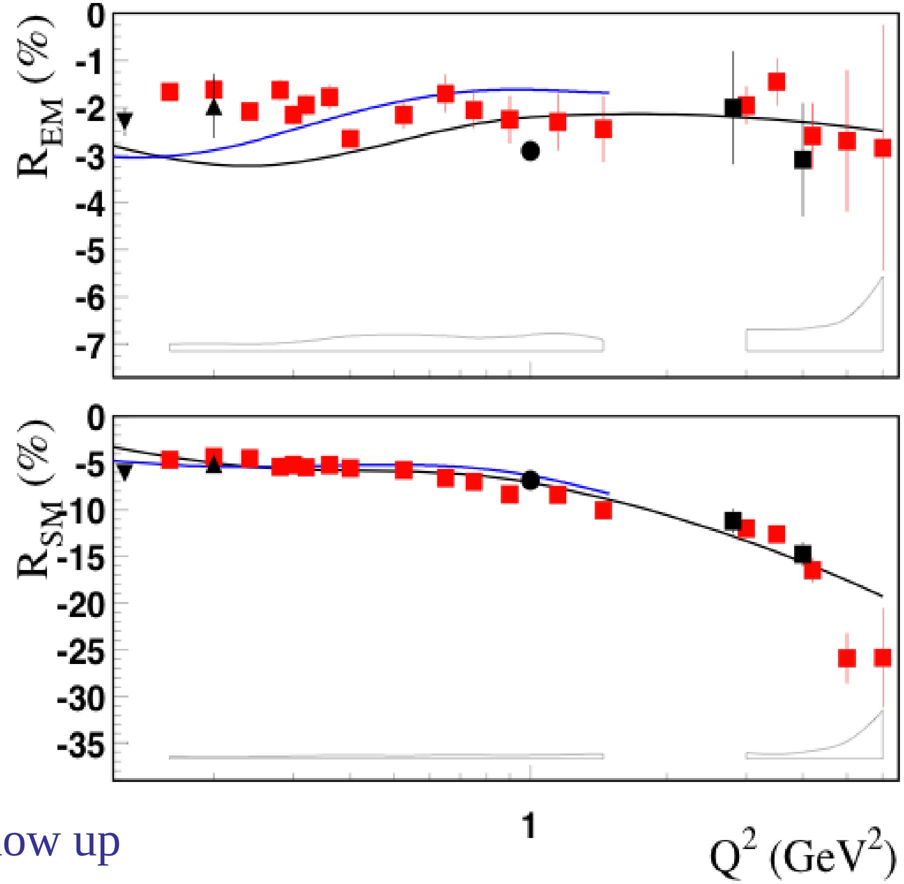


- $A_{1/2}$ α $1/Q^3$
- $A_{3/2}$ α $1/Q^5$
- G_M^* α $1/Q^4$

$N \rightarrow \Delta$ Multipole Ratios R_{EM} , R_{SM}

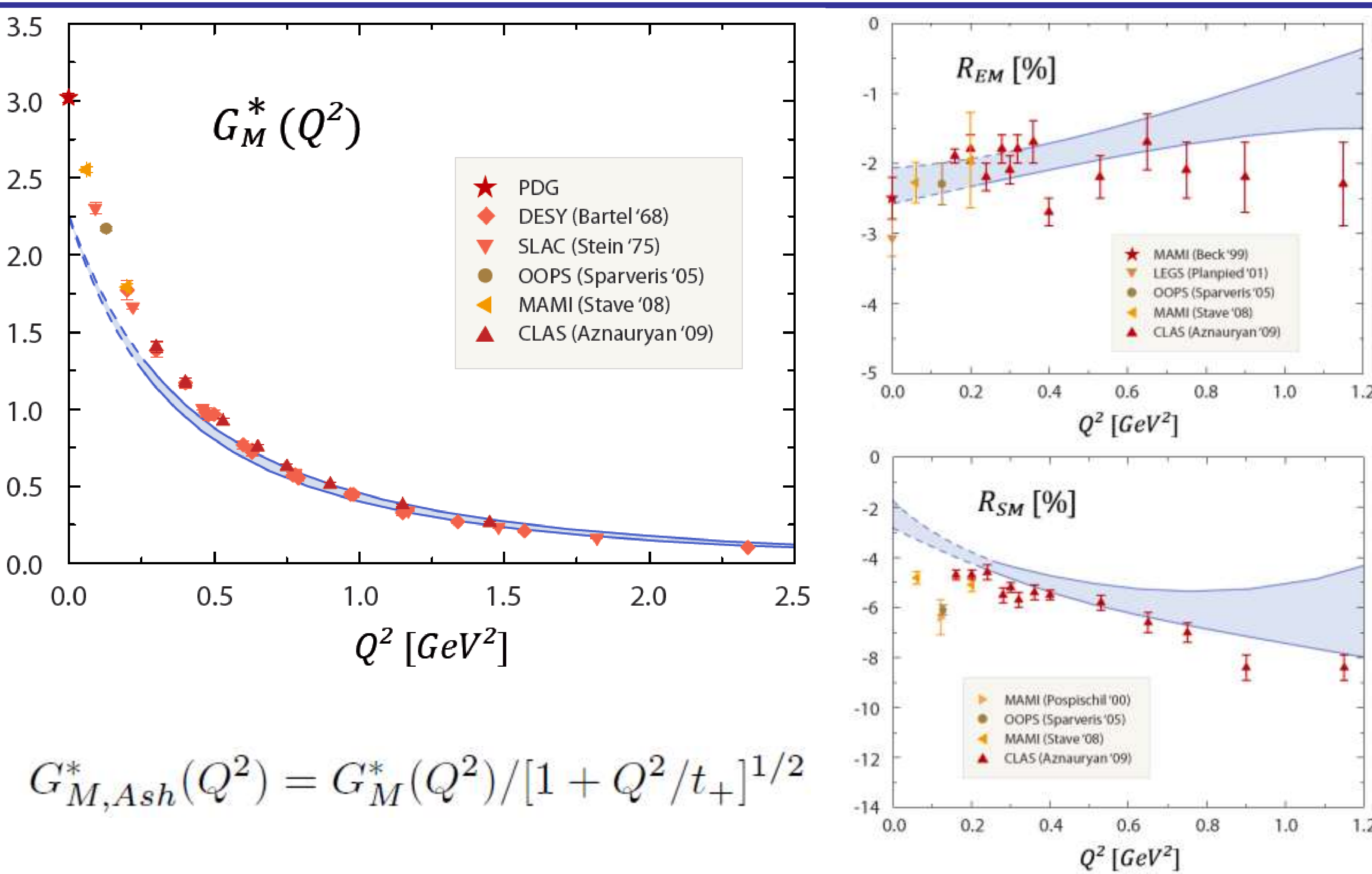


Phys. Rev. Lett. 97, 112003 (2006)



- New trend towards pQCD behavior does not show up
  - $R_{EM} \rightarrow +1$ $R_{SM} \rightarrow$ const
  - $G^*_M \rightarrow 1/Q^4$ $G^*_{M,Ash} \rightarrow 1/Q^5$
- CLAS12 can measure G^*_M, R_{EM}, and R_{SM} up to Q^2~12 GeV^2

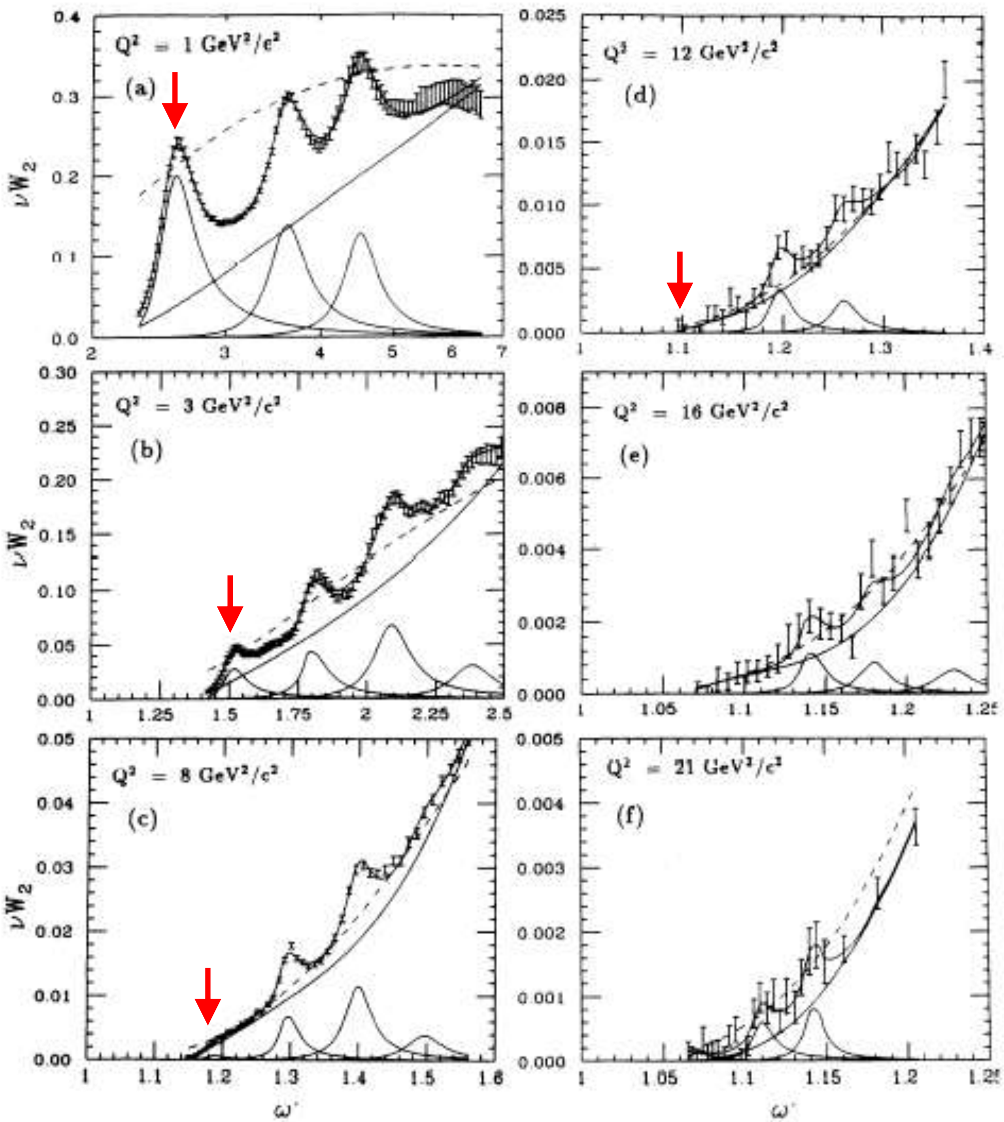
$N \rightarrow \Delta$ Multipole Ratios R_{EM} , R_{SM}

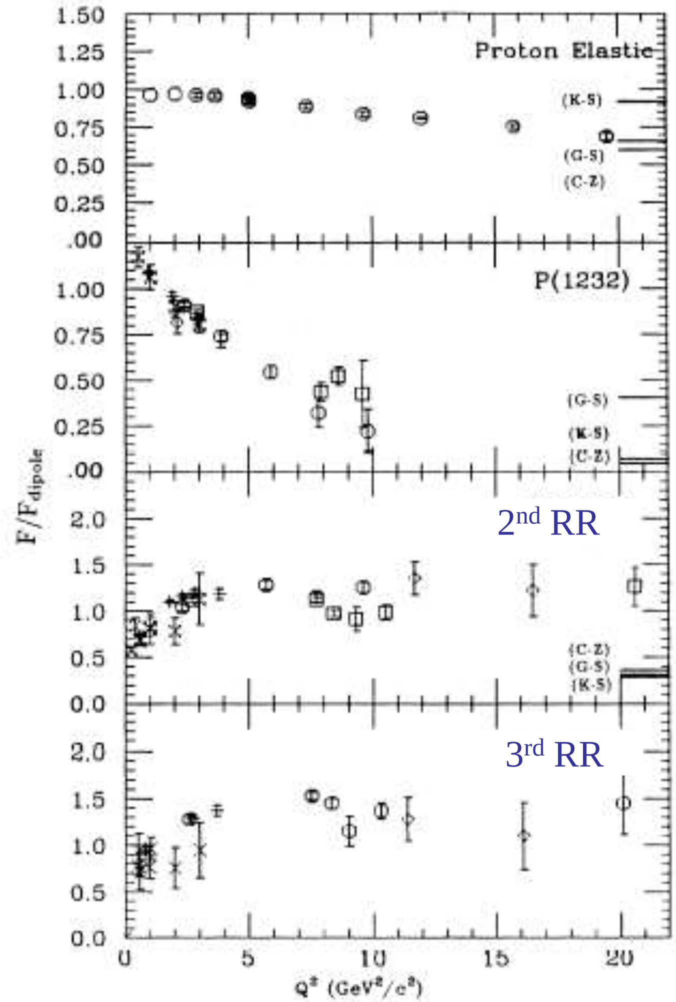


$$G^*_{M,Ash}(Q^2) = G^*_M(Q^2)/[1 + Q^2/t_+]^{1/2}$$

G. Eichmann et al., Phys. Rev. D85 (2012) 093004

Inclusive Structure Function in the Resonance Region

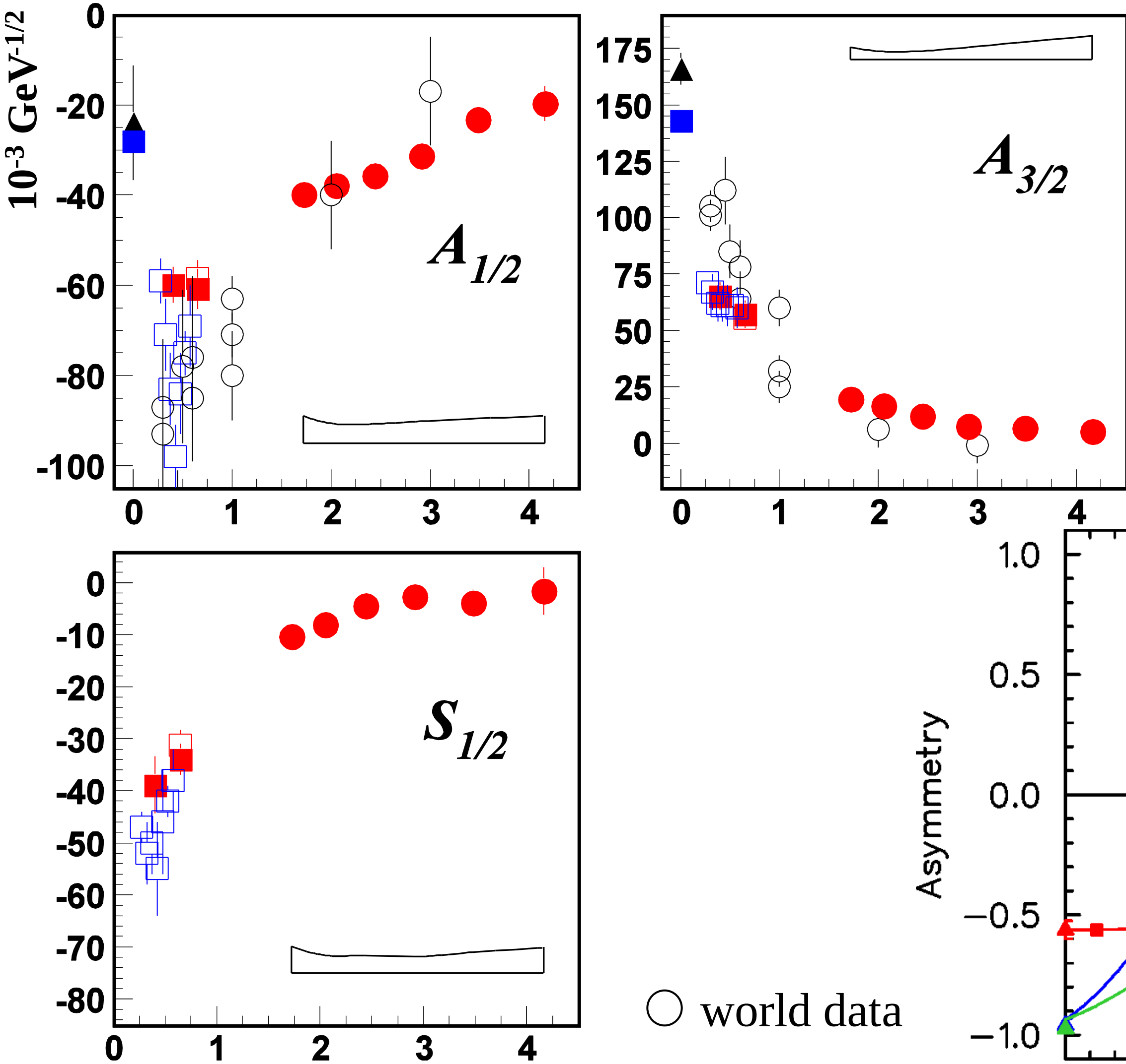




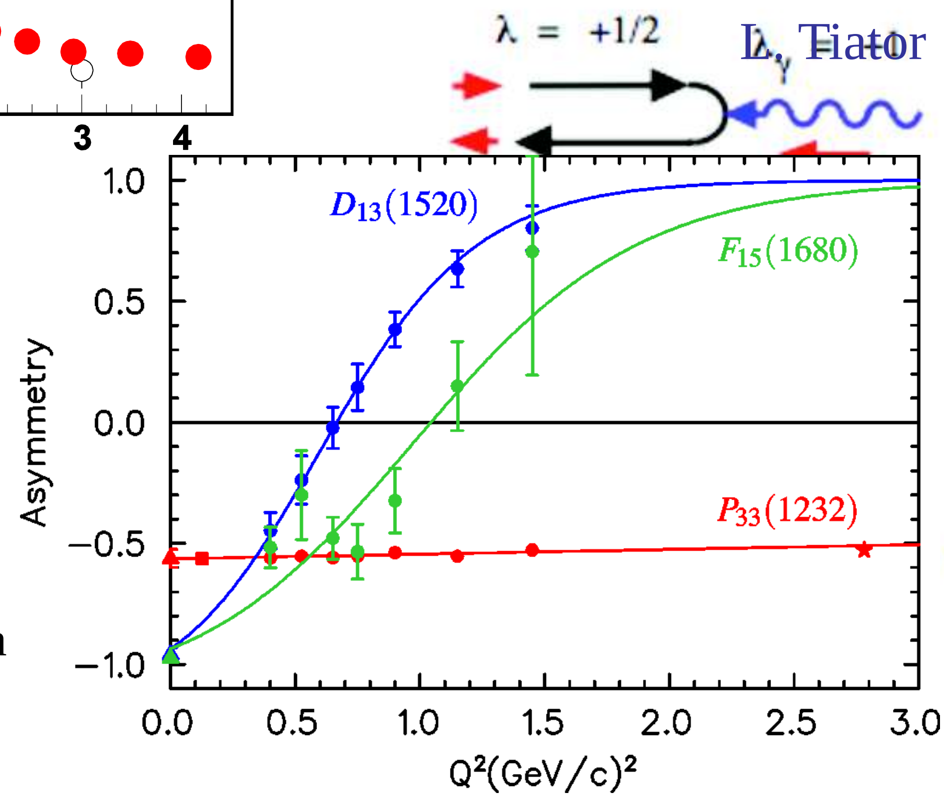
P. Stoler, PRPLCM 226, 3 (1993) 103-171

N(1520)D_{13} Helicity Asymmetry

$$A_{hel} = \frac{A_{1/2}^2 - A_{3/2}^2}{A_{1/2}^2 + A_{3/2}^2}$$

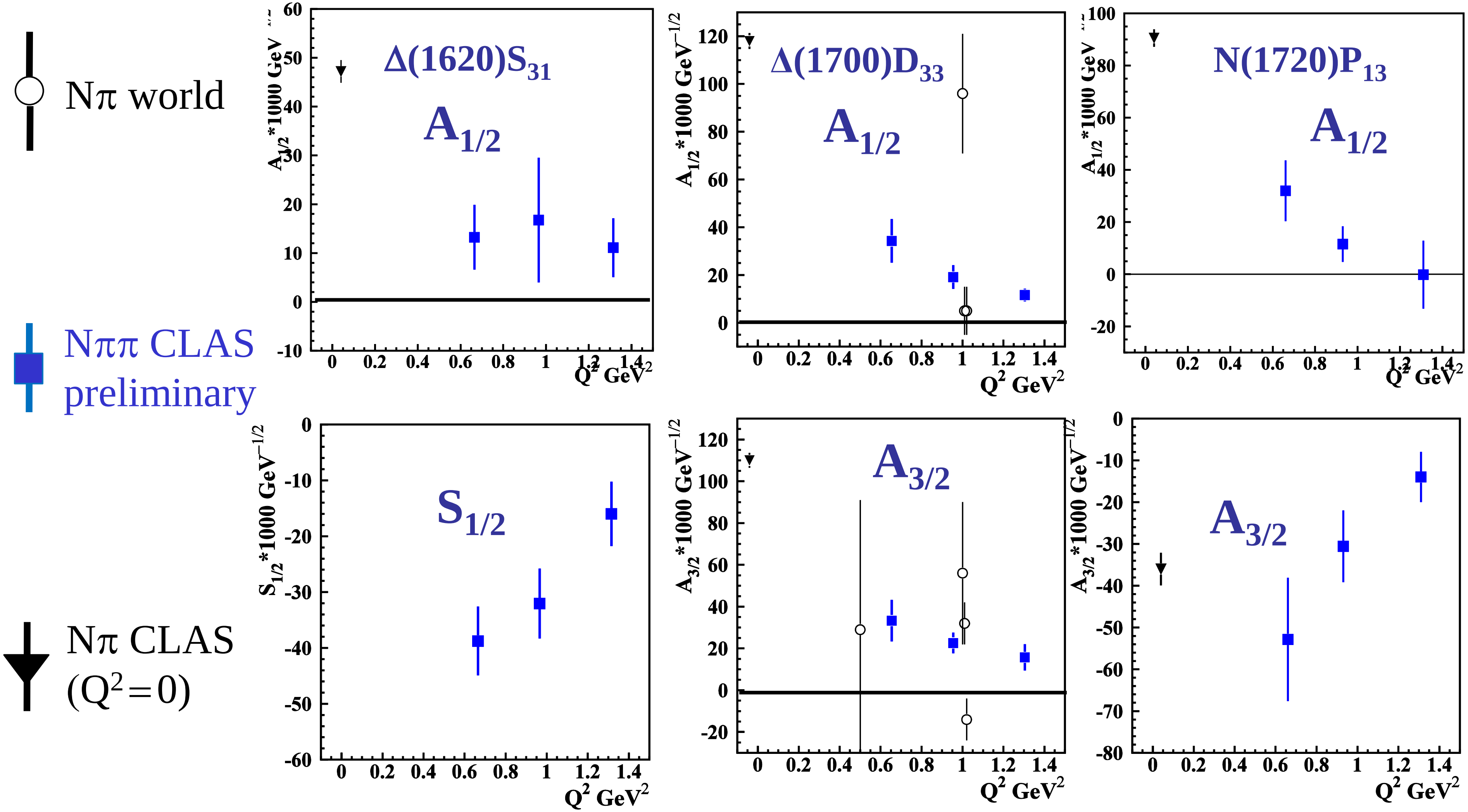


$A_{1/2}$



▲ PDG estimation ●■ Nπ (UIM, DR)

