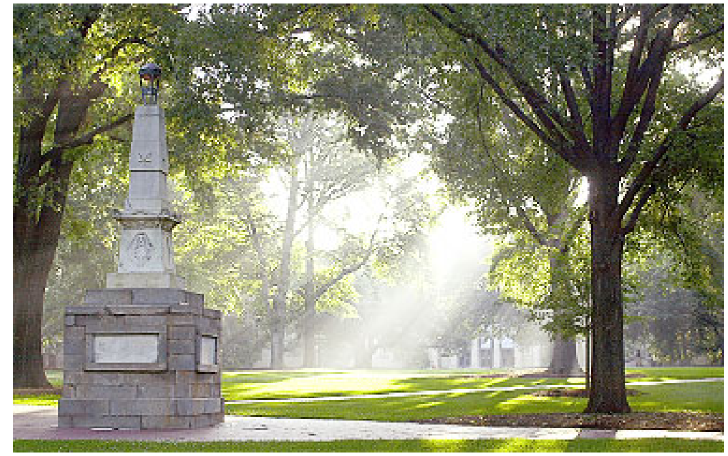
USC Summer Academy on Non-Perturbative Physics

The next workshop in our series "Nucleon Resonance Structure in Exclusive Electroproduction at High Photon Virtualities" will be held at the University of South Carolina on August 13-15, 2012. This three-day workshop will provide us extended opportunities to present and discuss in depth future developments and preliminary results on the continuous exploration of hadronic physics towards smaller distances. If you would like to participate please contact gothe@sc.edu or mokeev@jlab.org or visit www.jlab.org/conferences/EmNN2012/.



COLLEGE OF ARTS AND SCIENCES
PHYSICS AND ASTRONOMY

A first of its kind three-week graduate student summer school on "Dyson-Schwinger Equations (DSEs) to tackle non-perturbative physics, their applications in Quantum Chromodynamics (QCD) and condensed matter physics, and their mathematical connection to the Hopf algebras" will be held at USC from July 26 to August 11, directly preceding a three-day international workshop on "Nucleon Resonance Structure in Exclusive Electroproduction at High Photon Virtualities". The main lecturers are Piers Coleman, Ian Cloet, Craig Roberts, and Karen Yeats. There are a limited number of slots for outside graduate students available. If you would like to come or send a graduate student please contact gothe@sc.edu or webb@sc.edu and visit www.physics.sc.edu/~gothe/.

Hadron Spectroscopy

Ralf W. Gothe

UNIVERSITY OF SOUTH CAROLINA

2012 JLab Users Group Meeting

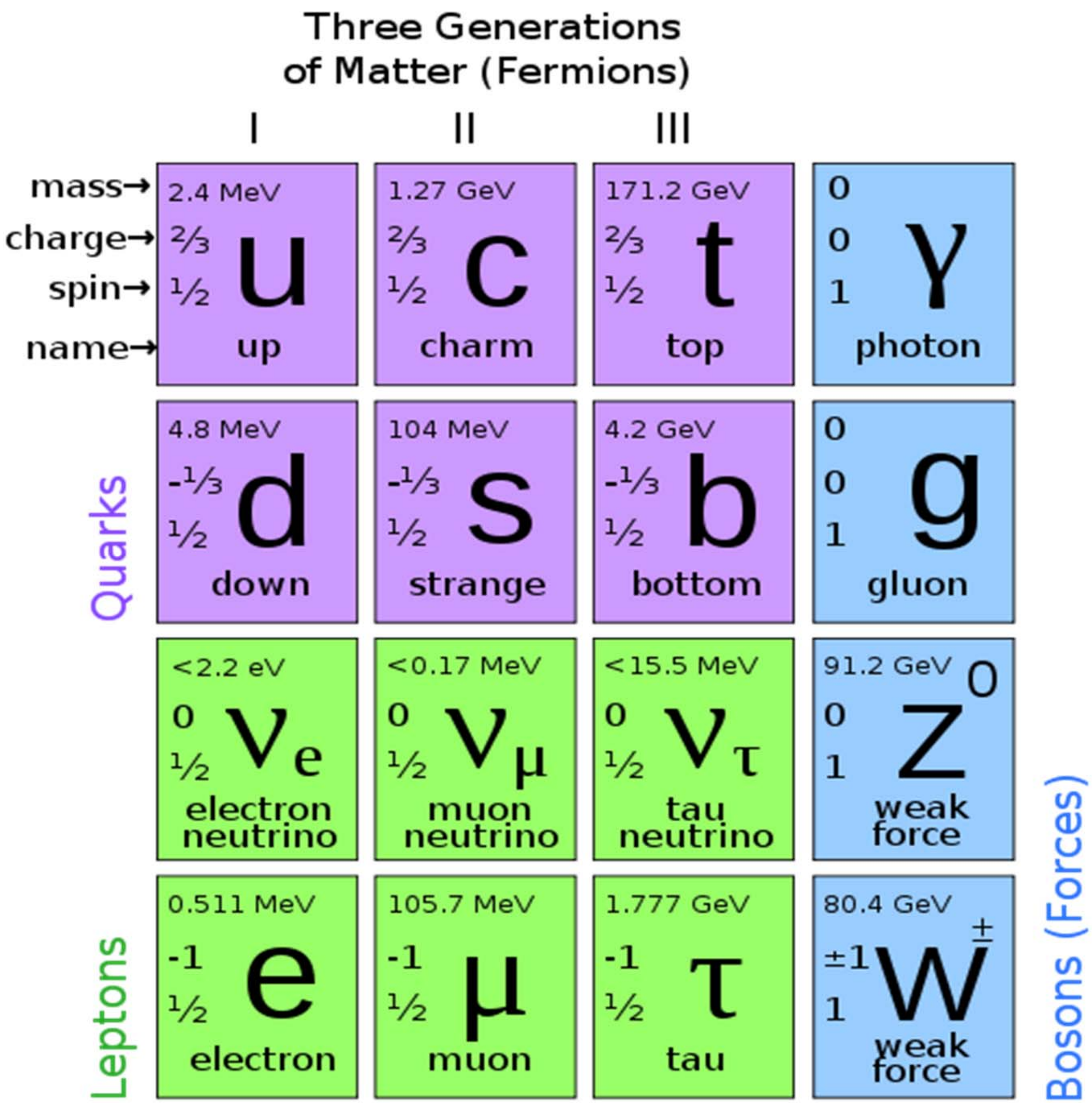
June 4 to 6, 2012

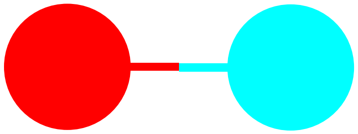
Jefferson Lab, Newport News, VA

- **Photoproduction Experiments:** Probe Hadrons in the Confinement Region
  - Are there any “Missing” Resonances or “Exotic” States?
- **γ_vNN* Experiments:** The Best Access to the Hadron and Quark Structure?
  - Elastic Form Factors and Transition Form Factors of Hadrons
- **Analysis:** Model Independent and Model Dependent?
  - Complete Experiments and Phenomenological Extraction
- **QCD based Theory:** Solve Non-Perturbative QCD and Confinement?

QCD for Bound and Confined Quarks?

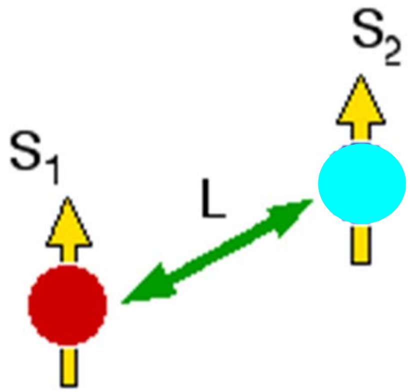
Build your Mesons…





Meson Spectroscopy

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

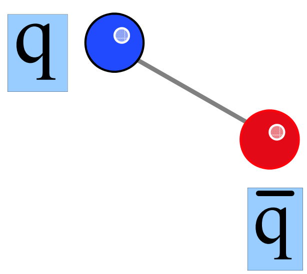


$S=S_1 \oplus S_2$ $J= L \oplus S$ $P = (-1)^{L+1}$ $C = (-1)^{L+S}$

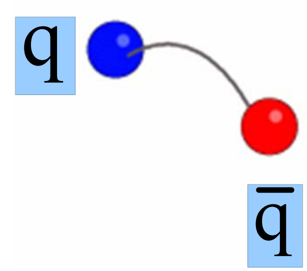
Not-allowed: $J^{PC} = 0^{--}, 0^{+-}, 1^{-+}, 2^{+-}$

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
$CP = (-1)^{S+1}$

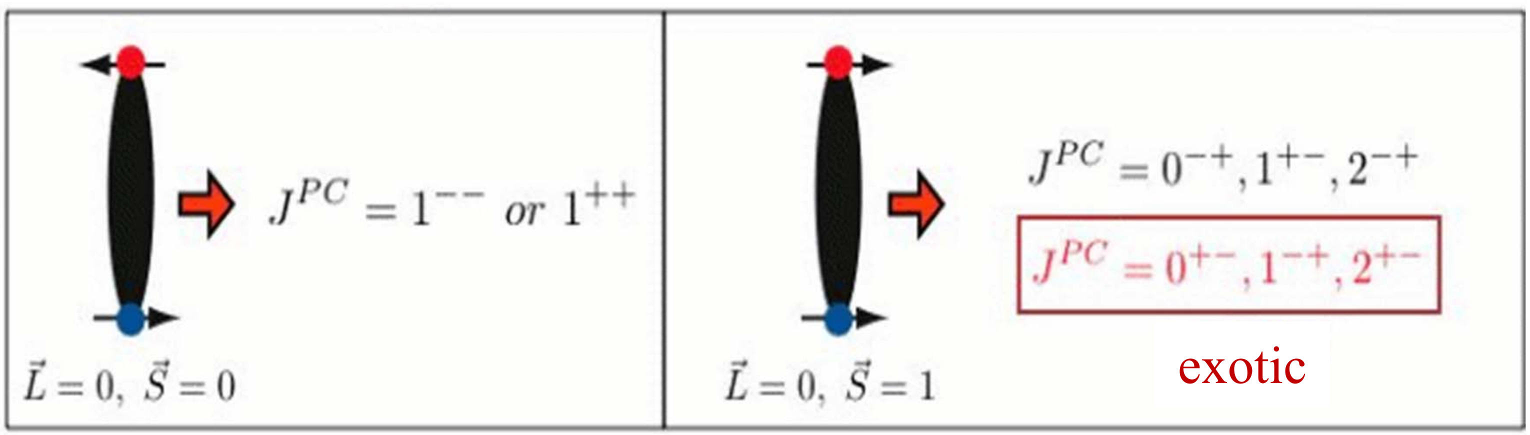


Hybrid meson:
flux tube in
excited state
m=1
$CP = (-1)^{S}$



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

Combine excited glue quantum number with those of the quarks



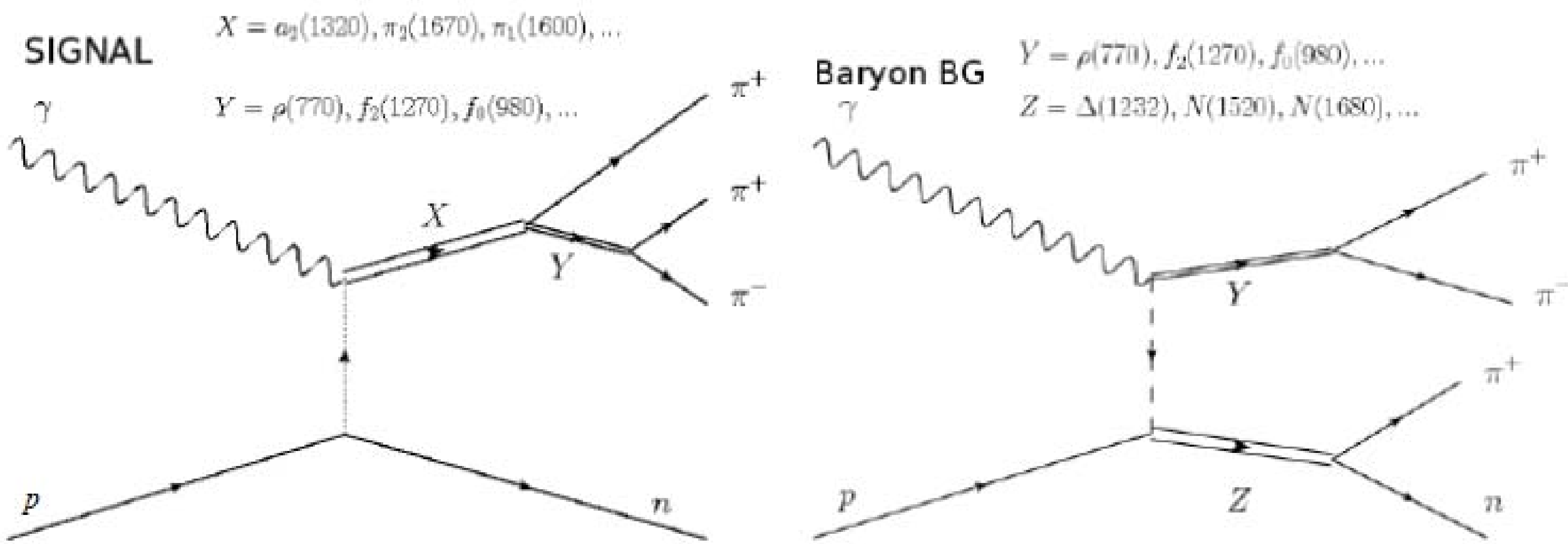
M.Battaglieri

Analysis of $\gamma p \to n\pi^+\pi^+\pi^-$

Identification of $\gamma\, p \to \pi^+\pi^+\pi^- n$ events

Craig Bookwalter

- $\pi^+\pi^+\pi^-$ events isolated by vertex and timing cuts
- neutron identified by missing mass



Identification of $\gamma\, p \to Xn \to \pi^+\pi^+\pi^- n$ events

- $\gamma\, p \to N^*\pi\pi$ events removed by requiring low-t' and small θ_{lab} for both π^+

PWA Wave Set

Major waves

Craig Bookwalter

J^{PC}	M^{ϵ}	L	Y	# waves
1^{++}	$1^{\pm}$	S	$\rho(770)$	2
1^{++}	$1^{\pm}, 0^{+}$	D	$\rho(770)$	3
1^{-+}	$0^{-}, 1^{\pm}$	P	$\rho(770)$	3
2^{++}	$1^{\pm}$	D	$\rho(770)$	2
2^{-+}	$0^{-}, 1^{\pm}$	S, P, D	$f_2(1270)$, $\rho(770)$	9

+ isotropic background wave

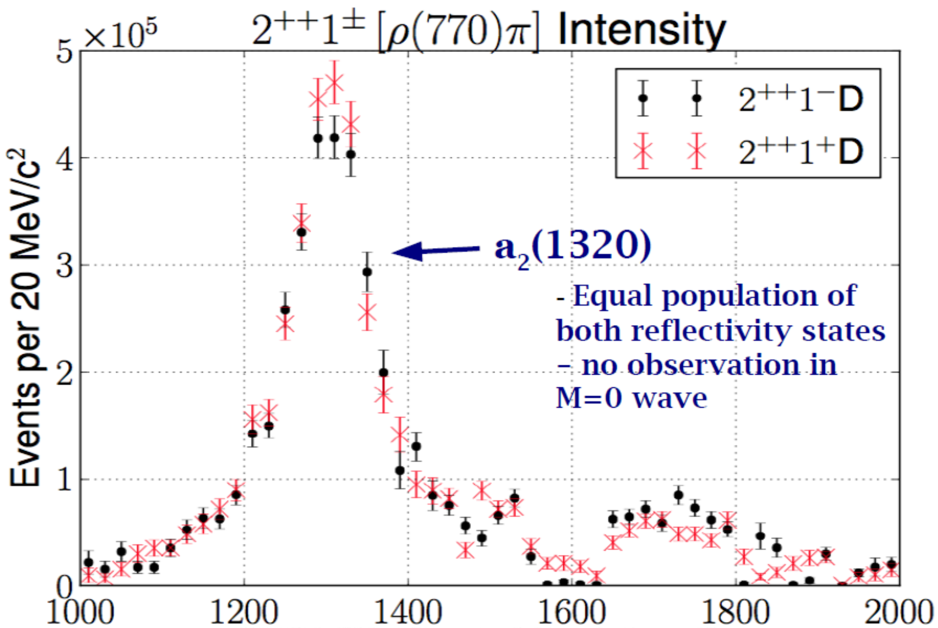
unpolarized beam

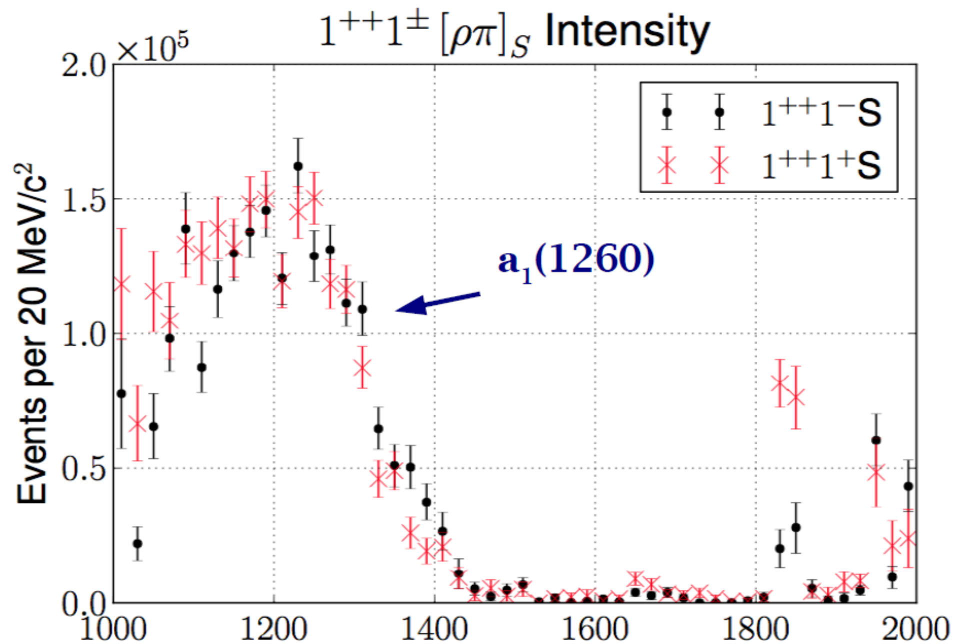
- Photon beam is a coherent mixture of both parity eigenstates

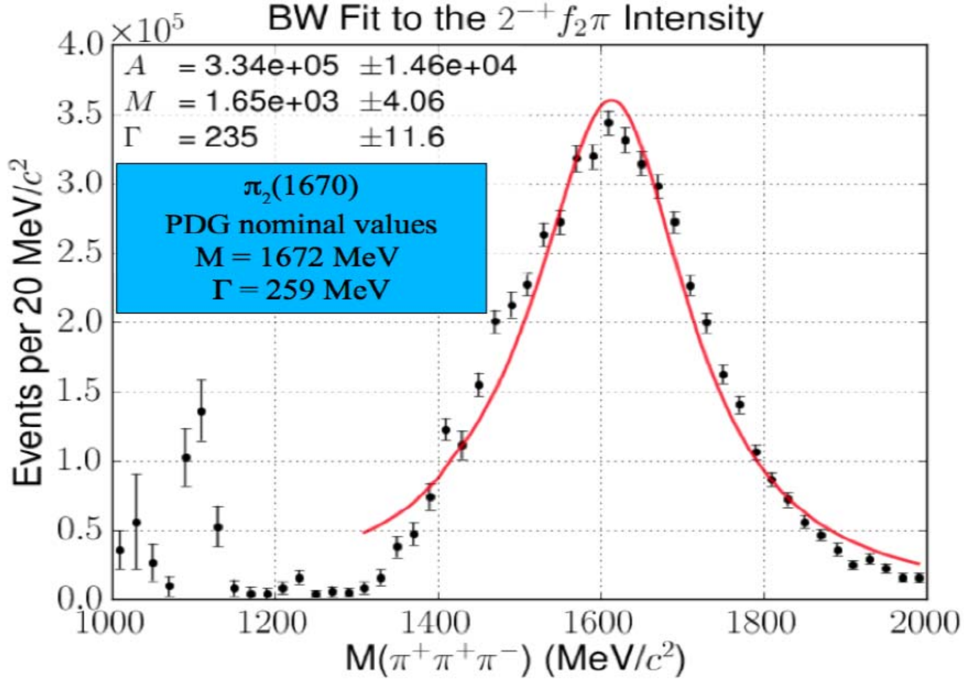
π exchange dominance

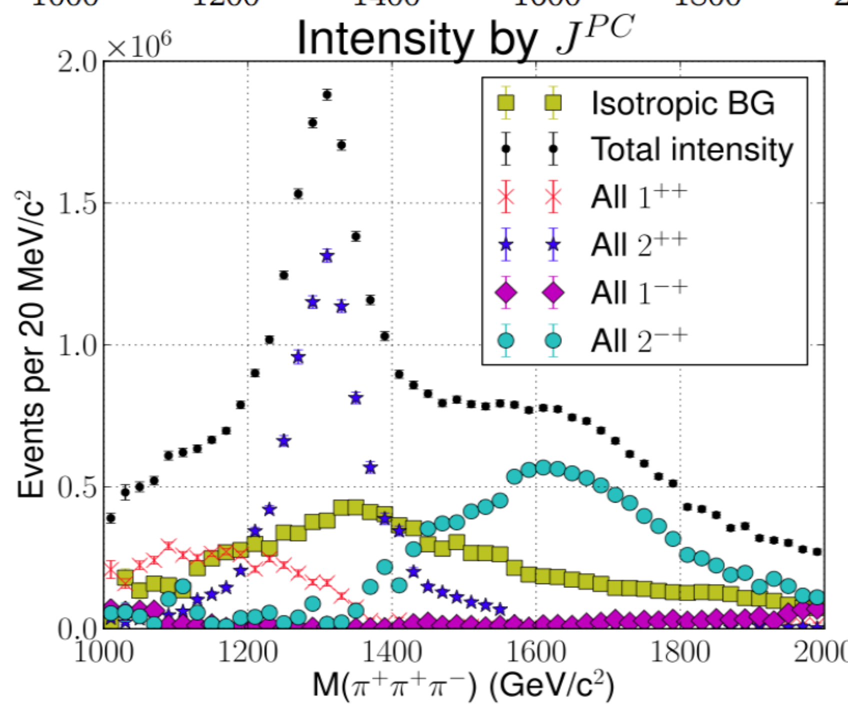
- Equal production of $M^{\varepsilon} = 1^{+}$ and 1^{-} (ambiguity)
- No $M^{\varepsilon} = 0^{\varepsilon}$
  - No J=0 meson production (spin zero filter)

Preliminary Partial Wave Analysis Results

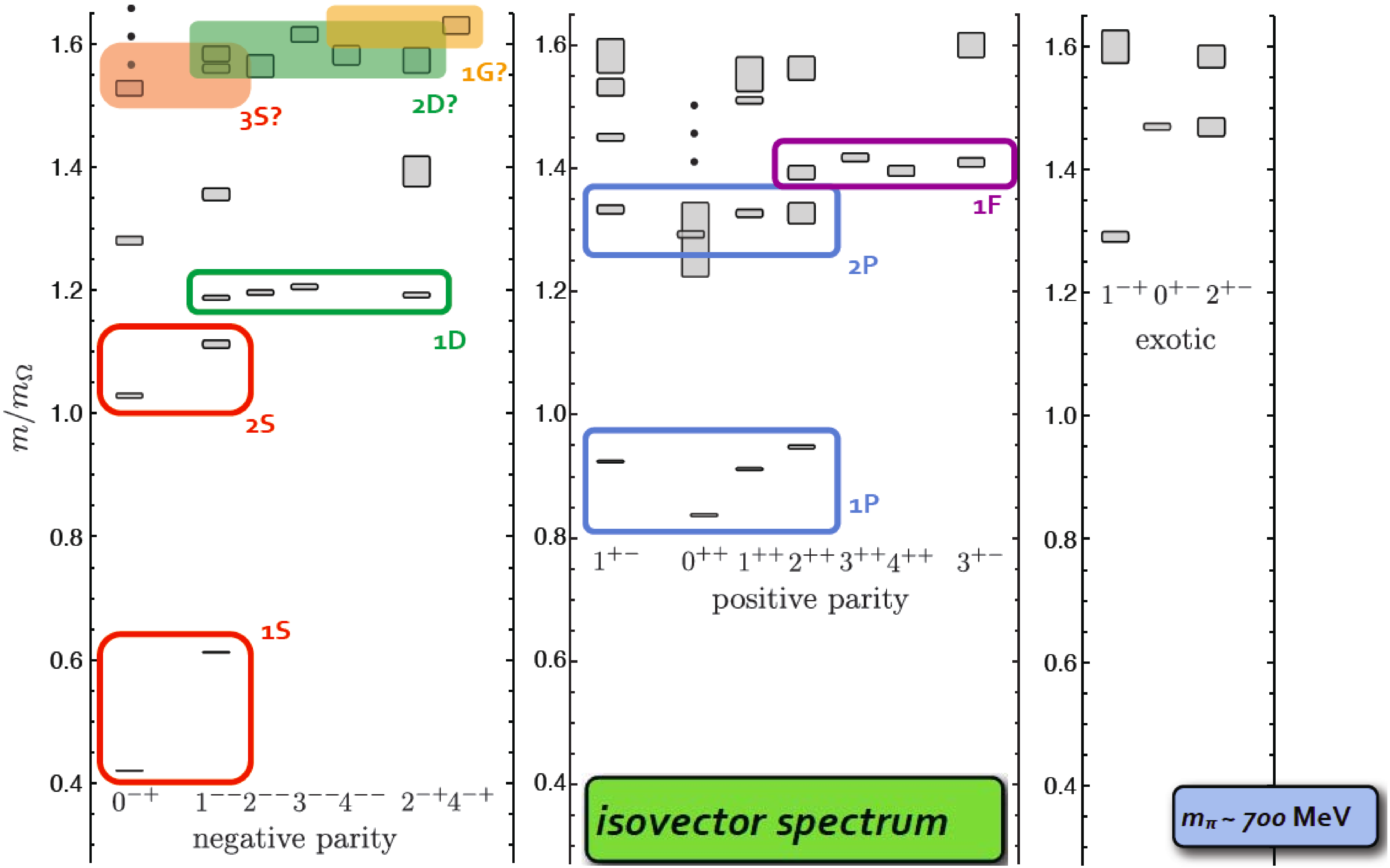






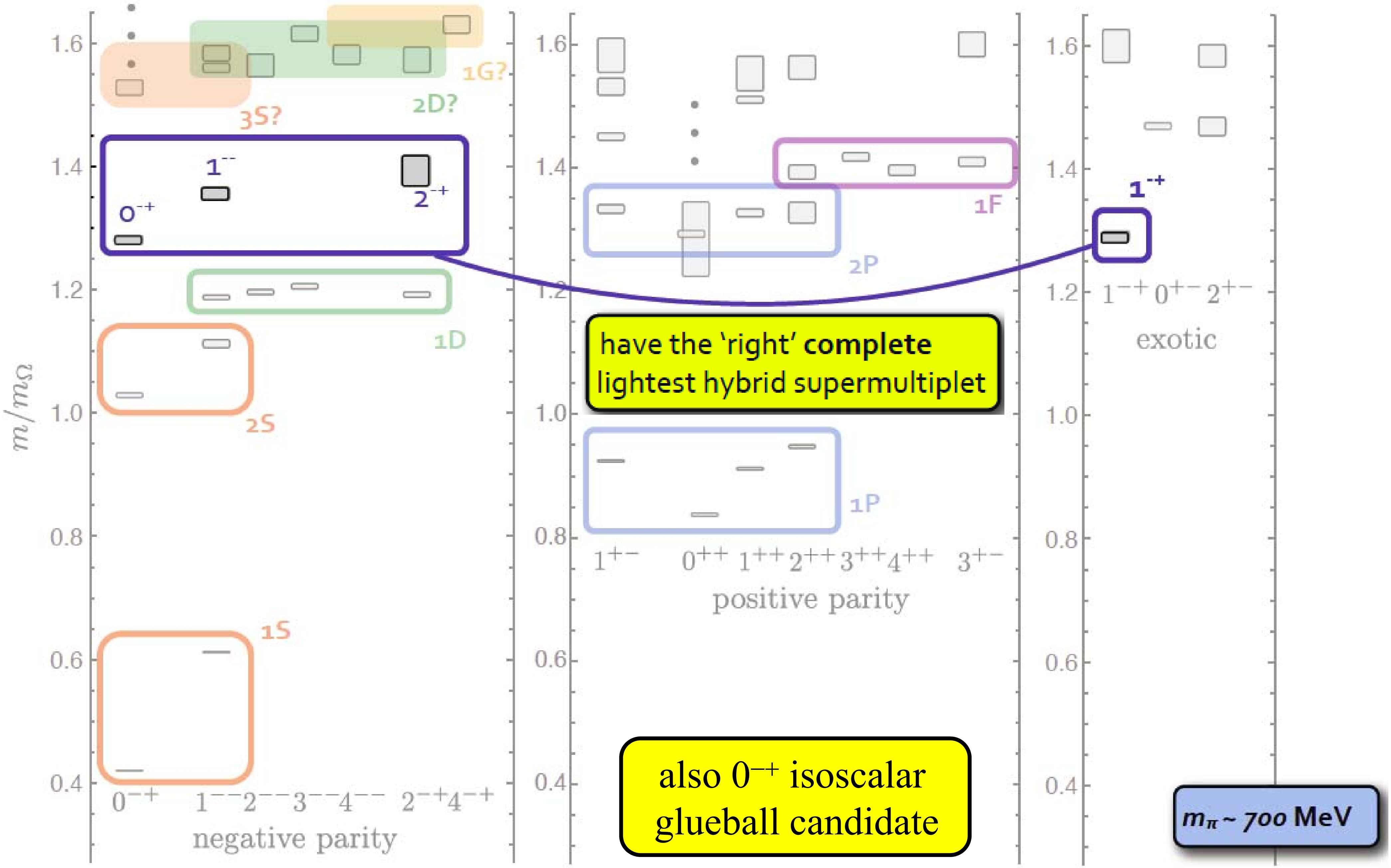


Meson Spectrum in QCD Lattice Calculations



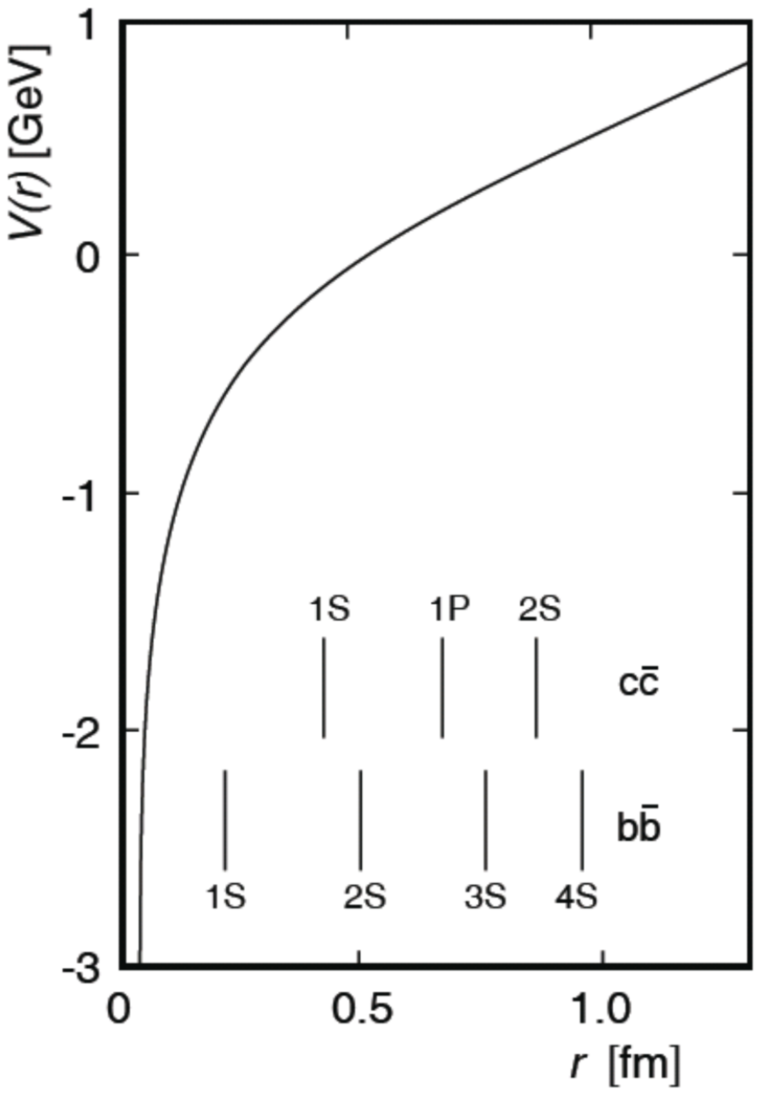
J. Dudek et al. Phys. Rev. D82 (2010) 034508