High-Lying Resonance in Nππ CLAS Data Analysis



- ➢ $\pi^+\pi^-p$ electroproduction channel provided first preliminary results on $S_{31}(1620)$, $S_{11}(1650)$, $F_{15}(1685)$, $D_{33}(1700)$, and $P_{13}(1720)$ electrocouplings of a good accuracy
- ➢ new features: a) $S_{1/2}$ dominance for $S_{31}(1620)$ and b) $|A_{3/2}| \geq |A_{1/2}|$ for $D_{33}(1700)$ and $P_{13}(1720)$

$\gamma_\nu NN^*$ Extraction

Phenomenological Analyses

- Unitary Isobar Model (UIM) approach in single pseudoscalar meson production
- Fixed-*t* Dispersion Relations (DR)
- Unitarized Isobar Model for $N\pi\pi$ final state (JM)

Int. J. Mod. Phys. E, Vol. 22, 1330015 (2013) 1-99

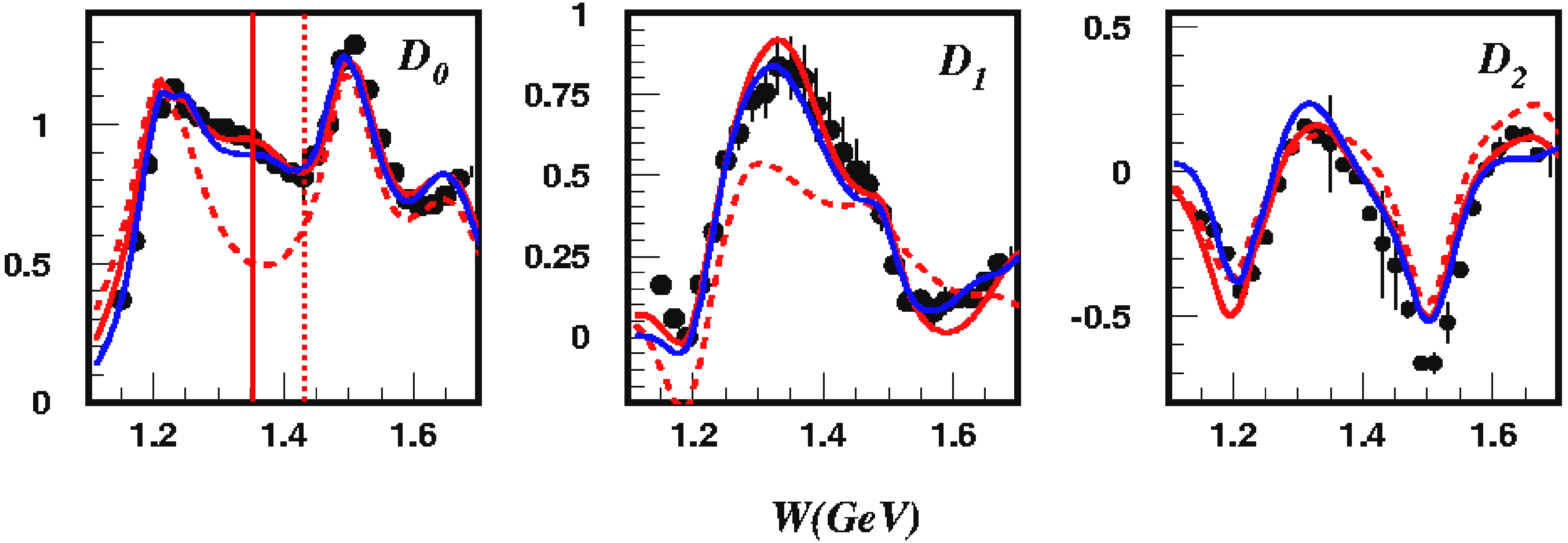
- Coupled-Channel Approach
  (EBAC, Argonne-Osaka, Georgia-Jülich)

Int. J. Mod. Phys. E, Vol. 22, 1330015 (2013) 1-99

Legendre Moments of Unpolarized Structure Functions

K. Park *et al.* (CLAS), Phys. Rev. C77, 015208 (2008)

Q^2=2.05GeV^2



$$\sigma_T + \epsilon\sigma_L = \sum_{l=0}^{n} D_l^{T+L} P_l(\cos\theta_\pi^*)$$

I. Aznauryan —— DR fit

I. Aznauryan - - - DR fit w/o P_{11}

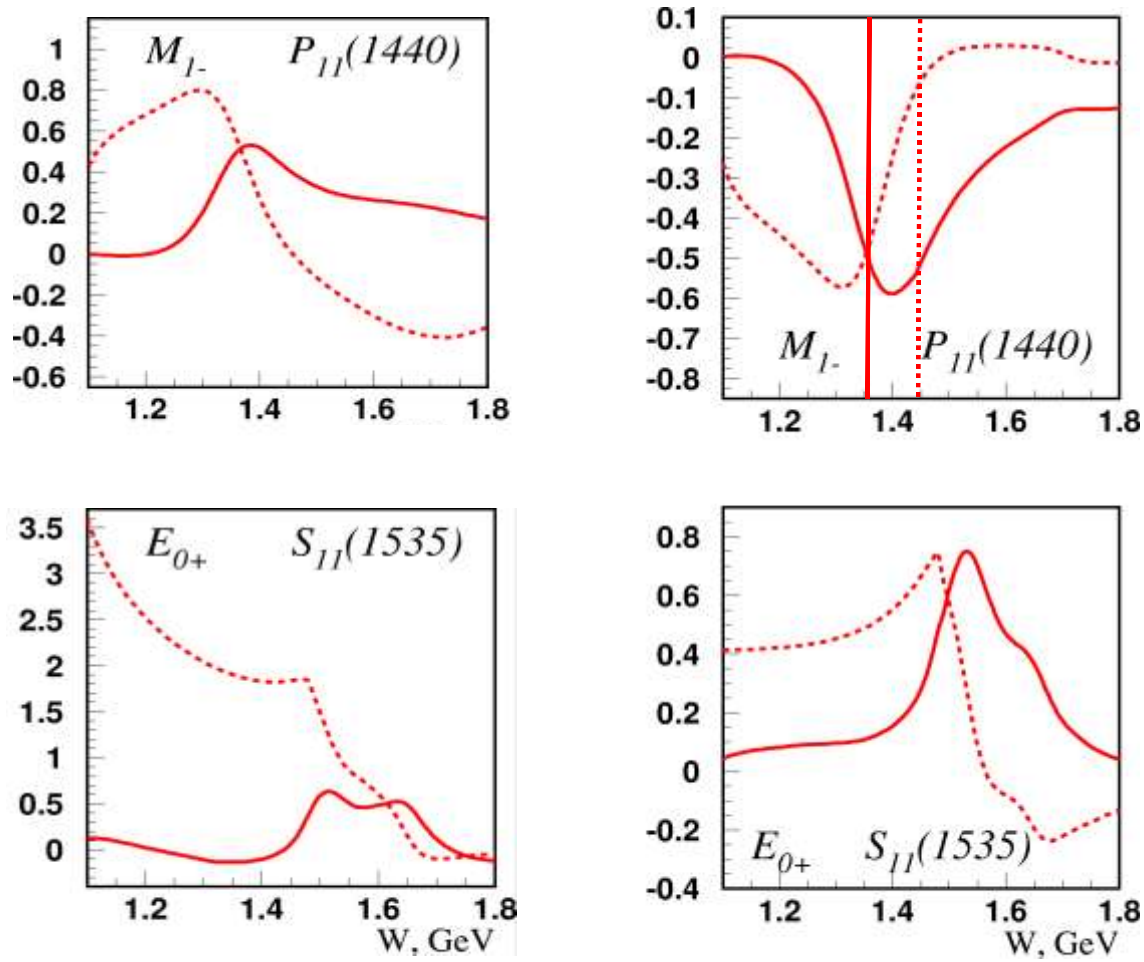
I. Aznauryan —— UIM fit

Two conceptually different approaches DR and UIM are consistent. CLAS data provide rigid constraints for checking validity of the approaches.

Energy-Dependence of π^+ Multipoles for P_{11}, S_{11}

$Q^2 = 0$ GeV^2 $\quad$ $Q^2 = 2.05$ GeV^2

The study of some baryon resonances becomes easier at higher Q^2.

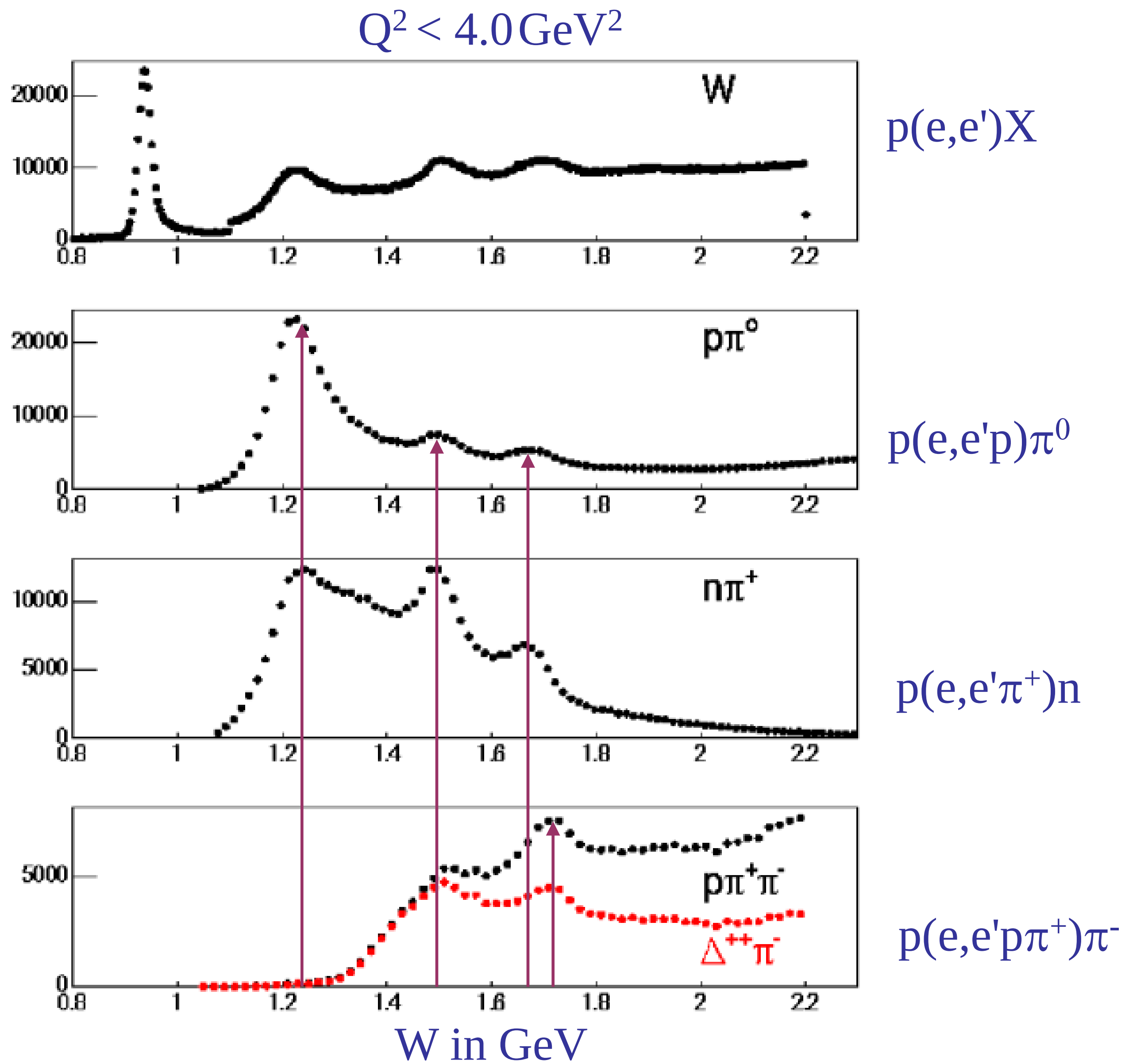


Cross sections are extracted in the $p\pi^0$, $p\pi^+$, $p\eta$; and more are currently under analysis in the $p\omega$ and $p\pi^-$ final states.

real part $\quad$ imaginary part

Nucleon Resonances in $N\pi$ and $N\pi\pi$ Electroproduction

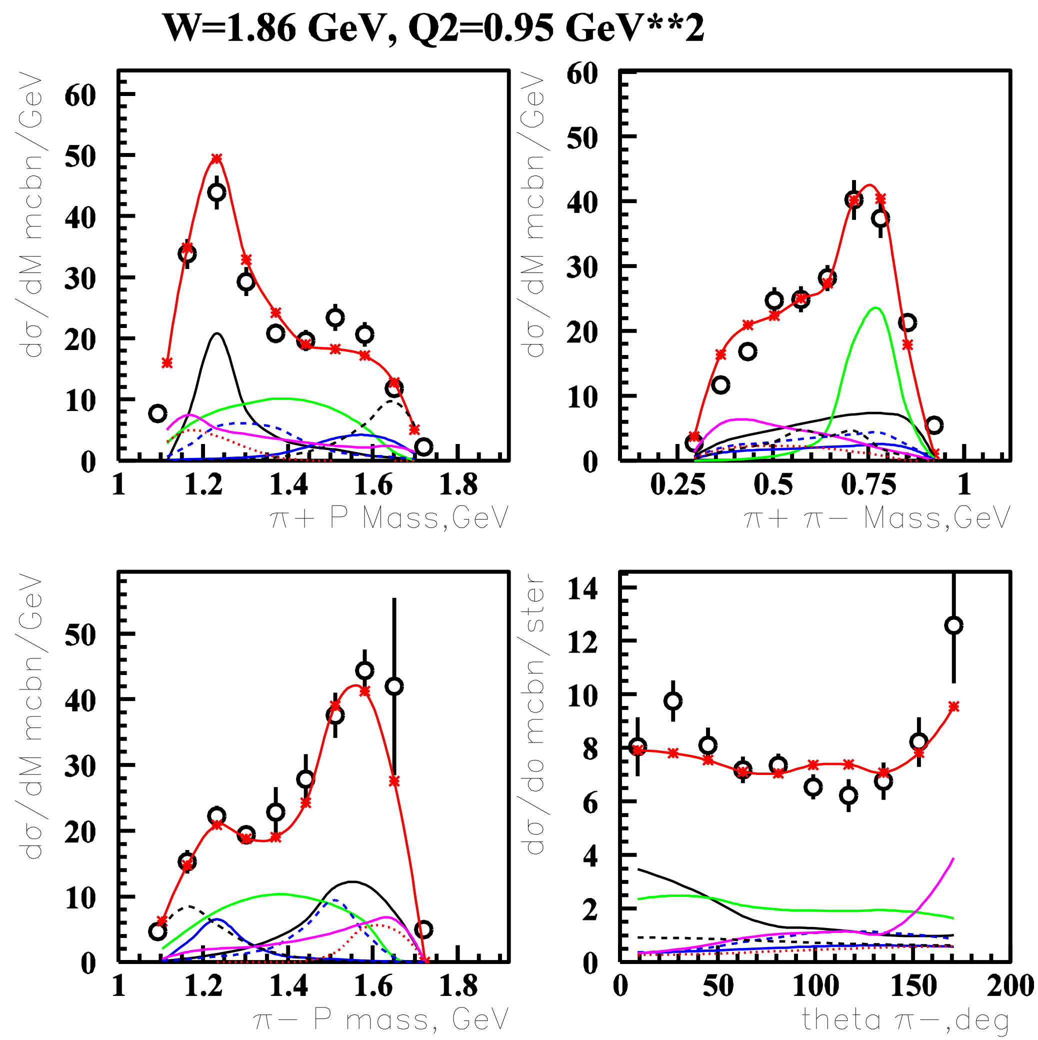
- $N\pi\pi$ channel is sensitive to N*s heavier than 1.4 GeV
- Provides information that is complementary to the $N\pi$ channel
- Many higher-lying N*s decay preferentially into $N\pi\pi$ final states



Contributing Mechanisms to $\gamma^{(*)}p \rightarrow p\pi^+\pi^-$

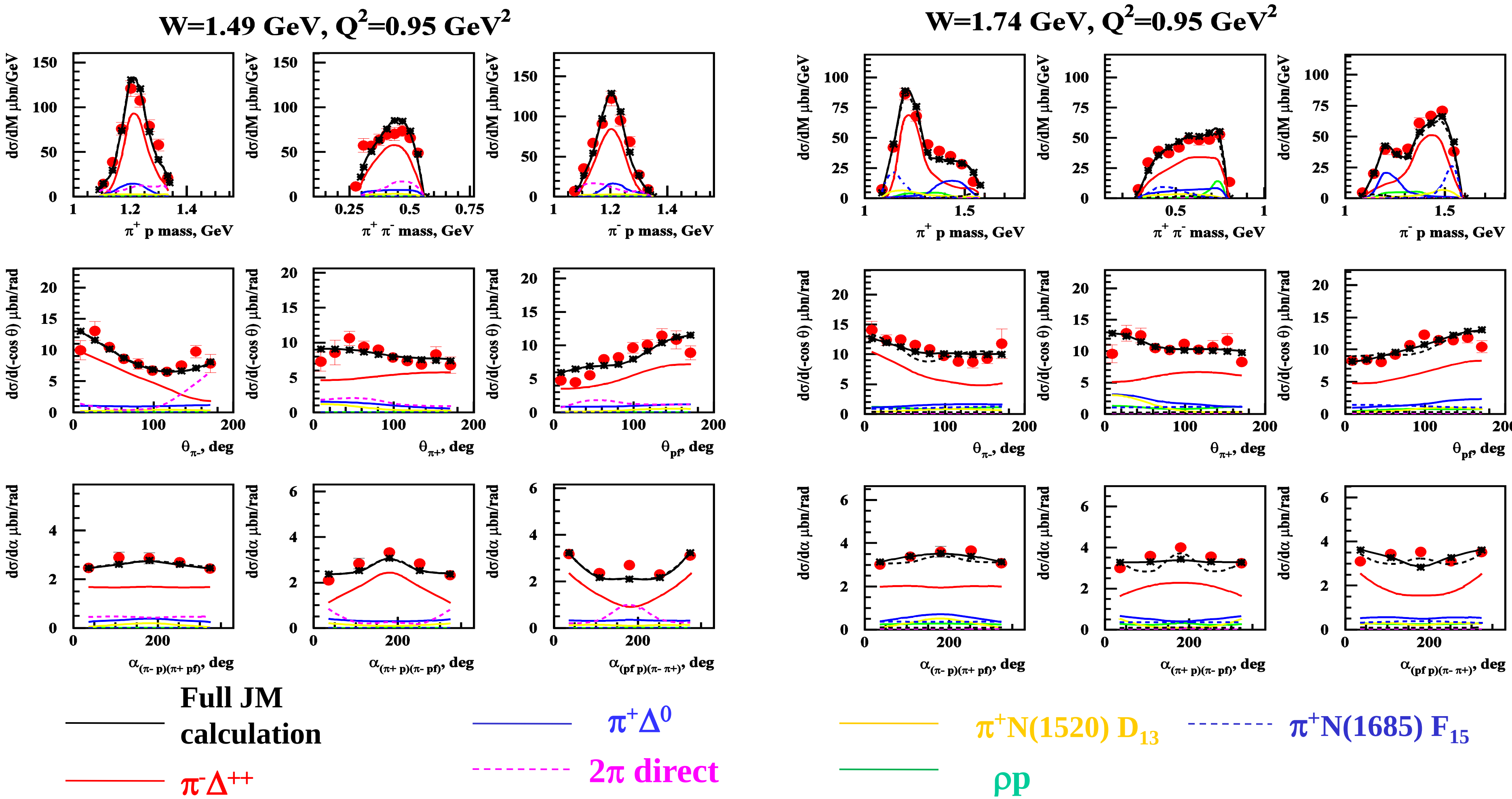
Isobar Model JM05

- (red solid line) Full calculations
- (black solid line) $\gamma p \rightarrow \pi^- \Delta^{++}$
- (blue solid line) $\gamma p \rightarrow \pi^+ \Delta^0$
- (blue dashed line) $\gamma p \rightarrow \pi^+ D_{13}(1520)$
- (green solid line) $\gamma p \rightarrow \rho p$
- (black dashed line) $\gamma p \rightarrow \pi^- \Delta^{++}(1600)$
- (red dotted line) $\gamma p \rightarrow \pi^+ F^0_{15}(1685)$
- (pink solid line) direct 2π production



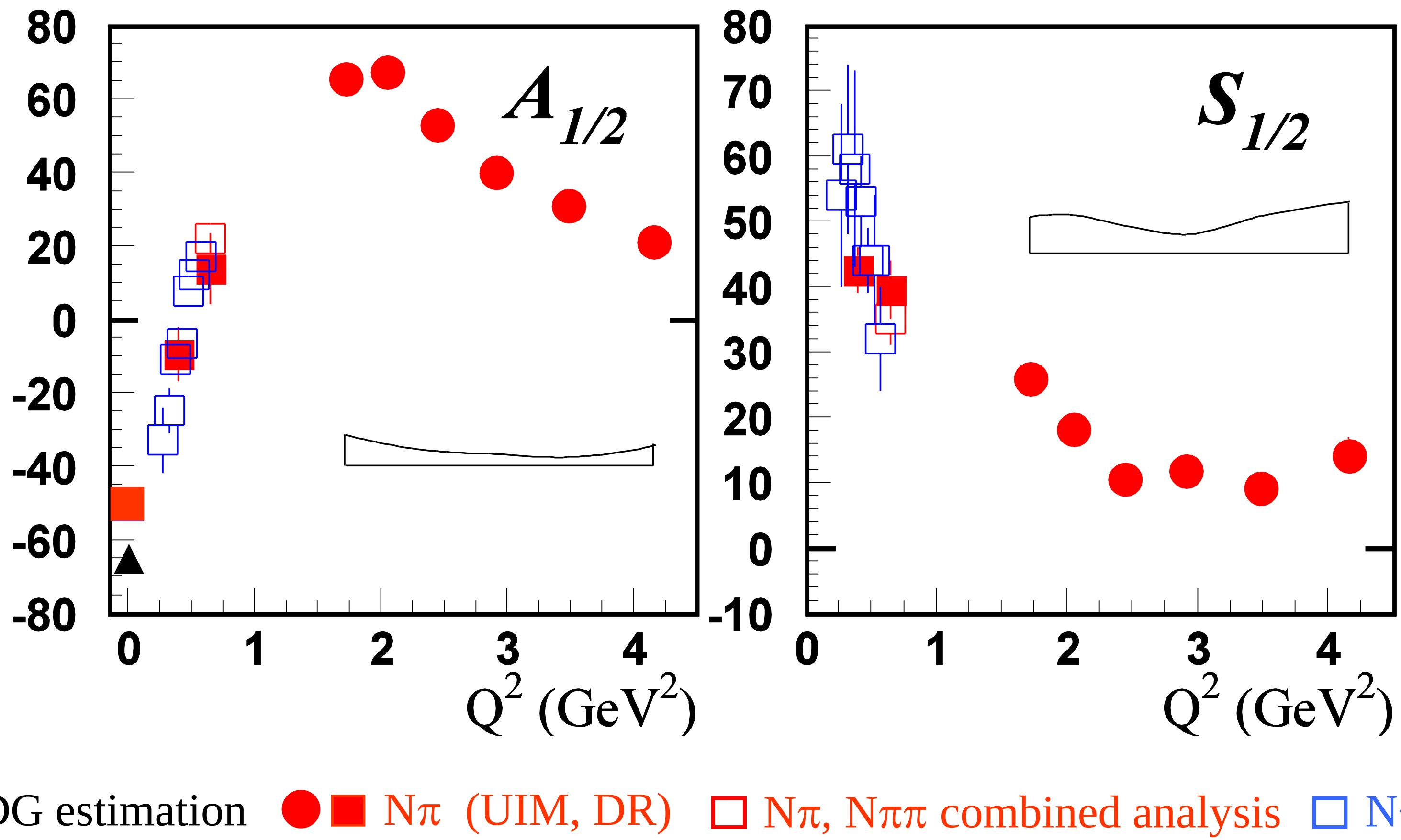
➢ The combined fit of nine single differential cross sections allowed to establish all significant mechanisms.