Meson Spectrum in QCD Lattice Calculations

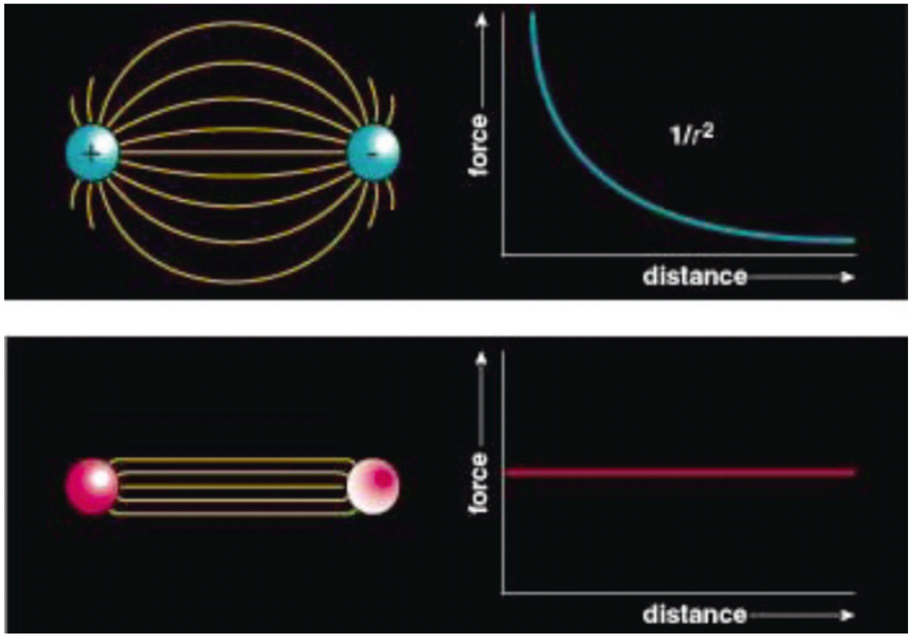


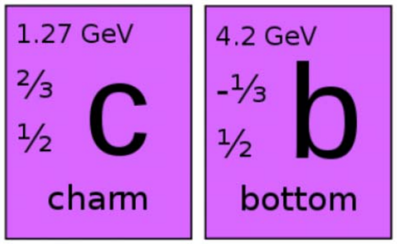
J. Dudek et al. Phys. Rev. D82 (2010) 034508

Heavy Quark Systems

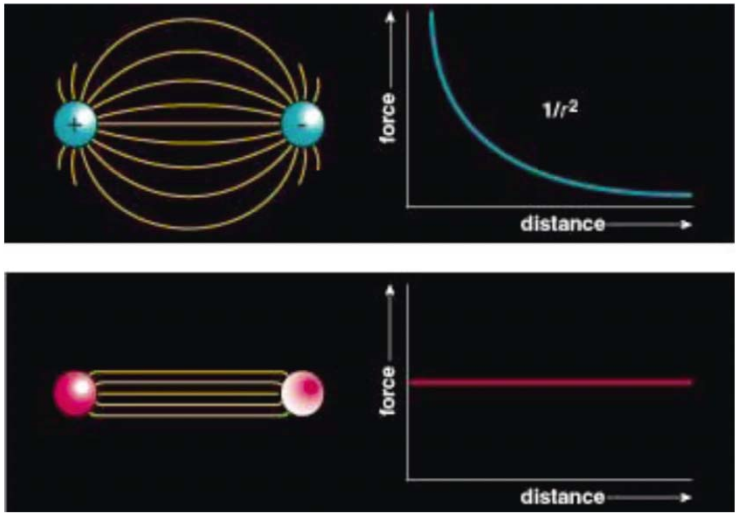


$$V = -\frac{4}{3}\frac{\alpha_s(r)\hbar c}{r} + k \cdot r$$



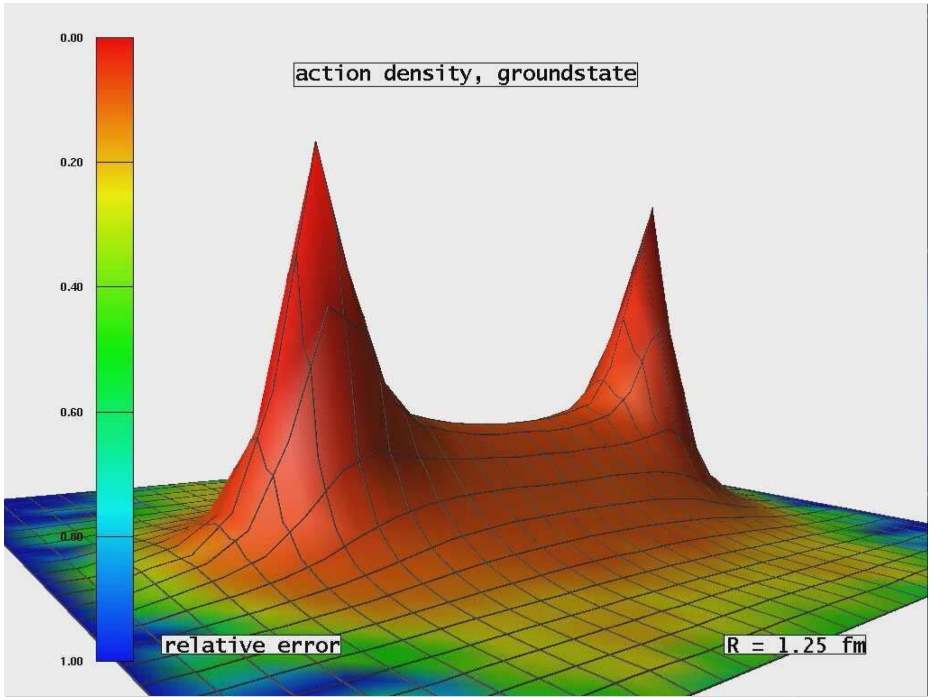


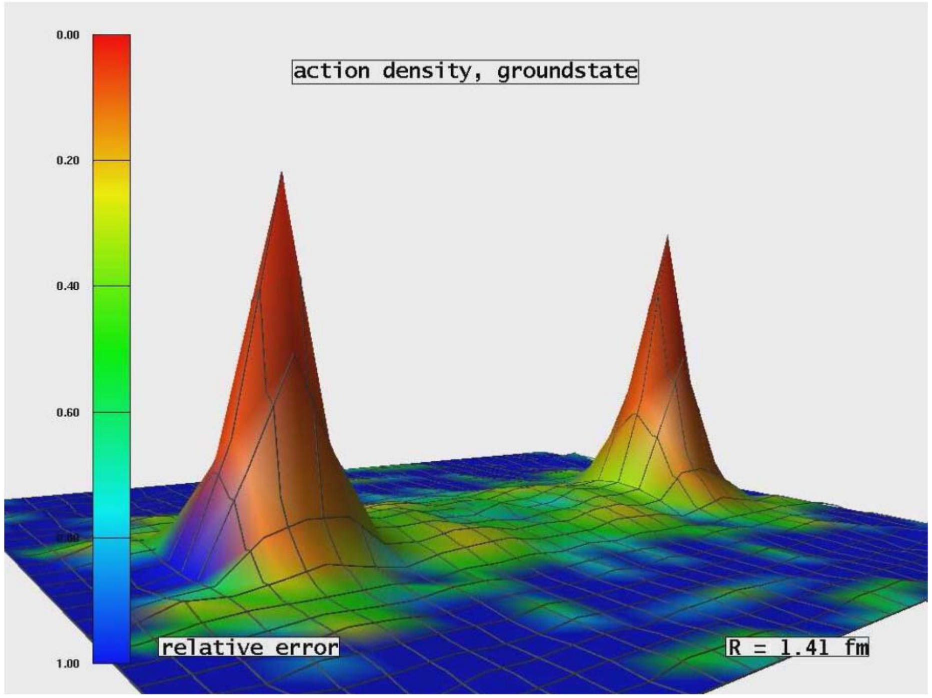
Heavy Quark Systems



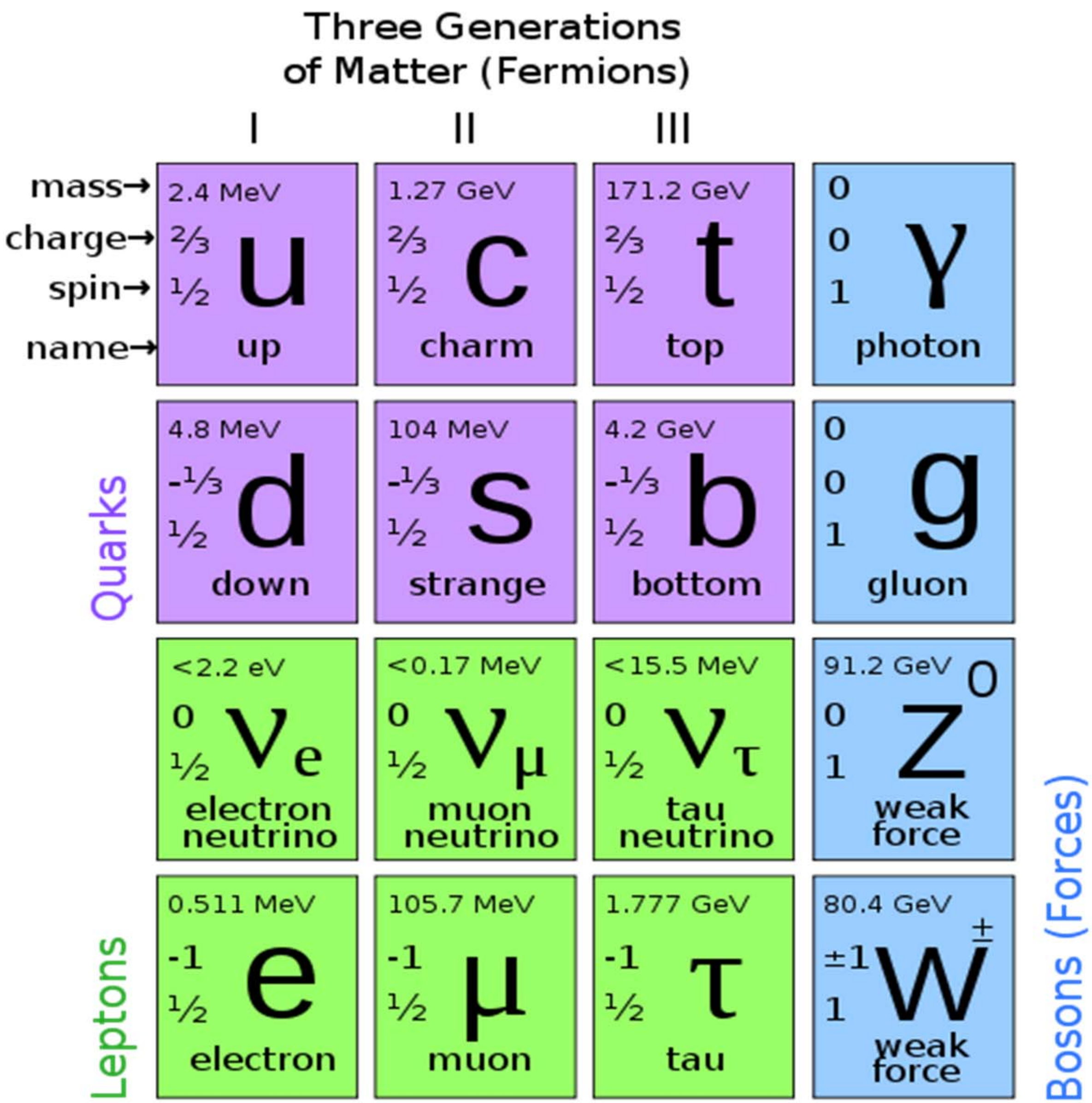
$$V = -\frac{4}{3}\frac{\alpha_s(r)\hbar c}{r} + k \cdot r$$

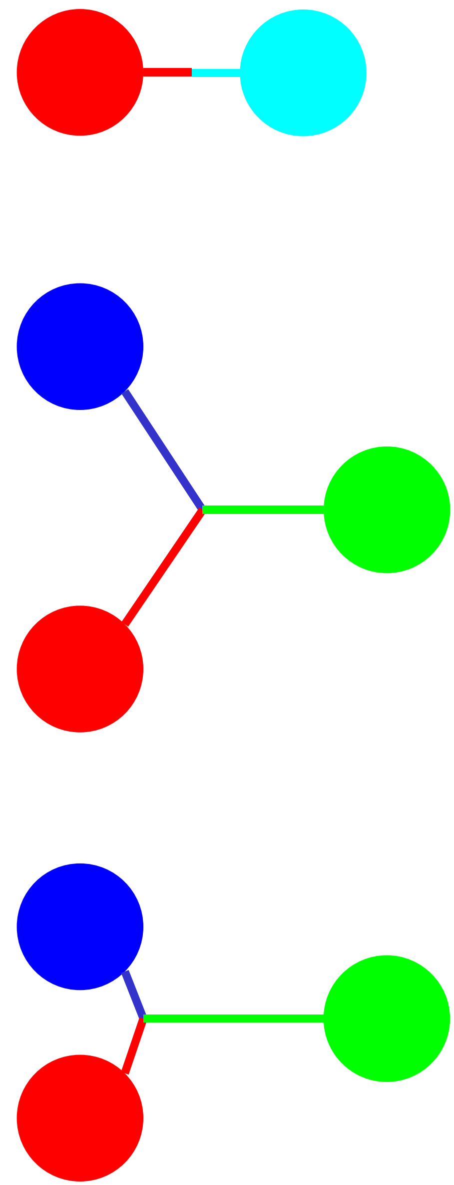
Bali *et al*. he-la/0512018





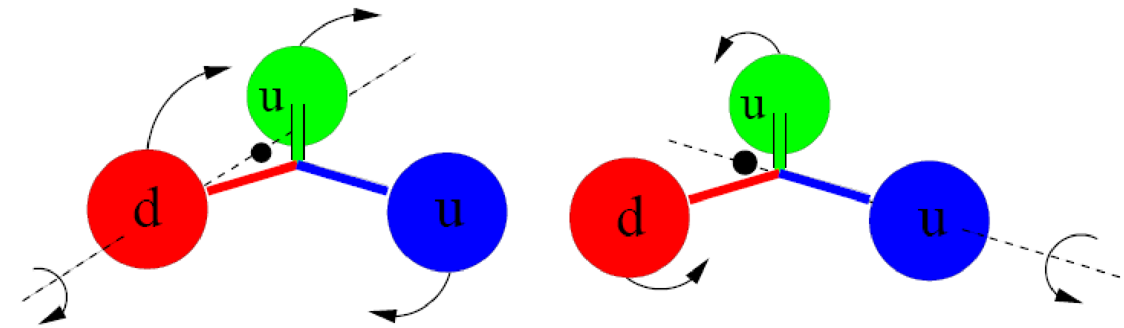
Build your Mesons and Baryons …



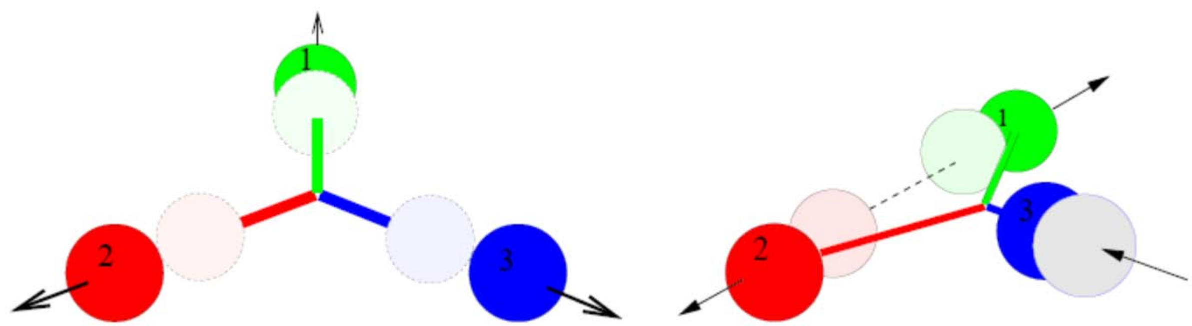


N and Δ Excited Baryon States …

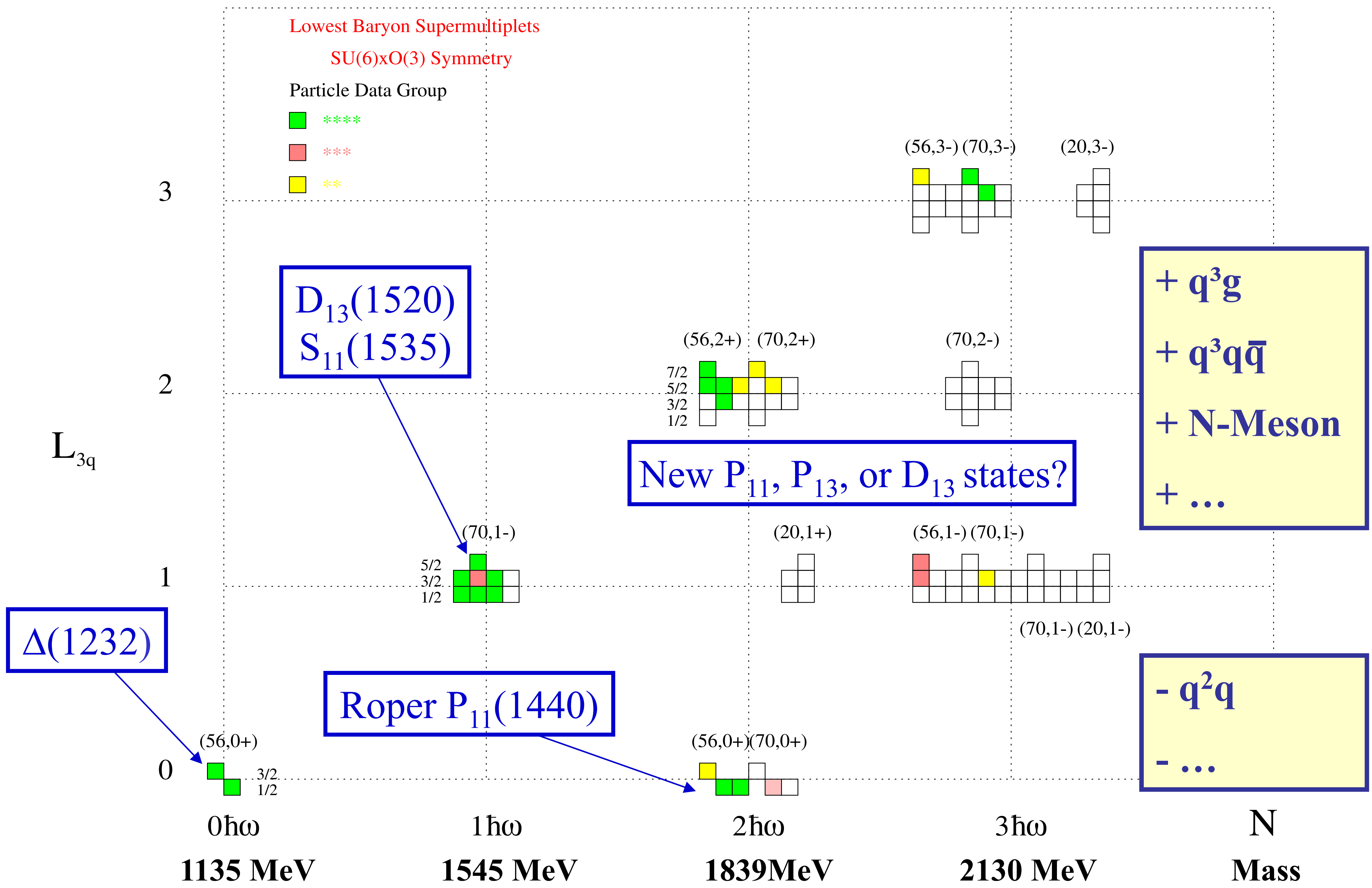
- Orbital excitations (two distinct kinds in contrast to mesons)



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



Quark Model Classification of N*



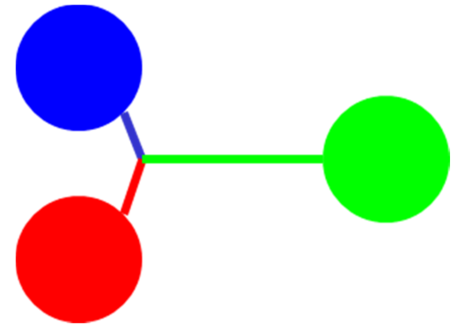
"Missing" Resonances?

Problem: symmetric CQM predicts many more states than observed (in πN scattering)

Possible solutions:

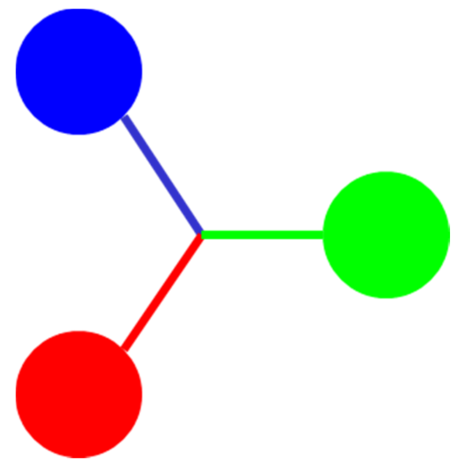
1. di-quark model — old but always young

   fewer degrees-of-freedom
   open question: mechanism for q^2 formation?



2. not all states have been found

   possible reason: decouple from πN-channel
   model calculations: missing states couple to
   Nππ (Δπ, Nρ), Nω, KY

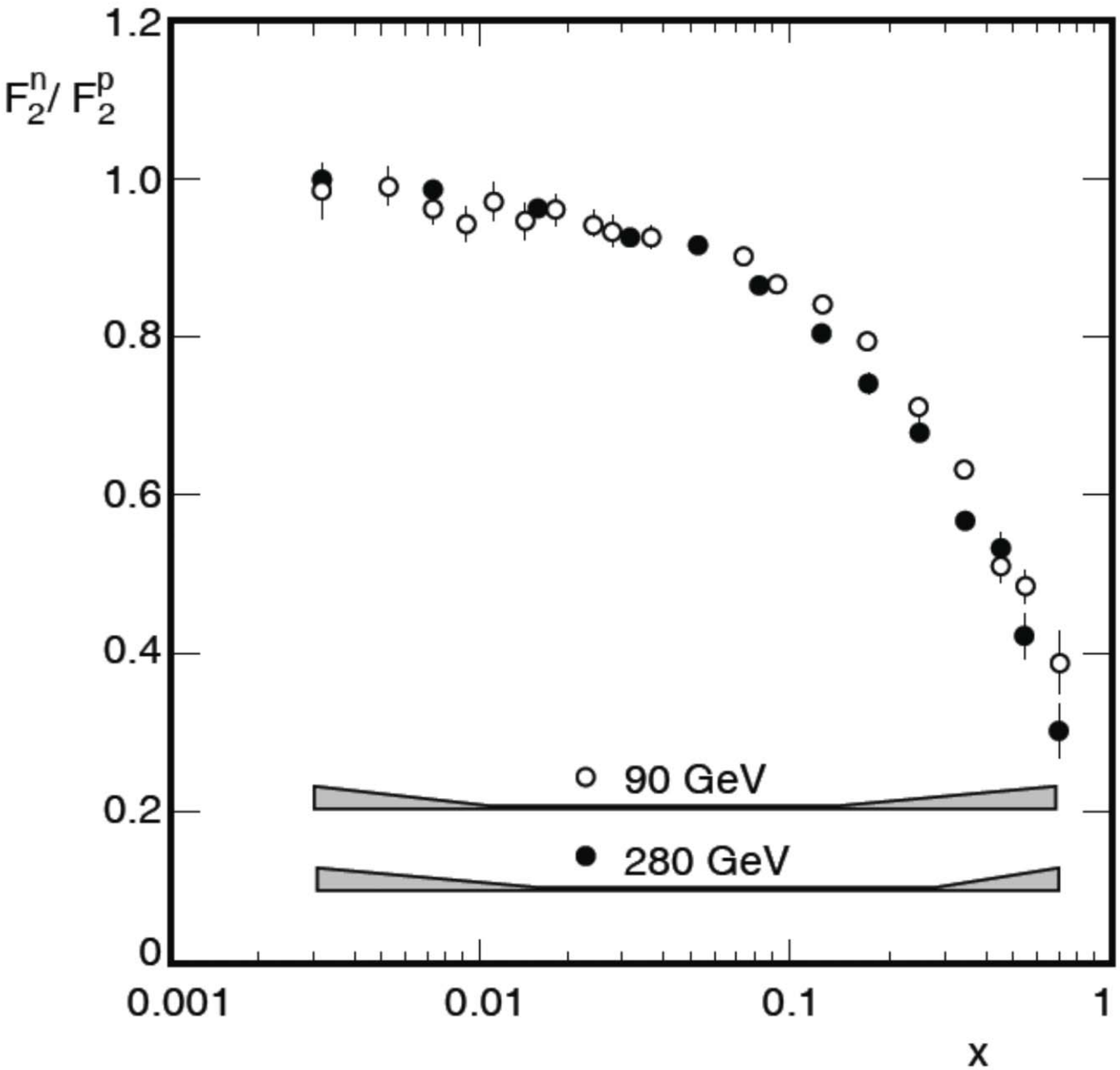


3. coupled channel dynamics — more recently

   all baryonic and mesonic excitations beyond the groundstate octets and decuplet are generated by coupled channel dynamics (not only Λ(1405), Λ(1520), S_{11}(1535) or f_0(980))