JM Contributions as Determined by the CLAS 2π Data



Each production mechanism contributes to all nine single differential cross sections in a unique way. Hence a successful description of all nine observables allows us to check and to establish the dynamics of all essential contributing mechanisms.

Electrocouplings of N(1440)P_{11} from CLAS Data

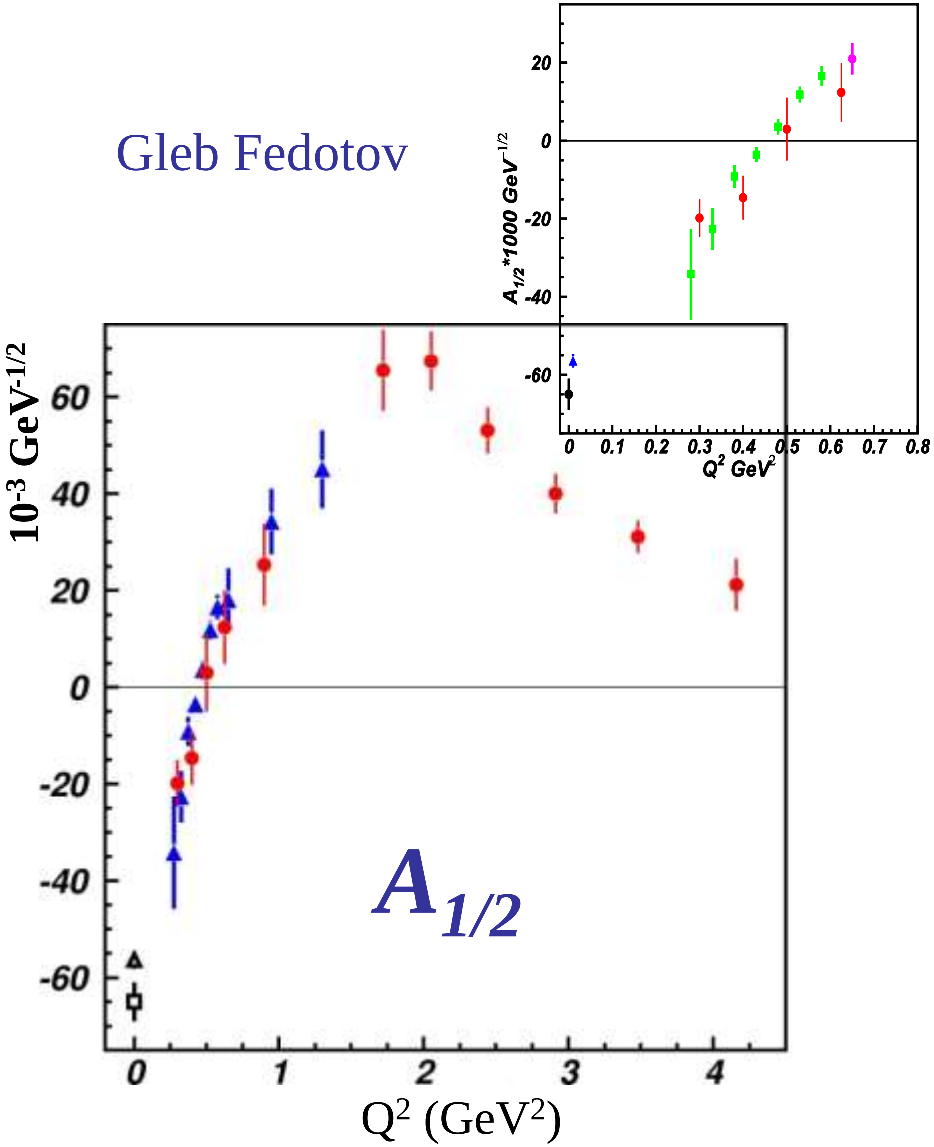


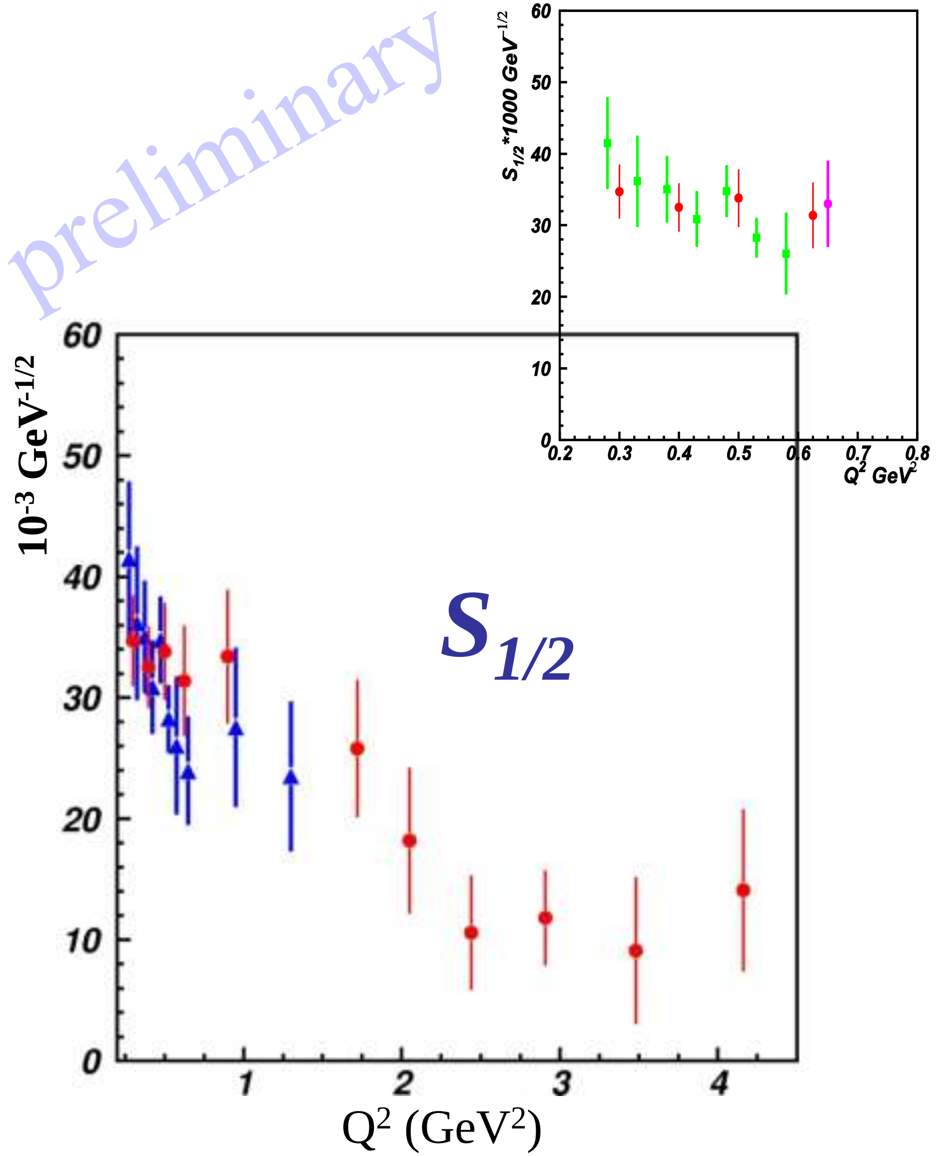
The good agreement on extracting the N* electrocouplings between the two exclusive channels (1π/2π) – having fundamentally different mechanisms for the nonresonant background – provides evidence for the reliable extraction of N* electrocouplings.

Phys. Rev. C 86, 035203 (2012) 1-22

Most recent Electrocouplings of $N(1440)P_{11}$

Gleb Fedotov



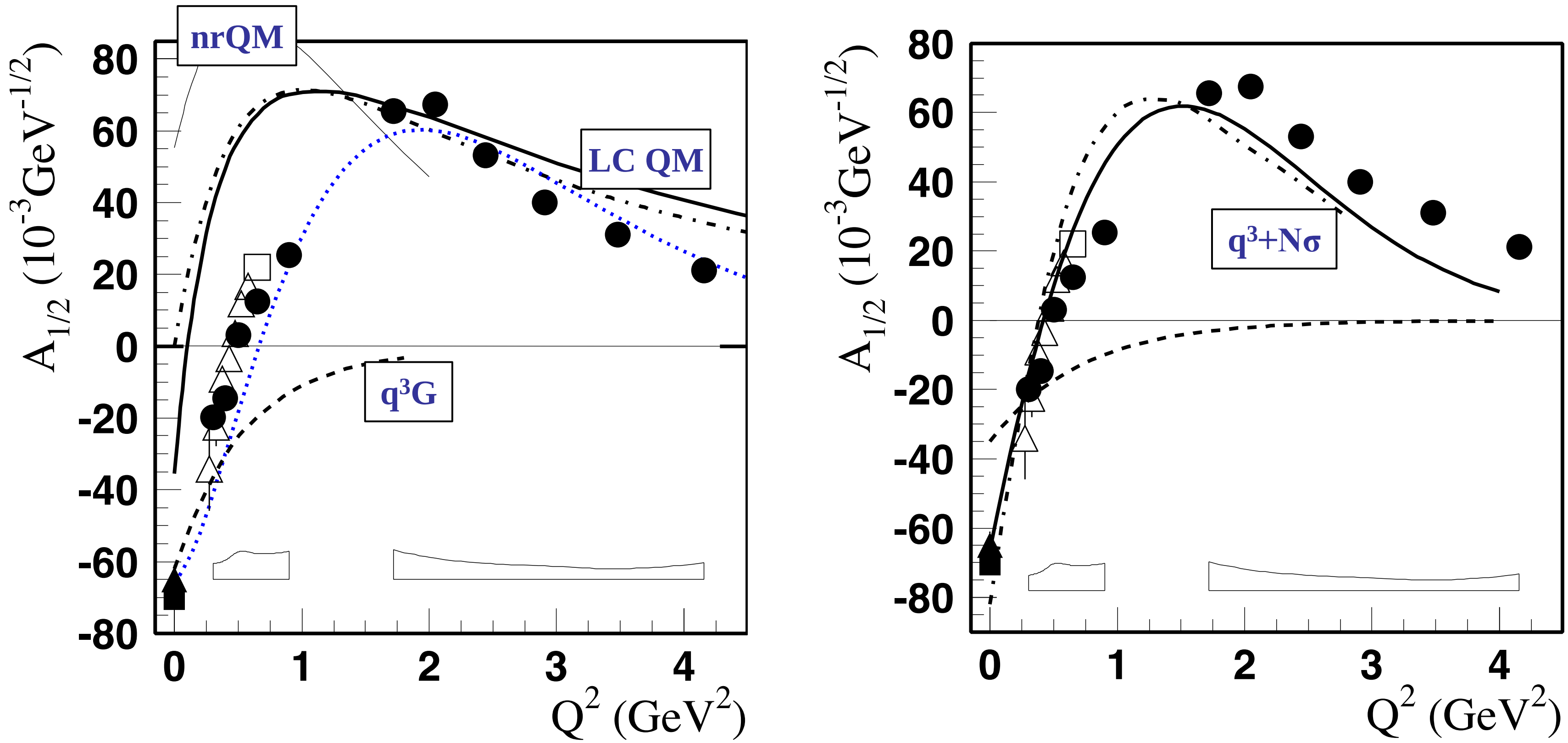


… and beam-helicity dependent 2π cross sections are currently under analysis.

QCD-Based Models and Theory?

Constituent Quark Models (CQM)

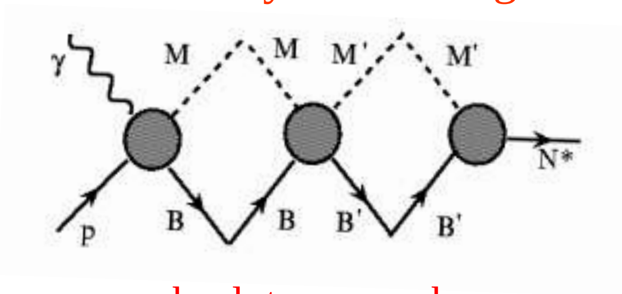
With Roper resonance $P_{11}(1440)$ data



- $A_{1/2}$ has zero-crossing near Q^2=0.5 and becomes dominant amplitude at high Q^2
- Eliminates gluonic excitation (q^3G) as a dominant contribution
- Consistent with radial excitation at high Q^2 and large meson-baryon coupling at small Q^2

Progress in Experiment and Phenomenology

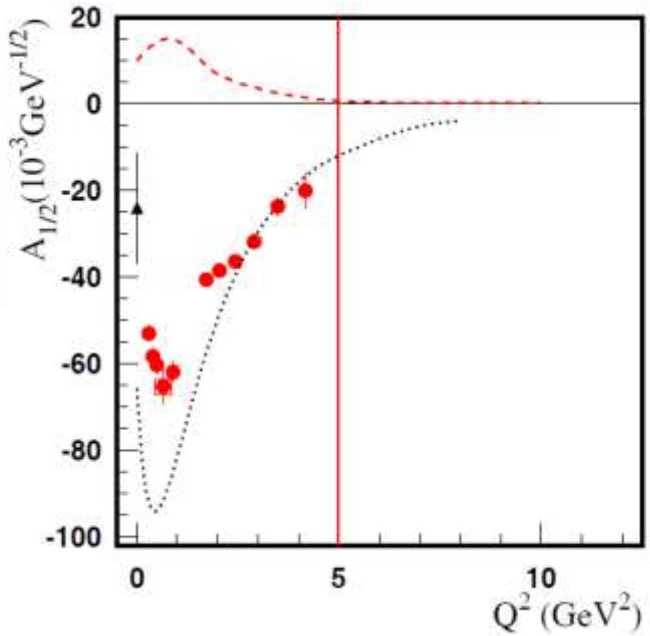
Meson-Baryon Dressing



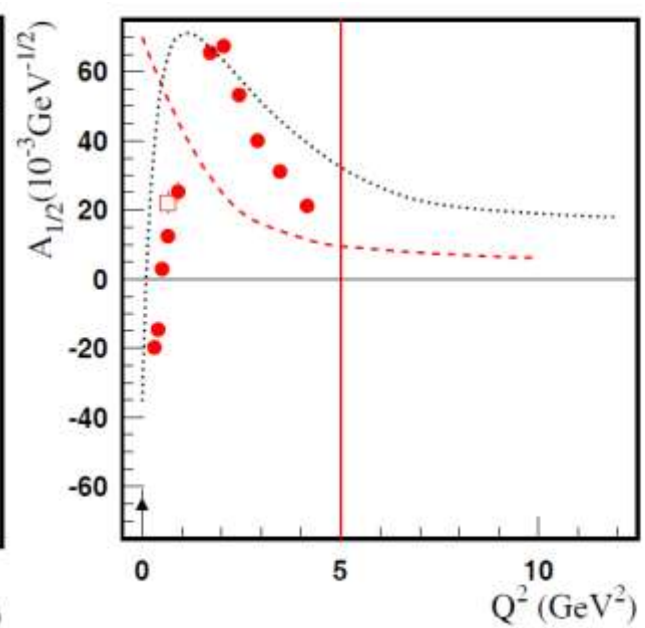
- - - absolute meson-baryon cloud amplitudes (EBAC now ANL-Osaka)

.... quark core contributions (constituent quark models)

$D_{13}(1520)$



$P_{11}(1440)$

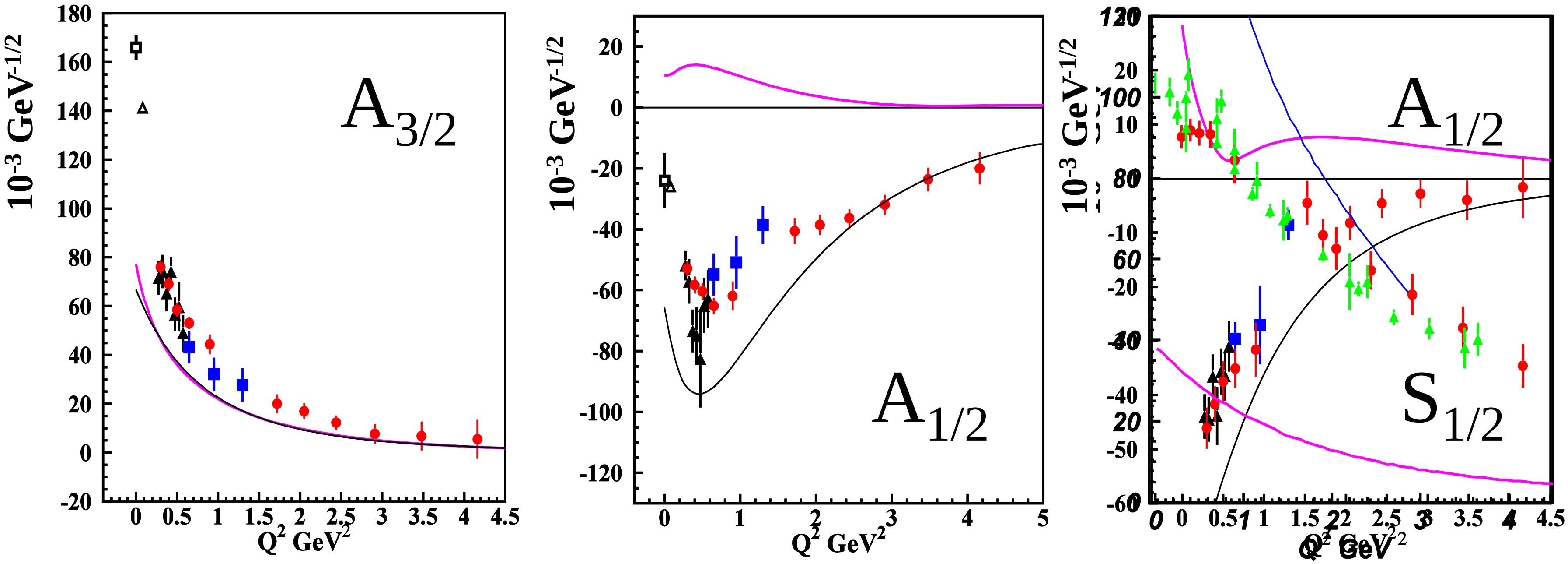


CLAS: Nπ and Nπ/Nππ combined (Phys. Rev. C80, 055203, 2009)

➢ Resonance structures can be described in terms of an internal quark core and a surrounding meson-baryon cloud whose relative contribution decreases with increasing Q^2.

➢ Data on $\gamma_v NN^*$ electrocouplings from this experiment ($Q^2 > 5$ GeV^2) will afford for the first time direct access to the non-perturbative strong interaction among dressed quarks, their emergence from QCD, and the subsequent N* formation.

Electrocouplings of N(1520)D_{13} and N(1535)S_{11}



Argonne Osaka / EBAC DCC MB dressing (absolute values)

M.Giannini/E.Santopinto, hCQM PRC 86, 065202 (2012)

S.Capstick, B..D.Keister (rCQM) PRD51, 3598 (1995)

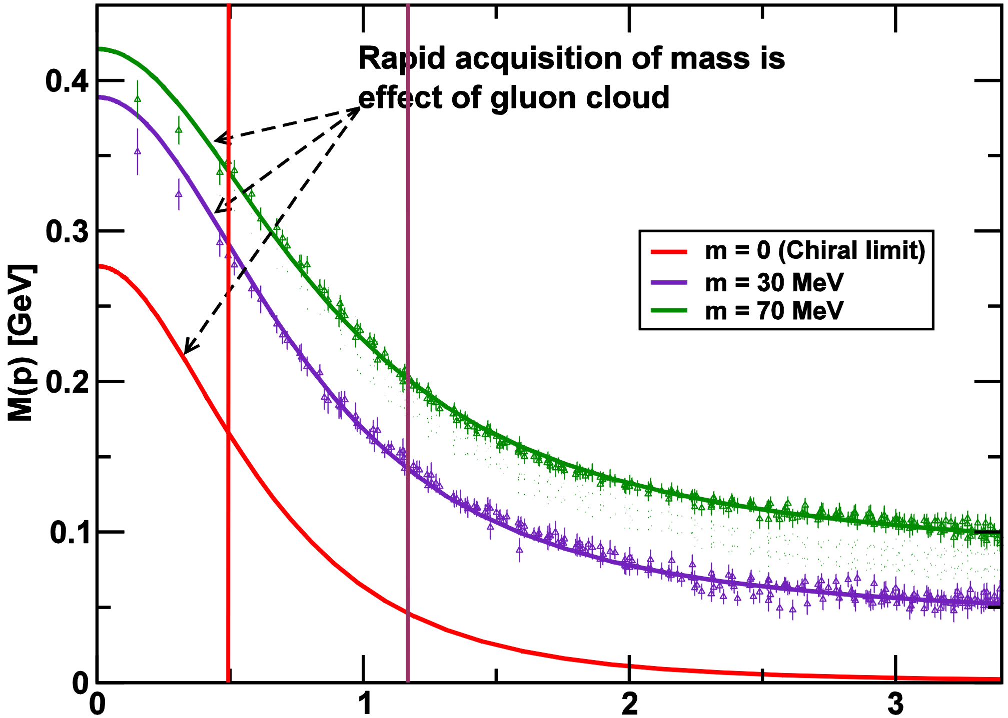
$\pi^+\pi^-p$ 2012

$\pi^+\pi^-p$ 2010

$N\pi$ 2009

ηp CLAS/Hall-C

Dynamical Mass of Light Dressed Quarks



$Q^2 = 2.75\ GeV^2$ p [GeV] per dressed quark

DSE and LQCD predict the dynamical generation of the momentum dependent dressed quark mass that comes from the gluon dressing of the current quark propagator.

These dynamical contributions account for more than 98% of the dressed light quark mass.