γ coupling not suppressed → electromagnetic excitation is ideal

Di-Quarks in Deep Inelastic Scattering



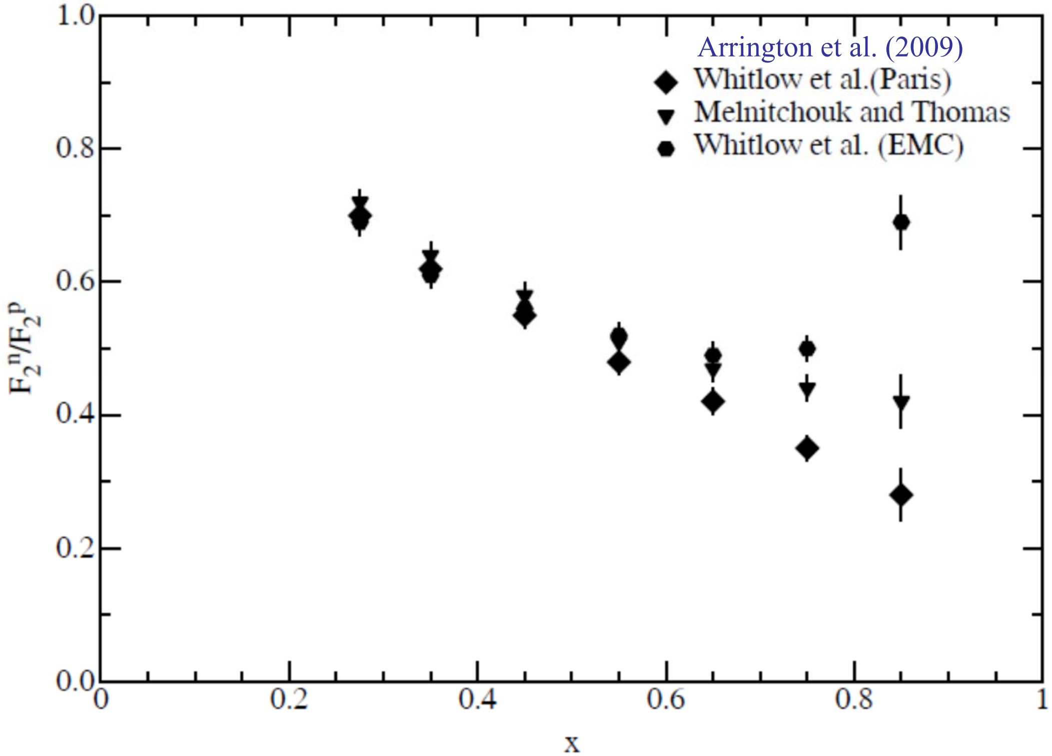
Nucl. Phys. **B371** (1992) 3

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

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

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

Di-Quarks in Deep Inelastic Scattering

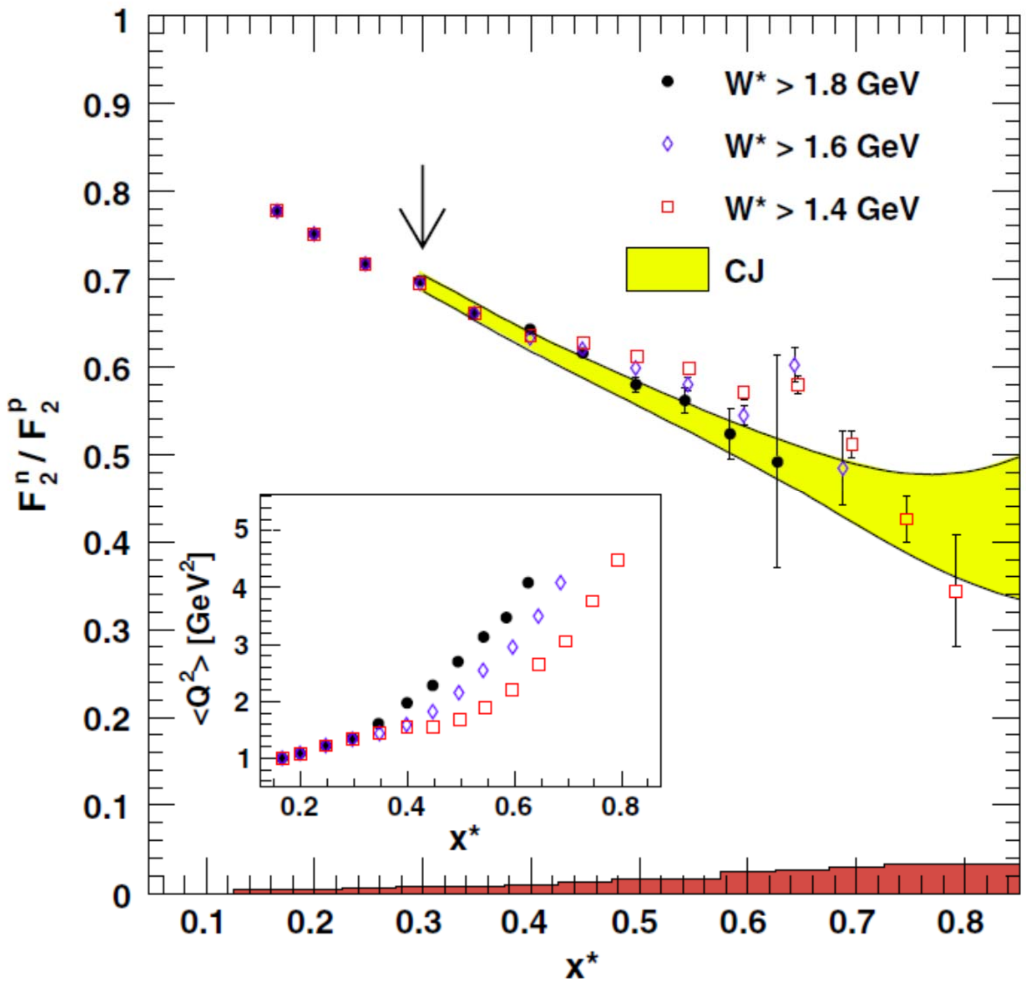


Holt and Roberts, arXiv:1002.4666v3 (2010)

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

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

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



Evidence for New N* States

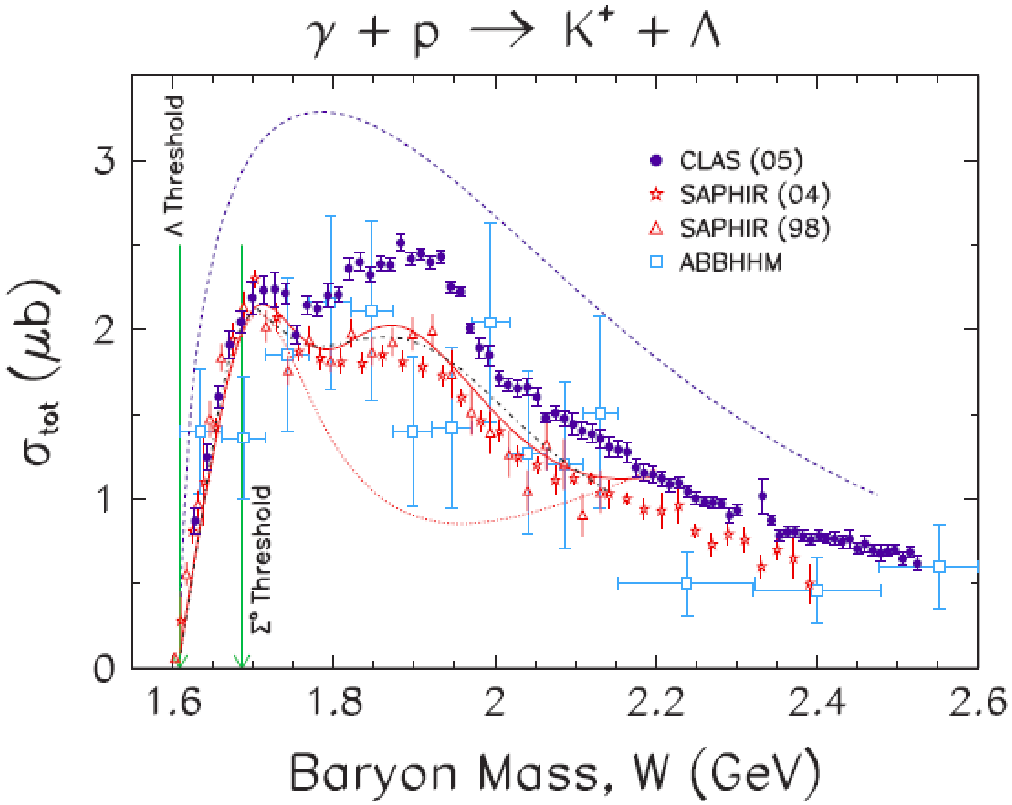


FIG. 20. (Color online) Total cross section for $\gamma + p \to K^+ + \Lambda$. The data from CLAS (blue circles) are shown with combined statistical and fitting uncertainties. Also shown are results from two publications from SAPHIR (red stars (2004) [18] and red triangles (1998) [8]) and the ABBHHM Collaboration (light blue squares) [43]. The curves are from a Regge model (dashed blue) [20,21], KAON-MAID (solid red) [5], KAON-MAID with the $D_{13}(1895)$ turned off (dotted red), and Saghai *et al*. (dot-dashed black) [9].

R. Bradford et al., Phys. Rev. C 73, 035202

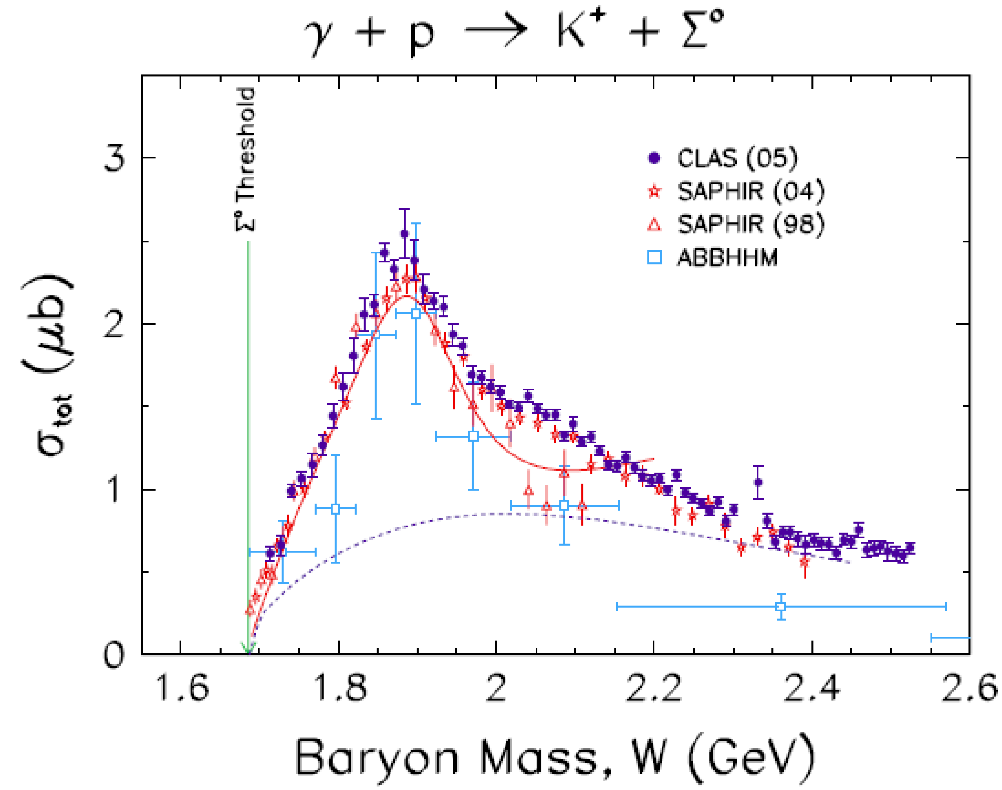
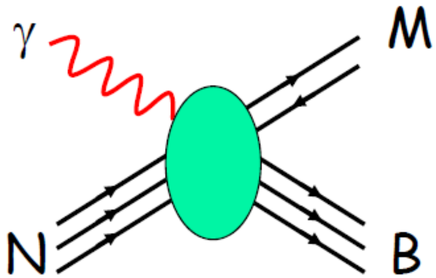


FIG. 21. (Color online) Total cross section for $\gamma + p \to K^+ + \Sigma^0$. The data from CLAS (blue circles) are shown with combined statistical and fitting uncertainties. Also shown are results from two publications from SAPHIR (red stars (2004) [18] and red triangles (1998) [8]) and the ABBHHM Collaboration (light blue squares) [43]. The curves are from a Regge model (dashed blue) [20,21] and from KAON-MAID (solid red) [5].

One or more D_{13} (Bennhold, Mart), P_{13} (BoGa), or P_{11} (Ghent) states needed in different models.

Scaled Cross Sections versus W

$$\frac{d\sigma}{dt} = f\left(\frac{t}{s}\right) s^{2-n}$$



n=9

- Constituent counting rules for exclusive scattering
- "Valid" for $s \to \infty$ and t/s fixed
  - $t/s \sim \cos(\theta_{cm})$ as $s \to \infty$
- n = number of point-like constituents
- Follows from pQCD… but also other models

cos θ

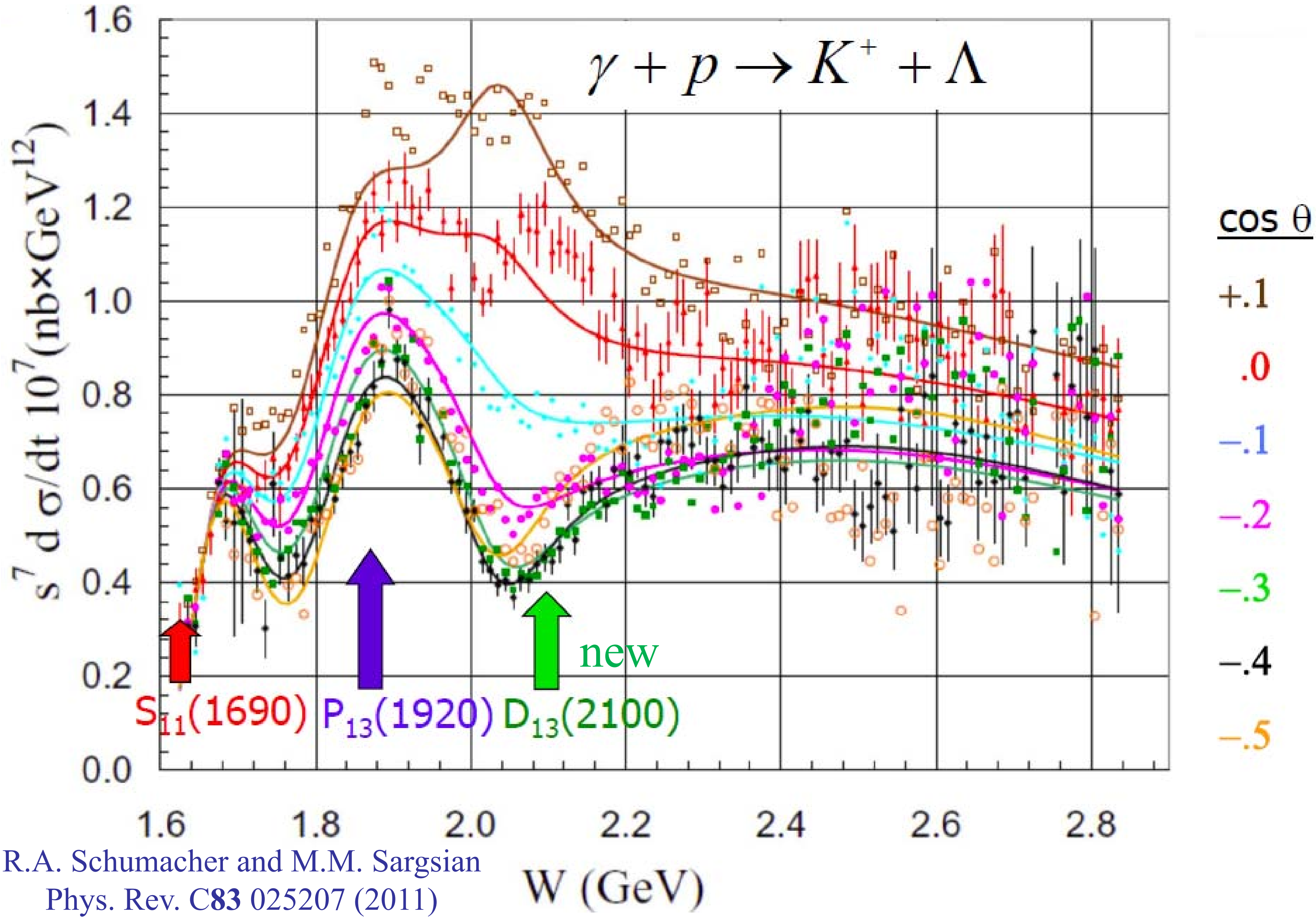
+.1
.0
−.1
−.2
−.3
−.4
−.5

$s^7\, d\sigma/dt\ 10^7 (\mathrm{nb} \times \mathrm{GeV}^{12})$: 1.6, 1.4, 1.2, 1.0, 0.8, 0.6, 0.4, 0.2, 0.0

W (GeV): 1.6, 1.8, 2.0, 2.2, 2.4, 2.6, 2.8

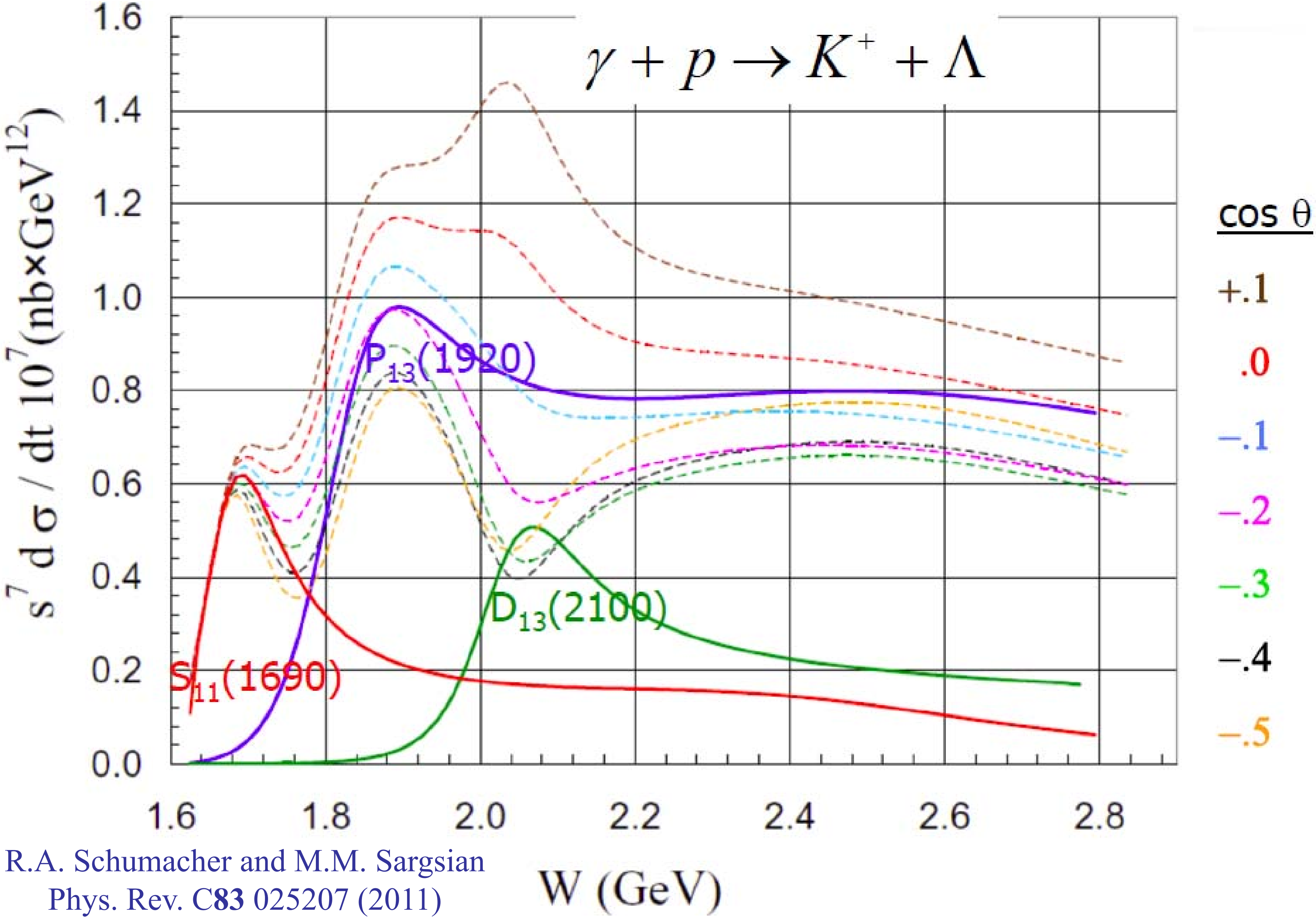
R.A. Schumacher and M.M. Sargsian
Phys. Rev. C**83** 025207 (2011)

Scaled Cross Sections versus W



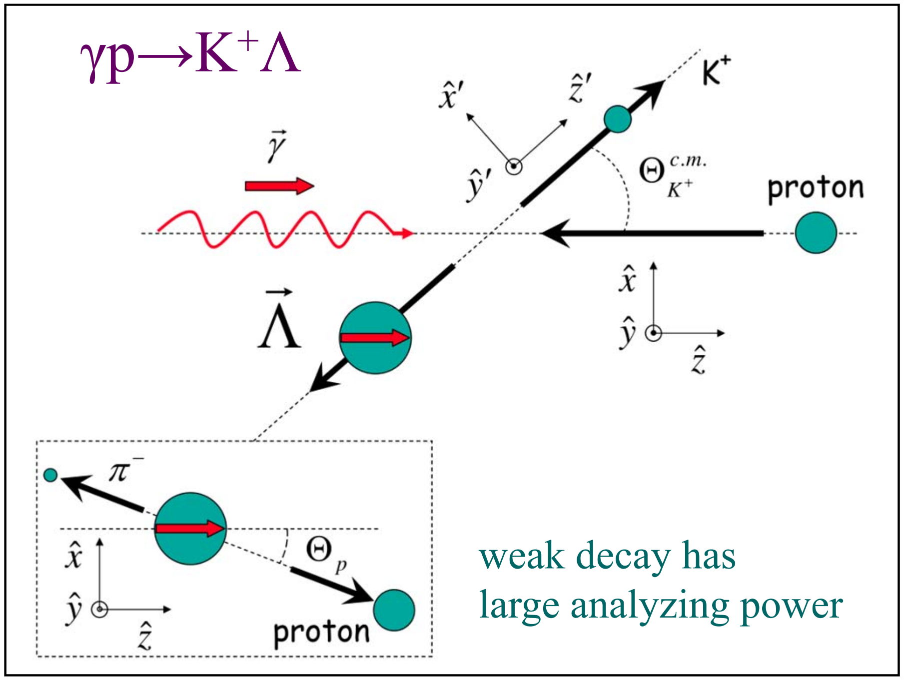
R.A. Schumacher and M.M. Sargsian
Phys. Rev. C**83** 025207 (2011)

Model Fits to the Scaled Cross Sections



R.A. Schumacher and M.M. Sargsian
Phys. Rev. C**83** 025207 (2011)

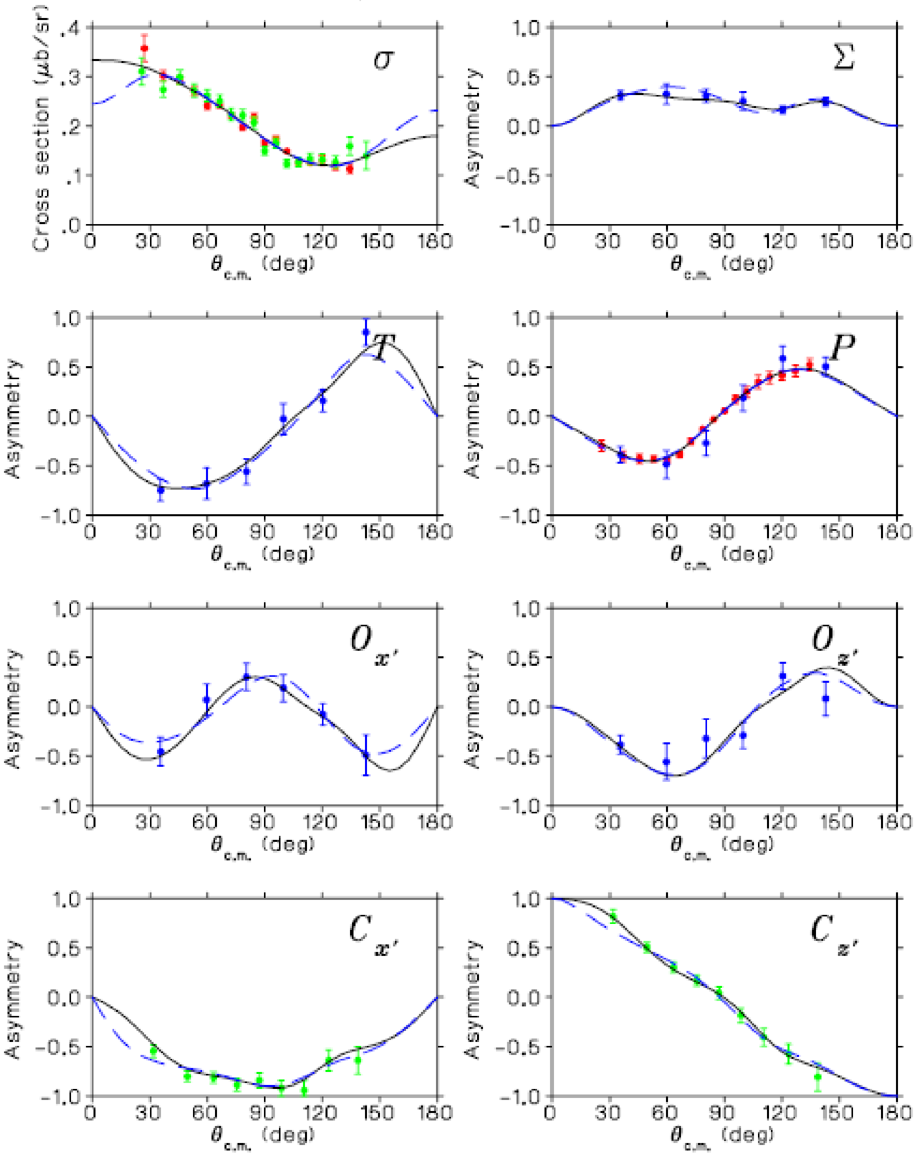
FROST/HD $\vec{\gamma}\vec{N} \rightarrow \pi N, \eta N, K\vec{\Lambda}, K\vec{\Sigma}, N\pi\pi$



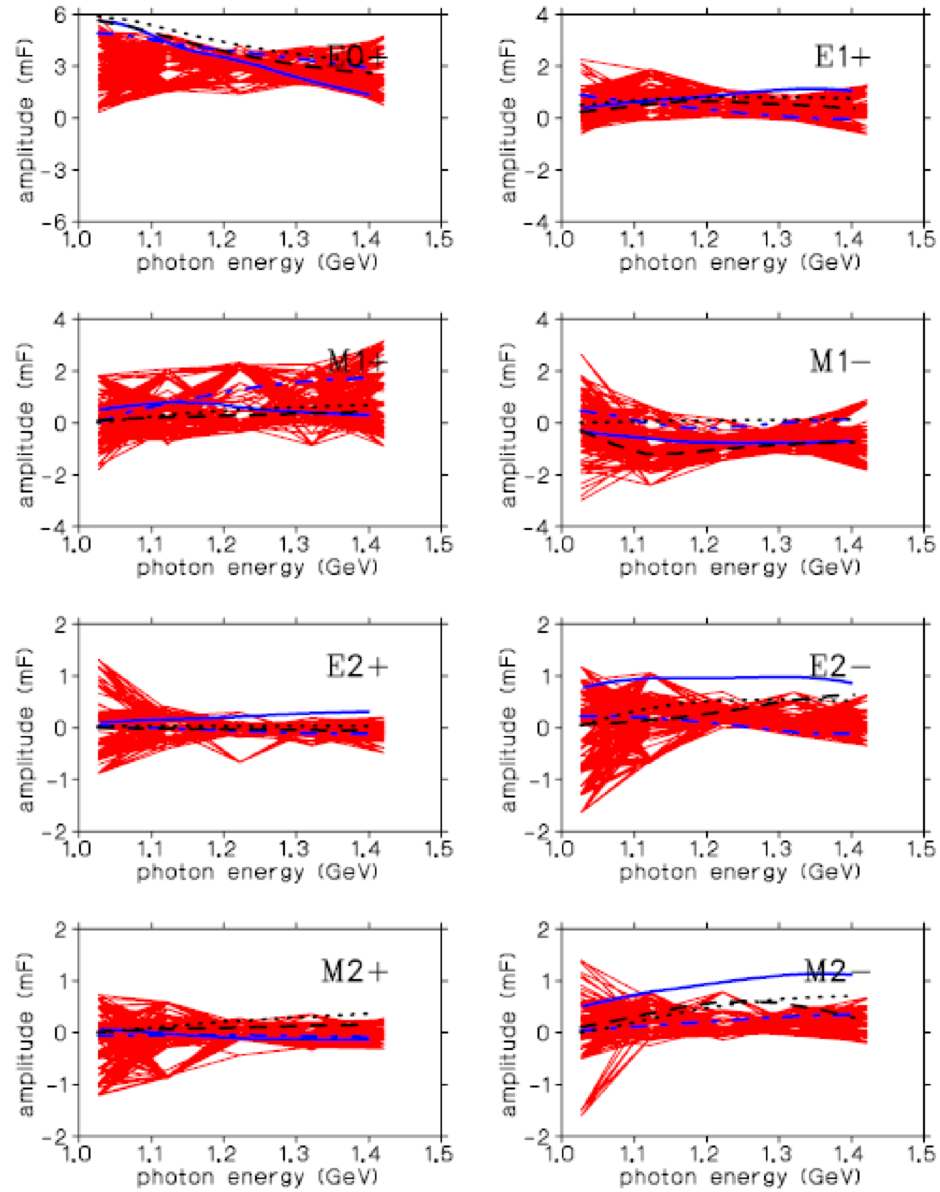
- Process is described by 4 complex, parity conserving amplitudes
- 8 well-chosen measurements are needed to determine amplitude
- For hyperon finals state 16 observables are measured in CLAS ➠ large redundancy in determining the photo-production amplitudes ➠ allows many cross checks and increased accuracy
- 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		$O_{x'}$	