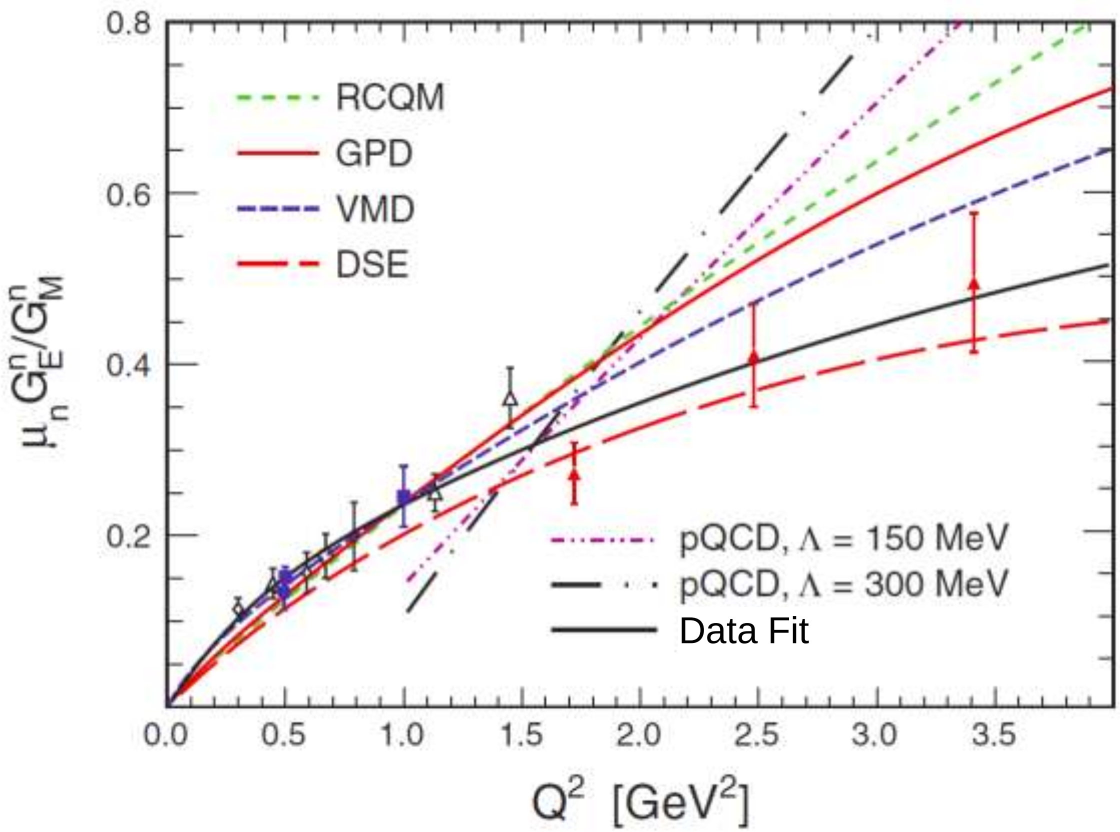
DSE: lines and LQCD: triangles

$Q^2 = 12\ GeV^2 = (p \text{ times number of quarks})^2 = 12\ GeV^2 \rightarrow p = 1.15\ GeV$

The data on N* electrocouplings at $5\ GeV^2 < Q^2 < 12\ GeV^2$ will allow us to chart the momentum evolution of dressed quark mass, and in particular, to explore the transition from dressed to almost bare current quarks as shown above.

Dyson-Schwinger Equation (DSE) Approach

DSE approaches provide links between dressed quark propagators, form factors, scattering amplitudes, and QCD.



N* electrocouplings can be determined by applying Bethe-Salpeter / Faddeev equations to 3 dressed quarks while the properties and interactions are derived from QCD.

The Faddeev-DSE calculation is very sensitive to the momentum dependence of the dressed-quark propagator.

By the time of the upgrade DSE electrocouplings of several excited nucleon states will be available as part of the commitment of the Argonne NL and the University of Adelaide.

Int. J. Mod. Phys. E, Vol. 22, 1330015 (2013) 1-99

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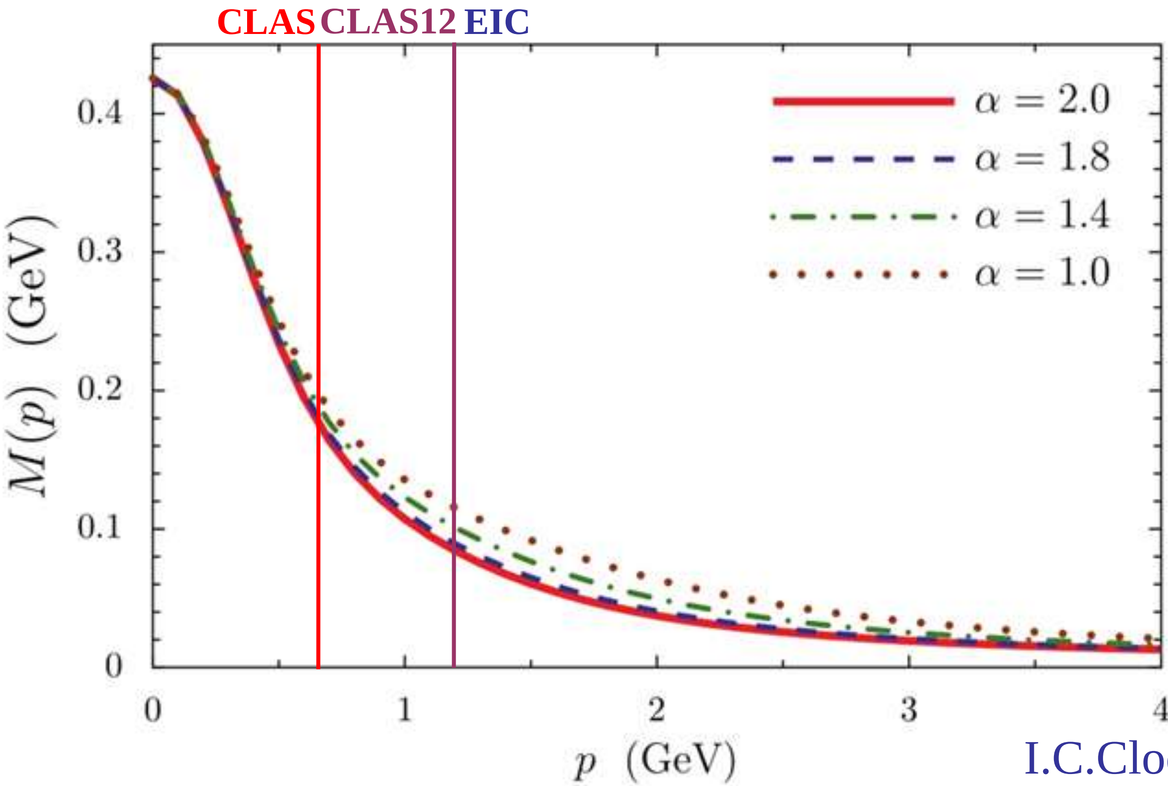

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I.C.Cloet et al., arXiv:1304.0855[nucl-th]

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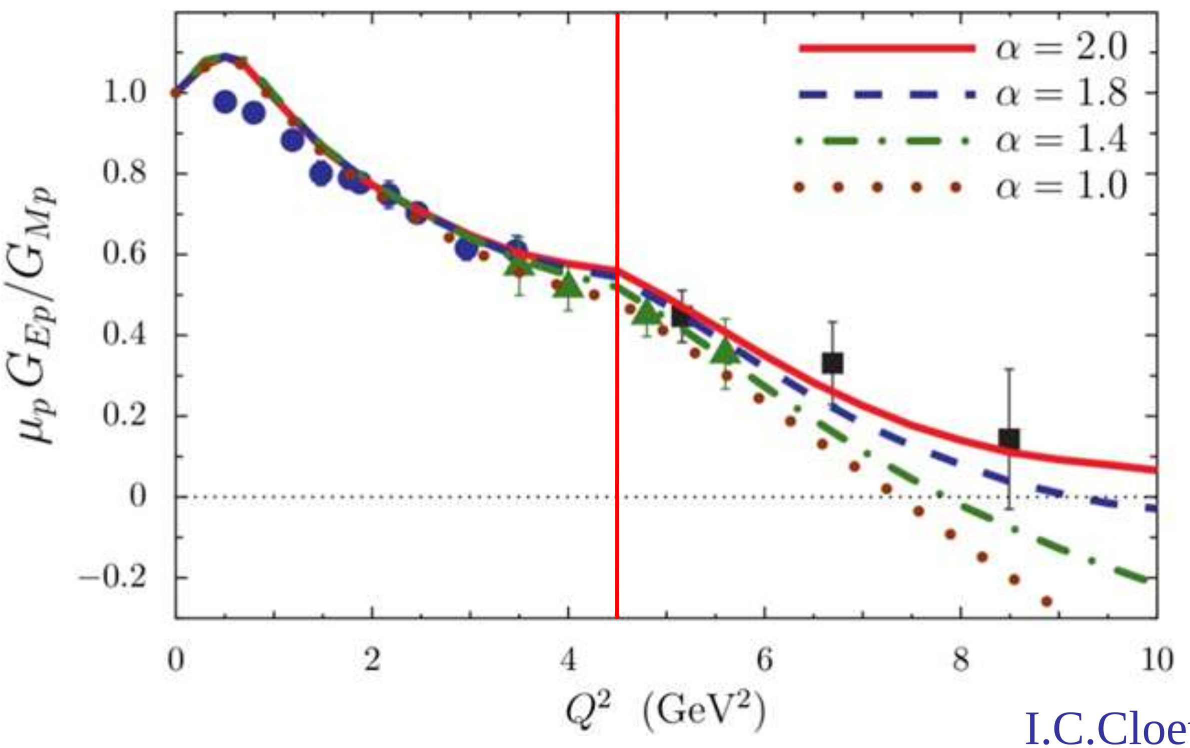
Int. J. Mod. Phys. E, Vol. 22, 1330015 (2013) 1-99

Dyson-Schwinger Equation (DSE) Approach

DSE approaches provide links between dressed quark propagators, form factors, scattering amplitudes, and QCD.



N* electrocouplings can be determined by applying Bethe-Salpeter / Faddeev equations to 3 dressed quarks while the properties and interactions are derived from QCD.

The Faddeev-DSE calculation is very sensitive to the momentum dependence of the dressed-quark propagator.

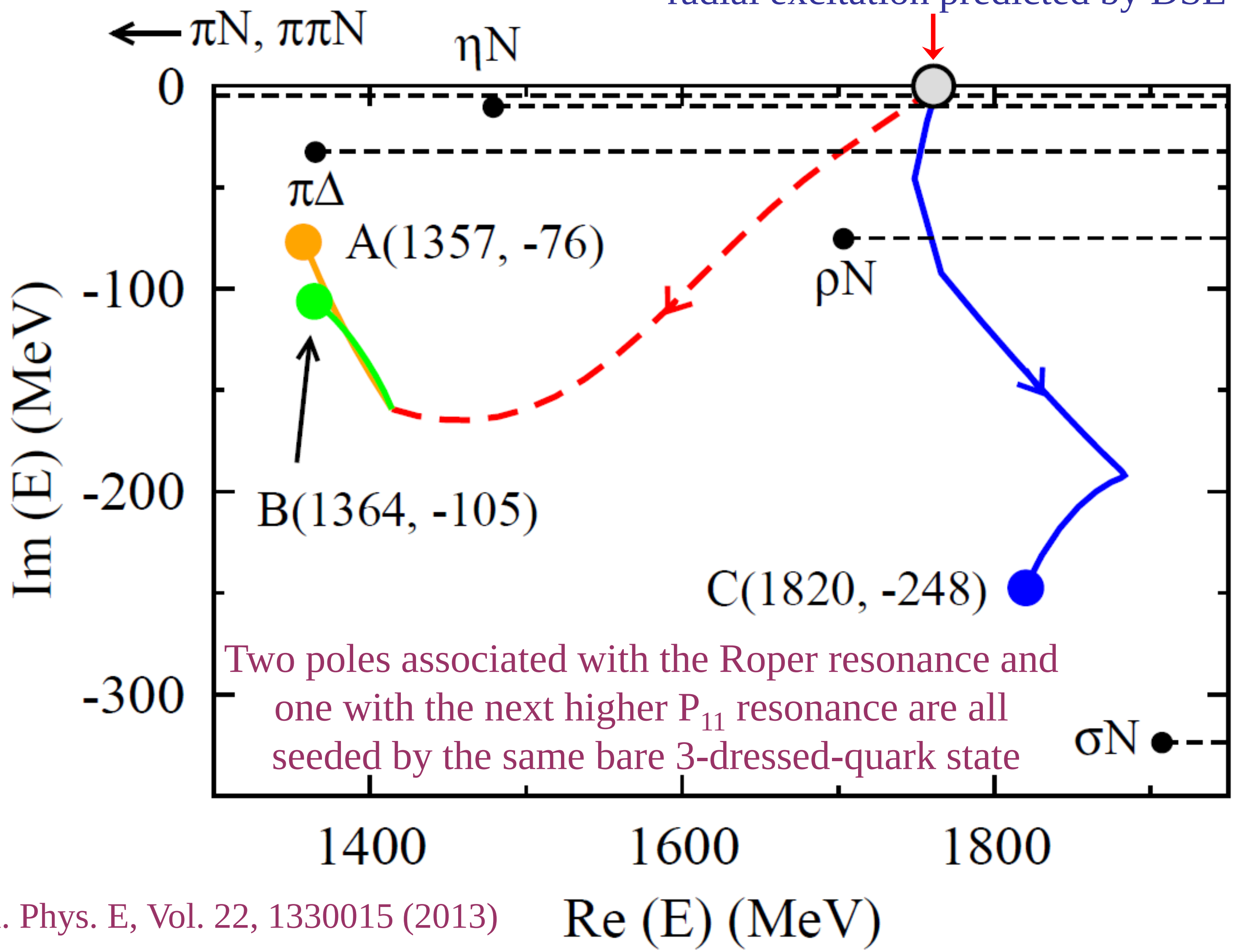
I.C.Cloet et al., arXiv:1304.0855[nucl-th]

By the time of the upgrade DSE electrocouplings of several excited nucleon states will be available as part of the commitment of the Argonne NL and the University of Adelaide.

Int. J. Mod. Phys. E, Vol. 22, 1330015 (2013) 1-99

DSE and EBAC Approaches

Location of the first 3-dressed-quark core radial excitation predicted by DSE



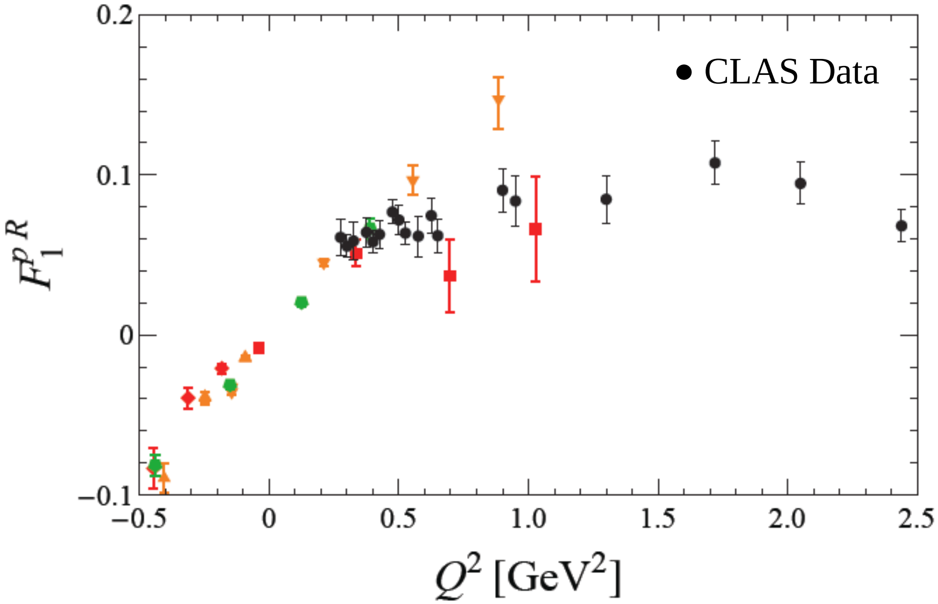
Two poles associated with the Roper resonance and one with the next higher P_{11} resonance are all seeded by the same bare 3-dressed-quark state

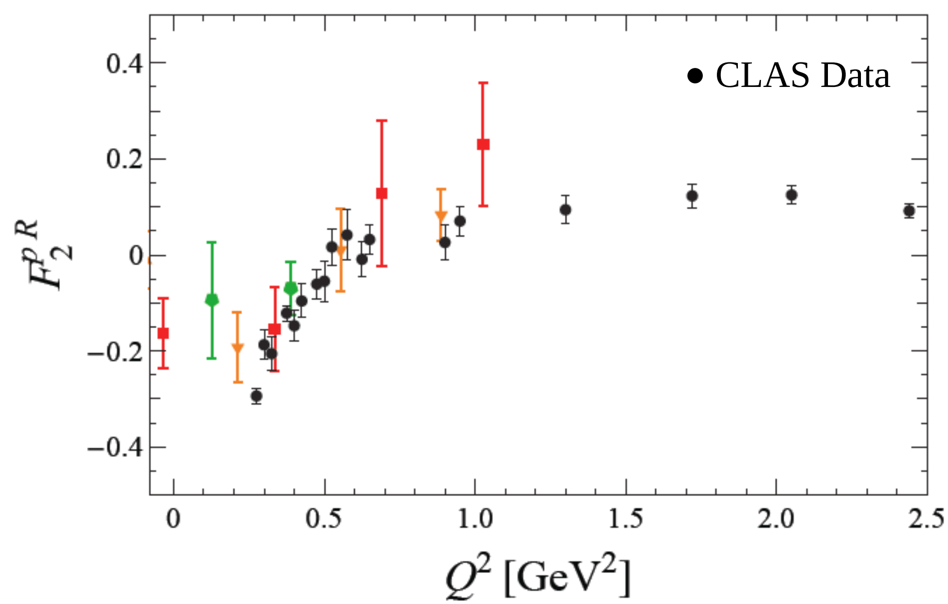
Int. J. Mod. Phys. E, Vol. 22, 1330015 (2013)

Roper Transition Form Factors in LQCD

p(1440)P_{11}

Huey-Wen Lin and S.D Cohen





Lattice QCD calculations of the p(1440)P_{11} transition form factors have been carried out with various pion masses, m_π= 390, 450, and 875 MeV. Particularly remarkable is the zero crossing in F_2 that appears at the current statistics in the unquenched but not in the quenched calculations. This suggests that at low Q^2 the pion-cloud dynamics are significant in full QCD.

By the time of the upgrade LQCD calculations of N* electrocouplings will be extended to Q^2 = 10 GeV^2 near the physical π-mass as part of the commitment of the JLab LQCD and EBAC groups in support of this proposal.

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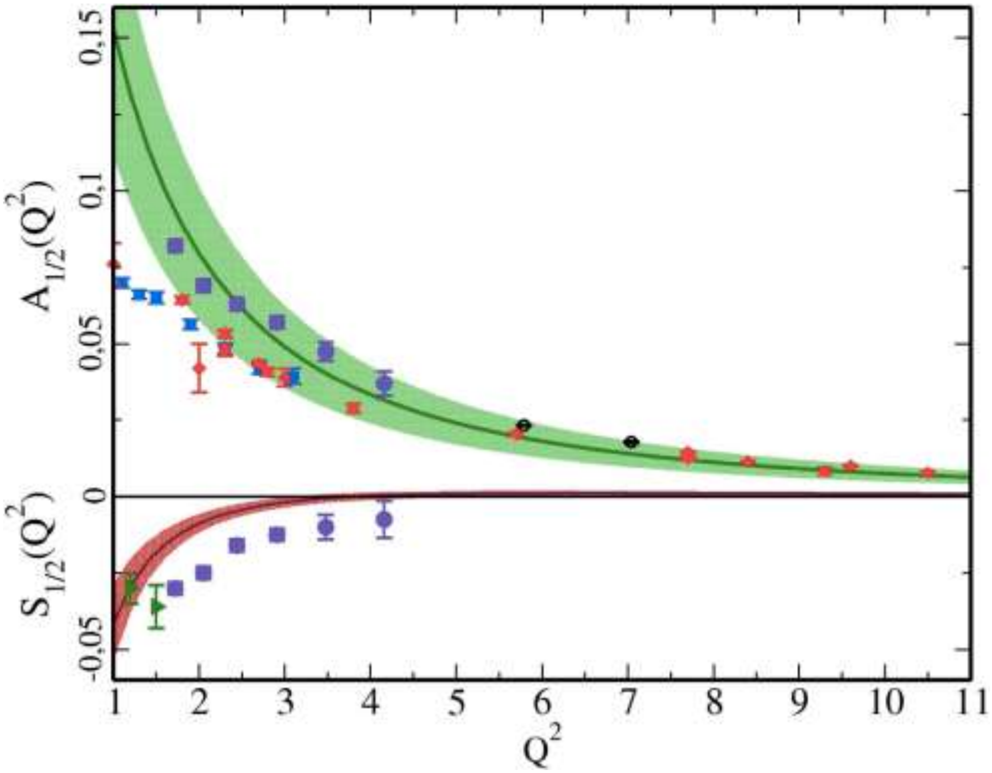
LQCD & Light Cone Sum Rule (LCSR) Approach

N(1535)S_{11}



LQCD is used to determine the moments of N* distribution amplitudes (DA) and the N* electrocouplings are determined from the respective DAs within the LCSR framework.

Calculations of N(1535)S_{11} electrocouplings at Q^2 up to 12 GeV^2 are already available and shown by shadowed bands on the plot.

By the time of the upgrade electrocouplings of others N*s will be evaluated. These studies are part of the commitment of the Univ. of Regensburg group in support of this proposal.

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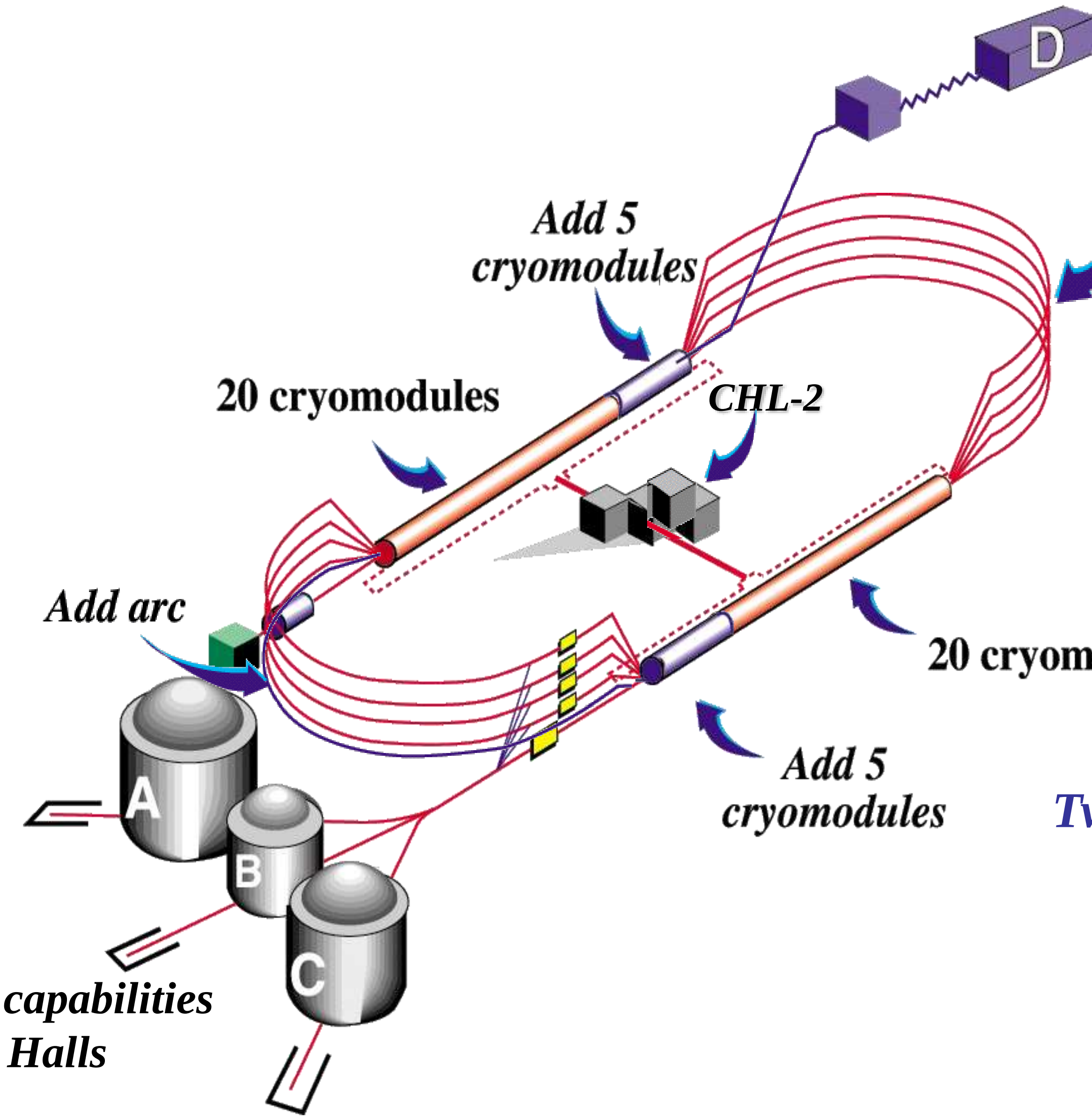
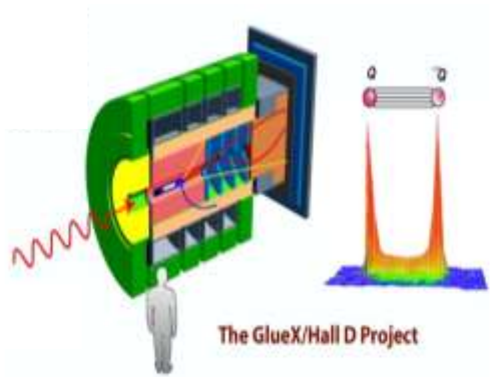
E-09-003

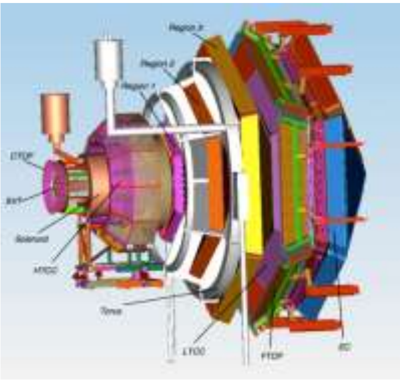
… and more?

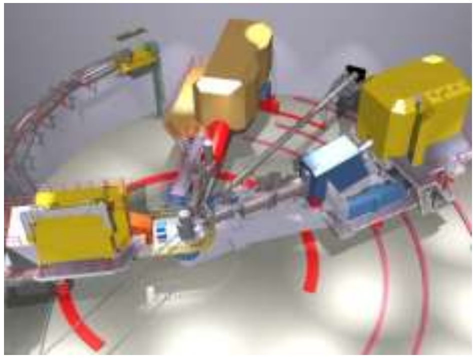
12 GeV CEBAF

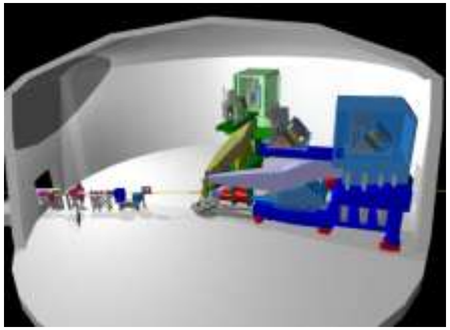

D
A
B
C
Upgrade magnets and power supplies
Add 5 cryomodules
20 cryomodules
CHL-2
Add arc
20 cryomodules
Add 5 cryomodules
Two 1.1 GeV linacs
Enhanced capabilities in existing Halls

Overview of Upgrade Technical Performance Requirements







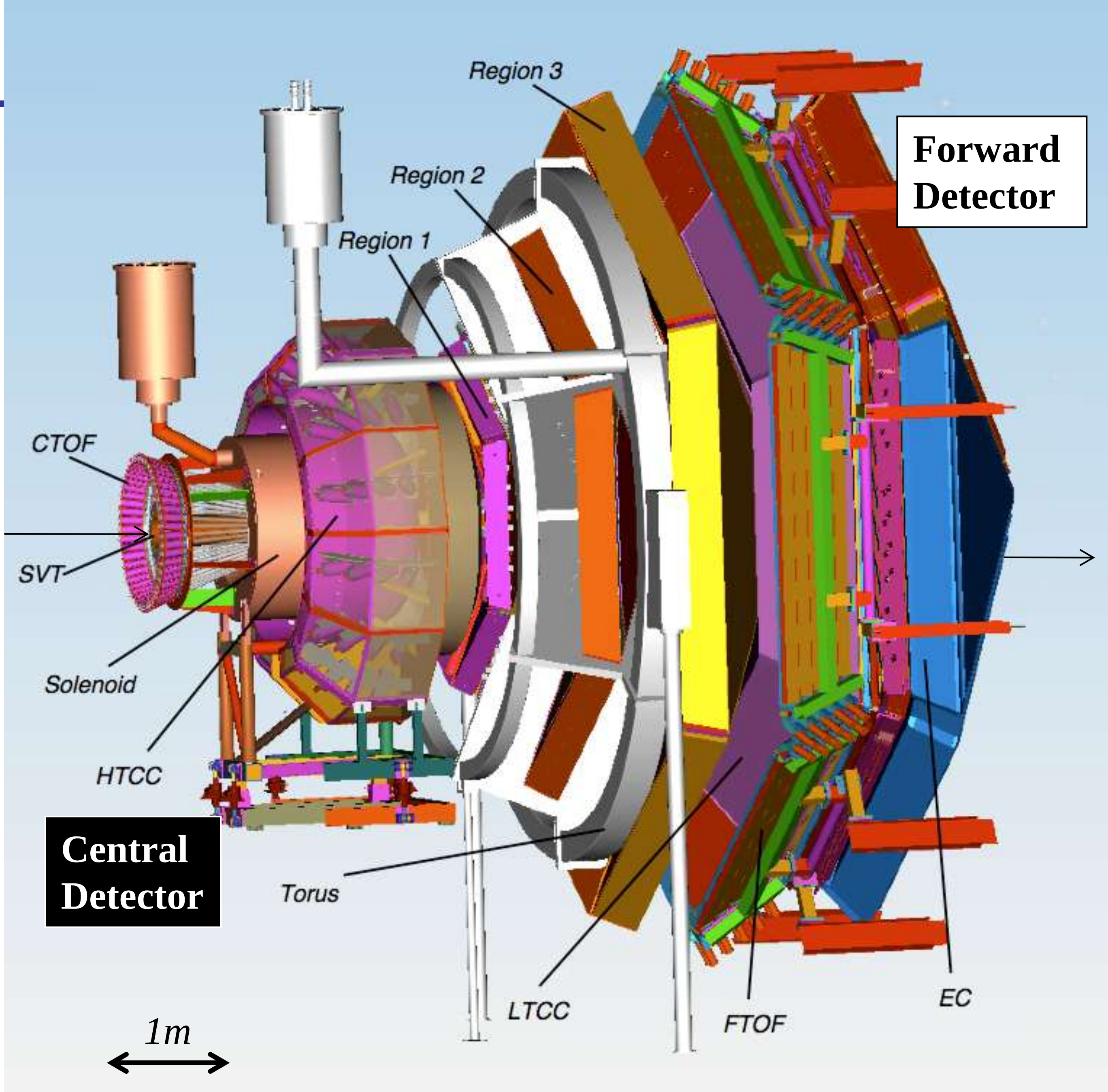


Hall D	Hall B	Hall C	Hall A
4π hermetic detector GlueEx	luminosity 10^{35} CLAS12	High Momentum Spectrometer SHRS	High Resolution Spectrometer HRS
polarized photons	hermeticity	precision	space
$E_\gamma \sim 8.5$-9.0 GeV	11 GeV beamline		
10^8 photons/s	target flexibility		
good momentum/angle resolution		excellent momentum resolution	
high multiplicity reconstruction		luminosity up to 10^{38}	

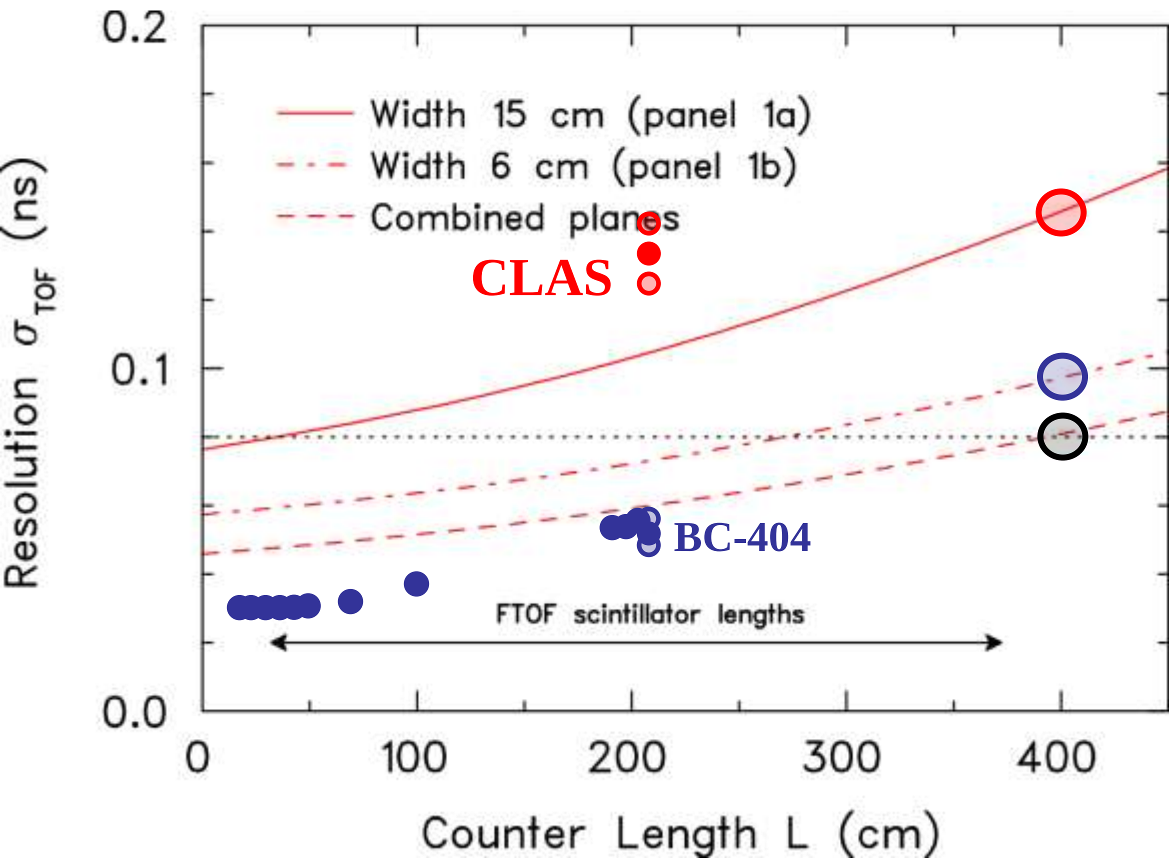
CLAS12

- Luminosity > 10^{35} cm^{-2}s^{-1}
- Hermeticity
- Polarization

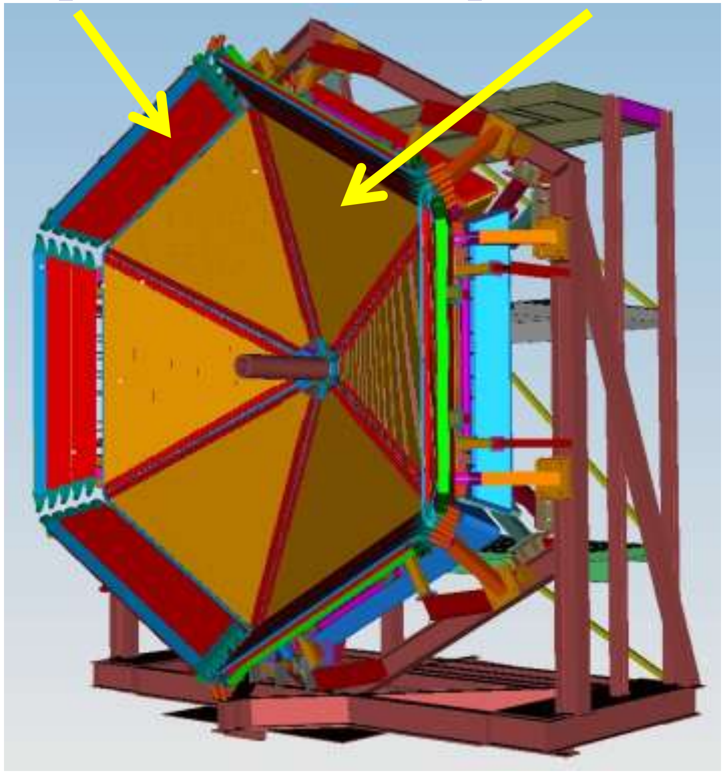
- Baryon Spectroscopy
- Elastic Form Factors
- N to N* Form Factors
- GPDs and TMDs
- DIS and SIDIS
- Nucleon Spin Structure
- Color Transparency
- …

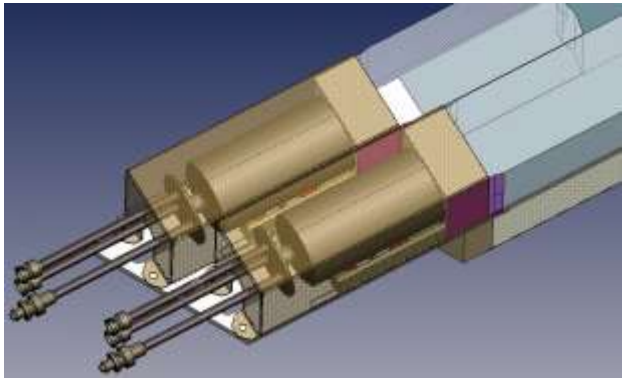


New Forward Time of Flight Detector for CLAS12



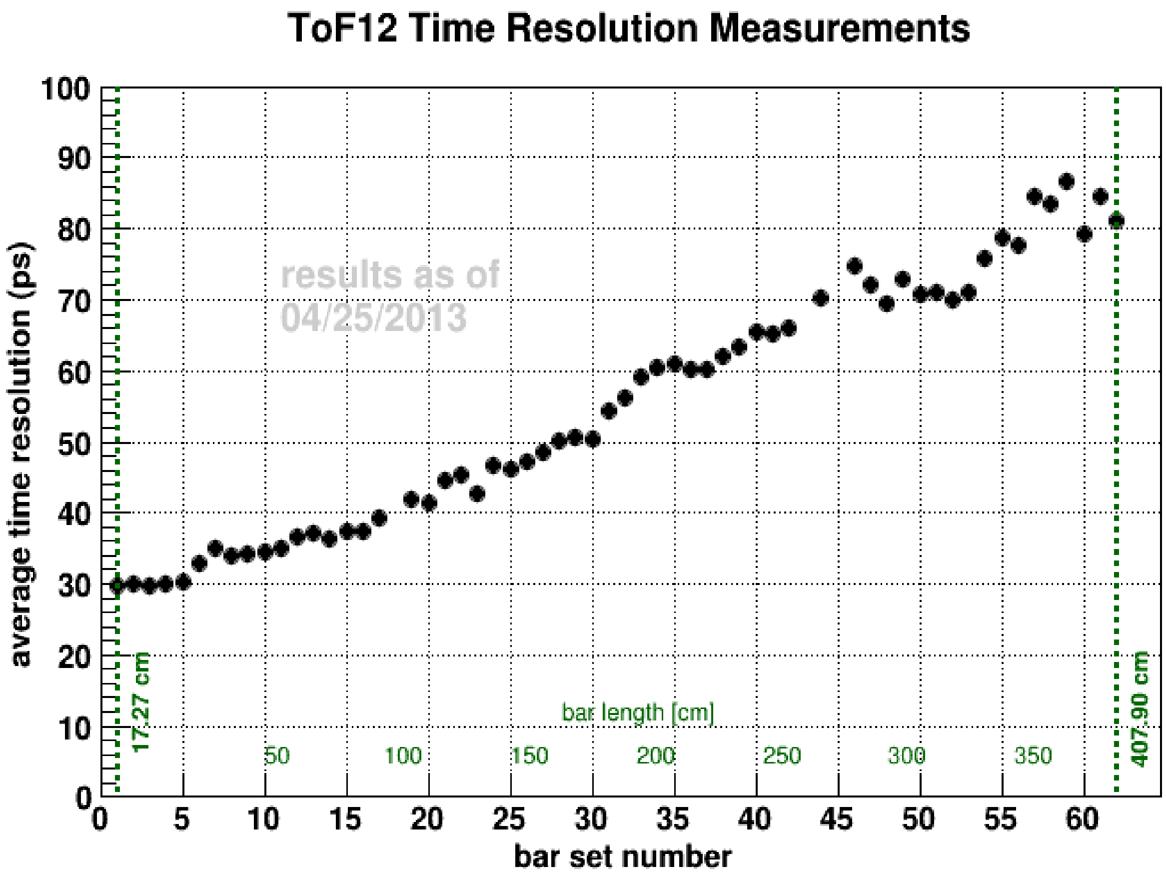
panel-2 panel-1b

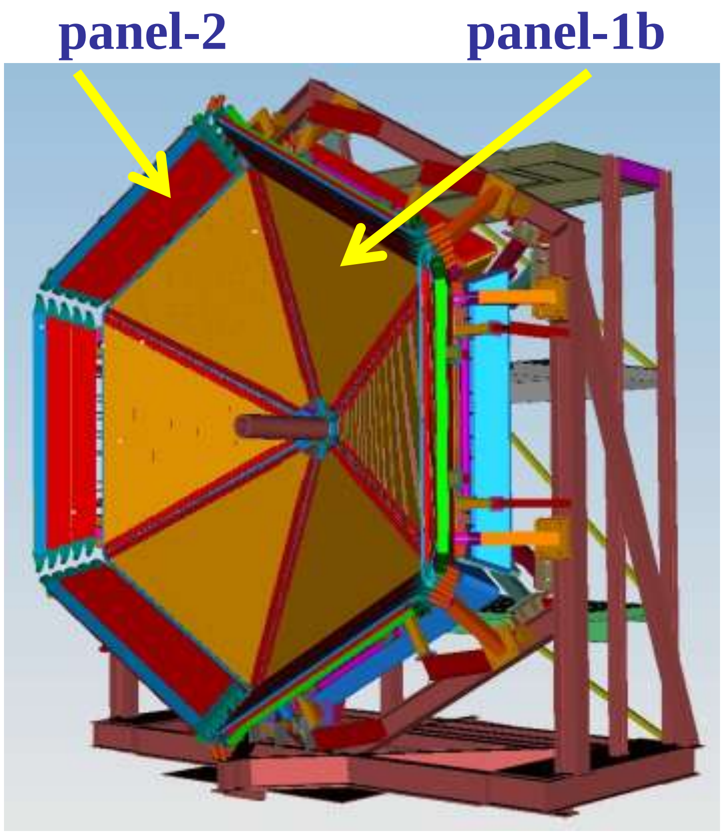


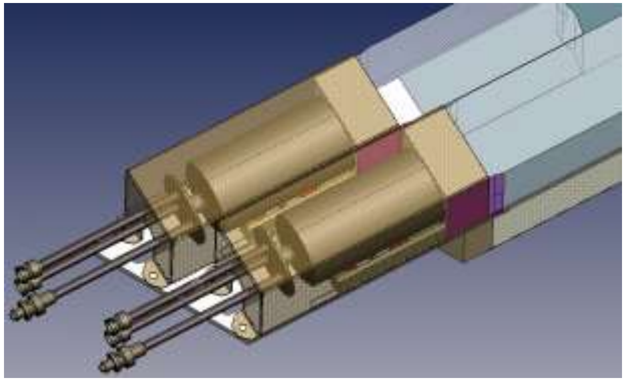


World-record time resolution of 48 ns
averaged over the full length of 210 cm

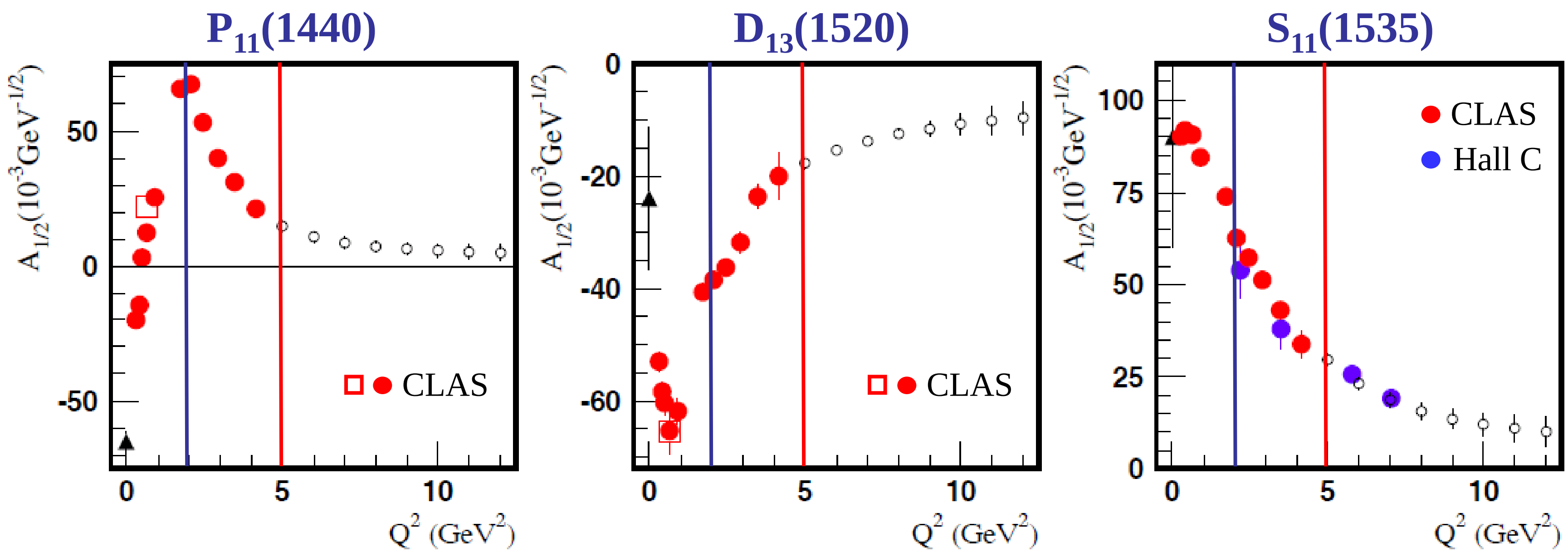
New Forward Time of Flight Detector for CLAS12







Anticipated N* Electrocouplings from a Combined Analysis of Nπ & Nππ



Open circles represent projections and all other markers the available results with the 6-GeV electron beam

➤ Examples of published and projected results obtained within 60d for three prominent excited proton states from analyses of Nπ and Nππ electroproduction channels. Similar results are expected for many other resonances at higher masses, e.g. $S_{11}(1650)$, $F_{15}(1685)$, $D_{33}(1700)$, $P_{13}(1720)$, …

➤ This experiment will – for the foreseeable future – be the only experiment that can provide data on $\gamma_v NN^*$ electrocouplings for almost all well established excited proton states at the highest photon virtualities ever achieved in N* studies up to Q^2 of 12 GeV^2.