Amplitude Uncertainty in $\vec{\gamma} p \rightarrow K^+ \vec{\Lambda}$



A. Sandorfi et al., J. Phys. G 38 (2011) 053001



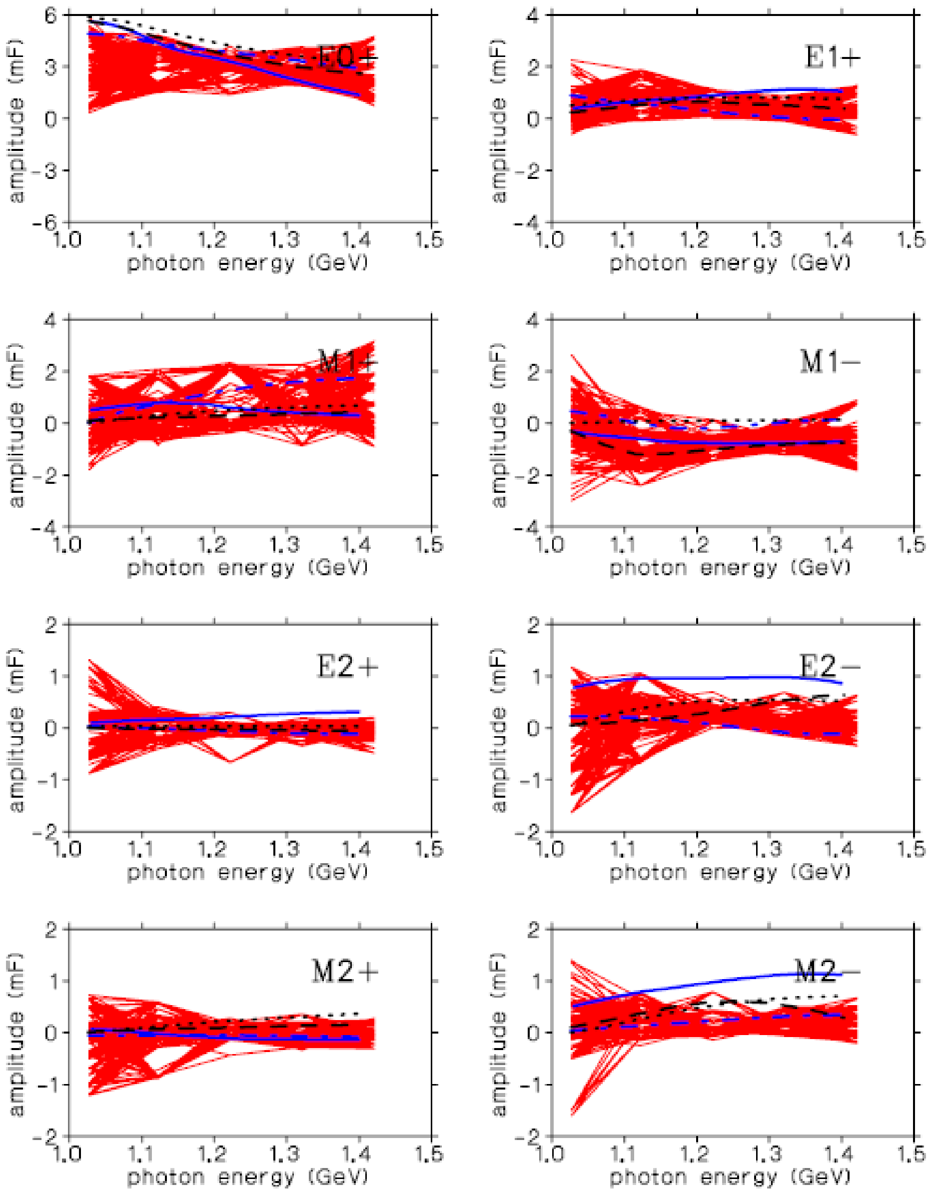
CLAS (g1c, g11a) and GRAAL

σ, $C_{x'}$, $C_{z'}$, σ , P and Σ, T, P, $O_{x'}$, $O_{z'}$

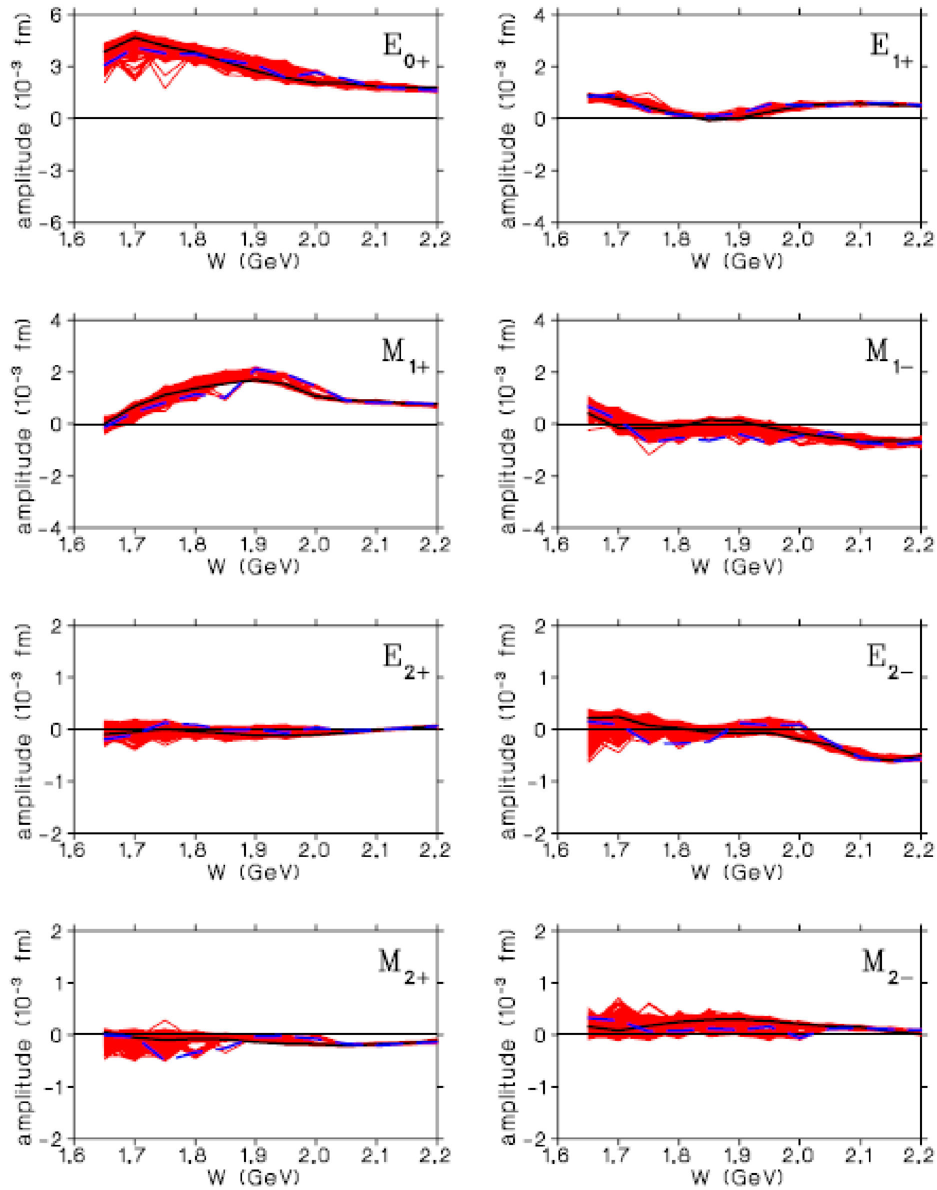
Real parts of the PWA multipoles

BoGa (dot-dashed), MAID (dashed), SAID (dotted), JSLT (solid)

Amplitude Uncertainty in $\vec{\gamma}\vec{p} \to K^+\vec{\Lambda}$



A. Sandorfi et al., J. Phys. G 38 (2011) 053001



Real parts of the PWA multipoles

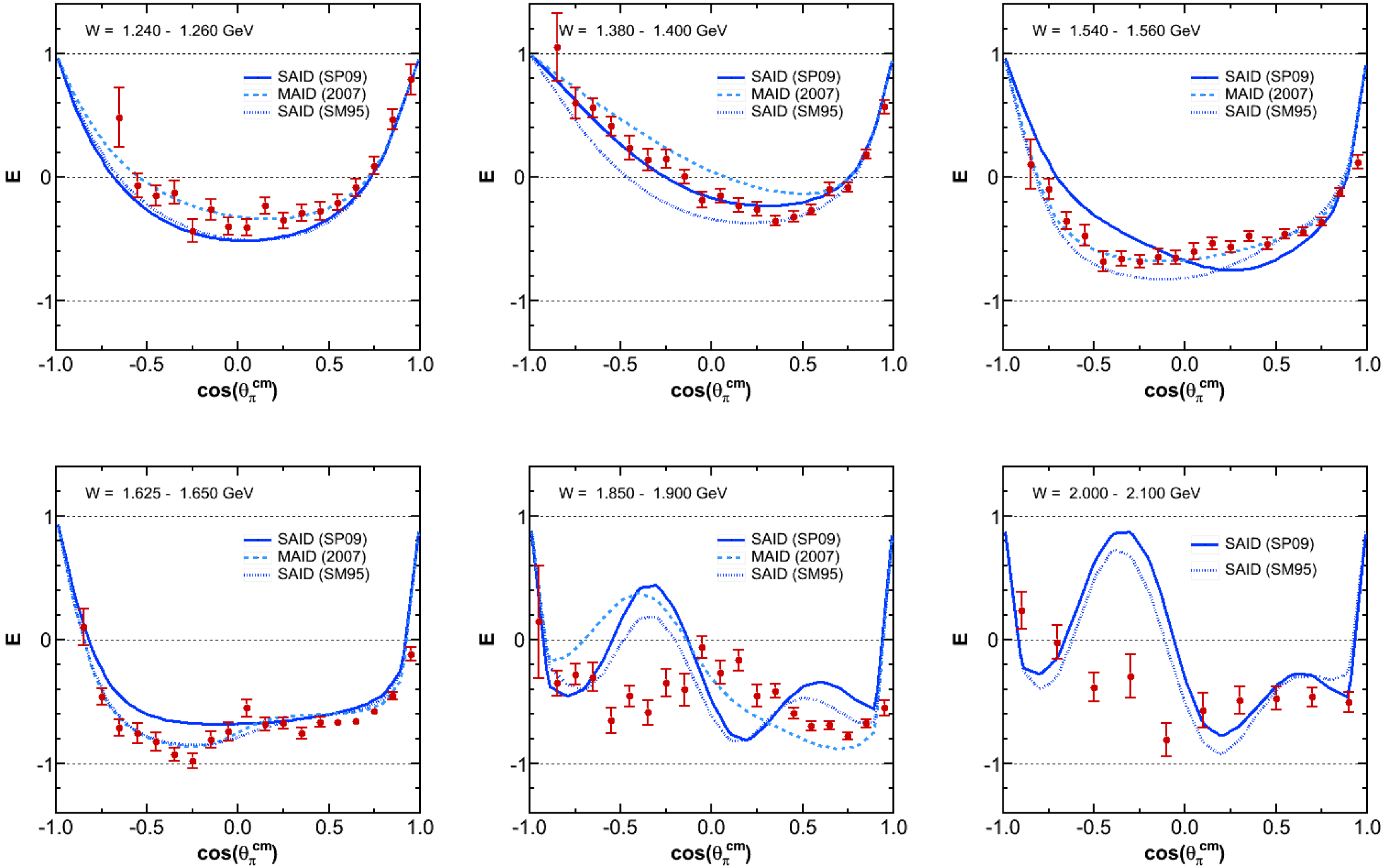
with 8 observables D_{13} excluded and with 16 observables P_{11} to be validated

$\vec{\gamma}(\vec{p},\pi^+)n$ - Selected Preliminary Results for E

Circular polarized beam and longitudinally polarized target

S. Strauch

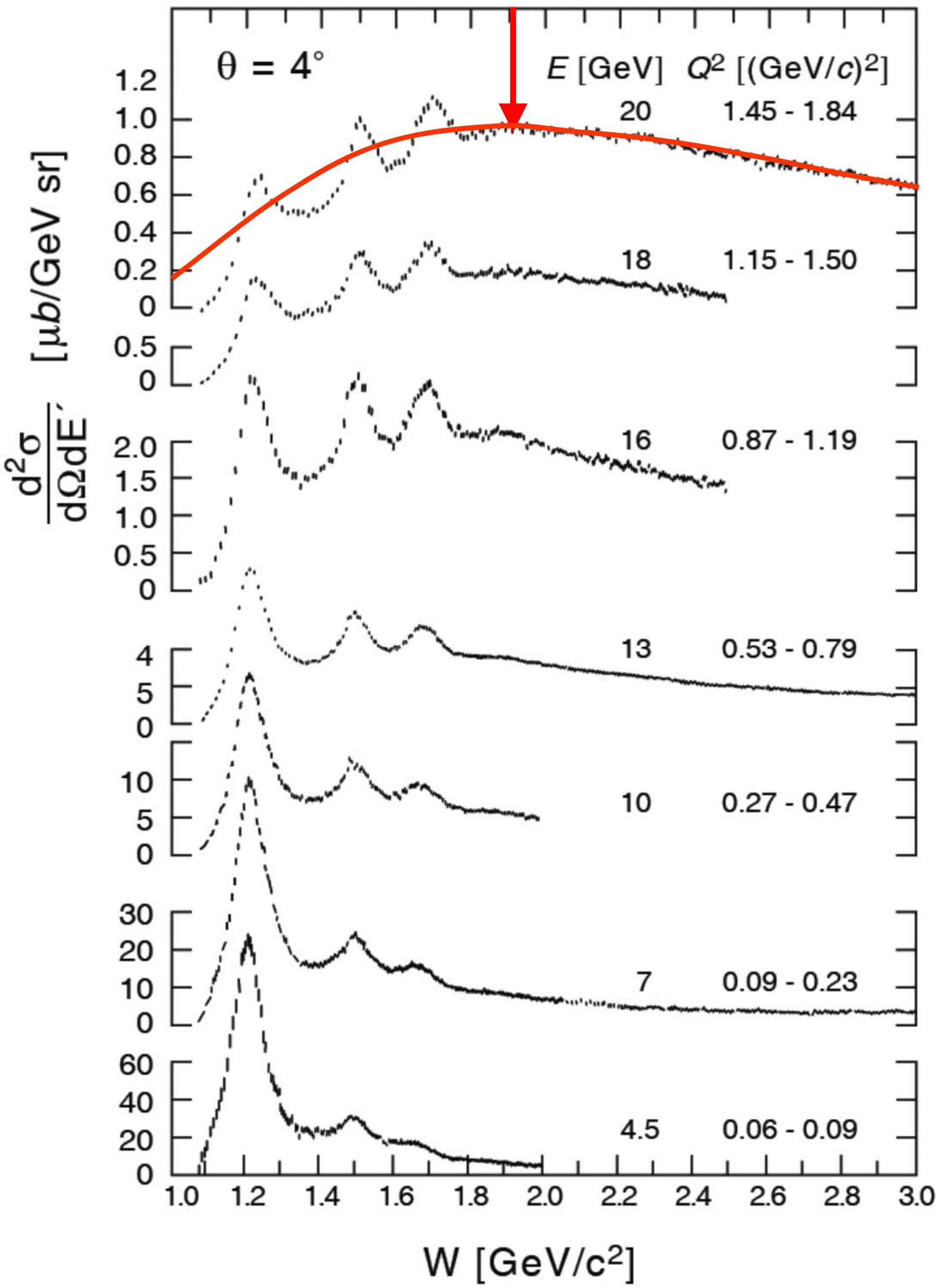
E



SP09: M. Dugger, et al., Phys. Rev. C 79, 065206 (2009); SM95: R. A. Arndt, I. I. Strakovsky, R. L. Workman, Phys. Rev. C 53, 430 (1996); MAID: D. Drechsel, S.S. Kamalov, L. Tiator Nucl. Phys. A645, 145 (1999)

Electron Scattering

Baryon Excitations and Quasi-Elastic Scattering



PRL **16** (1970) 1140, PR **D4** (1971) 2901
E.D. Bloom and F.J. Gilman

W = 1.9 GeV

E' = 17.6 GeV

ν = 2.37 GeV

Q^2 = 1.72 GeV

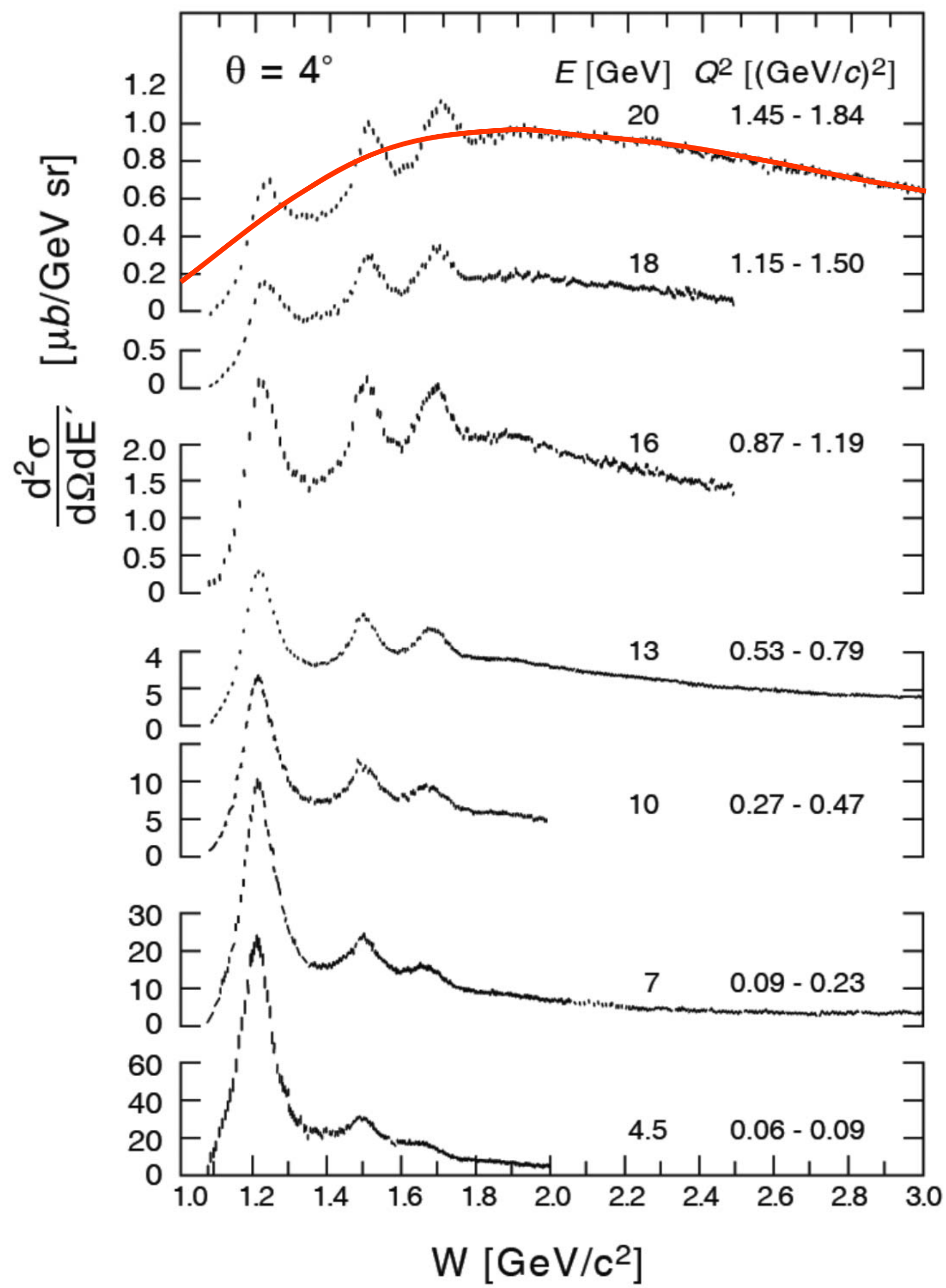
m_q = 0.36 GeV $\quad m_q = Q^2/2\nu$

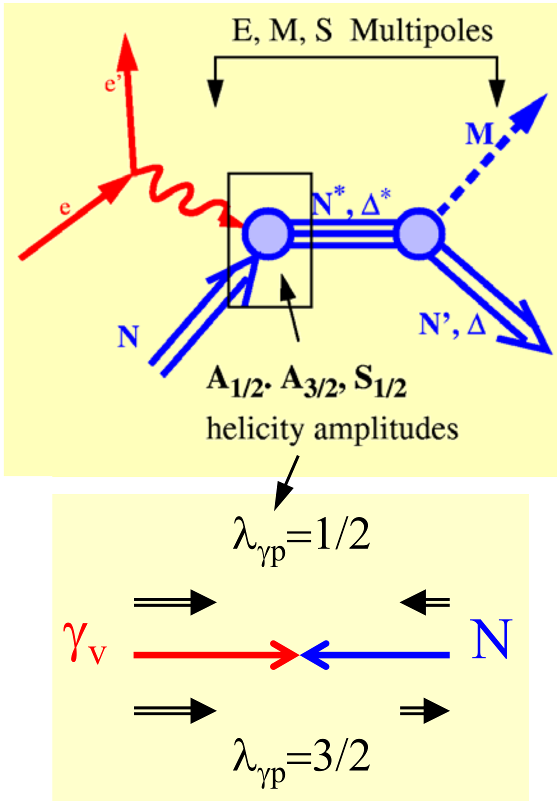
p_F = 0.67 GeV

r_F = 0.79 fm $\quad \Delta r_F = \frac{\hbar c}{\Delta p_F} * \sqrt{9\pi/2}$

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

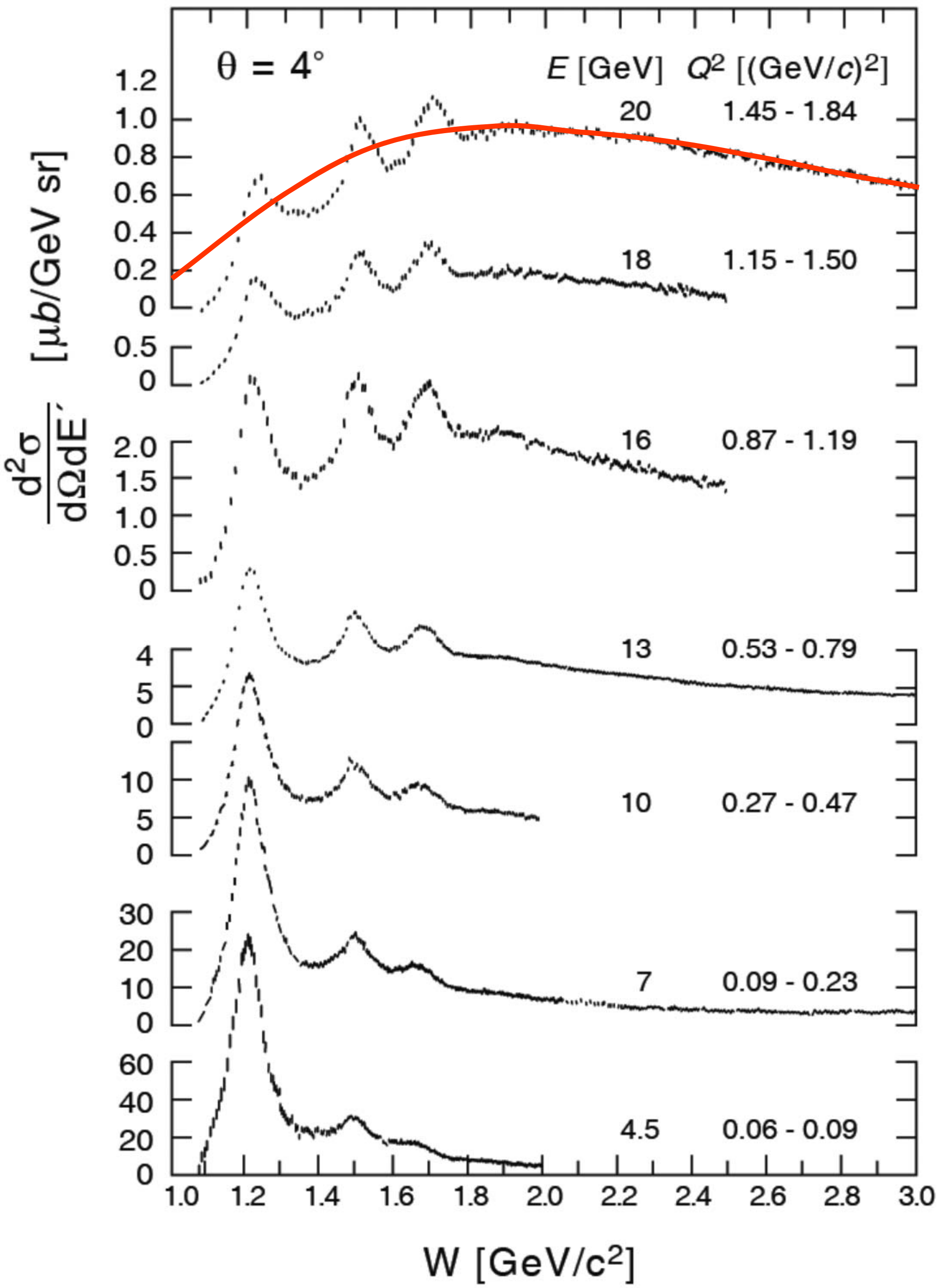
Baryon Excitations and Quasi-Elastic Scattering



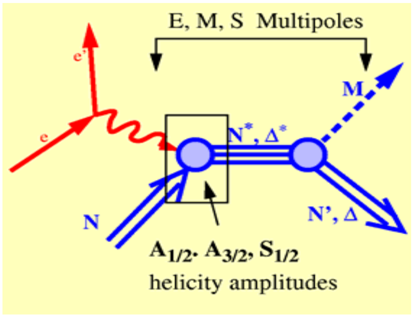


Deep Inelastic Scattering
S. Stein et al., PR **D22** (1975) 1884

Baryon Excitations and Quasi-Elastic Scattering



hard and confined

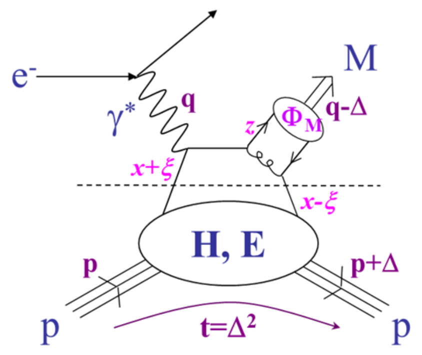


Elastic Form Factors

Transition Form Factors

hard

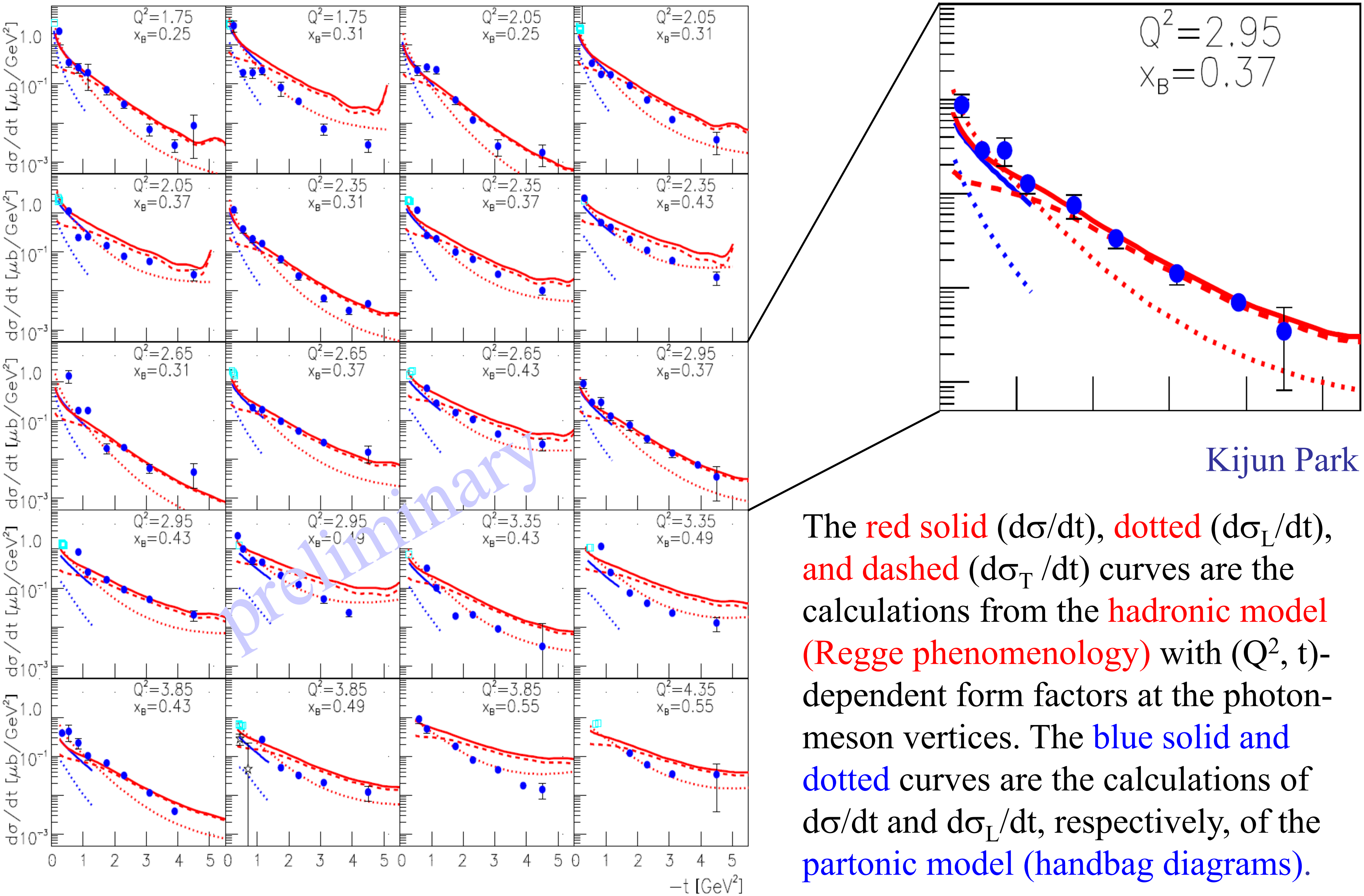
soft



Deep Inelastic Scattering

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

Deep exclusive π^+ electroproduction off the proton



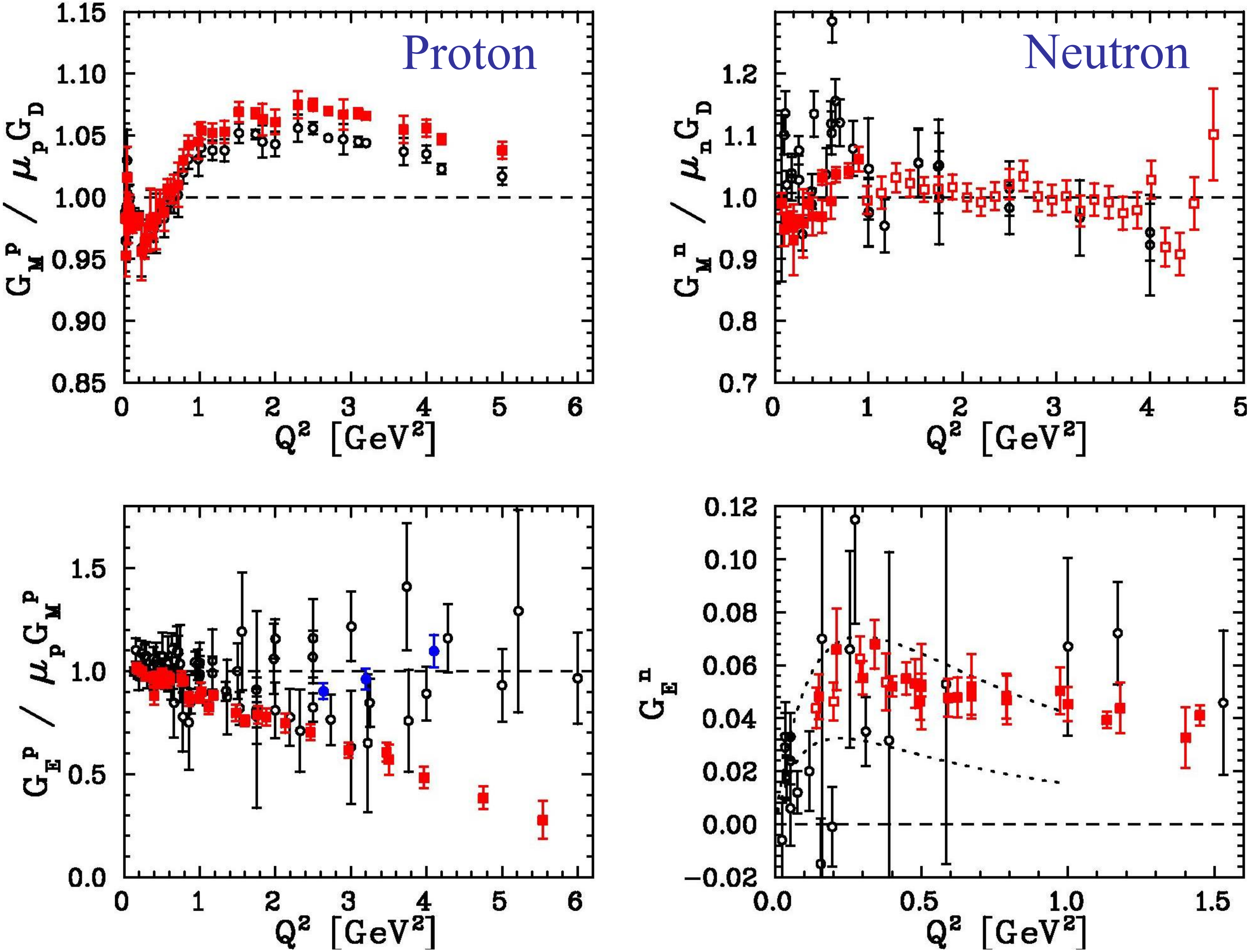
Kijun Park

The red solid ($d\sigma/dt$), dotted ($d\sigma_L/dt$), and dashed ($d\sigma_T/dt$) curves are the calculations from the 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 the partonic model (handbag diagrams).

Elastic Form Factors

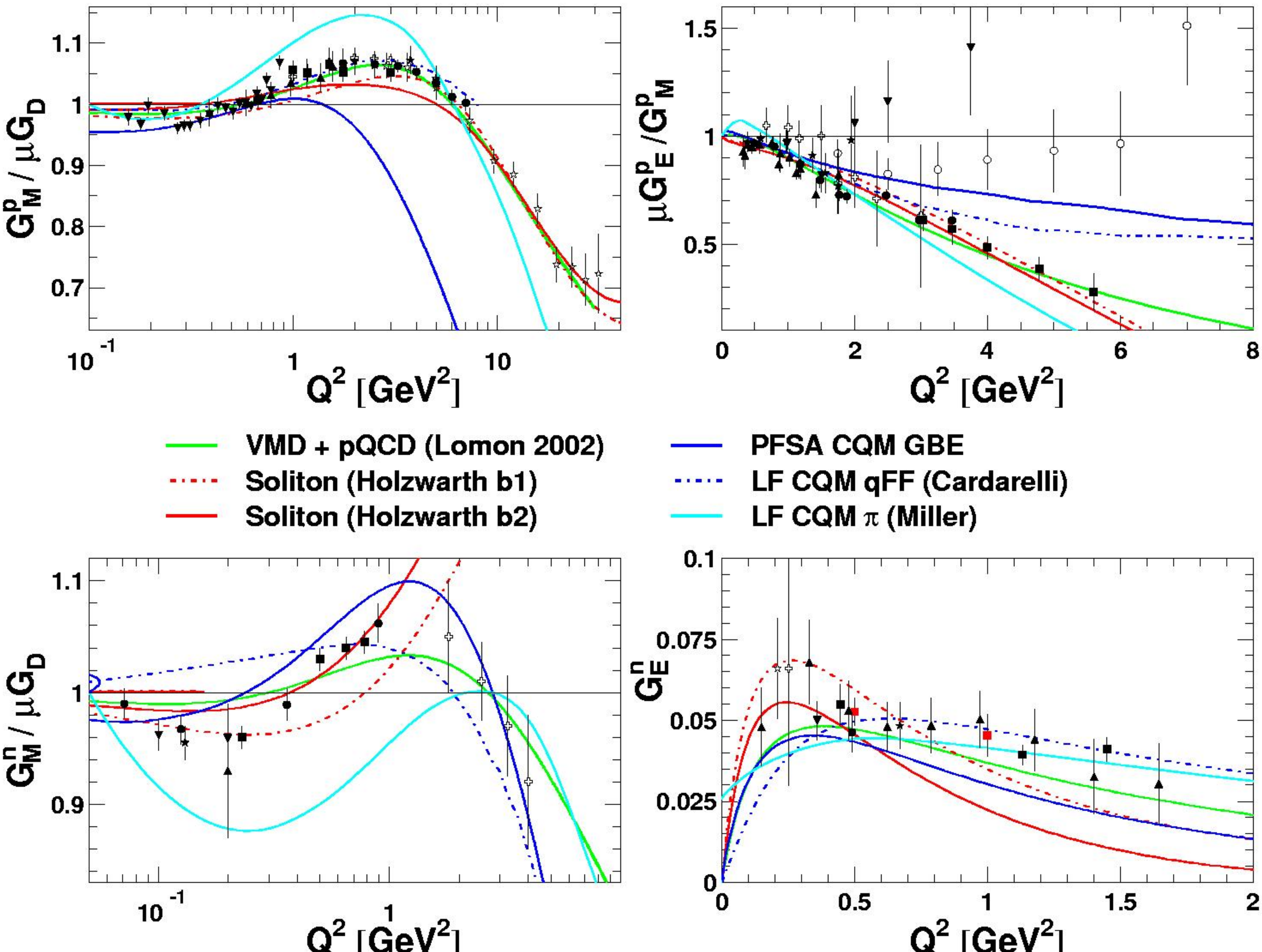
Nucleon Form Factors: Last Ten Years

J. Arrington



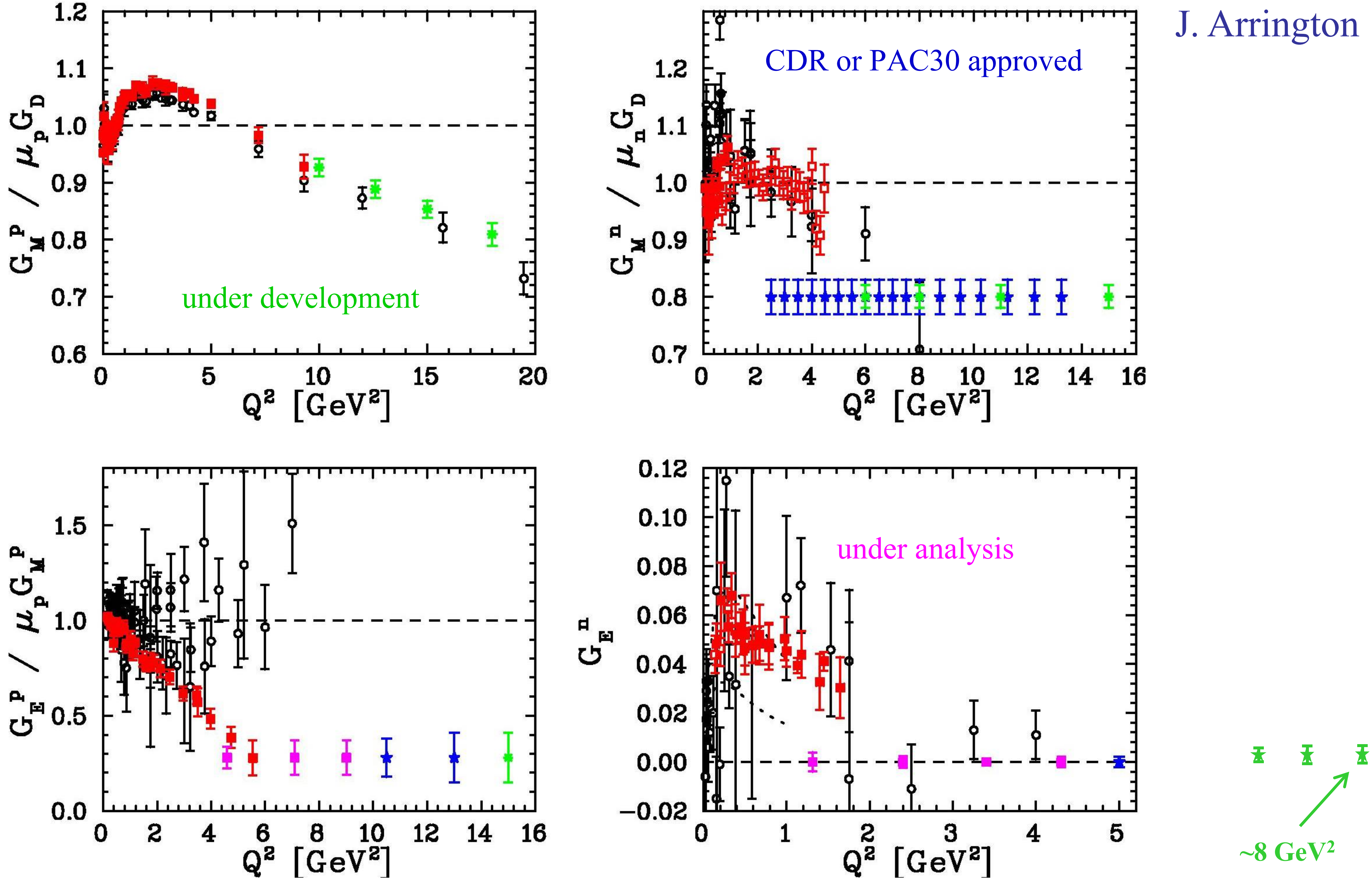
Small Sample of Recent Calculations

J. Arrington



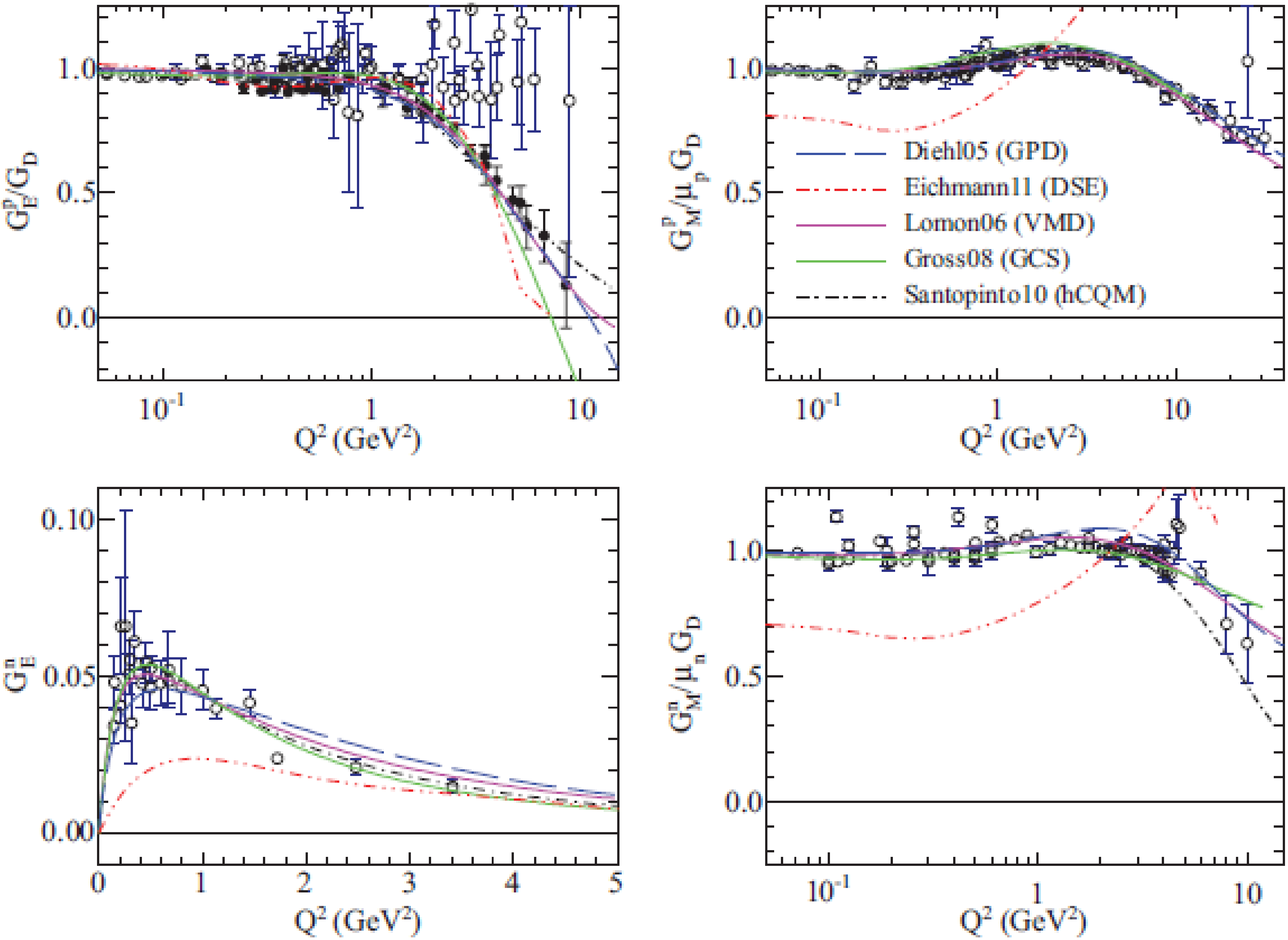
Extensions with JLab 12 GeV Upgrade

J. Arrington



Most Recent Proton Form Factor Overview

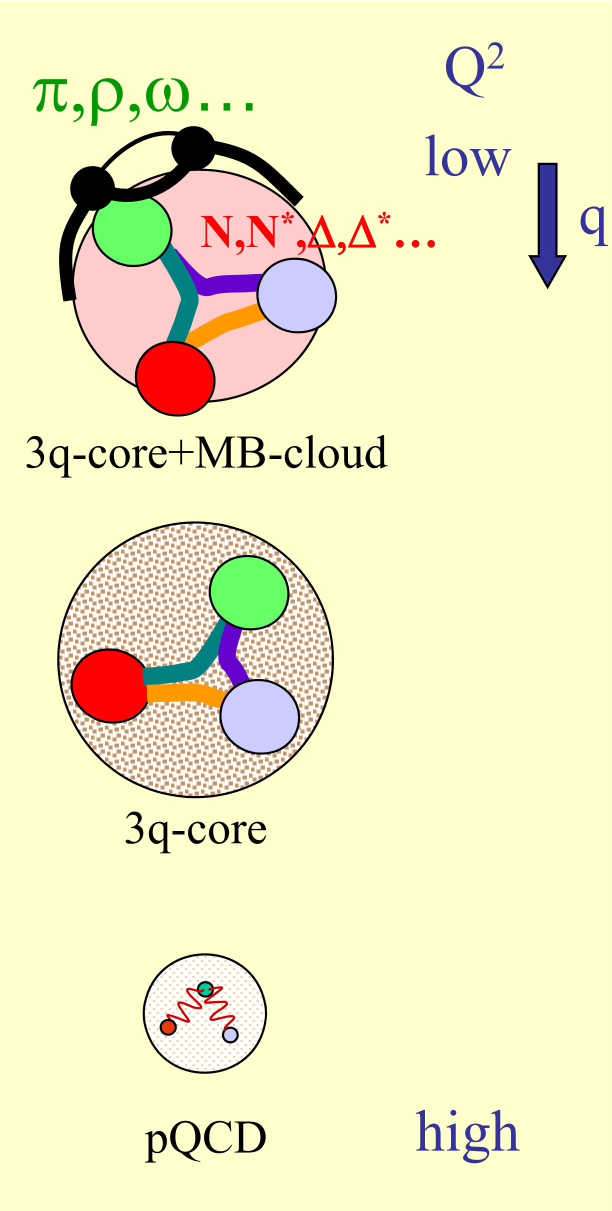
V. Punjabi



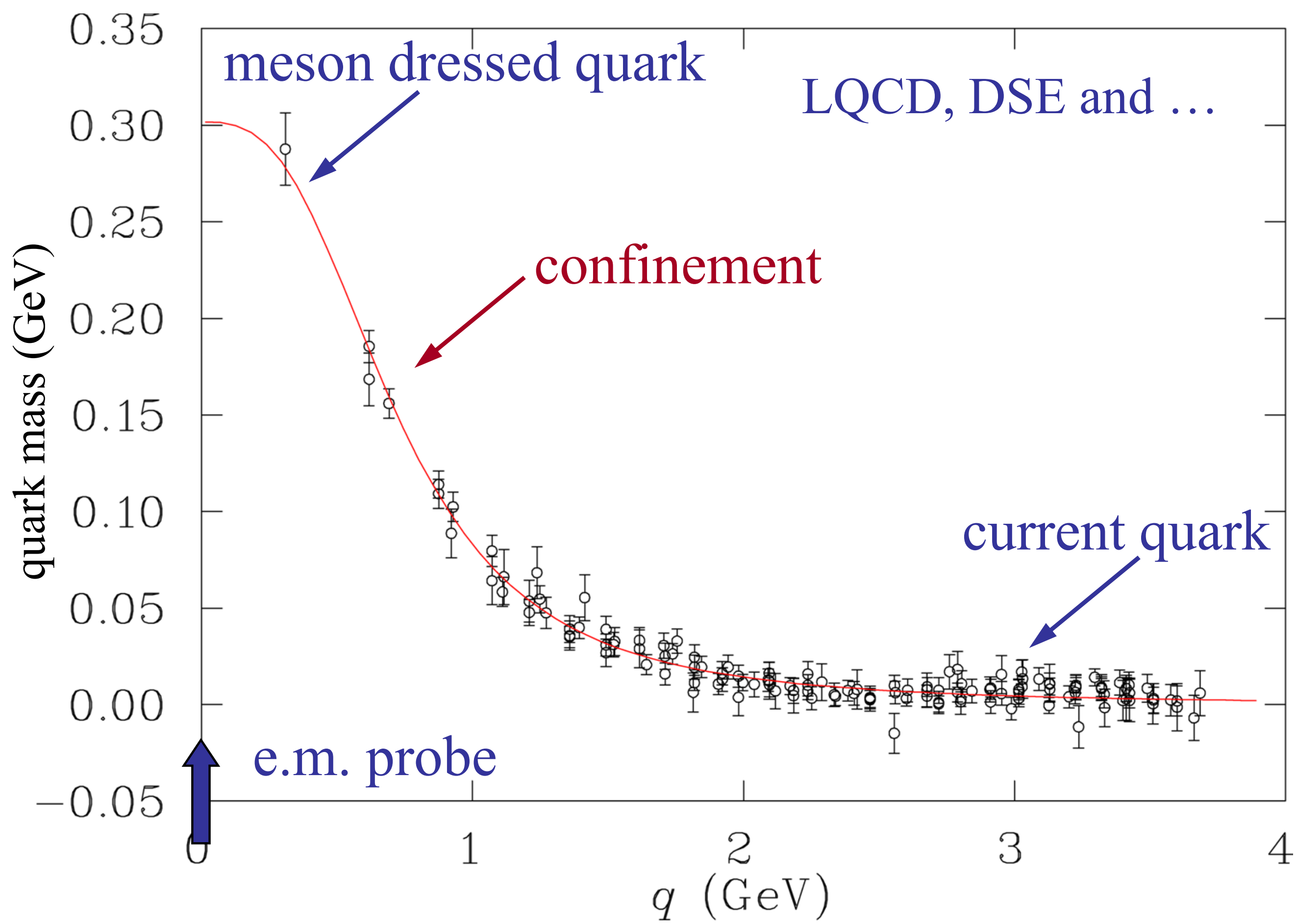
Phys. Rev. C 85, 045203 (2012)

Transition Form Factors

Hadron Structure with Electromagnetic Probes

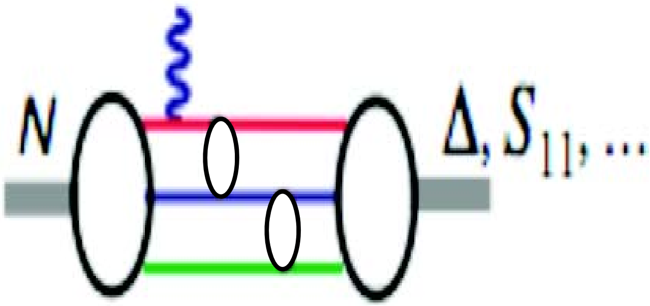


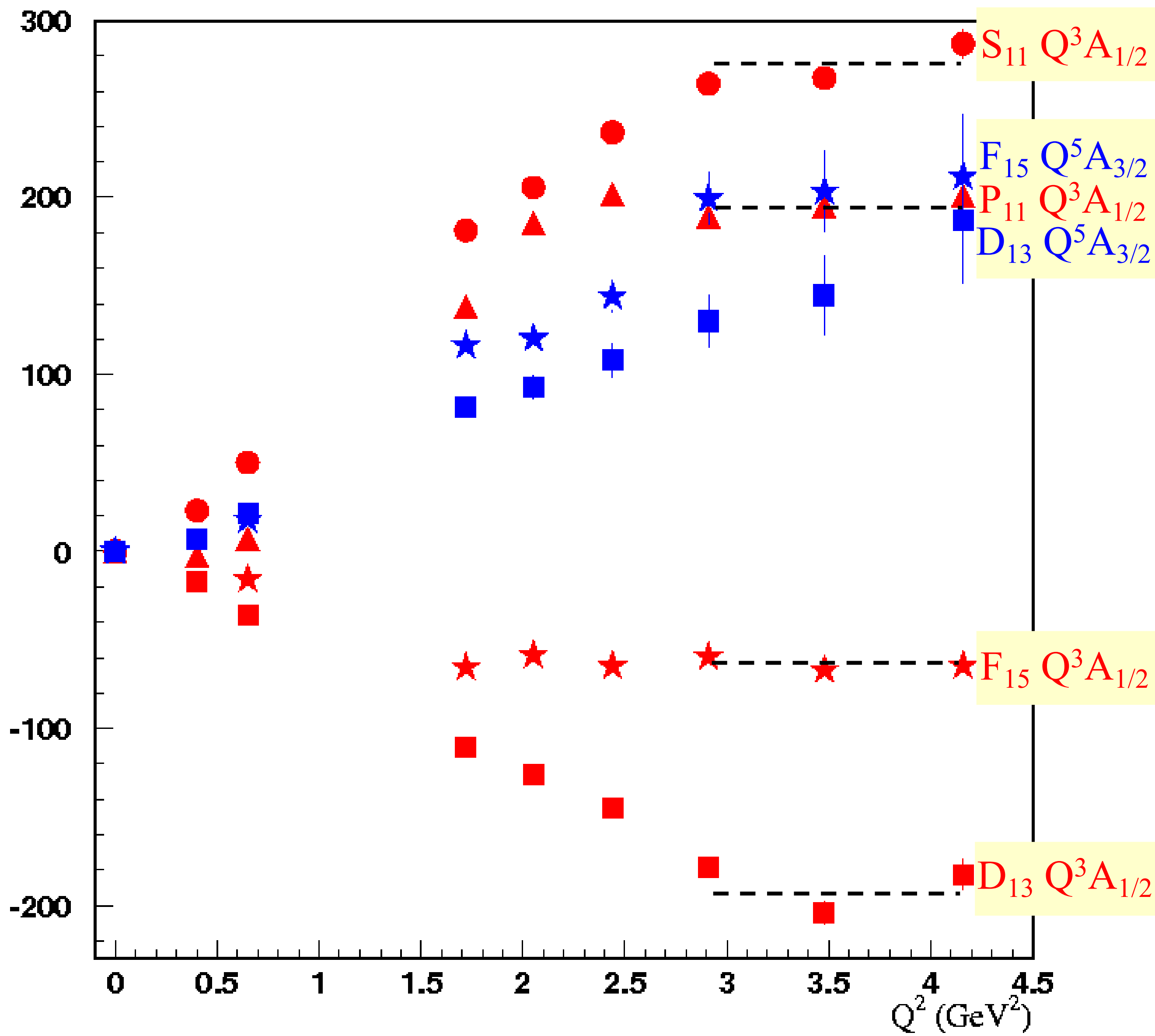
- Study the structure of the nucleon spectrum in the domain where dressed quarks are the major active degree of freedom.
- Explore the formation of excited nucleon states in interactions of dressed quarks and their emergence from QCD.



Evidence for the Onset of Scaling?

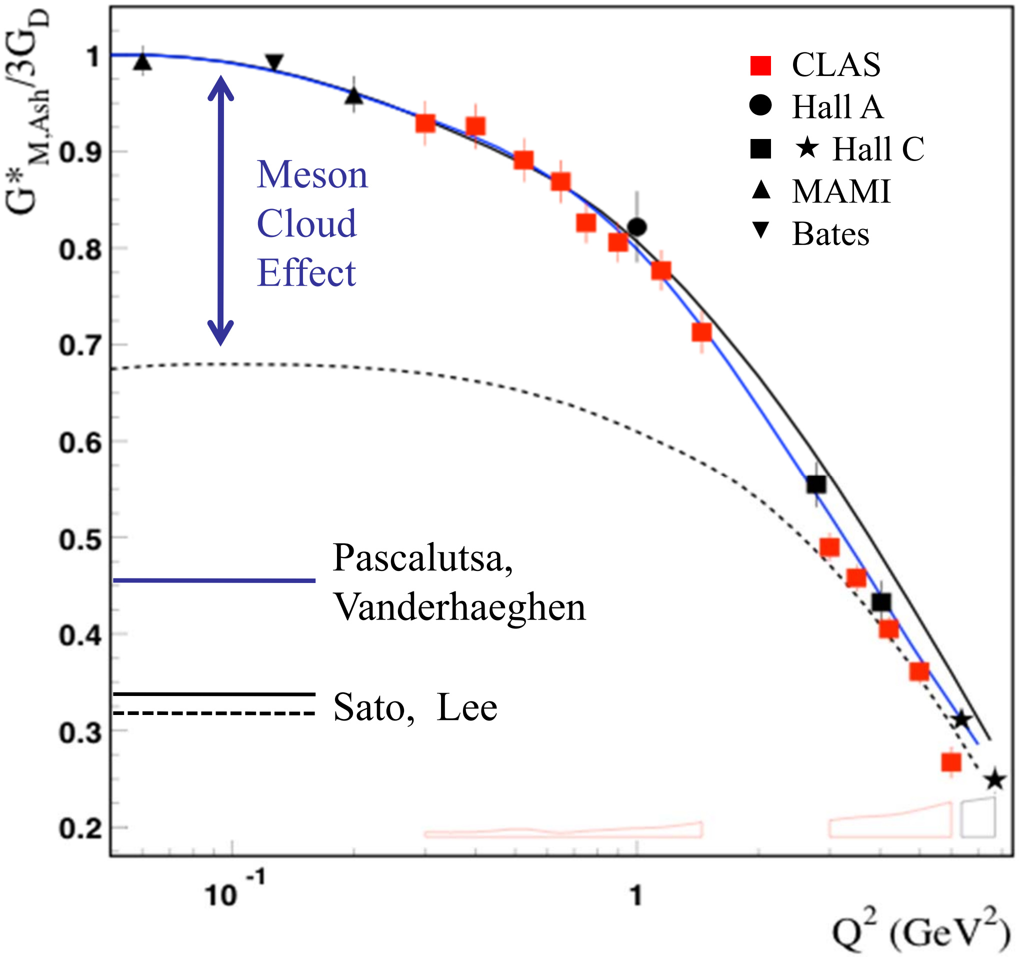
Phys. Rev. C80, 055203 (2009)