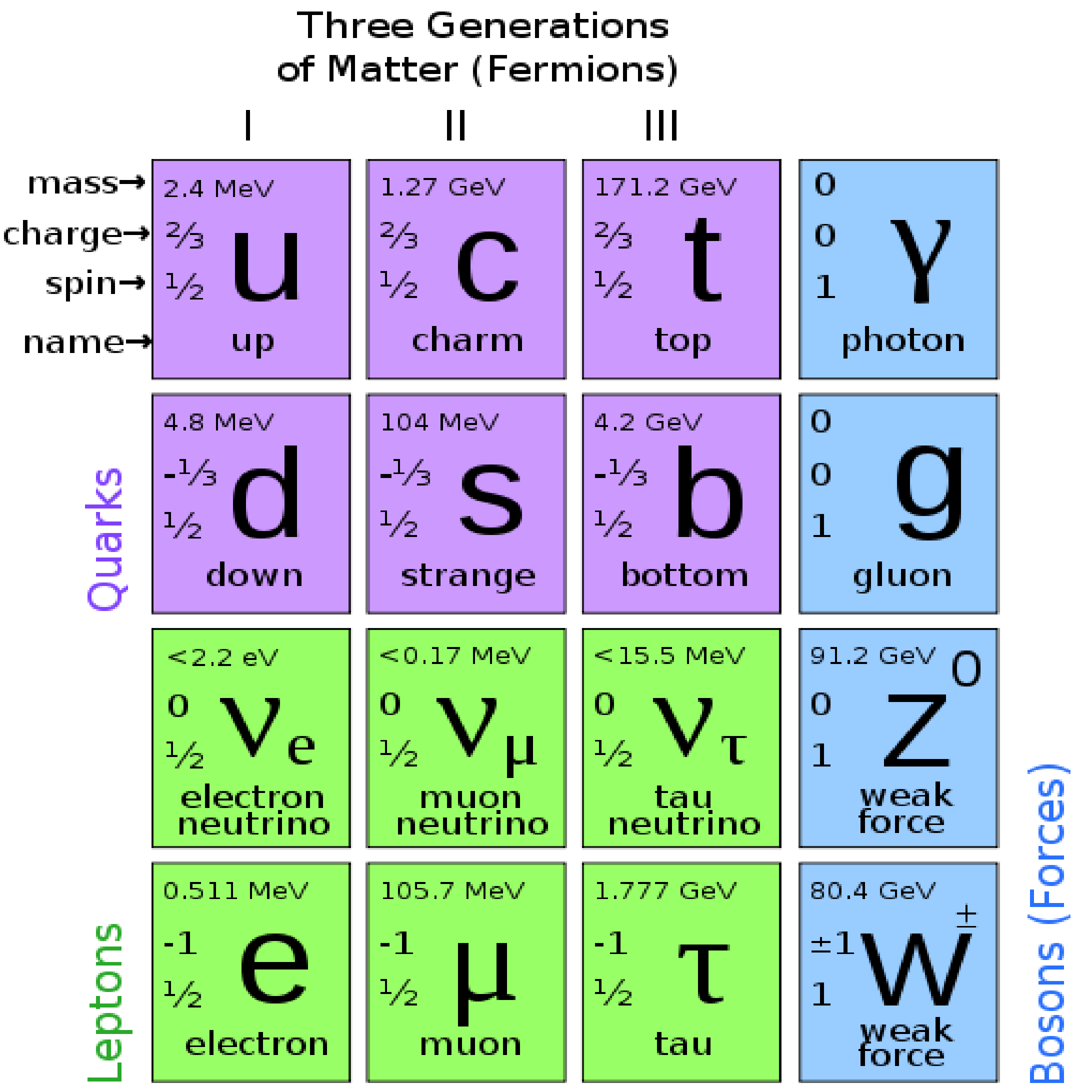
Summary

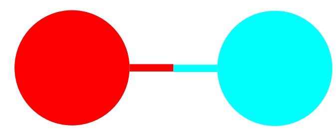
- We will measure and determine the electrocouplings $A_{1/2}$, $A_{3/2}$, $S_{1/2}$ as a function of Q^2 for prominent nucleon and Δ states,
  - see our Proposal http://www.physics.sc.edu/~gothe/research/pub/nstar12-12-08.pdf.
- Comparing our results with DSE, LQCD, LCSR, and rCQM will gain insight into
  - the strong interaction of dressed quarks and their confinement in baryons,
  - the dependence of the light quark mass on momentum transfer, thereby shedding light on dynamical chiral-symmetry breaking, and
  - the emergence of bare quark dressing and dressed quark interactions from QCD.
- This unique opportunity to understand origin of 98% of nucleon mass is also an experimental and theoretical challenge. A wide international collaboration is needed for:
  - the development of reaction models that will account for hard quark/parton contributions at high Q^2 and
  - the theoretical interpretation on N* electrocouplings, see our Review Article Int. J. Mod. Phys. E, Vol. 22, 1330015 (2013) 1-99.
- Any constructive criticism, help, or participation is always most welcomed, contact:
  - Viktor Mokeev mokeev@jlab.org or Ralf Gothe gothe@sc.edu.

Supplement

Spectroscopy

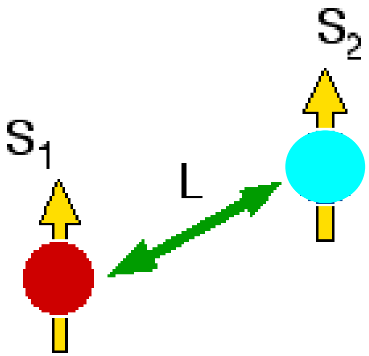
Build your Mesons…





Meson Spectroscopy

Search for mesons with 'exotic' quantum numbers (not compatible with quark-model)

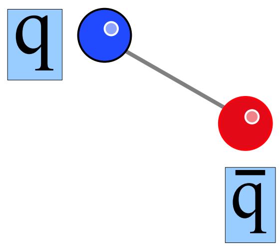


$S = S_1 \oplus S_2$ $J = L \oplus S$ $P = (-1)^{L+1}$ $C = (-1)^{L+S}$

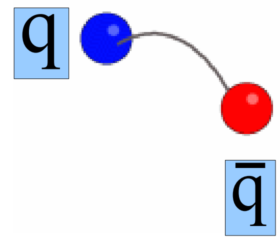
Not-allowed: $J^{PC} = 0^{--}, 0^{+-}, 1^{-+}, 2^{+-}$

Unambiguous experimental signature for the presence of gluonic degrees of freedom in the spectrum of mesonic states

Normal meson:
flux tube in
ground state
m=0
$CP = (-1)^{S+1}$

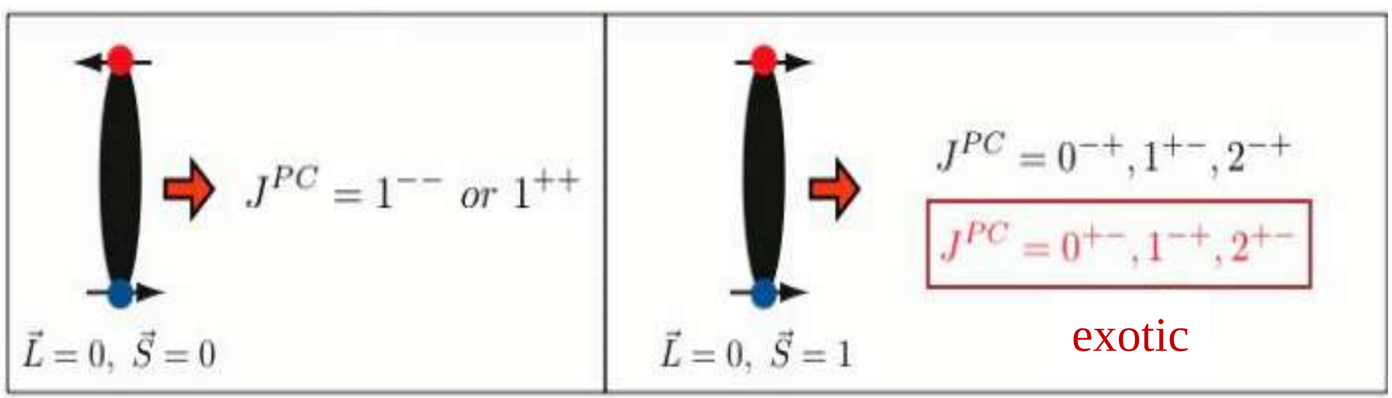


Hybrid meson:
flux tube in
excited state
m=1
$CP = (-1)^{S}$



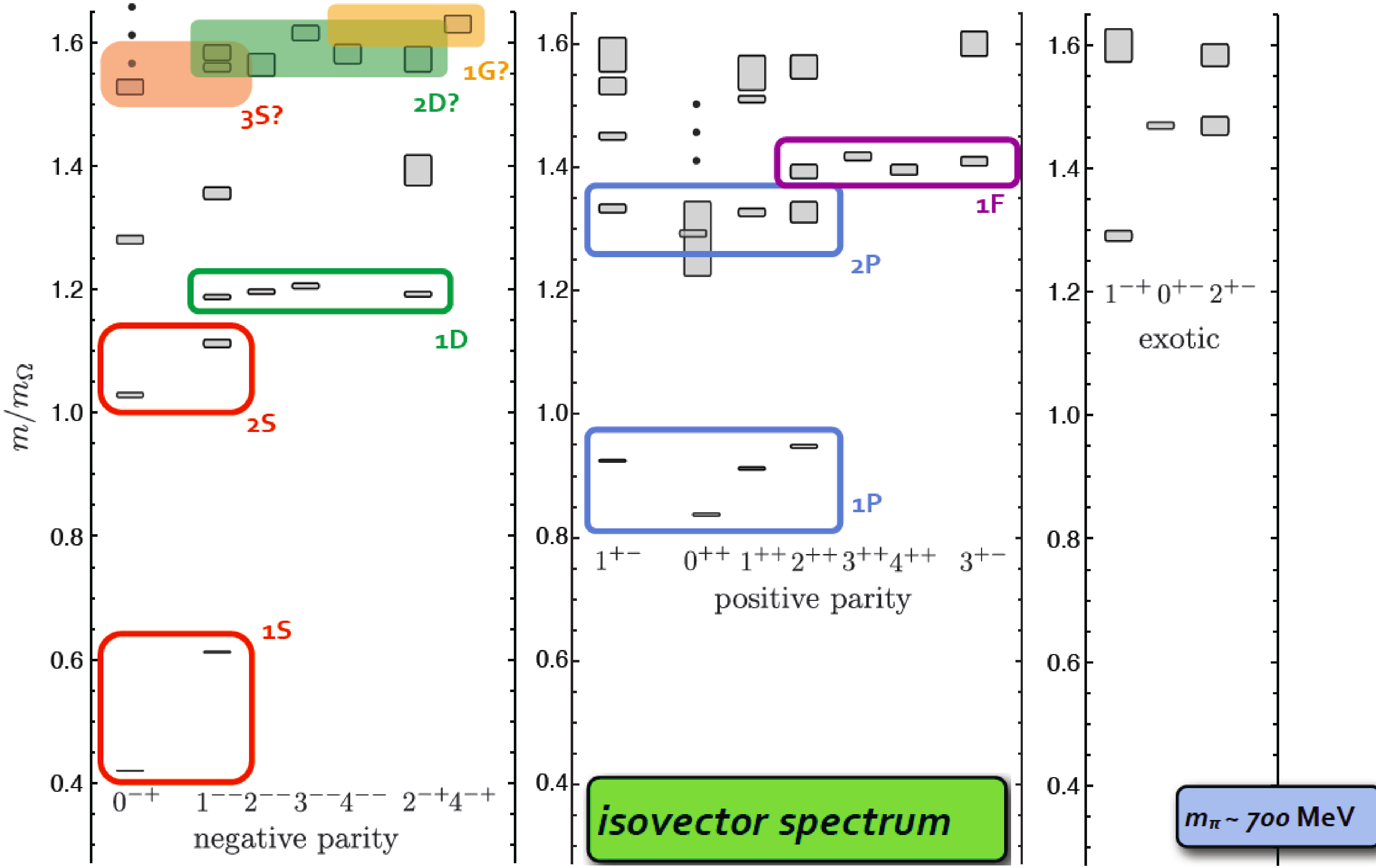
Flux tubes
J^{PC} 1^{-+}, 1^{+-}

Combine excited glue quantum number with those of the quarks



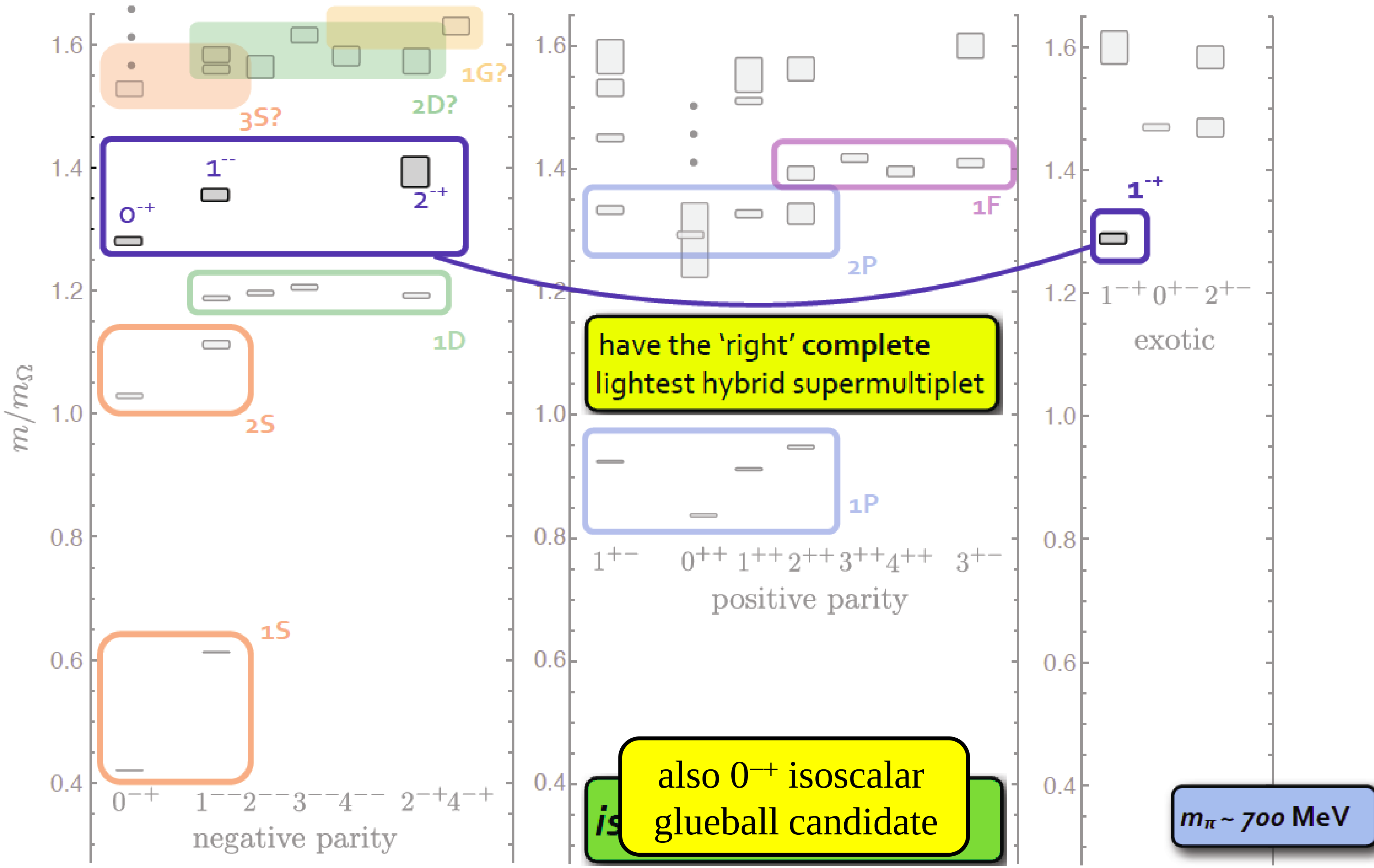
M. Battaglieri

Meson Spectrum in QCD Lattice Calculations



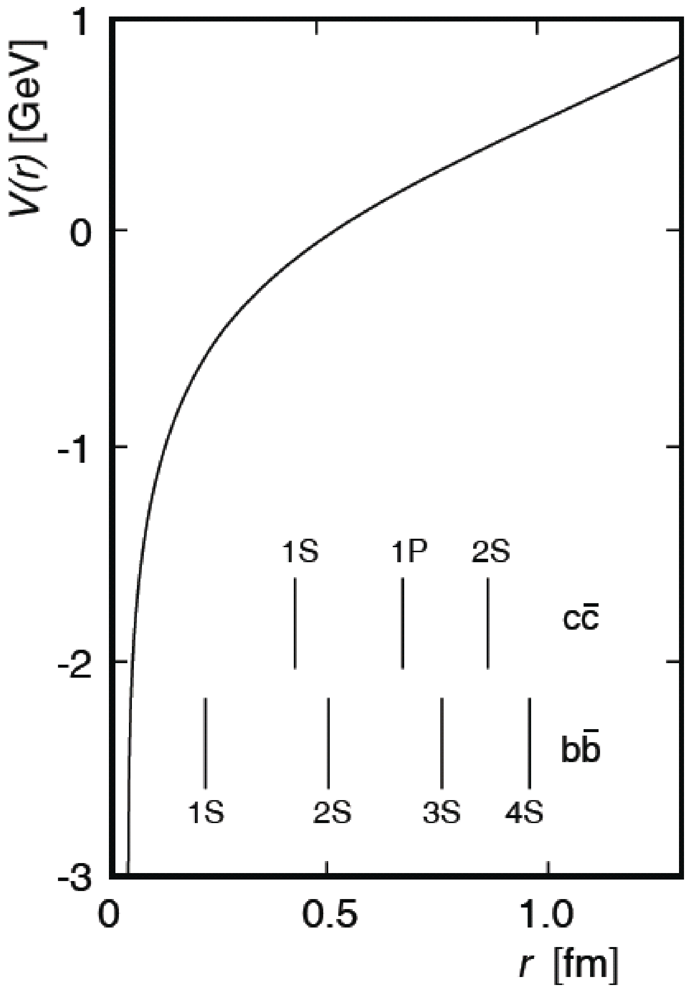
J. Dudek et al. Phys. Rev. D82 (2010) 034508

Meson Spectrum in QCD Lattice Calculations

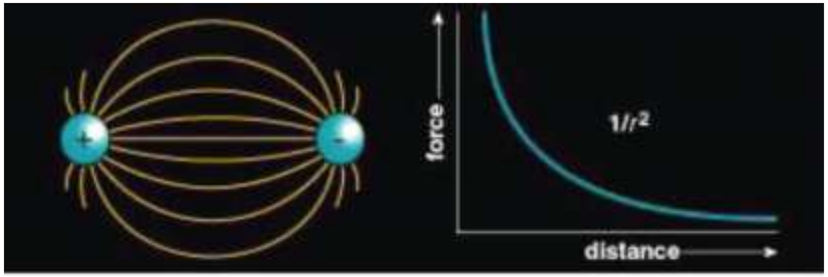


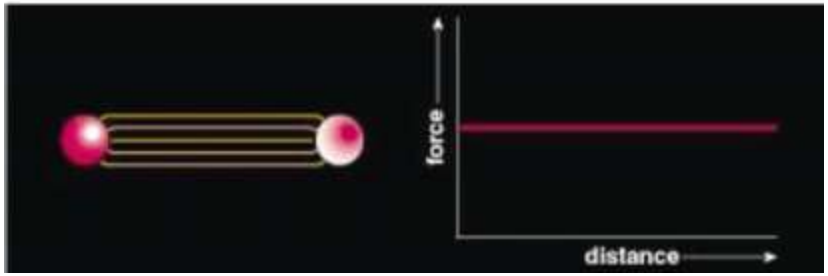
J. Dudek et al. Phys. Rev. D82 (2010) 034508

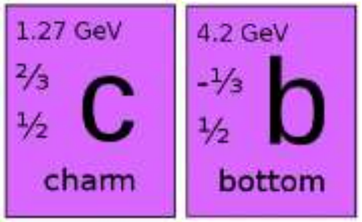
Heavy Quark Systems



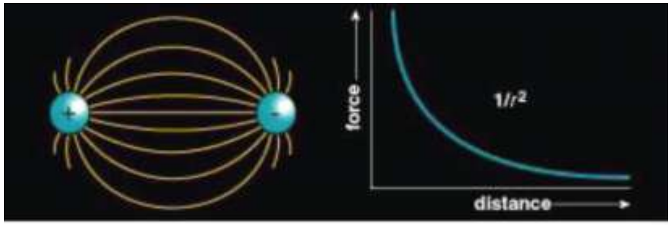
$$V = -\frac{4}{3}\frac{\alpha_s(r)\hbar c}{r} + k \cdot r$$