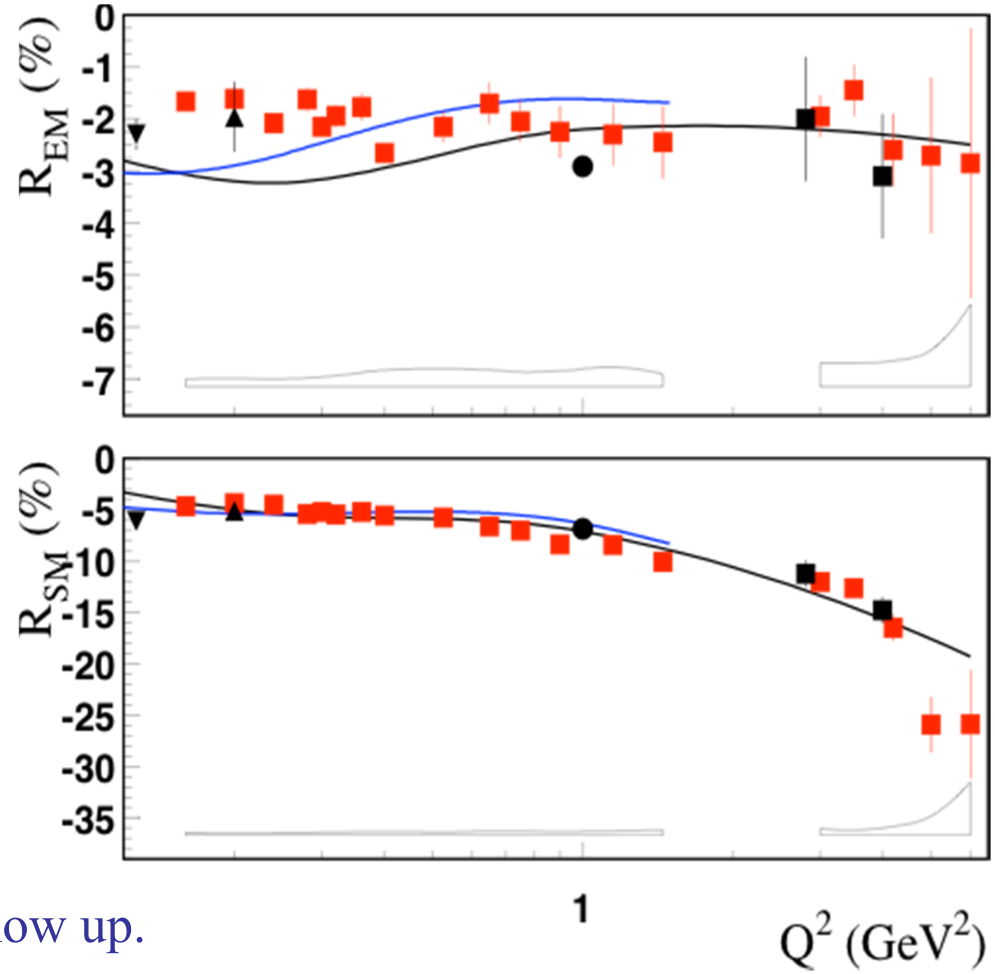


- $A_{1/2}$ α $1/Q^3$
- $A_{3/2}$ α $1/Q^5$
- G_M^* α $1/Q^4$

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

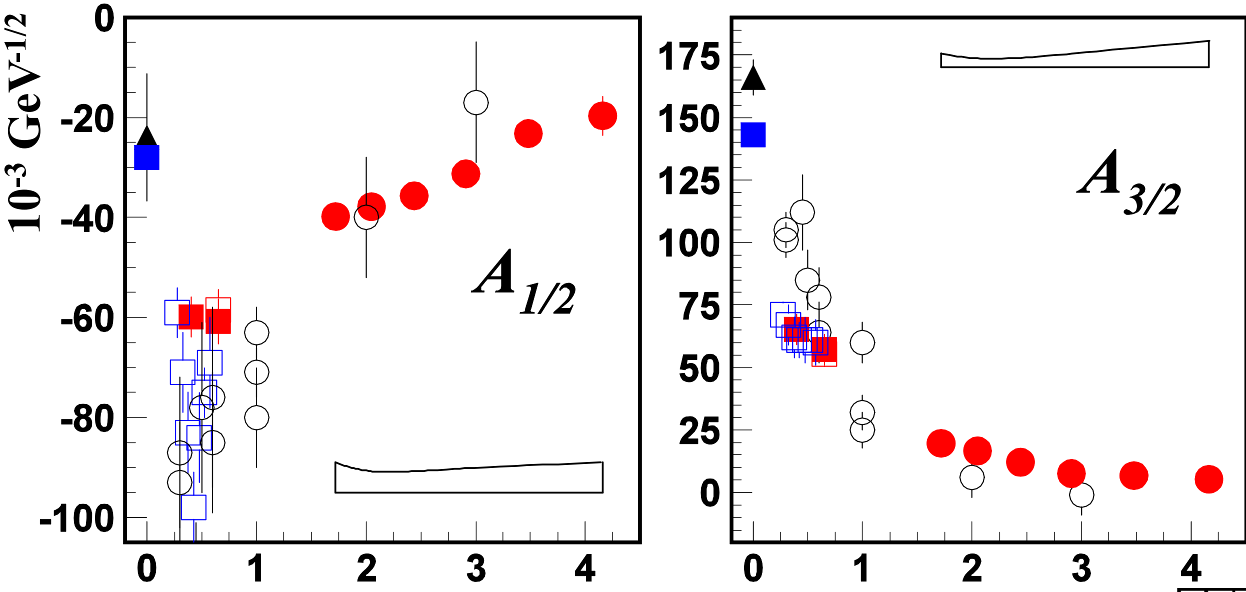


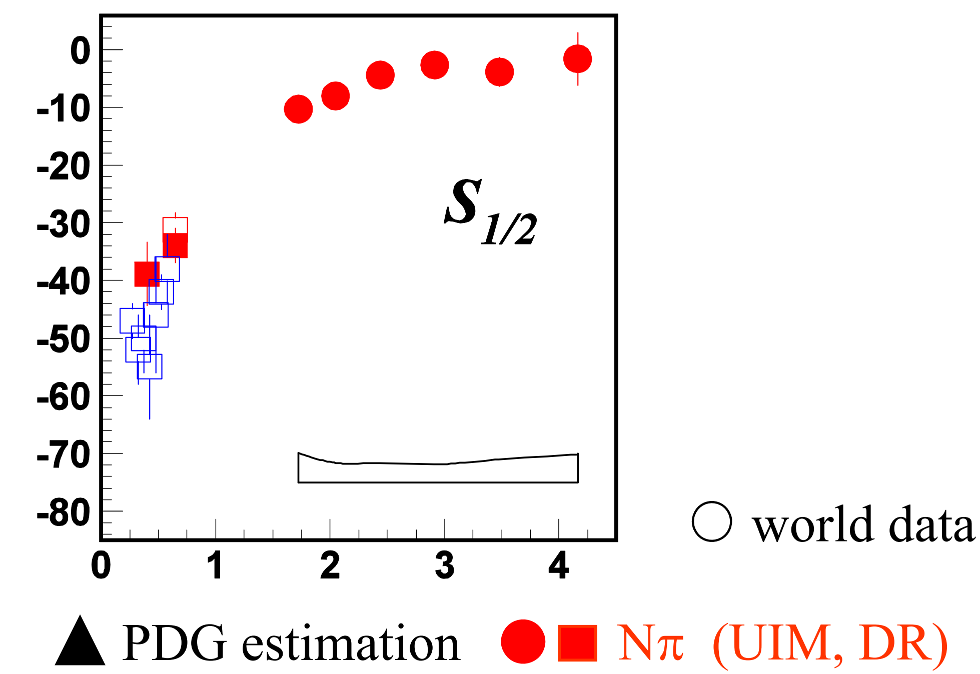
Phys. Rev. Lett. 97, 112003 (2006)



- New trend towards pQCD behavior does not show up.
  - $R_{EM} \rightarrow +1$
  - $G^*_M \rightarrow 1/Q^4$
- CLAS12 can measure G^*_M, R_{EM}, and R_{SM} up to Q^2~12 GeV².

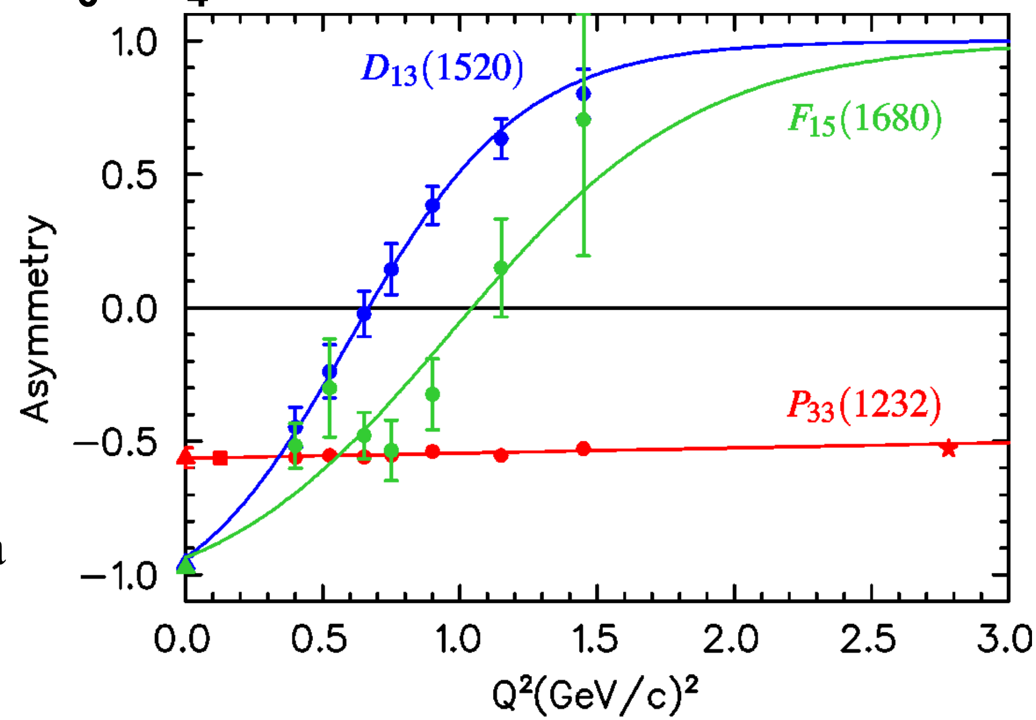
N(1520)D_{13} Helicity Asymmetry





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

L. Tiator



Phenomenological Analyses

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

see White Paper Sec. VII

- Coupled-Channel Approach (EBAC, Argonne-Osaka Collaboration (AOC))

see White Paper Sec. VIII

Phenomenological Analyses in Single Meson Production

Unitary Isobar Model (UIM)

Nonresonant amplitudes: gauge invariant Born terms consisting of *t*-channel exchanges and *s*- / *u*-channel nucleon terms, reggeized at high W.
πN rescattering processes in the final state are taken into account in a K-matrix approximation.

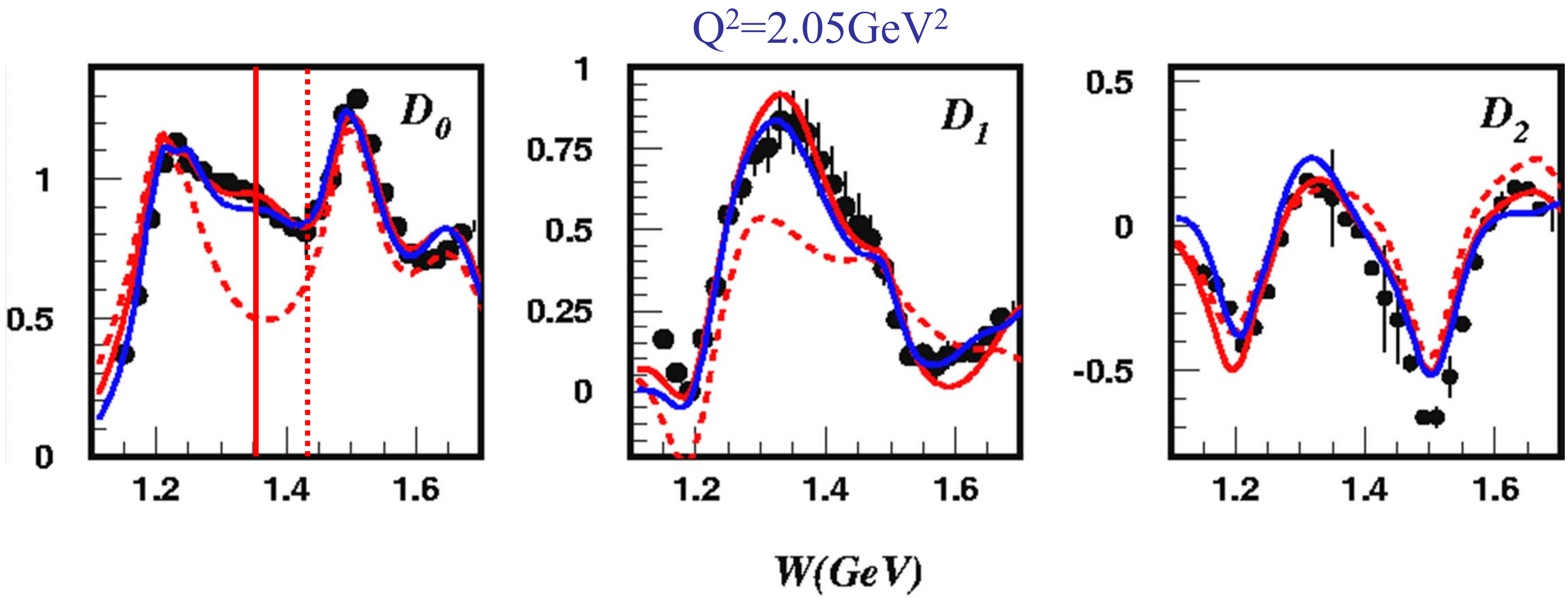
Fixed-*t* Dispersion Relations (DR)

Relates the real and the imaginary parts of the six invariant amplitudes in a model-independent way. The imaginary parts are dominated by resonance contributions.

see White Paper Sec. VII

Legendre Moments of Unpolarized Structure Functions

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



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

I. Aznauryan —— DR fit

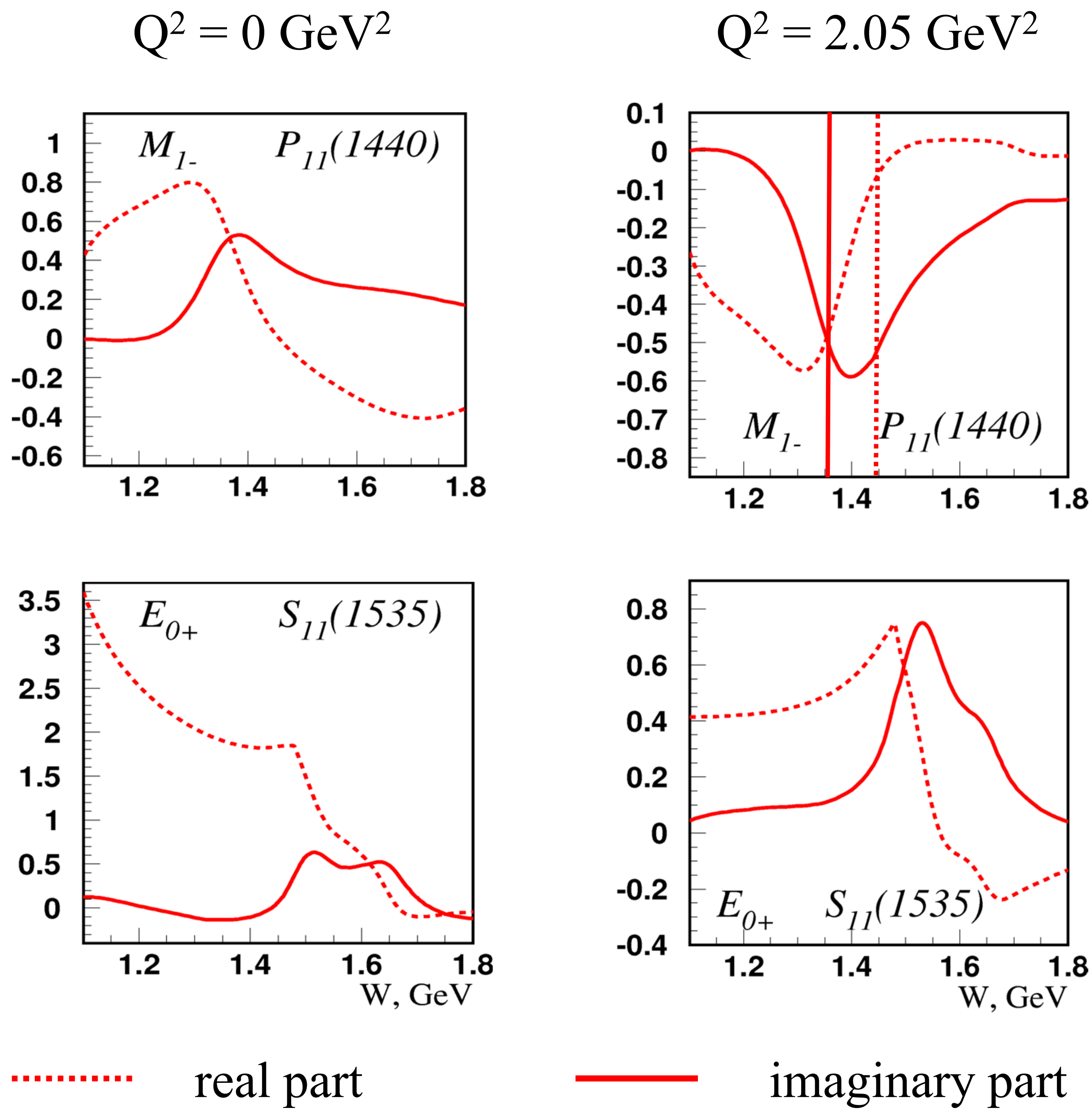
I. Aznauryan - - - DR fit w/o P_{11}

I. Aznauryan —— UIM fit

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

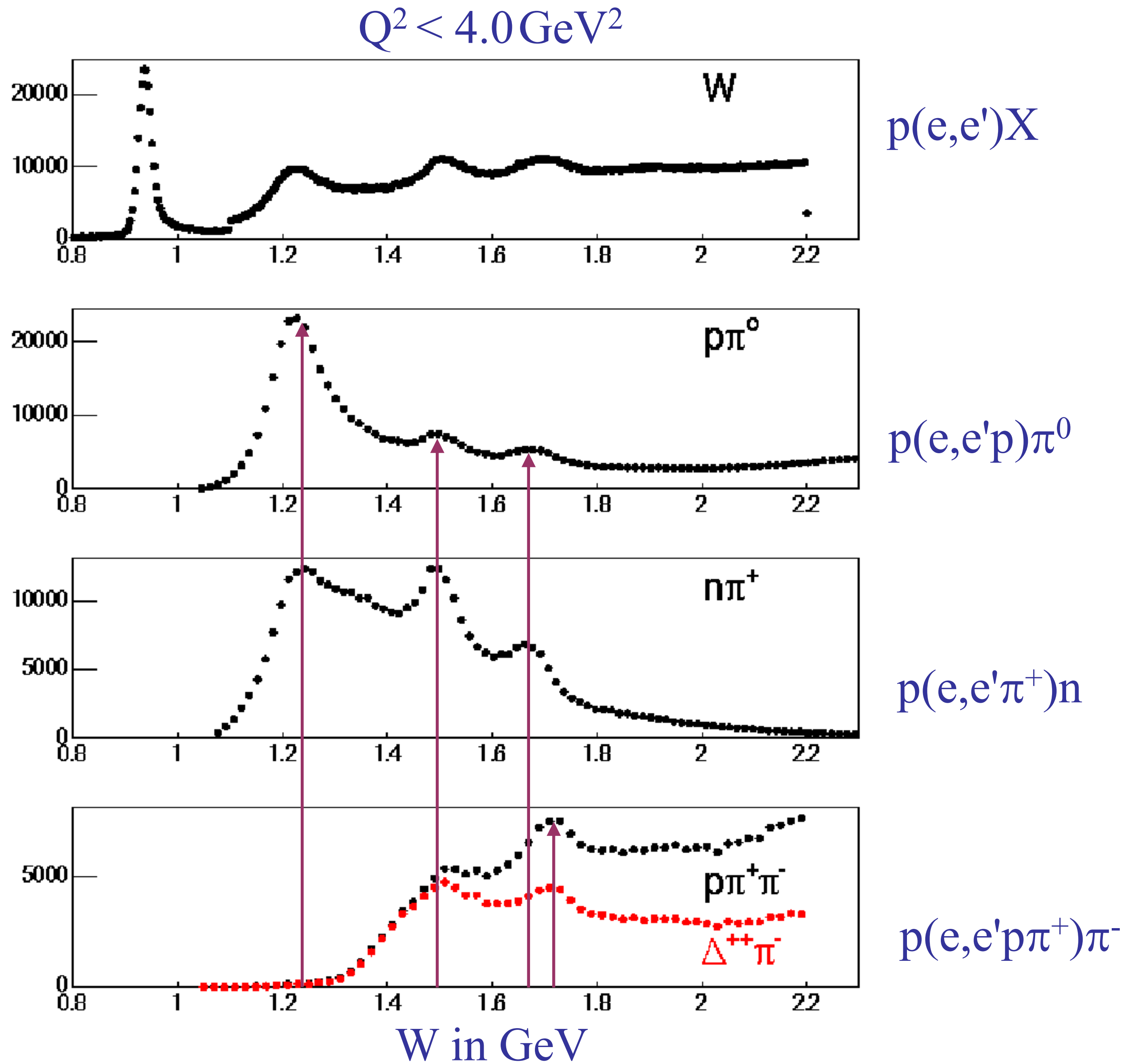
Energy-Dependence of π^+ Multipoles for P_{11}, S_{11}

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

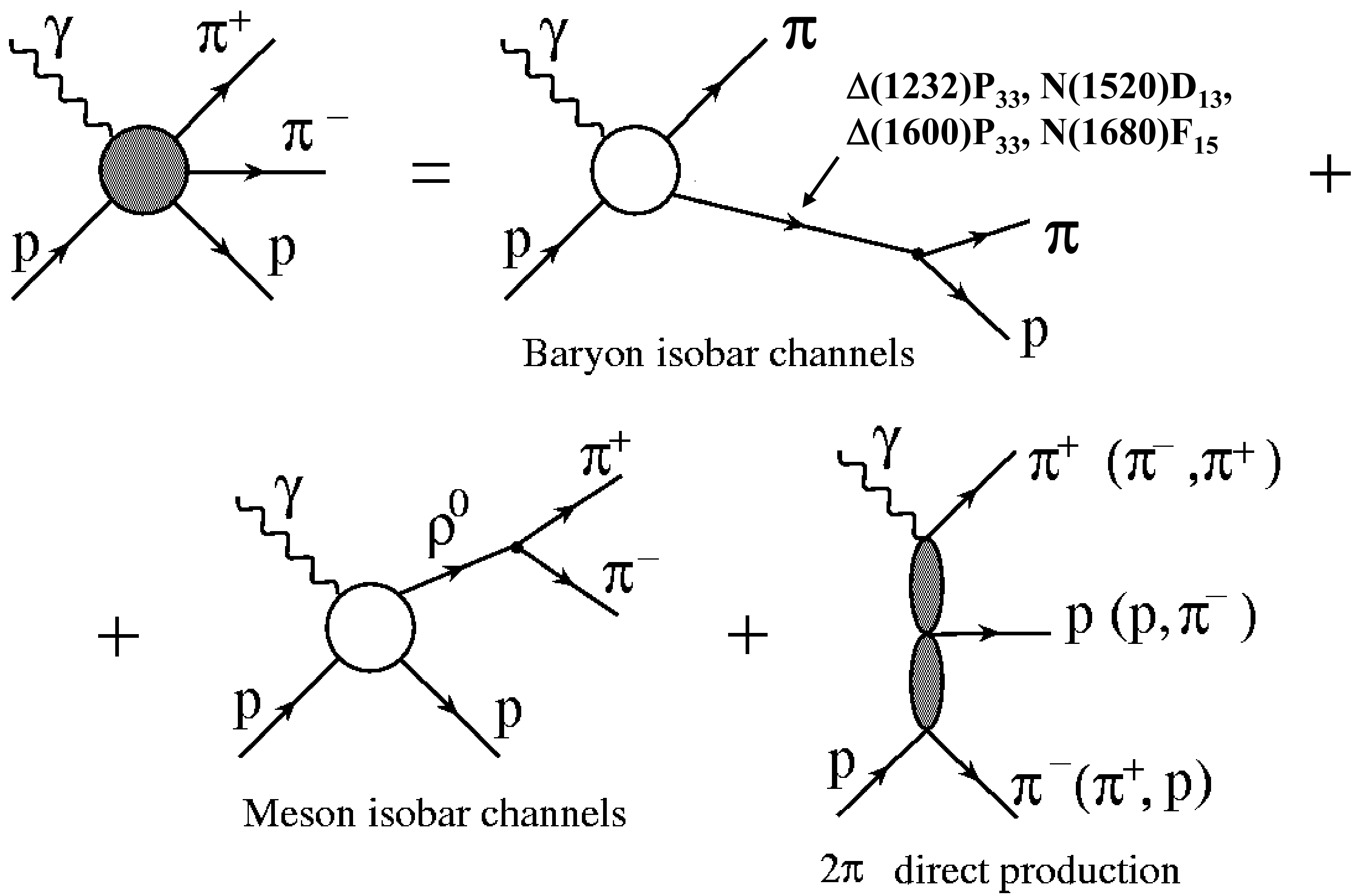


Nucleon Resonances in Nπ and Nππ Electroproduction

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



JM Model Analysis of the $p\pi^+\pi^-$ Electroproduction

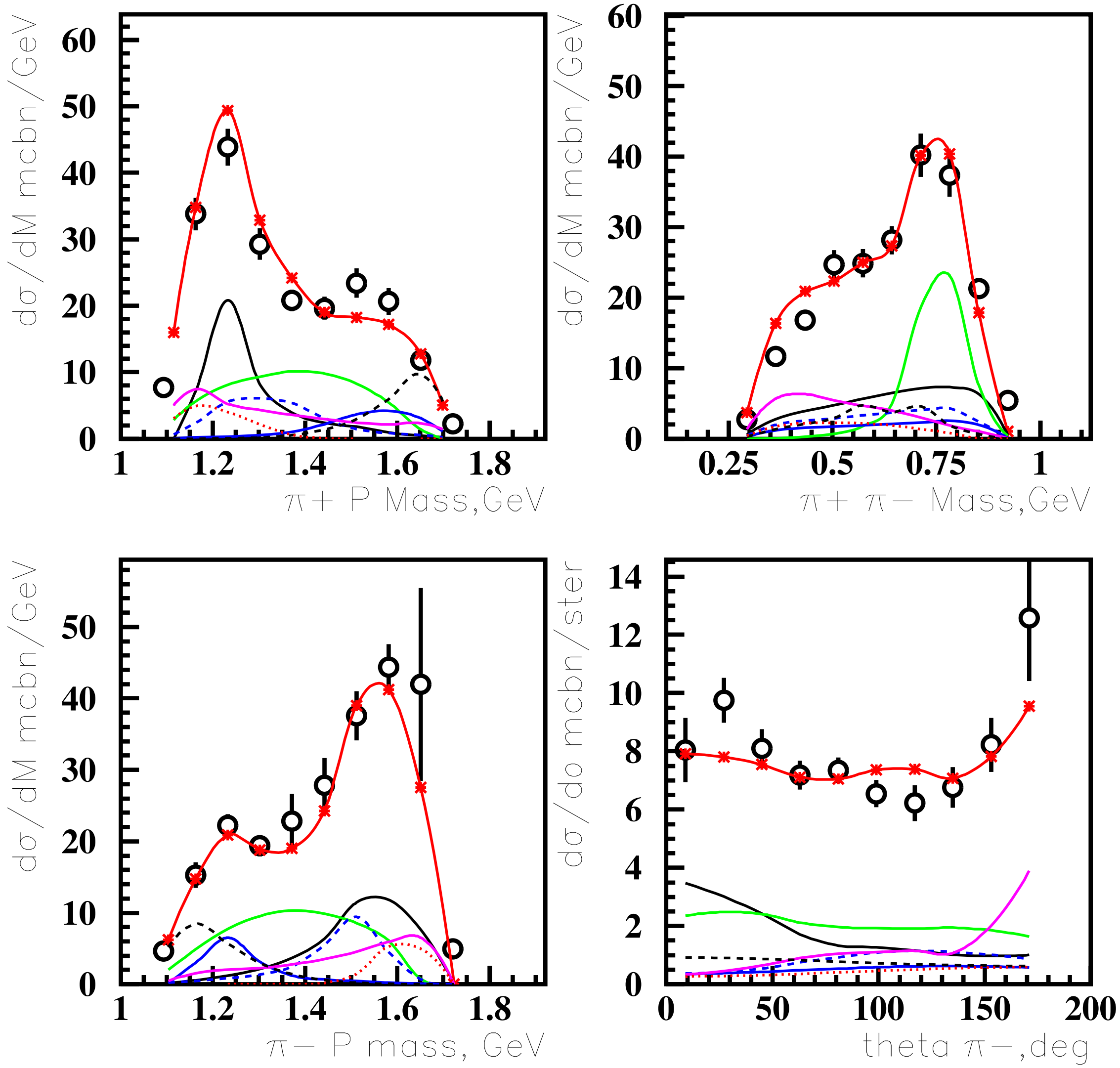


see White Paper Sec. VII

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

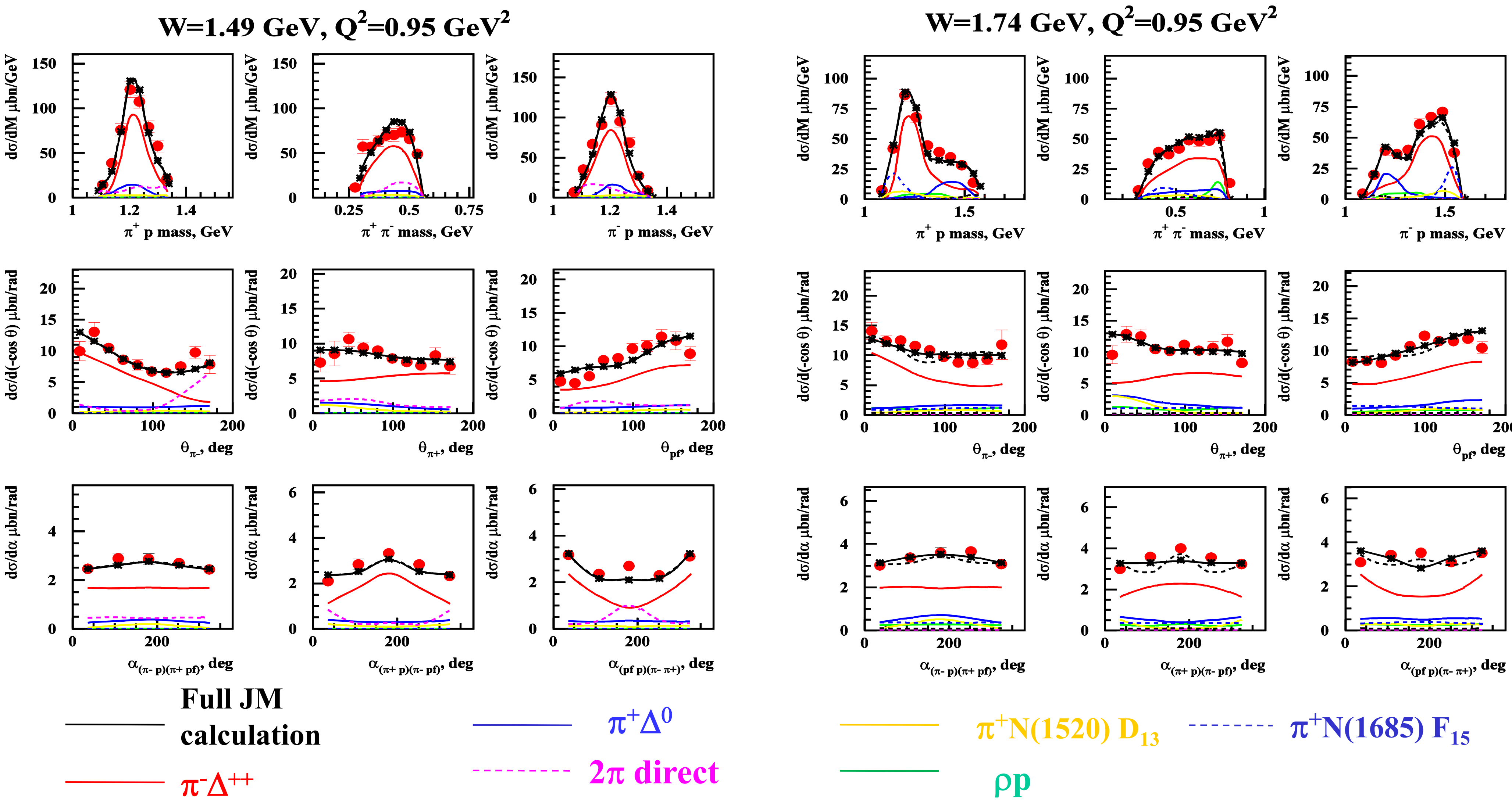
Isobar Model JM05

- Full calculations
- $\gamma p \rightarrow \pi^- \Delta^{++}$
- $\gamma p \rightarrow \pi^+ \Delta^0$
- $\gamma p \rightarrow \pi^+ D_{13}(1520)$
- $\gamma p \rightarrow \rho p$
- $\gamma p \rightarrow \pi^- \Delta^{++}(1600)$
- $\gamma p \rightarrow \pi^+ F^0_{15}(1685)$
- direct 2π production



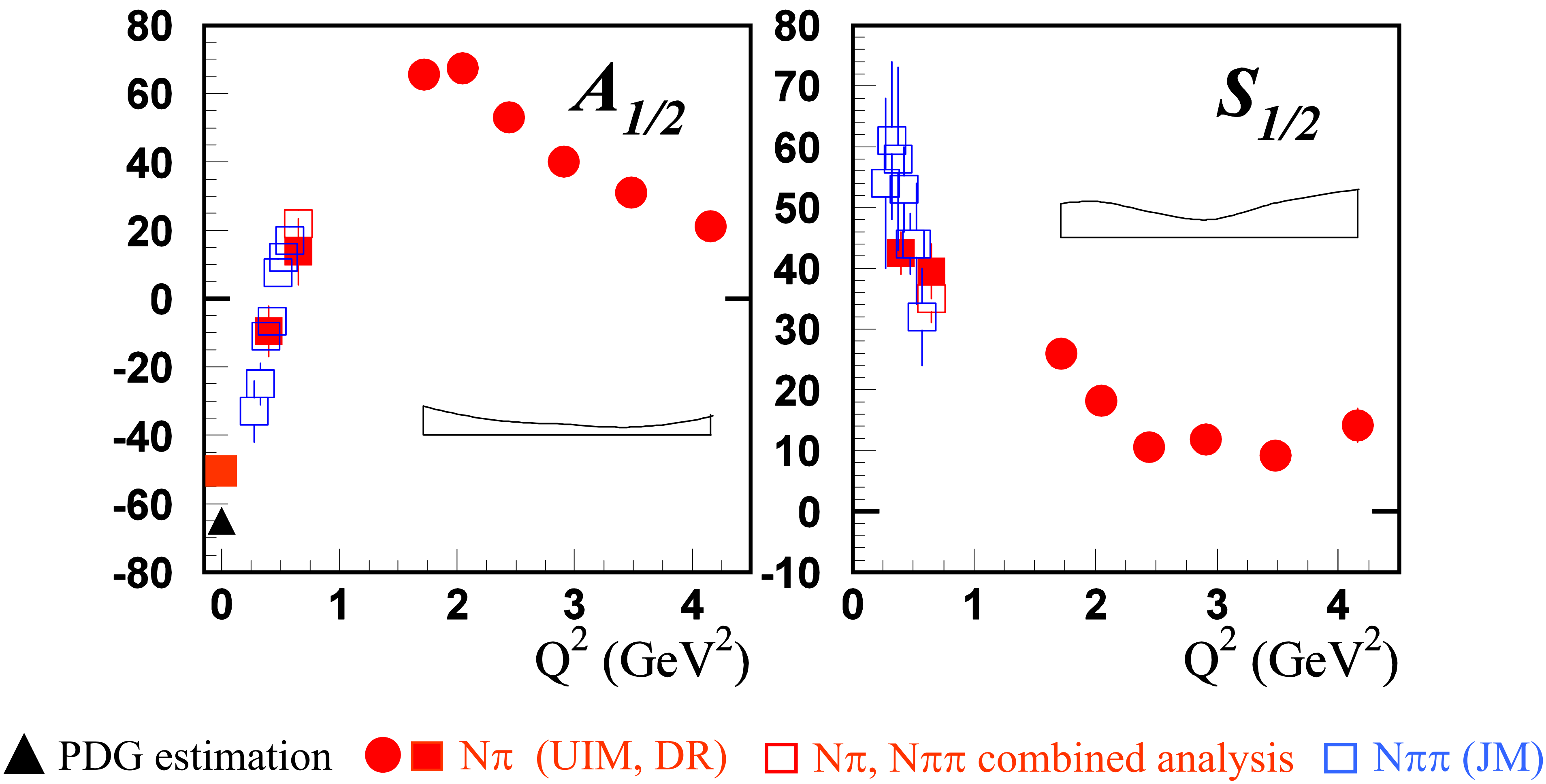
➢ The combined fit of nine single differential cross sections allowed to establish all significant mechanisms.