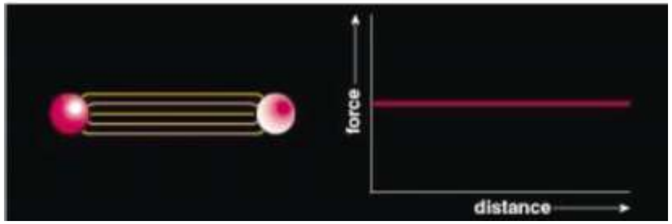






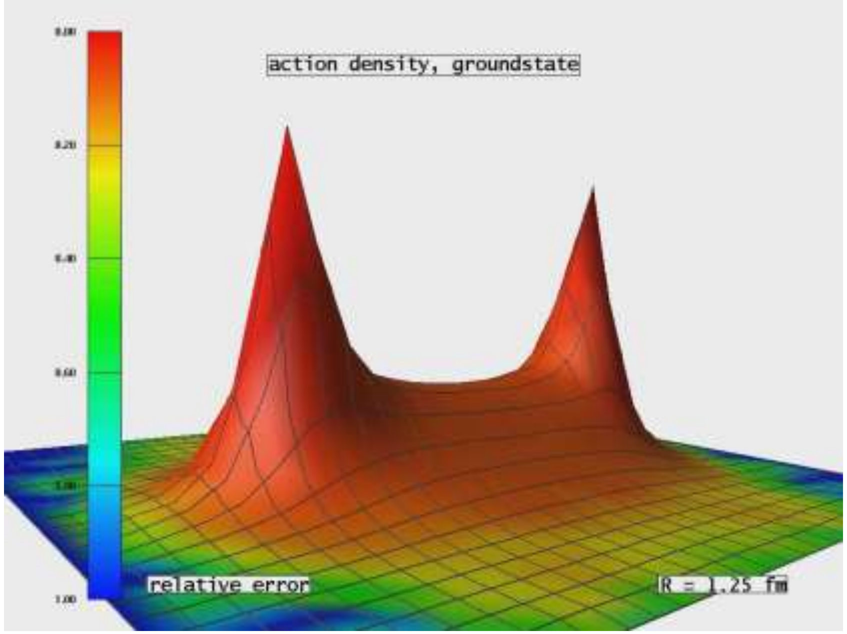
Heavy Quark Systems

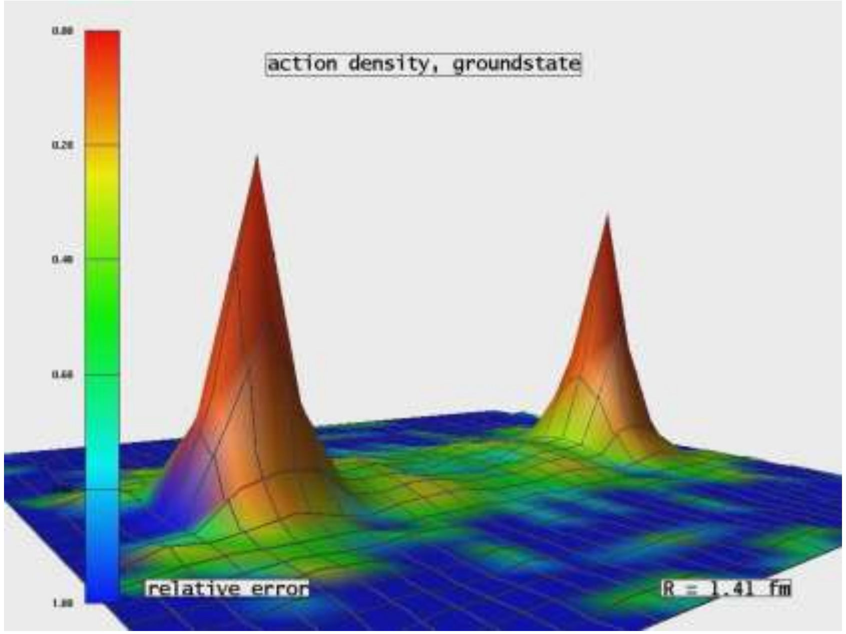




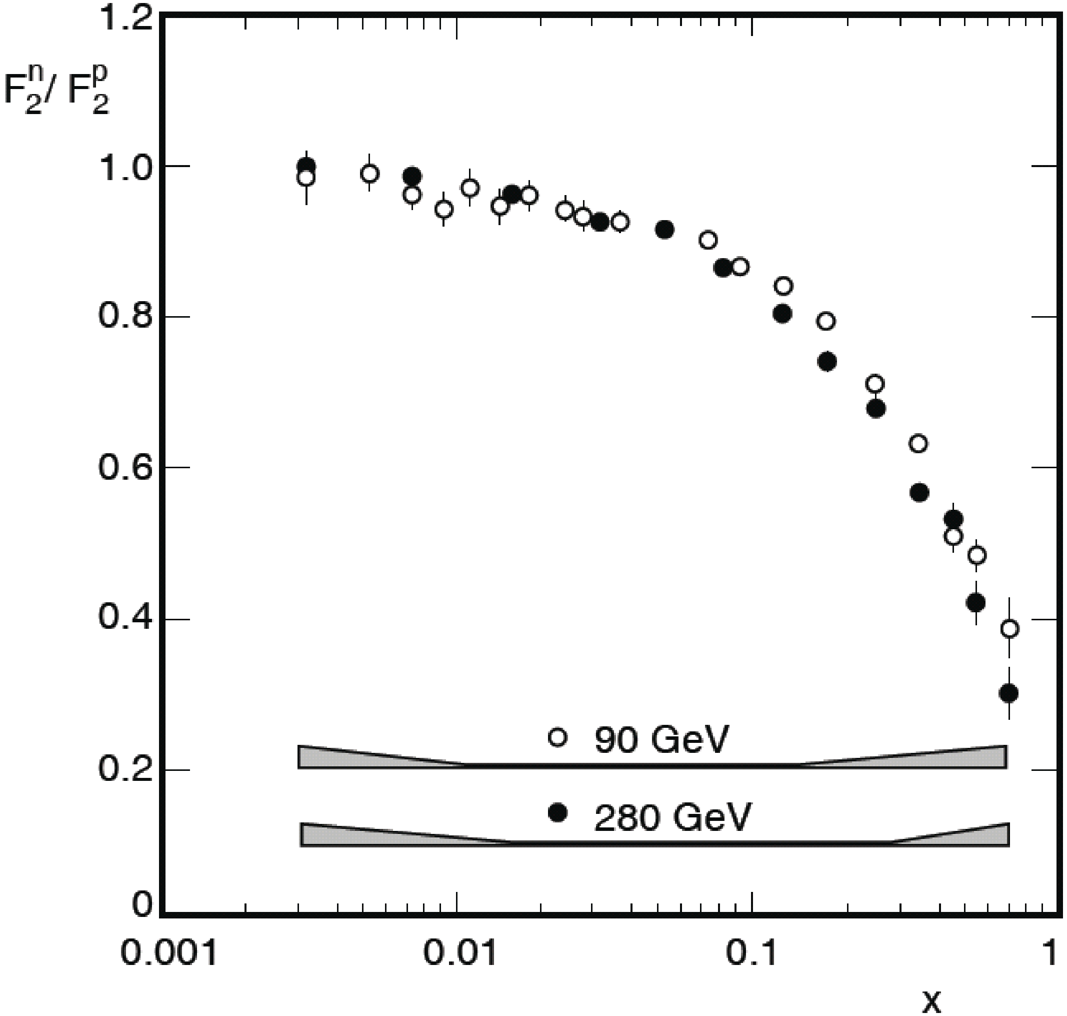
$$V = -\frac{4}{3}\,\frac{\alpha_s(r)\hbar c}{r} + k \cdot r$$

Bali *et al*. he-la/0512018





Di-Quarks in Deep Inelastic Scattering



Nucl. Phys. **B371** (1992) 3

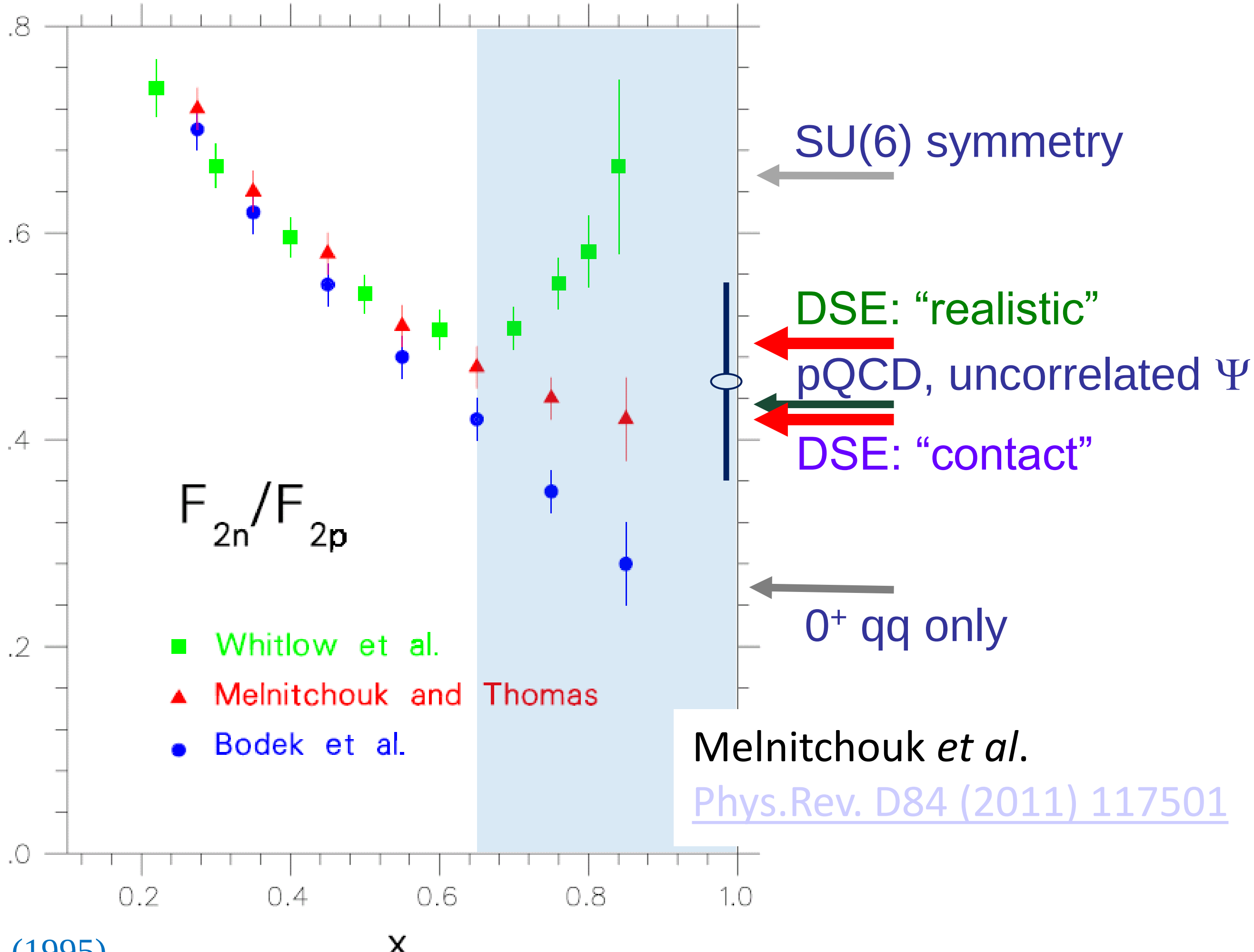
~~$(2z_d^2 + z_u^2)/(2z_u^2 + z_d^2)$ = 2/3~~

z_d^2/z_u^2 = 1/4

Only the **u** valence quark carries large x in the proton and the only the **d** valence quark in the neutron.

Neutron Structure Function at High x

I.C. Cloët, C.D. Roberts, *et al.*, arXiv:0812.0416 [nucl-th]
D. J. Wilson, I. C. Cloët, L. Chang, and C. D. Roberts, arXiv:1112.2212 [nucl-th], Phys. Rev. C85 (2012) 025205

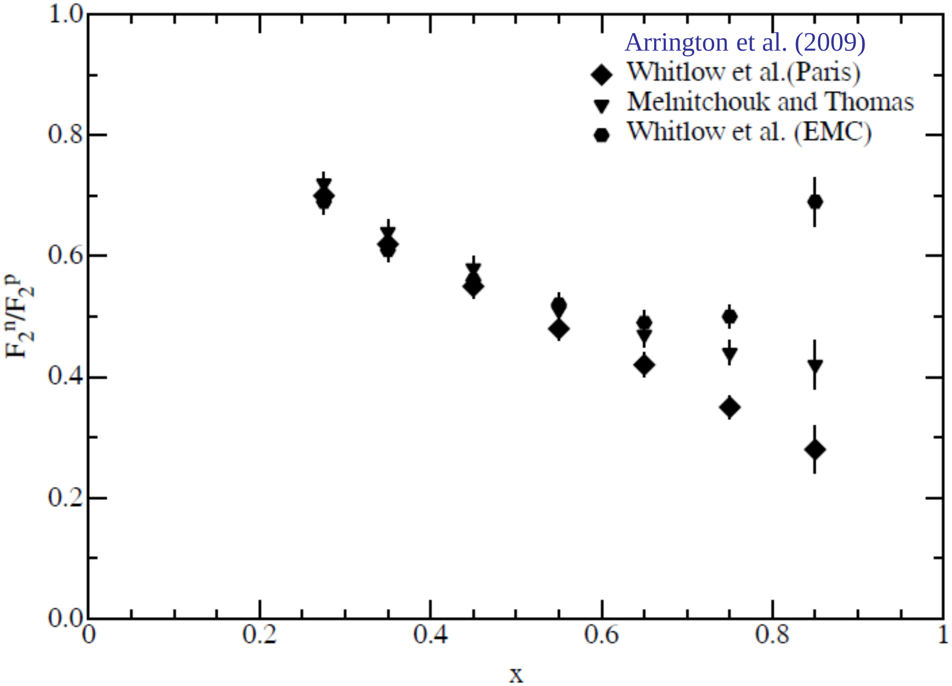


Melnitchouk *et al.*
Phys.Rev. D84 (2011) 117501

Reviews:
- N. Isgur, PRD 59 (1999)
- S. Brodsky *et al.*, NP B441 (1995)
- R.J. Holt & C.D. Roberts, RMP (2010)
- W. Melnitchouk & A.W. Thomas, PL B377 (1996) 11

C.D. Roberts

Di-Quarks in Deep Inelastic Scattering



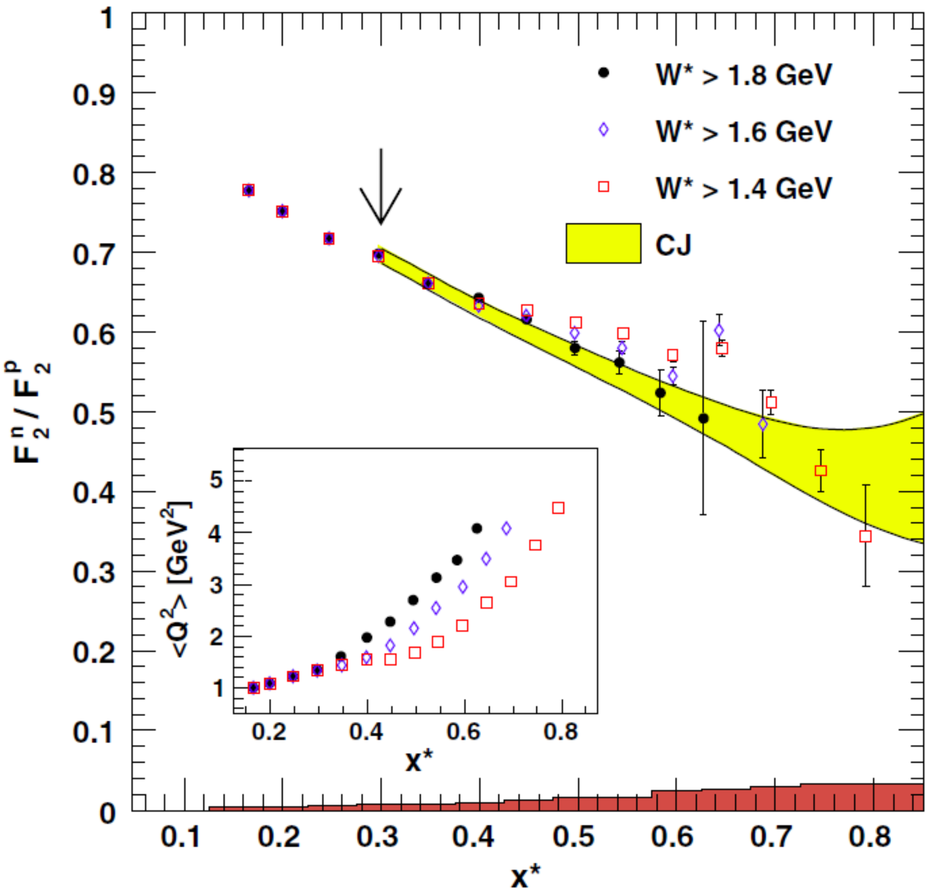
Holt and Roberts, arXiv:1002.4666v3, RMP (2010)

$$z_d^2/z_u^2 = 1/4$$

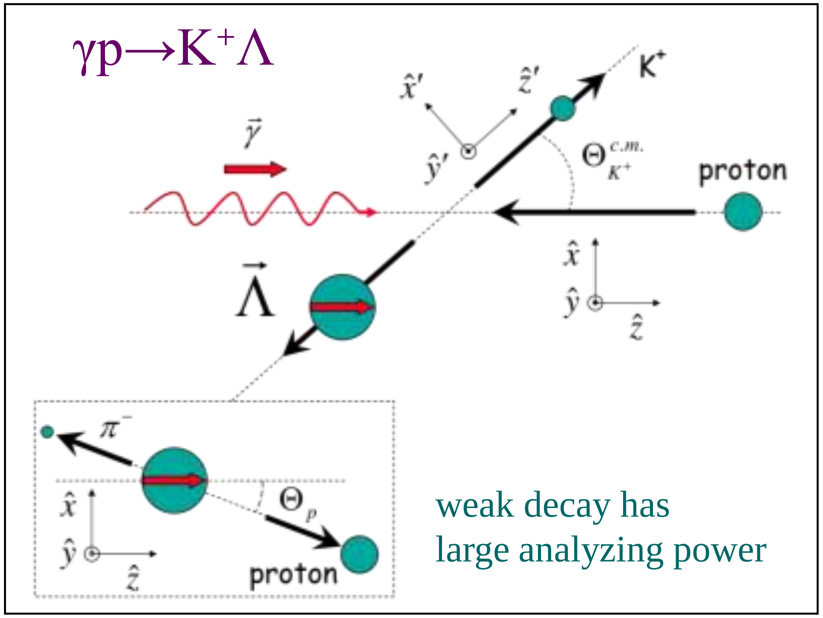
Only the **u** valence quark carries large x in the proton and the only the **d** valence quark in the neutron

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

Bonus, PRL **108** 142001 (2012)



FROST/HD $\vec{\gamma}\vec{N} \to \pi N, \eta N, K\vec{\Lambda}, K\vec{\Sigma}, N\pi\pi$

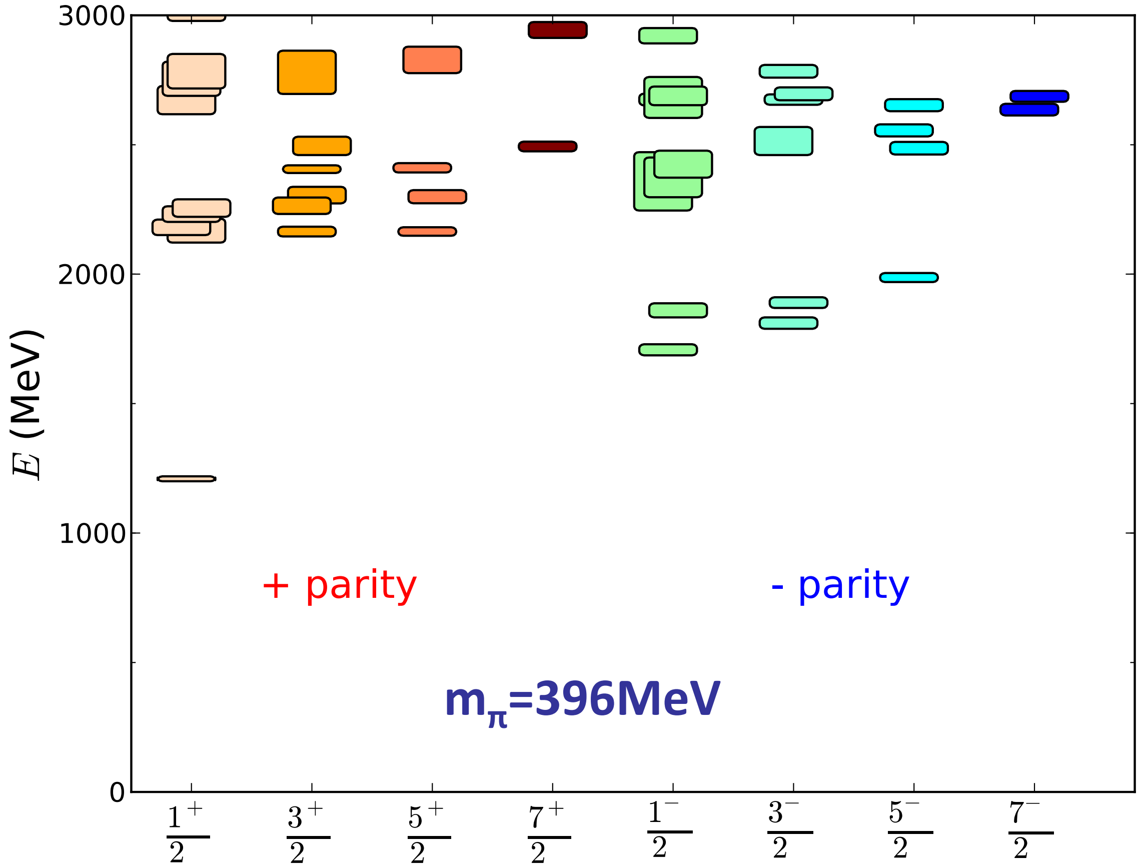


- Process is described by 4 complex, parity conserving amplitudes
- 8 well-chosen measurements are needed to determine amplitude
- For hyperon finals state 16 observables are measured in CLAS ➠ large redundancy in determining the photo-production amplitudes ➠ allows many cross checks and increased accuracy
- 8 observables measured in reactions without recoil polarization

Photon beam		Target			Recoil			Target - Recoil								
					x'	y'	z'	x'	x'	x'	y'	y'	y'	z'	z'	z'
		x	y	z				x	y	z	x	y	z	x	y	z
unpolarized	σ_0		T			P		$T_{x'}$		$L_{x'}$		Σ		$T_{z'}$		$L_{z'}$
linearly P_γ	Σ	H	P	G	$O_{x'}$	T	$O_{z'}$	$L_{z'}$	$C_{z'}$	$T_{z'}$	E		F	$L_{x'}$	$C_{x'}$	$T_{x'}$
circular P_γ		F		E	$C_{x'}$		$C_{z'}$		$O_{z'}$		G		H		$O_{x'}$	

N* Spectrum in LQCD

The strong interaction physics is encoded in the nucleon excitation spectrum that spans the degrees of freedom from meson-baryon and dressed quarks to elementary quarks and gluons