JM Mechanisms 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.

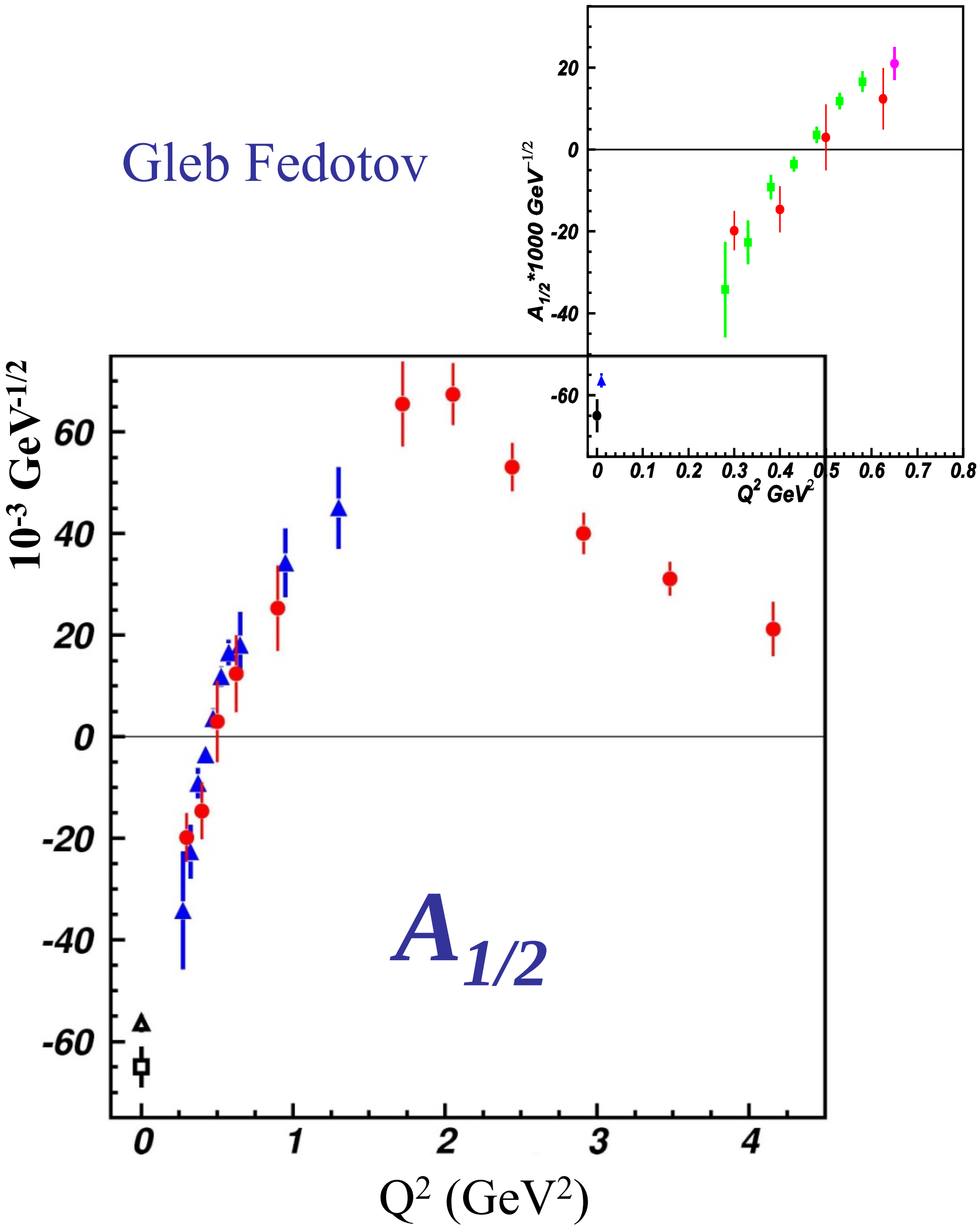
Electrocouplings of N(1440)P_{11} from CLAS Data

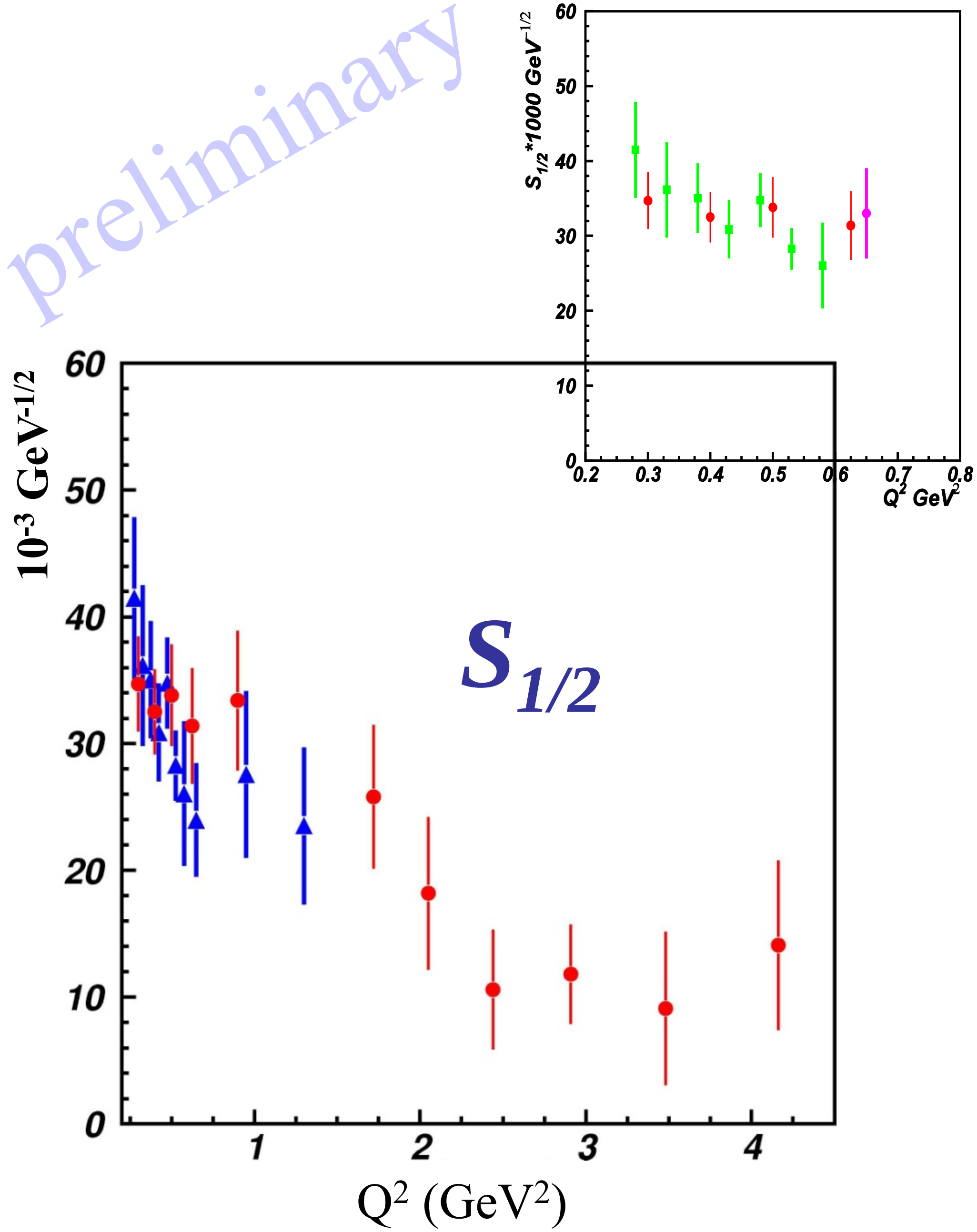


The good agreement on extracting the N* electrocouplings between the two exclusive channels (1π/2π) – having fundamentally different mechanisms for the nonresonant background – provides evidence for the reliable extraction of N* electrocouplings.

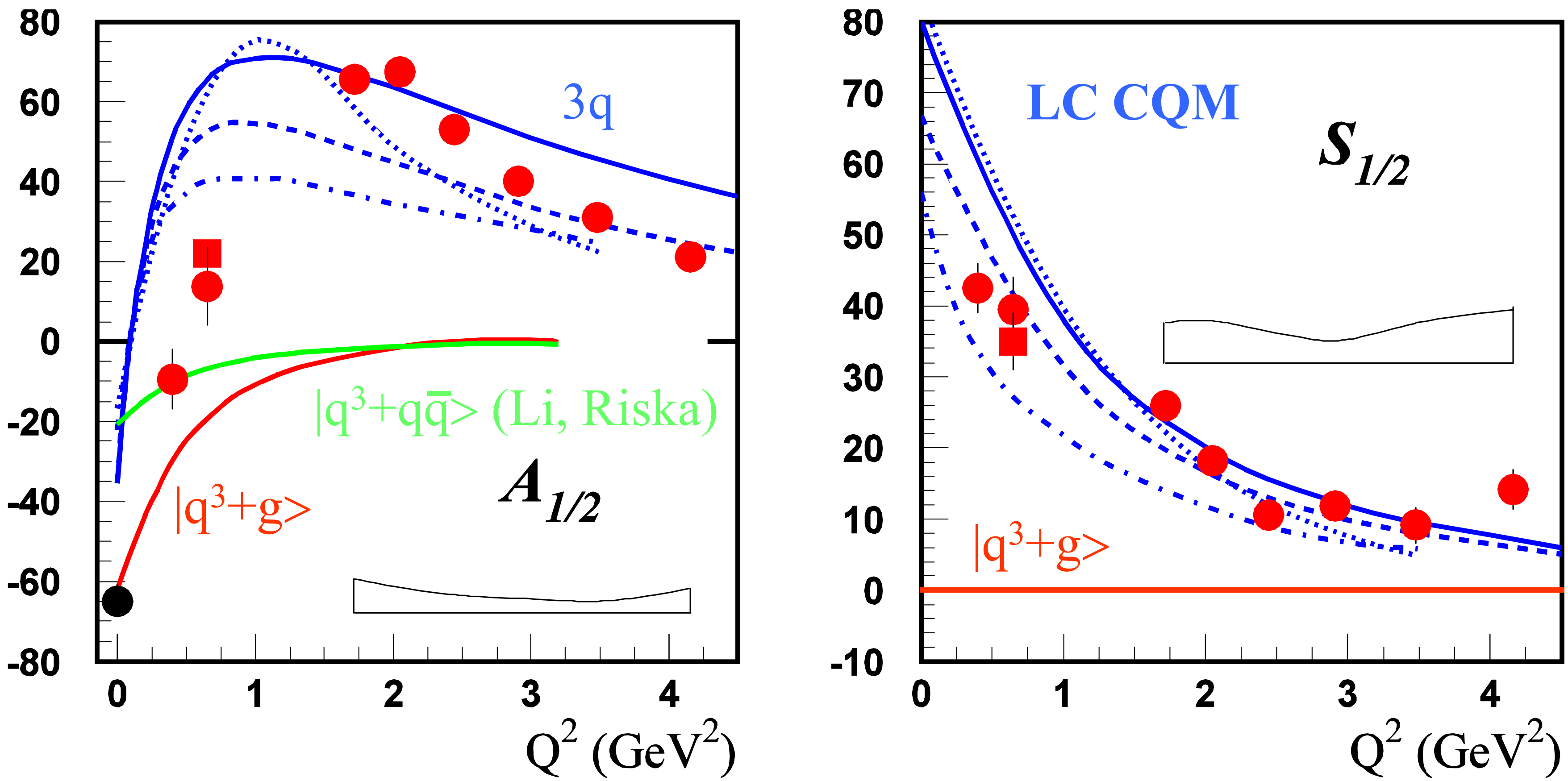
Most recent Electrocouplings of N(1440)P_{11}

Gleb Fedotov





Constituent Quark Models (CQM)



N(1440)P_{11}: ● PDG value ● Nπ ■ Nπ, Nππ combined analysis

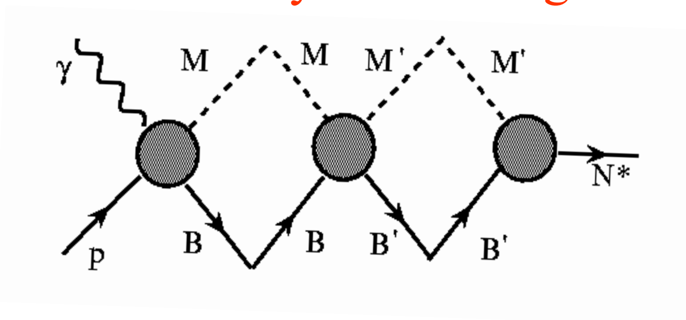
Relativistic CQM are **currently** the only available tool to study the electrocouplings for the majority of excited proton states.

This activity represent part of the commitment of the Yerevan Physics Institute, the University of Genova, INFN-Genova, and the Beijing IHEP groups to refine the model further, e.g., by including $q\bar{q}$ components.

see White Paper Sec. VI

Progress in Experiment and Phenomenology

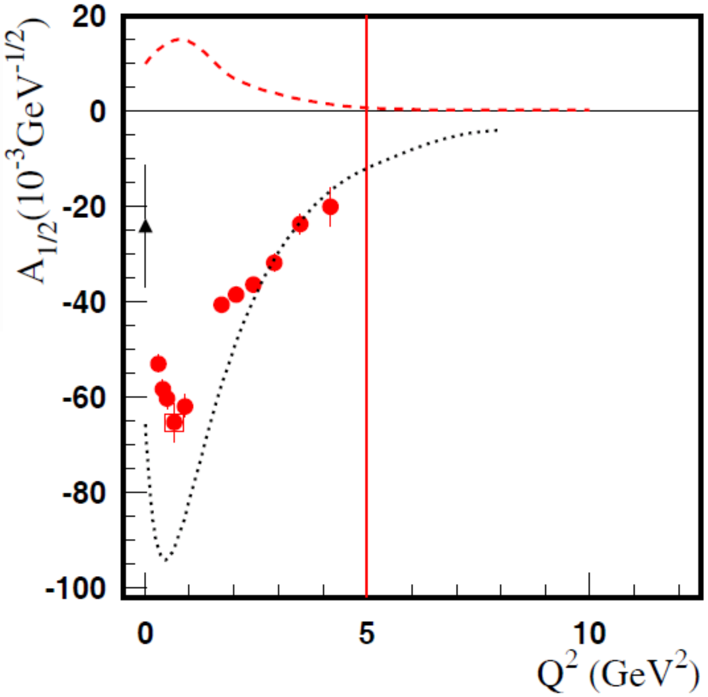
Meson-Baryon Dressing



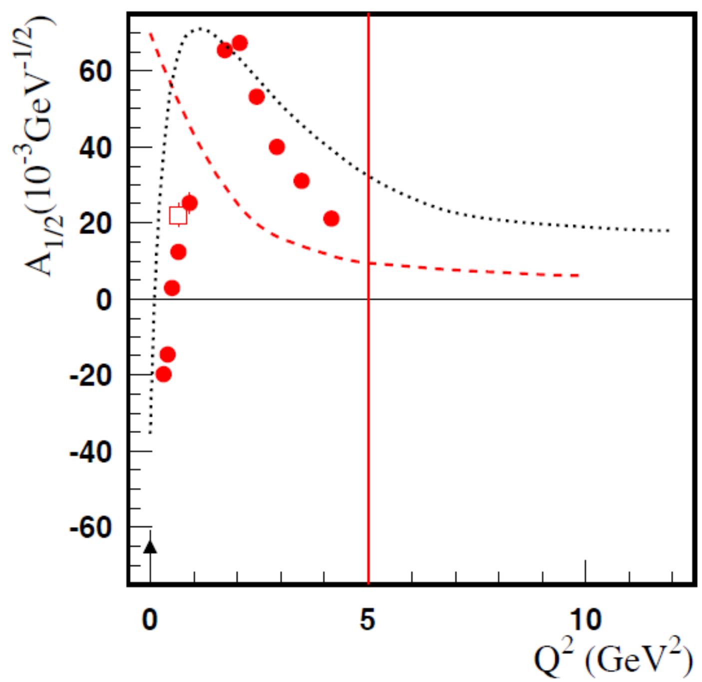
absolute meson-baryon cloud amplitudes (EBAC)

quark core contributions (constituent quark models)

$D_{13}(1520)$



$P_{11}(1440)$

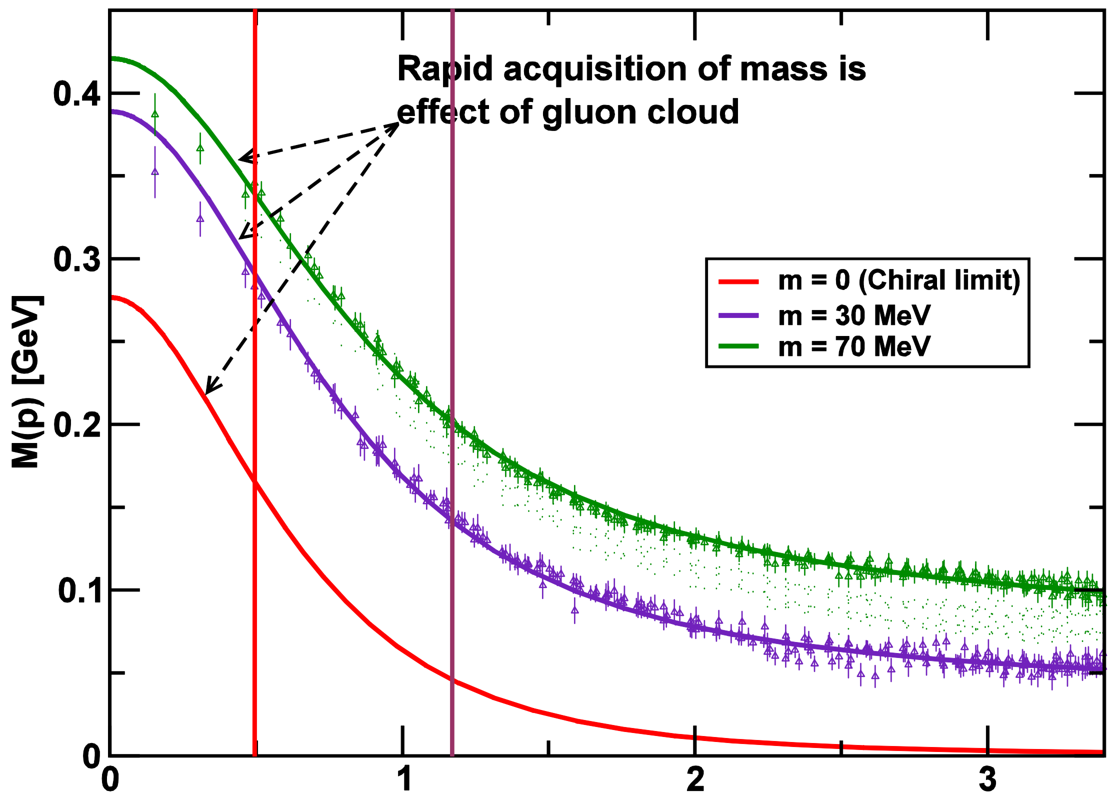


CLAS: Nπ and Nπ/Nππ combined (Phys. Rev. C80, 055203, 2009)

➢ 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.

Dynamical Mass of Light Dressed Quarks



$Q^2 = 2.75\ \mathrm{GeV}^2$ 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.

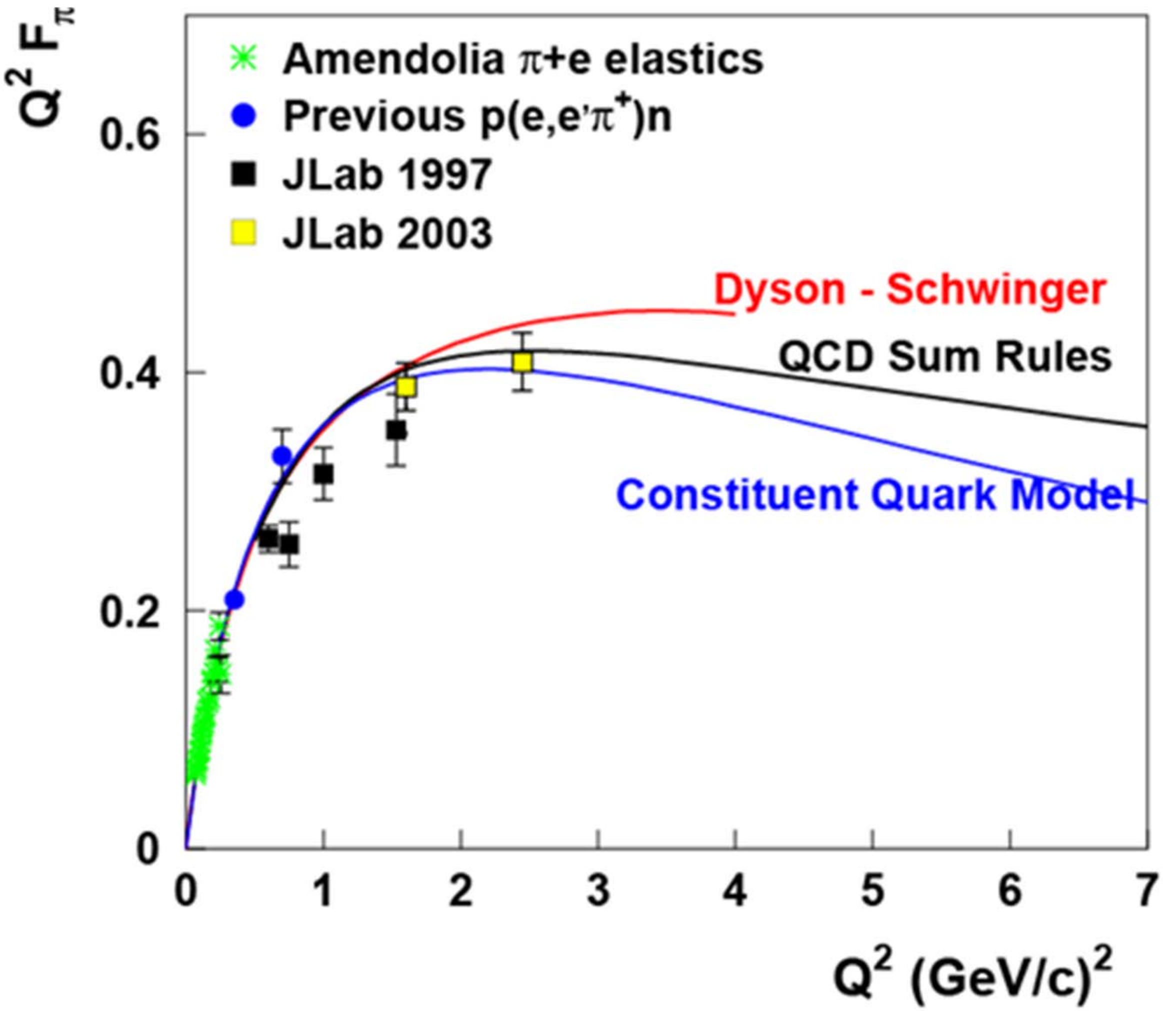
These dynamical contributions account for more than 98% of the dressed light quark mass.

DSE: lines and LQCD: triangles

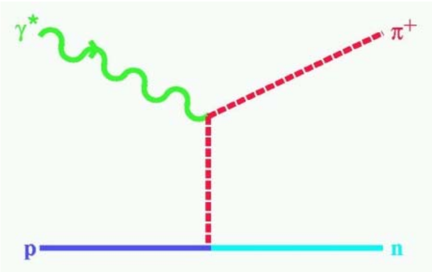
$Q^2 = 12\ \mathrm{GeV}^2 = (\text{p times number of quarks})^2 = 12\ \mathrm{GeV}^2 \rightarrow p = 1.15\ \mathrm{GeV}$

The data on N* electrocouplings at $5\ \mathrm{GeV}^2 < Q^2 < 12\ \mathrm{GeV}^2$ 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.

Pion Transition Form Factor



- At low $Q^2 < 0.3$ (GeV/c)^2: π^+ atomic electron scattering → $R_{rms} = 0.66$ fm
- At higher Q^2: $^1H(e,e'p^+)n$, measure σ_L

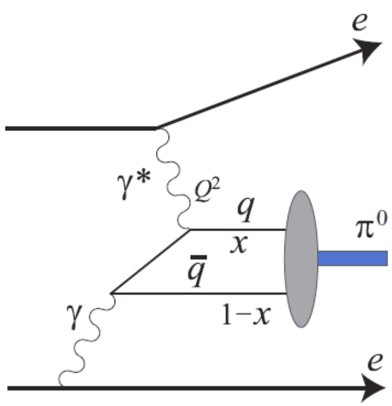


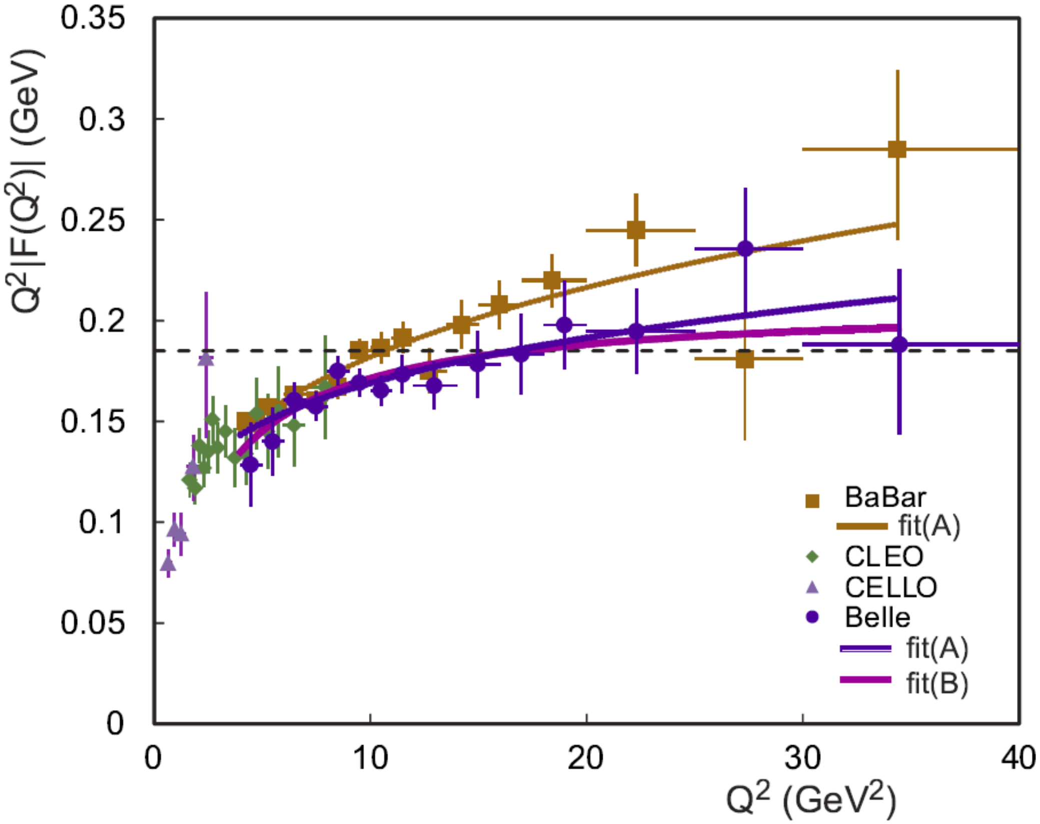
$t = (p_\pi - q)^2 < 0$

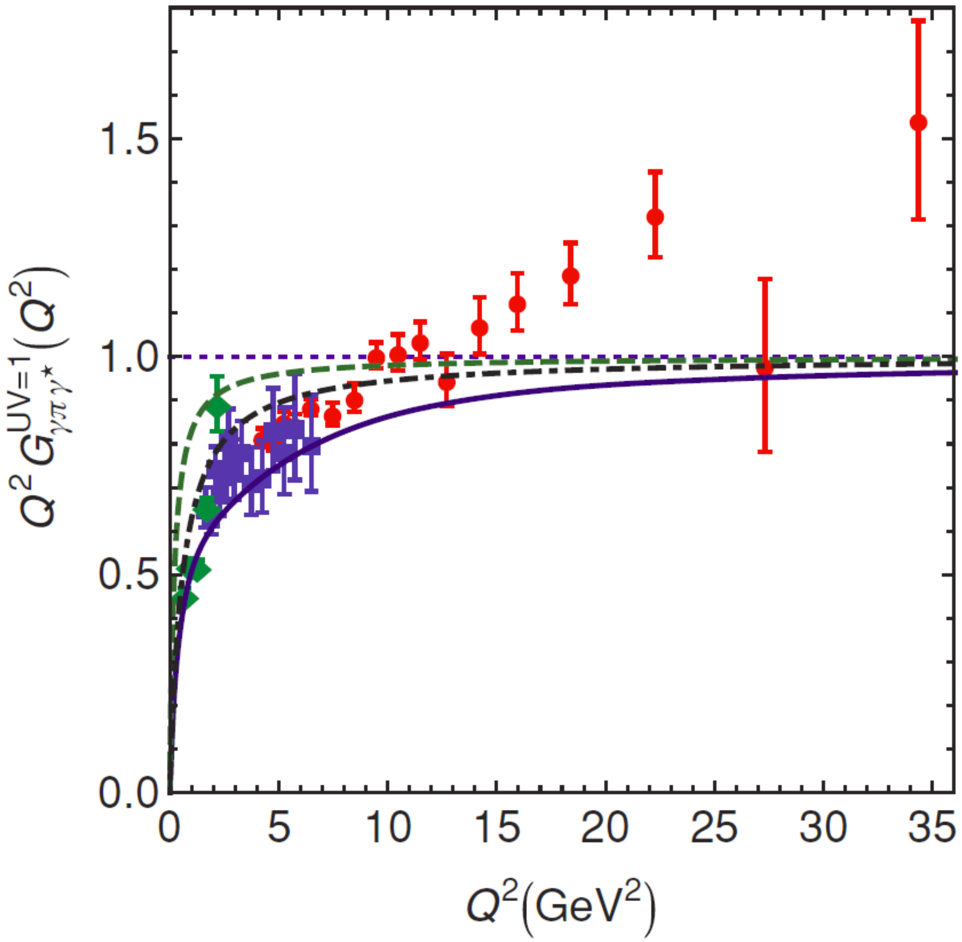
- "Extrapolate" σ_L to $t = +m_\pi^2$ using a realistic pion electroproduction (Regge-type) model to extract F_π

DSE: Phys. Rev. C **82**, 065202 (2010)

Pion Transition Form Factor







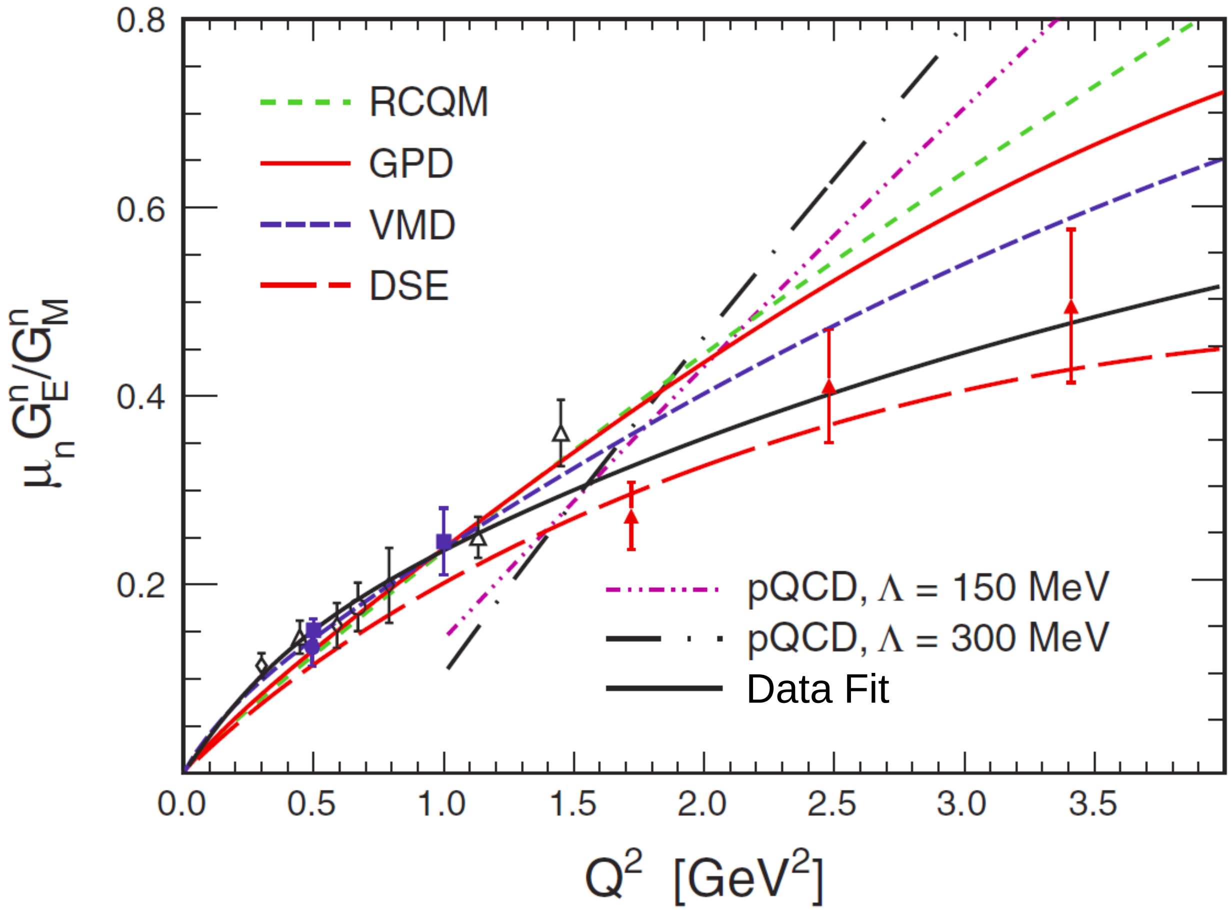
Dashed: monopol (upper bound)
Dot-dashed: monopol (fit to data)
Solid: DSE with momentum dependend quark mass

Belle: arXiv:1205.3249v1 [hep-ex] 15 May 2012

DSE: Phys. Rev. C **82**, 065202 (2010)

Dyson-Schwinger Equation (DSE) Approach

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



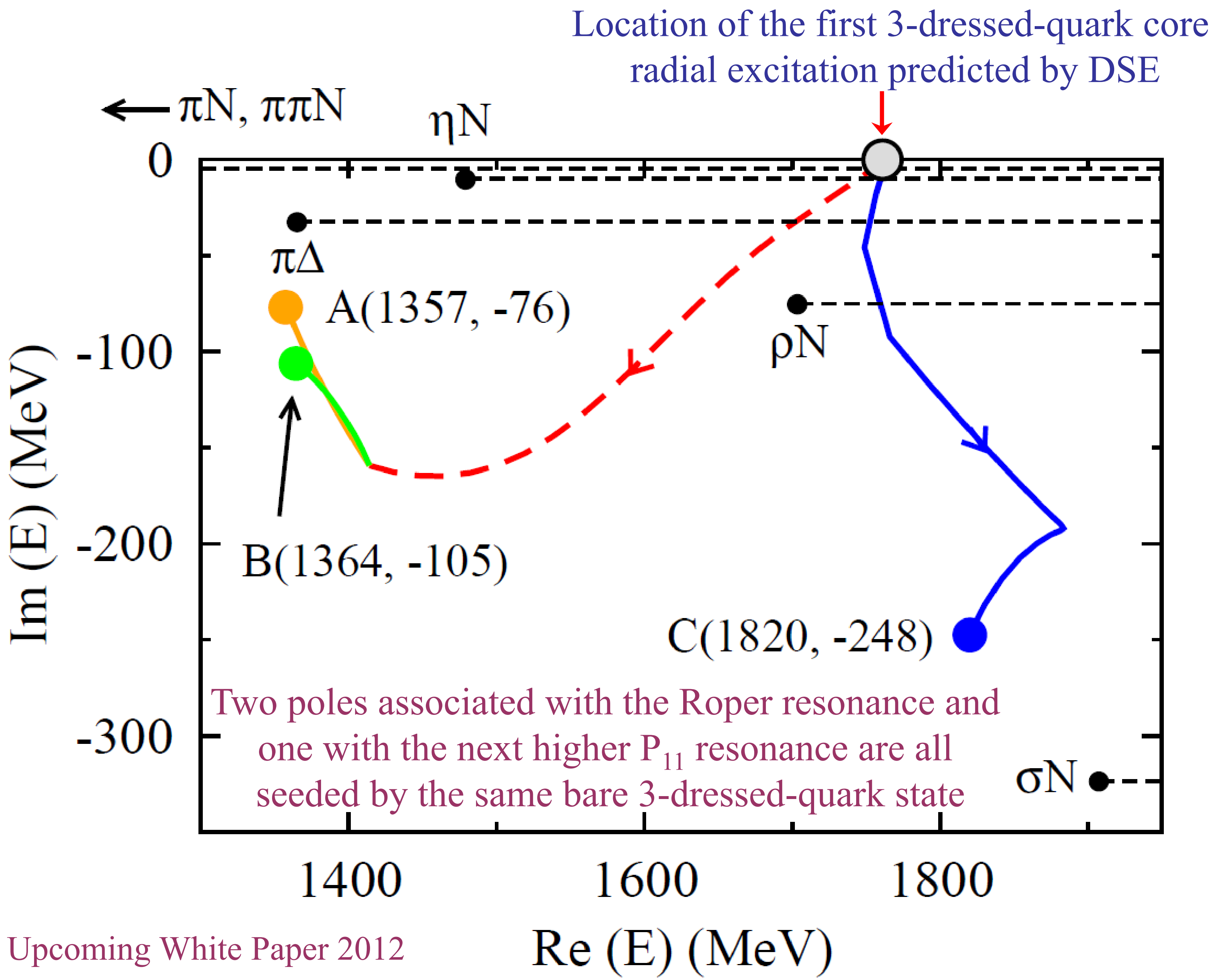
N* electrocouplings can be determined by applying Bethe-Salpeter / Faddeev equations to 3 dressed quarks while the properties and interactions are derived from QCD.

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.

see White Paper Sec. III

DSE and EBAC Approaches

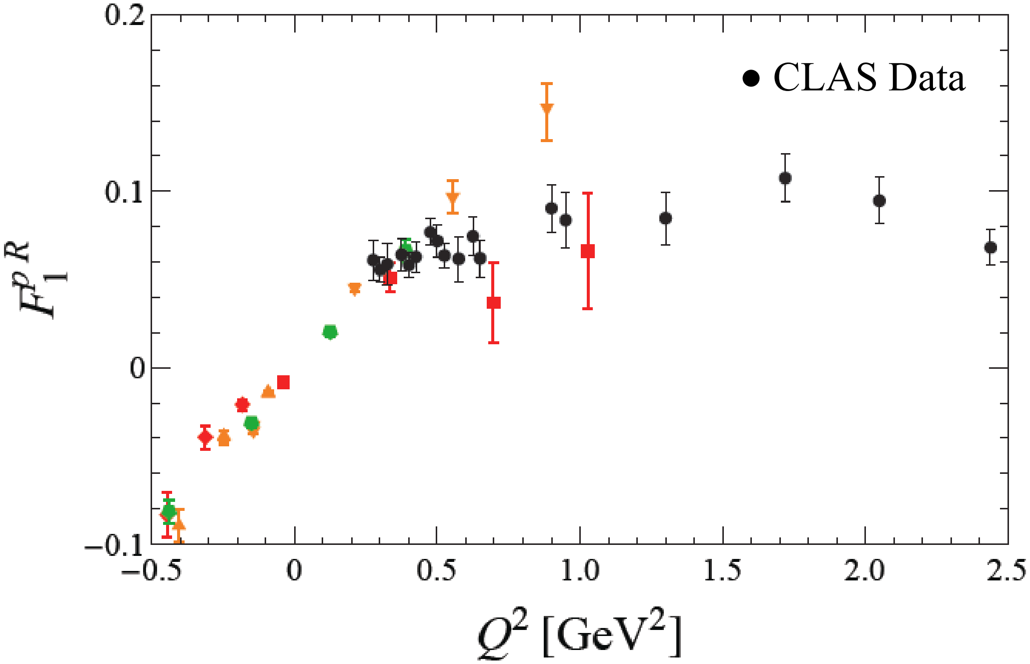


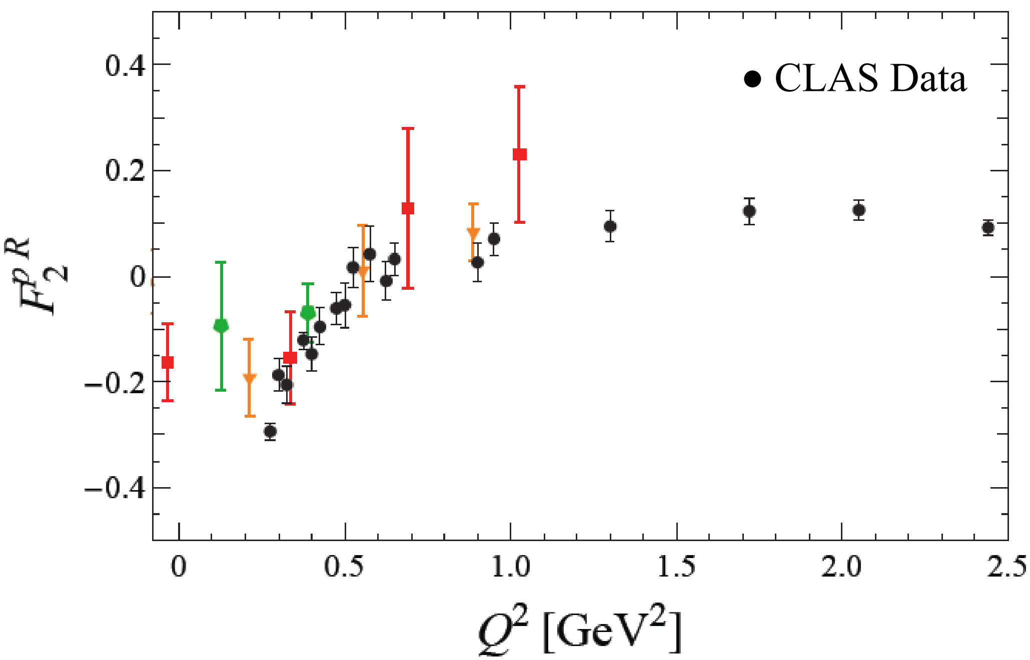
Upcoming White Paper 2012

Roper Transition Form Factors in LQCD

$p(1440)P_{11}$

Huey-Wen Lin and S.D. Cohen





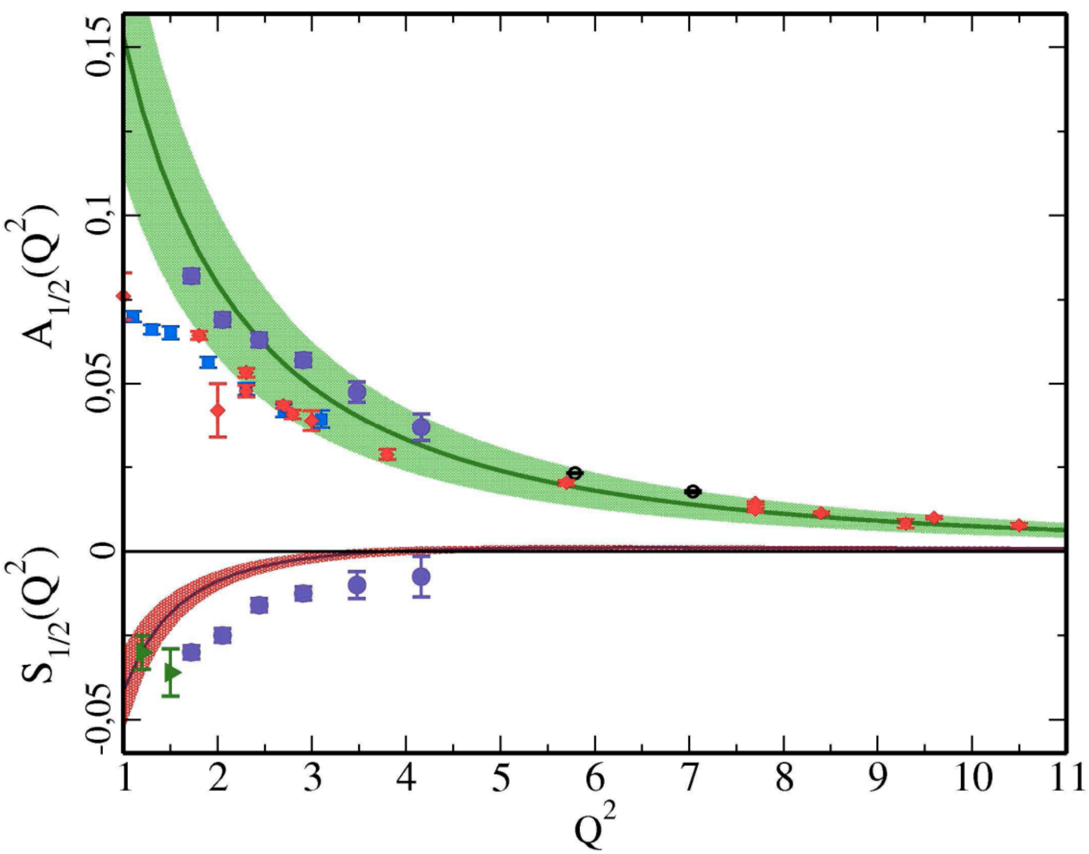
Latice QCD calculations of the $p(1440)P_{11}$ transition form factors have been carried out with various pion masses, m_π= 390, 450, and 875 MeV. Particularly remarkable is the zero crossing in F_2 that appears at the current statistics in the unquenched but not in the quenched calculations. This suggests 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.

Upcoming White Paper 2012

LQCD & Light Cone Sum Rule (LCSR) Approach

N(1535)S_{11}



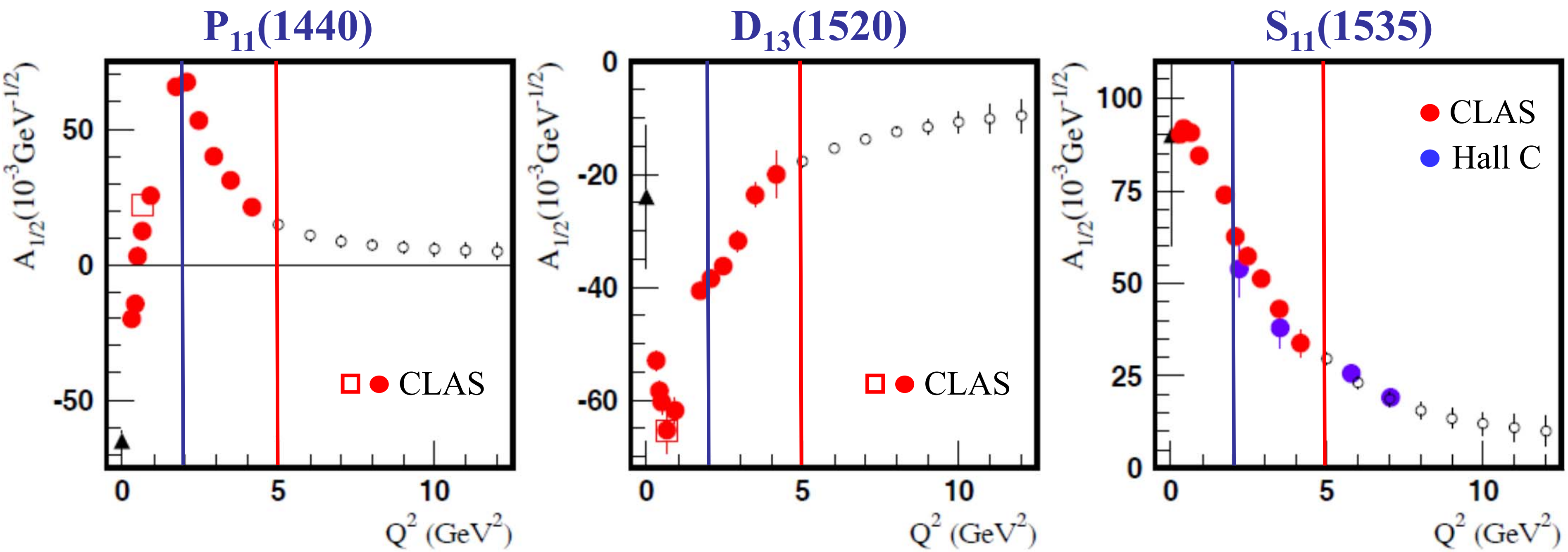
LQCD is used to determine the moments of N* distribution amplitudes (DA) and the N* electrocouplings are determined from the respective DAs within the LCSR framework.

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.

Upcoming White Paper 2012

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. $S_{11}(1650)$, $F_{15}(1685)$, $D_{33}(1700)$, $P_{13}(1720)$, …

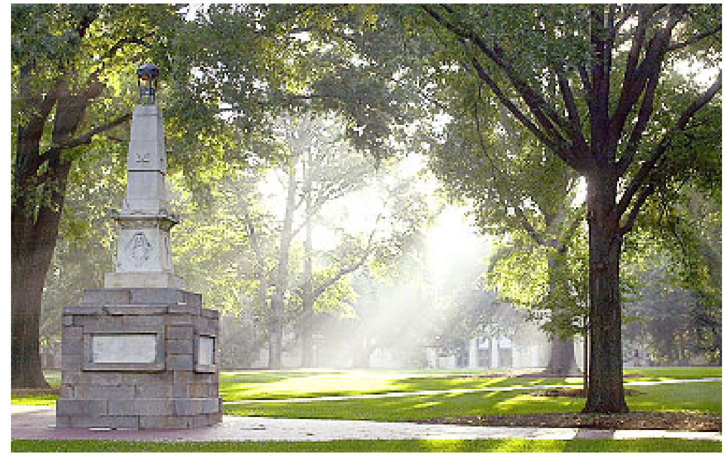
➢ This experiment will – for the foreseeable future – be the only experiment that can provide data on $\gamma_v NN^*$ electrocouplings for almost all well established excited proton states at the highest photon virtualities ever achieved in N* studies up to Q^2 of 12 GeV^2.

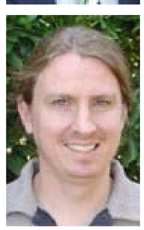
Summary

- We will measure and determine the hadron spectrum and 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:
  - theoretical interpretation on N* electrocouplings, see our previous White Paper arXiv:0907.1901v3 [nucl-th], and
  - development of reaction models that will account for hard quark/parton contributions at high Q^2.
- Any constructive criticism, help, or participation is very welcomed, please contact:
  - Viktor Mokeev mokeev@jlab.org or Ralf Gothe gothe@sc.edu.

USC Summer Academy on Non-Perturbative Physics

A first of its kind three-week graduate student summer school on "Dyson-Schwinger Equations (DSEs) to tackle non-perturbative physics, their applications in Quantum Chromodynamics (QCD) and condensed matter physics, and their mathematical connection to the Hopf algebras" will be held at USC from July 26 to August 10, directly preceding a three-day international workshop on "Nucleon Resonance Structure in Exclusive Electroproduction at High Photon Virtualities". There are a limited number of slots for outside graduate students available. If you would like to come or send a graduate student please contact gothe@sc.edu or webb@sc.edu.





Karen Yeats: "The Hopf Algebraic Approach to DSEs". DSEs are very useful in how they mirror the recursive decomposition of Feynman diagrams into subdiagrams. This simple combinatorial observation is surprisingly powerful as it gives us hints as to how to unwind the combinatorial difficulties from the analytic ones. Furthermore, the Slavnov-Taylor identities for the coupling constants correspond to certain Hopf ideals. The lectures will explain these connections without expecting prior algebraic experience.

Piers Coleman: "DSE Applications in Condensed Matter Physics". In his lectures, he explains the relevance of DSEs for condensed matter physics and will give a short introduction to interacting electron systems followed by five lectures on: "Feynman diagrams in many body physics", "The interacting electron plasma", "BCS theory I and II", and "The Kondo effect and heavy Fermions".

Craig Roberts: "The Emergence of DSEs in Real-World QCD". The properties of QCD are dominated by two emergent phenomena: confinement and dynamical chiral symmetry breaking (DCSB). These phenomena are not apparent in the formulae that define QCD, and DSEs play a critical role in exploring them and in predicting Nature's observable phenomena in the world of strong interactions.

Ian Cloet: "Hadron Phenomenology and QCD's DSEs". An understanding of how the colored quarks and gluons bind together to form the observed color singlet hadrons remains one of the most important questions in all of nuclear physics. His lectures will explore the interplay between experiment and theory using the DSEs and provide a perspective on answering key questions concerning QCD's nonperturbative structure.

USC Summer Academy on Non-Perturbative Physics

The next workshop in our series "Nucleon Resonance Structure in Exclusive Electroproduction at High Photon Virtualities" will be held at the University of South Carolina on August 13-15, 2012. This three-day workshop will provide us extended opportunities to present and discuss in depth future developments and preliminary results on the continuous exploration of hadronic physics towards smaller distances. If you would like to participate please contact gothe@sc.edu or mokeev@jlab.org or visit www.jlab.org/conferences/EmNN2012/.

In the tradition of this workshop, we will focus on the extension of the $\gamma_v NN^*$ electrocoupling studies to high photon virtualities from 5.0 to 12.0 GeV^2. This is the kinematic area, where the N* structure is still almost unexplored, and which will be comprehensively covered by the approved experiment PR12-09-003 on N* studies in exclusive meson electroproduction off protons with the CLAS12 detector. The experiment will be carried out in the first five years after the completion of the Jefferson Lab 12-GeV Upgrade Project.

By that time ready-to-use methods for the extraction of the $\gamma_v NN^*$ electrocouplings at high photon virtualities are needed as well as general QCD-based frameworks for the theoretical interpretation of these fundamental N* parameters. Resonance electrocouplings will be measured for the first time at distance scales, where quark degrees of freedom are expected to dominate. These studies will focus on the exploration of quark interactions in the QCD running coupling regime, which are responsible for the baryon formation. They are vital in order to explore confinement in the baryon sector and to understand how the complexity of non-perturbative strong interactions emerges from QCD.

The scope of this three-day workshop focuses particularly on the development of future strategies, methods, and approaches to extract the $\gamma_v NN^*$ electrocouplings, where hard quark interactions become relevant, and on the interpretation of hadronic physics in this non-perturbative regime. The workshop aims to foster already initiated efforts and create opportunities to facilitate and stimulate further growth in this field.

Your Next Opportunities to Get Involved …

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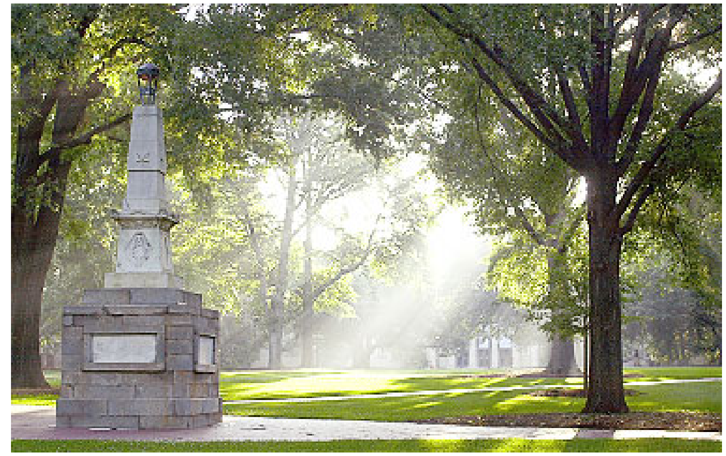

COLLEGE OF ARTS AND SCIENCES
PHYSICS AND ASTRONOMY

A first of its kind three-week graduate student summer school on "Dyson-Schwinger Equations (DSEs) to tackle non-perturbative physics, their applications in Quantum Chromodynamics (QCD) and condensed matter physics, and their mathematical connection to the Hopf algebras" will be held at USC from July 26 to August 10, directly preceding a three-day international workshop on "Nucleon Resonance Structure in Exclusive Electroproduction at High Photon Virtualities". The main lecturers are Piers Coleman, Ian Cloet, Craig Roberts, and Karen Yeats. There are a limited number of slots for outside graduate students available. If you would like to come or send a graduate student please contact gothe@sc.edu or webb@sc.edu and visit www.physics.sc.edu/~gothe/.