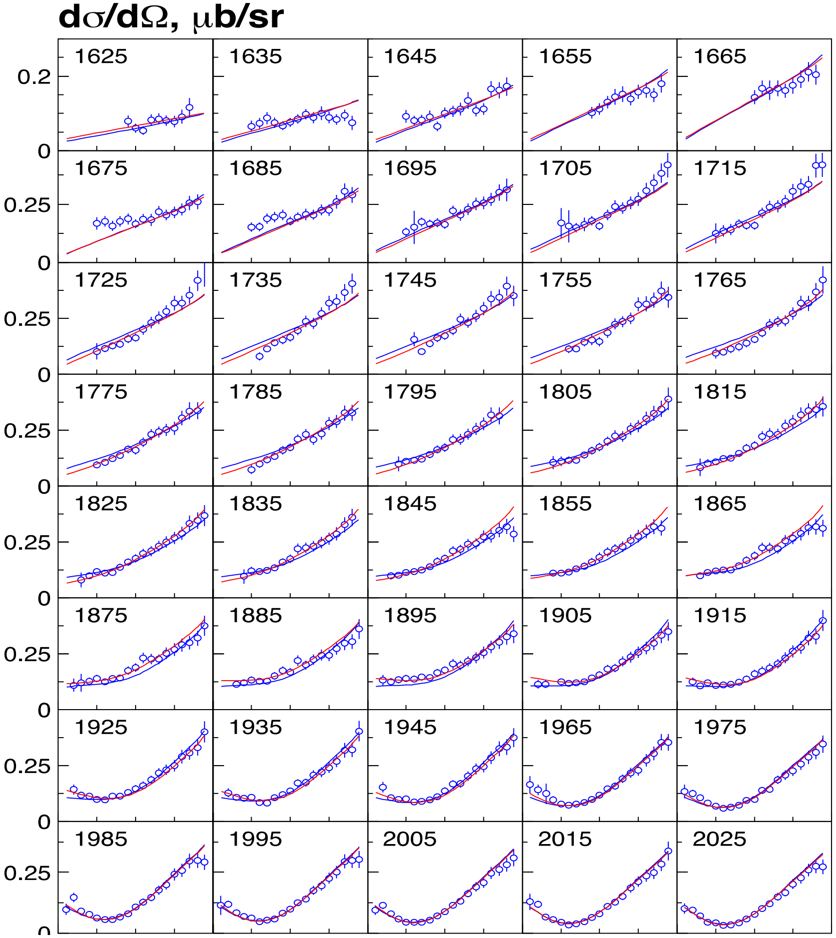
R. Edwards, J. Dudek, D. Richards, S. Wallace, PRD84 (2011) 074508

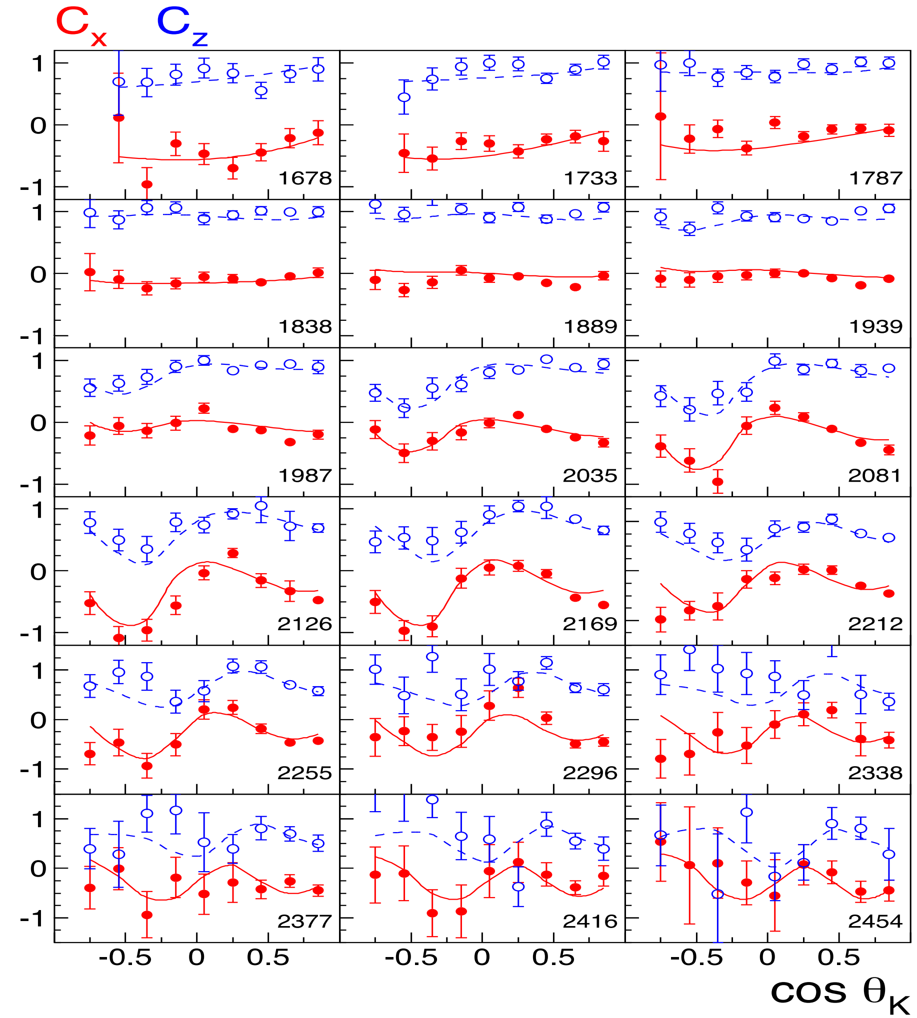
LQCD predicts states with the same quantum numbers as the CQM with underlying SU(6)xO(3) symmetry

CLAS Results on $\vec{\gamma}\vec{p} \rightarrow K^+\vec{\Lambda} \rightarrow K^+p\pi$

Bonn-Gatchina Coupled Channel Analysis, A.V. Anisovich et al., EPJ A48, 15 (2012)

(includes nearly all new photoproduction data)

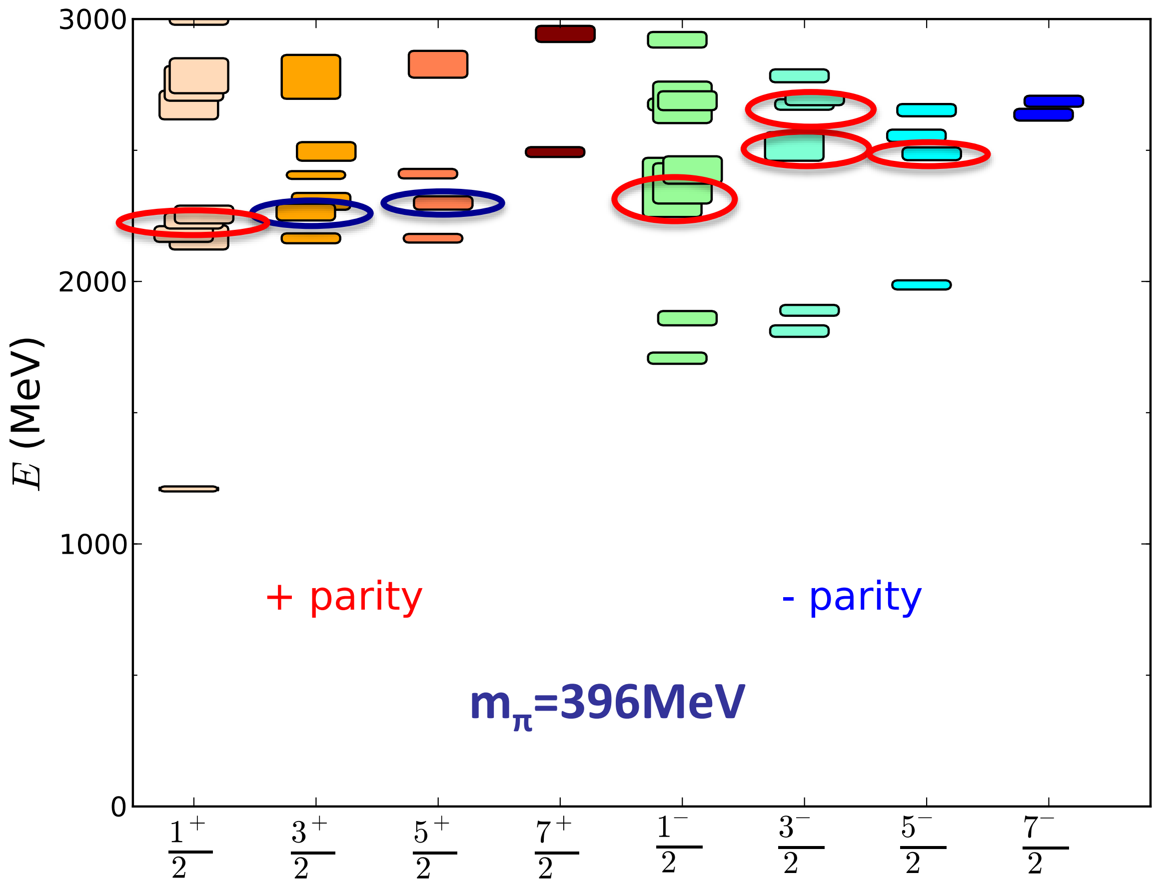




First New N* States in PDG 2012

BnGa energy-dependent coupled-channel PWA of CLAS $K^+\Lambda$ and other data

$P_{11}(1880)$
$P_{13}(1900)$
$F_{15}(2000)$



$S_{11}(1895)$
$D_{13}(1875)$
$D_{13}(2080)$
$D_{15}(2060)$

Much more data will still be analyzed

Photoproduction allows us to identify new states but tells us little about their nature

ANL-Osaka Nucleon Resonance Analysis (2012- 2013)

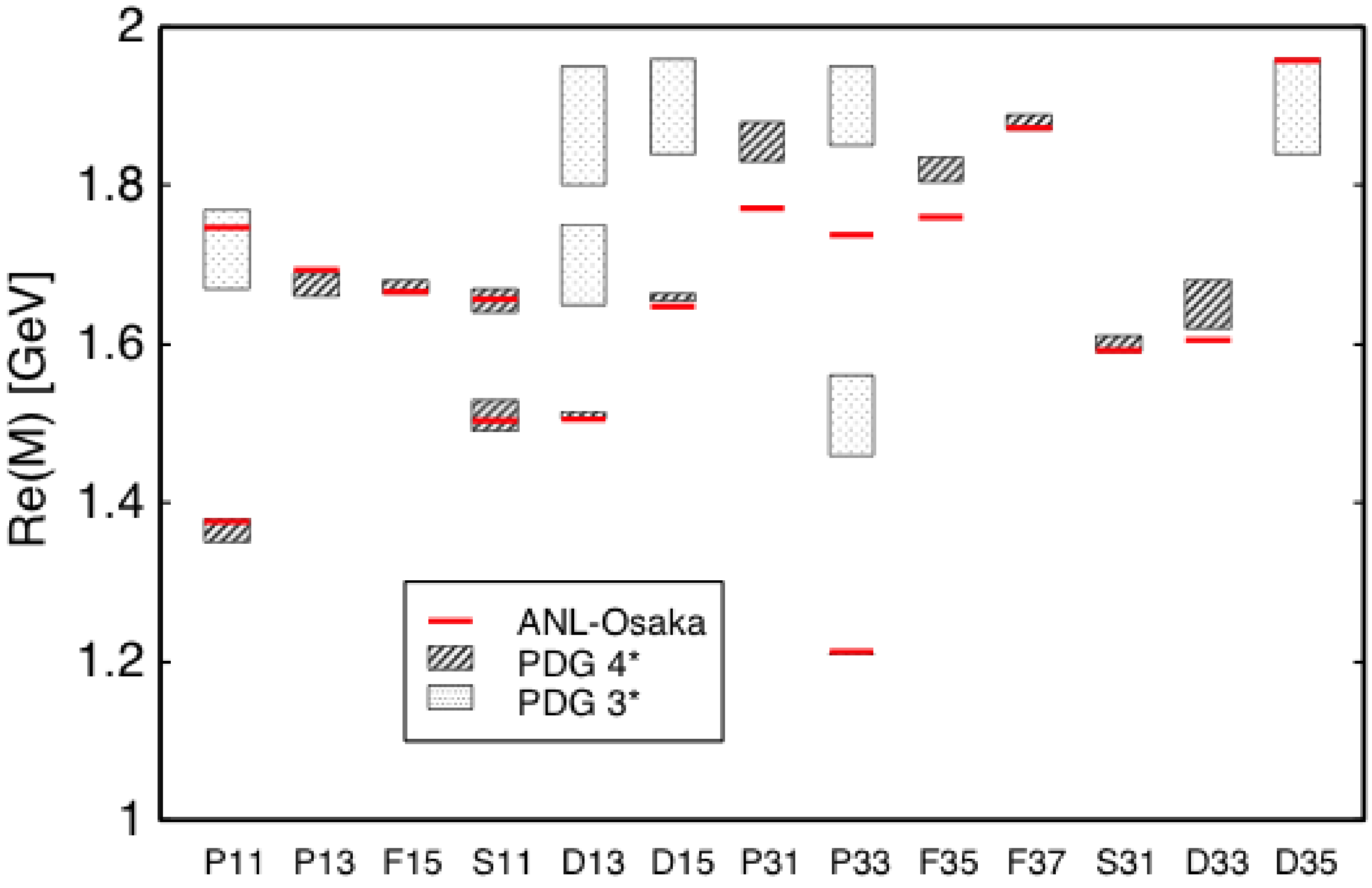
1. Based on a Dynamical Formulation
   which provides interpretation of
   the extracted resonances

2. Channels included:
   γN, πN, ηN, $K\Lambda$, $K\Sigma$, $\pi\pi N$ ($\pi\Delta$, ρN, σN)

3. Data included:
   γN, $\pi N \longrightarrow \pi N$, ηN, $K\Lambda$, $K\Sigma$

Int. J. Mod. Phys. E, Vol. 22, 1330015 (2013) 1-99

N* Spectrum from ANL-Osaka Collaboration

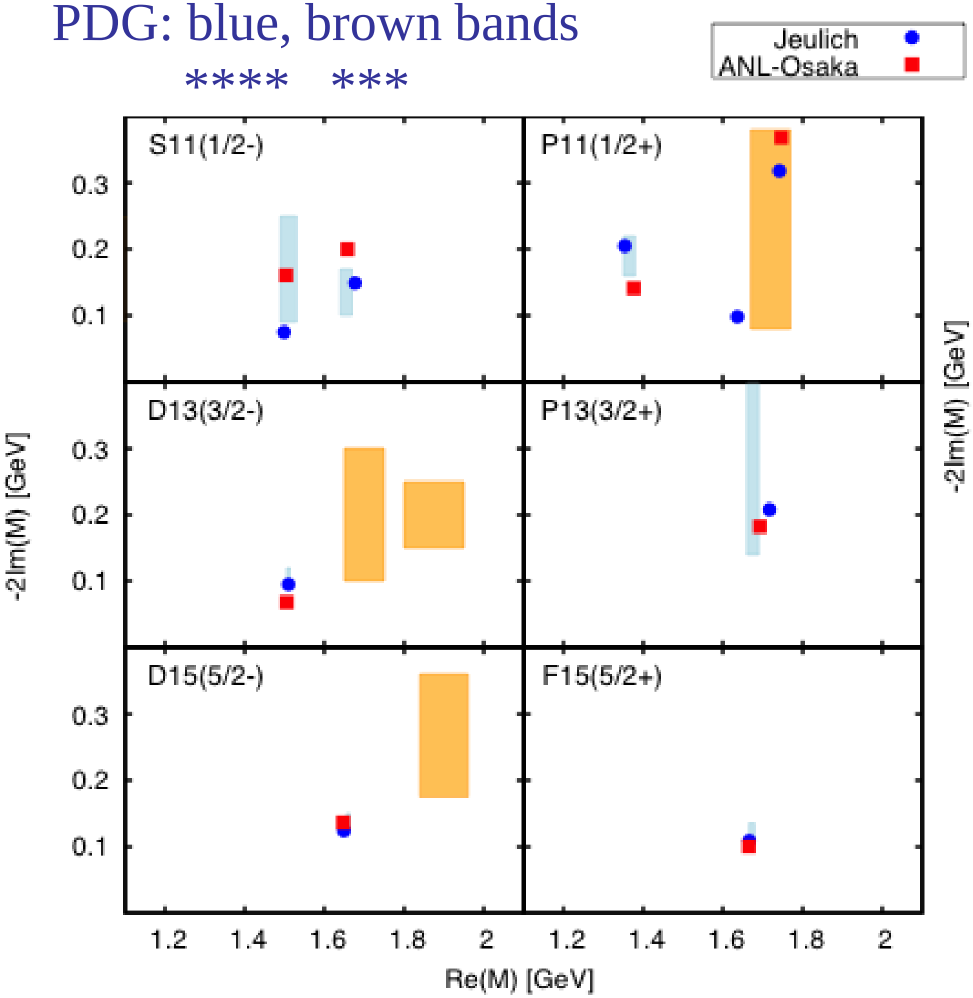


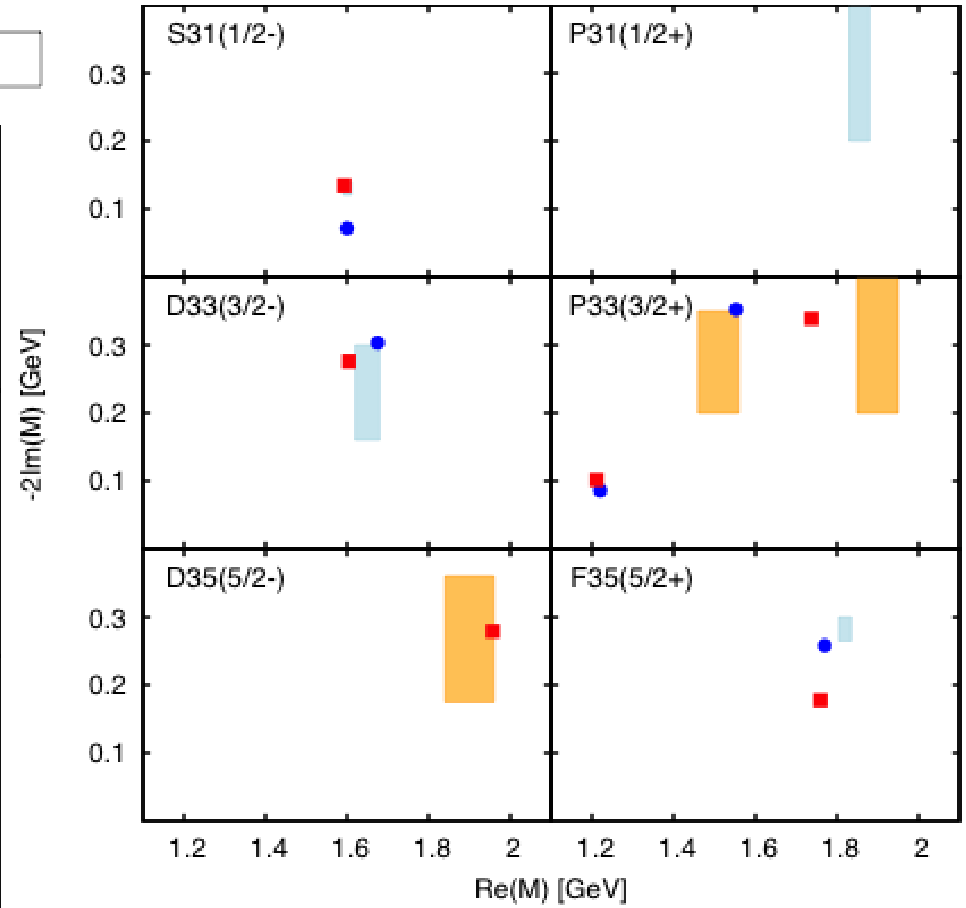
T.-S. H. Lee, arXiv:1208.5748 [nucl-th]

N* Spectrum from ANL-Osaka Collaboration

PDG: blue, brown bands

**** ***

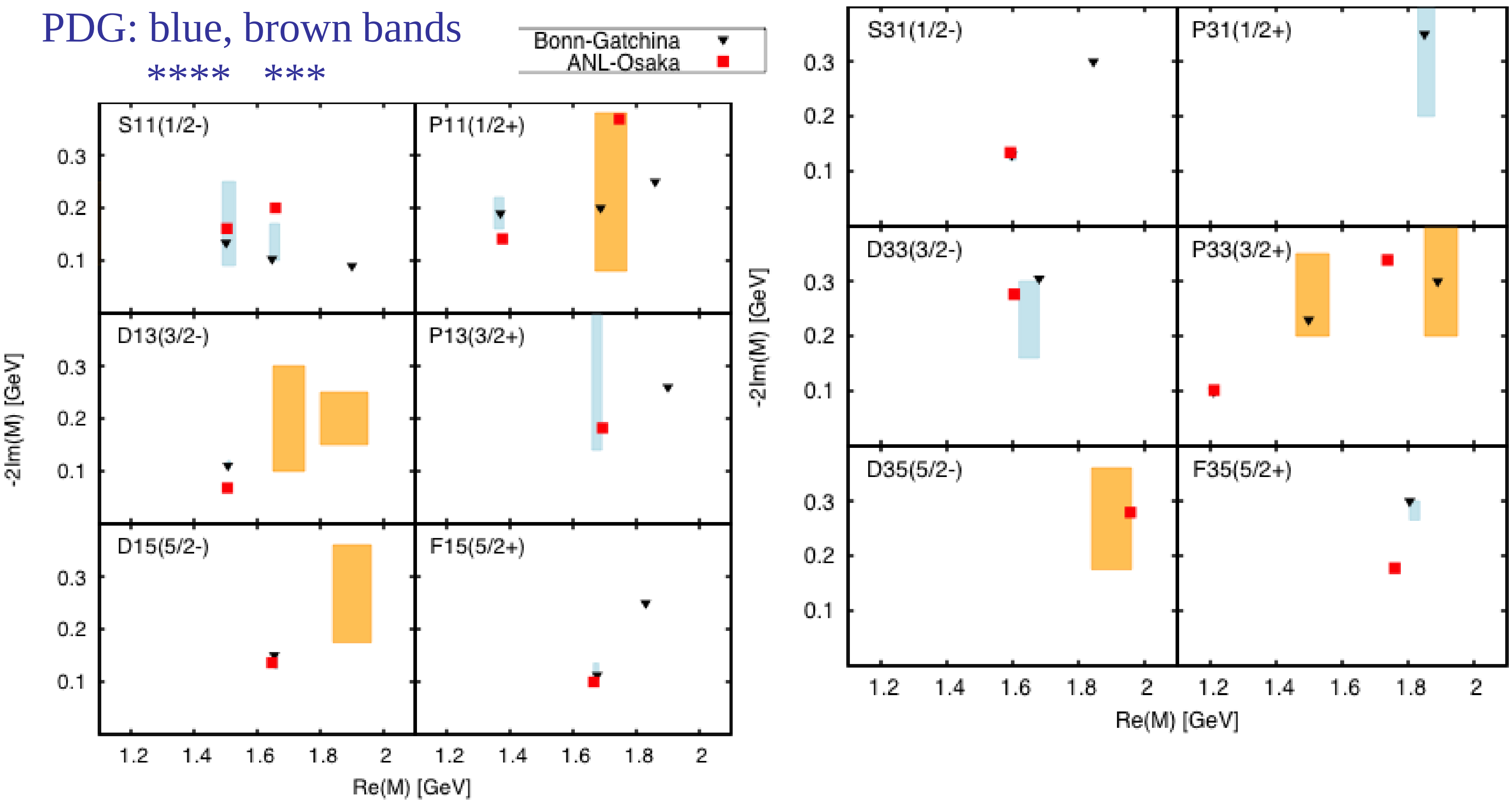




Agrees with Juelich except in 2nd P_{11} and D_{35}

N* Spectrum from ANL-Osaka Collaboration

PDG: blue, brown bands
**** ***



Disagrees with Bonn-Gatchina in the number of N* with masses > 1.7 GeV (they have six more)